COTTON LANE BRIDGE / KING RANCH
FLOODPLAIN REDELINEATION
GILA RIVER
GOODYEAR, ARIZONA

Prepared for:

S.D. Construction, L.L.C.

3040 N. 44th St, Suite 3
Phoenix, AZ 85018

Prepared by:

River Research & Design, Inc.
1345 E. Spur Ave
Gilbert, AZ 85296-1929

September 2006

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1. Introduction

The channel design team was tasked by S. D. Construction, LLC (SDC) in conjunction with Sontera Partners, LLC (Sontera), Maricopa County, the City of Goodyear and Estrella Mountain Ranch to assist in the design of a road crossing and associated bank protection. Additionally the team was asked to evaluate possible encroachment into the Gila River floodplain and floodway for approximately three and one half miles of riverbank immediately west of the Estrella Parkway Bridge along the north and south side of the river as shown in Figure 1. The channel design team has involved WEST Consultants, Inc. (WEST), Coe & Van Loo Consultants (CVL), and River Research & Design, Inc (R_2D). The property on the south side of the river is noted as the King Ranch property while that on the north bank is the Lakin property.

The purposes of this study were 1) to support the design of the Cotton Lane Bridge and to shorten the proposed bridge such that it could be economically built and 2) determine how much of the King Ranch and Lakin property along the river could be developed while recognizing the importance of river geomorphology as well as the function and value of this reach of river and 3) to prepare a Technical Data Notebook (TDN) submittal package and a Conditional Letter of Map Revision (CLOMR) submittal package.

1.1 Study Area

The approximately 5-mile long study reach of the Gila River is located in Maricopa County and the City of Goodyear, Arizona immediately downstream from the Estella Parkway Bridge. The area modeled in both hydraulic and sediment transport models extends approximately from the Agua Fria River confluence downstream to west of Tuthill Road. Figure 1 shows the project vicinity and Figure 2 shows the aerial photograph and the location of the King Ranch and Lakin Properties. The Agua Fria River is the first major tributary (not analyzed in this study) of Gila River below its confluence with the Salt River in Phoenix.

The Gila River in this reach currently consists of a braided system with three bridges at Bullard Avenue, Estrella Parkway and Tuthill Road in the study reach. The Bullard Avenue Bridge and Estrella Parkway Bridge are located approximately 4 miles and 5 miles downstream from the Salt-Gila confluence, respectively. The condition of the vegetation in the channel and floodplain has a high spatial variability, ranging from non-existent to extremely dense over very short distances.

1.2 The Project

The project consists of approximately 3.5 miles of bank protection along the south bank, 1.5 miles of protection on the north bank, construction of the Cotton Lane Bridge, and removal of material from the channel to improve flow characteristics of the river through the bridge.

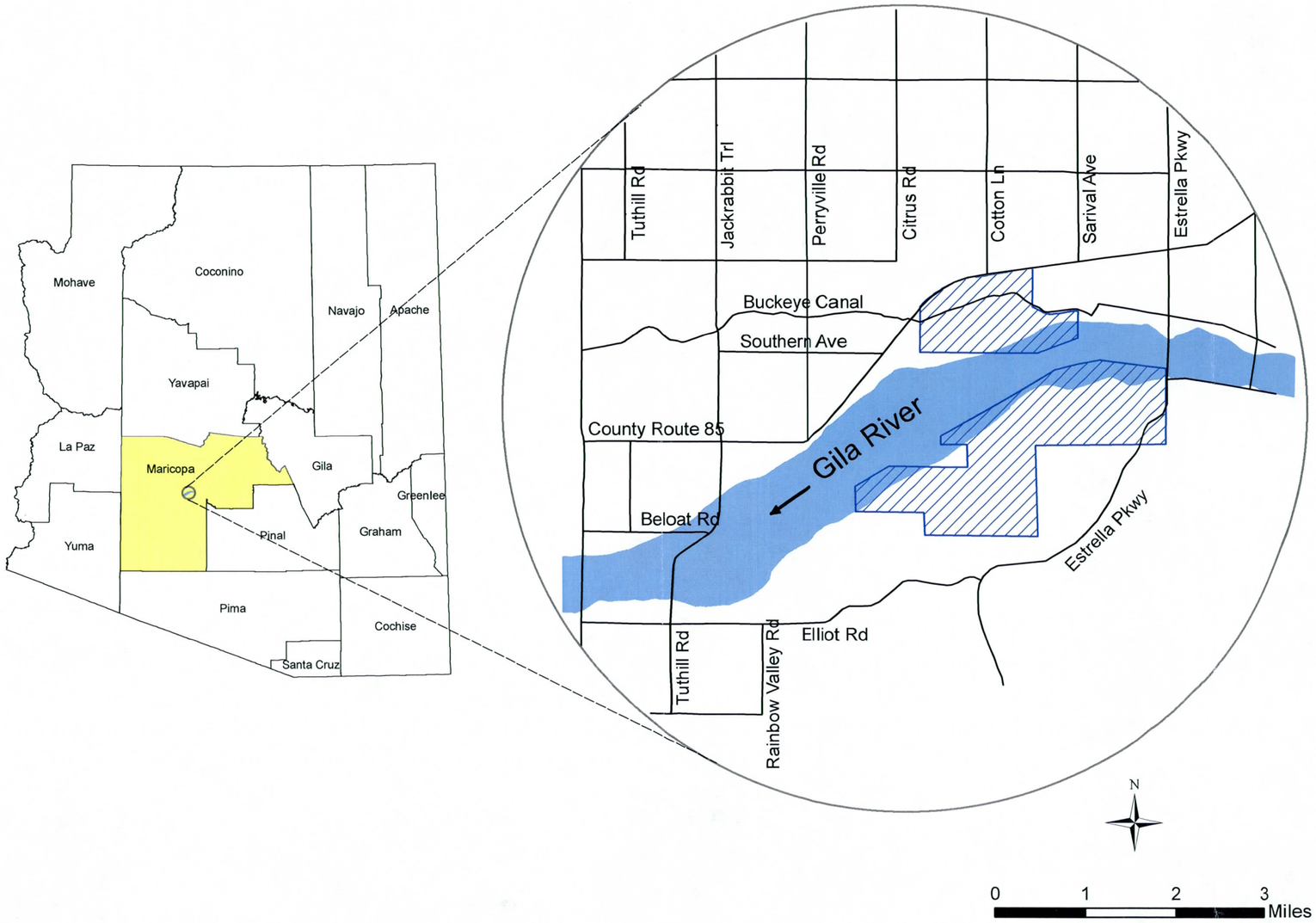

Figure 1. Project Vicinity Map

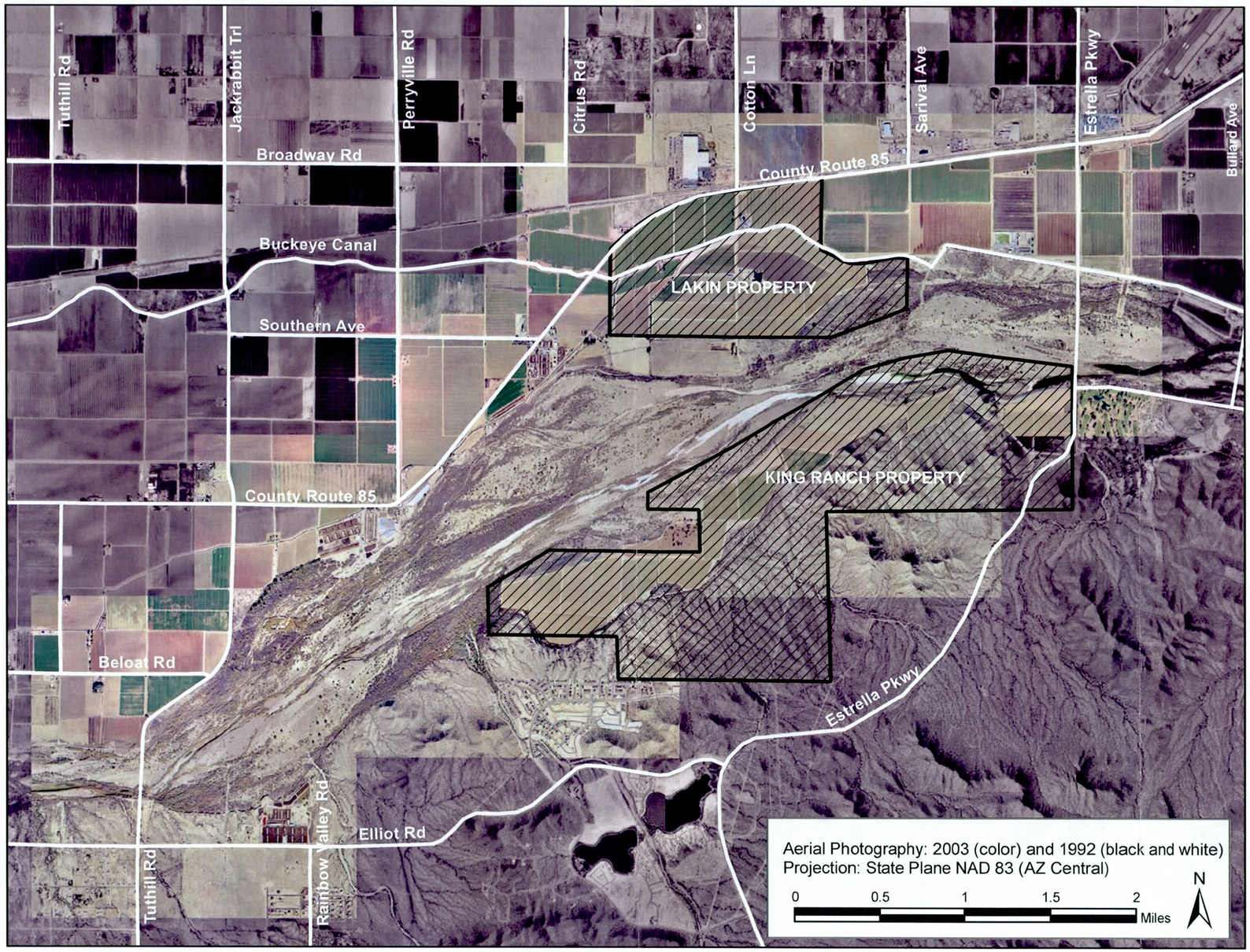

Figure 2. Area Map Showing Project Location and Surrounding Features

2. **FEMA Forms**

FEDERAL EMERGENCY MANAGEMENT AGENCY

OVERVIEW & CONCURRENCE FORM

O.M.B No. 3067-0148
Expires September 30, 2005

PAPERWORK BURDEN DISCLOSURE NOTICE

Public reporting burden for this form is estimated to average 1 hour per response. The burden estimate includes the time for reviewing instructions, searching existing data sources, gathering and maintaining the needed data, and completing, reviewing, and submitting the form. You are not required to respond to this collection of information unless a valid OMB control number appears in the upper right corner of this form. Send comments regarding the accuracy of the burden estimate and any suggestions for reducing this burden to: Information Collections Management, Federal Emergency Management Agency, 500 C Street, SW, Washington DC 20472, Paperwork Reduction Project (3067-0148). Submission of the form is required to obtain or retain benefits under the National Flood Insurance Program. **Please do not send your completed survey to the above address.**

A. REQUESTED RESPONSE FROM FEMA

This request is for a (check one):

☒ CLOMR: A letter from FEMA commenting on whether a proposed project, if built as proposed, would justify a map revision, or proposed hydrology changes (See 44 CFR Ch. 1, Parts 60, 65 & 72).

☐ LOMR: A letter from FEMA officially revising the current NFIP map to show the changes to floodplains, regulatory floodway or flood elevations. (See Parts 60 & 65 of the NFIP Regulations.)

B. OVERVIEW

1. The NFIP map panel(s) affected for all impacted communities is (are):

Community No.	Community Name	State	Map No.	Panel No.	Effective Date
Ex: 480301 480287	City of Katy Harris County	TX TX	480301 48201C	0005D 0220G	02/08/83 09/28/90
040046	City of Goodyear Panels 2350G, 2550G, 2065H, 7070H	AZ	04013C	2530G	9/30/05
040037	Maricopa County Panels 2350G, 2550 G, 2065H, 7070H	AZ	04013C	2550G	9/30/05

2. Flooding Source: Gila River

3. Project Name/Identifier: Cotton Lane Bridge / King Ranch Floodplain Redelineation

4. FEMA zone designations affected: AE (choices: A, AH, AO, A1-A30, A99, AE, AR, V, V1-V30, VE, B, C, D, X)

5. Basis for Request and Type of Revision:

a. The basis for this revision request is (check all that apply)

☒ Physical Change ☒ Improved Methodology/Data

☒ Regulatory Floodway Revision ☐ Other (Attach Description)

Note: A photograph and narrative description of the area of concern is not required, but is very helpful during review.

b. The area of revision encompasses the following types of flooding and structures (check all that apply)

Types of Flooding:	☒ Riverine	☐ Coastal	☐ Shallow Flooding (e.g., Zones AO and AH)
	☐ Alluvial fan	☐ Lakes	☐ Other (Attach Description)
Structures:	☒ Channelization	☐ Levee/Floodwall	☒ Bridge/Culvert
	☐ Dam	☒ Fill	☐ Other, Attach Description

C. REVIEW FEE

Has the review fee for the appropriate request category been included? ☒ Yes Fee amount: $4000.00

☐ No, Attach Explanation

Please see the FEMA Web site at http://www.fema.gov/fhm/frm_fees.shtm for Fee Amounts and Exemptions.

D. SIGNATURE

All documents submitted in support of this request are correct to the best of my knowledge. I understand that any false statement may be punishable by fine or imprisonment under Title 18 of the United States Code, Section 1001.

Name:	Company:	
Mailing Address:	Daytime Telephone No.:	Fax No.:
	E-Mail Address:	
Signature of Requester (required):		Date:

As the community official responsible for floodplain management, I hereby acknowledge that we have received and reviewed this Letter of Map Revision (LOMR) or conditional LOMR request. Based upon the community's review, we find the completed or proposed project meets or is designed to meet all of the community floodplain management requirements, including the requirement that no fill be placed in the regulatory floodway, and that all necessary Federal, State, and local permits have been, or in the case of a conditional LOMR, will be obtained. In addition, we have determined that the land and any existing or proposed structures to be removed from the SFHA are or will be reasonably safe from flooding as defined in 44CFR 65.2(c), and that we have available upon request by FEMA, all analyses and documentation used to make this determination.

Community Official's Name and Title: Timothy S. Phillips, PE, Chief Engineer and General Manager		Telephone No.: (602) 506-1601
Community Name: Maricopa County	Community Official's Signature (required):	Date:

CERTIFICATION BY REGISTERED PROFESSIONAL ENGINEER AND/OR LAND SURVEYOR

This certification is to be signed and sealed by a licensed land surveyor, registered professional engineer, or architect authorized by law to certify elevation information. All documents submitted in support of this request are correct to the best of my knowledge. I understand that any false statement may be punishable by fine or imprisonment under Title 18 of the United States Code, Section 1001.

Certifier's Name: Gary E. Freeman	License No.: 36225	Expiration Date: 6/30/2007
Company Name: River Research & Design, Inc.	Telephone No.: (480) 275-5077	Fax No.: (480) 275-5870
Signature:		Date: 6/05/2006

Ensure the forms that are appropriate to your revision request are included in your submittal.

Form Name and (Number)	Required if ...
☒ Riverine Hydrology and Hydraulics Form (Form 2)	New or revised discharges or water-surface elevations
☒ Riverine Structures Form (Form 3)	Channel is modified, addition/revision of bridge/culverts, addition/revision of levee/floodwall, addition/revision of dam
☐ Coastal Analysis Form (Form 4)	New or revised coastal elevations
☐ Coastal Structures Form (Form 5)	Addition/revision of coastal structure
☐ Alluvial Fan Flooding Form (Form 6)	Flood control measures on alluvial fans

Seal (Optional)

C. REVIEW FEE

Has the review fee for the appropriate request category been included? ☒ Yes Fee amount: $4000.00

☐ No, Attach Explanation

Please see the FEMA Web site at http://www.fema.gov/fhm/frm_fees.shtm **for Fee Amounts and Exemptions.**

D. SIGNATURE

All documents submitted in support of this request are correct to the best of my knowledge. I understand that any false statement may be punishable by fine or imprisonment under Title 18 of the United States Code, Section 1001.

Name:	Company:	
Mailing Address:	Daytime Telephone No.:	Fax No.:
	E-Mail Address:	
Signature of Requester (required):		Date:

As the community official responsible for floodplain management, I hereby acknowledge that we have received and reviewed this Letter of Map Revision (LOMR) or conditional LOMR request. Based upon the community's review, we find the completed or proposed project meets or is designed to meet all of the community floodplain management requirements, including the requirement that no fill be placed in the regulatory floodway, and that all necessary Federal, State, and local permits have been, or in the case of a conditional LOMR, will be obtained. In addition, we have determined that the land and any existing or proposed structures to be removed from the SFHA are or will be reasonably safe from flooding as defined in 44CFR 65.2(c), and that we have available upon request by FEMA, all analyses and documentation used to make this determination.

Community Official's Name and Title: Keith R Brown - Assistant City Engineer		Telephone No.: 623-882-7956
Community Name: City of Goodyear	Community Official's Signature (required): Keith R Brown	Date: 8-9-06

CERTIFICATION BY REGISTERED PROFESSIONAL ENGINEER AND/OR LAND SURVEYOR

This certification is to be signed and sealed by a licensed land surveyor, registered professional engineer, or architect authorized by law to certify elevation information. All documents submitted in support of this request are correct to the best of my knowledge. I understand that any false statement may be punishable by fine or imprisonment under Title 18 of the United States Code, Section 1001.

Certifier's Name:	License No.:	Expiration Date:
Company Name:	Telephone No.:	Fax No.:
Signature:		Date:

Ensure the forms that are appropriate to your revision request are included in your submittal.

Form Name and (Number)	Required if ...
☒ Riverine Hydrology and Hydraulics Form (Form 2)	New or revised discharges or water-surface elevations
☒ Riverine Structures Form (Form 3)	Channel is modified, addition/revision of bridge/culverts, addition/revision of levee/floodwall, addition/revision of dam
☐ Coastal Analysis Form (Form 4)	New or revised coastal elevations
☐ Coastal Structures Form (Form 5)	Addition/revision of coastal structure
☐ Alluvial Fan Flooding Form (Form 6)	Flood control measures on alluvial fans

Seal (Optional)

FEDERAL EMERGENCY MANAGEMENT AGENCY

RIVERINE HYDROLOGY & HYDRAULICS FORM

O.M.B No. 3067-0148
Expires September 30, 2005

PAPERWORK REDUCTION ACT

Public reporting burden for this form is estimated to average 3 hours per response. The burden estimate includes the time for reviewing instructions, searching existing data sources, gathering and maintaining the needed data, and completing, reviewing, and submitting the form. You are not required to respond to this collection of information unless a valid OMB control number appears in the upper right corner of this form. Send comments regarding the accuracy of the burden estimate and any suggestions for reducing this burden to: Information Collections Management, Federal Emergency Management Agency, 500 C Street, SW, Washington DC 20472, Paperwork Reduction Project (3067-0148). Submission of the form is required to obtain or retain benefits under the National Flood Insurance Program. **Please do not send your completed survey to the above address.**

Flooding Source: Gila River
Note: Fill out one form for each flooding source studied

A. HYDROLOGY

1. Reason for New Hydrologic Analysis (check all that apply)

☒ Not revised (skip to section 2) ☐ No existing analysis ☐ Improved data
☐ Alternative methodology ☐ Proposed Conditions (CLOMR) ☐ Changed physical condition of watershed

2. Comparison of Representative 1%-Annual-Chance Discharges

Location	Drainage Area (Sq. Mi.)	FIS (cfs)	Revised (cfs)

3. Methodology for New Hydrologic Analysis (check all that apply)

☐ Statistical Analysis of Gage Records ☐ Precipitation/Runoff Model [TR-20, HEC-1, HEC-HMS etc.]
☐ Regional Regression Equations ☐ Other (please attach description)

Please enclose all relevant models in digital format, maps, computations (including computation of parameters) and documentation to support the new analysis. The document, "Numerical Models Accepted by FEMA for NFIP Usage" lists the models accepted by FEMA. This document can be found at: http://www.fema.gov/fhm/en_modl.shtm.

4. Review/Approval of Analysis

If your community requires a regional, state, or federal agency to review the hydrologic analysis, please attach evidence of approval/review.

5. Impacts of Sediment Transport on Hydrology

Was sediment transport considered? ☐ Yes ☐ No If yes, then fill out Section F (Sediment Transport) of Form 3. If No, then attach your explanation for why sediment transport was not considered.

B. HYDRAULICS

1. Reach to be Revised

	Description	Cross Section	Water-Surface Elevations (ft.)	
			Effective	Proposed/Revised
Downstream Limit	Gila River near Tuthill Rd	188.59	876.44	876.44
Upstream Limit	Gila River near Bullard Ave	195.09	912.92	912.53

2. Hydraulic Method Used

Hydraulic Analysis HEC-RAS [HEC-2 , HEC-RAS, Other (Attach description)]

B. HYDRAULICS (CONTINUED)

3. Pre-Submittal Review of Hydraulic Models

FEMA has developed two review programs, CHECK-2 and CHECK-RAS, to aid in the review of HEC-2 and HEC-RAS hydraulic models, respectively. These review programs verify that the hydraulic estimates and assumptions in the model data are in accordance with NFIP requirements, and that the data are comparable with the assumptions and limitations of HEC-2/HEC-RAS. CHECK-2 and CHECK-RAS identify areas of potential error or concern. These tools do not replace engineering judgment. CHECK-2 and CHECK-RAS can be downloaded from http://www.fema.gov/fhm/frm_soft.shtm. We recommend that you review your HEC-2 and HEC-RAS models with CHECK-2 and CHECK-RAS. If you disagree with a message, please attach an explanation of why the message is not valid in this case. Review of your submittal and resolution of valid modeling discrepancies will result in reduced review time.

HEC-2/HEC-RAS models reviewed with CHECK-2/CHECK-RAS? ☒ Yes ☐ No

4. Models Submitted

Duplicate Effective Model*	Natural File Name: reach2	Floodway File Name: reach2
Corrected Effective Model*	Natural File Name: reach2c	Floodway File Name:
Existing or Pre-Project Conditions Model	Natural File Name: KRExistingFISFW2r	Floodway File Name: KRExistingFISFW2r
Revised or Post-Project Conditions Model	Natural File Name: KRrevisedFW4r	Floodway File Name: KRrevisedFW4r
Other - (attach description)	Natural File Name:	Floodway File Name:

*Not required for revisions to approximate 1%-annual-chance floodplains (Zone A) – for details, refer to the corresponding section of the instructions.

The document "Numerical Models Accepted by FEMA for NFIP Usage" lists the models accepted by FEMA. This document can be found at: http://www.fema.gov/fhm/en_modl.shtm.

C. MAPPING REQUIREMENTS

A **certified topographic map** must be submitted showing the following information (where applicable): the boundaries of the effective, existing, and proposed conditions 1%-annual-chance floodplain (for approximate Zone A revisions) or the boundaries of the 1%- and 0.2%-annual-chance floodplains and regulatory floodway (for detailed Zone AE, AO, and AH revisions); location and alignment of all cross sections with stationing control indicated; stream, road, and other alignments (e.g., dams, levees, etc.); current community easements and boundaries; boundaries of the requester's property; certification of a registered professional engineer registered in the subject State; location and description of reference marks; and the referenced vertical datum (NGVD, NAVD, etc.).

Note that the boundaries of the existing or proposed conditions floodplains and regulatory floodway to be shown on the revised FIRM and/or FBFM must tie-in with the effective floodplain and regulatory floodway boundaries. Please attach **a copy of the effective FIRM and/or FBFM,** annotated to show the boundaries of the revised 1%- and 0.2%-annual-chance floodplains and regulatory floodway that tie-in with the boundaries of the effective 1%- and 0.2%-annual-chance floodplain and regulatory floodway at the upstream and downstream limits of the area of revision.

D. COMMON REGULATORY REQUIREMENTS

1. For CLOMR requests, do Base Flood Elevations (BFEs) increase? ☐ Yes ☒ No

For CLOMR requests, if either of the following is true, please submit evidence of compliance with Section 65.12 of the NFIP regulations:
- The proposed project encroaches upon a regulatory floodway and would result in increases above 0.00 foot.
- The proposed project encroaches upon a SFHA with BFEs established and would result in increases above 1.00 foot.

2. Does the request involve the placement or proposed placement of fill? ☒ Yes ☐ No

If Yes, the community must be able to certify that the area to be removed from the special flood hazard area, to include any structures or proposed structures, meets all of the standards of the local floodplain ordinances, and is reasonably safe from flooding in accordance with the NFIP regulations set forth at 44 CFR 60.3(a)(3), 65.5(a)(4), and 65.6(a)(14). Please see the MT-2 instructions for more information.

3. For LOMR requests, is the regulatory floodway being revised? ☐ Yes ☐ No

If Yes, attach evidence of regulatory floodway revision notification. As per Paragraph 65.7(b)(1) of the NFIP Regulations, notification is required for requests involving revisions to the regulatory floodway. (Not required for revisions to approximate 1%-annual-chance floodplains [studied Zone A designation] unless a regulatory floodway is being added. Elements and examples of regulatory floodway revision notification can be found in the MT-2 Form 2 Instructions.)

4. For LOMR requests, does this request require property owner notification and acceptance of BFE increases? ☐ Yes ☐ No

If Yes, please attach proof of property owner notification and acceptance (if available). Elements of and examples of property owner notification can be found in the MT-2 Form 2 Instructions.

FEDERAL EMERGENCY MANAGEMENT AGENCY

RIVERINE STRUCTURES FORM

O.M.B. No. 3067-0148
Expires September 30, 2005

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Flooding Source: Gila River
Note: Fill out one form for each flooding source studied

A. GENERAL

Complete the appropriate section(s) for each Structure listed below:

Channelization ..... complete Section B
Bridge/Culvert ..... complete Section C
Dam..... complete Section D
Levee/Floodwall ..... complete Section E
Sediment Transport..... complete Section F (if required)

Description Of Structure

1. Name of Structure: Cotton Lane Bridge

Type (check one): ☐ Channelization ☒ Bridge/Culvert ☐ Levee/Floodwall ☐ Dam

Location of Structure: 192.4

Downstream Limit/Cross Section: 192.38

Upstream Limit/Cross Section: 192.41

2. Name of Structure: King Ranch Channelization

Type (check one): ☒ Channelization ☐ Bridge/Culvert ☐ Levee/Floodwall ☐ Dam

Location of Structure: 192.40

Downstream Limit/Cross Section: 189.30

Upstream Limit/Cross Section: 193.73

3. Name of Structure:

Type (check one) ☐ Channelization ☐ Bridge/Culvert ☐ Levee/Floodwall ☐ Dam

Location of Structure:

Downstream Limit/Cross Section:

Upstream Limit/Cross Section:

NOTE: For more structures, attach additional pages as needed.

B. CHANNELIZATION

Flooding Source: Gila River

Name of Structure: King Ranch Channelization

1. Accessory Structures

The channelization includes (check one):

- ☐ Levees [Attach Section E (Levee/Floodwall)]
- ☐ Superelevated sections
- ☐ Debris basin/detention basin
- ☐ Other (Describe):
- ☐ Drop structures
- ☒ Transitions in cross sectional geometry
- ☐ Energy dissipator

2. Drawing Checklist

Attach the plans of the channelization certified by a registered professional engineer, as described in the instructions.

3. Hydraulic Considerations

The channel was designed to carry 227,000 (cfs) and/or the 100-year flood.

The design elevation in the channel is based on (check one):

☒ Subcritical flow ☐ Critical flow ☐ Supercritical flow ☐ Energy grade line

If there is the potential for a hydraulic jump at the following locations, check all that apply and attach an explanation of how the hydraulic jump is controlled without affecting the stability of the channel.

☐ Inlet to channel ☐ Outlet of channel ☐ At Drop Structures ☐ At Transitions
☐ Other locations (specify):

4. Sediment Transport Considerations

Was sediment transport considered? ☒ Yes ☐ No If Yes, then fill out Section F (Sediment Transport).
If No, then attach your explanation for why sediment transport was not considered.

C. BRIDGE/CULVERT

Flooding Source: Gila River

Name of Structure: Cotton Lane Bridge

1. This revision reflects (check one):

- ☒ New bridge/culvert not modeled in the FIS
- ☐ Modified bridge/culvert previously modeled in the FIS
- ☐ New analysis of bridge/culvert previously modeled in the FIS

2. Hydraulic model used to analyze the structure (e.g., HEC-2 with special bridge routine, WSPRO, HY8): HEC-RAS
If different than hydraulic analysis for the flooding source, justify why the hydraulic analysis used for the flooding source could not analyze the structures. Attach justification.

3. Attach plans of the structures certified by a registered professional engineer. The plan detail and information should include the following (check the information that has been provided):

- ☒ Dimensions (height, width, span, radius, length)
- ☐ Shape (culverts only)
- ☒ Material
- ☒ Beveling or Rounding
- ☒ Wing Wall Angle
- ☒ Skew Angle
- ☒ Distances Between Cross Sections
- ☒ Erosion Protection
- ☒ Low Chord Elevations – Upstream and Downstream
- ☒ Top of Road Elevations – Upstream and Downstream
- ☒ Structure Invert Elevations – Upstream and Downstream
- ☒ Stream Invert Elevations – Upstream and Downstream
- ☒ Cross-Section Locations

4. Sediment Transport Considerations

Was sediment transport considered? ☒ Yes ☐ No If yes, then fill out Section F (Sediment Transport).
If No, then attach your explanation for why sediment transport was not considered.

D. DAM

Flooding Source:

Name of Structure:

1. This request is for (check one): ☐ Existing dam ☐ New dam ☐ Modification of existing dam

2. The dam was designed by (check one): ☐ Federal agency ☐ State agency ☐ Local government agency

   ☐ Private organization Name of the agency or organization:

3. Does the project involve revised hydrology? ☐ Yes ☐ No

   If Yes, complete the Riverine Hydrology & Hydraulics Form (Form 2).

4. Does the submittal include debris/sediment yield analysis? ☐ Yes ☐ No

   If yes, then fill out Section F (Sediment Transport).
   If No, then attach your explanation for why debris/sediment analysis was not considered.

5. Does the Base Flood Elevation behind the dam or downstream of the dam change?

   ☐ Yes ☐ No If Yes, complete the Riverine Hydrology & Hydraulics Form (Form 2) and complete the table below.

Stillwater Elevation Behind the Dam

FREQUENCY (% annual chance)	FIS	REVISED
10-year (10%)		
50-year (2%)		
100-year (1%)		
500-year (0.2%)		
Normal Pool Elevation		

6. Please attach a copy of the formal Operation and Maintenance Plan

E. LEVEE/FLOODWALL

1. System Elements

a. This Levee/Floodwall analysis is based on (check one):

☐ upgrading of an existing levee/floodwall system
☐ a newly constructed levee/floodwall system
☐ reanalysis of an existing levee/floodwall system

b. Levee elements and locations are (check one):

☐ earthen embankment, dike, berm, etc.	Station	to
☐ structural floodwall	Station	to
☐ Other (describe):	Station	to

c. Structural Type (check one):

☐ monolithic cast-in place reinforced concrete
☐ reinforced concrete masonry block
☐ sheet piling
☐ Other (describe):

d. Has this levee/floodwall system been certified by a Federal agency to provide protection from the base flood?

☐ Yes ☐ No

If Yes, by which agency?

e. Attach certified drawings containing the following information (indicate drawing sheet numbers):

1. Plan of the levee embankment and floodwall structures. Sheet Numbers:
2. A profile of the levee/floodwall system showing the Base Flood Elevation (BFE), levee and/or wall crest and foundation, and closure locations for the total levee system. Sheet Numbers:
3. A profile of the BFE, closure opening outlet and inlet invert elevations, type and size of opening, and kind of closure. Sheet Numbers:
4. A layout detail for the embankment protection measures. Sheet Numbers:
5. Location, layout, and size and shape of the levee embankment features, foundation treatment, floodwall structure, closure structures, and pump stations. Sheet Numbers:

2. Freeboard

a. The minimum freeboard provided above the BFE is:

Riverine

3.0 feet or more at the downstream end and throughout	☐ Yes	☐ No
3.5 feet or more at the upstream end	☐ Yes	☐ No
4.0 feet within 100 feet upstream of all structures and/or constrictions	☐ Yes	☐ No

Coastal

1.0 foot above the height of the one percent wave associated with the 1%-annual-chance stillwater surge elevation or maximum wave runup (whichever is greater).	☐ Yes	☐ No
2.0 feet above the 1%-annual-chance stillwater surge elevation	☐ Yes	☐ No

2. Freeboard (continued)

Please note, occasionally exceptions are made to the minimum freeboard requirement. If an exception is requested, attach documentation addressing Paragraph 65.10(b)(1)(ii) of the NFIP Regulations.

If No is answered to any of the above, please attach an explanation.

b. Is there an indication from historical records that ice-jamming can affect the BFE? ☐ Yes ☐ No

If Yes, provide ice-jam analysis profile and evidence that the minimum freeboard discussed above still exists.

3. Closures

a. Openings through the levee system (check one): ☐ exists ☐ does not exist

If opening exists, list all closures:

Channel Station	Left or Right Bank	Opening Type	Highest Elevation for Opening Invert	Type of Closure Device

(Extend table on an added sheet as needed and reference)

Note: Geotechnical and geologic data

In addition to the required detailed analysis reports, data obtained during field and laboratory investigations and used in the design analysis for the following system features should be submitted in a tabulated summary form. (Reference U.S. Army Corps of Engineers [USACE] EM-1110-2-1906 Form 2086.)

4. Embankment Protection

a. The maximum levee slope landside is:

b. The maximum levee slope floodside is:

c. The range of velocities along the levee during the base flood is: (min.) to (max.)

d. Embankment material is protected by (describe what kind):

e. Riprap Design Parameters (check one): ☐ Velocity ☐ Tractive stress
Attach references

Reach	Sideslope	Flow Depth	Velocity	Curve or Straight	Stone Riprap			Depth of Toedown
					D_{100}	D_{50}	Thickness	
Sta to								
Sta to								
Sta to								
Sta to								
Sta to								
Sta to								

(Extend table on an added sheet as needed and reference each entry)

E. LEVEE/FLOODWALL (CONTINUED)

4. Embankment Protection (continued)

f. Is a bedding/filter analysis and design attached? ☐ Yes ☐ No

g. Describe the analysis used for other kinds of protection used (include copies of the design analysis):

Attach engineering analysis to support construction plans.

5. Embankment And Foundation Stability

a. Identify locations and describe the basis for selection of critical location for analysis:

☐ Overall height: Sta. ; height ft.

☐ Limiting foundation soil strength:

Sta. , depth to

strength ϕ = degrees, c = psf

slope: SS = (h) to (v)

(Repeat as needed on an added sheet for additional locations)

b. Specify the embankment stability analysis methodology used (e.g., circular arc, sliding block, infinite slope, etc.):

c. Summary of stability analysis results:

Case	Loading Conditions	Critical Safety Factor	Criteria (Min.)
I	End of construction		1.3
II	Sudden drawdown		1.0
III	Critical flood stage		1.4
IV	Steady seepage at flood stage		1.4
VI	Earthquake (Case I)		1.0

(Reference: USACE EM-1110-2-1913 Table 6-1)

d. Was a seepage analysis for the embankment performed? ☐ Yes ☐ No

If Yes, describe methodology used:

e. Was a seepage analysis for the foundation performed? ☐ Yes ☐ No

f. Were uplift pressures at the embankment landside toe checked? ☐ Yes ☐ No

g. Were seepage exit gradients checked for piping potential? ☐ Yes ☐ No

h. The duration of the base flood hydrograph against the embankment is hours.

Attach engineering analysis to support construction plans.

6. Floodwall And Foundation Stability

a. Describe analysis submittal based on Code (check one):

☐ UBC (1988) or ☐ Other (specify):

b. Stability analysis submitted provides for:

☐ Overturning ☐ Sliding If not, explain:

c. Loading included in the analyses were:

☐ Lateral earth @ P_A = psf; P_p = psf

☐ Surcharge-Slope @ , ☐ surface psf

☐ Wind @ P_w = psf

☐ Seepage (Uplift); ☐ Earthquake @ P_{eq} = %g

☐ 1%-annual-chance significant wave height: ft.

☐ 1%-annual-chance significant wave period: sec.

d. Summary of Stability Analysis Results: Factors of Safety.

Itemize for each range in site layout dimension and loading condition limitation for each respective reach.

Loading Condition	Criteria (Min)		Sta	To	Sta	To
	Overturn	Sliding	Overturn	Sliding	Overturn	Sliding
Dead & Wind	1.5	1.5				
Dead & Soil	1.5	1.5				
Dead, Soil, Flood, & Impact	1.5	1.5				
Dead, Soil, & Seismic	1.3	1.3				

(Ref: FEMA 114 Sept 1986; USACE EM 1110-2-2502)

(Note: Extend table on an added sheet as needed and reference)

e. Foundation bearing strength for each soil type:

Bearing Pressure	Sustained Load (psf)	Short Term Load (psf)
Computed design maximum		
Maximum allowable		

f. Foundation scour protection ☐ is, ☐ is not provided. If provided, attach explanation and supporting documentation:

Attach engineering analysis to support construction plans.

E. LEVEE/FLOODWALL (CONTINUED)

7. Settlement

a. Has anticipated potential settlement been determined and incorporated into the specified construction elevations to maintain the established freeboard margin? ☐ Yes ☐ No

b. The computed range of settlement is ft. to ft.

c. Settlement of the levee crest is determined to be primarily from :

☐ Foundation consolidation
☐ Embankment compression
☐ Other (Describe):

d. Differential settlement of floodwalls ☐ has ☐ has not been accommodated in the structural design and construction.

Attach engineering analysis to support construction plans.

8. Interior Drainage

a. Specify size of each interior watershed:

Draining to pressure conduit: acres
Draining to ponding area: acres

b. Relationships Established

Ponding elevation vs. storage	☐ Yes	☐ No
Ponding elevation vs. gravity flow	☐ Yes	☐ No
Differential head vs. gravity flow	☐ Yes	☐ No

c. The river flow duration curve is enclosed: ☐ Yes ☐ No

d. Specify the discharge capacity of the head pressure conduit: cfs

e. Which flooding conditions were analyzed?

• Gravity flow (Interior Watershed)	☐ Yes	☐ No
• Common storm (River Watershed)	☐ Yes	☐ No
• Historical ponding probability	☐ Yes	☐ No
• Coastal wave overtopping	☐ Yes	☐ No

If No for any of the above, attach explanation.

f. Interior drainage has been analyzed based on joint probability of interior and exterior flooding and the capacities of pumping and outlet facilities to provide the established level of flood protection. ☐ Yes ☐ No

If No, attach explanation.

g. The rate of seepage through the levee system for the base flood is cfs

h. The length of levee system used to drive this seepage rate in item g: ft.

E. LEVEE/FLOODWALL (CONTINUED)

8. Interior Drainage (continued)

i. Will pumping plants be used for interior drainage? ☐ Yes ☐ No

If Yes, include the number of pumping plants:
For each pumping plant, list:

	Plant #1	Plant #2
The number of pumps		
The ponding storage capacity		
The maximum pumping rate		
The maximum pumping head		
The pumping starting elevation		
The pumping stopping elevation		
Is the discharge facility protected?		
Is there a flood warning plan?		
How much time is available between warning and flooding?		

Will the operation be automatic? ☐ Yes ☐ No

If the pumps are electric, are there backup power sources? ☐ Yes ☐ No

(Reference: USACE EM-1110-2-3101, 3102, 3103, 3104, and 3105)

Include a copy of supporting documentation of data and analysis. Provide a map showing the flooded area and maximum ponding elevations for all interior watersheds that result in flooding.

9. Other Design Criteria

a. The following items have been addressed as stated:

Liquefaction ☐ is ☐ is not a problem
Hydrocompaction ☐ is ☐ is not a problem
Heave differential movement due to soils of high shrink/swell ☐ is ☐ is not a problem

b. For each of these problems, state the basic facts and corrective action taken:

Attach supporting documentation

c. If the levee/floodwall is new or enlarged, will the structure adversely impact flood levels and/or flow velocities floodside of the structure?
☐ Yes ☐ No

Attach supporting documentation

d. Sediment Transport Considerations:

Was sediment transport considered? ☐ Yes ☐ No If Yes, then fill out Section F (Sediment Transport).
If No, then attach your explanation for why sediment transport was not considered.

E. LEVEE/FLOODWALL (CONTINUED)

10. Operational Plan And Criteria

    a. Are the planned/installed works in full compliance with Part 65.10 of the NFIP Regulations? ☐ Yes ☐ No

    b. Does the operation plan incorporate all the provisions for closure devices as required in Paragraph 65.10(c)(1) of the NFIP regulations? ☐ Yes ☐ No

    c. Does the operation plan incorporate all the provisions for interior drainage as required in Paragraph 65.10(c)(2) of the NFIP regulations? ☐ Yes ☐ No

    If the answer is No to any of the above, please attach supporting documentation.

11. Maintenance Plan

    a. Are the planned/installed works in full compliance with Part 65.10 of the NFIP Regulations? ☐ Yes ☐ No
    If No, please attach supporting documentation.

12. Operations and Maintenance Plan

    Please attach a copy of the formal Operations and Maintenance Plan for the levee/floodwall.

F. SEDIMENT TRANSPORT

Flooding Source: Gila River

Name of Structure: Cotton Lane Bridge / King Ranch Channelization

If there is any indication from historical records that sediment transport (including scour and deposition) can affect the Base Flood Elevation (BFE); and/or based on the stream morphology, vegetative cover, development of the watershed and bank conditions, there is a potential for debris and sediment transport (including scour and deposition) to affect the BFEs, then provide the following information along with the supporting documentation:

Sediment load associated with the base flood discharge: Volume 103,795 Total (8990 sand) acre-feet

Debris load associated with the base flood discharge: Volume Not Estimated acre-feet

Sediment transport rate 52,539 mg/l (percent concentration by volume)

Method used to estimate sediment transport: HEC-6T

Most sediment transport formulas are intended for a range of hydraulic conditions and sediment sizes; attach a detailed explanation for using the selected method.

Method used to estimate scour and/or deposition: Toffaleti/Meyer-Peter and Mueller-bed scour and USBR methods for toe scour

Method used to revise hydraulic or hydrologic analysis (model) to account for sediment transport:
Please note that bulked flows are used to evaluate the performance of a structure during the base flood; however, FEMA does not map BFEs based on bulked flows.

None

If a sediment analysis has not been performed, an explanation as to why sediment transport (including scour and deposition) will not affect the BFEs or structures must be provided.

3. Surveying and Mapping Information

Topography for the project area was obtained from a number of previous studies as well as new topo. New topography was obtained for the river channel from just upstream of Estrella Parkway Bridge to approximately the Jackrabbit Road Alignment. This topography included the channel for this entire reach as well as for the floodplains being developed by partners in the bridge and channel project.

Topography for the King Ranch and Lakin overbank areas (north and south bank) with a one-foot contour interval was provided by Coe & Van Loo Consultants, Inc. (CVL). Initially this topography covered only the south portion of the river and floodplain. These data were spliced into existing four-foot contour interval data that was used for the original FIS study and used for the preliminary modeling. Subsequent to early studies additional new topography (including both 1 ft and 2 ft contour data) was obtained for the remainder of the river (2 ft) and for Lakin property in the north overbank (1 ft). This confirmed observations made based on the partial river topography obtained earlier that portions of the Gila River Channel had eroded and changed significantly subsequent to the date when the 1993 topography was obtained.

3.1 Field Survey Information

Several field surveys were performed at various times during this study to compare previous mapping with existing topography in the area. All areas covered by field surveys were subsequently remapped using aerial photogrammetry. The field surveys then became irrelevant except as field checks for the aerial mapping. The main field mapping occurred on February 6, 2004 (a set of points, each with latitude and longitude, and elevation): This survey consists of spot elevations in the main channel at 4 cross-sections downstream of the 2003 aerial-topography, as well as spot elevations at a few other locations. These were later covered by mapping and were not used other than as a check on the aerial mapping.

3.2 Mapping

Three sources of mapping were used in the preparation of this CLOMR. Those data were combined to provide a single coverage of topographic information. The details of the methodology adopted to arrive at a combined topographic coverage are presented later in this document. The data which was collected and processed includes:

1) Flood Insurance Study (as ArcView GIS coverages obtained from Flood Control District of Maricopa County (FCD)): This consists of topography flown on 2/6/1993 (main channel and part of the adjacent overbanks), and topography flown on 11/14/1991 (the remainder of the mapping). This topography covers the entire study area. The contour interval is four feet. Spot elevations are also part of this data set.

2) Topography flown in 2003 This topography covers the main channel and the left descending overbank for about a 4 mile river reach, as well as covering King Ranch itself. The contour interval is one foot.

3) Additional aerial photography flown in 2004 covering the balance of the river channel as well as the active river channel west of King Ranch to near the Jackrabbit Road

alignment. The majority of this topography has a 2 foot contour interval. Areas covered by the 1 ft and 2 ft contour data flown in 2003 and 2004 are shown in Figure 3.

Figure 3 shows the locations of recent topographic and elevation data. All the available topographic data were combined to provide a single coverage of topographic information with the most accurate data available being used.

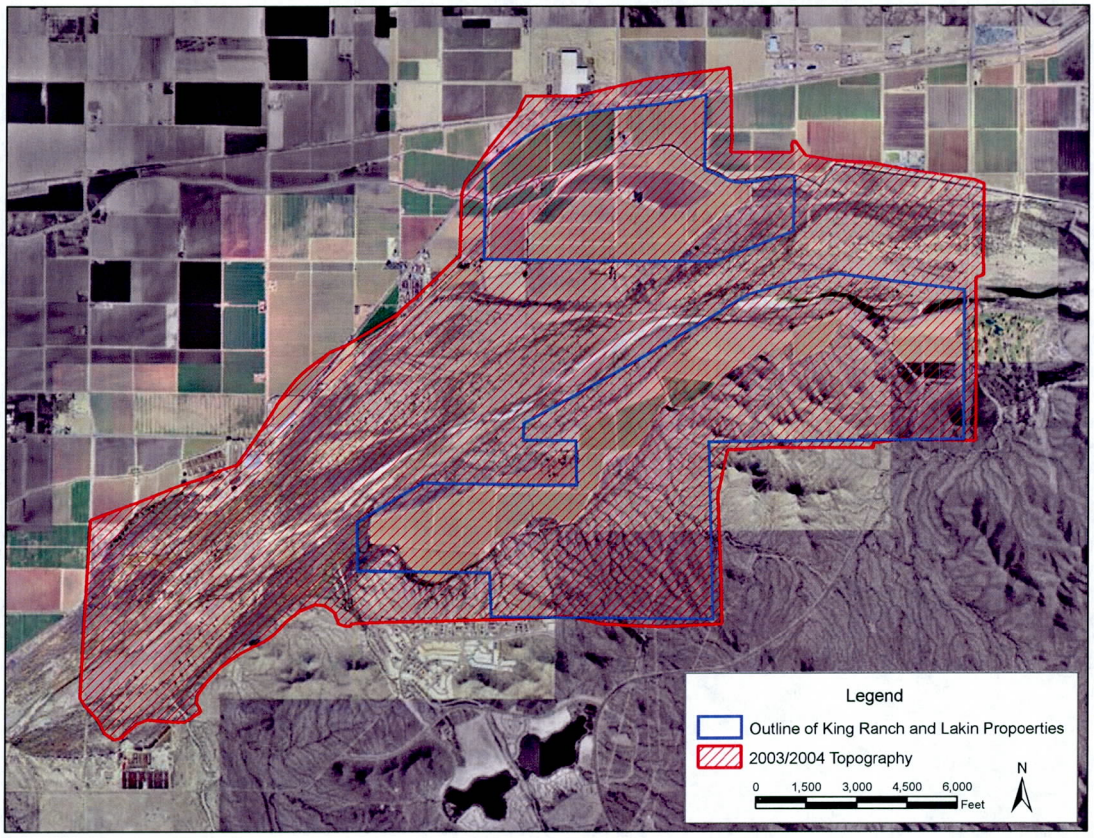

Figure 3. Updated Topography for King Ranch flown in 2003 and 2004. Areas outside the hatched area used the existing topography from the Baker FIS study (1999).

When the new topography was compared with that used in the FIS study (obtained in 1993) it was apparent that there were significant differences between the two sets of data. The principle difference between the topography from the Flood Insurance Study and the recent aerial and field surveys is that the main channel, which is about 800 to 1000 feet wide, is about 6 to 8 feet higher in the Flood Insurance Study. This was determined to be primarily due to water that was in the channel on the date the Flood Insurance Study topography was flown on February 6, 1993.

The horizontal datum of the Flood Insurance Study topography is Arizona State Plane Central, NAD83, International Feet. The vertical datum of the topography is stated on the Baker workmaps as being NGVD 1929. This statement was confirmed by comparison with the 1 ft

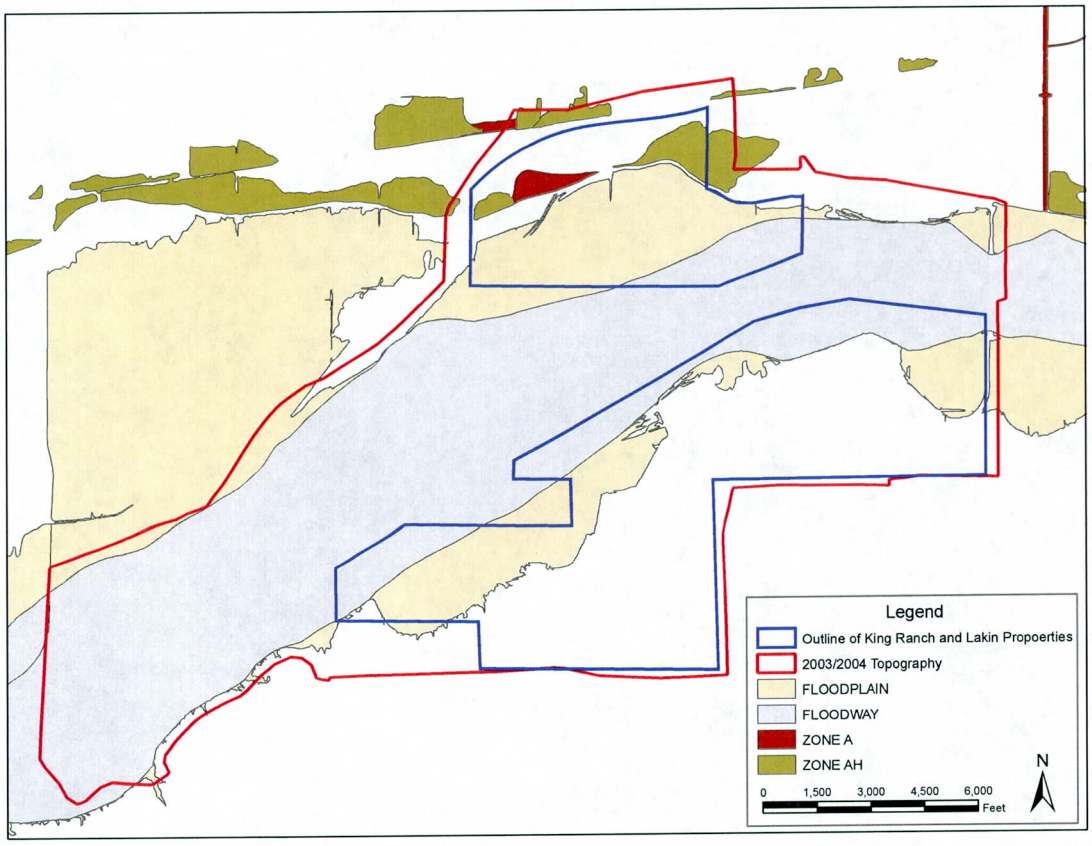

Figure 4. The Existing Floodplain, Floodway, and Limits of the 2003-2004 new Topography.

3.2.1.4 2004 Topography

The topography obtained in 2004 was designed to supplement that obtained in 2003 and allow modeling of the full width of the Gila River Floodway with new topography. This was due in part to the changes noted between the 1993 and 2003 topography where they overlapped. Based on the review of data available prior to the performing the 2004 mapping, it became apparent that the topography needed to cover the entire river to allow accurate modeling.

3.2.1.5 February 1990 versus 2003 Topography

The most notable difference between these two topographies is the scour that has occurred western portion of the main channel. For the western two miles of the Gila River north of King Ranch, there has been about 10 feet of scour with significantly more in some places. For the reach upstream of this, adjacent to the eastern portion of King Ranch, the main channel has also scoured, but less than the reach to the west.

3.2.1.6 1993 (FIS) Topography versus 2003 topography

It appears that the 1993 topography is not as accurate for the low flow channel in this river reach due to approximately 13,000 cfs flowing in the river on the day the topography was flown—leading to contours in the main channel that show the water surface elevation and not the ground

elevation. The eastern portion of the main channel, typically about 800 to 1,000 feet wide, is about 6 to 8 feet higher in the FIS topography than the 2003 topography.

A hydraulic simulation of the 13,200 cfs discharge was run in a preliminary HEC-RAS hydraulic model developed using the 2003 topography. The water surface elevations from this model (flowing about 6-10 feet deep) were typically within two feet of the 1993 contours of the channel bottom. Thus it appears that most of the difference in channel elevation between the 2003 and FIS topography is due to water in the channel with the exception of the western area of the study area where significant scour has occurred after the 1993 mapping was performed as discussed above.

Figure 5 shows a representative cross-section based on each of the topographies. The cross-section shown by the black line (with more points) is based on the 2003 topography while the cross-section shown by the magenta line (with few points) is based on the FIS topography.

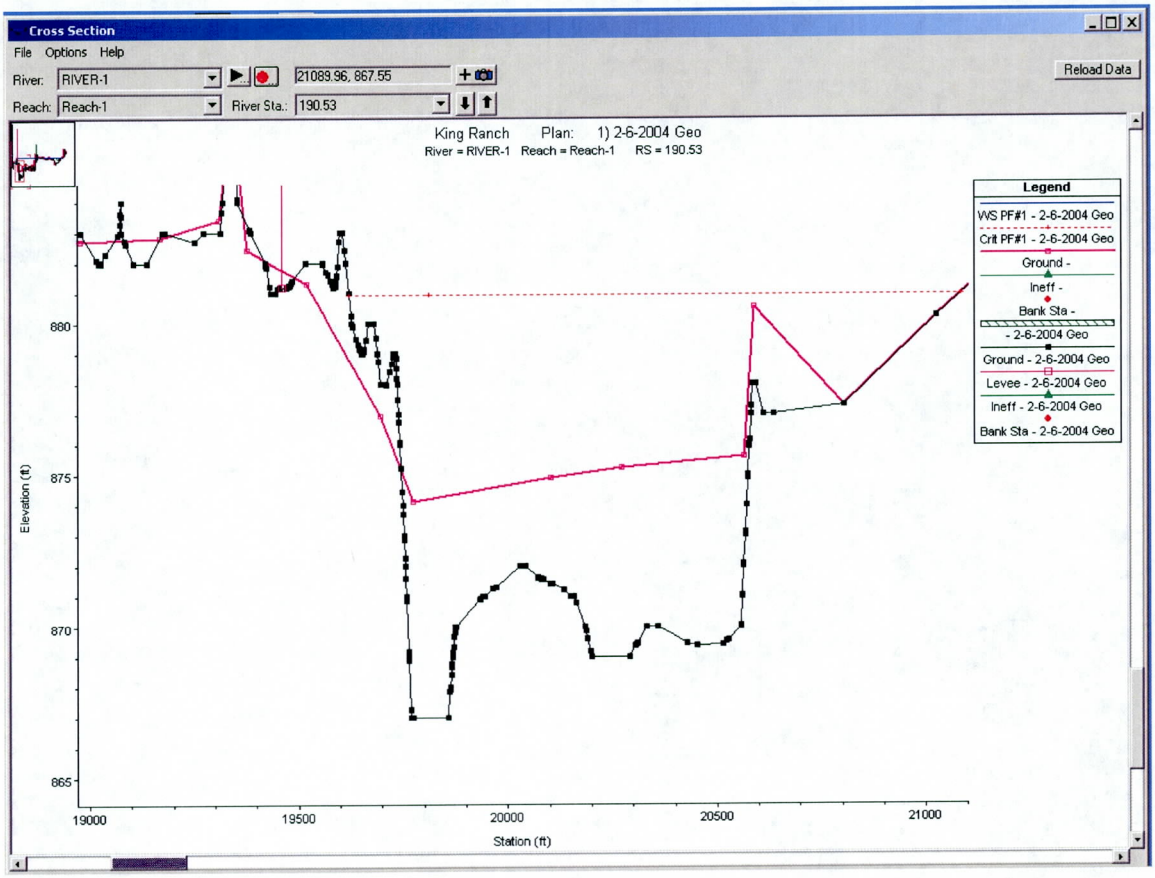

Figure 5. Typical Cross-section Detail for Main Channel. 2003 Topography shown in Black, FIS Topography shown in Magenta (with fewer points).

Figure 6 shows hydrographs of the two significant events that occurred on the Gila River in this time period. The dark vertical line indicates 2/6/1993, the date the FIS topography was flown in the main channel. Given that sediment transport tends to increase exponentially with discharge, the majority of sediment transport in the period between 1990 and the date of the 1993

topography likely occurred before 2/6/1993. It should be noted that the flood peak from the Upper Gila River of approximately 75,000 cfs occurred subsequent to the 1993 topography of the channel section. From the topography obtained in 2004 it is apparent that this event caused significant additional scour near the west end of the project reach with elevation differences of up to 16' being noted between the two topographies. A significant portion of this scour was apparently caused by flows subsequent to the January 1993 flood event. The changes, however, appear to be primarily limited to the main low flow channels with little change noted in the overbanks.

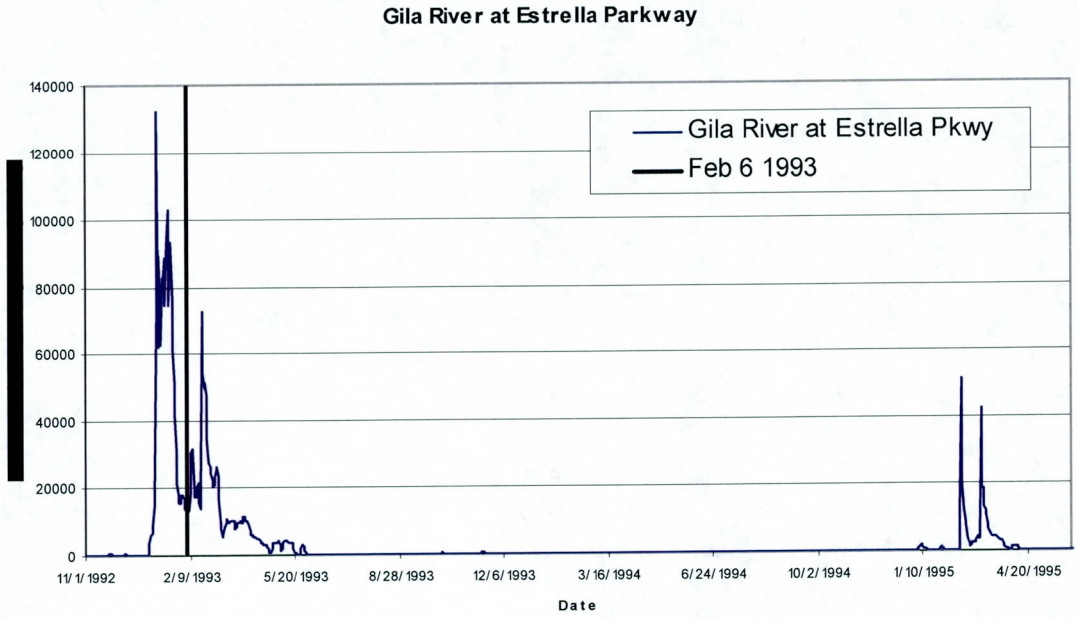

Figure 6. Daily average flows, Gila River at Estrella Parkway. Cause of Possible Changes in the Right Overbank

Comparisons were made for limited areas of the right overbank using topography in the FIS study from February 6, 1993 being combined with topography from December 14, 1991 for the analysis. Comparison of the part of the right overbank that appears in the February 6, 1993 topography to the February 1990 topography shows some areas with aggradation, others with scour, but little net change overall. Comparison of the 12/14/1991 topography in the right overbank also shows some areas with deposition, some smaller areas with scour, and the majority of the area with little net change. This analysis was not extended to the 2004 data since it was not necessary to account for changes in the right (north) overbank once the full topography for the river was obtained. These data have all been provided to the Flood Control District of Maricopa County to facilitate any future analysis.

contours with the contours from the FEMA study where the aerial (1-ft) contours are within 1 foot of NGVD 1929. The topography flown in 2003 was obtained in a ground coordinate system and thus slightly shifted from Arizona Central State Plane Coordinate system, NAD 83, and has a vertical datum of NGVD 1929. The data was shifted to the Arizona Central State Plane Coordinate System prior to its use.

3.2.1 Overview of Existing Topography near King Ranch

3.2.1.1 Flood Insurance Study Topography

The Flood Insurance Study (FIS) for the Gila River was prepared by Michael Baker Corporation in 1999. According to the Technical Documentation Notebook from the study (Salt/Gila Flood Delineation Study, May 1999), the topography for the Gila River near King Ranch is based on a 1991 survey and a 1993 re-survey which re-mapped the main portion of the channel after the January 1993 floods. The contour interval for the FIS topography is 4 feet.

Electronic files from the Michael Baker FIS indicate that the aerial re-survey over the main channel near King Ranch was flown on February 6, 1993. The United States Geological Survey (USGS) data show a discharge of 13,200 cfs for that day at the Estrella Parkway gage. A stage and flow measurement, taken the next day, by the USGS recorded a flow of 13,300 cfs and indicates a water depth of just over 7 feet at the gage. Therefore, it is concluded that the contours in the main channel show the water surface instead of the ground which accounts for most, if not all, of the 6' to 8' difference in mapped elevation data.

3.2.1.2 1990 Topography

Topography from the White Tanks-Agua Fria ADMS (another FCD study that covered the area) was also obtained in GIS format. In the area near King Ranch, the contours were flown on February 10 and February 15, 1990. The contour interval is 4 feet, and the topography also covers the entire study area.

3.2.1.3 2003 Topography

In conjunction with the proposed development of King Ranch, an aerial survey was commissioned by Sontera Partners in 2003 with additional mapping obtained in 2004. The extents of the aerial survey, as well as the floodway and floodplain limits from the 1999 Michael Baker study are shown in Figure 4. The 2003 topography covers primarily the King Ranch property and extends to just north of the main channel of the river, which is about 800-1000 feet wide. The 2004 topography (discussed below) covers the balance of the channel and much of the north floodplain as shown in Figure 4.

4. Hydrology

The peak discharges for the 5, 10, 20, 50, 100 and 500 year flood events were obtained from the report by US Army Corps of Engineers on Gila River Basin (US Army Corps of Engineers, 1996). The values of the peak discharges are presented in Table 2. These peak discharges were used in the steady-state hydraulic models and are the same as used in the Baker study from 1999. The peak discharges used in the hydraulic analysis of the conditions modeled are listed in Table 1.

Table 1. Peak Discharge Values Used in Hydraulic Models

River ID	River Station (miles)	Discharge (cfs)					
		5-Year	10-Year	20-Year	50-Year	100- Year	500-Year
Gila River	195.75	23,500	57,000	92,000	185,000	227,000	285,000

No changes were made or proposed to the existing hydrology for the project reach.

5. Hydraulics

5.1 Method Description

A hydraulic analysis of both existing conditions and proposed project conditions (with bank protection) for a reach from Estrella Parkway to the Jackrabbit Road alignment was performed. An effective existing conditions hydraulic analysis was performed using the topographic information and U.S. Army Corps of Engineer's HEC-RAS, v. 3.1.2 model from the most recent FEMA FIS study. The results from the proposed conditions model were used to provide velocities and depths for use in bank protection design calculations and to provide a preliminary analysis of possible alignments.

The HEC-RAS model was developed to adequately describe the study reach. The upstream most cross-section in the model is 195.75 while the last downstream cross-section is located at 186.87. The topography needed for the generation of the cross-section shapes were obtained using procedures described in Section 3. New geometry was incorporated for the channel and overbanks where new topography was available between cross-sections 188.69 and 194.21. The remaining cross-sections were used as obtained from the Michael Baker FIS study. Figure 7 shows the locations of the cross-section stations as used in the HEC-RAS and HEC6-T models for the proposed conditions with the Cotton Lane Bridge in place as well as the original FIS cross-sections.

During the design portion of the project it was determined that the cross-section alignment should be slightly modified to better represent the flows in the proposed channel as well as for existing conditions. The modifications were made based on both the existing and proposed channel conditions and the new cross-sections better represent flow directions for both the existing and proposed conditions model. The hydraulic baseline was also slightly modified to stay within the new channel. This resulted in a river mile difference of approximately 0.01 miles for the realigned cross-sections and at the upstream end of the modified reach. While the cross-sections are at the same location as the original FIS cross-sections where they cross the baseline, the alignment across the channel has been modified to place the cross-sections at more of a right angle to the flow. The Baker cross-sections were aligned to account for significant flows over the right descending (north) bank and into the farm areas. With the topography changes and proposed channel modifications we did not see the overbank flow occurring to the north and thus the cross-section need to be adjusted to better represent flow in this reach of the river. The original and modified cross-sections are shown in Figure 7.

