Technical Report No. ENV-2023-101

Lower San Acacia Reach: Geomorphology and Alternatives Description

Middle Rio Grande Project, New Mexico
Upper Colorado Basin Region

U.S. Department of the Interior **September 2023**

Mission Statements

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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.

Cover Photo – Aerial photograph looking southwest toward the Rio Grande just upstream of Black Mesa (Reclamation).

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Acronyms and Abbreviations

AAO	Albuquerque Area Office
ac	acres
ac-ft	acre-feet
Agg/Deg	Aggradation/Degradation
BDA	Bosque del Apache National Wildlife Refuge
cfs	cubic feet per second
cy	cubic yards
EB	Elephant Butte
ESA	Endangered Species Act
ft	feet
kaf	thousand acre-feet
LFCC	Low Flow Conveyance Channel
m	meters
mg/L	milligrams per liter
mm	millimeters
MRG	Middle Rio Grande
NAVD88	North American Vertical Datum of 1988
Reclamation	Bureau of Reclamation
RGSM	Rio Grande Silvery Minnow
RM	River Mile
SWFL	Southwestern Willow Flycatcher
TIHM	Time Integrated Habitat Metric
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
WRDA	Water Resources Development Act
WSE	water surface elevation
YBCU	Yellow-Billed Cuckoo
yr	year

Symbols

R^2	coefficient of determination
>	greater than
<	less than
%	percent
m	regression coefficient

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Executive Summary

The lower San Acacia Reach presents opportunities to improve water delivery, ecosystem function, and the benefits of maintenance actions. Improving the benefit of maintenance actions, or increasing the benefit-cost ratio of maintenance, involves working with the geomorphic trends of the river rather than maintaining features that may not be sustainable. Managing sediment deposition is paramount to achieving these goals of improved water delivery, ecosystem health, and maintenance benefits. A period of low-flow years during the mid to late-1940s allowed vegetation growth and sedimentation in the channel to disrupt downstream water delivery. The river had limited conveyance and did not maintain a continuous surface flow connection, especially near San Marcial, which was one of the motivating factors for establishing the Middle Rio Grande Project. The state of New Mexico also accrued a significant water delivery debt under the Rio Grande Compact during this time. To improve water delivery, river channelization and the Low Flow Conveyance Channel (LFCC) construction during the 1950s moved the river and floodplain to the east side of the valley from San Acacia Diversion Dam to the Narrows of Elephant Butte Reservoir. Spoil levees constructed during the channelization also confined sedimentation to the east side of the valley.

Since 2000, the ongoing drought has continued to exert pressure on water resources and ecosystem services along the Middle Rio Grande and the lower San Acacia Reach. Examples include New Mexico's Rio Grande Compact under-deliveries for 7 of the last 12 years and the continued listing of threatened and endangered species that rely on the river corridor for habitat. The Bureau of Reclamation and project partners developed alternatives to improve water delivery, ecosystem health, and the benefits of maintenance actions. These alternatives are described after first analyzing the historical and recent geomorphic conditions and dynamics of the project area along with upstream and downstream reaches. The project area for the current study is defined as the South Boundary of Bosque del Apache (BDA) National Wildlife (near River Mile (RM) 74) to the confluence of LFCC West (RM 54.5). Upstream and downstream reaches are also included in the analysis for additional context and to understand potential effects within the project area.

Channel and floodplain morphology are dynamic and continuously evolve in response to changes in flow, sediment, and base-level. There have been four distinct wet and dry periods since the early 1900s when gage data are available: flows were high through 1949, low from 1950 to 1978, high from 1979 to 1999, and low from 2000 to 2022. Construction of the LFCC and diversions beginning in 1952 also changed the flow characteristics in the project area. The LFCC, when in full operation, conveyed 68 percent (%) of total surface flows at San Marcial from 1952 to 1975, 5% during 1976 to 1983, 41% from 1984 to 1985, and 28% during 1986 to 2022.

Sediment loads have decreased significantly since Cochiti Dam began impounding water in 1973. After a transition period between 1974 and 1982 in which monsoons provided relatively high sediment deliveries to the project area, sediment concentrations further decreased in 1983. Suspended sediment concentrations at the San Marcial floodway gage during about the last 40 years (1983 to 2021) are about 30% of the concentrations during 1957 to 1973. Seasonal differences in sediment transport characteristics are also important to the geomorphology and channel evolution. Snowmelt runoff and monsoons have each transported about the same cumulative amount of sediment since 1957, but the monsoon season (July through October) has only conveyed about 20% of the water volume as the snowmelt runoff season (March through June).

The Elephant Butte Reservoir pool controls the bed and floodplain elevation throughout the project area. Channel and delta areas near the reservoir respond quickly to changes in pool elevation while locations farther upstream respond more slowly and at a reduced magnitude. When the reservoir rises and remains high there is significant sediment deposition that aggrades the channel and floodplain. When the reservoir lowers after being high, the next sufficiently large high flow event is likely to cause channel degradation (bed lowering due to sediment removal) throughout the project area. The timing and extent of upstream degradation associated with reservoir pool lowering depends on several factors such as vegetation growth, channel excavation, and the duration and magnitude of flow events. If the reservoir pool remains low, the channel will remain incised with a stable bed or minor additional erosion. Downstream of the project area closer to the reservoir, the channel tends to aggrade even during low reservoir periods because the sediment supply is greater than the transport capacity. Mechanical sediment removal has been needed in these downstream reaches since the reservoir lowered in the early 2000s.

Top of bank and floodplain elevations increase along with the channel bed during periods of deposition, but the bank and floodplain remain high and do not erode during periods of subsequent channel incision. Recent incision has lowered the channel bed to near the valley elevation west of the spoil levee; however, the top of bank and floodplain are about 10 to 20 feet above the valley floor. Additionally, upstream of RM 64 the channel bed and water surface are above the LFCC water surface, which causes seepage loss and contributes to river drying. The LFCC intercepts some of the river seepage losses and delivers that water downstream but the percentage is unknown. Seepage loss from the river is proportional to the height of the riverbed above the local shallow groundwater elevation. The incised channel geometry in the project area since 2005 suggests that seepage and riparian transpiration are more responsible for water loss in recent years than overbanking flow.

Channelization and construction of the LFCC in the project area during 1951 to 1953 involved about 5.5 million cubic yards (cy) of excavation and 5,200 acres of vegetation clearing. The reach between the Bosque del Apache (BDA) National Wildlife Refuge South Boundary and RM 60 has had a cumulative 30 million cy of sediment deposition from 1962 to 2012. Most of the sediment has deposited on the banks and floodplain with a smaller percentage within the active channel. The long-term and prevailing condition is a depositional environment despite periods of channel incision during low reservoir levels. Attaining an equilibrium condition or transporting all sediment delivered from upstream is likely not possible and yet it is important to manage how and where sediment is deposited in the project area. Engineers in the early 1950s expected that the constructed floodway and LFCC would have a lifespan of about 10 years before sedimentation would require relocating the features to the west. Now, 70 years later, this report develops feasibility-level alternatives to realign the river west of the spoil levee (Alternatives B and C) and considers the No Action scenario (Alternative A) to maintain the river and LFCC in their current configuration. Alternatives B and C both relocate the river to the west but differ in their starting locations and their interaction with the LFCC.

Alternative A would be the same as conditions during the last 10 to 15 years if the reservoir remains low with similar pool elevations downstream of the Narrows (RM 45). When the reservoir rises, the channel would return to a cycle of aggradation and the upstream bed elevation would increase. Continued high reservoir levels and bed deposition would reconnect the floodplain, and overbank flows would deposit sediment on the bed and banks. This condition would continue to pose a high risk to the spoil levee and would likely require levee raising and strengthening to prevent a levee breach. A levee failure in the project area would not likely endanger human life or property but would have significant consequences for water delivery because there would not be a return path to the river channel, and it would take years or decades for a new channel to form without mechanical intervention. Alternative A would require costly and intensive maintenance when the reservoir is high. Maintenance needs would be like the 1990s when there were two sediment plugs and a levee breach in the Tiffany area near RM 72 upstream of San Marcial.

Alternatives B and C would both realign the river through the western valley to better manage sediment deposition and reduce seepage loss and river drying by lowering the channel bed and water surface. Reducing the current channel perching by realigning the river would reduce stranding of water and improve sediment transport when overbanking occurs. There would be a shorter distance of the spoil levee and LFCC to maintain. Alternatives B and C would not prevent future sedimentation, especially when the reservoir pool rises. The banks would eventually become perched after overbanking flow events. The primary advantage of Alternatives B and C is that the river would be allowed to migrate without levee confinement so that sediment deposition could periodically move across the valley. Removing levee confinement would also prevent the active floodplain from being perched above the valley floor. Alternatives B and C would likely result in less reliable flow through the existing LFCC West channel between RM 60 and 54.5, which may impact avian habitat. The LFCC West currently receives flow from the LFCC at RM 60 throughout the year. For Alternatives B and C, the LFCC would merge with the river realignments further upstream; therefore, surface water in the LFCC West would need to come from an excavated inlet channel or a flow control structure between the realigned river and LFCC West.

The most significant difference between Alternatives B and C is the interaction between the LFCC and the river. Alternative B starts 1.5 miles farther upstream than Alternative C and the LFCC would flow into the river at RM 73.7, near the BDA South Boundary. Merging the river and the LFCC would add 100 to 200 cfs to the river discharge assuming typical recent LFCC operating conditions. Alternative B would also provide avian habitat opportunities along the western valley between RM 68 and 65. A disadvantage is that Alternative B requires more excavation because it starts further upstream, and it would allow overbanking flows to contact the Elmendorf Drain levee or the railroad embankment for a short distance near the upstream end of Tiffany Basin. Also, the proposed Alternative B riverbed elevation is higher than the LFCC bed elevation at RM 73.7 where the LFCC would flow into the realigned river. Connecting the LFCC at this location would cause a backwater effect and raise the LFCC water surface elevation for about four miles upstream to the diversion structure at RM 77.6. Future analysis to evaluate the alternatives will consider if the increased LFCC water surface elevation between RM 77.6 and 73.7 would impact possible diversions into the LFCC at San Acacia.

Alternative C would not affect the LFCC until downstream of the San Marcial Railroad Bridge (RM 68.6), where the LFCC would flow into the river near RM 67.3. This would result in lower flows in the upstream river and less potential avian habitat between RM 68 and 65 but would also have less risk to current LFCC and Elmendorf Drain operations.

The three alternatives will be evaluated during the next phase of the study to assess how well they meet the project purposes of improving water delivery, maintaining and enhancing ecosystem health, and increasing the benefit of system maintenance actions. The current report analyzes geomorphic data to understand how the system has evolved, identify issues with the current conditions, and identify opportunities to improve the trajectory of the future system.

1.0 Introduction

1.1 Purpose

The Bureau of Reclamation (Reclamation) and other agencies face the challenge of simultaneously managing the flow of water, the erosion and deposition of sediment, and managing environmental resources within the highly dynamic Middle Rio Grande (MRG) watershed. The purpose of the proposed alternatives is to improve water delivery to Elephant Butte Reservoir, to maintain and enhance ecosystem health (i.e., protecting and promoting recovery of endangered species, reducing river drying, and increasing available habitat), and to increase the benefit of system maintenance actions by working with the geomorphic trends of the river.

The purpose of this report is to provide the technical basis for developing three alternatives: Alternative A, Alternative B, and Alternative C. These alternatives are described herein and will be evaluated during the next phase of the study. To better understand the challenges and opportunities, we first analyzed the geomorphic conditions and dynamics of the lower San Acacia Reach using historical and recent data such as aerial imagery, topographic and bathymetric surveys, and measurements of water discharge and sediment transport. These data illustrate the evolution of the river and its floodplain while providing the foundation for alternatives to meet the project purpose. Therefore, the alternatives are described near the end of this report within the context of the geomorphic conditions and dynamics.

1.2 Authority

Reclamation is authorized to engage in planning for major rehabilitation and replacement of existing assets under:

- Reclamation Project Act of 1902 (32 Stat. 388) and supplementary acts
- Water Resources Planning Act of 1965, as amended
- Water Resources Development Act (WRDA) of 2007, (Pub. L. 110-114), Section 2031
- Departmental Manual Part 707 DM 1, Water and Land Related Resources – Principles, Requirements, and Guidelines, for Water and Land Related Resources Implementation Studies

Reclamation is authorized to seek funding for extraordinary maintenance work under:

- Omnibus Public Land Management Act of 2009 (Pub. L. 111-11), Title IX, Subtitle G

Reclamation is authorized to conduct work within the channel and floodplain, known as channel rectification and maintenance, of the Rio Grande under:

- Federal Flood Control Acts of 1948 and 1950 (62 Stat. 1171; 64 Stat. 163) and supplementary acts

The Albuquerque Area Office (AAO) is guided in planning for Extraordinary Maintenance Work under Reclamation Directive and Standard:

- CMP 09-04 Planning for Major Rehabilitation and Replacement of Existing Assets

1.3 Location

Figure 1 is a location map that shows the project area between River Mile (RM) 74 and 54.5 including key features such as the existing river channel, Low Flow Conveyance Channel (LFCC), Elmendorf Drain, Bosque del Apache (BDA) National Wildlife Refuge, and the Burlington Northern Santa Fe Railroad. There are United States Geological Survey (USGS) stream gages just downstream of the railroad crossing at San Marcial on the river (08358400) and LFCC (08358300). These gages provide flow and sediment data for geomorphic and design analyses. The study area initially comprised additional reaches upstream and downstream. During planning workshops with partner agencies in December 2020 the team decided that these reaches were better addressed by separate ongoing projects. Projects in the upstream reach include the completed BDA Pilot Realignment and the planned northern phase of the BDA Realignment. Projects in the downstream reach include the continuation of the delta channel maintenance program. Therefore, the current study focuses on the river, floodplain, and valley between RM 74 and 54.5. Information from upstream and downstream reaches is occasionally presented in this report to provide geomorphic context and describe potential impacts from the downstream reach geomorphology and delta channel maintenance.

Figure 2 shows the location of project alternatives. Alternative A maintains the river in its current alignment. Alternative B realigns the main channel to the west starting near RM 74. The channel would remain west of the existing spoil levee while flowing through the Tiffany Basin until reconnecting with the existing river shortly upstream of the San Marcial Railroad Bridge. Water from the LFCC would flow into the realigned river just downstream of the BDA South Boundary. Water from the Elmendorf Drain would flow through the existing culvert into the LFCC until near RM 68 where it would be connected to a historical side channel. The Rio Grande would again be realigned to the west downstream of the railroad bridge near RM 67.7 until returning to the current channel near RM 59.5. Alternative C would also realign the main channel to the west, but starting near RM 72.5, about 1.5 miles downstream of the Alternative B inlet. The LFCC would not be affected until flowing into the realigned channel downstream of the railroad bridge near RM 67.3. Elmendorf drainage flows from BDA would also not be affected. The location of the realigned main channel between RM 67.7 and 59.5 would be the same for Alternatives B and C.

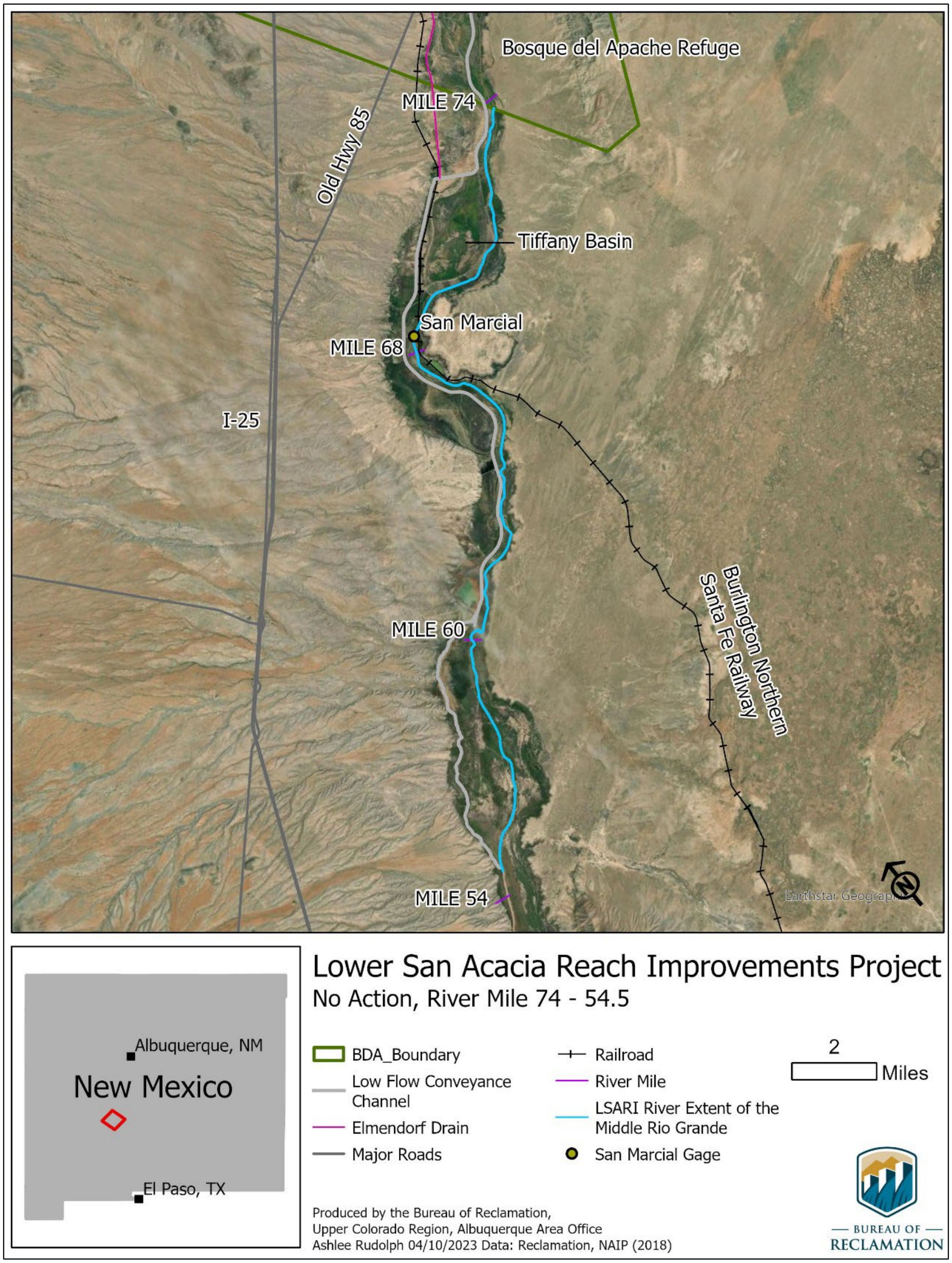


Figure 1.—The project area begins below the BDA Refuge near RM 74. It extends approximately 20 miles south to where the LFCC converges with the main stem of the Rio Grande near RM 54.5.

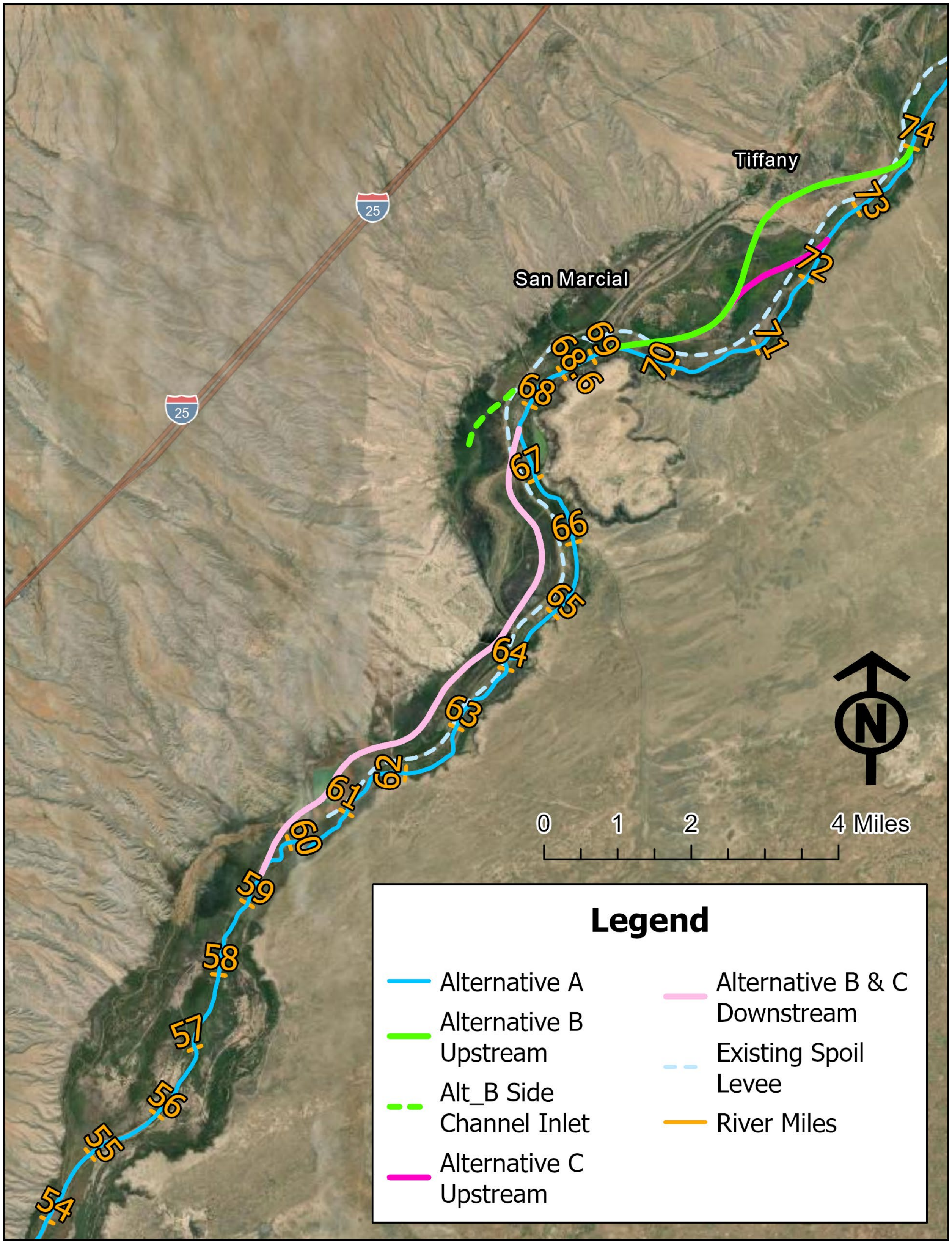


Figure 2.—Location map showing river alignments for project alternatives.

1.4 Historical Activities and Challenges

The MRG supports riparian vegetation, habitat for fish and wildlife, and human uses such as agriculture, municipal, and industrial. Indigenous people have used and interacted with the river for centuries, but demand for the river's water has steadily increased since the expansion of settlers during the late 1800s initiated a period of anthropogenic controls and manipulations that transformed the MRG from a natural stream to a heavily managed system (Scurlock 1998; Makar and AuBuchon 2012). Upstream irrigation diversions in the San Luis Valley during the 1870s to 1890s reduced flows in the river by about 50 percent (%) (National Resources Committee 1938). There were two other system-wide impacts to the MRG watershed during the late 1800s: construction of the Burlington Northern Santa Fe Railroad and upland livestock grazing. The railroad embankment isolated and encroached on the floodplain, bisected the valley at San Marcial, and caused backwater effects during large floods (Leopold et al. 1964). Upland livestock grazing and concurrent large floods caused arroyo incision that increased sediment supply to the main channel well above previous levels (Happ 1948; Leopold et al. 1964; Swanson et al. 2011).

Floods have historically caused the river to move across the valley while depositing sediment in the main channel and overbank areas (Nelson et al. 1914; Happ 1948; Scurlock 1998; Makar and AuBuchon 2012). High sediment loads and a variable flow regime were reflected in the channel planform evolution: a wide braided channel would narrow during periods of low flows, aggrade so that the channel was perched above the floodplain, and then avulse during a high flow event (Massong et al. 2010). Reclamation constructed Elephant Butte Dam that began impounding water in 1915, which caused backwater effects in the upstream river. Following a spill over the Elephant Butte Dam crest in 1942, the reservoir water level rapidly declined due to drought. This allowed for a proliferation of invasive salt cedar and other plants in the reservoir delta and on formerly cultivated land near San Marcial, preventing the river from maintaining a continuous channel at low flows. The impact of a dynamically shifting river channel on infrastructure, and the need for water diversions in an arid environment, has continued throughout the 1900s to the present. Agriculture suffered from damage to riverside facilities and the loss of productive farmlands before larger-scale efforts to control the river began in the mid-1900s (Scurlock 1998).

Initial construction activities to reduce water loss included excavating the LFCC, moving the river to the east side of the valley, building a spoil levee between the river and LFCC, and clearing the floodway of vegetation. This initial stage of channel rectification extended about 30 miles from the Narrows (near RM 45) to upstream of the BDA South Boundary (Chapman et al. 1952). The "floodway" was defined as the active Rio Grande channel and an adjacent strip cleared of vegetation on each side of the channel: total floodway width ranged from 1,000 to 1,400 feet (ft). Reclamation (1961) describes channelizing additional reaches, constructing drains and levees, and installing Kellner jetty jacks. As the era of channelization came to an end, the United States Army Corps of Engineers (USACE) constructed Cochiti Dam for flood control, which began impounding water in 1973. The dam significantly reduced the flood peaks and bedload supply, thereby altering the morphology of the downstream channel (Lagasse 1980; Makar and AuBuchon 2012). Greimann and Holste (2018) describe how the channel continued to narrow between 1962 and 2012 throughout the MRG. The onset of a drought in 2000 lowered the Elephant Butte Reservoir pool elevation and required excavating a channel through the delta to maintain surface flow connection between the river and reservoir.

Water managers continue to face the challenges of balancing human uses, infrastructure protection, and ecosystem needs. The most pressing of these challenges are New Mexico's current Rio Grande Compact debt and the management of five native species listed as threatened or endangered under the Endangered Species Act (ESA). The listed species are the New Mexico Meadow Jumping Mouse, Pecos Sunflower, Yellow-Billed Cuckoo (YBCU), Southwestern Willow Flycatcher (SWFL), and Rio Grande Silvery Minnow (RGSM). These challenges are most severe during periods of drought, such as 1950 to 1978 and 2000 to the present. The cumulative effects of human impacts to the river are decreased flow and increased lateral stability. Decreased river flow results from water use and diversions throughout the MRG and upstream dams controlling flood peaks. Increased stability and confinement from levees, bridges, channelization, jetty jacks, and bank protection have limited floodplain width, avulsions, and lateral migration. In the lower San Acacia Reach, decreased flow combined with the flatter slope approaching the reservoir delta causes the river to not transport the sediment supplied from upstream, and increased lateral stability confines deposited sediment to a relatively narrow area. Addressing these limiting factors should help meet the project goals of water delivery, ecosystem health, and maintenance benefits.

1.5 Key Issues and Considerations

Early in the planning process, Reclamation and its partners identified issues within the lower San Acacia Reach during workshops. Most issues within the lower San Acacia Reach are caused by a sediment transport imbalance or discontinuity owing to high sediment loads and the downstream base-level control of the Elephant Butte Reservoir pool. Essentially, geomorphic processes and prevailing trends are often at odds with the project goals and system constraints.

1.5.1 Channel Perching

Perching is generally defined as being on high ground or above another feature. For example, perched channel bed and banks are above the floodplain, and a perched floodplain is above the valley floor. Surface water and groundwater flow from high to low elevation along a hydraulic gradient, meaning that rivers naturally find the lowest point in a valley unless constrained. Like other rivers throughout history, people have moved the MRG away from its natural course to create larger, better drained fields for agriculture and to make space to build roads or railways. Channel perching occurs when high sediment loads are deposited on the bed and banks while the channel is not actively migrating or avulsing. Floodplain perching occurs when overbank sediment deposition is limited to a fraction of the valley width. Over a period of years to decades, a channel and floodplain can become perched if sediment deposits in the same location rather than intermittently shifting across the valley. A perched channel and floodplain are the cause of many of the issues within the lower San Acacia Reach because perching decreases the efficiency of downstream water and sediment movement.

In the lower San Acacia Reach the channel bed is perched above the floodplain, water table, and valley. There are two types of perching in the lower San Acacia Reach. First, the current floodplain east of the spoil levee is perched above the valley floor where the historical floodplain existed prior to river channelization and LFCC construction. The LFCC intercepts an unknown portion of the seepage from the perched floodplain enabling adjoining lands to be irrigable. Alternatives B and C partially address this perching by providing additional sediment depositional areas across the valley to the west of the spoil levee, thereby reducing elevations of floodplain sediment deposition. The currently incised main channel has reduced overbank flows, which limits this larger scale perching. Should the reservoir fill to near or at capacity in the future, sediment deposition will resume within the channel and floodplain corridor. For the reach upstream of the project area and Alternative A within the project area, future sediment deposition will further increase perching east of the spoil levee above the valley floor.

The second type of perching is the channel within the active floodplain, which is the space accessible to flows between geologic or infrastructure constraints. In this second type of perching, channel banks are perched above the adjacent floodplain, also known as natural levees. An aggraded riverbed above the water table elevation increases seepage loss and river drying. Perching reduces in-channel discharge at all flows and can strand water in the floodplain during overbanking, which reduces sediment transport capacity causing deposition and reduced conveyance. Perching increases sediment concentrations in the main channel, allowing sediment plugs to form which can then lead to levee breeches and significant losses as water spills into low-elevation areas disconnected from the main channel (Figure 3).

Perching is not a new phenomenon on the MRG, and the channel periodically become perched prior to the 1950s channelization. Historically, when the channel was perched high enough above the adjacent floodplain, the next flood event would cause an avulsion that moved the channel to a lower elevation (Massong et al. 2010). The river experienced high water losses during low flow years between avulsion-generating flood events (Figure 3). Avulsions have been limited since the 1950s because of lower peak flows, dense riparian vegetation, and channel and levee stabilization. Channel and floodplain perching has continued to increase without avulsions to periodically reset the river.

Figure 3.—Aerial photo from 1952 showing the river altering course due to the formation of a sediment plug within the San Acacia Reach above the Tiffany Basin. Low flows and dense vegetation prevented the river from cutting a new channel through the floodplain, losing surface flow connection in the upper left of the photo.

1.5.2 Conveyance Losses

Efficient delivery of water depends on minimizing losses from the river system. Within the Middle Rio Grande, several factors contribute to conveyance losses. Evapotranspiration, the combination of transpiration, water vapor released from plant leaves, and evaporation, water vapor transferred from open water and moist soil to the air, can significantly reduce flows (S.S. Papadopulos & Associates, Inc. 2000). The rate of evapotranspiration depends on vegetation density and species, depth to groundwater, surface area of open water, temperature, humidity, and wind. When in-channel flows are reduced to only a few cubic feet per second (cfs) the diurnal evapotranspiration cycle causes the variability of the in-channel discharge to increase, sometimes causing the channel to dry completely during the peak heat of the day.

Seepage, the infiltration of surface water into the ground, is another contributor to water loss. The rate of water loss due to seepage depends on the gradient to the water table, as well as soil properties. Between RM 87 and 64 the Rio Grande channel bed is perched an average of 10 feet above the Low Flow Conveyance Channel water surface, which is the valley drain and low point.

Stranded water, water that remains ponded and does not return to the river after an overbanking event, occurs when the floodplain is disconnected from the main channel during hydrograph recession. This can be caused by channel aggradation and the resulting channel perching. Stranded water results from channel banks that are higher than the floodplain. There is a one-way connection where flow overtops the channel and deposits suspended sediment on the banks, but the bank elevation increases faster than the floodplain elevation so that there is no return path for overbanking flow. The discharge at which overbanking occurs within the lower San Acacia Reach varies. Upstream of the BDA South Boundary, flow events above 2,000 cfs generally cause overbanking and move a significant amount of water to isolated, low-elevation floodplain areas. Overbanking downstream of the BDA South Boundary occurred at similar flows during the 1990s through mid-2000s but has been limited by channel incision in recent years. Stranded water evaporates or infiltrates and reduces the quantity of water delivered to the reservoir. Reaches that are currently incised receive overbanking flow from further upstream that becomes stranded in the floodplain.

1.5.3 Decline in Ecosystem Health

Historically a wide and shallow river, the Rio Grande now presents a narrow and uniform channel. Likely in response to changes in habitat conditions, the Rio Grande Silvery Minnow was listed as an endangered species in 1994 and the Southwestern Willow Flycatcher in 1995. Both species and their habitat require frequent floodplain inundation or proximity to thrive. Low-velocity inundated floodplain and near channel areas retain Rio Grande Silvery Minnow eggs and provide a place for larvae to develop. Less frequent floodplain inundation stresses native vegetation and allows invasive phreatophytes to dominate riparian areas, reducing the native habitat available for the Southwestern Willow Flycatcher. Flycatchers are now found nesting in tamarisk, which is defoliated by the Tamarisk beetle during the breeding season and can leave birds and their nests susceptible to extreme heat and predators. Additionally, drought or defoliation by the tamarisk beetle dries out the vegetation increasing fire risk. Climate change is also a factor in the decline of ecosystem health and water resources in the project area (Dunbar et al. 2022; Holmes et al. 2022).

1.5.4 Aging Infrastructure

Construction of the LFCC began in 1951 and was completed in 1959 to improve water delivery during a drought. From 1979 to 1999, the average annual flow of the Rio Grande was much greater than in the previous 30 years. As a result, Elephant Butte Reservoir remained relatively full starting in 1985. The higher flows and reservoir levels with coinciding sediment deposition created a new set of management problems.

As the reservoir filled, the lowest reaches of the channel system were inundated, buried in sediment, and maintaining an outlet for the LFCC became increasingly difficult. Diversions from the river at San Acacia during high flow events in the early to mid-1980s brought high sediment loads into the LFCC. Sediment transported within the LFCC then deposited near RM 60 due to backwater from the rising reservoir pool, which filled the outlet from the LFCC to the river. For this reason, diversions from the Rio Grande to the LFCC were suspended in 1985.

While the LFCC no longer functions as designed it is still maintained as a drain for the valley. Due to access issues and cost the LFCC is only maintained to RM 60. In 1987 the river breached the spoil levee and avulsed into the LFCC at RM 60. Water from the LFCC now flows in a historical side channel along the western margin of the valley and converges with the river downstream at RM 54.5. Construction is ongoing in spring and summer 2023 to install culverts that will discharge water from the LFCC to the main channel at RM 60. Holste et al. (2023) developed a monitoring and adaptive management plan to address potential impacts to a large avian habitat area along the western side channel, downstream of RM 60, termed LFCC West. Further analysis and monitoring of the potential impacts to endangered avian habitat is required, as well as determining the downstream extent of the LFCC function to best meet the needs within the lower San Acacia Reach.

2.0 Geomorphic Dynamics

The purpose and need for the project, and the key issues and considerations described above, derive from the geomorphic dynamics of the river and floodplain. Existing conditions are the integrated outcome of centuries of watershed factors and system inputs that drive the evolution of the channel and floodplain. For a large, reach-scale project it is essential to understand the history of the river and why it has evolved the way it has. A thorough analysis of the reach geomorphic dynamics provides an opportunity to identify causes and effects and to develop geomorphically-compatible designs that will be successful in the short-term and long-term.

2.1 Drivers and Controls

At the reach scale, the primary drivers of geomorphic evolution are the water discharge and sediment load inputs from upstream. Anthropogenic actions are also a driver of channel change. The primary control is the downstream base-level elevation of the Elephant Butte Reservoir pool. Riparian vegetation also controls channel adjustment by adding cohesion to banks and increasing the floodplain roughness. Changes to the drivers and controls throughout time govern the response of the alluvial channel and floodplain. Therefore, analyzing the hydrology, sediment, and Elephant Butte pool elevation provides insight about the timing and magnitude of morphologic adjustments and the corresponding adjustments to endangered species habitats.

2.1.1 Hydrology

Water provides energy to rework the alluvial system through erosion and local scour while also delivering sediment transported from upstream. Important elements of the hydrograph include peak flow magnitude, duration of high flow and base flow, and timing. Seasonal and interannual flow variability drives geomorphic variability; rivers with relatively constant hydrographs tend to be narrower and more uniform (Knighton 1998). Flow has been measured by the USGS in the middle of the project reach at San Marcial since 1899. Gages 08358500 (1899–1964) and 08358400 (1949–present) are termed “floodway” gages, meaning they record discharge in the main channel and adjacent floodplain. Gage 08358300 records discharge in the LFCC. Floodway data between 1899 and 1924 are not consistently reported, so flow analysis for this study begins in 1925. The LFCC gage was installed in 1951 when the LFCC was constructed. Figure 4 and Figure 5 are raster hydrographs of mean daily flow for the floodway and LFCC, respectively. The plots show seasonal trends on the x-axis and differences between years on the y-axis. Notable characteristics of the floodway data are larger snowmelt runoff events in May and June before 1950 and between 1979 and 1999. Low flows in the floodway, and higher flows in the LFCC, represent nearly all flow from the river being diverted into the LFCC between the mid-1950s and mid-1970s.

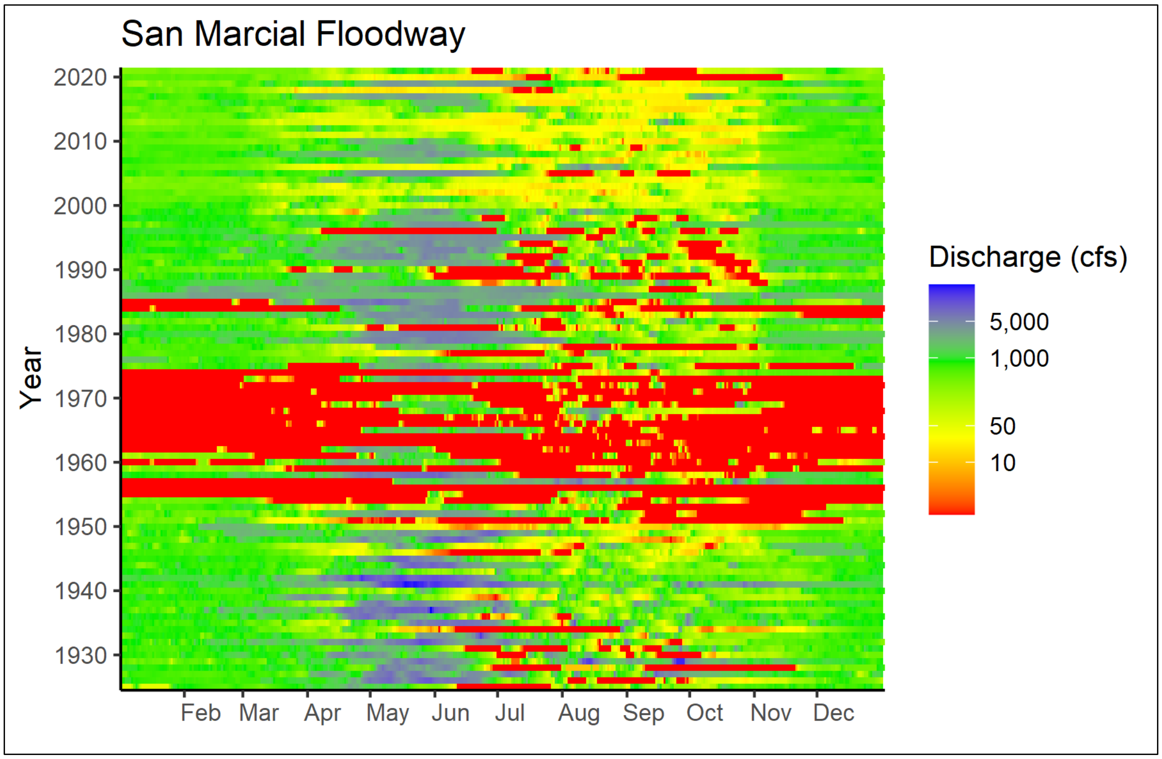


Figure 4.—Mean daily flow at San Marcial Floodway (USGS Gages 08358500 and 08358400), 1925–2021.

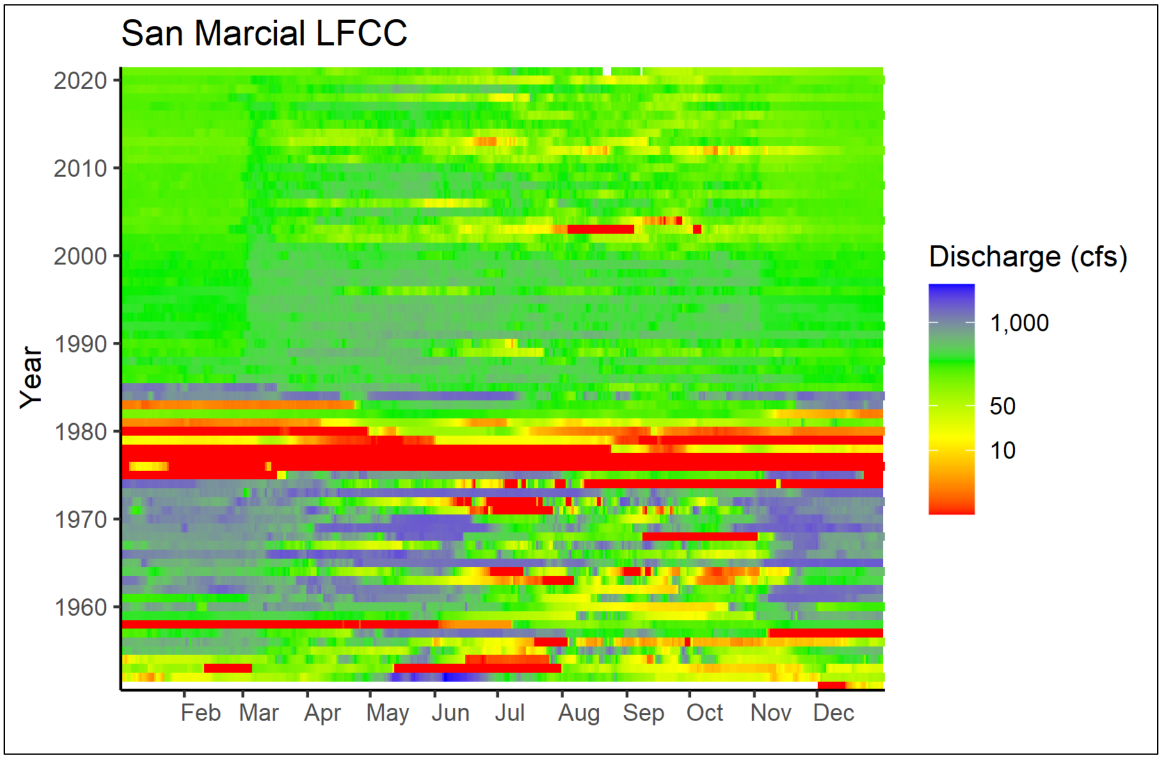


Figure 5.—Mean daily flow at San Marcial LFCC (USGS Gage 08358300), 1952–2021.

The raster hydrographs illustrate significantly different wet and dry periods that tend to alternate in 20-to-30-year cycles on the MRG. Figure 6 groups mean daily flow data for 1925 to 1949, 1950 to 1978, 1979 to 1999, and 2000 to 2021. For each period, lines on the graph represent the median discharge for a given day of the year. The 1925 to 1949 and 1979 to 1999 periods are similar with a large snowmelt runoff that typically peaks around 4,000 cfs in late May or early June. Flows during the other periods are much lower with minimal snowmelt runoff duration and magnitude. Monsoon events are important, but they are short-lived and the timing varies from year to year, so they are not reflected in the median discharge plots.

The difference in LFCC operation is evident when comparing the two dry periods because the median value in the river is 0 cfs for most days between 1950 and 1978, while there is flow in the river except for the summer months during 2000 to 2021. Figure 7 is a similar plot, except the periods are delineated by different LFCC operations. Unpublished Reclamation notes indicate that the LFCC was breached at Tiffany Junction in 1975 and water was diverted into the floodway through 1983 while the LFCC was rehabilitated. The LFCC resumed operations during 1984 and 1985 before inundation and sedimentation filled the outlet up to RM 60. The LFCC has acted as a drain for shallow groundwater and irrigation return flows since 1986, except for periodic experimental operations from San Acacia to Escondida in the late 1990s.

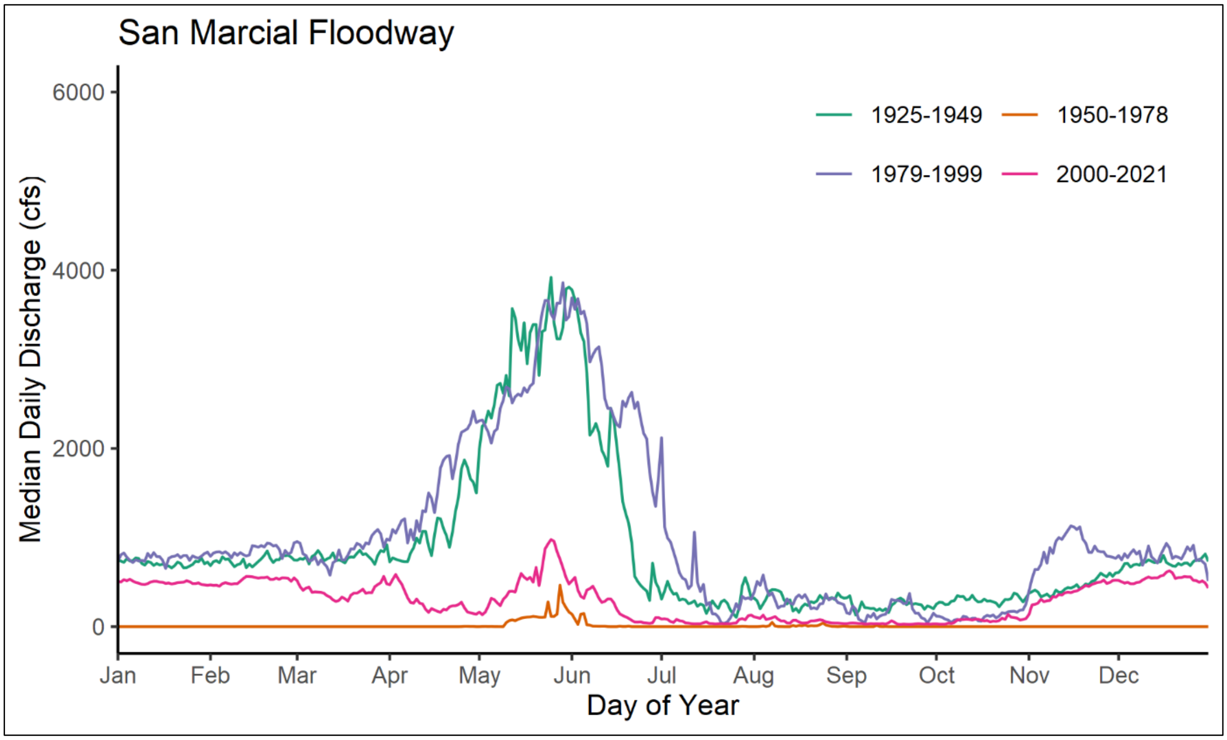


Figure 6.—Median daily flow at San Marcial Floodway (USGS Gages 08358500 and 08358400) showing wet and dry periods for 1925–2021.

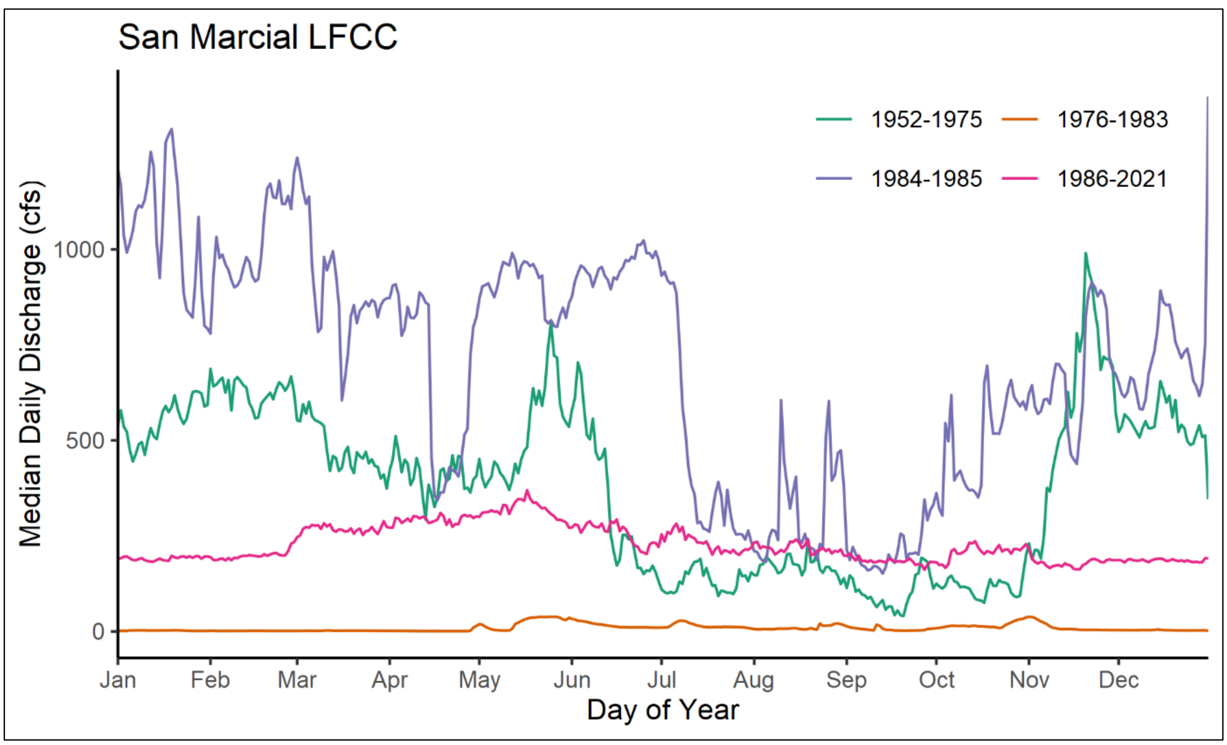


Figure 7.—Median daily flow at San Marcial LFCC (USGS Gage 08358300) showing different operational scenarios for 1952–2021.

Figure 8 and Figure 9 summarize several important hydrology metrics for the floodway and LFCC, respectively. The upper left panel presents the cumulative flow volume where the slope of the line is steeper for wet periods and flatter for dry periods. Breaks in slope correspond to the climatic or operational periods shown in previous figures. The upper right panel presents the annual peak flow with the timing delineated as either snowmelt (March through June) or monsoon (July through October). Before 1950 peak flow events frequently exceeded 10,000 cfs in the floodway. The 1980s had similar flow volumes but much lower peaks due to upstream dams. Annual median discharge is presented in the middle left panel while annual base flow (90% mean daily flow exceedance) is in the middle right panel. Black lines show the moving average for the previous 10 years. Median and base flow demonstrate similar temporal and operational trends as the other flow metrics. Finally, the bottom panels present ratios of the annual peak discharge to the annual median discharge or base flow. These ratios correlate to geomorphic variability for many rivers but are less instructive for the lower San Acacia Reach because of the number of zero flow days.

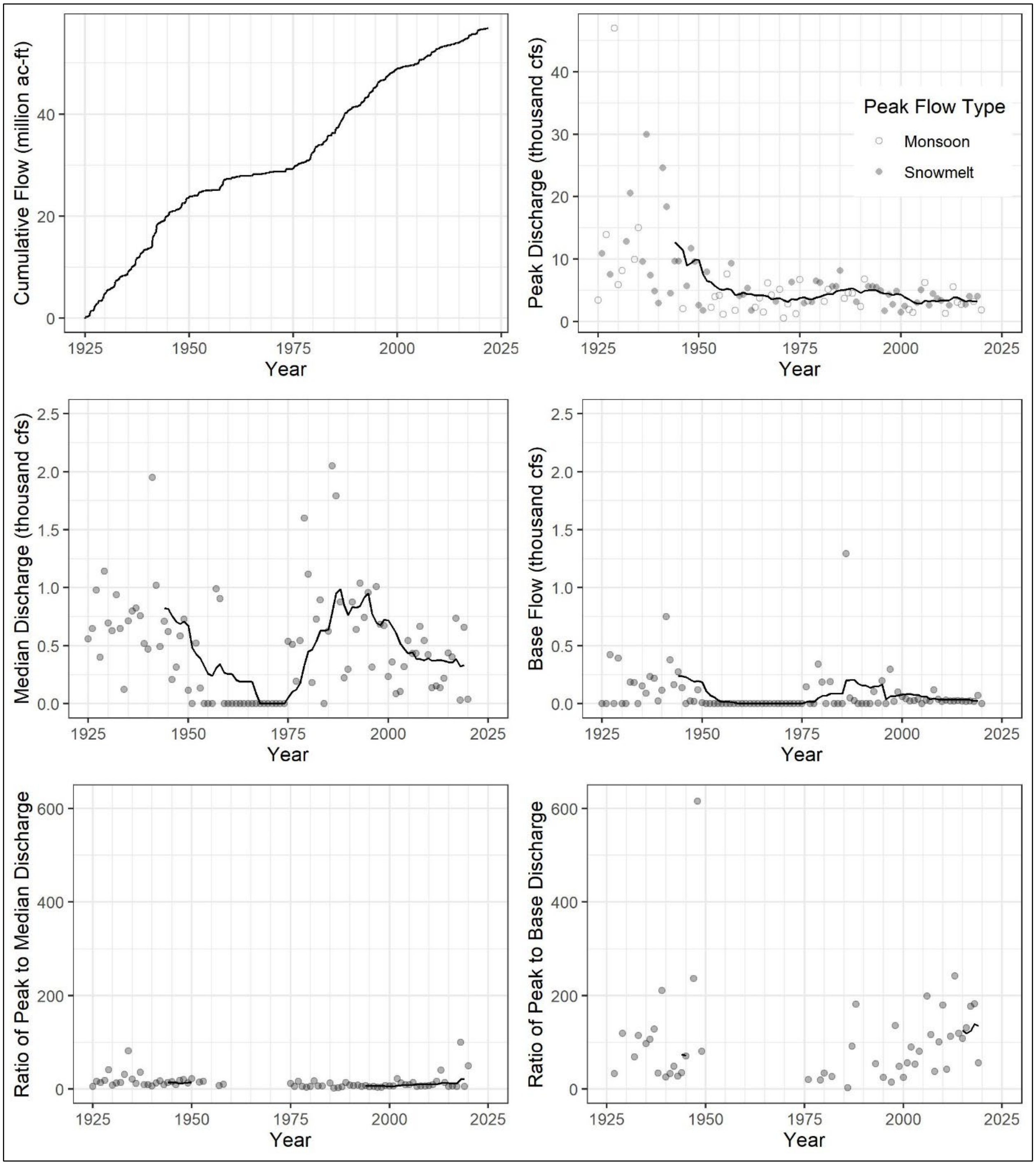


Figure 8.—Hydrology metrics at San Marcial Floodway (USGS Gages 08358500 and 08358400), 1925–2021. Annual ratios are not calculated when median or base discharge is zero.

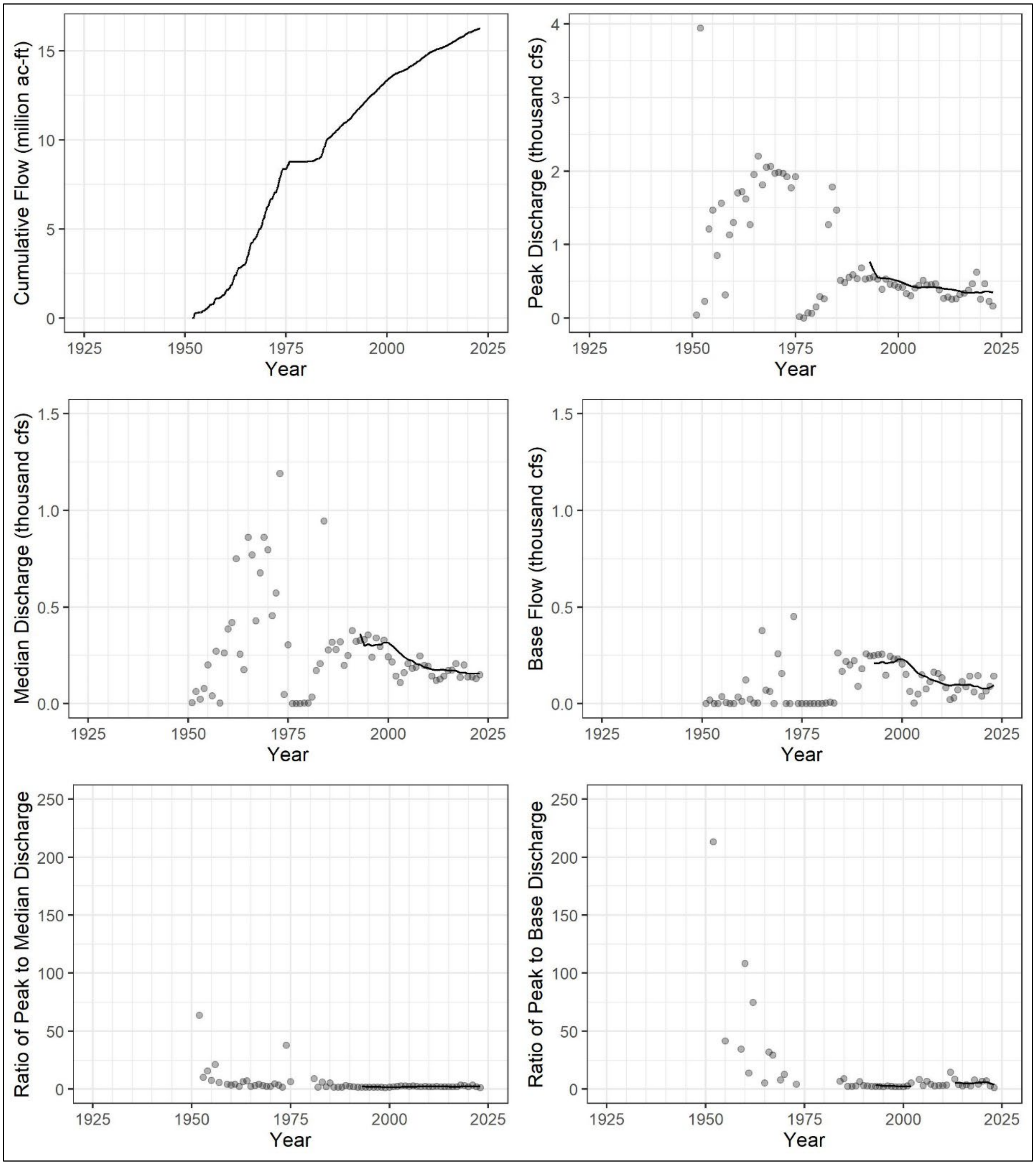


Figure 9.—Hydrology metrics at San Marcial LFCC (USGS Gage 08358300, 1952–2021). Peak discharge is annual maximum mean daily flow because USGS instantaneous peak data is only available from 1990 to 2021. Annual ratios are not calculated when median or base discharge is zero.

Figure 10 demonstrates the combined effect of LFCC operations and river flows. Mean annual flow data are plotted for the floodway gage and the combined floodway discharge added to the LFCC discharge. Symbology also distinguishes three temporal scales: annual, 10-year average, and historical average (1925 to 2021). Blue colors indicate years or periods that were above average (wet) and red colors indicate years or periods that were below average (dry). Comparing the two wet periods, the 1980s–1990s had lower flows in the river but higher total valley surface flow than the period before 1950. Comparing the two dry periods, recent years have similar total flows as the 1950s–1970s, but recent years have much larger flows in the river because of not actively diverting into the LFCC.

