River Mechanics Guest Lecture

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RECLAMATION

Googled to find Dr. Pierre Julien’s Web site

Found out he has talents he doesn’t advertise

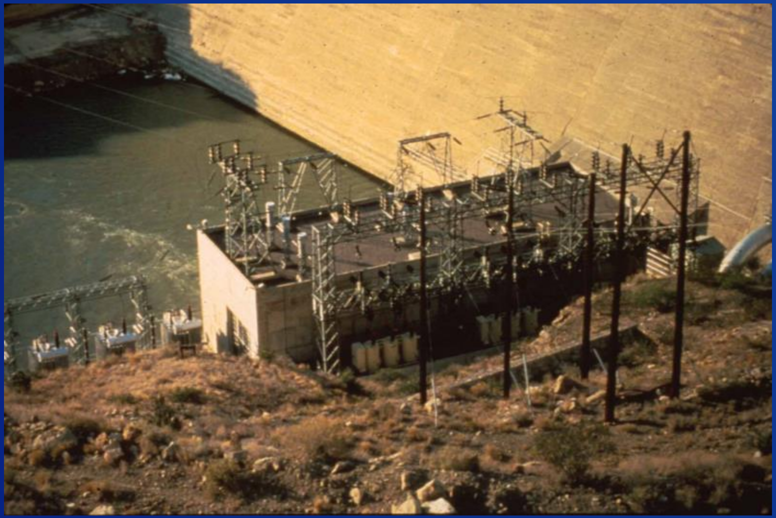
Pierre Julien-Moonlight French Sculptor (alter ego)

Acknowledgements

Anita Wood, Jan Oliver, Carolyn Donnelly, Cheryl Rolland, Viola Sanchez, Suzanne Devergie, Karl Martin, Steven Gonzales, Ron Ferrari, Kent Collins, David Varyu, Blair Greiman, Nathan Holste Tetra Tech EMI, Paula Makar, and Chris Gorbach, Dr. Pierre Julien and many CSU graduate students provided photographs and technical information for this presentation.

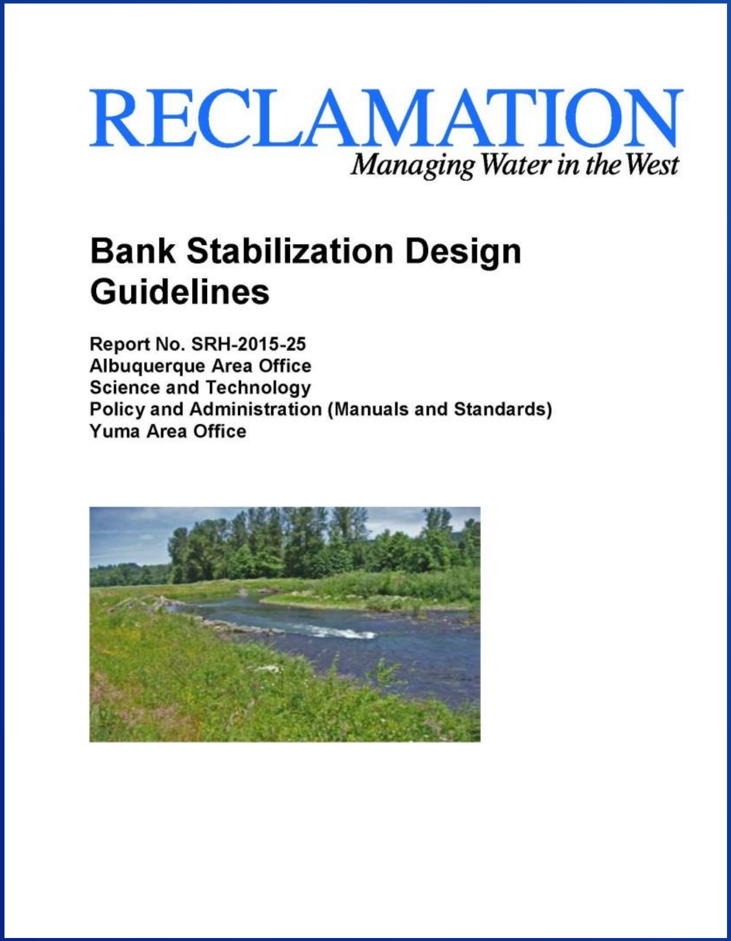
Material was also assembled from the Bosque Biological Management Plan, an Engineer Advisors Report 2-2009, AAO BDANWR Presentation 5-2008, SOBTF Presentation in 3-2006, and a USBR Regional Briefing 6-2005, and the Biological Assessment Baseline Geomorphology report by Makar.

WATER RESOURCES MANAGEMENT.....FOR THE FUTURE



- Provide wholesale water for ~40 million people
- Irrigate ~60% of fresh fruits and vegetables in the US
- 53 hydropower plants produce 40 billion kilowatt hours generating nearly a 1 billion dollar/yr. in power revenues

RECLAMATION



RECLAMATION

Managing Water in the West

Bank Stabilization Design Guidelines

Report No. SRH-2015-25
Albuquerque Area Office
Science and Technology
Policy and Administration (Manuals and Standards)
Yuma Area Office

Authors

- Drew Baird
- Lisa Fotherby
- Cassie Klumpp
- S. Michael Scurlock

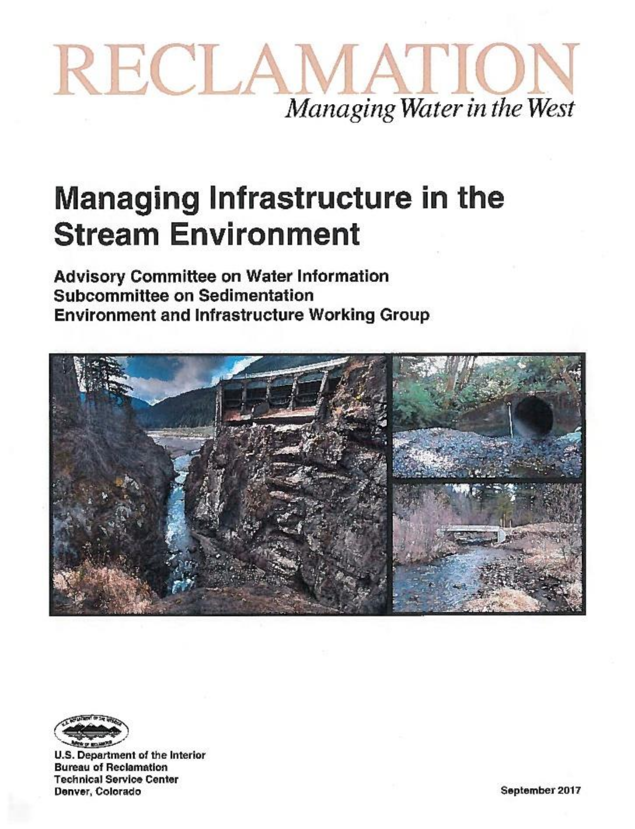
Bank Stabilization Design Guidelines

- Preliminary Investigations and Method Selection
  - Project Requirements and General Assessment
  - The Role of Geomorphology in River Projects
  - Hydraulic Assessment of Energy, River Form, and Shear Forces
  - Scour Assessment
  - Selecting a Bank Stabilization Method

Bank Stabilization Design Guidelines

- Design and Construction
  - Preserving the Floodplain
  - Re-establishing the Floodplain
  - Design of Vegetated, Deformable Bank Lines
  - Design of Wood and Boulders
  - Channel Relocation/Construction
  - Transverse or Indirect Methods
  - Hardened Banks
  - Future Directions

Managing Infrastructure in the Stream Environment



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Managing Water in the West

Managing Infrastructure in the Stream Environment

Advisory Committee on Water Information
Subcommittee on Sedimentation
Environment and Infrastructure Working Group

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

September 2017

JAWRA
JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION
AMERICAN WATER RESOURCES ASSOCIATION

Managing Infrastructure in the Stream Environment

Joel S. Sholtes, Caroline Ubing, Timothy J. Randle, Jon Fripp, Daniel Cenderelli, and Drew C. Baird

Research Impact Statement: We present a framework for infrastructure designers and managers to build and manage riverine infrastructure in a manner that is both resilient to hazards and more compatible with stream ecosystems.

ABSTRACT: Riverine infrastructure provides essential services for the operation and development of the world's nations and their economies. When much of this infrastructure was built in the United States, fluvial processes and stream ecology were not well understood, putting it in conflict with and at risk from the stream environment. High maintenance costs are often required to keep such infrastructure viable and some of it has led to the degradation of aquatic and riparian ecosystems. This commentary paper lays the foundation for infrastructure designers and managers to build and manage infrastructure in a manner both resilient to riverine hazards and more compatible with aquatic and riparian ecosystem needs. We introduce fundamental fluvial geomorphic and ecosystem concepts and provide a decision-making framework to replace or repair existing infrastructure or build new infrastructure. Common management challenges associated with 11 riverine infrastructure types are discussed and we provide suggestions on how each infrastructure type can be better built and managed within stream corridors. We close with a discussion on managing infrastructure under future hydrologic uncertainty and in response to natural disasters.

(KEYWORDS: rivers; aquatic ecology; riparian zone, sustainability; resiliency; restoration; floods; natural hazards.)

INTRODUCTION

Government agencies, along with private citizens, have worked to construct and manage a vast network of infrastructure within stream corridors. This riverine infrastructure and associated activities includes channel and floodplain works (channelization, large wood management, and floodplain encroachment), streamside infrastructure (roads, pipelines, levees, streambank protection), and stream crossing infrastructure (bridges and culverts, pipelines, grade control structures, dams, reservoirs, and surface water diversion structures). We define riverine infrastructure broadly herein to include a spectrum of human activities in the stream corridor that fall under the umbrella of public works, stream engineering, and stream management. Riverine infrastructure provides vital services but is frequently detrimental to stream ecosystems and can pose a liability in terms of public safety and maintenance costs (Doyle et al. 2003; Nilsson et al. 2005; TRB and NRC 2005).

A large proportion of the infrastructure in the United States (U.S.) was built in the early and middle 20th Century and is nearing the end of its

Paper No. JAWRA-17-0164-C of the *Journal of the American Water Resources Association* (JAWRA). Received December 15, 2017; accepted September 11, 2018. © 2018 American Water Resources Association. This article is a U.S. Government work and is in the public domain in the USA. **Discussions are open until six months from issue publication.**

Sedimentation and River Hydraulics Group (Sholtes, Ubing, Randle, Baird), Bureau of Reclamation, Denver, Colorado, USA; National Design, Construction, and Soil Mechanics Center (Fripp), Natural Resources Conservation Service, Fort Worth, Texas, USA; and National Stream and Aquatic Ecology Center (Cenderelli), U.S. Forest Service, Fort Collins, Colorado, USA (Correspondence to Sholtes: jsholtes@gmail.com).

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Managing Infrastructure in the Stream Environment, Journal of American Water Resources Association, Sept. 2018, by Sholtes, J.S., Ubing, C., Randle, T.J., Fripp, J., Cenderelli, D., and Baird, D.C.

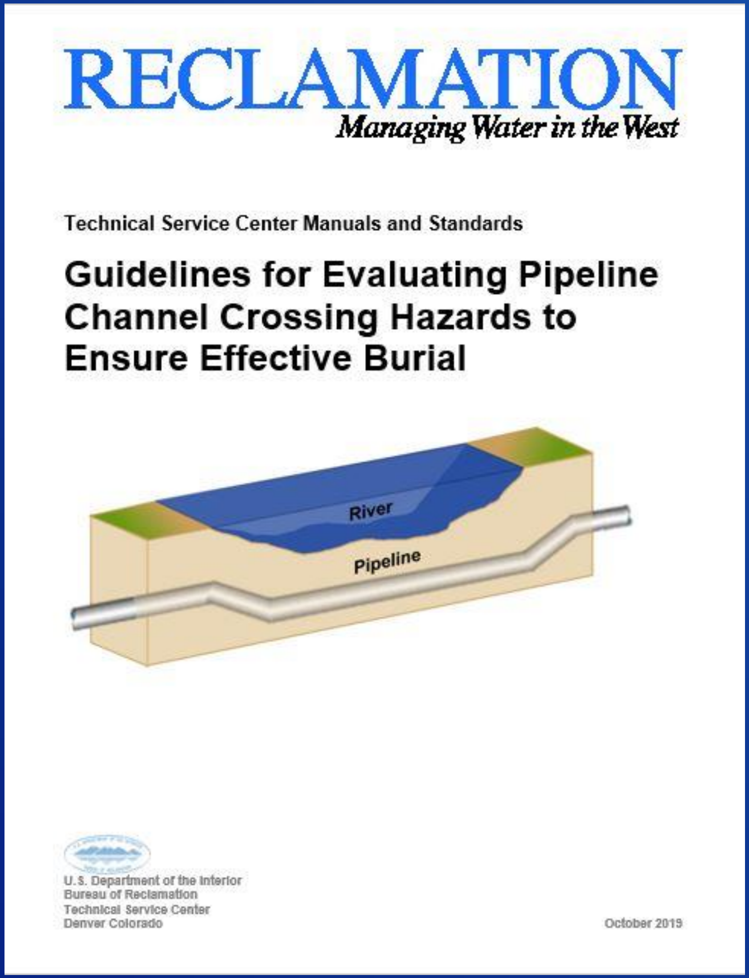
Managing Infrastructure in the Stream Environment

- Much infrastructure build before fluvial processes and stream ecology were well understood
- Thus in many cases existing infrastructure is in conflict with the stream environment or at risk from it.
- This report lays foundation to build, maintain, or decommission infrastructure in a manner that is resilient to floods and channel migration.
- Introduce geomorphic and ecosystem concepts and provides recommendations for replacing, repairing, or building new infrastructure
- 4 stages discussed
  - Identifying project goals, scope and constraints
  - Evaluating hazards and values of the project
  - Formulating alternatives
  - Evaluating alternative for decision-making process and implementation of the project

Managing Infrastructure in the Stream Environment

- 11 types of riverine infrastructure and management issues discussed:
  - floodplain encroachment (general development in the floodplain)
  - large wood management
  - pipelines
  - levees and dikes
  - streambank protection
  - stormwater infrastructure
  - channelized rivers
  - grade control structures
  - transportation infrastructure
  - dams and reservoirs
  - surface water diversions

Evaluating Pipeline Channel Crossing Hazards to Ensure Effective Burial



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Managing Water in the West

Technical Service Center Manuals and Standards

Guidelines for Evaluating Pipeline Channel Crossing Hazards to Ensure Effective Burial

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver Colorado

October 2019

- **Authors:**
  - Drew Baird
  - Michael Sixta
  - Melissa Foster
  - Keil Neff

Evaluating Pipeline Channel Crossing Hazards to Ensure Effective Burial

- Office-Based Analysis of potential crossing sites
- Field investigation
- Hydrologic Analysis
  - Statistical Approaches
  - Rainfall-Runoff Modeling
- Hydraulic Analysis
  - At a station, 1-D HEC-RAS, 2-D
  - SRH-2D or HEC-RAS2D
- Degradation and Scour Analysis
  - Field evidence
  - General Scour
  - Bend Scour
  - Bedform Scour
  - Culvert Scour

Evaluating Pipeline Channel Crossing Hazards to Ensure Effective Burial

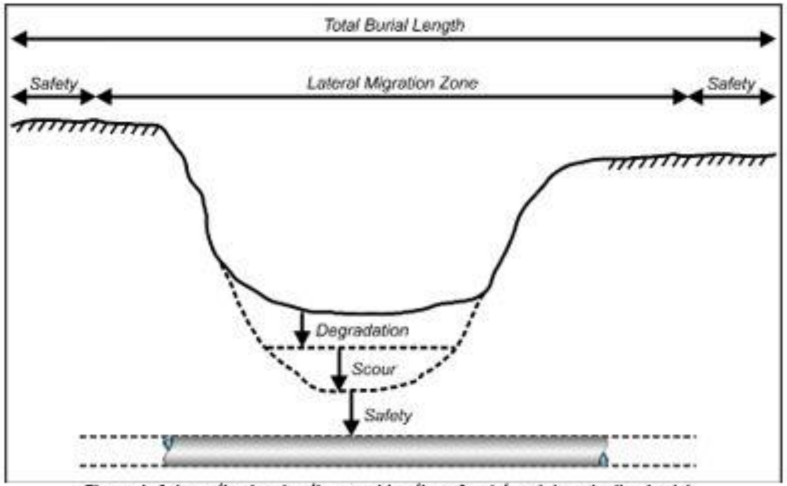


Figure 4. Schematic showing the considerations for determining pipeline burial depth.

$$Z_{event} = MAX(Z_{general}, Z_{bend}) + Z_{bedform}$$

$$Z_{total} = (Z_{event} + Z_{degradation})SF$$

$$L_{total} = L_{top\,width} + L_{movement} + SF$$

Scour SF 1.1 to 1.5
Lateral Migration SF 25-100 ft.

Geomorphic and Hydrologic

Western New Mexico

Channel Incision

- Washes actively incising
- Likely to continue
- Bed Lowering
- Potential Pipe Exposures
- Unsupported pipe suspension across wash

Apparent 5-8 ft. bed lowering,
Failed Gabion Basket

Geomorphic and Hydrologic Hazards

Headcuts

Head cut generated by subsurface flow

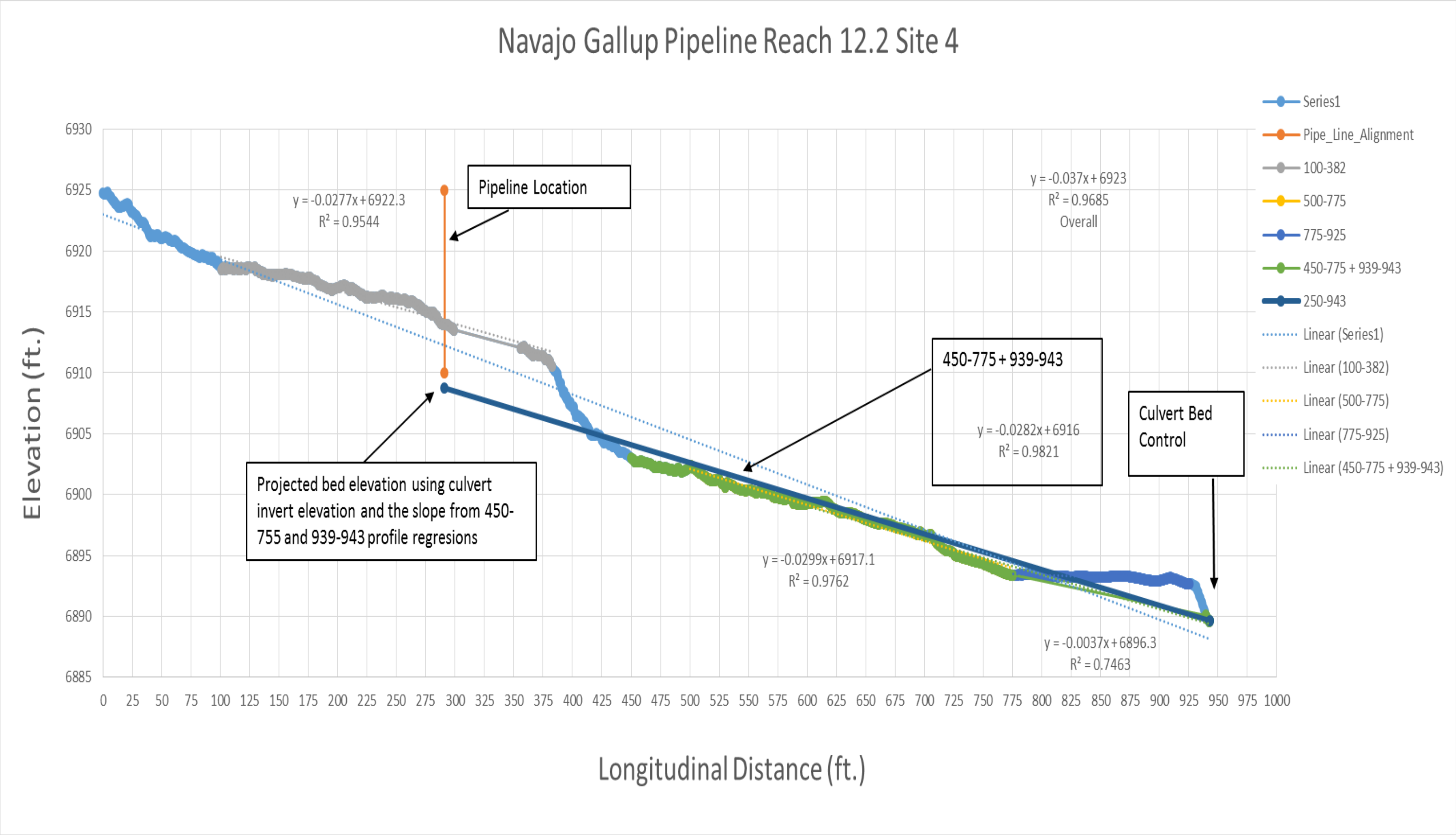
25 to 30 ft. deep head cut.
Pipeline about 75 ft away.

Geomorphic and Hydrologic Hazards

Down valley migration

- Upper bank material collapsed and deposited at the toe.
- Next large enough flow event transports material eroding toe
- Bank fails along vertical planes…apparent coehesion.

Degradation Estimate



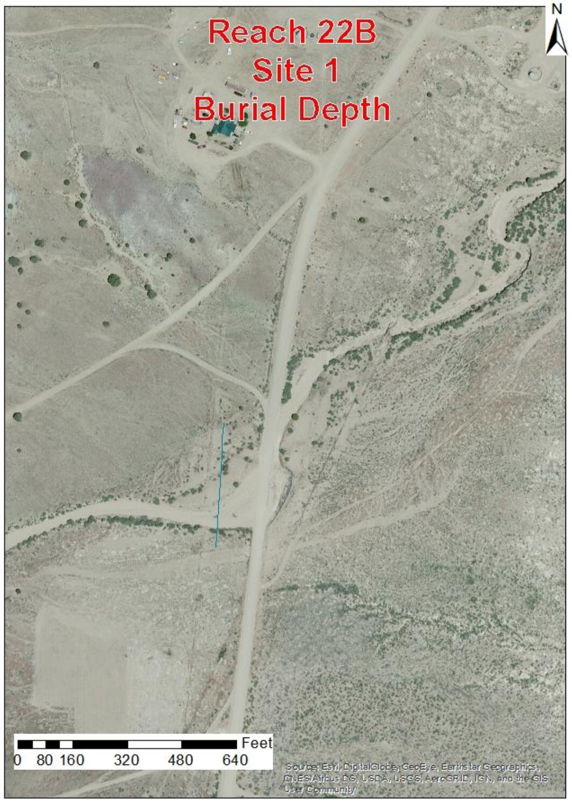
Pipeline Location

Projected bed elevation using culvert invert elevation and the slope from 450-755 and 939-943 profile regresions

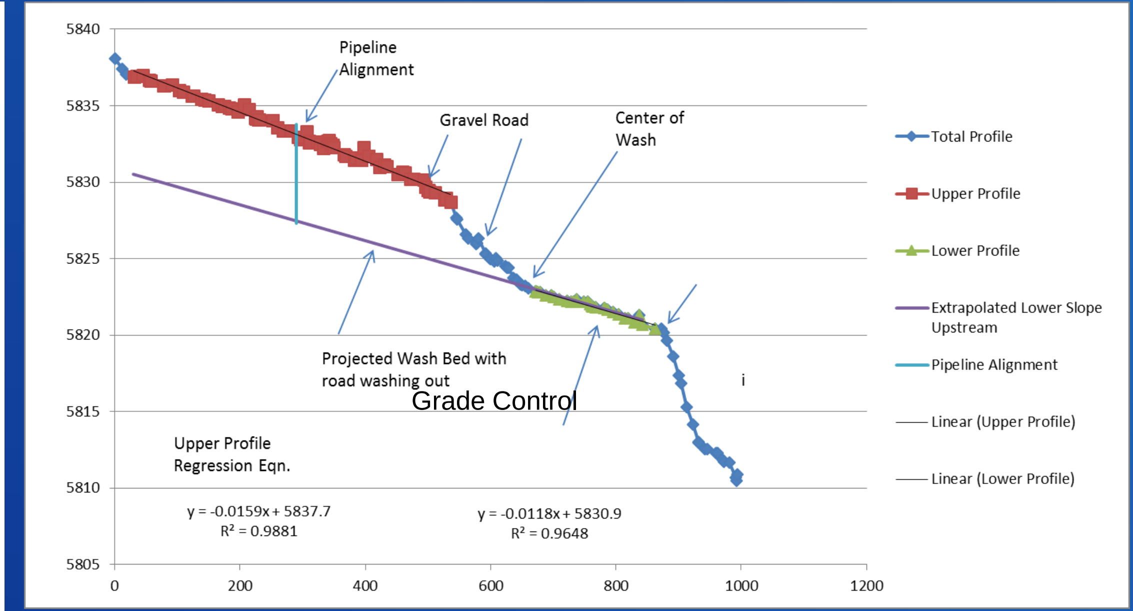
450-775 + 939-943

Culvert Bed Control

Navajo Gallup Reach 22B Site 1



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community



River Processes

- Geology
- Geomorphology
  - Dynamic Equilibrium
  - Relationship between flows and sediment transport supply and sediment transport capacity
    - Aggradation
    - Degradation
    - Particle Stability
    - Stable Slope Calculation
  - Base level changes

River Processes

- Dynamic Equilibrium
  - Balance between sediment transport capacity and sediment supply.
    - Cross section geometry and lateral location may change locally but the volume of sediment removal and the volume of deposition are nearly equal
  - Sediment transport capacity dependent upon slope, grain size, geometry, and hydrology.
  - Sediment supply dependent upon geology, upstream channel conditions, tributary input of sediment
  - More sediment supply than transport capacity leads to aggradation
  - Less sediment supply than transport capacity leads to degradation

River Processes

- Aggradation
  - Increased downstream bed slope
  - Decreased upstream bed slope
  - Reduced bank height
  - Potentially lower bank full flow capacity
  - Bed fining
  - Increased width
  - Tendency to decrease channel length
  - Potentially greater floodplain connectivity

River Processes

- Degradation
  - Decreased downstream slope
  - Increased upstream slope if local
  - Increased bank height
  - Bed coarsening
  - Potentially higher bank full flow capacity
  - Tendency to increase channel length
  - Potential for decreased floodplain connectivity

River Processes

- Base Level Changes
  - Reservoir or Diversion Structure
  - Channel incision downstream of Confluence
  - Effect can be Aggradation or Degradation
- Urbanization
  - Increased runoff
  - Same or lower washload supply
- Incised channels
  - Reduced sediment supply
  - Increased runoff from Urban development
  - Channel straightening

River Engineering/Restoration

- Develop hypothesis, channel processes, effects on resources and constraints
- Develop work plans to test hypothesis.
- Example hypothesis
  - Client: Erosion problems in the form of mass wasting causing deteriorated channel condition.
  - Questions:
    - What is the location of mass wasting in the water shed relative to causative factors such as base level changes, fire, human effects such as roads, railroads, bridges, land clearing, agricultural uses, or past channel straightening

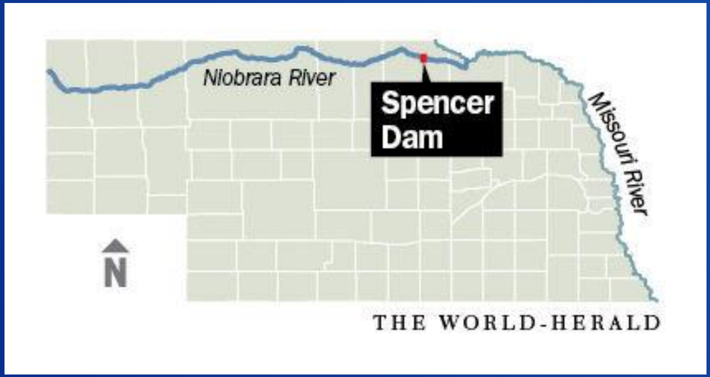
River Engineering/Restoration

- Questions continued:
  - What is the definition of “deteriorated channel condition”? Finer grained sediment fill active gravel deposits and preventing spawning, reduced channel capacity, or increase lateral migration into riverside infrastructure?
- What are client interest and goals

River Engineering/Restoration

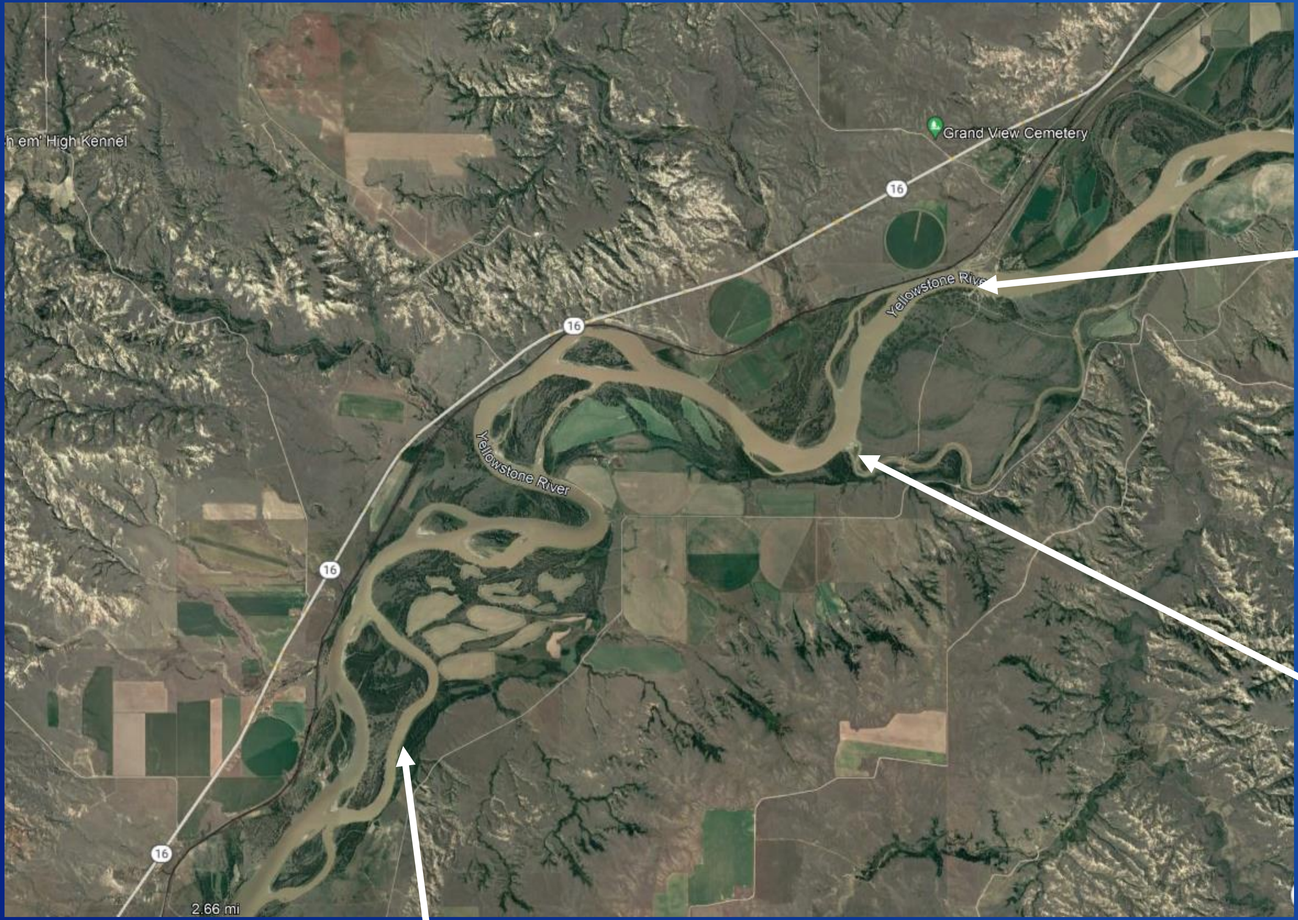
- Review aerial photographs, geology maps, topographic maps, hydrologic records, and interview local residents.
- Determine field reconnaissance plan to answer questions and develop hypothesis
- Field reconnaissance/evaluation
- Refined hypothesis
- Action plan to test hypothesis and answer study analysis questions