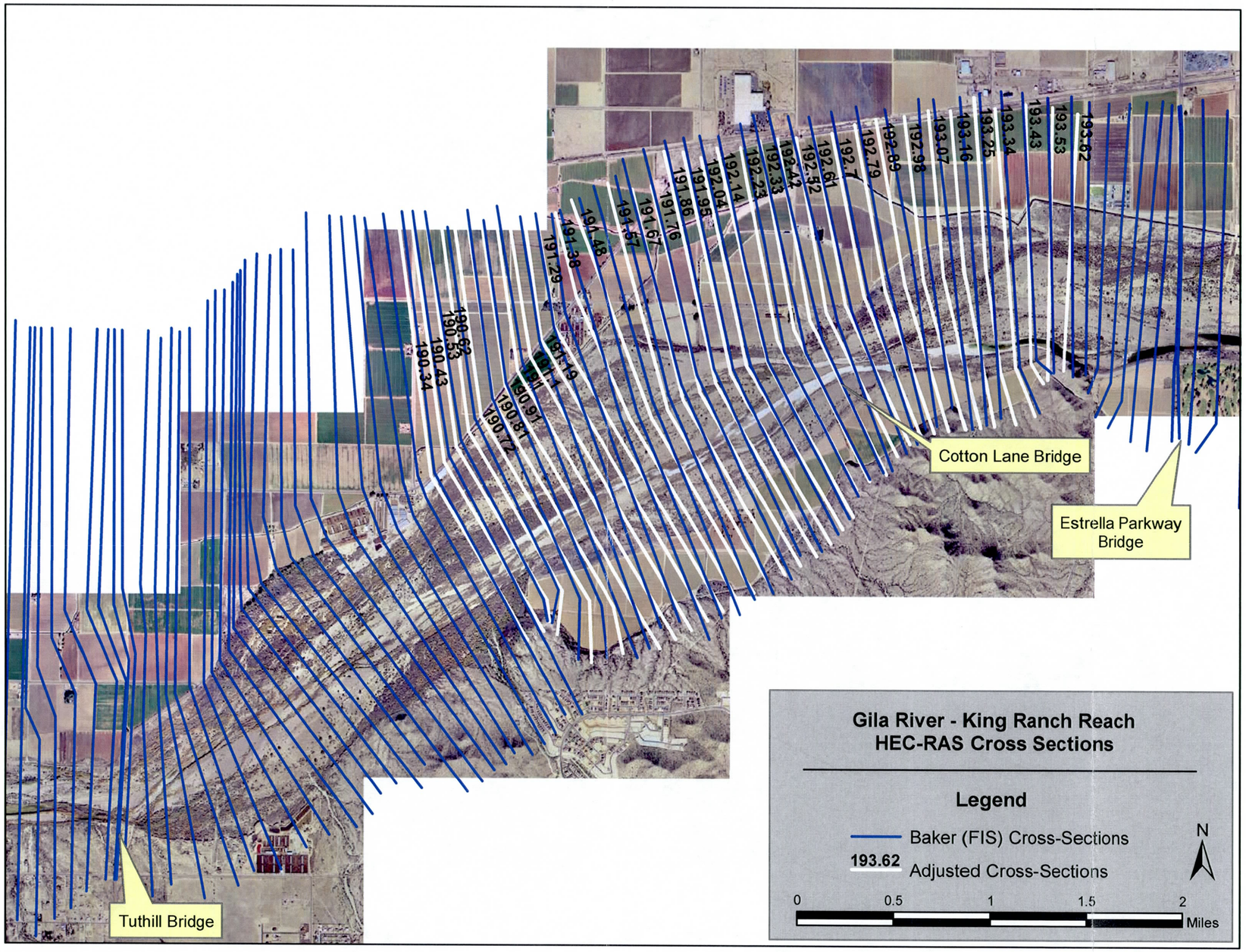

Figure 7. Cross-section cutlines used in HEC-RAS/HEC6-T models

5.2 Work Study Maps

The work study maps are included in the 24" x 36" materials at the end of the document. The work maps consist of 14 maps plus the cover and index sheets. They are produced at a scale of 1" = 400' and include both the effective, corrected effective and proposed floodplain and floodway lines for the project reach. The main sheets (3-9) have the effective and corrected effective (existing) floodplain and floodway shown while the alternate sheets (3a and 5a-9a – there are no proposed flood boundaries on sheet 4) show the corrected effective and revised (proposed) floodways and floodplains.

5.3 Parameter Estimation

5.3.1 Roughness Coefficients

The Mannings n values determine the resistance to the flow in the hydraulic models. The Mannings n values for the initial HEC-RAS model were chosen based on the information provided in the HEC-RAS model used in the Michael Baker FIS study. The validity of these values were checked to a limited extent but the Baker values were used for preliminary modeling since they were not too dissimilar to values used for the upstream Tres Rios study which was completed in 2004 (WEST 2004).

Manning's n values for the final models were developed based field visits and recent (2004) aerial photos provided by Maricopa County. The photographs taken during the field visits are presented in Appendix E.1.

The Manning's n-values used in the HEC-RAS model for the proposed King Ranch / Cotton Lane Bridge & Channel project have been determined by applying two methodologies found in the following reports:

"Roughness Coefficients for Channels in Arizona" (Aldridge and Garrett, 1973)

"Estimated Manning's Roughness Coefficients for Stream Channels and Flood Plains in Maricopa County, Arizona" (Thomsen and Hjalmarson, 1991)

"Verification of Roughness Coefficients for Selected Natural and Constructed Stream Channels in Arizona" (Phillips and Ingersoll, 1998)

5.3.1.1 Method 1: BASE "n" VALUES AND ADJUSTMENT FACTORS

The first methodology, which is addressed in the first two reports, is modified from the Chow (1959) approach of establishing a base n-value, which is a function of the stream bed material type and then applying adjustment factors that characterizes the stream irregularity, cross-sectional variations, obstructions, amount of vegetation, and degree of meandering. The consistency throughout all three of these reports indicates that the

subsequent two reports (Thomsen and Hjalmarson) and (Phillips and Ingersoll) have been developed based on the Aldridge and Garrett report. The added benefit from the subsequent two reports comes in the form of additional field studies, which have provided more sample n-values from a greater and more diverse set of streams throughout Arizona. The method in the third report, however; is to determine the n-value by analyzing the flow in a channel during a flow event and then calculating a resulting n-value. Although this report was considered to be a second phase follow-up to Thomsen and Hjalmarson (1991), data were not available for this methodology in this reach of the Gila River.

The first methodology consists of the following equation used to determine a Manning's n-value:

$$n = (n_b + n_1 + n_2 + n_3)m,$$

where,

n_b = base value of n for a straight uniform channel defined by the stream bed material.

n_1 = adjustment factor for surface irregularity

n_2 = adjustment factor for obstructions

n_3 = adjustment factor for vegetation

m = adjustment factor for meandering

Table 2 in "Roughness Coefficients for Channels in Arizona" (Aldridge and Garrett, 1973) provides n-value adjustment factors with their corresponding example descriptions for surface irregularity, obstructions, vegetation, and meandering. Table 1 of the Aldridge and Garrett report provides a list of channel materials and their corresponding n_b values defined by Chow (1959) and defined by Benson and Dalrymple (1967). The difference between Chow and Benson and Dalrymple is that the Chow n_b values characterize the smoothest reach attainable for a given bed material while the Benson and Dalrymple n_b values characterize conditions that are closer to average. Therefore, the Benson and Dalrymple n_b values are assumed to be more representative of natural conditions, and used for this analysis with the adjustment factors from Table 2 of the Aldridge and Garrett report.

The reach of the Gila River that is adjacent to the proposed King Ranch project primarily consists of material ranging from sands to fine gravels. There are, however, randomly distributed areas of bed load that include material up to cobble size material. The selected base n-value for this reach of the Gila River is $n_b = 0.028$, which is the same base n_b value selected by Thomsen and Hjalmarson during their study of the Gila River 1,000 feet upstream from the Bullard Avenue Bridge. This value also agrees well with the

value obtained using the Limerinos Equation for the bare bed (USACE 1991). Based on a D_{84} of 30 mm the Limerinos Equation gives a Manning's n value of 0.026.

The vegetation component is then added to the base n_b value to determine the overall n-values for low density, medium density, and high density. Surface irregularities, meandering, and obstructions are considered to be negligible in this reach. Values presented in Thomsen and Hjalmarson (1991) for only the vegetation portion of the equation are presented in Table 2.

Table 2. Description of Vegetation Densities and Associated n Value Adjustment Factors from Thomsen and Hjalmarson, 1991.

Vegetation	Manning's n Value Adjustment	Example
Small	0.002 to 0.010	Dense growth of flexible turf grass, such as Bermuda, or weeds where the average depth of flow is at least 2x the height of the vegetation; supple tree seedlings such as willow, cottonwood, arrow weed, or salt cedar where the average depth of flow is at least 3x the height of the vegetation.
Medium	0.010-0.025	Grass or weeds where the average depth of flow is from one to two times the height of the vegetation; moderately dense stemmy grass, weeds or tree seedlings where the average depth of flow is from 1x to 2x the height of the vegetation; moderately dense brush, similar to 1 to 2 year sold saltcedar in the dormant season, along the banks and no significant vegetation along the channel bottoms where the hydraulic radius exceeds 2 feet
Large	0.025-0.050	Turf grass or weeds where the average depth to flow is about equal to the height of vegetation; small trees intergrown with some weeds and brush where the hydraulic radius exceeds 2 feet.
Very Large	0.050-0.100	Turf grass or weeds where the average depth of flow is less than half the height of vegetation; small bushy trees intergrown with weeds along the side slopes o[r] dense cattails growing along channel bottom; trees intergrown with weeds and brush.

5.3.1.2 METHOD 2 – "n" Values Based on Predominant Vegetation

The second methodology for determining a stream n-value is vegetation dependent, and is addressed in "Roughness Coefficients for Channels in Arizona" (Aldridge and Garrett, 1973). If vegetation is the primary factor that affects the n-value, then the n-value is determined by the vegetation rather then by the stream bed material and adjustment factors. This consideration is usually consistent in floodplains or areas of the channel that are rarely flooded.

Research conducted by the U.S. Army Corps of Engineers tends to verify the validity of this approach finding that when vegetation was significant the roughness of the bed had little influence on the total n value and could be neglected (Freeman et. al., 2000). The Corps study found that roughness was dependent on flow properties – i.e. depth and velocity – as well as plant characteristics such as stiffness, density and size. This methodology has not been applied to the current study although in earlier studies by WEST, the value for very dense salt cedar communities was estimated to be near 0.200, which is the value determined by the other researchers cited in this analysis.

Table 3 in "Roughness Coefficients for Channels in Arizona" (Aldridge and Garrett, 1973) provides composite n-values for several degrees of vegetal cover in floodplains as well as in different types of constructed channels and provides the basis for this method.

5.3.2 Procedure for Determining the King Ranch Project n Values

Since the proposed Cotton Lane Project requires that a floodplain be delineated, the n-values have been determined by considering both the adjustment factor methodology as well as the vegetation dependent methodology. To apply these guidelines, aerial photography was first used to delineate land use polygons in ArcGIS 9. The study area was classified into eight land use types in which each type was assigned an n-value. Similar to the Thomsen and Hjalmarson report, which uses the adjustment factor methodology, the photographs show that the dominant factors are bed surface material and vegetation with negligible adjustments for surface irregularities and obstructions. However, an argument can also be made for considering the vegetation as the primary factor. Table 4 catalogs the photographs and describes the land use where the photographs were taken. Table 3 lists the land use type, description, and the assigned n-value.

Following the process of estimating the n-values from the aerial photography, a site visit was conducted to confirm the n-value of each land use type. During the field investigation, the above described methodologies were applied to determine if the estimated n-values were appropriate or if they required modification. Also, the field investigation allowed for an evaluation of the shape of the land use polygons delineated on the aerial photography.

Photographs were taken of the main channel and floodplain areas as a record of the field investigation. The photographs are included in Appendix A-1. The main channel and

floodplain areas consisted of the very low, low, medium, medium-high and high density vegetation land use types, which were the focus of this investigation. The general layout of the ArcMap shapefiles is shown in Figure 8. A range of photographs were referenced to (Global Positioning System) GPS points as shown on the aerial photograph in Figure 8 and Figure 9 which also shows the selected n values for the main portion of the study area.

Similar to the Thomsen and Hjalmarson report, which uses the adjustment factor methodology, the photographs show that the dominant factors are bed surface material and vegetation with negligible adjustments for surface irregularities and obstructions.

Table 4. List of Photographs and Locations with Description of Land Use and Vegetation Densitycatalogs the photographs and describes the land use where the photographs were taken while the location waypoints are shown in Figure 8.

Table 3. Assignment of Manning's n Values based on Land Use Type and Vegetation Density

Land Use	Description	n-value
Agricultural	Farmland	0.05
Mountain	Foothills	0.05
Residential	Low Density Industrial and Residential Development – No block walls.	0.04
Very Low Density Vegetation	Open channels with predominately bare bed material	0.03
Low Density Vegetation	Little significant vegetation in site	0.04
Medium Density Vegetation	Significant brush / trees but most of area still conveys flow during flood flows.	0.06
Medium-High Density Vegetation	70% of area or greater covered by dense woody vegetation but open paths exist through area for flows and can walk through most areas sometimes parting the vegetation. Flow depth approximately equal to or up to 2x the height of plants.	0.12
High Density Vegetation	Dense bushy willow, mesquite, and salt cedar (all vegetation in full foliage). Difficult if not impossible to walk through vegetation without either cutting or forcing vegetation out of way. Few, if any direct flow paths through area. Vegetation height is approximately equal to or greater than flow depth.	0.20

Table 4. List of Photographs and Locations with Description of Land Use and Vegetation Density

GPS Point	Photograph Numbers	Land Use Description
10	#4293 - #4296	Very low density vegetation located on the Gila River floodplain. High grass mixed in with light brush and trees. Maximum tree height is approximately 12 feet. Most of this material would either lay flat or be removed during high flows. 100 flood depths are approximately 10 ft in this area. Area could be classed as low density if more extensive.
11, 12, 14, 15, 16, 17	#4298 - #4305 #4306 - #4313	Pictures show both the density of the vegetation and the bed material along the Gila River main channel. If vegetation were more extensive this area would be classified as low density vegetation with light brush and trees. The bed material is mostly made up of coarse sand with random areas of cobble size bed load throughout the main channel. This vegetated area is relatively small and is neglected in comparison with large open areas. Maximum tree height is approximately 15 ft.
18	#4314 - #4320	Interface between farmland and very low density vegetation on the Gila River floodplain. Previously tilled farmland shows mostly tall weeds and some bare top soil
19	#4321 - #4336	Interface between very low density vegetation and low density vegetation. Low density vegetation located on the Gila River floodplain, and on the banks of the main channel. High grass mixed in with light brush and trees. Maximum tree height is approximately 12 feet. Very low density vegetation example photograph #4323 is of the Gila River main channel, and very low density vegetation example photograph #4329 is of the Gila River floodplain.
20	#4337 – 4358	Low density vegetation located near the Gila River main channel and floodplain. Bed material consists of mostly silty-clay with some random areas of cobble size bed load. Maximum tree height is approximately 15 feet. While some pockets of denser vegetation exist, overall this area is still open and does not have significant vegetation to hinder flows.

GPS Point	Photograph Numbers	Land Use Description
21	#4359 - #4361	Interface between very low density, low density and medium high density vegetation showing a prevalent area of cobble size bed load on the banks of the main channel. The medium high density vegetation is shown in the background beyond the bed material in photographs #4359 and #4360. Photograph # 4361 is looking up the cobble bed at an open area which has been classified low density for this study.
22, 24, 25	#4365 - #4381	Very low density vegetation located near the Gila River main channel. Bed material consists of mostly coarse sand and gravel with some random areas of cobble size bed load.
27, 28, 29	#4382 - #4391	Interface between medium density vegetation and farmland on the Gila River Flood plain showing existing rip-rap protection. Classed as medium density due to numerous flow paths through the vegetated area.
Pictures at Bullard Ave	#4392 - #4411	Photographs show same general vegetation distribution as shown in "Estimated Manning's Roughness Coefficients for Stream Channels and Flood Plains in Maricopa County, Arizona" (Thomsen and Hjalmarson, 1991)

Table 6 compares results from the methodologies used to determine n-values as well as those actually used for the proposed Cotton Lane project. Method 1 is n-values determined by bed material and adjustment factors, and Method 2 is n-values determined by predominant vegetation.

Table 5. Comparison of Manning's n Values Developed by Methods Used in Analysis.

Vegetation Land Use Type	Method 1 (add nb = 0.028) Base n + Adjustment Factors		Method 2 Vegetation Based Values Aldridge & Garrett, 1973		Cotton Lane
	Description	n	Description	n	n
Very Low Density	Dense growth of flexible turf grass (n = 0.002)	0.03	Cleared land with tree stumps, no sprouts (0.030-0.050)	0.03	0.03
Low Density	Occasional trees with some brush (n=0.010)	0.04	Scattered brush, heavy weeds (0.035-0.070)	0.05	0.04
Medium Density	Small trees intergrown with some weeds and brush where hydraulic radius is greater than 2 feet (n = 0.030)	0.06	Light brush and trees, in summer (0.04-0.08)	0.06	0.06
Medium High Density	Trees intergrown with weeds and brush (n = 0.100)	0.128	Heavy stand of timber, few down trees, little undergrowth, with stage reaching branches (0.08-0.16)	0.10	0.12
Very High Density			Dense willow, mesquite, and salt cedar (0.100-0.200)	0.20	0.20
Agricultural	Farmland		Cultivated areas (0.020-0.100)	0.04	0.05
Mountain					0.05
Residential					0.04

It should be noted that the 0.12 or medium-high density classification was added to this analysis since it was thought that the jump from 0.06 to 0.20 was too abrupt and an additional level was needed for vegetation that was dense but not so dense as to be nearly impenetrable by both water and man.

5.3.3 Future Conditions n Value Analysis

Post-Construction. Immediately after construction the channel and disturbed areas will consist primarily of unvegetated bed material with some vegetation in the main channel threads that have not been disturbed. This material should still be similar to the samples previously taken. The D_{84}, D_{50} and D_{16} are approximately 30 mm, 6 mm, and 0.4 mm, respectively (see later section on bed material analysis). Using the Limerinos Equation gives a Manning's n value of 0.026 which agrees with the 0.028 value used upstream by Aldridge and Garrett above the Bullard Avenue Bridge. This should serve as the lower limit and was used in the sediment models to predict the worst case scour depths.

Post-Construction with Vegetation. Subsequent to construction vegetation can be expected to grow in some portions of the channel. The amount and density of the vegetation will depend on the depth to water and other growing conditions in the reach of the river near the King Ranch. The existing vegetation is modeled using Manning's n values ranging from 0.03 to 0.20. It is unlikely that the entire channel will grow to a density sufficient for an n value of 0.2 although there is a slight possible if plenty of water is available for the growth of salt cedar or other similar vegetation as is the case in the Gila River just upstream of the Gila – Salt River confluence. In this area, however, the groundwater is deeper and does not provide adequate water for extremely dense vegetation from bank to bank.

Currently the most vegetated portions of the channel (near the Perryville Alignment – See Figure 1) contain a channel approximately 1300-1500' ft in total width that are relatively unvegetated (n = 0.03). The balance of the channel is much more vegetated and covers approximately 2,000 ft of the existing channel width. This would indicate that based on existing conditions the most vegetated area in this reach approximately 40% of the channel width has light vegetation while the remainder of the channel consists of medium to high density vegetation.

Given the past history of the channel it appears that during large event the river opens up a bare channel approximately 1500 ft in width to facilitate large flows. This should be expected to continue in the future. It is possible, however, that the channel could experience significant growth. A valid assumption would be that a 1500 ft corridor could be expected to either be open or to be opened during the rising stages of the flood. The worst case scenario would be that the balance of the channel was choked with salt cedar and passing little flow. A more realistic estimate may be that 35% (or a minimum of 1500' which ever is greater) is relatively open with an n value of 0.03, 20% of the channel is vegetated such that the n value is 0.06, 20% of the channel has an n value of 0.12, and the balance is choked with salt cedar with an n value of 0.20.

The worst case would be a condition with the channel choked with salt cedar except for the 1500 ft channel that was opened during the event. These values could be used as an estimate of the worst case for hydraulics in order to view the impacts of vegetation without a maintenance plan.

The proposed conditions with vegetation model are based on the n values developed for existing conditions since approximately 12 years have passed since the 1993 flood event with no maintenance of vegetation. These values were adjusted upwards by 10%, 20% and 30% to view the sensitivity of the model to increases in Manning's n values. This modeling indicated that a 10% increase in n values resulted in approximately a 0.6 ft rise in WSE while a 10% decrease in WSE resulted in a 0.65 ft decrease in WSE. The conditions described in the previous paragraphs were not modeled but could be used to view the impacts of a "worst case" scenario with no vegetative maintenance in support of maintenance provisions for the 404 permit. The results are shown in Table 6.

5.3.4 Summary of n Value Selection

Fortunately, one of the locations studied in "Estimated Manning's Roughness Coefficients for Stream Channels and Flood Plains in Maricopa County, Arizona" (Thomsen and Hjalmarson, 1991) is the Gila River, approximately 1000 feet upstream of the Bullard Avenue Bridge, and approximately 1 mile upstream from the proposed Cotton Lane project study area. The adjustment factors assessed by Thomsen and Hjalmarson at this cross-section were confirmed during the field investigation and therefore it was concluded that the n-values found in that report could be used as guideline values for the proposed King Ranch floodplain study.

After extensive review it is felt that the n-values determined for the proposed Cotton Lane project are appropriate for use in this reach of the river. The five levels of vegetation density have been the focus of the analysis since those are the land use areas that make up the majority of the Gila River along the proposed King Ranch project. Both methods facilitated an approach to determine an n-value. The n-values determined for low density and medium density by both methods result in approximately the same values. The n-value determined for high density by both methods did result in different values of which the most conservative was chosen. Photographs from the Bullard Avenue Bridge were taken to compare against the photographs found in "Estimated Manning's Roughness Coefficients for Stream Channels and Flood Plains in Maricopa County, Arizona" (Thomsen and Hjalmarson, 1991). The set of photographs provided in this report and the Thomsen and Hjalmarson (1991) report illustrate that the flow patterns and levels of vegetation are generally the same along that reach of the Gila River. The research performed in the Thomsen and Hjalmarson report provided an n-value determination based on depth of flow, while the n-value determination for the proposed King Ranch Project was for a floodplain delineation based on the 100-year storm event.

Table 6. Change in Water Surface Elevation by Percent Change in Manning's n.

Cotton Lane Bridge / King Ranch CLOMR 26-Jun-06

Change in WSE for Varying Changes in Mannning's n Value

	Percent Change in n Value					
	-30%	-20%	-10%	+10%	+20%	+30%
Average Change	-1.99	-1.30	-0.64	0.61	1.20	1.76
Difference	-0.69	-0.66			0.59	0.56
River Mile						
195.09	-2.09	-1.32	-0.64	0.6	1.15	1.68
195	-1.82	-1.18	-0.58	0.54	1.07	1.57
194.91	-1.8	-1.16	-0.57	0.54	1.07	1.58
194.81	-1.47	-0.99	-0.5	0.5	0.99	1.46
194.72	-1.37	-0.93	-0.48	0.48	0.95	1.42
194.62	-1.25	-0.86	-0.45	0.46	0.93	1.39
194.53	-1.15	-0.81	-0.43	0.46	0.93	1.4
194.4	-0.99	-0.76	-0.43	0.48	0.98	1.49
194.29	-1.88	-1.45	-0.68	0.67	1.32	1.91
194.21	-1.78	-1.22	-0.62	0.63	1.25	1.84
194.205	Estrella Parkway					
194.2	-2.2	-1.41	-0.69	0.66	1.3	1.9
194.1	-2.18	-1.4	-0.68	0.65	1.28	1.87
194.02	-2.17	-1.39	-0.68	0.65	1.28	1.87
193.94	-2.05	-1.34	-0.66	0.63	1.25	1.83
193.87	-1.98	-1.3	-0.64	0.62	1.23	1.8
193.79	-1.94	-1.27	-0.63	0.62	1.23	1.79
193.73	-2.03	-1.34	-0.66	0.64	1.26	1.83
193.62	-2.23	-1.44	-0.7	0.67	1.32	1.91
193.53	-2.22	-1.44	-0.7	0.67	1.32	1.9
193.43	-2.21	-1.44	-0.7	0.68	1.33	1.91
193.34	-2.2	-1.43	-0.7	0.68	1.32	1.91
193.25	-2.27	-1.48	-0.72	0.68	1.34	1.93
193.16	-2.29	-1.48	-0.72	0.69	1.35	1.94
193.07	-2.24	-1.46	-0.71	0.68	1.34	1.93
192.98	-2.18	-1.42	-0.7	0.67	1.31	1.89
192.89	-2.21	-1.44	-0.71	0.67	1.31	1.9
192.79	-2.23	-1.45	-0.71	0.67	1.32	1.92
192.7	-2.21	-1.44	-0.71	0.67	1.31	1.91
192.61	-2.13	-1.39	-0.68	0.65	1.28	1.87
192.52	-2.03	-1.34	-0.66	0.63	1.25	1.84
192.41	-2	-1.32	-0.65	0.63	1.24	1.81
192.39	Cotton Lane Bridge					
192.38	-2.13	-1.39	-0.68	0.64	1.26	1.83
192.33	-2.09	-1.37	-0.67	0.64	1.25	1.83

Table 6. Change in Water Surface Elevation by Percent Change in Manning's n (Cont).

	Percent Change in n Value						
	-30%	-20%	-10%	+10%	+20%	+30%	
192.23	-2.06	-1.35	-0.66	0.64	1.24	1.82	
192.14	-2.2	-1.41	-0.68	0.65	1.26	1.84	
192.04	-2.08	-1.34	-0.65	0.62	1.21	1.77	
191.95	-2	-1.3	-0.64	0.6	1.17	1.72	
191.86	-1.92	-1.25	-0.62	0.58	1.15	1.69	
191.76	-1.93	-1.26	-0.61	0.59	1.15	1.69	
191.67	-1.95	-1.27	-0.62	0.59	1.16	1.7	
191.57	-1.96	-1.27	-0.62	0.6	1.17	1.71	
191.48	-1.98	-1.28	-0.63	0.6	1.17	1.72	
191.38	-2.01	-1.3	-0.63	0.61	1.19	1.74	
191.29	-2	-1.3	-0.63	0.6	1.18	1.73	
191.19	-2.02	-1.31	-0.64	0.61	1.19	1.74	
191.1	-2.01	-1.31	-0.63	0.61	1.19	1.74	
191	-2.04	-1.32	-0.64	0.61	1.2	1.75	
190.91	-2.1	-1.36	-0.66	0.62	1.21	1.77	
190.81	-2.1	-1.35	-0.65	0.62	1.21	1.78	
190.72	-2.08	-1.35	-0.65	0.62	1.21	1.77	
190.62	-2.06	-1.33	-0.64	0.62	1.2	1.76	
190.53	-2.03	-1.32	-0.64	0.6	1.18	1.73	
190.43	-2.01	-1.3	-0.63	0.6	1.17	1.72	
190.34	-1.96	-1.27	-0.62	0.58	1.14	1.67	End of Project
190.24	-1.88	-1.22	-0.59	0.56	1.11	1.62	
190.15	-1.89	-1.22	-0.59	0.56	1.09	1.61	
190.05	-1.73	-1.12	-0.55	0.53	1.03	1.51	
189.96	-1.62	-1.06	-0.52	0.5	0.99	1.45	
189.87	-1.52	-0.99	-0.48	0.48	0.94	1.38	
189.77	-1.4	-0.92	-0.46	0.44	0.87	1.29	Not Used in Average Due to Drawdown / Backwater Effects from Boundary Condition
189.67	-1.3	-0.86	-0.43	0.42	0.82	1.22	
189.58	-1.21	-0.8	-0.4	0.39	0.77	1.14	
189.48	-1.1	-0.73	-0.37	0.36	0.72	1.07	
189.39	-1	-0.67	-0.33	0.34	0.68	1.01	
189.3	-0.91	-0.62	-0.31	0.31	0.62	0.93	
189.21	-0.78	-0.53	-0.26	0.28	0.55	0.83	
189.11	-0.64	-0.44	-0.23	0.23	0.46	0.71	
189.02	-0.52	-0.36	-0.18	0.19	0.39	0.59	
188.81	-0.29	-0.2	-0.1	0.12	0.24	0.37	
188.69	-0.17	-0.12	-0.06	0.07	0.14	0.21	
188.59	0	0	0	0	0	0	

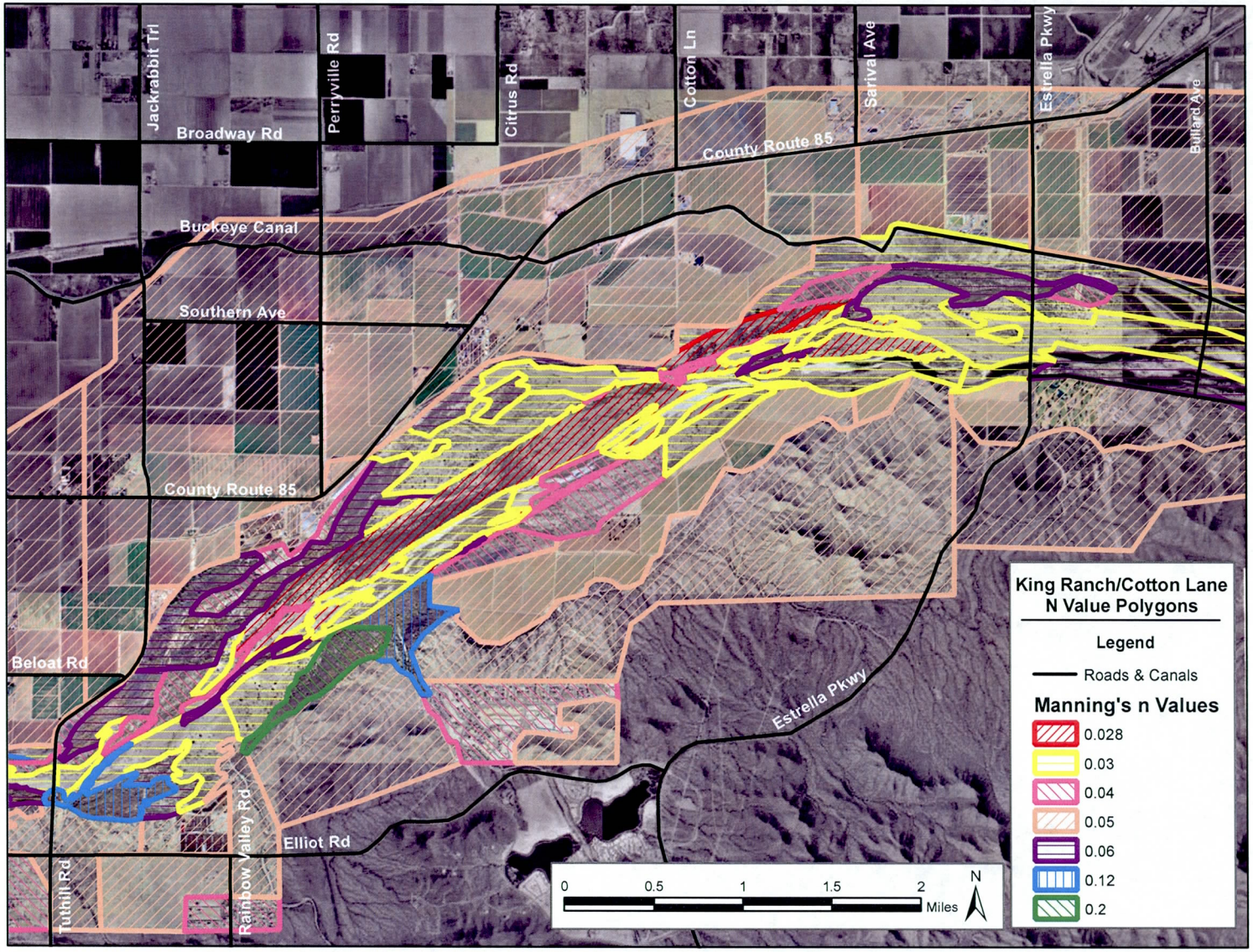

Figure 8. Overview of Selected Manning's n Values for the Cotton Lane Bridge Study Reach.

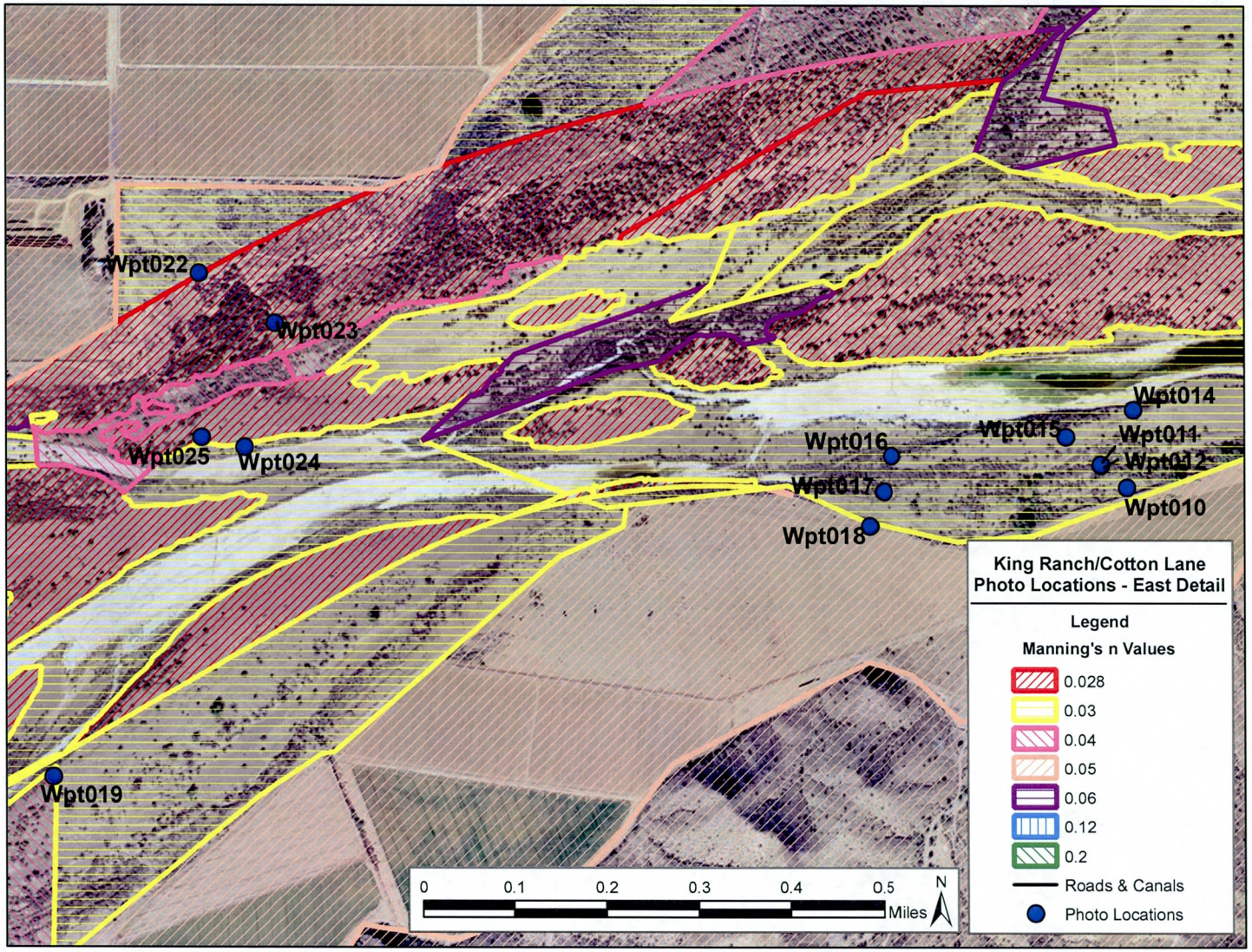

Figure 9. Cotton Lane Field Photo Locations and Associated n Values.

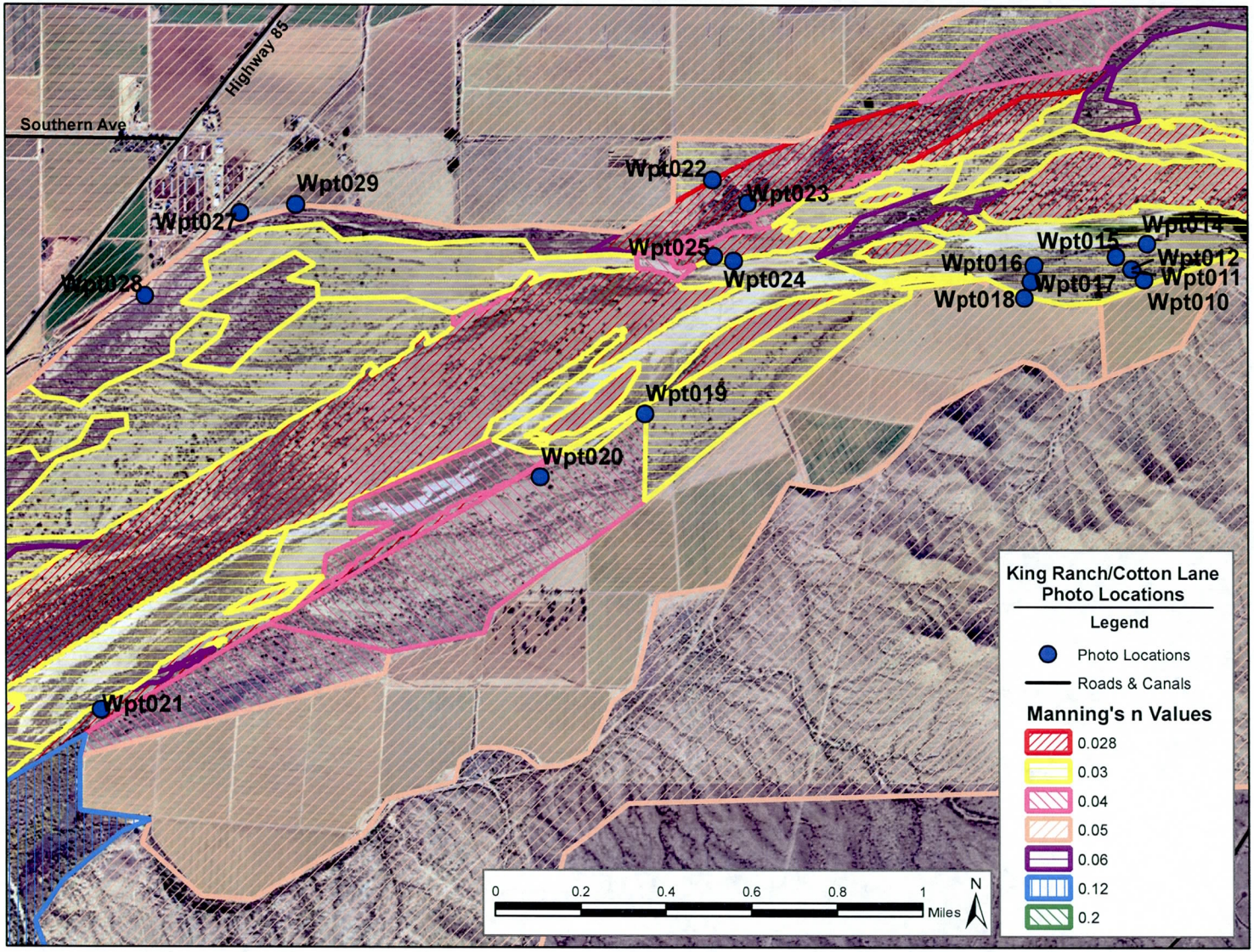

Figure 10. Cotton Lane Field Photo Locations for Central Portion of Study Area.

5.4 Expansion and Contraction Coefficients

The contraction and expansion coefficients of 0.1 and 0.3 respectively were used near the bridges to accommodate the hydraulic losses that occur due to the presence of the bridges.

5.5 Cross Section Descriptions

The HEC-RAS model was developed to adequately describe the study reach. The upstream most cross-section in the model is 195.75 while the last downstream cross-section is located at 186.87. New geometry was incorporated for the channel and overbanks where new topography was available between cross-sections 188.69 and 194.21. The remaining cross-sections and portions of the north overbank where new mapping was not available were used exactly as obtained from the Michael Baker FIS study. Figure 11 shows the locations of the cross-section stations as used in the HEC-RAS and HEC6-T models for the proposed conditions with the Cotton Lane Bridge in place as well as the original FIS cross-sections from the Baker study.

During the design portion of the project it was determined that the cross-section alignment should be slightly modified to better represent the flows in the proposed channel as well as for existing conditions. The modifications were made based on the results of a two-dimensional model as well as the proposed channel conditions. The new cross-sections are more correctly aligned with the flow in the reach under both existing and proposed conditions adequately represent flow for both the existing and proposed conditions model. The hydraulic baseline was also slightly modified to stay within the new channel. This resulted in a river mile difference of approximately 0.01 miles for the realigned cross-sections and at the upstream end of the modified reach. While the cross-sections are at the same location as the original FIS cross-sections where they cross the baseline, the alignment across the channel has been modified to place the cross-sections at more of a right angle to the flow. The Baker cross-sections were aligned to account for significant flows over the right descending (north) bank and into the farm areas. With the topography changes and proposed channel modifications we did not see the overbank flow occurring to the north and thus the cross-section need to be adjusted to better represent flow in this reach of the river. The original and modified cross-sections are shown in Figure 11.

The baseline was also modified slightly in this reach to keep it inside the new channel. This resulted in a slight increase in length. The difference was on the order of 0.01 miles at most cross sections. The maximum change in location was 0.02 miles. The location where the cross sections intersect the new base line were kept so as to make the cross sections as comparable as possible between the existing FIS model and the new existing and proposed conditions models.

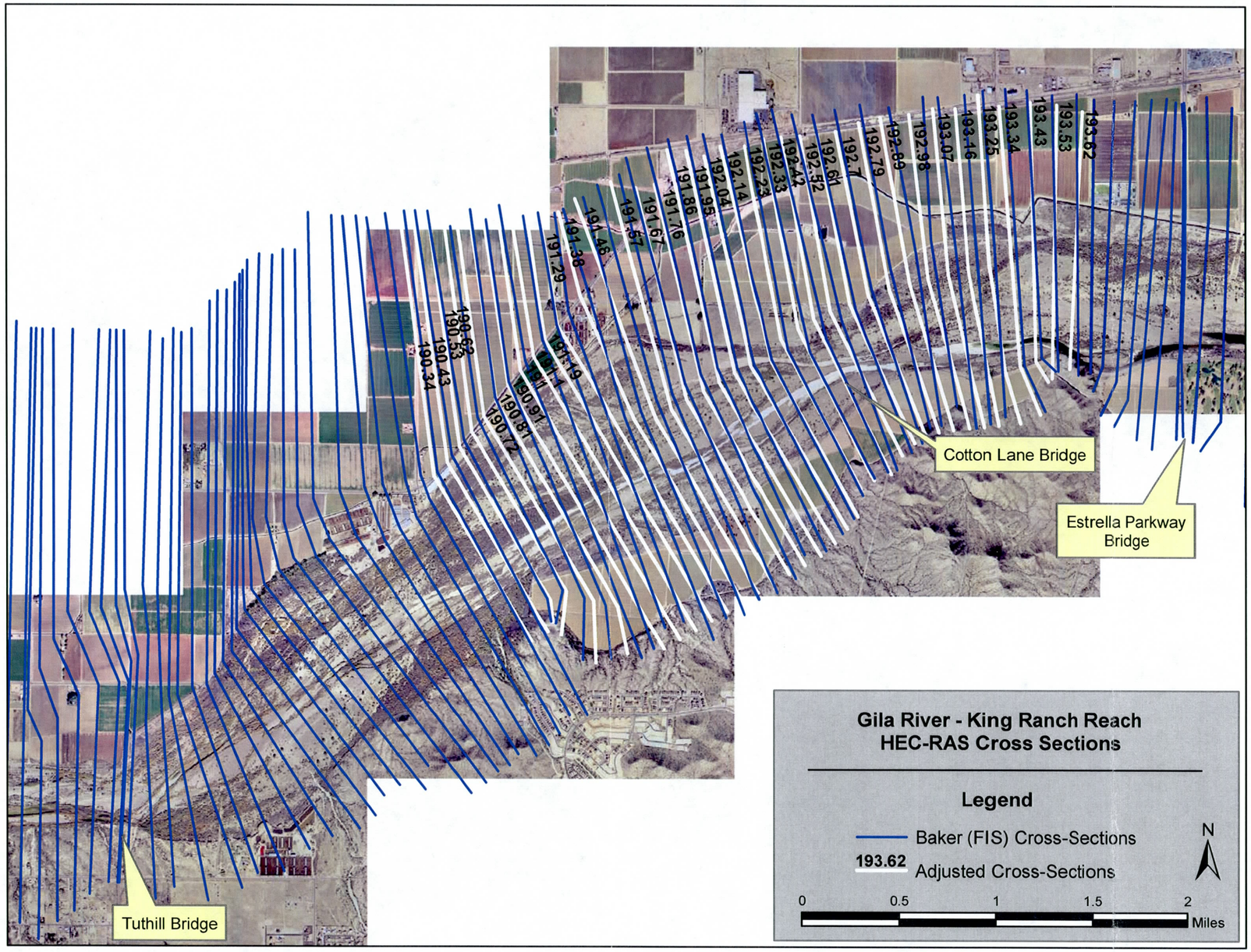

Figure 11. Cross-section cutlines used in HEC-RAS/HEC6-T models

5.6 Modeling considerations

5.6.1 Hydraulic Jump and Drop Analysis

No hydraulic jumps or drops are expected within this river reach.

5.6.2 Bridges and Culverts

Two existing bridges exist in the Baker FIS model in this reach. One is at Tuthill Road and on at Estrella Parkway. Both of these bridges are shown in Figure 11. Additionally a bridge is proposed at Cotton Lane which is a part of this project. The location of this bridge is also indicated in Figure 11. An additional bridge exists at Bullard Avenue just upstream of the tie in to the existing floodplain and floodway.

5.6.3 Levees and Dikes

There are no levees in the project. All areas behind the bank protection will be raised at least 1.0 ft above the resulting floodway WSE elevation with the exception of tributary channels and first flush basins. Finished floors are being deisgned to be in excess of 2.0 ft above the encroached 100 year water surface elevation. An elevation of 2.0 ft above the 100 year encroached flood elevation puts the finished floors above the 500 year water surface elevation in the project reach.

The project as designed contains five vane dikes – four on the north bank and one on the south bank. The purpose of the four northern vane dikes is to keep the main thalweg of the river away from the north bank in order to help protect an irrigation canal and highway from damage. The vane dikes are designed to be about half of the water depth in the area with toe downs calculated to protect against toe scour. This design will allow water to flow into the areas but prevent the main river channel from realigning itself on the north bank adjacent to the canal and highway. The dikes on the north side of the river have little impact on hydraulics and sediment transport. Gravel mining is now expected in the area to the northwest and the north vane dikes are being considered for removal from the project.

The vane dike on the south bank is designed to protect environmental enhancements on Arizona Game & Fish managed lands along the south bank. The vane dikes are to prevent the river thalweg from moving into the mitigation areas to be constructed on the Game & Fish lands behind the vane dikes. The use of vane dikes allows floodwaters to enter the area behind the vane dikes while still providing protection against deep scour.

5.6.4 Islands and Split Flows

There are no islands or split flow areas in the project reach. The models warn of split flows but the areas are in ineffective flow areas or areas that canals or other low areas.

5.6.5 Ineffective Flow Areas

The ineffective flow areas were originally prescribed based on the model used in Baker FIS study. The appropriateness of the ineffective flow areas to the model developed in this study was verified during this process and adjusted as necessary to represent any changes

since the Baker modeling was performed. All cross-sections were inspected for ineffective flow areas. A maximum of 4:1 expansion was maintained in developing these areas, where necessary. The ineffective area heights were raised vertically sufficient to contain high flows.

The contractions were modeled at 2:1 and the coefficients for expansion and contraction were 0.1 and 0.3 respectively. The only exception is in the reach near Estrella Parkway Bridge (194.2) where both the contraction and expansion coefficients were originally set to 0.3. This was modified as to be 0.1 and 0.3 as is standard practice since no clear reason was determined as to why the higher contraction loss coefficient should be used.

5.5.6 Supercritical Flow

No areas of supercritical flow were identified in the project.

5.7 Floodway Modeling

The floodway was modeled by using Method 1 encroachments. The encroached water surface elevations were less than 1.0 ft above the non-encroached water surface elevations. The bank stations were not allowed to encroach into the main channel and thus much of the reach has encroached water surface elevations that are significantly less than the allowable 1.0 ft.

5.8 Problems Encountered During the Study

5.8.1 Special Problems and Solutions

5.8.1.1 Merging of New and Old Topography

The change in the topography in this reach of the Gila River has caused a significant change in the floodplain and floodway elevations in this reach of the river. The differences between the existing FIS water surface elevations and those obtained after replacing the FIS bed elevations with those obtained during this study are shown in Figure 12. The exiting conditions HEC-RAS model data is included in APPENDIX A-2 and the model is included on the enclosed CD.

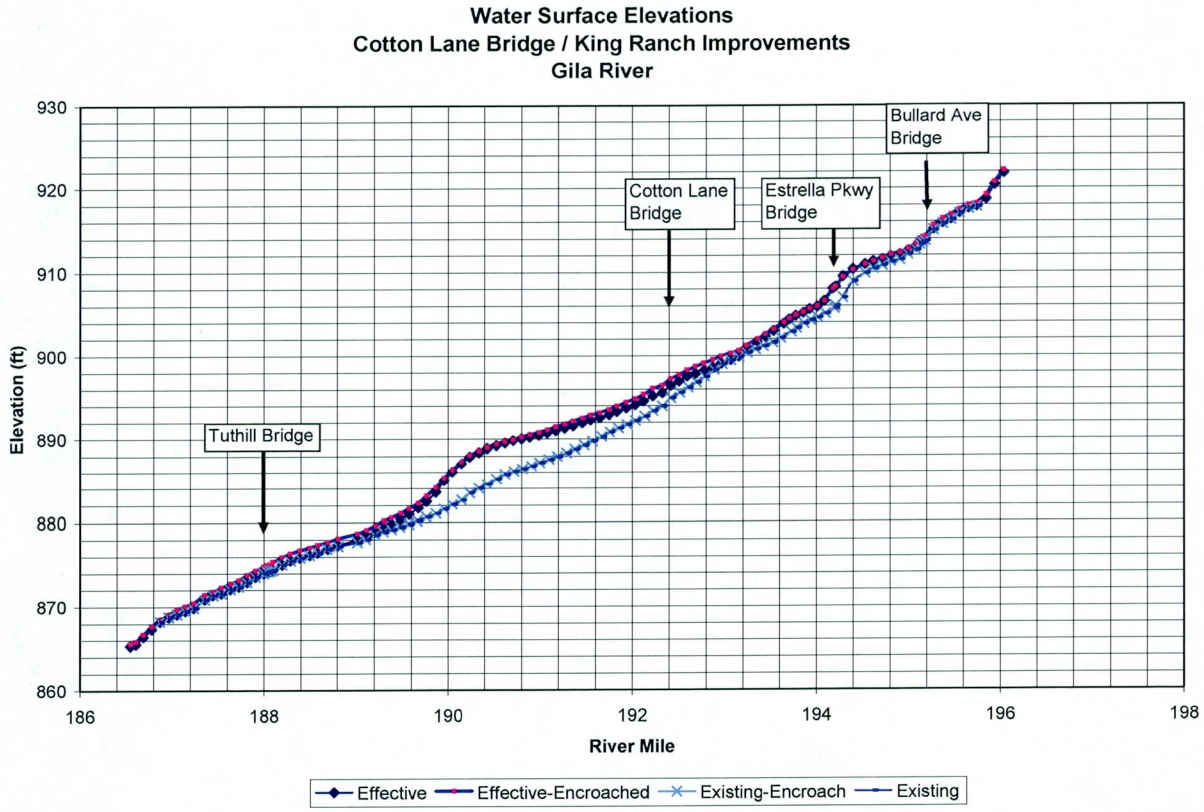

Figure 12. Floodway and Floodplain Elevations from Baker (1999) Study and Current Modeling

Figure 13 shows the water surface elevation profiles for the 5, 10, 20, 50 and 100 year events. The results show fairly uniform variation of the water surface profiles for all the flow events considered in this study. The rapid changes in the channel bottom due to the splicing of the new topography tend to influence the 5-year event the most with the 100 year event being impacted the least.

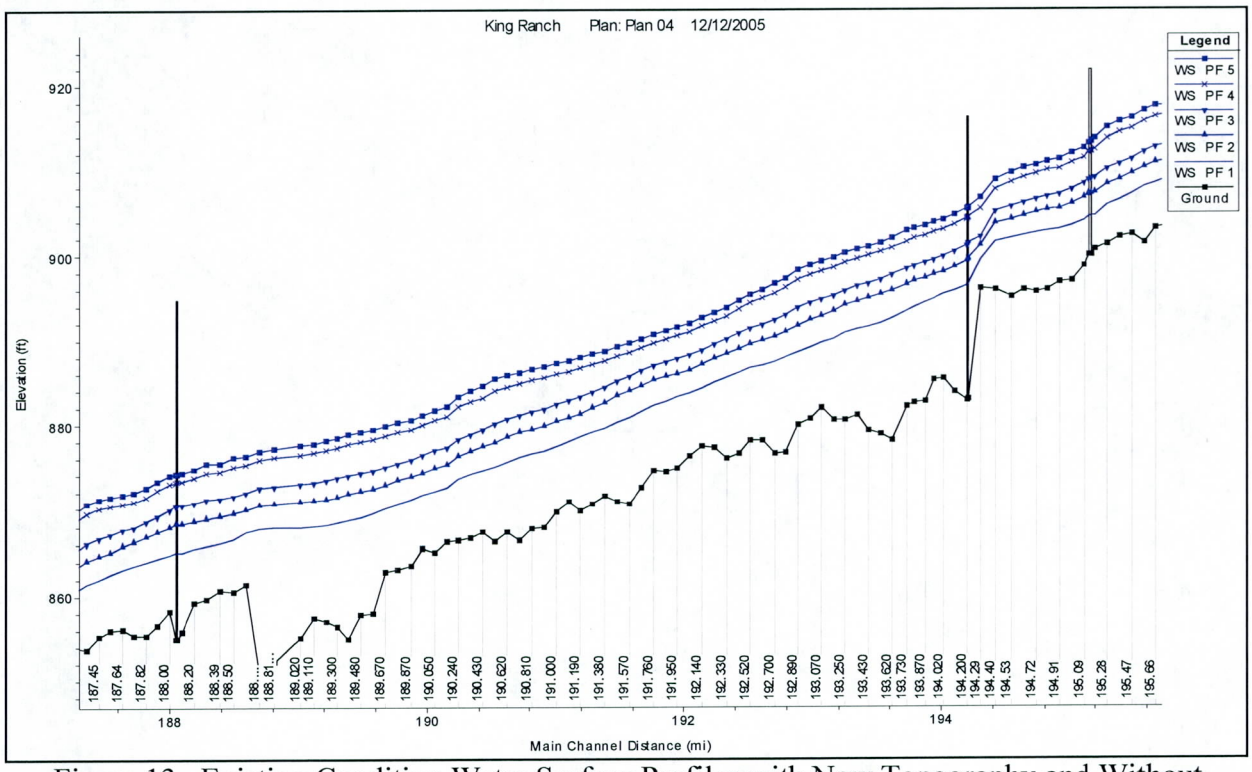

Figure 13. Existing Condition Water Surface Profiles with New Topography and Without Project.

The rapid change in thalweg elevation near the right side of Figure 13 (approximately cross-section 194.2) is located at the Estrella Parkway Bridge where new topography is blended with the older topography. This is most likely due to the transition from channel bed in the new topography to the water surface as the channel low point as described in the earlier section describing the topography. The new topography that was subsequently obtained provided new topography across the entire river upstream of the bridge and allowed the confirmation that the change is an artifact of the topography rather than a change in bed elevations for existing conditions. The same phenomenon also occurs towards the lower end of the model where bed elevations transition back into water surface elevations for the 13,000 cfs flow. The downstream transition occurs between cross-sections 188.59 and 188.69. The difference in thalweg elevations is shown in Figure 14. The maximum difference is in excess of 16 ft while the average difference is 7.8 ft.

The drop in bed elevation across the transition at 194.2 causes some model instability in HEC-RAS. The location of the floodway and floodplain lines were not modified in this reach as a result of the instability but were carried in their existing location from cross section 194.2 to the tie in at 195.09. This reach is also impacted by flow from the Agua Fria River which enters the Gila just upstream of the Bullard Avenue Bridge.

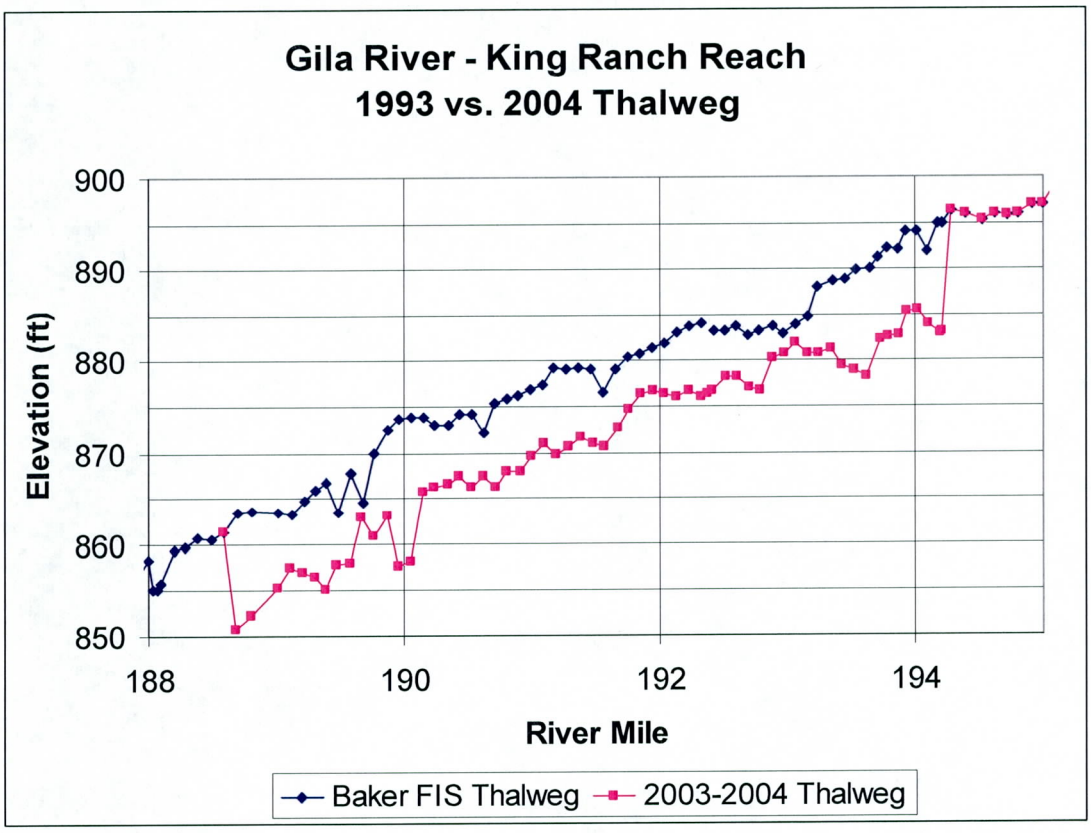

Figure 14. Difference in Thalweg Elevations between 1993 and 2003/2004 Surveys.

5.9 Modeling Warning and Error Messages

Several warnings and messages were noted. Most of the warnings dealt with divided flow situations. These involved areas of the far overbanks where berms, canals or other features have cut the floodplain off from the channel. These all occurred in areas of ineffective flow.

The most significant warning message occurs at cross section 194.29 which is immediately upstream of the Estrella Parkway Bridge. This is due to the change in topography from the old to the new at the cross section downstream. This change left a "bump" in the bed of the river due to both the flow in the river during the 1993 data collection and the change in river topography since 1993.

No errors were noted in the models.

5.10 Calibration

The effective model was originally run as accepted by FEMA with only minor changes at the bridge bounding cross sections to conform with the latest version of HEC-RAS. The updated topography was inserted into the approved model and changes noted. All other parameters were left as they were in the original FIS model. No other calibration was performed on the model.

5.11 Final Results

5.11.1 Hydraulic Analysis Results

The proposed conditions hydraulics model is based on the existing conditions hydraulics with the proposed channel and bank alignments incorporated to reflect the proposed conditions. Manning's n values were used as described above. The proposed conditions are modeled from a new TIN of the ground surface with the channel and bank elevations in place. The area behind the banks was modeled as a flat fill with a minimum elevation of 1.0 ft above the 100 year water surface elevation. On site plans will further define these elevations and the elevations will meet both FEMA and FCDMC criteria for design with finished floor elevations significantly above the minimum requirement for the project. Since the area will be significantly above the 100 year floodplain it was not felt that it was necessary to be extremely accurate in these areas prior to final modeling. Ineffective flow areas were developed based on the new bank lines and flow limits. No large differences are noted between the floodway and floodplain elevations due to the incised nature of the natural channel and the encroachment of the bank protection in the reach. The results of the hydraulics simulation are presented in Figure 15. The proposed condition HEC-RAS model results are included in APPENDIX E.

It can be noted that there is a large difference between the exiting and proposed floodplain elevations in this reach. The majority of this difference is due to the change in topography subsequent to the 1993 FIS model as well as the impact of the 13,000 cfs flow in the channel at the time the topography was flow in 1993. The channel improvements in this reach further reduce the water surface elevations where the channel bars are being lowered. It should be remembered that proposed conditions are being modeled with the existing vegetation having regrown in the channel rather than the new constructed bare channel being used for modeling purposes. The layout as modeled is shown in Figure 16

.

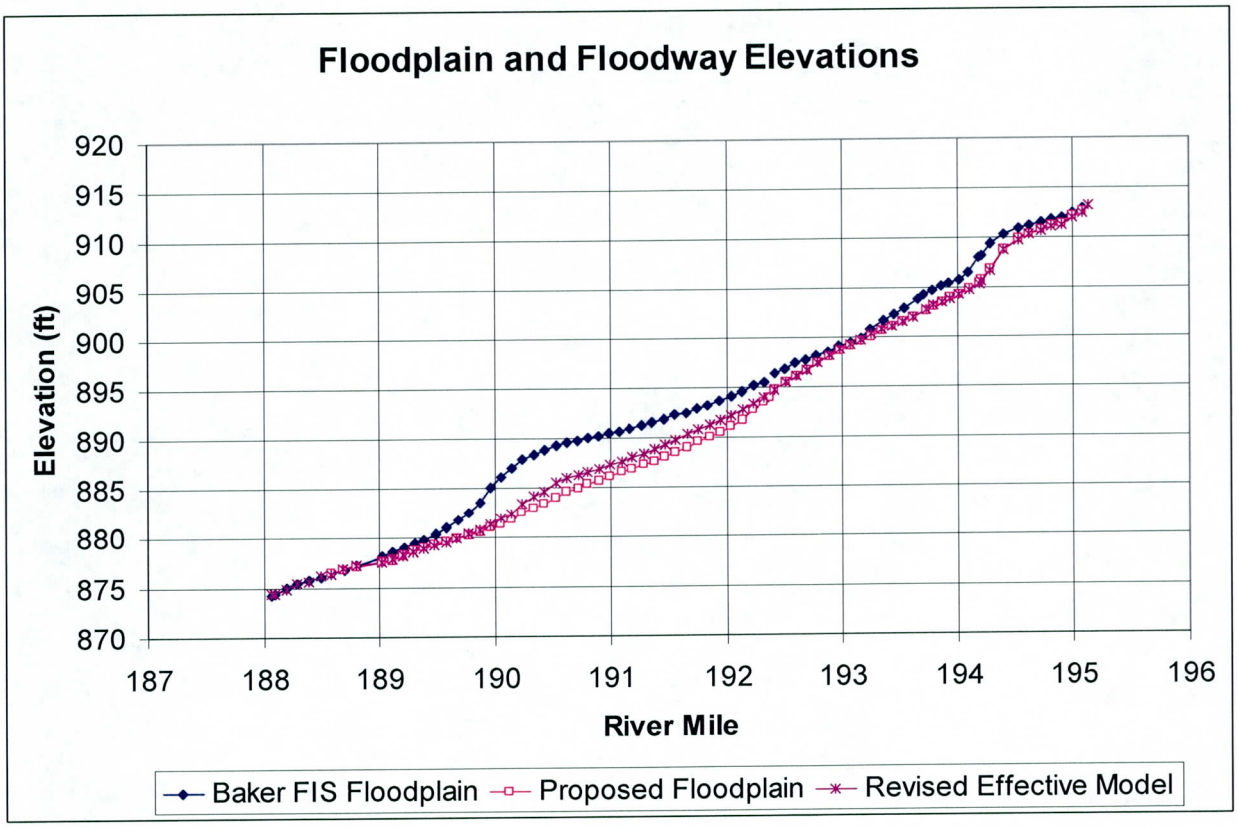

Figure 15. Comparison of Floodplain Elevations for Baker FIS, the Revised Effective and Proposed Conditions Models

The depth of cut and the location of the excavation for the proposed condition are shown in Figure 17. It can be noted from the figure that the low flow channels are not impacted by the excavation and that most of the excavation is obtained from the area west of the Cotton Lane Bridge.

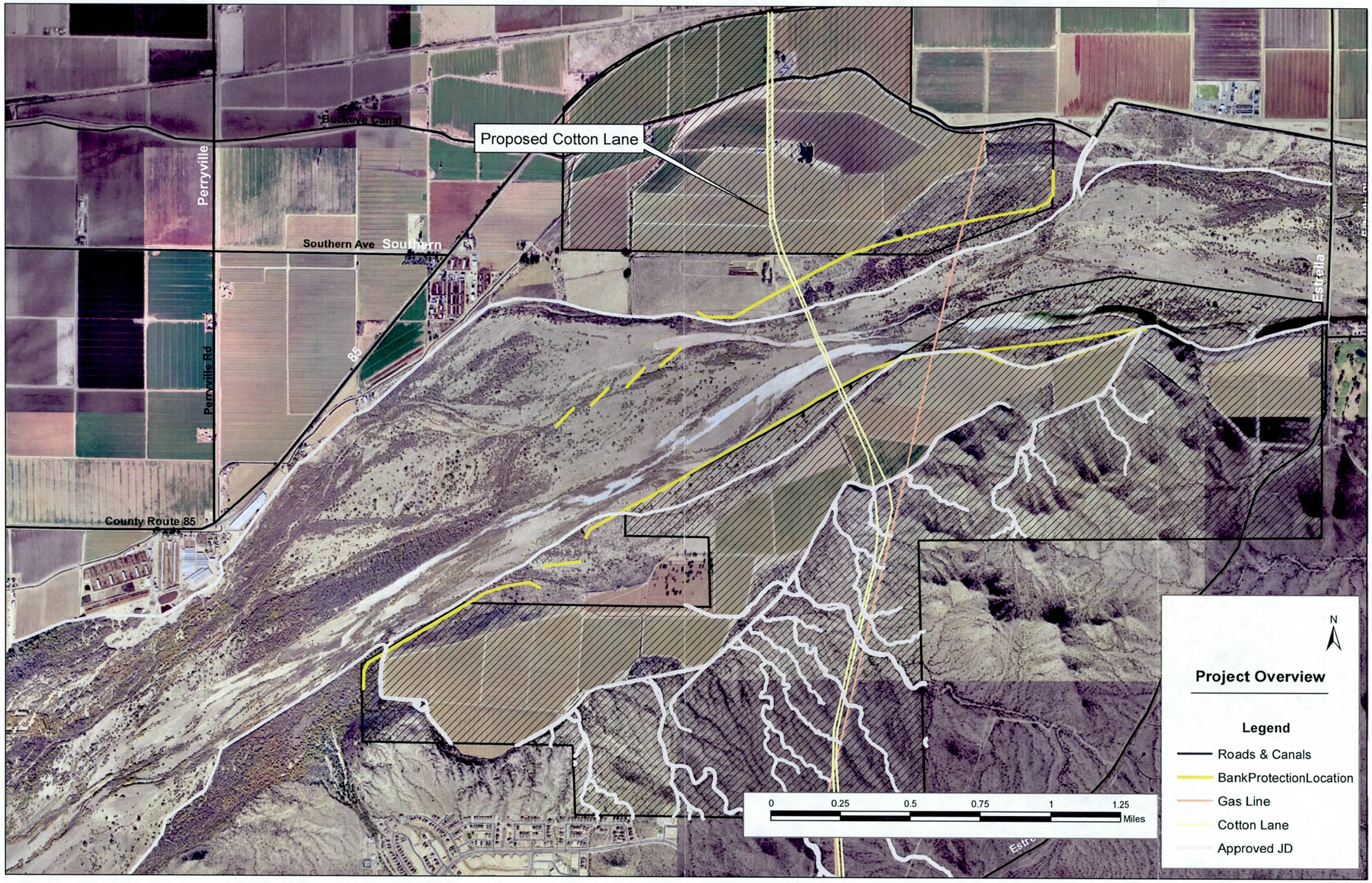

Figure 16. Aerial of King Ranch area showing Cotton Lane Alignment, property boundaries and proposed bank lines in yellow. Proposed cut areas shown in blue.