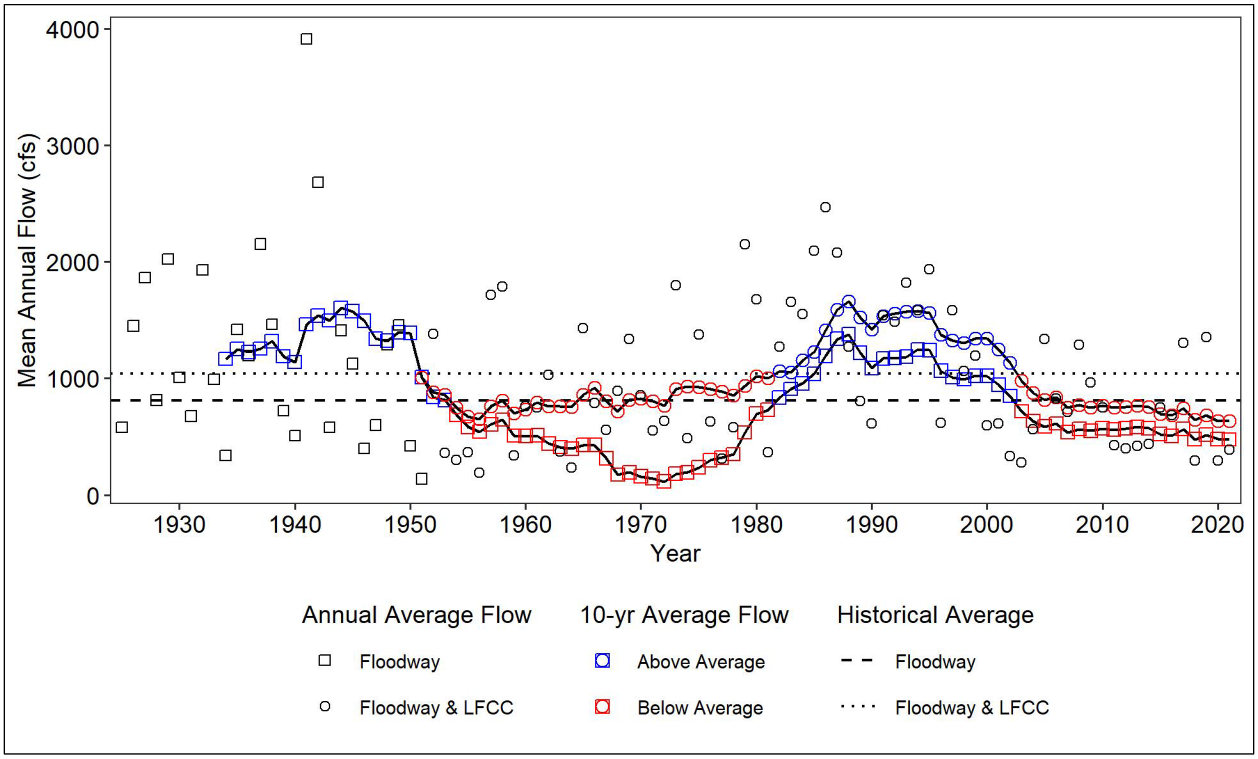


Figure 10.—Comparison of San Marcial Floodway to combined Floodway and LFCC gages showing the relative contribution of LFCC discharge. Solid black lines represent average of 10 previous years. Starting in 1952, the upper line connecting the 10-year flow data combines the LFCC and the Floodway, while the lower line is the Floodway only.

The percentage of flow in the LFCC has varied annually and seasonally depending on operations and climatic wet or dry periods. Figure 12 illustrates that the LFCC conveyed an average of 68% of the total surface flow at San Marcial between 1952 and 1975 with some years (1956, 1963, 1964, 1966, 1971) at 99% or 100%. This percentage decreased to 5% during 1976 to 1983 and then increased to 41% during 1984 to 1985. Since 1986 when the LFCC has functioned primarily as a drain, the LFCC has conveyed an average of 28% of the total valley surface flow at San Marcial. Figure 12 uses the full period of record from 1952 to 2022 and averages the flow for each month. LFCC discharge is relatively constant across seasons while the river discharge fluctuates significantly. The LFCC percentage approaches 50% during September and October when flows in the river are lowest.

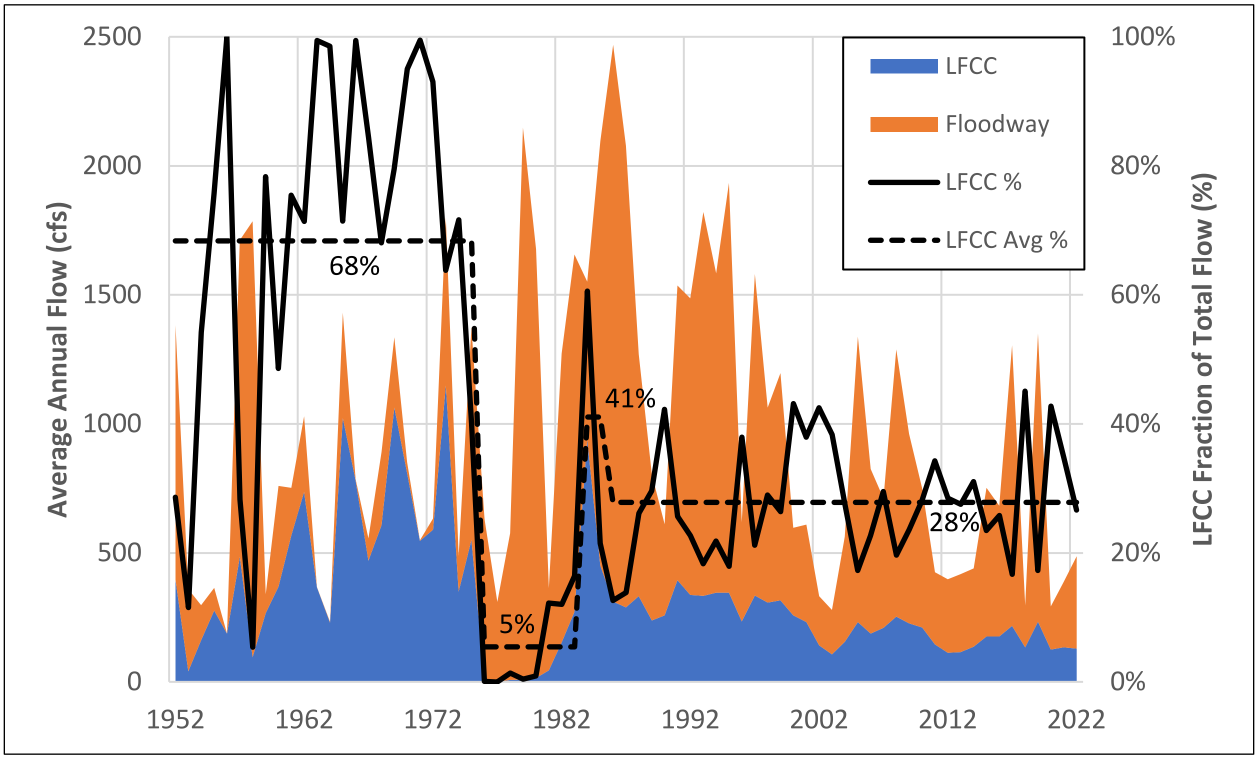


Figure 11.—LFCC discharge as percentage of total flow for operational periods 1952–1975, 1976–1983, 1984–1985, and 1986–2022.

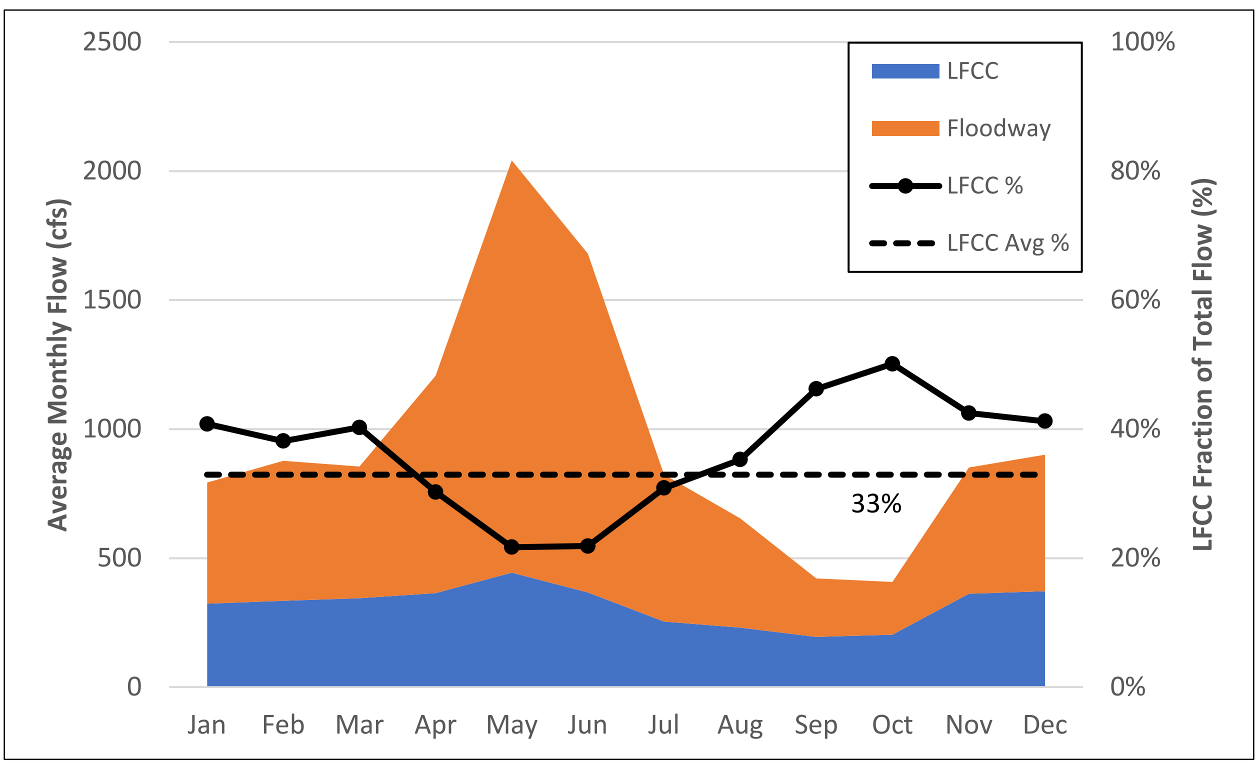


Figure 12.—Average monthly flow for San Marcial Floodway and LFCC gages, 1952–2022.

2.1.2 Sediment Load

Sediment transport is a function of river discharge, but the magnitude and gradation of the sediment load also depends on watershed factors and seasonal characteristics. Larger flows have more capacity to transport sediment, so transport rates increase with flow. Rain events deliver more sediment from overland areas and tributaries, whereas snowmelt events have more capacity to erode sediment from the bed and banks of the channel. Sediment load consists of bedload and suspended load. Bedload is sediment that maintains frequent contact with the bed while moving downstream by rolling, bouncing, or saltating. Suspended load is carried higher in the water column and has smaller particle sizes. Suspended load is measured at the USGS San Marcial floodway gage and was measured at the LFCC gage from late 1955 through 1994. Bedload is not measured at the gages so analysis in this section relies on suspended load data.

Figure 13 presents the cumulative suspended sediment load at the San Marcial floodway gage beginning in calendar year 1957. The slope of the line represents the sediment load per day moving past the San Marcial gage. Periods where the line has a steep slope represent events that transported high sediment loads, while periods where the line has a flatter slope represent lower sediment loads. Sediment loads are generally higher during wet periods and lower during dry periods and have also decreased over time. Figure 14 separates the suspended sediment load into seasons. Snowmelt is defined as March through June, monsoon is defined as July through October, and winter is defined as November through February. During years with a long duration snowmelt runoff, seasonal analysis delayed the delineation for the start of monsoon season after July 1 until the snowmelt runoff receded below 1,000 cfs. Relatively little sediment is transported during the winter and most sediment moves during snowmelt or monsoon runoff. Since 1957, slightly more sediment has been transported during the snowmelt season, but this is influenced by large snowmelt events in 1957 and 1958. Since 1959, monsoons have transported more sediment than any other season.

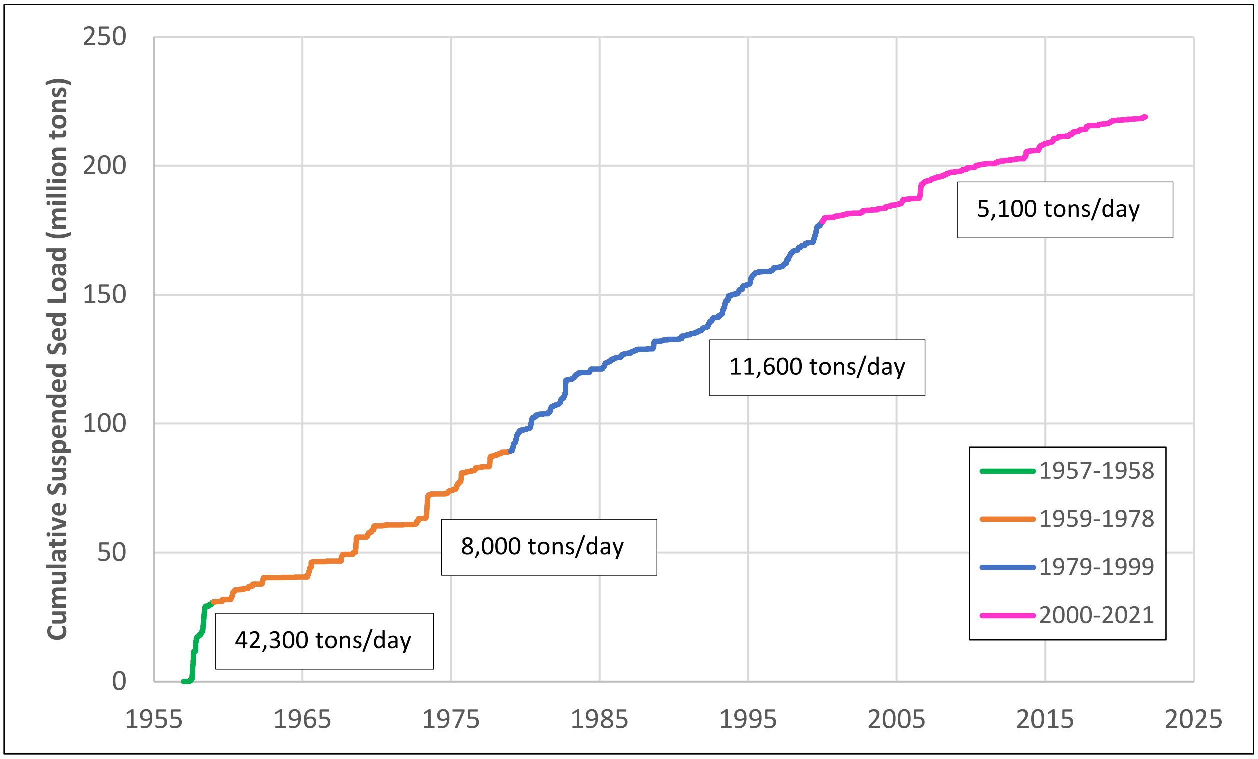


Figure 13.—Cumulative suspended sediment load over time at San Marcial Floodway (USGS Gage 08358400), 1957–2021. Slope of line represents rate of sediment transport.

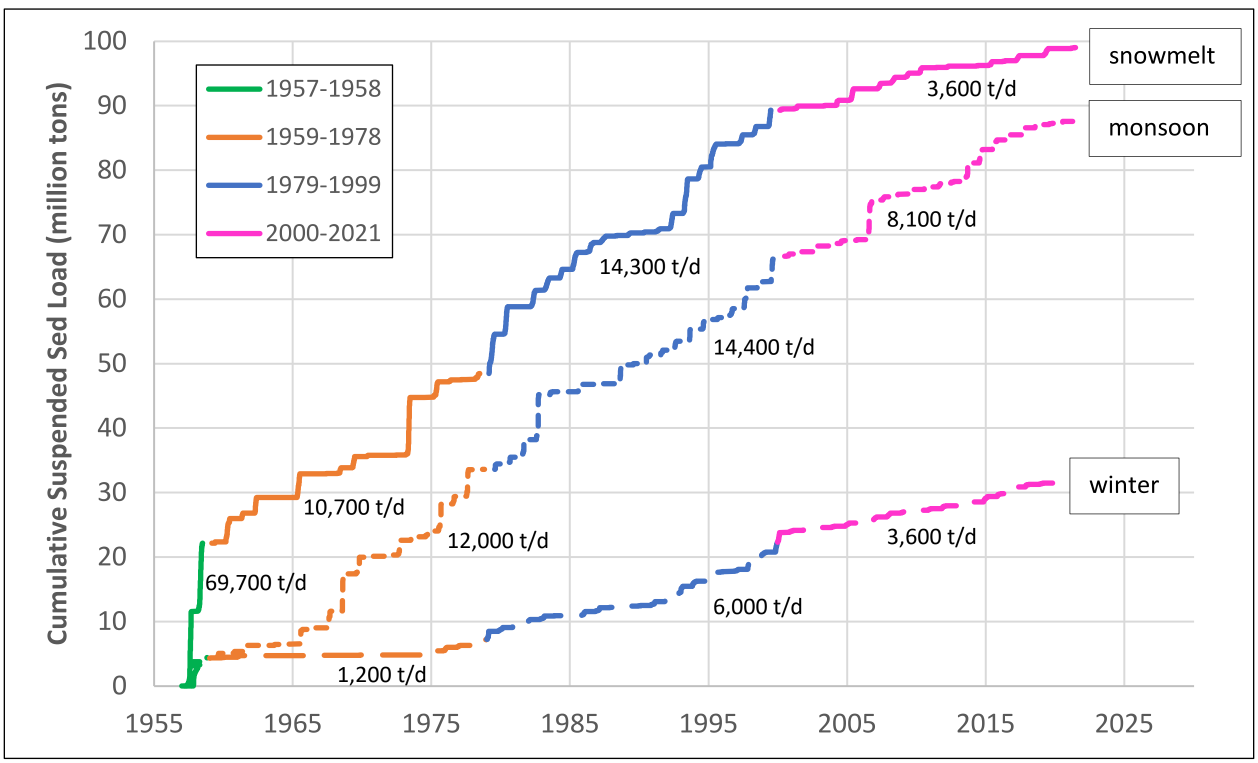


Figure 14.—Cumulative suspended sediment load at San Marcial Floodway during 1957–2021, separated into snowmelt (solid line), monsoon (short dash), and winter (long dash) seasons.

Figure 15 and Figure 16 present similar plots but show the cumulative suspended sediment load as a function of water discharge rather than time. These figures demonstrate the relationship between water and sediment because the slope of the line represents sediment concentration as mass per volume (milligrams per liter or mg/L). Sediment concentration reflects changes in land use and upstream dams rather than the effects of wet or dry periods. There is a notable change in sediment concentration in 1974 that corresponds to Cochiti Dam. Even though San Marcial is about 160 miles downstream, the sediment regime is still affected by storage at Cochiti. The mid-1980s had several large snowmelt events with relatively few monsoons, resulting in the lowest sediment concentrations. Overall, suspended sediment concentrations at San Marcial during the last few decades are about 30% of the pre-Cochiti period.

Sediment concentrations also vary significantly by season. Concentrations during snowmelt runoff are typically 20% to 40% of concentrations during the monsoon season. The snowmelt and monsoon seasons have transported a similar cumulative sediment load since 1957, but the cumulative water discharge in the river during the monsoon season has only been about 20% of the discharge during snowmelt season. Figure 17 summarizes the temporal and seasonal trends for water and sediment discharge by comparing annual averages. Lighter colors represent the monsoon season, medium colors represent the snowmelt season, and the darkest colors represent the winter season. For all periods, the proportion of sediment transported during the monsoon season is much larger than the proportion of water discharge. However, 1957 to 1973 and 1989 to 1999 had higher sediment loads during snowmelt runoff whereas 1974 to 1982 and 2000 to 2021 had higher sediment loads during the monsoon season. Earlier periods had relatively larger sediment loads compared to the water discharge, and the relationship has been more balanced in recent years. Seasonal differences remain significant during 2000 to 2021 because the snowmelt and winter had larger proportions of water discharge and the monsoon season had the largest proportion of sediment load.

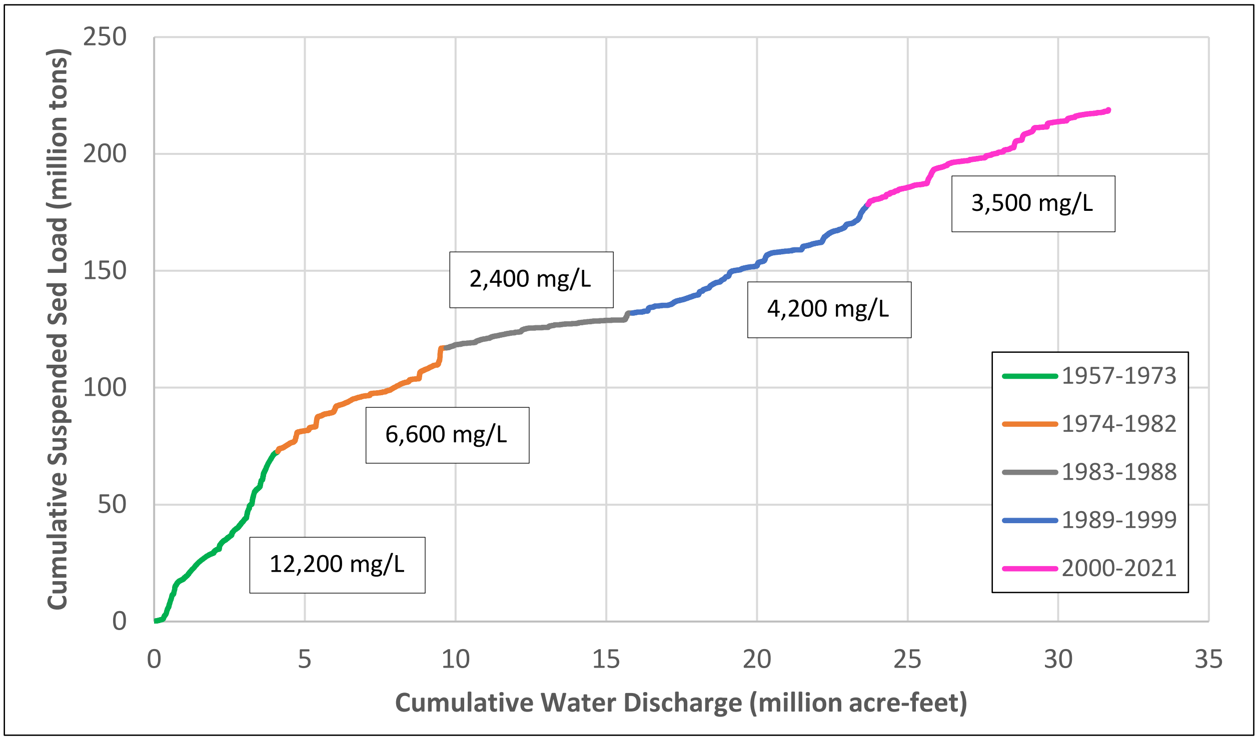


Figure 15.—Cumulative suspended sediment load as a function of water discharge at San Marcial Floodway (USGS Gage 08358400), 1957–2021. Slope of line represents sediment concentration.

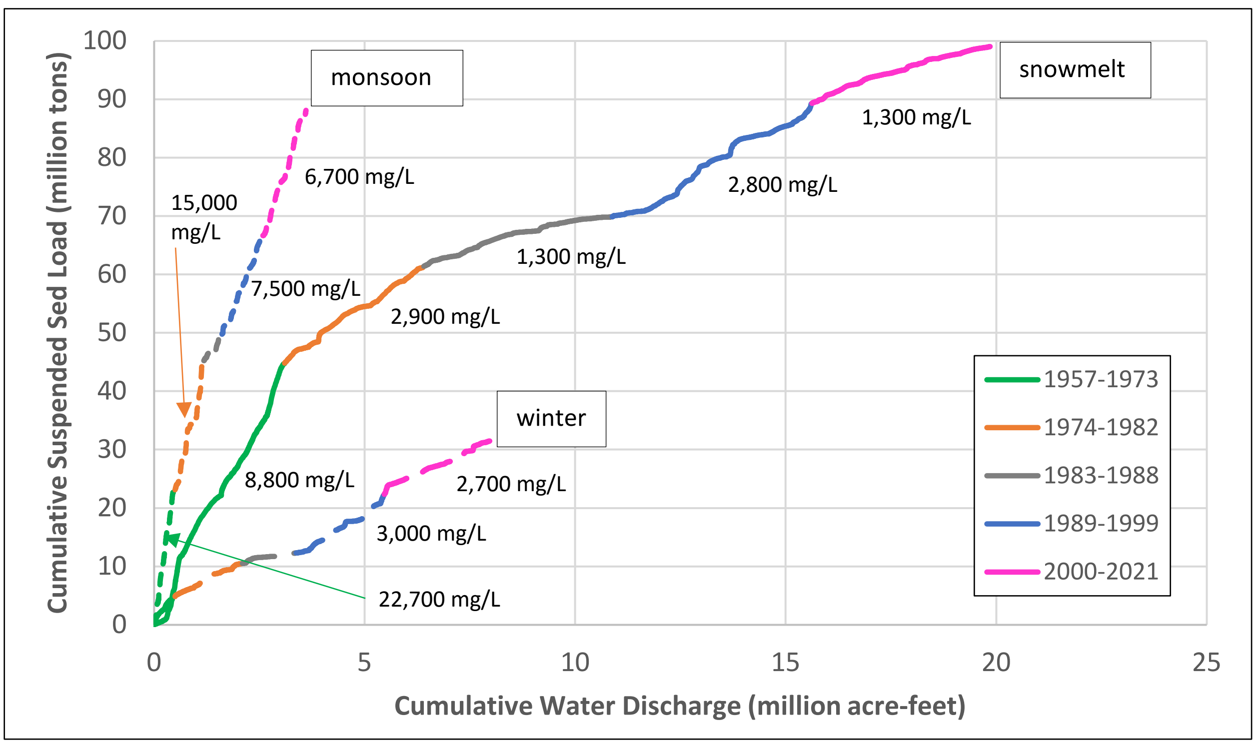


Figure 16.—Cumulative suspended sediment load as a function of water discharge at San Marcial Floodway during 1957–2021, separated into snowmelt, monsoon, and winter seasons.

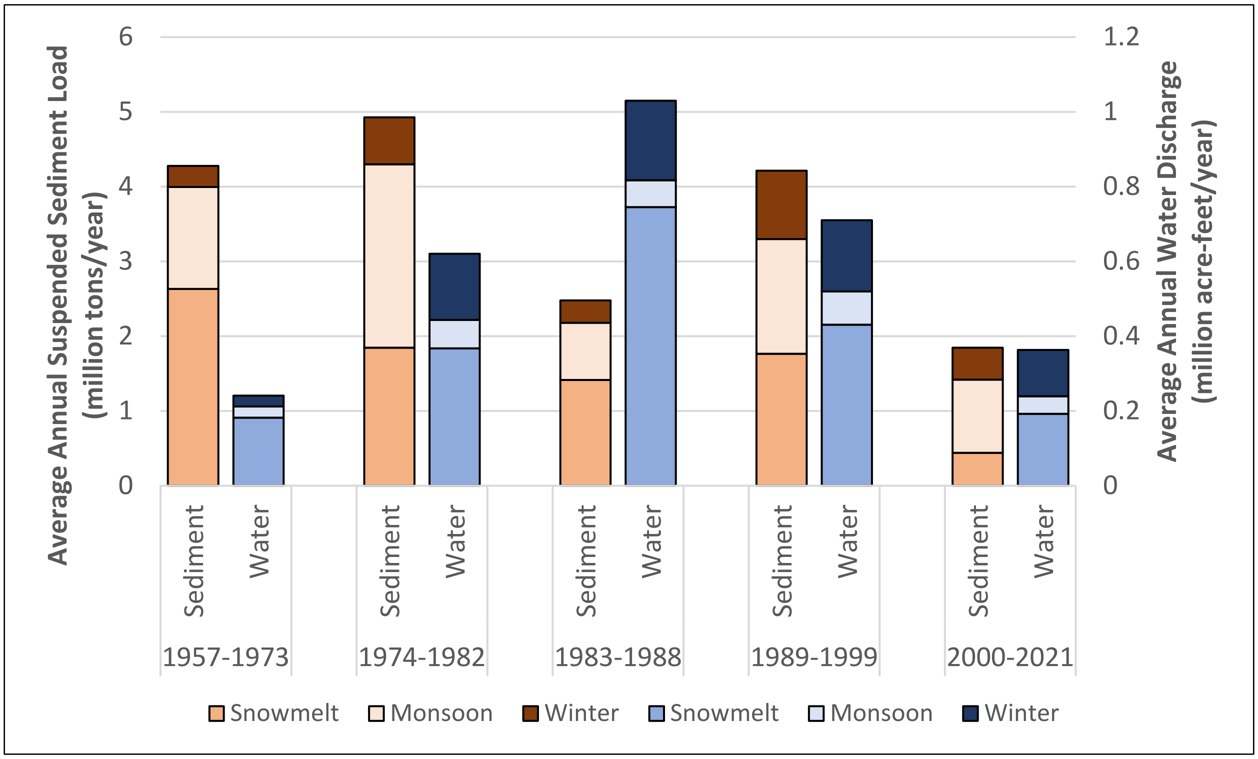


Figure 17.—Comparison of average annual suspended sediment load and water volume at San Marcial Floodway during 1957–2021. Stacked bars comprise snowmelt, monsoon, and winter seasons.

2.1.3 Elephant Butte Reservoir

Elephant Butte Reservoir plays a significant role in the geomorphology of the project area because the pool elevation controls the slope and the bed elevation of the upstream channel. Figure 18 is a conceptual geomorphic evolution model that relates the longitudinal profile, planform, and cross section of the delta channel to the reservoir pool elevation. When the reservoir pool is constant, the delta slowly progrades further downstream while transitioning from a single thread to multi-thread channel. There is mild aggradation as velocity slows and sediment deposits at the interface between the river and reservoir. When the reservoir pool rises, the delta moves upstream along with the pivot point where the slope changes between the flatter upstream topset slope and the steeper downstream foreset slope. As the pool rises, the planform evolves to a distributary channel network and sediment deposits on the bed and banks. Periods of rising or high reservoir levels cause the largest rates of deposition in the upstream channel and floodplain. When the reservoir pool falls, the slope becomes significantly steeper, and areas of former sediment deposits erode as the channel incises and the delta moves downstream to follow the lower reservoir pool. Channel incision and the lower reservoir pool cause the planform to transition from a multi-thread distributary network to a single thread channel.

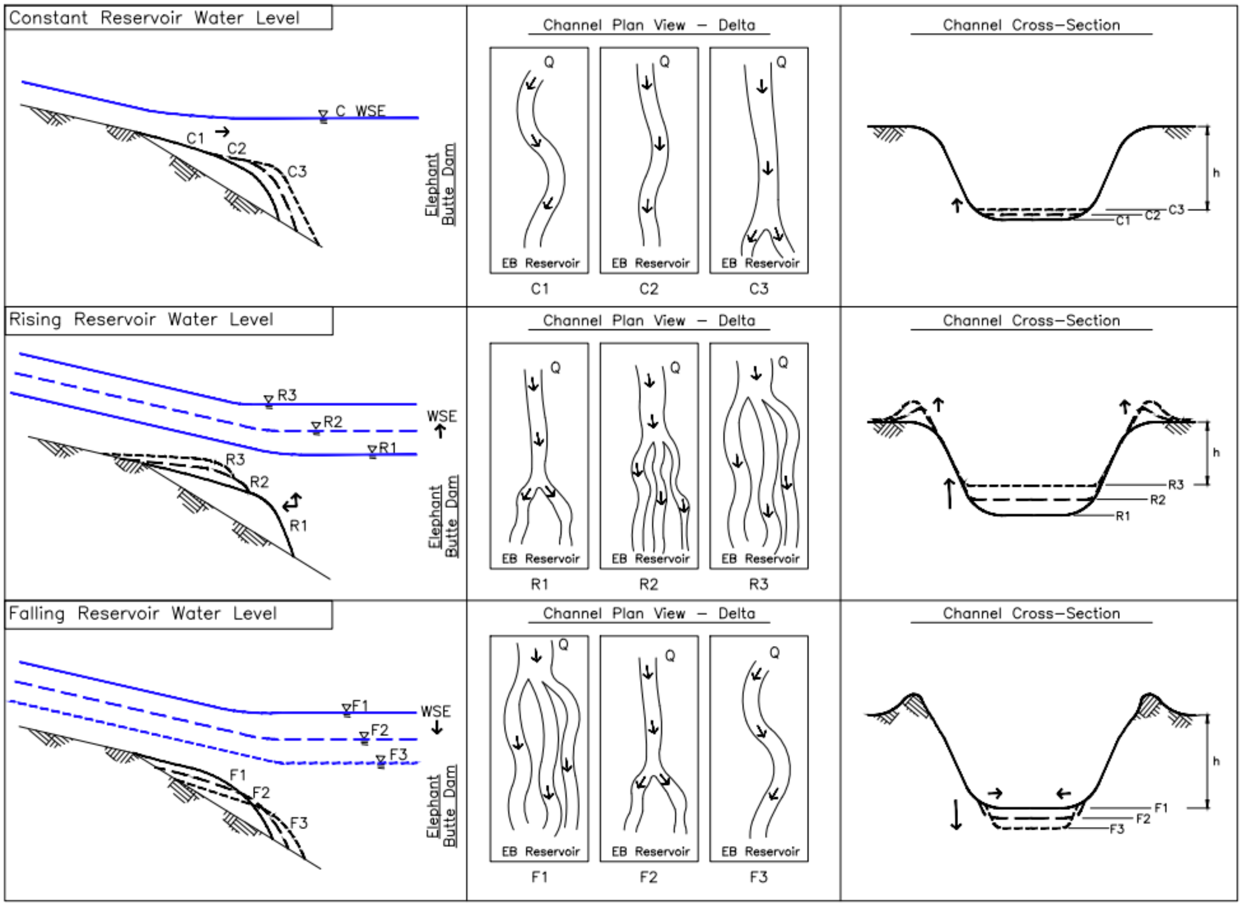


Figure 18.—Reservoir delta geomorphic evolution model (from Baird et al. 2023)

The Elephant Butte Reservoir pool has fluctuated dramatically based on climatic wet and dry periods. Elevation differences between the full pool and low pool are over 120 ft and spatial differences are over 25 river miles. Figure 19 overlays different pool elevations on a map of the project area. The full pool elevation of 4452.5 ft (NAVD88) intersects the river water surface and overbank topography between RM 60 and 61. The average pool elevation of 4392.5 ft (NAVD88), calculated between 1915 and 2021, extends from the dam to about RM 42. A recent low pool elevation, measured in January 2019 when lidar data were collected, intersects the river water surface and delta topography near RM 35.

Figure 20 illustrates these same reservoir pool elevations relative to longitudinal profiles of the river and delta. The profiles show the sedimentation that has developed since the dam was completed in 1915. Sedimentation causes a given reservoir pool elevation (e.g., full pool) to intersect the bed at locations that are farther downstream than the pre-dam profile. The longitudinal profiles demonstrate that the zone of thickest sedimentation is within the Narrows near the historical average pool elevation. The pivot point moved downstream from near rangeline EB-60 in 2007 to near Monticello Canyon in 2017 because the reservoir stayed low during this time. Because of the steeper foreset slope downstream of the Narrows, a pool elevation change of 50 ft translates to about 7 river miles. Upstream of the Narrows within the flatter foreset slope, a pool elevation change of 60 ft translates to about 18 river miles.

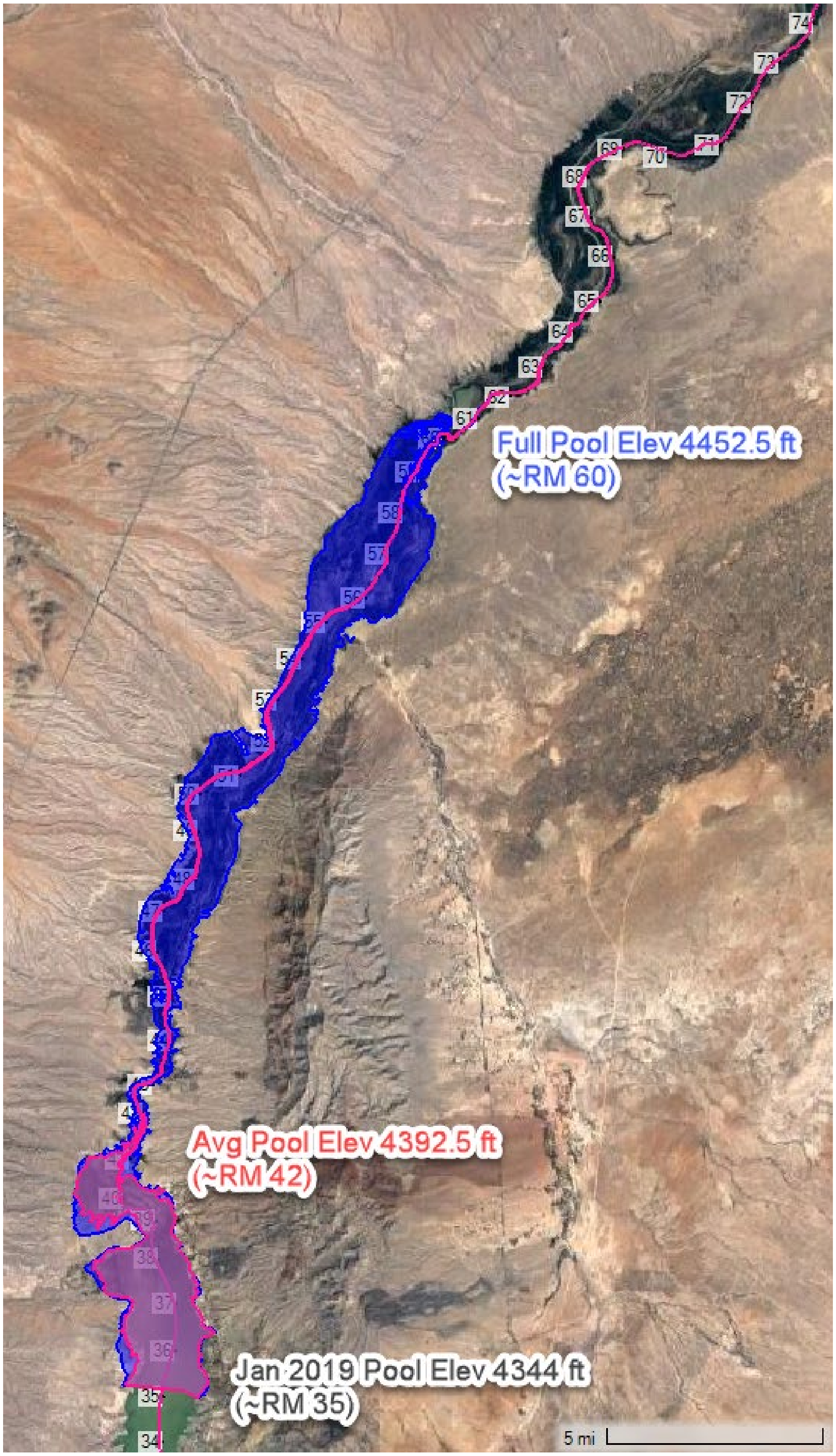


Figure 19.—Spatial extent of average (pink) and full pool (blue) reservoir elevations overlain on January 2019 terrain surface. River channel also shown in pink for reference.

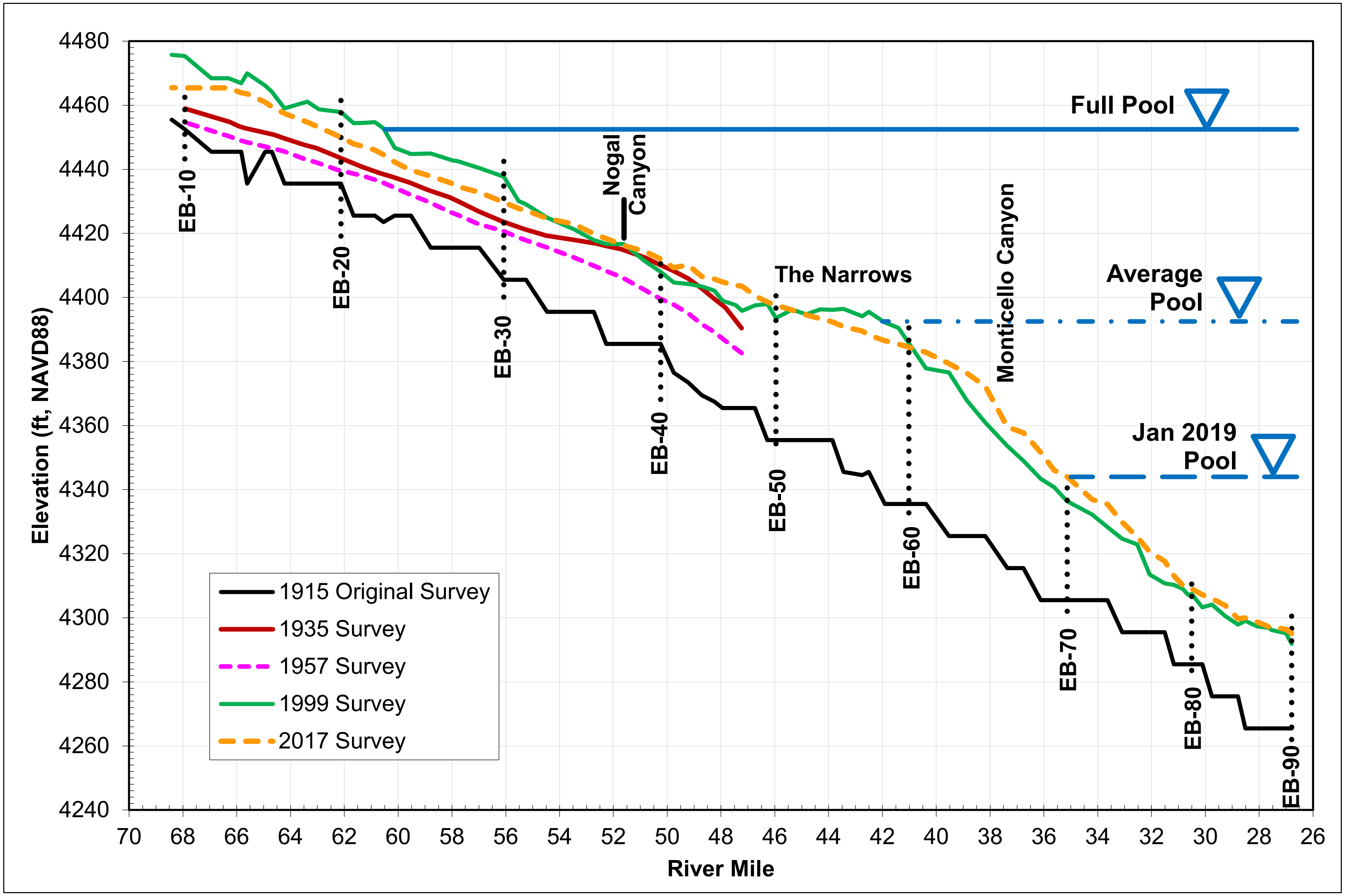


Figure 20.—Longitudinal extent of full pool, average pool, and January 2019 pool elevation overlain on reservoir longitudinal profiles (modified from Randle and Benoit, 2019). 1935 and 1999 profiles are at a high pool elevation, 1957 and 2017 profiles are at low pool.

Figure 21 links the reservoir pool changes to bed elevation adjustments at various locations upstream. The San Marcial floodway gage at RM 68.4 provides a continuous bed elevation record since 1899. The bed was aggrading prior to reservoir storage in 1915 due to high sediment load inputs from upstream tributary arroyos. The rate of aggradation increased in 1920 when the reservoir nearly filled. Aggradation continued until 1950 when the bed began to degrade, which continued until 1980 while the reservoir remained low. When the reservoir began rising in 1980, the cycle of bed aggradation resumed through 2005. A high flow snowmelt runoff in 2005, combined with construction of a channel to the reservoir pool and a low reservoir pool elevation, caused channel incision including a headcut to propagate upstream from the delta to near the BDA South Boundary. Locations upstream of San Marcial have continued to erode in recent years while downstream locations have maintained a relatively stable bed elevation. The figure illustrates that bed elevations are more sensitive to the reservoir pool at downstream locations. The bed near the reservoir shoreline responds quickly to changes in pool elevation, while the bed further upstream responds later in time and at a lower rate and magnitude.

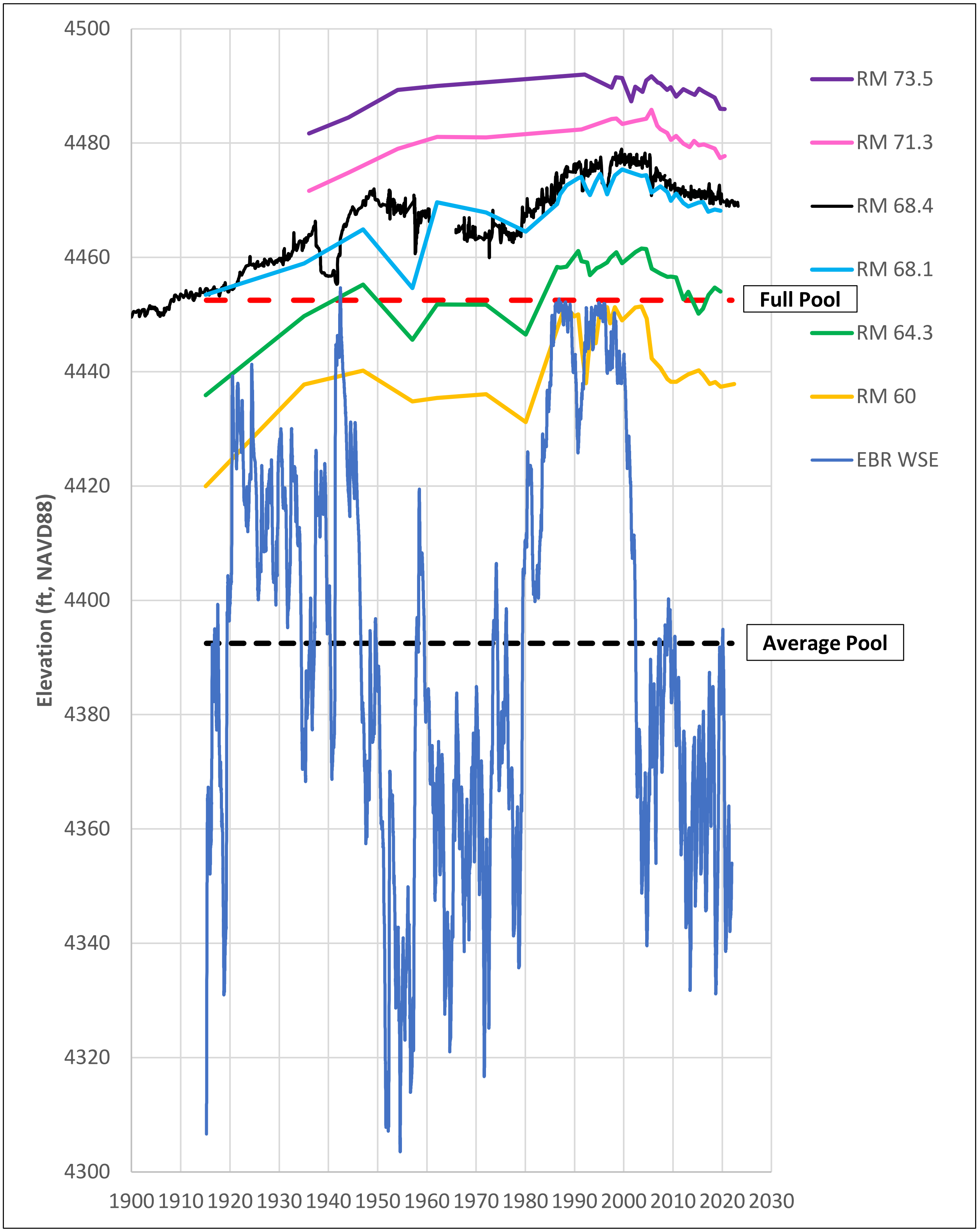


Figure 21.—Comparison of Elephant Butte Reservoir water surface elevation (EBR WSE) to channel bed elevation at various river miles. RM 68.4 is at the San Marcial floodway gage.

2.1.4 Maintenance Actions and Infrastructure

2.1.4.1 *Channelization*

Channelization work on the Middle Rio Grande (Figure 22 and Figure 23) began as a result of a joint plan and report by the USACE and Reclamation to rehabilitate the river and existing irrigation works, and to lower valley water levels. Years of sediment buildup in the river channel and irrigation works resulted in high water levels water-logging agricultural lands and reduced capability of irrigation facilities to transport water (Gahan 2013). The river channel was discontinuous downstream of the BDA South Boundary (Figure 24 and Figure 25), and Reclamation estimated annual water losses in this area due to vegetation and evaporation in the floodplain of 195,000 acre-feet (ac-ft) without precipitation and inflow (Chapman et al. 1951) or 143,000 ac-ft including precipitation and inflow (Chapman et al. 1952). Chapman et al. (1951) estimated that the project would save 46,000 ac-ft per year and Chapman et al. (1952) estimated the annual water salvage to be 37,000 ac-ft per year. Water salvage estimates attribute most of the savings to lowering the groundwater west of the spoil levee to reduce transpiration from salt cedar. Congress authorized the project as part of the Flood Control Acts of 1948 and 1950.

Figure 22.—Looking downstream at excavation of a pilot channel and construction of levee for diversion operations, July 1952 (Reclamation/Herman E. Carter).

Figure 23.—Looking upstream at channel excavation operations, August 1952 (Reclamation/Herman E. Carter).

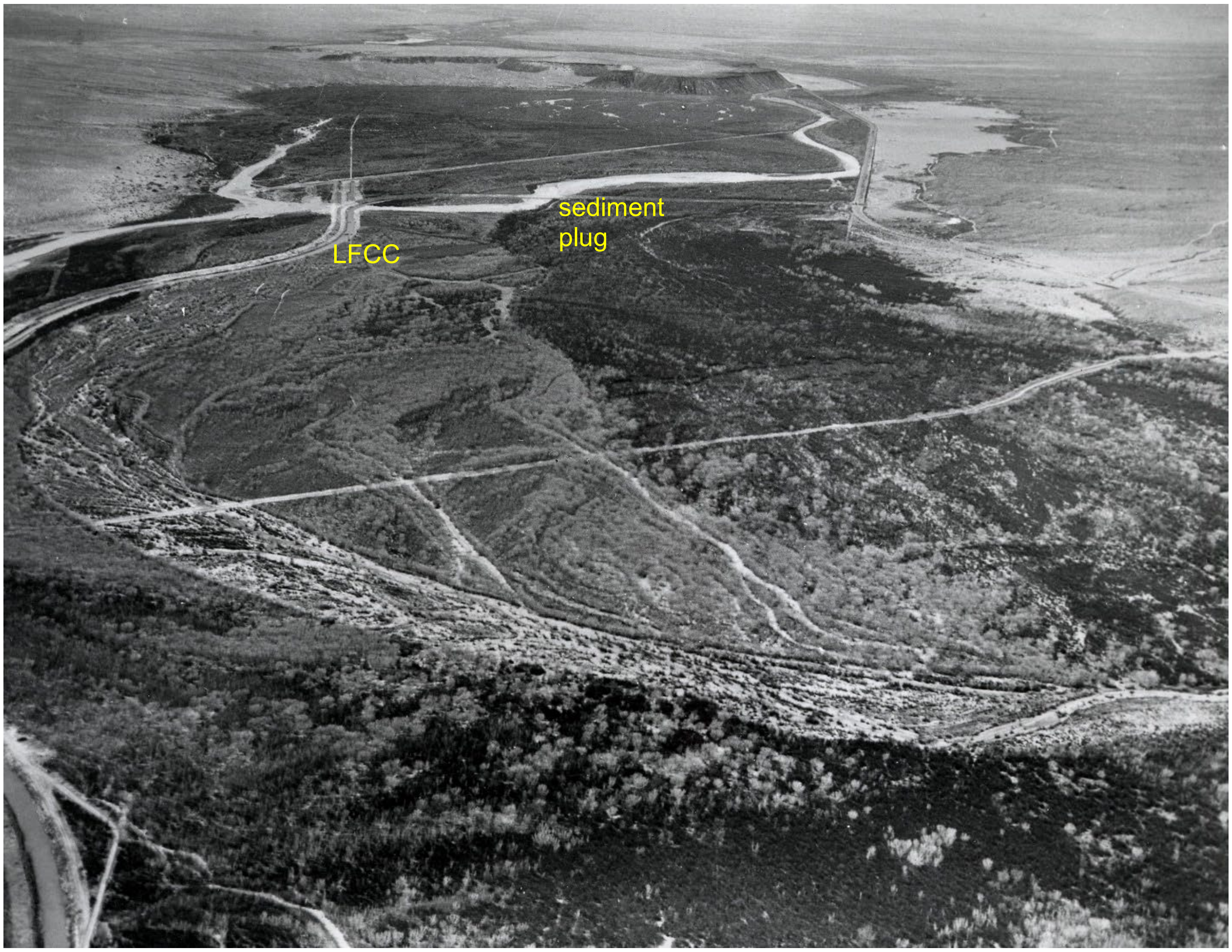


Figure 24.—Looking downstream toward San Marcial from near Bosque del Apache South Boundary, March 1953 (Reclamation/Herman E. Carter). Note abandoned river channel impinging on railroad embankment in upper right and San Marcial Lake to the right (west) of the railroad. River to the upper left of photo has lost surface flow connection.

Figure 25.—Looking downstream toward San Marcial at floodway, levee, and constructed channel, December 1953 (Reclamation/Herman E. Carter). Entire flow of Rio Grande (300 cfs) is being carried by pilot channel in left of floodway. The "H Line" cut-off channel used during construction can be seen traversing the Tiffany basin.

The Middle Rio Grande Project proposed by the agencies and funded by Congress included extensive channelization of the Rio Grande, and excavation work began in 1951 from Elephant Butte Narrows to San Marcial. This was followed by channelization of the section from San Marcial to BDA in 1952. The work consisted of excavation of a channel with 32-foot bottom width and 11-foot depth along with an adjacent levee for flood protection (Figure 26). The USGS first recorded flow in the LFCC at San Marcial in December 1951. Flow diversions from the river at a heading about two miles upstream of the BDA South Boundary began in November 1953, and in May 1954 the LFCC heading at BDA was diverting the entire flow of the Rio Grande. High flows in 1955 and 1957 breached the dike across the floodway that diverted the river into the LFCC. The LFCC between the BDA South Boundary heading and San Antonio, and then from San Antonio to Escondida, was constructed during 1956 and 1957. The LFCC from Escondida to San Acacia was constructed during 1957 and 1958, and the LFCC through San Marcial Lake was also constructed in 1958. Water was not diverted from the river to the LFCC during 1958 to accommodate construction activities. Finally, the headgates at San Acacia opened in May 1959 and all river flows less than 2,000 cfs were sent through the LFCC starting in 1960 (Reclamation project chronology timeline). The channelization work on the river and LFCC construction was credited almost immediately with savings of water and reduction of New

Mexico's debit status under the Rio Grande Compact, and debit status under the Compact was eliminated by 1972 (Gorbach 1999).

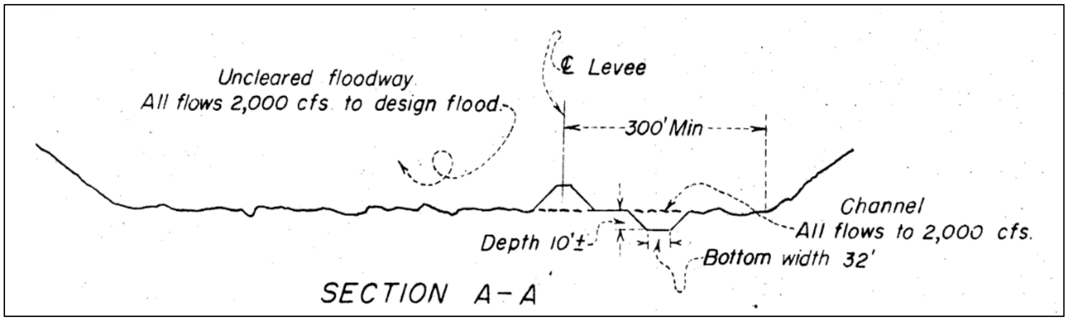


Figure *26*.—Typical valley cross section design for the channelization between San Marcial and Bosque del Apache. The LFCC and adjacent levee are shown (Chapman et al. 1951).

To channelize the reach south of BDA, contractors first excavated cut-off channels to divert flow downstream and lower water levels to excavate the LFCC (see Figure 25, Figure 27). The LFCC and adjacent levee were constructed beginning with the Elephant Butte Narrows to San Marcial in 1951. Initially crews encountered difficulty with sloughing and sliding of the channel banks, heaving of the channel bottom, and levee subsidence due to areas of heavy saturated clays. To alleviate these issues the channel side slopes were flattened and berm widths were increased. Engineers found that draining the saturated soils before placement also helped with these conditions. Excavation of the BDA to San Marcial Reach began nearly a year later, with reports indicating low channel capacity and perching of the channel above the floodplain. The Narrows to San Marcial Reach was channelized by late 1952 and the San Marcial to BDA Reach was initially completed October 1953. Diversion of river flows to the LFCC at a heading structure near the BDA South Boundary (Figure 27) began in November 1953. Earthwork quantities for the initial channelization effort are shown in Table 1 and include excavation and vegetation clearing downstream of the BDA South Boundary (Reclamation 1951; 1952; 1953). Reclamation's annual project histories do not describe the main river channel being excavated during the initial construction activities, only the LFCC construction and the floodway clearing. However, Figure 25 shows an excavated 1950s river channel east of the LFCC (left side of photo) in nearly the same location as the 2022 river (Figure 27).

Table 1.—Earthwork and vegetation clearing quantities from the channelization and levee construction in the 1950s from the South Boundary of Bosque del Apache to Elephant Butte Narrows

Year	Conveyance Channel Excavation (cy)	Temporary Drainage Channel Excavation (cy)	Excavation from Borrow for Levee Construction (cy)	Vegetation Clearing (ac)
1951	424,000	225,000		845
1952	1,949,500	263,500	263,500	2,020
1953	1,697,218	378,672	279,110	2,362
Total	4,070,718	867,172	542,610	5,227

As channelization efforts moved upstream, the LFCC was operated as proposed in the Joint Plan and Report by USACE and Reclamation with flows up to 2,000 cfs diverted into the LFCC at the heading structure near BDA South Boundary. Washouts of the levee occurred in the Tiffany area in 1955 because of monsoon flows, and by 1956 plans were in place to bypass the Tiffany Basin and channelize the San Marcial Lake area (Reclamation 1955; 1956). In 1958 the LFCC only operated as a drain due to this channelization effort and by September 1958 the current configuration of the LFCC upstream of RM 60 (as of 2023) was in place (Figure 27) (Reclamation 1958).

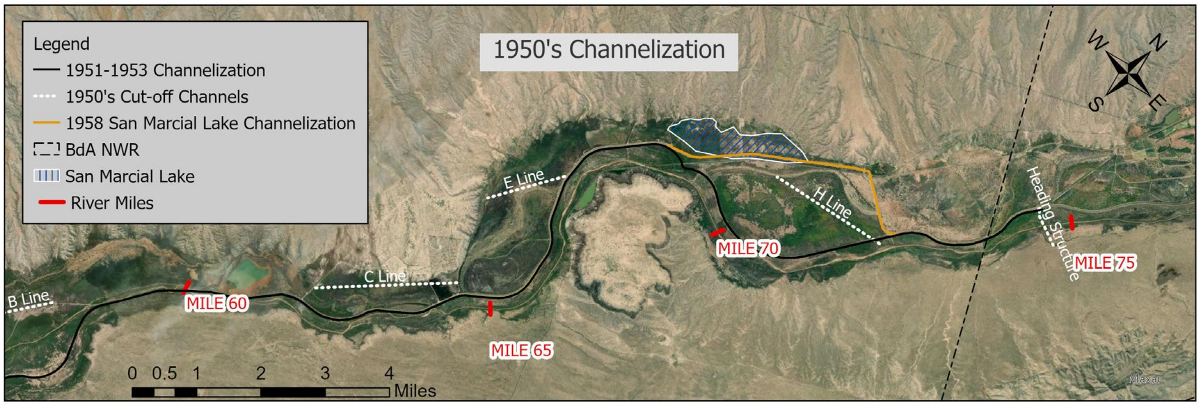


Figure 27—Map showing the alignment of the LFCC and channelization features from the 1950s channelization work overlaid on 2022 imagery.