Mar. 14, 2019 Nebraska (rain, bomb cyclone, melting snow, ice jams)



Current events, road failure due to flooding Nebraska, and Apron Repair San Acacia Diversion Dam, NM

Lower Yellowstone Fish Bypass Channel Site Visit. Post Ice Jam Breach March, 2022



Intake Diversion Dam

Fish bypass flow inlet and upstream fish outlet

Left Channel (looking downstream) covered with ice

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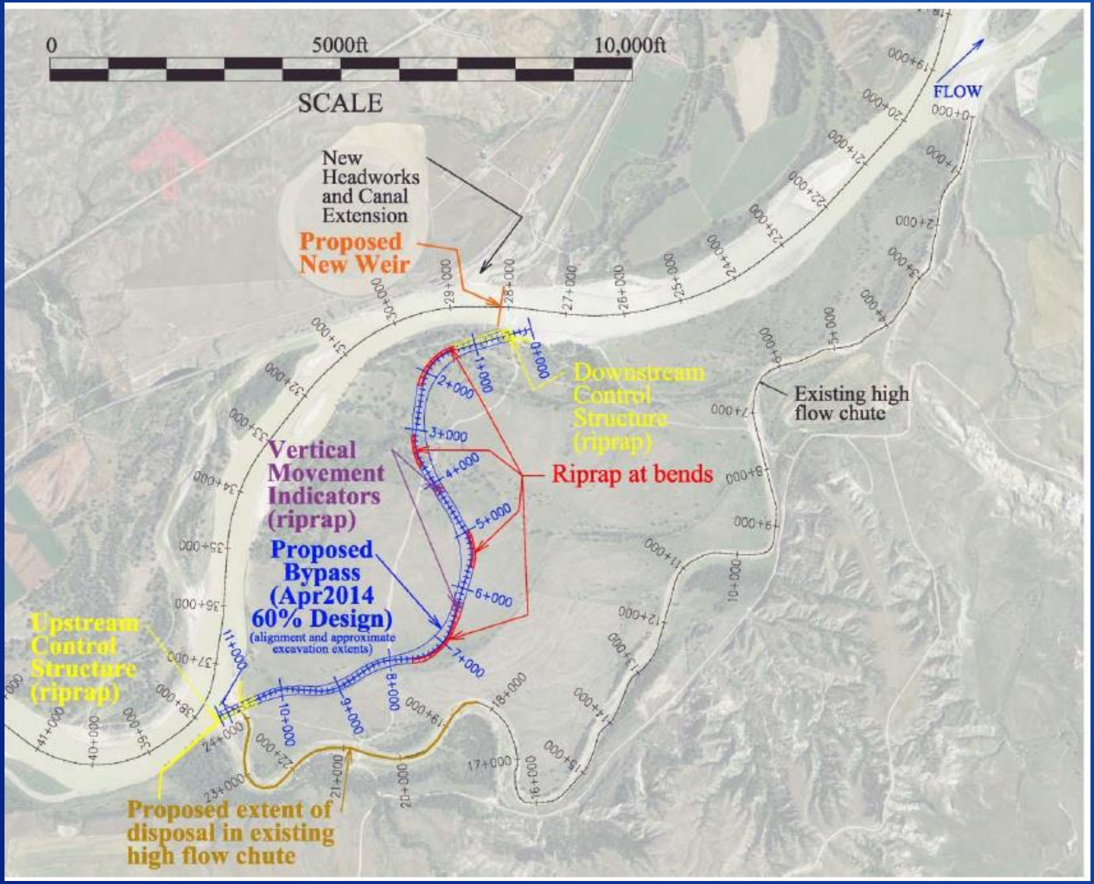
Lower Yellowstone Diversion Dam Fish Bypass



- Flow Frequency
  - 2 yr. 54,000 cfs
  - 10 yr. 87,600 cfs
  - 50 yr. 116,200 cfs
  - 100 yr. 128,300 cfs

Ice Jam and Cofferdam Breach

Flow surge in the fish bypass channel damaged and relocated contractor's pump

- Discovered by contractor employee who was intending to re-fuel this pump.
- Ice jam and cofferdam breach caused a flow surge with velocities potentially exceeding design flow velocity.

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Fish Inlet (water outlet)

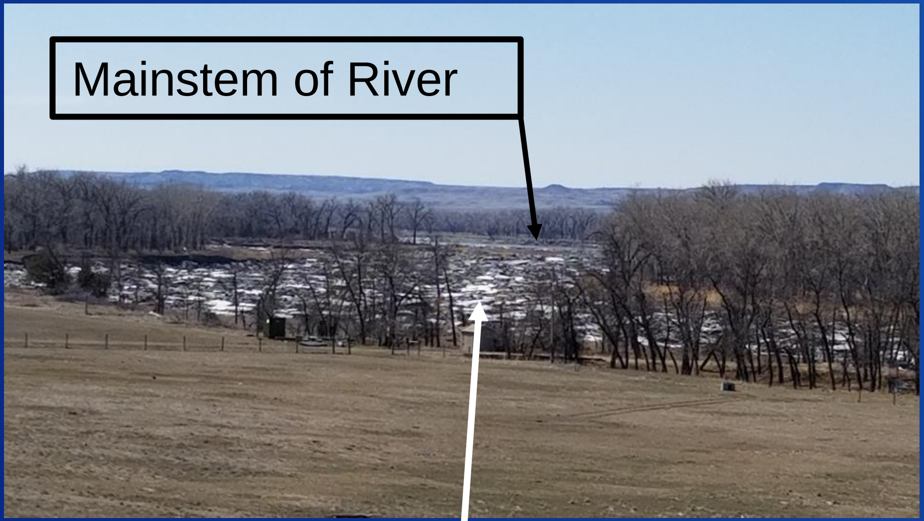
- Repair or bank erosion recommended
- Should bank line erosion continue would potentially change entrance angle. Designed based on nearby river characteristics
- Re-slope back to design and protect with riprap

Bend not protected with riprap

Continued erosion would potentially result in deep pool on outside of bend with larger flow velocity and shallow depths on inside of bend. Should extensive erosion occur the access road may need to be relocated.

Riprap bank protection is recommended with placement being on the existing eroded bank to provide some variable depth and velocity conditions.

Rational for Repairs and Hydraulic Analysis Recommendation



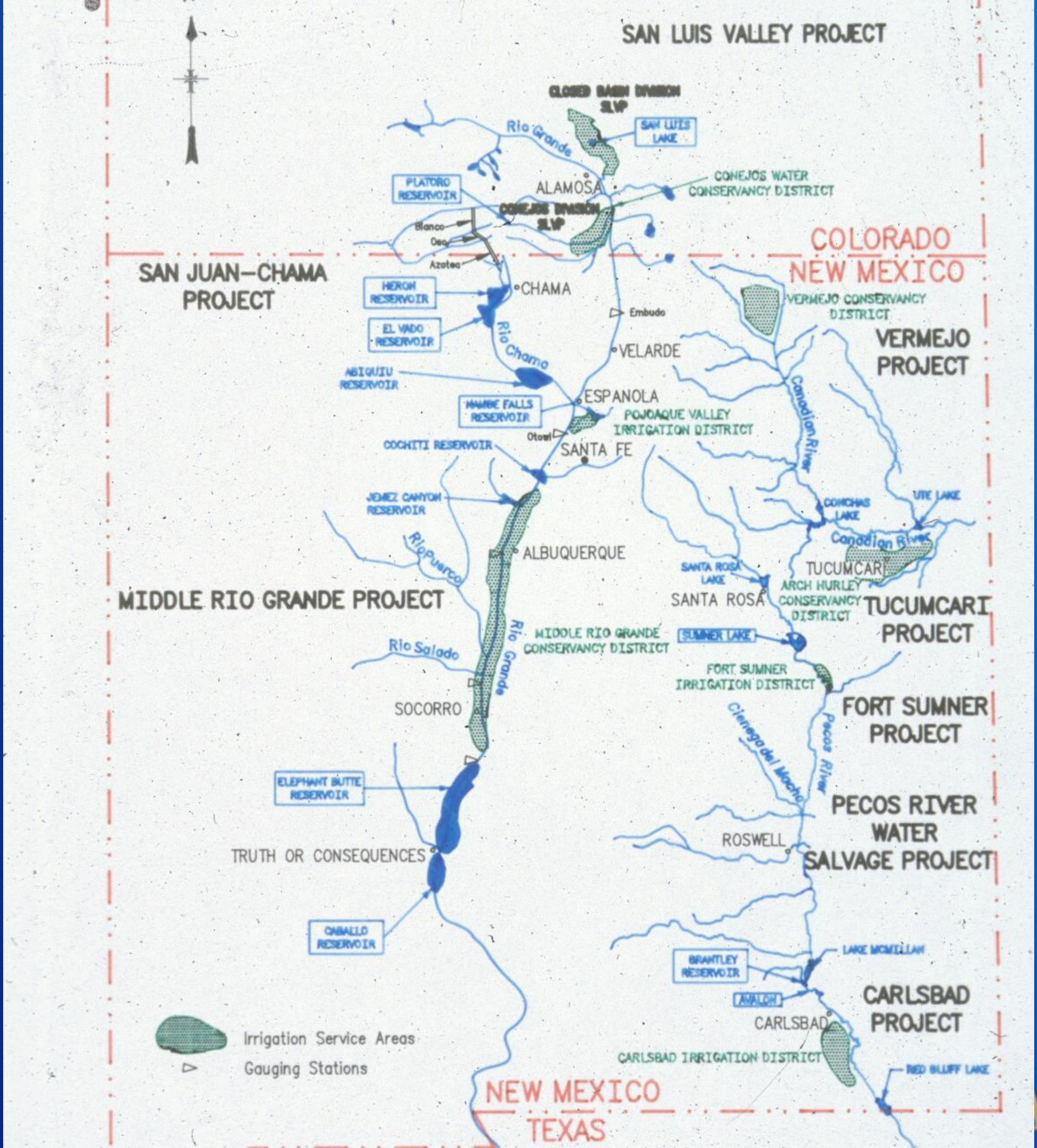
Mainstem of River

Ice completely covering secondary channel water surface, 3-30-2022. Upstream of Intake Diversion Dam

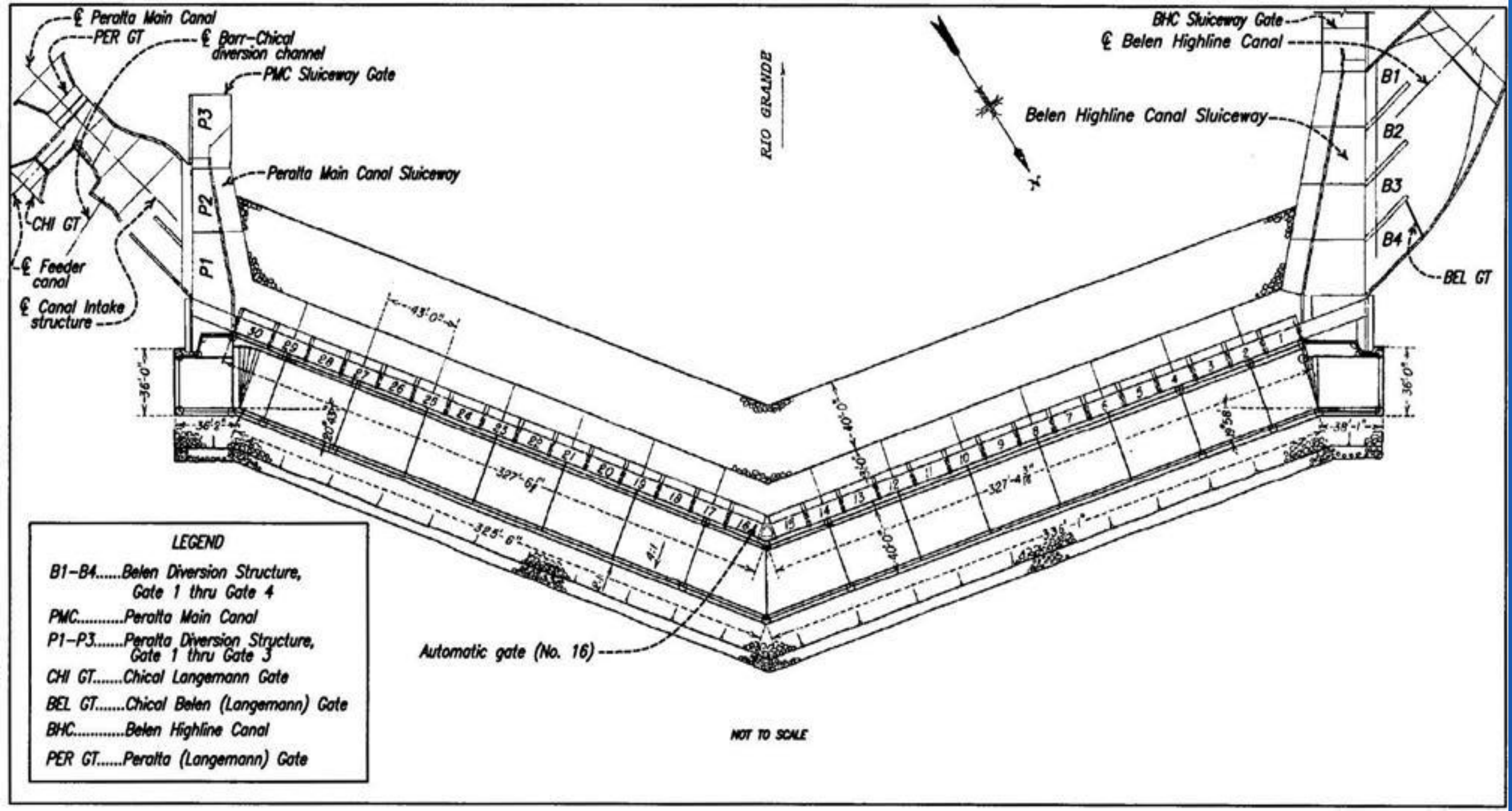
- Future ice jams could occur in the future that could continue erosion at these three sites.
- Mar 17, 2014, ice in past secondary did not result in erosion
- Appears that the critical hydraulic design case could be a smaller ice jam breach flow surges (when Joe's island is not inundated)
- We recommend this condition be hydraulically modeled to evaluate potential impacts and repairs from future surges using this event to evaluate
- Survey high water marks to calibrate HEC-RAS model to determine this surge's discharge

Repairs made 2 weeks later

Isleta Diversion Dam


SAN LUIS VALLEY PROJECT
CLOSED BASIN DIVISION SLVP
SAN LUIS LAKE
Rio Grande
PLATORO RESERVOIR
ALAMOSA
CONEJOS WATER CONSERVANCY DISTRICT
CONEJOS DIVISION SLVP
Blanco
Oso
Azotea
COLORADO
NEW MEXICO
SAN JUAN–CHAMA PROJECT
HERON RESERVOIR
CHAMA
EL VADO RESERVOIR
Embudo
VERMEJO CONSERVANCY DISTRICT
VERMEJO PROJECT
Rio Chama
VELARDE
ABIQUIU RESERVOIR
ESPANOLA
NAMBE FALLS RESERVOIR
POJOAQUE VALLEY IRRIGATION DISTRICT
Otowi
SANTA FE
COCHITI RESERVOIR
Canadian River
JEMEZ CANYON RESERVOIR
CONCHAS LAKE
UTE LAKE
Canadian River
Rio Puerco
ALBUQUERQUE
SANTA ROSA LAKE
TUCUMCARI
MIDDLE RIO GRANDE PROJECT
SANTA ROSA
ARCH HURLEY CONSERVANCY DISTRICT
TUCUMCARI PROJECT
Rio Grande
MIDDLE RIO GRANDE CONSERVANCY DISTRICT
SUMNER LAKE
Rio Salado
FORT SUMNER IRRIGATION DISTRICT
SOCORRO
FORT SUMNER PROJECT
Cienega del Macho
Pecos River
ELEPHANT BUTTE RESERVOIR
PECOS RIVER WATER SALVAGE PROJECT
ROSWELL
TRUTH OR CONSEQUENCES
CABALLO RESERVOIR
LAKE McMILLAN
BRANTLEY RESERVOIR
AVALON
CARLSBAD PROJECT
CARLSBAD
Irrigation Service Areas
Gauging Stations
CARLSBAD IRRIGATION DISTRICT
RED BLUFF LAKE
NEW MEXICO
TEXAS

Isleta Diversion Dam

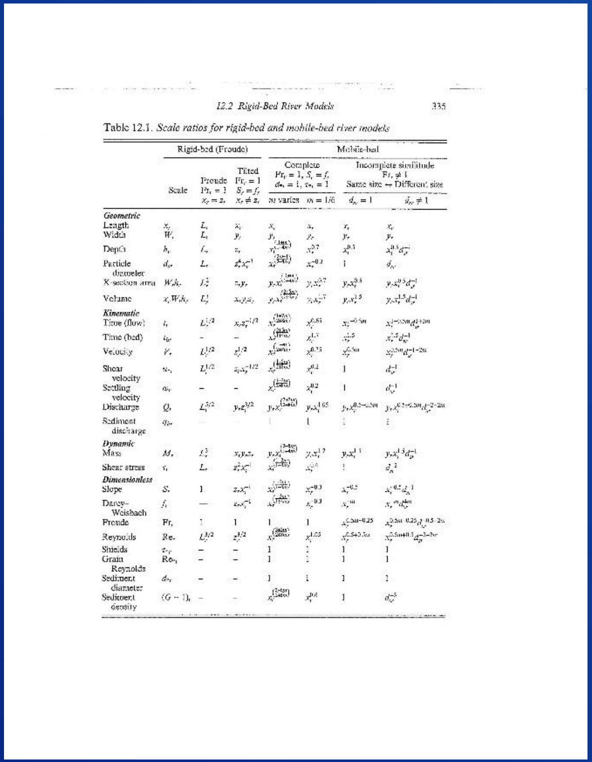


Conceptual Sediment Management Framework for East Sluiceway Modifications

1. Align flow approaching sluiceway
2. Reduce turbulence of flow entering the sluiceway
3. Increase transport of sediment through the sluiceway
4. Minimize frequency and duration of sluicing operations
5. Reduce sediment diverted into the canals
6. Minimize persistent reductions in diversion flow capacity
7. Better manage sediment that continues to enter the canals
8. Adaptively manage gate operations

Photo by Tetra Tech 2019
2019 MRGCD Spent in excess of $1.2 M on sediment removal

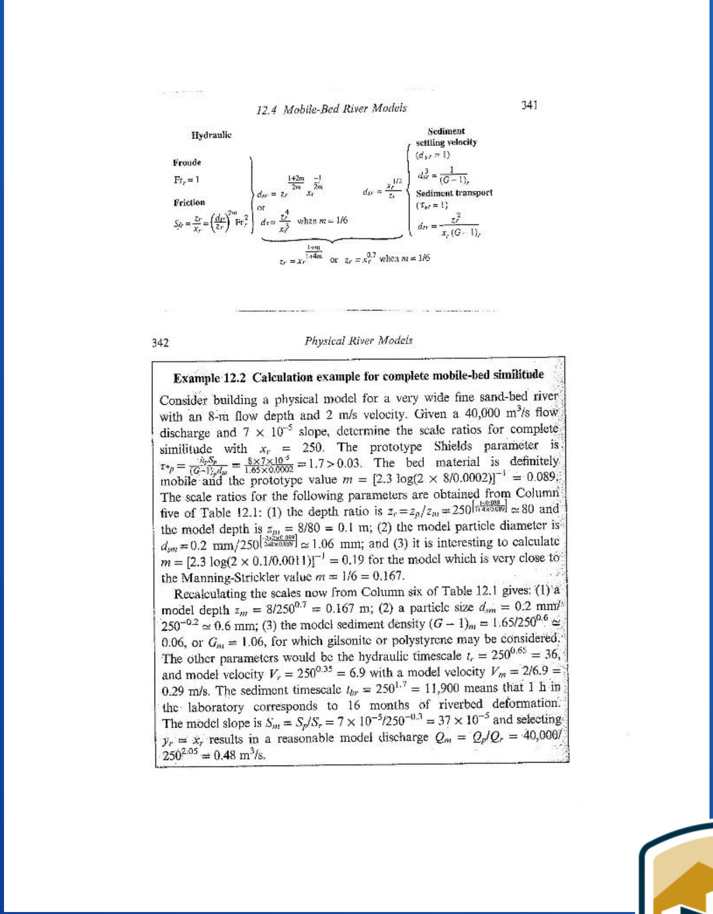
Mobile bed and suspended sediment physical modeling



12.2 *Rigid-Bed River Models* 335

Table 12.1. *Scale ratios for rigid-bed and mobile-bed river models*

	Rigid-bed (Froude)			Mobile-bed			
				Complete $Fr_r = 1, S_r = f_r$, $d_{*r} = 1, \tau_{*r} = 1$		Incomplete similitude $Fr_r \neq 1$ Same size ↔ Different size	
	Scale	Froude $Fr_r = 1$ $x_r = z_r$	Tilted $Fr_r = 1$ $S_r = f_r$ $x_r \neq z_r$	m varies	$m = 1/6$	$d_{sr} = 1$	$d_{sr} \neq 1$
Geometric							
Length	x_r	L_r	x_r	x_r	x_r	x_r	x_r
Width	W_r	L_r	y_r	y_r	y_r	y_r	y_r
Depth	h_r	L_r	z_r	$x_r^{\left(\frac{1+m}{1+4m}\right)}$	$x_r^{0.7}$	$x_r^{0.5}$	$x_r^{0.5}d_{sr}^{-1}$
Particle diameter	d_{sr}	L_r	$z_r^2x_r^{-1}$	$x_r^{\left(\frac{2m-1}{2+8m}\right)}$	$x_r^{-0.2}$	1	d_{sr}
X-section area	W_rh_r	L_r^2	z_ry_r	$y_rx_r^{\left(\frac{1+m}{1+4m}\right)}$	$y_rx_r^{0.7}$	$y_rx_r^{0.5}$	$y_rx_r^{0.5}d_{sr}^{-1}$
Volume	$x_rW_rh_r$	L_r^3	$x_ry_rz_r$	$y_rx_r^{\left(\frac{2+5m}{1+4m}\right)}$	$y_rx_r^{1.7}$	$y_rx_r^{1.5}$	$y_rx_r^{1.5}d_{sr}^{-1}$
Kinematic							
Time (flow)	t_r	$L_r^{1/2}$	$x_rz_r^{-1/2}$	$x_r^{\left(\frac{1+7m}{2+8m}\right)}$	$x_r^{0.65}$	$x_r^{1-0.5m}$	$x_r^{1-0.5m}d_{sr}^{1+2m}$
Time (bed)	t_{br}	–	–	$x_r^{\left(\frac{2+5m}{1+4m}\right)}$	$x_r^{1.7}$	$x_r^{1.5}$	$x_r^{1.5}d_{sr}^{-1}$
Velocity	V_r	$L_r^{1/2}$	$z_r^{1/2}$	$x_r^{\left(\frac{1+m}{2+8m}\right)}$	$x_r^{0.35}$	$x_r^{0.5m}$	$x_r^{0.5m}d_{sr}^{-1-2m}$
Shear velocity	u_{*r}	$L_r^{1/2}$	$z_rx_r^{-1/2}$	$x_r^{\left(\frac{1-2m}{2+8m}\right)}$	$x_r^{0.2}$	1	d_{sr}^{-1}
Settling velocity	ω_r	–	–	$x_r^{\left(\frac{1-2m}{2+8m}\right)}$	$x_r^{0.2}$	1	d_{sr}^{-1}
Discharge	Q_r	$L_r^{5/2}$	$y_rz_r^{3/2}$	$y_rx_r^{\left(\frac{3+3m}{2+8m}\right)}$	$y_rx_r^{1.05}$	$y_rx_r^{0.5+0.5m}$	$y_rx_r^{0.5+0.5m}d_{sr}^{-2-2m}$
Sediment discharge	q_{br}	–	–	1	1	1	1
Dynamic							
Mass	M_r	L_r^3	$x_ry_rz_r$	$y_rx_r^{\left(\frac{2+5m}{1+4m}\right)}$	$y_rx_r^{1.7}$	$y_rx_r^{1.5}$	$y_rx_r^{1.5}d_{sr}^{-1}$
Shear stress	τ_r	L_r	$z_r^2x_r^{-1}$	$x_r^{\left(\frac{1-2m}{1+4m}\right)}$	$x_r^{0.4}$	1	d_{sr}^{-2}
Dimensionless							
Slope	S_r	1	$z_rx_r^{-1}$	$x_r^{\left(\frac{-3m}{1+4m}\right)}$	$x_r^{-0.3}$	$x_r^{-0.5}$	$x_r^{-0.5}d_{sr}^{-1}$
Darcy–Weisbach	f_r	—	$z_rx_r^{-1}$	$x_r^{\left(\frac{-3m}{1+4m}\right)}$	$x_r^{-0.3}$	x_r^{-m}	$x_r^{-m}d_{sr}^{4m}$
Froude	Fr_r	1	1	1	1	$x_r^{0.5m-0.25}$	$x_r^{0.5m-0.25}d_{sr}^{-0.5-2m}$
Reynolds	Re_r	$L_r^{3/2}$	$z_r^{3/2}$	$x_r^{\left(\frac{3+3m}{2+8m}\right)}$	$x_r^{1.05}$	$x_r^{0.5+0.5m}$	$x_r^{0.5m+0.5}d_{sr}^{-1-2m}$
Shields	τ_{*r}	–	–	1	1	1	1
Grain Reynolds	Re_{*r}	–	–	1	1	1	1
Sediment diameter	d_{*r}	–	–	1	1	1	1
Sediment density	$(G-1)_r$	–	–	$x_r^{\left(\frac{3-6m}{2+8m}\right)}$	$x_r^{0.6}$	1	d_{sr}^{-3}



12.4 *Mobile-Bed River Models* 341

Hydraulic

Froude

$Fr_r = 1$

Friction

$$S_{fr} = \frac{z_r}{x_r} = \left(\frac{d_{sr}}{z_r}\right)^{2m} Fr_r^2$$

$$d_{sr} = z_r^{\frac{1+2m}{2m}} x_r^{\frac{-1}{2m}} \quad \text{or} \quad d_{sr} = \frac{z_r^4}{x_r^3} \text{ when } m = 1/6$$

$$d_{sr} = \frac{x_r^{1/2}}{z_r}$$

Sediment settling velocity

$(d_{*r} = 1)$

$$d_{sr}^3 = \frac{1}{(G-1)_r}$$

Sediment transport

$(\tau_{*r} = 1)$

$$d_{sr} = \frac{z_r^2}{x_r (G-1)_r}$$

$$z_r = x_r^{\frac{1+m}{1+4m}} \quad \text{or} \quad z_r = x_r^{0.7} \text{ when } m = 1/6$$

342 *Physical River Models*

Example 12.2 Calculation example for complete mobile-bed similitude

Consider building a physical model for a very wide fine sand-bed river with an 8-m flow depth and 2 m/s velocity. Given a 40,000 m^3/s flow discharge and 7×10^{-5} slope, determine the scale ratios for complete similitude with $x_r = 250$. The prototype Shields parameter is $\tau_{*p} = \frac{h_pS_p}{(G-1)_pd_{50}} = \frac{8\times7\times10^{-5}}{1.65\times0.0002} = 1.7 > 0.03$. The bed material is definitely mobile and the prototype value $m = [2.3 \log(2 \times 8/0.0002)]^{-1} = 0.089$. The scale ratios for the following parameters are obtained from Column five of Table 12.1: (1) the depth ratio is $z_r = z_p/z_m = 250^{\left[\frac{1+0.089}{1+4\times0.089}\right]} \simeq 80$ and the model depth is $z_m = 8/80 = 0.1$ m; (2) the model particle diameter is $d_{sm} = 0.2\ \mathrm{mm}/250^{\left[\frac{-1+2\times0.089}{2+8\times0.089}\right]} \simeq 1.06$ mm; and (3) it is interesting to calculate $m = [2.3 \log(2 \times 0.1/0.0011)]^{-1} = 0.19$ for the model which is very close to the Manning-Strickler value $m = 1/6 = 0.167$.

Recalculating the scales now from Column six of Table 12.1 gives: (1) a model depth $z_m = 8/250^{0.7} = 0.167$ m; (2) a particle size $d_{sm} = 0.2\ \mathrm{mm}/250^{-0.2} \simeq 0.6$ mm; (3) the model sediment density $(G-1)_m = 1.65/250^{0.6} \simeq 0.06$, or $G_m = 1.06$, for which gilsonite or polystyrene may be considered. The other parameters would be the hydraulic timescale $t_r = 250^{0.65} = 36$, and model velocity $V_r = 250^{0.35} = 6.9$ with a model velocity $V_m = 2/6.9 = 0.29$ m/s. The sediment timescale $t_{br} = 250^{1.7} = 11{,}900$ means that 1 h in the laboratory corresponds to 16 months of riverbed deformation. The model slope is $S_m = S_p/S_r = 7 \times 10^{-5}/250^{-0.3} = 37 \times 10^{-5}$ and selecting $y_r = x_r$ results in a reasonable model discharge $Q_m = Q_p/Q_r = 40{,}000/250^{2.05} = 0.48\ m^3/s$.