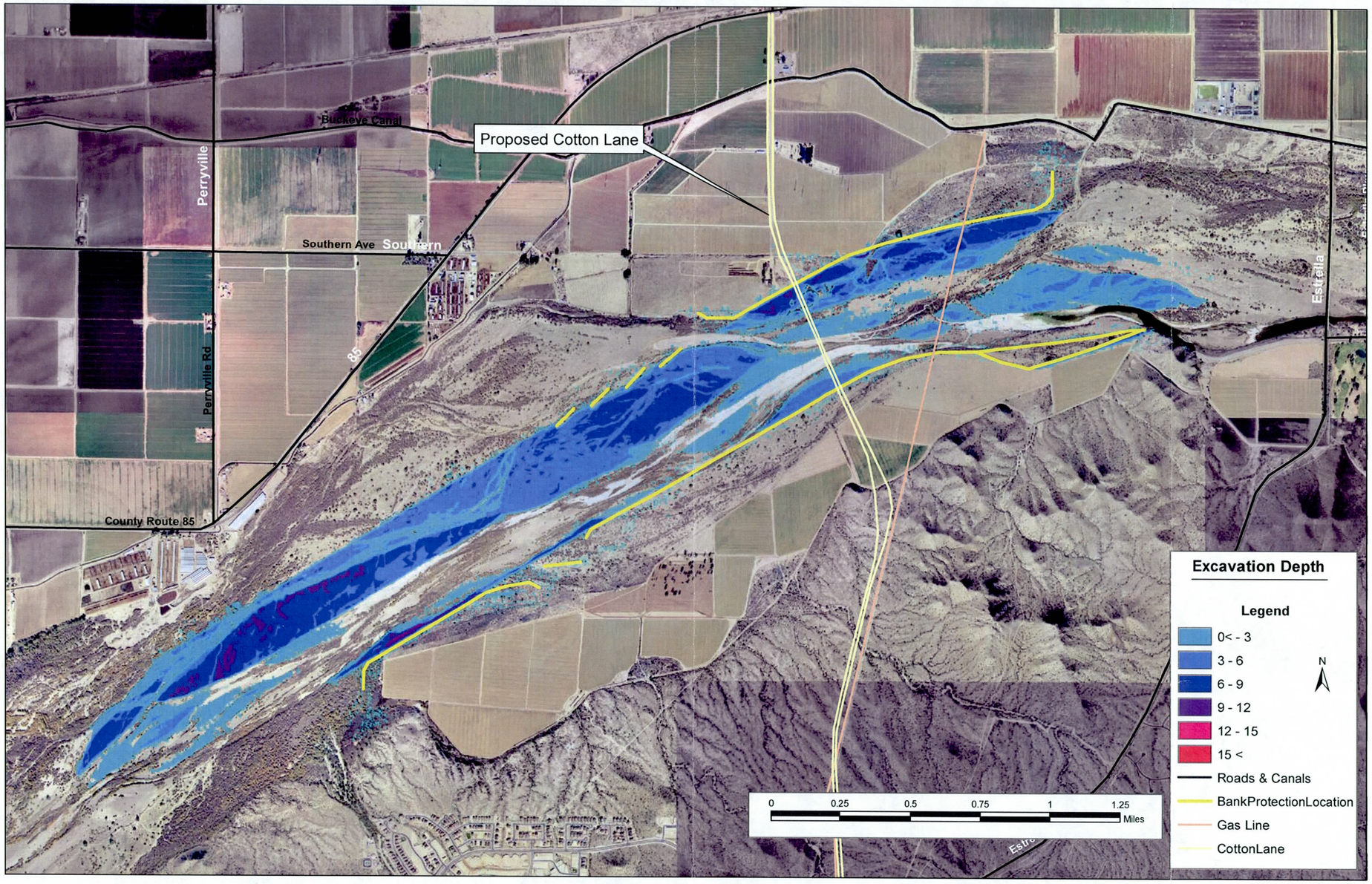

Figure 17. Depth of cut for Cotton Lane Bridge Channel Improvements.

5.11.2 Verification of Results

The RAS results correspond closely to the Duplicate Effective model where the old topography was used. The areas where new topography was used vary from the original HEC-RAS model. The stationing is somewhat different (up to 0.02 miles) due to the adjustment of the model baseline to keep it inside the modified channel under the proposed conditions. Thus differences of up to 0.02 river miles are due to changes in the base line rather than changes in the cross section location and the values can be compared directly.

Table 7. HEC-RAS Output for Effective, Existing and Proposed Models

HEC-RAS Output - Cotton Lane Bridge / King Ranch Development CLOMR										26-Jun-06	
River Sta	Q Total	Min Ch El	W.S. Elev	Delta W.S.	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude #
	(cfs)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	Channel
195.145	Bridge										
195.13	227000	900	913.49		908.67	914.95	0.0014	9.8	23909.51	2250.81	0.48
195.13	227000	900	913.23	0.26	908.68	914.76	0.001504	10.02	23346.1	2237.74	0.5
Tie In to Effective Flood Plain											
195.09	227000	898.8	912.92		909.2	914.55	0.0018	10.41	23265.98	3870.59	0.54
195.09	227000	898.8	912.57	0.35	909.24	914.32	0.002	10.76	22300.34	3658.25	0.57
195.09	227000	898.8	912.57	0	909.24	914.32	0.002001	10.76	22293.3	3656.43	0.57
195	227000	897	912.5		908.47	913.63	0.001335	8.77	28264.31	4603.89	0.46
195	227000	897	912.05	0.45	908.48	913.29	0.001539	9.18	26684.93	4366.24	0.49
195	227000	897	912.05	0	908.49	913.29	0.00154	9.18	26675.47	4364.6	0.49
194.91	227000	896.9	912.04		907.59	912.96	0.001156	7.95	31223.72	5049.52	0.43
194.91	227000	896.9	911.43	0.61	907.63	912.52	0.001445	8.55	28692.07	4973.53	0.47
194.91	227000	896.9	911.43	0	907.63	912.51	0.001446	8.56	28677.74	4973.36	0.47
194.81	227000	896	911.83		905.81	912.45	0.000657	6.51	38056.13	5295.81	0.33
194.81	227000	896	911.16	0.67	905.84	911.88	0.000817	7	35133.96	5166.01	0.37
194.81	227000	896	911.16	0	905.84	911.88	0.000818	7	35118.3	5164.77	0.37
194.72	227000	895.7	911.49		905.77	912.12	0.000721	6.53	37295.63	5052.69	0.34
194.72	227000	895.7	910.72	0.77	905.79	911.46	0.000926	7.07	34245.17	4727.53	0.38
194.72	227000	895.7	910.72	0	905.79	911.46	0.000927	7.08	34228.41	4725.73	0.38
194.62	227000	896	911.22		905.56	911.75	0.000632	6.02	39327.64	5483.84	0.32
194.62	227000	896	910.34	0.88	905.58	910.99	0.000859	6.67	35670.97	5295.66	0.36
194.62	227000	896	910.33	0.01	905.57	910.99	0.000861	6.67	35650.46	5294.07	0.36
194.53	227000	895.2	910.88		905.18	911.43	0.000668	6.07	39260.35	6542.15	0.32
194.53	227000	895.2	909.83	1.05	905.21	910.53	0.000967	6.87	34578.52	5578.04	0.38
194.53	227000	895.2	909.82	0.01	905.21	910.53	0.000963	6.89	34550	5571.13	0.38
194.4	227000	896	910.3		904.74	910.94	0.000737	6.63	36875.15	6723.23	0.34
194.4	227000	896	908.85	1.45	904.77	909.76	0.001219	7.83	30963.52	5836.13	0.43
194.4	227000	896	908.85	0	904.77	909.76	0.00122	7.83	30952.59	5834.55	0.43
194.29	227000	896.2	909.44		904.95	910.32	0.001108	7.68	30594.8	5971.81	0.41
194.29	227000	896.2	906.82	2.62	904.97	908.45	0.002921	10.4	22651.53	5082.51	0.65
194.29	227000	896.2	906.81	0.01	904.97	908.44	0.002932	10.41	22623.04	5079.93	0.65
194.21	227000	895	908.21		903.81	909.56	0.001488	9.33	24318.3	2140.39	0.49
194.21	227000	883.1	905.83	2.38	902.4	907.38	0.001654	9.66	22951.31	2979.2	0.52
194.21	227000	883.1	905.84	-0.01	902.06	907.36	0.00166	9.89	22969.06	2979.7	0.53
194.195	Bridge										
194.18	227000	895	907.96		903.82	909.38	0.0016	9.54	23789.32	2138.49	0.5
194.2	227000	883.11	905.55	2.41		907.16	0.001765	9.86	22506.82	2482.05	0.54
194.2	227000	882.97	905.54	0.01	901.99	907.12	0.001785	10.1	22472.19	2117.26	0.55
194.09	227000	891.9	906.48		904.24	908.19	0.002975	10.48	21662.34	5496.83	0.64
194.1	227000	883.87	904.93	1.55		906.22	0.001551	9.13	24897.76	4409.68	0.5
194.1	227000	883.87	904.88	0.05	901.13	906.19	0.001565	9.17	24765.32	3014.25	0.51
194.01	227000	894.1	905.82		902.57	906.93	0.001899	8.45	26851.08	5422.54	0.5
194.02	227000	885.49	904.39	1.43		905.49	0.001368	8.36	26960.34	4277.07	0.47
194.02	227000	885.49	904.34	0.05	900.33	905.45	0.001387	8.46	26835.07	3215.48	0.47
193.93	227000	894.1	905.53		901.11	906.28	0.001111	6.96	32683.19	4960.4	0.4
193.94	227000	885.38	904.08	1.45		904.96	0.001111	7.51	30115.46	4742.98	0.41
193.94	227000	885.38	904.02	0.06	899.4	904.92	0.001126	7.58	29956.84	3507.09	0.42

HEC-RAS Output - Cotton Lane Bridge / King Ranch Development CLOMR										26-Jun-06	
River Sta	Q Total	Min Ch El	W.S. Elev	Delta W.S.	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude #
	(cfs)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	Channel
193.86	227000	892	905.11		900.72	905.85	0.001114	6.93	32754.09	4575.14	0.4
193.87	227000	882.8	903.66	1.45		904.44	0.001473	6.95	32170.73	4426.25	0.39
193.87	227000	882.8	903.7	-0.04	898.77	904.47	0.00101	7.02	32317.08	3573.4	0.39
193.78	227000	892.2	904.75		899.61	905.37	0.00097	6.33	35874.51	4101.58	0.35
193.79	227000	882.55	903.23	1.52		903.93	0.000893	6.64	33764.48	4073.02	0.37
193.79	227000	882.55	903.24	-0.01	898.25	903.95	0.001372	6.73	33826.84	3717.02	0.37
193.71	227000	891.3	904.31		899.44	905	0.001157	6.69	33916.86	3491.22	0.38
193.73	227000	882.18	902.84	1.47		903.61	0.000961	6.8	32546.94	3422.17	0.39
193.73	227000	882.18	902.72	0.12	897.93	903.48	0.001317	7.03	32639.32	3421.62	0.4
193.65	227000	890	903.8		899.04	904.56	0.001228	7.01	32396.94	3334.06	0.39
193.62	227000	880.86	901.91	1.89		902.97	0.00121	7.2	29432.48	3218.17	0.43
193.62	227000	878.21	901.93	-0.02	897.55	902.79	0.001092	7.51	30757.47	3218.46	0.42
193.54	227000	889.8	902.93		898.85	903.82	0.001382	7.6	29965.48	3343.41	0.44
193.53	227000	878.96	901.48	1.45		902.34	0.00115	7.45	30591.29	3342.47	0.42
193.53	227000	878.96	901.49	-0.01	896.73	902.27	0.000946	7.1	32216.98	3319.36	0.39
193.45	227000	888.9	902.25		898.16	903.1	0.00162	7.43	30532.26	3530.87	0.43
193.43	227000	879.37	901.04	1.21		901.79	0.000988	6.96	32771.98	3705.46	0.4
193.43	227000	879.37	901.08	-0.04	896.02	901.82	0.000885	6.88	33182.05	3565.7	0.38
193.36	227000	888.7	901.61		897.56	902.41	0.001162	7.17	32169.3	3878.69	0.42
193.34	227000	881.18	900.65	0.96		901.33	0.000871	6.65	34459.46	3879.22	0.38
193.34	227000	881.18	900.66	-0.01	895.21	901.41	0.00082	6.98	32690.88	3675.54	0.37
193.24	227000	888	900.72		897.03	901.57	0.001645	7.39	31096.13	4150.35	0.46
193.25	227000	880.67	900.21	0.51		900.86	0.001089	6.52	35355.93	4129.69	0.38
193.25	227000	880.67	900.05	0.16	894.47	900.93	0.001183	7.54	30109.36	2637.22	0.39
193.16	227000	884.8	899.83		896.53	900.78	0.002012	7.81	29367.2	4179.14	0.5
193.16	227000	880.66	899.65	0.18		900.36	0.000975	6.78	34147.72	4279.17	0.41
193.16	227000	880.66	899.49	0.16	894.1	900.41	0.000963	7.72	29424.64	2539.44	0.4
193.07	227000	883.9	899.45		893.8	900.06	0.000903	6.25	36849.99	4364.17	0.36
193.07	227000	881.99	899.24	0.21		899.9	0.000871	6.55	35952.78	4496.02	0.39
193.07	227000	881.99	899.08	0.16	893.35	899.96	0.000881	7.5	30247	2538.03	0.38
192.97	227000	883	899.04		893.58	899.58	0.000806	5.98	38933.91	5020.38	0.33
192.98	227000	880.71	898.77	0.27		899.46	0.000944	6.71	35725.35	4482.61	0.39
192.98	227000	880.71	898.69	0.08	892.52	899.51	0.000904	7.28	31189.38	2521.54	0.36
192.88	227000	883.7	898.53		893.45	899.15	0.000925	6.43	37040.82	5456.87	0.35
192.89	227000	880.29	898.11	0.42		898.93	0.001139	7.25	34130.1	4859.98	0.42
192.89	227000	880.29	898.09	0.02	892.19	899.02	0.001053	7.74	29320.36	2381.65	0.39
192.78	227000	883.3	898.14		892.6	898.73	0.000708	6.41	38897.05	6211.91	0.34
192.79	227000	876.81	897.36	0.78		898.29	0.00141	7.91	33351.17	5331.77	0.45
192.79	227000	876.74	897.4	-0.04	891.76	898.43	0.001312	8.17	27792.78	2265.15	0.41
192.69	227000	882.7	897.8		892.38	898.38	0.000677	6.53	39839.49	6880.9	0.33
192.7	227000	876.64	896.69	1.11		897.61	0.001341	8.09	34851.54	5678.49	0.43
192.7	227000	877.01	896.68	0.01	891.15	897.77	0.001376	8.41	26999.82	2194.89	0.42
192.6	227000	883.7	897.49		892.82	897.99	0.000799	6.06	40748.27	6443.24	0.32
192.61	227000	878.15	896.1	1.39		897	0.001149	8.11	35263.39	5870.4	0.42
192.61	227000	878.15	896.06	0.04	890.41	897.16	0.001206	8.43	26932.69	2156.06	0.42
192.51	227000	883.3	896.86		893.11	897.54	0.000955	7.21	36499.68	7531.29	0.39
192.52	227000	878.23	895.48	1.38		896.41	0.001151	8.13	33997.84	6073.07	0.42
192.52	227000	878.23	895.42	0.06	889.84	896.55	0.001209	8.52	26637.11	2133.56	0.42

HEC-RAS Output - Cotton Lane Bridge / King Ranch Development CLOMR										26-Jun-06	
River Sta	Q Total	Min Ch El	W.S. Elev	Delta W.S.	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude #
	(cfs)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	Channel
192.42	227000	883.2	896.36		892.53	897.03	0.001202	7.18	36197.65	7133.5	0.4
192.42	227000	876.63	894.84	1.52		895.79	0.001351	8.36	32310.25	5822.81	0.45
192.41	227000	876.67	894.65	0.19	889.52	895.86	0.001302	8.83	25704.92	2147.49	0.45
192.39	Bridge										
192.38	227000	876.41	893.98		889.3	895.28	0.001443	9.17	24753.31	2144.55	0.47
192.33	227000	884.2	895.51		892.55	896.37	0.001428	8.1	33196.34	6171.17	0.47
192.33	227000	876.06	893.92	1.59		895.03	0.00163	8.8	30618.5	5999.18	0.49
192.33	227000	876.06	893.52	0.4	888.89	894.84	0.001471	9.2	24665.93	2851.47	0.48
192.23	227000	883.7	895.12		891.32	895.67	0.001029	6.25	38850.88	6812.12	0.36
192.23	227000	876.72	893.33	1.79		894.2	0.001427	7.76	34011.28	5911.64	0.44
192.23	227000	876.72	892.68	0.65	888.24	894.04	0.001749	9.34	24293.64	3055.32	0.49
192.13	227000	883.1	894.53		891.07	895.04	0.001305	5.62	39743.08	7677.62	0.34
192.14	227000	875.94	892.69	1.84		893.5	0.00138	7.48	35660.62	6576.49	0.44
192.14	227000	875.94	891.71	0.98	887.75	893.13	0.001893	9.56	23751.93	3297.97	0.51
192.04	227000	882	894.07		890.72	894.52	0.000824	5.6	42423.25	7766.62	0.34
192.04	227000	876.36	892.13	1.94		892.82	0.001193	6.89	38584.27	6338.6	0.41
192.04	227000	876.36	891.06	1.07	886.85	892.21	0.00155	8.6	26396.7	3671.07	0.47
191.94	227000	881.4	893.7		889.76	894.09	0.000797	5.07	45582.94	7948.91	0.3
191.95	227000	874.98	891.65	2.05		892.25	0.001002	6.38	40417.83	6284.77	0.38
191.95	227000	876.68	890.52	1.13	885.96	891.45	0.001238	7.8	29573.75	3987.16	0.43
191.84	227000	880.8	893.24			893.64	0.000912	5.26	45221.15	7847.56	0.32
191.86	227000	874.43	891.2	2.04		891.74	0.000966	6.05	41203.33	6192.23	0.36
191.86	227000	876.27	890.05	1.15	885.29	890.84	0.001057	7.16	32085.39	4306.03	0.39
191.75	227000	880.4	892.86		888.66	893.19	0.000796	4.82	49968.42	8659.89	0.29
191.76	227000	874.62	890.73	2.13		891.22	0.001036	5.8	43450.47	6600.39	0.35
191.76	227000	874.62	889.52	1.21	885.02	890.29	0.001121	7.04	32590.99	4514.06	0.4
191.65	227000	879.1	892.5		887.63	892.8	0.000606	4.57	53246.92	9077.15	0.27
191.67	227000	872.6	890.16	2.34		890.66	0.001217	5.81	42068.05	6300.75	0.37
191.67	227000	872.6	888.99	1.17	884.41	889.69	0.001188	6.74	33741.53	5162.56	0.39
191.55	227000	876.5	892.22		887.36	892.5	0.000677	4.39	54703.18	9150.72	0.26
191.57	227000	870.63	889.64	2.58		890.07	0.001069	5.38	44583.45	6248.42	0.34
191.57	227000	870.63	888.5	1.14	883.35	889.1	0.001046	6.21	36535.39	5065.55	0.37
191.46	227000	879	891.88		887.3	892.16	0.000657	4.34	53803.55	8798.08	0.27
191.48	227000	870.93	889.15	2.73		889.55	0.000969	5.16	45416	7125.76	0.33
191.48	227000	870.93	888.09	1.06	882.78	888.6	0.000879	5.71	39791.98	5545.91	0.34
191.36	227000	879.2	891.53		887.19	891.8	0.000745	4.16	54771.66	9220.32	0.26
191.38	227000	871.69	888.63	2.9		889.05	0.001012	5.27	44272.57	6645.04	0.34
191.38	227000	871.69	887.67	0.96	882.49	888.17	0.000822	5.67	40716.73	6150.25	0.34
191.27	227000	879	891.23		886.2	891.46	0.00057	3.81	59113.68	9572.64	0.23
191.29	227000	870.63	888.17	3.06		888.57	0.000895	5.1	45761.17	7103.59	0.32
191.29	227000	870.63	887.28	0.89	881.98	887.74	0.000837	5.46	41582	5890.63	0.32
191.17	227000	879.3	890.94		885.68	891.18	0.000553	3.96	58002.43	9540.25	0.23
191.19	227000	869.78	887.73	3.21		888.14	0.000828	5.21	45264.89	7687.83	0.31
191.19	227000	869.78	886.85	0.88	881.32	887.32	0.000873	5.5	41486.89	5263.42	0.32
191.08	227000	877.3	890.65		885.4	890.9	0.000536	4.07	57635.91	9711.52	0.23
191.1	227000	870.88	887.35	3.3		887.77	0.000666	5.25	45859.08	7151.76	0.3
191.1	227000	870.88	886.46	0.89	880.92	886.92	0.000707	5.43	41874.25	4764.65	0.31

HEC-RAS Output - Cotton Lane Bridge / King Ranch Development CLOMR										26-Jun-06	
River Sta	Q Total	Min Ch El	W.S. Elev	Delta W.S.	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude #
	(cfs)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	Channel
190.99	227000	876.8	890.4		884.26	890.66	0.000469	4.2	57791.12	7494.28	0.23
191	227000	869.64	886.94	3.46		887.41	0.000731	5.58	43443.77	7165.36	0.32
191	227000	869.64	886.1	0.84	880.28	886.56	0.000725	5.45	41632.96	4424.7	0.31
190.89	227000	876.2	890.18		883.86	890.41	0.000487	4.04	58720.83	10378.27	0.22
190.91	227000	867.98	886.51	3.67		887.02	0.00084	5.81	41964.3	7825.18	0.33
190.91	227000	867.98	885.66	0.85	880.17	886.16	0.000868	5.71	39776.48	4946.74	0.32
190.8	227000	875.8	889.97		883.72	890.2	0.000447	3.9	60413.77	11719.19	0.21
190.81	227000	867.86	886.12	3.85		886.63	0.000729	5.78	42564.52	8035.98	0.33
190.81	227000	867.86	885.25	0.87	879.57	885.75	0.000781	5.65	40207.38	4700.58	0.32
190.71	227000	875.3	889.76		883.4	889.98	0.000456	3.86	61068.23	11919.52	0.21
190.72	227000	866.3	885.77	3.99		886.26	0.000728	5.7	43702.13	8190.13	0.32
190.72	227000	866.3	884.88	0.89	879.07	885.36	0.000754	5.55	40921	4965.37	0.31
190.62	227000	872.2	889.5		882.51	889.75	0.000472	3.97	57867.45	11205.92	0.2
190.62	227000	867.37	885.37	4.13		885.87	0.000818	5.78	42981.69	7389.84	0.32
190.62	227000	867.37	884.49	0.88	878.51	884.97	0.000807	5.52	41334.29	5151.48	0.3
190.53	227000	874.1	889.2		882.14	889.47	0.000687	4.22	54384.06	11111.72	0.22
190.53	227000	866.16	884.88	4.32		885.42	0.000988	5.96	40865.06	6138.07	0.33
190.53	227000	866.16	883.96	0.92	877.87	884.43	0.001456	5.55	40922.51	4531.19	0.3
190.43	227000	874.2	888.82		881.51	889.12	0.00075	4.47	54840.89	11248.14	0.23
190.43	227000	867.42	884.37	4.45		884.92	0.000978	6.04	40364.69	5751.12	0.34
190.43	227000	867.42	883.34	1.03	877.12	883.85	0.000945	5.73	39593.25	4121.85	0.31
190.34	227000	873	888.35		881.35	888.65	0.001233	4.39	52086.86	11643.59	0.24
190.34	227000	866.61	883.9	4.45		884.4	0.001053	5.71	41339.93	5674.24	0.32
190.34	227000	866.61	882.9	1	876.54	883.36	0.000967	5.46	41552.79	4995.83	0.29
190.24	227000	873	887.82		880.83	888.13	0.000861	4.46	51606.19	11848.11	0.24
190.24	227000	866.29	883.36	4.46		883.82	0.001194	5.43	41980.61	5541.04	0.31
190.24	227000	866.29	882.37	0.99	876.03	882.83	0.001114	5.45	41656.73	4852.75	0.29
190.15	227000	873.8	887.02		882.18	887.5	0.002	5.62	41357.09	12521.37	0.34
190.15	227000	865.74	882.51	4.51		883.13	0.001569	6.34	35973.13	5047.02	0.38
190.15	227000	865.74	881.66	0.85	876.05	882.22	0.001342	6.02	37695.06	4656.45	0.33
190.05	227000	873.8	885.99		881.77	886.56	0.001708	6.12	37818.29	12160.36	0.38
190.05	227000	858.06	881.94	4.05		882.41	0.001131	5.56	41614.51	5686.45	0.31
190.05	227000	858.06	881.17	0.77	874.35	881.63	0.000919	5.44	41711.88	5055.07	0.29
189.96	227000	873.7	884.93		881.26	885.56	0.00254	6.41	35768.85	11879.18	0.4
189.96	227000	857.56	881.36	3.57		881.84	0.001235	5.58	41135.82	5106.92	0.31
189.96	227000	857.56	880.76	0.6	874.21	881.21	0.000826	5.34	42565.66	4707.4	0.29
189.87	227000	872.5	883.54		880.39	884.24	0.002852	6.75	33881.78	11839.79	0.44
189.87	227000	862.94	880.79	2.75		881.25	0.001186	5.41	42518.59	8662.42	0.3
189.87	227000	862.94	880.39	0.4	873.61	880.79	0.000817	5.07	45018.3	8082.38	0.27
189.77	227000	869.9	882.48		878.24	882.95	0.001849	5.49	41246.32	12202.11	0.34
189.77	227000	860.75	880.35	2.13		880.69	0.000828	4.77	49254.38	10345.5	0.26
189.77	227000	860.75	880.07	0.28	872.72	880.38	0.000654	4.56	51391.65	9558.24	0.24
189.68	227000	864.6	881.65		877.26	882.1	0.001501	5.42	42377.59	12292.87	0.33
189.67	227000	862.77	879.92	1.73		880.26	0.00084	4.69	50209.07	9767.06	0.26
189.67	227000	862.77	879.72	0.2	872.39	880.04	0.00069	4.56	51402.32	9169.72	0.24
189.58	227000	867.7	880.91		876.34	881.36	0.001514	5.53	42682.45	11905.41	0.34
189.58	227000	857.92	879.52	1.39		879.86	0.000765	4.71	51074.2	8771.74	0.26
189.58	227000	857.92	879.4	0.12	872	879.7	0.000623	4.51	53120.89	8605.12	0.24

HEC-RAS Output - Cotton Lane Bridge / King Ranch Development CLOMR										26-Jun-06	
River Sta	Q Total	Min Ch El	W.S. Elev	Delta W.S.	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude #
	(cfs)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	Channel
189.49	227000	863.4	880.32		875.26	880.7	0.001081	5.1	47016.13	10728.3	0.31
189.48	227000	857.85	879.17	1.15		879.49	0.000701	4.62	52973.88	8529.58	0.24
189.48	227000	857.85	879.1	0.07	871.42	879.4	0.000595	4.45	54919.66	8453.95	0.23
189.39	227000	866.8	879.75		874.85	880.15	0.001145	5.29	46037.47	10705.54	0.32
189.39	227000	855.02	878.84	0.91		879.16	0.000605	4.64	53320.42	9277.73	0.24
189.39	227000	855.02	878.77	0.07	871.26	879.1	0.000598	4.63	53336.2	9144.26	0.24
189.31	227000	865.8	879.34		874.19	879.7	0.001026	5.02	48026.97	10326.02	0.3
189.3	227000	856.36	878.52	0.82		878.86	0.000716	4.79	51770.92	8795.11	0.25
189.3	227000	856.36	878.45	0.07	871.42	878.8	0.000733	4.83	51323.42	8652.06	0.26
189.22	227000	864.7	878.92		874.02	879.26	0.001017	4.89	48878.31	9433.05	0.29
189.21	227000	856.97	878.2	0.72		878.51	0.00072	4.64	54724.3	8572.87	0.25
189.21	227000	856.97	878.11	0.09	870.93	878.43	0.00074	4.69	54184.91	8481.39	0.25
189.12	227000	863.1	878.47		873.73	878.81	0.001015	4.97	49122.77	9037.03	0.3
189.11	227000	857.4	877.88	0.59		878.17	0.000584	4.45	56635.83	8079.89	0.23
189.11	227000	857.4	877.79	0.09	869.75	878.09	0.000601	4.5	56004.5	7944.71	0.23
189.02	227000	863.4	878		873.76	878.37	0.000958	5.15	49359.91	9413.65	0.32
189.02	227000	855.16	877.62	0.38		877.89	0.000495	4.3	58870.63	8955.39	0.23
189.02	227000	855.16	877.52	0.1	869	877.8	0.000511	4.35	58129.04	8839.55	0.23
188.81	227000	863.5	877.31		871.66	877.6	0.000604	4.41	53905.06	8506.56	0.25
188.81	227000	852.24	877.19	0.12		877.43	0.000348	4.09	62725.53	8318.66	0.2
188.81	227000	852.24	877.07	0.12	866.9	877.33	0.000358	4.14	61905.59	7986.71	0.2
188.7	227000	863.3	876.86		872.2	877.19	0.000909	4.79	49807.88	8743.87	0.28
188.69	227000	850.62	876.87	-0.01		877.15	0.0007	4.35	59160.1	8930.4	0.21
188.69	227000	850.62	876.79	0.08	867.82	877.08	0.000483	4.43	58559.81	8830.76	0.21
Tie in to Effective Flood Study											
188.59	227000	861.4	876.44		871.15	876.76	0.000765	4.67	50875.8	7530.8	0.27
188.59	227000	861.4	876.44	0	871.17	876.76	0.000765	4.67	50873.55	7530.72	0.27
188.59	227000	861.4	876.44	0	871.17	876.76	0.000764	4.67	50872.18	7530.67	0.27

6. Erosion and Sediment Transport

Sediment transport was modeled using HEC-6T. The models used a hydrographic record developed by the U.S. Army Corps of Engineers for the upstream Tres Rio Study Reach of the Gila and Salt Rivers.

6.1 Method Description

HEC-6T was used to model sediment transport in the reach. The model was developed based on HEC-RAS data with the exception of the bank stations. The stations were narrowed in HEC-6T to properly model an area of sediment transport that was approximately 1500 ft wide in the main channel of the river. The HEC-6T model was calibrated to give the same water surface elevation as the HEC-RAS model with the narrowed bank stations. Thus both models were predicting the same flow conditions.

The HEC-6T model was run using a 105 year flow hydrograph that was developed by the U.S. Army Corps of Engineers for the Tres Rios Project which is immediately upstream from this project. The hydrograph was adjusted for existing dams and changes in the watershed and included two large events – one at the beginning of the record and another at the end. The first of these events approached the 100 year hydrograph.

6.2 Parameter Estimation

6.2.1 Estimation of Bed Sediment Sizes and Sediment Load

Soil and bed material samples were taken by Western Technologies for Cavalier Development the predecessor to Sonterra Partners as well as for prior studies for bridges at the current Cotton Lane Alignment, by WEST as a part of this study and by Stantec as a part of the regional El Rio Watercourse Master Plan. The sediment sample data were obtained from these various sources and are presented in Figure 18. These samples indicate that this reach of the river is predominately a gravel bed system while the Gila River below Tuthill Road behaves as a sand bed river system (Stantec - El Rio Study). The bold lines in Figure 18 show the samples that have been taken to be most representative of the Gila River in the Cotton Lane Bridge Reach. Further discussion on incorporation of these data in HEC6-T sediment transport model is presented in Section 6.2.3.

6.2.2 Sediment Data

The decisive factor in selecting the proper sediment transport function was based on available bed gradation and maximum grain size. Bed material in the project location is comprised of significant quantities of both sand and gravel, making it necessary to use an appropriate transport function. A combination of the Toffaleti and Meyer-Peter and Muller (TMPM) (US Army 1989) transport functions was used in the study. This combination accounts for sand and gravel, giving a higher, realistic measure of total sediment concentration (and thus total sediment load). Based on field observations, to facilitate modeling and to represent larger diameter cobbles noted in the bed, a maximum grain size of 200mm was used in the final sediment transport runs in HEC-6T. Additional transport equations were also used as a sensitivity analysis and results were not significantly different in terms of final bed configuration for the reach even though transport rates varied through the models.

6.2.3 Bed Sediment Characteristics

The available sediment gradation data is presented in Figure 18and includes data from Western Technologies, Stantec, AMEC, and WEST. Most of the sediment data that shows a predominance of sand (see Figure 18) are taken from the overbank regions but the channel data agrees well with most of the data provided by Stantec as well as that obtained by WEST and other sources. The available samples indicate that this reach of the river is predominately a gravel bed system while the Gila River below Tuthill Road behaves as a sand bed river system (Stantec - El Rio Study – personal communication).

Upon careful investigation and comparing the sediment gradation curves with the sediment data from the Tres Rios PED study (located upstream of this study reach), it was concluded that the samples obtained by WEST and Stantec showing significant gravel adequately represent the conditions in the channel. Therefore, the data from Stantec locations 4, 9, 10, and 11 were used in conjunction with samples, WP161, WP 163, WP169 and WP170 obtained by WEST in the development HEC6-T sediment transport model. The samples used in the HEC-6T model are shown in Figure 19 and the locations of the WEST and Stantec samples (those actually used in the mode) are shown in Figure 20. The AMEC samples were obtained near the proposed Cotton Lane Bridge Crossing.

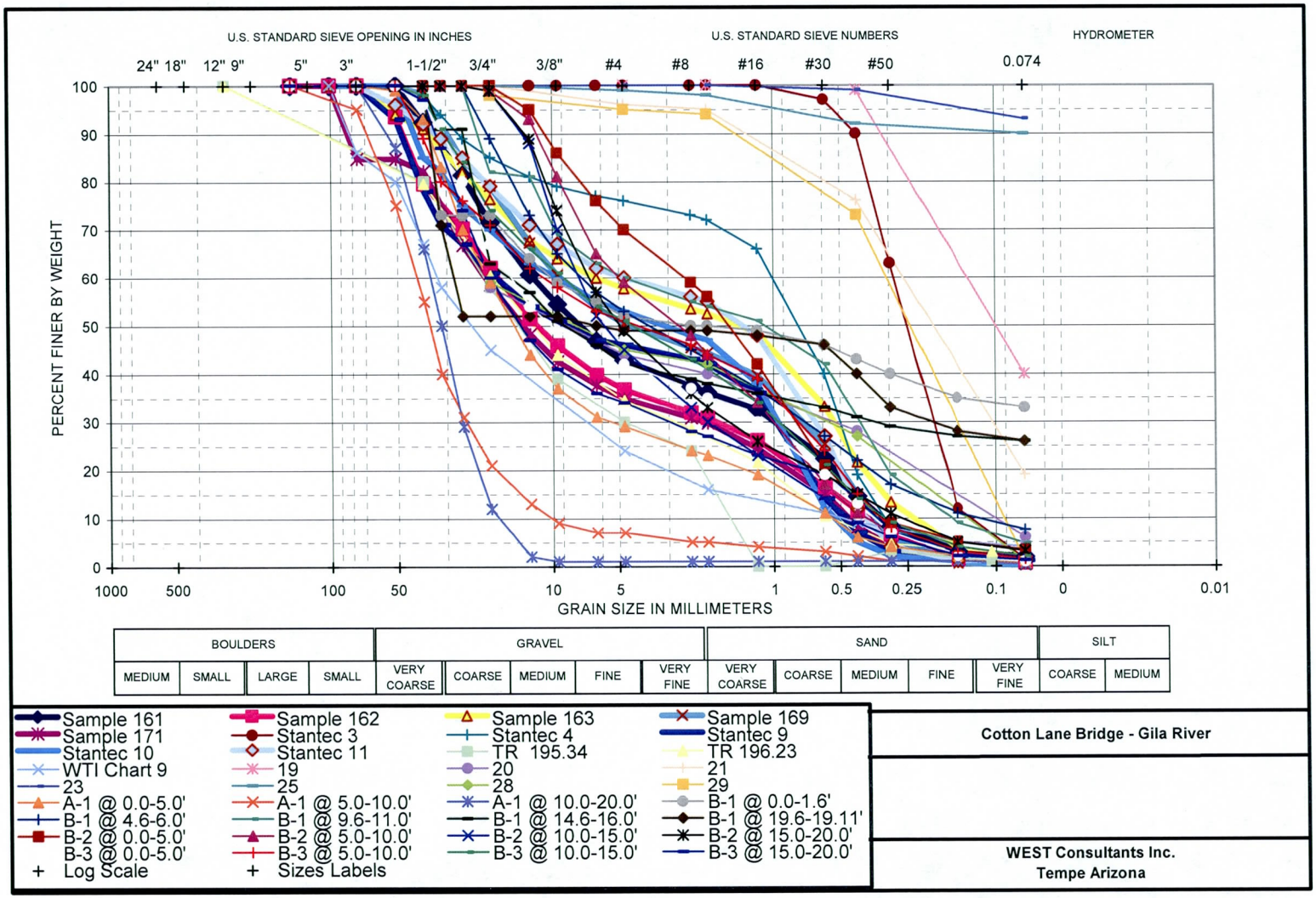

Figure 18. Available Bed Sediment Gradation Data for Gila River Adjacent to King Ranch.

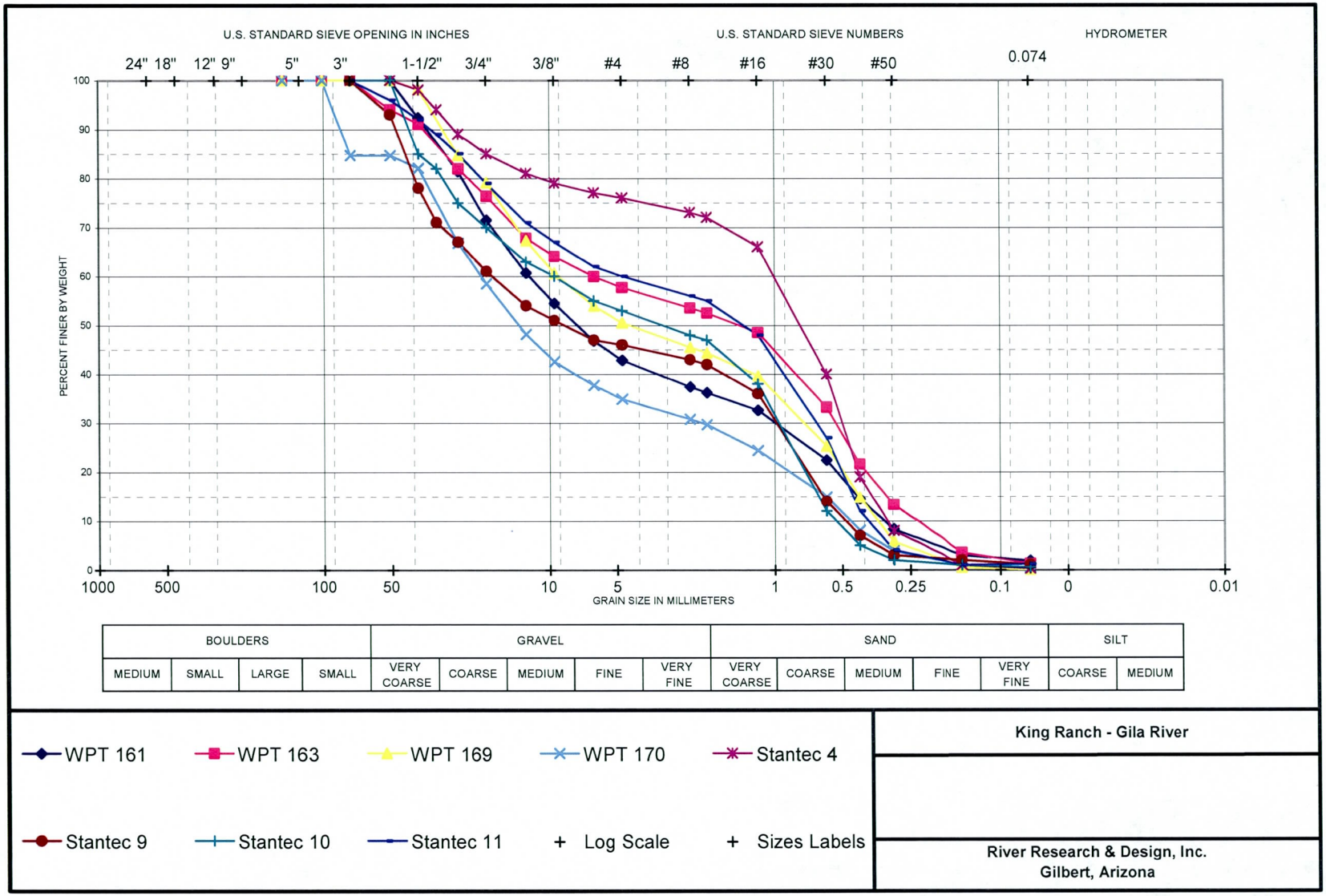

Figure 19. Gradations used in HEC-6T Modeling.

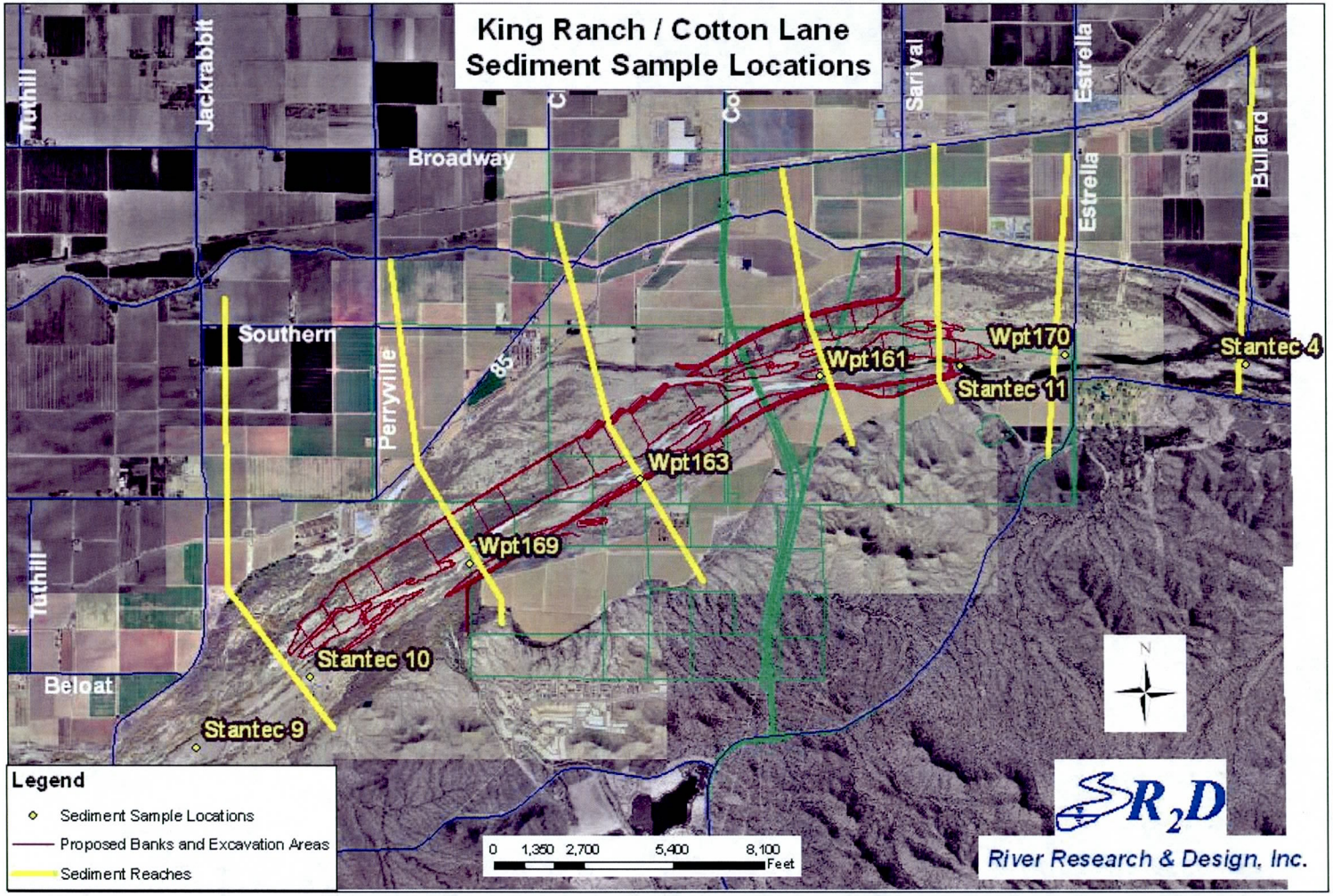

Figure 20. Sediment Sample Locations used for HEC-6T Modeling. Samples identified at Stantec # are from Stantec Study. Samples identified with WPT+ numbers are from WEST work. The reaches where the sediment data was used are immediately upstream from the samples. The boundaries are shown by the yellow cross sections.

6.2.4 Bank Station Locations

Two sets of channel banks stations were developed. One set identified the banks of the main channel as defined for FEMA studies and one set was narrower and used to predict sediment transport. It has been found that active sediment transport does not occur over the entire width of a very wide channel such as the Gila River but in a much narrower width of the channel. The channel banks for the hydraulic and FEMA studies were placed close if not at the same locations of the Baker study except in areas where the banks or ineffective flow areas were changed due to the construction of banks and related channel features.

Channel bank stations for the sediment modeling were identified based on a regime equation proposed by Blench (1970). In general, the channel-forming discharge for a river system such as the Gila River is responsible for the bulk of sediment transport. For this study, the 10-year discharge (57,000) was used as the channel-forming discharge and channel width (distance between bank stations) was based on this value. The application of this modeling approach helps to maintain channel velocities which better ensure that sediment transport is maintained throughout the study reach.

Most regime formulations include three relations that yield values of the channel width, depth, and slope as functions of the water discharge and bed material size. Some of the more refined equations also take into account bank cohesiveness, sediment discharge or concentration, and fluid viscosity. The regime equation used in this study is that of Blench (1970) where the channel width, w, is given by

$$w = \sqrt{\frac{F_b Q}{F_s}}$$

where F_b is the so-called bed factor and is defined as the product of g (gravitational acceleration) and the Froude number squared, $F_s = 0.10$ for friable banks, and Q is the water discharge (Vanoni, 1975). Based on average Froude number from initial HEC-RAS modeling results, the regime low-flow channel widths were calculated to be approximately 1200 ft for the Gila River.

Stantec in the El Rio Study estimates that sediment transport occurs over a width of approximately 1500 ft in this portion of the Gila River. Based on these findings the value channel banks were placed approximately 1200-1500 feet apart for the sediment modeling through this reach. In braided or very wide sections (such as west of Cotton Lane Bridge) the bank stations were widened slightly to include the main portion of the channel.

6.2.5 Inflowing Sediment Load

The sediment transport model cannot be directly calibrated to historical conditions because detailed historical bed elevation data are not readily available. The HEC-6T model requires input of the bed material load at the upstream limit of the project reach for the entire range of discharges. For this purpose, data from the HEC6-T model developed for the Tres Rios PED Study was used.

The Tres Rios model considers the reach immediately upstream of the study reach. Therefore, the outflowing sediment load from the Tres Rios model (WEST sediment load) was originally

used as the inflowing sediment load for the model developed in this study. A 30 day steady state simulation of the Tres Rios PED model was performed for a range of discharges to generate the inflowing sediment load table. The values obtained in this manner were input into the present HEC-6T model at the upstream most cross-section located at 195.75. The sediment inflow for the Tres Rios model was also compared with the outflowing sediment load for the Rio Salado Oeste model located immediately upstream from the Tres Rios Study area.

After review by Stantec and the FCD, and in conjunction with Mr. Tony Thomas (the original developer of HEC-6) it was suggested that using a higher inflowing concentration with more of the wash load accounted for in the load curve would be more accurate. The wash load was high enough to impact the transport of bed material due to the increased density of the water and sediment mixture. A sensitivity analysis was performed which indicated that this reach of the river is not overly sensitive to changes made to the inputs of sediment transport models. Large changes in inputs resulted in relatively minor changes in bed elevation with changes in final bed elevations on the order of 1-2 ft after a 105 year simulation. This was deemed to be relatively minor for the Cotton Lane Bridge reach of the Gila River. Final modeling used an inflowing sediment load that was acceptable for both the El Rio and King Ranch studies.

6.3 Modeling considerations

6.3.1 HEC-RAS Model Conversion

6.3.1.1 Model Geometry

The geometry of the HEC-RAS hydraulic model was converted into a text file with the format required by the HEC-6T program. Roughness coefficients (Manning's n) in the cross-sections of the river models were varied with depth. After running the 5-, 20- and 100-year flood events in HEC-RAS, the profile output tables were used to extract conveyance weighted Manning's n values for the channel, the left and the right overbanks for the different discharges. The modified data was then entered into the HEC-6T input file using NV records. A default value of 0.065 was used to fill blanks when the conveyance in an overbank area was zero. The result was a configuration of roughness coefficients changing vertically by discharge rather than horizontally by distance as in the HEC-RAS models.

Using normal flow considerations, an elevation-discharge Rating Curve was developed at the downstream boundary of the Gila River (cross-section 186.87) for starting water surface elevations. The rating curve at this point was generated for discharges ranging from 0-292,500 cfs, at 7500 cfs increments for a bed slope of 0.002 ft/ft which is shown in Figure 21.

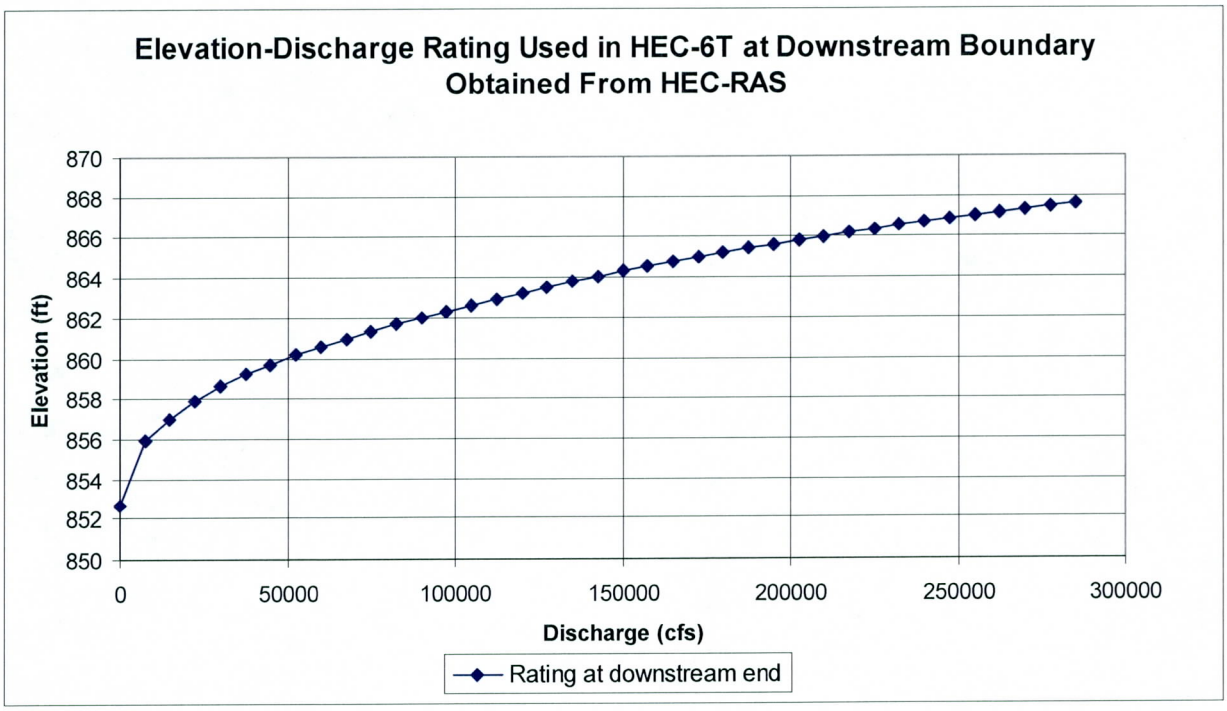

Figure 21. Downstream WSE Boundary Condition for HEC-6T Model.

6.3.1.2 Fixed Bed Model Calibration

Initially, the HEC-6T model was calibrated with a fixed bed using the 5-, 20- and 100-year flows, and the resulting water surface profiles were compared to the HEC-RAS Existing Conditions results. Adjustments of Manning's n were performed for calibration purposes for all cross-sections beginning with the downstream section in the Gila reach. These adjustments were performed to reach agreement between the HEC-RAS and HEC-6T water surface elevations and channel velocities within a difference of 0.1 for both parameters.

6.3.1.3 Movable Bed and Erosion Limits

In general, sediment dynamics tend to be more significant within the active channel, where the bed can either degrade or aggrade in response to erosion or deposition. The overbank areas tend to be more stable and normally are free of erosion, but can experience deposition. HD records were used to specify a bed sediment depth of 25 feet for all cross-sections. Movable bed limits were identified at the boundary of the main channel in HD records (the narrower set of bank stations as described in the Hydraulics section). The movable bed limits extend beyond the 5-year low flow channel (regime channel) and the defined bank stations. During high flows, significant deposition and scour was expected to occur within the movable bed limits but not expected to extend to the overbank areas.

Average bed elevations were generated using a 50-year flow applied to the model for a few seconds. This allowed wetting of the movable bed cross-sections and provide average elevation across the cross-section while not allowing enough transport to distort the model calculations.

This process allows the comparison of different model results without the plotting of each individual cross-section.

6.3.2 Hydrologic Data

A 105-year (1889-1993) series of hydrographs at the Salt-Gila confluence consisting of historical flows was developed by WEST for the Tres Rios PED study as discussed previously.

6.3.3 Computation Options in HEC-6T

The supercritical option ($SCRT card) was turned off in the HEC-6T model to prevent supercritical velocities, which could produce unrealistic scour depths, from being used in the sediment transport calculations.

The $SMOOTH command was also used to prevent the cross-section geometry from becoming irregular (i.e., having spurious spikes) during the simulation. The command instructs HEC-6T to test the slope across the movable bed versus the angle of repose for sand. An angle of repose is calculated between each set of coordinates using the initial cross-section stations and elevations. The HEC-6T program assumes the bed material to be sand and assigns a value of 0.3 as the angle of repose. When the calculated values are larger than 0.3, the computed angle of repose is used to calculate the slope between cross-section stations. This results in more uniform cross-sections while not impacting the average bed elevations.

6.4 Problems Encountered During the Study

The main problem encountered during the study was the result of merging of topographies from different sources. This was overcome by the careful analysis of results in the area near the changes in topography as described in other parts of this report.

6.4.1 Special Problems and Solutions

No special problems other than the topography were noted.

6.4.2 Modeling Warning and Error Messages

No critical warnings or errors were found in the model output.

6.5 Calibration

No data existed for calibration or verification of the model but sensitivity analyses were run to insure that the parameters were in the proper range as well as to view model sensitivity to the various input parameters. No problems or particular sensitivity were noted to the range of variables modeled. The HEC-6T model hydraulic data were, however; calibrated to the HEC-RAS results

6.6 Final Results

6.6.1 Existing Conditions Sediment Results

The HEC-6T model simulation was performed for 105 years with two major events in 1891 and 1993. Figure 22 shows the impact of the project on the stability of the Gila River. As can be noted the reach appears to be slightly erosional under existing conditions but relatively stable under proposed conditions.

In Figure 23, the results of the simulation for existing conditions are presented which show that the channel is subject to very little change due to sedimentation under the WEST inflowing load and a slightly different inflowing load gradation. This again indicates a general stability of the reach in response to major floods. It can also be noted that after a relatively minor initial adjustment the bed is stable for the entire range of events in the historical record after 1891.

Several feet of erosion can be noted at the upstream portion of the model (cross-section 194.5) at the Estrella Parkway Bridge but is due to the change in topography sources. It should be remembered that this area is where the topography changes from the channel bed to the top of the 13,000 cfs water surface elevation. This change in topography accounts for the erosion noted in the models at the location of the Estrella Parkway Bridge. It is expected that this project will have no impact on erosion at Estrella Parkway since any channel modifications are relatively distant from the bridge.

An apparent accumulation occurs at Station 190.5 in Figure 23 and Figure 24. It must be noted that the original topography data ended near this station and the downstream cross-sections use the old data (top of water surface) from the FIS study. In the later data shown in Figure 22 (whose results are based on additional downstream topography) it can be noted that this deposition is eliminated. This indicates that this deposition is indeed the result of the model adjusting itself to the discrepancies between the two sets of topographic data.

6.6.2 Proposed Conditions Sediment Results

The proposed conditions HEC6-T model was developed using the existing conditions model as the base and by incorporating the new bank alignment as encroachments using the X3 cards for the north and south banks, adding the Cotton Lane Bridge, and the inclusion of a 2000 ft wide channel. These results are presented in Figure 22 and Figure 24 and again show stability for the design channel through this reach. The models all indicate that deposition can be expected outside the main channel for both existing and plan conditions. The average bed elevations, however, do not change significantly indicating the main channel of the river will remain relatively stable.

The HEC-6T model was also run for proposed conditions with a 0.028 n value wherever excavation is planned to occur. The remaining n values were not changed since they represent existing conditions and are not expected to change. The model results show some slight differences including slightly more deposition in the downstream cut area from River Mile 189.5 to about River Mile 191.0 as shown in Figure 25.

Based on the sediment transport results it appears that the river may reform some bars in the most downstream reach of the excavation area but the water surfaces will remain within approximately 1.0 ft of those calculated for both existing conditions as well as the proposed conditions models. The channel between the Cotton Lane Bridge and River Mile 189.0 should be monitored after large events to insure that deposition in this reach does not seriously impact flood elevations. While the models predict stability in this reach it is possible that deposition could occur due to debris jams or other obstructions that have not been modeled in this study.

6.6.3 Verification of Results

No verification was possible since no historical bed elevation data was available for verification of model results. However several sensitivity runs were made varying the inflowing load, the bed gradation, the sediment transport equation and other factors. None of these changes made significant differences in the sediment transport model in this reach. It appears that this reach of the river is relatively stable under both the existing and proposed conditions.

6.6.4 Outflowing Sediment Loads

The outflowing sediment loads were compared for the two models using the $VOL card in HEC-6T. The results were very similar at the end of the 105 year simulation. The model results indicate that the project has no significant impacts upstream and downstream of the project. The load results for the simulations are shown in

Table 8. The sediment output from HEC-6T indicates that 100% of the silts and clays pass through this reach and only the sand and larger size classes tend to deposit in this reach. The trap efficiencies for both silts and clays are 0.00 while the trap efficiency for sand is on the order of 0.40. A small increase in the transport of sand is seen under proposed conditions but the increase in within the uncertainty of the modeling. This indicates that the proposed project does not significantly impact sediment transport into the river downstream of the project.

Table 8. Sediment Loads for Existing and Proposed Simulations.

Model	Inflowing Load (Acre Feet)		Outflowing Load (Acre Feet)	Trap Efficiency
Existing	Clay	280,534	280,531	0.00
	Silt	64,738	64,710	0.00
	Sand	15,078	8,990	0.40
Proposed Conditions	Clay	280,476	280,472	0.00
	Silt	64,725	64,694	0.00
	Sand	15,079	9,721	0.36

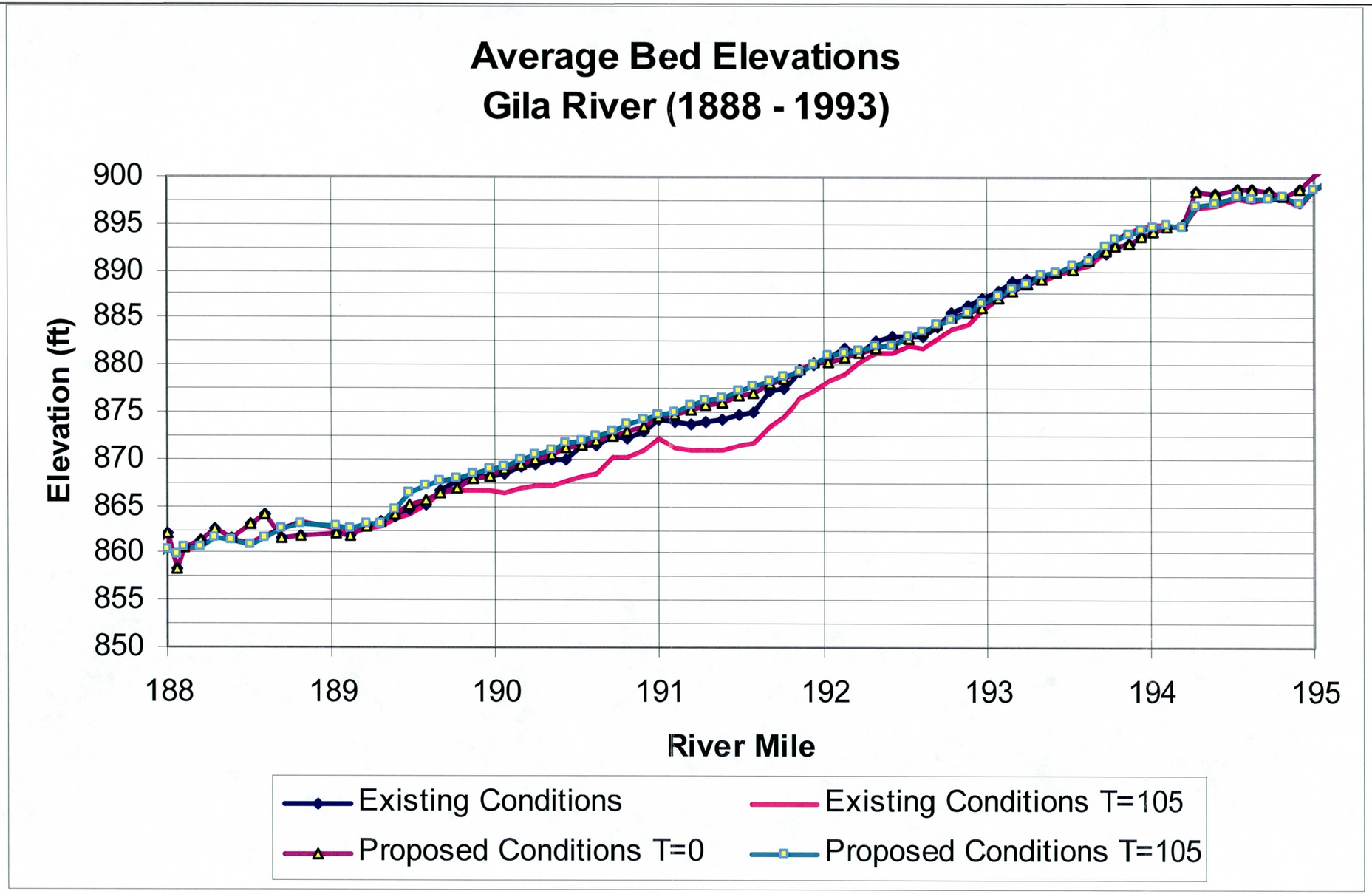

Figure 22. Average Bed Elevations for 105 Simulation of Historical Peak Flows on the Gila River at Cotton Lane Bridge

King Ranch
Average Bed Elevations for the 105-Year Simulation (1898-1993)
Existing Conditions

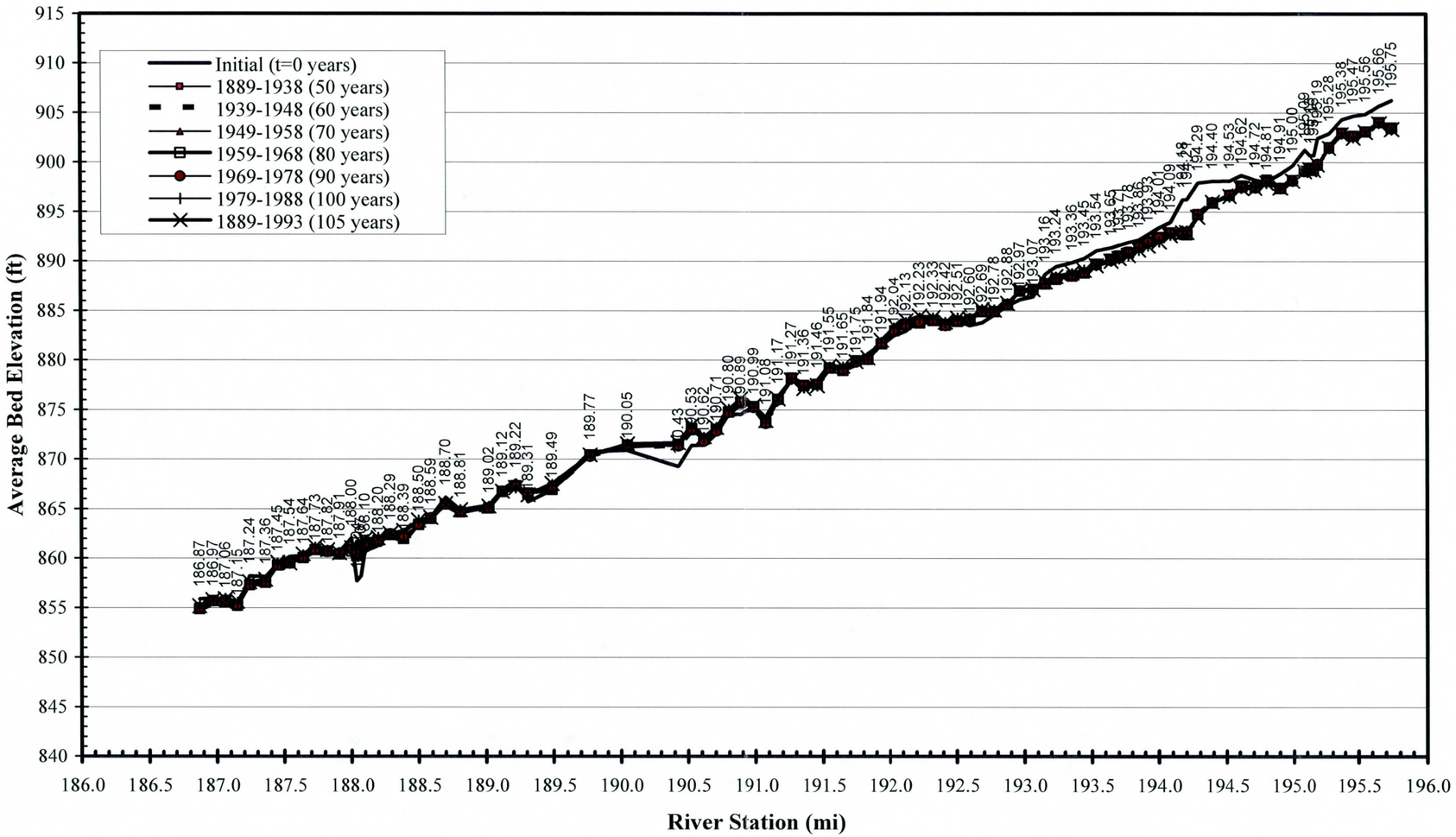

Figure 23. Average Bed Elevation Comparison After 105 Years for Existing conditions

King Ranch
Average Bed Elevations for the 105-Year Simulation (1898-1993)
Alternate Bank Alignment with 2000 ft Channel, 4ft higher

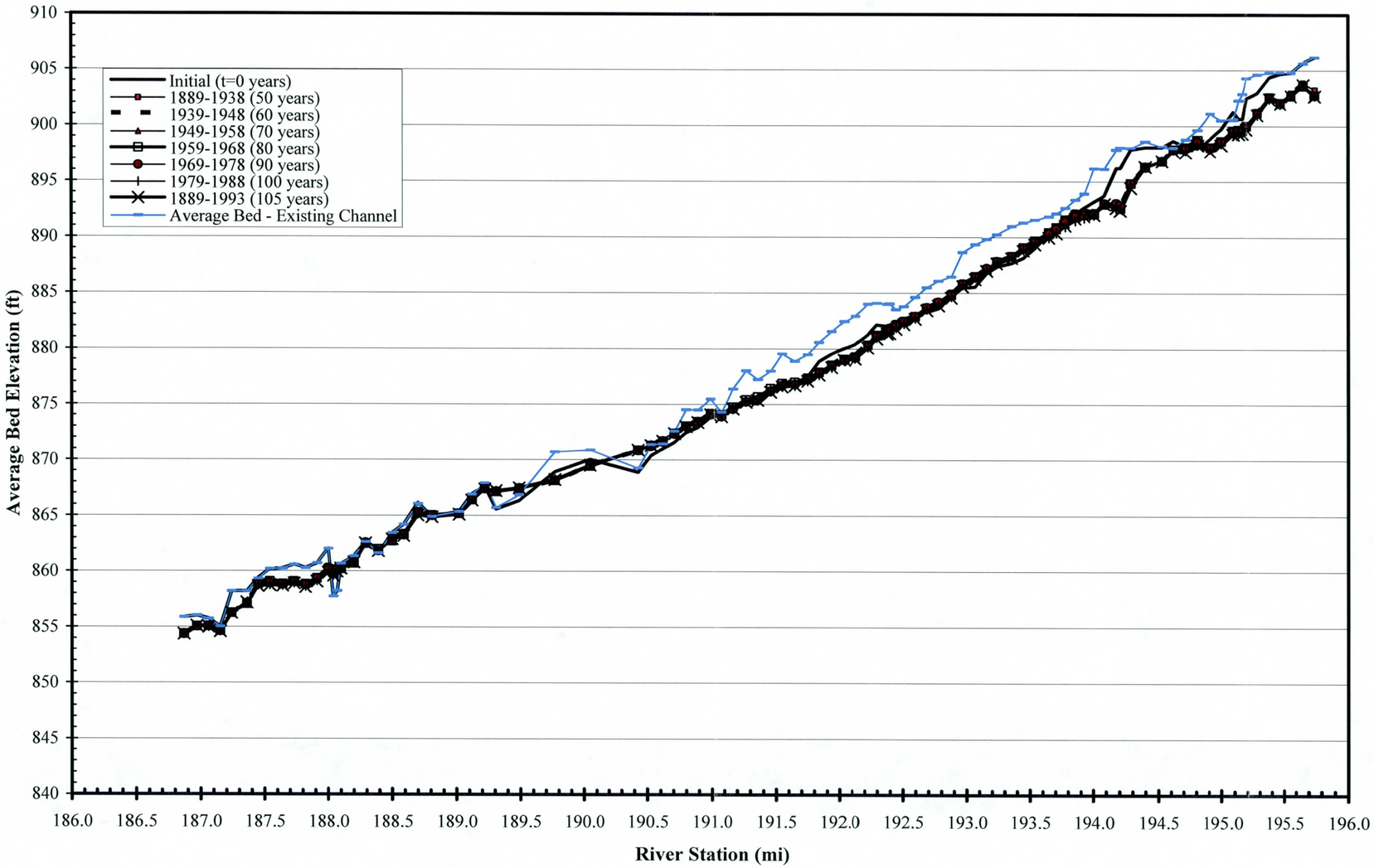

Figure 24. Average Bed Elevation Comparison After 105 Years for Proposed Conditions.