Maintenance of the channelized areas continued along with vegetation management as the river channelization efforts continued upstream. Notable events and records in the BDA and San Marcial areas in the years following the channelization work include the following from Reclamation Annual Reports:

1955

- Reclamation and State of New Mexico entered into an agreement to clear vegetation from the floodway in the San Marcial Reach.

1956

- Sediment deposition in the channelized reach above San Marcial was estimated at 81,000 ac-ft.
- Rio Grande Underground Basin declared under the 1931 New Mexico Underground Water Law.
- Numerous suits were filed against Reclamation for flooding of properties in the San Marcial area.

1957

- Significant erosion and downcutting of the channel were observed along the San Marcial channelization. Sloughing and scour caused the Nogal Canyon Bridge to fail.

- 8 feet of silt deposition was measured near current RM 78 in the BDA Refuge above the San Marcial heading structure.

- The cooperative agreement with State of New Mexico for floodway clearing continued and expanded to include drain units.

1958

- LFCC functioned only as a drain (average discharge of 300 cfs) while the San Marcial Lake channelization was completed.

- Reservoir backwater extended into the LFCC due to high storage.

1959

- Studies were conducted to determine the amount of levee raising required from San Marcial to Brushy Lake near the Narrows.

- USACE and Reclamation entered into a Memorandum of Agreement for channel maintenance.

- Aerial spraying operations for vegetation management along the LFCC and floodway began.

2.1.4.2 *Lateral Constraints*

The channelization in the early 1950s reduced the floodplain width available to flood flows dramatically in the reach south of RM 79, or Aggradation/Degradation (Agg/Deg) Line 1575 (Figure 28). Upstream of this point the western valley was used for agriculture and isolated from surface flows by the San Antonio Riverside Drain. Below RM 76 (Agg/Deg 1608) the only infrastructure confining the floodplain was the railroad embankment beginning at the northern end of Tiffany Basin and departing the floodplain just south of the railroad crossing at San Marcial. Compared to the condition prior to construction, the floodplain width was reduced by more than half for nearly the entire reach south of the BDA agricultural areas (RM 78 or Agg/Deg 1584).

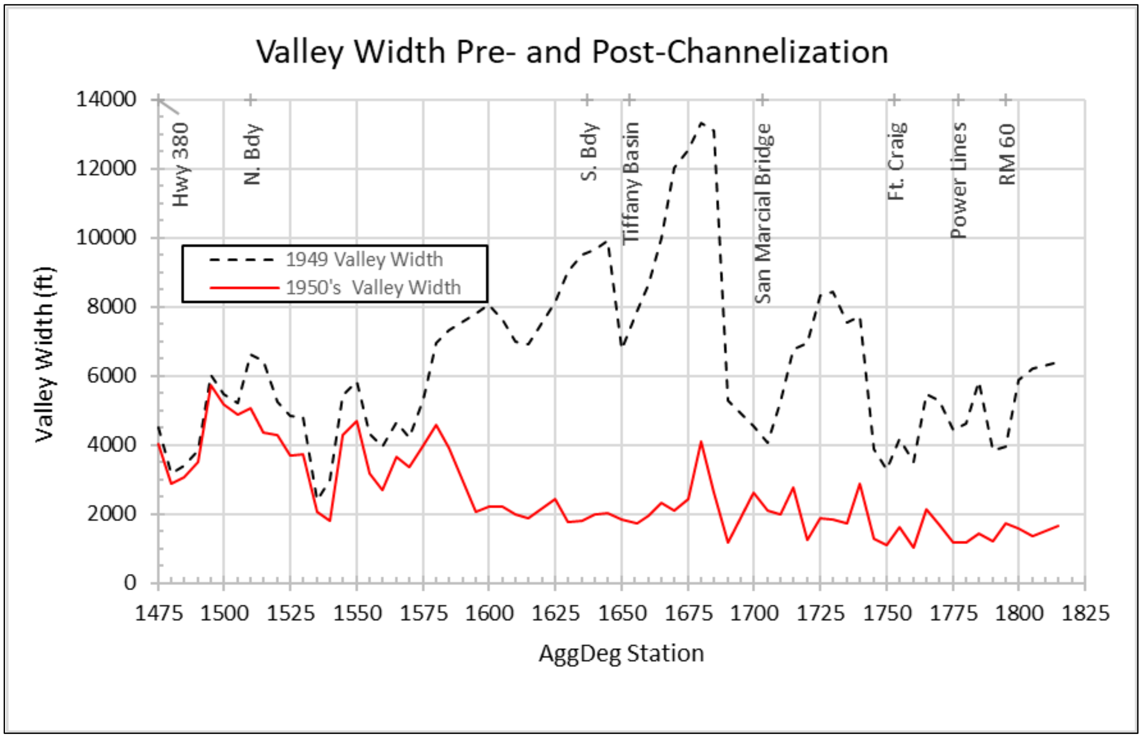


Figure 28.—Longitudinal plot showing the valley width available to Rio Grande flows before and after the 1950s channelization upstream of Elephant Butte.

2.1.5 Riparian Vegetation

Figure 29 shows significant increases in the vegetated fraction of bankline distance between 1962 and 2012 with the largest change occurring between 1972 and 1992. Following the construction of the LFCC in the 1950s, Reclamation and the State of New Mexico regularly cleared the floodway and LFCC of vegetation by either clearing and root plowing, piling and burning the material, mowing, or by aerial spraying. Reclamation issued contracts for vegetation control to reduce non-beneficial consumption of water by phreatophytes in the floodplain shortly after the channelization efforts, which continued through the 1970s (Figure 30 and Figure 31, upper left panel). By the 1980s, reports indicate that several below-average runoff years and supplemental river flows during summer months resulted in significant vegetation establishment in the San Marcial Reach (Reclamation 2002). By the 2000s the channel planform had further stabilized as lowered reservoir levels led to incision of downstream of San Marcial and mature woody vegetation established along the banks. The reduced floodplain connection can be seen in Figure 30 and Figure 31 as the valley flow paths present in the 1987 imagery are completely covered in vegetation by 2012. By 2022 a considerable area near San Marcial was affected by fires along the floodplain. In addition to fire damage, further lowering of the bed level in this reach has caused the floodplain vegetation to be less dense than upstream of the BDA South Boundary.

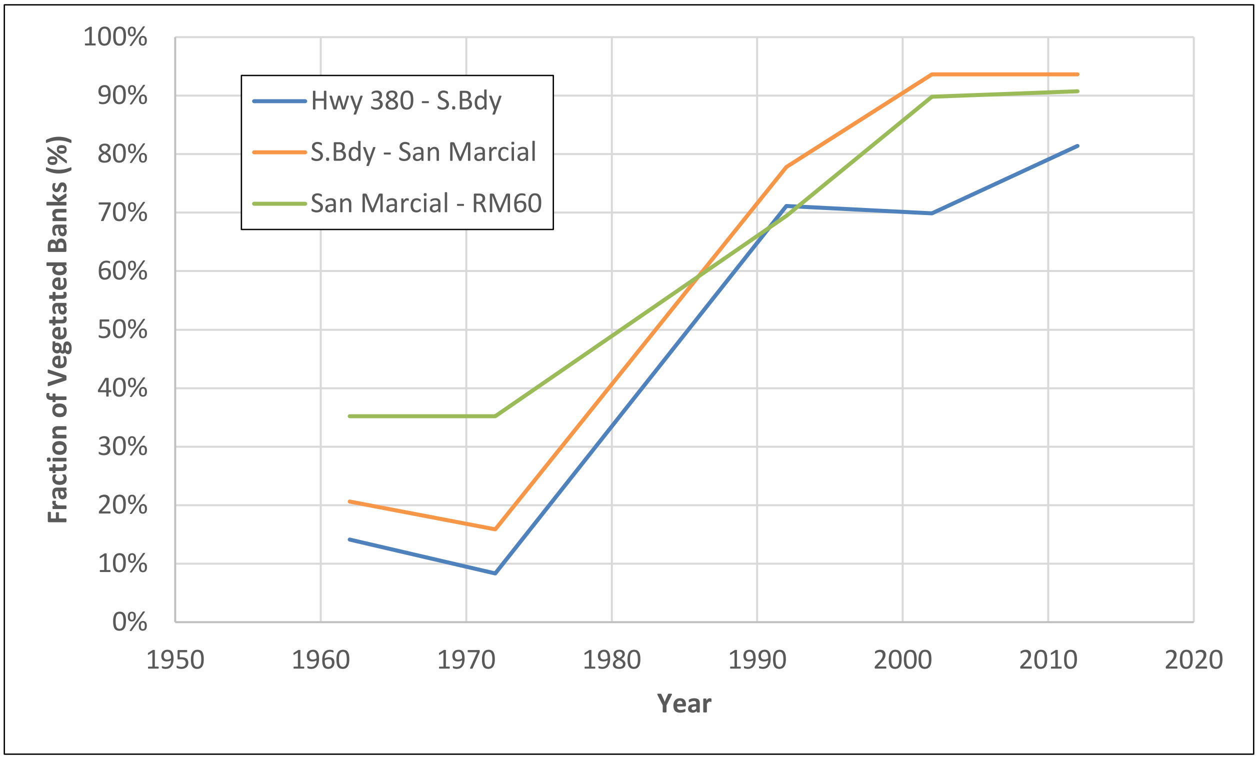


Figure 29.—Changes in fraction of vegetated bankline between 1962 and 2012 (modified from Greimann and Holste 2018)

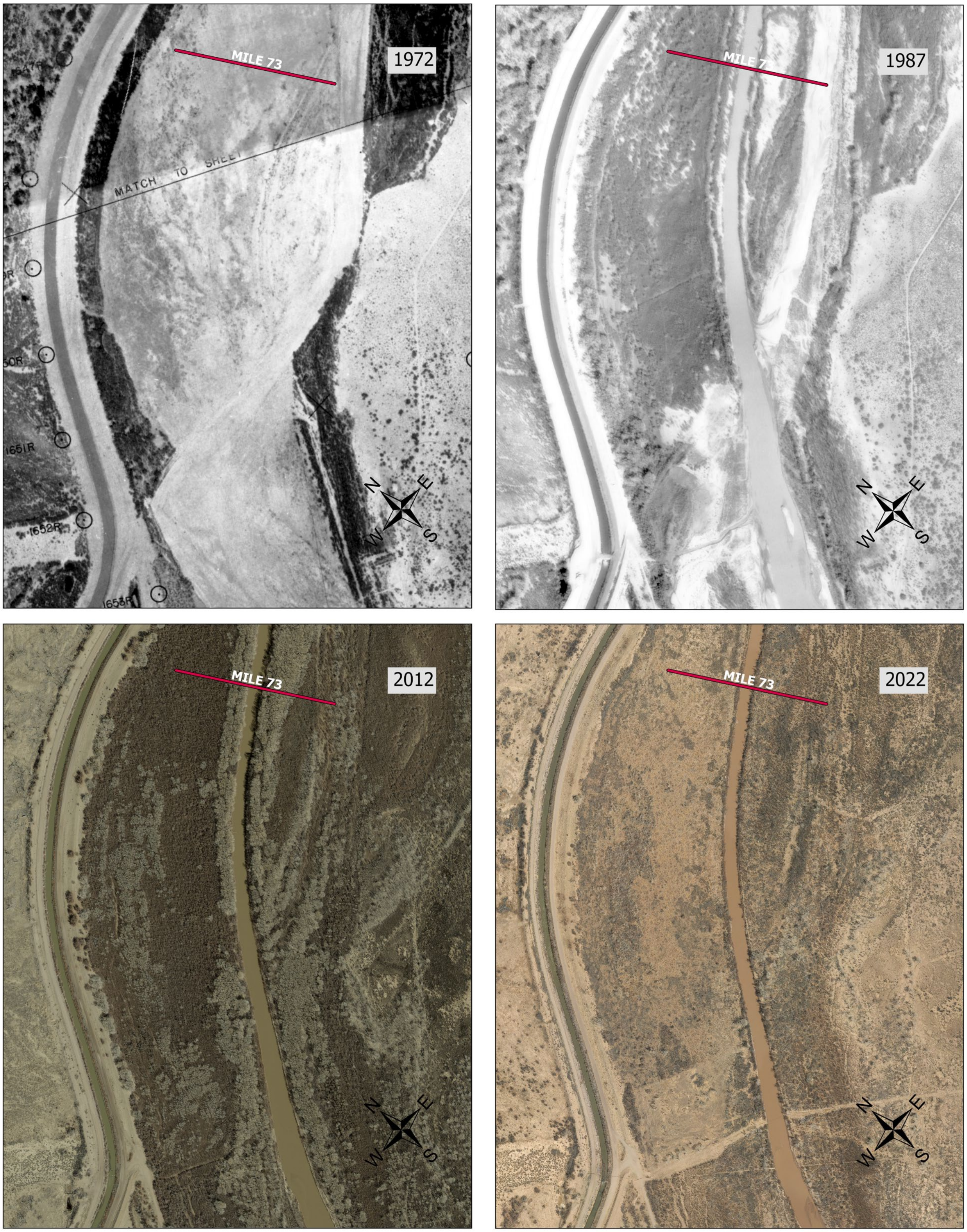


Figure 30—Aerial imagery from 1972, 1987, 2012, and 2022 showing the channel and floodplain near RM 73.

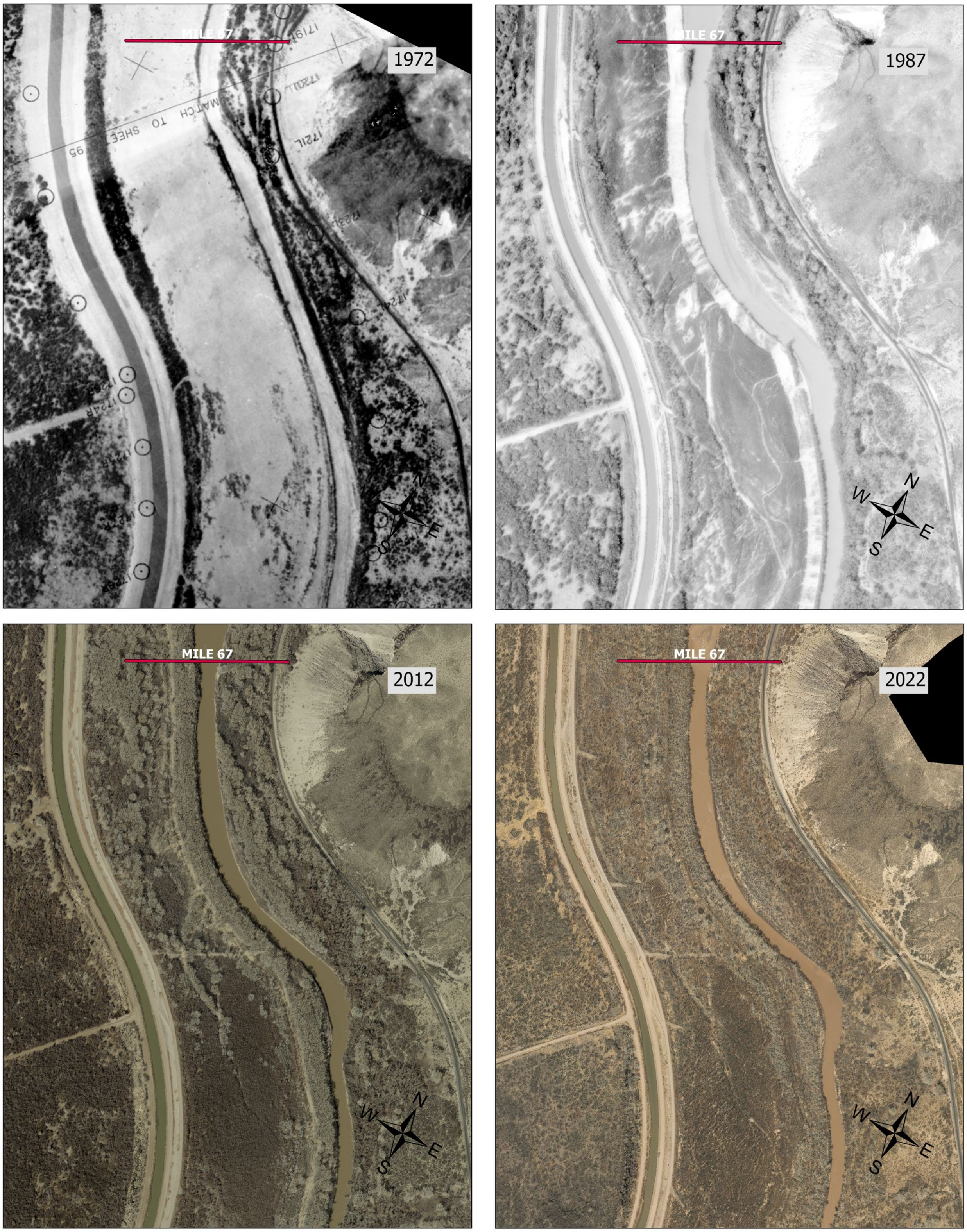


Figure 31—Aerial imagery from 1972, 1987, 2012, and 2022 showing the channel and floodplain near RM 67.

2.2 Channel and Floodplain Response

Channel and floodplain morphology adjusts to the water and sediment supplied from upstream, human actions, and the downstream base-level of Elephant Butte Reservoir. Previous sections have described the drivers and controls while the following sections describe the response of the channel and floodplain.

2.2.1 Bed Elevation

Bed elevation data for the project reach are available dating back to 1915 contour maps and 1917 surveys associated with the construction of Elephant Butte Dam. Figure 32 presents longitudinal profiles compiled from a variety of sources. The profiles show a consistent rise in bed elevation through 2002 and then erosion between 2002 and 2012. Changes between 1915 and 1935 represent the wedge of sediment deposition mostly caused by initial filling of Elephant Butte Reservoir. Profiles from years between 1962 and 2012 all converge near RM 78 (Agg/Deg 1584), about four miles upstream of the BDA South Boundary near the downstream-most LFCC check structure, indicating that the reservoir pool has the strongest influence downstream of this location. Upstream of RM 78, the bed has continued to aggrade, indicating a local sediment transport deficiency separate from the influence of the reservoir.

Thalweg profiles between 1999 and 2019 also demonstrate the influence of the reservoir while showing the local effects of sediment plugs (Figure 33). In 1999 the reservoir was nearly full, and the upstream backwater-induced aggradation extended to near the BDA South Boundary. The reservoir pool lowered at the onset of the drought in 2000 and a headcut formed that progressed upstream. In 2005, the river plugged with sediment near Agg/Deg 1675, which caused upstream deposition and downstream erosion. Sediment plugs essentially create a dam in the river that reduces the upstream slope and prevents sediment from moving downstream. Overbank flows that return to the river downstream of a plug are mostly clear water that erode the downstream bed. Removing the plug restores flow and sediment continuity so that the upstream bed erodes and the downstream bed deposits to resemble the pre-plug profile. Sediment plugs formed within BDA near Agg/Deg 1550 in 2008, 2017, and 2019. The 2019 profile shows that the BDA plugs had similar effects as the Tiffany plugs by causing upstream deposition and downstream erosion.

Figure 34 compares select bed profiles in 1915, 1935, 1999, and 2019 to the current (2019 or 2022 lidar) valley profile and the LFCC water surface elevation (WSE) profile. The valley profile is derived from a centerline west of the spoil levee until the spoil levee ends at RM 60, where the valley profile generally follows the low point outside the river. The current valley and LFCC profiles are similar to the 1915 bed profile upstream of the BDA South Boundary. Downstream of the BDA South Boundary, the 2019 thalweg profile has incised to nearly the same elevation as the 1935 profile. The LFCC is generally the valley low point upstream of RM 64 (Agg/Deg 1750) and partly controls the shallow groundwater and river seepage rates throughout the reach while intercepting groundwater and moving it downstream as surface water. Figure 35 compares the bed elevation for various years to the current LFCC water surface. The bed is typically 5 to 15 ft above the LFCC WSE and was most perched in 2002.

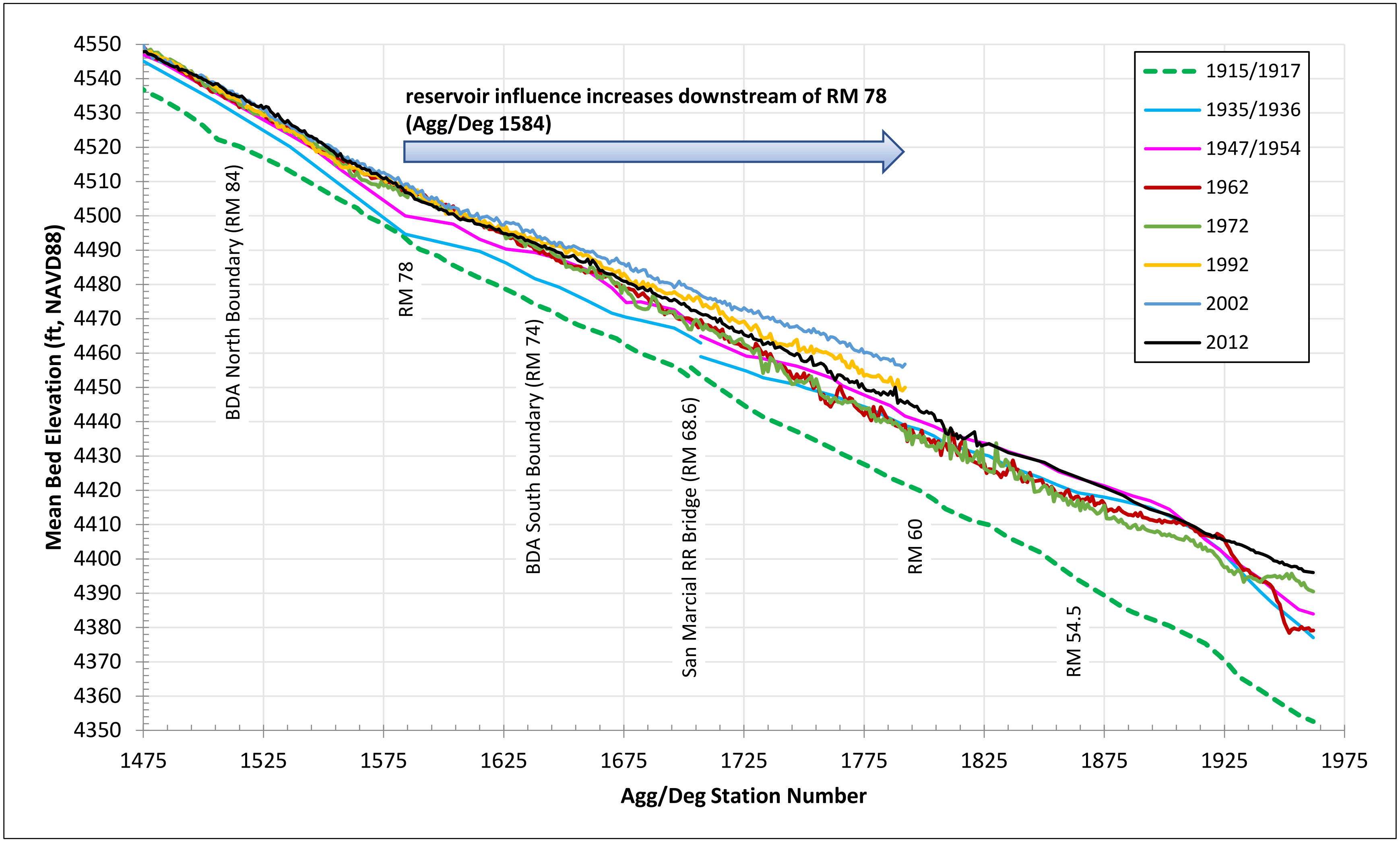


Figure 32.—Historical bed elevation profiles compiled from Elephant Butte Reservoir data (1915, 1935, 1947), digitized Soil Conservation Service cross sections (1936, 1954), Reclamation photogrammetry (1962, 1972, 1992, 2002), and Reclamation lidar (2012).

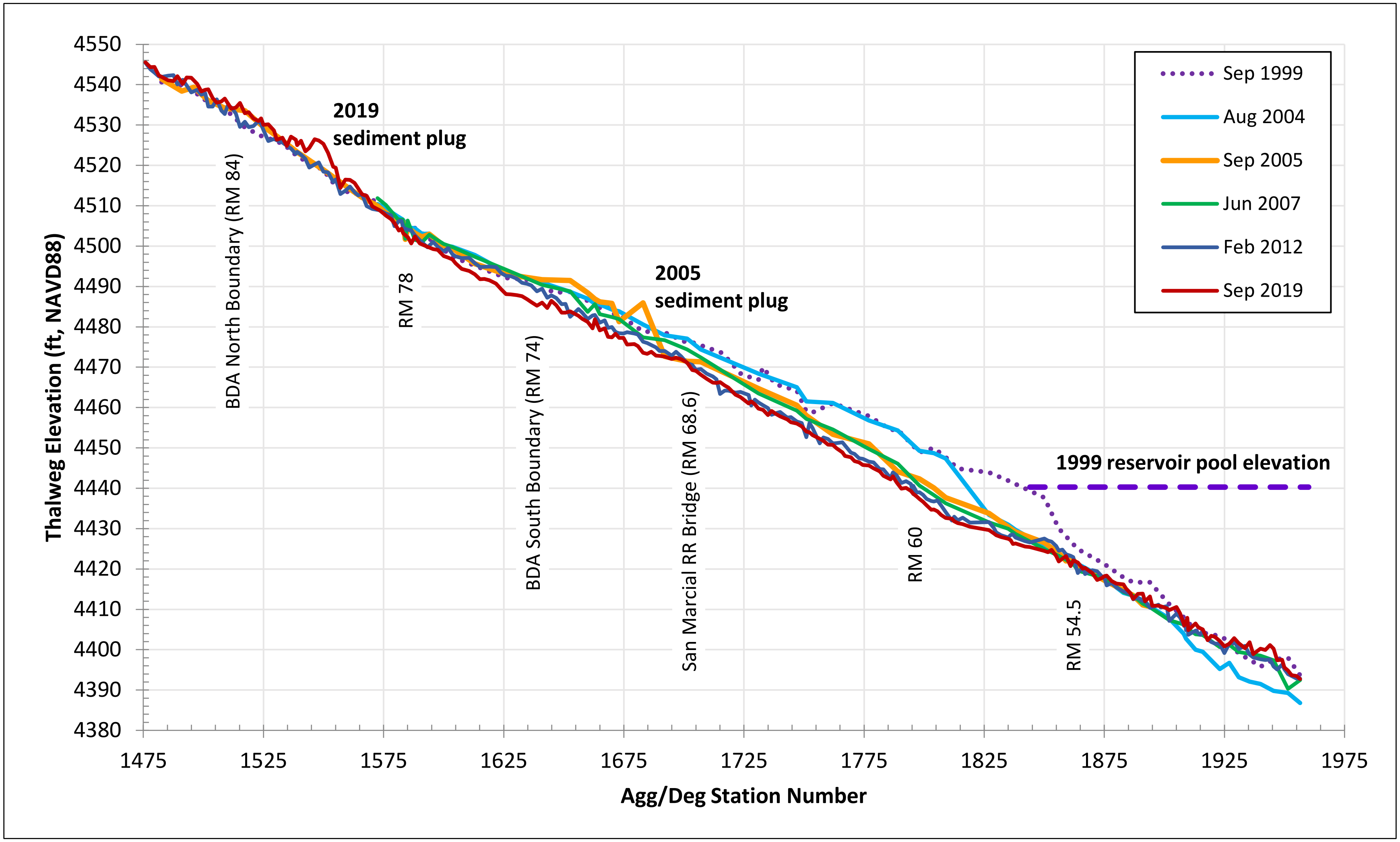


Figure 33.—Thalweg elevation profiles between 1999 and 2019 compiled from cross section surveys conducted by Reclamation contractors.

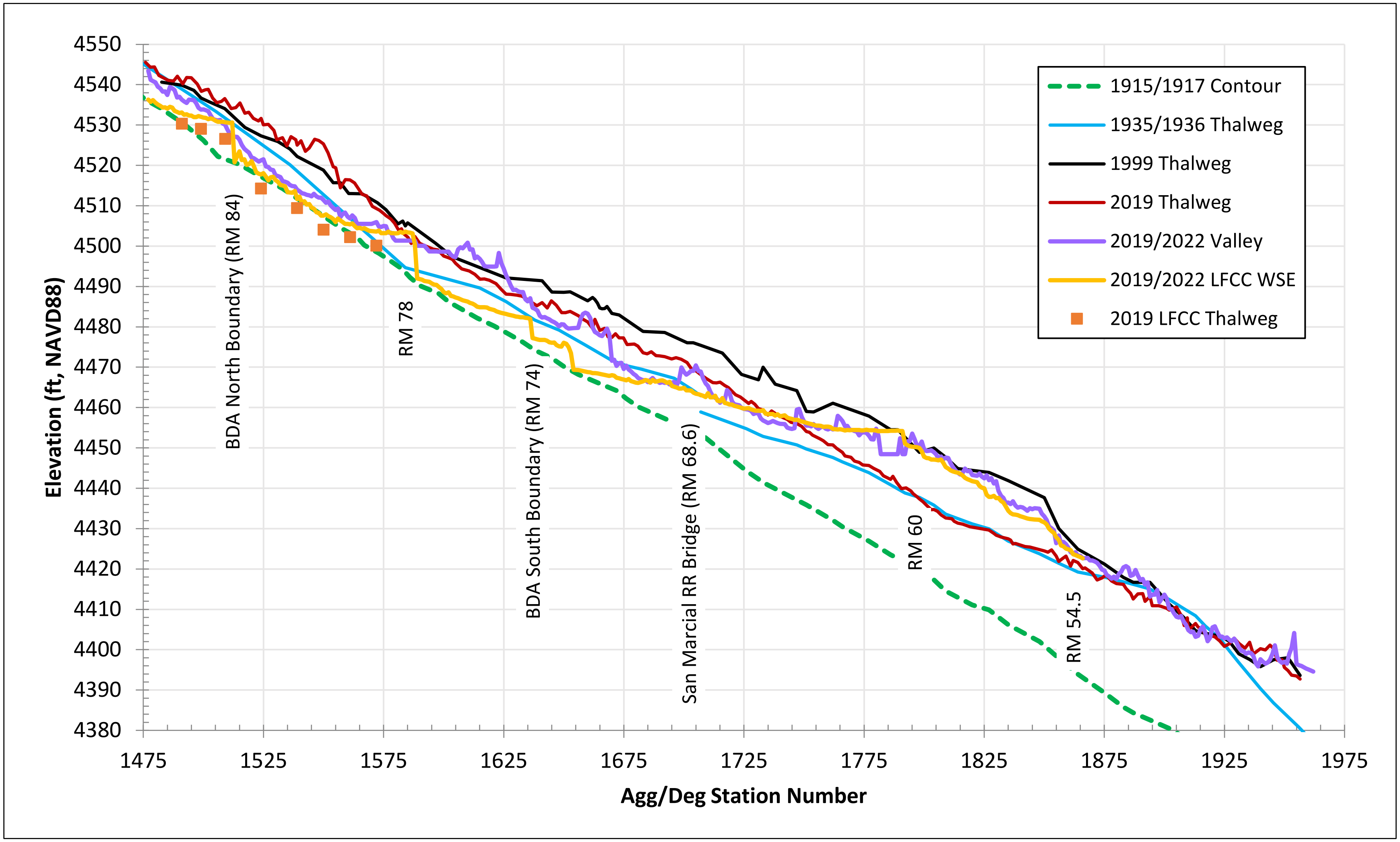


Figure 34.—Comparison of river thalweg profiles to valley elevation and LFCC water surface elevation.

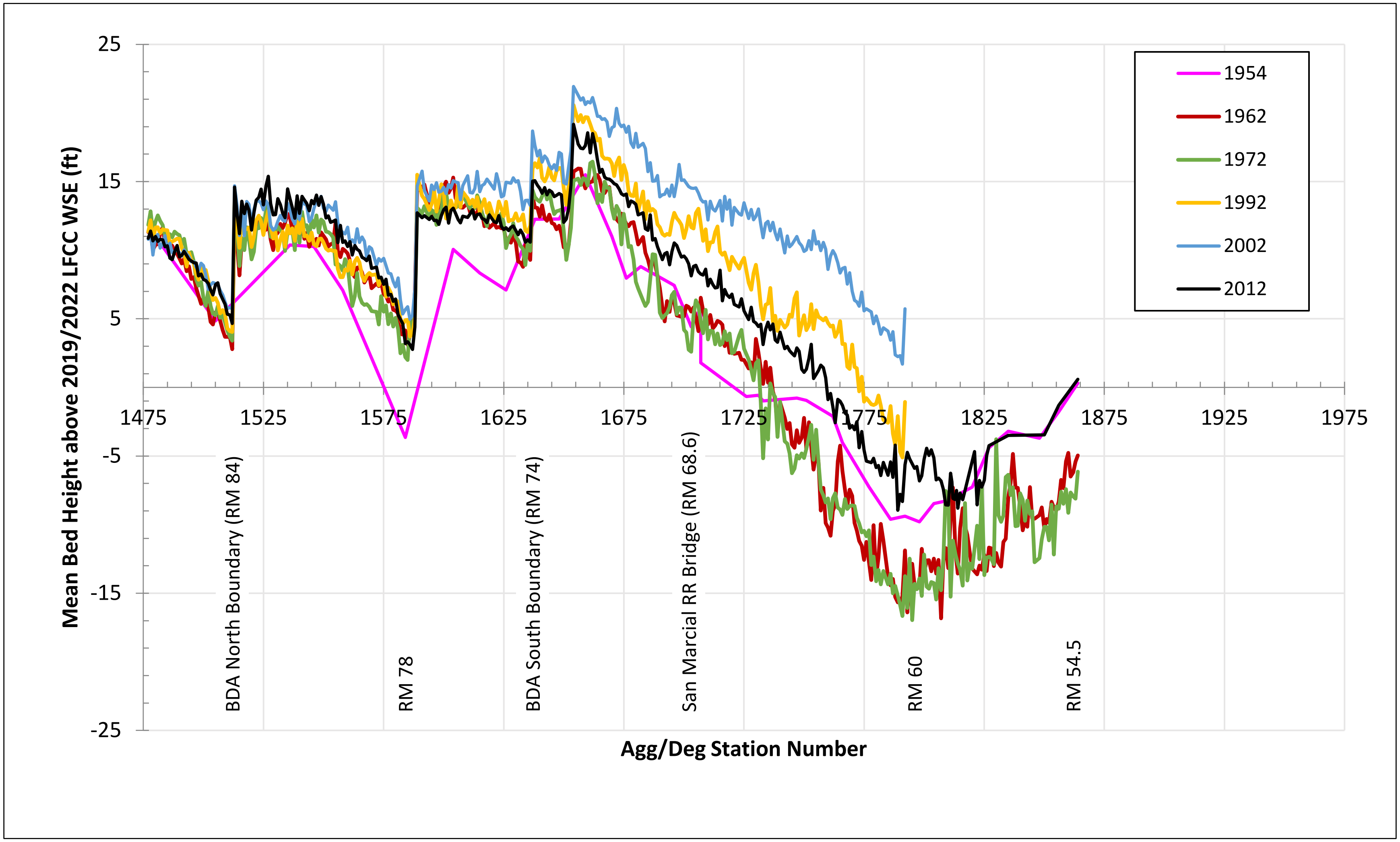


Figure 35.—Bed perching over time relative to current winter base flow water surface in the LFCC. 2012 bed profile is lower than LFCC water surface downstream of Agg/Deg 1760 (RM 63.5).

2.2.2 Top of Bank Elevation and Bank Height

Geomorphic analyses typically focus on the bed elevation and profile, but the top of bank elevation also changes over time. Flow that goes overbank carries suspended sediment that deposits when interacting with the increased roughness on the top of bank. There is a steep velocity gradient between the higher main channel velocities and the reduced bank and floodplain velocities that causes sediment to deposit. The depth of sediment deposition and the grain size of deposited sediments both decrease when moving away from the channel because the larger particles deposit first while the smaller particles remain suspended in the water column.

Top of bank and floodplain elevations have increased over time due to this process (Figure 36). There are changes in slope along the top of bank profiles at RM 78 (Agg/Deg 1584) and RM 60 (Agg/Deg 1800). RM 78 is the transition to base-level control of Elephant Butte Reservoir and RM 60 is the full pool of the reservoir. Between RM 78 and 60, there is almost no change to the top of bank elevations between 2002 and 2019. After the channel incised during and after the 2005 snowmelt runoff, there has been little to no overbanking in this reach so there has not been an opportunity for sediment to deposit on the top of bank. The top of bank elevations increase during periods of overbanking or remain unchanged when there is not overbanking. Unlike the bed elevations, there are no periods when the top of bank elevations incise or lower. Banks may erode laterally but do not erode vertically because water flowing over the top of bank has relatively low velocity and shear stress.

The combination of a lowered bed and higher top of bank elevation has increased the bank height in recent years (Figure 37). Bank height is calculated as the average bank elevation minus the average bed elevation at each cross section. The bank height was around 4 ft in 2002 and over 10 ft in 2012 and 2019. Tall banks do not allow any overbanking with the current flow regime. This condition is expected to persist until the reservoir pool rises again, which will cause deposition on the bed. Continued bed deposition will eventually reactivate the floodplain and overbanking flows will resume depositing sediment on the top of banks. The bed and banks will then rise together while the reservoir pool remains high. After the reservoir lowers, there will likely be another cycle of bed incision, but the top of banks will remain at the higher elevation.

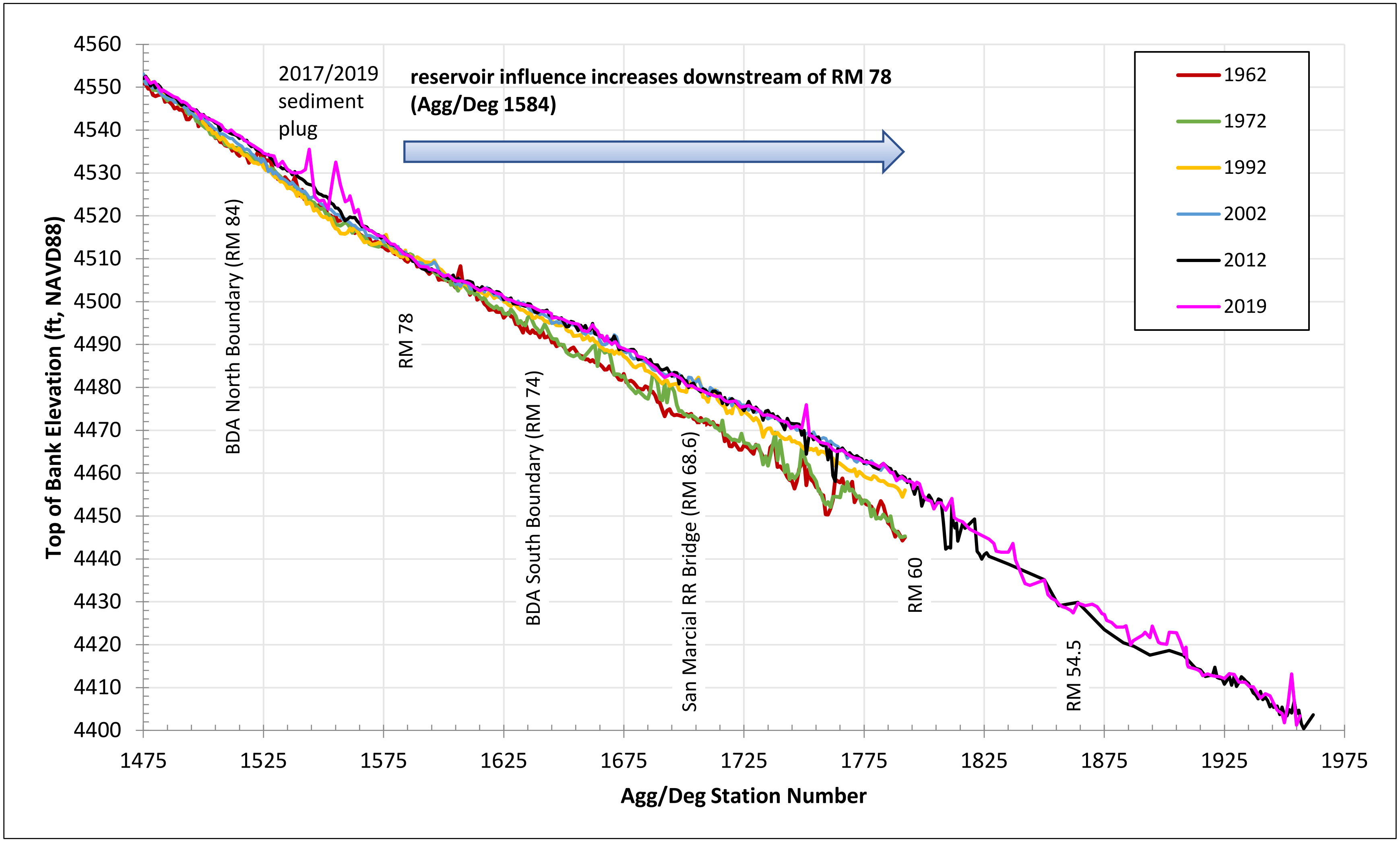


Figure 36.—Top of bank profiles over time, 1962–2019, calculated as average left and right bank elevation. Note increased bank elevations downstream of RM 78 (Agg/Deg 1584) due to the influence of Elephant Butte Reservoir.

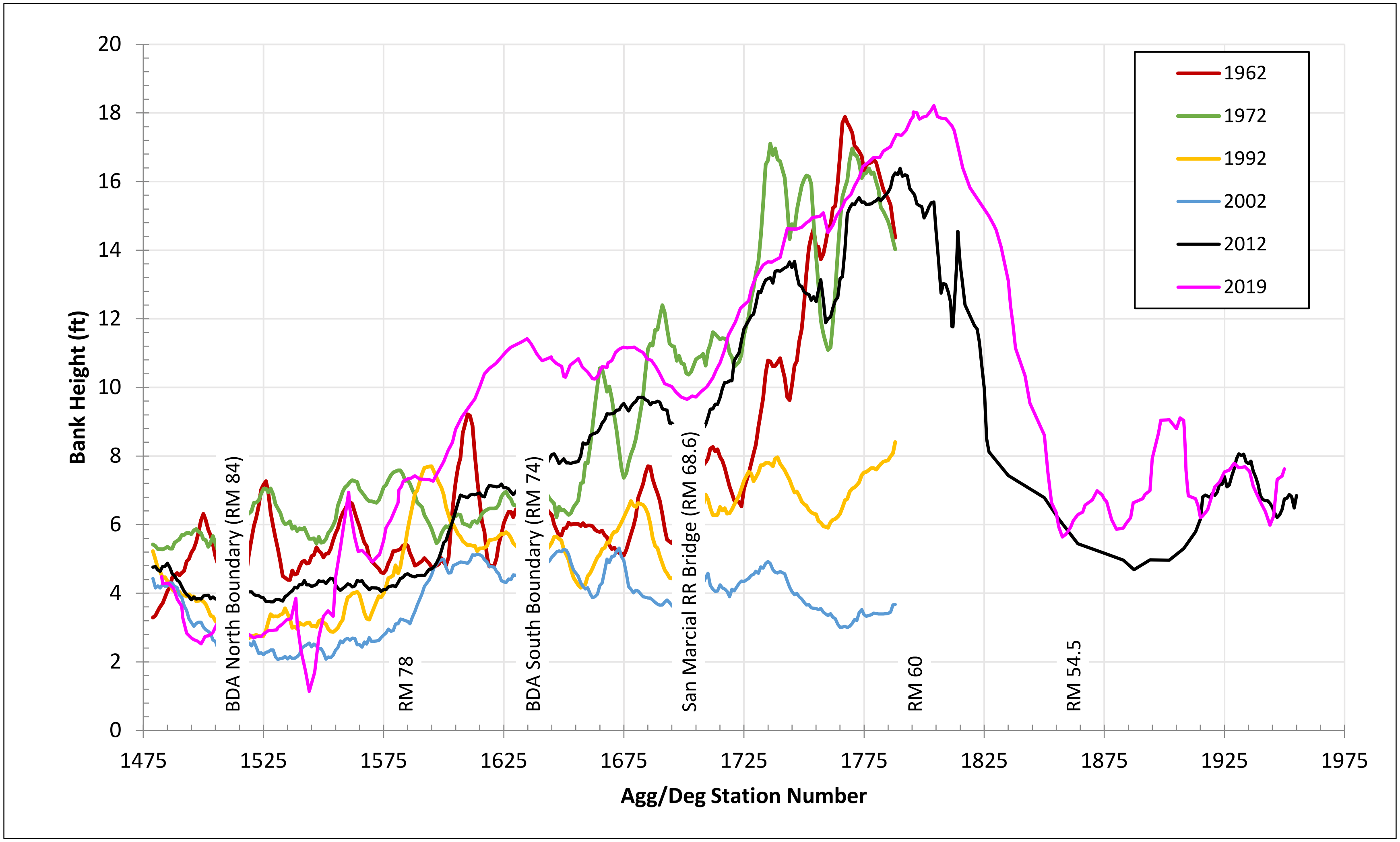


Figure 37.—Bank height elevation over time, calculated as average left and right bank elevation minus bed elevation. Note decreasing bank heights during reservoir filling between 1972 and 2002 and then increasing bank heights after 2002 as the reservoir pool lowered.

2.2.3 Channel Width

Like adjustments for most of the Rio Grande below Cochiti Dam, channel narrowing has been a dominant trend in recent years because upstream regulation limits the ability of flood flows to widen the channel and extended releases in the summer have helped vegetation remain established. Figure 38 shows the trend in channel narrowing through the study reach based on the active channel width, defined as the unvegetated channel corridor delineated from aerial images. Channel widths in BDA are noticeably lower in 2002 than the previous years, and the years following 2002 show further narrowing of the channel except for the BDA Realignment area constructed in 2019 (Agg/Deg 1540 to 1565). Below the San Marcial Bridge channel widths have been much less dynamic because the floodplain width was limited to the far eastern side of the valley.

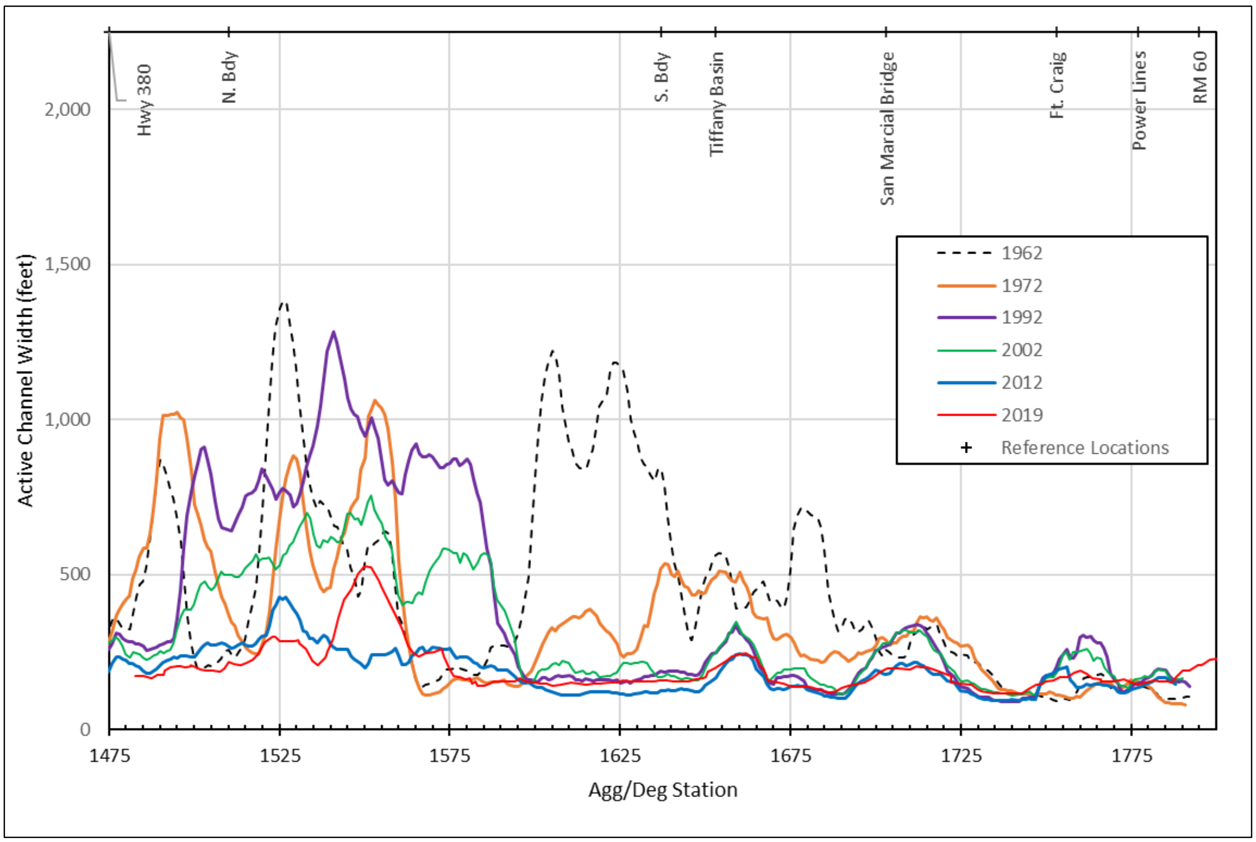


Figure 38.—Active channel width as a function of longitudinal station from decadal Agg/Deg datasets.

The trend of channel narrowing and incision is evident in the temporal change in wetted top width. Figure 39 shows that channel widths increased as flow increased for each subreach in the study reach in 1962; the reach from San Marcial to RM 60 showed the least increase in top width relative to flow rate. Wetted top widths in the two lower subreaches steadily declined from 1962 to 2019 and had very little change in width during later years even at high flow. In these reaches the channel is static with high banks and high channel capacity. Flows up to 6,000 cfs stay within the main channel and increase wetted width very little compared to earlier periods.

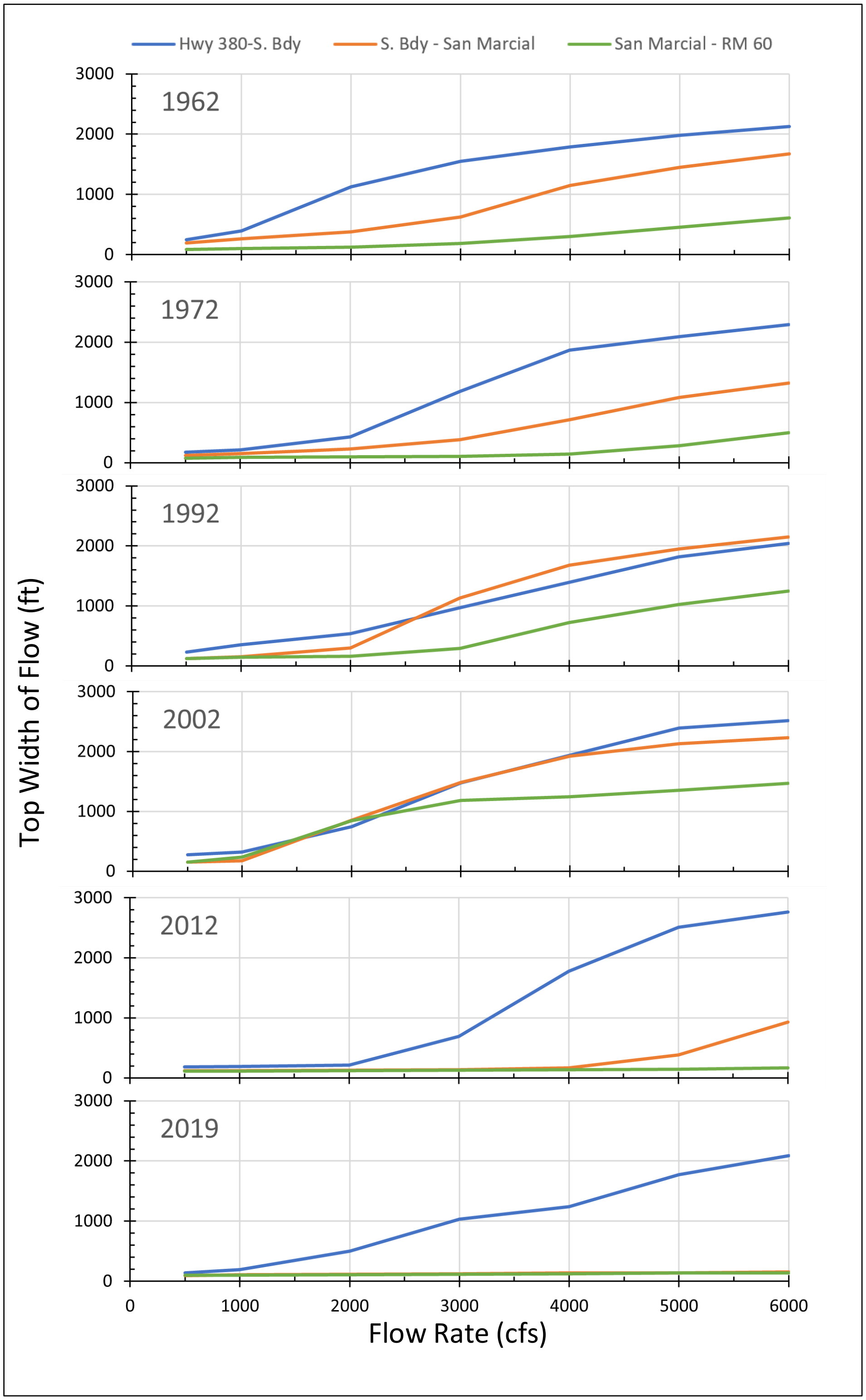


Figure 39.—Subreach-average wetted top width by year.

2.2.4 Channel Capacity and Overbanking Flow

Channel capacity to contain flows without overbanking has largely been dependent on reservoir levels and their effect on channel aggradation and degradation in the channel and floodplain. Figure 40 shows a moving average of channel capacity calculated from a one-dimensional (1D) hydraulic model using the decadal Agg/Deg datasets depicting the floodplain and calculated underwater prism (Varyu 2013a). Channel capacity is determined here based on the flow rate the channel section can contain before the banks are overtopped. In 1962 channel capacity was relatively low in the wide and flat-sloped area of the BDA, generally increasing in the downstream direction. By 2002 higher reservoir levels reduced channel capacity in the South Boundary to RM 60 reach, which then increased as the channel incised by 2012 after reservoir levels receded. The 2019 survey was completed while the BDA sediment plug was in place, which caused a lower channel capacity upstream of Agg/Deg 1550 and a higher channel capacity downstream of the plug between Agg/Deg 1550 and 1580.

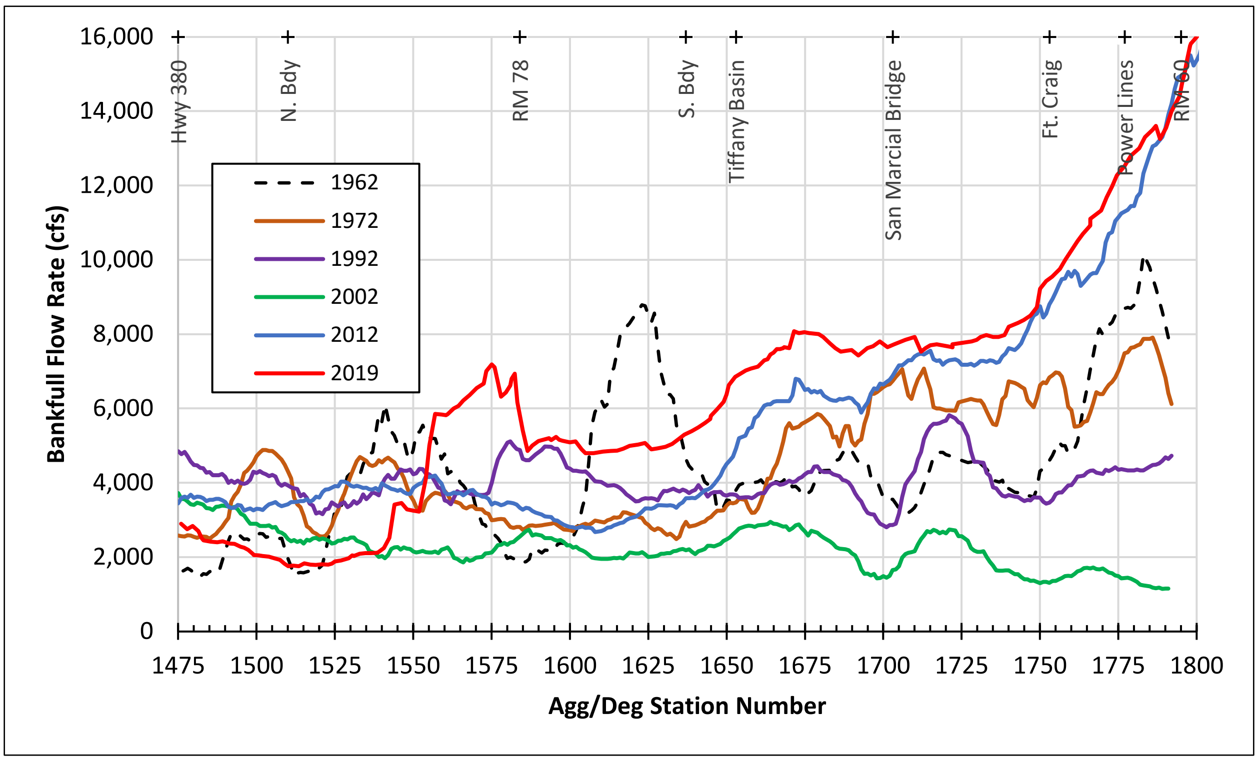


Figure 40.—Plot of bankfull discharge vs. Agg/Deg line number for the decadal Agg/Deg datasets.

The Highway 380 to BDA Reach had the lowest reach-average channel capacity for 3 out of 6 of the decadal datasets since 1962 (Figure 41). The effect of the higher reservoir levels is evident in the decrease of channel capacity in the South Boundary to San Marcial and San Marcial to RM 60 reaches between 1972 and 2002. These downstream reaches have increased channel capacity since 2002 while the Highway 380 to BDA South Boundary Reach had less change. Note that values in Figure 41 are averaged by reach and that some cross sections overbank at higher or lower flows (see Figure 40 above).