We used length scale determined by physical size of lab space, number of gates and suspended sediment fall velocity

Physical Model and Instrumentation at Reclamation's Hydraulics Laboratory in Denver Colorado

- Constructed 1:8 exact scale physical model of Peralta sluiceway and headworks and 10 adjacent river gates
- Constructed mixing boxes for continuous measurement of sediment concentration in the river channel, sluiceway and headworks.

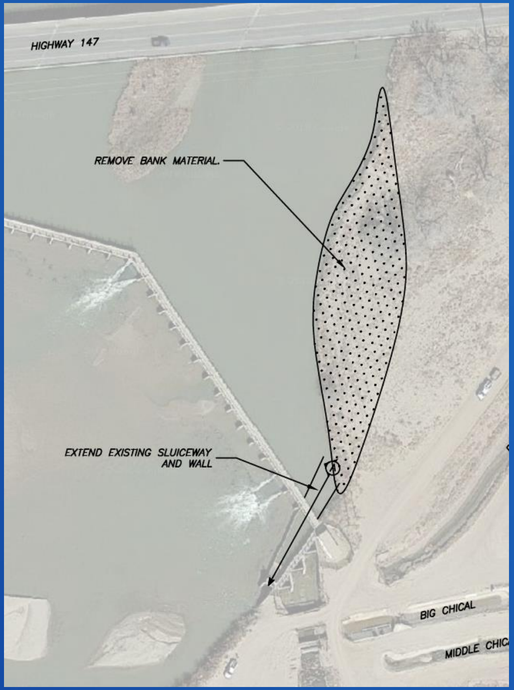
Physical Model Design and Testing a combined team effort of MRGCD, POI (Tetra Tech) and Reclamation

- Test Flows Represent 4,900 cfs in the river (2050 for 10 gates plus diversions and sluiceway outflow)
- Option performance comparison based on concentration in the headworks/concentration in the river (C_H/C_R)

Lab Team: Reclamation, Joseph Kubitschek, Drew Baird; MRGCD, David Gensler; Tetra Tech, David Pizzi

East Sluiceway Sediment Management Options Tested in the Physical Model

- Existing configuration (Baseline)
- Realign east bank upstream of sluiceway
- Slope the sluiceway floor (into and out of sluiceway)
- Lengthen the sluiceway (straight and curved inlets)
- Widen the sluiceway
- Combinations

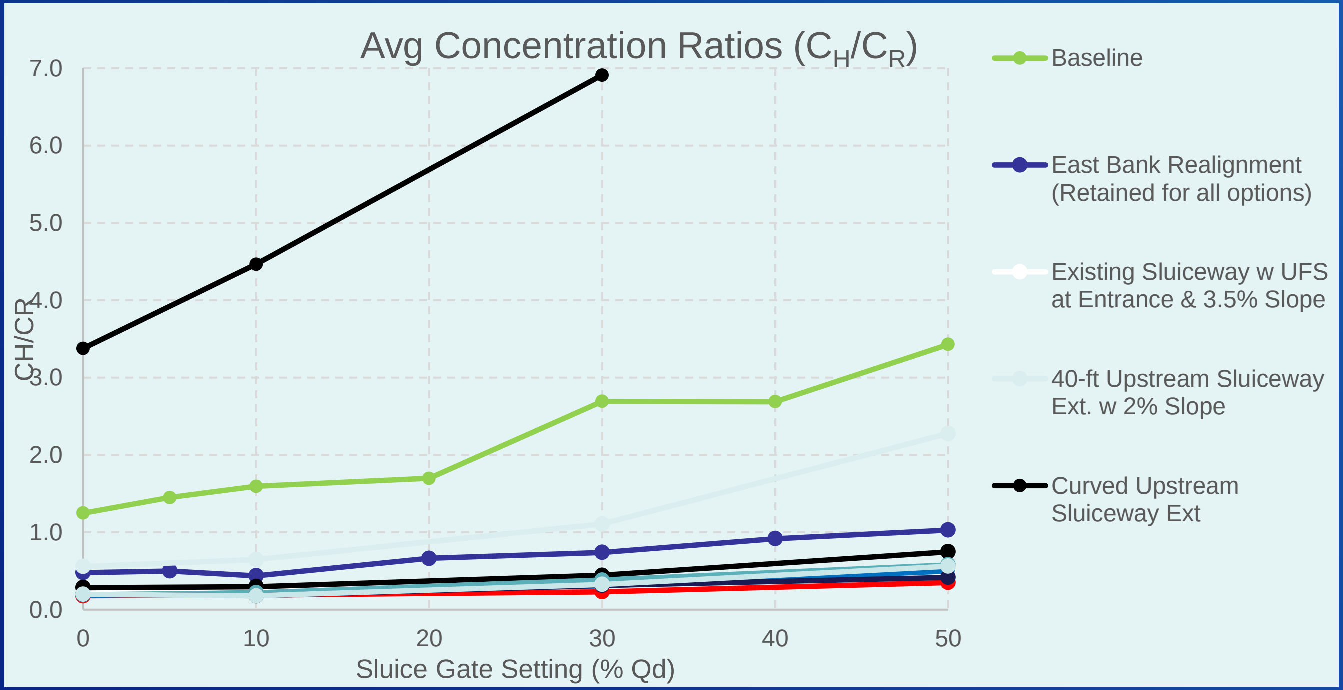


Well represents sediment movement at Isleta. Flows could not transport sediment from flat sloped sluiceway

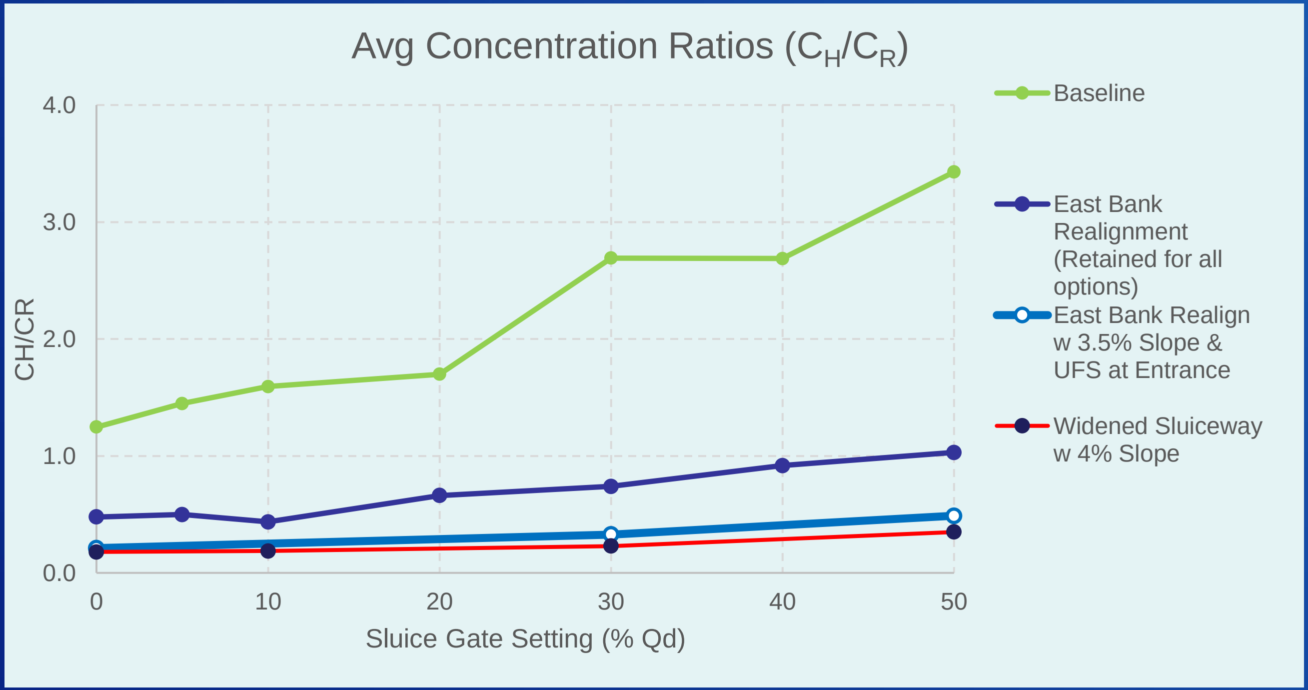
Tested 3.5% Sluiceway Bed Slope, Sluice Ops

Curved Sluiceway Extension Continuous Sluice Ops. Head loss from additional length caused deposition. Secondary currents from curved guidewall were ineffective.

Concentration Ratio Performance Headworks Concentration/River Concentration (C_H/C_R Ratio)



Headworks to River Concentration Ratios for various sluiceway gate discharges and options



- Realigning the east bank provided most benefit
- Preferred alternative East Bank realignment w/3.5% slope and UFS entrance.

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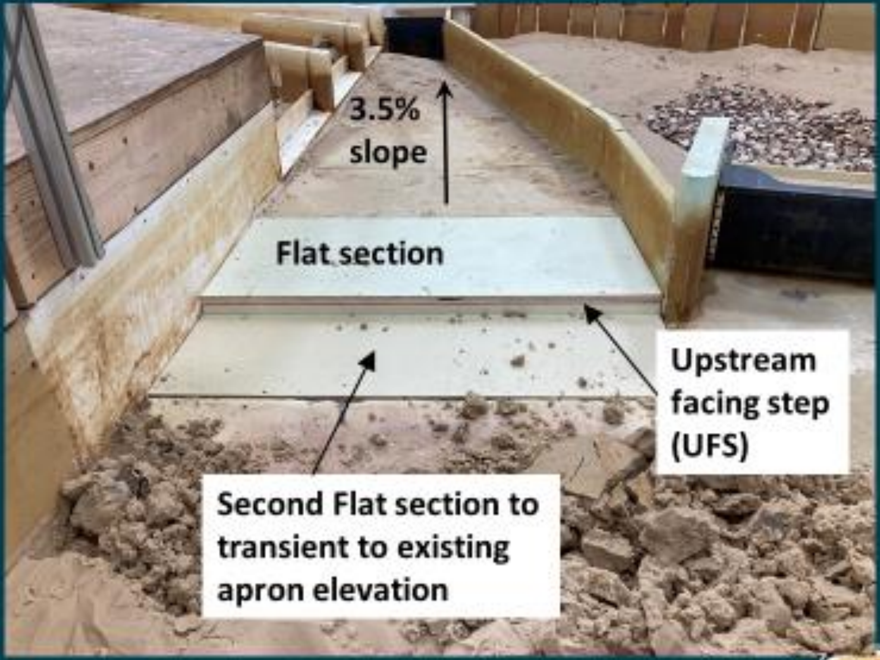
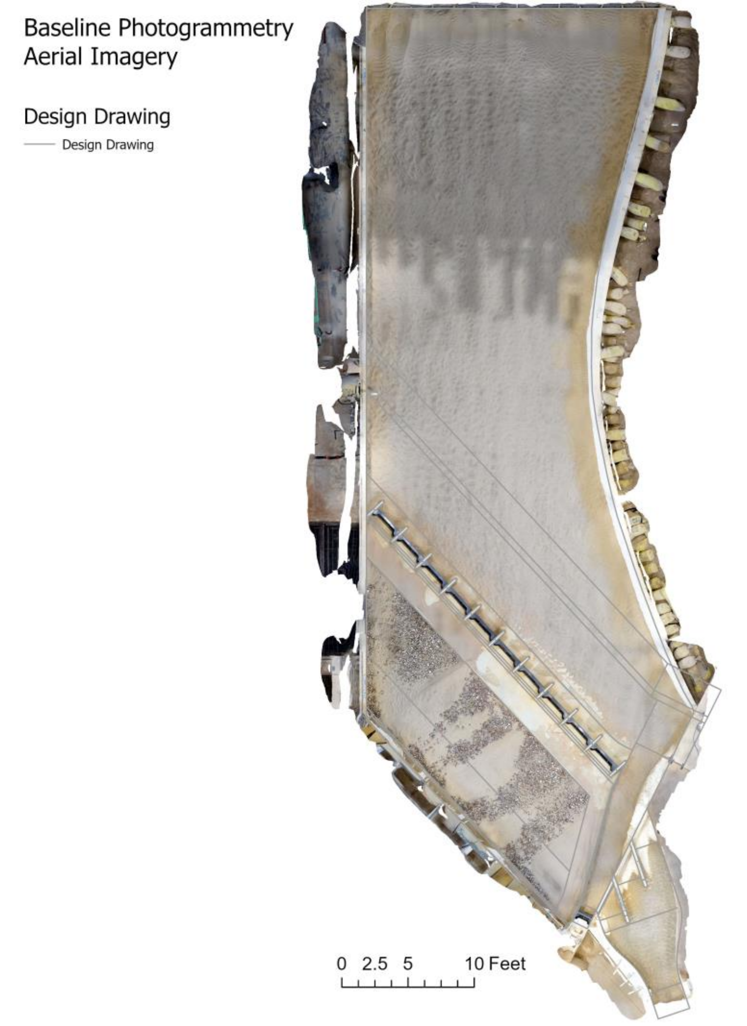
TETRA TECH

Existing Sluiceway with 3.5% slope, flat section and upstream facing step (UFS)



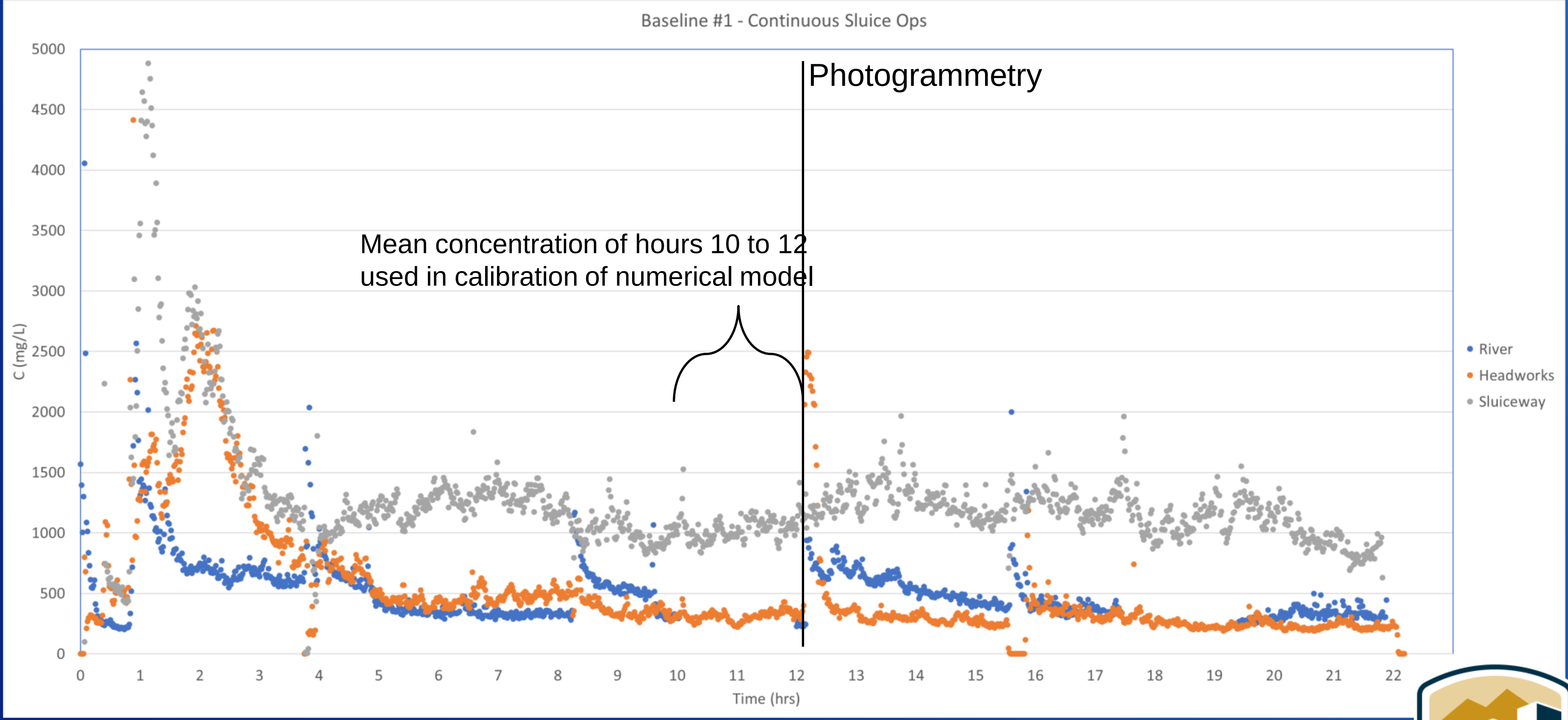
New 2-D Mobile Bed with Gate Functions (State of the Art by Dr. Yong Lai) Beta Test Case



- **Model Domain**

Byrne and Baird 2022 (Draft)

Laboratory Sediment Data

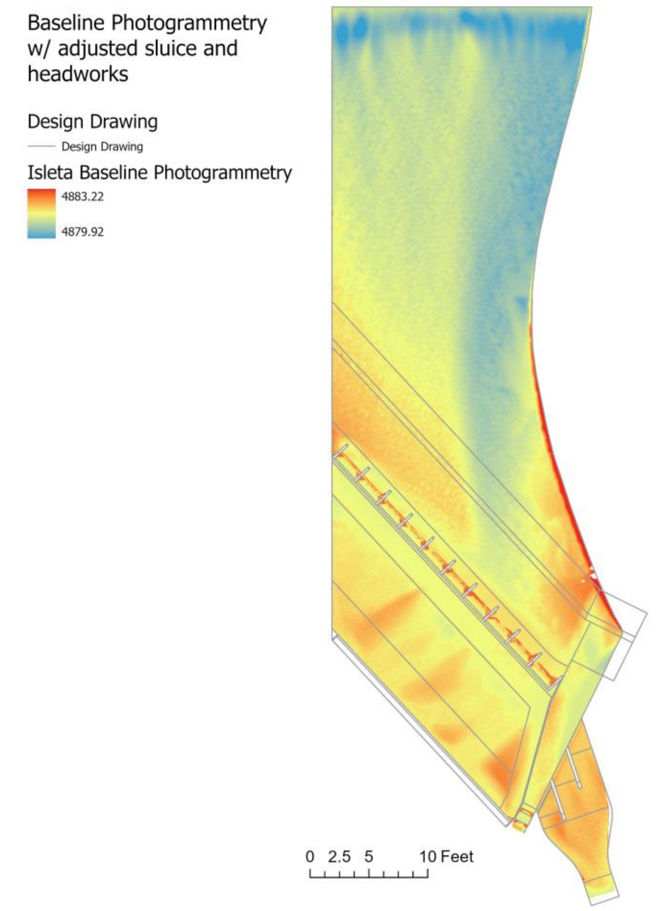


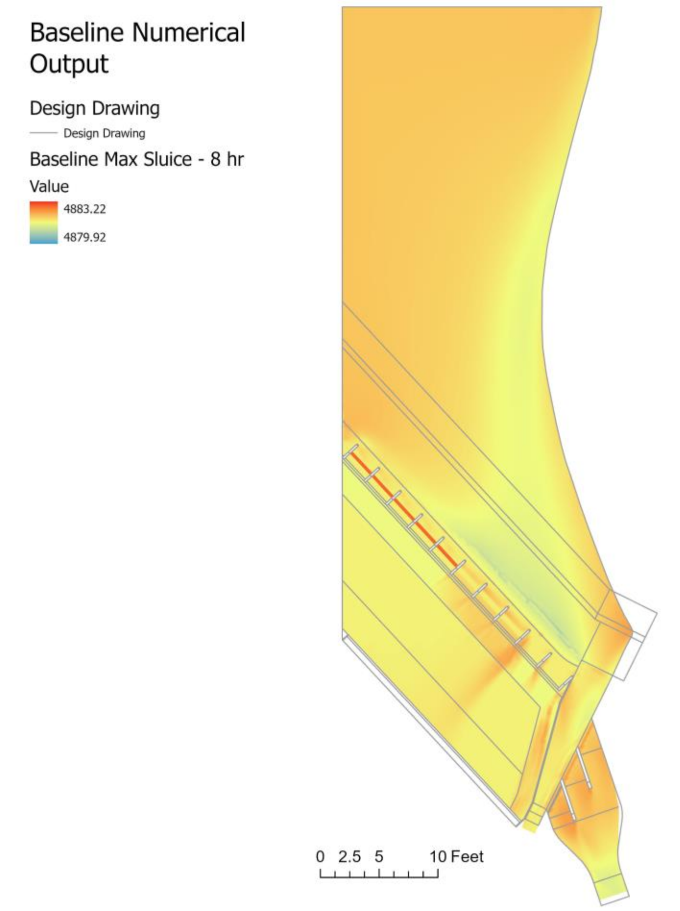
Photogrammetry

Mean concentration of hours 10 to 12 used in calibration of numerical model

Model Final Results

Overall, numerical model had similar trends in deposition and erosion compared with the physical model





Model Final Results

- Final calibration parameters
  - Manning’s n-values
    - Sand = 0.022
    - Gravel = 0.025
    - Apron = 0.012
    - Sluiceway = 0.013
    - Headworks = 0.013
  - Sand ripple factor = 0.9 (90%)

- Final numerical model percentage (negative numbers represent under prediction by the numerical model)
  - Total sediment transport = 13.38%
    - River = 13.33%
    - Sluiceway = -18.16%
    - Headworks = -16.54%

River Processes

- Middle Rio Grande as example---why?
  - Just about every geomorphic process can be found on the Middle Rio Grande
  - Non-equilibrium river with
    - Aggradation and Delta Depositional Process
    - Channel incision (Upstream Reservoir Construction)
    - Development of Inset Floodplain
    - Significant Lateral Confinements
    - Significant water with drawls
    - Channelization
    - Base level changes

Historical Channel Characteristics

- Historically high sediment load causing channel aggradation (raising of the river bed and floodplain due to sediment deposition).
- Avulsions
  - Channel would fill, especially during hydrograph recessions.
  - During subsequent high flows, river waters would go overbank, and create new channel along lower valley areas.
- Resulting river channel was wide, shallow and generally sand bedded with small pockets of gravel.

Happp (1948), Lagasse (1980), and
Scurlock (1998)

RECLAMATION

Contemporary Channel Characteristics

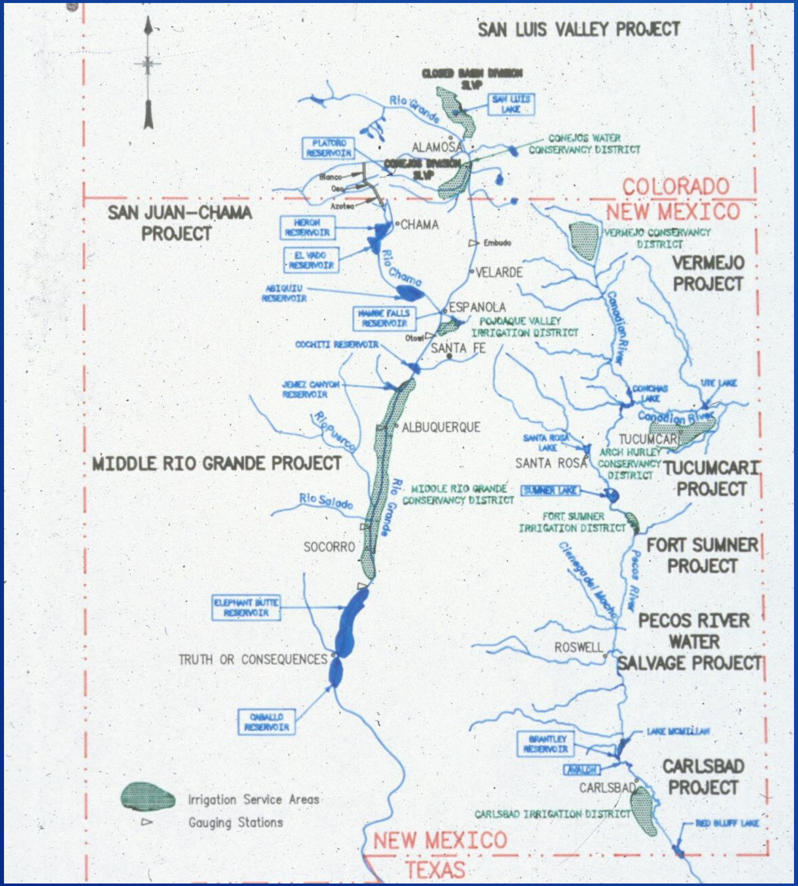
- Lower Sediment Load.
- Lower Flood Peaks (after the 1940’s; Lagasse, 1980).
- Narrower Channel.
- Channel Incision (bed lowering).
- Coarser Bed Sediment.
- Aggradation upstream of Elephant Butte Reservoir

Causes of Contemporary Channel Conditions

- Climate conditions reduced flood peaks. (Since 1940’s).
- Reduced tributary sediment supply-reduced grazing, tributary dams (Lagasse, 1980 and Massong and Porter, 2010).
- Human activities:
  - Irrigation Diversions.
  - Levee and river side drain construction.
  - Channel rehabilitation and maintenance.
  - Upstream sediment and flood control reservoirs.
  - Trans-mountain diversions.
  - Urbanization.
  - Downstream Elephant Butte Reservoir.

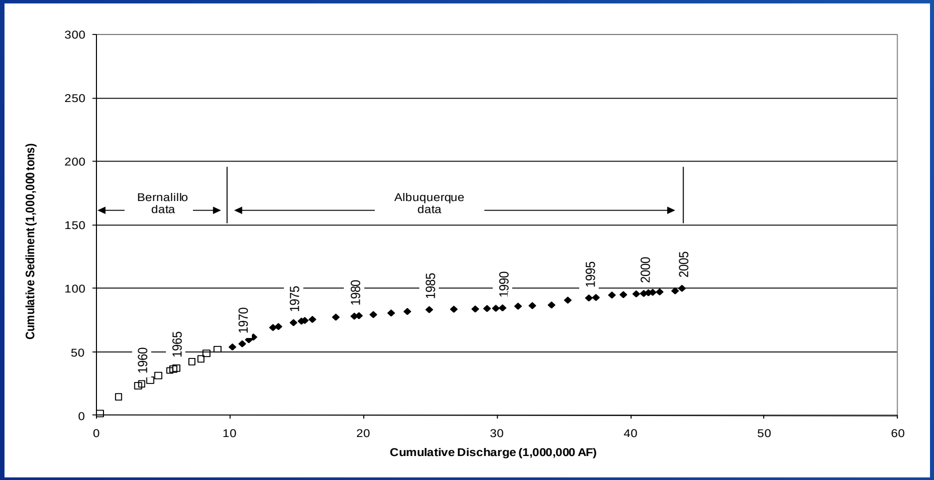
Aggradation/Degradation

- Aggradation
  - River channel and floodplain raising due to sediment accumulation.
  - Sediment supply greater than transport capacity.
- Degradation
  - River channel lowering due to sediment removal.
  - Sediment supply less than transport capacity.
- Reducing historical aggradation was one of the original purposes of upstream flood and sediment control reservoirs.
- Since 1973 Cochiti Dam to About Escondido, NM. the river has been degrading.
- From San Antonio, NM though Elephant Butte Reservoir Delta channel is aggrading.