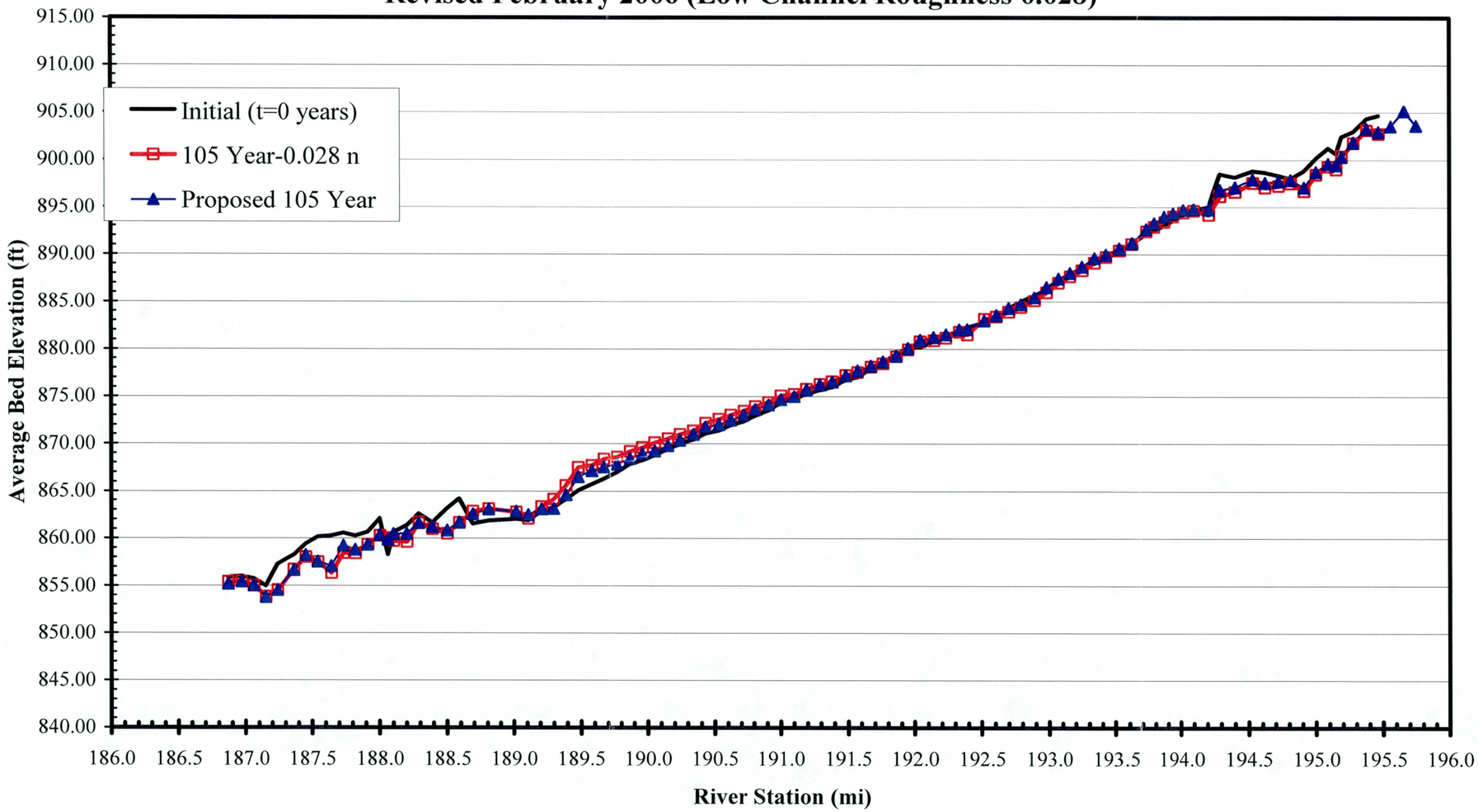

Figure 25. Impact of Low Manning's n Value for Disturbed Sections of Channel

7. Monitoring, Maintenance and Changing Conditions.

7.1 Design Philosophy

The Cotton Lane Bridge / King Ranch Channel design project involved modifications to the river channel to help lower the 100 year flood elevations in the reach west of Cotton Lane Bridge. This was designed to assist landowners on both the north and south bank of the Gila River by reducing flooding depths and durations. The channel was designed to be self sustaining to the extent possible, however it is possible that large events or modifications to sediment loading or flows from upstream projects could impact the design reach since the river does expand significantly in this reach. Future sand and gravel mining operations may also have a significant impact on the channel. The impacts of mining in the reach need to be evaluated since they may not be harmful to flood elevations in the reach if the associated scour can be controlled.

The project was based on the concept of narrowing the river at the Cotton Lane Bridge Crossing and redirecting flow down the current main channel of the river to reduce the tendency to deposit material in the main channel at the river expansion just west of Cotton Lane. The modeling showed that this area has a tendency to refill after large events – especially in the portion of the channel to the northwest of the excavated channel. Both the 1D and 2D models show a tendency to fill along the north edge of the excavation and in the area to the northwest of the excavation. This is the area that is currently proposed for a mining operation.

The Gila River Channel from Estrella Parkway to the end of the modified channel for the Cotton Lane Bridge reach involved the removal of a portion of a mid-channel bar and alignment of flow through the Cotton Lane Bridge. The mid-channel bar will tend to rebuild during large events (when flows are deep enough that a significant portion of the flow moves across the bar and into the north channel - probably near or in excess of the 20 year flood). The river may again tend to remove the deposits during flows in the 80,000 cfs range as apparently happened during 1993 and subsequent to the approximate 125,000 flow of January 1993. The rebuilding of the bar is anticipated and should not be alarming unless something in excess of approximately 50% or more of the removed material is redeposited along the north side of the channel excavation. The total flow area should be evaluated to insure that the area is not reduced below approximately that existing subsequent to project completion. If the capacity is replaced with flow through a gravel mine it may be that the excavated channel can be left to fill and flow allowed to redirect through the gravel mine. The modeling should be accomplished using a two-dimensional model to account for impacts from vegetation and changed topography. It is doubtful that a one-dimensional model will adequately model this reach with a gravel mine in place.

Ideally the channel should be evaluated after each event larger than approximately 50,000 cfs using new topography. This could be incorporated into the existing two-dimensional model to view the impacts of deposition and scour (as well as vegetation) on flows in the reach. It would normally be sufficient to visually observe the smaller events to note any changes or debris build up.

7.2 Vegetation

It is expected that vegetation will regrow in the areas that currently have vegetation. This is should not be a cause for removal or thinning unless the vegetation becomes dense and tall in relation to the flow depths. If the vegetation is 6-8 feet in height and covers 50% or less of the channel surface area it can be left to grow. Once the height passes 10 feet with a surface coverage of 50% or more of the channel area it should be thinned or removed (thinned at a minimum) to reduce the coverage below 20-25% of the surface area. This density should allow flows to pass around the vegetation with sufficient velocity so as to remove it if necessary for large flood capacity while allowing enough vegetation to retain the ecological benefits. The amount of growth could also be related to the amount of cross sectional area that is obstructed by the vegetation. When this amount of area becomes significant and causes a rise in flood elevations it would be time to thin or remove the vegetation.

It is not expected that major problems will result from the construction of the channel unless the channel lowers the elevation of plant roots such that they can reach the water table and become viable in the area. The areas that currently support vegetation can be expected to continue to support vegetation while those that do not currently support vegetation can be expected to remain relatively void of significant plant material. This should be verified on an on-going basis, however.

It is recommended that methodology developed by the U.S. Army Corps of Engineers be used to estimate Manning's n values for any future modeling of the reach. (See CLOMR TDN Appendices for a copy of the report by Freeman and others).

7.3 Debris

If debris trapping becomes a significant after an event it would be advisable to remove the debris and to eliminate any vegetation responsible for trapping significant amounts of debris. Debris accumulation has been noted upstream in the Tres Rios reach of the river and caused significant changes in flow patterns in the 1983 flood event. These changes resulted in bank erosion and additional overbank flooding.

7.4 Monitoring

Monitoring via aerial photography currently flown by Maricopa County each year could be used to estimate the density of vegetation in the channel area. This could be combined with a site visit on an annual or biennial basis to insure vegetation has not grown to the extent that it is beginning to cause problems in terms of height.

The soil cement protection is designed with a steepened toe down. If after an event this steepened (2H:1V) is visible action should be taken immediately to reinforce the toe of the soil cement. Inspections should be performed after any major event to insure continued stability and integrity of the bank protection.

7.5 Sand and Gravel Mining

The area is a very attractive site for sand and gravel mining since the river expands significantly at this location. The removal of material from the river will cause the river to redeposit the material in the reach west of Cotton Lane Bridge becoming a continuing source of sand and gravel for construction activities. The excavation of material will also improve channel conveyance and aid in the maintenance of long term channel capacity.

The rivers thalweg or lowest portion of the channel will be diverted into the mine unless protective measures area taken. Some care will have to be exercised to prevent a headcut from moving upstream and impacting the Cotton Lane Bridge as well as other infrastructure further upstream. The end of the bank protection on the north bank just west of the Cotton Lane Bridge would be a logical location for a grade control structure in this reach.

8. Draft FIS Report Data

8.1 Summary of Discharges

The peak discharges used in the hydraulic analysis of all the conditions modeled were developed by the U.S. Army Corps of Engineers (1996) and are shown in Table 7.

Table 9. Peak Discharge Values Used in Hydraulic Models

River ID	River Station (miles)	Discharge (cfs)					
		5-Year	10-Year	20-Year	50-Year	100- Year	500-Year
Gila River	195.75	23,500	57,000	92,000	185,000	227,000	285,000

8.2 Floodway Data

The encroached floodway surcharge data is shown in Table 8 along with the tie in cross sections and water surface elevations for both the floodway and floodplain.

Table 10. Floodway and Floodplain Water Surface Elevations and Encroachment Depths.

King Ranch / Cotton Lane Bridge CLOMR

Effective Model					Existing			Proposed/Revised				
River Sta	W.S. Elev (ft)	Profile Delta WSE (ft)	Delta WSE Exist-Eff (ft)		River Sta	W.S. Elev (ft)	Profile Delta WSE (ft)	River Sta	W.S. Elev Profile (ft)	Profile Delta WSE (ft)		Delta WSE Prop-CEff (ft)
195.09	912.92		-0.39	TIE IN	195.09	912.53		195.09	912.53		TIE IN	0
195.09	913.3	0.37	-0.33		195.09	912.97	0.44	195.09	912.91	0.38		-0.06
195	912.5		-0.5		195	912		195	911.99			-0.01
195	912.75	0.25	-0.42		195	912.33	0.33	195	912.25	0.26		-0.08
194.91	912.04		-0.68		194.91	911.36		194.91	911.35			-0.01
194.91	912.26	0.23	-0.52		194.91	911.74	0.38	194.91	911.63	0.28		-0.11
194.81	911.83		-0.75		194.81	911.08		194.81	911.06			-0.02
194.81	912.05	0.22	-0.58		194.81	911.47	0.39	194.81	911.35	0.29		-0.12
194.72	911.49		-0.86		194.72	910.63		194.72	910.61			-0.02
194.72	911.67	0.18	-0.67		194.72	911	0.37	194.72	910.85	0.25		-0.15
194.62	911.22		-1		194.62	910.22		194.62	910.2			-0.02
194.62	911.28	0.06	-0.79		194.62	910.49	0.27	194.62	910.31	0.11		-0.18
												0
194.53	910.88		-1.2		194.53	909.68		194.53	909.65			-0.03
194.53	910.9	0.01	-0.92		194.53	909.98	0.29	194.53	909.76	0.11		-0.22
194.4	910.3		-1.6		194.4	908.7		194.4	908.65			-0.05
194.4	910.25	-0.05	-1.19		194.4	909.06	0.36	194.4	908.77	0.12		-0.29
												0
194.29	909.44		-2.66		194.29	906.78		194.29	906.79			0.01
194.29	909.38	-0.06	-1.81		194.29	907.57	0.78	194.29	906.98	0.18		-0.59
194.21	908.21		-2.43		194.21	905.78		194.21	905.76			-0.02
194.21	908.23	0.02	-1.88		194.21	906.35	0.57	194.21	905.98	0.22		-0.37
194.195 BR	907.98		-2.43		194.205 BR	905.55		194.205 BR	905.54			-0.01
194.195 BR	908	0.02	-1.98		194.205 BR	906.02	0.47	194.205 BR	905.67	0.14		-0.35
	Estrella Parkway											
194.195 BR	907.86		-2.31		194.205 BR	905.55		194.205 BR	905.43			-0.12
194.195 BR	907.88	0.02	-2.09		194.205 BR	905.79	0.24	194.205 BR	905.44	0.01		-0.35
194.18	907.96		-2.41		194.2	905.55		194.2	905.52			-0.03
194.18	907.98	0.02	-2.01		194.2	905.97	0.41	194.2	905.62	0.1		-0.35
194.09	906.48		-1.55		194.1	904.93		194.1	904.87			-0.06
194.09	906.54	0.05	-1.22		194.1	905.32	0.39	194.1	904.93	0.06		-0.39
194.01	905.82		-1.43		194.02	904.39		194.02	904.3			-0.09
194.01	905.9	0.08	-1.06		194.02	904.84	0.45	194.02	904.33	0.03		-0.51
193.93	905.53		-1.45		193.94	904.08		193.94	903.98			-0.1
193.93	905.61	0.08	-1.05		193.94	904.56	0.48	193.94	904.02	0.04		-0.54
193.86	905.11		-1.45		193.87	903.66		193.87	903.66			0
193.86	905.21	0.1	-1.03		193.87	904.18	0.52	193.87	903.71	0.05		-0.47
193.78	904.75		-1.52		193.79	903.23		193.79	903.21			-0.02
193.78	904.86	0.11	-1.12		193.79	903.74	0.52	193.79	903.24	0.03		-0.5
193.71	904.31		-1.47		193.73	902.84		193.73	902.71			-0.13
193.71	904.44	0.13	-1.1		193.73	903.34	0.5	193.73	902.74	0.03		-0.6

King Ranch / Cotton Lane Bridge CLOMR

Effective Model				Existing			Proposed/Revised			
River Sta	W.S. Elev (ft)	Profile Delta WSE (ft)	Delta WSE Exist-Eff (ft)	River Sta	W.S. Elev (ft)	Profile Delta WSE (ft)	River Sta	W.S. Elev Profile (ft)	Profile Delta WSE (ft)	Delta WSE Prop-CEff (ft)
193.65	903.8		-1.89	193.62	901.91		193.62	901.92		0.01
193.65	903.96	0.16	-1.56	193.62	902.4	0.49	193.62	901.92	0	-0.48
193.54	902.93		-1.45	193.53	901.48		193.53	901.48		0
193.54	903.14	0.22	-1.21	193.53	901.93	0.45	193.53	901.47	0	-0.46
193.45	902.25		-1.21	193.43	901.04		193.43	901.06		0.02
193.45	902.53	0.28	-0.97	193.43	901.56	0.52	193.43	901.06	0	-0.5
193.36	901.61		-0.96	193.34	900.65		193.34	900.65		0
193.36	901.95	0.33	-0.72	193.34	901.23	0.59	193.34	900.64	-0.01	-0.59
193.24	900.72		-0.51	193.25	900.21		193.25	900.05		-0.16
193.24	901.21	0.49	-0.37	193.25	900.84	0.64	193.25	900.05	0	-0.79
193.16	899.83		-0.18	193.16	899.65		193.16	899.49		-0.16
193.16	900.56	0.72	-0.16	193.16	900.4	0.74	193.16	899.49	0	-0.91
193.07	899.45		-0.21	193.07	899.24		193.07	899.08		-0.16
193.07	900.27	0.82	-0.2	193.07	900.07	0.83	193.07	899.09	0	-0.98
192.97	899.04		-0.27	192.98	898.77		192.98	898.69		-0.08
192.97	899.92	0.88	-0.27	192.98	899.65	0.88	192.98	898.69	0	-0.96
192.88	898.53		-0.42	192.89	898.11		192.89	898.09		-0.02
192.88	899.48	0.95	-0.52	192.89	898.96	0.85	192.89	898.09	0	-0.87
192.78	898.14		-0.78	192.79	897.36		192.79	897.4		0.04
192.78	899.03	0.9	-0.94	192.79	898.09	0.73	192.79	897.4	0	-0.69
192.69	897.8		-1.11	192.7	896.69		192.7	896.68		-0.01
192.69	898.67	0.87	-1.3	192.7	897.37	0.69	192.7	896.68	0	-0.69
192.6	897.49		-1.39	192.61	896.1		192.61	896.06		-0.04
192.6	898.24	0.75	-1.62	192.61	896.62	0.52	192.61	896.06	0.01	-0.56
192.51	896.86		-1.38	192.52	895.48		192.52	895.42		-0.06
192.51	897.67	0.82	-1.65	192.52	896.02	0.54	192.52	895.43	0.01	-0.59
192.42	896.36		-1.52	192.42	894.84		192.41	894.65		-0.19
192.42	897.21	0.85	-2.18	192.42	895.03	0.19	192.41	894.66	0.01	-0.37
							192.39 BR	894.35		
							192.39 BR	894.36	0.01	
	Cotton Lane Bridge									
							192.39 BR	893.8		
							192.39 BR	893.81	0.01	
							192.38	893.98		
							192.38	893.99	0.01	
192.33	895.51		-1.59	192.33	893.92		192.33	893.52		-0.4
192.33	896.36	0.85	-2.16	192.33	894.2	0.28	192.33	893.53	0.01	-0.67
192.23	895.12		-1.79	192.23	893.33		192.23	892.68		-0.65
192.23	896.01	0.89	-2.39	192.23	893.62	0.3	192.23	892.7	0.02	-0.92
192.13	894.53		-1.84	192.14	892.69		192.14	891.71		-0.98
192.13	895.34	0.82	-2.42	192.14	892.92	0.23	192.14	891.74	0.02	-1.18

King Ranch / Cotton Lane Bridge CLOMR

Effective Model				Existing			Proposed/Revised			
River Sta	W.S. Elev (ft)	Profile Delta WSE (ft)	Delta WSE Exist-Eff (ft)	River Sta	W.S. Elev (ft)	Profile Delta WSE (ft)	River Sta	W.S. Elev Profile (ft)	Profile Delta WSE (ft)	Delta WSE Prop-CEff (ft)
192.04	894.07		-1.94	192.04	892.13		192.04	891.06		-1.07
192.04	894.81	0.74	-2.48	192.04	892.33	0.2	192.04	891.09	0.03	-1.24
191.94	893.7		-2.05	191.95	891.65		191.95	890.52		-1.13
191.94	894.41	0.71	-2.57	191.95	891.84	0.19	191.95	890.54	0.02	-1.3
191.84	893.24		-2.04	191.86	891.2		191.86	890.05		-1.15
191.84	893.93	0.69	-2.54	191.86	891.39	0.2	191.86	890.07	0.02	-1.32
191.75	892.86		-2.13	191.76	890.73		191.76	889.52		-1.21
191.75	893.5	0.64	-2.6	191.76	890.9	0.17	191.76	889.54	0.02	-1.36
191.65	892.5		-2.34	191.67	890.16		191.67	888.99		-1.17
191.65	893.14	0.64	-2.83	191.67	890.31	0.15	191.67	889.02	0.03	-1.29
191.55	892.22		-2.58	191.57	889.64		191.57	888.5		-1.14
191.55	892.83	0.61	-3.06	191.57	889.77	0.13	191.57	888.54	0.04	-1.23
191.46	891.88		-2.73	191.48	889.15		191.48	888.09		-1.06
191.46	892.5	0.61	-3.2	191.48	889.3	0.15	191.48	888.14	0.05	-1.16
191.36	891.53		-2.9	191.38	888.63		191.38	887.67		-0.96
191.36	892.11	0.58	-3.3	191.38	888.81	0.18	191.38	887.73	0.05	-1.08
191.27	891.23		-3.06	191.29	888.17		191.29	887.28		-0.89
191.27	891.78	0.55	-3.41	191.29	888.37	0.2	191.29	887.34	0.06	-1.03
191.17	890.94		-3.21	191.19	887.73		191.19	886.85		-0.88
191.17	891.41	0.48	-3.49	191.19	887.92	0.19	191.19	886.91	0.06	-1.01
191.08	890.65		-3.3	191.1	887.35		191.1	886.46		-0.89
191.08	891.05	0.39	-3.51	191.1	887.54	0.19	191.1	886.54	0.07	-1
190.99	890.4		-3.46	191	886.94		191	886.1		-0.84
190.99	890.77	0.37	-3.63	191	887.14	0.2	191	886.18	0.08	-0.96
190.89	890.18		-3.67	190.91	886.51		190.91	885.66		-0.85
190.89	890.48	0.3	-3.77	190.91	886.71	0.21	190.91	885.75	0.1	-0.96
190.8	889.97		-3.85	190.81	886.12		190.81	885.25		-0.87
190.8	890.2	0.23	-3.88	190.81	886.32	0.2	190.81	885.35	0.09	-0.97
190.71	889.76		-3.99	190.72	885.77		190.72	884.88		-0.89
190.71	889.91	0.14	-3.97	190.72	885.94	0.17	190.72	884.99	0.11	-0.95
190.62	889.5		-4.13	190.62	885.37		190.62	884.49		-0.88
190.62	889.66	0.15	-4.14	190.62	885.52	0.15	190.62	884.61	0.12	-0.91
190.53	889.2		-4.32	190.53	884.88		190.53	883.96		-0.92
190.53	889.37	0.17	-4.36	190.53	885.01	0.13	190.53	884.1	0.14	-0.91
190.43	888.82		-4.45	190.43	884.37		190.43	883.34		-1.03
190.43	889.01	0.19	-4.5	190.43	884.51	0.14	190.43	883.52	0.17	-0.99
190.34	888.35		-4.45	190.34	883.9		190.34	882.9		-1
190.34	888.57	0.22	-4.52	190.34	884.05	0.15	190.34	883.1	0.2	-0.95
190.24	887.82		-4.46	190.24	883.36		190.24	882.37		-0.99
190.24	888.07	0.24	-4.53	190.24	883.54	0.18	190.24	882.6	0.23	-0.94

King Ranch / Cotton Lane Bridge CLOMR

Effective Model					Existing			Proposed/Revised				
River Sta	W.S. Elev (ft)	Profile Delta WSE (ft)	Delta WSE Exist-Eff (ft)		River Sta	W.S. Elev (ft)	Profile Delta WSE (ft)	River Sta	W.S. Elev Profile (ft)	Profile Delta WSE (ft)		Delta WSE Prop-CEff (ft)
190.15	887.02		-4.51		190.15	882.51		190.15	881.66			-0.85
190.15	887.28	0.27	-4.54		190.15	882.74	0.24	190.15	881.95	0.29		-0.79
190.05	885.99		-4.05		190.05	881.94		190.05	881.17			-0.77
190.05	886.27	0.28	-4.06		190.05	882.21	0.27	190.05	881.5	0.33		-0.71
189.96	884.93		-3.57		189.96	881.36		189.96	880.76			-0.6
189.96	885.28	0.35	-3.6		189.96	881.68	0.32	189.96	881.14	0.37		-0.54
189.87	883.54		-2.75		189.87	880.79		189.87	880.39			-0.4
189.87	884.09	0.55	-2.91		189.87	881.18	0.38	189.87	880.81	0.41		-0.37
189.77	882.48		-2.13		189.77	880.35		189.77	880.07			-0.28
189.77	883.1	0.62	-2.34		189.77	880.76	0.41	189.77	880.5	0.43		-0.26
189.68	881.65		-1.73		189.67	879.92		189.67	879.72			-0.2
189.68	882.27	0.61	-1.89		189.67	880.38	0.45	189.67	880.19	0.47		-0.19
189.58	880.91		-1.39		189.58	879.52		189.58	879.4			-0.12
189.58	881.56	0.66	-1.55		189.58	880.01	0.49	189.58	879.89	0.5		-0.12
189.49	880.32		-1.15		189.48	879.17		189.48	879.1			-0.07
189.49	881.02	0.7	-1.32		189.48	879.7	0.53	189.48	879.63	0.53		-0.07
189.39	879.75		-0.91		189.39	878.84		189.39	878.77			-0.07
189.39	880.52	0.77	-1.11		189.39	879.41	0.58	189.39	879.35	0.58		-0.06
189.31	879.34		-0.82		189.3	878.52		189.3	878.45			-0.07
189.31	880.13	0.79	-0.99		189.3	879.14	0.62	189.3	879.07	0.62		-0.07
189.22	878.92		-0.72		189.21	878.2		189.21	878.11			-0.09
189.22	879.66	0.74	-0.81		189.21	878.85	0.66	189.21	878.78	0.66		-0.07
189.12	878.47		-0.59		189.11	877.88		189.11	877.79			-0.09
189.12	879.17	0.71	-0.58		189.11	878.59	0.71	189.11	878.51	0.72		-0.08
189.02	878		-0.38		189.02	877.62		189.02	877.52			-0.1
189.02	878.73	0.72	-0.35		189.02	878.38	0.76	189.02	878.29	0.77		-0.09
188.81	877.31		-0.12		188.81	877.19		188.81	877.07			-0.12
188.81	878.12	0.8	-0.11		188.81	878.01	0.82	188.81	877.91	0.84		-0.1
188.7	876.86		0.01		188.69	876.87		188.69	876.79			-0.08
188.7	877.7	0.84	0.03		188.69	877.73	0.86	188.69	877.66	0.87		-0.07
188.59	876.44		0	TIE IN	188.59	876.44		188.59	876.44		TIE IN	0
188.59	877.33	0.89	0		188.59	877.33	0.89	188.59	877.33	0.89		0

8.3 Annotated Flood Insurance Rate Maps

Draft Flood Insurance Rate Maps are included in the Exhibits section following the Appendices.

8.4 Flood Profiles

Flood Profiles are shown in Figure 26.

Water Surface Elevations
Cotton Lane Bridge / King Ranch Improvements
Gila River

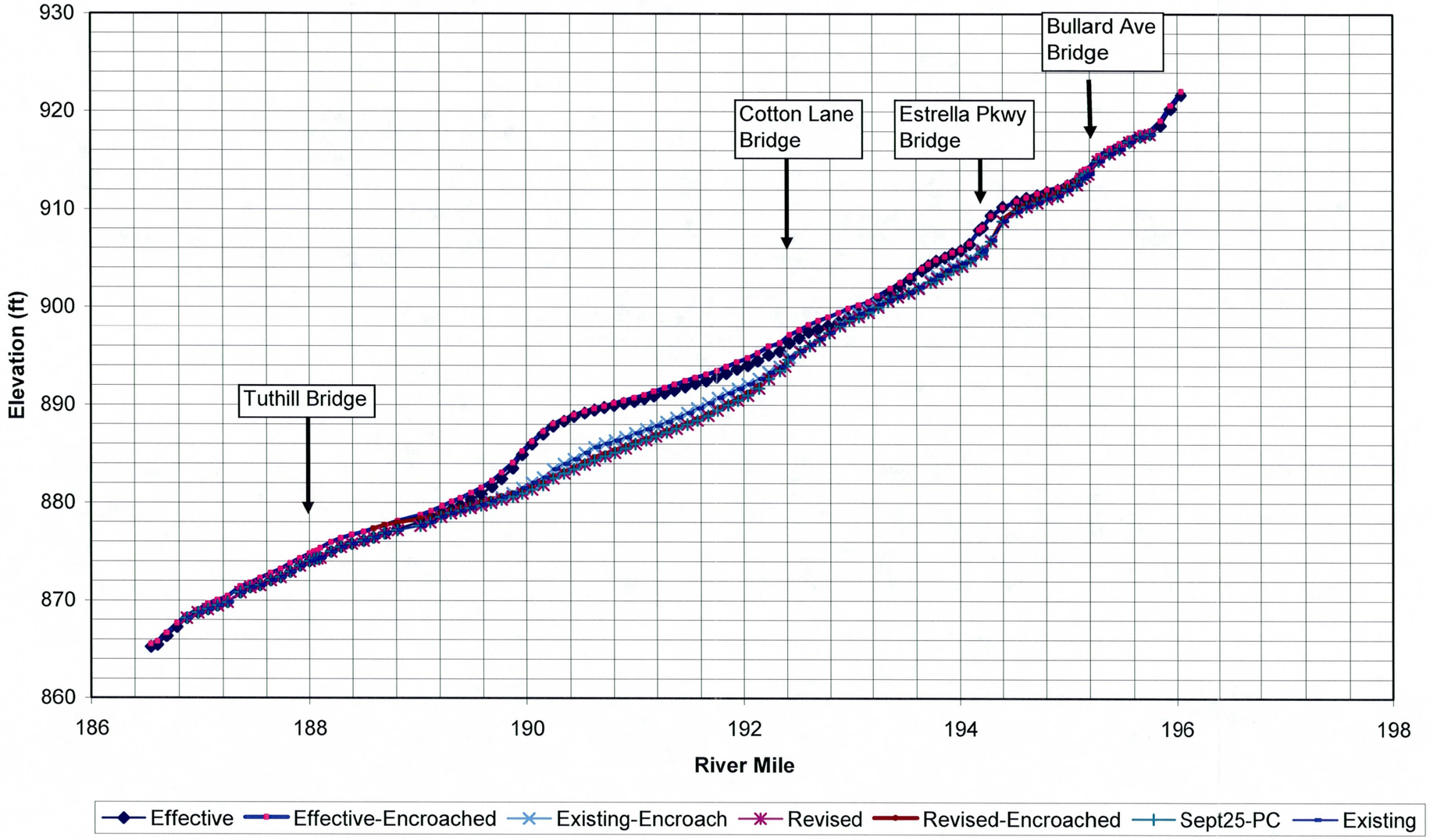

Figure 26. Floodplain and Floodway Profiles for Effective, Existing and Proposed Conditions.

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B.2 Contact (telephone) Reports

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F.2 Sediment Transport HEC-6T Model Results – Proposed Conditions

F.3 Scour Calculations

G CHECKRAS Output

APPENDIX A

References

A.1 Data Collection Summary

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1. Gila River Basin, Section 7 Study for Modified Roosevelt Dam, Arizona, U.S. Army Corps of Engineers, Los Angeles District, March 1996.

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A.2 Data Referenced documents

ERDC/CHL TR-00-25

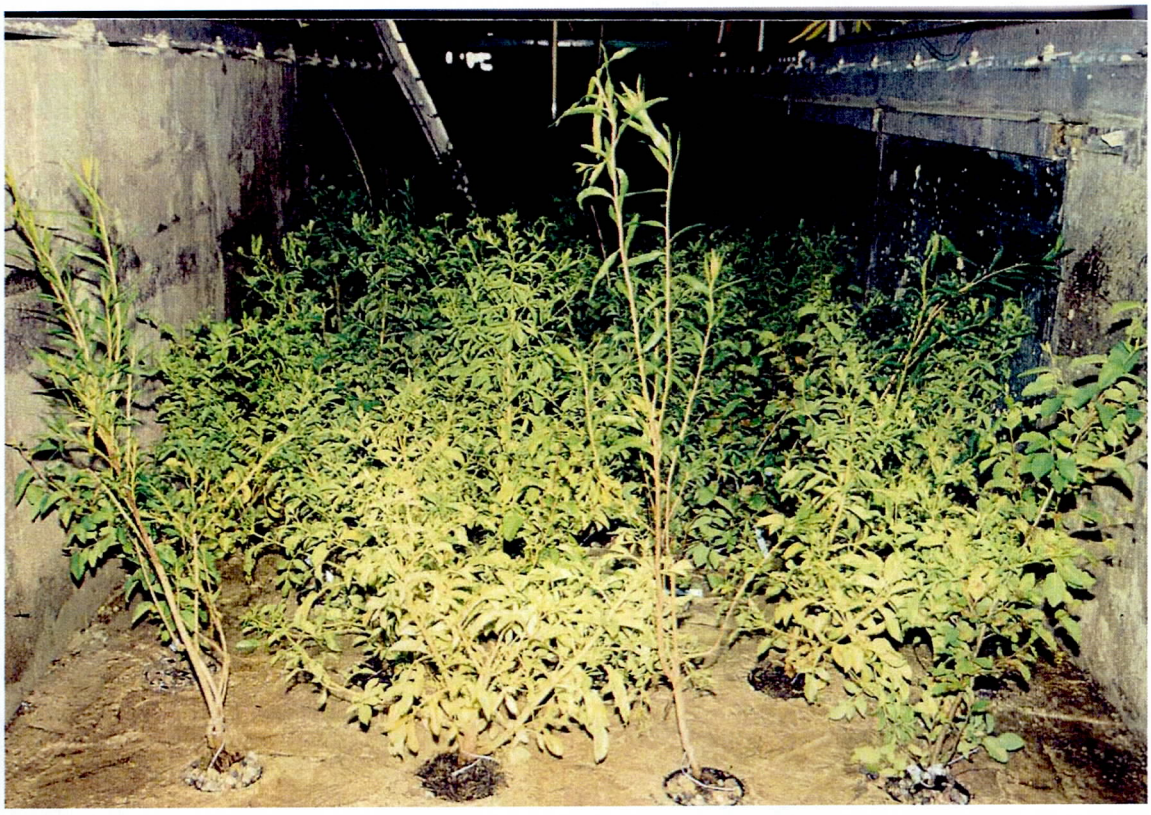
Coastal and Hydraulics Laboratory

US Army Corps
of Engineers®
Engineer Research and
Development Center

Determination of Resistance Due to Shrubs and Woody Vegetation

Gary E. Freeman, William H. Rahmeyer,
and Ronald R. Copeland

October 2000



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Determination of Resistance Due to Shrubs and Woody Vegetation

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Preface

The investigation reported herein was conducted by and for the U.S. Army Engineer Research and Development Center. The majority of the research was funded under Contract DACW39-94-K-0009 and conducted by the Utah Water Research Laboratory. A smaller portion of the research was funded under DACW39-97-M-1413 consisting of field investigations of plant stiffness and conducted by Dengari, Inc. Field measurements of hydraulic losses under actual high-water conditions and subsequent determinations of plant stiffness were conducted by Dr. Gary Freeman, former research hydraulic engineer, ERDC. All research reported herein was funded by the ERDC, Vicksburg, MS, as a part of the Flood Control Channels and Flood Damage Reduction Research Programs. Dr. Ronald R. Copeland, ERDC, supervised this research.

Research at the Utah Water Research Laboratory was conducted by and under the supervision of Dr. William Rahmeyer with the assistance of Mr. David Werth and other graduate research assistants. Dr. Gary Freeman conducted the research for Dengari, Inc. The authors of this technical report were Drs. Gary Freeman, William Rahmeyer, and Ronald Copeland.

The studies reported herein have been conducted over the period from 1993 to 1998 and were under the general supervision of Mr. F.A. Herrmann, Director of the Hydraulics Laboratory, Dr. J. R. Houston, former Director of the Coastal and Hydraulics Laboratory, Mr. M. B. Boyd, Dr. L. Daggett, Dr. W. H. McAnally, Jr., and Dr. P. G. Combs, Division Chiefs. The work was performed initially under the supervision of Mr. William A. Thomas with supervision subsequently transferred to Dr. Ronald R. Copeland, Research Hydraulic Engineers. Mr. D. L. Derrick, Research Hydraulic Engineer, was also involved in the supervision of contracts, research coordination, and field research efforts.

At the time of publication of this report, Dr. James R. Houston was Director of ERDC, and COL James S. Weller, EN, was Commander.

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List of Variables

Numerous variables are used throughout this report. These variables are listed here for convenience. Figures 1 and 2 show the measurements that define the variables involving the leaf mass and plant dimensions for submerged and emergent (unsubmerged or partially submerged) flow conditions.

The variables are defined as follows:

A	Cross sectional flow area, ft^2 or m^2
Ai	Frontal area of an individual plant blocking flow, approximated by the equivalent rectangular area of blockage H' by We, ft^2 or m^2
*Ai**	Net submerged frontal area of a partially submerged plant, ft^2 or m^2
As	Total cross-sectional area of all of the stem(s) of an individual plant, measured at H/4, ft^2 or m^2
b	width of channel flume, ft or m
C	Chezy resistance coefficient, ft½/s or m ½/s
CD	Drag coefficient of vegetation, dimensionless
Ds	Stem diameter, measured at a height of H/4, ft or m
Es	Modulus of plant stiffness, lbf/ft^2 or N/m^2
f	Darcy-Weisbach friction factor, dimensionless
fb	friction factor for the bed and plants, dimensionless
fw	friction factor for the walls, dimensionless
*F*45	The horizontal force necessary to bend a plant stem 45 deg, lbf or N
FD	Drag force, lbf or N
Fr	Froude number, dimensionless

g	Acceleration due to gravity = 32.17 ft/s^2 or 9.806 m/s^2
H	Average undeflected plant height, ft or m
H'	Undeflected height of the leaf mass of a plant, ft or m
H^*	Undeflected height of leaf mass that is below water surface for a partially submerged plant, ft or m (See Figure 2)
I	Second moment of inertia of cross section of plant stem, ft^4 or m^4
K_n	Units conversion factor for Manning's equation, 1.4861 ft$^{1/3}$/s or 1.0 m$^{1/3}$/s
L	Channel reach length, ft or m
M	Relative plant density, number of plants per ft^2 or m^2
n	Total Manning's roughness coefficient, including sidewall roughness
n_b	Manning's resistance coefficient for vegetation and channel bed
n_{veg}	Manning's resistance coefficient for vegetation
n_o	Manning's resistance coefficient for the bed
P	Wetted perimeter, ft or m
R_e	Reynolds number, $R_e = V R_h / \nu$
R_h	Hydraulic radius, R_h = flow area / wetted perimeter, ft or m
R_b	Hydraulic radius for the bed and plants, ft or m
R_w	Hydraulic radius for the walls, ft or m
S	Bed or energy slope, dimensionless
S_o	Bed slope , dimensionless
S_f	Energy slope, dimensionless
V	Mean channel velocity, ft/s or m/s
V_P	Local plant approach velocity in front of the leaf mass, ft/s or m/s
V_*	Shear velocity, $V_* = (g R_h S)^{1/2}$, ft/s or m/s
V_*/V	Resistance coefficient, dimensionless

Y_o Flow depth, ft or m

W_e Equivalent average plant width, $W_e = A_i / H'$, ft or m
dy/dx Unit change in slope of the water surface

γ Specific weight of water, lbf/ft^3 or N/m^3

ν Fluid dynamic viscosity, ft^2/s or m^2/s

ρ Fluid density, $slugs/ft^3$ (lbf-sec/ft) or kg/m^3

τo Shear stress on channel bottom, ($\tau o = \gamma Rh S$), lbf/ft^2 or N/m^2

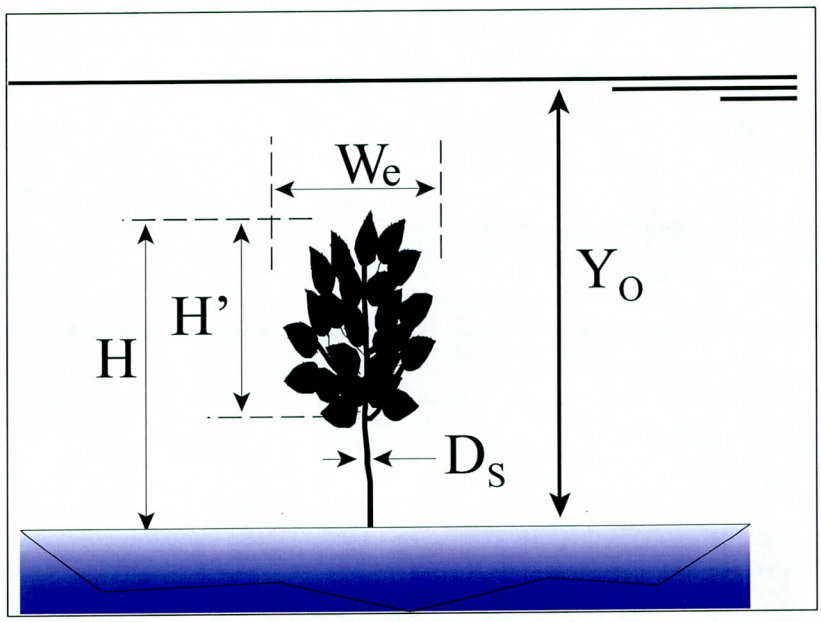

Figure 1. Plant dimension definitions for submerged plants

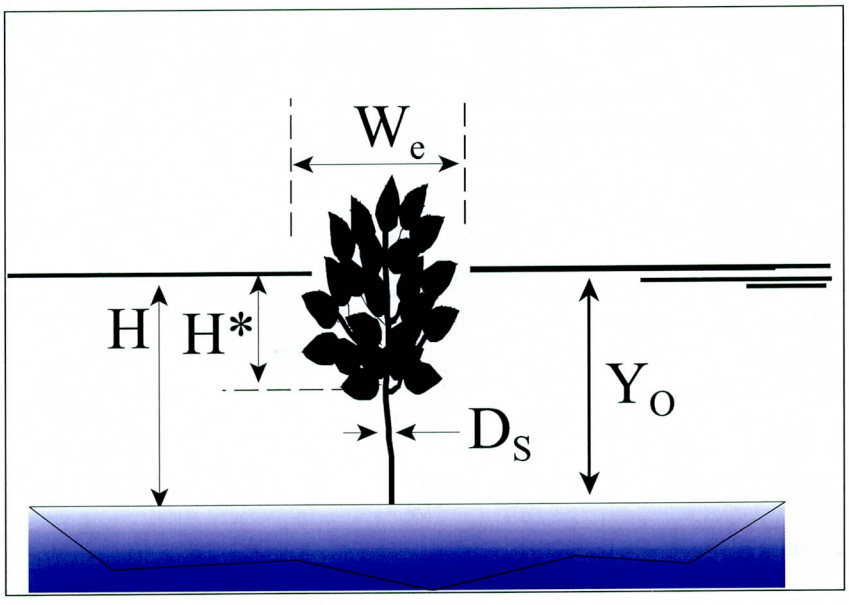

Figure 2. Plant dimension definitions for partially submerged plants

1 Introduction

Background

An important consideration for determining the stage-discharge relationship in rivers and streams is the effect or influence of vegetation on the overall head loss along a channel and in the overbank. Plants in the floodplain and along the banks can increase or even decrease the effective flow resistance. The vegetation may be natural or it may have been planted to improve aesthetics or habitat, to prevent erosion, or for other reasons.

The impetus for this study came as a result of numerous inquiries from U.S. Army Corps of Engineer District offices regarding the proper hydraulic roughness values to use for shrubs and other aesthetically and environmentally desirable plants. The District offices were involved in the evaluation of vegetative impacts on proposed and existing channels to determine flow capacity and water surface elevations. Given the near complete lack of hydraulic roughness values for shrubs and similar vegetation, the accurate estimation of channel capacity and water surface elevations was difficult at best. The work described herein was carried out under the Flood Control Channels and Flood Damage Reduction Research Programs starting in 1993 and completed in 1997. It was a direct result of District requests for research through the Flood Control Channels Field Review Group

Previous research has been conducted on vegetation such as grasses, agricultural crops, and on the rigid blockage of cylindrical tree trunks. However, little had been studied on the resistance effects of plants and shrubs that are either submerged or partially submerged by turbulent flows. The flexible stems and varying shapes of plant leaf mass greatly complicate the understanding of this resistance. The deformation of plant shape with flow precludes the use of a constant blockage area or the density of plant frontal area in predicting resistance.

The purpose of this study was to investigate the effect of vegetation, particularly ground cover plants, small trees, and shrubs, on flow resistance. Hydraulic losses and drag due to actual plants were measured at the Utah Water Research Laboratory utilizing a large wide flume and a smaller sectional flume.

Research in the flume resulted in the collection of data from more than 220 experiments with 20 different plant species. Experiments were conducted with both homogeneous and mixed plant groupings. Single-stem and multiple-stem plants were included in the plant types evaluated. Plants with and without leaves were evaluated. Plant density, spacing, and size were varied in the experiments. Plants were evaluated over a range of velocities and depths.

A methodology was developed from the laboratory data to predict head loss and resistance coefficients as a function of slope and depth. Input data for the methodology can be collected from the field or estimated plant characteristics may be used.

Resistance Coefficients

Resistance to flow is typically characterized by a roughness coefficient. The most commonly used equation for flow resistance is the Manning's equation:

$$V = \frac{K_n}{\mathrm{n}} R_h^{2/3} S^{1/2} \quad (1)$$

where

V = mean velocity of flow

R_h = hydraulic radius

S = slope of the energy grade

n = Manning's resistance coefficient

K_n = unit correction factor of 1.0 for SI units and 1.486 for non-SI units

Although Manning's equation is used extensively for calculating flow resistance, Manning himself did not recommend it for use, because his research found that n was not constant but varied with velocity and depth.

The ratio of shear velocity to mean velocity, V_*/V, is another form of resistance coefficient. Keulegan (1938) used it to calculate average velocity based on the theoretical vertical velocity profile. The ratio of shear velocity to average velocity may be thought of as the ratio of shear stress to inertial force as indicated in Equation 2.

$$\frac{V_*}{V} = \frac{\sqrt{gR_hS}}{V} = \left(\frac{\tau_o}{\rho V^2}\right)^{1/2} \quad (2)$$

V_* is the shear velocity, g is the acceleration due to gravity, τ_o is the shear stress, and ρ is the density of water.

There are other resistance coefficients in use including the Darcy-Weisbach friction factor, f, and the Chezy C. These can be converted easily to Manning's n as shown in Equation 3.

$$\frac{V_*}{V} = \sqrt{\frac{f}{8}} = \frac{n}{K_n}\sqrt{\frac{g}{R_h^{1/3}}} = \frac{\sqrt{g}}{C} \quad (3)$$

Note that the Chezy coefficient is not dimensionless, and will vary with units. The Manning coefficient is dimensionless only in the sense that K_n will make it dimensionless when units of feet or meters are used in Equation 3.

In this study, resistance equations were developed for the shear velocity to average velocity ratio because it is dimensionless and has a sound theoretical basis, and for the Manning's coefficient because its use is widespread.

The Manning's resistance coefficient for vegetation is calculated in conformity with the Cowan (1956) method for additive resistance. This method consists of additions to roughness for various surface irregularities and vegetation. The equation that describes the method is:

$$n = (n_o + n_1 + n_2 + n_3 + n_4)m \quad (4)$$

where n_o is the base value for a straight, uniform, smooth channel in natural materials; n_1 is an additive value to account for surface irregularities; n_2 is added to account for variations in the channel geometry along the reach; n_3 is an additive value to account for obstructions; n_4 accounts for vegetation; and m is a correction factor for meandering or sinuosity of the channel. The n_4 coefficient used in Cowan's method is based on the net effect of vegetation.

Many published values of Manning's roughness coefficients related to vegetated surfaces include the base resistance, n_0, as a part of the reported vegetation resistance. This is the convention followed in this report. Thus, roughness coefficients reported herein include the effects of both the bed and the vegetation. In Cowan notion this would be expressed as $n = n_0 + n_4$.

The resistance values can be composited into channel averages using several methods. One of the methods is Lotter's 1933 method shown in Equation 5. The Lotter method, presented by Chow (1959), uses vertical bisecting lines to subdivide the channel cross section into subareas for the calculation of flow. This method assumes that the total flow is the sum of the flows in the separate subareas. The equivalent resistance thus developed accounts for the variability in resistance across the channel.

$$n = \frac{PR_h^{5/3}}{\sum_{i=1}^{N}\left(\frac{P_i R_{h_i}^{5/3}}{n_i}\right)} \quad (5)$$

P is the wetted perimeter. N is the number of i subsections.

Substitution of Equation 5 into Equation 3 yields a dimensionless compositing equation for V_*/V given in Equation 6.

$$\frac{V_*}{V} = \frac{PR_h^{3/2}}{\sum_{i=1}^{N}\left(\frac{P_i\ R_{h_i}^{3/2}}{\left(V_*/V\right)_i}\right)} \tag{6}$$

Resistance Equation for Large Woody Vegetation

Usually, vegetation on the flood plains is larger than that found in the main channel. This vegetation has a major influence on flow depth and resistance during overbank flooding. Petryk and Bosmajian (1975) proposed a method to calculate flow resistance based on the drag forces created by the larger plants and trees that constitute much of the resistance on the flood plains. They derived Equation 7 for Manning's n by summing the forces in the longitudinal direction. The forces include pressure forces, the gravitational force, shear forces, and the drag forces.

$$n = n_o\sqrt{1.0+\left(\frac{C_D\sum A_i}{2g\,A\,L}\right)\left(\frac{K_n}{n_o}\right)^2\left(\frac{A}{P}\right)^{4/3}} \tag{7}$$

Here C_D is the effective drag coefficient for the vegetation in the direction of the flow, A is the cross-sectional area of the flow, in ft^2, ΣA_i is the total frontal area of vegetation blocking the flow in the reach, in ft^2, L is the length of the channel reach being considered, in ft. The expression $C_D \Sigma A_i/(AL)$ represents the vegetation blockage, or the density of vegetation in the floodplain. This expression must be either directly or indirectly measured. The total boundary roughness, n_o, excludes the additive resistance, n_4, for other types of vegetation such as shrubs.

There are several limitations to using Petryk and Bosmajian's equation. The channel velocity must be small enough to prevent bending or distortion of the vegetation, and large variations in velocity cannot occur across the channel. Vegetation such as grasses and shrubs are then excluded. Vegetation must also be distributed relatively uniformly in the lateral direction. Finally, according to Petryk and Bosmajian, the flow depth must be less than or equal to the maximum vegetation height. During flooding, the velocities over the floodplains can be relatively high and large degrees of bending and distortion of vegetation often occur. Vegetation types and densities can also vary widely across a floodplain, and water depths often submerge vegetation. However, when tree trunks dominate sections of a floodplain, this method can be used to predict the total resistance coefficient, n.

2 Laboratory Setup and Procedures

Experimental Plants

Two flumes at the Utah Water Research Laboratory were used for laboratory experiments during this study. The large flume (Figure 3), 2.44 m (8 ft) wide by 1.82 m (6 ft) deep by 152.4 m (500 ft) long, was used to measure in situ flow resistance and drag force for groups of uniform sized plants and groups of mixed plants with varying plant density, sizes, and shapes. A sectional flume, 0.91 m (3 ft) wide by 0.91 m (3 ft) deep, was used to measure drag force of individual plants. Thirteen different plant types were evaluated in the large laboratory flume and 10 plant types in the sectional flume. Six combinations of plants typical of different ecosystems were also studied in the large flume. In total, 21 different plant types were evaluated in the two flumes. The plants and their characteristics are listed in Table 1. Field measurements of plant stiffness (Freeman 1997) for four plant types are also listed in Table 1. All plants evaluated were broadleaf deciduous vegetation commonly found in floodplain and riparian zones.

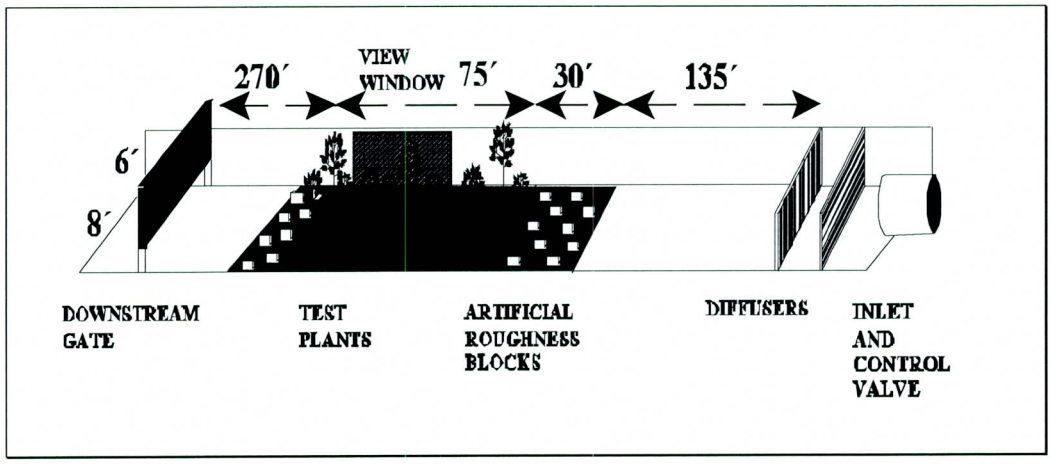

Figure 3. Layout of large flume for plant roughness experiments (To convert feet to meters, multiply by 0.3048)

The plants evaluated in the large flume were placed in staggered rows along the 22.9-m (75-ft) length of the experimentation section (Figure 3). The spacing selected for the plants was based on typical plant spacing found in floodplains. The plant density, M, was calculated as the number of plants per unit area. The plants evaluated in the small flume were placed in a single row of four to five plants along the center line of the flume. A single plant was instrumented for measuring drag force in both flumes. The instrumented plant in the larger flume was located in the center of the 22.9-m (75 ft) by 2.44-m (8-ft) experimentation section. The plant selected for measurement in the small flume was the downstream plant, with four plants located upstream. The experimental setup for the small flume allowed for a more accurate measurement of plant approach velocity (V_P) and drag force (F_D). Roots had to be removed from all the plants used in the small flume, but only the plant used to measure drag force in the large flume required root removal. All other plants in the large flume were placed intact, with root structure and original soil, into a 20.3-cm (8-in) deep experimental bed.

The range of variables measured in the large flume were:

a. Flow depths from 0.4 to 1.4 m (1.3 to 4.7 ft).

b. Average flow velocities from 0.15 to 1.1 m/s (0.5 to 3.6 ft/s).

c. Measured resistance V_*/V from 0.13 to 0.45 and n from 0.04 to 0.14.

d. Plant heights from 0.20 to 1.52 m (0.66 to 5 ft).

e. Plant widths from 0.076 to 0.91 m (0.25 to 3 ft).

f. Plant densities from 0.53 to 13 plants / m^2 (0.05 to 1.2 plants / ft^2).

g. Plant modulus of stiffness from 5.3×10^7 to 4.8×10^9 N/m^2 (1.1×10^6 to 1.0×10^8 lbf/ ft^2).

h. Reynolds numbers from 1.4×10^5 to 1.6×10^6.

Large Flume Experimental Setup

The large flume experimentation section had a bed that would accept plants with their root systems intact. In the first phase of the study, the bed consisted of a layer of gravel, to assist in drainage, covered with a cap of compacted clay. This material supported the plants and was intended to prevent them from washing downstream. In the second phase of the study, the compacted clay was replaced with a gravel bed and a mortar cap. The mortar cap greatly facilitated the changing of plants and experimental setups. The mortar cap had 158 3.8-L (1-gal) plant containers in the bed in staggered rows of four and five plants per row. When particular containers were not in use they were capped flush with the top of the mortar cap to prevent the introduction of additional roughness.

Upstream and downstream of the experimentation section the flume contained a section of roughened bed. The roughness elements consisted of cinder blocks that were adjusted until they produced a fully-developed turbulent velocity distribution upstream and downstream of the experimentation section.

At the beginning of each experiment, at the downstream end of the clay or mortar bed, stop logs were inserted to allow for slow filling of the flume. This was done to protect plants during filling. As discharge was slowly increased to the desired level, stop logs were removed. Some stop logs remained during the experiment to maintain a constant velocity profile throughout the experimentation section. At the downstream end of the flume, 91.4 m (300 ft) downstream of the experimental section, a hydraulic gate was used to control flow depth.

Water from the river adjacent to the laboratory entered the flume from a 122-cm (48-in) pipe 50.3 m (165 ft) upstream from the experimentation section. Water temperature was measured and found to be 10°C (50°F) for all experiments. A remote controlled butterfly valve in the 122-cm (48-in) pipeline was used to control the flow of water into the flume. A Mapco sonic meter was used to measure the flow rate in the inlet pipe. Downstream from the inlet pipe, jet flow was dissipated using a series of vertical and horizontal distribution vanes.

A wheeled platform that moved on tracks adjacent to the flume sides was used to take depth and velocity measurements. This platform was positioned at 1.52-m (5-ft) intervals along the length of the experimental section to facilitate measurements. Water-surface elevations were measured with the help of a stationary transit and a measuring rod along the center line of the flume. Flow velocities were taken with a Marsh McBirney Model 201 portable water current meter.

A single plant centered horizontally in the flume was selected to measure drag force. An average-sized plant was selected and inserted into a platform. The platform was a shallow metal box with ball bearings in the bottom and a metal plate resting upon the ball bearings as shown in Figure 4. The instrumented plant, with its roots removed, was attached to the plate. A Vishay Instrument Model P-350 strain indicator was then attached to the downstream end of the plate to measure the drag force applied to the plant by the moving water column. This drag force was measured as a compression force. During the experiment the platform was covered with a section of drain cloth to prevent soil from interfering with the ball bearings and movement of the plate. The platform was also covered with a plastic lid to reduce friction drag on the platform. The strain gage was zeroed at the start of each series of experiments. The range of the strain gage was 0 to 44.5 N (10 lbf). The sensitivity of the strain gage was 45 micro-cm per cm per N (200 micro-inches per inch per pound). Measurements were taken to the nearest 2.5 micro-cm (1.0 micro-inch.)

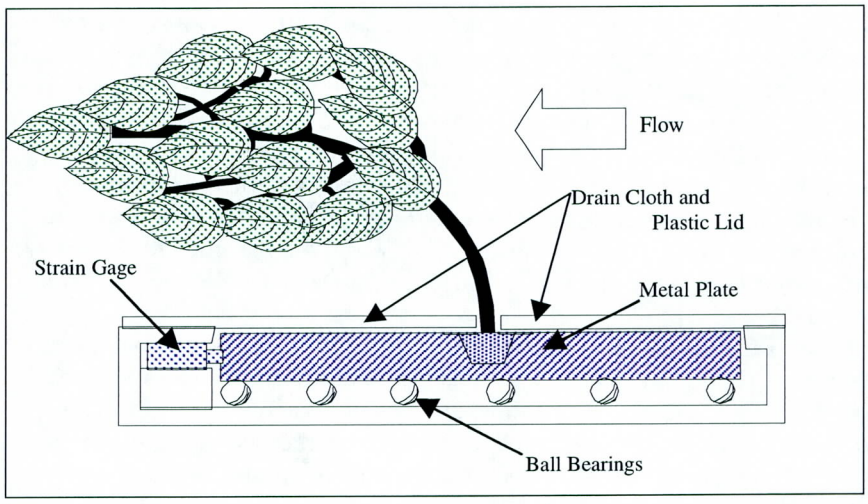

Figure 4. Experimental setup to measure plant drag

Large Flume Operating Procedures

Measurements were made of plant dimensions and plant characteristics before each series of experiments. Plant height and width, leaf size, and stem height were measured. The number of branches and stems were counted. The diameter of stems and branches was recorded, and bending characteristics were measured. The forces required to bend the plant 45 deg and horizontal at different heights along the stem were determined. A strain gage was first attached to the top of the plant. After the bending forces and deflection were determined there, the gage was hooked to the center of the plant and the bending forces were again measured.

During the first phase of the study, prior to beginning each series of experiments, the bed was leveled and a layer of topsoil placed and compacted on top of the clay bed. The mortar cap used in second phase of the study did not require maintenance and leveling for each series of runs. The plants were placed in the flume just prior to the experiment and the flume was slowly filled with water, with the stop logs in place and the downstream gate closed. With the flume filled and no flow, the strain gage was zeroed. Flow and depth were controlled with the downstream gate and the 122-cm (48-in) inlet butterfly valve. Time was allowed for the flume to reach equilibrium before measurements were taken for each run.

Typically, nine runs were made for each series of experiments. The first three runs were made at high depths, with the flume nearly full, and at three different velocities. The next three runs were made at a medium depth, and the last three runs were made at a low depth. The plants were usually submerged, even at low depths, because the flow forces were adequate to bend the plants with the flow. Some runs were conducted near the end of the study with the larger plants partially submerged, to aid in determining a relationship for partially submerged plants.

Water-surface elevation was measured at 1.52-m (5-ft) intervals along the length of the flume's experimentation section. At the midpoint of the experimental section, velocity measurements were taken at different depths to establish a vertical velocity profile. Velocity measurements were also taken at the center of the leaf mass just upstream of the plant used to measure drag force. The plant approach velocity was measured 5.1 cm (2 in) upstream of the instrumented plant to avoid making a measurement in what could have been a stagnation region at the upstream face of the plant. It was determined early in the study that velocity measurements taken in the plant mass and at the upstream face of the plant were inconsistent because of the interference of individual leaves, but the velocity measurements did show that there was still substantial velocity and flow through the plant mass. Drag force was determined from the strain gage measurements for many, but not all, experimental runs. As the depths and velocities were varied, the plants and bed (for Phase I) were observed through the view window to document soil movement, plant distortion, and plant failure.

Small Sectional Flume Setup

A smaller sectional flume was used to study the drag forces developed on single plants. Water was supplied by a 0.914-m- (3-ft-) wide by 0.914-m- (3-ft-) high channel running perpendicular to the flume entrance. A baffle was placed at the entrance of the flume to straighten the incoming flow and a Plexiglas observation window was installed in the side of the flume.

Since the bottom of the flume consisted of smooth steel, it was necessary to devise a method to secure the plants in the flume. A 3.81-cm- (1½-in.-) thick false deck was constructed of smooth, painted plywood. The deck was bolted through the bottom of the flume and sealed with silicon caulk. Several 2.54-cm (1.0-in) holes were drilled through the plywood to the steel bottom. These holes were designed to hold plants in a layout that would create a flow regime around the plant similar to the flow regime of the plant in the large flume.

To attach the plants to the flume bottom, a beveled rubber grommet and wide-flanged washers were used. The roots of the plants were cut off at the base of the stem, and the plant stem inserted through the washer into the grommet. The rubber grommet was used to protect the base of the stem and prevent breakage of the stem. Without the grommet, the plant tended to break where the stem contacted the surface of the plywood floor when the plants were subjected to high velocities. The rubber in the grommet would give slightly, however, allowing the plant to bend a small amount at the base rather than shear off against the sharp edges of the plywood floor. This is similar to the conditions that the plant experiences in the field with soil around its base. The wide flanged washers had two holes that allowed the grommet to be attached to the plywood floor with screws. The beveled grommet was slightly larger than the holes and when the screws were tightened, the washer compressed the grommet into the hole, securing the plant to the floor of the flume.

The instrumented plant in the small flume also had a grommet, but was attached to a smooth aluminum plate rather than the plywood floor. The plate

was 15.2-cm (6-in) wide by 30.5-cm (12-in) long and 2.54-cm (1-in) thick. The plate provided a platform by which to measure the drag force produced on the plant. A hole was drilled in the plate and a shorter grommet was used because the plate was not as thick as the false deck. The plant was inserted through the washer and the grommet screwed to the plate in the same method as with the other plants.

To allow placement of the plate into the flume floor, a 16.5-cm (6-½ in.) by 31.8 cm (12-½ in.) rectangle was cut in the center of the floor along the center line of the flume. Since the floor was 3.81-cm (1-½ in.) thick, 1.27-cm- (½-in.-) diam ball bearings were placed directly on the smooth steel floor where the plywood was removed. This allowed the plate to move smoothly on the steel deck. It also raised the top of the plate to a height of 3.81 cm (1-½ in.), exactly flush with the rest of the floor. This prevented the water from striking the face of the plate and adding to the measured drag force.

The same strain gage used in the large flume experiments was used in the small flume. It was placed and centered directly behind the aluminum plate to measure the drag force as compression. The gage and connections were sealed in waterproof bags. The strain gage was temperature compensating and always zeroed in place and underwater. The calibration of the gage was checked before each series of experiments.

Elastic bands or springs were attached to both the plate and the plywood floor immediately downstream and to the sides of the plate. This held the plate firmly in contact with the strain gage and centered in the floor cavity.