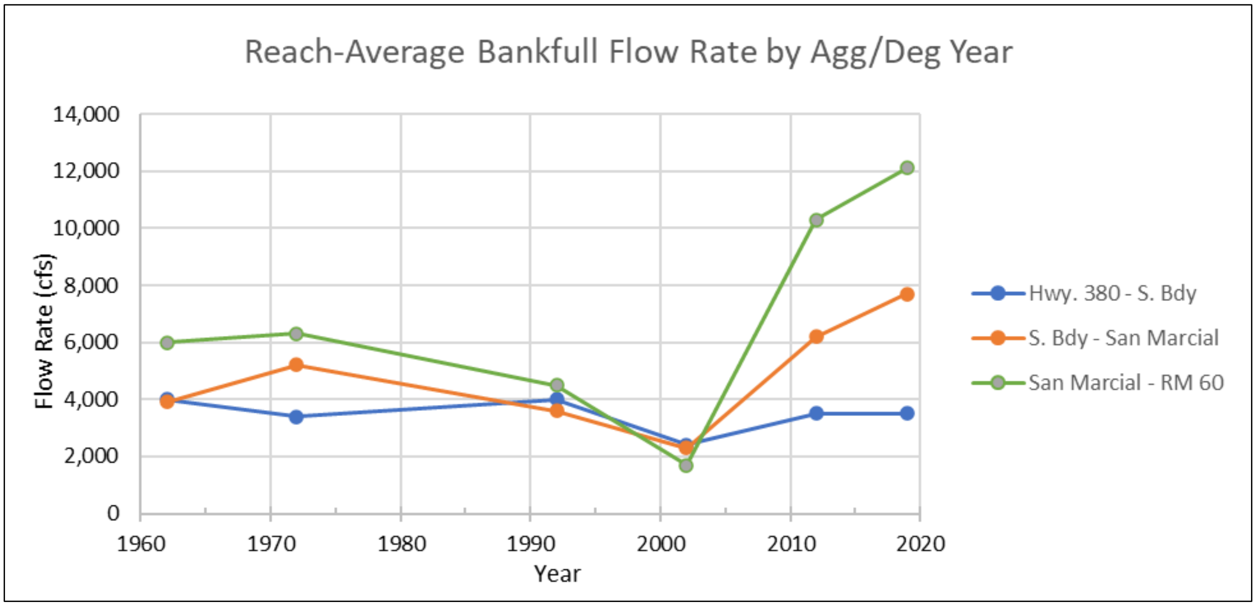


Figure 41.—Reach-average bankfull flow rates for the decadal Agg/Deg datasets.

Channel capacity and incoming flows determine the degree of overbanking flows at any river section. Overbanking flows are linked to suitable habitat for RGSM spawning and growth as well as habitat for the YBCU and SWFL. The number of days per year that flows were above the reach-average channel capacity was estimated using average daily flow from the USGS gage at San Marcial and the reach-average channel capacity flow rates. Figure 42 shows the estimated days overbanking per year. The 1980s and 1990s were a relatively wet period and had numerous years with more than 20 days of overbanking in each reach. The 1960s and early 1970s were a dry period and had more years with no days of flows above the reach-average capacity. Overbanking days have decreased again with the recent drought with only a few days per year in select years estimated to be above the average capacity of the Highway 380 to BDA South Boundary Reach. Overbanking in the area between South Boundary and RM 60 has been almost nonexistent since 2005.

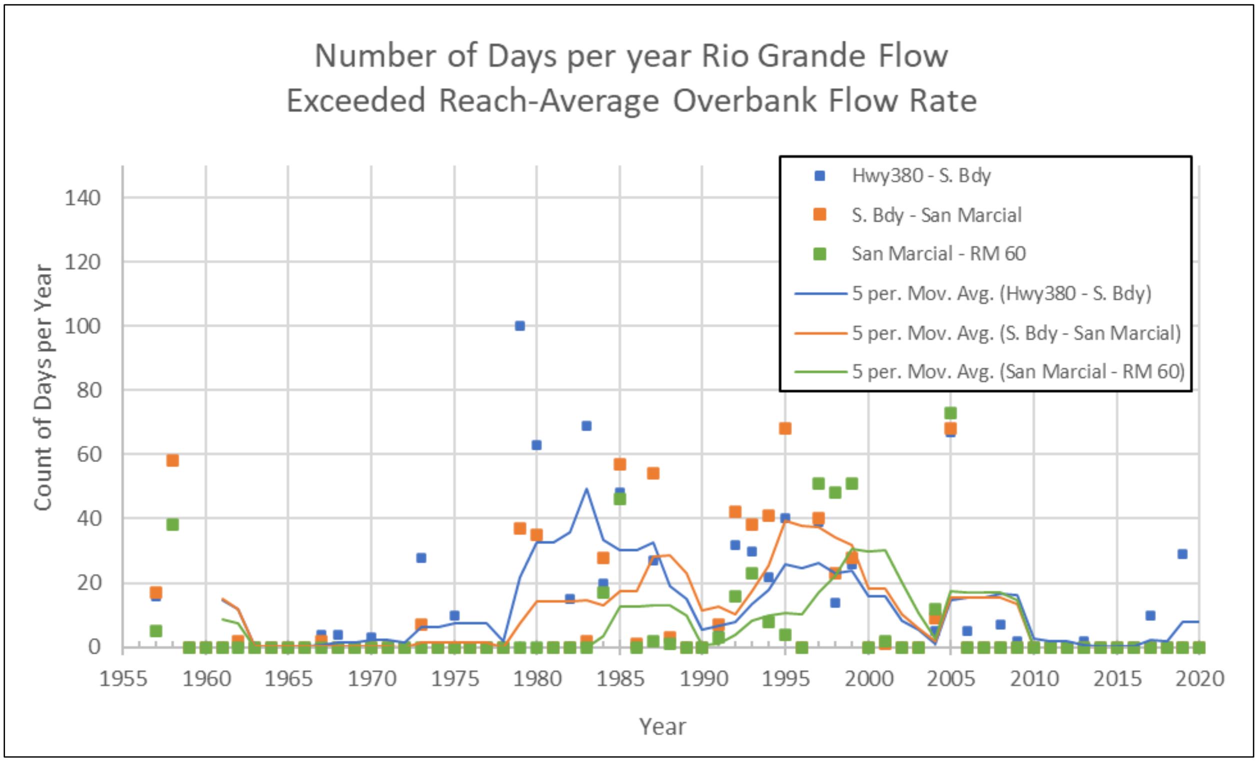


Figure 42.—Plot of the number of days per year that reach-average overbank flow rates were exceeded for the decadal Agg/Deg datasets and the years in which they were collected.

2.2.5 Erosion-Deposition Volumes

Changes to the elevation of the bed, banks, and floodplain are the result of erosion or deposition. Flowing water may remove material from the reach and transport it downstream or may deposit sediment within the reach that was sourced from upstream. Erosion and deposition volumes are the net change in elevation for different time intervals applied to a given reach. The calculation compares cross sections at two different times to determine the change in cross-sectional area and then multiplies this change in area by the distance between consecutive cross sections. The method thereby estimates the volume change between each cross section for each time interval and delineates the volume change for the main channel, the overbank, and the total cross section (Varyu 2013b). Channel volume change is a useful metric in addition to bed elevation change because volume change accounts for lateral adjustments such as narrowing and growth of bank-attached bars whereas elevation change only accounts for vertical adjustments. The project area is within the historical delta of Elephant Butte Reservoir, where sediment deposition is also referred to as sediment storage.

Erosion and deposition volumes presented in this section demonstrate how the available sediment storage changed for the channel and floodplain east of the 1950s-constructed spoil levee. Between Highway 380 and RM 60, a net volume of 46 million cubic yards (cy) of sediment deposited between 1962 and 2012, including 33 million cy in the floodplain (72%) and 13 million cy in the channel (28%). Between the BDA South Boundary and RM 60, a net volume of 30 million cy deposited between 1962 and 2012, including 22.5 million cy in the floodplain (75%) and 7.5 million cy in the channel (25%). Most (80%) of the deposition downstream of the BDA South Boundary occurred during the period 1972 to 1992 while some (16%) occurred during 1992 to 2002. Essentially, sediment deposition during high reservoir pool stages filled in the floodplain storage that had originally existed east of the spoil levee when the LFCC was constructed in the 1950s. The valley west of the spoil levee has remained at the pre-1950s elevation, providing opportunities for future sediment storage if the channel is realigned to the west.

Figure 43 focuses on the main channel and adds the volume change between each cross section in the downstream direction to develop a cumulative volume change per reach for each Agg/Deg period. The largest change occurred in the downstream reach between 1972 and 1992 where about 5 million cy of sediment deposited while the reservoir rose in the early 1980s and remained nearly full for several years. About 2 million cy eroded from this reach between 2002 and 2012 when the channel incised after the pool elevation lowered. The middle reach between the BDA South Boundary and the San Marcial Railroad Bridge also had the most deposition between 1972 and 1992, about 3 million cy, and was relatively stable during other periods. The upstream reach between Highway 380 and the BDA South Boundary was stable during earlier years before aggrading between 1992 and 2002 and continuing to aggrade between 2002 and 2012. To normalize the volume change by accounting for different reach lengths and different time periods, Figure 44 presents the volume change per mile per year. The trends are similar where the most deposition occurred in the two downstream reaches between 1972 and 1992 and the most erosion occurred in the downstream reach between 2002 and 2012.

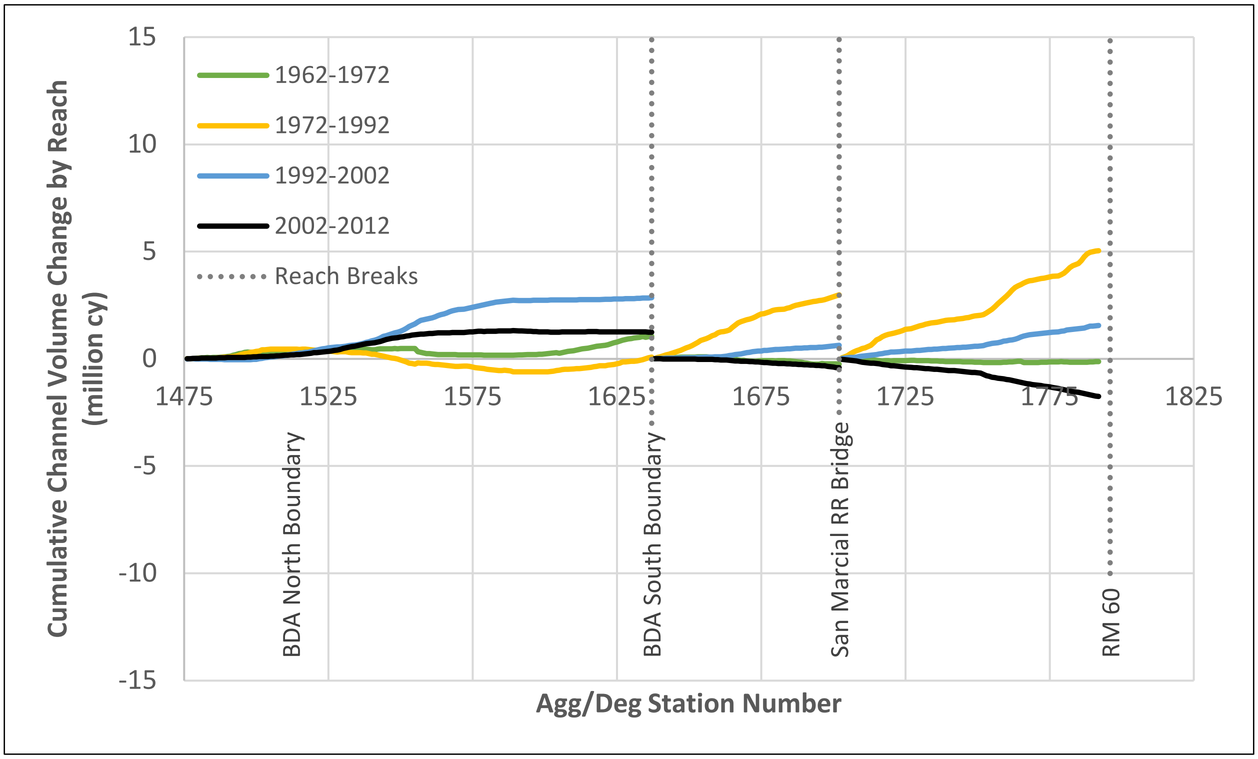


Figure 43.—Cumulative volume change by reach for the main channel.

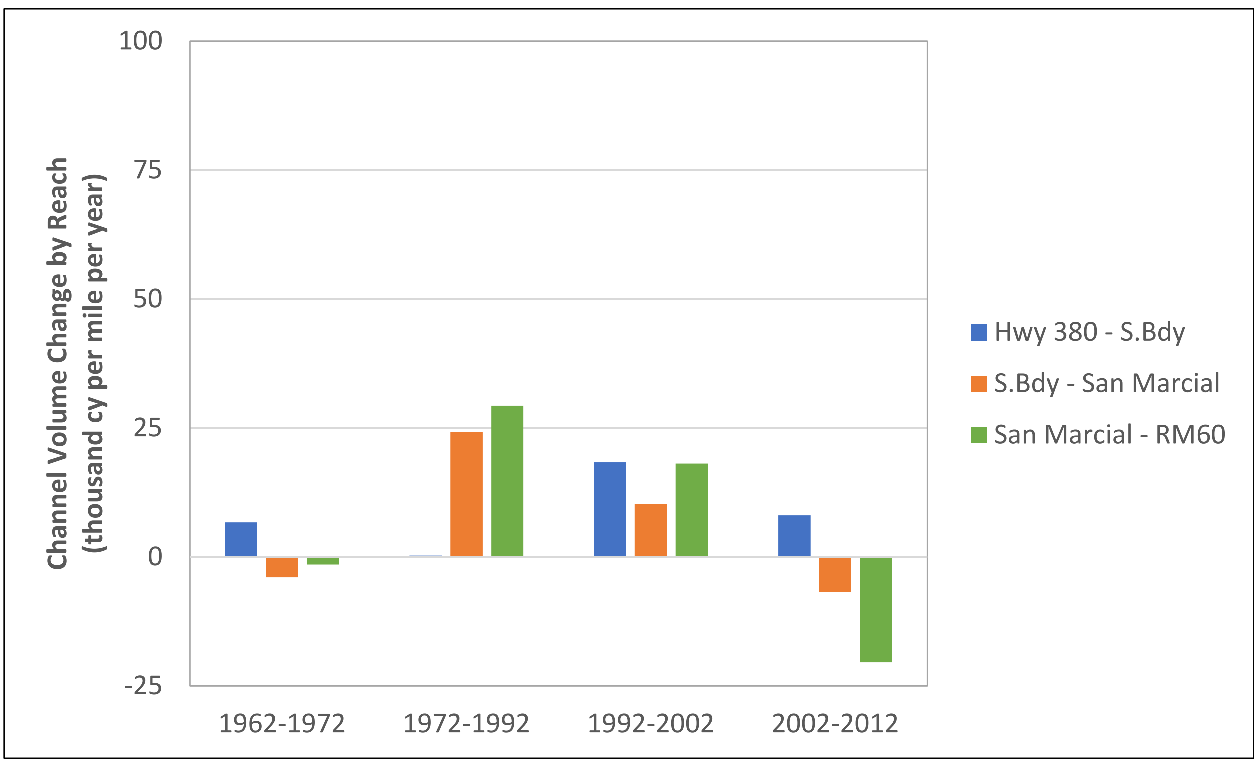


Figure 44.—Normalized volume change by reach for the main channel over time.

Volume changes for the overbank (Figure 45 and Figure 46) and total cross section (Figure 47 and Figure 48) exhibit similar trends but with larger magnitudes. The overbank for the two downstream reaches each had about 8 million cy of sediment deposition between 1972 and 1992, resulting in 11 to 13 million cy of deposition per reach for the total cross section when adding the main channel and overbank together. As discussed for the top of bank profiles, there was little to no erosion in the overbank even when the main channel eroded. The upstream reach from Highway 380 to the BDA South Boundary displayed a different sequence between the main channel and overbank. More channel deposition occurred between 1992 and 2002 while the most overbank deposition occurred between 2002 and 2012. Long duration overbanking events such as the 2005 snowmelt runoff and the 2008 sediment plug likely contributed to increased floodplain deposition along with the 2006 monsoon.

The two downstream reaches between the BDA South Boundary and RM 60 have had a cumulative 30 million cy of sediment deposition from 1962 to 2012. The long-term and prevailing condition for the reach is a depositional environment despite periods of channel incision caused by low reservoir levels. Attaining an equilibrium condition or transporting all sediment delivered from upstream is likely not possible and it is important to manage how sediment is deposited in the project area. Any alternative, whether it be the current channel or a realignment, will need a maintenance plan to address future deposition, especially when the reservoir pool is high.

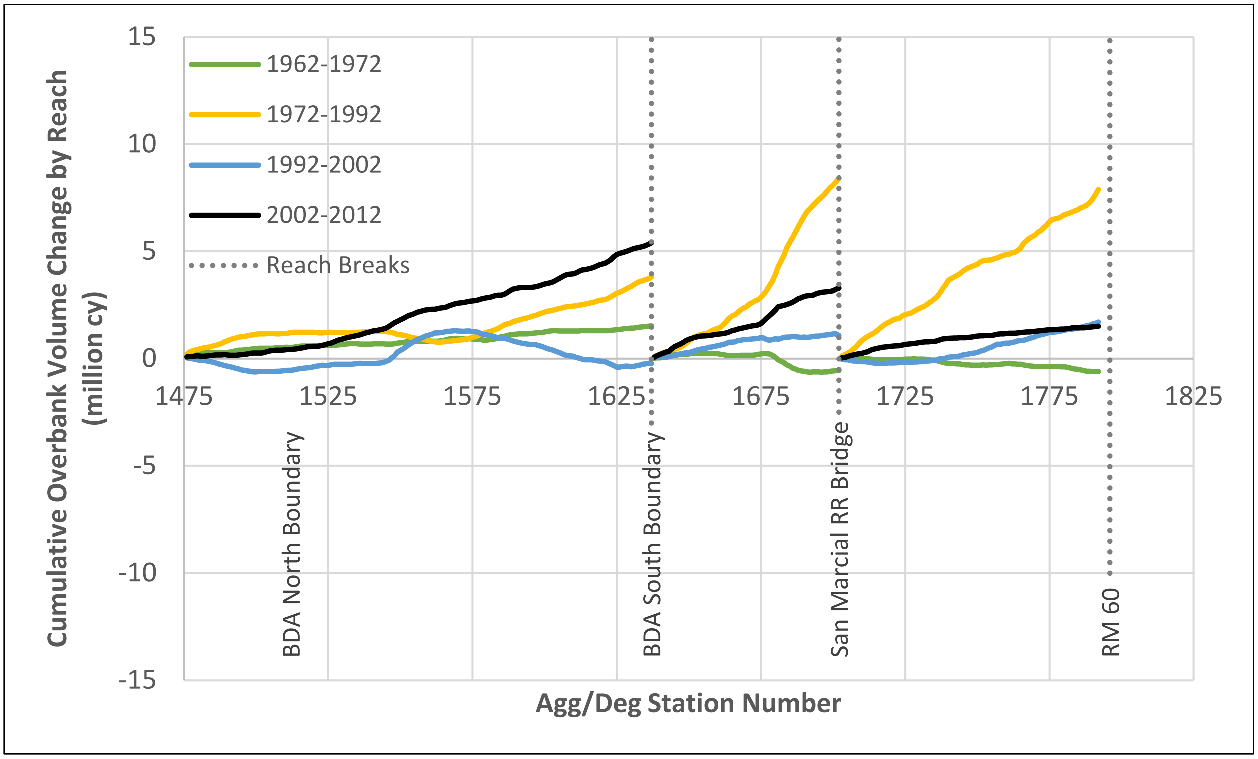


Figure 45.—Cumulative volume change by reach for the overbank.

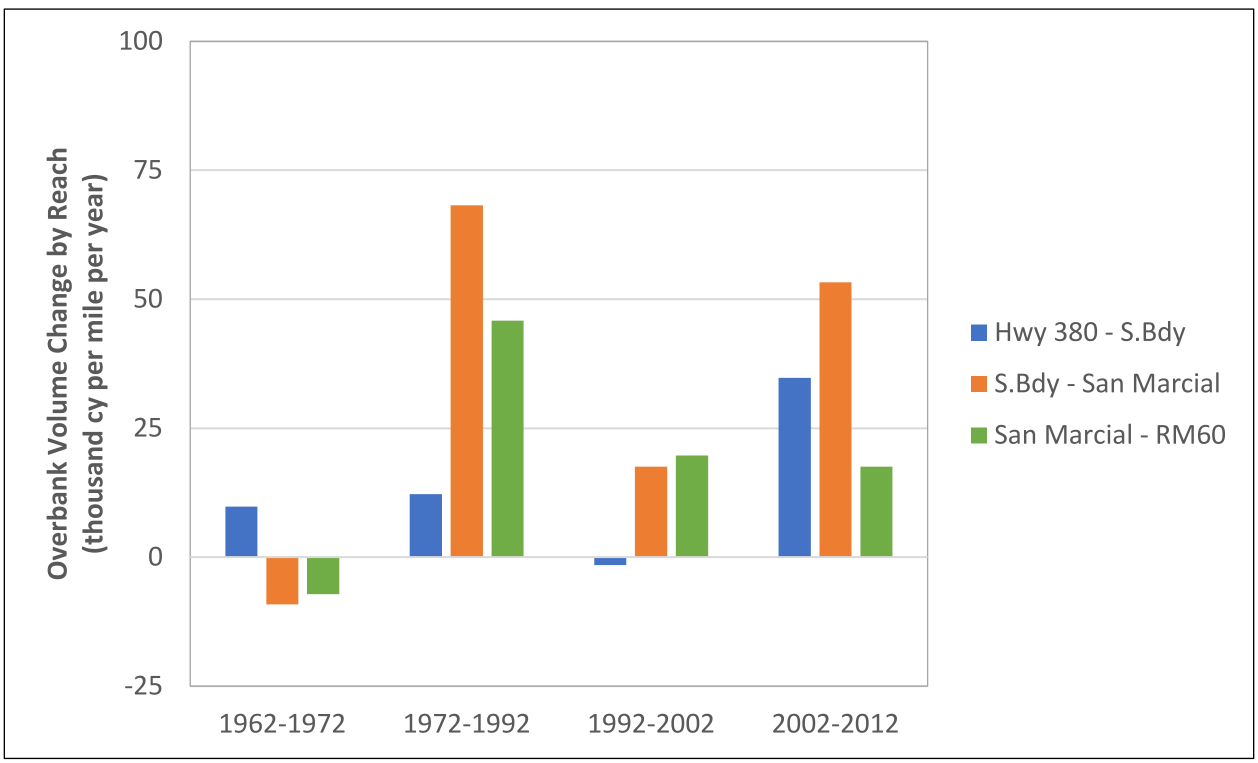


Figure 46.—Normalized volume change by reach for the overbank over time.

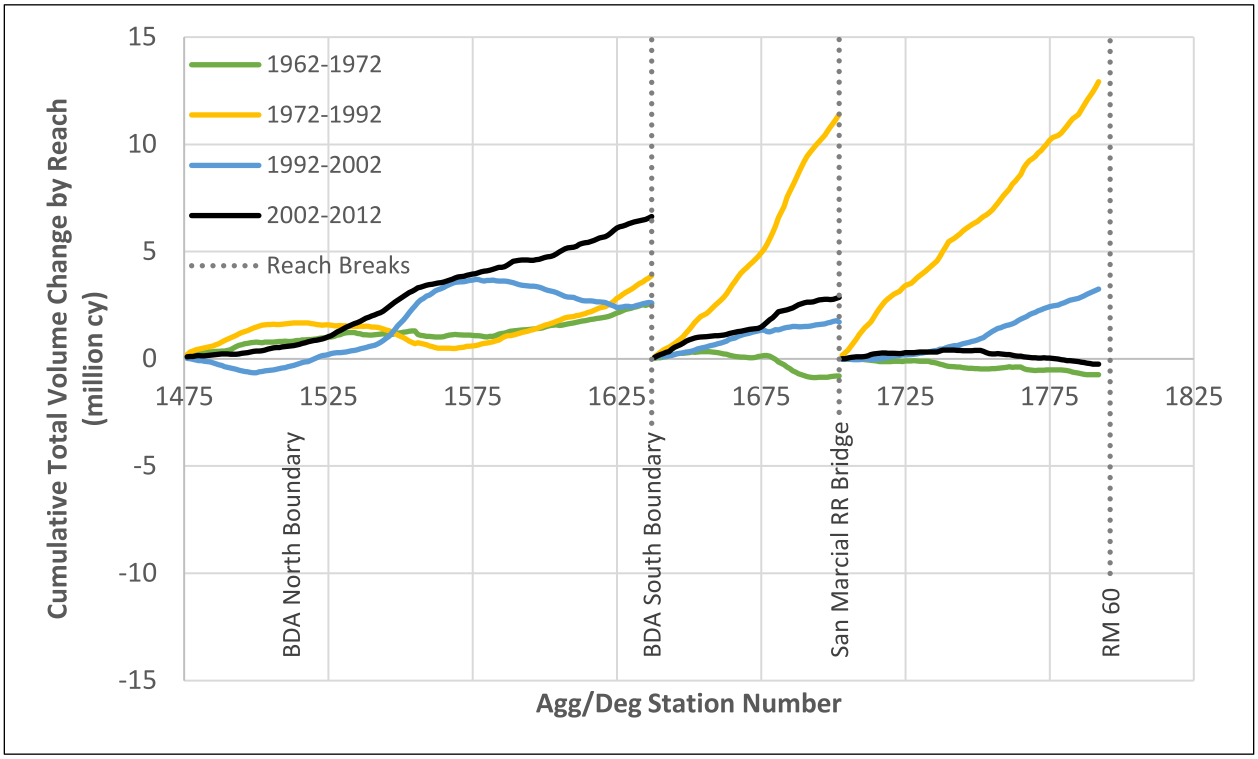


Figure 47.—Cumulative volume change by reach for the total cross section.

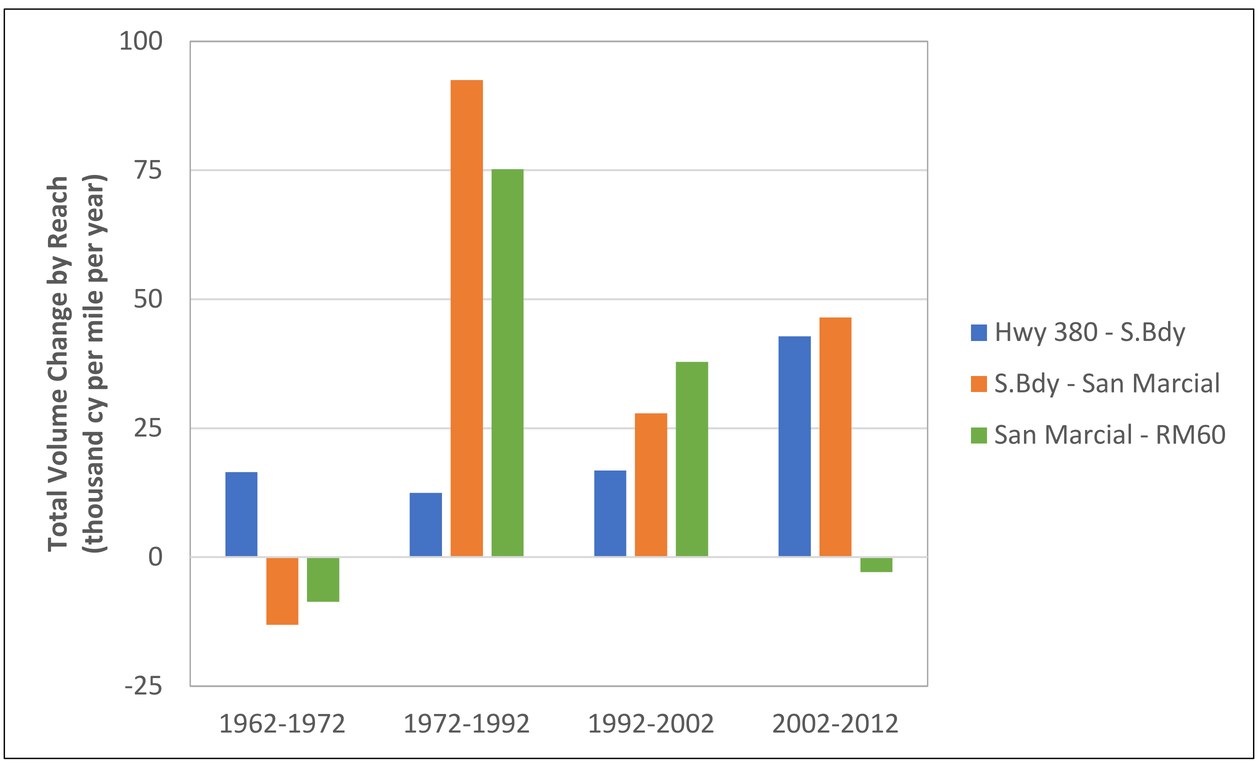


Figure 48.—Normalized volume change by reach for the total cross section over time.

2.2.6 Lateral Migration and Sinuosity

Previous sections of this report have focused on vertical and volumetric change owing to sedimentation and erosion. The channel location and planform are also important and dynamic geomorphic parameters. Rivers with erodible banks tend to migrate and meander over time. Figure 49 presents the calculated migration rate and distance for every MRG geomorphic reach. Reaches upstream of the project area are included for context and comparison. There is a notably high migration rate for the three downstream reaches between 1949 and 1962, which is not a natural migration rate but was caused by the 1950s channelization and river relocation. After 1962, the three downstream reaches have had lower migration rates than nearly all other reaches, with the San Marcial to Full Pool (RM 60) Reach only moving an average of 6 ft per year. Note that migration rates are not additive because different bends move in different directions, so the net effect is a channel planform that has remained in nearly the same location since 1962.

The 1950s channelization also had a significant effect on sinuosity (Figure 50). Sinuosity is calculated as the channel centerline length divided by the valley centerline length before 1950 and as the channel centerline divided by the centerline between lateral constraints after 1950. Before 1950, sinuosity typically varied between 1.1 and 1.2 with the San Marcial to RM 60 Reach having a sinuosity of 1.3 in 1918. After 1950, sinuosity has remained less than 1.05. The MRG has never been a highly sinuous or meandering river. However, the straightening in the 1950s combined with cohesive banks, lower peak flows, levees, and channel maintenance actions have caused the river to remain in a nearly straight alignment for several decades.

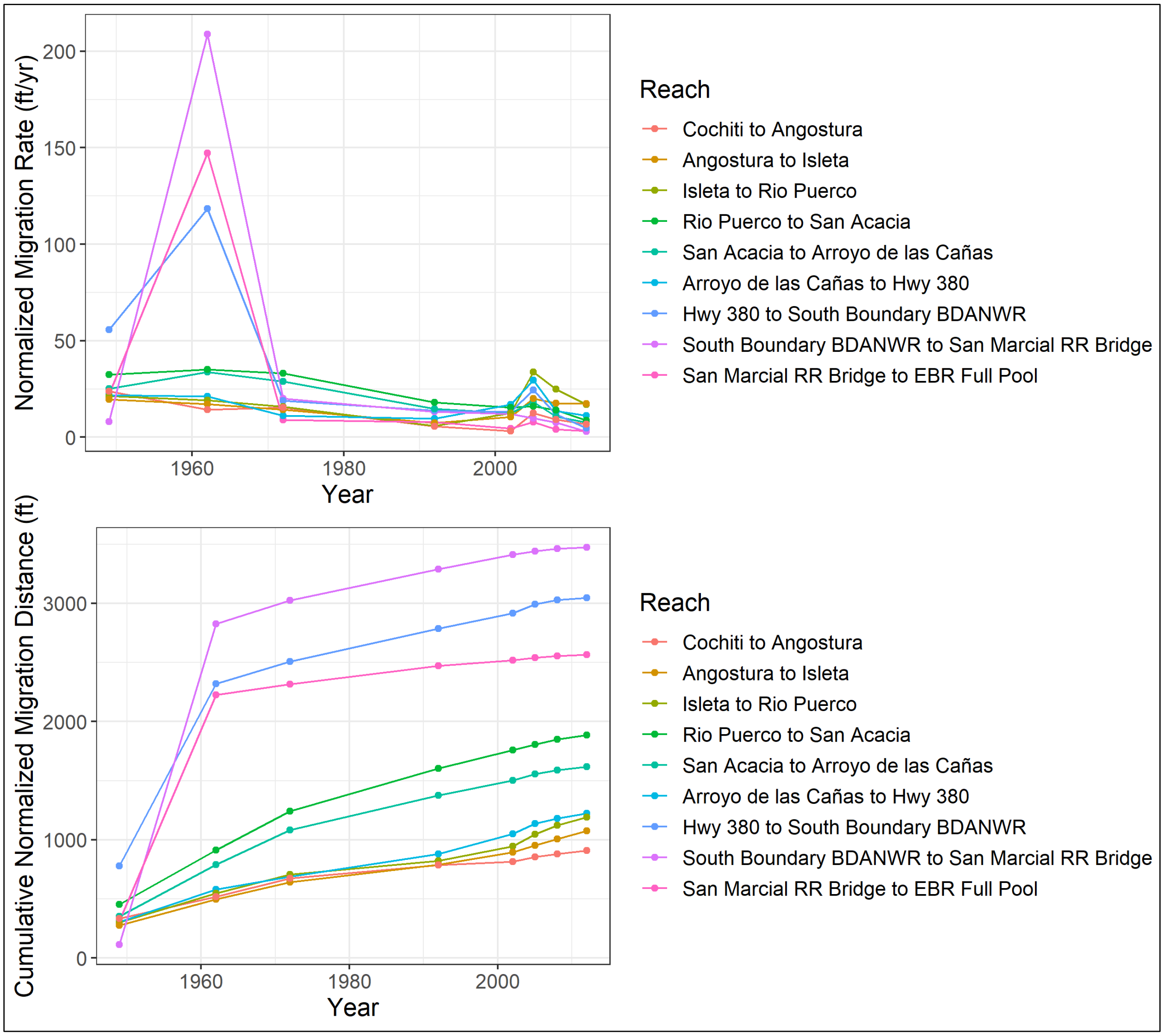


Figure 49.—Normalized migration rate and cumulative distance over time for various reaches (modified from Holste, Hurst, and Byrne 2023). Migration between 1949 and 1962 for the three downstream reaches is the result of channel reconstruction rather than natural river processes. Average migration rates between 1962 and 2012 are 14 ft/yr for Hwy 380 to South Boundary, 11 ft/yr for South Boundary to San Marcial, and 6 ft/yr for San Marcial to Full Pool.

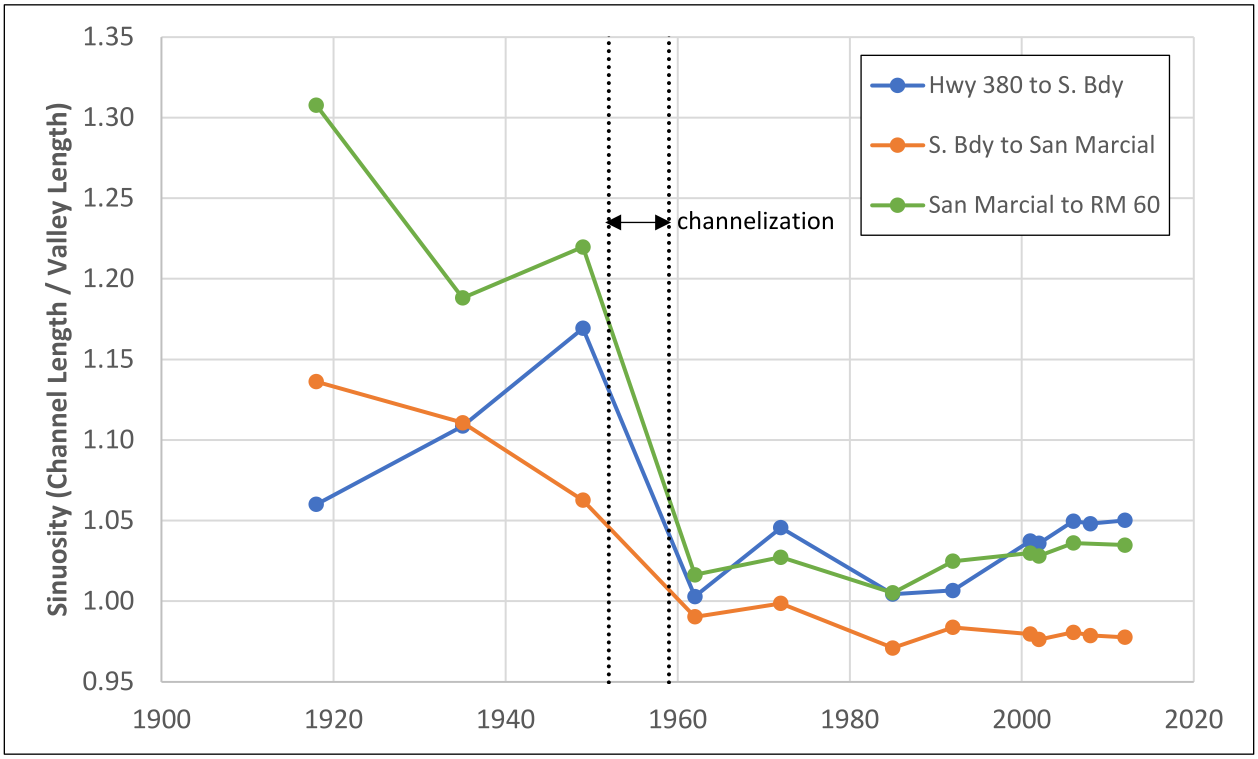


Figure 50.—Sinuosity by reach from 1918 to 2012. Note decrease in sinuosity after 1950s channelization. Values less than one indicate the valley centerline between lateral constraints has more curvature than the river centerline.

2.2.7 Longitudinal Slope

Longitudinal slope represents the potential energy of the river to perform geomorphic work. Steeper slopes tend to result in higher velocities and larger sediment transport capacity than the same river with a flatter slope. Slope considers the bed elevation difference from upstream to downstream and the channel length. Previous longitudinal profile plots have used a consistent stationing to compare elevations at the same Agg/Deg lines. Calculating slope for different years requires that changes in channel length be integrated with changes in bed elevation. Figure 51 compares the longitudinal bed slope for different reaches over time. The upstream reach was slightly steeper before 1940, flatter during 1949 to 2002, and steepened between 2002 and 2019. Overall, the slope of the upstream reach has been relatively consistent at about 0.00072. The slope of the downstream reaches has varied significantly in response to fluctuations in the reservoir pool elevation. These reaches had a slope of about 0.0005 when the reservoir pool is high and a slope approaching 0.0007 when the reservoir pool is low. The long-term average slope for the two downstream reaches is about 0.0006.

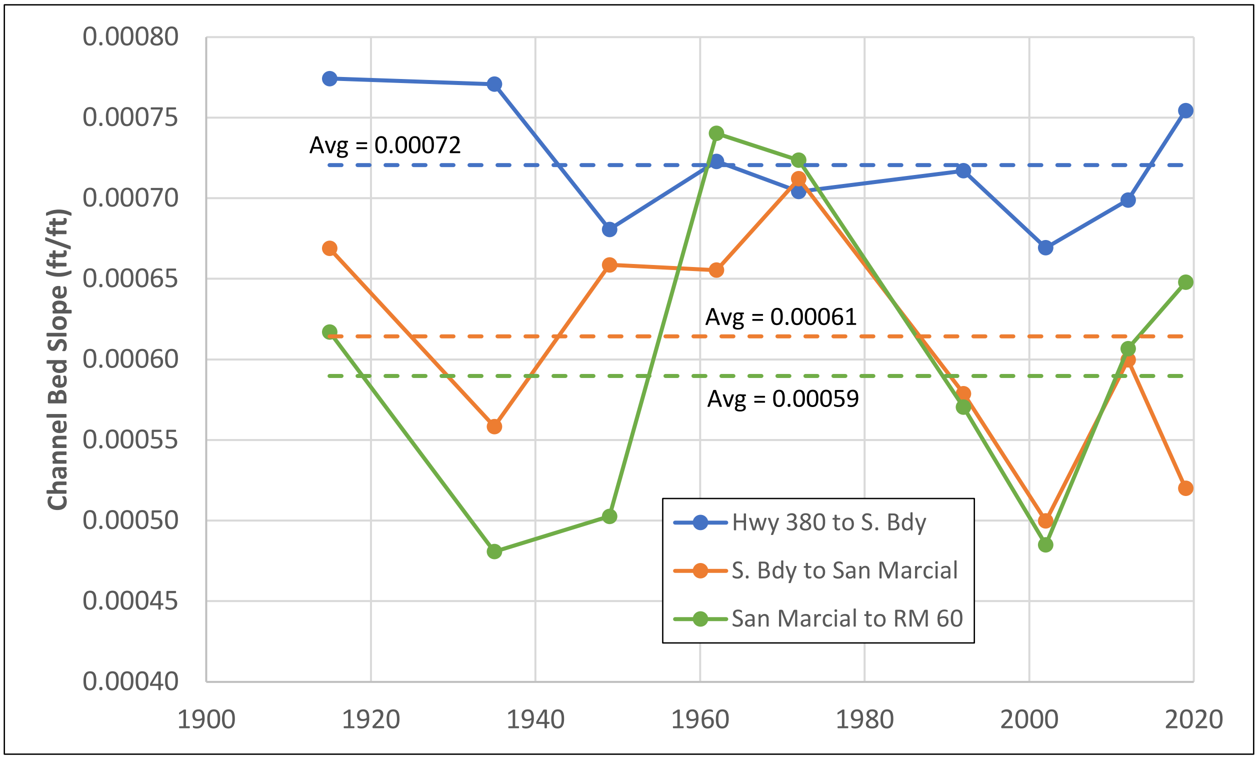


Figure 51.—Channel bed slope by reach from 1915 to 2019 including time-weighted averages.

2.2.8 Bed Material

Main channel bed material in the study reach consists of relatively uniform sand with some finer material in years when the reservoir was high and exerting a backwater effect. Hydraulic sorting causes larger grain sizes to deposit upstream, which creates a consistent and uniform gradation in the lower reach. The absence of arroyos connected to the main channel also contributes to the uniform sand-sized bed material in the project reach. Of samples taken between 1986 and 2022, bed samples have most of the material within the range of medium (0.25–0.5 mm) to fine sand (0.125–0.25 mm), with some samples having a small proportion of very fine sand. For example, samples taken at EB-20 during higher reservoir levels (Figure 55, 1986 to 1999) feature 40–50% fines (silt and clays) by mass. Gravels or cobbles were not a significant proportion of the bed samples collected in the study reach during the period of record available. Main channel bed material data does not show the significant amounts of silt and clay being transported to and deposited in the active delta.

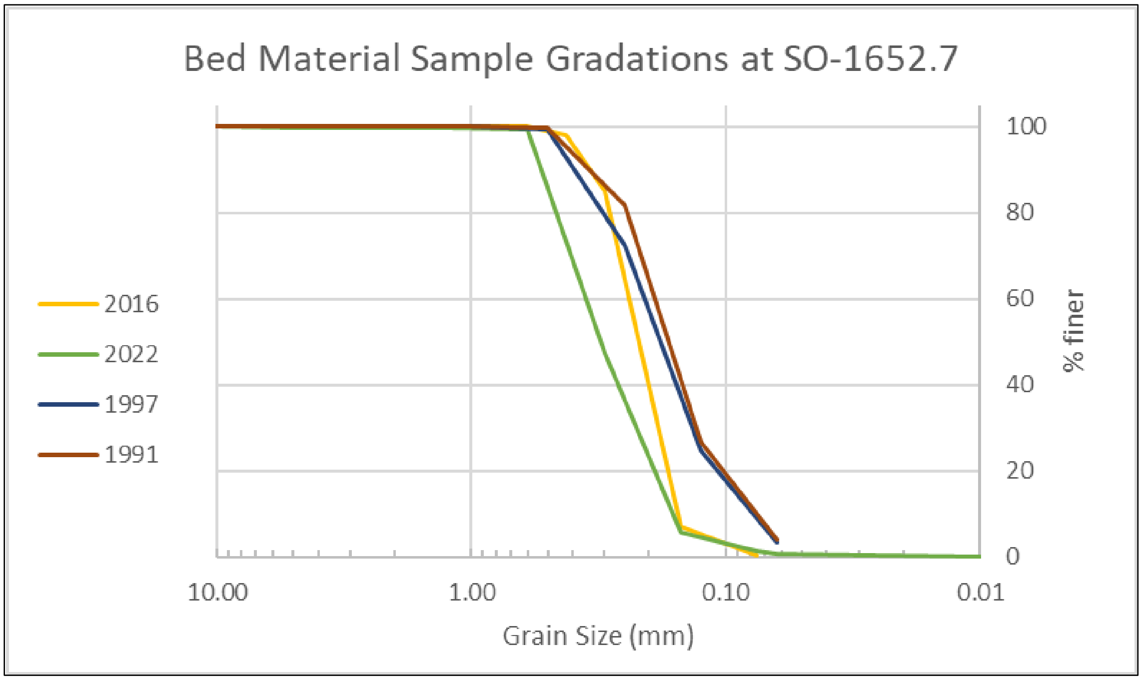


Figure 52.—Grain size distributions of bed material samples taken at SO-1652.7 near the upstream end of the study reach.

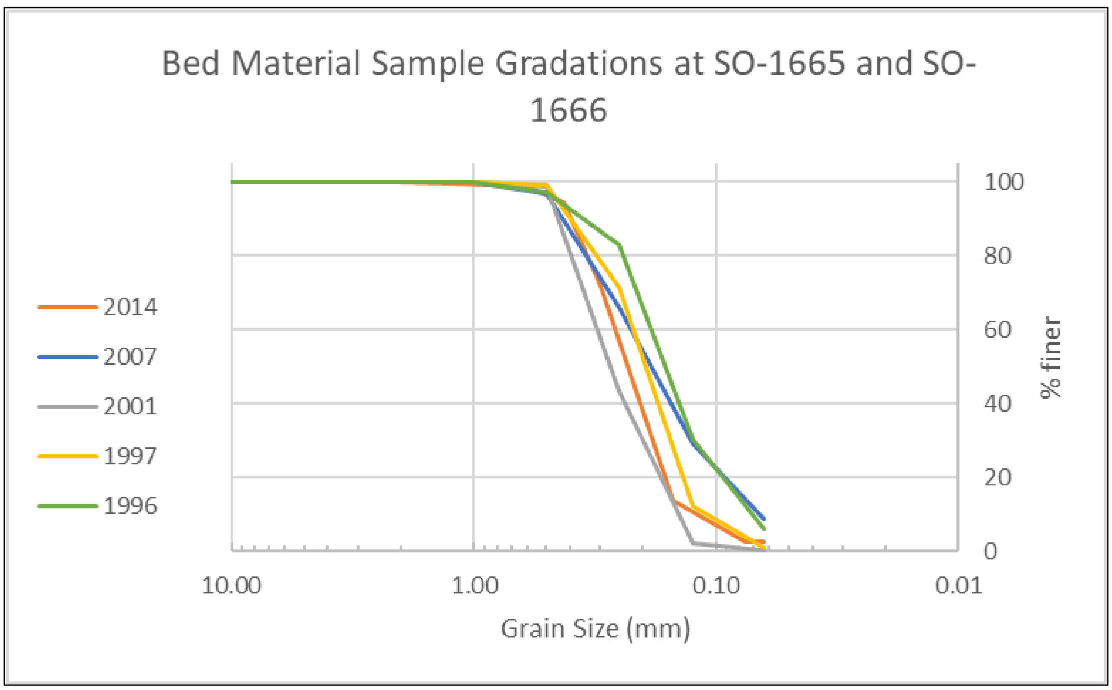


Figure 53.—Grain size distributions of bed material samples taken at SO-1665 and SO-1666 just upstream of the San Marcial Railroad Bridge.

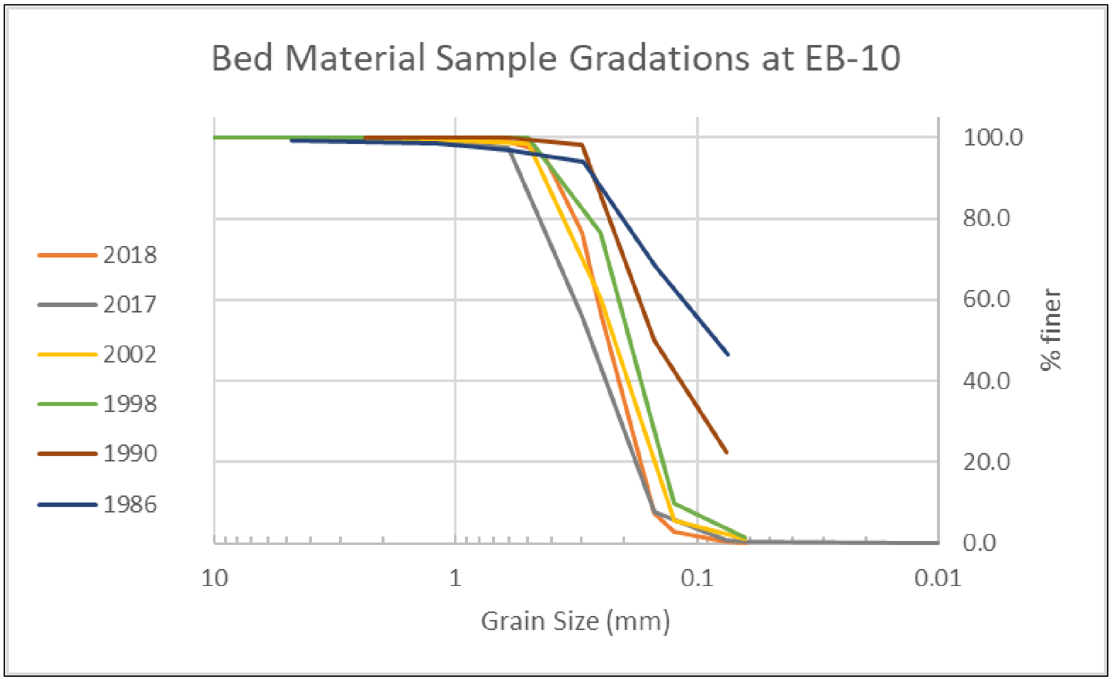


Figure 54.—Grain size distributions of bed material samples taken at EB-10 just downstream of the San Marcial Railroad Bridge.

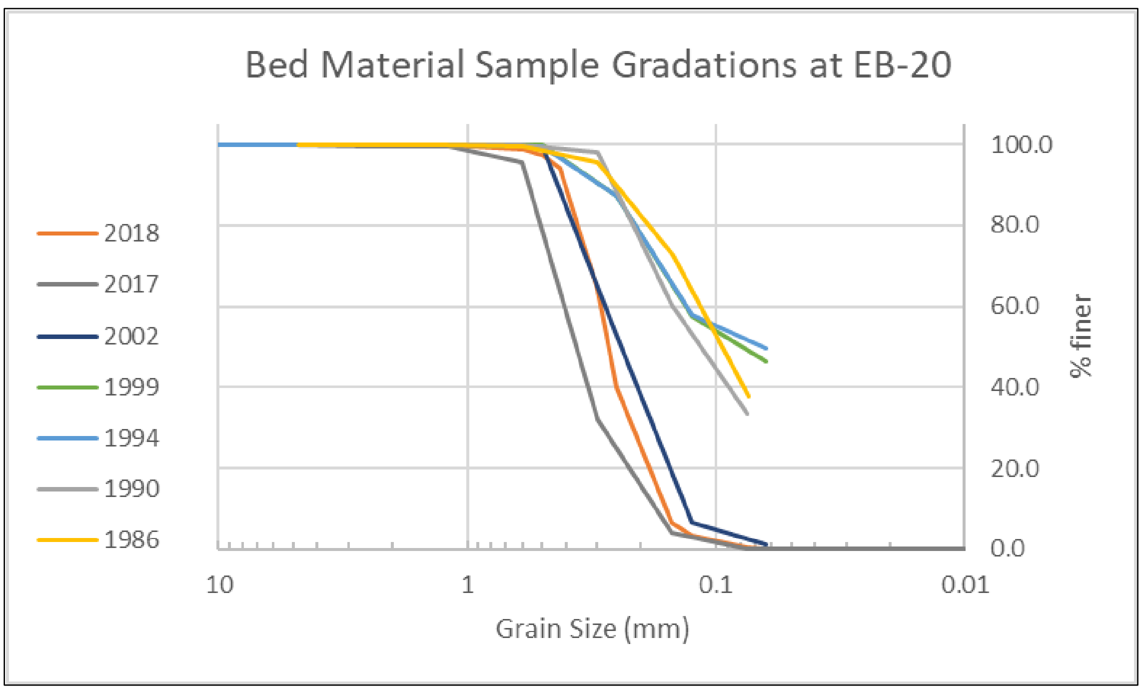


Figure 55.—Grain size distributions of bed material samples taken at EB-10 just upstream of RM 60.

2.2.9 Channel Evolution

The concept of graded equilibrium and long-term sediment balance can be a useful geomorphic theory but does not apply to the project area (Phillips 2010). The river is constantly adjusting its dimensions, pattern, and profile in response to changes in flow, sediment, and base-level. Conceptual models are a useful tool for understanding these changes. Massong et al. (2010) developed a planform evolution model based on observations, aerial photography, and data, which was expanded by Schied et al. (2022) to include cross sections (Figure 56). The evolution model shows how the MRG was historically a wide shallow channel with macroscale bedforms (Stage 1). During low flows the channel would narrow with medial and lateral bars becoming vegetated. In reaches with excess sediment supply, the channel would aggrade and become perched as sediment deposited on the bed and banks. Occasionally, the channel would plug with sediment as in the Tiffany area in 1991, 1995, and 2005 and in BDA in 2008, 2017, and 2019. The historical (pre-1950s) response after a sediment plug was for the channel to avulse to a new location in the floodplain, but the recent Tiffany and BDA plugs were excavated before an avulsion could occur. An avulsion in the current system is unlikely due to the flood control provided by upstream reservoirs. Reclamation constructed a river realignment project during 2019 to 2022 to simulate an avulsion around the 2019 BDA plug.

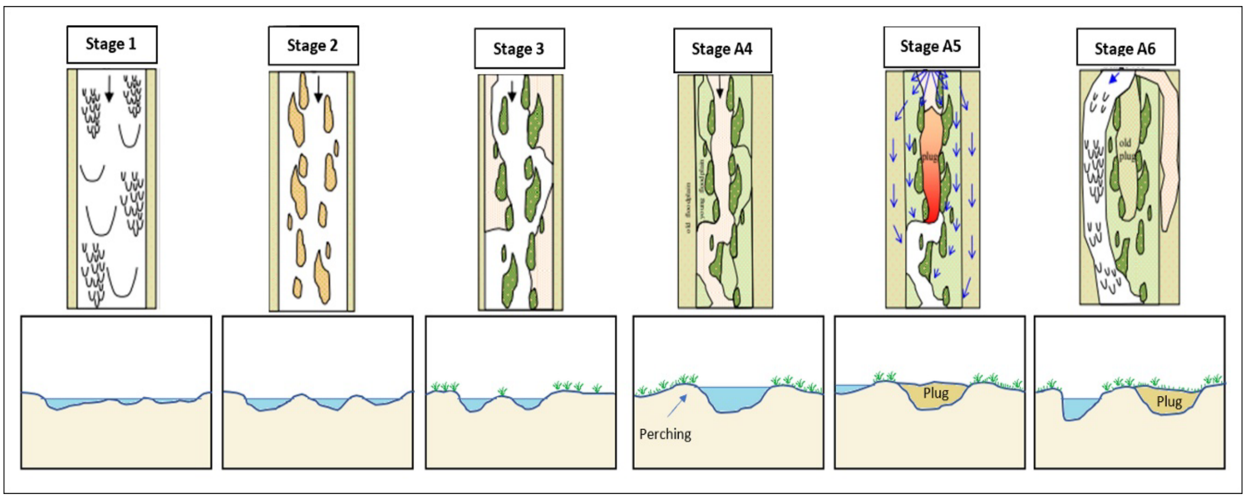


Figure 56.—Middle Rio Grande evolution model for aggrading reaches where sediment supply exceeds transport capacity (Schied et al. 2022, adapted from Massong et al. 2010). Top row shows channel planform while bottom row shows corresponding cross sections for Stages 1 through A6.

Aerial images from 1935 and 1949 illustrate the process of sediment plugs and avulsions in the project area (Figure 57). The river was much wider in 1935 than present conditions and meandered across the valley. There was an avulsion upstream of RM 74, a sediment plug near RM 72, and a series of temporary avulsions between RM 72 and 70. The San Marcial township is visible near RM 71 in the 1935 image, which became a vegetated marsh by 1949. Figure 58 provides a better view of this area after the 1941 or 1942 flood. The river channel flowed adjacent to the railroad embankment along the west side of the valley and was perched above the floodplain to the east. Water appeared to be ponded within the low elevation east floodplain and there are formerly cultivated lands in the center of the photo. These lands became colonized with invasive vegetation and a sediment plug in the former channel prevented a continuous flow path.

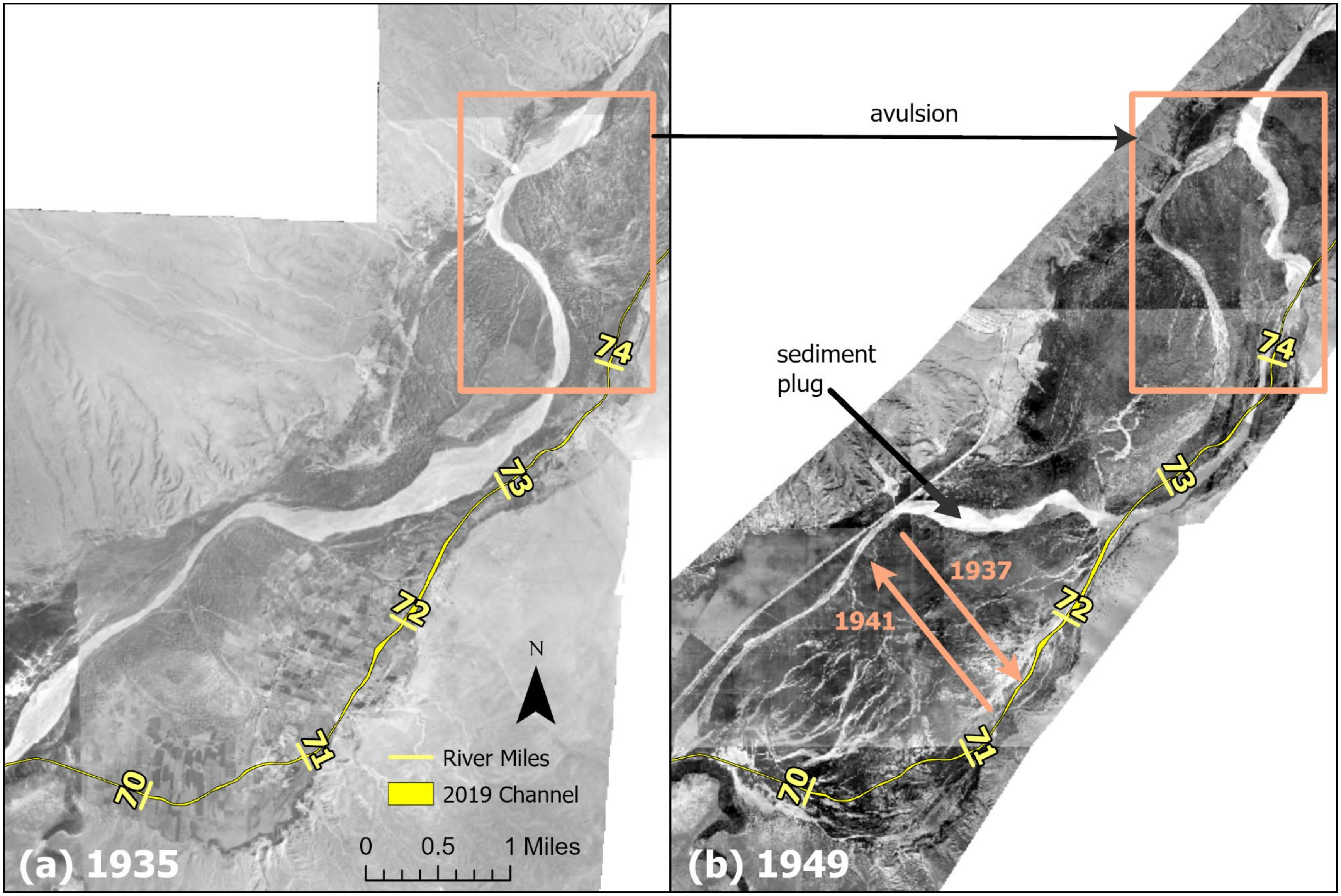


Figure 57.—Tiffany Basin area and former old township of San Marcial in (a) 1935 and (b) 1949. Happ (1948) describes the river avulsing to the east during the 1937 flood and back to the west during the 1941 flood. Note avulsion upstream of RM 74 and sediment plug near RM 72.