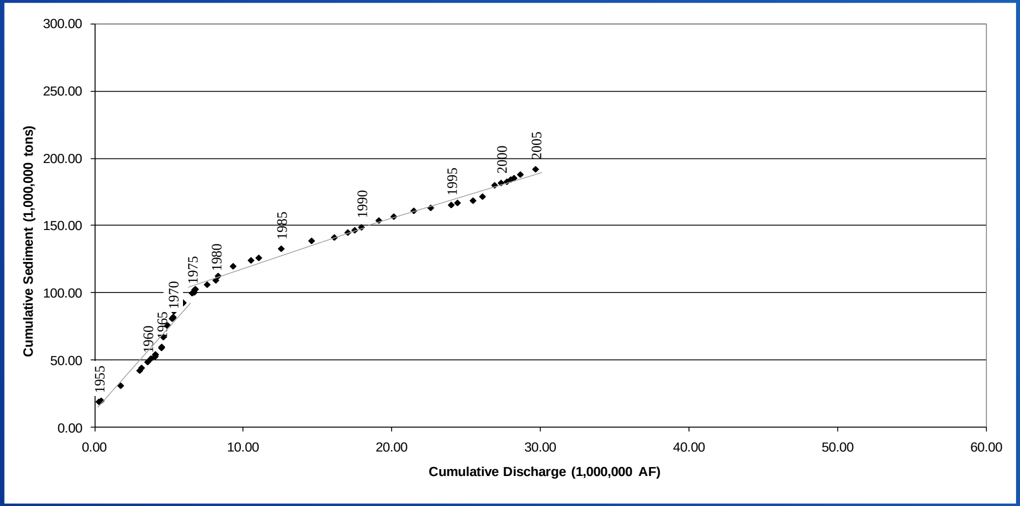
RECLAMATION

Cumulative Suspended Sediment vs. Cumulative Discharge



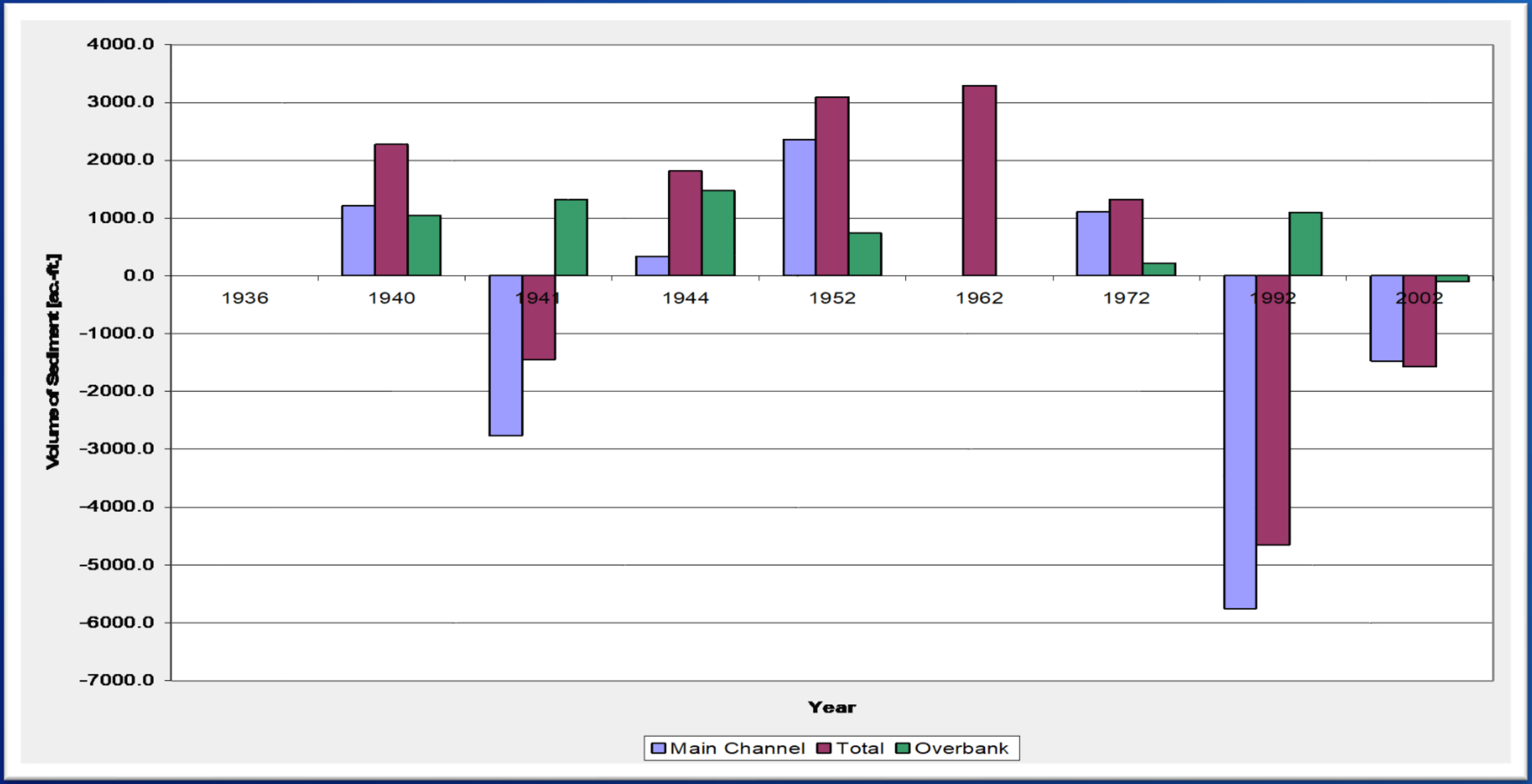
Albuquerque Gage

San Acacia Gage



Makar 2010

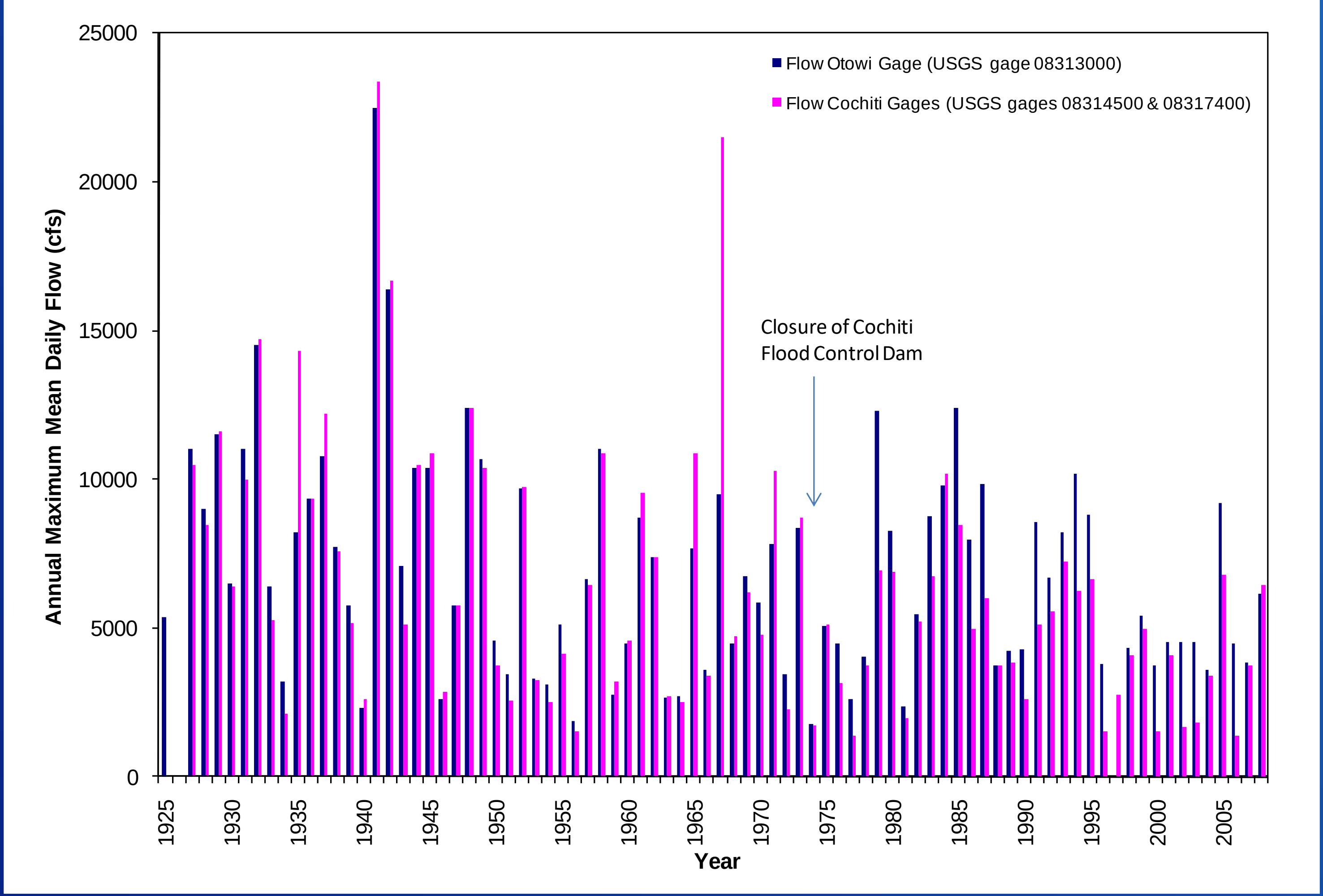
Albuquerque Reach- Angostura to Isleta Aggradation/Degradation 1936 to 2002



1936 to 1972 generally aggradational

Degradation since 1972

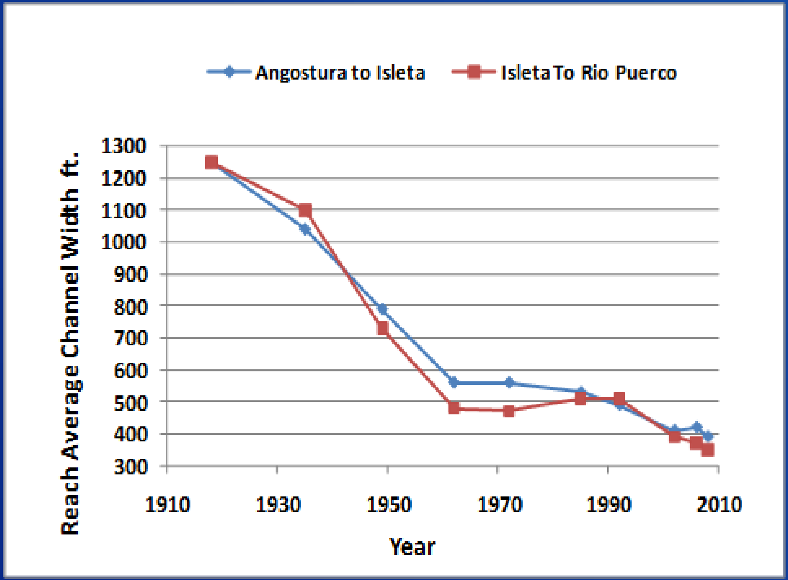
Otowi and Cochiti Mean Daily peak Flows



Makar 2011

RECLAMATION

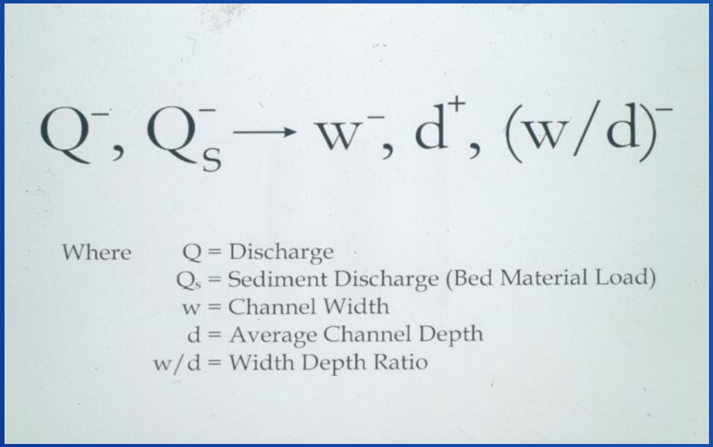
Reach Average Channel Width 1918 to 2010



1935 Aerial Photographs show evidence of MRGCD levees and drains.

After 1949 width changes attributed to:

- Reclamation Channelization
- Upstream Sediment and Flood Control Dams (reduced sediment loads and peak flows.
- Trans-mountain diversions can encourage channel narrowing (vegetation growth).



$$Q^-, Q_S^- \longrightarrow w^-, d^+, (w/d)^-$$

Where Q = Discharge
Q_s = Sediment Discharge (Bed Material Load)
w = Channel Width
d = Average Channel Depth
w/d = Width Depth Ratio

The most recent width reduction is also related to drought conditions

RECLAMATION

Average Bed Elevation

Angostura to Bernalillo

1971-1995 lowered 7.3 Ft.

Bernalillo to Corralles

1972-1992 lowered 3.5 Ft.

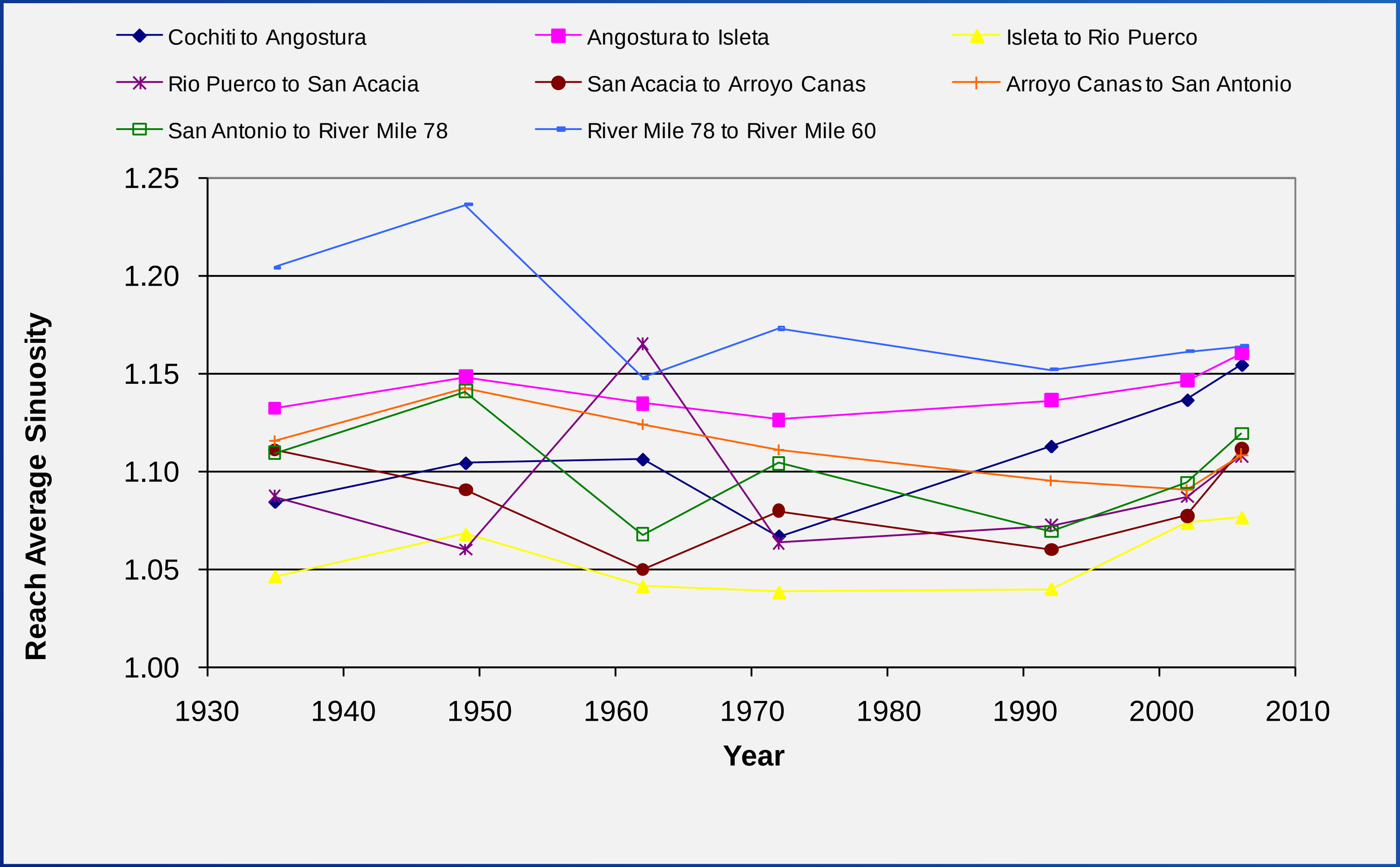
Rio Puerco to San Acacia

1962-1992 lowered 3 Ft.

San Acacia to Escondida

1962-1999 lowered 9.6 Ft.

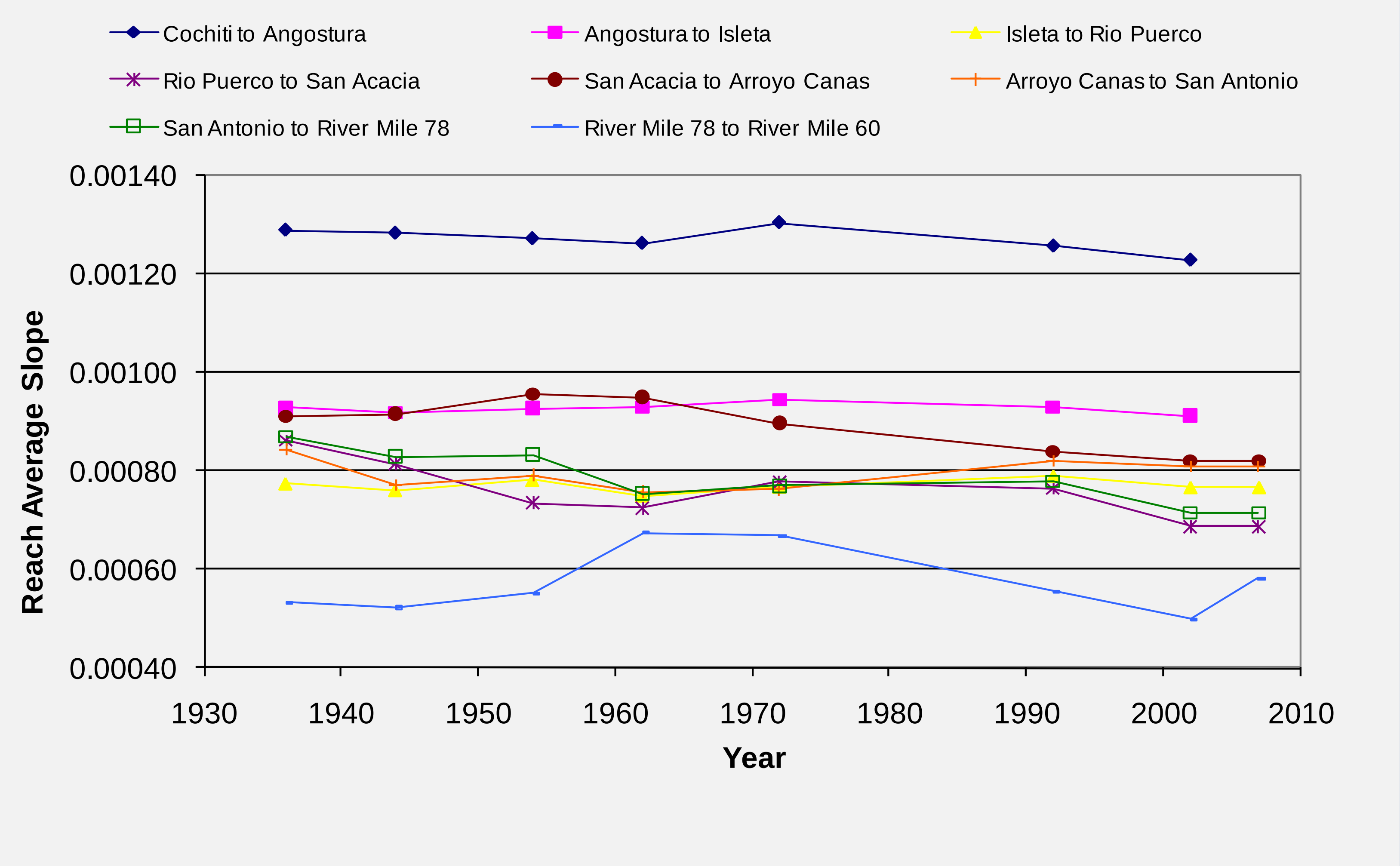
Reach Average Sinuosity Over Time



Makar 2010

RECLAMATION

Reach Average Slopes Over Time

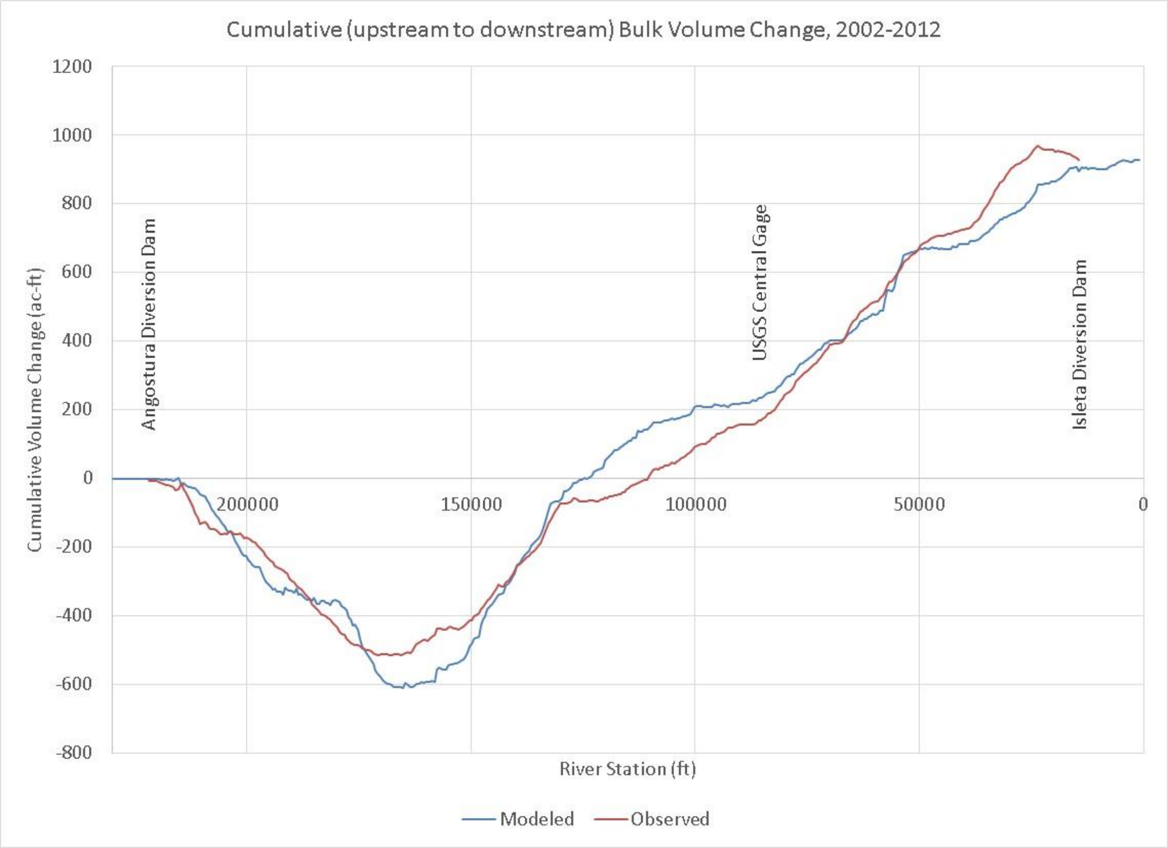


Makar 2010

RECLAMATION

Sediment Transport Modeling Angostura Diversion Dam To Isleta Diversion Dam. (Albuquerque Area)

- Objective: Match main channel sediment volume changes between 2002 and 2012 data sets.
- Can calibrate model with measured data
  - Model tends to smooth bed elevation changes between adjoining cross sections (In general model smooths in time and space)

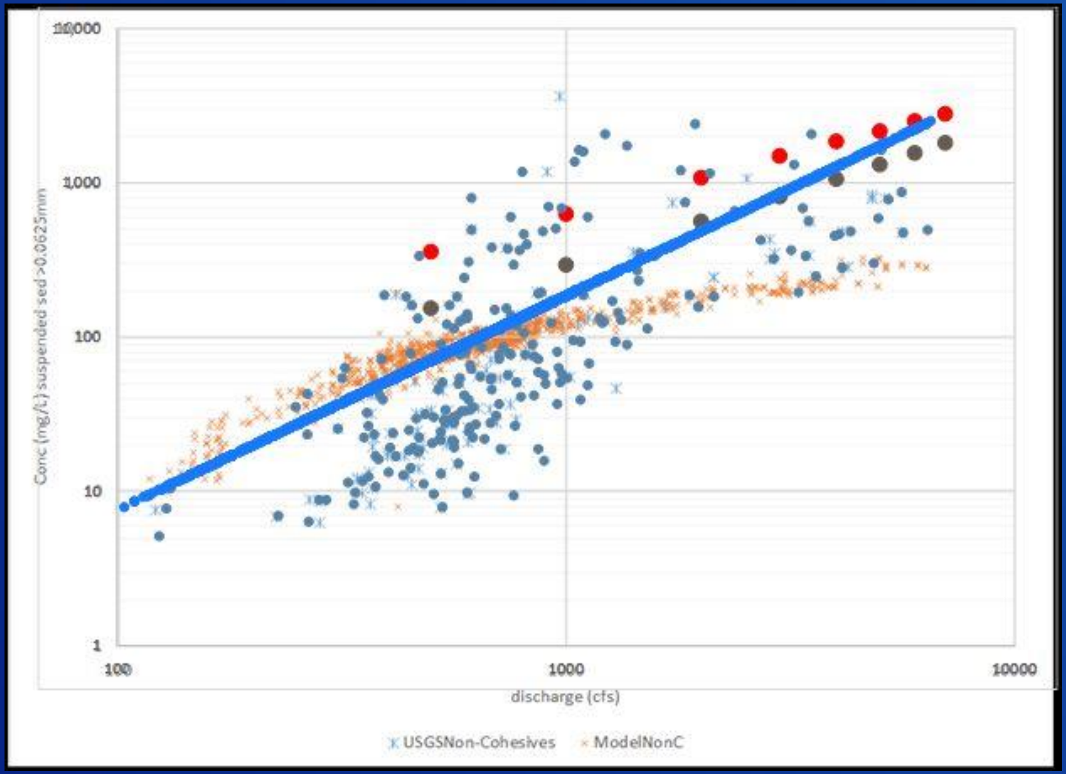


- **Calibrate Process:**
  - **Alter hiding factor (0.67)**
  - **Alter active thickness layer (0.50 ft. tested range 0.25 to 1 ft)**
  - **Alter reference or critical shear stress (0.034 tested range 0.033 to 0.037)**

Varyu, 2018

RECLAMATION

Albuquerque Gage BORAMEP, Modeled Bed Material Load

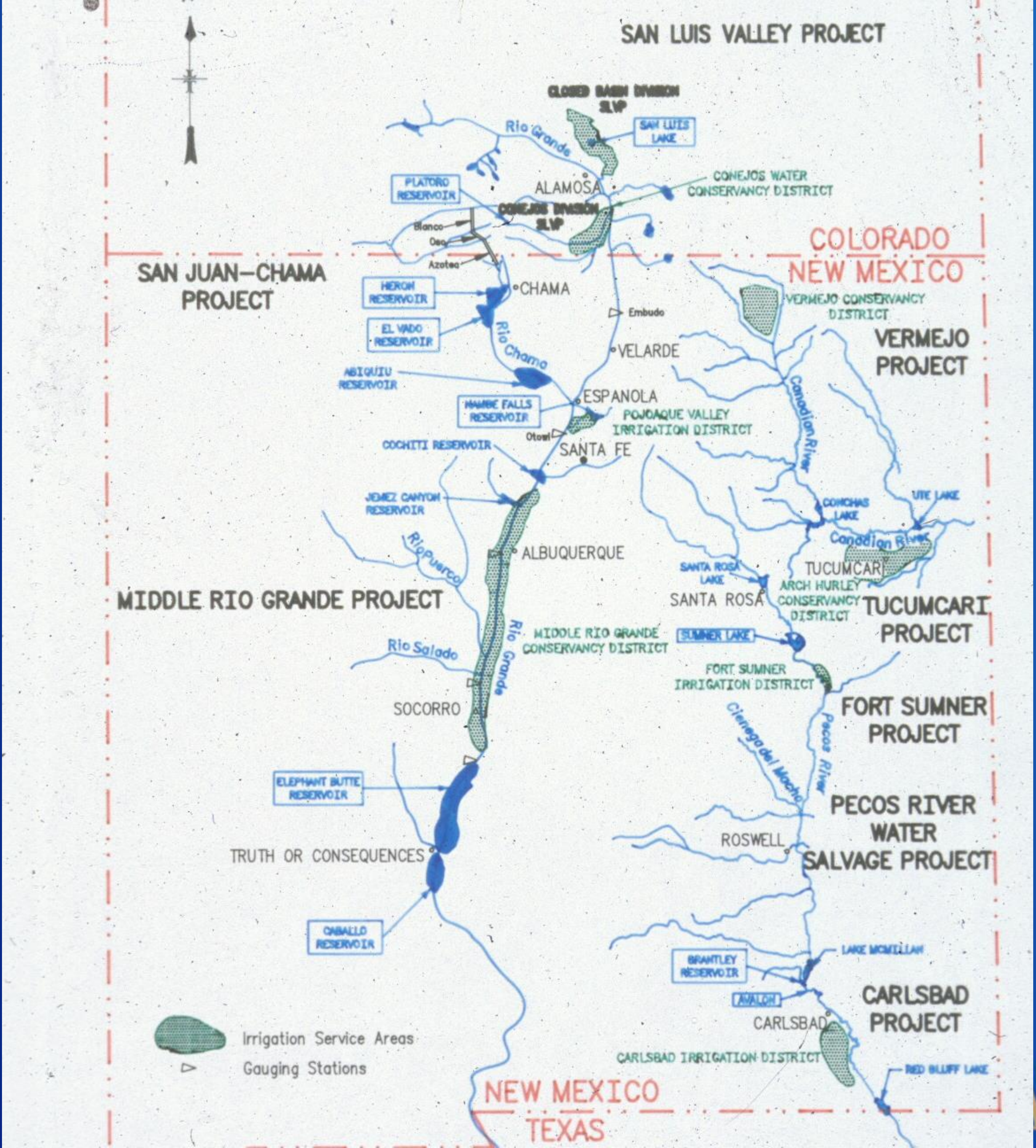


- Common for 1D model to over estimate the low flows and underestimate high flows
- Not the same bed material size is available.
- Low flows-flow focused in area of the channel with the coarsest sediment, so bed is coarser than input sediment size
- High flows-finer bar deposits available to the flow and more sediment gets mobilized
- 1D assumptions break down when flow goes out of bank where average velocity is lower than the main channel velocity (Blair Greimann)

Potential Restoration Activities

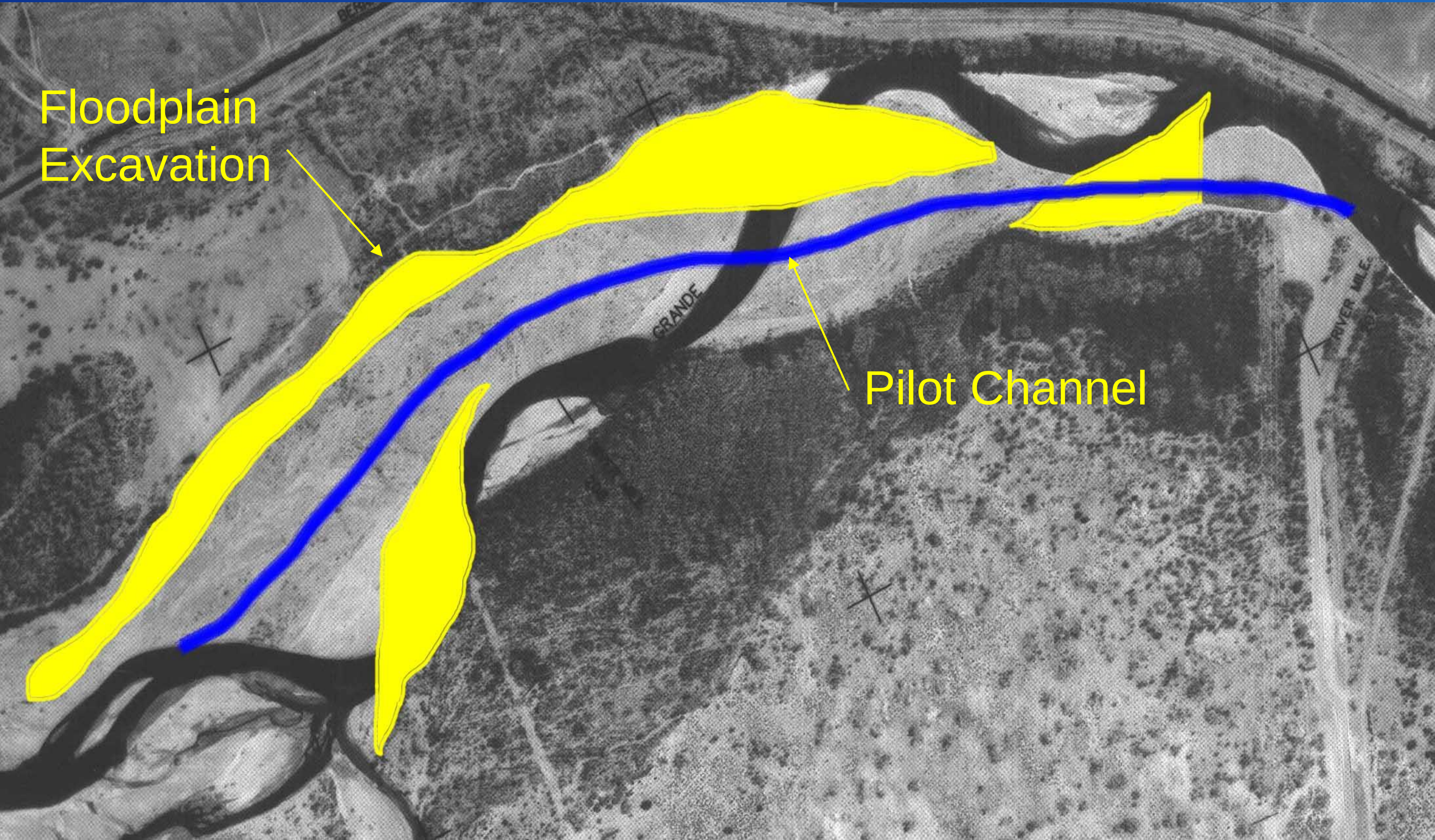
- **Channel Widening**
- **Terrace or Overbank Lowering**
- **Gradient Restoration Facilities (GRF)**
- **High flow side channels**
- **Micro-habitat Inlets**
- **Restore native riparian habitat mosiac, including salt grass, shrub, and bosque communities**
- **Combinations of the above**