Velocity measurements were made using a propeller type Ott velocity meter. Velocity measurements were taken at the center of the leaf mass just upstream of the instrumented plant.

Small Sectional Flume Operating Procedures

Measurements were made of plant dimensions and plant characteristics before each series of experiments. Plant height and width, leaf size, and stem height were measured. The number of branches, stems, and leaves were counted. The diameter of stems and branches was recorded, and bending characteristics were measured.

The roots of the plants were then removed and attached to either the plywood floor or the aluminum plate. Stop logs were placed to a height of 0.914-m (3 ft) at the downstream end of the flume. This allowed the flume to be completely filled and the strain gage set to 0 to compensate for any buoyancy effects.

Each plant was subjected to a series of 10 runs. Each run was at an increasing velocity, ranging from approximately 0.076 to 2.43 m/sec (0.25 to 8 ft/sec.) During each run, the velocity directly upstream of the plant and the compression on the strain gage were recorded. This velocity was taken at the center line of the effective leaf area. As velocity increased, the velocity probe

was lowered to compensate for plant bending. This insured that the velocity of each run was being recorded at the vertical center line of the leaf mass. The angle the plant deflected was determined from marks drawn on the sidewalls of the flume. Videotapes were taken to allow for more detailed observation of the plants at a later time.

After the plant was subjected to 10 different velocities, all leaves were removed. The plant was then immediately subjected to 10 more runs. Velocity, drag, and deflection data were again recorded as previously described.

3 Results and Analysis

Resistance Coefficients from Head Loss Measurements

Twenty-one different series of experiments were completed in the large flume using different plant types, plant combinations, plant heights, plant spacings, flow velocities, and depths. Plant characteristics are listed in Tables 1 and 2 in SI and non-SI units, respectively. The runs were videotaped as well as photographed. One run was made to determine the bed roughness of the flume without plants on each bed type (clay and mortar).

Tables 3 and 4 present results from the large-flume homogeneous-plant-grouping experiments in SI and non-SI units, respectively. Tables 5 and 6 present the results from large-flume mixed-plant-grouping experiments in SI and non-SI units, respectively. Water-surface elevation, average depth, and discharge were measured. Average velocity was determined from the continuity equation. The average roughness coefficient came from an iterative solution of the backwater equation in which calculated water-surface elevations were matched to measured water-surface elevations. In the backwater equation, Equation 1 was used to determine n and Equation 2 to determine V_*/V. Average energy slope is presented in Tables 3-6. Flume wall effects were accounted for by the method advanced by Vanoni and Brooks (1957).

A typical velocity profile measurement is shown in Figure 5. The profile demonstrates the effect of leaf mass on velocity. The plant approach velocity is the velocity that occurred upstream at the center line of the leaf mass of the plant. The velocity significantly increased below the leaf mass. Velocity profile measurements are reported in Rahmeyer et al. 1996.

Average channel velocities between 0.914 and 1.22 m/s (3 and 4 ft/sec) were necessary to cause either the leaves to break off the plants or for the stems to break. These velocities also caused significant movement of bed material in the Phase I experiments. It is possible that many of the leaf and stem failures may have been due to the impact from large bed material, i.e., gravel size particles, being transported by the flow.

Another observation was that shrubs with open areas beneath the primary leaf mass were diverting significant amounts of flow beneath the leaf mass. In

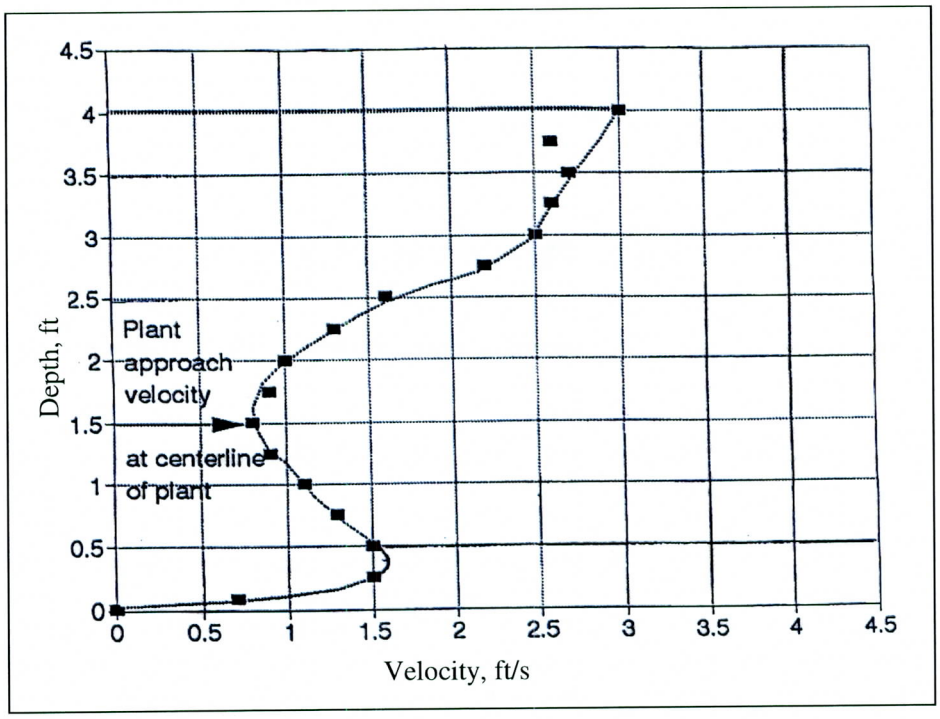

Figure 5. Example velocity profile for an experimental run with dogwoods (To convert feet to meters, multiply by 0.3048)

some cases velocities below the leaf mass approached surface velocities and were sufficient to transport even the largest size gravel particles.

The *Euonymus* plants were ground cover plants with leaves extending to the bed. These plants, when used in a typical spacing, left areas of the bed exposed to flow. Measurable scour was noted in these areas for all Phase I experiments. The *Euonymus* plant experiments were stopped when scour began to wash the plants away. Only the wire attached to the plant stems kept the plants from being washed downstream. It was observed that local scour was occurring from three-dimensional vortices that appeared to be similar to those typically associated with scour around bridge piers.

Figures 6-11 demonstrate the effect of velocity on plant deformation, sediment transport, and scour.

Calculation of Roughness Coefficients

The hydraulic roughness and the Manning's coefficient n for plant resistance were calculated by using an initial estimate of a total Manning's roughness coefficient and then adjusting the n value to best fit the gradually varied backwater curve of measured water-surface elevations along the experimental section. Equation 8 was the equation used to fit the backwater curve.

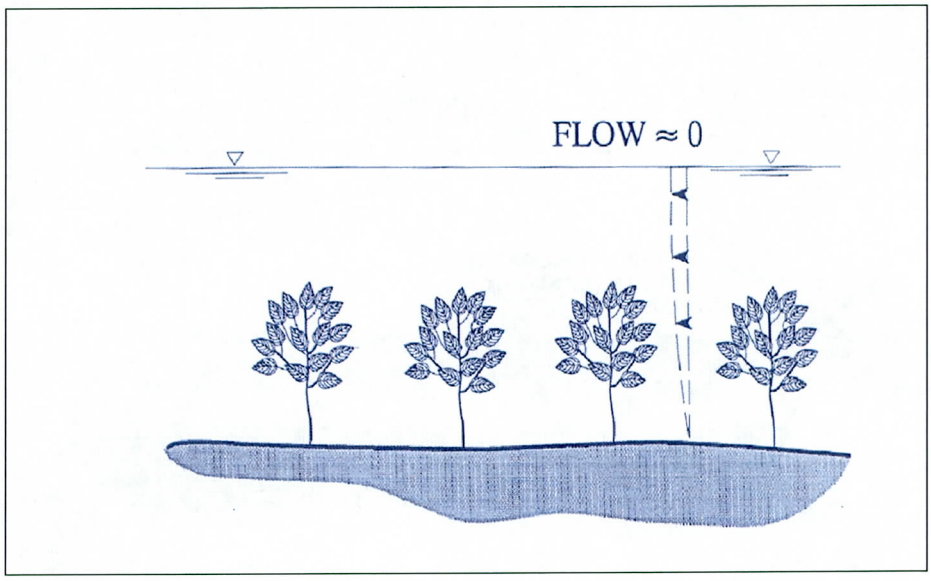

Figure 6. Plants at zero flow

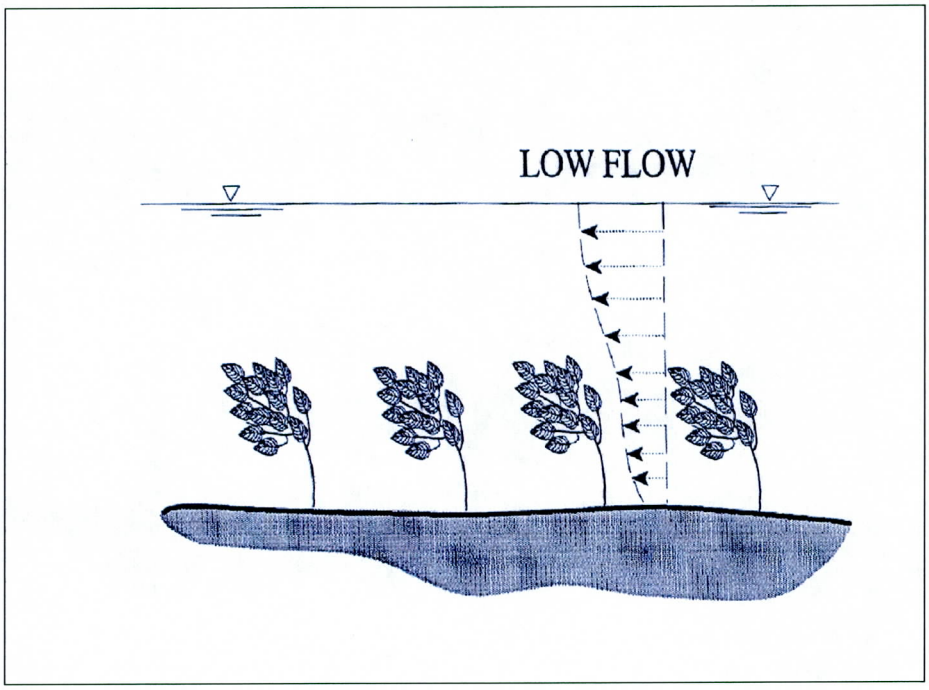

Figure 7. Plants at low flow

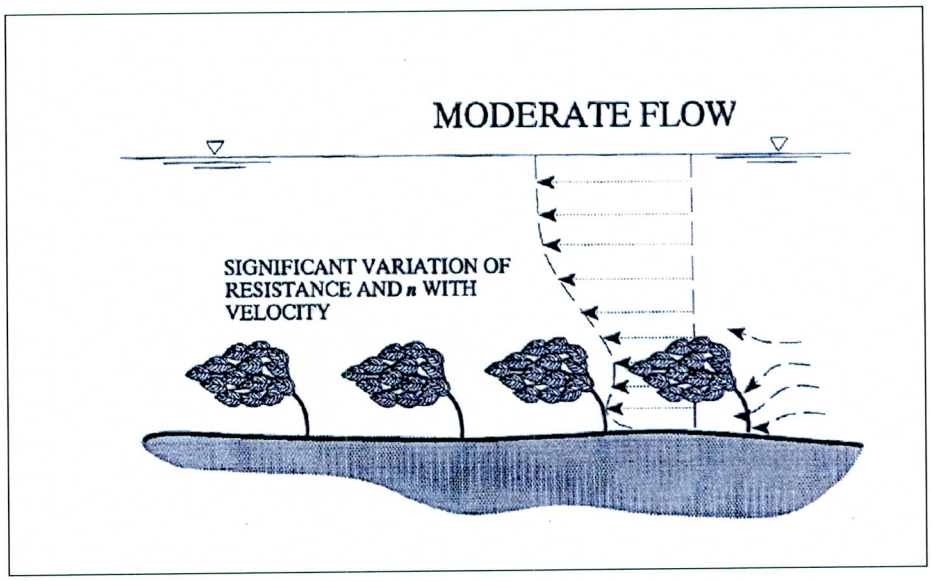

Figure 8. Plants at moderate flow

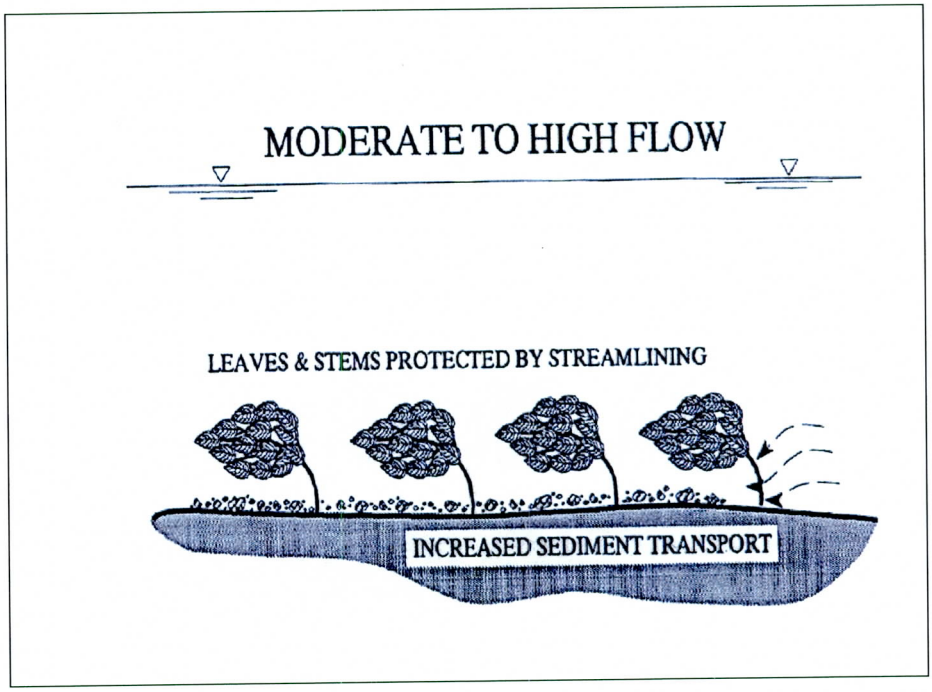

Figure 9. Plants with sediment transport

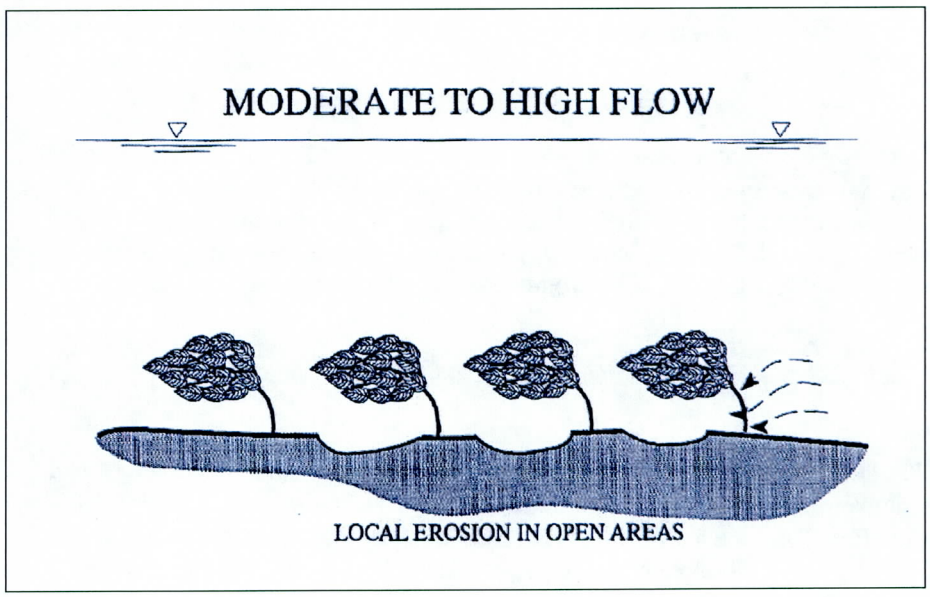

Figure 10. Plants with local erosion

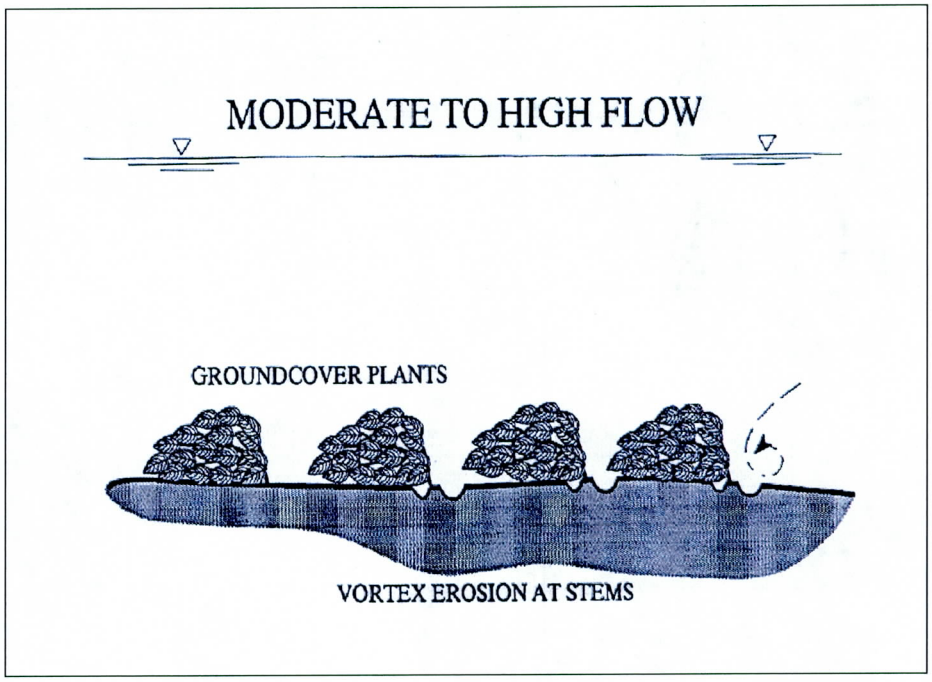

Figure 11. Plants with stem erosion

$$\frac{dy}{dx} = \left(\frac{S_0 - S_f}{1.0 - F_r^2} \right) \tag{8}$$

Here dy/dx is the unit change in slope of the water surface; S_o is the slope of the bed; S_f is the slope of the energy line; and F_r is the Froude number. S_f is calculated from the Manning's equation (Equation 1) using the estimate of Manning's n, the mean velocity, V, calculated from the continuity equation, and the hydraulic radius, R_h. The Froude number was calculated from Equation 9.

$$F_r = \frac{V}{\sqrt{g\ R_h}} \tag{9}$$

The Manning's n for the vegetation and the bed was then iteratively solved using a trial and error process until the shape of the backwater curve predicted by Equation 8 was the same as the measured curve of the actual water surface. Figure 12 is an example of the backwater curve fit for a run with a total Manning's n of 0.062.

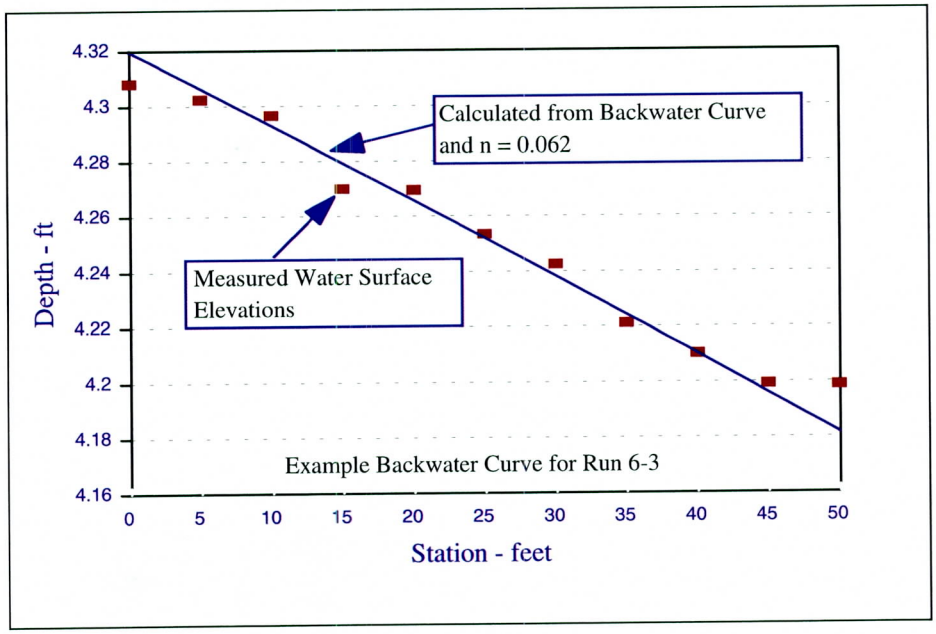

Figure 12. Typical backwater curve for experimental runs (To convert feet to meters, multiply by 0.3048)

From the total Manning's n the value of n_b, the bed and plant roughness, was determined. The first step in this determination was to convert the total n to a Darcy-Weisbach friction factor, *f*, by Equation 10.

$$\sqrt{f} = \frac{n\sqrt{8\,g}}{K_n\, R_h^{1/6}} \tag{10}$$

The coefficient of friction for the bed and plants, f_b, was determined using a correction for flume wall effects. The coefficient of friction for the walls, f_w, was determined from Equation 11. This equation was regressed for this study to fit the correction figure presented by Vanoni and Brooks (1957).

$$f_w = 0.274367\left(\frac{R_e}{f}\right)^{-0.175092} \tag{11}$$

R_e is the Reynolds number. Equation 11 was a power fit regression with an R^2 of 99.98 percent. The friction factor for the bed and plants, f_b, was then calculated with Equation 12.

$$f_b = f + \frac{2Y_o}{b}(f - f_w) \tag{12}$$

Here b is the width of the channel, and Y_o is the flow depth. The hydraulic radius associated with the bed and plants, R_b, was determined by Equation 13.

$$\frac{R_b}{f_b} = \frac{R_w}{f_w} = \frac{R_h}{f} \tag{13}$$

R_w is the hydraulic radius for the walls; and R_h is the total hydraulic radius. Equations 12 and 13 are from Vanoni and Brooks (1957). Finally, the Manning's coefficient n_b for the bed and vegetation roughness was calculated using R_b in Equation 1.

The coefficient n_b is the resistance of both the bed and vegetation roughness. Equation 14 can be used to calculate the resistance coefficient n_{veg} for the net resistance of the vegetation.

$$n_{veg} = n_b - n_o \tag{14}$$

where n_{veg} is the Manning's coefficient for vegetation; n_b is the bed and vegetation resistance; and n_o is the bed roughness. The value for n_o for both the clay and mortar beds (corrected for wall effects) was determined to be approximately 0.020. V_*/V was found to have a value of 0.069. Resistance coefficients reported in this report show the combined value for the bed and the plants. This combined value is typically reported in field investigations. Roughness coefficients reported herein may be reduced to strictly vegetation roughness coefficients by subtracting 0.020 from reported Manning's n values and 0.069 from reported V_*/V values.

Measured Drag Forces

Drag forces were measured in both the large and small flumes. More than 100 experiments were conducted in the small flume using 10 different plant types, and more than 20 experiments were conducted in the large flume using four plant types. Measured approach velocities and drag forces are shown in Tables 7 and 8 for the small and large flumes, respectively. Data from four different dogwood plants are plotted in Figure 13 showing the repeatability of drag force measurements between the large and small flumes. This is important because it demonstrated that the experimental data from the small flume could be directly compared to the plants and resistance coefficients determined in the large flume. In Figure 13, note that the drag force increases linearly with velocity instead of with the square of velocity as one would expect from the drag force equation (15). This occurred in the experiment because the drag coefficient and blockage area were reduced as the plant was streamlined by the increasing velocities.

$$F_D = \frac{\rho C_D A_i V_p^2}{2} \tag{15}$$

In Equation 15, F_D is the drag force, ρ is the density of water, C_D is the drag coefficient, V_P is the approach velocity, and A_i is the blockage area of an individual plant.

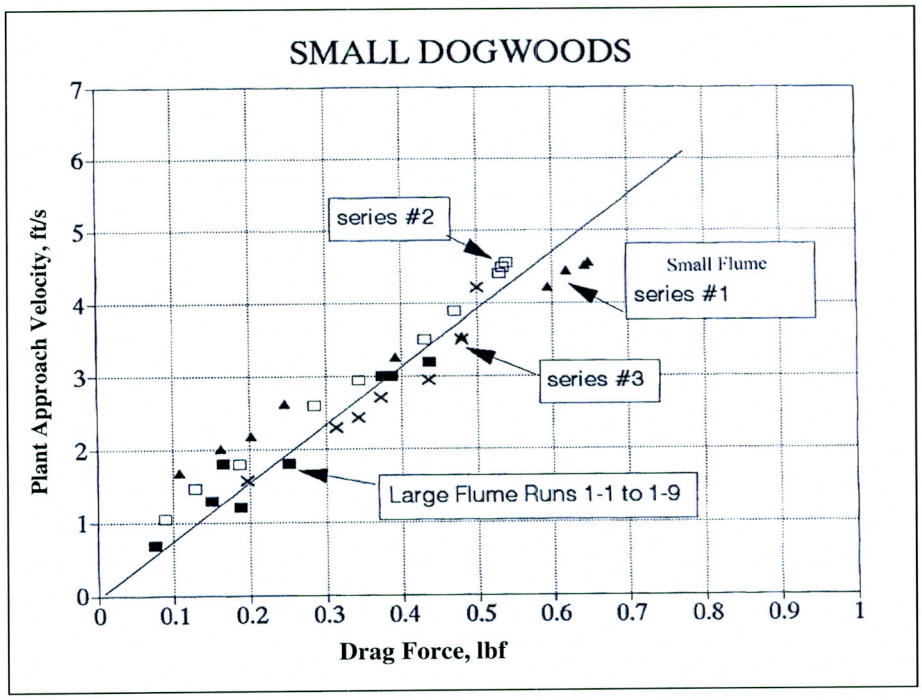

Figure 13. Plant approach velocity versus drag force (To convert feet to meters, multiply by 0.3048) [To convert pounds (force) to newtons, multiply by 4.448222]

The small flume had a large plastic window through which plant distortion could be viewed and measured. It was observed that the plants easily bent with the flow, and the leaf mass trailed downstream forming a streamlined, almost teardrop-shaped profile. The leaf mass changed with velocity and became more streamlined with increased velocity. This observation explains the significant decrease in resistance with increase in velocity. The changing shape of the leaf mass means that the roughness coefficient will change with velocity and that the assignment of a constant roughness coefficient to determine a stage-discharge curve would be invalid and produce significantly incorrect results.

If plant resistance were constant with increasing velocities, a plot of velocity versus drag force would appear as a smooth exponentially increasing curve. A typical curve from the data is shown in Figure 14. In this figure the drag varies almost linearly with velocity as the leaf mass continues to streamline. At a velocity of about 1.2 m/sec (4 ft/sec) the leaf mass has reached its streamlining limit and the curve begins to take on the expected exponential form. Above this limiting velocity it would be appropriate to assign a constant roughness coefficient.

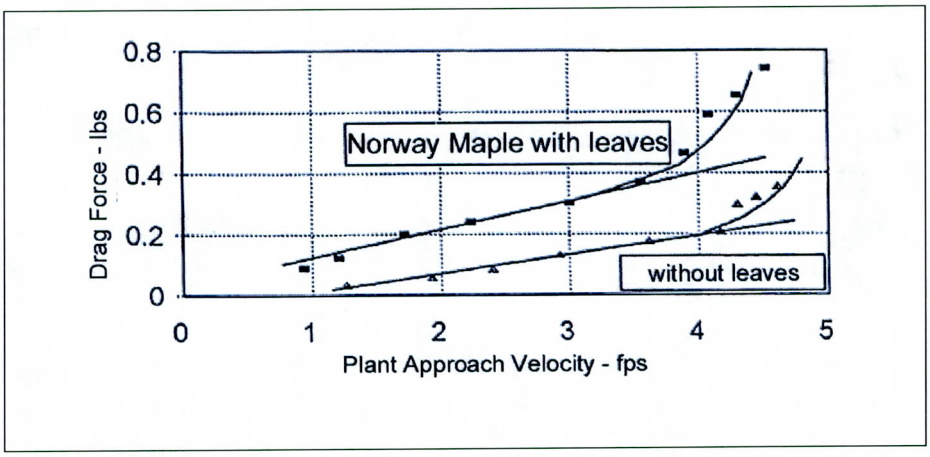

Figure 14. Drag force versus velocity (To convert feet to meters, multiply by 0.3048) [To convert pounds (force) to newtons, multiply by 4.448222]

Development of Resistance Methodology

The methodology developed in this report was based on the premise that the flow resistance due to vegetation on a floodplain is equal to the sum of the total drag forces produced by that vegetation. Kadlec (1990) presented such a hypothesis and, assuming that the drag forces on the bed are negligible, gave the following conceptual equation relating shear stress to drag force.

$$\tau_o = \sum \frac{F_D}{area} = F_D M \qquad (16)$$

where

area = total bed surface area of interest

τ_o = shear stress ($\tau_o = \gamma R_h S$)

M = plant density

The shear velocity V_* is related to shear stress, and a commonly used resistance coefficient that is associated with shear stress is V_*/V (Equation 2).

$$\frac{V_*}{V} = \frac{\sqrt{gR_hS}}{V} = \left(\frac{\tau_o}{\rho V^2}\right)^{1/2} \quad (2)$$

The shear velocity and shear stress can then be related to drag force by using Equation 17:

$$V_* = \sqrt{\frac{\tau_o}{\rho}} = \sqrt{\frac{F_D M}{\rho}} \quad (17)$$

Using Equations 15 through 17, an equation relating the drag coefficient, C_D, to the resistance can be developed.

$$\frac{V_*}{V} = \left(\frac{A_i \; M \; C_D}{2}\right)^{0.5} \quad (18)$$

The blockage area, A_i, of a plant with dense foliage is approximated by multiplying the effective plant height times the effective plant width ($H' \times W_e$). This effective area is the equivalent rectangular area of the leaf mass discounting small stems that are not part of the average leaf mass. For plants that have voids in their leaf mass or few leaves with a large number of stems, A_i is the rectangular area equivalent to the net frontal blockage. For example, plants without leaves would have a blockage area equal to the number of stems times the stem diameter times the stem length. Blockage areas for the laboratory experiments were determined from digital photographs of the plant against a white background marked with grid lines. H' is the actual height of the undistorted leaf mass and W_e is the effective width that produces the measured A_i.

It has been established that the drag coefficient for a rigid body is not a constant and varies with Reynolds number, R_e. The Reynolds number used in this study is based on the length variable of hydraulic radius, R_h, and the mean channel velocity. For flexible plants, the drag coefficient is a function of a number of factors as shown in Equation 19.

$$C_D = f\left(R_e, \; Y_o, H, \textit{plant type, plant shape, plant flexibility}, M\right) \quad (19)$$

The experimental data from both the large and small flumes were used to determine appropriate dimensionless parameters to define the drag force. These experiments were conducted for a large matrix of variables including Y_o, V, plant type, leaf density, plant density, plant shape, plant size, and blockage area. The runs were made in a sequence so that each variable could be evaluated by keeping the other variables constant. It was found that the drag coefficient decreased with an increase in velocity, depth, plant density, plant flexibility, and plant spacing. Drag coefficient or resistance could not be related solely to flow conditions, leaf density, or plant blockage because of the flexibility of the plants. For example, different plants with the same size leaves and blockage had significantly different resistance depending upon how much the plants deformed and bent with flow.

Dimensional analysis was used to aid in the selection of dimensionless parameters that could relate drag or resistance to flow and plant variables. The four parameters that were found to have a significant effect were as follows:

a. Ratio of the flow drag force to the forces resisting plant distortion.

b. Ratio of the flow depth to the plant height.

c. Blockage of the plants to the flow on the channel bottom.

d. Reynolds number.

The last three parameters are corrections or modifiers to the ratio parameter of drag force to the force resisting plant deformation. This ratio parameter also incorporates plant stiffness or flexibility. These parameters are shown in Equation 20.

$$C_D \text{ or } \frac{V_*}{V} = f\left(\frac{\rho V^2 A_i}{E_s A_s}, \frac{Y_o}{H}, M A_i, R_e\right) \tag{20}$$

When there are several stems emerging from the base of the plant, the stiffness modulus, E_s, is determined for a single stem. The stem area, A_s, is the sum of all the stem areas. The stem area for a plant with multiple stems is thus calculated as the number of stems times π times the stem diameter squared divided by 4.

Resistance Equation for Submerged Vegetation

The results from the large flume experiments were analyzed to determine the regression of the variables of Equation 20 for submerged vegetation. The regression analysis found that log and polynomial relationships gave a poor data fit while a power relationship had very good results. Equations 21 and 22 were found to fit the data with a regression coefficient of $R^2 = 96$ percent and a maximum scatter of 15 percent for predicted values of V_*/V with measured values. The parameters in the equations were modified to allow a direct solution

for resistance (for a given depth) by combining the original parameters with Manning's equation and the equation for shear velocity. This modification and combination of equations resulted in Equations 21 for shear velocity and Equation 22 for Manning's n.

$$\frac{V_*}{V}=\frac{\sqrt{g}}{C}=0.183\left(\frac{E_s A_s}{\rho A_i V_*^2}\right)^{0.183}\left(\frac{H}{Y_O}\right)^{0.243}(M\ A_i)^{0.273}\left(\frac{\nu}{V_* R_h}\right)^{0.115} \quad (21)$$

$$n=K_n\ 0.183\left(\frac{E_s\ A_s}{\rho\ A_i\ V_*^2}\right)^{0.183}\left(\frac{H}{Y_O}\right)^{0.243}(M\ A_i)^{0.273}\left(\frac{\nu}{V_* R_h}\right)^{0.115}\left(\frac{1}{V^*}\right)(R_h)^{2/3}(S)^{1/2} \quad (22)$$

It is important to note that the plant characteristics H, A_i, and A_S are the initial characteristics of the plants without the effects of flow distortion. During the experiments, it was observed that since the plants bent with flow, submergence occurred when flow depths reached 80 percent of the plant height. Equations 21 and 22 are to be applied only for submerged flow defined by Y_o >0.8 H. Equations 23 and 24 are for partially submerged flow with Y_o <0.8 H. Both sets of equations converged to approximately the same result at the flow depth Y_o =0.8 H.

Resistance Equation for Partially Submerged Vegetation

The data for partially submerged vegetation were analyzed to determine the regression of the variables of Equation 20. The regression analysis again found that a log relationship gave a poor fit of data while a power relationship produced very good results. Equations 23 and 24 were found to fit the data with a regression coefficient of R^2= 85 percent and a maximum scatter of 18 percent for predicted values of V*/V compared to measured values. These equations again allow direct solution for resistance if the flow depth is known.

$$\frac{V_*}{V}=\frac{\sqrt{g}}{C}=3.487E-05\left(\frac{E_s A_s}{\rho A_i^* V_*^2}\right)^{0.150}\left(MA_i^*\right)^{0.166}\left(\frac{V_* R_h}{\upsilon}\right)^{0.622} \quad (23)$$

$$\mathrm{n}=K_n\ 3.487E-05\left(\frac{E_s\ A_s}{\rho\ A_i^*\ V_*^2}\right)^{0.150}\left(M\ A_i^*\right)^{0.166}\left(\frac{V_* R_h}{\nu}\right)^{0.622}\left(\frac{R_h^{2/3}\ S^{1/2}}{V_*}\right) \quad (24)$$

The blockage area in Equations 23 and 24 was changed to an effective area, A_{i*}, since only a portion of the leaf mass produces blockage under partially submerged flow conditions. The effective blockage area can be approximated using Equation 25 if the actual geometry of the plant and leaf mass has not been measured (see Figure 2).

$$A_i^* = [Y_o - (H - H')] W_e \quad (25)$$

The analysis of data and the regression fit of Equations 21 through 24 included many other parameters and ratios. The equations, parameters, and methods developed by other researchers for a combined density and blockage of heavy ground cover and grasses did not produce satisfactory results. These methods included those developed by Kowen and Li (1980), Ree and Crow (1977), and other methods. It should be noted that some of the methods evaluated were not developed with shrubs in mind. In the case of Ree and Crow, agricultural crops were the focus of the methodology. Many of the equations developed by other researchers were evaluated, but none proved to be satisfactory in the prediction of roughness values for shrubs. The results of this study emphasize that the plant stiffness modulus, E_s, must be considered to obtain a satisfactory prediction of roughness. The definition and method to determine E_s are discussed in a following section.

Equations 21 through 24 also include plants with multiple stems. The blockage area A_i is for an individual or average plant, the plant density is the number of plants (not stems) per unit area, and A_s is the sum of the cross-sectional area of all of the stems of an individual average plant. Figure 15 shows the correlation of calculated V_*/V with the observed data from the flumes for submerged, partially submerged, multiple plant species.

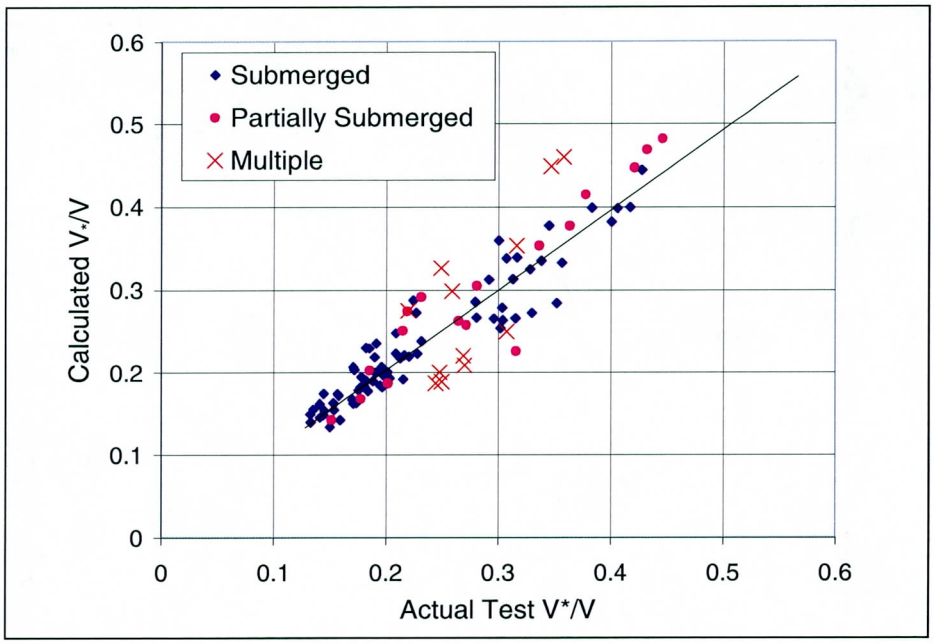

Figure 15. Comparison of calculated versus actual resistance V_*/V

Multiple Plant Combinations

Six combinations of plant types were evaluated. The combinations of species were selected to represent typical plant groups found in different ecosystems. Equations 21 through 24 worked equally well for plant combinations when average plant characteristics were used. The average plant characteristics were obtained by weighting individual plant characteristics by the number of plants per unit area or densities of each type of plant. The comparisons of calculated and observed data for multiple plant groupings are shown in Figure 15.

The purpose of the weighted averages is to formulate the average shear stress created by the plant combinations. Each plant group then will have an average blockage area or effective blockage area, an average modulus of plant stiffness, an average total plant stem area, an average plant height, and an average effective plant height. A weighted average for the plant groups is then based on the ratio of the plant density of each plant type divided by the total plant density of all the plants and plant types. Equations 21 through 24 do not use an average plant density, but use the total or combined density of all of the plants. The method for combining these densities is shown in the example that follows.

The plant characteristics are determined by weighting the individual plant characteristics according to their relative density in the area of interest. The weighted values are then summed to obtain the combined plant characteristic as shown in Equations 26-32.

$$A_{ave} = \sum_{i=1}^{N}\left(A_i \frac{M_i}{M_{total}}\right) \tag{26}$$

$$E_{s\,ave} = \sum_{i=1}^{N}\left(E_{s\,i} \frac{M_i}{M_{total}}\right) \tag{27}$$

$$A_{s\,ave} = \sum_{i=1}^{N}\left(A_{s\,i} \frac{M_i}{M_{total}}\right) \tag{28}$$

$$H_{ave} = \sum_{i=1}^{N}\left(H_i \frac{M_i}{M_{total}}\right) \tag{29}$$

$$H'_{ave} = \sum_{i=1}^{N}\left(H'_i \frac{M_i}{M_{total}}\right) \tag{30}$$

$$A^*_{i\,ave} = \sum_{i=1}^{N}\left(A^*_{i\,i} \frac{M_i}{M_{total}}\right) \tag{31}$$

$$M_{total} = \sum_{i=1}^{N} M_i \quad (32)$$

Using Equation 29, the average plant height for an area with a group of three plants with heights, H, of 0.5, 1.0, and 2.0 ft; and densities, M, of 0.25, 0.50, and 0.20 plants / ft^2; would be determined as follows:

$$Havg = H_1 \times M_1 / M_{total} + H_2 \times M_2 / M_{total} + H_3 \times M_3 / M_{total}$$

$$Havg = 0.5 \times 0.25 / (0.25+0.5+0.2) + 1.0 \times 0.5 / 0.95 + 2.0 \times 0.2 / 0.95$$

$$Havg = 0.132 + 0.526 + 0.421 = 1.079 \text{ ft}$$

Stiffness Modulus

The modulus of plant stiffness, E_s, is critical to the calculation of resistance because of the flexibility of the plants and the deformation of leaf masses due to the flow forces. The modulus of plant stiffness is calculated by Equation 33.

$$E_S = \frac{F_{45} H^2}{3 I} = 6.791 \left(\frac{F_{45} H^2}{D_S^4} \right) \quad (33)$$

The data necessary to use Equation 33 is obtained by measuring the force, F_{45}, necessary to bend the plant to an angle of 45 deg. The 45-deg angle is measured from the initial vertical position to the stem or leaf mass at the point where the force is measured, i.e., at H/2 as shown in Figure 16.

I is the second area moment of inertia calculated for a circular shape ($I = \pi D_s^4/64$). The stem diameter D_s is measured at a height of H/4 above the ground.

Data were collected both in the laboratory and in the field to determine a relationship that defined plant stiffness. Freeman (1997) collected data for five types of willows in floodplains and on sand bars to determine if stiffness in the field could be predicted from plant size parameters such as stem diameter and plant height to reduce the number of parameters that must be collected to determine the plant stiffness modulus. Data collected included samples from *Salix exigua* willows in Utah and Idaho, *Salix lasiandra, Salix lamonii*, a wild rose bush common to the area, and young cottonwood trees growing on sandbars. He also noted in his data collection efforts that plant stiffness was measurably different in the upstream and downstream directions in streams subject to long periods of high water (i.e., snow melt). Where the plants were not subject to velocities high enough to keep the plant bent and /or deformed for prolonged periods of time this difference in the stiffness modulus did not seem to exist or was not noticeable.

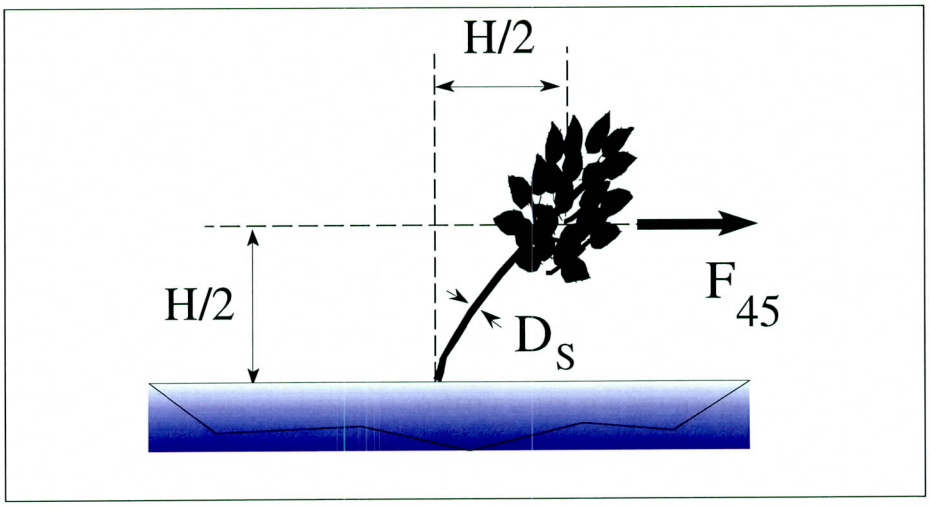

Figure 16. Methodology for measurement of plant stiffness for calculation of E_s in the field for plants with effective height of leaf mass approximately equal to the plant height

The research performed in the laboratory and in the field indicated that the stiffness modulus can be estimated from the relationship of E_s to the ratio of H/D_s. The analysis of measurements made in the field and in the laboratory led to the development of Equations 34 and 35 to explain the relationship between H/D_s and E_s. The relationship between the data observed in Freeman's field measurements (Freeman 1997, Freeman, et al. 1998) and the values predicted by Equation 34 is shown in Figure 17. Equation 34 (shown in Figure 17 as "Rahmeyer Predicted") was developed based on laboratory observations and gives the modulus in pounds per square foot while Equation 35 gives the value in newtons per square meter. It must be cautioned that the fit of Equations 34 and 35 have a regression (R^2) of less than 90 percent, and the scatter is significant as shown in Figure 17.

$$E_s\left(lbf/ft^2\right) = 1.597E05\left(\frac{H}{D_S}\right) + 454\left(\frac{H}{D_S}\right)^2 37.8\left(\frac{H}{D_S}\right)^3 \quad (34)$$

$$E_s\left(N/m^2\right) = 7.648E06\left(\frac{H}{D_S}\right) + 2.174E04\left(\frac{H}{D_s}\right) + 1.809E03\left(\frac{H}{D_S}\right) \quad (35)$$

Actual field measurements of E_s are recommended where possible. The stiffness modulus can also be estimated from measured values of similar plants. Since the stiffness modulus varies depending on the plant size, it was determined that if the calculated modulus for a particular plant size was divided by $(H/D_s)^{1.5}$, the stiffness modulus became independent of plant size and one value could be used for all plant sizes. Thus, to calculate the plant stiffness modulus for Alder, the value from Table 9 is multiplied by $(H/D_s)^{1.5}$ which gives the stiffness modulus

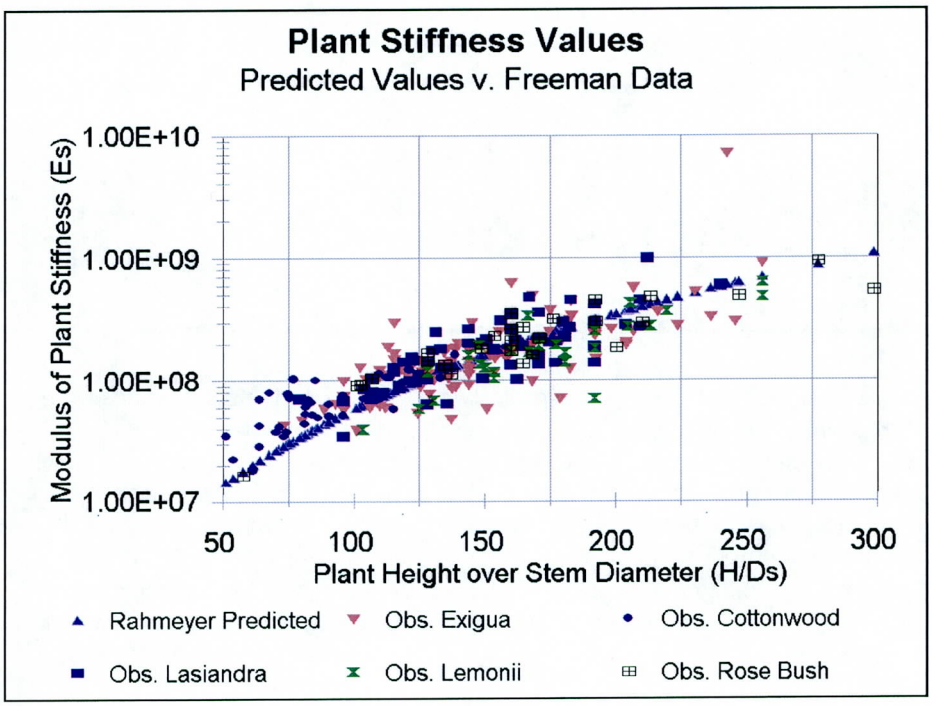

Figure 17. Measured versus calculated plant stiffness modulus, E_s

for a particular size plant in pounds per square foot. The exponent for the term H/D_s was determined to remove most effects of plant size from the Plant Stiffness Modulus.

4 Conclusions

A total of 20 different plant species were evaluated in either a large 2.44-m- (8-ft-) wide flume or a small 0.46-m- (1.5-ft-) wide flume to determine flow resistance and drag force. More than 220 experiments were conducted. Fifteen homogeneous plant groupings were evaluated in the large flume. Six multiple plant groupings were evaluated in the large flume. Vegetation was evaluated under both submerged and partially submerged conditions. Velocity, depths, plant density, plant dimensions, and plant types were varied in the experiments. The range of experimental conditions used to develop the regression equations were as follows:

a. Flow depths from 0.4 to 1.4 m (1.3 to 4.7 ft).

b. Average flow velocities from 0.15 to 1.1 m/s (0.5 to 3.6 ft/s).

c. Measured resistance V_*/V from 0.13 to 0.43 and n from 0.04 to 0.14.

d. Plant heights from 0.20 to 1.52 m (0.66 to 5 ft).

e. Plant widths from 0.076 to 0.91 m (0.25 to 3 ft).

f. Plant densities from 0.53 to 13 plants / m^2 (0.05 to 1.2 plants / ft^2).

g. Plant modulus of stiffness from 5.3×10^7 to 4.8×10^9 N/m^2 (1.1×10^6 to 1.0×10^8 lbf/ ft^2).

h. Reynolds numbers from 1.4×10^5 to 1.6×10^6.

An important observation made during the flume studies was that the plant leaf mass trailed downstream forming a streamlined, almost teardrop-shaped profile. The leaf mass shape changed with velocity and became more streamlined with increasing velocity. The effect of this phenomenon was a significant decrease in the drag coefficient and resistance coefficient with velocity. On the other hand, resistance increased with depth for partially submerged plants as the blockage area increased with depth until the plants were submerged. The transition between submerged and partially submerged flow occurred at a depth of about 80 percent of the undeflected plant height.

Another observation made during the study was that the leaf mass or foliage canopy diverted flow beneath the canopy. The bottom flow resulted in significant velocities along the channel bed causing general scour and increased sediment transport. The bed velocities were sufficient to transport and move the largest sizes of gravel found in the flume bed.

The hydraulic roughness of a vegetated channel was shown to be a function of the stiffness of the plants growing in the channel, the depth, velocity, and hydraulic radius of the channel, plant density, and frontal area of the plant obstructing the flow. It was determined that the roughness can be calculated directly if the depth of flow is known. The roughness can be determined in terms of Manning's n, Chezy C, or the shear velocity ratio, V_*/V.

Regression equations were developed for submerged vegetation and found to fit the data with a regression coefficient of $R^2 = 96$ percent and a maximum scatter of 15 percent for predicted values of V_*/V with measured values. The parameters in the equations were modified to allow a direct solution for resistance (for a given depth) by combining the original parameters with Manning's equation and the equation for shear velocity. This modification and combination of equations resulted in Equations 21 for shear velocity and Equation 22 for Manning's n.

$$\frac{V_*}{V} = \frac{\sqrt{g}}{C} = 0.183 \left(\frac{E_s A_s}{\rho A_i V_*^2} \right)^{0.183} \left(\frac{H}{Y_O} \right)^{0.243} (M\ A_i)^{0.273} \left(\frac{\nu}{V_* R_h} \right)^{0.115} \tag{21}$$

$$n = K_n\ 0.183 \left(\frac{E_s\ A_s}{\rho\ A_i\ V_*^2} \right)^{0.183} \left(\frac{H}{Y_O} \right)^{0.243} (M\ A_i)^{0.273} \left(\frac{\nu}{V_* R_h} \right)^{0.115} \left(\frac{1}{V^*} \right) (R_h)^{2/3} (S)^{1/2} \tag{22}$$

It is important to note that the plant characteristics H, A_i, and A_S are the initial characteristics of the plants without the effects of flow distortion. Equations 21 and 22 are to be applied only for submerged flow defined by $Y_o > 0.8$ H.

The experimental data for partially submerged vegetation were analyzed to develop regression Equations 23 and 24. These equations were found to fit the data with a regression coefficient of $R^2 = 85$ percent and a maximum scatter of 18 percent for predicted values of V_*/V compared to measured values. These equations again allow direct solution for resistance if the flow depth is known.

$$\frac{V_*}{V} = \frac{\sqrt{g}}{C} = 3.487E-05 \left(\frac{E_s\ A_s}{\rho\ A_i^*\ V_*^2} \right)^{0.150} \left(M\ A_i^* \right)^{0.166} \left(\frac{V_*\ R_h}{\nu} \right)^{0.622} \tag{23}$$

$$n = K_n\ 3.487E-05 \left(\frac{E_s\ A_s}{\rho\ A_i^*\ V_*^2} \right)^{0.150} \left(M\ A_i^* \right)^{0.166} \left(\frac{V_* R_h}{\nu} \right)^{0.622} \left(\frac{R_h^{2/3}\ S^{1/2}}{V_*} \right) \tag{24}$$

The blockage area in Equations 23 and 24 was changed to an effective area, A_{i*}, since only a portion of the leaf mass produces blockage under partially submerged flow conditions. The effective blockage area can be approximated using Equation 25 if the actual geometry of the plant and leaf mass has not been measured.

$$A_i^* = \left[Y_o - (H - H')\right] W_e \tag{25}$$

The resistance coefficients predicted by Equations 21 through 24 represent the combined resistance of the bed and the plants. Resistance coefficients due only to vegetation must be calculated by subtracting the bed resistance. In these experiments the Manning's bed resistance coefficient was found to be 0.02 and V_*/V for the bed was found to be 0.069.

The modulus of plant stiffness, E_s, is critical to the calculation of resistance because of the flexibility of the plants and the deformation of leaf masses due to the flow forces. The research performed in the laboratory and in the field indicated that the stiffness modulus can be estimated from the relationship of E_S to the ratio of H/D_s. The analysis of measurements made in the field and in the laboratory led to the development of equations to explain the relationship between H/D_s and E_s. The equations had a regression (R^2) of less than 90 percent. Actual field measurements of E_s are recommended where possible.

The stiffness modulus can also be estimated from measured values of similar plants. Since the stiffness modulus varies depending on the plant size, it was determined that if the calculated modulus for a particular plant size was divided by $(H/D_s)^{1.5}$, the stiffness modulus became independent of plant size and one value could be used for all plant sizes. Stiffness modulus' of plants used in this study are provided in Table 9.

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Table 1
Dimensions and Characteristics of Plants (SI Units)

Common Name	Scientific Name	Plant Height *H*, m	Plant Width *We*, m	Effective Height, *H'*, m	Blockage Area *A* m^2	Stem Diameter *Ds*, M	Stem Number	Elasticity *Es*, $N/m^2 x10^8$
Large Flume								
Yellow Twig Dogwood	*Cornus Stolonifera Flaviramea*	0.51	0.229	0.33	0.076	0.0095	1	3.210
Berried Elderberry	*Sambucus Racemosa*	0.71	0.356	0.51	0.181	0.0095	1	0.526
Purpleleaf Euonymus	*Euonymus Fortunei Colorata*	0.20	0.254	0.20	0.052	0.0063	2	4.140
Red Twig Dogwood	*Cornus Sericea*	0.97	0.482	0.76	0.368	0.0252	2	10.200
Service Berry	*Amelanchier*	0.71	0.178	0.51	0.090	0.0063	6	47.600
Yellow Twig Dogwood	*Cornus Stolonifera Flaviramea*	0.71	0.254	0.61	0.155	0.0095	2	29.900
Mulefat	*Baccharis Glutinosa*	0.97	0.076	0.51	0.039	0.0126	1	5.950
Alder	*Alnus Incana*	0.76	0.152	0.70	0.107	0.0079	1	17.000
Valley Elderberry	*Sambucus Mexicana*	0.97	0.762	0.91	0.697	0.0268	1	16.500
Salt Cedar	*Tamarix spp.*	1.52	0.61	1.37	0.836	0.0316	1	13.100
Black Willow	*Salix Nigra*	1.22	0.305	1.22	0.372	0.0189	1	1.500
Red Willow	*Salix spp.*	0.61	0.152	0.61	0.093	0.0095	1	4.500
Mountain Willow	*Salix Monticola*	1.52	0.914	1.22	1.115	0.0254	4	3.410
Small Flume								
Yellow Twig Dogwood	*Cornus Stolonifera Flaviramea*	0.51	0.229	0.33	0.076		0.0095	3.210
Purpleleaf Eunonyus	*Euonymus Fortunei Colorata*	0.20	0.254	0.20	0.052	0.0063	2	4.140
Artic Blue Williow	*Salix Purpurea Nana*	0.56	0.305	0.51	0.155	0.0126	1	1.190
Norway Maple	*Acer Platenoides*	0.71	0.305	0.30	0.093	0.0126	1	19.100
Common Privet	*Ligustrum Vulgare*	0.81	0.254	0.69	0.174	0.0126	1	3.940
Blue Elderberry	*Sambucus Canadensis*	0.53	0.457	0.41	0.186	0.0252	1	0.263
French Pink Pussywillow	*Salix Caprea Pendula*	0.91	0.254	0.25	0.065	0.0190	1	1.110
Sycamore	*Platenus Acer Ifolia*	0.91	0.203	0.84	0.170	0.0101	1	27.500
Western Sand Cherry	*Prunis Besseyi*	0.74	0.152	0.51	0.077	0.0084	1	28.800
Staghorn Sumac	*Rhus Typhina*	0.76	0.254	0.31	0.077	0.0126	1	5.080
Sand Bar Willow	*Salix exigua*	2.18		1.8	0.65	0.015	1	86.2
Pacific Willow	*Salix lasiandra*	2.39		2.0	1.98	0.017	1	99.0
Lemon's Willow	*Salix Lemonii*	2.13		1.7	0.38	0.013	1	86.0
Wild Rose Bush	*Rosa spp.*	1.18		.108	1.05	0.007	1	130.0

Table 2
Dimensions and Characteristics of Plants (Non-SI Units)

Common Name	Scientific Name	Plant Height *H*, ft	Plant Width *We*, ft	Effective Height, *H'*, ft	Blockage Area *A* Ft^2	Stem Diameter *Ds*, ft	Stem Number	Elasticity *Es*, lbf/ft^2
Large Flume								
Yellow Twig Dogwood	Cornus Stolonifera Flaviramea	1.67	0.750	1.08	0.818	0.0313	1	6.706
Berried Elderberry	Sambucus Racemosa	2.33	1.167	1.67	1.948	0.0313	1	1.099
Purpleleaf Euonymus	Euonymus Fortunei Colorata	0.67	0.833	0.67	0.560	0.0208	2	8.648
Red Twig Dogwood	Cornus Sericea	3.18	1.583	2.50	3.958	0.0833	2	21.308
Service Berry	Amelanchier	2.33	0.583	1.67	0.969	0.0208	6	99.436
Yellow Twig Dogwood	Cornus Stolonifera Flaviramea	2.33	0.833	2.00	1.666	0.0313	2	62.461
Mulefat	Baccharis Glutinosa	3.18	0.250	1.67	0.420	0.0420	1	12.430
Alder	Alnus Incana	2.50	0.500	2.33	1.150	0.0260	1	35.513
Valley Elderberry	Sambucus Mexicana	3.18	2.500	3.00	7.503	0.0879	1	34.469
Salt Cedar	Tamarix spp.	5.00	2.000	4.50	9.001	0.1040	1	27.366
Black Willow	Salix Nigra	4.00	1.000	4.00	4.005	0.0630	1	3.134
Red Willow	Salix spp.	2.00	0.500	2.00	1.001	0.0310	1	9.401
Mountain Willow	Salix Monticola	5.00	3.000	4.00	12.003	0.0840	4	7.123
Small Flume								
Yellow Twig Dogwood	Cornus Stolonifera Flaviramea	1.67	0.750	1.08	0.818	0.0313	1	6.706
Purpleleaf Eunonyus	Euonymus Fortunei Colorata	0.67	0.833	0.67	0.560	0.0208	2	8.648
Artic Blue Williow	Salix Purpurea Nana	1.84	1.000	1.67	1.669	0.0417	1	2.486
Norway Maple	Acer Platenoides	2.33	1.000	1.00	1.001	0.0417	1	39.900
Common Privet	Ligustrum Vulgare	2.67	0.833	2.25	1.873	0.0417	1	8.231
Blue Elderberry	Sambucus Canadensis	1.75	1.500	1.33	1.997	0.0833	1	0.549
French Pink Pussywillow	Salix Caprea Pendula	3.00	0.833	0.83	0.700	0.0625	1	2.319
Sycamore	Platenus Acer Ifolia	3.00	0.667	2.75	1.831	0.0333	1	57.448
Western Sand Cherry	Prunis Besseyi	2.43	0.500	1.67	0.829	0.0278	1	60.163
Staghorn Sumac	Rhus Typhina	2.50	0.833	1.00	0.829	0.0417	1	10.612
Sand Bar Willow	Salix exigua	7.15		5.91	7.09	0.0492	1	180
Pacific Willow	Salix lasiandra	7.84		6.56	21.31	0.0558	1	207
Lemon's Willow	Salix lemonii	7.0		5.58	4.09	0.0427	1	180
Wild Rose Bush	Rosa spp.	3.87		0.354	11.30	0.0230	1	272

Table 3
Summary of Large Flume Results with Homogeneous Groupings (SI Units)

Run	Plant	Plant Height *H*, m	Plant Density *M*, 1/m^2	Water Depth Y_o, M	Mean Velocity *V*, m/sec	Energy Slope *S*	Average *n*	Bed Hydraulic Radius *m*	Bed *V*/V*	Bed Manning's n
II 0-1	none			0.718	0.388	0.00013		0.562	0.069	0.0200
II 0-2	none			1.321	0.209	0.00002	0.016	0.884	0.064	0.0200
II 0-3	none			1.459	0.591	0.00015	0.016	1.011	0.069	0.0220
I 1-1	Yellow Twig Dogwood	0.51	5.360	1.271	0.366	0.00053	0.046	1.202	0.216	0.0710
I 1-2	Yellow Twig Dogwood	0.51	5.360	1.256	0.610	0.00124	0.042	1.184	0.198	0.0650
I 1-3	Yellow Twig Dogwood	0.51	5.360	1.122	0.750	0.00184	0.040	1.059	0.185	0.0590
I 1-4	Yellow Twig Dogwood	0.51	5.360	0.942	0.482	0.00119	0.047	0.902	0.213	0.0670
I 1-5	Yellow Twig Dogwood	0.51	5.360	1.021	0.588	0.00140	0.043	0.971	0.196	0.0620
I 1-6	Yellow Twig Dogwood	0.51	5.360	1.049	0.689	0.00163	0.040	0.991	0.183	0.0580
I 1-7	Yellow Twig Dogwood	0.51	5.360	0.536	0.878	0.00582	0.048	0.521	0.197	0.0560
I 1-8	Yellow Twig Dogwood	0.51	5.360	0.716	0.991	0.00477	0.041	0.688	0.181	0.0540
I 1-9	Yellow Twig Dogwood	0.51	5.360	0.887	1.091	0.00418	0.038	0.843	0.170	0.0530
I 2-1	Yellow Twig Dogwood	0.51	2.379	1.356	0.765	0.00102	0.031	1.232	0.145	0.0480
I 2-2	Yellow Twig Dogwood	0.51	2.379	1.149	0.924	0.00165	0.031	1.056	0.142	0.0460
I 2-3	Yellow Twig Dogwood	0.51	2.379	0.515	1.058	0.00693	0.040	0.499	0.174	0.0500
I 2-4	Yellow Twig Dogwood	0.51	2.379	0.396	0.750	0.00496	0.042	0.421	0.191	0.0530
I 3-1	Berried Elderberry	0.71	2.691	1.207	0.294	0.00030	0.042	1.134	0.195	0.0640
I 3-2	Berried Elderberry	0.71	2.691	0.983	0.479	0.00063	0.035	0.918	0.157	0.0500
I 3-3	Berried Elderberry	0.71	2.691	1.064	0.589	0.00085	0.034	0.989	0.154	0.0490
I 3-4	Berried Elderberry	0.71	2.691	0.953	0.304	0.00043	0.045	0.908	0.204	0.0640
I 3-5	Berried Elderberry	0.71	2.691	0.706	0.518	0.00125	0.040	0.676	0.176	0.0530
I 3-6	Berried Elderberry	0.71	2.691	0.782	0.614	0.00110	0.033	0.735	0.145	0.0440
I 3-7	Berried Elderberry	0.71	2.691	0.849	0.692	0.00123	0.032	0.793	0.141	0.0430
I 3-8	Berried Elderberry	0.71	2.691	0.816	0.769	0.00167	0.033	0.767	0.146	0.0450
I 3-9	Berried Elderberry	0.71	2.691	0.748	0.862	0.00199	0.031	0.702	0.136	0.0410
I 3-10	Berried Elderberry	0.71	2.691	0.915	0.945	0.00191	0.030	0.849	0.133	0.0410
I 4-1	Purpleleaf Euonymus	0.20	12.809	1.182	0.319	0.00041	0.045	1.120	0.209	0.0680
I 4-2	Purpleleaf Euonymus	0.20	12.809	1.195	0.420	0.00055	0.040	1.122	0.186	0.0600
I 4-3	Purpleleaf Euonymus	0.20	12.809	1.120	0.669	0.00159	0.042	1.063	0.195	0.0630

Table 3 (Continued)