Figure 58.—Oblique aerial photo after the 1941 or 1942 flood looking southeast across Tiffany Basin with the San Marcial Railroad and the Rio Grande in the foreground (source unknown). Flow is left to right. Current channel location is in flooded area near the middle-top of photo.

Historical channel mapping further elaborates the channel planform evolution. Figure 59 shows historical channel centerlines starting in 1918. The map includes the channel avulsion near RM 74 between 1935 and 1949 and illustrates the channelization between 1949 and 1962. There has been little change since 1962 except for the development of meander bends near RM 78. The map labels cross section 1670, which has a long-term record of topographic surveys (Figure 60). Changes between 1936 and 1945 indicate how sediment deposition spread across the width of the floodplain, although the channel was becoming perched along the west side of the valley (river right) between 1936 and 1962. The 1962 cross section represents the first post-channelization survey when the LFCC and spoil levee were constructed while the river was moved to the east. Since 1962, sediment has continued to deposit within the confined river and floodplain corridor.

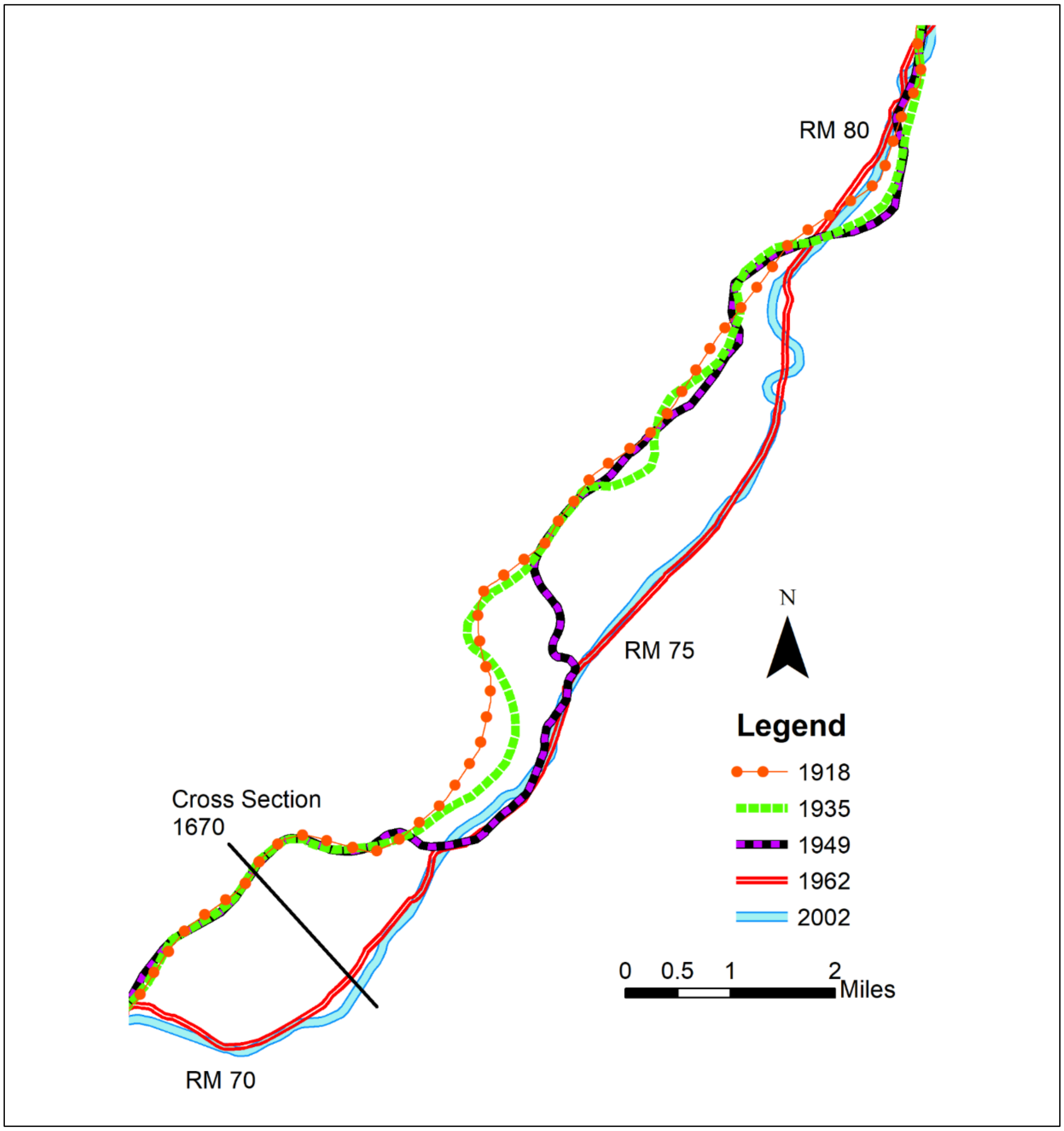


Figure 59.—Historical Rio Grande centerlines upstream of the San Marcial Railroad Bridge. Note avulsion near RM 75 between 1935 and 1949 and channelization to the east between 1949 and 1962. Channel has remained in about the same location since 1962.

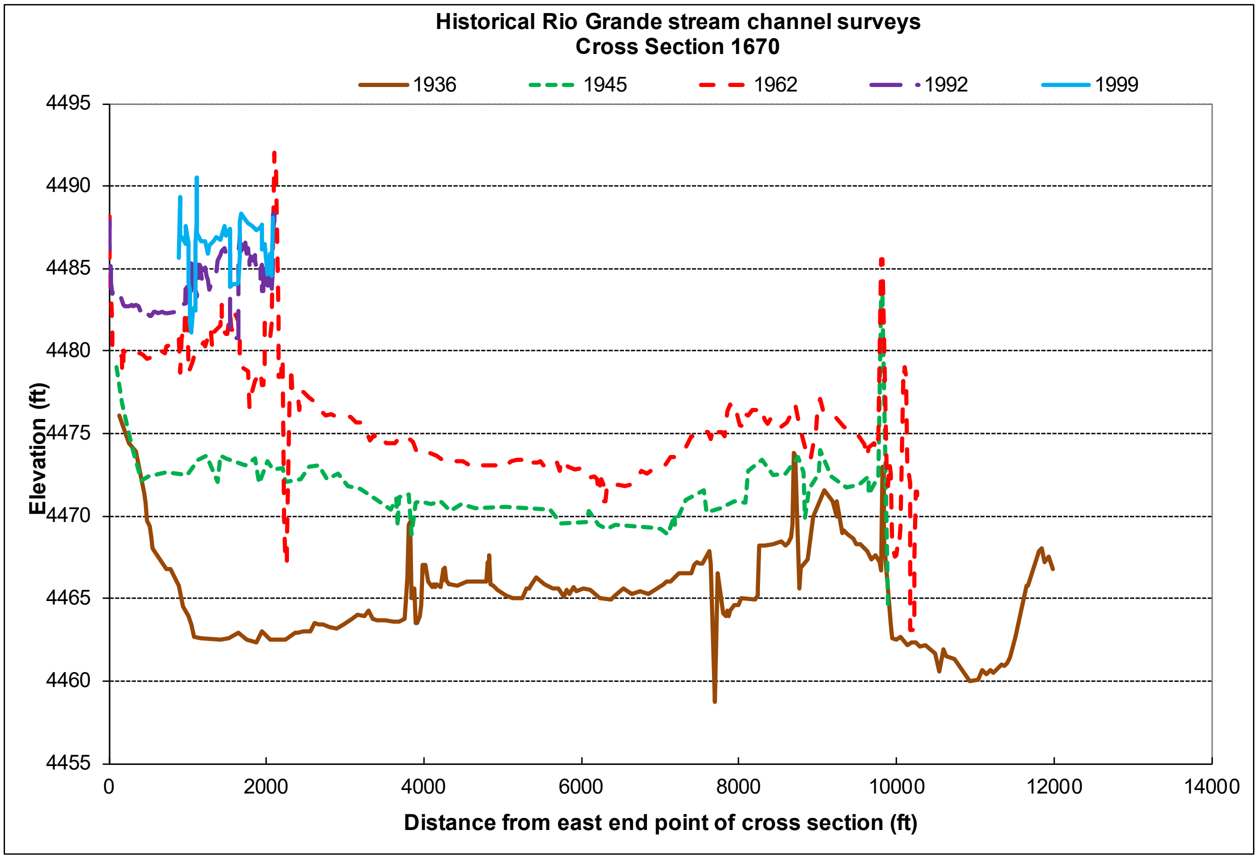


Figure 60.—Historical cross section surveys at SO-1670 between 1936 and 1999, looking downstream.

2.3 Water Delivery and Rio Grande Compact Trends

One of the project goals is to improve water delivery to Elephant Butte Reservoir. Water delivery depends on many interrelated factors such as the upstream flow, the morphology of the channel and floodplain, riparian vegetation, temperature, and humidity. Surface water discharge is reported at USGS gages, but these gages are only an indirect measurement because they apply a stage-discharge rating curve to estimate flow rate from a given water surface elevation. The accuracy of this method is limited by the frequently shifting sand substrate in downstream reaches. Inflows to Elephant Butte Reservoir are also estimated based on the stage of the reservoir pool and measured outflows from the reservoir, which has similar challenges associated with the shifting volume-elevation tables but deemed to be more reliable.

For this analysis, water delivery trends are assessed using the annual Rio Grande Compact data. The Rio Grande Compact was ratified in 1939 and is an interstate agreement between Colorado, New Mexico, and Texas. New Mexico's delivery is calculated as the annual difference between the Otowi Index (annual flow volume at Otowi gage) and Elephant Butte Index (annual volume of reservoir inflow). The annual delivery obligation varies between 57% and 87% depending on the upstream Otowi Index. Over-delivery occurs when the annual Compact delivery exceeds the obligation and under-delivery occurs when the annual Compact delivery is less than the obligation. Credits and debits are carried over between years, meaning that the Compact status is the accrued or cumulative total for many years. However, analysis in this section only considers annual data rather than the accrued surplus or deficit because the cumulative totals can mask variability within individual years. Individual years also provide a better opportunity to link cause and effect. Another consideration is that deliveries are affected by conditions upstream of the project area, which is outside the scope of this report.

Figure 61 tracks the annual over- or under-delivery from 1943 to 2022 with colored dots corresponding to the dry period that ended in 1978, the wet period that ended in 1999, and the ongoing dry period through 2022. Averages for various periods are labeled at the bottom of the graph. The three periods with the largest under-deliveries are 1943 to 1956, 1973 to 1981, and 2011 to 2022. The three periods with the largest over-deliveries are 1966 to 1972, 1982 to 1988, and 2004 to 2010. All three under-delivery periods are during droughts. Two of the three over-delivery periods are also during droughts but include some high flow years and large monsoons. The 1980s and 1990s had mostly positive annual deliveries and were the wettest sustained period since the Compact was signed.

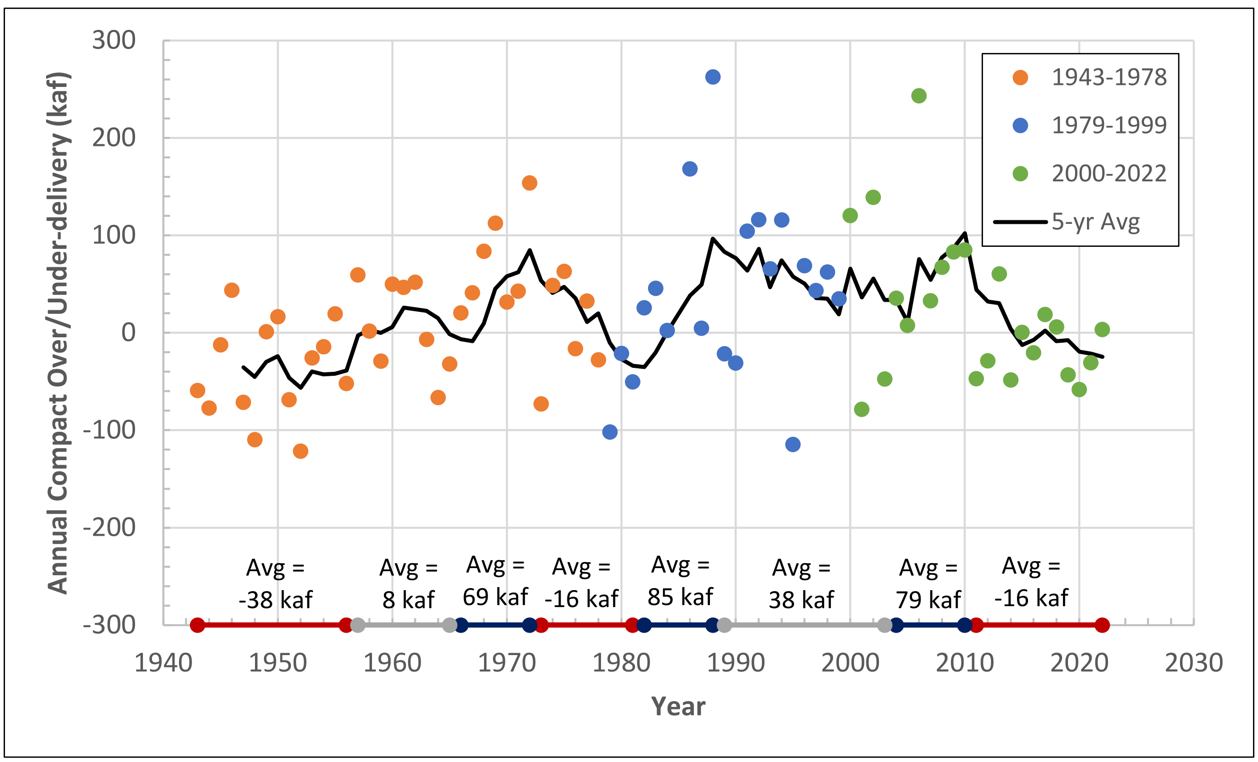


Figure 61.—Annual Rio Grande Compact accounting and trends, 1943–2022. Colors represent dry (1943–1978, 2000–2022) and wet (1979–1999) periods. Over- or under-delivery calculated in thousand acre-feet (kaf) as New Mexico's annual Compact delivery minus the annual Compact obligation. Periods of low deliveries (1943–1956, 1973–1981, 2011–2022) and high deliveries (1966–1972, 1982–1988, 2004–2010) labeled at bottom of graph.

To assess the potential impact of LFCC construction and operation on the Compact deliveries, Figure 62 compares the annual average LFCC discharge at San Acacia and San Marcial to the Compact data presented above. The increase in diversions upstream of San Marcial in 1957, and full operation at San Acacia in 1959 into 1960, appear to correlate to an improvement in Compact deliveries. The largest LFCC flow to date in 1965 coincides with an under-delivery year, before the period 1966 to 1972 exceeded delivery requirements while the LFCC was being operated with relatively high diversion rates. This period was responsible for eliminating New Mexico's debt under the Compact. However, 1973 was nearly the largest flow year on record in the LFCC and resulted in an under-delivery of about 73 kaf. Diversions at San Acacia remained relatively high through 1980 and the Compact had a slight under-delivery on average, perhaps due to repairs that prevented continuous LFCC operation for its full length. High flow years in the 1980s resulted in the highest average Compact deliveries. The LFCC was operated in 1984 and 1985 before diversions ceased and it began functioning as a drainage channel. Interannual variability complicates the analysis, but the data generally corroborate previous assertions (e.g., Gorbach 1999) that the LFCC improved Compact deliveries during the drought from about 1957 to 1972.

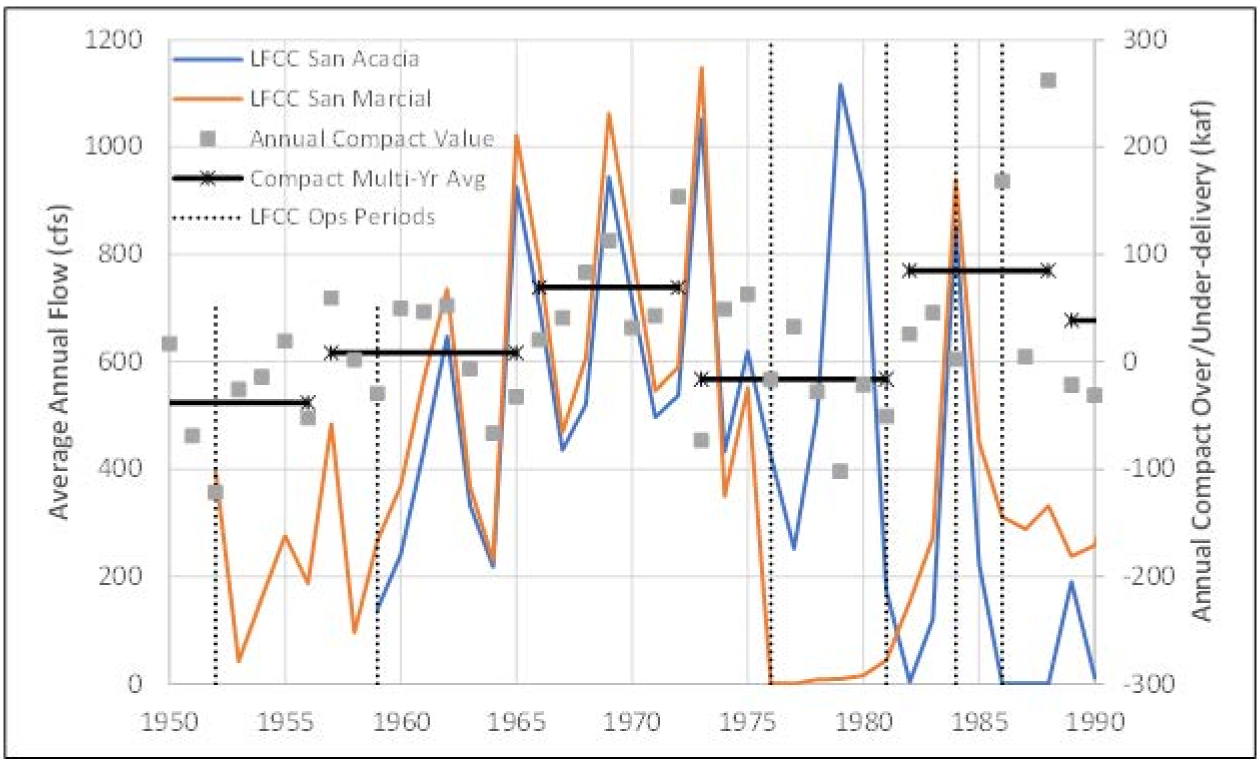


Figure 62.—LFCC annual average discharge at San Acacia and San Marcial (primary y-axis) compared to annual and multi-year Compact over- or under-delivery (secondary y-axis). Vertical dashed lines denote the following LFCC operational periods: 1952–1958 (downstream operation), 1959–1975 (full operation), 1976–1980 (upstream operation), 1981–1983 (no operation), 1984–1985 (full operation), 1986–present (no operation).

Table 2 presents results from several single variable linear regression models to understand if the annual Compact deliveries correlate to any independent flow metrics. The analysis includes annual flow volumes at the San Marcial floodway and LFCC gages, the monsoon season flow volume at the floodway gage, and the number of overbanking days for three geomorphic reaches. Nearly all regression models have low values for the coefficient of determination (R^2) indicating that there is no relationship with Compact deliveries. The most significant variable is the monsoon season volume during the 2000 to 2022 period. Compact deliveries improve with larger monsoons because the monsoons provide water to the reach that is often not accounted for in the delivery obligation calculated at the upstream Otowi gage. The year with the largest monsoon volume, 2006, had the second largest over-delivery in the period of record.

Table 2.—Results from linear regression analyses that compare annual Compact over/under-delivery (dependent variable) to various annual independent variables.

Independent Variable	Analysis Period	Regression Coefficient (m)	Coefficient of Determination (R^2)
San Marcial LFCC Flow Volume (kaf)	1952–2022	0.063	0.024
	1952–1978	0.067	0.070
	1979–1999	0.159	0.061
	2000–2022	0.603	0.080
San Marcial Floodway Flow Volume (kaf)	1949–2022	0.015	0.007
	1949–1978	0.023	0.017
	1979–1999	-0.001	0.000
	2000–2022	0.051	0.023
San Marcial Total Flow Volume (kaf)	1949–2022	0.028	0.025
	1949–1978	0.014	0.008
	1979–1999	0.018	0.007
	2000–2022	0.052	0.031
San Marcial LFCC Flow Percentage (%)	1952–2022	3.447	0.000
	1952–1978	33.41	0.037
	1979–1999	93.66	0.021
	2000–2022	-101.9	0.014
San Marcial Floodway Monsoon Volume (kaf)	1952–2022	0.584	0.172
	1952–1978	0.084	0.003
	1979–1999	0.586	0.138
	2000–2022	**0.952**	**0.443**
Hwy 380 – S. BDA Overbanking Days (count)	1957–2022	-0.709	0.040
	1957–1978	-0.786	0.038
	1979–1999	-1.407	0.181
	2000–2022	-0.262	0.003
S. BDA – San Marcial Overbanking Days (count)	1957–2022	-0.463	0.013
	1957–1978	0.447	0.011
	1979–1999	-1.294	0.097
	2000–2022	-0.210	0.002
San Marcial – RM 60 Overbanking Days (count)	1957–2022	0.180	0.001
	1957–1978	-0.565	0.007
	1979–1999	0.439	0.008
	2000–2022	-0.207	0.002

The absence of any clear trends or correlations except for monsoon volume suggests that Compact deliveries depend on several different factors. Next, the data were sorted from the lowest to highest annual delivery status to identify any patterns or differences. Table 3 summarizes these results for the largest over-deliveries (4th quartile) and under-deliveries (1st quartile). Over-delivery years were more common in the 1990s and 2000s and typically had larger San Juan Chama Project supplemental releases, larger annual and monsoon flow volumes at San Marcial, and more overbanking days. Under-delivery years were more common in the 1950s, 2010s, and 2020s and typically had lower supplemental releases, lower annual and monsoon flows at San Marcial, and fewer overbanking days.

Table 3.—Flow characteristics of the years between 1949 and 2022 with annual Rio Grande Compact credits above 60,000 acre-feet (4th quartile) and annual debits above 29,000 acre-feet (1st quartile). Data for all parameters not available in all years.

Parameter	4th Quartile (upper 25%) Over-delivery > 60 kaf	1st Quartile (lower 25%) Under-delivery < -29 kaf
Distribution by Decade	1950s: 0 years 1960s: 2 years (1968, 1969) 1970s: 2 years (1972, 1975) 1980s: 2 years (1986, 1988) 1990s: 6 years (1991, 1992, 1993, 1994, 1996, 1998) 2000s: 5 years (2000, 2002, 2006, 2008, 2009) 2010s: 2 years (2010, 2013) 2020s: 0 years	1950s: 4 years (1951, 1952, 1956, 1959) 1960s: 2 years (1964, 1965) 1970s: 2 years (1973, 1979) 1980s: 1 year (1981) 1990s: 2 years (1990, 1995) 2000s: 2 years (2001, 2003) 2010s: 3 years (2011, 2014, 2019) 2020s: 2 years (2020, 2021)
San Juan Chama Project Supplemental Release	8 of 9 years above median (20 kaf)	2 of 7 years above median (20 kaf)
San Marcial LFCC Flow Volume (kaf)	14 of 19 years above median (170 kaf)	6 of 18 years above median (170 kaf)
San Marcial Floodway Flow Volume (kaf)	12 of 19 years above median (296 kaf)	6 of 18 years above median (296 kaf)
San Marcial Total Flow Volume (kaf)	13 of 19 years above median (545 kaf)	6 of 18 years above median (545 kaf)
San Marcial LFCC Flow Percentage (%)	7 of 19 years above median (29%)	12 of 17 years above median (29%)
San Marcial Floodway Monsoon Volume (kaf)	16 of 19 years above median (41 kaf)	7 of 17 years above median (41 kaf)
Hwy 380 – S. BDA Overbanking Days	12 of 19 years above median (0 days)	5 of 15 years above median (0 days)
S. BDA – San Marcial Overbanking Days	7 of 19 years above median (0 days)	4 of 15 years above median (0 days)
San Marcial – RM 60 Overbanking Days	6 of 19 years above median (0 days)	2 of 15 years above median (0 days)

Figure 63 plots annual over- or under-delivery as a function of the Otowi Supply Index. The Compact specifies an allowable depletion volume depending on the Otowi Index. The allowable depletion ranges from 43% during low flow years (57% required delivery) to 13% during high flow years (87% required delivery). For example, when the Otowi Index is 100 kaf, 57 kaf must be delivered to Elephant Butte. Depletions are allowed to increase as the Otowi Index increases up to 1500 kaf when the allowable depletions become fixed at 405 kaf. For the 74 years between 1949 and 2022, the average Otowi Index was 893 kaf and the median was 796 kaf. For the last 30 years between 1993 and 2022, the average Otowi Index was 821 kaf and the median was 786 kaf.

Under-delivery typically occurs during low flow years (Otowi less than 800 kaf) or high flow years (Otowi greater than 1400 kaf). Years when the Otowi Index is between 800 and 1400 kaf usually result in over-delivery. These are average to above average flow years in which the depletions are allowed to increase as the flow volume increases. Over-delivery outliers during low flow years are explained by large monsoon events or above average supplemental releases. Under-delivery during low flow years is likely caused by the allowable depletion not being enough to offset losses from seepage, riparian transpiration, and other uses. These losses are relatively constant for different water years and are estimated at about 210 kaf based on calculating total depletions minus open water evaporation for 2020 and 2021. There is less uncertainty in calculating open water evaporation during low flow years, which is why other losses are estimated using data from 2020 and 2021. The Compact does not allow more than 210 kaf of depletions until the Otowi Index exceeds 500 kaf and does not allow more than 300 kaf of depletions until the Otowi Index exceeds 700 kaf. Therefore, low flow years tend to under deliver water to Elephant Butte unless there is a significant monsoon or supplemental release. Improving deliveries at low flows may be an effective way to improve the Compact status, especially during periods of drought. Conceptual ideas to improve deliveries at low flows include reducing seepage loss by reducing the height of the riverbed above the shallow groundwater (i.e., reducing perching) and reducing transpiration loss by reducing the area or density of riparian vegetation.

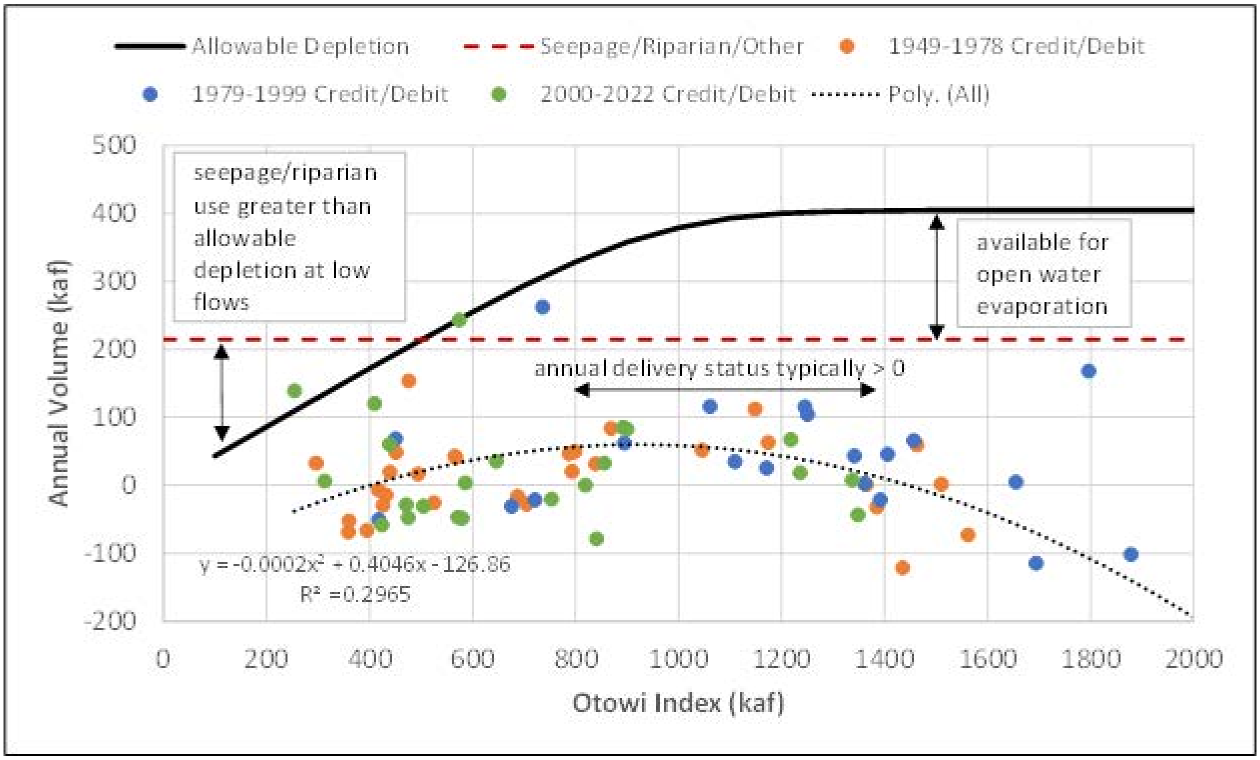


Figure 63.—Allowable annual depletion as a function of Otowi Supply Index according to Rio Grande Compact schedule. Annual over/under-delivery volumes also plotted against Otowi Index. Seepage, riparian transpiration, and other uses estimated as a constant value. Open water evaporation varies with water volume and inundated area. Outliers above trendline explained by monsoons and supplemental releases.

2.4 Habitat Dynamics

2.4.1 Avian Habitat

The federally endangered southwestern willow flycatcher (*Empidonax traillii extimus*; hereafter SWFL) and the federally threatened yellow-billed cuckoo (*Coccyzus americanus occidentalis*; hereafter YBCU) have established territories within the Project Area (Figure 64 and Figure 65). Within the Middle Rio Grande, the highest quality SWFL breeding habitat is dominated by developing stands of willows and contains saturated soils or flooded conditions throughout the SWFL breeding and vegetative growing seasons (April to October) (Siegle and Moore 2022). Occupied sites usually consist of dense vegetation in the patch interior, or an aggregate of dense patches interspersed with openings. In most cases this dense vegetation occurs within the first 4 to 5 m (13 to 16 ft) above ground. These dense patches are often interspersed with small openings, open water or marsh, or shorter/sparser vegetation, creating a mosaic that is not uniformly dense. Hydrology is important as it not only supports the vegetative species composition and structure preferred by SWFLs, but also provides microclimate characteristics and a food base necessary for successful reproduction. Ninety percent of SWFL nests in the Middle Rio Grande between 2004 and 2022 were within 100 meters of water (Moore 2023). The timing of hydrologic inputs (via the snowmelt-dominated hydrograph) is important as well, as higher flows and the potential for flooding in late spring and early summer benefit habitat maintenance, seedling establishment, and SWFL territory selection.

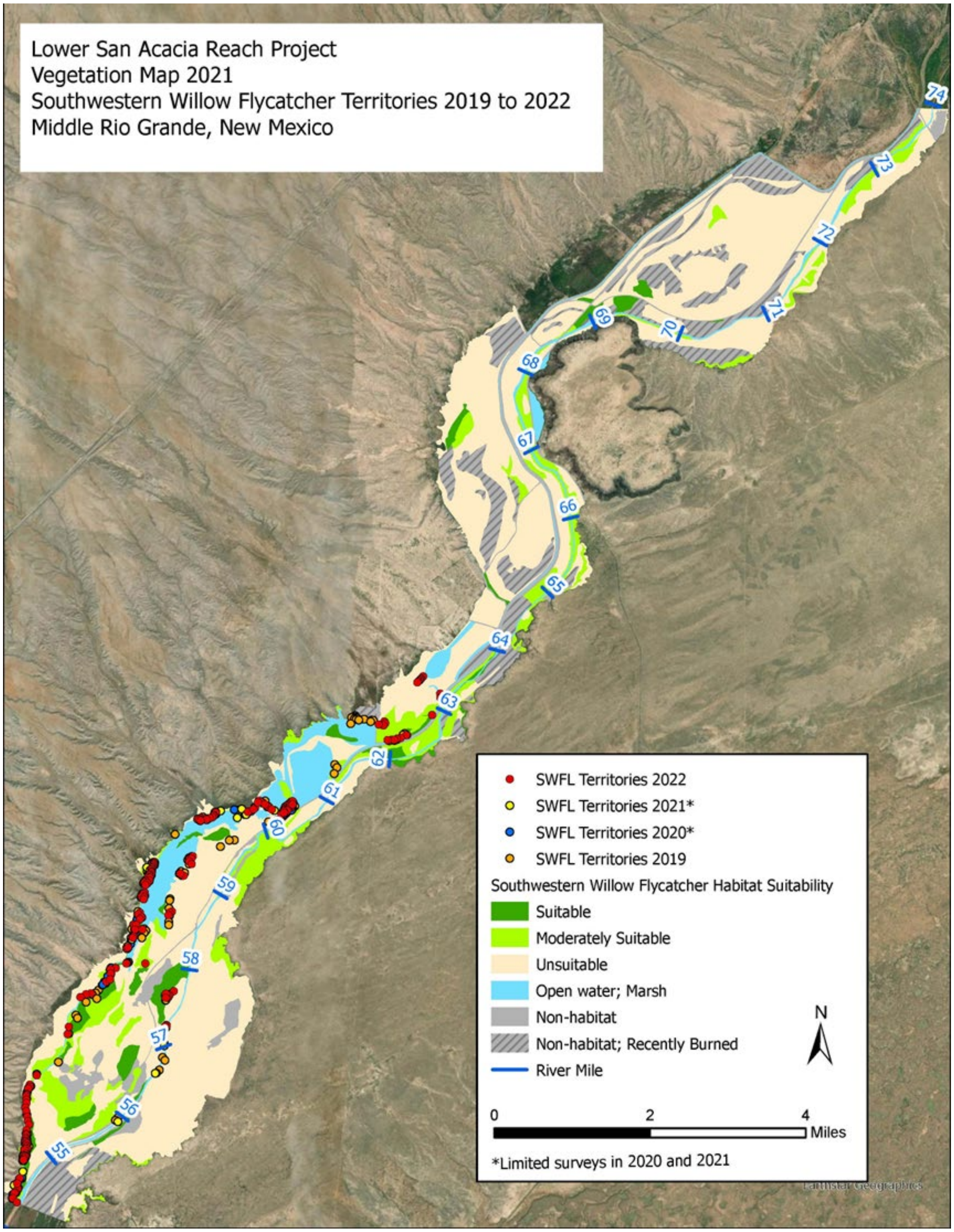


Figure 64.—Recent (2019 to 2022) Southwestern willow flycatcher territories and habitat suitability (2021) in project area (see Siegle and Moore 2022 for description of habitat suitability).

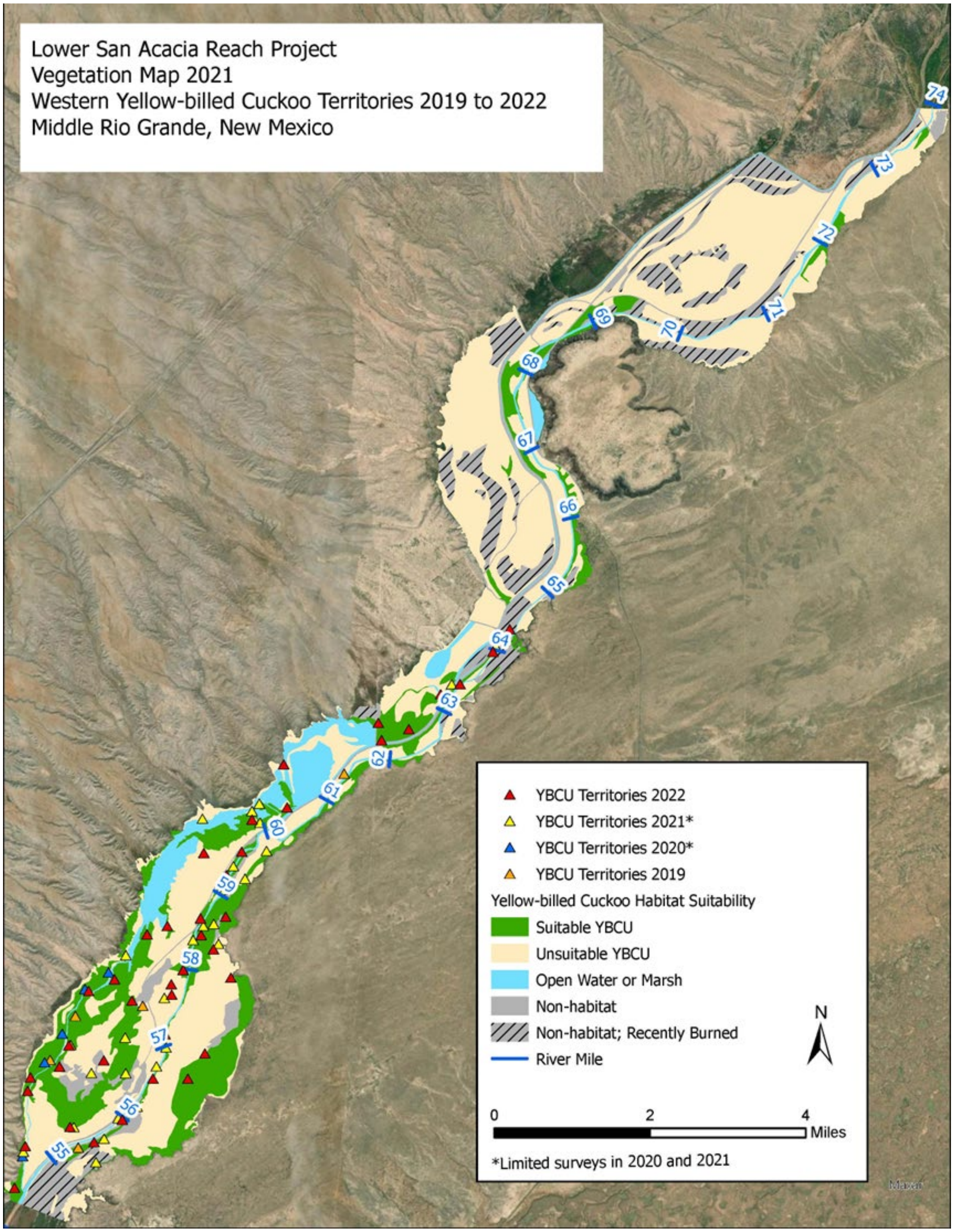


Figure 65.—Recent (2019 to 2022) yellow-billed cuckoo territories and habitat suitability (2021) in project area (see Siegle et al. 2022 for description of habitat suitability).

Suitable SWFL breeding habitat within the Project Area consisted of nearly monotypic stands of Goodding's willow (*Salix gooddingii*) in 2005. It is now comprised of a mixture of Rio Grande cottonwood (*Populus deltoides*), Goodding's willow, coyote willow (*Salix exigua*), and exotic saltcedar (*Tamarix* spp.; Siegle and Moore 2022). Vegetation categorized as unsuitable within the Project Area mostly included tall (greater than 40 ft) cottonwood and/or Goodding's willow without a willow understory component and monotypic saltcedar stands. Suitable breeding habitat for YBCUs is like SWFLs in the plant species composition, however areas with more mature vegetation, including cottonwood and Goodding's willow greater than 40 ft in height, can typically support breeding habitat for this species. Also, an understory component does not appear to be as important in YBCU habitat as it is in SWFL habitat. Suitable YBCU breeding habitat mapped in 2021 included cottonwood and/or Goodding's willow overstory patches greater than 15 ft in height, greater than 8 hectares in area, greater than 30 meters (m) in width, and with a Goodding's willow component. If these criteria were not met, the habitat was deemed unsuitable for YBCU breeding; within the Project Area much of the unsuitable habitat was saltcedar monocultures.

A few SWFL territories were documented in the upper end of the Elephant Butte Reservoir pool immediately following its listing in 1995. This population expanded, peaking in 2009 (Figure 66), as the quantity of suitable breeding habitat increased from 2008 to 2012 (Table 4), and quickly comprised the majority of SWFL territories in the Middle Rio Grande. Figure 66 shows that the SWFL population declined between 2009 and 2018 and now appears to be increasing through 2022 (survey data for 2020 and 2021 are incomplete due to COVID-related staff restrictions). In 2022, SWFL territory detections within the entire MRG survey area increased to an all-time high of 504, indicating that this population has been successful in reproducing returning birds. The SWFL has high site fidelity, and the population may return to a site for several years following a decline in habitat conditions. Examination of the data indicated that, for the most part, SWFL territory locations have followed a similar pattern over time. Although suitable habitat has decreased overall (Table 4), there has been an increase in territories in the downstream southwest portion of the project area since around 2019 in conjunction with an increase in suitable breeding habitat from 2016 to 2022 in this area (Figure 64). Formal surveys for YBCUs were first conducted in the upper Elephant Butte Reservoir delta in 2009. A small breeding population has been documented annually (Figure 66). A breeding habitat suitability model for YBCU was not developed until 2016, therefore the number of suitable habitat acres in Table 4 only includes 2016 and 2021. The amount of suitable YBCU habitat increased, as did the number of territories (Figure 66), in 2021 and 2022.

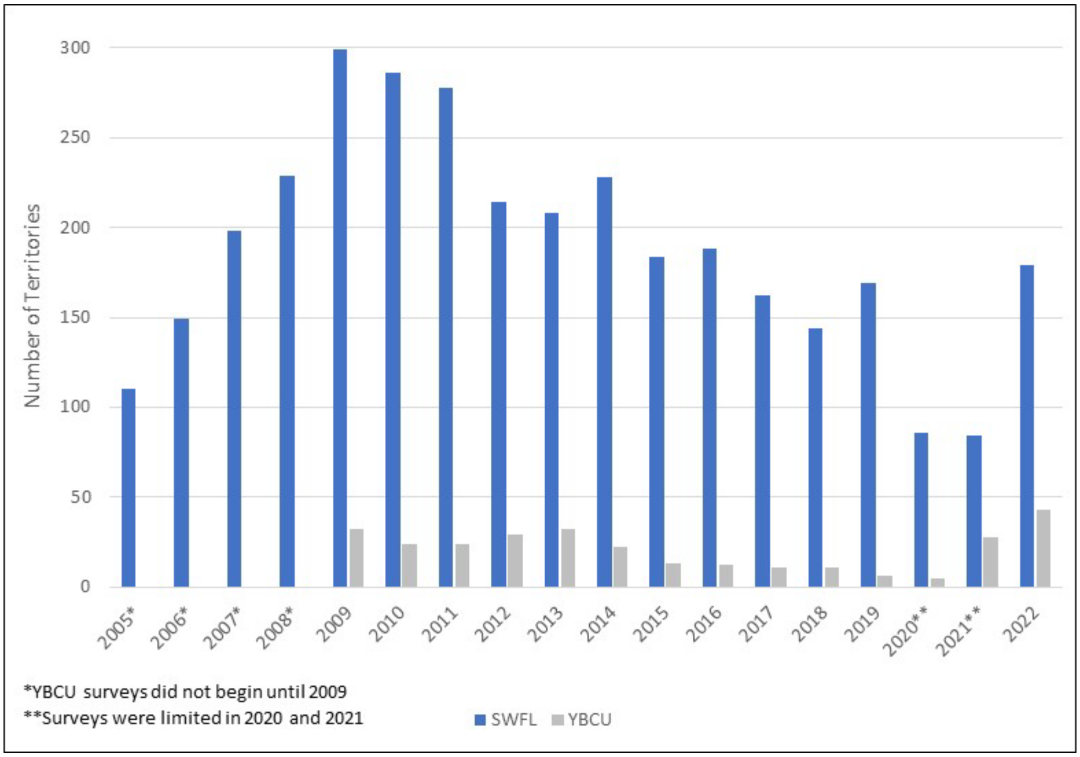


Figure 66.—Southwestern willow flycatcher and yellow-billed cuckoo territory numbers by year; river mile 74 to 54.5.

Table 4.—The number of acres of suitable SWFL and YBCU breeding habitat within the project area by year that vegetation was mapped. Vegetation was also mapped in 2005 but only included the area south of RM 60 and is therefore not comparable to data from other years.

	2008	2012	2016	2021
Suitable SWFL Habitat (ac)	2,979	3,280	2,915	1,862
Suitable YBCU Habitat (ac)	NA	NA	2,590	2,979

Figure 67 illustrates the spatial distribution of SWFL and YBCU territories in the Project Area, where the greatest SWFL abundance from 2005 to 2022 has occurred between RM 58 and 59 and the greatest YBCU abundance from 2009 to 2022 has occurred between RM 56 and 57. Divisions shown in Figure 68 were used to keep territory counts consistent between river miles over time. The most current data documented all territories of both species downstream of RM 64 (Figure 64 and Figure 65). The transition in habitat based on dominant species in the areas where SWFL (Figure 69) and YBCU (Figure 70) were most abundant was relatively consistent in that dominance of Goodding’s willow decreased while saltcedar increased in both areas. Another common trend was an increase in the cottonwood-Goodding's willow vegetation type, which was primarily comprised of a tall canopy and representative of the maturation of these species over time. This trend likely occurred in other habitat segments downstream of RM 63 where water from the LFCC supports the greatest number of territories. There have been few territories upstream of RM 63 since monitoring began. The sustaining marsh habitat between RM 58 to 59 from 2005 to 2021 most likely continued to support SWFL habitat and the increase in the mature cottonwood and cottonwood/Goodding's willow types probably helped maintain YBCU habitat between RM 56 and 57.

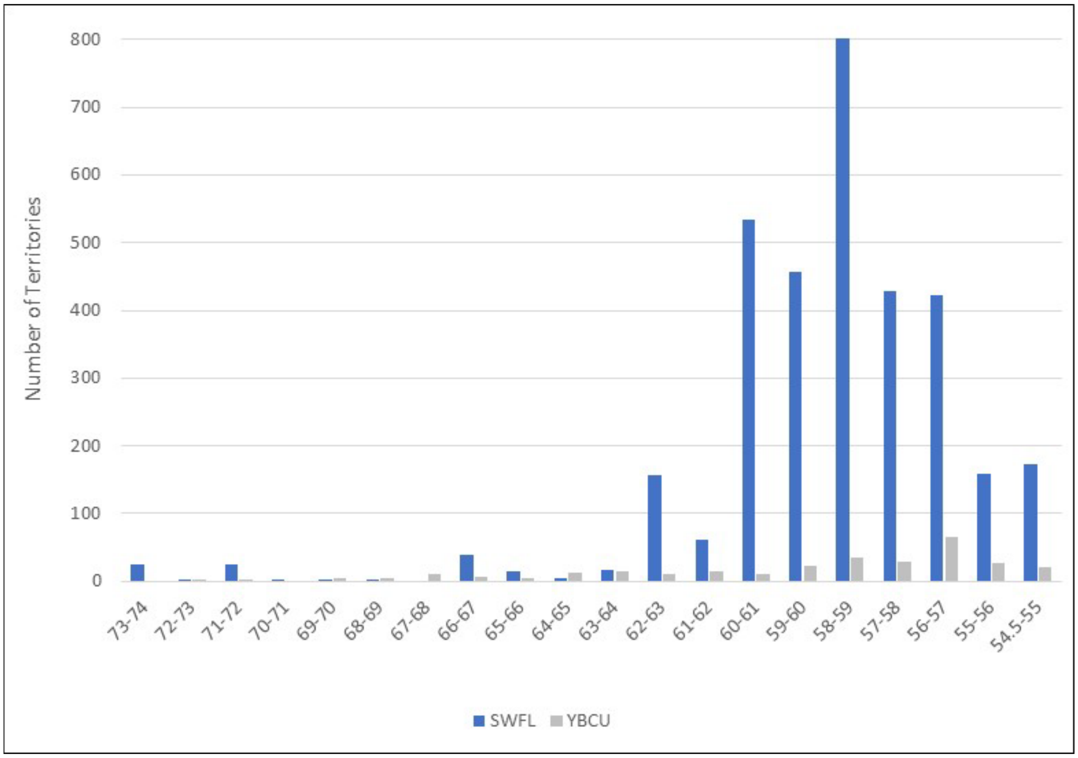


Figure 67.—Southwestern willow flycatcher and yellow-billed cuckoo territory numbers by river mile; cumulative 2005 to 2022.

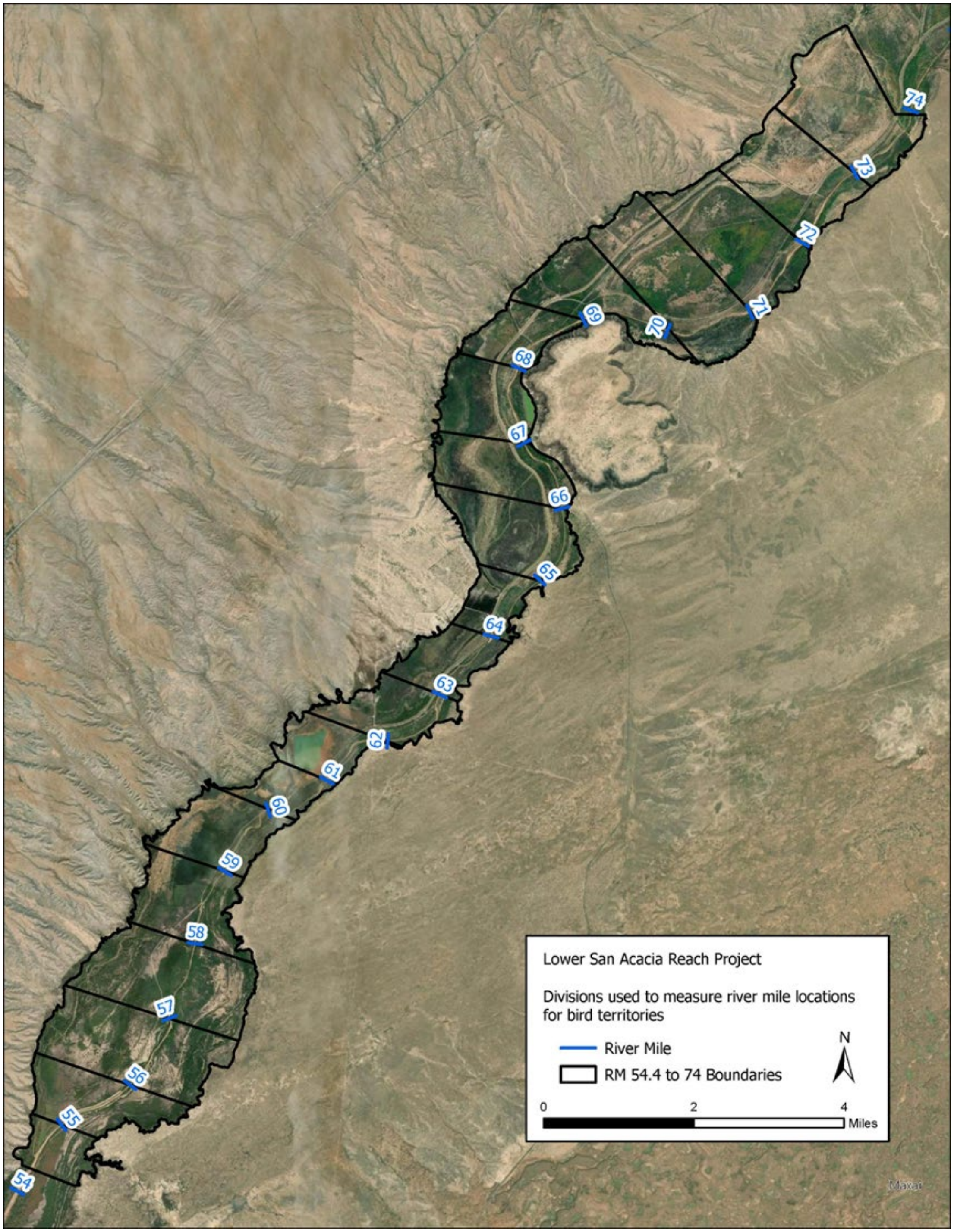
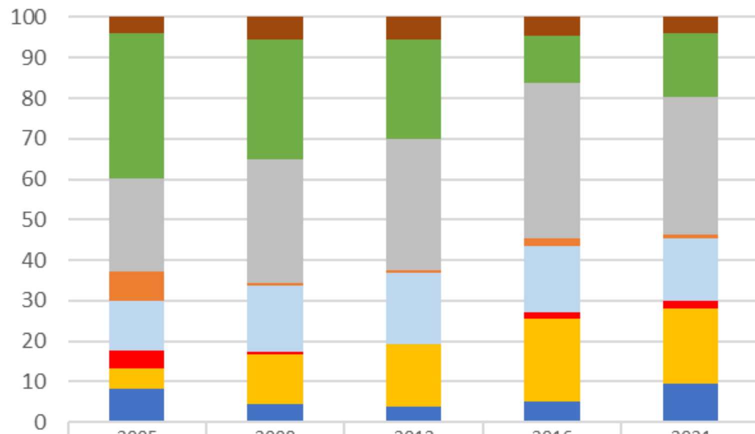
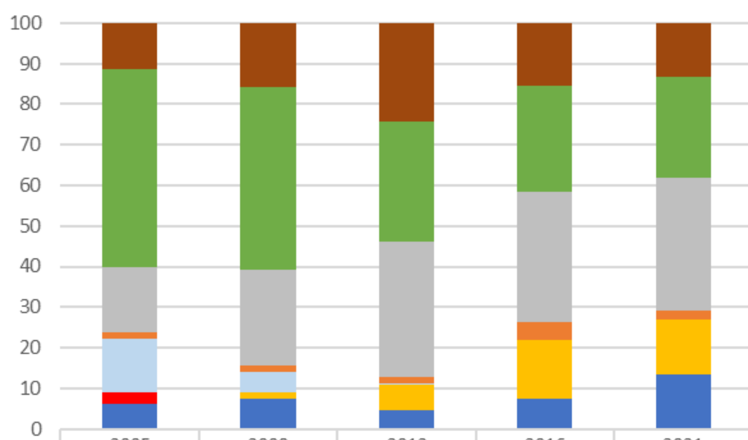


Figure 68.—Project area map (2020 NAIP imagery) showing division of river mile polygons used for spatial analysis of flycatcher and cuckoo territories.



	2005	2008	2012	2016	2021
Other	4.1	5.5	5.4	4.7	4.0
Goodding's willow	35.6	29.7	24.7	11.5	15.7
Saltcedar	23.0	30.4	32.4	38.5	33.8
Saltcedar-willow species	7.5	0.6	0.6	2.0	1.0
Cattail Marsh (including Cattail-willow)	12.2	16.4	17.6	16.2	15.5
Coyote willow	4.3	0.9	0.1	1.5	1.7
Cottonwood - Goodding's willow	5.3	12.2	15.3	20.7	18.6
Cottonwood	8.1	4.5	3.9	5.0	9.6

Figure 69.—Vegetation type based on dominant plant species mapped in 2005, 2008, 2012, 2016, and 2021 between RM 58 and 59 where SWFL territories were most abundant from 2005 to 2022.



	2005	2008	2012	2016	2021
Other	11.2	15.8	24.4	15.6	13.1
Goodding's willow	48.8	44.9	29.6	26.0	24.9
Saltcedar	16.1	23.8	33.4	32.1	32.7
Saltcedar-willow species	1.6	1.3	1.7	4.5	2.3
Cattail Marsh (including Cattail-willow)	13.3	5.0	0.3	0.0	0.0
Coyote willow dominant	2.8	0.0	0.0	0.0	0.0
Cottonwood - Goodding's willow	0.0	1.9	6.2	14.4	13.7
Cottonwood	6.2	7.3	4.6	7.5	13.3

Figure 70.—Vegetation type based on dominant plant species mapped in 2005, 2008, 2012, 2016, and 2021 between RM 56 and 57 where YBCU territories were most abundant from 2009 to 2022.

The spatial distribution of territories by year are graphed in Figure 71 and Figure 72. The values for "River Mile" in these figures represent the downstream boundary of areas delineated between river miles (Figure 68). For example, River Mile 72 represents the area between RM 72 and 73. The number of SWFL territories in peak years 2009 to 2011 (Figure 66) were mostly detected between RM 56 and 59 (Figure 71). The highest number of YBCU territories were detected in the Project Area in 2009, 2013, and 2022 (Figure 66). Territories were mostly concentrated between RM 55 and 59 in 2022, between RM 56 and 59 in 2013, but were randomly spread across the Project Area in 2009 (Figure 72).

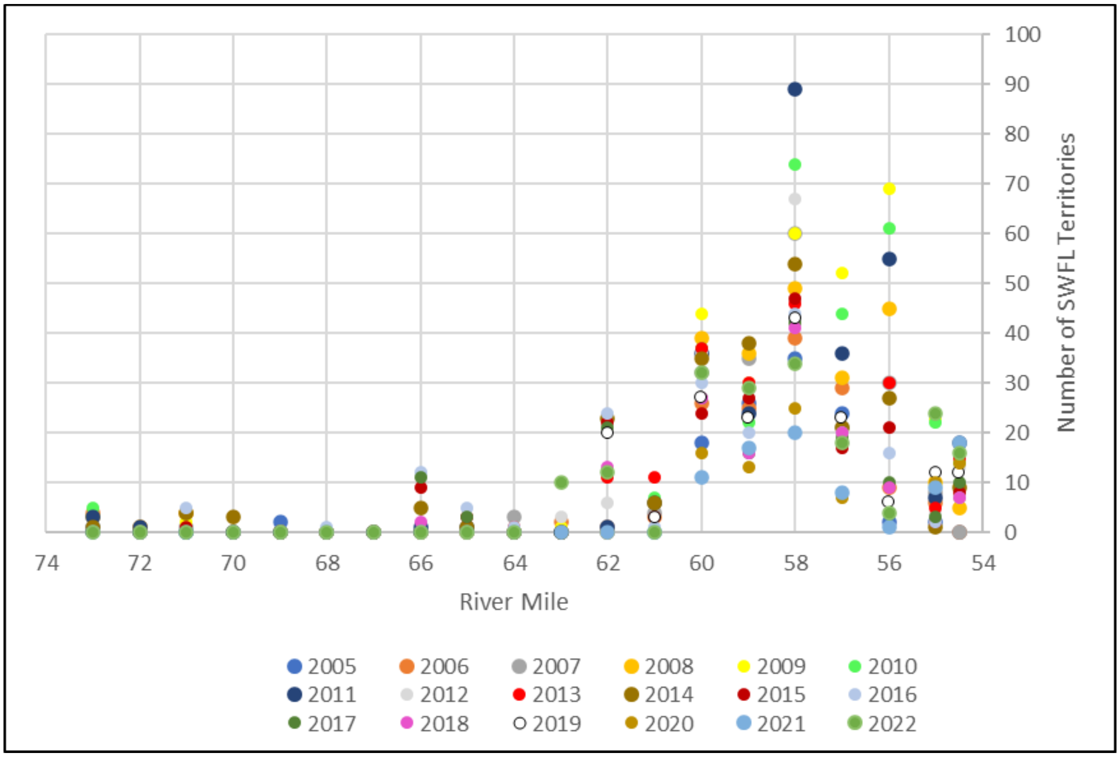


Figure 71.—Number of Southwestern willow flycatchers by year and river mile.