Santa Ana Project Example of Large-Scale River Restoration Project


SAN LUIS VALLEY PROJECT
CLOSED BASIN DIVISION SLVP
SAN LUIS LAKE
Rio Grande
PLATORO RESERVOIR
ALAMOSA
CONEJOS WATER CONSERVANCY DISTRICT
CONEJOS DIVISION SLVP
Blanco
Oso
Azotea
COLORADO
NEW MEXICO
SAN JUAN-CHAMA PROJECT
HERON RESERVOIR
CHAMA
EL VADO RESERVOIR
Embudo
VERMEJO CONSERVANCY DISTRICT
VERMEJO PROJECT
Rio Chama
VELARDE
ABIQUIU RESERVOIR
ESPANOLA
NAMBE FALLS RESERVOIR
POJOAQUE VALLEY IRRIGATION DISTRICT
Otowi
SANTA FE
COCHITI RESERVOIR
Canadian River
JEMEZ CANYON RESERVOIR
CONCHAS LAKE
UTE LAKE
Canadian River
Rio Puerco
ALBUQUERQUE
SANTA ROSA LAKE
TUCUMCARI
ARCH HURLEY CONSERVANCY DISTRICT
MIDDLE RIO GRANDE PROJECT
SANTA ROSA
TUCUMCARI PROJECT
Rio Grande
MIDDLE RIO GRANDE CONSERVANCY DISTRICT
SUMNER LAKE
Rio Salado
FORT SUMNER IRRIGATION DISTRICT
SOCORRO
FORT SUMNER PROJECT
Cienega del Macho
Pecos River
ELEPHANT BUTTE RESERVOIR
PECOS RIVER WATER SALVAGE PROJECT
ROSWELL
TRUTH OR CONSEQUENCES
CABALLO RESERVOIR
LAKE MCMILLAN
BRANTLEY RESERVOIR
AVALON
CARLSBAD PROJECT
CARLSBAD
Irrigation Service Areas
Gauging Stations
CARLSBAD IRRIGATION DISTRICT
RED BLUFF LAKE
NEW MEXICO
TEXAS

RECLAMATION

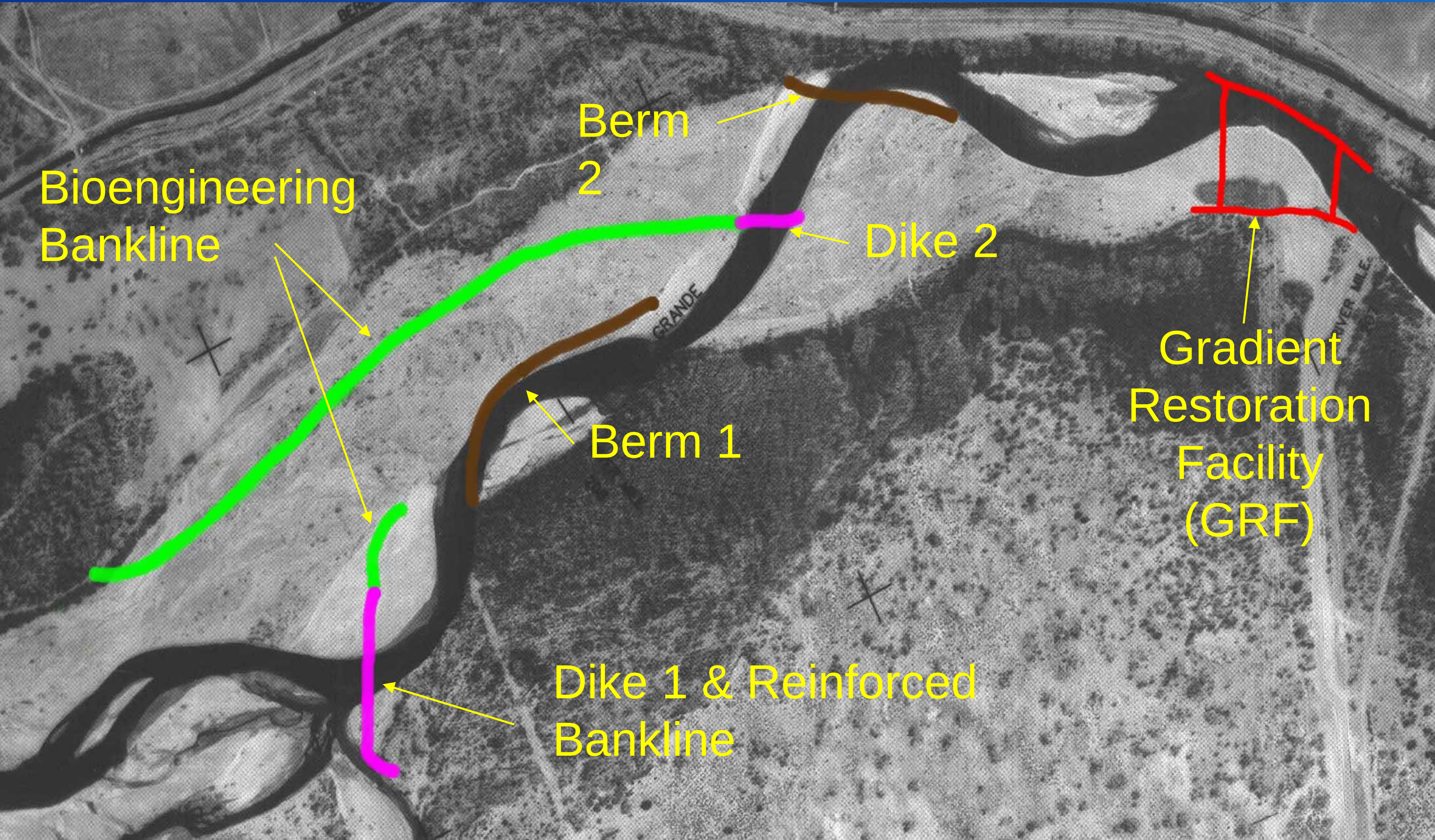
Santa Ana Phase 1
Earth Work



Floodplain Excavation

Pilot Channel

Santa Ana Phase 1
Structural Elements

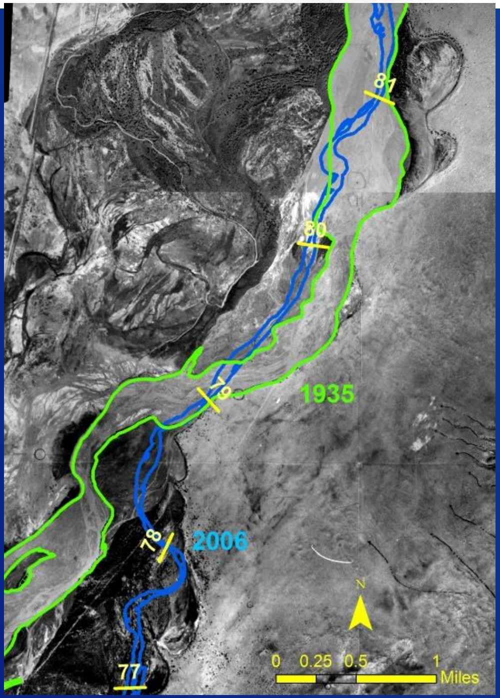


Develop Width Equation for Middle Rio Grande
Study Objectives

1. Develop an improved method/equation to define a stable active channel width for the MRG, and
2. Use existing methods and the newly developed equation to assess various stable and unstable width locations on the MRG

- **Does the term “stable active channel width” even apply?**

Holste and Greimann, 2019



Planform Change

- Historically: wide, braided channel that frequently shifted position
- Currently: narrow, single thread channel with relatively fixed position (Fossilized)

RECLAMATION

Background

- **1961 MRG Width Equation**
  - Relationship to estimate stable channel width
- 301 measurements during 1952-1957 (Cochiti to San Antonio)
  - Mostly low flow years
- MEP used to calculate total load
- Statistical regression to test 13 variables (7 found significant)
- Regression equations for: flow velocity and Manning’s n
- Multi-variable regression using width as dependent variable was never conducted
- Velocity and Manning’s regression equations combined with continuity ($Q = VA$) and standard Manning’s formula to derive expression for width

Background

- 1961 MRG Width Equation

$$V = 0.6385 d^{0.485} w^{0.0306} {C_t}^{0.170} {V_t}^{0.112} \qquad n = 0.5295 {D_{35}}^{0.163} {C_{sn}}^{-0.156} T^{-0.184}$$

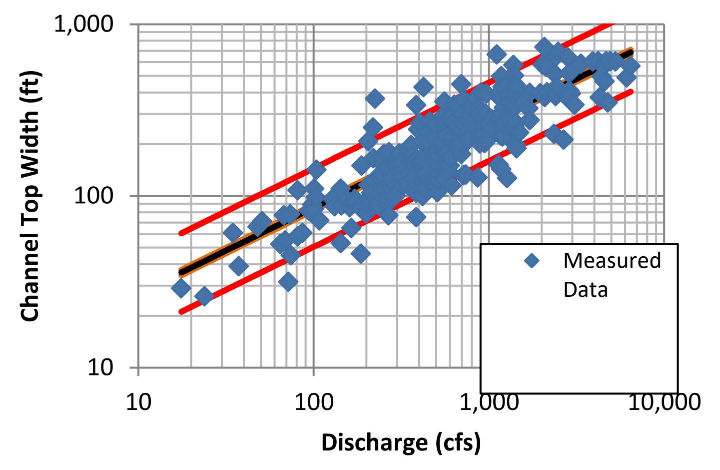
combined with

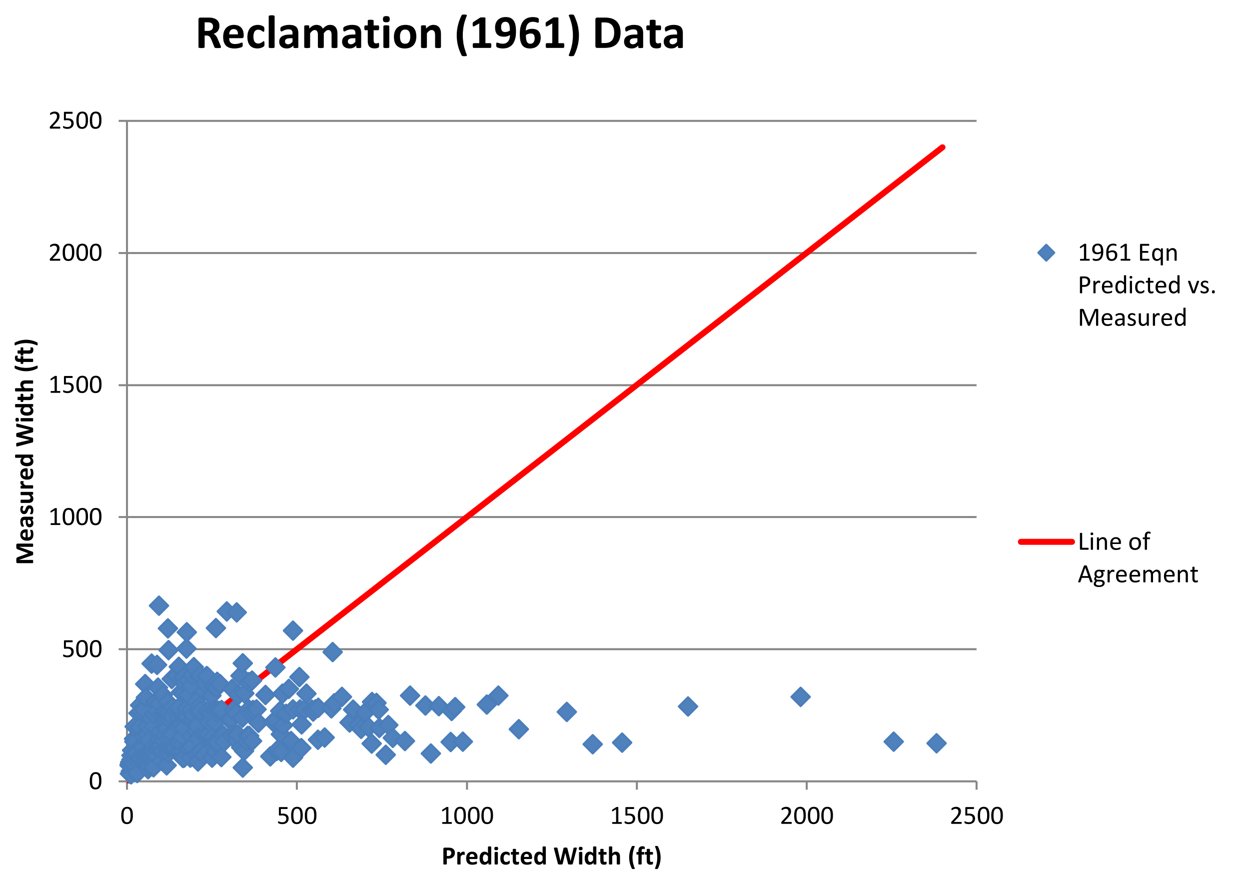
$$Q = VA \qquad V = \frac{1.486}{n} d^{2/3} S^{1/2}$$

$$\boxed{W = \frac{17{,}470 * Q^{0.778} S^{3.184} {C_{sn}}^{0.992} T^{1.171}}{{C_t}^{1.214} {V_t}^{0.800} {D_{35}}^{1.035}}}$$

Background

- Width Regression Eqn




Reclamation (1961) Data

Flow

- Found maximum daily average flow from each year
- Computed R^2 between Q and W for Q computed various ways
  - Computed maximum 1 through 7 day average for every year than computed average or maximum of those values over the previous 5 to 12 years
- The Q that gave the highest R^2 was the average of the annual maximum daily average flows from previous 9 years

Reach Averaged Regression

Regression analysis using all variables

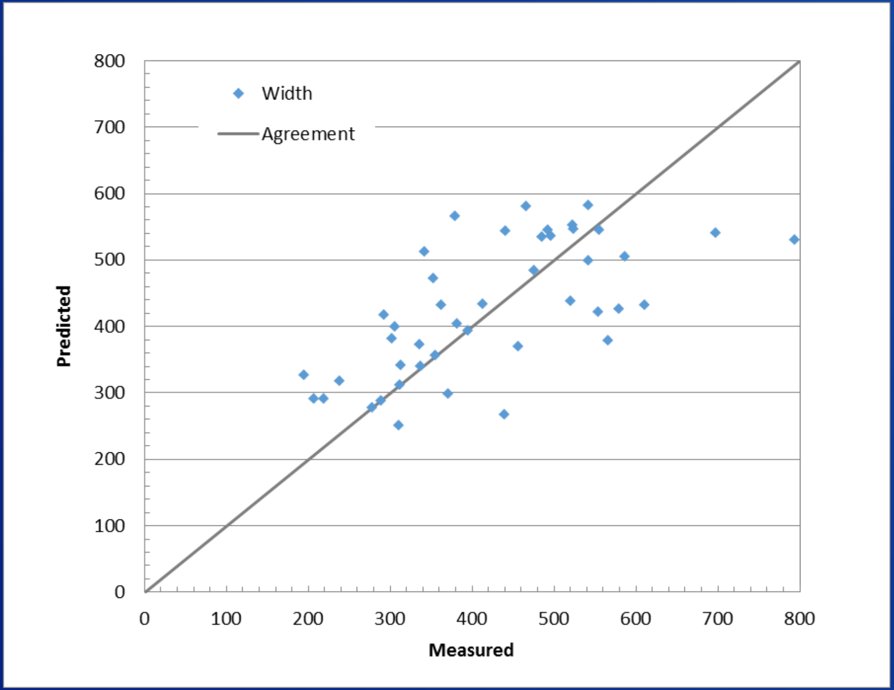
$$W = a\, Q^{b}\, D_{50}{}^{c}\, S^{d}$$

Coefficient	*Value*	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
A	-0.54	2.50	-0.22	0.83	-5.59	4.52
B	1.34	0.20	6.60	0.00	0.93	1.75
C	-0.06	0.03	-1.99	0.05	-0.13	0.00
D	0.66	0.23	2.86	0.01	0.19	1.13

Recommended Reach Averaged Regression (Downstream Hydraulic Geometry)

$$W = 0.11\,Q^{1.25}\,D_{50}^{-0.1}$$

R^2	0.43
ave error (ft)	2.4
std err (ft)	101.1



Percentile	% W error
0.25	6%
0.5	19%
0.75	29%
0.95	48%
0.99	58%

RECLAMATION

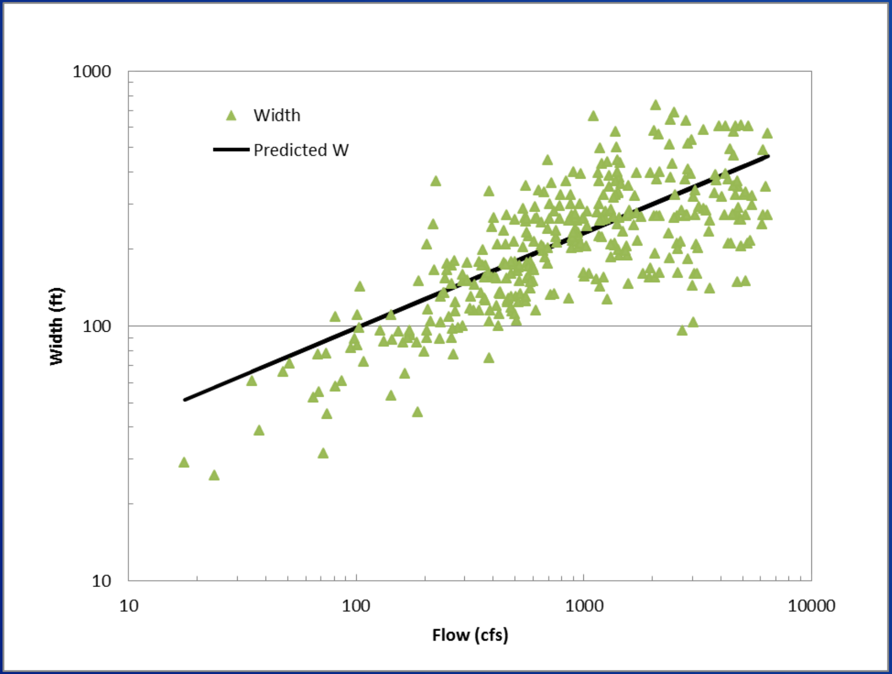
At-a-Station Regression

Parameter significance and correlation

- Only Q coefficient is significant at the 95% level

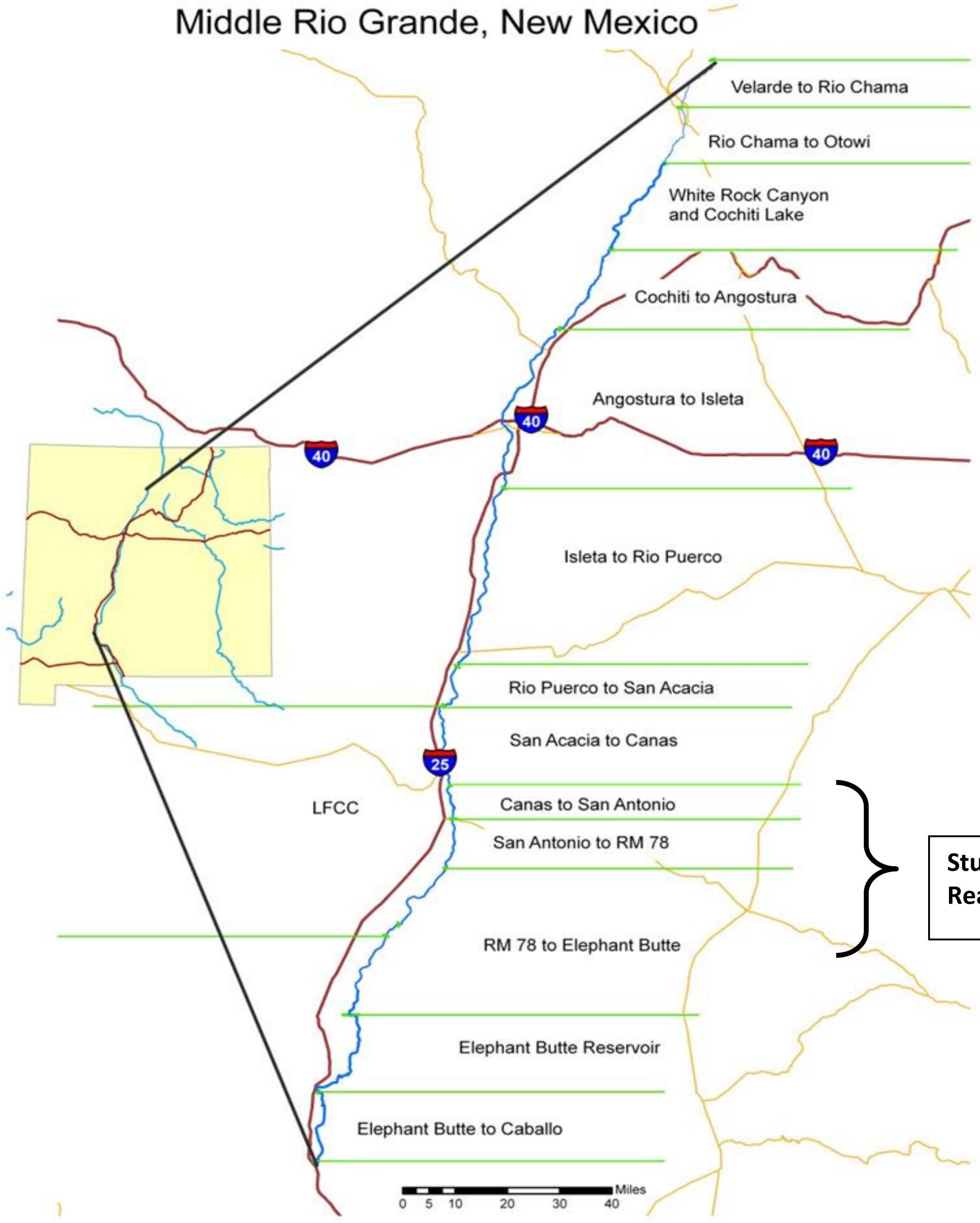
$$W = 17.7\,Q^{0.37}$$

R^2	0.37
ave error (ft)	1.6
std err (ft)	105



Percentile	% W error
0.25	12%
0.5	27%
0.75	46%
0.95	98%
0.99	180%

Location



Study Reach

Sediment Plugs

- What are Sediment Plugs?
  - Channel aggradation and reduced bank height
  - Perched channel
  - High flows top of water column flows laterally out of channel leaving more sediment laden waters with less transport capacity
  - Continued aggradation and lateral flow
  - Reaches a point where nearly all flows go overbank

Sediment Plug Slides by Nathan Holste and Drew Baird

RECLAMATION

Sediment Plugs

- 1991, 1995, 2005, 2008*, & 2017 (2019??)

Ponded Water

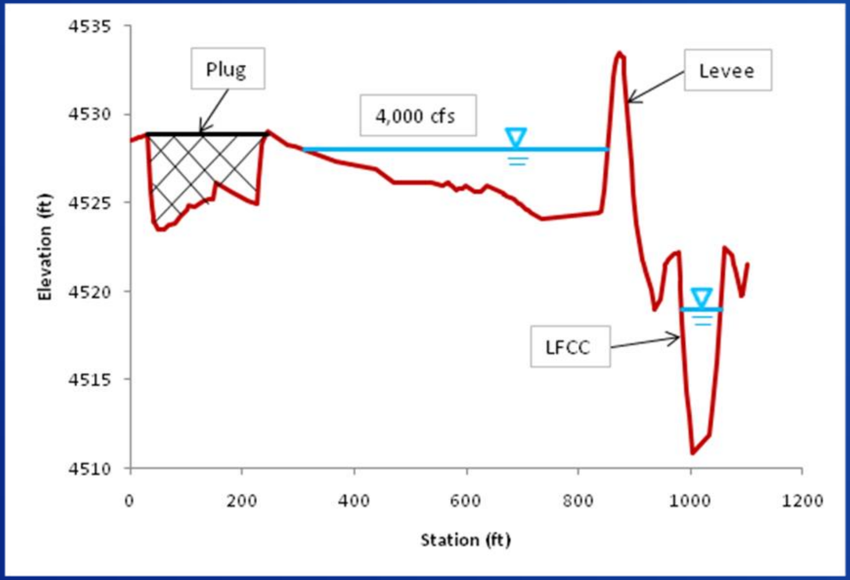
*July 4, 2008: 1600 cfs

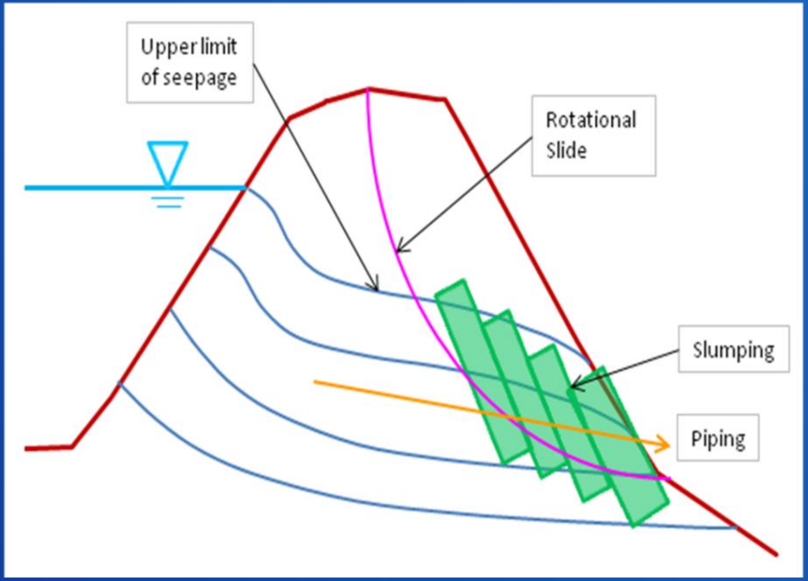
*June 3, 2008: 3700 cfs

Piping, Slope failures, levee raising and widening

1991 Tiffany Levee Breach

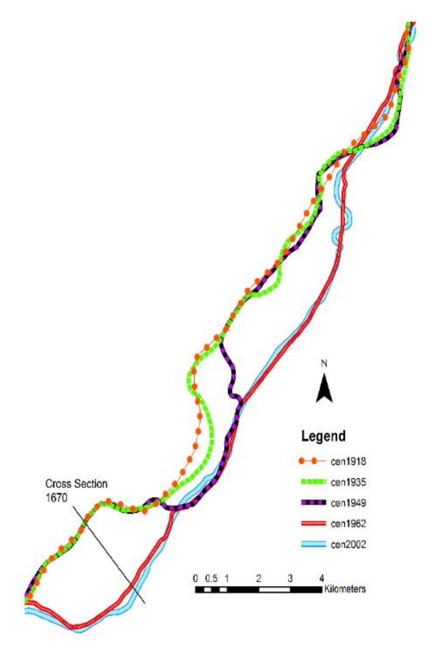
Levee Failure due to Seepage

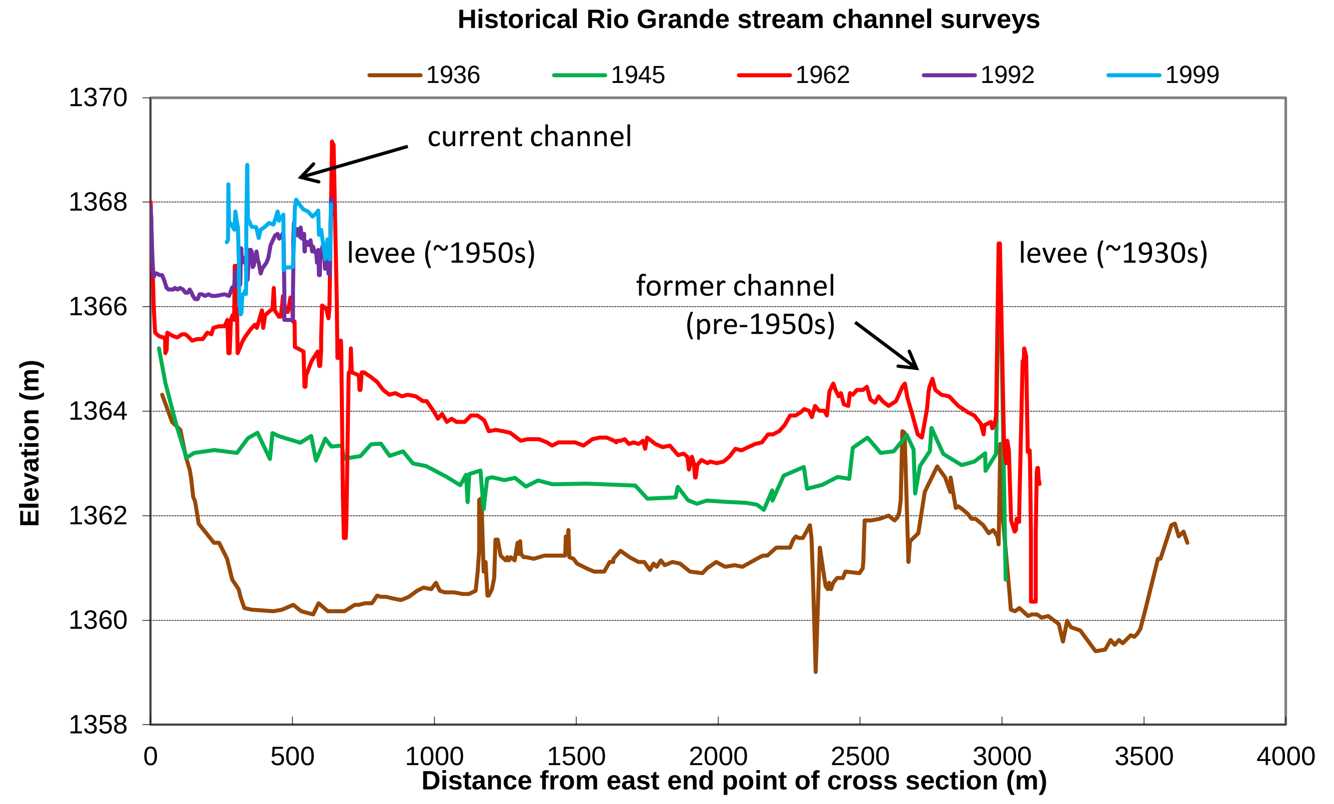




Geomorphic Trends: Perching

- **Channel and floodplain laterally constricted by spoil levees Valley Range Line 1670**