Run	Plant	Plant Height *H*, m	Plant Density *M*, 1/m^2	Water Depth Y_o, M	Mean Velocity *V*, m/sec	Energy Slope *S*	Average *n*	Bed Hydraulic Radius *m*	Bed *V*/V*	Bed Manning's n
I 4-4	Purpleleaf Euonymus	0.20	12.809	0.842	0.662	0.00225	0.045	0.810	0.202	0.0620
I 4-5	Purpleleaf Euonymus	0.20	12.809	0.887	0.766	0.00251	0.042	0.849	0.189	0.0590
I 4-6	Purpleleaf Euonymus	0.20	12.809	0.781	0.974	0.00408	0.041	0.751	0.178	0.0560
I 4-7	Purpleleaf Euonymus	0.20	12.809	0.491	0.817	0.00477	0.042	0.477	0.183	0.0520
I 5-1	Purpleleaf Euonymus	0.20	5.694	1.032	0.411	0.00053	0.038	0.968	0.172	0.0550
I 5-2	Purpleleaf Euonymus	0.20	5.694	1.034	0.632	0.00106	0.035	0.967	0.159	0.0500
I 5-3	Purpleleaf Euonymus	0.20	5.694	0.707	0.963	0.00436	0.040	0.680	0.177	0.0530
I 6-1	Red Twig Dogwood	0.97	1.216	1.263	0.323	0.00110	0.075	1.233	0.357	0.1190
I 6-2	Red Twig Dogwood	0.97	1.216	1.264	0.479	0.00213	0.070	1.233	0.336	0.1110
I 6-3	Red Twig Dogwood	0.97	1.216	1.296	0.611	0.00266	0.062	1.259	0.297	0.0990
I 6-4	Red Twig Dogwood	0.97	1.216	0.940	0.347	0.00204	0.085	0.925	0.390	0.1230
I 6-5	Red Twig Dogwood	0.97	1.216	0.757	0.609	0.00508	0.070	0.744	0.313	0.0950
I 6-6	Red Twig Dogwood	0.97	1.216	0.829	0.953	0.00582		0.804	0.225	0.0693
I 6-7	Red Twig Dogwood	0.97	1.216	0.537	0.683	0.00833	0.070	0.530	0.308	0.0890
I 6-8	Red Twig Dogwood	0.97	1.216	0.934	0.962	0.00540	0.050	0.905	0.227	0.0720
I 7-1	Red Twig Dogwood	0.97	0.527	1.184	0.348	0.00117	0.070	1.155	0.330	0.1080
I 7-2	Red Twig Dogwood	0.97	0.527	0.818	0.504	0.00322	0.070	0.803	0.316	0.0973
II 1-1	Service Berry	0.71	0.538	0.690	0.350	0.00145	0.063	0.676	0.280	0.0840
II 1-2	Service Berry	0.71	0.538	0.967	0.562	0.00180	0.050	0.933	0.228	0.0720
II 1-3	Service Berry	0.71	0.538	0.803	0.685	0.00229	0.043	0.771	0.192	0.0590
II 1-4	Service Berry	0.71	0.538	0.933	0.903	0.00276	0.038	0.886	0.171	0.0540
II 1-5	Service Berry	0.71	0.538	1.154	0.513	0.00132	0.050	1.108	0.234	0.0760
II 1-6	Service Berry	0.71	0.538	1.275	0.688	0.00157	0.042	1.206	0.198	0.0650
II 4-1	Yellow Twig Dogwood		1.830	1.358	0.145	0.00019	0.071	1.316	0.344	0.1150
II 4-2	Yellow Twig Dogwood		1.830	1.389	0.343	0.00059	0.053	1.330	0.254	0.0850
II 4-3	Yellow Twig Dogwood		1.830	1.261	0.608	0.00112	0.040	1.186	0.189	0.0620
II 4-4	Yellow Twig Dogwood		1.830	1.081	0.967	0.00201	0.032	1.003	0.144	0.0460
II 6-1	Mulefat	0.97	0.646	1.423	0.408	0.00040	0.037	1.314	0.177	0.0590
II 6-2	Mulefat	0.97	0.646	1.265	0.643	0.00095	0.035	1.173	0.162	0.0530
II 6-3	Mulefat	0.97	0.646	1.364	0.724	0.00103	0.033	1.252	0.154	0.0510

Table 3 (Concluded)

Run	Plant	Plant Height H, m	Plant Density M, 1/m^2	Water Depth Y_o, M	Mean Velocity V, m/sec	Energy Slope S	Average n	Bed Hydraulic Radius m	Bed V^*/V	Bed Manning's n
II 6-4	Mulefat	0.97	0.646	1.072	0.791	0.00119	0.030	0.984	0.135	0.0430
II 9-1	Vally Elberberry	0.97	1.722	1.366	0.282	0.00099	0.083	1.337	0.418	0.1350
II 9-2	Vally Elberberry	0.97	1.722	1.330	0.427	0.00163	0.070	1.296	0.339	0.1130
II 9-3	Vally Elberberry	0.97	1.722	1.071	0.522	0.00267	0.068	1.047	0.317	0.1020
II 9-4	Vally Elberberry	0.97	1.722	0.914	0.621	0.00475	0.072	0.897	0.329	0.1030
II 10-1	Salt Cedar	1.52	0.624	1.430	0.416	0.00156	0.072	1.394	0.352	0.1190
II 10-2	Salt Cedar	1.52	0.624	1.378	0.580	0.00238	0.063	1.338	0.305	0.1020
II 10-3	Salt Cedar	1.52	0.624	1.116	0.716	0.00380	0.060	1.085	0.281	0.0910
II 10-4	Salt Cedar	1.52	0.624	0.933	0.685	0.00369	0.058	0.909	0.264	0.0830
II 10-5	Salt Cedar	1.52	0.624	0.844	0.750	0.00513	0.060	0.824	0.272	0.0840
II 10-6	Salt Cedar	1.52	0.624	0.827	0.935	0.00517	0.048	0.801	0.215	0.0660
II	Black Willow	1.22	2.293	1.416	0.313	0.00084		1.090	0.303	0.0980
II	Black Willow	1.22	2.293	1.426	0.551	0.00113		1.337	0.221	0.0740
II	Black Willow	1.22	2.293	1.388	0.763	0.00210		1.312	0.216	0.0720
II	Black Willow	1.22	2.293	0.680	0.688	0.00175		0.637	0.152	0.0450
II	Black Willow	1.22	2.293	0.906	0.910	0.00333		0.874	0.186	0.0580
II	Black Willow	1.22	2.293	0.821	0.789	0.00326		0.794	0.202	0.0620
II	Black Willow	1.22	2.293	0.776	0.726	0.00228		0.743	0.178	0.0540
II 13-1	Mountain Willow	1.52	4.844	0.678	0.628	0.00323	0.052	0.661	0.231	0.0690
II 13-2	Mountain Willow	1.52	4.844	0.605	0.704	0.00414	0.050	0.590	0.219	0.0640
II 13-3	Mountain Willow	1.52	4.844	0.747	0.651	0.00666	0.075	0.736	0.336	0.1020
II 13-4	Mountain Willow	1.52	4.844	0.818	0.609	0.00616	0.080	0.806	0.363	0.1120
II 13-5	Mountain Willow	1.52	4.844	0.934	0.610	0.00584	0.082	0.919	0.378	0.1190
II 13-6	Mountain Willow	1.52	4.844	1.092	0.521	0.00459	0.090	1.076	0.421	0.1360
II 13-7	Mountain Willow	1.52	4.844	1.251	0.446	0.00306	0.090	1.230	0.432	0.1430
II 13-8	Mountain Willow	1.52	4.844	1.326	0.447	0.00283	0.088	1.303	0.428	0.1420
II 13-9	Mountain Willow	1.52	4.844	1.414	0.526	0.00335	0.083	1.387	0.406	0.1370
II 13-10	Mountain Willow	1.52	4.844	1.278	0.600	0.00432	0.080	1.254	0.383	0.1270
II 13-11	Mountain Willow	1.52	4.844	1.382	0.895	0.00549	0.062	1.343	0.301	0.1010
II 14-1	Mt Willow w/o leaves	1.52	4.844	0.874	0.595	0.00379	0.066	0.856	0.299	0.0930
II 14-2	Mt Willow w/o leaves	1.52	4.844	1.376	0.368	0.00136	0.075	1.343	0.364	0.1220

Table 4
Summary of Large Flume Results with Homogeneous Groupings (Non-SI Units)

Run	Plant	Plant Height H, ft	Plant Density M, 1/ft^2	Water Depth Y_o, ft	Mean Velocity V, ft/s	Energy Slope S	Average n	Bed Hydraulic Radius ft	Bed V^*/V	Bed Manning's n
II 0-1	none		0.000	2.355	1.274	0.00013		1.844	0.069	0.0200
II 0-2	none		0.000	4.334	0.687	0.00002	0.016	2.901	0.064	0.0200
II 0-3	none		0.000	4.788	1.940	0.00015	0.016	3.318	0.069	0.0220
I 1-1	Yellow Twig Dogwood	1.67	0.498	4.170	1.200	0.00053	0.046	3.944	0.216	0.0710
I 1-2	Yellow Twig Dogwood	1.67	0.498	4.120	2.000	0.00124	0.042	3.885	0.198	0.0650
I 1-3	Yellow Twig Dogwood	1.67	0.498	3.680	2.460	0.00184	0.040	3.474	0.185	0.0590
I 1-4	Yellow Twig Dogwood	1.67	0.498	3.090	1.580	0.00119	0.047	2.959	0.213	0.0670
I 1-5	Yellow Twig Dogwood	1.67	0.498	3.350	1.930	0.00140	0.043	3.185	0.196	0.0620
I 1-6	Yellow Twig Dogwood	1.67	0.498	3.440	2.260	0.00163	0.040	3.252	0.183	0.0580
I 1-7	Yellow Twig Dogwood	1.67	0.498	1.760	2.880	0.00582	0.048	1.710	0.197	0.0560
I 1-8	Yellow Twig Dogwood	1.67	0.498	2.350	3.250	0.00477	0.041	2.258	0.181	0.0540
I 1-9	Yellow Twig Dogwood	1.67	0.498	2.910	3.580	0.00418	0.038	2.766	0.170	0.0530
I 2-1	Yellow Twig Dogwood	1.67	0.221	4.450	2.510	0.00102	0.031	4.041	0.145	0.0480
I 2-2	Yellow Twig Dogwood	1.67	0.221	3.770	3.030	0.00165	0.031	3.463	0.142	0.0460
I 2-3	Yellow Twig Dogwood	1.67	0.221	1.690	3.470	0.00693	0.040	1.636	0.174	0.0500
I 2-4	Yellow Twig Dogwood	1.67	0.221	1.300	2.460	0.00496	0.042	1.382	0.191	0.0530
I 3-1	Berried Elderberry	2.33	0.250	3.959	0.963	0.00030	0.042	3.720	0.195	0.0640
I 3-2	Berried Elderberry	2.33	0.250	3.225	1.570	0.00063	0.035	3.011	0.157	0.0500
I 3-3	Berried Elderberry	2.33	0.250	3.490	1.934	0.00085	0.034	3.244	0.154	0.0490
I 3-4	Berried Elderberry	2.33	0.250	3.125	0.996	0.00043	0.045	2.979	0.204	0.0640
I 3-5	Berried Elderberry	2.33	0.250	2.317	1.699	0.00125	0.040	2.219	0.176	0.0530
I 3-6	Berried Elderberry	2.33	0.250	2.565	2.013	0.00110	0.033	2.410	0.145	0.0440
I 3-7	Berried Elderberry	2.33	0.250	2.787	2.270	0.00123	0.032	2.603	0.141	0.0430
I 3-8	Berried Elderberry	2.33	0.250	2.676	2.522	0.00167	0.033	2.516	0.146	0.0450
I 3-9	Berried Elderberry	2.33	0.250	2.454	2.827	0.00199	0.031	2.303	0.136	0.0410
I 3-10	Berried Elderberry	2.33	0.250	3.002	3.102	0.00191	0.030	2.784	0.133	0.0410
I 4-1	Purpleleaf Euonymus	0.67	1.190	3.878	1.048	0.00041	0.045	3.674	0.209	0.0680
I 4-2	Purpleleaf Euonymus	0.67	1.190	3.921	1.377	0.00055	0.040	3.681	0.186	0.0600
I 4-3	Purpleleaf Euonymus	0.67	1.190	3.673	2.195	0.00159	0.042	3.489	0.195	0.0630
I 4-4	Purpleleaf Euonymus	0.67	1.190	2.762	2.172	0.00225	0.045	2.658	0.202	0.0620
I 4-5	Purpleleaf Euonymus	0.67	1.190	2.911	2.512	0.00251	0.042	2.787	0.189	0.0590

Table 4 (Continued)

Run	Plant	Plant Height *H*, ft	Plant Density *M*, 1/ft^2	Water Depth Y_o, ft	Mean Velocity *V*, ft/s	Energy Slope *S*	Average *n*	Bed Hydraulic Radius ft	Bed *V*/V*	Bed Manning's n
I 4-6	Purpleleaf Euonymus	0.67	1.190	2.563	3.195	0.00408	0.041	2.463	0.178	0.0560
I 4-7	Purpleleaf Euonymus	0.67	1.190	1.610	2.679	0.00477	0.042	1.565	0.183	0.0520
I 5-1	Purpleleaf Euonymus	0.67	0.529	3.385	1.348	0.00053	0.038	3.177	0.172	0.0550
I 5-2	Purpleleaf Euonymus	0.67	0.529	3.394	2.074	0.00106	0.035	3.172	0.159	0.0500
I 5-3	Purpleleaf Euonymus	0.67	0.529	2.320	3.158	0.00436	0.040	2.231	0.177	0.0530
I 6-1	Red Twig Dogwood	3.17	0.113	4.143	1.059	0.00110	0.075	4.046	0.357	0.1190
I 6-2	Red Twig Dogwood	3.17	0.113	4.148	1.573	0.00213	0.070	4.046	0.336	0.1110
I 6-3	Red Twig Dogwood	3.17	0.113	4.252	2.005	0.00266	0.062	4.129	0.297	0.0990
I 6-4	Red Twig Dogwood	3.17	0.113	3.085	1.139	0.00204	0.085	3.036	0.390	0.1230
I 6-5	Red Twig Dogwood	3.17	0.113	2.485	1.997	0.00508	0.070	2.442	0.313	0.0950
I 6-6	Red Twig Dogwood	3.17	0.113	2.719	3.127	0.00582		2.639	0.225	0.0693
I 6-7	Red Twig Dogwood	3.17	0.113	1.762	2.241	0.00833	0.070	1.739	0.308	0.0890
I 6-8	Red Twig Dogwood	3.17	0.113	3.065	3.157	0.00540	0.050	2.968	0.227	0.0720
I 7-1	Red Twig Dogwood	3.17	0.049	3.885	1.142	0.00117	0.070	3.788	0.330	0.1080
I 7-2	Red Twig Dogwood	3.17	0.049	2.685	1.653	0.00322	0.070	2.635	0.316	0.0973
II 1-1	Service Berry	2.33	0.050	2.265	1.148	0.00145	0.063	2.217	0.280	0.0840
II 1-2	Service Berry	2.33	0.050	3.173	1.844	0.00180	0.050	3.060	0.228	0.0720
II 1-3	Service Berry	2.33	0.050	2.634	2.249	0.00229	0.043	2.531	0.192	0.0590
II 1-4	Service Berry	2.33	0.050	3.062	2.964	0.00276	0.038	2.908	0.171	0.0540
II 1-5	Service Berry	2.33	0.050	3.786	1.684	0.00132	0.050	3.634	0.234	0.0760
II 1-6	Service Berry	2.33	0.050	4.182	2.257	0.00157	0.042	3.958	0.198	0.0650
II 4-1	Yellow Twig Dogwood		0.170	4.455	0.477	0.00019	0.071	4.319	0.344	0.1150
II 4-2	Yellow Twig Dogwood		0.170	4.558	1.124	0.00059	0.053	4.362	0.254	0.0850
II 4-3	Yellow Twig Dogwood		0.170	4.136	1.994	0.00112	0.040	3.892	0.189	0.0620
II 4-4	Yellow Twig Dogwood		0.170	3.546	3.173	0.00201	0.032	3.290	0.144	0.0460
II 6-1	Mulefat	3.17	0.060	4.668	1.339	0.00040	0.037	4.311	0.177	0.0590
II 6-2	Mulefat	3.17	0.060	4.151	2.108	0.00095	0.035	3.848	0.162	0.0530
II 6-3	Mulefat	3.17	0.060	4.474	2.375	0.00103	0.033	4.107	0.154	0.0510
II 6-4	Mulefat	3.17	0.060	3.518	2.594	0.00119	0.030	3.228	0.135	0.0430
II 9-1	Vally Elberberry	3.17	0.160	4.482	0.926	0.00099	0.083	4.387	0.418	0.1350
II 9-2	Vally Elberberry	3.17	0.160	4.365	1.400	0.00163	0.070	4.253	0.339	0.1130

Table 4 (Concluded)

Run	Plant	Plant Height H, ft	Plant Density M, 1/ft^2	Water Depth Y_o, ft	Mean Velocity V, ft/s	Energy Slope S	Average n	Bed Hydraulic Radius ft	Bed V^*/V	Bed Manning's n
II 9-3	Vally Elberberry	3.17	0.160	3.515	1.714	0.00267	0.068	3.434	0.317	0.1020
II 9-4	Vally Elberberry	3.17	0.160	2.999	2.038	0.00475	0.072	2.944	0.329	0.1030
II 10-1	Salt Cedar	5.00	0.058	4.692	1.364	0.00156	0.072	4.573	0.352	0.1190
II 10-2	Salt Cedar	5.00	0.058	4.522	1.902	0.00238	0.063	4.389	0.305	0.1020
II 10-3	Salt Cedar	5.00	0.058	3.660	2.350	0.00380	0.060	3.560	0.281	0.0910
II 10-4	Salt Cedar	5.00	0.058	3.062	2.246	0.00369	0.058	2.981	0.264	0.0830
II 10-5	Salt Cedar	5.00	0.058	2.768	2.462	0.00513	0.060	2.704	0.272	0.0840
II 10-6	Salt Cedar	5.00	0.058	2.714	3.067	0.00517	0.048	2.629	0.215	0.0660
II	Black Willow	4.00	0.213	4.646	1.028	0.00084		3.578	0.303	0.0980
II	Black Willow	4.00	0.213	4.677	1.809	0.00113		4.387	0.221	0.0740
II	Black Willow	4.00	0.213	4.554	2.503	0.00210		4.305	0.216	0.0720
II	Black Willow	4.00	0.213	2.232	2.257	0.00175		2.088	0.152	0.0450
II	Black Willow	4.00	0.213	2.974	2.984	0.00333		2.867	0.186	0.0580
II	Black Willow	4.00	0.213	2.693	2.590	0.00326		2.604	0.202	0.0620
II	Black Willow	4.00	0.213	2.547	2.381	0.00228		2.439	0.178	0.0540
II 13-1	Mountain Willow	5.00	0.450	2.226	2.061	0.00323	0.052	2.168	0.231	0.0690
II 13-2	Mountain Willow	5.00	0.450	1.986	2.309	0.00414	0.050	1.937	0.219	0.0640
II 13-3	Mountain Willow	5.00	0.450	2.451	2.137	0.00666	0.075	2.414	0.336	0.1020
II 13-4	Mountain Willow	5.00	0.450	2.683	1.999	0.00616	0.080	2.644	0.363	0.1120
II 13-5	Mountain Willow	5.00	0.450	3.063	2.000	0.00584	0.082	3.016	0.378	0.1190
II 13-6	Mountain Willow	5.00	0.450	3.582	1.710	0.00459	0.090	3.530	0.421	0.1360
II 13-7	Mountain Willow	5.00	0.450	4.104	1.462	0.00306	0.090	4.037	0.432	0.1430
II 13-8	Mountain Willow	5.00	0.450	4.351	1.465	0.00283	0.088	4.275	0.428	0.1420
II 13-9	Mountain Willow	5.00	0.450	4.639	1.725	0.00335	0.083	4.549	0.406	0.1370
II 13-10	Mountain Willow	5.00	0.450	4.194	1.967	0.00432	0.080	4.114	0.383	0.1270
II 13-11	Mountain Willow	5.00	0.450	4.534	2.936	0.00549	0.062	4.406	0.301	0.1010
II 14-1	Mt Willow w/o leaves	5.00	0.450	2.869	1.952	0.00379	0.066	2.809	0.299	0.0930
II 14-2	Mt Willow w/o leaves	5.00	0.450	4.515	1.207	0.00136	0.075	4.407	0.364	0.1220

Table 5
Summary of Large Flume Results with Mixed Plant Groupings (SI Units)

Run	Plants	Plant Density M, 1/m^2	Water Depth Yo, M	Mean Velocity V, m/sec	Energy Slope S	Average n	Hydraulic Radius R_h (bed), m	Shear Ratio V^*/V (bed)	Manning's n (bed)
2-1	20 Service Berry, 68 Yellow Twig Dogwood, 68 Euonymus	4.20	1.414	0.353	0.00084	0.062	1.366	0.300	0.101
2-2	20 Service Berry, 68 Yellow Twig Dogwood, 68 Euonymus	4.20	1.398	0.486	0.00122	0.054	1.343	0.259	0.087
2-3	20 Service Berry, 68 Yellow Twig Dogwood, 68 Euonymus	4.20	1.287	0.659	0.00219	0.052	1.238	0.248	0.082
2-4	20 Service Berry, 68 Yellow Twig Dogwood, 68 Euonymus	4.20	0.908	0.742	0.00398	0.055	0.883	0.249	0.078
2-5	20 Service Berry, 68 Yellow Twig Dogwood, 68 Euonymus	4.20	0.944	0.560	0.00253	0.059	0.919	0.270	0.085
2-6	20 Service Berry, 68 Yellow Twig Dogwood, 68 Euonymus	4.20	0.685	0.779	0.00551	0.055	0.670	0.244	0.073
3-1	68 Yellow Twig Dogwood, 68 Euonymus	3.66	1.410	0.360	0.00069	0.055	1.353	0.265	0.089
3-2	68 Yellow Twig Dogwood, 68 Euonymus	3.66	1.266	0.537	0.00125	0.048	1.209	0.228	0.075
3-3	68 Yellow Twig Dogwood, 68 Euonymus	3.66	0.728	0.638	0.00290	0.050	0.707	0.222	0.067
3-4	68 Yellow Twig Dogwood, 68 Euonymus	3.66	0.982	0.473	0.00126	0.050	0.946	0.228	0.072
7-1	22 Mulefat, 70 Alders	2.48	1.332	0.366	0.00107	0.066	1.293	0.318	0.106
7-2	22 Mulefat, 70 Alders	2.48	1.344	0.456	0.00102	0.052	1.288	0.249	0.083
7-3	22 Mulefat, 70 Alders	2.48	1.148	0.624	0.00173	0.047	1.099	0.219	0.071
7-4	22 Mulefat, 70 Alders	2.48	1.006	0.845	0.00395	0.050	0.972	0.230	0.073
8-1	22 Mulefat, 70 Alders, 66 Valley Elderberry	4.20	1.373	0.488	0.00228	0.073	1.341	0.355	0.119
8-2	22 Mulefat, 70 Alders, 66 Valley Elderberry	4.20	1.340	0.572	0.00292	0.070	1.308	0.338	0.113
8-3	22 Mulefat, 70 Alders, 66 Valley Elderberry	4.20	1.377	0.751	0.00427	0.065	1.340	0.316	0.106
8-4	22 Mulefat, 70 Alders, 66 Valley Elderberry	4.20	1.189	0.533	0.00315	0.075	1.164	0.354	0.116
8-5	22 Mulefat, 70 Alders, 66 Valley Elderberry	4.20	1.113	0.567	0.00372	0.075	1.091	0.352	0.114
8-6	22 Mulefat, 70 Alders, 66 Valley Elderberry	4.20	1.166	0.678	0.00390	0.065	1.137	0.306	0.100
11-1	23 Salt Cedar, 83 Black Willows, 50 Red Willows	4.20	1.433	0.658	0.00290	0.062	1.390	0.302	0.102
11-2	23 Salt Cedar, 83 Black Willows, 50 Red Willows	4.20	1.320	0.794	0.00445	0.062	1.283	0.297	0.099
11-3	23 Salt Cedar, 83 Black Willows, 50 Red Willows	4.20	1.437	0.401	0.00158	0.075	1.403	0.367	0.124
11-4	23 Salt Cedar, 83 Black Willows, 50 Red Willows	4.20	0.955	0.528	0.00314	0.070	0.935	0.323	0.102
11-5	23 Salt Cedar, 83 Black Willows, 50 Red Willows	4.20	0.787	0.646	0.00471	0.065	0.772	0.291	0.089
11-6	23 Salt Cedar, 83 Black Willows, 50 Red Willows	4.20	0.814	0.959	0.00834	0.059	0.796	0.267	0.082
11-7	23 Salt Cedar, 83 Black Willows, 50 Red Willows	4.20	0.665	0.726	0.00456	0.053	0.649	0.236	0.070
12-1	83 Black Willows, 50 Red Willows	3.58	1.416	0.354	0.00079	0.060	1.366	0.291	0.098

(Continued)

Table 5 (Concluded)

Run	Plants	Plant Density M, 1/m^2	Water Depth Y_o, m	Mean Velocity V, m/sec	Energy Slope S	Average n	Hydraulic Radius R_h (bed), m	Shear Ratio V^*/V (bed)	Manning's n (bed)
12-2	83 Black Willows, 50 Red Willows	3.58	1.426	0.551	0.00113	0.046	1.353	0.220	0.074
12-3	83 Black Willows, 50 Red Willows	3.58	1.388	0.763	0.00210	0.045	1.320	0.215	0.072
12-4	83 Black Willows, 50 Red Willows	3.58	0.906	0.910	0.00333	0.041	0.867	0.186	0.058
12-5	83 Black Willows, 50 Red Willows	3.58	0.821	0.789	0.00326	0.045	0.791	0.202	0.062
12-6	83 Black Willows, 50 Red Willows	3.58	0.776	0.726	0.00228	0.040	0.743	0.178	0.054
12-7	83 Black Willows, 50 Red Willows	3.58	0.680	0.688	0.00175	0.035	0.647	0.151	0.045

Table 6
Summary of Large Flume Results with Mixed Plant Groupings (Non-SI Units)

Run	Plants	Plant Density *M*, 1/ft^2	Water Depth *Yo*, ft	Mean Velocity *V*, ft/s	Energy Slope *S*	Average n	Hydraulic Radius R_h (bed), ft	Shear Ratio *V*/V* (bed)	Manning's n (bed)
2-1	20 Service Berry, 68 Yellow Twig Dogwood, 68 Euonymus	0.39	4.638	1.159	0.00084	0.062	4.483	0.300	0.101
2-2	20 Service Berry, 68 Yellow Twig Dogwood, 68 Euonymus	0.39	4.588	1.594	0.00122	0.054	4.407	0.259	0.087
2-3	20 Service Berry, 68 Yellow Twig Dogwood, 68 Euonymus	0.39	4.222	2.161	0.00219	0.052	4.061	0.248	0.082
2-4	20 Service Berry, 68 Yellow Twig Dogwood, 68 Euonymus	0.39	2.979	2.434	0.00398	0.055	2.896	0.249	0.078
2-5	20 Service Berry, 68 Yellow Twig Dogwood, 68 Euonymus	0.39	3.096	1.837	0.00253	0.059	3.014	0.270	0.085
2-6	20 Service Berry, 68 Yellow Twig Dogwood, 68 Euonymus	0.39	2.249	2.557	0.00551	0.055	2.197	0.244	0.073
3-1	68 Yellow Twig Dogwood, 68 Euonymus	0.34	4.627	1.181	0.00069	0.055	4.439	0.265	0.089
3-2	68 Yellow Twig Dogwood, 68 Euonymus	0.34	4.152	1.761	0.00125	0.048	3.966	0.228	0.075
3-3	68 Yellow Twig Dogwood, 68 Euonymus	0.34	2.388	2.094	0.00290	0.050	2.319	0.222	0.067
3-4	68 Yellow Twig Dogwood, 68 Euonymus	0.34	3.222	1.552	0.00126	0.050	3.103	0.228	0.072
7-1	22 Mulefat, 70 Alders	0.23	4.370	1.201	0.00107	0.066	4.243	0.318	0.106
7-2	22 Mulefat, 70 Alders	0.23	4.411	1.496	0.00102	0.052	4.227	0.249	0.083
7-3	22 Mulefat, 70 Alders	0.23	3.766	2.048	0.00173	0.047	3.605	0.219	0.071
7-4	22 Mulefat, 70 Alders	0.23	3.301	2.772	0.00395	0.050	3.189	0.230	0.073
8-1	22 Mulefat, 70 Alders, 66 Valley Elderberry	0.39	4.506	1.601	0.00228	0.073	4.399	0.355	0.119
8-2	22 Mulefat, 70 Alders, 66 Valley Elderberry	0.39	4.397	1.876	0.00292	0.070	4.290	0.338	0.113
8-3	22 Mulefat, 70 Alders, 66 Valley Elderberry	0.39	4.517	2.463	0.00427	0.065	4.396	0.316	0.106
8-4	22 Mulefat, 70 Alders, 66 Valley Elderberry	0.39	3.901	1.750	0.00315	0.075	3.820	0.354	0.116
8-5	22 Mulefat, 70 Alders, 66 Valley Elderberry	0.39	3.650	1.860	0.00372	0.075	3.578	0.352	0.114
8-6	22 Mulefat, 70 Alders, 66 Valley Elderberry	0.39	3.826	2.225	0.00390	0.065	3.731	0.306	0.100
11-1	23 Salt Cedar, 83 Black Willows, 50 Red Willows	0.39	4.702	2.159	0.00290	0.062	4.560	0.302	0.102
11-2	23 Salt Cedar, 83 Black Willows, 50 Red Willows	0.39	4.330	2.604	0.00445	0.062	4.209	0.297	0.099
11-3	23 Salt Cedar, 83 Black Willows, 50 Red Willows	0.39	4.716	1.317	0.00158	0.075	4.602	0.367	0.124
11-4	23 Salt Cedar, 83 Black Willows, 50 Red Willows	0.39	3.133	1.731	0.00314	0.070	3.069	0.323	0.102
11-5	23 Salt Cedar, 83 Black Willows, 50 Red Willows	0.39	2.583	2.120	0.00471	0.065	2.532	0.291	0.089
11-6	23 Salt Cedar, 83 Black Willows, 50 Red Willows	0.39	2.669	3.147	0.00834	0.059	2.610	0.267	0.082
11-7	23 Salt Cedar, 83 Black Willows, 50 Red Willows	0.39	2.182	2.383	0.00456	0.053	2.130	0.236	0.070
12-1	83 Black Willows, 50 Red Willows	0.333	4.646	1.162	0.00079	0.060	4.482	0.291	0.098

(Continued)

Table 6 (Concluded)

Run	Plants	Plant Density M, 1/ft^2	Water Depth Y_o, ft	Mean Velocity V, ft/s	Energy Slope S	Average n	Hydraulic Radius R_h (bed), ft	Shear Ratio V^*/V (bed)	Manning's n (bed)
12-2	83 Black Willows, 50 Red Willows	0.333	4.677	1.809	0.00113	0.046	4.440	0.220	0.074
12-3	83 Black Willows, 50 Red Willows	0.333	4.554	2.503	0.00210	0.045	4.330	0.215	0.072
12-4	83 Black Willows, 50 Red Willows	0.333	2.974	2.984	0.00333	0.041	2.845	0.186	0.058
12-5	83 Black Willows, 50 Red Willows	0.333	2.693	2.590	0.00326	0.045	2.596	0.202	0.062
12-6	83 Black Willows, 50 Red Willows	0.333	2.547	2.381	0.00228	0.040	2.438	0.178	0.054
12-7	83 Black Willows, 50 Red Willows	0.333	2.232	2.257	0.00175	0.035	2.123	0.151	0.045

Table 7
Small Flume Results, Drag Measurements

Run	Plant	With Leaves				Without Leaves			
		Approach Velocity		Drag Force		Approach Velocity		Drag Force	
		ft/sec	m/sec	lbf	N	ft/sec	m/sec	lbf	N
1	Staghorn Sumac	1.63	0.50	0.216	0.961	1.63	0.50	0.052	0.231
2	Staghorn Sumac	2.15	0.66	0.310	1.379	2.01	0.61	0.095	0.423
3	Staghorn Sumac	2.62	0.80	0.362	1.610	2.12	0.65	0.108	0.480
4	Staghorn Sumac	2.70	0.82	0.388	1.726	2.51	0.77	0.172	0.765
5	Staghorn Sumac	2.84	0.87	0.414	1.842	3.06	0.93	0.216	0.961
6	Staghorn Sumac	3.37	1.03	0.431	1.917	3.34	1.02	0.237	1.054
7	Staghorn Sumac	3.64	1.11	0.466	2.073	3.48	1.06	0.280	1.245
8	Staghorn Sumac	4.17	1.27	0.569	2.531	3.92	1.19	0.401	1.784
9	Staghorn Sumac	4.31	1.31	0.603	2.682	4.44	1.35	0.474	2.108
10	Staghorn Sumac	4.44	1.35	0.638	2.838	4.80	1.46	0.526	2.340
1	Artic Blue Willow	1.02	0.31	0.207	0.921	1.43	0.44	0.129	0.574
2	Artic Blue Willow	1.32	0.40	0.289	1.286	1.82	0.55	0.155	0.689
3	Artic Blue Willow	1.79	0.55	0.366	1.628	2.46	0.75	0.207	0.921
4	Artic Blue Willow	2.15	0.66	0.431	1.917	2.95	0.90	0.224	0.996
5	Artic Blue Willow	2.34	0.71	0.483	2.148	3.50	1.07	0.272	1.210
6	Artic Blue Willow	2.73	0.83	0.526	2.340	4.25	1.30	0.345	1.535
7	Artic Blue Willow	2.92	0.89	0.560	2.491	4.66	1.42	0.397	1.766
8	Artic Blue Willow	2.98	0.91	0.578	2.571	4.77	1.45	0.440	1.957
9	Artic Blue Willow	3.48	1.06	0.733	3.261	4.94	1.51	0.466	2.073
10	Artic Blue Willow	4.39	1.34	0.922	4.101	5.19	1.58	0.517	2.300
1	Norway Maple	0.94	0.29	0.089	0.396	1.27	0.39	0.036	0.160
2	Norway Maple	1.21	0.37	0.125	0.556	1.93	0.59	0.058	0.258
3	Norway Maple	1.71	0.52	0.201	0.894	2.40	0.73	0.085	0.378
4	Norway Maple	2.23	0.68	0.241	1.072	2.92	0.89	0.134	0.596
5	Norway Maple	3.01	0.92	0.304	1.352	3.61	1.10	0.179	0.796
6	Norway Maple	3.56	1.09	0.371	1.650	4.17	1.27	0.210	0.934
7	Norway Maple	3.89	1.19	0.464	2.064	4.31	1.31	0.299	1.330
8	Norway Maple	4.08	1.24	0.589	2.620	4.44	1.35	0.321	1.428
9	Norway Maple	4.31	1.31	0.652	2.900	4.61	1.41	0.357	1.588
10	Norway Maple	4.53	1.38	0.741	3.296		0.00		0.000
1	Western Sand Cherry	1.10	0.34	0.071	0.316	1.43	0.44	0.031	0.138
2	Western Sand Cherry	1.68	0.51	0.107	0.476	2.01	0.61	0.071	0.316
3	Western Sand Cherry	2.12	0.65	0.143	0.636	2.54	0.77	0.098	0.436
4	Western Sand Cherry	2.51	0.77	0.170	0.756	2.79	0.85	0.125	0.556
5	Western Sand Cherry	2.81	0.86	0.205	0.912	3.17	0.97	0.161	0.716
6	Western Sand Cherry	3.20	0.98	0.250	1.112	3.50	1.07	0.174	0.774
7	Western Sand Cherry	3.39	1.03	0.308	1.370	3.84	1.17	0.196	0.872
8	Western Sand Cherry	3.64	1.11	0.348	1.548	4.00	1.22	0.223	0.992
9	Western Sand Cherry	3.75	1.14	0.384	1.708	4.17	1.27	0.254	1.130
10	Western Sand Cherry	3.89	1.19	0.420	1.868	4.53	1.38	0.348	1.548
1	Common Privet	1.13	0.34	0.198	0.881	1.32	0.40	0.075	0.334
2	Common Privet	1.71	0.52	0.472	2.100	2.10	0.64	0.302	1.343
3	Common Privet	2.18	0.66	0.731	3.252	2.57	0.78	0.377	1.677
4	Common Privet	2.90	0.88	0.811	3.607	2.73	0.83	0.396	1.761
5	Common Privet	3.34	1.02	0.972	4.324	3.23	0.98	0.708	3.149
6	Common Privet	3.59	1.09	1.274	5.667	3.42	1.04	0.797	3.545
7	Common Privet	3.75	1.14	1.585	7.050	3.73	1.14	0.943	4.195
8	Common Privet	4.11	1.25	1.896	8.434	4.03	1.23	1.085	4.826
9	Common Privet	4.39	1.34	2.132	9.484	4.17	1.27	1.189	5.289
10	Common Privet	4.44	1.35	2.179	9.693	4.66	1.42	1.302	5.792
1	Blue Elberberry	1.21	0.37	0.269	1.197	1.27	0.39	0.113	0.503
2	Blue Elberberry	1.68	0.51	0.491	2.184	1.57	0.48	0.170	0.756
3	Blue Elberberry	1.96	0.60	0.745	3.314	1.99	0.61	0.212	0.943
4	Blue Elberberry	2.46	0.75	1.415	6.294	2.18	0.66	0.259	1.152
5	Blue Elberberry	2.76	0.84	1.745	7.762	2.73	0.83	0.410	1.824
6	Blue Elberberry	2.98	0.91	2.052	9.128	3.31	1.01	0.552	2.455

(Continued)

Table 7 (Concluded)

Run	Plant	With Leaves				Without Leaves			
		Approach Velocity		Drag Force		Approach Velocity		Drag Force	
		ft/sec	m/sec	lbf	N	ft/sec	m/sec	lbf	N
7	Blue Elberberry	3.39	1.03	2.406	10.702	3.61	1.10	0.717	3.189
8	Blue Elberberry	3.89	1.19	2.783	12.379	4.06	1.24	1.024	4.555
9	Blue Elberberry	4.25	1.30	3.349	14.897	5.11	1.56	1.434	6.379
10	Blue Elberberry		0.00		0.000	5.33	1.62	1.991	8.856
1	French Pink Pussywillow	1.35	0.41	0.192	0.854	1.41	0.43	0.192	0.854
2	French Pink Pussywillow	1.99	0.61	0.625	2.780	1.54	0.47	0.288	1.281
3	French Pink Pussywillow	2.26	0.69	0.673	2.994	2.32	0.71	0.375	1.668
4	French Pink Pussywillow	2.57	0.78	0.827	3.679	2.40	0.73	0.452	2.011
5	French Pink Pussywillow	2.84	0.87	1.106	4.920	2.51	0.77	0.529	2.353
6	French Pink Pussywillow	3.34	1.02	1.346	5.987	2.90	0.88	0.837	3.723
7	French Pink Pussywillow	3.61	1.10	1.827	8.127	3.34	1.02	1.010	4.493
1	Sycamore	1.21	0.37	0.144	0.641	1.35	0.41	0.058	0.258
2	Sycamore	1.63	0.50	0.264	1.174	1.90	0.58	0.096	0.427
3	Sycamore	1.93	0.59	0.341	1.517	2.07	0.63	0.135	0.601
4	Sycamore	2.65	0.81	0.538	2.393	2.51	0.77	0.183	0.814
5	Sycamore	3.12	0.95	0.740	3.292	2.79	0.85	0.231	1.028
6	Sycamore	3.20	0.98	0.817	3.634	3.06	0.93	0.245	1.090
7	Sycamore	3.59	1.09	0.952	4.235	3.23	0.98	0.274	1.219
8	Sycamore	3.78	1.15	1.096	4.875	3.70	1.13	0.452	2.011
9	Sycamore	4.55	1.39	1.442	6.414	3.81	1.16	0.529	2.353
10	Sycamore	4.66	1.42	1.490	6.628	3.89	1.19	0.553	2.460
1	Yellow Twig Dogwood type 1	1.68	0.51	0.108	0.480	1.41	0.43	0.108	0.480
2	Yellow Twig Dogwood type 1	2.01	0.61	0.162	0.721	2.04	0.62	0.206	0.916
3	Yellow Twig Dogwood type 1	2.18	0.66	0.201	0.894	2.51	0.77	0.294	1.308
4	Yellow Twig Dogwood type 1	2.62	0.80	0.245	1.090	3.31	1.01	0.412	1.833
5	Yellow Twig Dogwood type 1	3.26	0.99	0.392	1.744	3.61	1.10	0.451	2.006
6	Yellow Twig Dogwood type 1	3.53	1.08	0.480	2.135	3.92	1.19	0.451	2.006
7	Yellow Twig Dogwood type 1	4.22	1.29	0.593	2.638	4.44	1.35	0.623	2.771
8	Yellow Twig Dogwood type 1	4.44	1.35	0.618	2.749	4.50	1.37	0.627	2.789
9	Yellow Twig Dogwood type 1	4.55	1.39	0.647	2.878	4.55	1.39	0.657	2.922
10	Yellow Twig Dogwood type 1	4.53	1.38	0.642	2.856	4.75	1.45	0.588	2.616
1	Yellow Twig Dogwood type 2	1.05	0.32	0.088	0.391	1.27	0.39	0.059	0.262
2	Yellow Twig Dogwood type 2	1.46	0.45	0.127	0.565	1.65	0.50	0.103	0.458
3	Yellow Twig Dogwood type 2	1.79	0.55	0.186	0.827	2.04	0.62	0.162	0.721
4	Yellow Twig Dogwood type 2	2.59	0.79	0.284	1.263	2.79	0.85	0.255	1.134
5	Yellow Twig Dogwood type 2	2.95	0.90	0.343	1.526	3.06	0.93	0.294	1.308
6	Yellow Twig Dogwood type 2	3.50	1.07	0.431	1.917	3.84	1.17	0.348	1.548
7	Yellow Twig Dogwood type 2	3.89	1.19	0.471	2.095	3.84	1.17	0.348	1.548
8	Yellow Twig Dogwood type 2	4.42	1.35	0.529	2.353	4.17	1.27	0.373	1.659
9	Yellow Twig Dogwood type 2	4.50	1.37	0.534	2.375	4.33	1.32	0.392	1.744
10	Yellow Twig Dogwood type 2	4.55	1.39	0.539	2.398	4.50	1.37	0.422	1.877
1	Euonymus	1.13	0.34	0.093	0.414	0.94	0.29	0.074	0.329
2	Euonymus	1.52	0.46	0.176	0.783	1.46	0.45	0.098	0.436
3	Euonymus	2.48	0.76	0.324	1.441	1.77	0.54	0.167	0.743
4	Euonymus	2.84	0.87	0.353	1.570	2.18	0.66	0.225	1.001
5	Euonymus	3.31	1.01	0.500	2.224	2.87	0.87	0.363	1.615
6	Euonymus	3.78	1.15	0.500	2.224	3.23	0.98	0.436	1.939
7	Euonymus	3.84	1.17	0.510	2.269	3.73	1.14	0.490	2.180
8	Euonymus	4.39	1.34	0.539	2.398	4.28	1.30	0.534	2.375
9	Euonymus	4.47	1.36	0.564	2.509	4.44	1.35	0.539	2.398
10	Euonymus	4.69	1.43	0.588	2.616		0.00		0.000
1	Yellow Twig Dogwood type 3	1.57	0.48	0.196	0.872	2.15	0.66	0.157	0.698
2	Yellow Twig Dogwood type 3	2.29	0.70	0.314	1.397	2.46	0.75	0.206	0.916
3	Yellow Twig Dogwood type 3	2.43	0.74	0.343	1.526	2.90	0.88	0.255	1.134
4	Yellow Twig Dogwood type 3	2.70	0.82	0.373	1.659	3.45	1.05	0.275	1.223
5	Yellow Twig Dogwood type 3	2.95	0.90	0.436	1.939	4.28	1.30	0.284	1.263
6	Yellow Twig Dogwood type 3	3.50	1.07	0.480	2.135				
7	Yellow Twig Dogwood type 3	4.22	1.29	0.500	2.224				

Table 8
Large Flume Results, Drag Measurements

		With Leaves			
		Approach Velocity		Drag Force	
Run	Plant	ft/sec	m/sec	lbf	N
6-2:1	Mulefat	1.10	0.34	0.083	0.369
6-2:2	Mulefat	1.50	0.46	0.130	0.578
6-2:3	Mulefat	1.70	0.52	0.172	0.765
6-2:4	Mulefat	2.40	0.73	0.232	1.032
6-2:5	Mulefat	2.70	0.82	0.362	1.610
6-2:6	Mulefat	3.10	0.94	0.426	1.895
7-1:1	Alder	0.43	0.13	0.040	0.178
7-1:2	Alder	0.88	0.27	0.109	0.485
7-1:3	Alder	1.10	0.34	0.234	1.041
7-1:4	Alder	1.60	0.49	0.404	1.797
8-1:1	Valley Elderberry	0.40	0.12	0.294	1.308
8-1:2	Valley Elderberry	0.50	0.15	0.438	1.948
8-1:3	Valley Elderberry	0.60	0.18	0.574	2.553
8-1:4	Valley Elderberry	0.70	0.21	0.745	3.314
8-1:5	Valley Elderberry	0.80	0.24	0.989	4.399
8-1:6	Valley Elderberry	1.10	0.34	1.277	5.680
8-1:7	Valley Elderberry	1.40	0.43	1.404	6.245
11-1:1	Black Willow	0.85	0.26	0.110	0.489
11-1:2	Black Willow	1.00	0.30	0.170	0.756
11-1:3	Black Willow	1.10	0.34	0.210	0.934
11-1:4	Black Willow	1.30	0.40	0.320	1.423
11-1:5	Black Willow	1.50	0.46	0.470	2.091
11-1:6	Black Willow	1.65	0.50	0.510	2.269
11-1:7	Black Willow	1.70	0.52	0.680	3.025
11-1:8	Black Willow	1.90	0.58	0.770	3.425
11-1:9	Black Willow	2.10	0.64	0.960	4.270
11-1:10	Black Willow	2.30	0.70	1.230	5.471

Table 9
Modulus of Plant Stiffness for Evaluated Plants

Plant name		$E_S/(H/D_S)^{1.5}$ N/m²	$E_S/(H/D_S)^{1.5}$ lbf/ft²
Alder	*Alnus incana*	1.804e+06	3.768e+04
Arctic Blue Willow	*Salix purpurea nana*	4.091e+05	8.544e+03
Black Willow	*Salix nigra*	2.930e+05	6.119e+03
Blue Elderberry	*Sambucus Canadensis*	2.733e+05	5.708e+03
Common Privet	*Ligustrum vulgare*	7.7040e+05	1.609e+04
Yellow Twig Dogwood	*Cornus stolonifera flaviramea*	2.550e+06	5.326e+04
Red-osier Dogwood	*Cornus Sericea*	4.342e+06	9.069e+04
Berried Elderberry	*Sambucus racemosa*	8.168e+04	1.706e+03
Purpleleaf Euonymus	*Euonymus fortunei colorata*	2.278e+06	4.758e+04
Mountain Black Willow	*Salix monticola*	7.430e+05	1.552e+04
Mulefat	*Baccharis glutinosa*	8.992e+05	1.878e+04
Norway Maple	*Acer platenoides*	4.569e+06	9.542e+04
French Pink Pussywillow	*Salix caprea pendula*	3.345e+05	6.986e+03
Red Willow	*Salix spp.*	8.810e+05	1.840e+04
Salt Cedar	*Tamarix spp.*	3.930e+06	8.207e+04
Service Berry	*Amelanchier*	4.003e+06	8.360e+04
Staghorn Sumac	*Rhus typhina*	1.095e+06	2.288e+04
Sycamore	*Platenus acer ifolia*	3.244e+06	6.774e+04
Valley Elderberry	*Sambucus mexicana*	7.672e+06	1.602e+05
Western Sand Cherry	*Prunis besseyi*	3.567e+06	7.449e+04
Sand Bar Willow	*Salix exigua*	4.990e+06	1.040e+05
Pacific Willow	*Salix lasiandra*	5.300e+06	1.120e+05
Lemon's Willow	Salix lemonii	4.090e+06	8.530e+04
Wild Rose Bush	Rosa spp.	6.070e+06	1.250e+05

Appendix A
Example Problem

The equations developed in this report allow hydraulic roughness values to be determined for homogenous and nonhomogeneous flood plains. When a number of species are present in the floodplain or area of interest, the values for the various plants are either combined, as shown in Equation 29, or the flood plain is broken into homogenous areas that are then either solved simultaneously for the flow or aggregated to provide a representative roughness (i.e., Manning's n) value.

The following is an example for determining the vegetative resistance and the equivalent resistance of the left bank of a floodplain. The left bank is divided into three subareas with the far left area vegetated with shrubs, the middle area vegetated with three different plant types, and the right subarea vegetated with willows as shown in Figure A1. For a given flow depth in the main channel, Table A1 shows the flow depth, area, wetted perimeter, and hydraulic radius for each subarea. The slope of each area is 0.0002, the fluid density is 1,000 kg/m^3, and the kinematic viscosity is 1.3E+06 m^2/s. The properties of the channel are summarized in Table A1 for ease of reference.

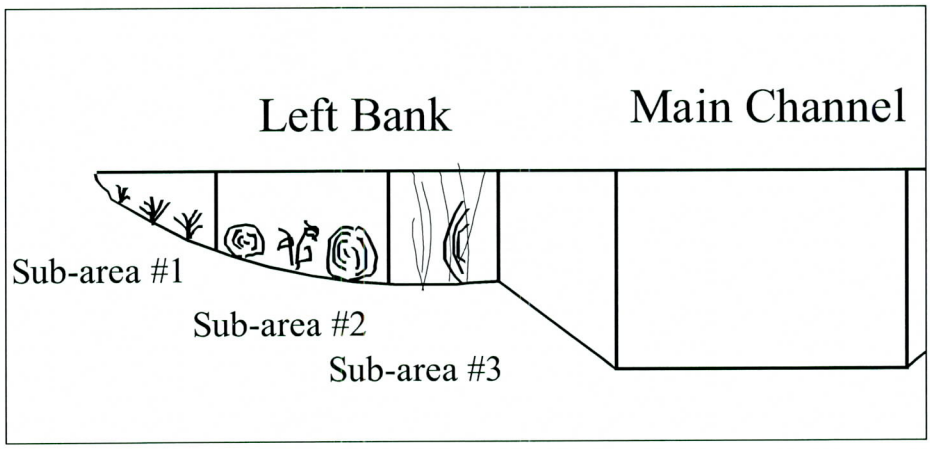

Figure A1. Left bank floodplain for example problem showing calculation subareas based on vegetation types

Table A1
Channel Properties for Example Problem

Channel Properties	Subarea 1	Subarea 2	Subarea 3	Overbank Total
S	0.0002	0.0002	0.0002	.0002
Y_o m	0.61	1.524	2.134	
Flow Area m^2	27.87	46.45	32.52	106.84
P m	31.39	31.09	15.85	78.33
R_h m	0.89	1.49	2.05	1.364

Table A2 lists the plant characteristics and properties for the shrubs in subareas 1 through 3. The stiffness modulus was measured in the field by applying Equation 33 for subarea 1, by using Equation 35 for weighted plant characteristic values for subarea 2, and by using the value for Pacific willows from Table 9 for subarea 3 multiplied by the $(H/D_s)^{1.5}$ value for the willows in subarea 3. The use of the value from Table 9 and the H/D parameter for the willows in subarea 3 provides an estimate of the actual E_s for the willows in the subarea that are different in size from those evaluated in the compilation of the data presented in Table 9.

Table A2 also lists the plant characteristics and shows the calculations to determine the weighted average characteristics to be used for the resistance calculations. This is done by multiplying the various plant characteristics by that plant's relative density on the floodplain in decimal form, H_1M_1/M_{total}, where the subscript 1 refers to plant type 1. These values are then summed for all three plant types to arrive at the weighted value for H. Thus, the equation for the weighted value becomes as follows:

$$H_{ave} = H_1 \frac{M_1}{M_{total}} + H_2 \frac{M_2}{M_{total}} + H_3 \frac{M_2}{M_{total}}$$

This averaging technique was verified using flume data from the Utah Water Research Laboratory Study and provides the correct average values for use in the equations presented herein.

Equation 23 was used to calculate V_*/V for the partially submerged vegetation in subarea 1 while Equation 21 was used for the fully submerged subareas 2 and 3. Manning's n values were calculated in the same way using Equation 24 for subarea 1 and Equation 22 for subareas 2 and 3.

The calculated Manning's n values for subareas 1 through 3 are 0.075, 0.088, and 0.127, respectively, while the V_*/V values are 0.240, 0.257, and 0.353, respectively. The values for the various subareas can then be used individually in a hydraulic model or composited to obtain a value for the entire channel. Methods described in the SAM User's Manual (Thomas et al. in preparation)[1] are recommended for compositing the subareas if that is necessary.

[1] References in this appendix are cited in the References section at the end of the main text.

Table A2
Plant Characteristics and Roughness Calculations for Subareas 1-3

Plant Characteristics	Sub area 1	Subarea 2				Subarea 3 (Pacific Willow)
		Plant Type 1	Plant Type 2	Plant Type 3	Weighted Values	
H m	0.91	0.2	0.71	0.99	0.59	1.83
H' m	0.76	0.2	0.51	0.81	0.49	1.52
We m	0.76	0.254	0.18	0.86	0.48	1.22
No. of Stems	4	2	6	1	2.20	4
D_s cm	1.27	0.64	0.64	1.2	0.86	1.3
A_s m^2 π D_s^2 / 4 x (no. of stems)	5.06E-04	6.43E-05	1.93E-04	1.13E-04	1.03E-04	5.31E-04
M (plants / m^2)	0.52	1.83	0.61	1.62	4.06	0.11
M / M total (%)		45.0	15.0	39.9	100.0	
H/D_s	72	31	111	82	64	141
F_{45}, N	8.08					
Es, N/m^2, Eq 33	1.75E+09					
Es, N/m^2, Eq 35	1.33E+09	3.15E+08	3.59E+09	1.49E+09	1.28E+09	6.56E+09
Es, N/m^2, Table 9 x $(H/D_s)^{1.5}$						8.85E+09
Vegetative Resistance						
Y_o / H	0.67				2.72	1.17
Submergence $P \leq 0.8H \leq$ Full	Partial				Full	Full
A_i or A_i^* (m^2)	0.35				0.24	1.85
$V_* = (gR_hS)^{1/2}$	4.18E-02				5.41E-02	6.34E-02
Es As / $\rho A_i V_*^2$	1449447				207582	630112
M A_i^*	0.182				0.964	0.204
$V_* R_h / \nu$	28608				61971	100009
V_*/V (Eq 23)	.130					
V_*/V (Eq 21)					0.380	0.350
Manning's n (Eq 22 or 24)	0.075 (Eq 24)				0.130 (Eq 22)	0.126

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Flume studies were conducted to determine hydraulic resistance of flexible plants that deform with turbulent flow. Both partially submerged and fully submerged plants were studied. The flexible stems and varying shapes of a plant leaf mass greatly complicate the understanding of resistance. The deformation of plant shape with flow precludes the use of constant blockage or plant density in predicting resistance. This study considers the effects on channel resistance for the variables of plant type, plant geometry, plant density, plant flexibility, and submerged and partially submerged plants. Regression equations were developed for determining the Manning's roughness coefficient.

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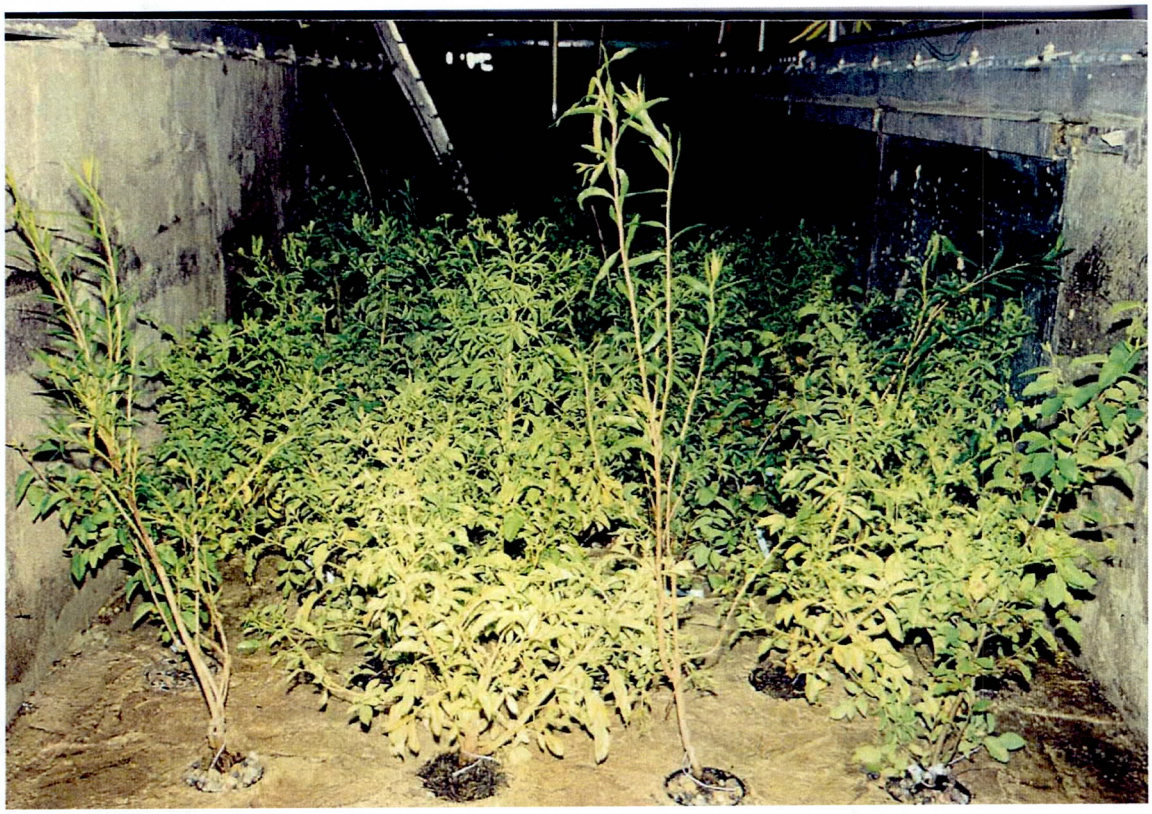
Gary E. Freeman, William H. Rahmeyer,
and Ronald R. Copeland

October 2000



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Preface

The investigation reported herein was conducted by and for the U.S. Army Engineer Research and Development Center. The majority of the research was funded under Contract DACW39-94-K-0009 and conducted by the Utah Water Research Laboratory. A smaller portion of the research was funded under DACW39-97-M-1413 consisting of field investigations of plant stiffness and conducted by Dengari, Inc. Field measurements of hydraulic losses under actual high-water conditions and subsequent determinations of plant stiffness were conducted by Dr. Gary Freeman, former research hydraulic engineer, ERDC. All research reported herein was funded by the ERDC, Vicksburg, MS, as a part of the Flood Control Channels and Flood Damage Reduction Research Programs. Dr. Ronald R. Copeland, ERDC, supervised this research.

Research at the Utah Water Research Laboratory was conducted by and under the supervision of Dr. William Rahmeyer with the assistance of Mr. David Werth and other graduate research assistants. Dr. Gary Freeman conducted the research for Dengari, Inc. The authors of this technical report were Drs. Gary Freeman, William Rahmeyer, and Ronald Copeland.

The studies reported herein have been conducted over the period from 1993 to 1998 and were under the general supervision of Mr. F.A. Herrmann, Director of the Hydraulics Laboratory, Dr. J. R. Houston, former Director of the Coastal and Hydraulics Laboratory, Mr. M. B. Boyd, Dr. L. Daggett, Dr. W. H. McAnally, Jr., and Dr. P. G. Combs, Division Chiefs. The work was performed initially under the supervision of Mr. William A. Thomas with supervision subsequently transferred to Dr. Ronald R. Copeland, Research Hydraulic Engineers. Mr. D. L. Derrick, Research Hydraulic Engineer, was also involved in the supervision of contracts, research coordination, and field research efforts.

At the time of publication of this report, Dr. James R. Houston was Director of ERDC, and COL James S. Weller, EN, was Commander.

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List of Variables

Numerous variables are used throughout this report. These variables are listed here for convenience. Figures 1 and 2 show the measurements that define the variables involving the leaf mass and plant dimensions for submerged and emergent (unsubmerged or partially submerged) flow conditions.

The variables are defined as follows:

A	Cross sectional flow area, ft^2 or m^2
Ai	Frontal area of an individual plant blocking flow, approximated by the equivalent rectangular area of blockage H' by We, ft^2 or m^2
*Ai**	Net submerged frontal area of a partially submerged plant, ft^2 or m^2
As	Total cross-sectional area of all of the stem(s) of an individual plant, measured at H/4, ft^2 or m^2
b	width of channel flume, ft or m
C	Chezy resistance coefficient, ft½/s or m ½/s
CD	Drag coefficient of vegetation, dimensionless
Ds	Stem diameter, measured at a height of H/4, ft or m
Es	Modulus of plant stiffness, lbf/ft^2 or N/m^2
f	Darcy-Weisbach friction factor, dimensionless
fb	friction factor for the bed and plants, dimensionless
fw	friction factor for the walls, dimensionless
*F*45	The horizontal force necessary to bend a plant stem 45 deg, lbf or N
FD	Drag force, lbf or N
Fr	Froude number, dimensionless

g	Acceleration due to gravity = 32.17 ft/s^2 or 9.806 m/s^2
H	Average undeflected plant height, ft or m
H'	Undeflected height of the leaf mass of a plant, ft or m
H^*	Undeflected height of leaf mass that is below water surface for a partially submerged plant, ft or m (See Figure 2)
I	Second moment of inertia of cross section of plant stem, ft^4 or m^4
K_n	Units conversion factor for Manning's equation, 1.4861 ft$^{1/3}$/s or 1.0 m$^{1/3}$/s
L	Channel reach length, ft or m
M	Relative plant density, number of plants per ft^2 or m^2
n	Total Manning's roughness coefficient, including sidewall roughness
n_b	Manning's resistance coefficient for vegetation and channel bed
n_{veg}	Manning's resistance coefficient for vegetation
n_o	Manning's resistance coefficient for the bed
P	Wetted perimeter, ft or m
R_e	Reynolds number, $R_e = V R_h / \nu$
R_h	Hydraulic radius, R_h = flow area / wetted perimeter, ft or m
R_b	Hydraulic radius for the bed and plants, ft or m
R_w	Hydraulic radius for the walls, ft or m
S	Bed or energy slope, dimensionless
S_o	Bed slope , dimensionless
S_f	Energy slope, dimensionless
V	Mean channel velocity, ft/s or m/s
V_P	Local plant approach velocity in front of the leaf mass, ft/s or m/s
V_*	Shear velocity, $V_* = (g R_h S)^{1/2}$, ft/s or m/s
V_*/V	Resistance coefficient, dimensionless

Y_o Flow depth, ft or m

W_e Equivalent average plant width, $W_e = A_i / H'$, ft or m
dy/dx Unit change in slope of the water surface

γ Specific weight of water, lbf/ft^3 or N/m^3

ν Fluid dynamic viscosity, ft^2/s or m^2/s

ρ Fluid density, $slugs/ft^3$ (lbf-sec/ft) or kg/m^3

τo Shear stress on channel bottom, ($\tau o = \gamma Rh S$), lbf/ft^2 or N/m^2

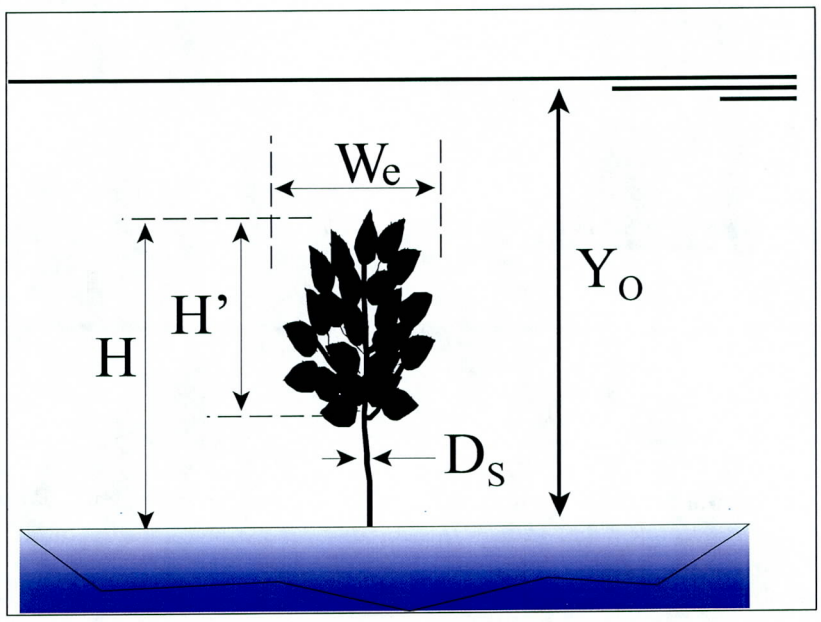

Figure 1. Plant dimension definitions for submerged plants

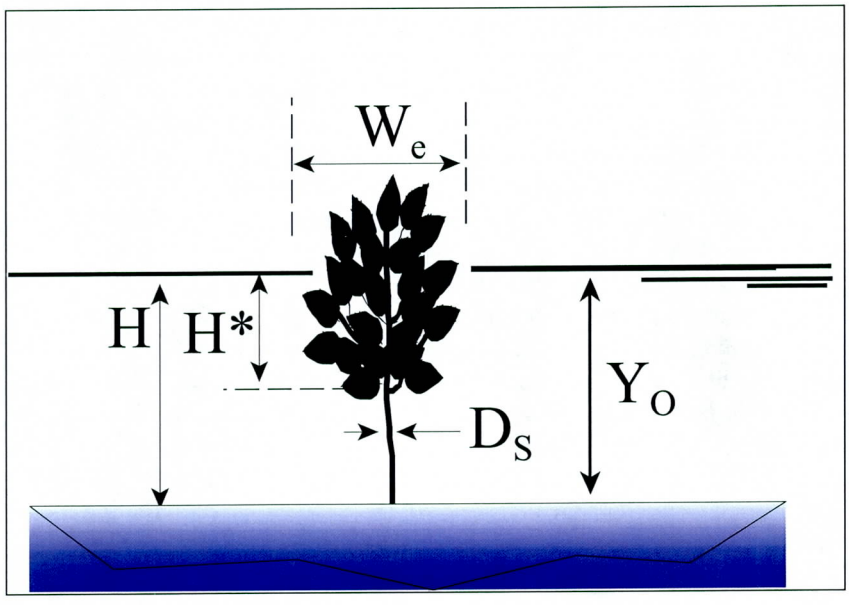

Figure 2. Plant dimension definitions for partially submerged plants

1 Introduction

Background

An important consideration for determining the stage-discharge relationship in rivers and streams is the effect or influence of vegetation on the overall head loss along a channel and in the overbank. Plants in the floodplain and along the banks can increase or even decrease the effective flow resistance. The vegetation may be natural or it may have been planted to improve aesthetics or habitat, to prevent erosion, or for other reasons.

The impetus for this study came as a result of numerous inquiries from U.S. Army Corps of Engineer District offices regarding the proper hydraulic roughness values to use for shrubs and other aesthetically and environmentally desirable plants. The District offices were involved in the evaluation of vegetative impacts on proposed and existing channels to determine flow capacity and water surface elevations. Given the near complete lack of hydraulic roughness values for shrubs and similar vegetation, the accurate estimation of channel capacity and water surface elevations was difficult at best. The work described herein was carried out under the Flood Control Channels and Flood Damage Reduction Research Programs starting in 1993 and completed in 1997. It was a direct result of District requests for research through the Flood Control Channels Field Review Group

Previous research has been conducted on vegetation such as grasses, agricultural crops, and on the rigid blockage of cylindrical tree trunks. However, little had been studied on the resistance effects of plants and shrubs that are either submerged or partially submerged by turbulent flows. The flexible stems and varying shapes of plant leaf mass greatly complicate the understanding of this resistance. The deformation of plant shape with flow precludes the use of a constant blockage area or the density of plant frontal area in predicting resistance.

The purpose of this study was to investigate the effect of vegetation, particularly ground cover plants, small trees, and shrubs, on flow resistance. Hydraulic losses and drag due to actual plants were measured at the Utah Water Research Laboratory utilizing a large wide flume and a smaller sectional flume.

Research in the flume resulted in the collection of data from more than 220 experiments with 20 different plant species. Experiments were conducted with both homogeneous and mixed plant groupings. Single-stem and multiple-stem plants were included in the plant types evaluated. Plants with and without leaves were evaluated. Plant density, spacing, and size were varied in the experiments. Plants were evaluated over a range of velocities and depths.