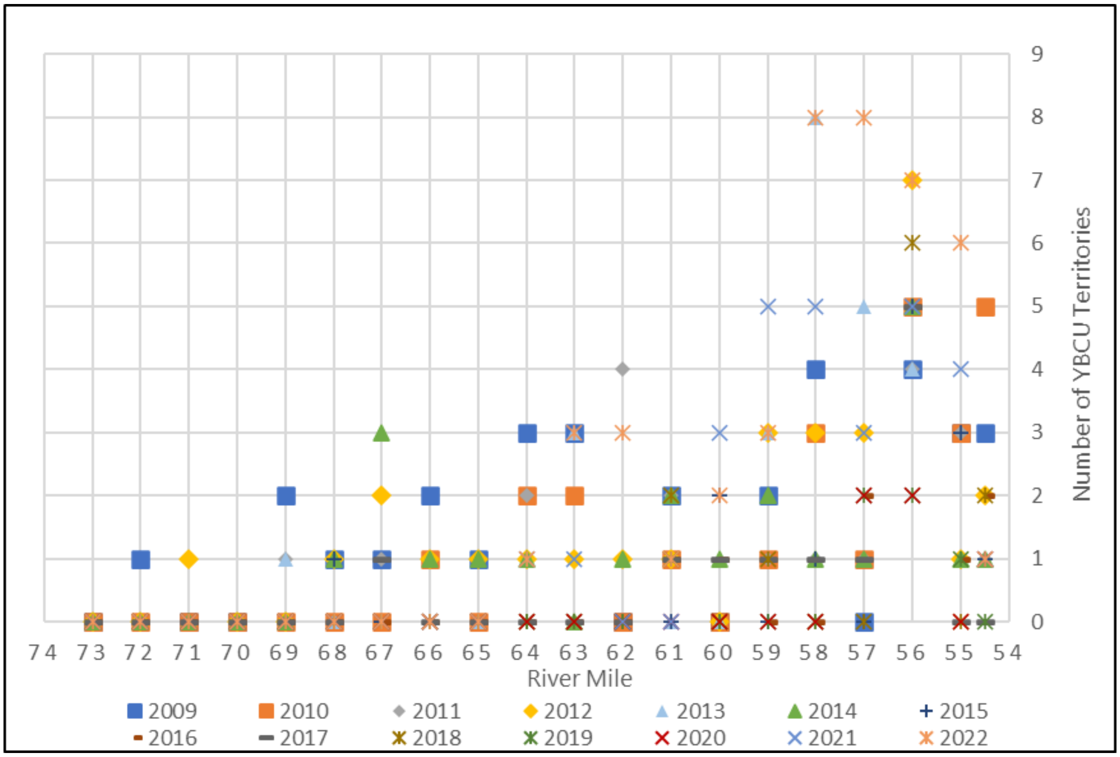


Figure 72.—Number of yellow-billed cuckoo territories by year and river mile.

2.4.2 Aquatic Habitat

Rio Grande Silvery Minnow (*Hybognathus amarus*; RGSM or silvery minnow) is a relatively small and short-lived minnow of the cyprinid family (Mortensen et al. 2019). The primary threats to RGSM include alteration of the natural hydrograph and habitat loss. Alterations to the hydrograph and channel morphology have decreased the availability and persistence of RGSM spawning and RGSM nursery habitats and reduced the frequency and magnitude of recruitment (from eggs to larvae to juveniles) events. These habitats are primarily in the main river channel, but during spring runoff, overbanking flows inundate floodplain areas that can meet hydraulic criteria used for estimating larval habitats that are crucial for recruitment. The reduction in the magnitude and frequency of floodplain inundation is linked with changes to hydrologic and geomorphic processes. Furthermore, the availability and complexity of main channel habitats have also decreased, and the frequency and duration of river drying has increased, which affects RGSM distribution and survival. Mortensen et al. (2023) modeled the hydraulic habitat of RGSM life stages (larvae, juvenile, and adult) in the San Acacia Reach (San Acacia Diversion Dam to Elephant Butte), including in the Elephant Butte Subreach downstream of BDA (Sperry et al. 2022). This is a summary of their works along with that of others to characterize RGSM habitats in the Project Area (Elephant Butte Subreaches EB1–EB5).

Figure 73 shows long-term RGSM monitoring sites between the San Acacia Diversion Dam and Elephant Butte Reservoir. Unlike the SWFL, RGSM do not establish nests or territories at specific locations, so the population must be estimated across a larger reach using statistical methods. Figure 74 provides the annual RGSM population density estimates for the entire San Acacia Reach. Mortensen et al. (2023) found that flow and habitat metrics corresponding to the larval life-stage were the most reliable predictors of the RGSM density and occurrence and that flow metrics explained more variation in population estimates across years. Additionally, analyses demonstrated a link between habitat availability and prolonged overbanking flow. Mortensen et al. (2023) used observations and data synthesis to develop a simplified (Figure 75) and more robust (Figure 76) conceptual model to understand the interaction between hydrology, geomorphology, habitat conditions, and the RGSM population. Drivers and controls at the watershed scale, including anthropogenic factors, govern the fluvial geomorphic processes, which in turn produce channel and floodplain geomorphic attributes. The relationship between geomorphic processes, attributes, and watershed inputs then produces habitat conditions that dictate biological response and species life history.

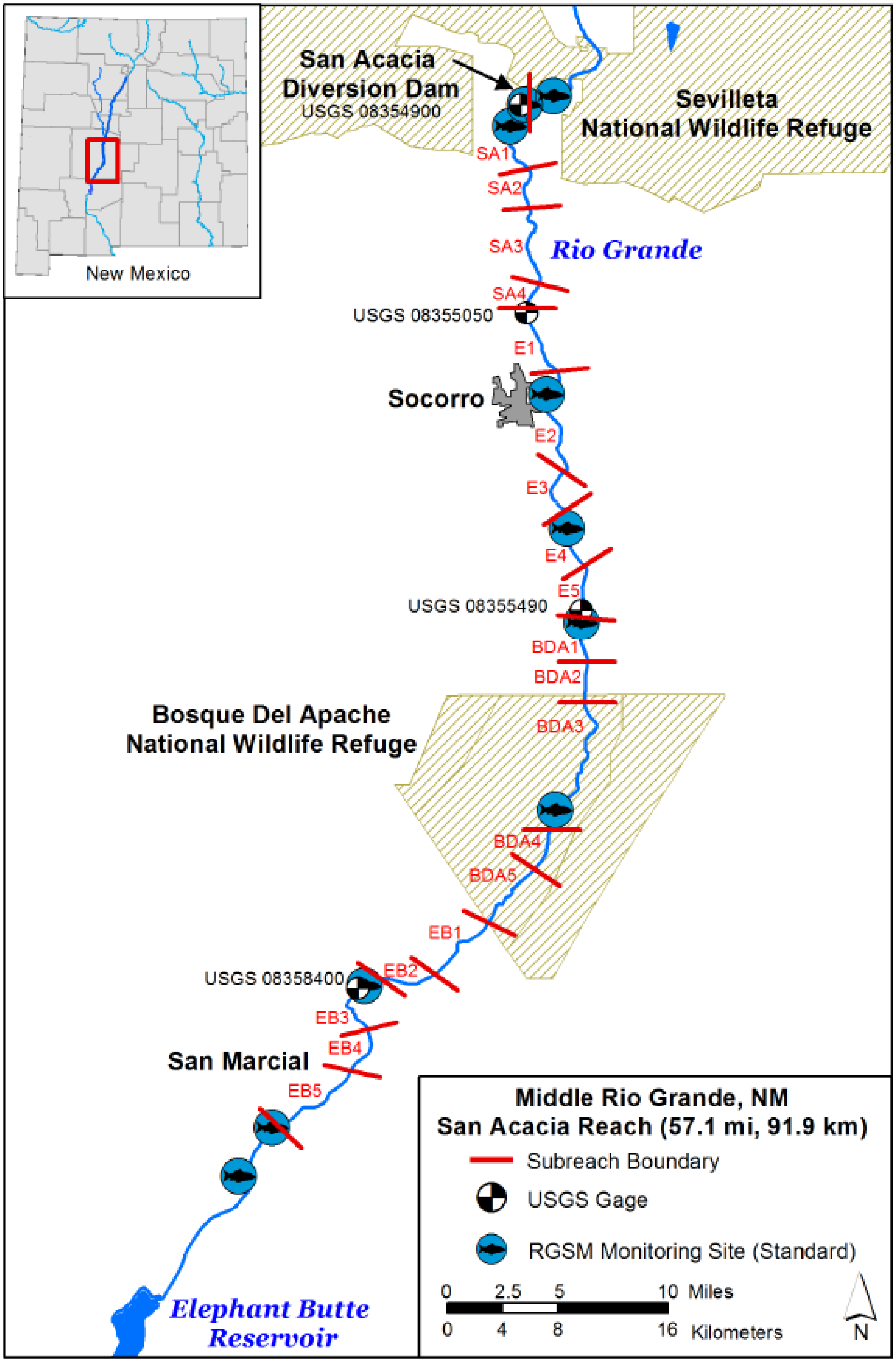


Figure 73.—Map of the entire San Acacia Reach with RGSM monitoring sites (from Mortensen et al. 2023). The Project Area includes subreaches EB1 to EB5.

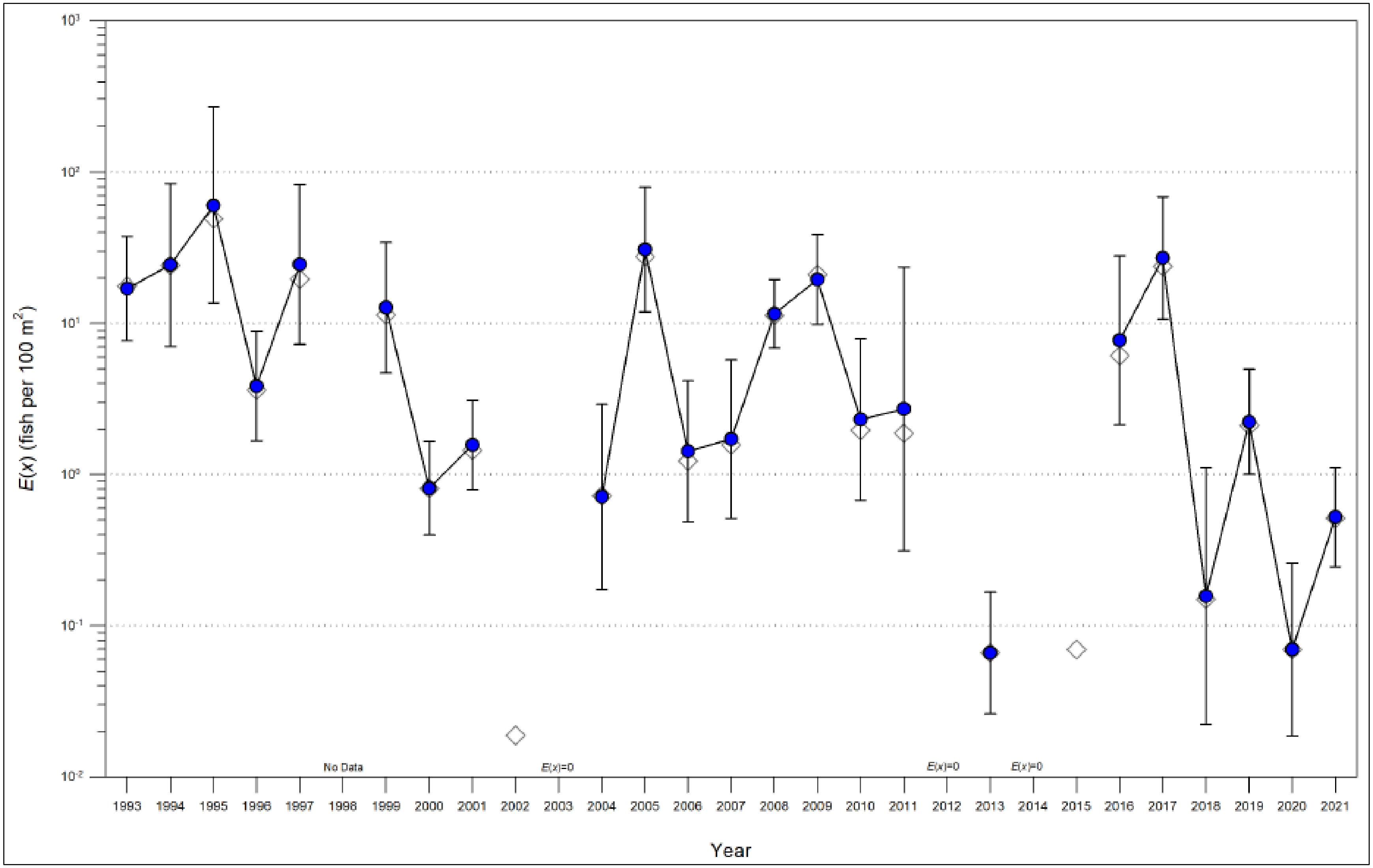


Figure 74.—Densities of the Rio Grande Silvery Minnow (E(x); estimated using October sampling-site data) from the San Acacia Reach during 1993 to 2021. Sampling did not occur in 1998, E(x) could not be computed for 2002 or 2015, and E(x) was zero in 2003, 2012, and 2014. Symbols indicate modeled estimates (circles), 95% confidence intervals (bars), and method-of-moments (diamonds) (from Mortensen et al. 2023).

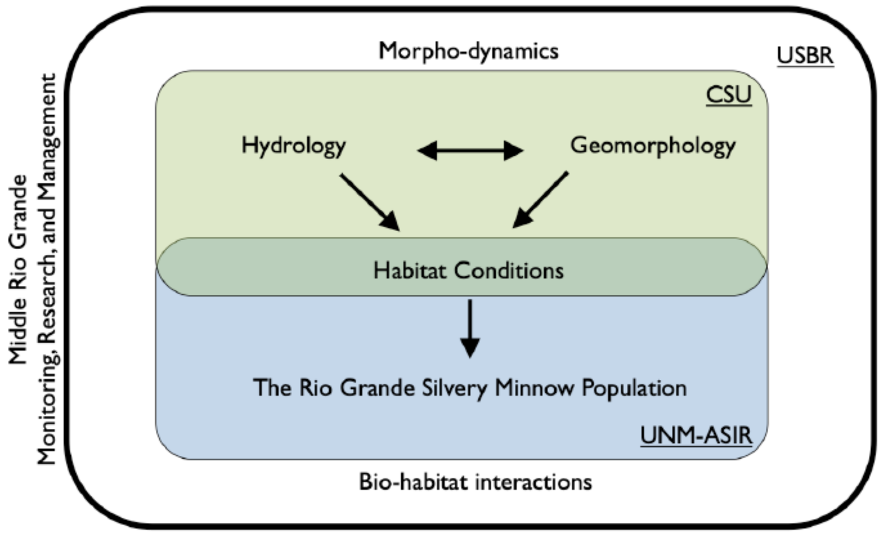


Figure 75.—Simplified conceptual diagram of linkages among morpho-dynamic processes and bio-habitat interactions (from Mortensen et al. 2023).

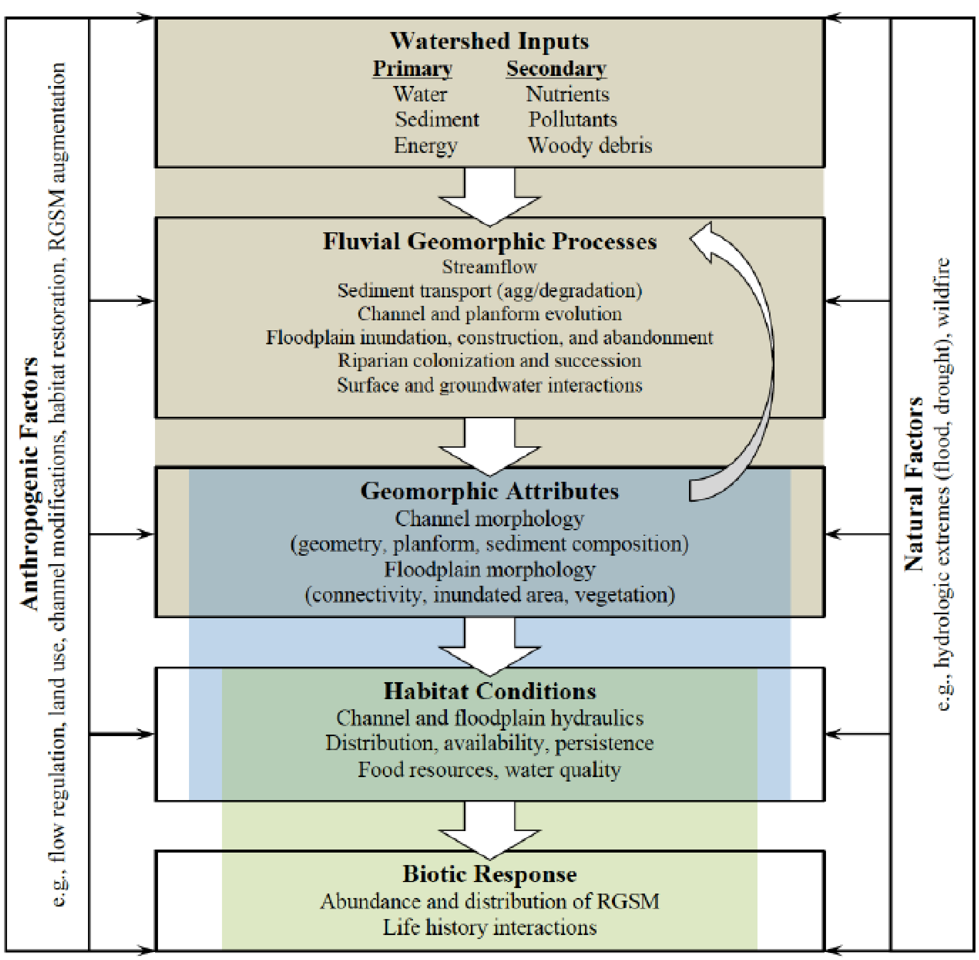


Figure 76.—Conceptual model of linkages between watershed inputs, fluvial geomorphic processes and attributes, habitat conditions, and the biotic response (from Mortensen et al. 2023).

Mortensen et al. (2023) reported a significant relationship between the interaction of seasonal flows, the RGSM lifecycle, and various habitat conditions in the channel and floodplain (Figure 77). Complicating that relationship was highly variable flows and often harsh environmental conditions (e.g., spring flooding, high suspended sediment concentrations, high-intensity precipitation events, drought periods) that affected the shape of the channel as well as the abundance and distribution of silvery minnows in the San Acacia Reach of the MRG. Some specialized silvery minnow life history strategies to these environmental conditions are the production of numerous eggs (high fecundity; Caldwell et al. 2018) and the broadcasting of their semi-buoyant eggs into the water currents during seasonally predictable flood events (Platania and Altenbach 1998; Worthington et al. 2018; Dudley et al. 2022). Those adaptations can result in a widespread distribution of eggs (and later larvae), in shallow, slow velocity, and productive aquatic habitats (where available) throughout the river reach, often maximizing their occupancy of newly flooded areas such as adjacent floodplain, side channels, backwaters, and formerly dried sections of the river channel. Mortensen et al. (2023) concluded that flows interacting with the channel morphology as evaluated by their modeled larval habitat metrics (of velocities and depths, Figure 78) were a reliable predictor of subsequent RGSM density and occurrence in the San Acacia Reach over the 5 decades evaluated (1962, 1972, 1992, 2002, and 2012).

Figure 79 further explains the modeling methodology and the link between flow, hydraulics, habitat criteria, life history, and habitat availability. Mortensen et al. (2023) applied a one-dimensional hydraulic model of channel cross sections to estimate depth and velocity for a given flow. Model results were then integrated over annual hydrographs to predict available habitat for each RGSM life stage. It is important to note that although habitat availability is calculated on a sectional basis (i.e., area meeting habitat criteria), these quantities should be interpreted as indicators of physical habitat availability, not necessarily as precise quantifiers of habitat areas (Reiser and Hilgert 2018).

Hydraulics (depth and velocity) represent the interaction of discharge with channel morphology. A narrow and deep channel subject to a high flow event will experience high depths and velocities, whereas a shallower channel that overbanks during the same flow event will inundate a larger area and encounter more roughness, which decreases the depth and velocity. Therefore, RGSM habitat availability tends to increase as inundated area increases and depth and velocity decrease. Figure 80 illustrates these principles for different subreaches and time periods. The Escondida and BDA subreaches generally have well-connected floodplains and experience large increases in habitat availability when overbanking begins between 2,000 and 3,000 cfs. The San Acacia and Elephant Butte subreaches are not connected to their floodplains and have lower habitat availability. Changes to the Elephant Butte subreach between 2002 and 2012 are particularly instructive. In 2002, the floodplain was activated at about 1,500 cfs, which produced a moderate amount of available habitat. In 2012, the floodplain was not activated until about 5,000 cfs, which resulted in very small habitat abundance at lower flows.

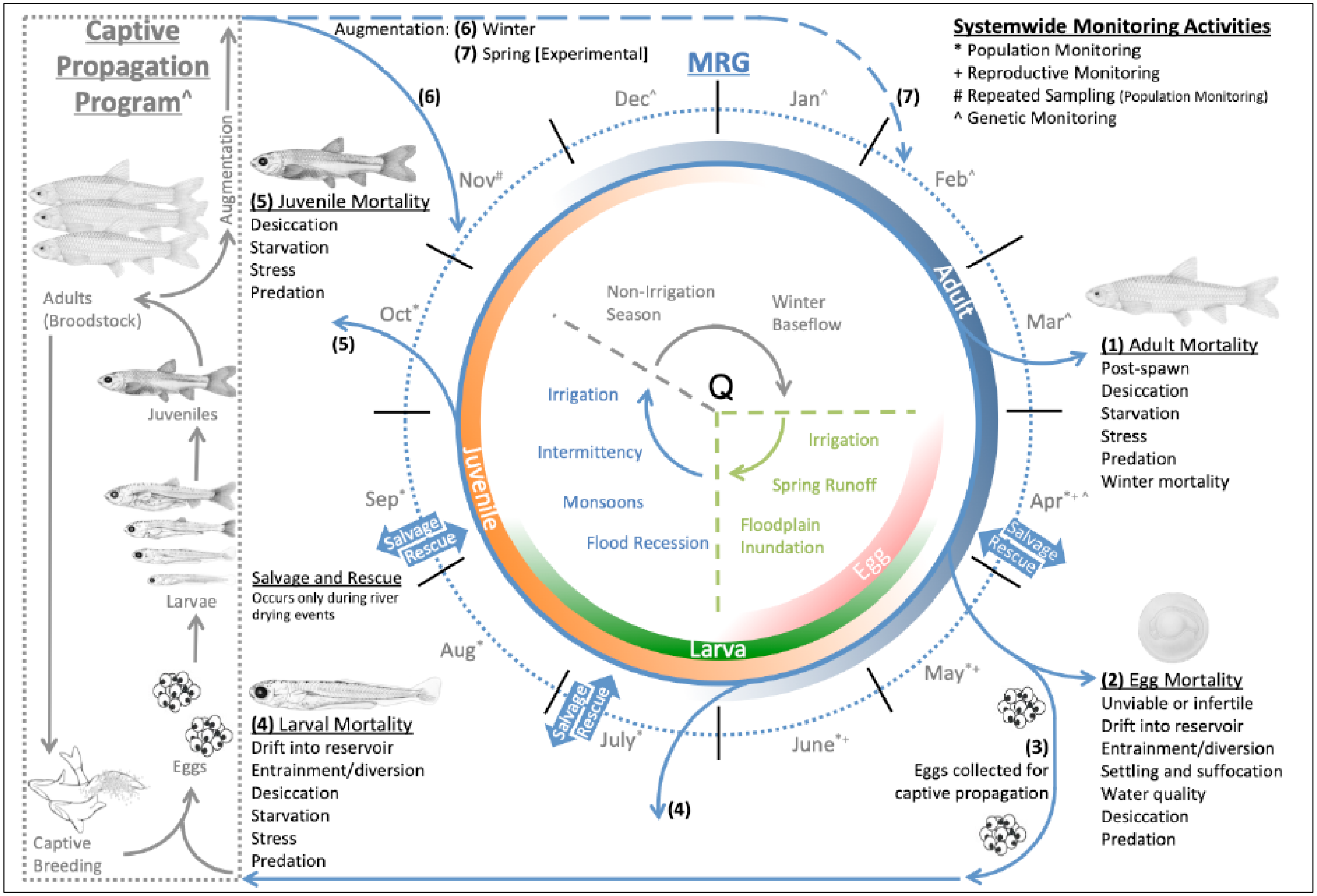


Figure 77.—Conceptual life history model of the Rio Grande Silvery Minnow. Life history is largely driven by streamflow (Q at center) over the course of one year. The approximate timing and duration of life-stages are shown as concentric colored bars (from Mortensen et al. 2023).

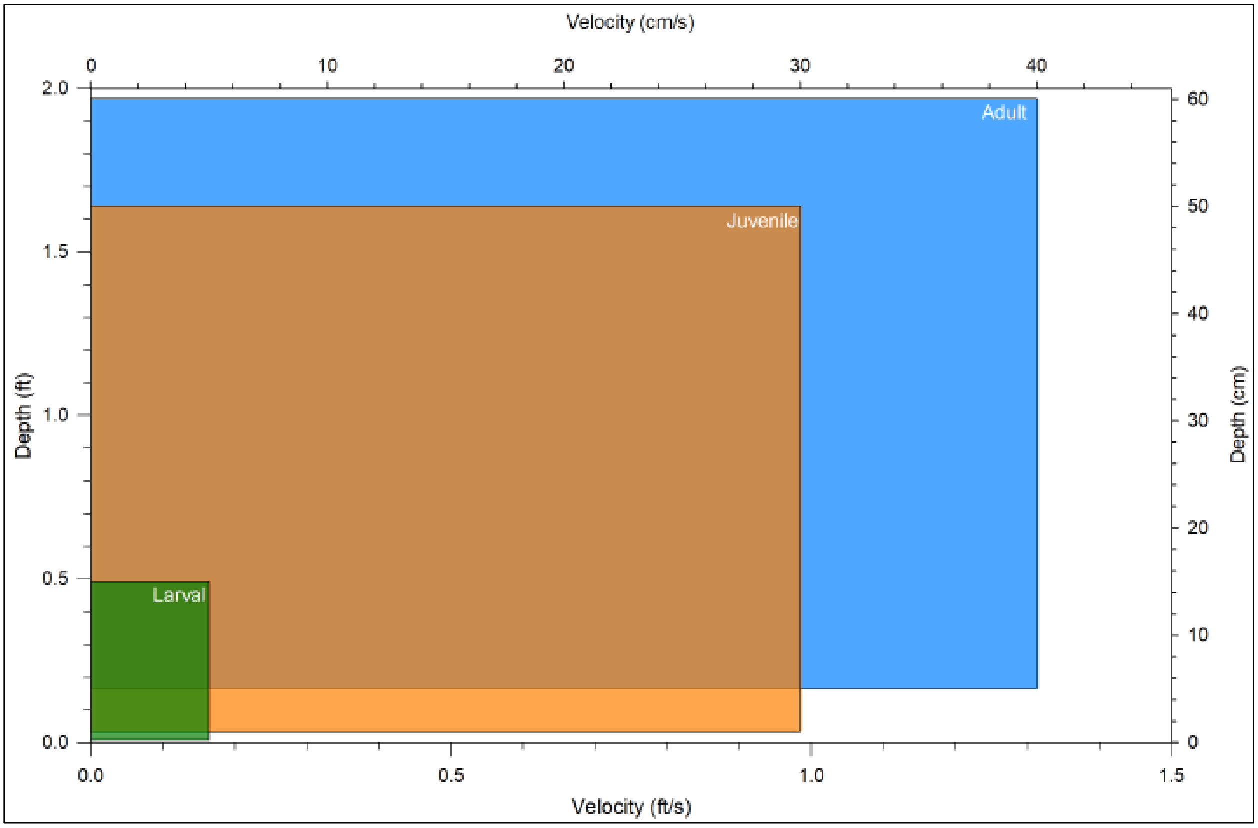


Figure 78.—Hydraulically suitable habitat criteria (water velocity and depth) for the Rio Grande Silvery Minnow life-stages: adult, juvenile, and larval (from Mortensen et al. 2023).

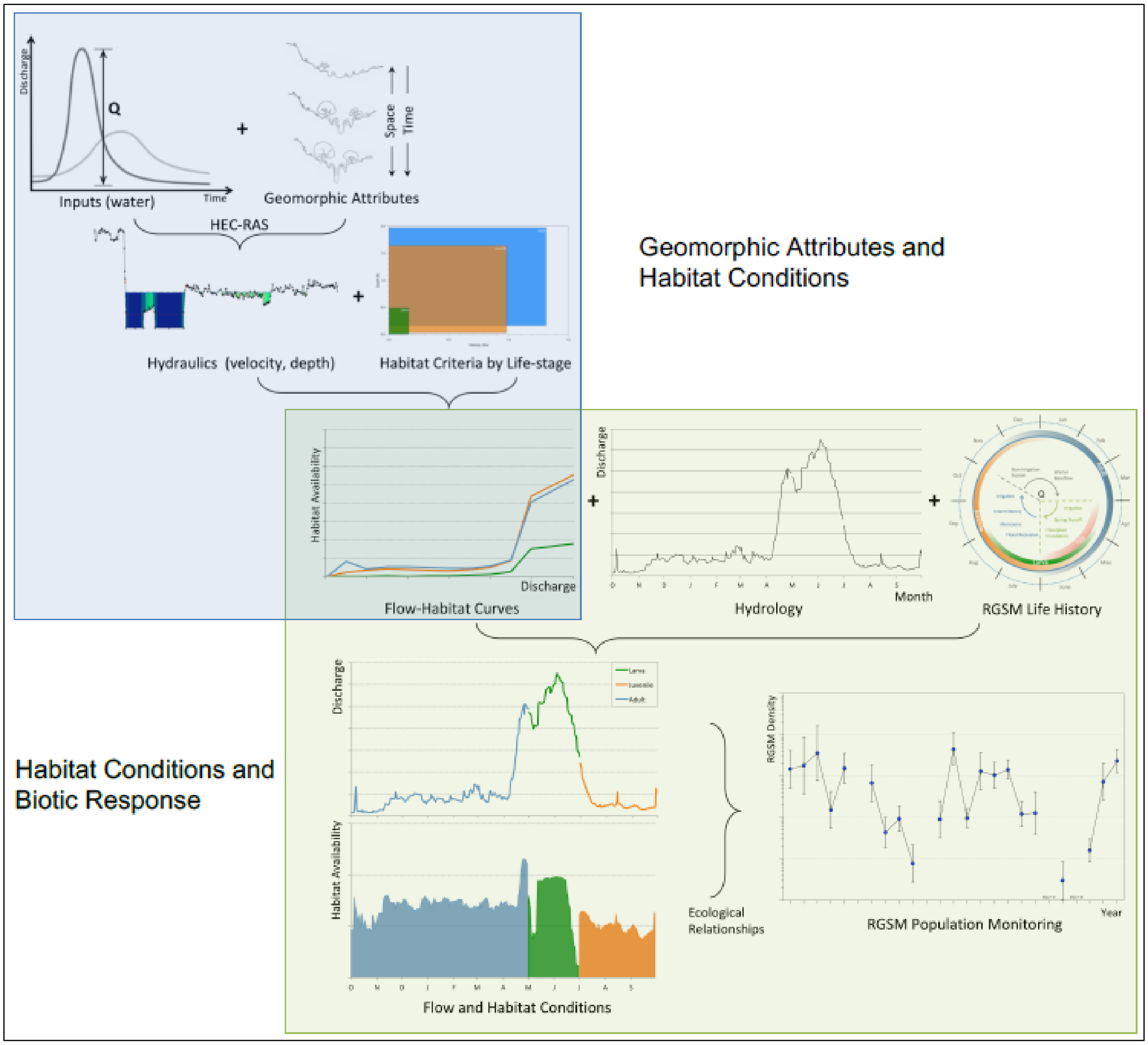


Figure 79.—Characterization and assessment of geomorphic attributes, hydraulics, and physical habitat conditions through time including their interaction with environmental factors and the life history of the RGSM (from Mortensen et al. 2023).

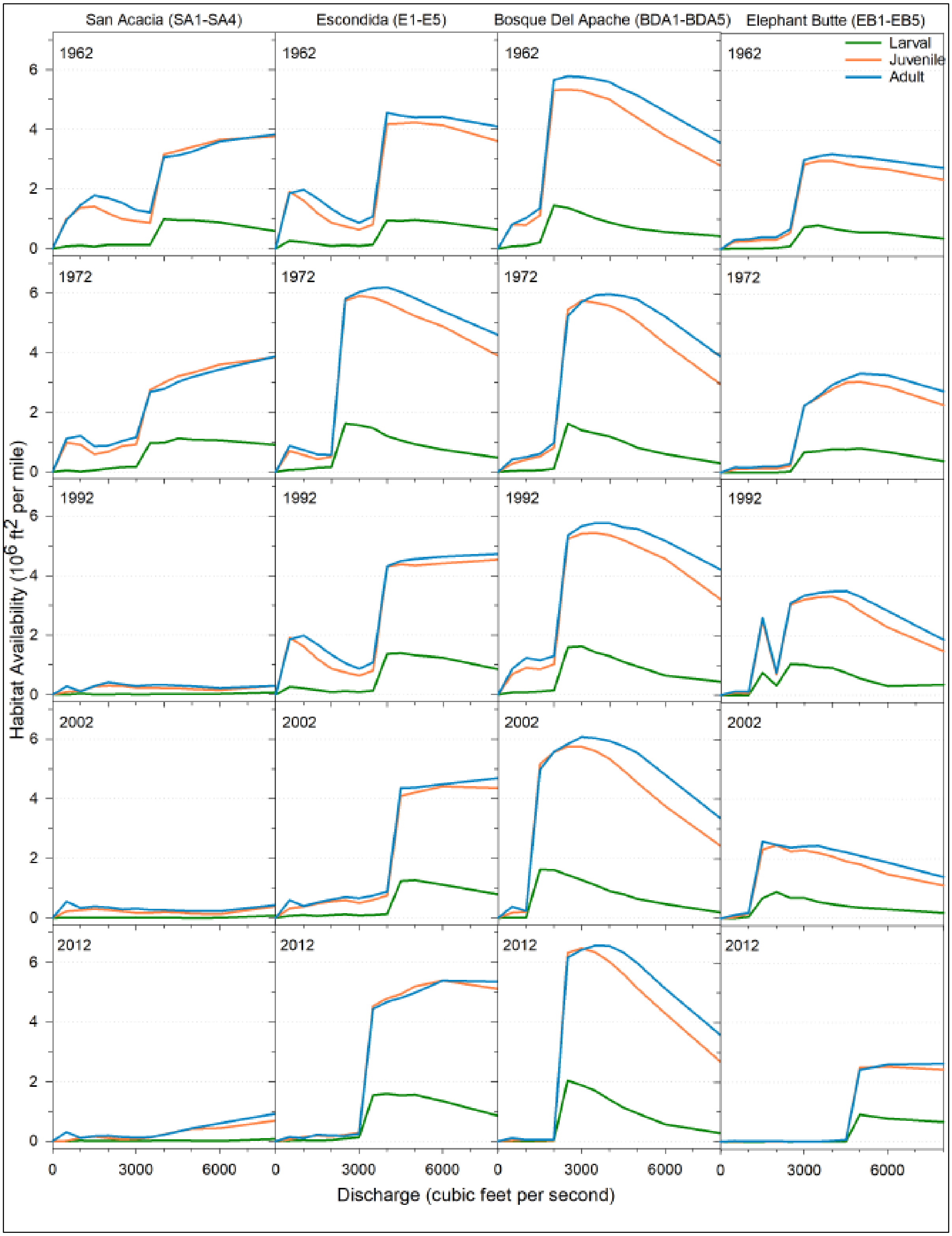


Figure 80.—Flow-habitat curves for the San Acacia Reach. Columns left to right are subreaches. Curves are shown through time top to bottom (1962–2012). Line colors represent the primary lifestages of the RGSM. Habitat availability was normalized by reach length (from Mortensen et al. 2023).

Mortensen et al. (2023) developed a Time Integrated Habitat Metric (TIHM) to compare the annual modeled habitat availability to the population estimates (Figure 81). The Elephant Butte subreach contributes a very small percentage of the overall habitat for the San Acacia Reach, especially at the critical larval life-stage. Variations in the larval life-stage predicted habitat availability explain more of the variability in annual population estimates than the juvenile or adult life-stages. Additionally, variations in the BDA larval habitat have the strongest correlation to the annual population estimates (second darkest bar, second panel from top). This further reinforces the importance of a wider, shallower channel and a well-connected floodplain to the RGSM population.

Figure 82 summarizes the link between channel planform evolution, cross-section morphology, and RGSM habitat in the Project Area. The river evolved from a wide, braided channel (Stage 1) to a single thread aggrading channel (Stage A4) when the reservoir pool filled during the 1980s and 1990s. Channel incision after 2005 shifted the trajectory to a migrating channel (Stage M4) that is disconnected from its floodplain. In 1962 and 1972, overbanking and the corresponding increase in habitat availability occurred at about 2,500 cfs. In 1992 and 2002, the habitat curves shifted to the left and overbanking began at about 1,500 cfs. In 2012, the habitat curves shifted significantly to the right because overbanking did not occur until about 5,000 cfs. Depending on the hydrograph each year, the discharge at which the floodplain is activated can have a substantial impact on habitat availability and the RGSM population.

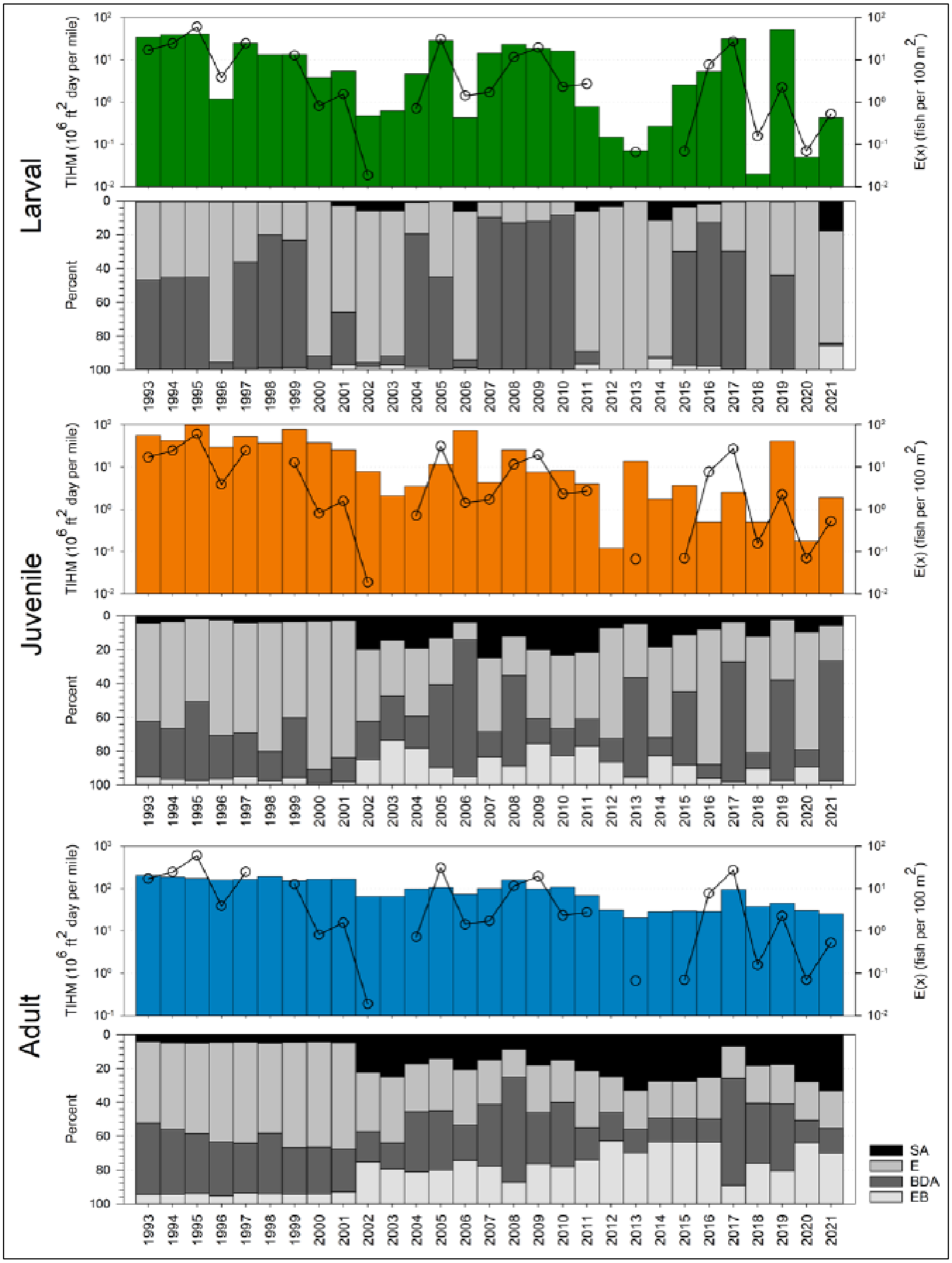


Figure 81.—Annual Time Integrated Habitat Metrics (TIHMs; colored bars), by life-stages of the RGSM, during the study period (1993–2021), annual estimated densities of the RGSM in October (E(x); black circles and lines), and percentage contribution by subreach (stacked bars). Note the log scale of the Y-axis (from Mortensen et al. 2023).

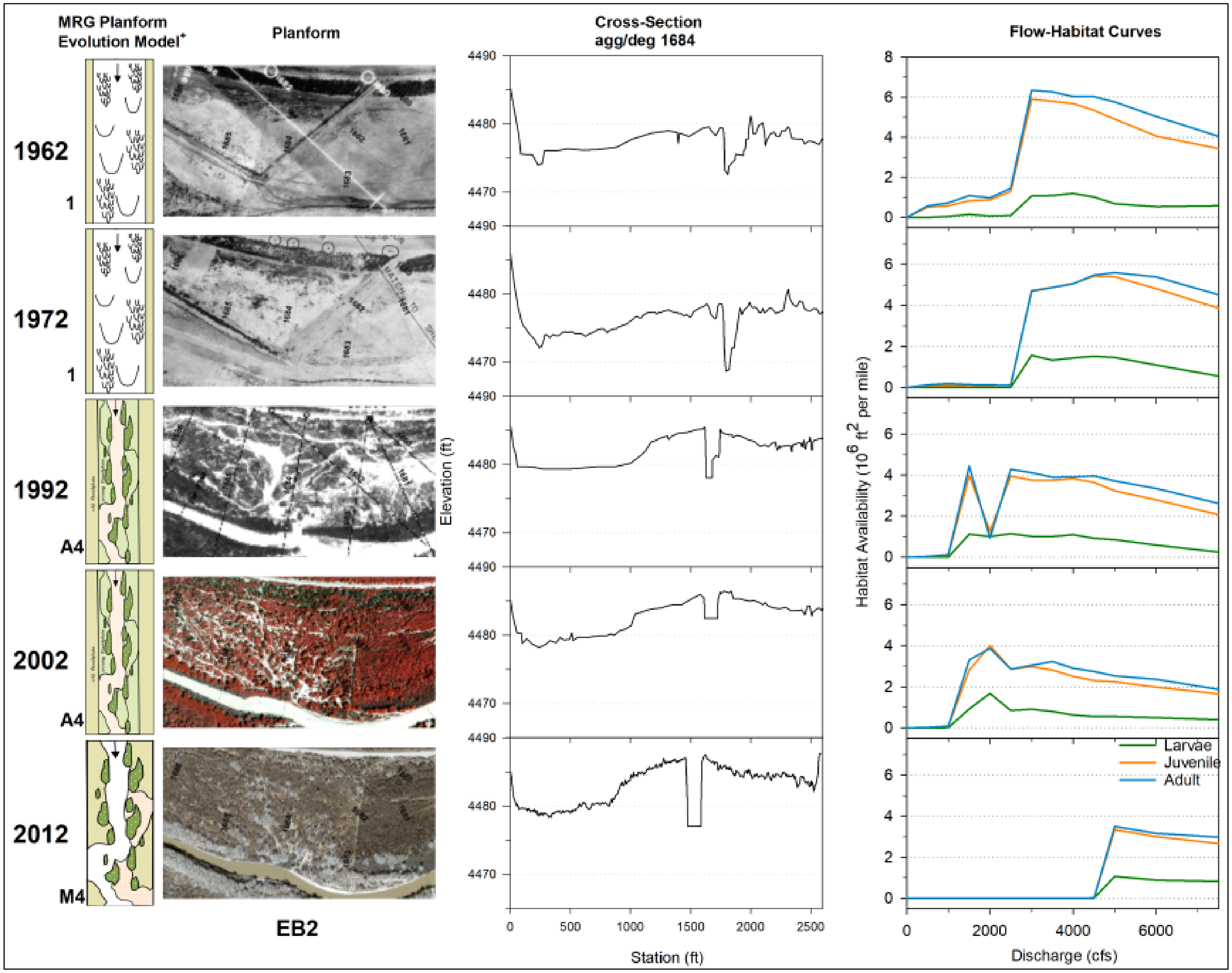


Figure 82.—Channel-habitat evolution model for subreach EB2. Stages of the planform evolution model (Massong et al., 2010) were estimated from geometry and planform data. Flow-habitat curves corresponding to each stage are shown at right (from Mortensen et al. 2023).

2.5 Discussion

The existing conditions in the project area between the BDA South Boundary and RM 54.5 (LFCC West outfall) consist of a narrow, uniform, and incised channel confined to the east side of the valley. The floodplain east of the spoil levee is perched well above the valley to the west. The channel bed is perched above the LFCC water surface upstream of RM 64 and is the valley low point downstream of RM 64. The current morphology results in efficient conveyance at medium to high flows because the reach-averaged bankfull discharge is about 8,000 cfs between the BDA South Boundary and San Marcial and about 12,000 cfs between San Marcial and RM 60. However, Rio Grande Compact deliveries have generally been poor during low-flow years. This is likely caused by high seepage losses from the perched channel and transpiration losses from riparian vegetation. Aquatic and terrestrial habitat has also been poor. Hydraulics result in unsuitable conditions for the RGSM because of deep water and high velocities. There is little edge complexity for refugia during high flows. Vegetation has suffered from channel incision and limited overbanking flow, so that avian habitat is unsuitable except for the west edge of the valley downstream of RM 63 where water from the LFCC flows through a historical side channel. The benefit of the incised channel is that it doesn't require maintenance to protect infrastructure or increase capacity. Recent maintenance needs have focused on the LFCC, which requires ongoing mowing and dredging.

Geomorphic analyses and history suggest that when the reservoir pool rises above the Narrows the cycle of deposition within the project area will resume. Sediment will begin depositing on the channel bed because of backwater effects from the reservoir. Continued bed deposition and a reservoir level that approaches full pool will cause overbanking that deposits sediment on the banks and floodplain. Previous sedimentation has filled most of the cross-sectional area to the east of the spoil levee and there is little floodplain storage available to accommodate future sedimentation. Therefore, a future sustained rise of the reservoir pool will require strengthening and raising the levees downstream of the BDA South Boundary to prevent the spoil levee from breaching or overtopping. However, the railroad crosses at a low point of the Tiffany and San Marcial levees, which would prevent future levee raises due to the elevation of the railroad tracks. Water that breaches or overtops the spoil levee to the west will not have a path to return to the river and will be stranded in the west valley.

It is important to consider moving the river to the west of the spoil levee before the pool rises and there is significant deposition in the current floodway. Future deposition will eventually cause the channel and floodplain to aggrade above the levels from the early 2000s. This would increase seepage losses and require constant maintenance to keep the river east of the spoil levee. Although conveyance is currently efficient at medium to high flows and maintenance needs are relatively low, waiting until after there is deposition will make implementing a realignment project much more difficult. The bed has incised to near the pre-1950s elevation, meaning that the longitudinal profile and slope is currently viable to transition between the existing channel and the western valley. Relocating the river after the existing bed has aggraded will cause large slope discontinuities: the slope will be steep at the realignment inlet and will be too flat or have an adverse slope at the realignment outlet. Moving the river to the west will also be subject to future sedimentation from a higher reservoir pool, but there is space available for sediment storage in the floodplain without the risk of a levee failure.

3.0 Design Alternatives

Synthesizing the geomorphic dynamics and channel response demonstrates that sediment loads are lower than when the reach was channelized in the 1950s. However, aggradation and related issues have generally continued during the last 70 years. The current conditions and long-term response to the previous channelization should be considered when developing design alternatives. It is instructive to revisit predictions from the design engineers and planners responsible for implementing the initial channelization and LFCC construction. As in the current analysis, Chapman et al. (1952) noted the continued deposition of sediment in the reach and discussed the expected project lifespan:

> …in approximately 10 years the floodway may be aggraded to such an elevation that it will no longer function properly and will have to be relocated to carry floods in excess of the capacity of the conveyance channel (2,000 cfs). This relocation would require that a considerable part of the levee and conveyance channel would have to be rebuilt to the west of the location where first constructed. (p. 29)

Through continued maintenance, the original system has far exceeded the predicted 10-year lifespan. The initial project generally functioned as designed for 25 to 30 years until the mid-1980s when sedimentation and reservoir inundation covered and obliterated all the LFCC and levee works downstream of RM 60. Upstream of RM 60, there have been numerous near-levee sediment plugs, levee breaches or levee raises, and channel excavation until the post-2005 channel incision. Maintenance needs have decreased with the incised channel; however, annual excavation of the delta channel into Elephant Butte upstream of the Narrows continues. Water delivery, as measured by the Rio Grande Compact, has been poor since about 2011. Habitat has also been poor since the post-2005 channel incision except for avian habitat along the west edge of the valley downstream of RM 63. Therefore, design alternatives consider and incorporate the recommendation from Chapman et al. (1952) to relocate the floodway to the west. Topography west of the spoil levee has remained at the 1950s elevation because spoil levees have confined the last 70 years of sedimentation to the east side of the valley.

Alternatives compare an option to maintain the river and LFCC within their current location to options that relocate the river to the west. Alternative A is the "no action" scenario where the current system will be maintained in response to future reservoir levels and flow events. Alternative B and C both relocate the river to the west but differ in their starting locations and their interaction with the LFCC. The three alternatives are intended to represent a range of possible actions. Different combinations are possible upstream and downstream of the San Marcial Railroad Bridge because all alternatives must have the same general alignment to have the river flow under the bridge in its current location (Table 5). Analysis during the alternatives evaluation should help optimize and identify the best combination of alternatives by considering the project as two reaches divided at the railroad bridge.

Table 5.—Additional alternatives derived from possible combinations of Alternatives A, B, and C upstream and downstream of the San Marcial Railroad Bridge

Upstream of Bridge	Downstream of Bridge	Notes
Alternative A	Alternative B	Maintain existing channel and LFCC upstream while realigning the river downstream with the RM 68-65 western habitat area. Water from LFCC enters river at RM 67.5 and water from Elmendorf enters river at RM 64.5.
Alternative A	Alternative C	Maintain existing channel and LFCC upstream while realigning the river downstream without the RM 68-65 western habitat area. Water from LFCC and Elmendorf enters river at RM 67.5 to create a single channel.
Alternative B	Alternative C	Start the realignment near RM 74 as in Alternative B, but downstream of San Marcial realign the river as a single channel without the RM 68-65 western habitat area. Water from LFCC enters river at RM 73.7 and water from Elmendorf enters river at RM 67.5.
Alternative C	Alternative B	Start the realignment near RM 72.5 as in Alternative C, but downstream of San Marcial divert the LFCC flows into the RM 68-65 western habitat area. Water from LFCC and Elmendorf enters river at RM 64.5.
Alternative C	Modified Alternative B	Start the realignment near RM 72.5 as in Alternative C, but downstream of San Marcial divert part of the LFCC flows into the RM 68-65 western habitat area using a bifurcation structure. Instead of reconnecting to the river at RM 64.5, excavate a new channel along the west edge of the valley between RM 64.5 and RM 60. This would provide a continuous channel along the west edge of the valley from RM 68 to 54.5 to increase opportunities for avian habitat while minimizing risk to the current habitat between RM 60 and 54.5. Downstream of the RM 68 bifurcation structure, part of the water from the LFCC and Elmendorf enters the river at RM 67.5 and the remaining water enters the river at RM 54.5.
Alternative A or C	new	Downstream of San Marcial, reconstruct the LFCC (including spoil levees) along the west side of the valley to about RM 60, with a bifurcation structure to divert some flow into the river channel at RM 67.5. The reconstructed LFCC would have an outfall to the river or to the LFCC West channel near RM 60. Realign the river to the west as in Alternatives B and C. Part of the water from the LFCC and Elmendorf enters the river at RM 67.5 and the remaining water enters the river at RM 60 or 54.5.

3.1 Alternative A

Alternative A does not construct any new features and maintains the river and LFCC where they have been since the 1950s. Earlier sections of this report thoroughly described the geomorphic conditions for this alternative. If the reservoir remains below the long-term average pool elevation, the trends observed during the last 10 to 15 years will continue. The channel downstream of the BDA South Boundary will remain incised and the bed elevation will likely stabilize or may experience additional minor vertical and lateral erosion. High flow events will not overtop the channel banks and the river will be a transport reach delivering nearly all sediment supplied from upstream of the project area to the downstream Delta Channel and the current location of backwater-induced deposition. Future maintenance, such as periodic dredging, of the Delta Channel will affect the bed elevation within the project reach along with the future pool elevation of the reservoir. Maintenance needs for Alternative A with a low reservoir pool and incised channel within the project area would focus on mowing and dredging within the LFCC. Maintenance may increase or decrease depending on the LFCC response to the RM 60 culverts and any operational changes at San Acacia Diversion Dam.

If the reservoir pool rises and remains above the Narrows for a sustained period, especially if near full pool, conditions and trends will be similar to the 1980s and 1990s. Significant channel bed aggradation will resume starting near the reservoir pool and progressing upstream to about RM 78 within BDA. Once the bed elevation rises high enough to reconnect the floodplain, deposition on the banks and overbank areas will also resume. Any new deposits will be added to the previous floodplain sedimentation, further decreasing floodway capacity and increasing the risk of a spoil levee breach or overtopping event (Figure 83). Construction crews constantly had to monitor, maintain, and raise the spoil levees during high flows in the 1980s and 1990s. A future rise in pool elevation would eventually require strengthening or raising the levees. Channel maintenance needs would be intensive to frequently dredge sediment from the channel and remove sediment plugs every few years.

Figure 83.—Looking downstream at sediment plug and levee breach near RM 71.6 in 1991 (Reclamation/Drew Baird).

Figure 84 is an elevation map of the Tiffany Basin area between RM 73 and 69. The pink cross section line at RM 71.6 marks the location of the 1991 levee breach. This levee breach deposited sediment in the former drainage channel to the west of the spoil levee. A cross section view at this location shows the elevation of the incised existing channel, the aggraded floodplain east of the spoil levee, the valley to the west, the railroad embankment, and the LFCC (Figure 85). The center of Tiffany Basin is about 15 ft lower than the channel top of bank. There is high ground along the west edge of Tiffany Basin due to the 1940s channel and high ground to the east of Tiffany Basin due to the post-1950s channel.

Figure 86 is an elevation map downstream of San Marcial between RM 67 and 65 with a typical cross section at RM 66 (Figure 87). The low point in the valley occurs just west of the LFCC. Sedimentation is visible along the banks of the pre-1950s main channel and there is a historical side channel along the west edge of the valley. Like upstream of San Marcial, the existing top of bank elevations are 15 to 20 ft above the valley low point and the current floodplain east of the spoil levee is mostly fill in with sediment.

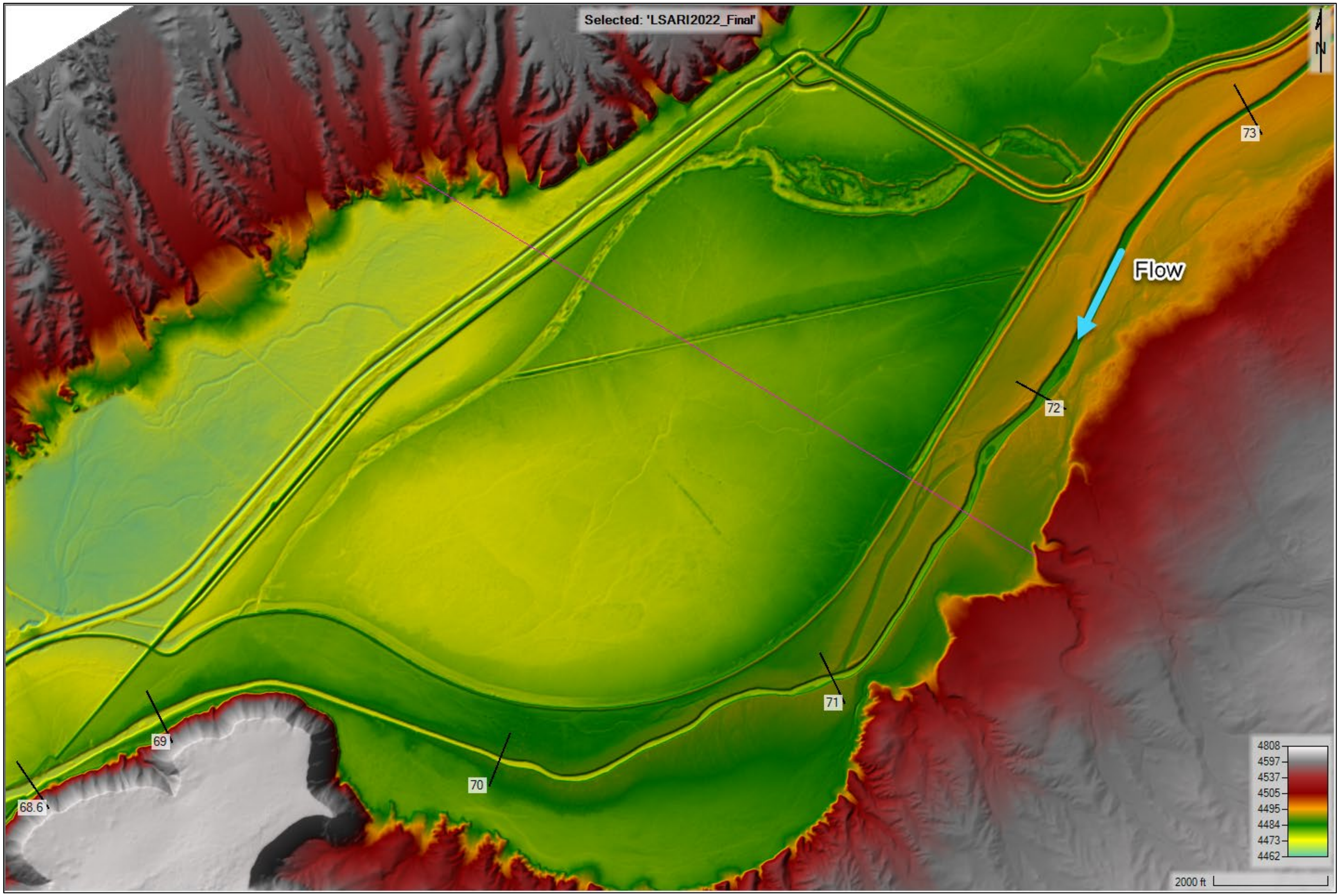


Figure 84.—Tiffany Basin topographic surface (2022 lidar) with location of 1991 levee breach near RM 71.6 denoted by pink line.