Sediment Plug Factors

Channel Geometry

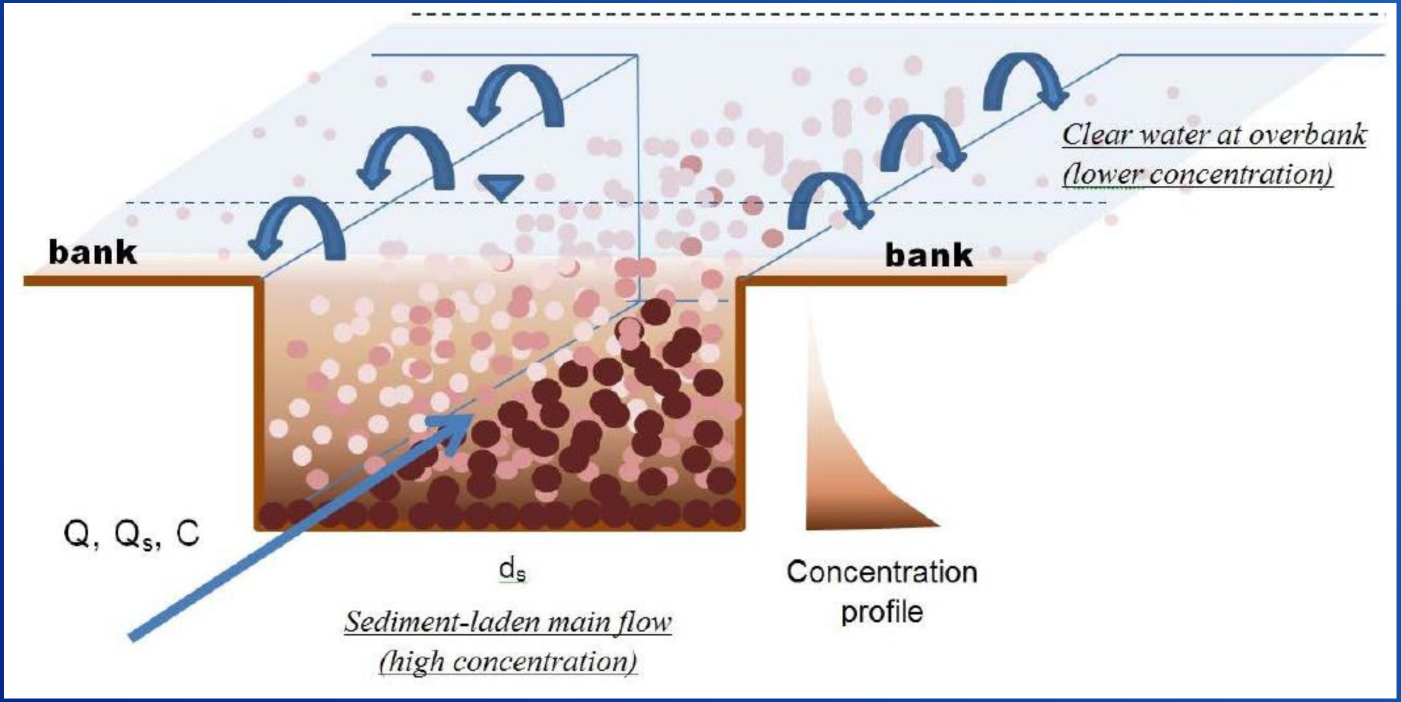
- Narrow channel and/or local constriction
- Limited main channel flow and sediment transport capacity
- Perched channel above floodplain
- Local energy losses (upstream from abrupt bends or bridges)

Hydrology

- Long duration, high magnitude, snowmelt runoff
  - Every year since 2000, and almost every year since 1990, a sediment plug has occurred whenever there is a suitably large spring runoff

Sediment Plugs

- **Flow lost to overbank, sediment remains in channel**

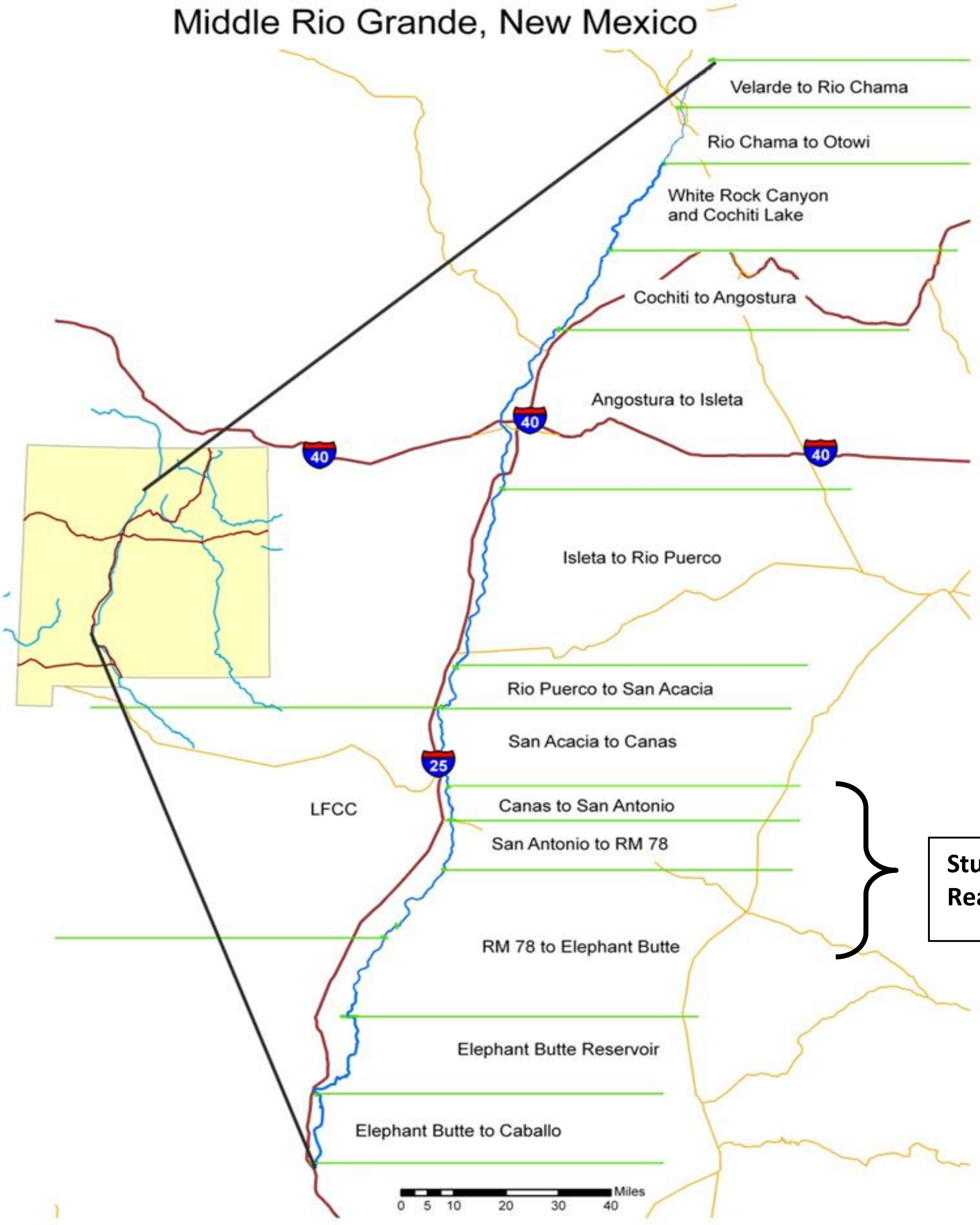


(Park and Julien, 2011)

San Acacia to the Narrows of Elephant Butte

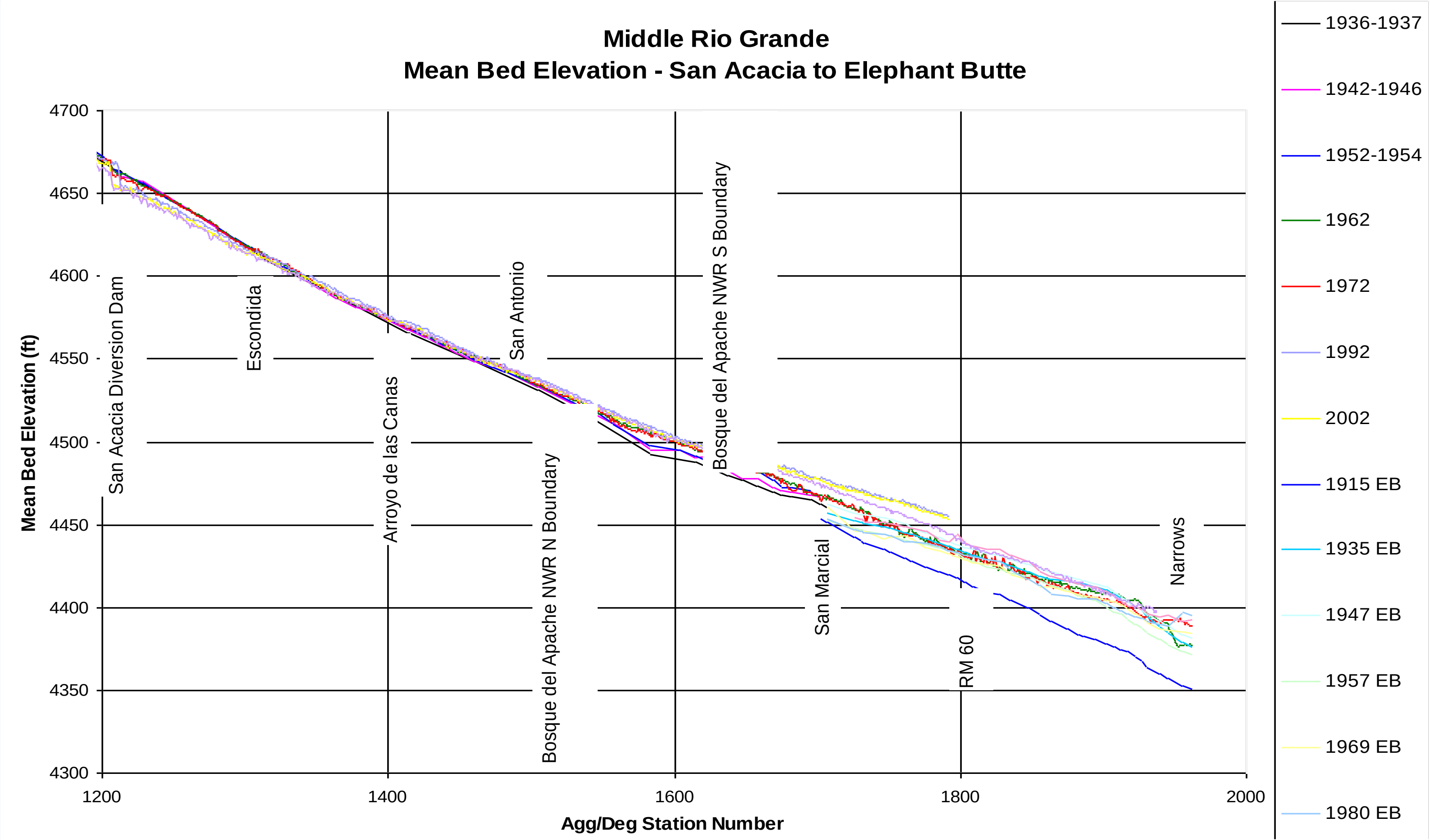
Degradation, Aggradation and Delta Deposition Processes

Location



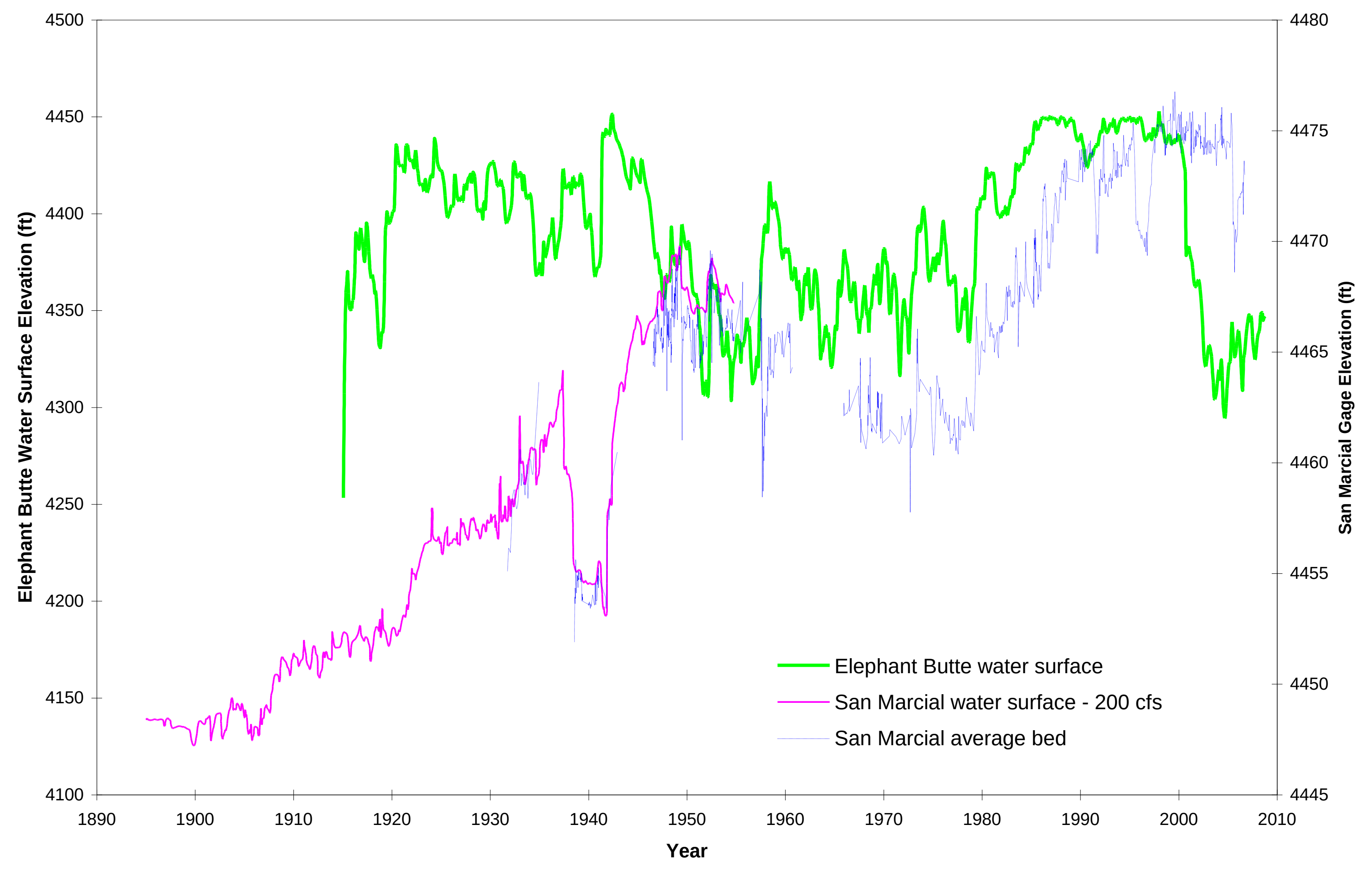
Study Reach

San Acacia to Elephant Butte Longitudinal Profile

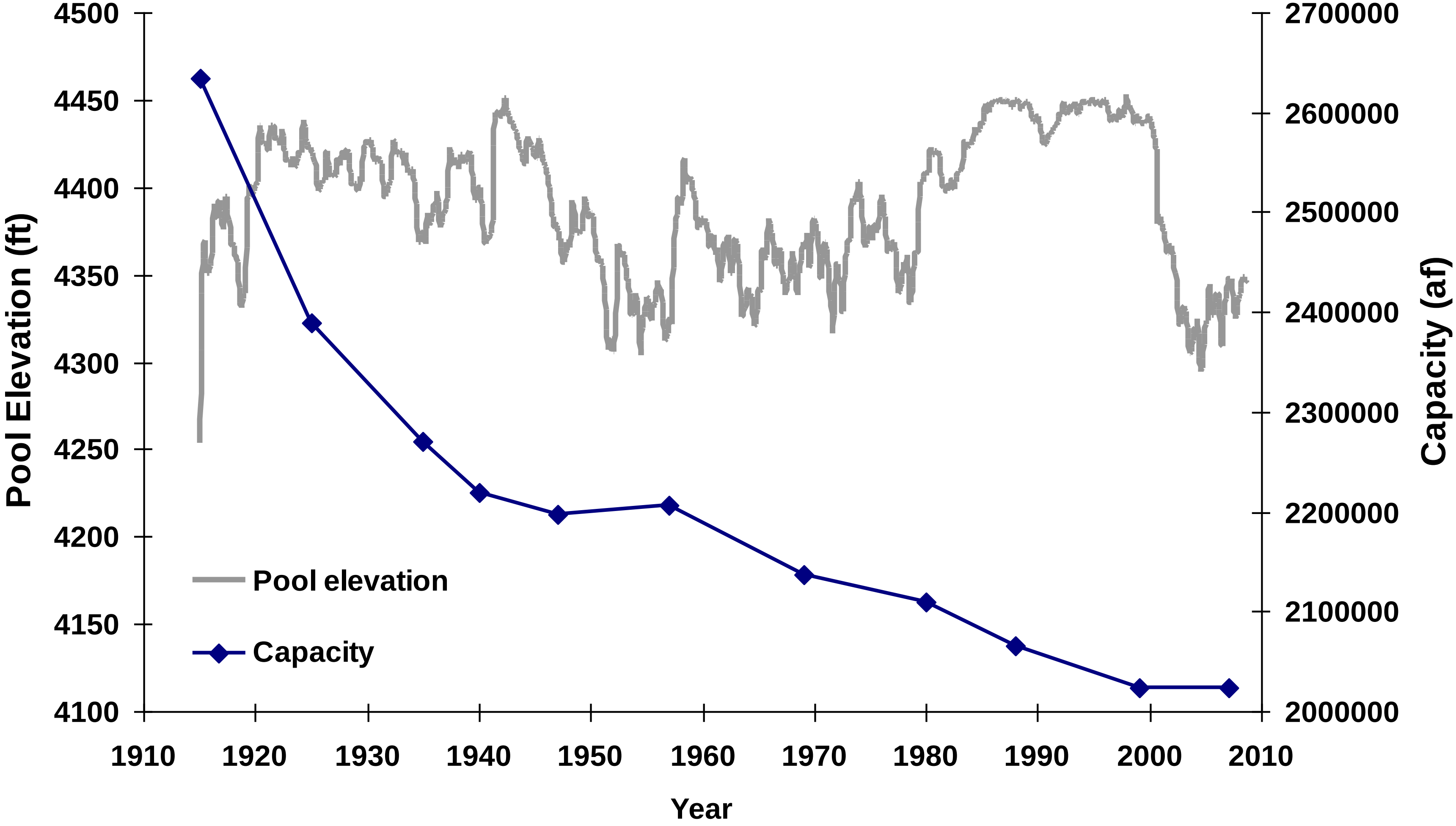


Channelization into Elephant Butte

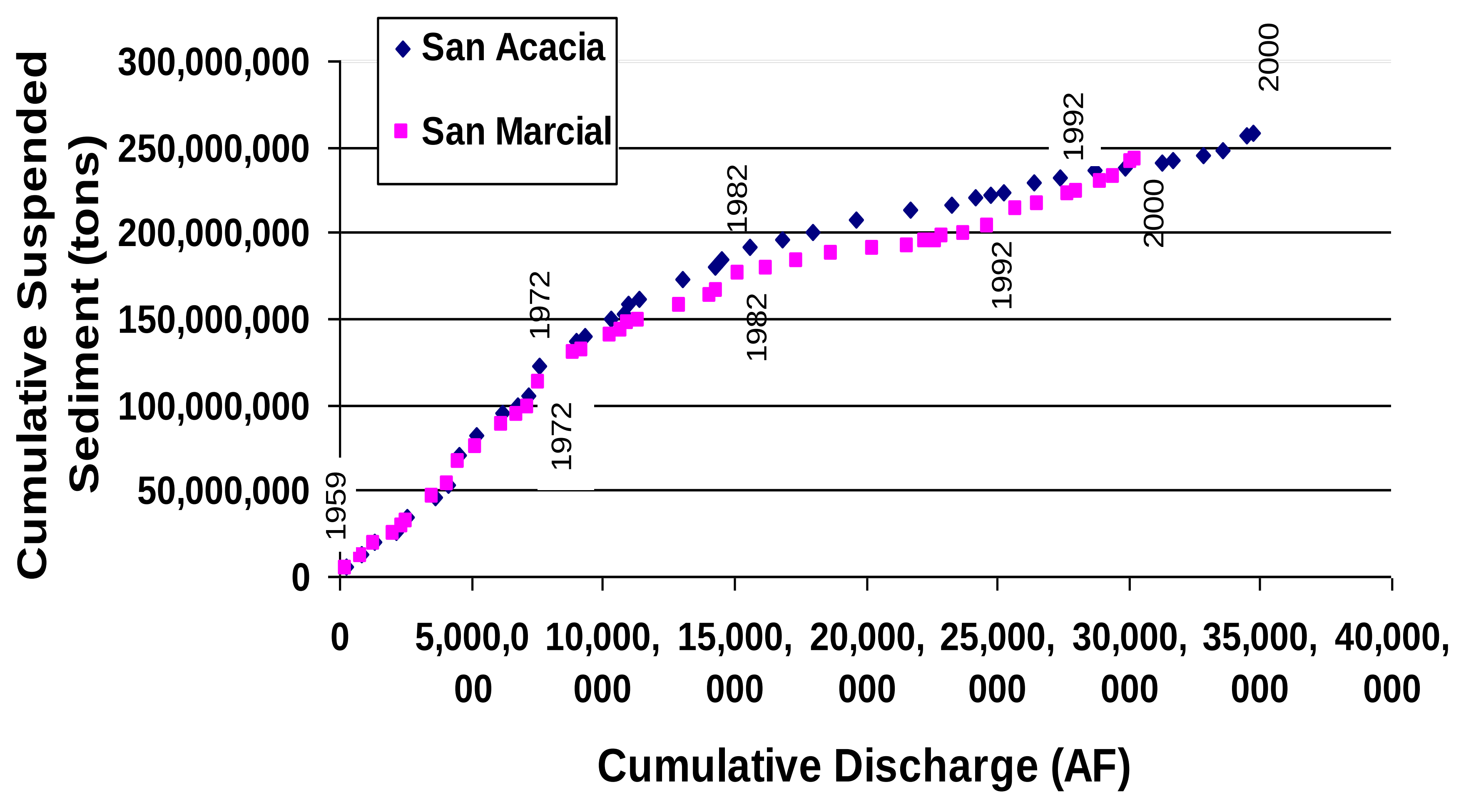
Elephant Butte and San Marcial Bed Elevations



Elephant Butte Reservoir, NM
Pool Elevation and Capacity



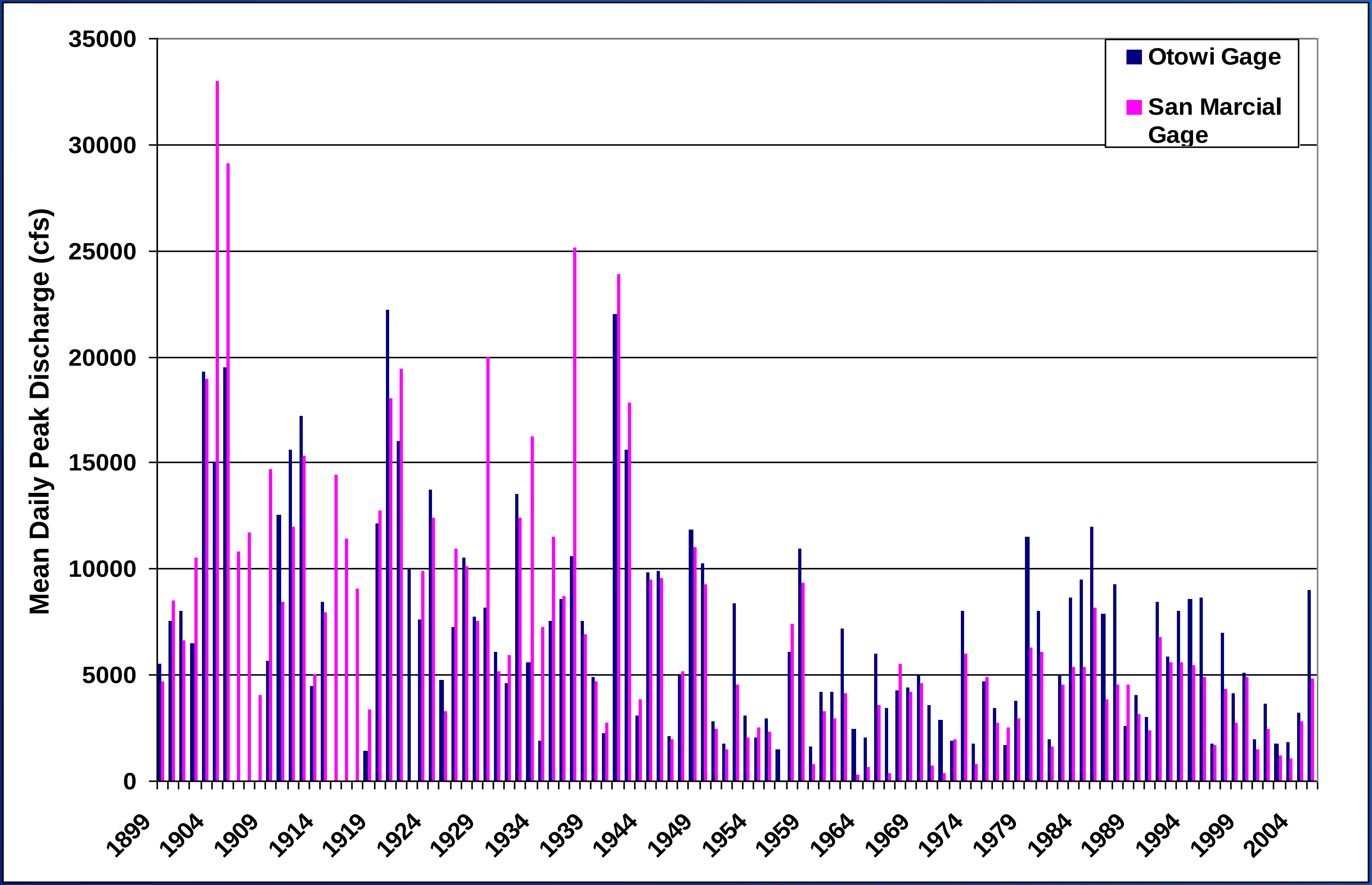
Water Sediment Relationship



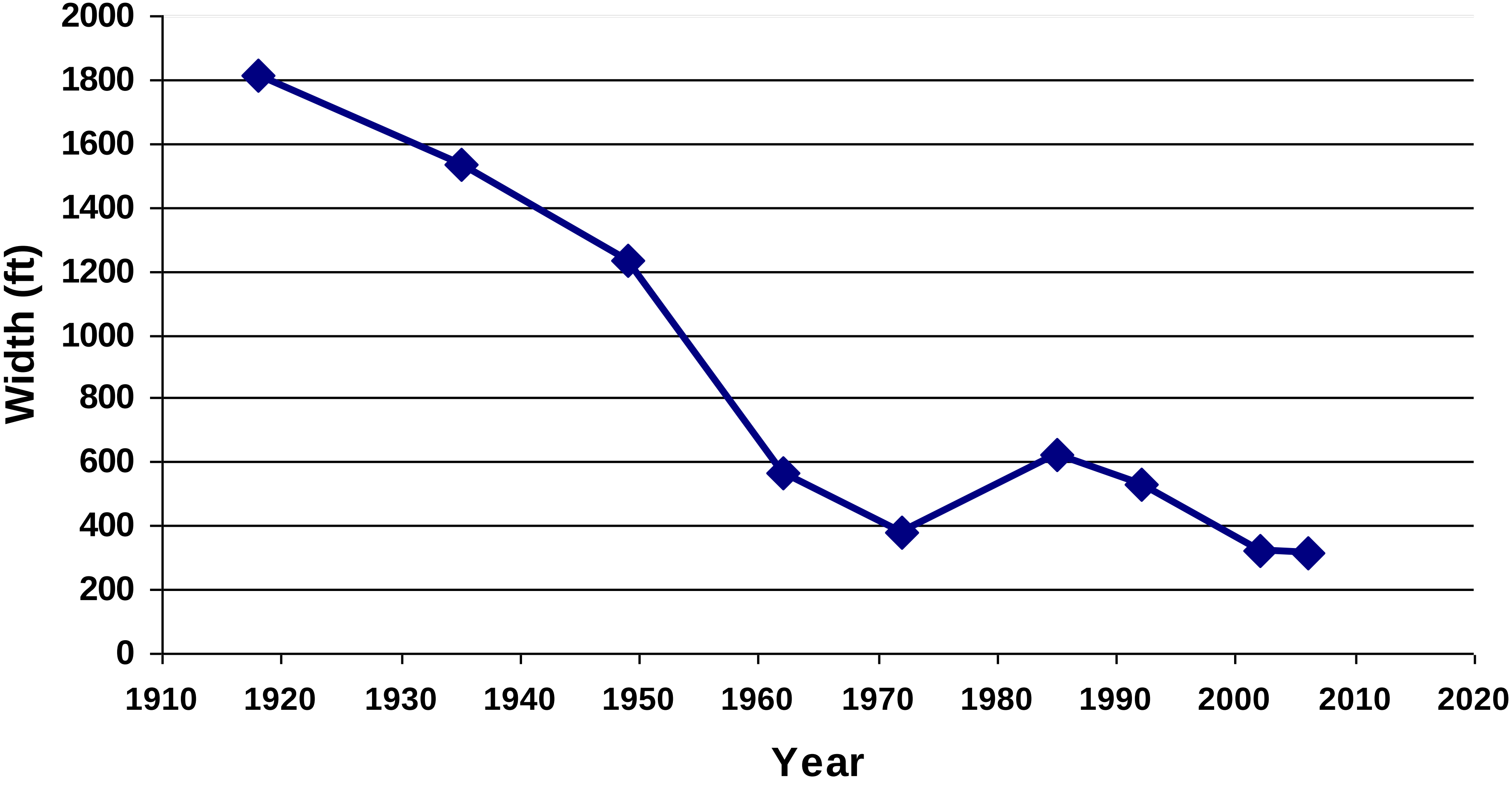
RECLAMATION

Paula Makar

Mean Daily Peak Discharge (cfs)