A methodology was developed from the laboratory data to predict head loss and resistance coefficients as a function of slope and depth. Input data for the methodology can be collected from the field or estimated plant characteristics may be used.

Resistance Coefficients

Resistance to flow is typically characterized by a roughness coefficient. The most commonly used equation for flow resistance is the Manning's equation:

$$V = \frac{K_n}{\mathrm{n}} R_h^{2/3} S^{1/2} \quad (1)$$

where

V = mean velocity of flow

R_h = hydraulic radius

S = slope of the energy grade

n = Manning's resistance coefficient

K_n = unit correction factor of 1.0 for SI units and 1.486 for non-SI units

Although Manning's equation is used extensively for calculating flow resistance, Manning himself did not recommend it for use, because his research found that n was not constant but varied with velocity and depth.

The ratio of shear velocity to mean velocity, V_*/V, is another form of resistance coefficient. Keulegan (1938) used it to calculate average velocity based on the theoretical vertical velocity profile. The ratio of shear velocity to average velocity may be thought of as the ratio of shear stress to inertial force as indicated in Equation 2.

$$\frac{V_*}{V} = \frac{\sqrt{gR_hS}}{V} = \left(\frac{\tau_o}{\rho V^2}\right)^{1/2} \quad (2)$$

V_* is the shear velocity, g is the acceleration due to gravity, τ_o is the shear stress, and ρ is the density of water.

There are other resistance coefficients in use including the Darcy-Weisbach friction factor, f, and the Chezy C. These can be converted easily to Manning's n as shown in Equation 3.

$$\frac{V_*}{V} = \sqrt{\frac{f}{8}} = \frac{n}{K_n}\sqrt{\frac{g}{R_h^{1/3}}} = \frac{\sqrt{g}}{C} \quad (3)$$

Note that the Chezy coefficient is not dimensionless, and will vary with units. The Manning coefficient is dimensionless only in the sense that K_n will make it dimensionless when units of feet or meters are used in Equation 3.

In this study, resistance equations were developed for the shear velocity to average velocity ratio because it is dimensionless and has a sound theoretical basis, and for the Manning's coefficient because its use is widespread.

The Manning's resistance coefficient for vegetation is calculated in conformity with the Cowan (1956) method for additive resistance. This method consists of additions to roughness for various surface irregularities and vegetation. The equation that describes the method is:

$$n = (n_o + n_1 + n_2 + n_3 + n_4)m \quad (4)$$

where n_o is the base value for a straight, uniform, smooth channel in natural materials; n_1 is an additive value to account for surface irregularities; n_2 is added to account for variations in the channel geometry along the reach; n_3 is an additive value to account for obstructions; n_4 accounts for vegetation; and m is a correction factor for meandering or sinuosity of the channel. The n_4 coefficient used in Cowan's method is based on the net effect of vegetation.

Many published values of Manning's roughness coefficients related to vegetated surfaces include the base resistance, n_0, as a part of the reported vegetation resistance. This is the convention followed in this report. Thus, roughness coefficients reported herein include the effects of both the bed and the vegetation. In Cowan notion this would be expressed as $n = n_0 + n_4$.

The resistance values can be composited into channel averages using several methods. One of the methods is Lotter's 1933 method shown in Equation 5. The Lotter method, presented by Chow (1959), uses vertical bisecting lines to subdivide the channel cross section into subareas for the calculation of flow. This method assumes that the total flow is the sum of the flows in the separate subareas. The equivalent resistance thus developed accounts for the variability in resistance across the channel.

$$n = \frac{PR_h^{5/3}}{\sum_{i=1}^{N}\left(\frac{P_i R_{hi}^{5/3}}{n_i}\right)} \quad (5)$$

P is the wetted perimeter. N is the number of i subsections.

Substitution of Equation 5 into Equation 3 yields a dimensionless compositing equation for V_*/V given in Equation 6.

$$\frac{V_*}{V} = \frac{PR_h^{3/2}}{\sum_{i=1}^{N}\left(\frac{P_i\ R_{h_i}^{3/2}}{\left(V_*/V\right)_i}\right)} \tag{6}$$

Resistance Equation for Large Woody Vegetation

Usually, vegetation on the flood plains is larger than that found in the main channel. This vegetation has a major influence on flow depth and resistance during overbank flooding. Petryk and Bosmajian (1975) proposed a method to calculate flow resistance based on the drag forces created by the larger plants and trees that constitute much of the resistance on the flood plains. They derived Equation 7 for Manning's n by summing the forces in the longitudinal direction. The forces include pressure forces, the gravitational force, shear forces, and the drag forces.

$$n = n_o\sqrt{1.0+\left(\frac{C_D\sum A_i}{2g\,A\,L}\right)\left(\frac{K_n}{n_o}\right)^2\left(\frac{A}{P}\right)^{4/3}} \tag{7}$$

Here C_D is the effective drag coefficient for the vegetation in the direction of the flow, A is the cross-sectional area of the flow, in ft^2, ΣA_i is the total frontal area of vegetation blocking the flow in the reach, in ft^2, L is the length of the channel reach being considered, in ft. The expression $C_D\Sigma A_i/(AL)$ represents the vegetation blockage, or the density of vegetation in the floodplain. This expression must be either directly or indirectly measured. The total boundary roughness, n_o, excludes the additive resistance, n_4, for other types of vegetation such as shrubs.

There are several limitations to using Petryk and Bosmajian's equation. The channel velocity must be small enough to prevent bending or distortion of the vegetation, and large variations in velocity cannot occur across the channel. Vegetation such as grasses and shrubs are then excluded. Vegetation must also be distributed relatively uniformly in the lateral direction. Finally, according to Petryk and Bosmajian, the flow depth must be less than or equal to the maximum vegetation height. During flooding, the velocities over the floodplains can be relatively high and large degrees of bending and distortion of vegetation often occur. Vegetation types and densities can also vary widely across a floodplain, and water depths often submerge vegetation. However, when tree trunks dominate sections of a floodplain, this method can be used to predict the total resistance coefficient, n.

2 Laboratory Setup and Procedures

Experimental Plants

Two flumes at the Utah Water Research Laboratory were used for laboratory experiments during this study. The large flume (Figure 3), 2.44 m (8 ft) wide by 1.82 m (6 ft) deep by 152.4 m (500 ft) long, was used to measure in situ flow resistance and drag force for groups of uniform sized plants and groups of mixed plants with varying plant density, sizes, and shapes. A sectional flume, 0.91 m (3 ft) wide by 0.91 m (3 ft) deep, was used to measure drag force of individual plants. Thirteen different plant types were evaluated in the large laboratory flume and 10 plant types in the sectional flume. Six combinations of plants typical of different ecosystems were also studied in the large flume. In total, 21 different plant types were evaluated in the two flumes. The plants and their characteristics are listed in Table 1. Field measurements of plant stiffness (Freeman 1997) for four plant types are also listed in Table 1. All plants evaluated were broadleaf deciduous vegetation commonly found in floodplain and riparian zones.

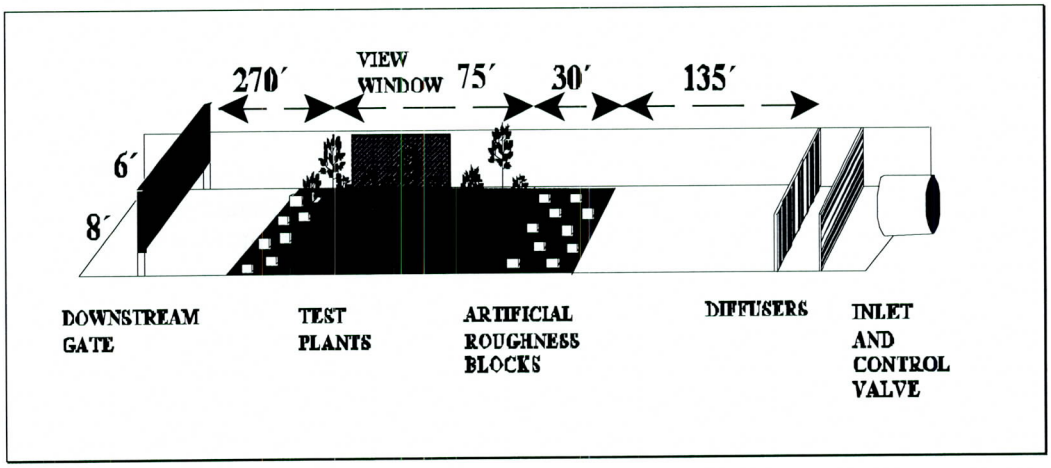

Figure 3. Layout of large flume for plant roughness experiments (To convert feet to meters, multiply by 0.3048)

The plants evaluated in the large flume were placed in staggered rows along the 22.9-m (75-ft) length of the experimentation section (Figure 3). The spacing selected for the plants was based on typical plant spacing found in floodplains. The plant density, M, was calculated as the number of plants per unit area. The plants evaluated in the small flume were placed in a single row of four to five plants along the center line of the flume. A single plant was instrumented for measuring drag force in both flumes. The instrumented plant in the larger flume was located in the center of the 22.9-m (75 ft) by 2.44-m (8-ft) experimentation section. The plant selected for measurement in the small flume was the downstream plant, with four plants located upstream. The experimental setup for the small flume allowed for a more accurate measurement of plant approach velocity (V_P) and drag force (F_D). Roots had to be removed from all the plants used in the small flume, but only the plant used to measure drag force in the large flume required root removal. All other plants in the large flume were placed intact, with root structure and original soil, into a 20.3-cm (8-in) deep experimental bed.

The range of variables measured in the large flume were:

a. Flow depths from 0.4 to 1.4 m (1.3 to 4.7 ft).

b. Average flow velocities from 0.15 to 1.1 m/s (0.5 to 3.6 ft/s).

c. Measured resistance V_*/V from 0.13 to 0.45 and n from 0.04 to 0.14.

d. Plant heights from 0.20 to 1.52 m (0.66 to 5 ft).

e. Plant widths from 0.076 to 0.91 m (0.25 to 3 ft).

f. Plant densities from 0.53 to 13 plants / m^2 (0.05 to 1.2 plants / ft^2).

g. Plant modulus of stiffness from 5.3×10^7 to 4.8×10^9 N/m^2 (1.1×10^6 to 1.0×10^8 lbf/ ft^2).

h. Reynolds numbers from 1.4×10^5 to 1.6×10^6.

Large Flume Experimental Setup

The large flume experimentation section had a bed that would accept plants with their root systems intact. In the first phase of the study, the bed consisted of a layer of gravel, to assist in drainage, covered with a cap of compacted clay. This material supported the plants and was intended to prevent them from washing downstream. In the second phase of the study, the compacted clay was replaced with a gravel bed and a mortar cap. The mortar cap greatly facilitated the changing of plants and experimental setups. The mortar cap had 158 3.8-L (1-gal) plant containers in the bed in staggered rows of four and five plants per row. When particular containers were not in use they were capped flush with the top of the mortar cap to prevent the introduction of additional roughness.

Upstream and downstream of the experimentation section the flume contained a section of roughened bed. The roughness elements consisted of cinder blocks that were adjusted until they produced a fully-developed turbulent velocity distribution upstream and downstream of the experimentation section.

At the beginning of each experiment, at the downstream end of the clay or mortar bed, stop logs were inserted to allow for slow filling of the flume. This was done to protect plants during filling. As discharge was slowly increased to the desired level, stop logs were removed. Some stop logs remained during the experiment to maintain a constant velocity profile throughout the experimentation section. At the downstream end of the flume, 91.4 m (300 ft) downstream of the experimental section, a hydraulic gate was used to control flow depth.

Water from the river adjacent to the laboratory entered the flume from a 122-cm (48-in) pipe 50.3 m (165 ft) upstream from the experimentation section. Water temperature was measured and found to be 10°C (50°F) for all experiments. A remote controlled butterfly valve in the 122-cm (48-in) pipeline was used to control the flow of water into the flume. A Mapco sonic meter was used to measure the flow rate in the inlet pipe. Downstream from the inlet pipe, jet flow was dissipated using a series of vertical and horizontal distribution vanes.

A wheeled platform that moved on tracks adjacent to the flume sides was used to take depth and velocity measurements. This platform was positioned at 1.52-m (5-ft) intervals along the length of the experimental section to facilitate measurements. Water-surface elevations were measured with the help of a stationary transit and a measuring rod along the center line of the flume. Flow velocities were taken with a Marsh McBirney Model 201 portable water current meter.

A single plant centered horizontally in the flume was selected to measure drag force. An average-sized plant was selected and inserted into a platform. The platform was a shallow metal box with ball bearings in the bottom and a metal plate resting upon the ball bearings as shown in Figure 4. The instrumented plant, with its roots removed, was attached to the plate. A Vishay Instrument Model P-350 strain indicator was then attached to the downstream end of the plate to measure the drag force applied to the plant by the moving water column. This drag force was measured as a compression force. During the experiment the platform was covered with a section of drain cloth to prevent soil from interfering with the ball bearings and movement of the plate. The platform was also covered with a plastic lid to reduce friction drag on the platform. The strain gage was zeroed at the start of each series of experiments. The range of the strain gage was 0 to 44.5 N (10 lbf). The sensitivity of the strain gage was 45 micro-cm per cm per N (200 micro-inches per inch per pound). Measurements were taken to the nearest 2.5 micro-cm (1.0 micro-inch.)

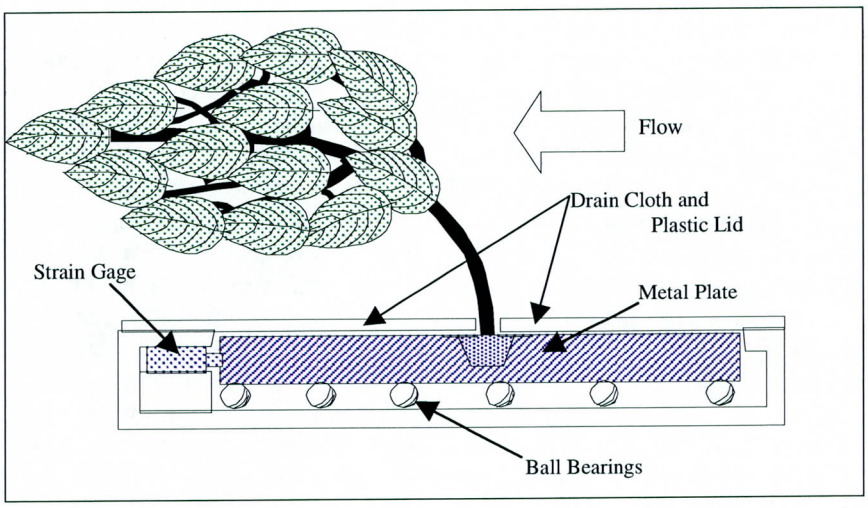

Figure 4. Experimental setup to measure plant drag

Large Flume Operating Procedures

Measurements were made of plant dimensions and plant characteristics before each series of experiments. Plant height and width, leaf size, and stem height were measured. The number of branches and stems were counted. The diameter of stems and branches was recorded, and bending characteristics were measured. The forces required to bend the plant 45 deg and horizontal at different heights along the stem were determined. A strain gage was first attached to the top of the plant. After the bending forces and deflection were determined there, the gage was hooked to the center of the plant and the bending forces were again measured.

During the first phase of the study, prior to beginning each series of experiments, the bed was leveled and a layer of topsoil placed and compacted on top of the clay bed. The mortar cap used in second phase of the study did not require maintenance and leveling for each series of runs. The plants were placed in the flume just prior to the experiment and the flume was slowly filled with water, with the stop logs in place and the downstream gate closed. With the flume filled and no flow, the strain gage was zeroed. Flow and depth were controlled with the downstream gate and the 122-cm (48-in) inlet butterfly valve. Time was allowed for the flume to reach equilibrium before measurements were taken for each run.

Typically, nine runs were made for each series of experiments. The first three runs were made at high depths, with the flume nearly full, and at three different velocities. The next three runs were made at a medium depth, and the last three runs were made at a low depth. The plants were usually submerged, even at low depths, because the flow forces were adequate to bend the plants with the flow. Some runs were conducted near the end of the study with the larger plants partially submerged, to aid in determining a relationship for partially submerged plants.

Water-surface elevation was measured at 1.52-m (5-ft) intervals along the length of the flume's experimentation section. At the midpoint of the experimental section, velocity measurements were taken at different depths to establish a vertical velocity profile. Velocity measurements were also taken at the center of the leaf mass just upstream of the plant used to measure drag force. The plant approach velocity was measured 5.1 cm (2 in) upstream of the instrumented plant to avoid making a measurement in what could have been a stagnation region at the upstream face of the plant. It was determined early in the study that velocity measurements taken in the plant mass and at the upstream face of the plant were inconsistent because of the interference of individual leaves, but the velocity measurements did show that there was still substantial velocity and flow through the plant mass. Drag force was determined from the strain gage measurements for many, but not all, experimental runs. As the depths and velocities were varied, the plants and bed (for Phase I) were observed through the view window to document soil movement, plant distortion, and plant failure.

Small Sectional Flume Setup

A smaller sectional flume was used to study the drag forces developed on single plants. Water was supplied by a 0.914-m- (3-ft-) wide by 0.914-m- (3-ft-) high channel running perpendicular to the flume entrance. A baffle was placed at the entrance of the flume to straighten the incoming flow and a Plexiglas observation window was installed in the side of the flume.

Since the bottom of the flume consisted of smooth steel, it was necessary to devise a method to secure the plants in the flume. A 3.81-cm- (1½-in.-) thick false deck was constructed of smooth, painted plywood. The deck was bolted through the bottom of the flume and sealed with silicon caulk. Several 2.54-cm (1.0-in) holes were drilled through the plywood to the steel bottom. These holes were designed to hold plants in a layout that would create a flow regime around the plant similar to the flow regime of the plant in the large flume.

To attach the plants to the flume bottom, a beveled rubber grommet and wide-flanged washers were used. The roots of the plants were cut off at the base of the stem, and the plant stem inserted through the washer into the grommet. The rubber grommet was used to protect the base of the stem and prevent breakage of the stem. Without the grommet, the plant tended to break where the stem contacted the surface of the plywood floor when the plants were subjected to high velocities. The rubber in the grommet would give slightly, however, allowing the plant to bend a small amount at the base rather than shear off against the sharp edges of the plywood floor. This is similar to the conditions that the plant experiences in the field with soil around its base. The wide flanged washers had two holes that allowed the grommet to be attached to the plywood floor with screws. The beveled grommet was slightly larger than the holes and when the screws were tightened, the washer compressed the grommet into the hole, securing the plant to the floor of the flume.

The instrumented plant in the small flume also had a grommet, but was attached to a smooth aluminum plate rather than the plywood floor. The plate

was 15.2-cm (6-in) wide by 30.5-cm (12-in) long and 2.54-cm (1-in) thick. The plate provided a platform by which to measure the drag force produced on the plant. A hole was drilled in the plate and a shorter grommet was used because the plate was not as thick as the false deck. The plant was inserted through the washer and the grommet screwed to the plate in the same method as with the other plants.

To allow placement of the plate into the flume floor, a 16.5-cm (6-½ in.) by 31.8 cm (12-½ in.) rectangle was cut in the center of the floor along the center line of the flume. Since the floor was 3.81-cm (1-½ in.) thick, 1.27-cm- (½-in.-) diam ball bearings were placed directly on the smooth steel floor where the plywood was removed. This allowed the plate to move smoothly on the steel deck. It also raised the top of the plate to a height of 3.81 cm (1-½ in.), exactly flush with the rest of the floor. This prevented the water from striking the face of the plate and adding to the measured drag force.

The same strain gage used in the large flume experiments was used in the small flume. It was placed and centered directly behind the aluminum plate to measure the drag force as compression. The gage and connections were sealed in waterproof bags. The strain gage was temperature compensating and always zeroed in place and underwater. The calibration of the gage was checked before each series of experiments.

Elastic bands or springs were attached to both the plate and the plywood floor immediately downstream and to the sides of the plate. This held the plate firmly in contact with the strain gage and centered in the floor cavity.

Velocity measurements were made using a propeller type Ott velocity meter. Velocity measurements were taken at the center of the leaf mass just upstream of the instrumented plant.

Small Sectional Flume Operating Procedures

Measurements were made of plant dimensions and plant characteristics before each series of experiments. Plant height and width, leaf size, and stem height were measured. The number of branches, stems, and leaves were counted. The diameter of stems and branches was recorded, and bending characteristics were measured.

The roots of the plants were then removed and attached to either the plywood floor or the aluminum plate. Stop logs were placed to a height of 0.914-m (3 ft) at the downstream end of the flume. This allowed the flume to be completely filled and the strain gage set to 0 to compensate for any buoyancy effects.

Each plant was subjected to a series of 10 runs. Each run was at an increasing velocity, ranging from approximately 0.076 to 2.43 m/sec (0.25 to 8 ft/sec.) During each run, the velocity directly upstream of the plant and the compression on the strain gage were recorded. This velocity was taken at the center line of the effective leaf area. As velocity increased, the velocity probe

was lowered to compensate for plant bending. This insured that the velocity of each run was being recorded at the vertical center line of the leaf mass. The angle the plant deflected was determined from marks drawn on the sidewalls of the flume. Videotapes were taken to allow for more detailed observation of the plants at a later time.

After the plant was subjected to 10 different velocities, all leaves were removed. The plant was then immediately subjected to 10 more runs. Velocity, drag, and deflection data were again recorded as previously described.

3 Results and Analysis

Resistance Coefficients from Head Loss Measurements

Twenty-one different series of experiments were completed in the large flume using different plant types, plant combinations, plant heights, plant spacings, flow velocities, and depths. Plant characteristics are listed in Tables 1 and 2 in SI and non-SI units, respectively. The runs were videotaped as well as photographed. One run was made to determine the bed roughness of the flume without plants on each bed type (clay and mortar).

Tables 3 and 4 present results from the large-flume homogeneous-plant-grouping experiments in SI and non-SI units, respectively. Tables 5 and 6 present the results from large-flume mixed-plant-grouping experiments in SI and non-SI units, respectively. Water-surface elevation, average depth, and discharge were measured. Average velocity was determined from the continuity equation. The average roughness coefficient came from an iterative solution of the backwater equation in which calculated water-surface elevations were matched to measured water-surface elevations. In the backwater equation, Equation 1 was used to determine n and Equation 2 to determine V_*/V. Average energy slope is presented in Tables 3-6. Flume wall effects were accounted for by the method advanced by Vanoni and Brooks (1957).

A typical velocity profile measurement is shown in Figure 5. The profile demonstrates the effect of leaf mass on velocity. The plant approach velocity is the velocity that occurred upstream at the center line of the leaf mass of the plant. The velocity significantly increased below the leaf mass. Velocity profile measurements are reported in Rahmeyer et al. 1996.

Average channel velocities between 0.914 and 1.22 m/s (3 and 4 ft/sec) were necessary to cause either the leaves to break off the plants or for the stems to break. These velocities also caused significant movement of bed material in the Phase I experiments. It is possible that many of the leaf and stem failures may have been due to the impact from large bed material, i.e., gravel size particles, being transported by the flow.

Another observation was that shrubs with open areas beneath the primary leaf mass were diverting significant amounts of flow beneath the leaf mass. In

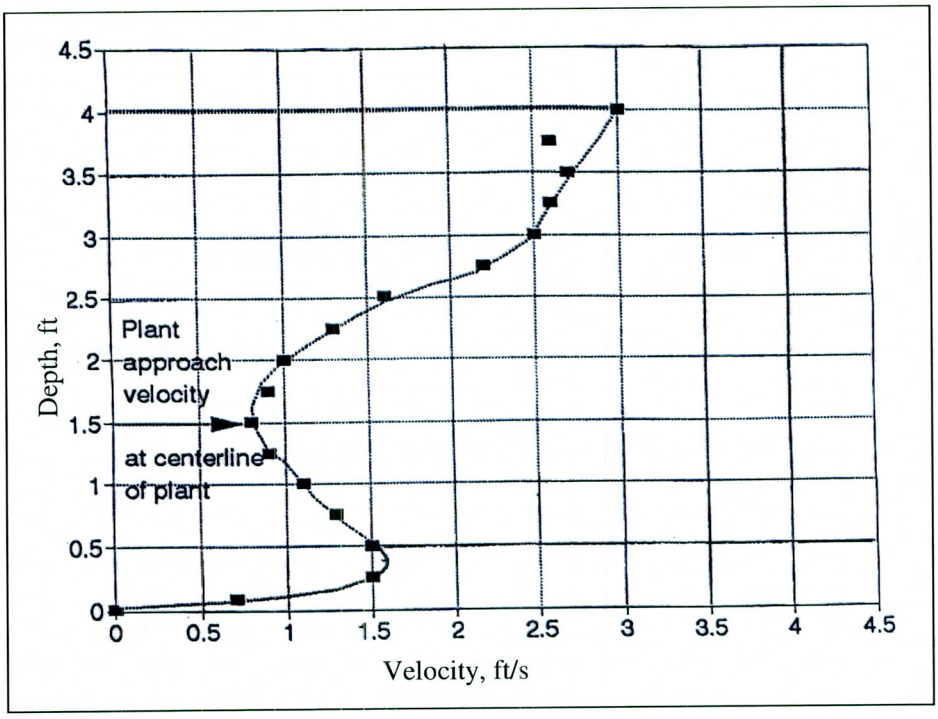

Figure 5. Example velocity profile for an experimental run with dogwoods (To convert feet to meters, multiply by 0.3048)

some cases velocities below the leaf mass approached surface velocities and were sufficient to transport even the largest size gravel particles.

The *Euonymus* plants were ground cover plants with leaves extending to the bed. These plants, when used in a typical spacing, left areas of the bed exposed to flow. Measurable scour was noted in these areas for all Phase I experiments. The *Euonymus* plant experiments were stopped when scour began to wash the plants away. Only the wire attached to the plant stems kept the plants from being washed downstream. It was observed that local scour was occurring from three-dimensional vortices that appeared to be similar to those typically associated with scour around bridge piers.

Figures 6-11 demonstrate the effect of velocity on plant deformation, sediment transport, and scour.

Calculation of Roughness Coefficients

The hydraulic roughness and the Manning's coefficient n for plant resistance were calculated by using an initial estimate of a total Manning's roughness coefficient and then adjusting the n value to best fit the gradually varied backwater curve of measured water-surface elevations along the experimental section. Equation 8 was the equation used to fit the backwater curve.

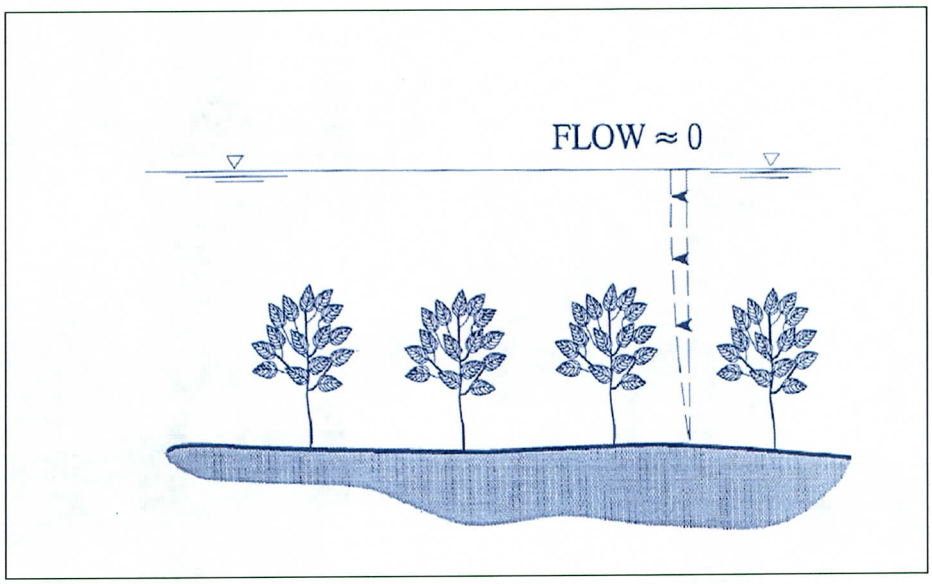

Figure 6. Plants at zero flow

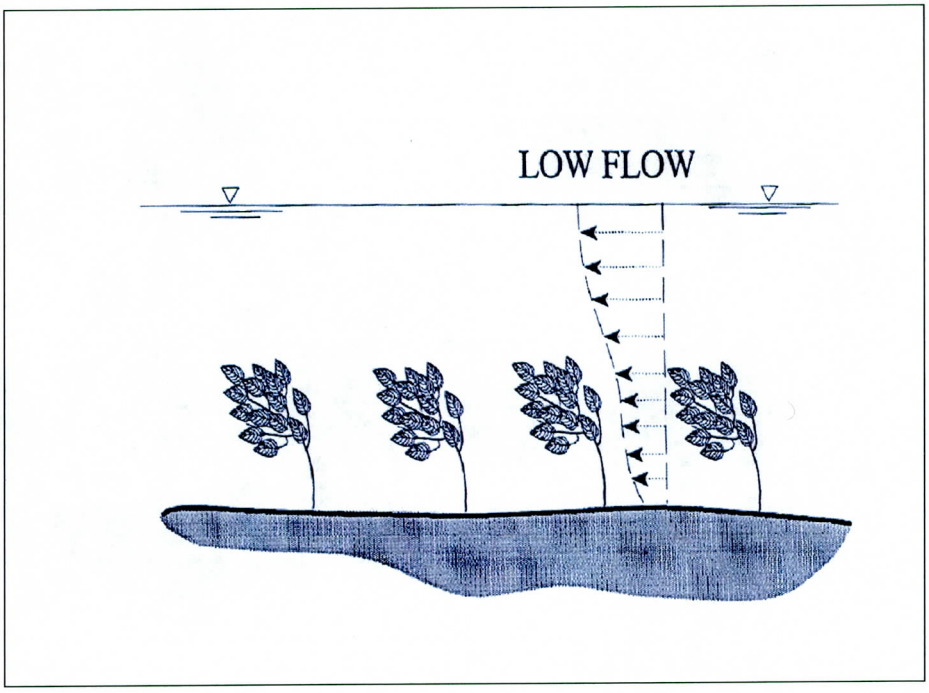

Figure 7. Plants at low flow

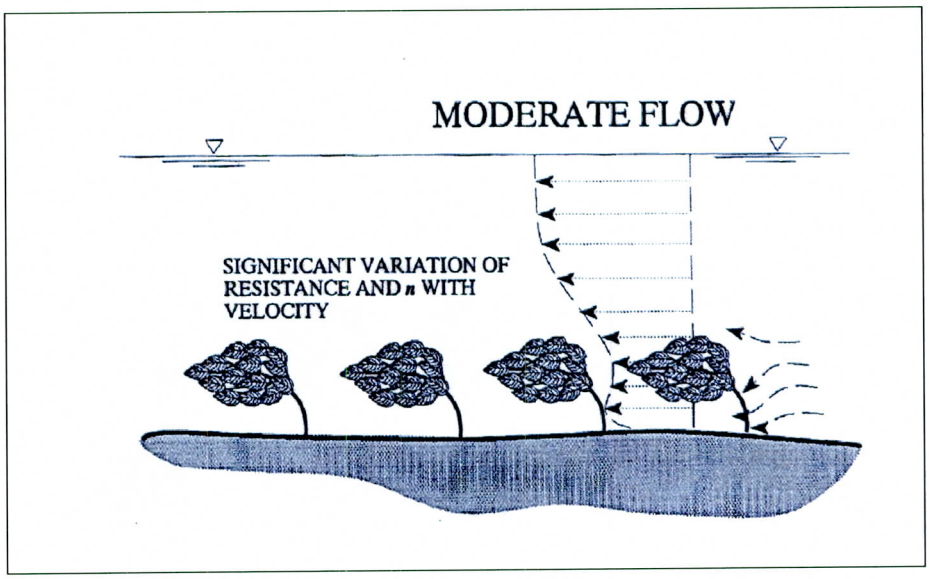

Figure 8. Plants at moderate flow

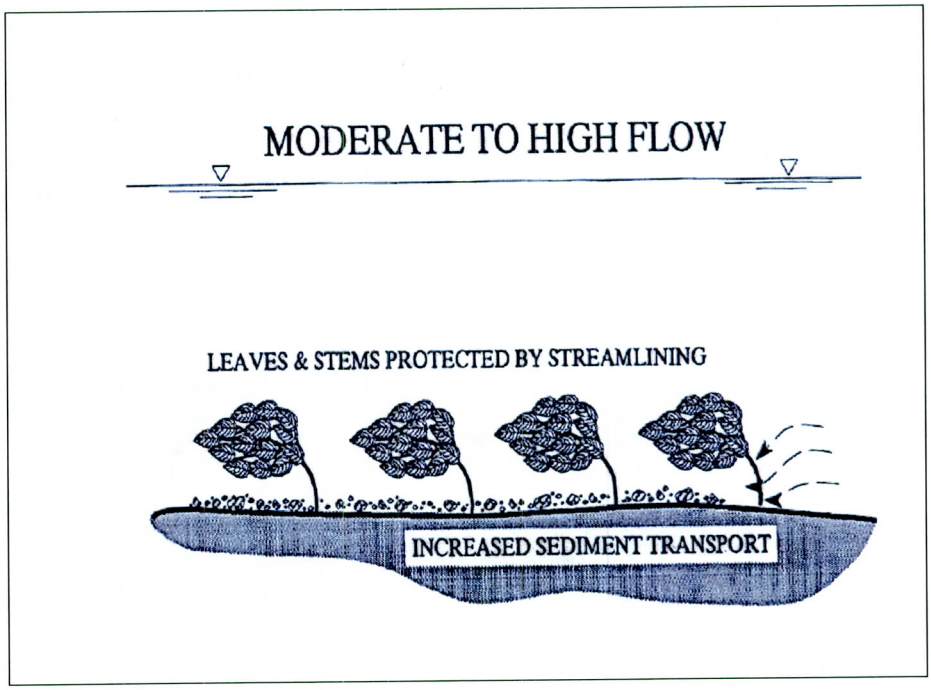

Figure 9. Plants with sediment transport

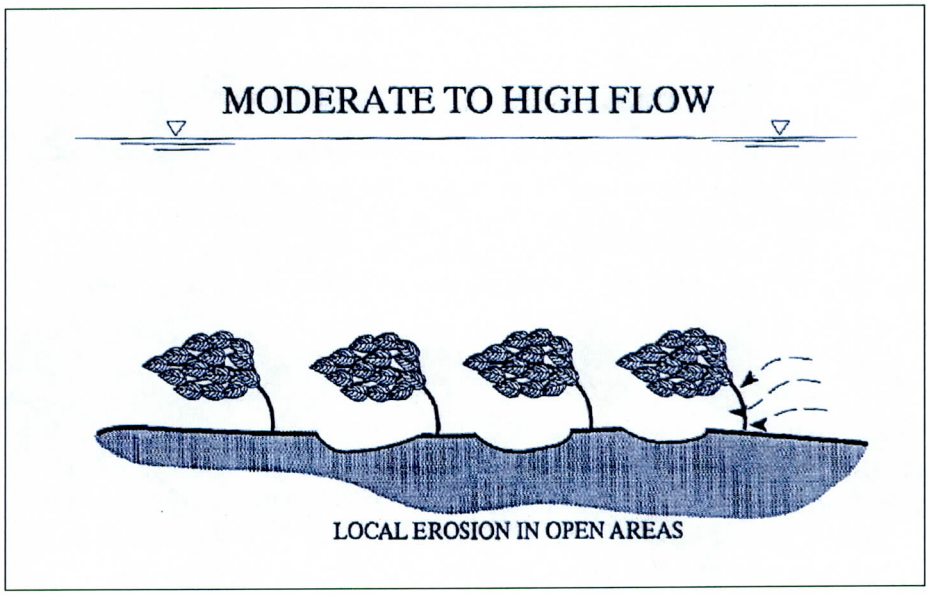

Figure 10. Plants with local erosion

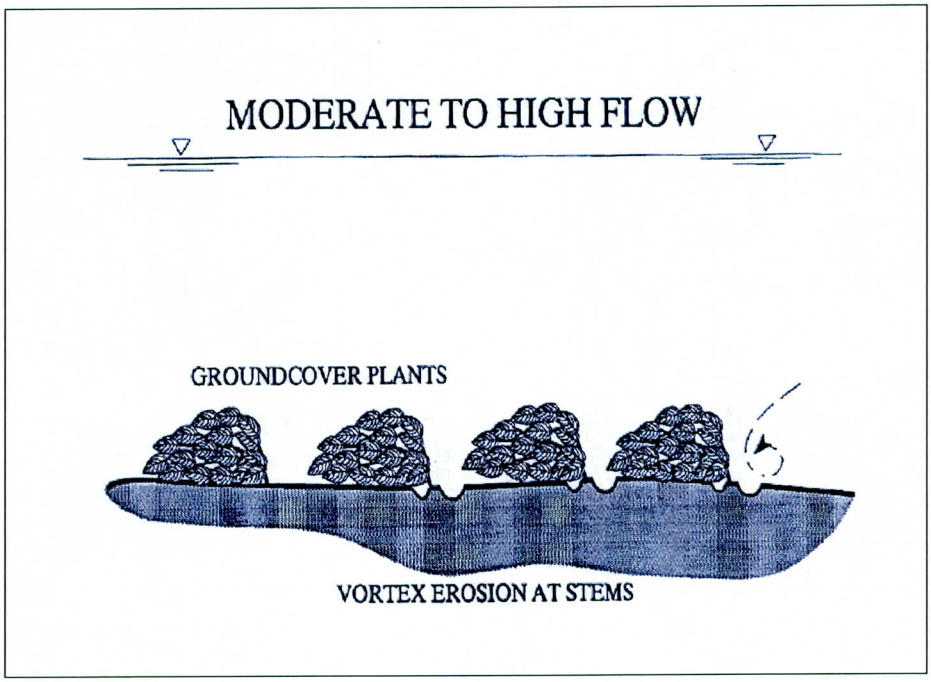

Figure 11. Plants with stem erosion

$$\frac{dy}{dx} = \left(\frac{S_0 - S_f}{1.0 - F_r^2} \right) \tag{8}$$

Here dy/dx is the unit change in slope of the water surface; S_o is the slope of the bed; S_f is the slope of the energy line; and F_r is the Froude number. S_f is calculated from the Manning's equation (Equation 1) using the estimate of Manning's n, the mean velocity, V, calculated from the continuity equation, and the hydraulic radius, R_h. The Froude number was calculated from Equation 9.

$$F_r = \frac{V}{\sqrt{g\ R_h}} \tag{9}$$

The Manning's n for the vegetation and the bed was then iteratively solved using a trial and error process until the shape of the backwater curve predicted by Equation 8 was the same as the measured curve of the actual water surface. Figure 12 is an example of the backwater curve fit for a run with a total Manning's n of 0.062.

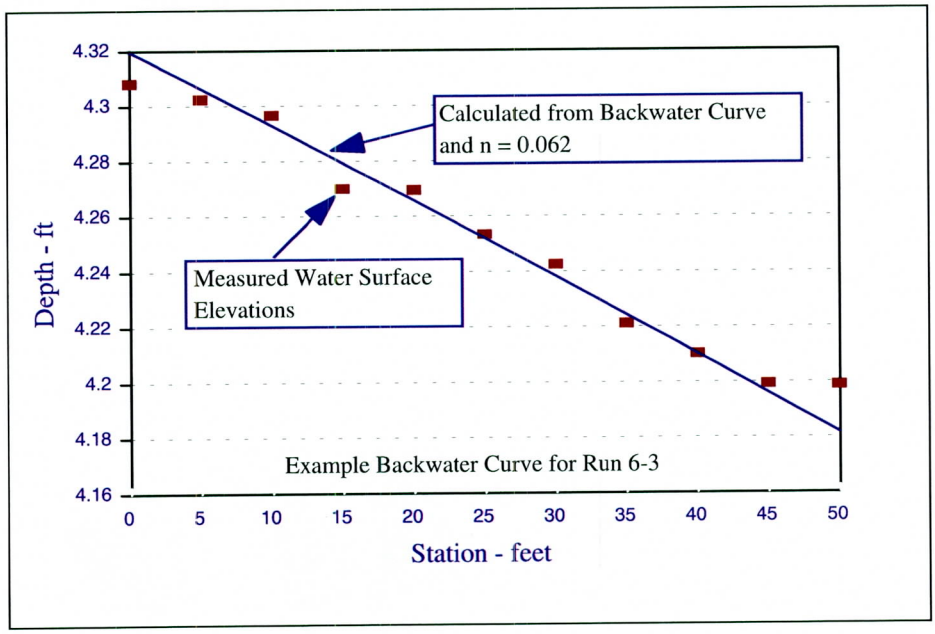

Figure 12. Typical backwater curve for experimental runs (To convert feet to meters, multiply by 0.3048)

From the total Manning's n the value of n_b, the bed and plant roughness, was determined. The first step in this determination was to convert the total n to a Darcy-Weisbach friction factor, *f*, by Equation 10.

$$\sqrt{f} = \frac{n\sqrt{8\,g}}{K_n\,R_h^{1/6}} \tag{10}$$

The coefficient of friction for the bed and plants, f_b, was determined using a correction for flume wall effects. The coefficient of friction for the walls, f_w, was determined from Equation 11. This equation was regressed for this study to fit the correction figure presented by Vanoni and Brooks (1957).

$$f_w = 0.274367\left(\frac{R_e}{f}\right)^{-0.175092} \tag{11}$$

R_e is the Reynolds number. Equation 11 was a power fit regression with an R^2 of 99.98 percent. The friction factor for the bed and plants, f_b, was then calculated with Equation 12.

$$f_b = f + \frac{2Y_o}{b}(f - f_w) \tag{12}$$

Here b is the width of the channel, and Y_o is the flow depth. The hydraulic radius associated with the bed and plants, R_b, was determined by Equation 13.

$$\frac{R_b}{f_b} = \frac{R_w}{f_w} = \frac{R_h}{f} \tag{13}$$

R_w is the hydraulic radius for the walls; and R_h is the total hydraulic radius. Equations 12 and 13 are from Vanoni and Brooks (1957). Finally, the Manning's coefficient n_b for the bed and vegetation roughness was calculated using R_b in Equation 1.

The coefficient n_b is the resistance of both the bed and vegetation roughness. Equation 14 can be used to calculate the resistance coefficient n_{veg} for the net resistance of the vegetation.

$$n_{veg} = n_b - n_o \tag{14}$$

where n_{veg} is the Manning's coefficient for vegetation; n_b is the bed and vegetation resistance; and n_o is the bed roughness. The value for n_o for both the clay and mortar beds (corrected for wall effects) was determined to be approximately 0.020. V_*/V was found to have a value of 0.069. Resistance coefficients reported in this report show the combined value for the bed and the plants. This combined value is typically reported in field investigations. Roughness coefficients reported herein may be reduced to strictly vegetation roughness coefficients by subtracting 0.020 from reported Manning's n values and 0.069 from reported V_*/V values.

Measured Drag Forces

Drag forces were measured in both the large and small flumes. More than 100 experiments were conducted in the small flume using 10 different plant types, and more than 20 experiments were conducted in the large flume using four plant types. Measured approach velocities and drag forces are shown in Tables 7 and 8 for the small and large flumes, respectively. Data from four different dogwood plants are plotted in Figure 13 showing the repeatability of drag force measurements between the large and small flumes. This is important because it demonstrated that the experimental data from the small flume could be directly compared to the plants and resistance coefficients determined in the large flume. In Figure 13, note that the drag force increases linearly with velocity instead of with the square of velocity as one would expect from the drag force equation (15). This occurred in the experiment because the drag coefficient and blockage area were reduced as the plant was streamlined by the increasing velocities.

$$F_D = \frac{\rho C_D A_i V_p^2}{2} \tag{15}$$

In Equation 15, F_D is the drag force, ρ is the density of water, C_D is the drag coefficient, V_P is the approach velocity, and A_i is the blockage area of an individual plant.

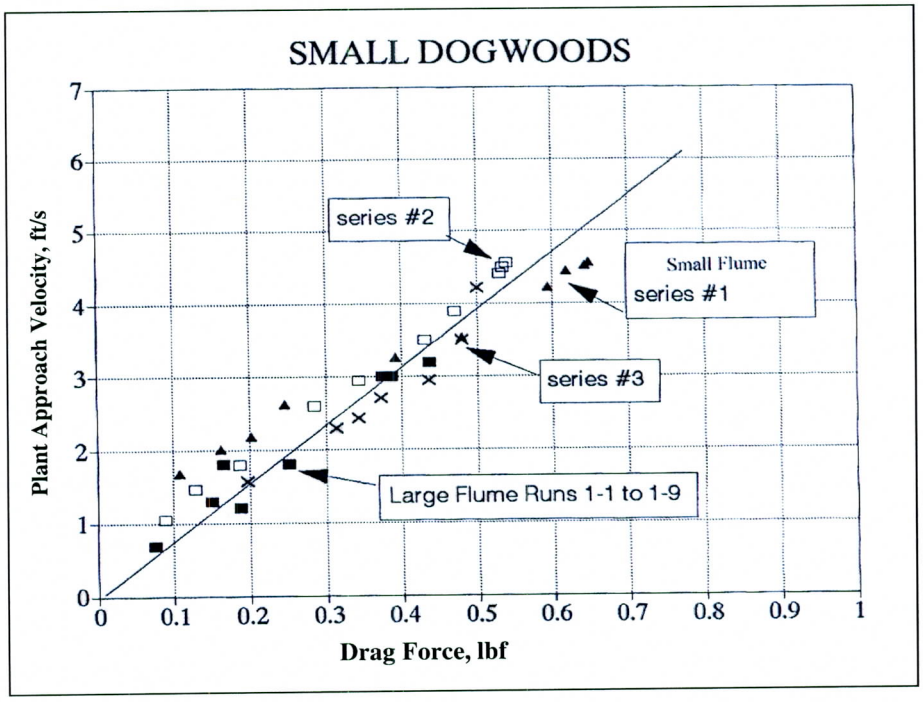

Figure 13. Plant approach velocity versus drag force (To convert feet to meters, multiply by 0.3048) [To convert pounds (force) to newtons, multiply by 4.448222]

The small flume had a large plastic window through which plant distortion could be viewed and measured. It was observed that the plants easily bent with the flow, and the leaf mass trailed downstream forming a streamlined, almost teardrop-shaped profile. The leaf mass changed with velocity and became more streamlined with increased velocity. This observation explains the significant decrease in resistance with increase in velocity. The changing shape of the leaf mass means that the roughness coefficient will change with velocity and that the assignment of a constant roughness coefficient to determine a stage-discharge curve would be invalid and produce significantly incorrect results.

If plant resistance were constant with increasing velocities, a plot of velocity versus drag force would appear as a smooth exponentially increasing curve. A typical curve from the data is shown in Figure 14. In this figure the drag varies almost linearly with velocity as the leaf mass continues to streamline. At a velocity of about 1.2 m/sec (4 ft/sec) the leaf mass has reached its streamlining limit and the curve begins to take on the expected exponential form. Above this limiting velocity it would be appropriate to assign a constant roughness coefficient.

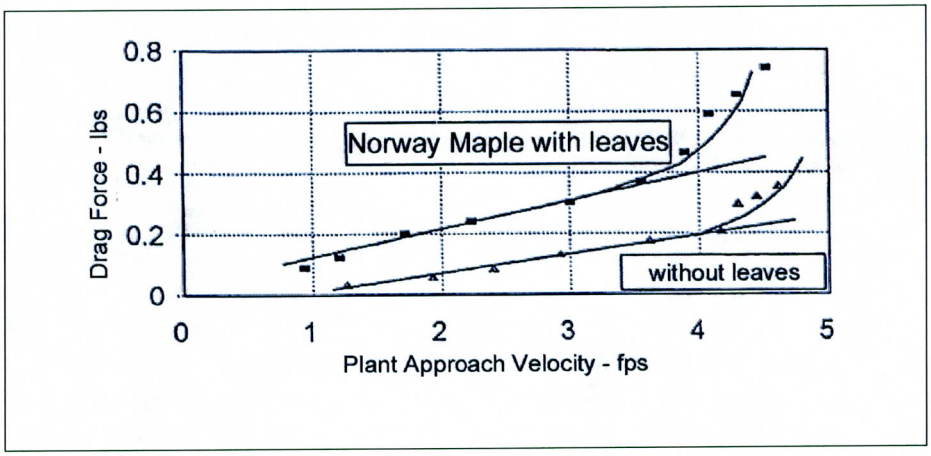

Figure 14. Drag force versus velocity (To convert feet to meters, multiply by 0.3048) [To convert pounds (force) to newtons, multiply by 4.448222]

Development of Resistance Methodology

The methodology developed in this report was based on the premise that the flow resistance due to vegetation on a floodplain is equal to the sum of the total drag forces produced by that vegetation. Kadlec (1990) presented such a hypothesis and, assuming that the drag forces on the bed are negligible, gave the following conceptual equation relating shear stress to drag force.

$$\tau_o = \sum \frac{F_D}{area} = F_D M \qquad (16)$$

where

area = total bed surface area of interest

τ_o = shear stress ($\tau_o = \gamma R_h S$)

M = plant density

The shear velocity V_* is related to shear stress, and a commonly used resistance coefficient that is associated with shear stress is V_*/V (Equation 2).

$$\frac{V_*}{V} = \frac{\sqrt{gR_hS}}{V} = \left(\frac{\tau_o}{\rho V^2}\right)^{1/2} \quad (2)$$

The shear velocity and shear stress can then be related to drag force by using Equation 17:

$$V_* = \sqrt{\frac{\tau_o}{\rho}} = \sqrt{\frac{F_D M}{\rho}} \quad (17)$$

Using Equations 15 through 17, an equation relating the drag coefficient, C_D, to the resistance can be developed.

$$\frac{V_*}{V} = \left(\frac{A_i \; M \; C_D}{2}\right)^{0.5} \quad (18)$$

The blockage area, A_i, of a plant with dense foliage is approximated by multiplying the effective plant height times the effective plant width ($H' \times W_e$). This effective area is the equivalent rectangular area of the leaf mass discounting small stems that are not part of the average leaf mass. For plants that have voids in their leaf mass or few leaves with a large number of stems, A_i is the rectangular area equivalent to the net frontal blockage. For example, plants without leaves would have a blockage area equal to the number of stems times the stem diameter times the stem length. Blockage areas for the laboratory experiments were determined from digital photographs of the plant against a white background marked with grid lines. H' is the actual height of the undistorted leaf mass and W_e is the effective width that produces the measured A_i.

It has been established that the drag coefficient for a rigid body is not a constant and varies with Reynolds number, R_e. The Reynolds number used in this study is based on the length variable of hydraulic radius, R_h, and the mean channel velocity. For flexible plants, the drag coefficient is a function of a number of factors as shown in Equation 19.

$$C_D = f\left(R_e,\ Y_o, H,\ \textit{plant type, plant shape, plant flexibility}, M\right) \quad (19)$$

The experimental data from both the large and small flumes were used to determine appropriate dimensionless parameters to define the drag force. These experiments were conducted for a large matrix of variables including Y_o, V, plant type, leaf density, plant density, plant shape, plant size, and blockage area. The runs were made in a sequence so that each variable could be evaluated by keeping the other variables constant. It was found that the drag coefficient decreased with an increase in velocity, depth, plant density, plant flexibility, and plant spacing. Drag coefficient or resistance could not be related solely to flow conditions, leaf density, or plant blockage because of the flexibility of the plants. For example, different plants with the same size leaves and blockage had significantly different resistance depending upon how much the plants deformed and bent with flow.

Dimensional analysis was used to aid in the selection of dimensionless parameters that could relate drag or resistance to flow and plant variables. The four parameters that were found to have a significant effect were as follows:

a. Ratio of the flow drag force to the forces resisting plant distortion.

b. Ratio of the flow depth to the plant height.

c. Blockage of the plants to the flow on the channel bottom.

d. Reynolds number.

The last three parameters are corrections or modifiers to the ratio parameter of drag force to the force resisting plant deformation. This ratio parameter also incorporates plant stiffness or flexibility. These parameters are shown in Equation 20.

$$C_D \text{ or } \frac{V_*}{V} = f\left(\frac{\rho V^2 A_i}{E_s A_s}, \frac{Y_o}{H}, M A_i, R_e\right) \tag{20}$$

When there are several stems emerging from the base of the plant, the stiffness modulus, E_s, is determined for a single stem. The stem area, A_s, is the sum of all the stem areas. The stem area for a plant with multiple stems is thus calculated as the number of stems times π times the stem diameter squared divided by 4.

Resistance Equation for Submerged Vegetation

The results from the large flume experiments were analyzed to determine the regression of the variables of Equation 20 for submerged vegetation. The regression analysis found that log and polynomial relationships gave a poor data fit while a power relationship had very good results. Equations 21 and 22 were found to fit the data with a regression coefficient of $R^2 = 96$ percent and a maximum scatter of 15 percent for predicted values of V_*/V with measured values. The parameters in the equations were modified to allow a direct solution

for resistance (for a given depth) by combining the original parameters with Manning's equation and the equation for shear velocity. This modification and combination of equations resulted in Equations 21 for shear velocity and Equation 22 for Manning's n.

$$\frac{V_*}{V}=\frac{\sqrt{g}}{C}=0.183\left(\frac{E_s A_s}{\rho A_i V_*^2}\right)^{0.183}\left(\frac{H}{Y_O}\right)^{0.243}(M\,A_i)^{0.273}\left(\frac{\nu}{V_* R_h}\right)^{0.115} \quad (21)$$

$$n=K_n\,0.183\left(\frac{E_s\,A_s}{\rho\,A_i\,V_*^2}\right)^{0.183}\left(\frac{H}{Y_O}\right)^{0.243}(M\,A_i)^{0.273}\left(\frac{\nu}{V_* R_h}\right)^{0.115}\left(\frac{1}{V^*}\right)(R_h)^{2/3}(S)^{1/2} \quad (22)$$

It is important to note that the plant characteristics H, A_i, and A_S are the initial characteristics of the plants without the effects of flow distortion. During the experiments, it was observed that since the plants bent with flow, submergence occurred when flow depths reached 80 percent of the plant height. Equations 21 and 22 are to be applied only for submerged flow defined by Y_o >0.8 H. Equations 23 and 24 are for partially submerged flow with Y_o <0.8 H. Both sets of equations converged to approximately the same result at the flow depth Y_o =0.8 H.

Resistance Equation for Partially Submerged Vegetation

The data for partially submerged vegetation were analyzed to determine the regression of the variables of Equation 20. The regression analysis again found that a log relationship gave a poor fit of data while a power relationship produced very good results. Equations 23 and 24 were found to fit the data with a regression coefficient of R^2= 85 percent and a maximum scatter of 18 percent for predicted values of V*/V compared to measured values. These equations again allow direct solution for resistance if the flow depth is known.

$$\frac{V_*}{V}=\frac{\sqrt{g}}{C}=3.487E-05\left(\frac{E_s A_s}{\rho A_i^* V_*^2}\right)^{0.150}\left(MA_i^*\right)^{0.166}\left(\frac{V_* R_h}{\upsilon}\right)^{0.622} \quad (23)$$

$$\mathrm{n}=K_n\,3.487E-05\left(\frac{E_s\,A_s}{\rho\,A_i^*\,V_*^2}\right)^{0.150}\left(M\,A_i^*\right)^{0.166}\left(\frac{V_* R_h}{\nu}\right)^{0.622}\left(\frac{R_h^{2/3}\,S^{1/2}}{V_*}\right) \quad (24)$$

The blockage area in Equations 23 and 24 was changed to an effective area, A_{i*}, since only a portion of the leaf mass produces blockage under partially submerged flow conditions. The effective blockage area can be approximated using Equation 25 if the actual geometry of the plant and leaf mass has not been measured (see Figure 2).

$$A_i^* = [Y_o - (H - H')] W_e \quad (25)$$

The analysis of data and the regression fit of Equations 21 through 24 included many other parameters and ratios. The equations, parameters, and methods developed by other researchers for a combined density and blockage of heavy ground cover and grasses did not produce satisfactory results. These methods included those developed by Kowen and Li (1980), Ree and Crow (1977), and other methods. It should be noted that some of the methods evaluated were not developed with shrubs in mind. In the case of Ree and Crow, agricultural crops were the focus of the methodology. Many of the equations developed by other researchers were evaluated, but none proved to be satisfactory in the prediction of roughness values for shrubs. The results of this study emphasize that the plant stiffness modulus, E_s, must be considered to obtain a satisfactory prediction of roughness. The definition and method to determine E_s are discussed in a following section.

Equations 21 through 24 also include plants with multiple stems. The blockage area A_i is for an individual or average plant, the plant density is the number of plants (not stems) per unit area, and A_s is the sum of the cross-sectional area of all of the stems of an individual average plant. Figure 15 shows the correlation of calculated V_*/V with the observed data from the flumes for submerged, partially submerged, multiple plant species.

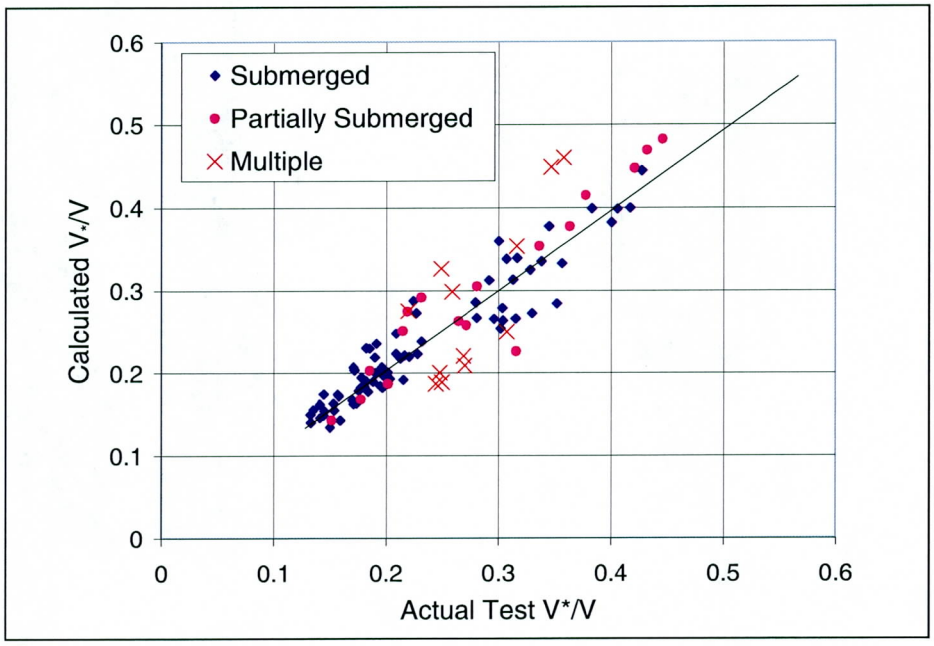

Figure 15. Comparison of calculated versus actual resistance V_*/V

Multiple Plant Combinations

Six combinations of plant types were evaluated. The combinations of species were selected to represent typical plant groups found in different ecosystems. Equations 21 through 24 worked equally well for plant combinations when average plant characteristics were used. The average plant characteristics were obtained by weighting individual plant characteristics by the number of plants per unit area or densities of each type of plant. The comparisons of calculated and observed data for multiple plant groupings are shown in Figure 15.

The purpose of the weighted averages is to formulate the average shear stress created by the plant combinations. Each plant group then will have an average blockage area or effective blockage area, an average modulus of plant stiffness, an average total plant stem area, an average plant height, and an average effective plant height. A weighted average for the plant groups is then based on the ratio of the plant density of each plant type divided by the total plant density of all the plants and plant types. Equations 21 through 24 do not use an average plant density, but use the total or combined density of all of the plants. The method for combining these densities is shown in the example that follows.

The plant characteristics are determined by weighting the individual plant characteristics according to their relative density in the area of interest. The weighted values are then summed to obtain the combined plant characteristic as shown in Equations 26-32.

$$A_{ave} = \sum_{i=1}^{N}\left(A_i \frac{M_i}{M_{total}}\right) \tag{26}$$

$$E_{s\,ave} = \sum_{i=1}^{N}\left(E_{s\,i} \frac{M_i}{M_{total}}\right) \tag{27}$$

$$A_{s\,ave} = \sum_{i=1}^{N}\left(A_{s\,i} \frac{M_i}{M_{total}}\right) \tag{28}$$

$$H_{ave} = \sum_{i=1}^{N}\left(H_i \frac{M_i}{M_{total}}\right) \tag{29}$$

$$H'_{ave} = \sum_{i=1}^{N}\left(H'_i \frac{M_i}{M_{total}}\right) \tag{30}$$

$$A^*_{i\,ave} = \sum_{i=1}^{N}\left(A^*_{i\,i} \frac{M_i}{M_{total}}\right) \tag{31}$$

$$M_{total} = \sum_{i=1}^{N} M_i \quad (32)$$

Using Equation 29, the average plant height for an area with a group of three plants with heights, H, of 0.5, 1.0, and 2.0 ft; and densities, M, of 0.25, 0.50, and 0.20 plants / ft^2; would be determined as follows:

$$Havg = H_1 \times M_1 / M_{total} + H_2 \times M_2 / M_{total} + H_3 \times M_3 / M_{total}$$

$$Havg = 0.5 \times 0.25 / (0.25+0.5+0.2) + 1.0 \times 0.5 / 0.95 + 2.0 \times 0.2 / 0.95$$

$$Havg = 0.132 + 0.526 + 0.421 = 1.079 \text{ ft}$$

Stiffness Modulus

The modulus of plant stiffness, E_s, is critical to the calculation of resistance because of the flexibility of the plants and the deformation of leaf masses due to the flow forces. The modulus of plant stiffness is calculated by Equation 33.

$$E_S = \frac{F_{45} H^2}{3 I} = 6.791 \left(\frac{F_{45} H^2}{D_S^4} \right) \quad (33)$$

The data necessary to use Equation 33 is obtained by measuring the force, F_{45}, necessary to bend the plant to an angle of 45 deg. The 45-deg angle is measured from the initial vertical position to the stem or leaf mass at the point where the force is measured, i.e., at H/2 as shown in Figure 16.

I is the second area moment of inertia calculated for a circular shape ($I = \pi D_s^4/64$). The stem diameter D_s is measured at a height of H/4 above the ground.

Data were collected both in the laboratory and in the field to determine a relationship that defined plant stiffness. Freeman (1997) collected data for five types of willows in floodplains and on sand bars to determine if stiffness in the field could be predicted from plant size parameters such as stem diameter and plant height to reduce the number of parameters that must be collected to determine the plant stiffness modulus. Data collected included samples from *Salix exigua* willows in Utah and Idaho, *Salix lasiandra, Salix lamonii*, a wild rose bush common to the area, and young cottonwood trees growing on sandbars. He also noted in his data collection efforts that plant stiffness was measurably different in the upstream and downstream directions in streams subject to long periods of high water (i.e., snow melt). Where the plants were not subject to velocities high enough to keep the plant bent and /or deformed for prolonged periods of time this difference in the stiffness modulus did not seem to exist or was not noticeable.

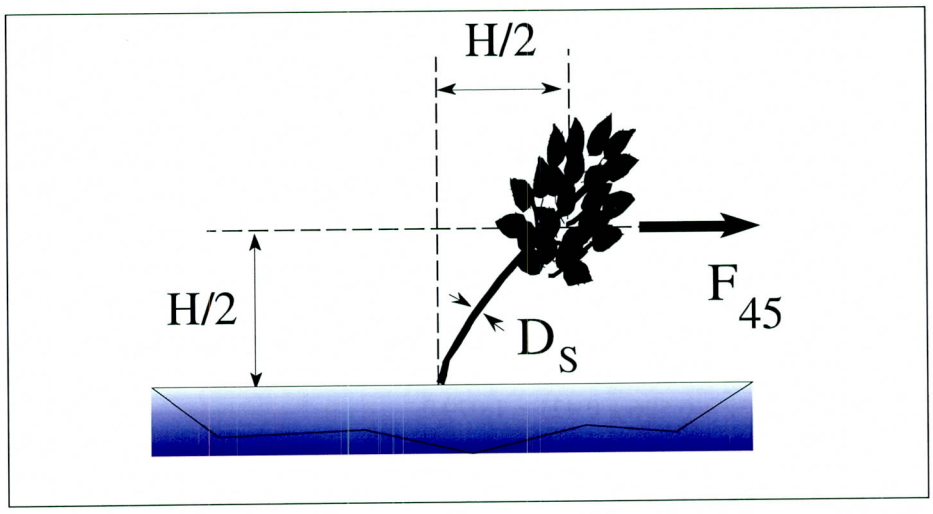

Figure 16. Methodology for measurement of plant stiffness for calculation of E_s in the field for plants with effective height of leaf mass approximately equal to the plant height

The research performed in the laboratory and in the field indicated that the stiffness modulus can be estimated from the relationship of E_s to the ratio of H/D_s. The analysis of measurements made in the field and in the laboratory led to the development of Equations 34 and 35 to explain the relationship between H/D_s and E_s. The relationship between the data observed in Freeman's field measurements (Freeman 1997, Freeman, et al. 1998) and the values predicted by Equation 34 is shown in Figure 17. Equation 34 (shown in Figure 17 as "Rahmeyer Predicted") was developed based on laboratory observations and gives the modulus in pounds per square foot while Equation 35 gives the value in newtons per square meter. It must be cautioned that the fit of Equations 34 and 35 have a regression (R^2) of less than 90 percent, and the scatter is significant as shown in Figure 17.

$$E_s\left(lbf/ft^2\right) = 1.597E05\left(\frac{H}{D_S}\right) + 454\left(\frac{H}{D_S}\right)^2 37.8\left(\frac{H}{D_S}\right)^3 \quad (34)$$

$$E_s\left(N/m^2\right) = 7.648E06\left(\frac{H}{D_S}\right) + 2.174E04\left(\frac{H}{D_s}\right) + 1.809E03\left(\frac{H}{D_S}\right) \quad (35)$$

Actual field measurements of E_s are recommended where possible. The stiffness modulus can also be estimated from measured values of similar plants. Since the stiffness modulus varies depending on the plant size, it was determined that if the calculated modulus for a particular plant size was divided by $(H/D_s)^{1.5}$, the stiffness modulus became independent of plant size and one value could be used for all plant sizes. Thus, to calculate the plant stiffness modulus for Alder, the value from Table 9 is multiplied by $(H/D_s)^{1.5}$ which gives the stiffness modulus

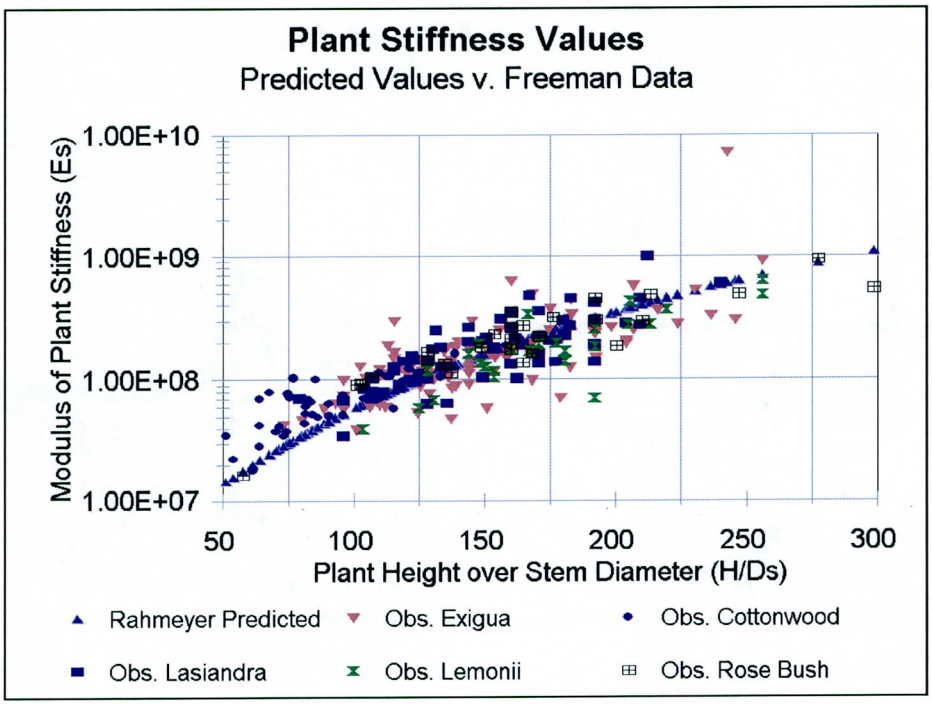

Figure 17. Measured versus calculated plant stiffness modulus, E_s

for a particular size plant in pounds per square foot. The exponent for the term H/D_s was determined to remove most effects of plant size from the Plant Stiffness Modulus.