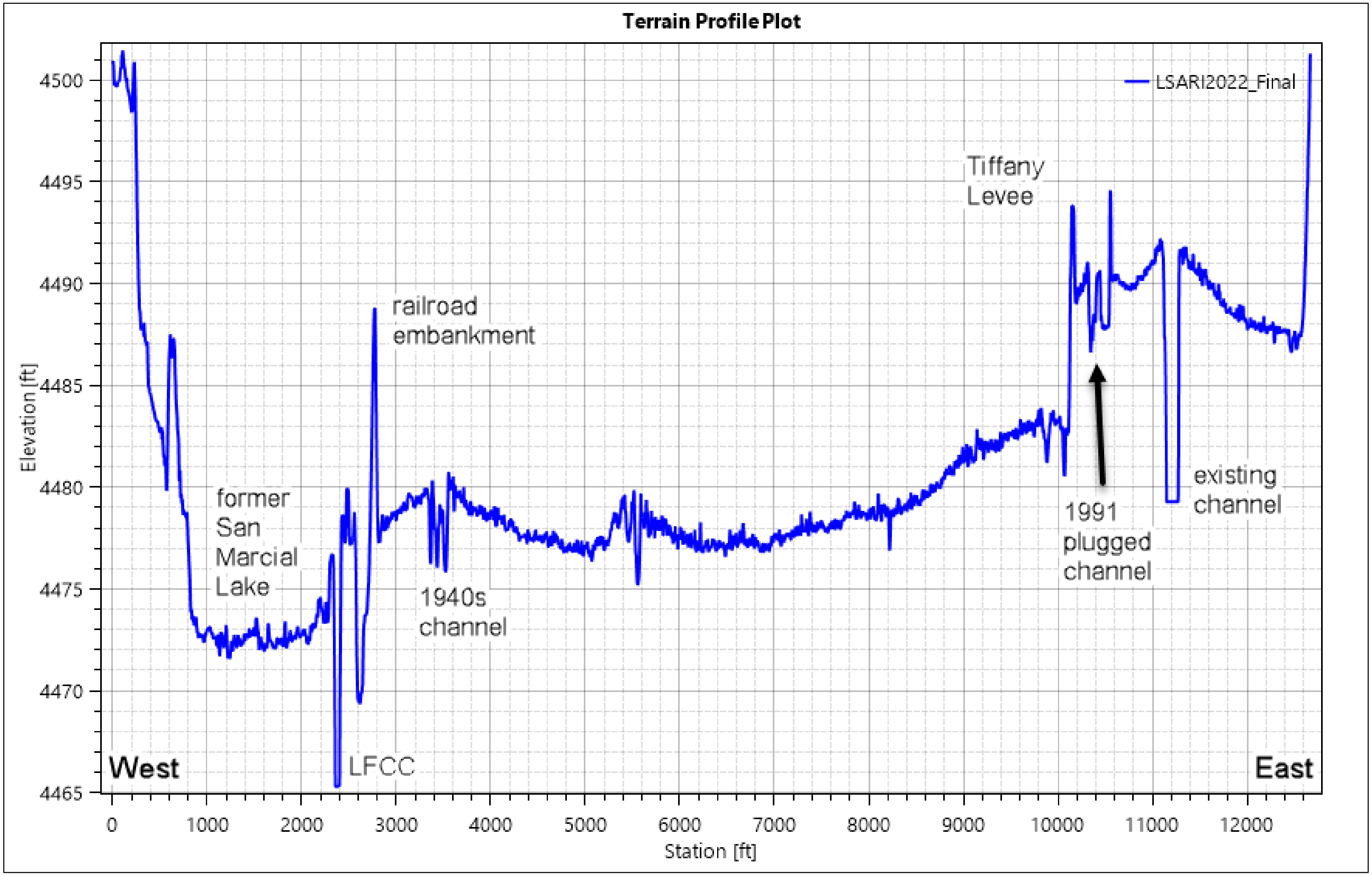


Figure 85.—Cross section looking upstream near RM 71.6 (2022 lidar with mean bed elevation for river and LFCC).

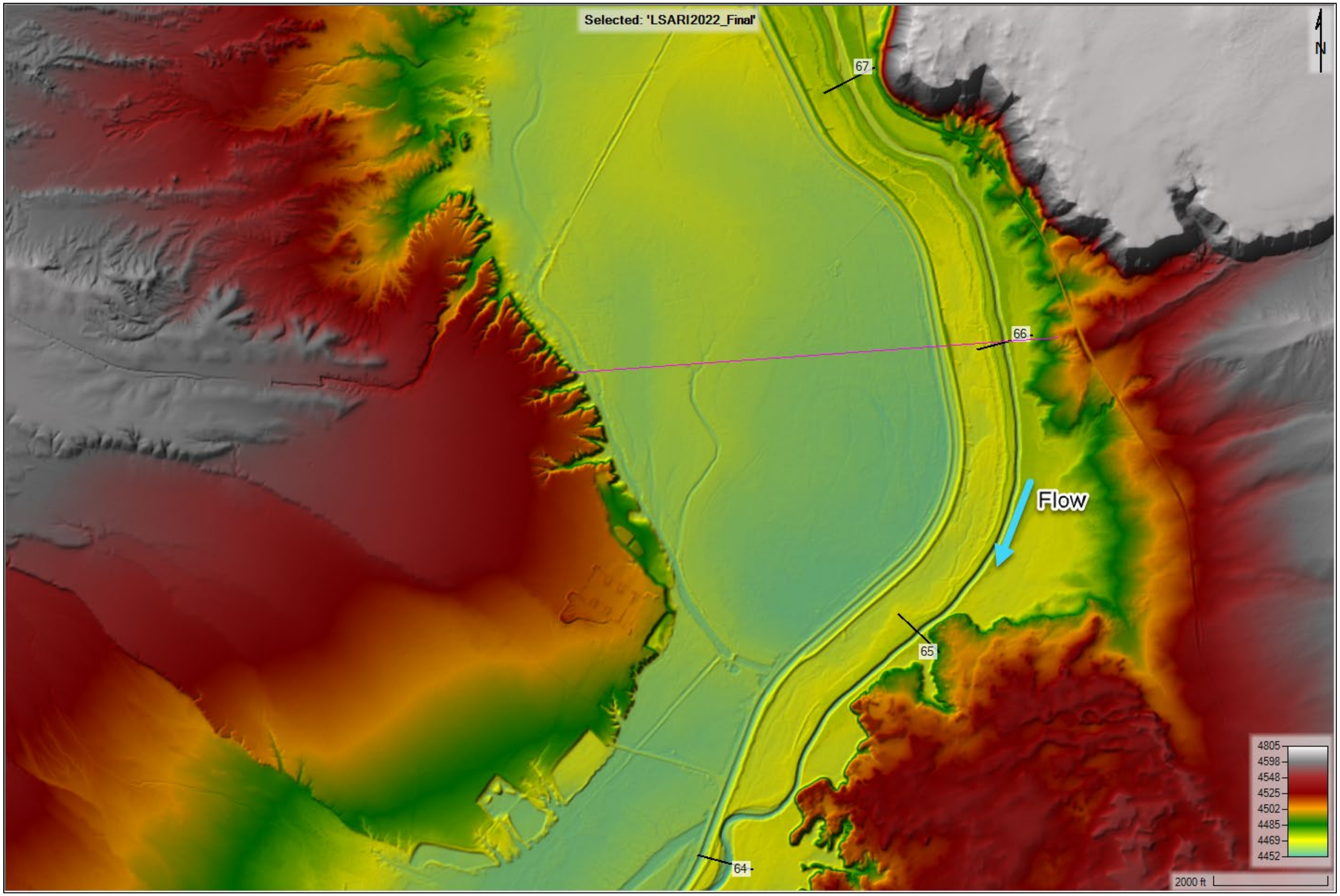


Figure 86.—Topographic surface (2022 lidar) downstream of San Marcial with cross section at RM 66 denoted by pink line.

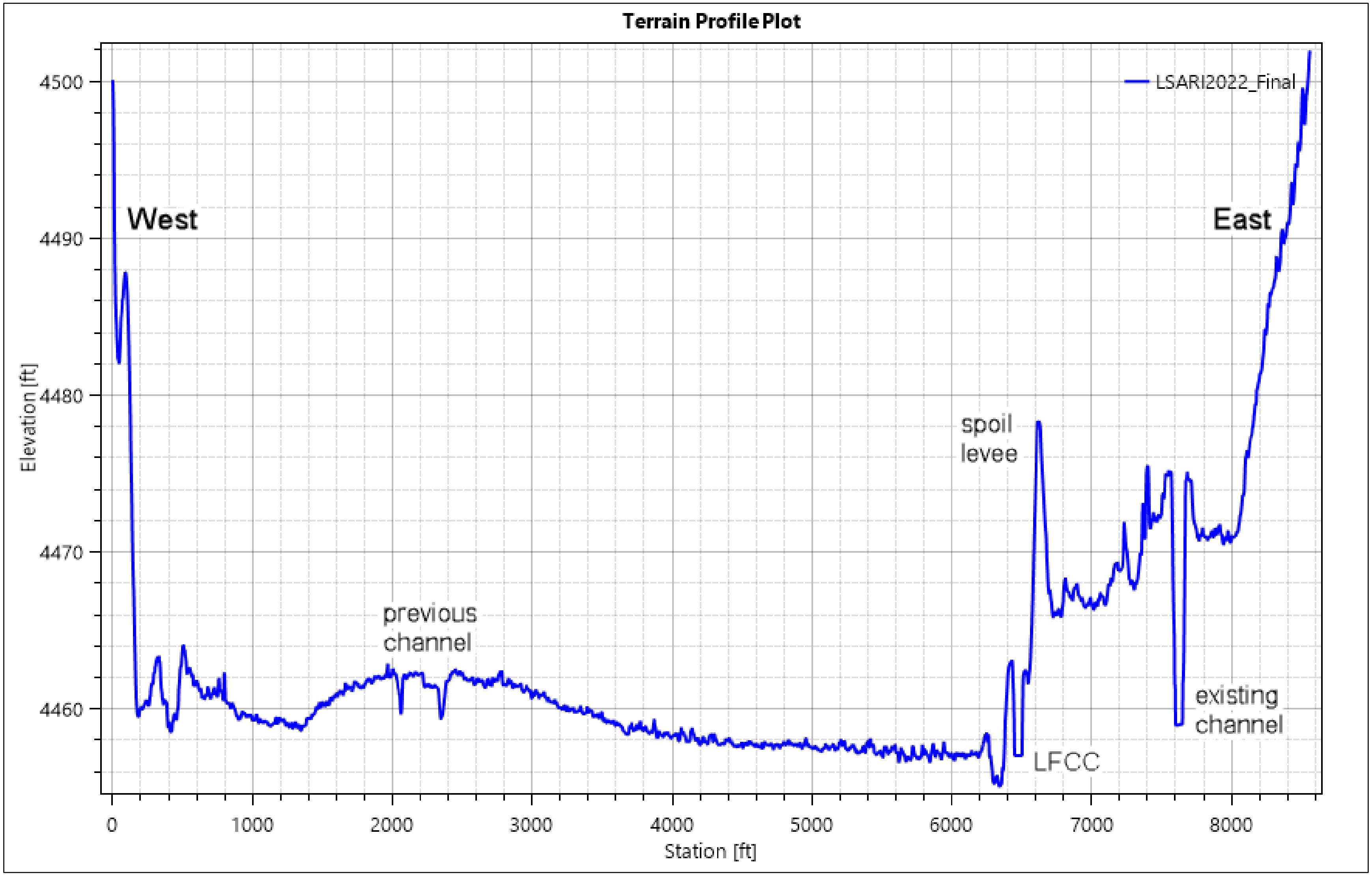


Figure 87.—Cross section looking upstream near RM 66 (2022 lidar with mean bed elevation for river and LFCC).

3.2 Alternative B

Alternative B begins realigning the river to the west near RM 74, just upstream of the BDA South Boundary (Figure 88 and Figure 89). The realigned river crosses the LFCC near RM 73.3 where it will collect water from the LFCC thereby increasing the flow in the river by 100 to 200 cfs. The river will cross the LFCC again upstream of Tiffany Basin near RM 72.5, which will require filling in the LFCC and removing the existing levees to create a floodplain. The river will flow through Tiffany Basin and reconnect with the existing channel near RM 69.3 upstream of the San Marcial Railroad Bridge. Additional features upstream of the railroad bridge include:

- filling the previous channel and LFCC at the start of the realignment and constructing a berm and flow path to connect upstream overbanking flow with the new channel
- reinforcing the railroad embankment near the Elmendorf Drain outlet to redirect any overbanking flows into the 1940s channel
- placing a berm in the LFCC east of the Elmendorf culvert outlet so that water from the Elmendorf will continue to enter the LFCC and flow downstream to the west of the railroad embankment (in the current LFCC alignment) until RM 68
- excavating the floodplain, levees, and outlet channels from the floodplain to the river near RM 69.3 so that any overbanking flow can enter the existing river channel upstream of the bridge

Downstream of San Marcial, Alternative B realigns the river to the west starting near RM 67.7 and crosses the LFCC near RM 67.3 (Figure 88 and Figure 90). The river continues flowing downstream through the western valley until reconnecting with the existing channel near RM 59.5. Water from the Elmendorf Drain enters the LFCC through the existing culvert upstream and near to the railroad embankment. Starting near RM 68, the existing LFCC will be blocked and a small channel about 5,000 ft long will be excavated to connect the LFCC to an existing flow path along the west edge of the valley. This flow path appears to be a historical side channel like the LFCC West channel downstream of RM 60. The goal of this feature is to improve avian habitat by recreating similar conditions to the LFCC West downstream of RM 60. Water from the Elmendorf and the western channel will flow into the realigned Rio Grande near RM 64.5. Alternative B intersects the ponds near RM 61 and will require constructing a small outlet feature to allow water from the river to periodically enter the LFCC West channel downstream of RM 60. The connection between the realigned river and LFCC West will be prone to sedimentation, unlike the existing flow from the LFCC to LFCC West, which has low sediment concentrations.

Figure 91 presents a typical cross section and the longitudinal profile for Alternative B. The cross section was developed using a 300 ft top width, informed by Greimann and Holste (2018) and the BDA Pilot Realignment design (Holste 2021). Width calculations assumed an average 3-ft bank height and 3,000 cfs channel capacity. Variations in the longitudinal profile and valley topography result in localized areas that are above and below the average bank height and channel capacity. The longitudinal profile maintains the existing reach slope of 0.0006 and adjusts the local slope based on existing bed elevations and valley topography. Local undulations in the design slope are expected to smooth out once water begins flowing through the constructed project. Figure 92 through Figure 99 show typical cross sections at various river miles along the length of the project. The overall goal is to move the river to the low point in the valley while considering continuity in the planform alignment.

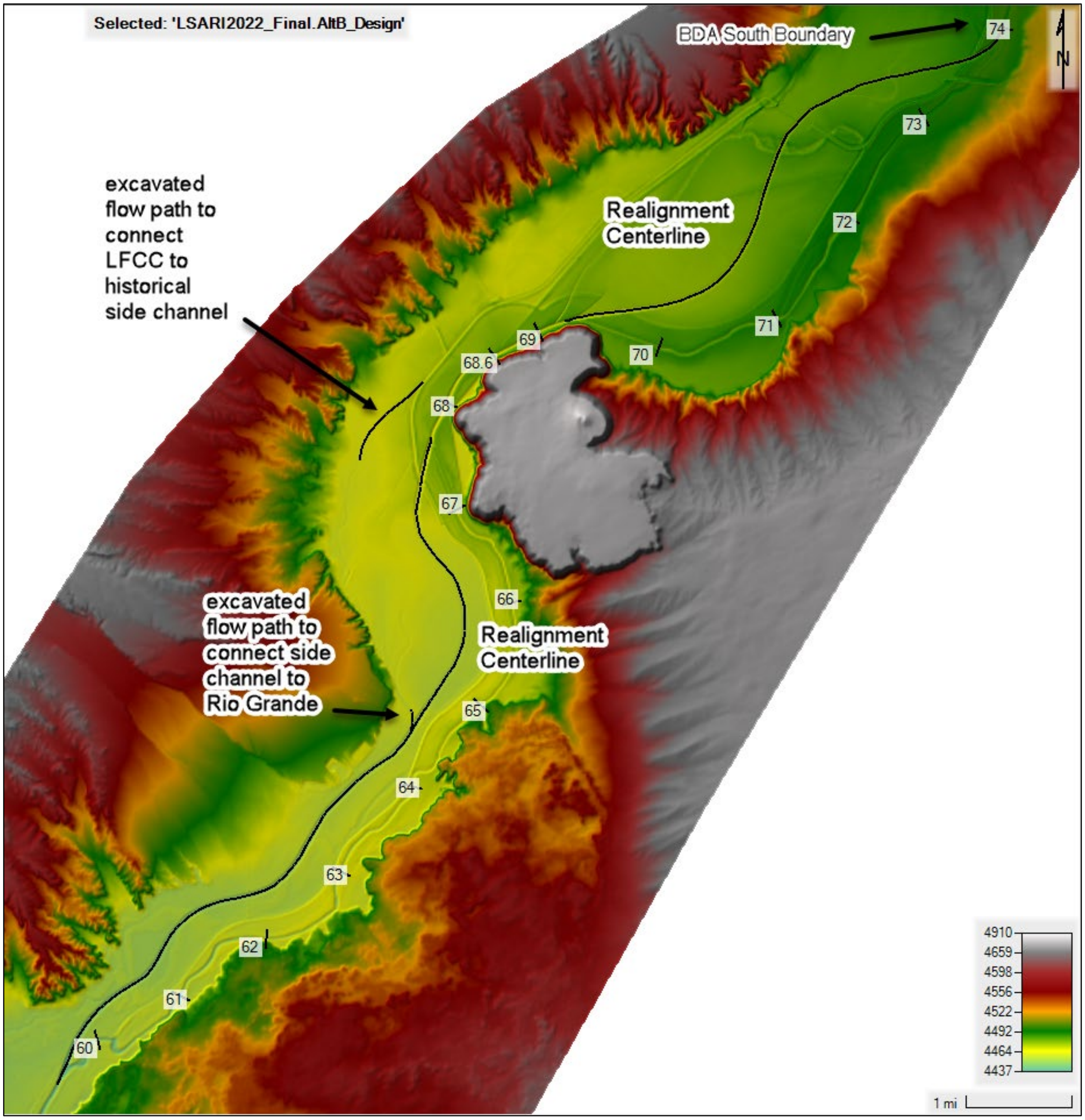


Figure 88.—Overview map of Alternative B channel realignment and excavated flow paths between RM 74 and RM 59.5. Water from LFCC enters realigned river at RM 73.7 and water from Elmendorf enters realigned river at RM 64.5.

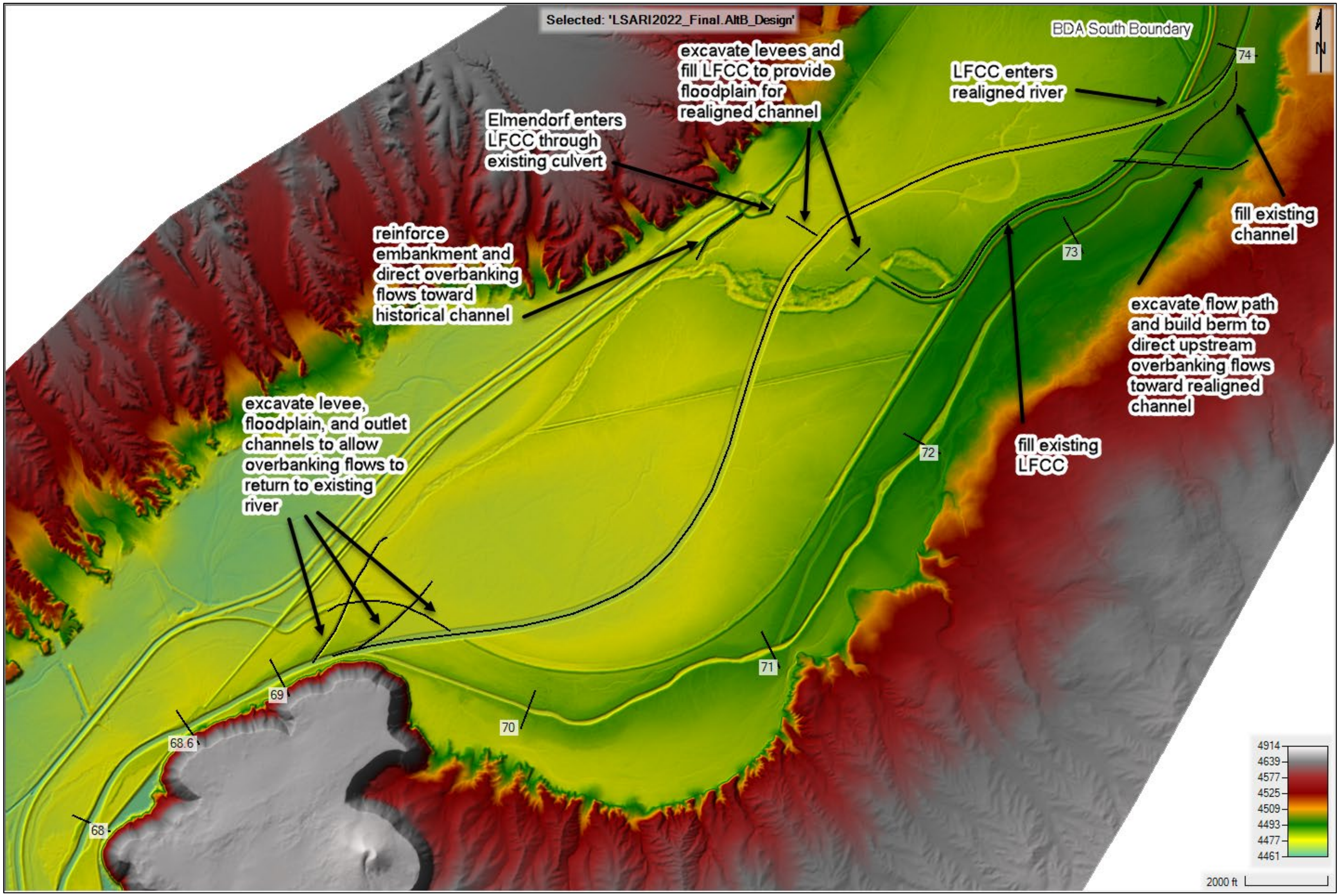


Figure 89.—Alternative B project features between RM 74 and RM 68.

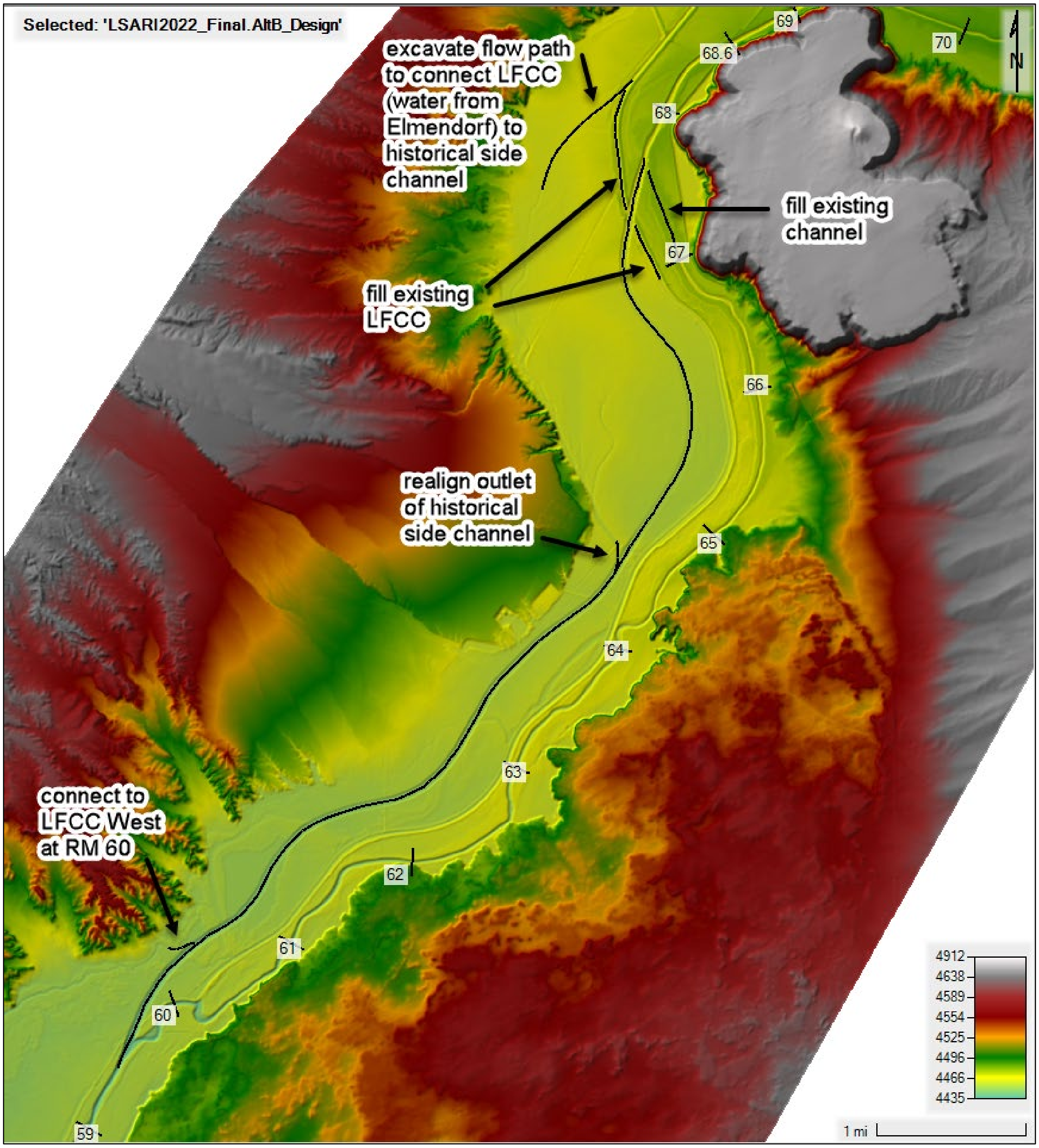


Figure 90.—Alternative B project features between RM 68 and RM 59.

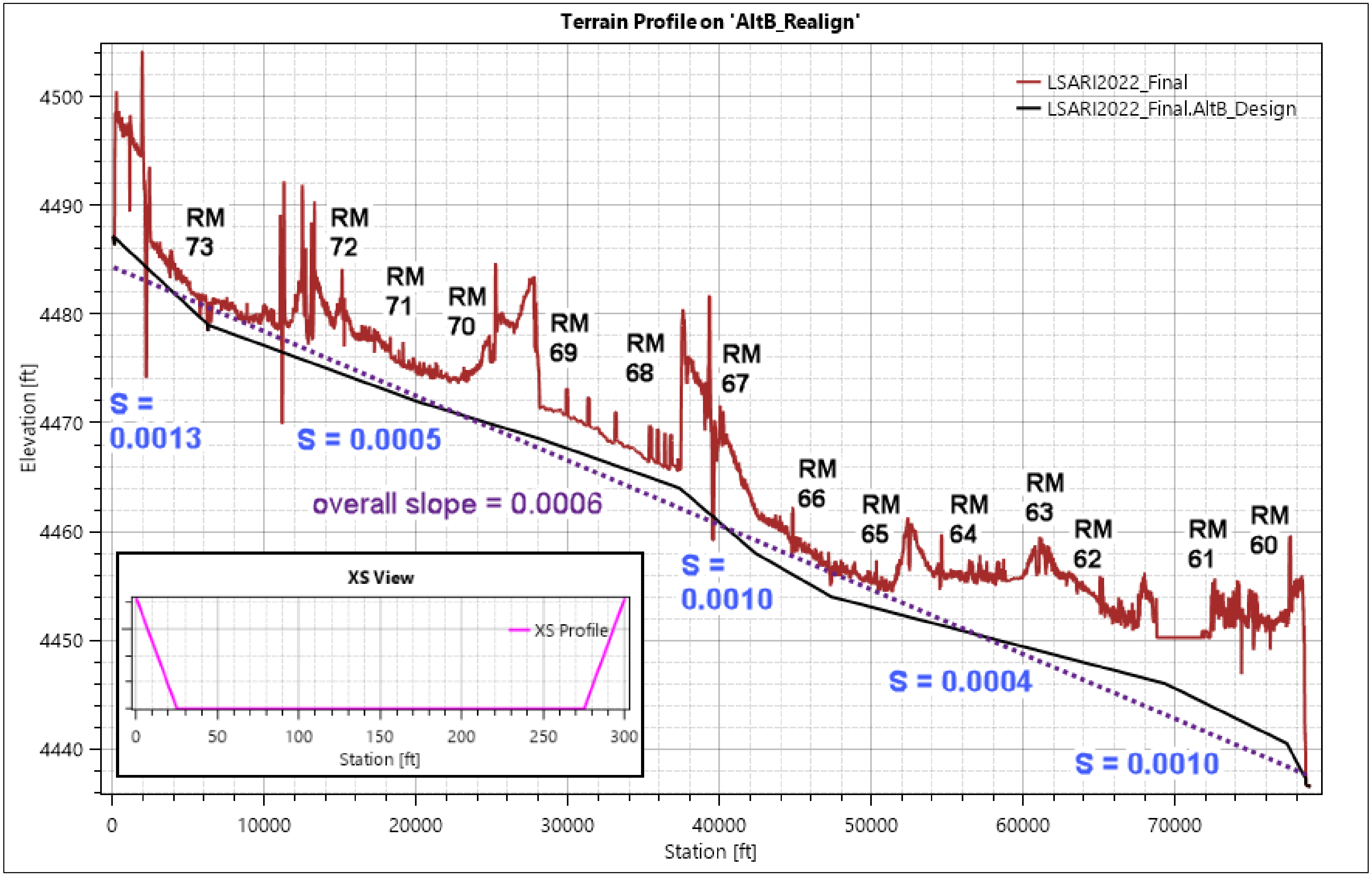


Figure 91.—Alternative B design elevations. Inset graph (lower left) shows typical cross section with 3:1 side slope, 250 ft bottom width, and maximum 300 ft top width. Main graph shows longitudinal profile where brown line represents existing ground, dark blue line represents constructed profile, and purple dashed line represents best-fit profile along constructed alignment.

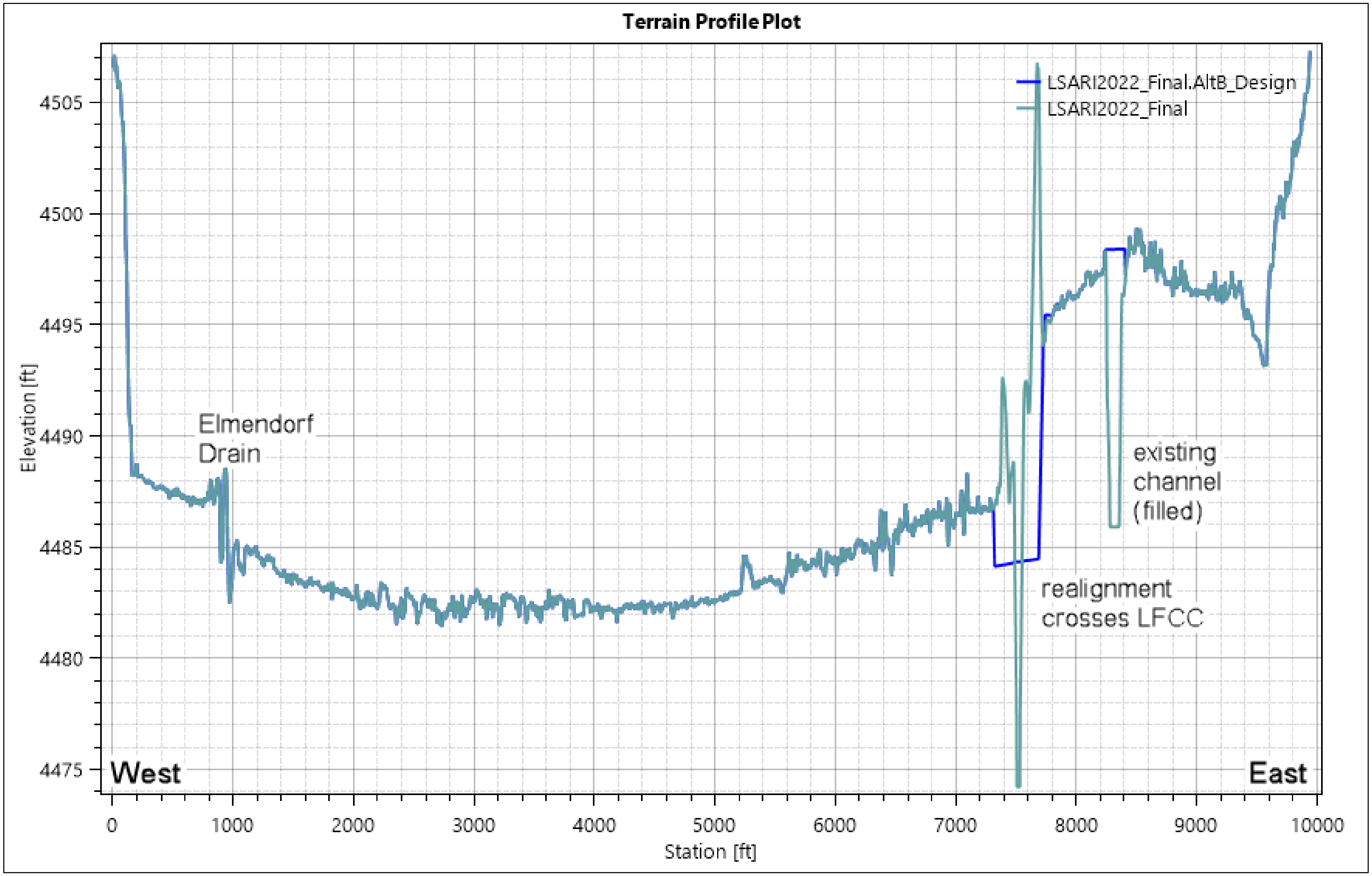


Figure 92.—Alternative B (dark blue) and existing ground (light blue) cross section looking upstream at RM 73.5.

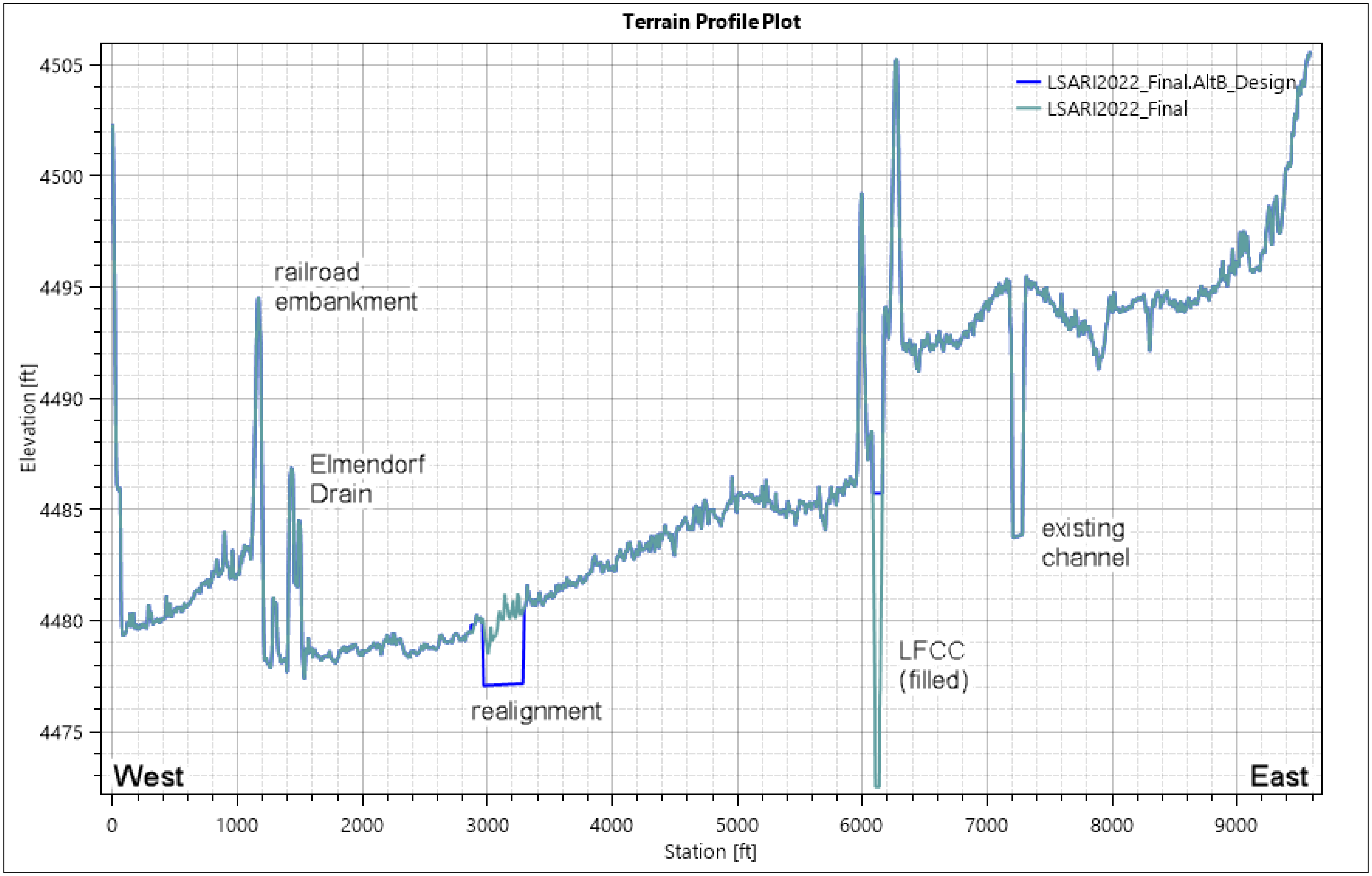


Figure 93.—Alternative B (dark blue) and existing ground (light blue) cross section looking upstream at RM 72.8.

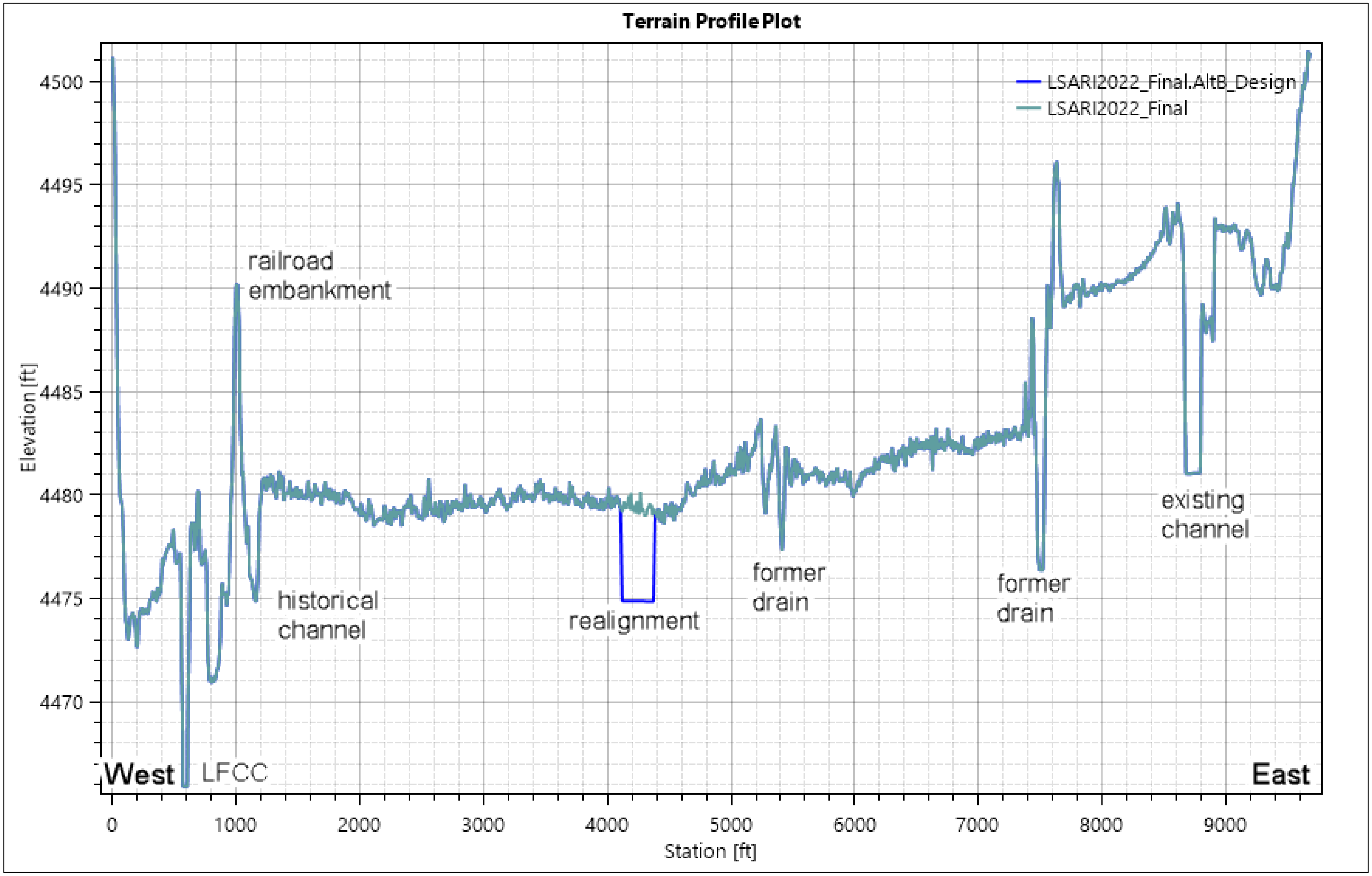


Figure 94.—Alternative B (dark blue) and existing ground (light blue) cross section looking upstream at RM 72.

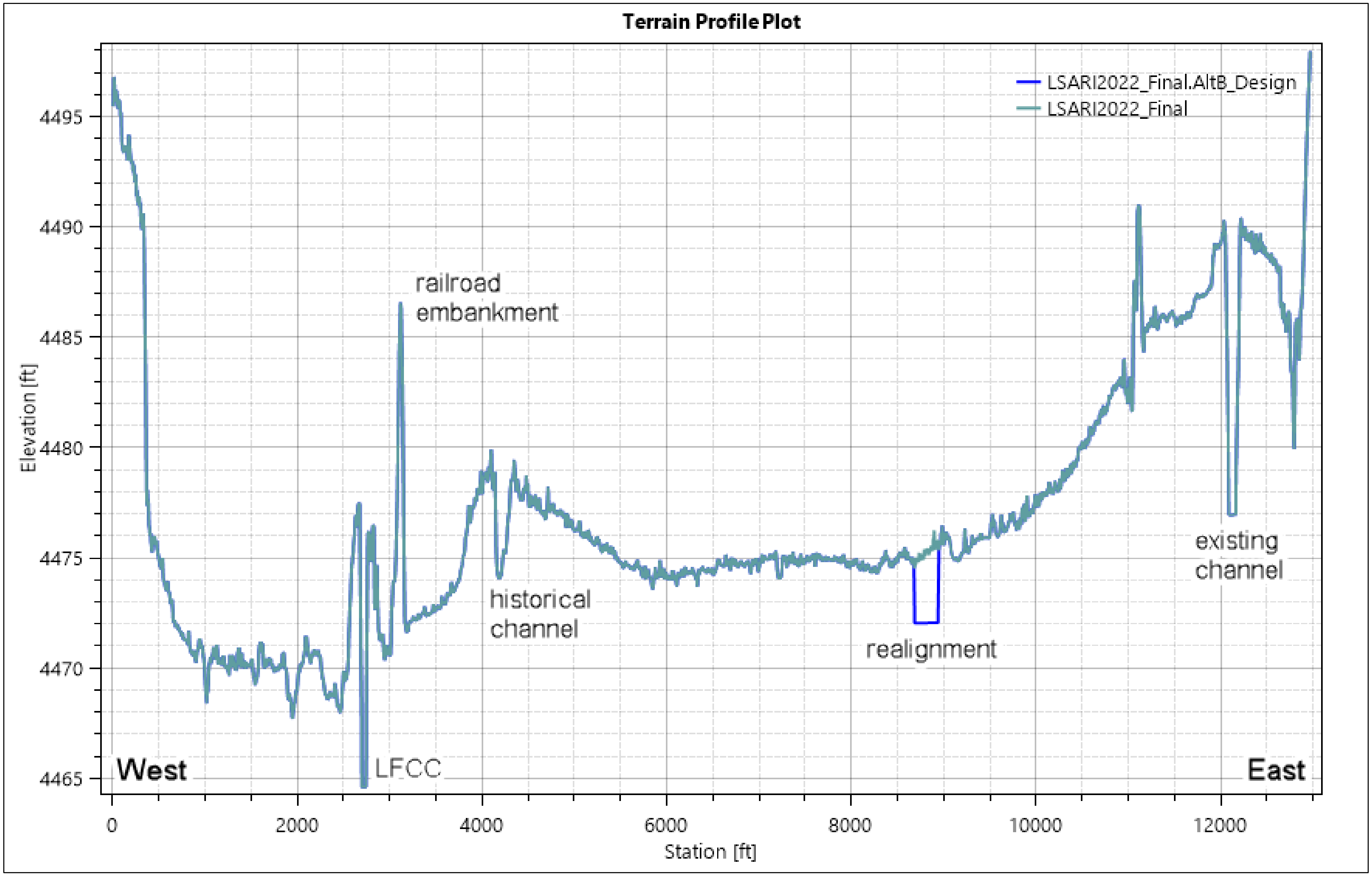


Figure 95.—Alternative B (dark blue) and existing ground (light blue) cross section looking upstream at RM 71.

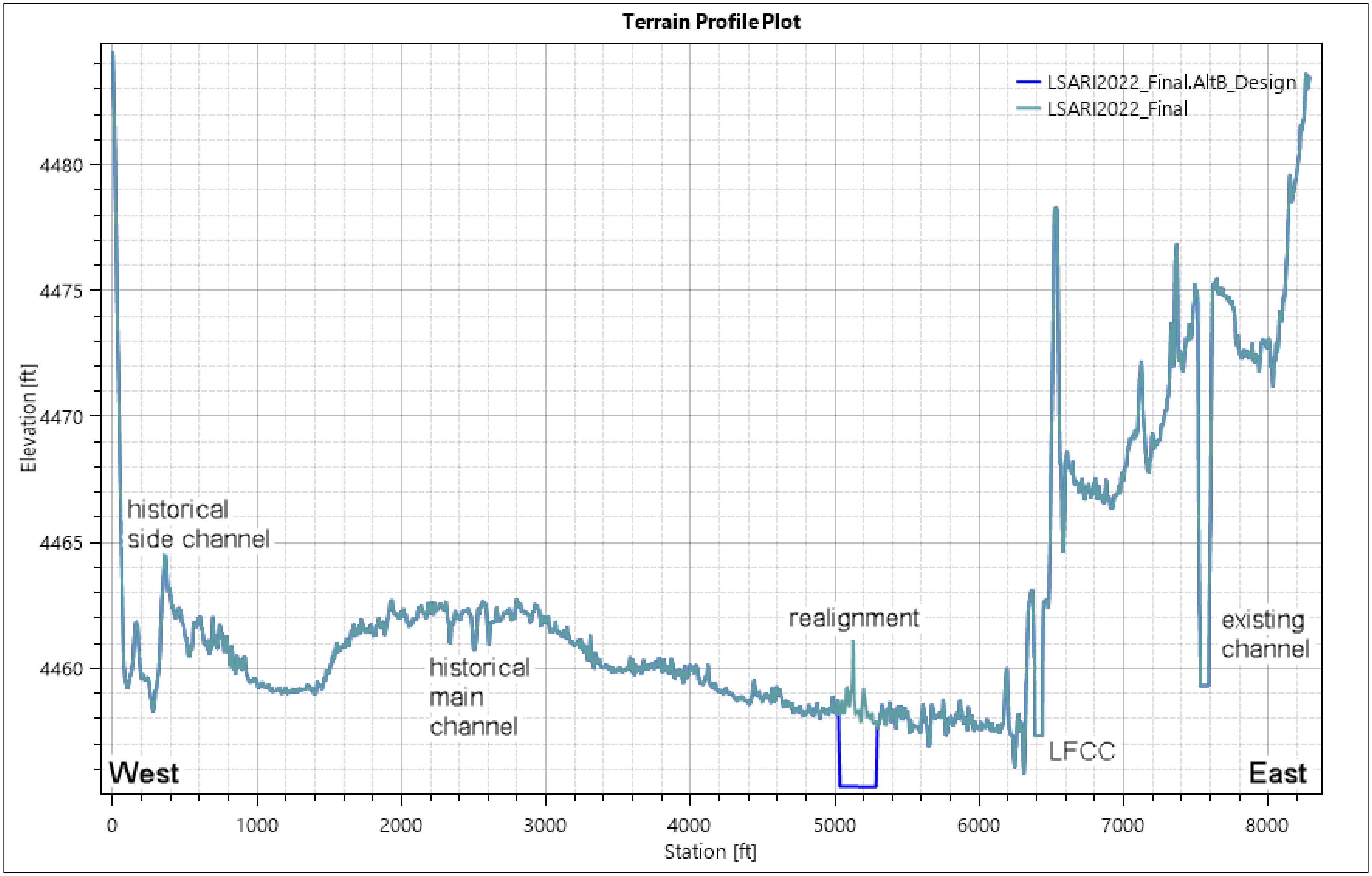


Figure 96.—Alternative B (dark blue) and existing ground (light blue) cross section looking upstream at RM 66.2.

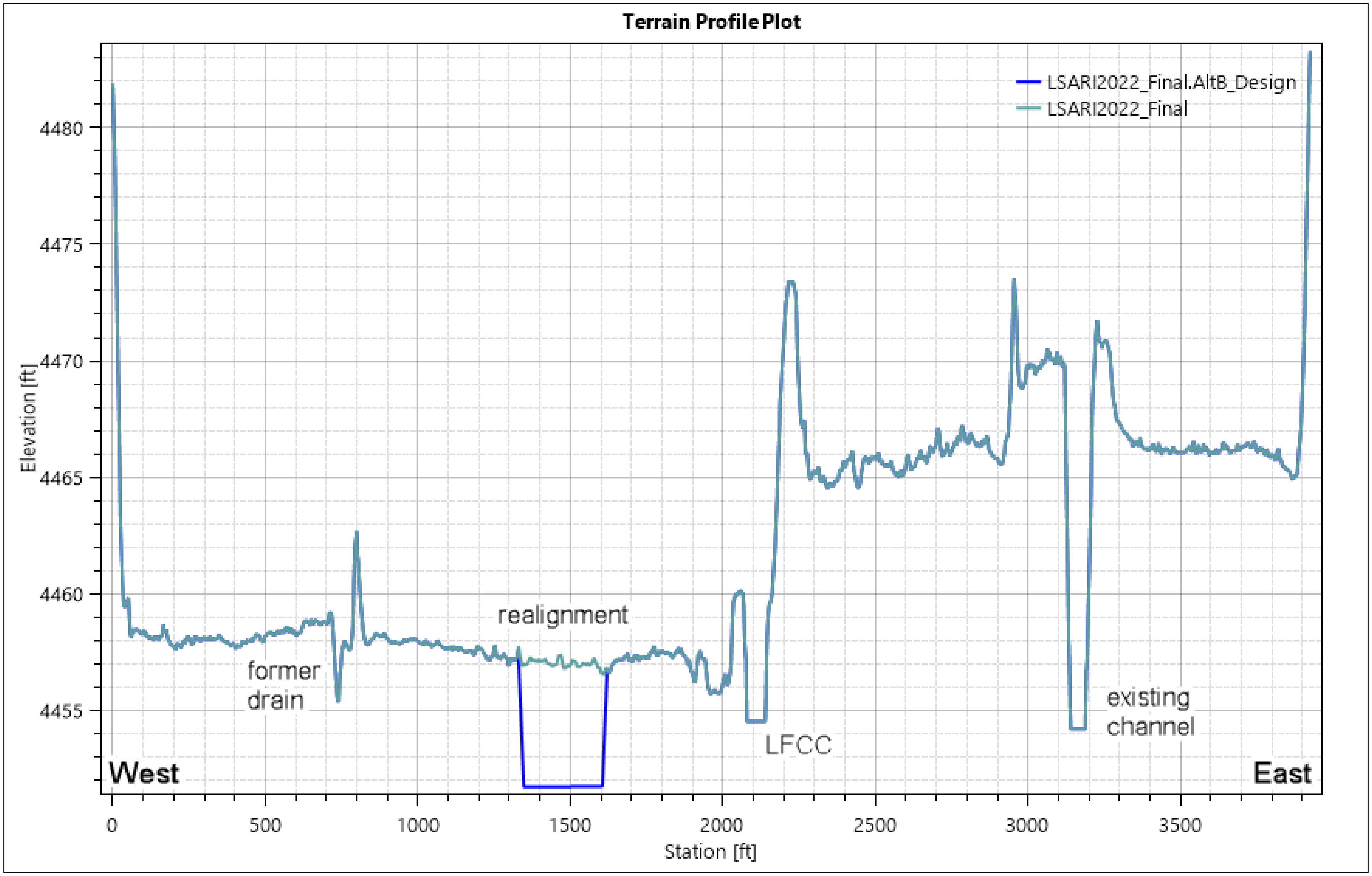


Figure 97.—Alternative B (dark blue) and existing ground (light blue) cross section looking upstream at RM 64.4.

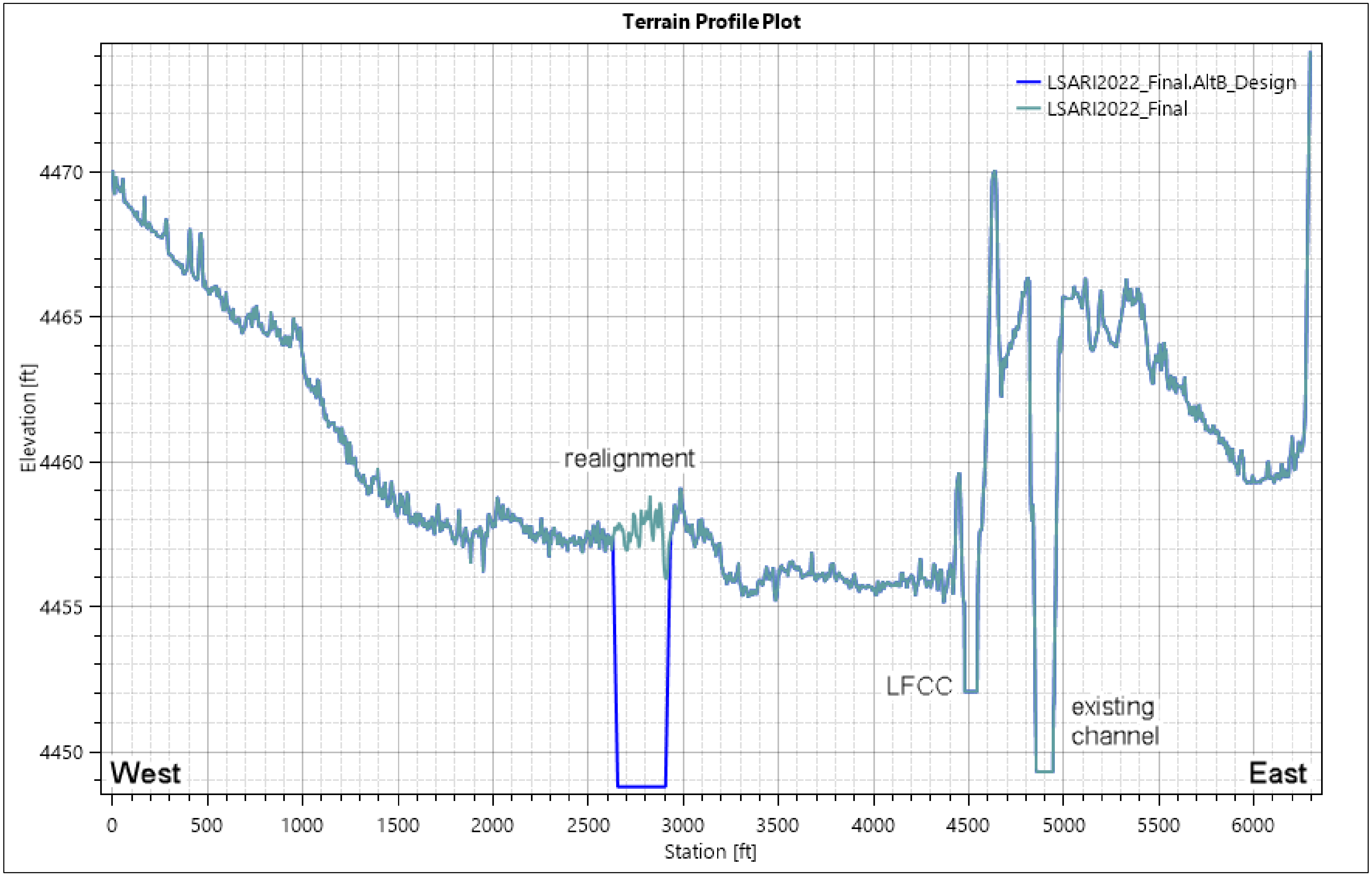


Figure 98.—Alternative B (dark blue) and existing ground (light blue) cross section looking upstream at RM 63.

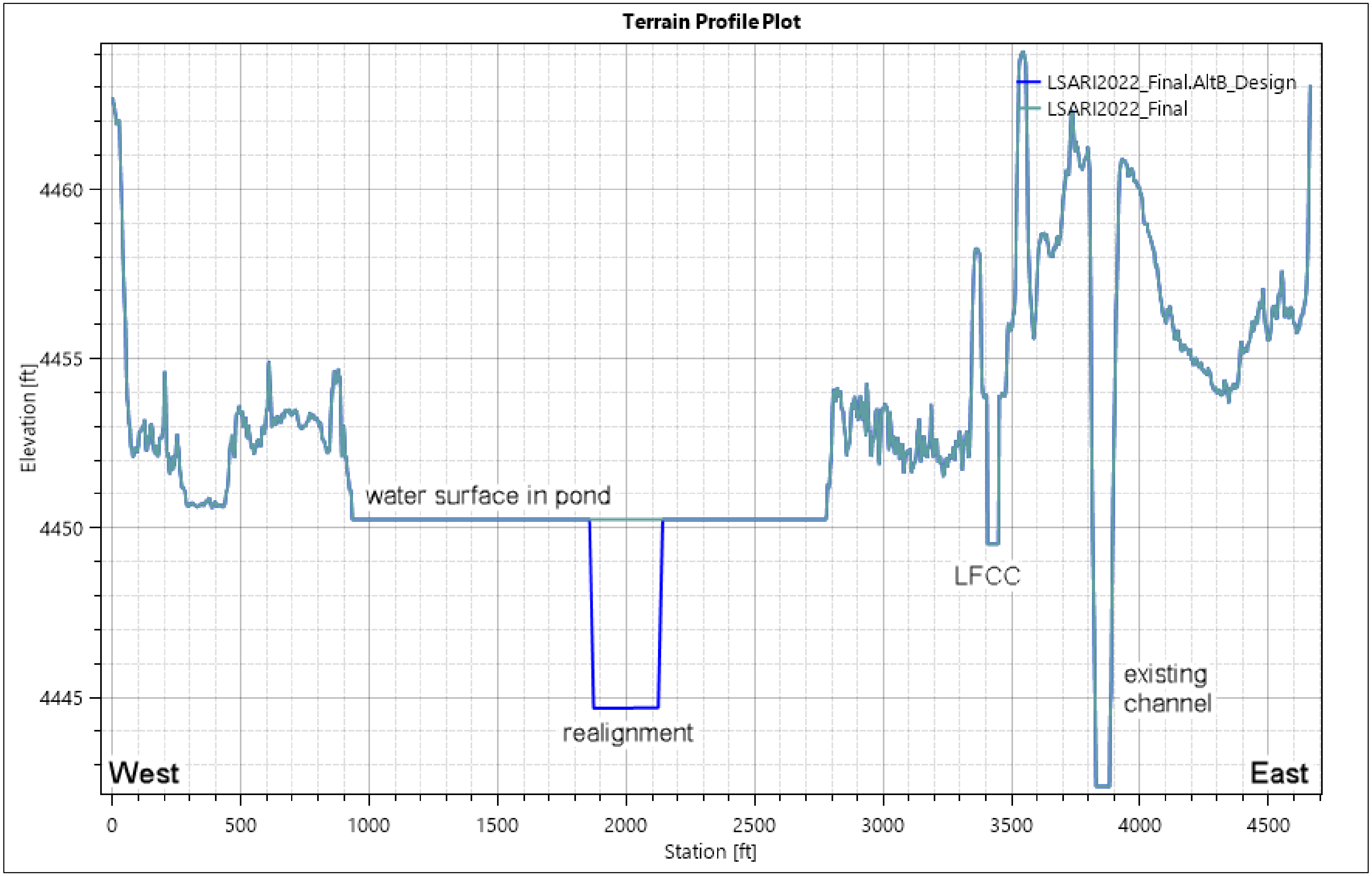


Figure 99.—Alternative B (dark blue) and existing ground (light blue) cross section looking upstream at RM 61.1.