Rio Grande Reach Mean Channel Width
San Acacia to San Marcial General Narrowing Trend
between 1918 and 2008---Snapshot in Time



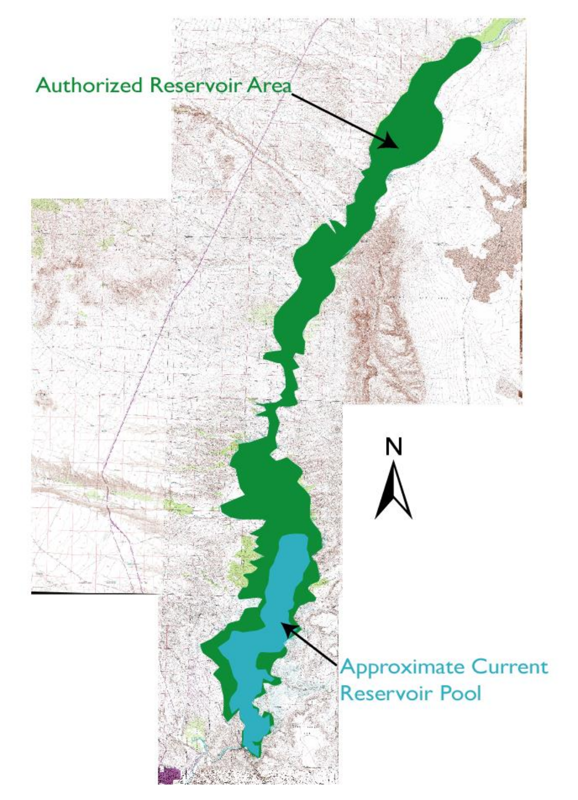
Elephant Butte Delta

Late 1990's

2001

Amphibious Excavators Operate in 1 psf soil conditions

Temporary Channel Sediment Deposition



Thank you!
Question/Discussion

BUREAU OF RECLAMATION

Washington State Salmon Recovery and Fish Passage

Examples of restoration

RECLAMATION

Salmon Recovery Columbia River Basin

- Multi-Agency Approach
- COE Passage at Large Dams
- BPA Water Operations and Funding some Restoration
- Reclamation Passage in tributary diversions
- Reclamation Main channel Habitat Restoration

RECLAMATION


03/02/2005

03/02/2005

RECLAMATION

RECLAMATION

RECLAMATION


03/02/2005

RECLAMATION

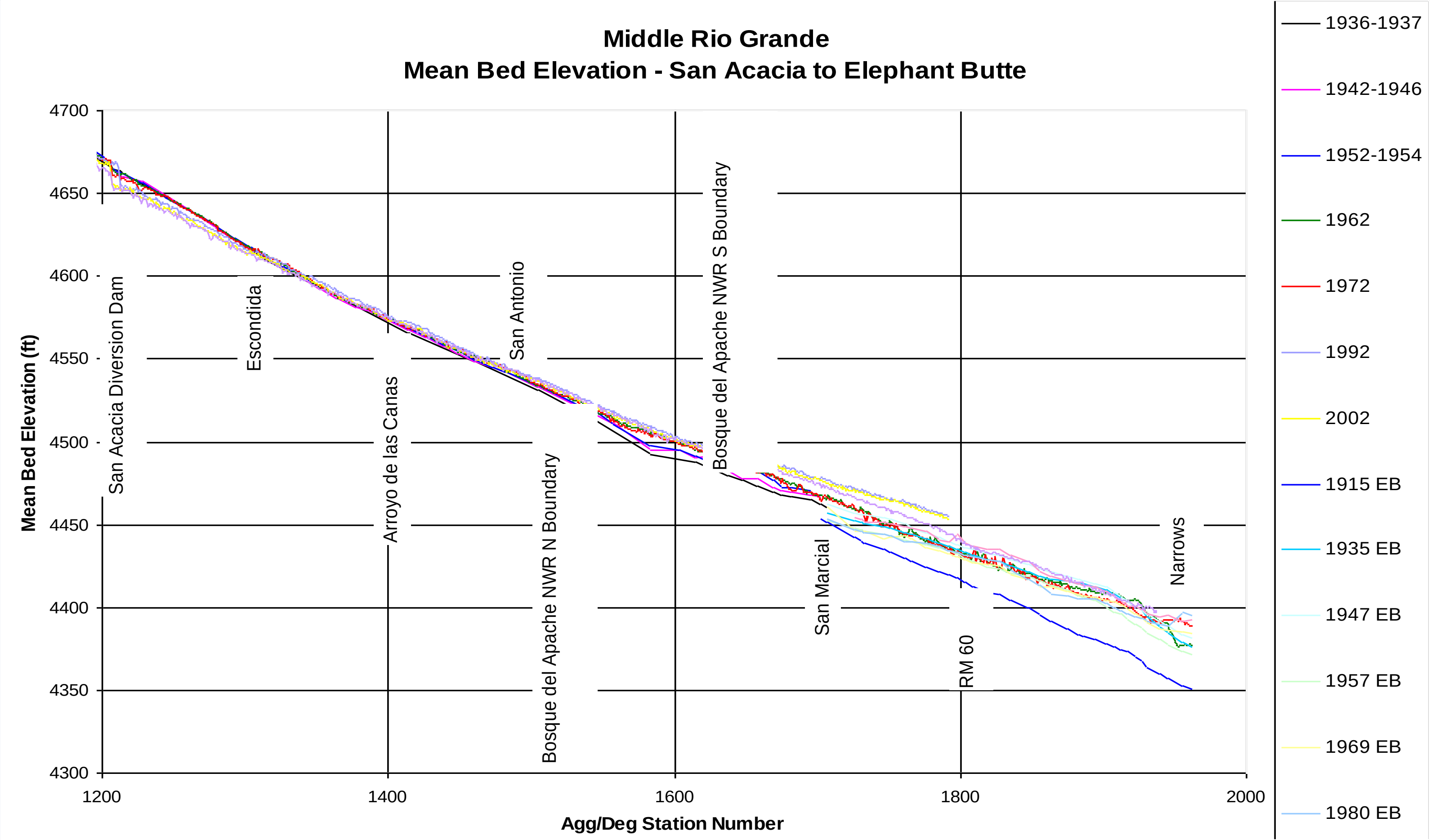
02/28/2005


03/01/2005

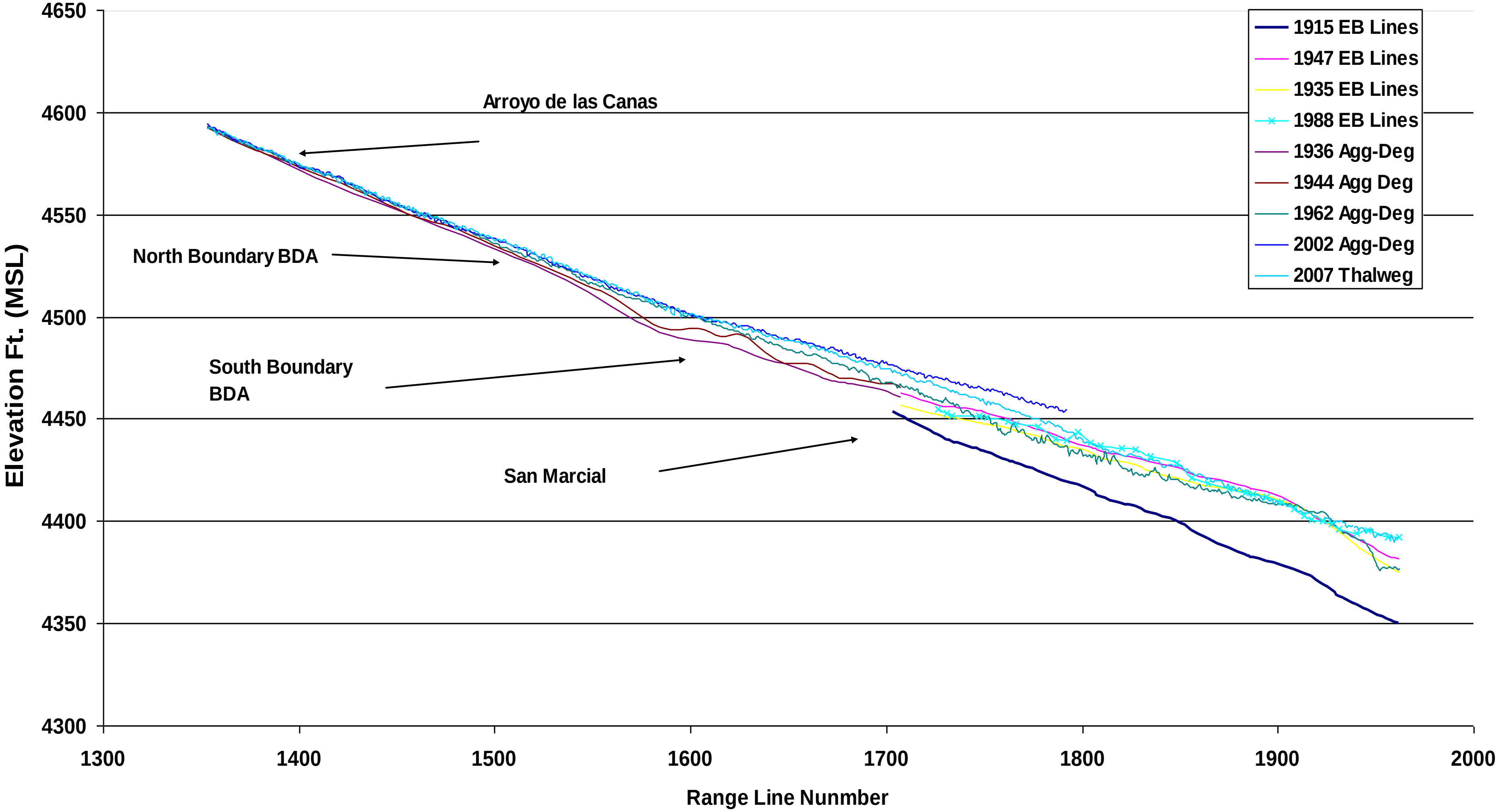
RECLAMATION

RECLAMATION

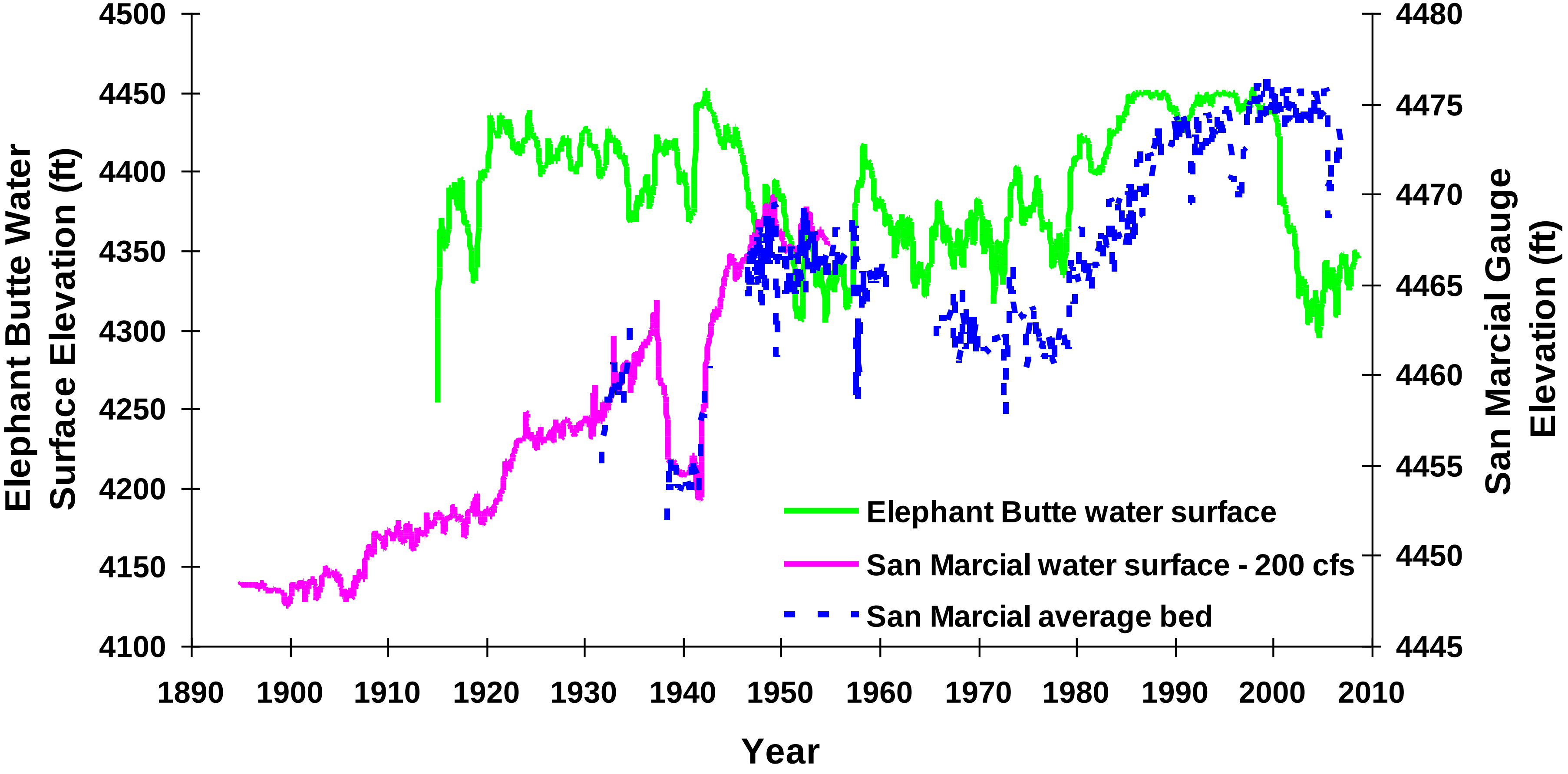
This one showing less data Lower Reach Channel Degradation



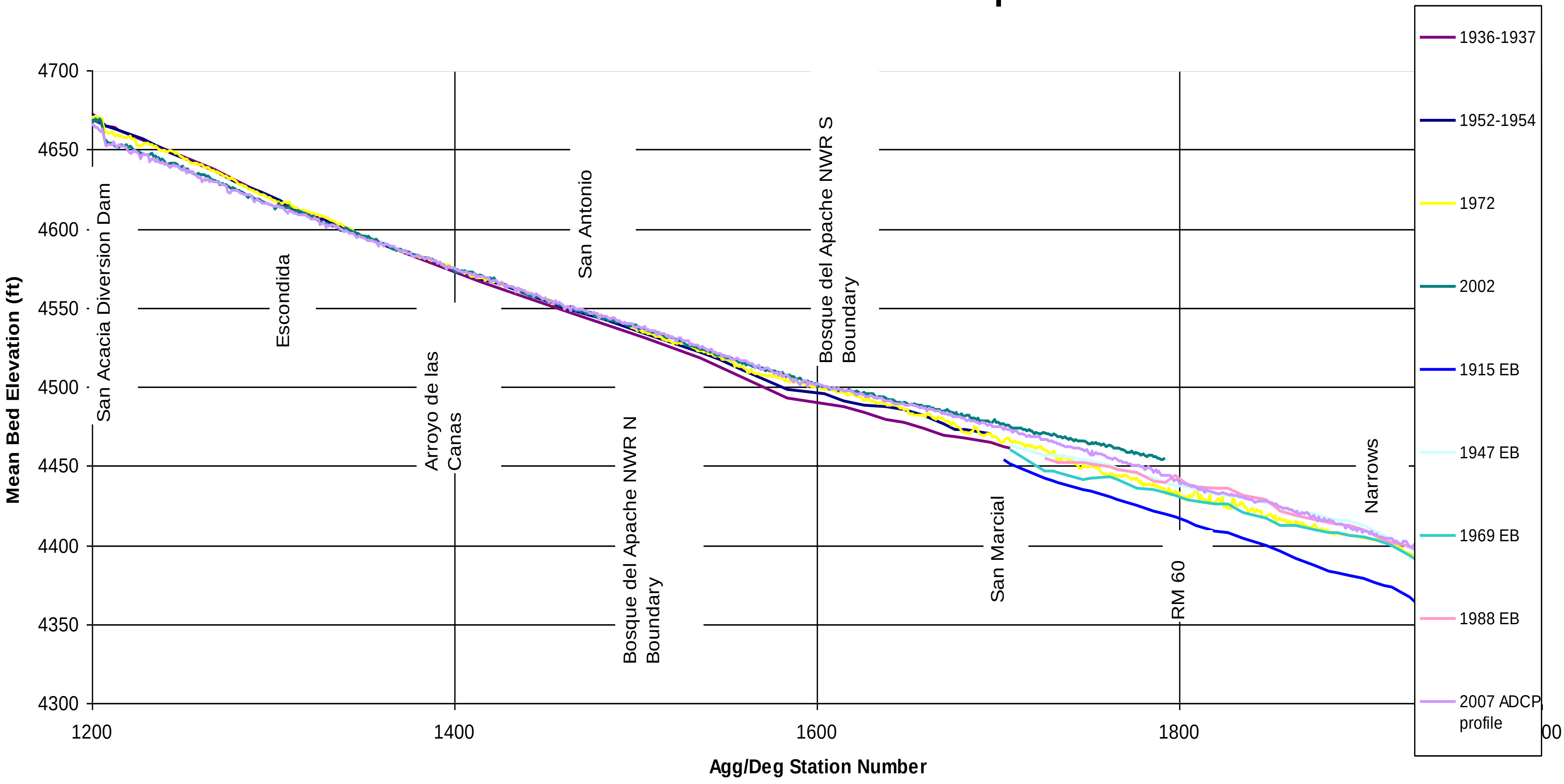
Profile Arroyo de las Canas to the Narrows of Elephant Butte Reservoir



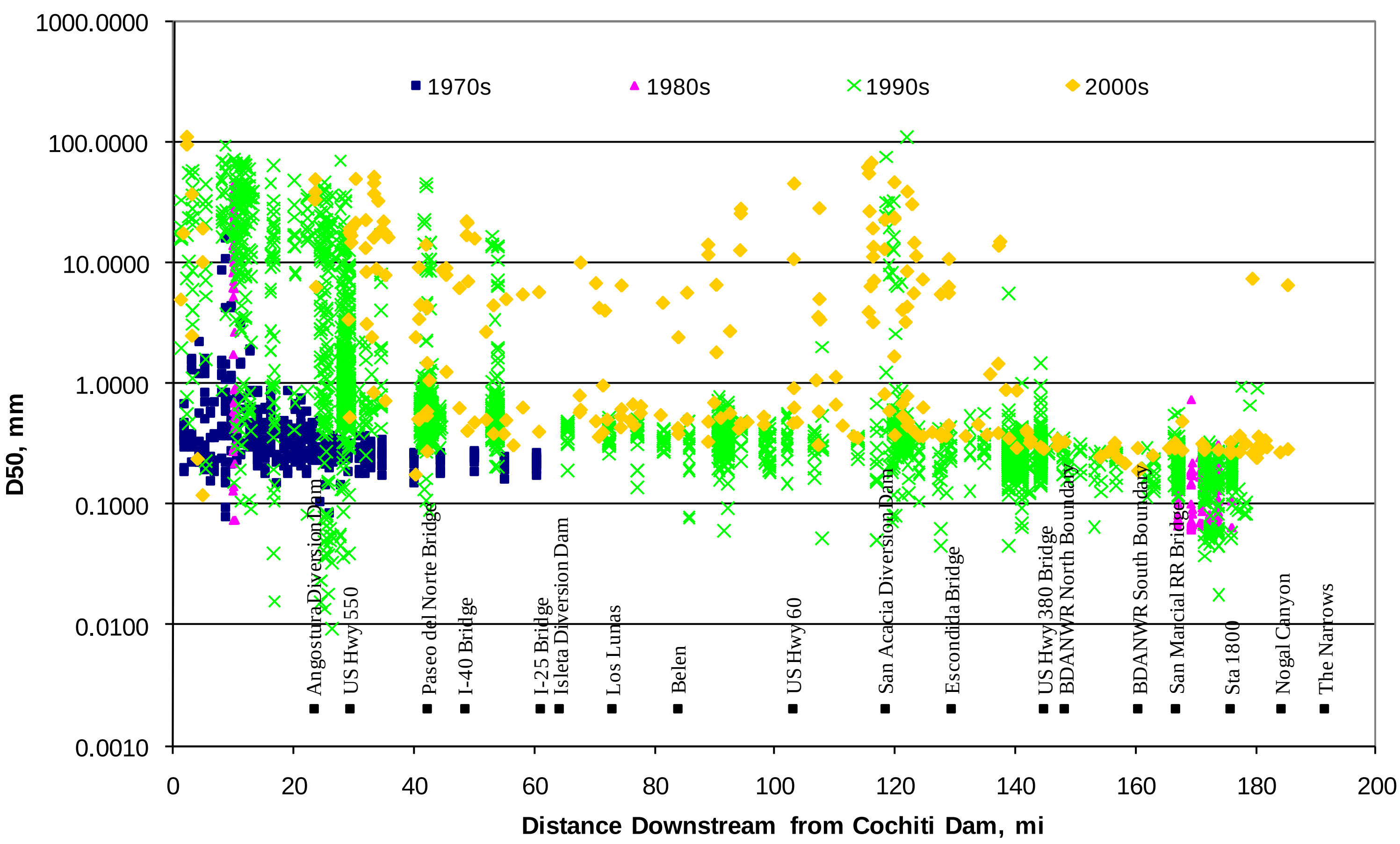
Middle Rio Grande San Marcial Gauge Elevations and Elephant Butte Water Surface Elevation



Middle Rio Grande
Mean Bed Elevation - San Acacia to Elephant Butte



Spatial and Temporal Variation of Median Bed Material Size

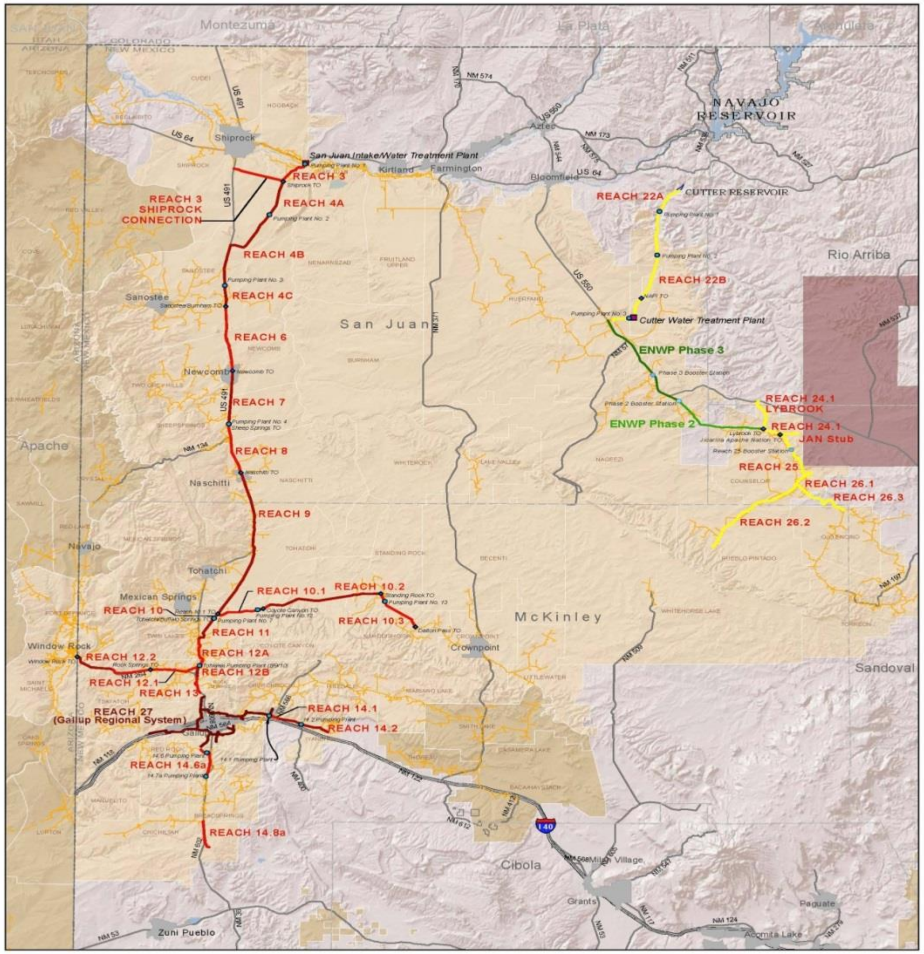


Bauer 2009

RECLAMATION

Navajo-Gallup Water Supply Project

- 280 miles of pipeline
- Several pumping plants
- Two water treatment plant
- About 37,700 Acre-Ft. of water
- Water for about 250,000 people
  - Main water supply for Navajo Nation
  - Augment City of Gallup NM Water Supply
  - Water for the Jicarilla-Apache Nation
- 48” line



LEGEND

- 🟥 San Juan Lateral
- ▬ Gallup Regional System
- 🟨 Cutter Lateral
- 🟩 Eastern Navajo Water Pipeline (ENWP) Phase 2
- 🟩 Eastern Navajo Water Pipeline (ENWP) Phase 3
- ■ Water Treatment Plant
- ● Pumping Plant
- ◆ Turnout
- ▬ Navajo Tribal Utility Authority Distribution System
- ▨ Jicarilla Apache Nation (JAN)
- ▨ Navajo Nation Serviced Chapters
- ▨ Navajo Nation Non-Serviced Chapters

Navajo Gallup Water Supply Project

RECLAMATION
Managing Water in the West

Note: Pumping Plant numbers reflect FEIS designations. Some pumping plants in original FEIS design have been combined and/or eliminated as a result of additional analyses and optimization studies.

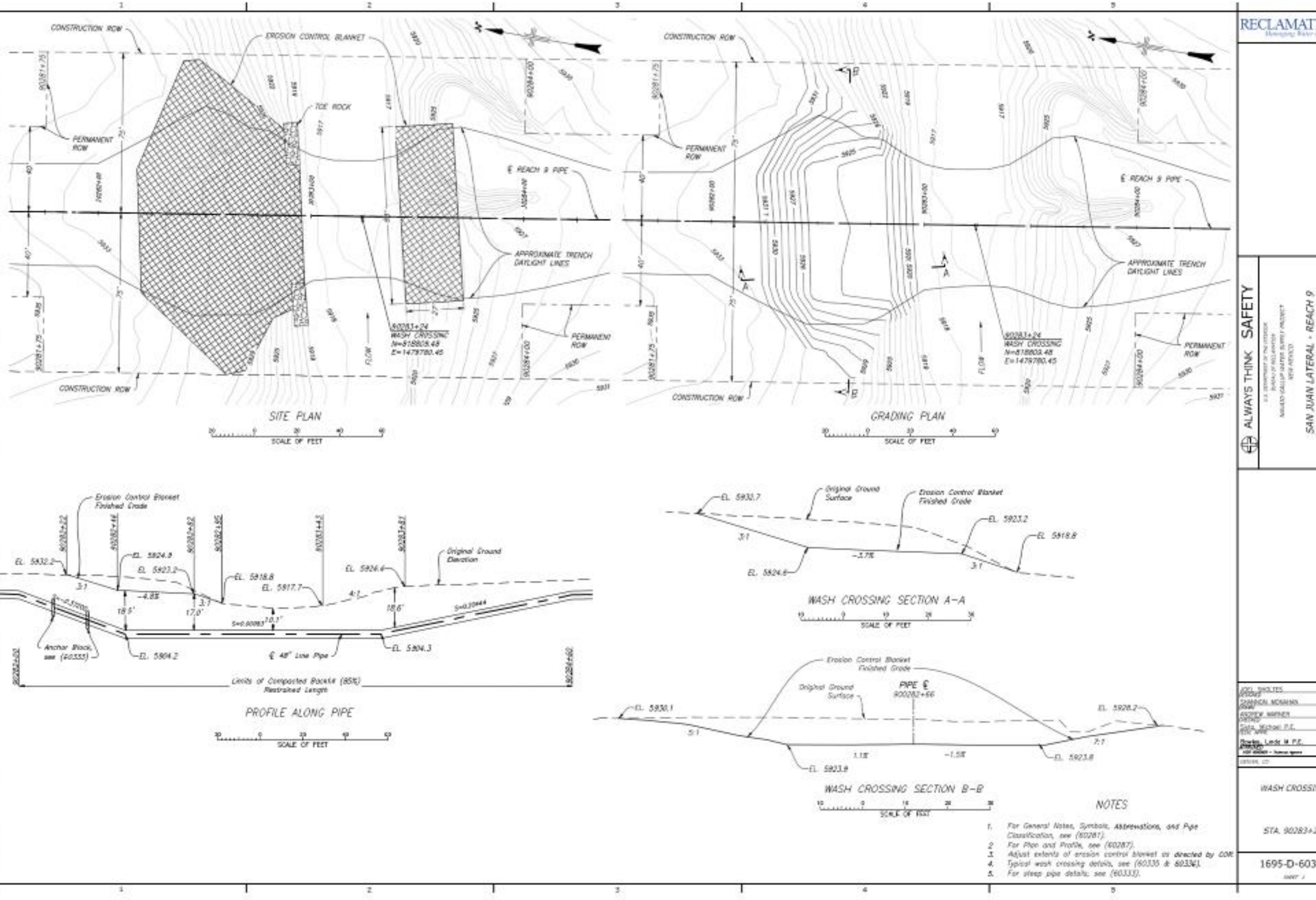
Disclaimer: Not for construction purposes. Alignment may be refined as designs and field reviews are completed.

N

0 5 10 15 20 30
Miles

NAVAJO GALLUP WATER SUPPLY PROJECT

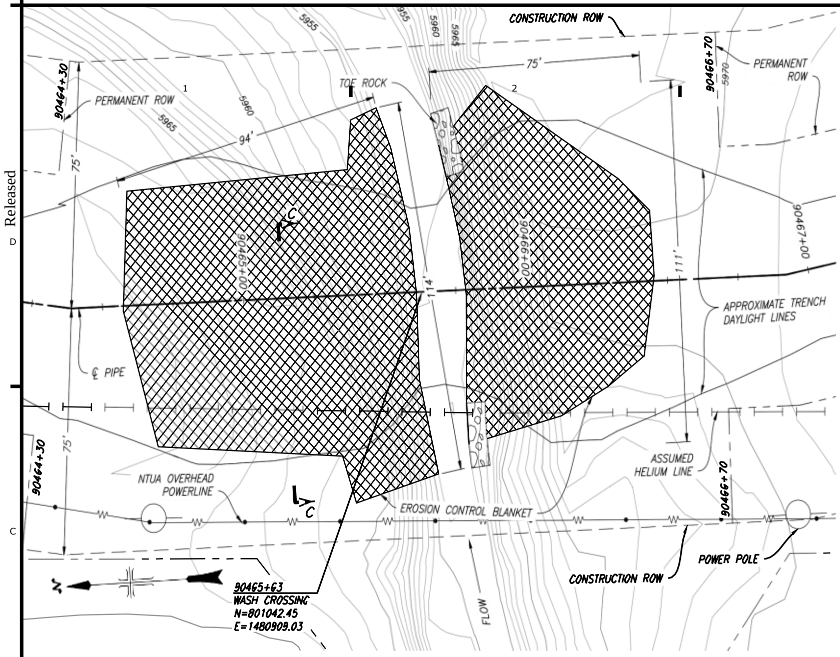
1695-529-537
Last Update: April 28, 2015
Print Date: 4/28/2015



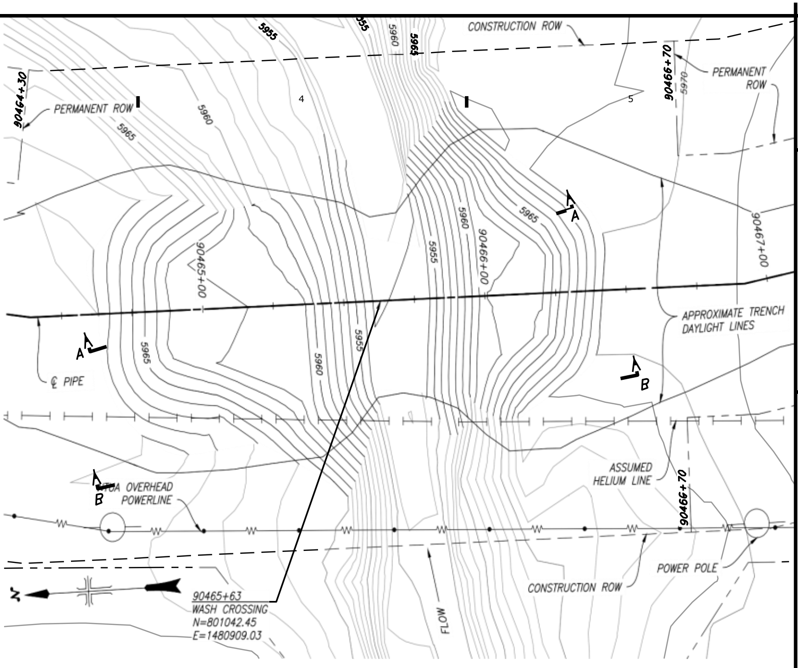
NOTES

1. For General Notes, Symbols, Abbreviations, and Pipe Classification, see (60281).
2. For Plan and Profile, see (60287).
3. Adjust extents of erosion control blanket as directed by COR.
4. Typical wash crossing details, see (60335 & 60336).
5. For steep pipe details, see (60333).

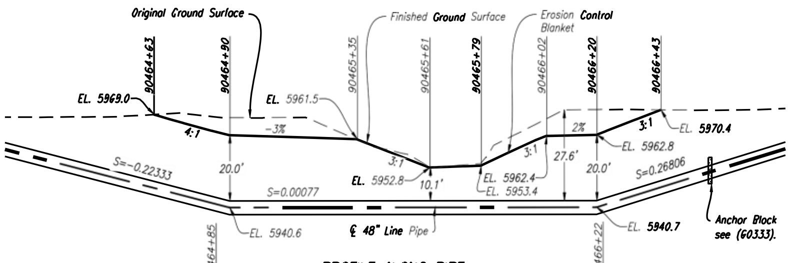
Released



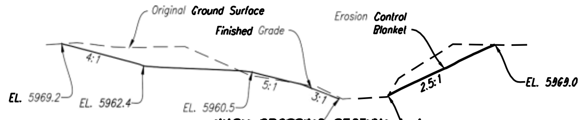
SITE PLAN



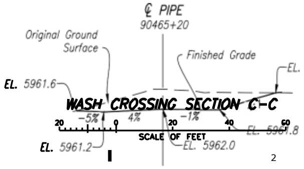
GRADING PLAN



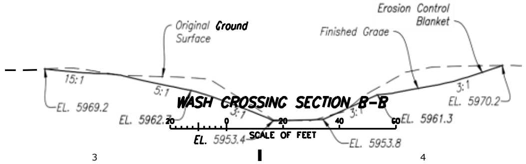
PROFILE ALONG PIPE



WASH CROSSING SECTION A-A



WASH CROSSING SECTION C-C



WASH CROSSING SECTION B-B

NOTES

1. For General Notes, Symbols, **Abbreviations, and Pipe** Classification, see (60281).
2. For Plan and Profile, see (60291).
3. Adjust extents of erosion control blanket **as directed** by COR.
4. For typical wash crossing details, see (60335 **&** 60336).
5. For steep pipe details, see (60333).

RECLAMATION
Managing Water in the West

ALWAYS THINK SAFETY

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
NAVAJO-GALLUP WATER SUPPLY PROJECT
NEW MEXICO

SAN JUAN LATERAL - REACH 9

LINE PIPE

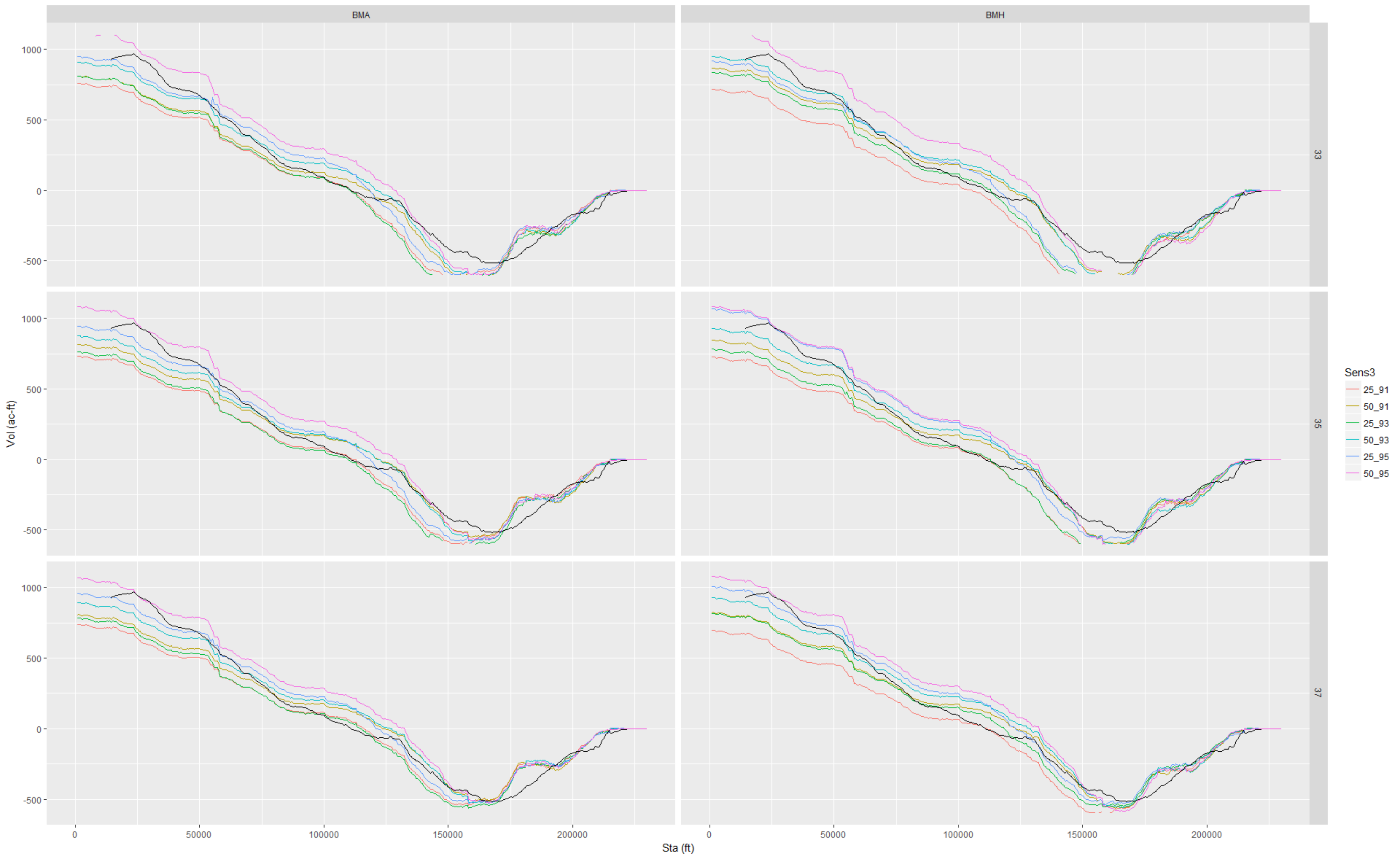
JOEL SHOLTES
DESIGNED
SHANNON MONAHAN
DRAWN
ANDREW MARNER
CHECKED
Sixta, Michael P.E.
TECH. APPR.
Bowles, Linda M. P.E.
APPROVED
PEER REVIEWER - Technical Approve

WASH CROSSING

STA 90465+63

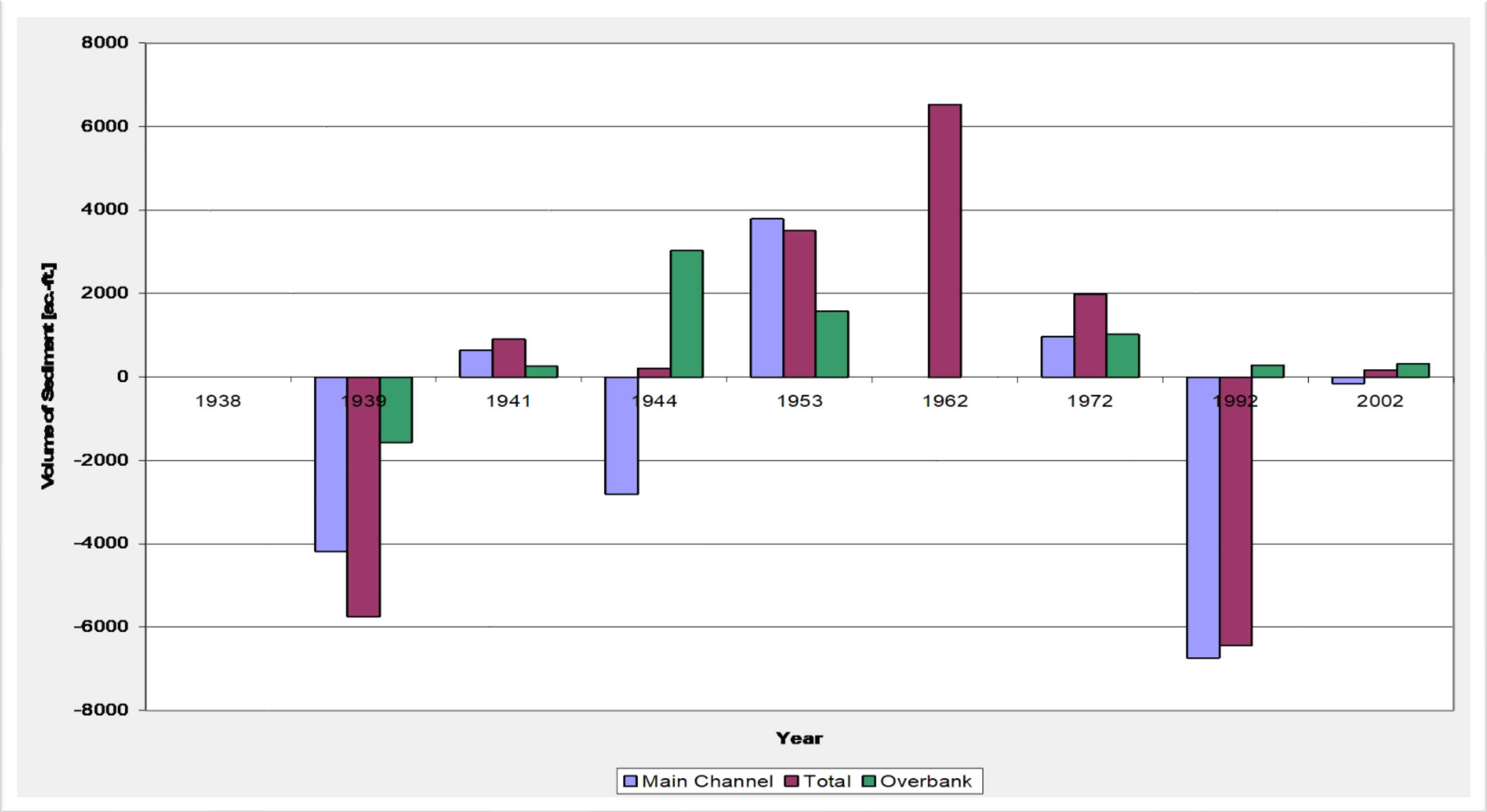
1695-D-60349

SHEET 1


BMA
BMH
33
35
37
Vol (ac-ft)
1000
500
0
-500
Sta (ft)
0
50000
100000
150000
200000
Sens3
25_91
50_91
25_93
50_93
25_95
50_95

Varyu (2018)

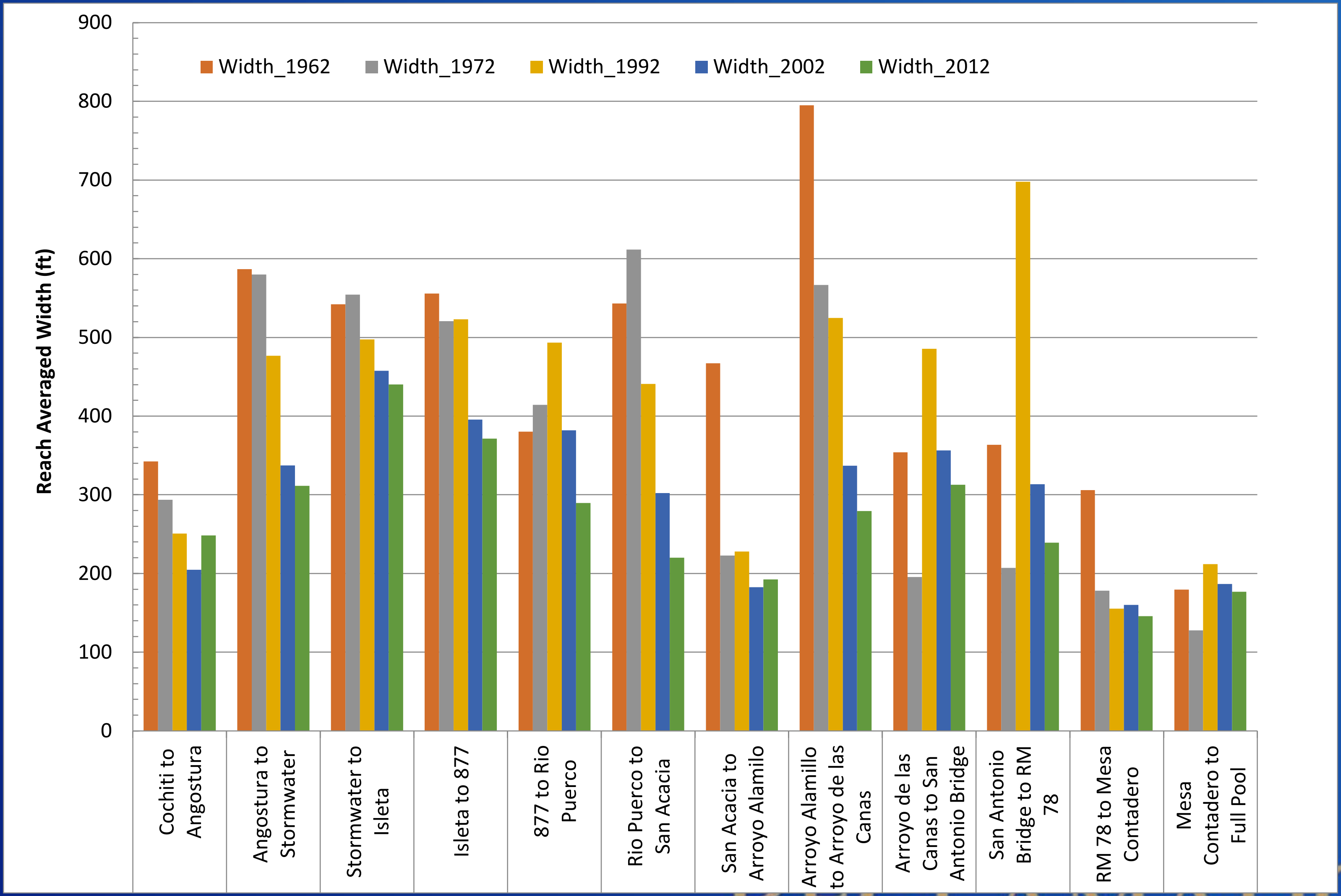
Belen Reach-Isleta to San Acacia Aggradation/Degradation 1936 to 2002



1936 to 1972 generally aggradational

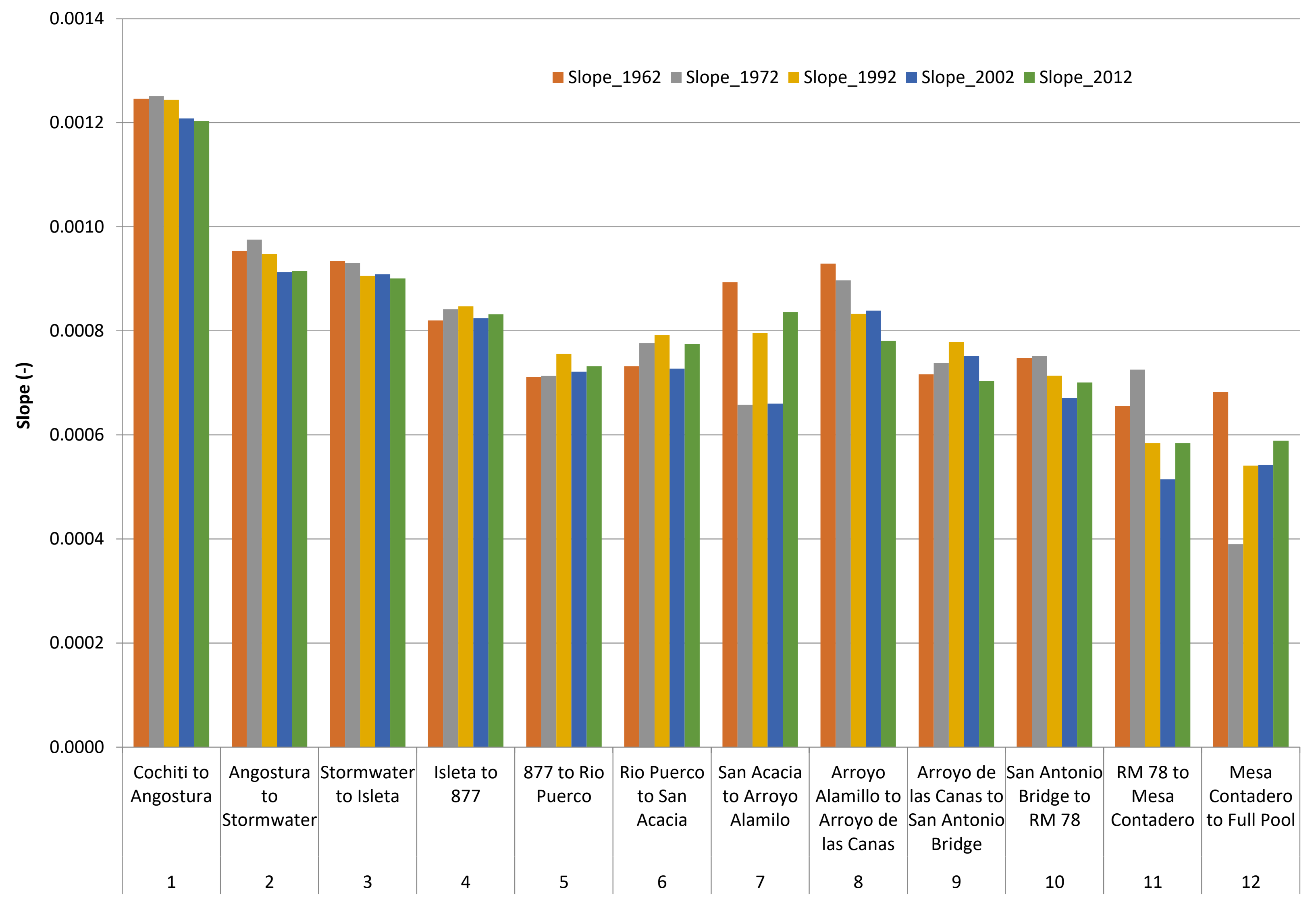
Degradation since 1972, except between 1992 and 2002, slight main channel degradation and overbank deposition.

Width (W)

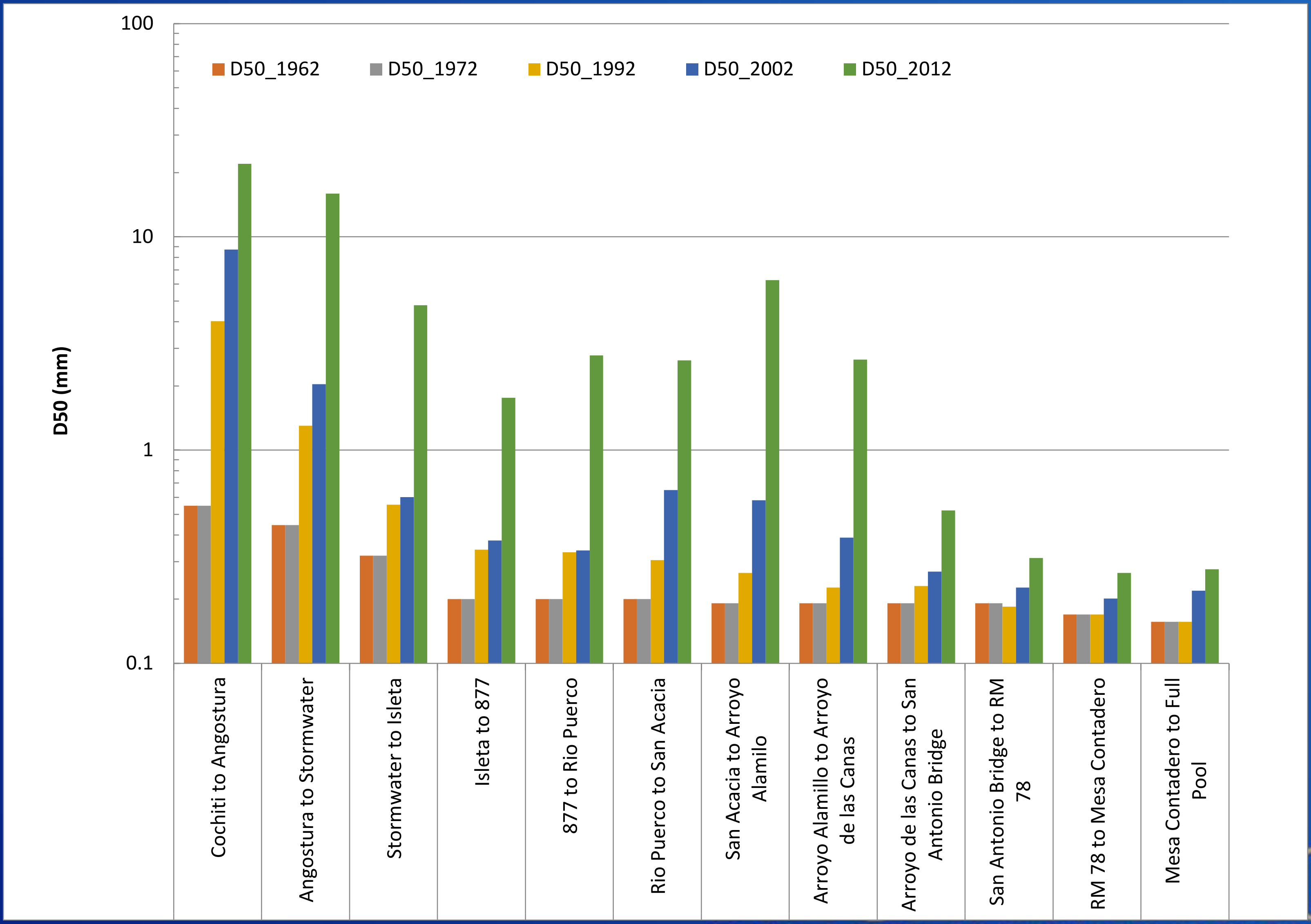


RECLAMATION

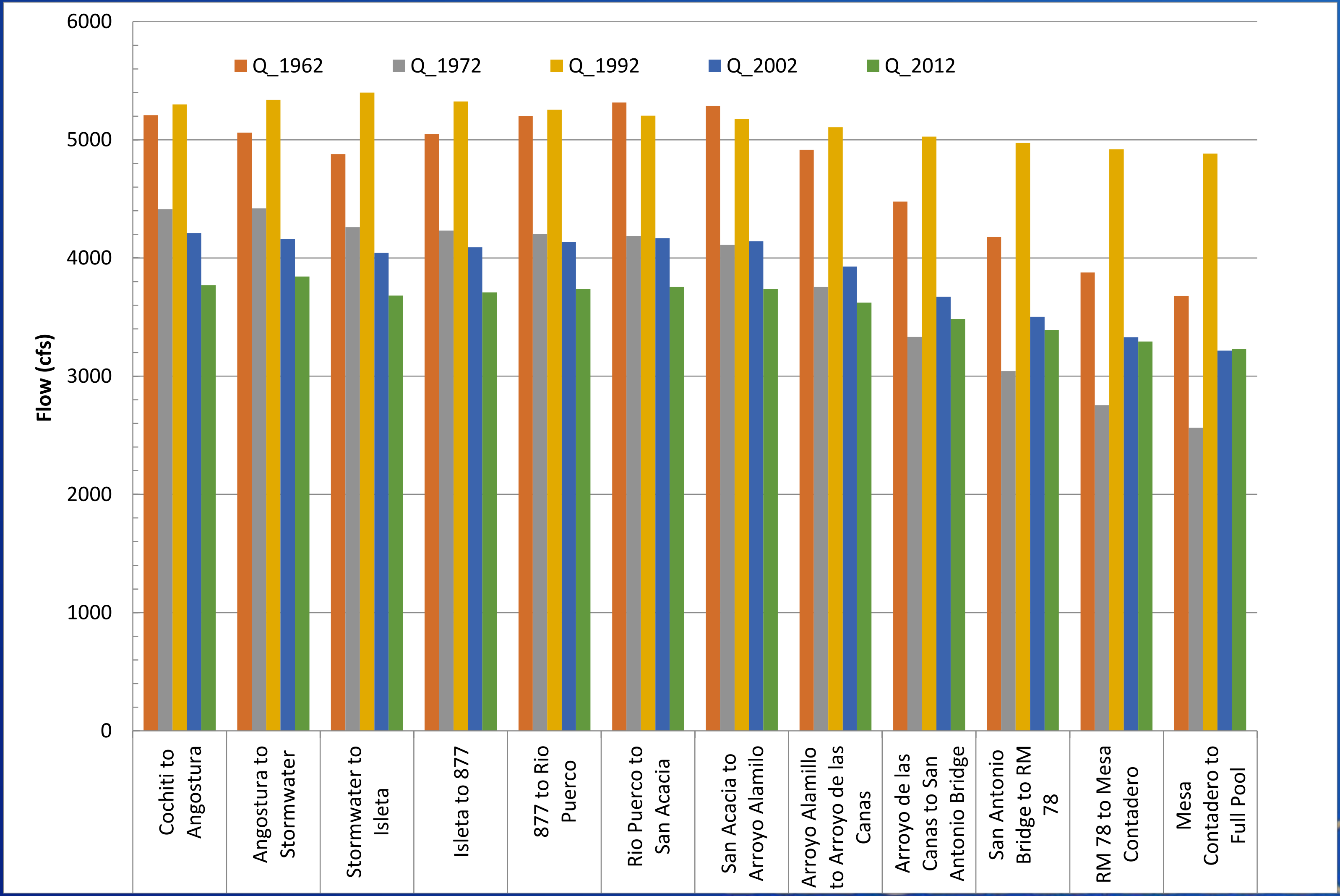
Slope (S)


0.0014
0.0012
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
Slope (-)
Slope_1962
Slope_1972
Slope_1992
Slope_2002
Slope_2012
Cochiti to Angostura
1
Angostura to Stormwater
2
Stormwater to Isleta
3
Isleta to 877
4
877 to Rio Puerco
5
Rio Puerco to San Acacia
6
San Acacia to Arroyo Alamilo
7
Arroyo Alamillo to Arroyo de las Canas
8
Arroyo de las Canas to San Antonio Bridge
9
San Antonio Bridge to RM 78
10
RM 78 to Mesa Contadero
11
Mesa Contadero to Full Pool
12

Median Diameter (D50)



Flow (Q)



6000
5000
4000
3000
2000
1000
0
Flow (cfs)
Q_1962
Q_1972
Q_1992
Q_2002
Q_2012
Cochiti to Angostura
Angostura to Stormwater
Stormwater to Isleta
Isleta to 877
877 to Rio Puerco
Rio Puerco to San Acacia
San Acacia to Arroyo Alamilo
Arroyo Alamillo to Arroyo de las Canas
Arroyo de las Canas to San Antonio Bridge
San Antonio Bridge to RM 78
RM 78 to Mesa Contadero
Mesa Contadero to Full Pool