Table 6 is an initial estimate of material quantities for Alternative B. Earthwork quantities are similar to the channelization between 1951 and 1953 but the area of vegetation clearing and grubbing is much smaller. Excavation quantities could be reduced if the initial channel capacity were reduced, which would provide increased overbanking. In areas with deep excavation such as downstream of RM 62, implementing a multi-tiered cross section would also reduce the excavation volume. The large excavation quantities are much less than the cumulative 30 million cy of sediment that have deposited in the project area between 1962 and 2012.

Table 6.—Quantity estimate summary for Alternative B

Item	Quantity	Unit
Clearing and Grubbing	540	acres
Excavation	4,327,000	cy
Fill	610,000	cy
Spoils Disposal*	3,717,000	cy

*Likely to require temporary stockpile areas. Final spoils locations could include abandoned river channel or LFCC and low-lying areas along edge of floodplain.

3.3 Alternative C

Alternative C begins realigning the river to the west near RM 72.5, just downstream of where the LFCC turns to the west above Tiffany Basin (Figure 100 and Figure 101). The river will flow through Tiffany Basin and reconnect with the existing channel near RM 69.3 upstream of the San Marcial Railroad Bridge. Additional features upstream of the railroad bridge include:

- filling the previous main channel and drainage channel at the start of the realignment and constructing a berm and flow path to connect upstream overbanking flow with the new channel
- excavating the floodplain, levees, and outlet channels near RM 69.3 so that any overbanking flow can enter the existing river channel upstream of the bridge

Downstream of San Marcial, Alternative C realigns the river to the west starting near RM 67.7 and crosses the LFCC near RM 67.3 (Figure 100 and Figure 102), thereby increasing the flow in the river by 100 to 200 cfs, but reduces flow to the LFCC West channel by the same amount. The river continues flowing downstream through the western valley until reconnecting with the existing channel near RM 59.5. Alternative C intersects the ponds near RM 61 and will require constructing a small outlet feature to allow water from the river to periodically enter the LFCC West channel downstream of RM 60.

Figure 103 presents a typical cross section and the longitudinal profile for Alternative C. The cross section was developed using a 300 ft top width, informed by Greimann and Holste (2018) and the BDA Pilot Realignment design (Holste 2021). Width calculations assumed an average 3-

ft bank height and 3,000 cfs channel capacity. Variations in the longitudinal profile and valley topography result in localized areas that are above and below the average bank height and channel capacity. The longitudinal profile maintains the existing reach slope of 0.0006 and adjusts the local slope based on existing bed elevations and valley topography. Local undulations in the design slope are expected to smooth out once water begins flowing through the constructed project. Figure 104 through Figure 109 show typical cross sections at various river miles along the length of the project. The overall goal is to move the river to the low point in the valley while considering continuity in the planform alignment.

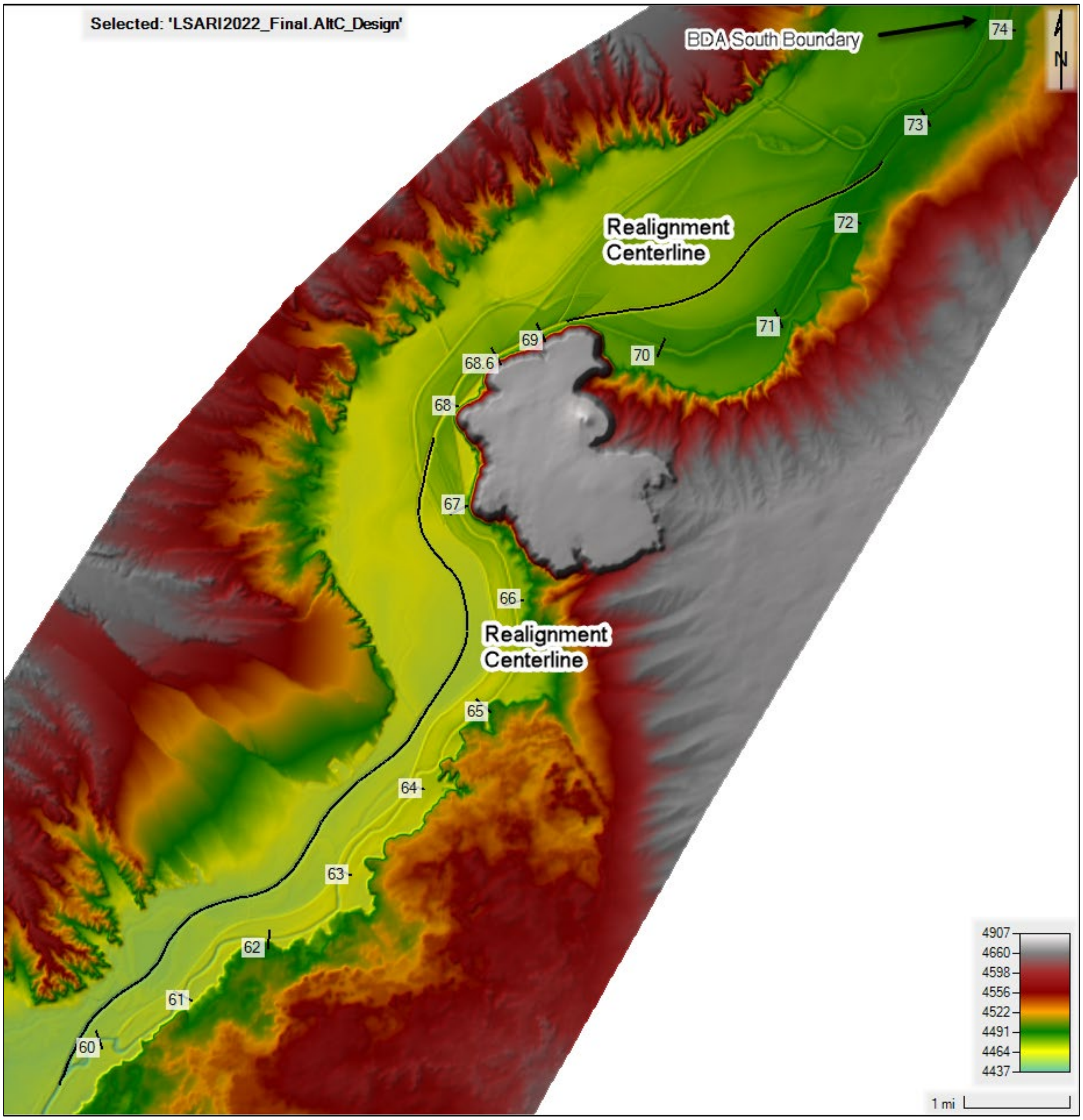


Figure 100.—Overview map of Alternative C channel realignment between RM 72.5 and RM 59.5. Water from LFCC and Elmendorf enters realigned river at RM 67.5.

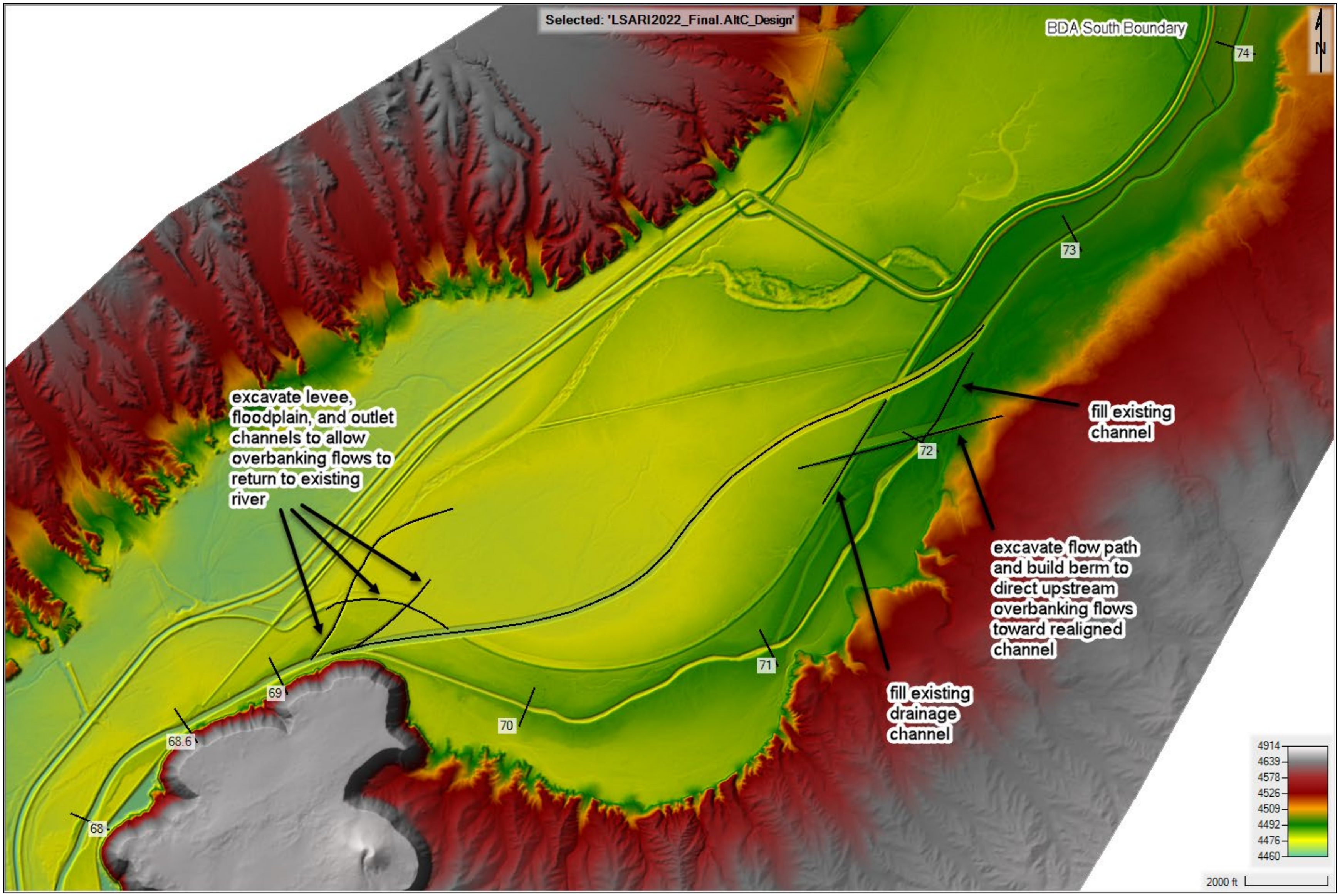


Figure 101.—Alternative C project features between RM 72.5 and RM 68.

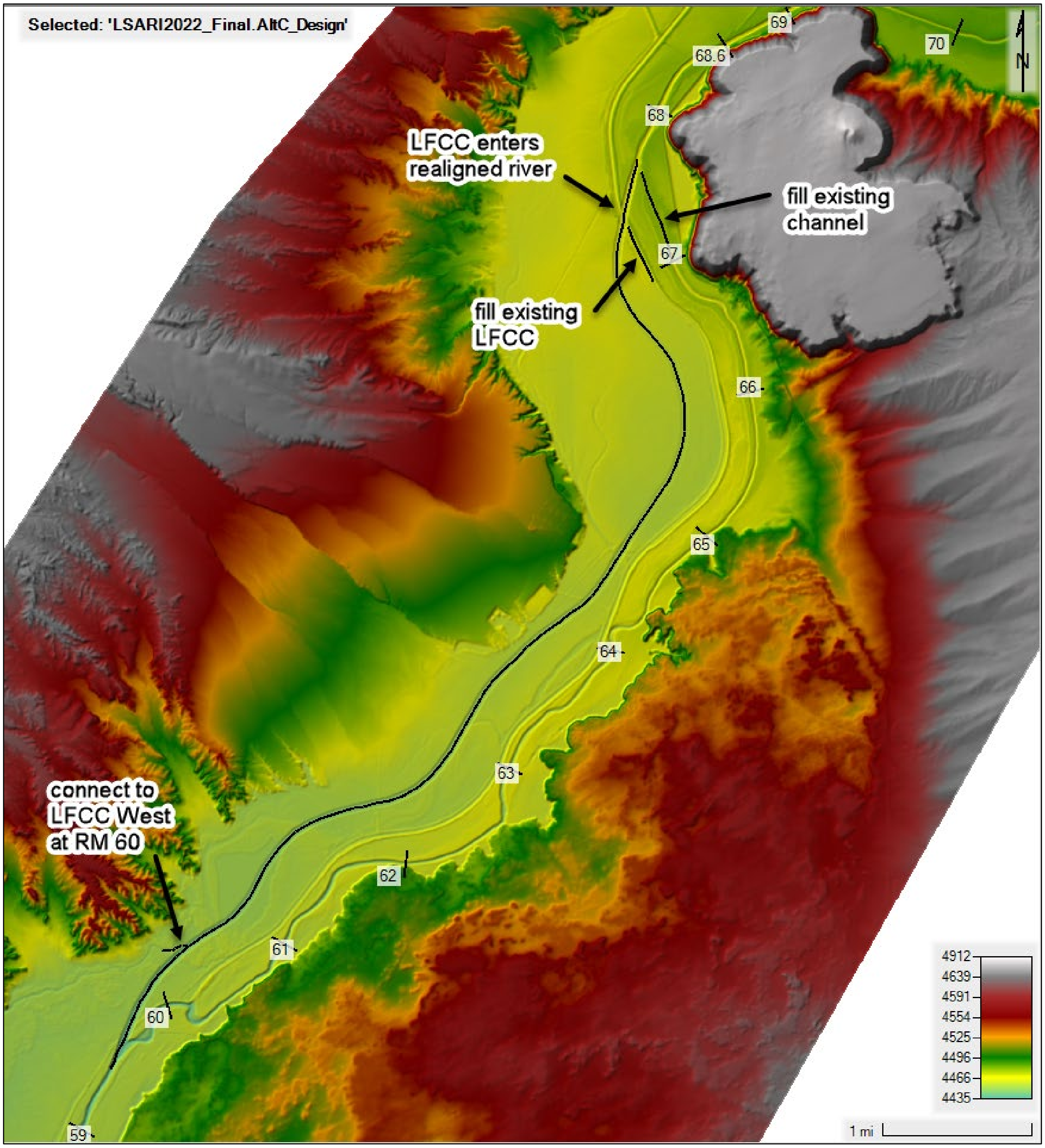


Figure 102.—Alternative C project features between RM 68 and RM 59.

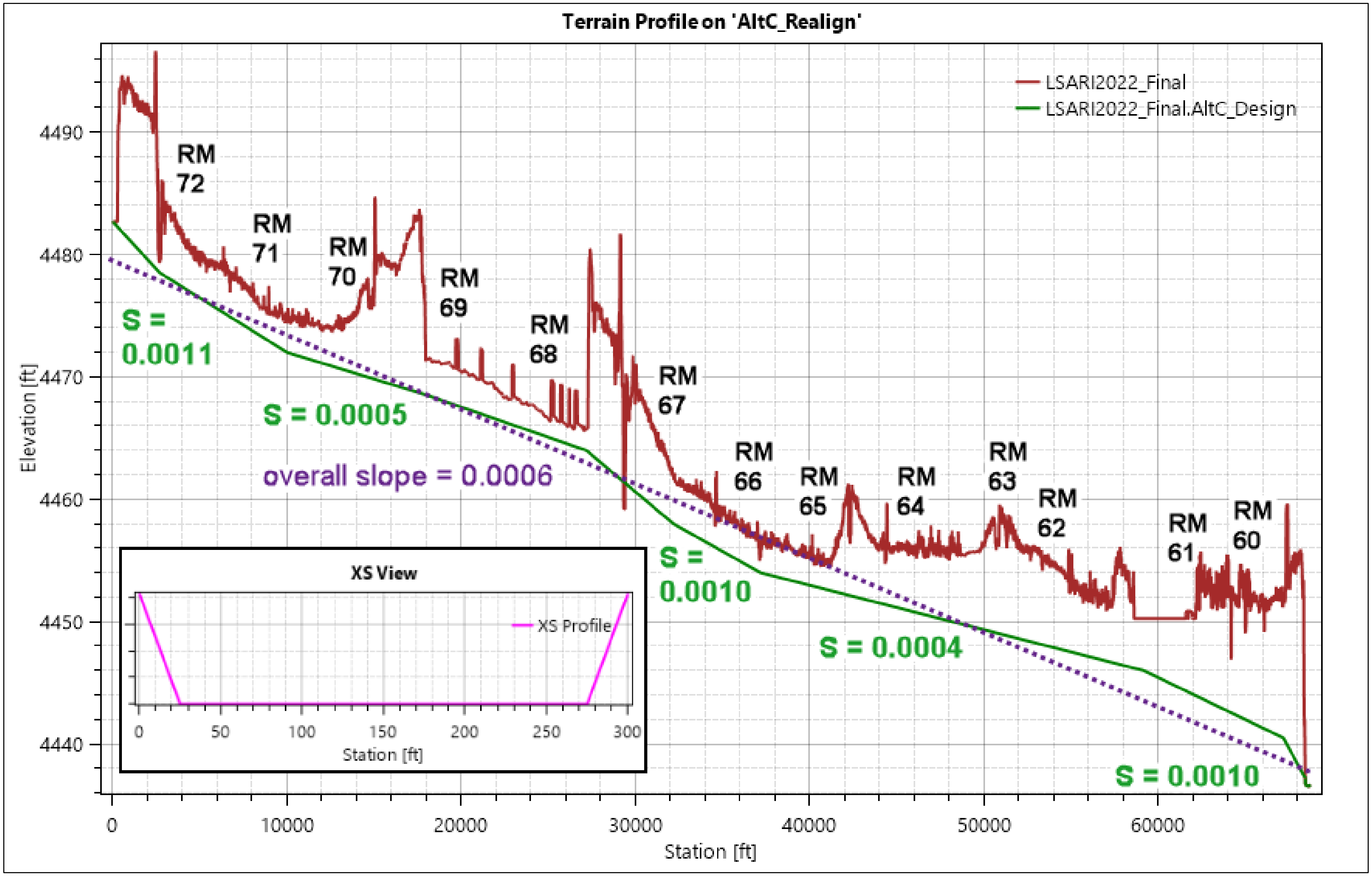


Figure 103. —Alternative C design elevations. Inset graph (lower left) shows typical cross section with 3:1 side slope, 250 ft bottom width, and maximum 300 ft top width. Main graph shows longitudinal profile where brown line represents existing ground, green line represents constructed profile, and purple dashed line represents best-fit profile along constructed alignment.

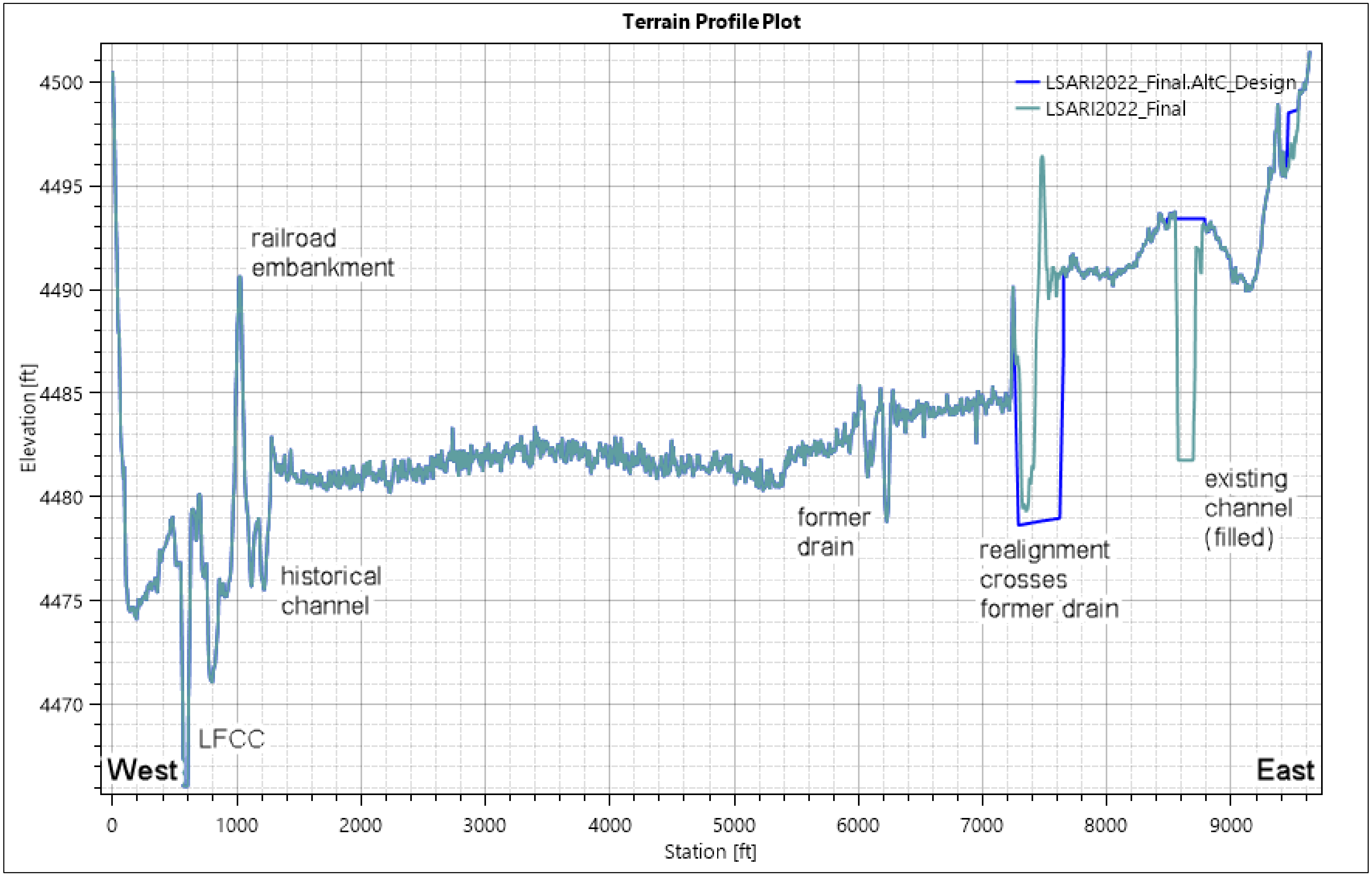


Figure 104.—Alternative C (dark blue) and existing ground (light blue) cross section looking upstream at RM 72.1.

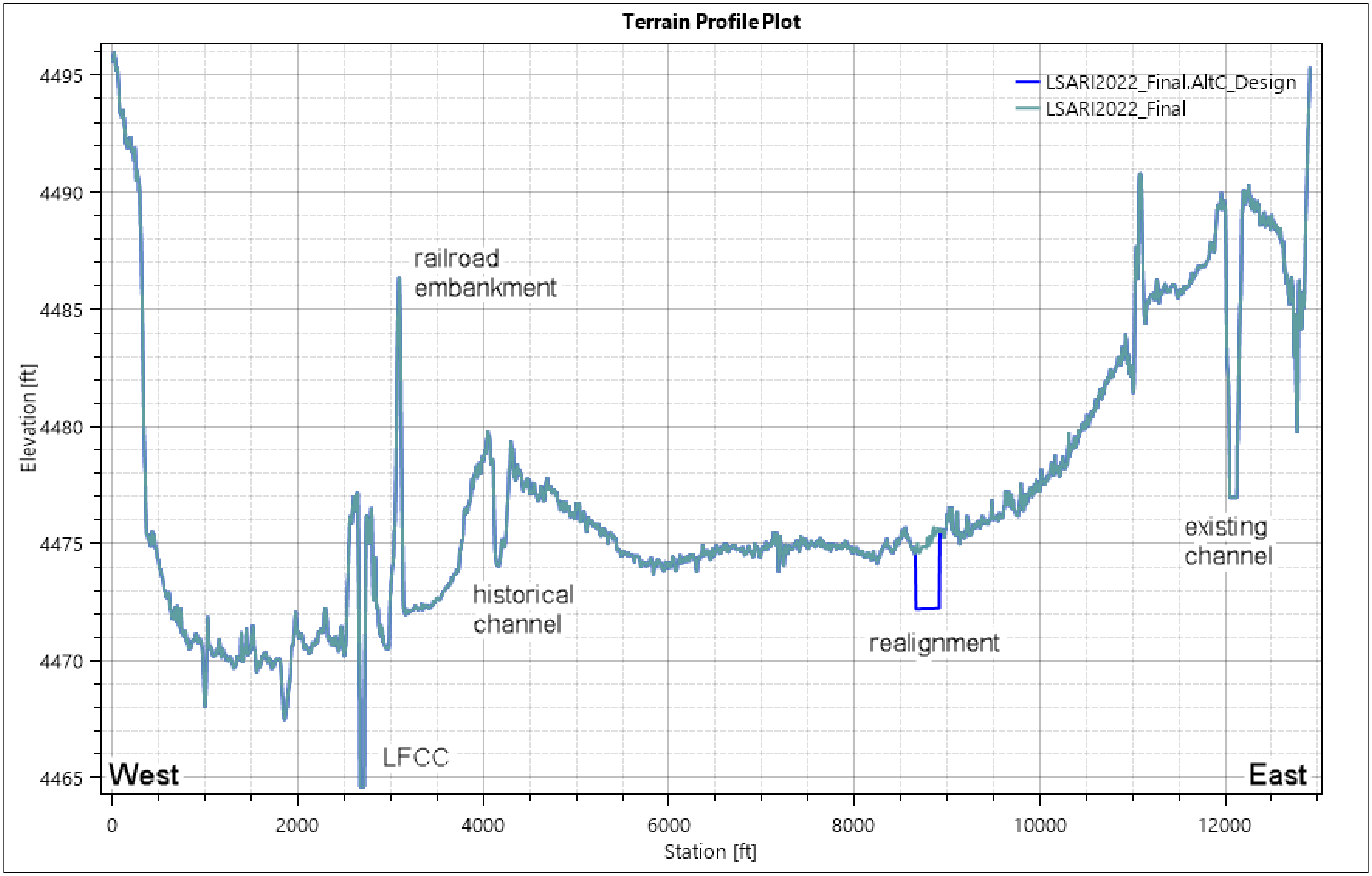


Figure 105.—Alternative C (dark blue) and existing ground (light blue) cross section looking upstream at RM 71.

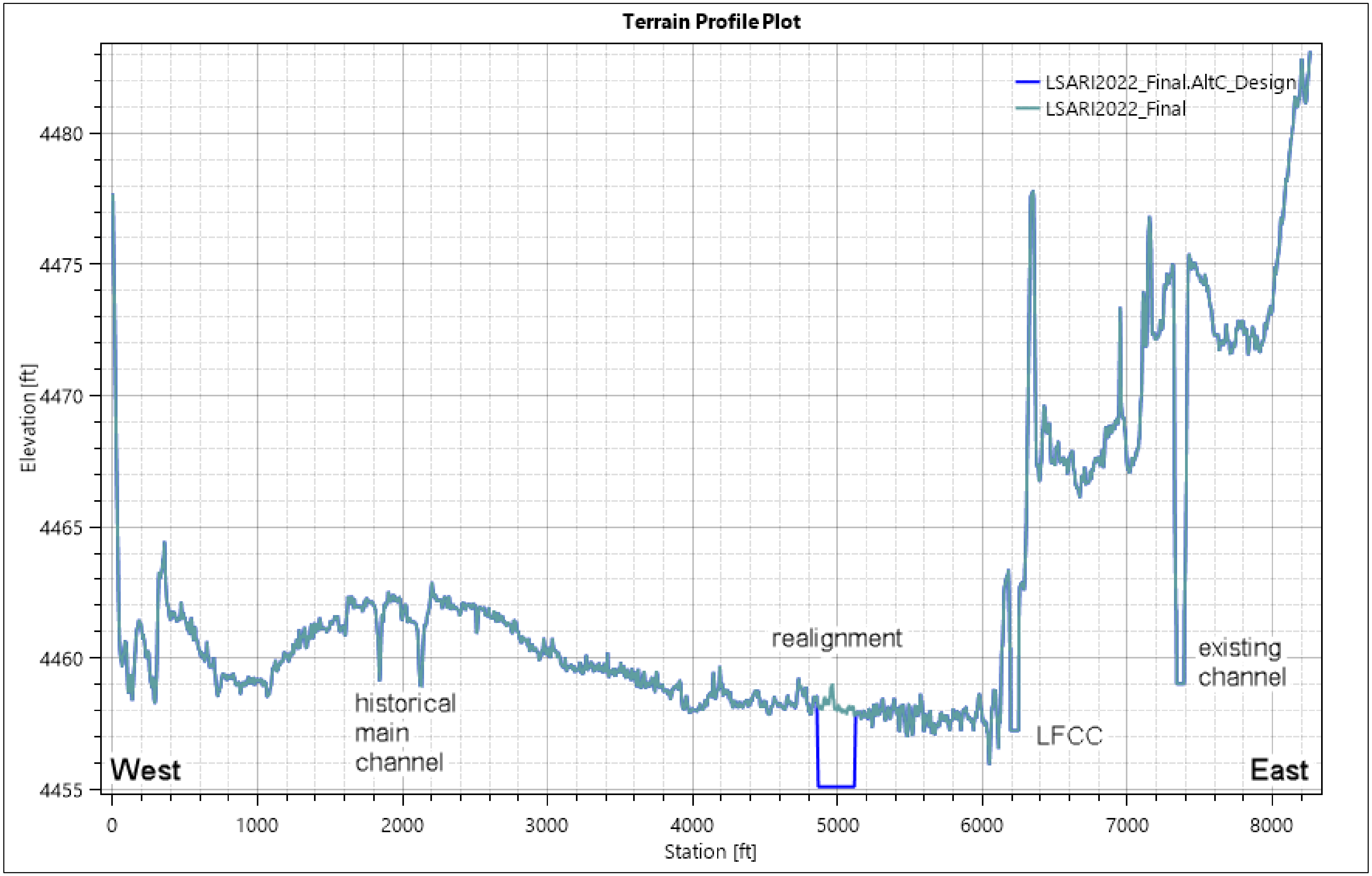


Figure 106.—Alternative C (dark blue) and existing ground (light blue) cross section looking upstream at RM 66.2.

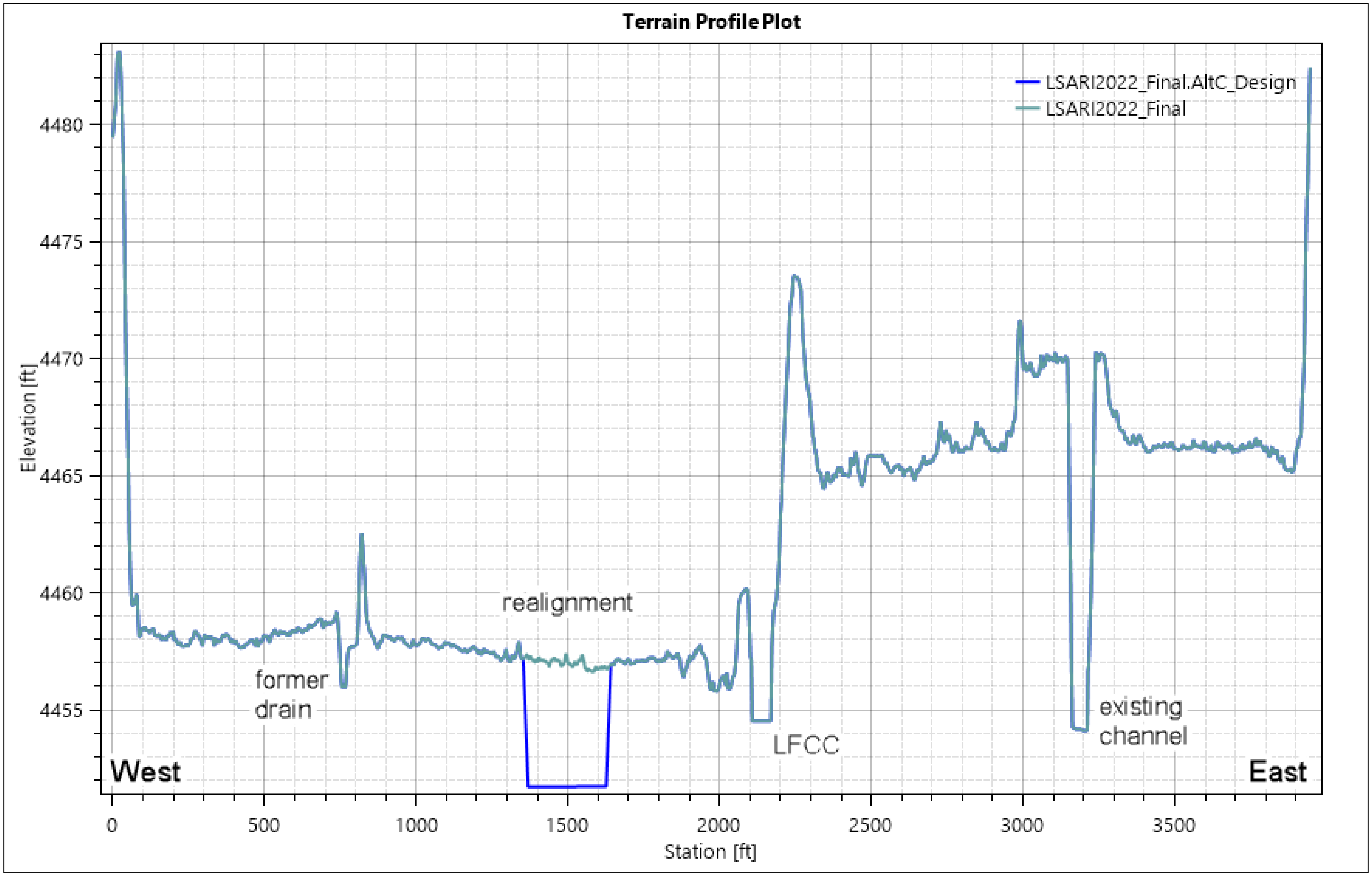


Figure 107.—Alternative B (dark blue) and existing ground (light blue) cross section looking upstream at RM 64.4.

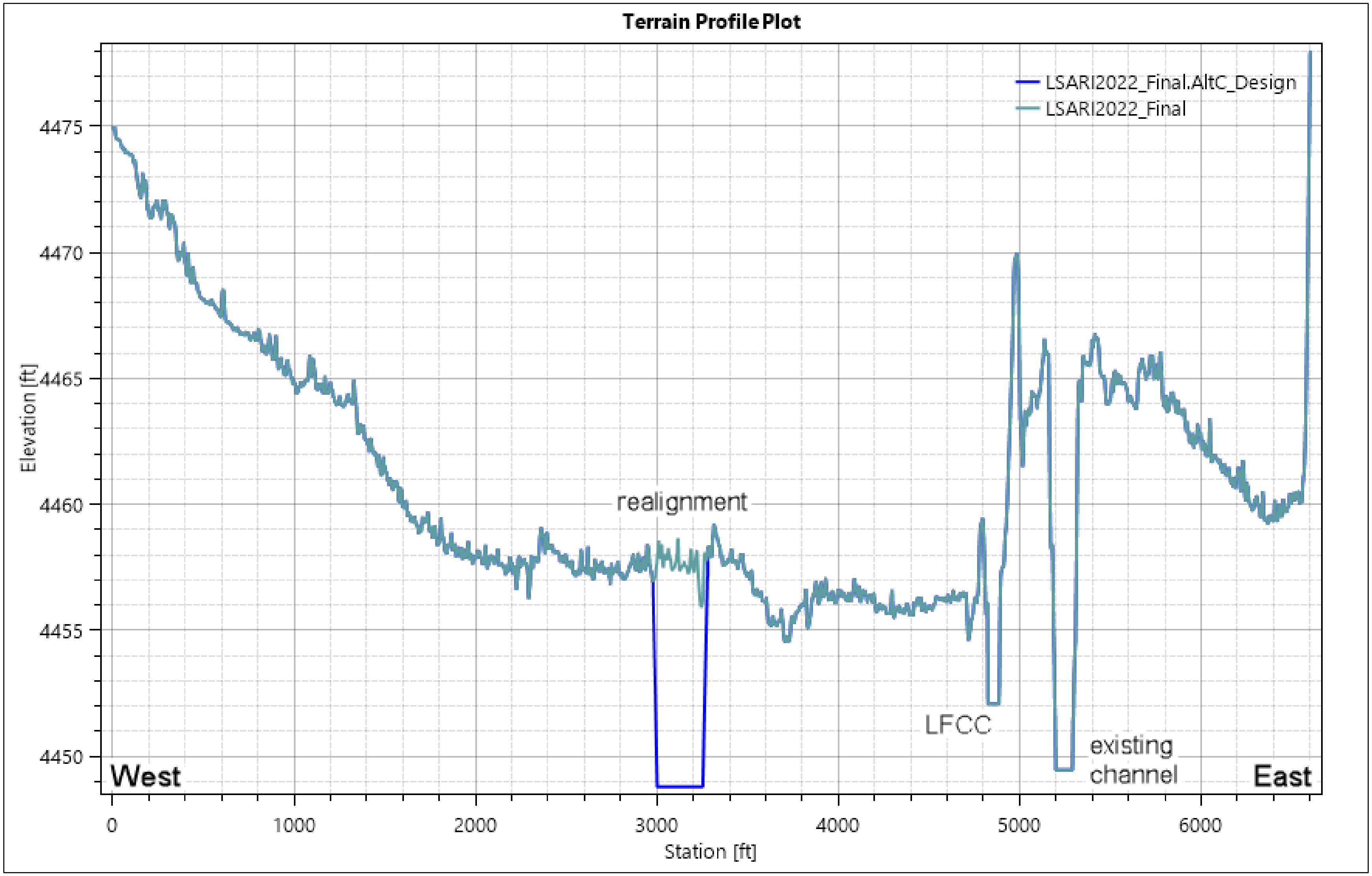


Figure 108.—Alternative B (dark blue) and existing ground (light blue) cross section looking upstream at RM 63.

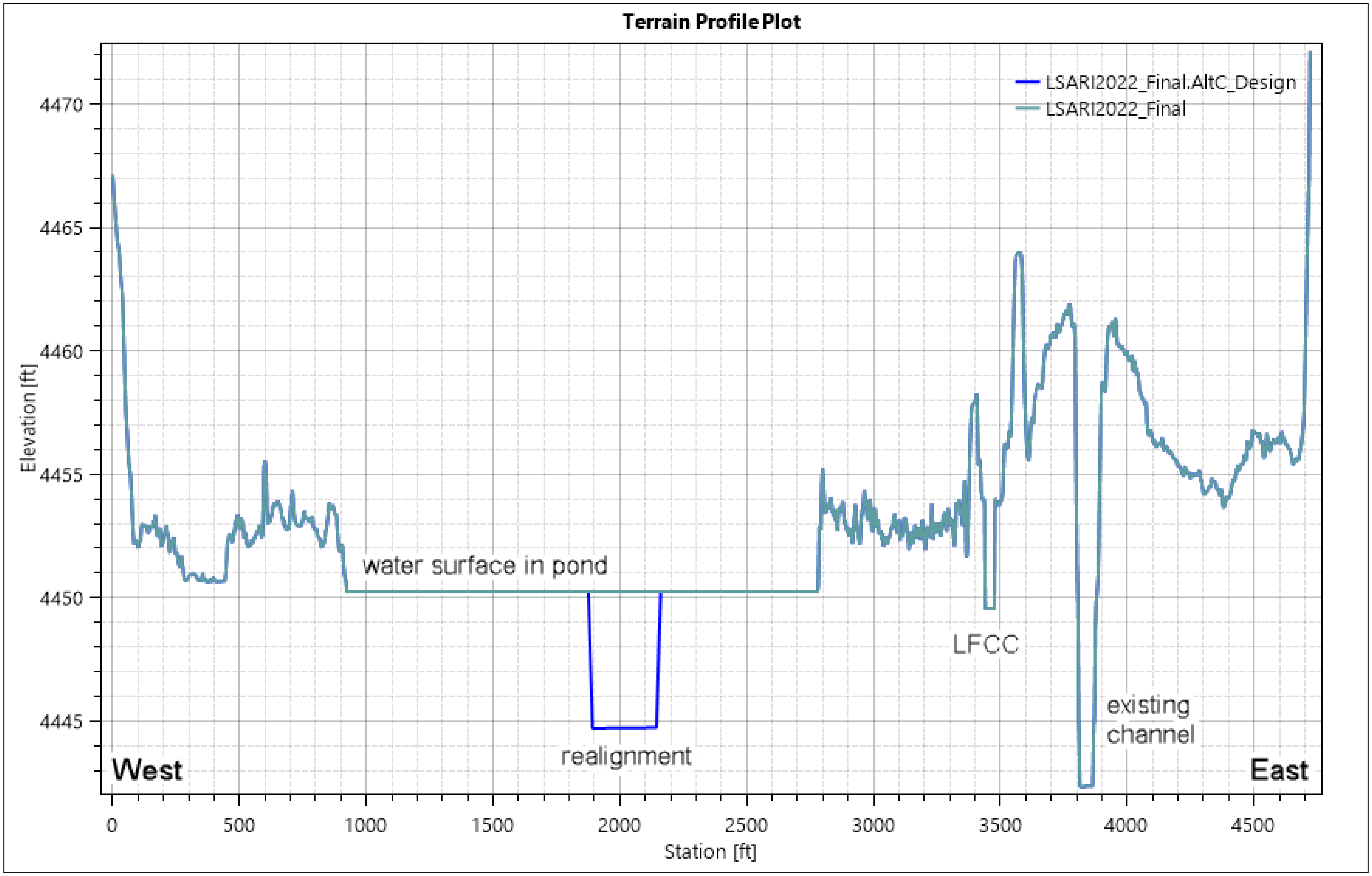


Figure 109.—Alternative B (dark blue) and existing ground (light blue) cross section looking upstream at RM 61.1.

Table 7 is an initial estimate of material quantities for Alternative C. Alternative C has less excavation than Alternative B because the realigned main channel is 1.5 miles shorter. Earthwork quantities are similar to the channelization between 1951 and 1953 but the area of vegetation clearing and grubbing is much smaller. Excavation quantities could be reduced if the initial channel capacity were reduced, which would provide increased overbanking. In areas with deep excavation such as downstream of RM 62, implementing a multi-tiered or compound cross section would also reduce the excavation volume. The large excavation quantities are much less than the cumulative 30 million cy of sediment that have deposited in the project area between 1962 and 2012.

Table 7.—Quantity estimate summary for Alternative C

Item	Quantity	Unit
Clearing and Grubbing	470	acres
Excavation	3,825,000	cy
Fill	599,000	cy
Spoils Disposal*	3,226,000	cy

*Likely to require temporary stockpile areas. Final spoils locations could include abandoned river channel or LFCC and low-lying areas along edge of floodplain.

4.0 Summary, Conclusions, and Next Steps

The lower San Acacia Reach presents opportunities to improve water delivery, ecosystem function, and the benefits of maintenance actions. The river and floodplain within the project area, between RM 74 and 54.5, were confined to the east side of the valley during the 1950s. Channel and floodplain morphology are dynamic and continuously evolving in response to changes in flow, sediment, and base-level. There have been four distinct wet and dry periods since the early 1900s when gage data are available: flows were high through 1949, low from 1950 to 1978, high from 1979 to 1999, and low from 2000 to 2022. Construction of the LFCC and diversions beginning in 1952 also changed the flow characteristics in the river. The LFCC conveyed 68% of total surface flows at San Marcial from 1952 to 1975, 5% during 1976 to 1983, 41% from 1984 to 1985, and 28% during 1986 to 2022. Sediment loads have decreased significantly since Cochiti Dam began impounding water in 1973. Suspended sediment concentrations at the San Marcial floodway gage during the last 40 years are about 30% of the concentrations during 1957 to 1973. Seasonal differences in sediment transport characteristics are also important to the geomorphology and channel evolution. Snowmelt runoff and monsoons have each transported about the same cumulative amount of sediment since 1957, but the monsoon season (July through October) has only conveyed about 20% of the water volume as the snowmelt runoff season (March through June).

The Elephant Butte Reservoir pool controls the bed and floodplain elevation throughout the project area. Channel and delta areas near the reservoir respond quickly to changes in pool elevation while locations farther upstream respond more slowly and at a reduced magnitude.

When the reservoir rises and remains high there is significant deposition that aggrades the channel and floodplain. When the reservoir lowers after being high, the next high flow event causes a headcut to migrate upstream throughout the project area. If the reservoir pool remains low, the channel will remain incised with a stable bed or minor additional erosion.

Top of bank and floodplain elevations increase along with the channel bed during periods of deposition, but the bank and floodplain remain high and do not erode during periods of channel incision. Recent incision has lowered the channel bed to near the valley elevation west of the spoil levee; however, the top of bank and floodplain are 10 to 20 ft above the valley floor. Additionally, upstream of RM 64 the riverbed and water surface are above the LFCC water surface, which causes seepage loss and contributes to river drying. Rio Grande Compact deliveries have been relatively poor since 2011, especially during low-flow years, even though the incised channel efficiently conveys medium to high flows without overbanking. This suggests that within the project area seepage and riparian transpiration are more responsible for water loss in recent years than overbanking flow.

Channelization and construction in the project area during 1951 to 1953 required about 5.5 million cy of excavation and 5,200 acres of vegetation clearing. The reach between the BDA South Boundary and RM 60 had a cumulative 30 million cy of sediment deposition from 1962 to 2012. The long-term and prevailing condition is a depositional environment despite periods of channel incision caused by low reservoir levels. Attaining an equilibrium condition or transporting all sediment delivered from upstream is likely not possible and it is important to manage how sediment is deposited in the project area and extend the functional capacity of Elephant Butte Reservoir. Engineers in the early 1950s expected that the constructed floodway and LFCC would have a lifespan of about 10 years before sedimentation would require relocating the features to the west. Now, 70 years later, this report develops feasibility-level alternatives to realign the river west of the spoil levee (Alternatives B and C) and considers the No Action scenario (Alternative A) to maintain the river and LFCC in their current configuration.

Alternative A would remain the same as conditions during the last 10 to 15 years if the reservoir remains low with similar pool elevations downstream of the Narrows (RM 45). When the reservoir rises, the channel would return to a cycle of aggradation and the bed elevation would increase. Continued high reservoir levels and bed deposition would reconnect the floodplain and overbank flows would deposit sediment on the bed and banks. This condition would continue to pose a high risk to the spoil levee and would likely require levee raising and strengthening to prevent a levee breach. A levee failure in the project area would not likely endanger human life or property but would have significant consequences for water delivery because there would not be a return path to the river channel, and it would take years or decades for a new channel to form without mechanical intervention. Alternative A would require costly and intensive maintenance when the reservoir is high. Maintenance needs would be like the 1990s when there were two sediment plugs and a levee breach in the Tiffany area near RM 72 upstream of San Marcial.

Alternatives B and C would both realign the river to the western valley. The benefits are to reduce seepage loss and river drying by lowering the channel bed and water surface. Eliminating channel perching would reduce stranding of water and improve sediment transport when overbanking occurs. The spoil levee would no longer need to be maintained and there would be a shorter distance of the LFCC to maintain. Alternatives B and C would not prevent future sedimentation, especially when the reservoir pool rises. The banks would eventually become perched after overbanking flow events. The primary advantage of Alternatives B and C is that the river would be allowed to migrate without levee confinement so that sediment deposition could periodically move across the valley. Removing levee confinement would also prevent the active floodplain from being perched above the valley floor.

The most significant difference between Alternatives B and C is the interaction between the LFCC and the river. Alternative B starts 1.5 miles farther upstream than Alternative C and the LFCC flows into the river near RM 73.7. Merging the river and the LFCC would add 100 to 200 cfs to the river discharge assuming recent typical LFCC operating conditions. Alternative B also provides avian habitat opportunities along the western valley between RM 68 and 65. A disadvantage is that Alternative B requires more excavation because it starts further upstream and would allow overbanking flows to contact the Elmendorf Drain levee or the railroad embankment for a short distance near the upstream end of Tiffany Basin.

Alternative C would not affect the LFCC until downstream of the San Marcial Railroad Bridge, where the LFCC would flow into the river near RM 67.3. This would result in lower flows in the upstream river and less potential avian habitat between RM 68 and 65 but would also have less risk to current LFCC operations.

The next steps for the project are to systematically evaluate the alternatives and select a preferred alternative to advance to the 30% design phase. Evaluation will begin with a conceptual geomorphic model that applies the findings of previous geomorphic analyses to the expected performance and evolution of the alternatives. A conceptual model is a qualitative description and often includes sketches or diagrams that illustrate important physical processes. The conceptual geomorphic model for the project alternatives should describe how the planform, profile, and cross sections may evolve under different flow, sediment, and reservoir pool conditions. The conceptual model may infer how future channel and floodplain evolution will affect how the alternative may achieve the project goals. Alternatives evaluation will also include maintenance actions needed to enable project benefits to continue. Potential maintenance actions would be sediment excavation, vegetation clearing, LFCC or spoil levee repairs, and future channel realignments.

The conceptual geomorphic model will also guide the development of new numerical models to quantify the alternatives' performance and response. A two-dimensional (2D) fixed bed model will calculate hydraulics for the existing and design conditions. Results from this model will be used to evaluate inundated area and overbanking, open water evaporation, stranded water, seepage, infrastructure impacts, and RGSM habitat availability. A 1D mobile bed model will estimate future channel and floodplain elevation changes and erosion or deposition volumes over a 50-year period. The model will incorporate several different hydrology storylines to analyze the effects of flow volume and magnitude, climate change, and reservoir pool elevation. Results will be output from the model at approximately decadal increments over the 50-year period to compare the geomorphic response of the alternatives. The 2D and 1D models will quantify various indicators, along with technical interpretation of previous data, to evaluate and compare how well the alternatives meet the project goals of improved water delivery and ecosystem health while increasing the benefit of maintenance actions.

5.0 References

Baird, D.C., J. Sperry, A. Schied, A. Posner, N. Holste, and P. Julien. 2023. Geomorphic evolution model for the Middle Rio Grande. In SEDHYD 2023 Proceedings, May 2023, St. Louis, Missouri. https://www.sedhyd.org

Caldwell, C.A., H. Falco, W. Knight, M. Ulibarri, and W.R. Gould. 2018. Reproductive potential of captive Rio Grande Silvery Minnow. North American Journal of Aquaculture 81(1):47–54.

Chapman, O.L., M.W. Straus, and H.E. Robbins. 1951. Initial Stage Channel Rectification, Middle Rio Grande Project, Rio Grande Basin, New Mexico. U.S. Department of Interior, Bureau of Reclamation, Region 5.

Chapman, O.L., M.W. Straus, and H.E. Robbins. 1952. Definite Plan Report Volume 1A Initial stage Channel Rectification Middle Rio Grande Project Basin New Mexico. U.S. Department of Interior, Bureau of Reclamation, Region 5.

Dudley, R.K., S.P. Platania, and G.C. White. 2022. Rio Grande Silvery Minnow population monitoring during 2021. Report to the U.S. Bureau of Reclamation, Albuquerque, New Mexico.

Dunbar, N.W., D.S. Gutzler, K.S. Pearthree, F.M. Phillips, P.W. Bauer, C.D. Allen, D. DuBois, M.D. Harvey, J.P. King, L.D. McFadden, B.M. Thomson, and A.C. Tillery. 2022. Climate change in New Mexico over the next 50 years: Impacts on water resources. New Mexico Bureau of Geology and Mineral Resources, Bulletin 164, 218 p.

Gahan, A.H. 2013 Middle Rio Grande Project. US Department of Interior, Bureau of Reclamation. 28 p. https://digitalrepository.unm.edu/uc_rio_chama/86

Gorbach, C. 1999. History and Significance of the Low-Flow Conveyance Channel: What is its Future? WRRI Conference Proceedings 1999. 5p

Greimann, B. and N. Holste. 2018. Analysis and Design Recommendations of Rio Grande Width. Technical Report No. SRH-2018-24. Bureau of Reclamation, Technical Service Center, Denver, Colorado.

Happ, S. 1948. Sedimentation in the Middle Rio Grande Valley, New Mexico. Bulletin of the Geological Society of America 59:1191–1216.

Holmes, R. N., A. Meyer, D. S. Gutzler, and L. G. Chavira. 2022. Assessing the effects of climate change on middle Rio Grande surface water supplies using a simple water balance reservoir model. Earth Interactions 26:168-179.

Holste, N., A. Hurst, and C. Byrne. 2023. Side Channel Evolution and Design: Achieving Sustainable Habitat for Aquatic Species Recovery. Bureau of Reclamation, Technical Service Center, Denver, Colorado.

Holste, N., S.D. Moore, and R. Siegle. 2023. Monitoring and Experimental Operations for Proposed Culverts at River Mile 60. Technical Report No. ENV-2023-035. Bureau of Reclamation, Technical Service Center, Denver, Colorado.

Knighton, D. 1998. Fluvial Forms and Processes: A New Perspective. Arnold and Oxford University Press, London, England and New York, New York.

Lagasse, P. 1980. An Assessment of the Response of the Rio Grande to Dam Construction – Cochiti to Isleta Reach. Technical Report for U.S. Army Corps of Engineers, Albuquerque District.

Leopold, L.M., M.G. Wolman, and J.P. Miller. 1964. Fluvial Processes in Geomorphology. W. H. Freeman and Company, San Francisco, California.

Makar, P. and J. AuBuchon. 2012. Channel Conditions and Dynamics of the Middle Rio Grande. Bureau of Reclamation, Technical Service Center and Albuquerque Area Office, Denver, Colorado and Albuquerque, New Mexico.

Massong, T., P. Makar, and T. Bauer. 2010. Planform evolution model for the Middle Rio Grande, NM. Proceedings of the 2nd Joint Federal Interagency Conference on Sedimentation and Hydrologic Modeling. Las Vegas, Nevada.

Moore, D. 2023. 2022 Middle Rio Grande Southwestern Willow Flycatcher Study Results: Selected Sites along the Rio Grande from Bandelier National Monument to Elephant Butte Reservoir, New Mexico. Bureau of Reclamation, Technical Service Center, Denver, Colorado.

Mortensen, J.G., R.K. Dudley, S.P. Platania, and T.F. Turner. 2019. Rio Grande Silvery Minnow biology and habitat syntheses. Report to U.S. Bureau of Reclamation, Albuquerque, New Mexico.

Mortensen, J.G., R.K. Dudley, S.P. Platania, G.C. White, T.F. Turner, P.Y. Julien, S. Doidge, T. Beckwith, A. Schied, and J. Sperry. 2023. Linking Morpho-Dynamics and Bio-Habitat Conditions on the Middle Rio Grande: Process-Linkage Report II – San Acacia Reach Analyses. American Southwest Ichthyological Researchers, L.L.C., Division of Fishes, Museum of Southwestern Biology, University of New Mexico, and Colorado State University Cooperative Agreement R17AC00064 Final Report to Bureau of Reclamation.

National Resources Committee. 1938. Regional Planning, Part IV: The Rio Grande Joint Investigation in the upper Rio Grande Basin in Colorado, New Mexico, and Texas, 1936–1937. U.S. Government Printing Office, Washington, D.C.

Nelson, J., L. Holmes, and E. Eckmann. 1914. Soil Survey of the Middle Rio Grande Valley Area, New Mexico. U.S. Department of Agriculture, Bureau of Soils, Washington, D.C.

Phillips, J. 2010. The job of the river. Earth Surface Processes and Landforms 35:305–313. doi:10.1002/esp.1915

Platania, S.P. and C.S. Altenbach. 1998. Reproductive strategies and egg types of seven Rio Grande Basin Cyprinids. Copeia 1998(3):559–569.

Randle, T. and V. Benoit. 2019. Elephant Butte Reservoir 2017 and 2019 Sedimentation Survey. Technical Report No. ENV-2020-019. Bureau of Reclamation, Technical Service Center, Denver, Colorado.

Reclamation. 1951. Middle Rio Grande Project Albuquerque New Mexico Volume I Annual Project History. U.S. Department of Interior, Bureau of Reclamation.

Reclamation. 1952. Middle Rio Grande Project Albuquerque New Mexico Volume I Annual Project History. U.S. Department of Interior, Bureau of Reclamation.

Reclamation. 1953. Middle Rio Grande Project Albuquerque New Mexico Volume I Annual Project History. U.S. Department of Interior, Bureau of Reclamation.

Reclamation. 1961. Sediment Studies for Channelization of the Rio Grande between Cochiti and Mouth of Rio Puerco, New Mexico. Bureau of Reclamation, Albuquerque Project Office, Albuquerque, New Mexico.

Reclamation. 2002. Rio Grande Channelization Historical Operations & Maintenance Records 1957–2002. U.S. Department of Interior, Bureau of Reclamation.

Reiser, D.W., and P.J. Hilgert. 2018. A practitioner's perspective on the continuing technical merits of PHABSIM. Fisheries 43(6):278–283.

Schied, A., J. Sperry, and P. Julien. 2022. Middle Rio Grande Bosque del Apache Reach Report: Morpho-dynamic Processes and Silvery Minnow Habitat from US-380 Bridge to the Southern Boundary of Bosque del Apache National Wildlife Refuge. Report to U.S. Bureau of Reclamation, Albuquerque, New Mexico.

Scurlock, D. 1998. From the Rio to the Sierra: An Environmental History of the Middle Rio Grande Basin. General Technical Report RMRS-GTR-5. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, Colorado.

Siegle, R. and D. Moore. 2022. Southwestern Willow Flycatcher Breeding Habitat Suitability 2021; Middle Rio Grande, New Mexico. Technical Service Center Report Number ENV-2022-050. U. S. Department of the Interior, Bureau of Reclamation, Denver, Colorado.

Siegle, R., D. Moore, and K. Dillon. 2022. Western Yellow-billed Cuckoo Habitat Suitability; Middle Rio Grande, New Mexico. Technical Service Center Report Number ENV-2022-058. U. S. Department of the Interior, Bureau of Reclamation, Denver, Colorado.

Sperry, J., A. Schied, and P. Julien. 2022. Middle Rio Grande Elephant Butte Reach Report: Morpho-dynamic Processes and Silvery Minnow Habitat from the Southern Boundary of Bosque del Apache National Wildlife Refuge to the Elephant Butte Reservoir. Report to U.S. Bureau of Reclamation, Albuquerque, New Mexico.

S.S. Papadopulos & Associates, Inc. 2000. Middle Rio Grande Water Supply Study, Contract No. DACW47-99-C-0012 Report. Boulder, CO.

Swanson, B., G. Meyer, and J. Coonrod. 2011. Historical channel narrowing along the Rio Grande near Albuquerque, New Mexico in response to peak discharge reductions and engineering: magnitude and uncertainty of change from air photo measurements. Earth Surface Processes and Landforms 36:885–900. doi:10.1002/esp.2119

Varyu, D. 2013a. 2012 Cross-Section Geometry Generation and Validation. Technical Report No. SRH-2013-21. Bureau of Reclamation, Technical Service Center, Denver, Colorado.

Varyu, D. 2013b. Aggradation / Degradation Volume Calculations: 2002–2012. Technical Report No. SRH-2013-28. Bureau of Reclamation, Technical Service Center, Denver, Colorado.

Worthington, T.A., A.A. Echelle, J.S. Perkin, R. Mollenhauer, N. Farless, J.J. Dyer, D. Logue, and S.K. Brewer. 2018. The emblematic minnows of the North American Great Plains: A synthesis of threats and conservation opportunities. Fish and Fisheries 19(2):271–307.

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