4 Conclusions

A total of 20 different plant species were evaluated in either a large 2.44-m- (8-ft-) wide flume or a small 0.46-m- (1.5-ft-) wide flume to determine flow resistance and drag force. More than 220 experiments were conducted. Fifteen homogeneous plant groupings were evaluated in the large flume. Six multiple plant groupings were evaluated in the large flume. Vegetation was evaluated under both submerged and partially submerged conditions. Velocity, depths, plant density, plant dimensions, and plant types were varied in the experiments. The range of experimental conditions used to develop the regression equations were as follows:

a. Flow depths from 0.4 to 1.4 m (1.3 to 4.7 ft).

b. Average flow velocities from 0.15 to 1.1 m/s (0.5 to 3.6 ft/s).

c. Measured resistance V_*/V from 0.13 to 0.43 and n from 0.04 to 0.14.

d. Plant heights from 0.20 to 1.52 m (0.66 to 5 ft).

e. Plant widths from 0.076 to 0.91 m (0.25 to 3 ft).

f. Plant densities from 0.53 to 13 plants / m^2 (0.05 to 1.2 plants / ft^2).

g. Plant modulus of stiffness from 5.3×10^7 to 4.8×10^9 N/m^2 (1.1×10^6 to 1.0×10^8 lbf/ ft^2).

h. Reynolds numbers from 1.4×10^5 to 1.6×10^6.

An important observation made during the flume studies was that the plant leaf mass trailed downstream forming a streamlined, almost teardrop-shaped profile. The leaf mass shape changed with velocity and became more streamlined with increasing velocity. The effect of this phenomenon was a significant decrease in the drag coefficient and resistance coefficient with velocity. On the other hand, resistance increased with depth for partially submerged plants as the blockage area increased with depth until the plants were submerged. The transition between submerged and partially submerged flow occurred at a depth of about 80 percent of the undeflected plant height.

Another observation made during the study was that the leaf mass or foliage canopy diverted flow beneath the canopy. The bottom flow resulted in significant velocities along the channel bed causing general scour and increased sediment transport. The bed velocities were sufficient to transport and move the largest sizes of gravel found in the flume bed.

The hydraulic roughness of a vegetated channel was shown to be a function of the stiffness of the plants growing in the channel, the depth, velocity, and hydraulic radius of the channel, plant density, and frontal area of the plant obstructing the flow. It was determined that the roughness can be calculated directly if the depth of flow is known. The roughness can be determined in terms of Manning's n, Chezy C, or the shear velocity ratio, V_*/V.

Regression equations were developed for submerged vegetation and found to fit the data with a regression coefficient of $R^2 = 96$ percent and a maximum scatter of 15 percent for predicted values of V_*/V with measured values. The parameters in the equations were modified to allow a direct solution for resistance (for a given depth) by combining the original parameters with Manning's equation and the equation for shear velocity. This modification and combination of equations resulted in Equations 21 for shear velocity and Equation 22 for Manning's n.

$$\frac{V_*}{V} = \frac{\sqrt{g}}{C} = 0.183 \left(\frac{E_s A_s}{\rho A_i V_*^2} \right)^{0.183} \left(\frac{H}{Y_O} \right)^{0.243} (M\ A_i)^{0.273} \left(\frac{\nu}{V_* R_h} \right)^{0.115} \quad (21)$$

$$n = K_n\ 0.183 \left(\frac{E_s\ A_s}{\rho\ A_i\ V_*^2} \right)^{0.183} \left(\frac{H}{Y_O} \right)^{0.243} (M\ A_i)^{0.273} \left(\frac{\nu}{V_* R_h} \right)^{0.115} \left(\frac{1}{V^*} \right) (R_h)^{2/3} (S)^{1/2} \quad (22)$$

It is important to note that the plant characteristics H, A_i, and A_S are the initial characteristics of the plants without the effects of flow distortion. Equations 21 and 22 are to be applied only for submerged flow defined by $Y_o > 0.8$ H.

The experimental data for partially submerged vegetation were analyzed to develop regression Equations 23 and 24. These equations were found to fit the data with a regression coefficient of $R^2 = 85$ percent and a maximum scatter of 18 percent for predicted values of V_*/V compared to measured values. These equations again allow direct solution for resistance if the flow depth is known.

$$\frac{V_*}{V} = \frac{\sqrt{g}}{C} = 3.487E-05 \left(\frac{E_s\ A_s}{\rho\ A_i^*\ V_*^2} \right)^{0.150} \left(M\ A_i^* \right)^{0.166} \left(\frac{V_*\ R_h}{\nu} \right)^{0.622} \quad (23)$$

$$n = K_n\ 3.487E-05 \left(\frac{E_s\ A_s}{\rho\ A_i^*\ V_*^2} \right)^{0.150} \left(M\ A_i^* \right)^{0.166} \left(\frac{V_* R_h}{\nu} \right)^{0.622} \left(\frac{R_h^{2/3}\ S^{1/2}}{V_*} \right) \quad (24)$$

The blockage area in Equations 23 and 24 was changed to an effective area, A_{i*}, since only a portion of the leaf mass produces blockage under partially submerged flow conditions. The effective blockage area can be approximated using Equation 25 if the actual geometry of the plant and leaf mass has not been measured.

$$A_i^* = [Y_o - (H - H')] W_e \quad (25)$$

The resistance coefficients predicted by Equations 21 through 24 represent the combined resistance of the bed and the plants. Resistance coefficients due only to vegetation must be calculated by subtracting the bed resistance. In these experiments the Manning's bed resistance coefficient was found to be 0.02 and V_*/V for the bed was found to be 0.069.

The modulus of plant stiffness, E_s, is critical to the calculation of resistance because of the flexibility of the plants and the deformation of leaf masses due to the flow forces. The research performed in the laboratory and in the field indicated that the stiffness modulus can be estimated from the relationship of E_S to the ratio of H/D_s. The analysis of measurements made in the field and in the laboratory led to the development of equations to explain the relationship between H/D_s and E_s. The equations had a regression (R^2) of less than 90 percent. Actual field measurements of E_s are recommended where possible.

The stiffness modulus can also be estimated from measured values of similar plants. Since the stiffness modulus varies depending on the plant size, it was determined that if the calculated modulus for a particular plant size was divided by $(H/D_s)^{1.5}$, the stiffness modulus became independent of plant size and one value could be used for all plant sizes. Stiffness modulus' of plants used in this study are provided in Table 9.

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Table 1
Dimensions and Characteristics of Plants (SI Units)

Common Name	Scientific Name	Plant Height *H*, m	Plant Width *We*, m	Effective Height, *H'*, m	Blockage Area *A* m^2	Stem Diameter *Ds*, M	Stem Number	Elasticity *Es*, $N/m^2 x10^8$
Large Flume								
Yellow Twig Dogwood	*Cornus Stolonifera Flaviramea*	0.51	0.229	0.33	0.076	0.0095	1	3.210
Berried Elderberry	*Sambucus Racemosa*	0.71	0.356	0.51	0.181	0.0095	1	0.526
Purpleleaf Euonymus	*Euonymus Fortunei Colorata*	0.20	0.254	0.20	0.052	0.0063	2	4.140
Red Twig Dogwood	*Cornus Sericea*	0.97	0.482	0.76	0.368	0.0252	2	10.200
Service Berry	*Amelanchier*	0.71	0.178	0.51	0.090	0.0063	6	47.600
Yellow Twig Dogwood	*Cornus Stolonifera Flaviramea*	0.71	0.254	0.61	0.155	0.0095	2	29.900
Mulefat	*Baccharis Glutinosa*	0.97	0.076	0.51	0.039	0.0126	1	5.950
Alder	*Alnus Incana*	0.76	0.152	0.70	0.107	0.0079	1	17.000
Valley Elderberry	*Sambucus Mexicana*	0.97	0.762	0.91	0.697	0.0268	1	16.500
Salt Cedar	*Tamarix spp.*	1.52	0.61	1.37	0.836	0.0316	1	13.100
Black Willow	*Salix Nigra*	1.22	0.305	1.22	0.372	0.0189	1	1.500
Red Willow	*Salix spp.*	0.61	0.152	0.61	0.093	0.0095	1	4.500
Mountain Willow	*Salix Monticola*	1.52	0.914	1.22	1.115	0.0254	4	3.410
Small Flume								
Yellow Twig Dogwood	*Cornus Stolonifera Flaviramea*	0.51	0.229	0.33	0.076		0.0095	3.210
Purpleleaf Eunonyus	*Euonymus Fortunei Colorata*	0.20	0.254	0.20	0.052	0.0063	2	4.140
Artic Blue Williow	*Salix Purpurea Nana*	0.56	0.305	0.51	0.155	0.0126	1	1.190
Norway Maple	*Acer Platenoides*	0.71	0.305	0.30	0.093	0.0126	1	19.100
Common Privet	*Ligustrum Vulgare*	0.81	0.254	0.69	0.174	0.0126	1	3.940
Blue Elderberry	*Sambucus Canadensis*	0.53	0.457	0.41	0.186	0.0252	1	0.263
French Pink Pussywillow	*Salix Caprea Pendula*	0.91	0.254	0.25	0.065	0.0190	1	1.110
Sycamore	*Platenus Acer Ifolia*	0.91	0.203	0.84	0.170	0.0101	1	27.500
Western Sand Cherry	*Prunis Besseyi*	0.74	0.152	0.51	0.077	0.0084	1	28.800
Staghorn Sumac	*Rhus Typhina*	0.76	0.254	0.31	0.077	0.0126	1	5.080
Sand Bar Willow	*Salix exigua*	2.18		1.8	0.65	0.015	1	86.2
Pacific Willow	*Salix lasiandra*	2.39		2.0	1.98	0.017	1	99.0
Lemon's Willow	*Salix Lemonii*	2.13		1.7	0.38	0.013	1	86.0
Wild Rose Bush	*Rosa spp.*	1.18		.108	1.05	0.007	1	130.0

Table 2
Dimensions and Characteristics of Plants (Non-SI Units)

Common Name	Scientific Name	Plant Height *H*, ft	Plant Width *We*, ft	Effective Height, *H'*, ft	Blockage Area *A* Ft^2	Stem Diameter *Ds*, ft	Stem Number	Elasticity *Es*, lbf/ft^2
Large Flume								
Yellow Twig Dogwood	Cornus Stolonifera Flaviramea	1.67	0.750	1.08	0.818	0.0313	1	6.706
Berried Elderberry	Sambucus Racemosa	2.33	1.167	1.67	1.948	0.0313	1	1.099
Purpleleaf Euonymus	Euonymus Fortunei Colorata	0.67	0.833	0.67	0.560	0.0208	2	8.648
Red Twig Dogwood	Cornus Sericea	3.18	1.583	2.50	3.958	0.0833	2	21.308
Service Berry	Amelanchier	2.33	0.583	1.67	0.969	0.0208	6	99.436
Yellow Twig Dogwood	Cornus Stolonifera Flaviramea	2.33	0.833	2.00	1.666	0.0313	2	62.461
Mulefat	Baccharis Glutinosa	3.18	0.250	1.67	0.420	0.0420	1	12.430
Alder	Alnus Incana	2.50	0.500	2.33	1.150	0.0260	1	35.513
Valley Elderberry	Sambucus Mexicana	3.18	2.500	3.00	7.503	0.0879	1	34.469
Salt Cedar	Tamarix spp.	5.00	2.000	4.50	9.001	0.1040	1	27.366
Black Willow	Salix Nigra	4.00	1.000	4.00	4.005	0.0630	1	3.134
Red Willow	Salix spp.	2.00	0.500	2.00	1.001	0.0310	1	9.401
Mountain Willow	Salix Monticola	5.00	3.000	4.00	12.003	0.0840	4	7.123
Small Flume								
Yellow Twig Dogwood	Cornus Stolonifera Flaviramea	1.67	0.750	1.08	0.818	0.0313	1	6.706
Purpleleaf Eunonyus	Euonymus Fortunei Colorata	0.67	0.833	0.67	0.560	0.0208	2	8.648
Artic Blue Williow	Salix Purpurea Nana	1.84	1.000	1.67	1.669	0.0417	1	2.486
Norway Maple	Acer Platenoides	2.33	1.000	1.00	1.001	0.0417	1	39.900
Common Privet	Ligustrum Vulgare	2.67	0.833	2.25	1.873	0.0417	1	8.231
Blue Elderberry	Sambucus Canadensis	1.75	1.500	1.33	1.997	0.0833	1	0.549
French Pink Pussywillow	Salix Caprea Pendula	3.00	0.833	0.83	0.700	0.0625	1	2.319
Sycamore	Platenus Acer Ifolia	3.00	0.667	2.75	1.831	0.0333	1	57.448
Western Sand Cherry	Prunis Besseyi	2.43	0.500	1.67	0.829	0.0278	1	60.163
Staghorn Sumac	Rhus Typhina	2.50	0.833	1.00	0.829	0.0417	1	10.612
Sand Bar Willow	Salix exigua	7.15		5.91	7.09	0.0492	1	180
Pacific Willow	Salix lasiandra	7.84		6.56	21.31	0.0558	1	207
Lemon's Willow	Salix lemonii	7.0		5.58	4.09	0.0427	1	180
Wild Rose Bush	Rosa spp.	3.87		0.354	11.30	0.0230	1	272

Table 3
Summary of Large Flume Results with Homogeneous Groupings (SI Units)

Run	Plant	Plant Height *H*, m	Plant Density *M*, 1/m^2	Water Depth Y_o, M	Mean Velocity *V*, m/sec	Energy Slope *S*	Average *n*	Bed Hydraulic Radius *m*	Bed *V*/V*	Bed Manning's n
II 0-1	none			0.718	0.388	0.00013		0.562	0.069	0.0200
II 0-2	none			1.321	0.209	0.00002	0.016	0.884	0.064	0.0200
II 0-3	none			1.459	0.591	0.00015	0.016	1.011	0.069	0.0220
I 1-1	Yellow Twig Dogwood	0.51	5.360	1.271	0.366	0.00053	0.046	1.202	0.216	0.0710
I 1-2	Yellow Twig Dogwood	0.51	5.360	1.256	0.610	0.00124	0.042	1.184	0.198	0.0650
I 1-3	Yellow Twig Dogwood	0.51	5.360	1.122	0.750	0.00184	0.040	1.059	0.185	0.0590
I 1-4	Yellow Twig Dogwood	0.51	5.360	0.942	0.482	0.00119	0.047	0.902	0.213	0.0670
I 1-5	Yellow Twig Dogwood	0.51	5.360	1.021	0.588	0.00140	0.043	0.971	0.196	0.0620
I 1-6	Yellow Twig Dogwood	0.51	5.360	1.049	0.689	0.00163	0.040	0.991	0.183	0.0580
I 1-7	Yellow Twig Dogwood	0.51	5.360	0.536	0.878	0.00582	0.048	0.521	0.197	0.0560
I 1-8	Yellow Twig Dogwood	0.51	5.360	0.716	0.991	0.00477	0.041	0.688	0.181	0.0540
I 1-9	Yellow Twig Dogwood	0.51	5.360	0.887	1.091	0.00418	0.038	0.843	0.170	0.0530
I 2-1	Yellow Twig Dogwood	0.51	2.379	1.356	0.765	0.00102	0.031	1.232	0.145	0.0480
I 2-2	Yellow Twig Dogwood	0.51	2.379	1.149	0.924	0.00165	0.031	1.056	0.142	0.0460
I 2-3	Yellow Twig Dogwood	0.51	2.379	0.515	1.058	0.00693	0.040	0.499	0.174	0.0500
I 2-4	Yellow Twig Dogwood	0.51	2.379	0.396	0.750	0.00496	0.042	0.421	0.191	0.0530
I 3-1	Berried Elderberry	0.71	2.691	1.207	0.294	0.00030	0.042	1.134	0.195	0.0640
I 3-2	Berried Elderberry	0.71	2.691	0.983	0.479	0.00063	0.035	0.918	0.157	0.0500
I 3-3	Berried Elderberry	0.71	2.691	1.064	0.589	0.00085	0.034	0.989	0.154	0.0490
I 3-4	Berried Elderberry	0.71	2.691	0.953	0.304	0.00043	0.045	0.908	0.204	0.0640
I 3-5	Berried Elderberry	0.71	2.691	0.706	0.518	0.00125	0.040	0.676	0.176	0.0530
I 3-6	Berried Elderberry	0.71	2.691	0.782	0.614	0.00110	0.033	0.735	0.145	0.0440
I 3-7	Berried Elderberry	0.71	2.691	0.849	0.692	0.00123	0.032	0.793	0.141	0.0430
I 3-8	Berried Elderberry	0.71	2.691	0.816	0.769	0.00167	0.033	0.767	0.146	0.0450
I 3-9	Berried Elderberry	0.71	2.691	0.748	0.862	0.00199	0.031	0.702	0.136	0.0410
I 3-10	Berried Elderberry	0.71	2.691	0.915	0.945	0.00191	0.030	0.849	0.133	0.0410
I 4-1	Purpleleaf Euonymus	0.20	12.809	1.182	0.319	0.00041	0.045	1.120	0.209	0.0680
I 4-2	Purpleleaf Euonymus	0.20	12.809	1.195	0.420	0.00055	0.040	1.122	0.186	0.0600
I 4-3	Purpleleaf Euonymus	0.20	12.809	1.120	0.669	0.00159	0.042	1.063	0.195	0.0630

Table 3 (Continued)

Run	Plant	Plant Height H, m	Plant Density M, 1/m^2	Water Depth Y_o, M	Mean Velocity V, m/sec	Energy Slope S	Average n	Bed Hydraulic Radius m	Bed V^*/V	Bed Manning's n
I 4-4	Purpleleaf Euonymus	0.20	12.809	0.842	0.662	0.00225	0.045	0.810	0.202	0.0620
I 4-5	Purpleleaf Euonymus	0.20	12.809	0.887	0.766	0.00251	0.042	0.849	0.189	0.0590
I 4-6	Purpleleaf Euonymus	0.20	12.809	0.781	0.974	0.00408	0.041	0.751	0.178	0.0560
I 4-7	Purpleleaf Euonymus	0.20	12.809	0.491	0.817	0.00477	0.042	0.477	0.183	0.0520
I 5-1	Purpleleaf Euonymus	0.20	5.694	1.032	0.411	0.00053	0.038	0.968	0.172	0.0550
I 5-2	Purpleleaf Euonymus	0.20	5.694	1.034	0.632	0.00106	0.035	0.967	0.159	0.0500
I 5-3	Purpleleaf Euonymus	0.20	5.694	0.707	0.963	0.00436	0.040	0.680	0.177	0.0530
I 6-1	Red Twig Dogwood	0.97	1.216	1.263	0.323	0.00110	0.075	1.233	0.357	0.1190
I 6-2	Red Twig Dogwood	0.97	1.216	1.264	0.479	0.00213	0.070	1.233	0.336	0.1110
I 6-3	Red Twig Dogwood	0.97	1.216	1.296	0.611	0.00266	0.062	1.259	0.297	0.0990
I 6-4	Red Twig Dogwood	0.97	1.216	0.940	0.347	0.00204	0.085	0.925	0.390	0.1230
I 6-5	Red Twig Dogwood	0.97	1.216	0.757	0.609	0.00508	0.070	0.744	0.313	0.0950
I 6-6	Red Twig Dogwood	0.97	1.216	0.829	0.953	0.00582		0.804	0.225	0.0693
I 6-7	Red Twig Dogwood	0.97	1.216	0.537	0.683	0.00833	0.070	0.530	0.308	0.0890
I 6-8	Red Twig Dogwood	0.97	1.216	0.934	0.962	0.00540	0.050	0.905	0.227	0.0720
I 7-1	Red Twig Dogwood	0.97	0.527	1.184	0.348	0.00117	0.070	1.155	0.330	0.1080
I 7-2	Red Twig Dogwood	0.97	0.527	0.818	0.504	0.00322	0.070	0.803	0.316	0.0973
II 1-1	Service Berry	0.71	0.538	0.690	0.350	0.00145	0.063	0.676	0.280	0.0840
II 1-2	Service Berry	0.71	0.538	0.967	0.562	0.00180	0.050	0.933	0.228	0.0720
II 1-3	Service Berry	0.71	0.538	0.803	0.685	0.00229	0.043	0.771	0.192	0.0590
II 1-4	Service Berry	0.71	0.538	0.933	0.903	0.00276	0.038	0.886	0.171	0.0540
II 1-5	Service Berry	0.71	0.538	1.154	0.513	0.00132	0.050	1.108	0.234	0.0760
II 1-6	Service Berry	0.71	0.538	1.275	0.688	0.00157	0.042	1.206	0.198	0.0650
II 4-1	Yellow Twig Dogwood		1.830	1.358	0.145	0.00019	0.071	1.316	0.344	0.1150
II 4-2	Yellow Twig Dogwood		1.830	1.389	0.343	0.00059	0.053	1.330	0.254	0.0850
II 4-3	Yellow Twig Dogwood		1.830	1.261	0.608	0.00112	0.040	1.186	0.189	0.0620
II 4-4	Yellow Twig Dogwood		1.830	1.081	0.967	0.00201	0.032	1.003	0.144	0.0460
II 6-1	Mulefat	0.97	0.646	1.423	0.408	0.00040	0.037	1.314	0.177	0.0590
II 6-2	Mulefat	0.97	0.646	1.265	0.643	0.00095	0.035	1.173	0.162	0.0530
II 6-3	Mulefat	0.97	0.646	1.364	0.724	0.00103	0.033	1.252	0.154	0.0510

Table 3 (Concluded)

Run	Plant	Plant Height *H*, m	Plant Density *M*, 1/m^2	Water Depth Y_o, M	Mean Velocity *V*, m/sec	Energy Slope *S*	Average *n*	Bed Hydraulic Radius *m*	Bed *V*/V*	Bed Manning's n
II 6-4	Mulefat	0.97	0.646	1.072	0.791	0.00119	0.030	0.984	0.135	0.0430
II 9-1	Vally Elberberry	0.97	1.722	1.366	0.282	0.00099	0.083	1.337	0.418	0.1350
II 9-2	Vally Elberberry	0.97	1.722	1.330	0.427	0.00163	0.070	1.296	0.339	0.1130
II 9-3	Vally Elberberry	0.97	1.722	1.071	0.522	0.00267	0.068	1.047	0.317	0.1020
II 9-4	Vally Elberberry	0.97	1.722	0.914	0.621	0.00475	0.072	0.897	0.329	0.1030
II 10-1	Salt Cedar	1.52	0.624	1.430	0.416	0.00156	0.072	1.394	0.352	0.1190
II 10-2	Salt Cedar	1.52	0.624	1.378	0.580	0.00238	0.063	1.338	0.305	0.1020
II 10-3	Salt Cedar	1.52	0.624	1.116	0.716	0.00380	0.060	1.085	0.281	0.0910
II 10-4	Salt Cedar	1.52	0.624	0.933	0.685	0.00369	0.058	0.909	0.264	0.0830
II 10-5	Salt Cedar	1.52	0.624	0.844	0.750	0.00513	0.060	0.824	0.272	0.0840
II 10-6	Salt Cedar	1.52	0.624	0.827	0.935	0.00517	0.048	0.801	0.215	0.0660
II	Black Willow	1.22	2.293	1.416	0.313	0.00084		1.090	0.303	0.0980
II	Black Willow	1.22	2.293	1.426	0.551	0.00113		1.337	0.221	0.0740
II	Black Willow	1.22	2.293	1.388	0.763	0.00210		1.312	0.216	0.0720
II	Black Willow	1.22	2.293	0.680	0.688	0.00175		0.637	0.152	0.0450
II	Black Willow	1.22	2.293	0.906	0.910	0.00333		0.874	0.186	0.0580
II	Black Willow	1.22	2.293	0.821	0.789	0.00326		0.794	0.202	0.0620
II	Black Willow	1.22	2.293	0.776	0.726	0.00228		0.743	0.178	0.0540
II 13-1	Mountain Willow	1.52	4.844	0.678	0.628	0.00323	0.052	0.661	0.231	0.0690
II 13-2	Mountain Willow	1.52	4.844	0.605	0.704	0.00414	0.050	0.590	0.219	0.0640
II 13-3	Mountain Willow	1.52	4.844	0.747	0.651	0.00666	0.075	0.736	0.336	0.1020
II 13-4	Mountain Willow	1.52	4.844	0.818	0.609	0.00616	0.080	0.806	0.363	0.1120
II 13-5	Mountain Willow	1.52	4.844	0.934	0.610	0.00584	0.082	0.919	0.378	0.1190
II 13-6	Mountain Willow	1.52	4.844	1.092	0.521	0.00459	0.090	1.076	0.421	0.1360
II 13-7	Mountain Willow	1.52	4.844	1.251	0.446	0.00306	0.090	1.230	0.432	0.1430
II 13-8	Mountain Willow	1.52	4.844	1.326	0.447	0.00283	0.088	1.303	0.428	0.1420
II 13-9	Mountain Willow	1.52	4.844	1.414	0.526	0.00335	0.083	1.387	0.406	0.1370
II 13-10	Mountain Willow	1.52	4.844	1.278	0.600	0.00432	0.080	1.254	0.383	0.1270
II 13-11	Mountain Willow	1.52	4.844	1.382	0.895	0.00549	0.062	1.343	0.301	0.1010
II 14-1	Mt Willow w/o leaves	1.52	4.844	0.874	0.595	0.00379	0.066	0.856	0.299	0.0930
II 14-2	Mt Willow w/o leaves	1.52	4.844	1.376	0.368	0.00136	0.075	1.343	0.364	0.1220

Table 4
Summary of Large Flume Results with Homogeneous Groupings (Non-SI Units)

Run	Plant	Plant Height *H*, ft	Plant Density *M*, 1/ft^2	Water Depth Y_o, ft	Mean Velocity *V*, ft/s	Energy Slope *S*	Average *n*	Bed Hydraulic Radius ft	Bed *V*/V*	Bed Manning's n
II 0-1	none		0.000	2.355	1.274	0.00013		1.844	0.069	0.0200
II 0-2	none		0.000	4.334	0.687	0.00002	0.016	2.901	0.064	0.0200
II 0-3	none		0.000	4.788	1.940	0.00015	0.016	3.318	0.069	0.0220
I 1-1	Yellow Twig Dogwood	1.67	0.498	4.170	1.200	0.00053	0.046	3.944	0.216	0.0710
I 1-2	Yellow Twig Dogwood	1.67	0.498	4.120	2.000	0.00124	0.042	3.885	0.198	0.0650
I 1-3	Yellow Twig Dogwood	1.67	0.498	3.680	2.460	0.00184	0.040	3.474	0.185	0.0590
I 1-4	Yellow Twig Dogwood	1.67	0.498	3.090	1.580	0.00119	0.047	2.959	0.213	0.0670
I 1-5	Yellow Twig Dogwood	1.67	0.498	3.350	1.930	0.00140	0.043	3.185	0.196	0.0620
I 1-6	Yellow Twig Dogwood	1.67	0.498	3.440	2.260	0.00163	0.040	3.252	0.183	0.0580
I 1-7	Yellow Twig Dogwood	1.67	0.498	1.760	2.880	0.00582	0.048	1.710	0.197	0.0560
I 1-8	Yellow Twig Dogwood	1.67	0.498	2.350	3.250	0.00477	0.041	2.258	0.181	0.0540
I 1-9	Yellow Twig Dogwood	1.67	0.498	2.910	3.580	0.00418	0.038	2.766	0.170	0.0530
I 2-1	Yellow Twig Dogwood	1.67	0.221	4.450	2.510	0.00102	0.031	4.041	0.145	0.0480
I 2-2	Yellow Twig Dogwood	1.67	0.221	3.770	3.030	0.00165	0.031	3.463	0.142	0.0460
I 2-3	Yellow Twig Dogwood	1.67	0.221	1.690	3.470	0.00693	0.040	1.636	0.174	0.0500
I 2-4	Yellow Twig Dogwood	1.67	0.221	1.300	2.460	0.00496	0.042	1.382	0.191	0.0530
I 3-1	Berried Elderberry	2.33	0.250	3.959	0.963	0.00030	0.042	3.720	0.195	0.0640
I 3-2	Berried Elderberry	2.33	0.250	3.225	1.570	0.00063	0.035	3.011	0.157	0.0500
I 3-3	Berried Elderberry	2.33	0.250	3.490	1.934	0.00085	0.034	3.244	0.154	0.0490
I 3-4	Berried Elderberry	2.33	0.250	3.125	0.996	0.00043	0.045	2.979	0.204	0.0640
I 3-5	Berried Elderberry	2.33	0.250	2.317	1.699	0.00125	0.040	2.219	0.176	0.0530
I 3-6	Berried Elderberry	2.33	0.250	2.565	2.013	0.00110	0.033	2.410	0.145	0.0440
I 3-7	Berried Elderberry	2.33	0.250	2.787	2.270	0.00123	0.032	2.603	0.141	0.0430
I 3-8	Berried Elderberry	2.33	0.250	2.676	2.522	0.00167	0.033	2.516	0.146	0.0450
I 3-9	Berried Elderberry	2.33	0.250	2.454	2.827	0.00199	0.031	2.303	0.136	0.0410
I 3-10	Berried Elderberry	2.33	0.250	3.002	3.102	0.00191	0.030	2.784	0.133	0.0410
I 4-1	Purpleleaf Euonymus	0.67	1.190	3.878	1.048	0.00041	0.045	3.674	0.209	0.0680
I 4-2	Purpleleaf Euonymus	0.67	1.190	3.921	1.377	0.00055	0.040	3.681	0.186	0.0600
I 4-3	Purpleleaf Euonymus	0.67	1.190	3.673	2.195	0.00159	0.042	3.489	0.195	0.0630
I 4-4	Purpleleaf Euonymus	0.67	1.190	2.762	2.172	0.00225	0.045	2.658	0.202	0.0620
I 4-5	Purpleleaf Euonymus	0.67	1.190	2.911	2.512	0.00251	0.042	2.787	0.189	0.0590

Table 4 (Continued)

Run	Plant	Plant Height H, ft	Plant Density M, 1/ft^2	Water Depth Y_o, ft	Mean Velocity V, ft/s	Energy Slope S	Average n	Bed Hydraulic Radius ft	Bed V^*/V	Bed Manning's n
I 4-6	Purpleleaf Euonymus	0.67	1.190	2.563	3.195	0.00408	0.041	2.463	0.178	0.0560
I 4-7	Purpleleaf Euonymus	0.67	1.190	1.610	2.679	0.00477	0.042	1.565	0.183	0.0520
I 5-1	Purpleleaf Euonymus	0.67	0.529	3.385	1.348	0.00053	0.038	3.177	0.172	0.0550
I 5-2	Purpleleaf Euonymus	0.67	0.529	3.394	2.074	0.00106	0.035	3.172	0.159	0.0500
I 5-3	Purpleleaf Euonymus	0.67	0.529	2.320	3.158	0.00436	0.040	2.231	0.177	0.0530
I 6-1	Red Twig Dogwood	3.17	0.113	4.143	1.059	0.00110	0.075	4.046	0.357	0.1190
I 6-2	Red Twig Dogwood	3.17	0.113	4.148	1.573	0.00213	0.070	4.046	0.336	0.1110
I 6-3	Red Twig Dogwood	3.17	0.113	4.252	2.005	0.00266	0.062	4.129	0.297	0.0990
I 6-4	Red Twig Dogwood	3.17	0.113	3.085	1.139	0.00204	0.085	3.036	0.390	0.1230
I 6-5	Red Twig Dogwood	3.17	0.113	2.485	1.997	0.00508	0.070	2.442	0.313	0.0950
I 6-6	Red Twig Dogwood	3.17	0.113	2.719	3.127	0.00582		2.639	0.225	0.0693
I 6-7	Red Twig Dogwood	3.17	0.113	1.762	2.241	0.00833	0.070	1.739	0.308	0.0890
I 6-8	Red Twig Dogwood	3.17	0.113	3.065	3.157	0.00540	0.050	2.968	0.227	0.0720
I 7-1	Red Twig Dogwood	3.17	0.049	3.885	1.142	0.00117	0.070	3.788	0.330	0.1080
I 7-2	Red Twig Dogwood	3.17	0.049	2.685	1.653	0.00322	0.070	2.635	0.316	0.0973
II 1-1	Service Berry	2.33	0.050	2.265	1.148	0.00145	0.063	2.217	0.280	0.0840
II 1-2	Service Berry	2.33	0.050	3.173	1.844	0.00180	0.050	3.060	0.228	0.0720
II 1-3	Service Berry	2.33	0.050	2.634	2.249	0.00229	0.043	2.531	0.192	0.0590
II 1-4	Service Berry	2.33	0.050	3.062	2.964	0.00276	0.038	2.908	0.171	0.0540
II 1-5	Service Berry	2.33	0.050	3.786	1.684	0.00132	0.050	3.634	0.234	0.0760
II 1-6	Service Berry	2.33	0.050	4.182	2.257	0.00157	0.042	3.958	0.198	0.0650
II 4-1	Yellow Twig Dogwood		0.170	4.455	0.477	0.00019	0.071	4.319	0.344	0.1150
II 4-2	Yellow Twig Dogwood		0.170	4.558	1.124	0.00059	0.053	4.362	0.254	0.0850
II 4-3	Yellow Twig Dogwood		0.170	4.136	1.994	0.00112	0.040	3.892	0.189	0.0620
II 4-4	Yellow Twig Dogwood		0.170	3.546	3.173	0.00201	0.032	3.290	0.144	0.0460
II 6-1	Mulefat	3.17	0.060	4.668	1.339	0.00040	0.037	4.311	0.177	0.0590
II 6-2	Mulefat	3.17	0.060	4.151	2.108	0.00095	0.035	3.848	0.162	0.0530
II 6-3	Mulefat	3.17	0.060	4.474	2.375	0.00103	0.033	4.107	0.154	0.0510
II 6-4	Mulefat	3.17	0.060	3.518	2.594	0.00119	0.030	3.228	0.135	0.0430
II 9-1	Vally Elberberry	3.17	0.160	4.482	0.926	0.00099	0.083	4.387	0.418	0.1350
II 9-2	Vally Elberberry	3.17	0.160	4.365	1.400	0.00163	0.070	4.253	0.339	0.1130

Table 4 (Concluded)

Run	Plant	Plant Height *H*, ft	Plant Density *M*, 1/ft^2	Water Depth Y_o, ft	Mean Velocity *V*, ft/s	Energy Slope *S*	Average *n*	Bed Hydraulic Radius ft	Bed *V*/V*	Bed Manning's n
II 9-3	Vally Elberberry	3.17	0.160	3.515	1.714	0.00267	0.068	3.434	0.317	0.1020
II 9-4	Vally Elberberry	3.17	0.160	2.999	2.038	0.00475	0.072	2.944	0.329	0.1030
II 10-1	Salt Cedar	5.00	0.058	4.692	1.364	0.00156	0.072	4.573	0.352	0.1190
II 10-2	Salt Cedar	5.00	0.058	4.522	1.902	0.00238	0.063	4.389	0.305	0.1020
II 10-3	Salt Cedar	5.00	0.058	3.660	2.350	0.00380	0.060	3.560	0.281	0.0910
II 10-4	Salt Cedar	5.00	0.058	3.062	2.246	0.00369	0.058	2.981	0.264	0.0830
II 10-5	Salt Cedar	5.00	0.058	2.768	2.462	0.00513	0.060	2.704	0.272	0.0840
II 10-6	Salt Cedar	5.00	0.058	2.714	3.067	0.00517	0.048	2.629	0.215	0.0660
II	Black Willow	4.00	0.213	4.646	1.028	0.00084		3.578	0.303	0.0980
II	Black Willow	4.00	0.213	4.677	1.809	0.00113		4.387	0.221	0.0740
II	Black Willow	4.00	0.213	4.554	2.503	0.00210		4.305	0.216	0.0720
II	Black Willow	4.00	0.213	2.232	2.257	0.00175		2.088	0.152	0.0450
II	Black Willow	4.00	0.213	2.974	2.984	0.00333		2.867	0.186	0.0580
II	Black Willow	4.00	0.213	2.693	2.590	0.00326		2.604	0.202	0.0620
II	Black Willow	4.00	0.213	2.547	2.381	0.00228		2.439	0.178	0.0540
II 13-1	Mountain Willow	5.00	0.450	2.226	2.061	0.00323	0.052	2.168	0.231	0.0690
II 13-2	Mountain Willow	5.00	0.450	1.986	2.309	0.00414	0.050	1.937	0.219	0.0640
II 13-3	Mountain Willow	5.00	0.450	2.451	2.137	0.00666	0.075	2.414	0.336	0.1020
II 13-4	Mountain Willow	5.00	0.450	2.683	1.999	0.00616	0.080	2.644	0.363	0.1120
II 13-5	Mountain Willow	5.00	0.450	3.063	2.000	0.00584	0.082	3.016	0.378	0.1190
II 13-6	Mountain Willow	5.00	0.450	3.582	1.710	0.00459	0.090	3.530	0.421	0.1360
II 13-7	Mountain Willow	5.00	0.450	4.104	1.462	0.00306	0.090	4.037	0.432	0.1430
II 13-8	Mountain Willow	5.00	0.450	4.351	1.465	0.00283	0.088	4.275	0.428	0.1420
II 13-9	Mountain Willow	5.00	0.450	4.639	1.725	0.00335	0.083	4.549	0.406	0.1370
II 13-10	Mountain Willow	5.00	0.450	4.194	1.967	0.00432	0.080	4.114	0.383	0.1270
II 13-11	Mountain Willow	5.00	0.450	4.534	2.936	0.00549	0.062	4.406	0.301	0.1010
II 14-1	Mt Willow w/o leaves	5.00	0.450	2.869	1.952	0.00379	0.066	2.809	0.299	0.0930
II 14-2	Mt Willow w/o leaves	5.00	0.450	4.515	1.207	0.00136	0.075	4.407	0.364	0.1220

Table 5
Summary of Large Flume Results with Mixed Plant Groupings (SI Units)

Run	Plants	Plant Density M, 1/m^2	Water Depth Yo, M	Mean Velocity V, m/sec	Energy Slope S	Average n	Hydraulic Radius R_h (bed), m	Shear Ratio V^*/V (bed)	Manning's n (bed)
2-1	20 Service Berry, 68 Yellow Twig Dogwood, 68 Euonymus	4.20	1.414	0.353	0.00084	0.062	1.366	0.300	0.101
2-2	20 Service Berry, 68 Yellow Twig Dogwood, 68 Euonymus	4.20	1.398	0.486	0.00122	0.054	1.343	0.259	0.087
2-3	20 Service Berry, 68 Yellow Twig Dogwood, 68 Euonymus	4.20	1.287	0.659	0.00219	0.052	1.238	0.248	0.082
2-4	20 Service Berry, 68 Yellow Twig Dogwood, 68 Euonymus	4.20	0.908	0.742	0.00398	0.055	0.883	0.249	0.078
2-5	20 Service Berry, 68 Yellow Twig Dogwood, 68 Euonymus	4.20	0.944	0.560	0.00253	0.059	0.919	0.270	0.085
2-6	20 Service Berry, 68 Yellow Twig Dogwood, 68 Euonymus	4.20	0.685	0.779	0.00551	0.055	0.670	0.244	0.073
3-1	68 Yellow Twig Dogwood, 68 Euonymus	3.66	1.410	0.360	0.00069	0.055	1.353	0.265	0.089
3-2	68 Yellow Twig Dogwood, 68 Euonymus	3.66	1.266	0.537	0.00125	0.048	1.209	0.228	0.075
3-3	68 Yellow Twig Dogwood, 68 Euonymus	3.66	0.728	0.638	0.00290	0.050	0.707	0.222	0.067
3-4	68 Yellow Twig Dogwood, 68 Euonymus	3.66	0.982	0.473	0.00126	0.050	0.946	0.228	0.072
7-1	22 Mulefat, 70 Alders	2.48	1.332	0.366	0.00107	0.066	1.293	0.318	0.106
7-2	22 Mulefat, 70 Alders	2.48	1.344	0.456	0.00102	0.052	1.288	0.249	0.083
7-3	22 Mulefat, 70 Alders	2.48	1.148	0.624	0.00173	0.047	1.099	0.219	0.071
7-4	22 Mulefat, 70 Alders	2.48	1.006	0.845	0.00395	0.050	0.972	0.230	0.073
8-1	22 Mulefat, 70 Alders, 66 Valley Elderberry	4.20	1.373	0.488	0.00228	0.073	1.341	0.355	0.119
8-2	22 Mulefat, 70 Alders, 66 Valley Elderberry	4.20	1.340	0.572	0.00292	0.070	1.308	0.338	0.113
8-3	22 Mulefat, 70 Alders, 66 Valley Elderberry	4.20	1.377	0.751	0.00427	0.065	1.340	0.316	0.106
8-4	22 Mulefat, 70 Alders, 66 Valley Elderberry	4.20	1.189	0.533	0.00315	0.075	1.164	0.354	0.116
8-5	22 Mulefat, 70 Alders, 66 Valley Elderberry	4.20	1.113	0.567	0.00372	0.075	1.091	0.352	0.114
8-6	22 Mulefat, 70 Alders, 66 Valley Elderberry	4.20	1.166	0.678	0.00390	0.065	1.137	0.306	0.100
11-1	23 Salt Cedar, 83 Black Willows, 50 Red Willows	4.20	1.433	0.658	0.00290	0.062	1.390	0.302	0.102
11-2	23 Salt Cedar, 83 Black Willows, 50 Red Willows	4.20	1.320	0.794	0.00445	0.062	1.283	0.297	0.099
11-3	23 Salt Cedar, 83 Black Willows, 50 Red Willows	4.20	1.437	0.401	0.00158	0.075	1.403	0.367	0.124
11-4	23 Salt Cedar, 83 Black Willows, 50 Red Willows	4.20	0.955	0.528	0.00314	0.070	0.935	0.323	0.102
11-5	23 Salt Cedar, 83 Black Willows, 50 Red Willows	4.20	0.787	0.646	0.00471	0.065	0.772	0.291	0.089
11-6	23 Salt Cedar, 83 Black Willows, 50 Red Willows	4.20	0.814	0.959	0.00834	0.059	0.796	0.267	0.082
11-7	23 Salt Cedar, 83 Black Willows, 50 Red Willows	4.20	0.665	0.726	0.00456	0.053	0.649	0.236	0.070
12-1	83 Black Willows, 50 Red Willows	3.58	1.416	0.354	0.00079	0.060	1.366	0.291	0.098

(Continued)

Table 5 (Concluded)

Run	Plants	Plant Density M, 1/m^2	Water Depth Y_o, m	Mean Velocity V, m/sec	Energy Slope S	Average n	Hydraulic Radius R_h (bed), m	Shear Ratio V^*/V (bed)	Manning's n (bed)
12-2	83 Black Willows, 50 Red Willows	3.58	1.426	0.551	0.00113	0.046	1.353	0.220	0.074
12-3	83 Black Willows, 50 Red Willows	3.58	1.388	0.763	0.00210	0.045	1.320	0.215	0.072
12-4	83 Black Willows, 50 Red Willows	3.58	0.906	0.910	0.00333	0.041	0.867	0.186	0.058
12-5	83 Black Willows, 50 Red Willows	3.58	0.821	0.789	0.00326	0.045	0.791	0.202	0.062
12-6	83 Black Willows, 50 Red Willows	3.58	0.776	0.726	0.00228	0.040	0.743	0.178	0.054
12-7	83 Black Willows, 50 Red Willows	3.58	0.680	0.688	0.00175	0.035	0.647	0.151	0.045

Table 6
Summary of Large Flume Results with Mixed Plant Groupings (Non-SI Units)

Run	Plants	Plant Density M, 1/ft^2	Water Depth Yo, ft	Mean Velocity V, ft/s	Energy Slope S	Average n	Hydraulic Radius R_h (bed), ft	Shear Ratio V^*/V (bed)	Manning's n (bed)
2-1	20 Service Berry, 68 Yellow Twig Dogwood, 68 Euonymus	0.39	4.638	1.159	0.00084	0.062	4.483	0.300	0.101
2-2	20 Service Berry, 68 Yellow Twig Dogwood, 68 Euonymus	0.39	4.588	1.594	0.00122	0.054	4.407	0.259	0.087
2-3	20 Service Berry, 68 Yellow Twig Dogwood, 68 Euonymus	0.39	4.222	2.161	0.00219	0.052	4.061	0.248	0.082
2-4	20 Service Berry, 68 Yellow Twig Dogwood, 68 Euonymus	0.39	2.979	2.434	0.00398	0.055	2.896	0.249	0.078
2-5	20 Service Berry, 68 Yellow Twig Dogwood, 68 Euonymus	0.39	3.096	1.837	0.00253	0.059	3.014	0.270	0.085
2-6	20 Service Berry, 68 Yellow Twig Dogwood, 68 Euonymus	0.39	2.249	2.557	0.00551	0.055	2.197	0.244	0.073
3-1	68 Yellow Twig Dogwood, 68 Euonymus	0.34	4.627	1.181	0.00069	0.055	4.439	0.265	0.089
3-2	68 Yellow Twig Dogwood, 68 Euonymus	0.34	4.152	1.761	0.00125	0.048	3.966	0.228	0.075
3-3	68 Yellow Twig Dogwood, 68 Euonymus	0.34	2.388	2.094	0.00290	0.050	2.319	0.222	0.067
3-4	68 Yellow Twig Dogwood, 68 Euonymus	0.34	3.222	1.552	0.00126	0.050	3.103	0.228	0.072
7-1	22 Mulefat, 70 Alders	0.23	4.370	1.201	0.00107	0.066	4.243	0.318	0.106
7-2	22 Mulefat, 70 Alders	0.23	4.411	1.496	0.00102	0.052	4.227	0.249	0.083
7-3	22 Mulefat, 70 Alders	0.23	3.766	2.048	0.00173	0.047	3.605	0.219	0.071
7-4	22 Mulefat, 70 Alders	0.23	3.301	2.772	0.00395	0.050	3.189	0.230	0.073
8-1	22 Mulefat, 70 Alders, 66 Valley Elderberry	0.39	4.506	1.601	0.00228	0.073	4.399	0.355	0.119
8-2	22 Mulefat, 70 Alders, 66 Valley Elderberry	0.39	4.397	1.876	0.00292	0.070	4.290	0.338	0.113
8-3	22 Mulefat, 70 Alders, 66 Valley Elderberry	0.39	4.517	2.463	0.00427	0.065	4.396	0.316	0.106
8-4	22 Mulefat, 70 Alders, 66 Valley Elderberry	0.39	3.901	1.750	0.00315	0.075	3.820	0.354	0.116
8-5	22 Mulefat, 70 Alders, 66 Valley Elderberry	0.39	3.650	1.860	0.00372	0.075	3.578	0.352	0.114
8-6	22 Mulefat, 70 Alders, 66 Valley Elderberry	0.39	3.826	2.225	0.00390	0.065	3.731	0.306	0.100
11-1	23 Salt Cedar, 83 Black Willows, 50 Red Willows	0.39	4.702	2.159	0.00290	0.062	4.560	0.302	0.102
11-2	23 Salt Cedar, 83 Black Willows, 50 Red Willows	0.39	4.330	2.604	0.00445	0.062	4.209	0.297	0.099
11-3	23 Salt Cedar, 83 Black Willows, 50 Red Willows	0.39	4.716	1.317	0.00158	0.075	4.602	0.367	0.124
11-4	23 Salt Cedar, 83 Black Willows, 50 Red Willows	0.39	3.133	1.731	0.00314	0.070	3.069	0.323	0.102
11-5	23 Salt Cedar, 83 Black Willows, 50 Red Willows	0.39	2.583	2.120	0.00471	0.065	2.532	0.291	0.089
11-6	23 Salt Cedar, 83 Black Willows, 50 Red Willows	0.39	2.669	3.147	0.00834	0.059	2.610	0.267	0.082
11-7	23 Salt Cedar, 83 Black Willows, 50 Red Willows	0.39	2.182	2.383	0.00456	0.053	2.130	0.236	0.070
12-1	83 Black Willows, 50 Red Willows	0.333	4.646	1.162	0.00079	0.060	4.482	0.291	0.098

(Continued)

Table 6 (Concluded)

Run	Plants	Plant Density M, 1/ft^2	Water Depth Y_o, ft	Mean Velocity V, ft/s	Energy Slope S	Average n	Hydraulic Radius R_h (bed), ft	Shear Ratio V^*/V (bed)	Manning's n (bed)
12-2	83 Black Willows, 50 Red Willows	0.333	4.677	1.809	0.00113	0.046	4.440	0.220	0.074
12-3	83 Black Willows, 50 Red Willows	0.333	4.554	2.503	0.00210	0.045	4.330	0.215	0.072
12-4	83 Black Willows, 50 Red Willows	0.333	2.974	2.984	0.00333	0.041	2.845	0.186	0.058
12-5	83 Black Willows, 50 Red Willows	0.333	2.693	2.590	0.00326	0.045	2.596	0.202	0.062
12-6	83 Black Willows, 50 Red Willows	0.333	2.547	2.381	0.00228	0.040	2.438	0.178	0.054
12-7	83 Black Willows, 50 Red Willows	0.333	2.232	2.257	0.00175	0.035	2.123	0.151	0.045

Table 7
Small Flume Results, Drag Measurements

		With Leaves				Without Leaves			
		Approach Velocity		Drag Force		Approach Velocity		Drag Force	
Run	Plant	ft/sec	m/sec	lbf	N	ft/sec	m/sec	lbf	N
1	Staghorn Sumac	1.63	0.50	0.216	0.961	1.63	0.50	0.052	0.231
2	Staghorn Sumac	2.15	0.66	0.310	1.379	2.01	0.61	0.095	0.423
3	Staghorn Sumac	2.62	0.80	0.362	1.610	2.12	0.65	0.108	0.480
4	Staghorn Sumac	2.70	0.82	0.388	1.726	2.51	0.77	0.172	0.765
5	Staghorn Sumac	2.84	0.87	0.414	1.842	3.06	0.93	0.216	0.961
6	Staghorn Sumac	3.37	1.03	0.431	1.917	3.34	1.02	0.237	1.054
7	Staghorn Sumac	3.64	1.11	0.466	2.073	3.48	1.06	0.280	1.245
8	Staghorn Sumac	4.17	1.27	0.569	2.531	3.92	1.19	0.401	1.784
9	Staghorn Sumac	4.31	1.31	0.603	2.682	4.44	1.35	0.474	2.108
10	Staghorn Sumac	4.44	1.35	0.638	2.838	4.80	1.46	0.526	2.340
1	Artic Blue Willow	1.02	0.31	0.207	0.921	1.43	0.44	0.129	0.574
2	Artic Blue Willow	1.32	0.40	0.289	1.286	1.82	0.55	0.155	0.689
3	Artic Blue Willow	1.79	0.55	0.366	1.628	2.46	0.75	0.207	0.921
4	Artic Blue Willow	2.15	0.66	0.431	1.917	2.95	0.90	0.224	0.996
5	Artic Blue Willow	2.34	0.71	0.483	2.148	3.50	1.07	0.272	1.210
6	Artic Blue Willow	2.73	0.83	0.526	2.340	4.25	1.30	0.345	1.535
7	Artic Blue Willow	2.92	0.89	0.560	2.491	4.66	1.42	0.397	1.766
8	Artic Blue Willow	2.98	0.91	0.578	2.571	4.77	1.45	0.440	1.957
9	Artic Blue Willow	3.48	1.06	0.733	3.261	4.94	1.51	0.466	2.073
10	Artic Blue Willow	4.39	1.34	0.922	4.101	5.19	1.58	0.517	2.300
1	Norway Maple	0.94	0.29	0.089	0.396	1.27	0.39	0.036	0.160
2	Norway Maple	1.21	0.37	0.125	0.556	1.93	0.59	0.058	0.258
3	Norway Maple	1.71	0.52	0.201	0.894	2.40	0.73	0.085	0.378
4	Norway Maple	2.23	0.68	0.241	1.072	2.92	0.89	0.134	0.596
5	Norway Maple	3.01	0.92	0.304	1.352	3.61	1.10	0.179	0.796
6	Norway Maple	3.56	1.09	0.371	1.650	4.17	1.27	0.210	0.934
7	Norway Maple	3.89	1.19	0.464	2.064	4.31	1.31	0.299	1.330
8	Norway Maple	4.08	1.24	0.589	2.620	4.44	1.35	0.321	1.428
9	Norway Maple	4.31	1.31	0.652	2.900	4.61	1.41	0.357	1.588
10	Norway Maple	4.53	1.38	0.741	3.296		0.00		0.000
1	Western Sand Cherry	1.10	0.34	0.071	0.316	1.43	0.44	0.031	0.138
2	Western Sand Cherry	1.68	0.51	0.107	0.476	2.01	0.61	0.071	0.316
3	Western Sand Cherry	2.12	0.65	0.143	0.636	2.54	0.77	0.098	0.436
4	Western Sand Cherry	2.51	0.77	0.170	0.756	2.79	0.85	0.125	0.556
5	Western Sand Cherry	2.81	0.86	0.205	0.912	3.17	0.97	0.161	0.716
6	Western Sand Cherry	3.20	0.98	0.250	1.112	3.50	1.07	0.174	0.774
7	Western Sand Cherry	3.39	1.03	0.308	1.370	3.84	1.17	0.196	0.872
8	Western Sand Cherry	3.64	1.11	0.348	1.548	4.00	1.22	0.223	0.992
9	Western Sand Cherry	3.75	1.14	0.384	1.708	4.17	1.27	0.254	1.130
10	Western Sand Cherry	3.89	1.19	0.420	1.868	4.53	1.38	0.348	1.548
1	Common Privet	1.13	0.34	0.198	0.881	1.32	0.40	0.075	0.334
2	Common Privet	1.71	0.52	0.472	2.100	2.10	0.64	0.302	1.343
3	Common Privet	2.18	0.66	0.731	3.252	2.57	0.78	0.377	1.677
4	Common Privet	2.90	0.88	0.811	3.607	2.73	0.83	0.396	1.761
5	Common Privet	3.34	1.02	0.972	4.324	3.23	0.98	0.708	3.149
6	Common Privet	3.59	1.09	1.274	5.667	3.42	1.04	0.797	3.545
7	Common Privet	3.75	1.14	1.585	7.050	3.73	1.14	0.943	4.195
8	Common Privet	4.11	1.25	1.896	8.434	4.03	1.23	1.085	4.826
9	Common Privet	4.39	1.34	2.132	9.484	4.17	1.27	1.189	5.289
10	Common Privet	4.44	1.35	2.179	9.693	4.66	1.42	1.302	5.792
1	Blue Elberberry	1.21	0.37	0.269	1.197	1.27	0.39	0.113	0.503
2	Blue Elberberry	1.68	0.51	0.491	2.184	1.57	0.48	0.170	0.756
3	Blue Elberberry	1.96	0.60	0.745	3.314	1.99	0.61	0.212	0.943
4	Blue Elberberry	2.46	0.75	1.415	6.294	2.18	0.66	0.259	1.152
5	Blue Elberberry	2.76	0.84	1.745	7.762	2.73	0.83	0.410	1.824
6	Blue Elberberry	2.98	0.91	2.052	9.128	3.31	1.01	0.552	2.455

(Continued)

Table 7 (Concluded)

Run	Plant	With Leaves				Without Leaves			
		Approach Velocity		Drag Force		Approach Velocity		Drag Force	
		ft/sec	m/sec	lbf	N	ft/sec	m/sec	lbf	N
7	Blue Elberberry	3.39	1.03	2.406	10.702	3.61	1.10	0.717	3.189
8	Blue Elberberry	3.89	1.19	2.783	12.379	4.06	1.24	1.024	4.555
9	Blue Elberberry	4.25	1.30	3.349	14.897	5.11	1.56	1.434	6.379
10	Blue Elberberry		0.00		0.000	5.33	1.62	1.991	8.856
1	French Pink Pussywillow	1.35	0.41	0.192	0.854	1.41	0.43	0.192	0.854
2	French Pink Pussywillow	1.99	0.61	0.625	2.780	1.54	0.47	0.288	1.281
3	French Pink Pussywillow	2.26	0.69	0.673	2.994	2.32	0.71	0.375	1.668
4	French Pink Pussywillow	2.57	0.78	0.827	3.679	2.40	0.73	0.452	2.011
5	French Pink Pussywillow	2.84	0.87	1.106	4.920	2.51	0.77	0.529	2.353
6	French Pink Pussywillow	3.34	1.02	1.346	5.987	2.90	0.88	0.837	3.723
7	French Pink Pussywillow	3.61	1.10	1.827	8.127	3.34	1.02	1.010	4.493
1	Sycamore	1.21	0.37	0.144	0.641	1.35	0.41	0.058	0.258
2	Sycamore	1.63	0.50	0.264	1.174	1.90	0.58	0.096	0.427
3	Sycamore	1.93	0.59	0.341	1.517	2.07	0.63	0.135	0.601
4	Sycamore	2.65	0.81	0.538	2.393	2.51	0.77	0.183	0.814
5	Sycamore	3.12	0.95	0.740	3.292	2.79	0.85	0.231	1.028
6	Sycamore	3.20	0.98	0.817	3.634	3.06	0.93	0.245	1.090
7	Sycamore	3.59	1.09	0.952	4.235	3.23	0.98	0.274	1.219
8	Sycamore	3.78	1.15	1.096	4.875	3.70	1.13	0.452	2.011
9	Sycamore	4.55	1.39	1.442	6.414	3.81	1.16	0.529	2.353
10	Sycamore	4.66	1.42	1.490	6.628	3.89	1.19	0.553	2.460
1	Yellow Twig Dogwood type 1	1.68	0.51	0.108	0.480	1.41	0.43	0.108	0.480
2	Yellow Twig Dogwood type 1	2.01	0.61	0.162	0.721	2.04	0.62	0.206	0.916
3	Yellow Twig Dogwood type 1	2.18	0.66	0.201	0.894	2.51	0.77	0.294	1.308
4	Yellow Twig Dogwood type 1	2.62	0.80	0.245	1.090	3.31	1.01	0.412	1.833
5	Yellow Twig Dogwood type 1	3.26	0.99	0.392	1.744	3.61	1.10	0.451	2.006
6	Yellow Twig Dogwood type 1	3.53	1.08	0.480	2.135	3.92	1.19	0.451	2.006
7	Yellow Twig Dogwood type 1	4.22	1.29	0.593	2.638	4.44	1.35	0.623	2.771
8	Yellow Twig Dogwood type 1	4.44	1.35	0.618	2.749	4.50	1.37	0.627	2.789
9	Yellow Twig Dogwood type 1	4.55	1.39	0.647	2.878	4.55	1.39	0.657	2.922
10	Yellow Twig Dogwood type 1	4.53	1.38	0.642	2.856	4.75	1.45	0.588	2.616
1	Yellow Twig Dogwood type 2	1.05	0.32	0.088	0.391	1.27	0.39	0.059	0.262
2	Yellow Twig Dogwood type 2	1.46	0.45	0.127	0.565	1.65	0.50	0.103	0.458
3	Yellow Twig Dogwood type 2	1.79	0.55	0.186	0.827	2.04	0.62	0.162	0.721
4	Yellow Twig Dogwood type 2	2.59	0.79	0.284	1.263	2.79	0.85	0.255	1.134
5	Yellow Twig Dogwood type 2	2.95	0.90	0.343	1.526	3.06	0.93	0.294	1.308
6	Yellow Twig Dogwood type 2	3.50	1.07	0.431	1.917	3.84	1.17	0.348	1.548
7	Yellow Twig Dogwood type 2	3.89	1.19	0.471	2.095	3.84	1.17	0.348	1.548
8	Yellow Twig Dogwood type 2	4.42	1.35	0.529	2.353	4.17	1.27	0.373	1.659
9	Yellow Twig Dogwood type 2	4.50	1.37	0.534	2.375	4.33	1.32	0.392	1.744
10	Yellow Twig Dogwood type 2	4.55	1.39	0.539	2.398	4.50	1.37	0.422	1.877
1	Euonymus	1.13	0.34	0.093	0.414	0.94	0.29	0.074	0.329
2	Euonymus	1.52	0.46	0.176	0.783	1.46	0.45	0.098	0.436
3	Euonymus	2.48	0.76	0.324	1.441	1.77	0.54	0.167	0.743
4	Euonymus	2.84	0.87	0.353	1.570	2.18	0.66	0.225	1.001
5	Euonymus	3.31	1.01	0.500	2.224	2.87	0.87	0.363	1.615
6	Euonymus	3.78	1.15	0.500	2.224	3.23	0.98	0.436	1.939
7	Euonymus	3.84	1.17	0.510	2.269	3.73	1.14	0.490	2.180
8	Euonymus	4.39	1.34	0.539	2.398	4.28	1.30	0.534	2.375
9	Euonymus	4.47	1.36	0.564	2.509	4.44	1.35	0.539	2.398
10	Euonymus	4.69	1.43	0.588	2.616		0.00		0.000
1	Yellow Twig Dogwood type 3	1.57	0.48	0.196	0.872	2.15	0.66	0.157	0.698
2	Yellow Twig Dogwood type 3	2.29	0.70	0.314	1.397	2.46	0.75	0.206	0.916
3	Yellow Twig Dogwood type 3	2.43	0.74	0.343	1.526	2.90	0.88	0.255	1.134
4	Yellow Twig Dogwood type 3	2.70	0.82	0.373	1.659	3.45	1.05	0.275	1.223
5	Yellow Twig Dogwood type 3	2.95	0.90	0.436	1.939	4.28	1.30	0.284	1.263
6	Yellow Twig Dogwood type 3	3.50	1.07	0.480	2.135				
7	Yellow Twig Dogwood type 3	4.22	1.29	0.500	2.224				

Table 8
Large Flume Results, Drag Measurements

Run	Plant	With Leaves			
		Approach Velocity		Drag Force	
		ft/sec	m/sec	lbf	N
6-2:1	Mulefat	1.10	0.34	0.083	0.369
6-2:2	Mulefat	1.50	0.46	0.130	0.578
6-2:3	Mulefat	1.70	0.52	0.172	0.765
6-2:4	Mulefat	2.40	0.73	0.232	1.032
6-2:5	Mulefat	2.70	0.82	0.362	1.610
6-2:6	Mulefat	3.10	0.94	0.426	1.895
7-1:1	Alder	0.43	0.13	0.040	0.178
7-1:2	Alder	0.88	0.27	0.109	0.485
7-1:3	Alder	1.10	0.34	0.234	1.041
7-1:4	Alder	1.60	0.49	0.404	1.797
8-1:1	Valley Elderberry	0.40	0.12	0.294	1.308
8-1:2	Valley Elderberry	0.50	0.15	0.438	1.948
8-1:3	Valley Elderberry	0.60	0.18	0.574	2.553
8-1:4	Valley Elderberry	0.70	0.21	0.745	3.314
8-1:5	Valley Elderberry	0.80	0.24	0.989	4.399
8-1:6	Valley Elderberry	1.10	0.34	1.277	5.680
8-1:7	Valley Elderberry	1.40	0.43	1.404	6.245
11-1:1	Black Willow	0.85	0.26	0.110	0.489
11-1:2	Black Willow	1.00	0.30	0.170	0.756
11-1:3	Black Willow	1.10	0.34	0.210	0.934
11-1:4	Black Willow	1.30	0.40	0.320	1.423
11-1:5	Black Willow	1.50	0.46	0.470	2.091
11-1:6	Black Willow	1.65	0.50	0.510	2.269
11-1:7	Black Willow	1.70	0.52	0.680	3.025
11-1:8	Black Willow	1.90	0.58	0.770	3.425
11-1:9	Black Willow	2.10	0.64	0.960	4.270
11-1:10	Black Willow	2.30	0.70	1.230	5.471

Table 9
Modulus of Plant Stiffness for Evaluated Plants

Plant name		$E_S/(H/D_S)^{1.5}$ N/m²	$E_S/(H/D_S)^{1.5}$ lbf/ft²
Alder	*Alnus incana*	1.804e+06	3.768e+04
Arctic Blue Willow	*Salix purpurea nana*	4.091e+05	8.544e+03
Black Willow	*Salix nigra*	2.930e+05	6.119e+03
Blue Elderberry	*Sambucus Canadensis*	2.733e+05	5.708e+03
Common Privet	*Ligustrum vulgare*	7.7040e+05	1.609e+04
Yellow Twig Dogwood	*Cornus stolonifera flaviramea*	2.550e+06	5.326e+04
Red-osier Dogwood	*Cornus Sericea*	4.342e+06	9.069e+04
Berried Elderberry	*Sambucus racemosa*	8.168e+04	1.706e+03
Purpleleaf Euonymus	*Euonymus fortunei colorata*	2.278e+06	4.758e+04
Mountain Black Willow	*Salix monticola*	7.430e+05	1.552e+04
Mulefat	*Baccharis glutinosa*	8.992e+05	1.878e+04
Norway Maple	*Acer platenoides*	4.569e+06	9.542e+04
French Pink Pussywillow	*Salix caprea pendula*	3.345e+05	6.986e+03
Red Willow	*Salix spp.*	8.810e+05	1.840e+04
Salt Cedar	*Tamarix spp.*	3.930e+06	8.207e+04
Service Berry	*Amelanchier*	4.003e+06	8.360e+04
Staghorn Sumac	*Rhus typhina*	1.095e+06	2.288e+04
Sycamore	*Platenus acer ifolia*	3.244e+06	6.774e+04
Valley Elderberry	*Sambucus mexicana*	7.672e+06	1.602e+05
Western Sand Cherry	*Prunis besseyi*	3.567e+06	7.449e+04
Sand Bar Willow	*Salix exigua*	4.990e+06	1.040e+05
Pacific Willow	*Salix lasiandra*	5.300e+06	1.120e+05
Lemon's Willow	Salix lemonii	4.090e+06	8.530e+04
Wild Rose Bush	Rosa spp.	6.070e+06	1.250e+05

Appendix A
Example Problem

The equations developed in this report allow hydraulic roughness values to be determined for homogenous and nonhomogeneous flood plains. When a number of species are present in the floodplain or area of interest, the values for the various plants are either combined, as shown in Equation 29, or the flood plain is broken into homogenous areas that are then either solved simultaneously for the flow or aggregated to provide a representative roughness (i.e., Manning's n) value.

The following is an example for determining the vegetative resistance and the equivalent resistance of the left bank of a floodplain. The left bank is divided into three subareas with the far left area vegetated with shrubs, the middle area vegetated with three different plant types, and the right subarea vegetated with willows as shown in Figure A1. For a given flow depth in the main channel, Table A1 shows the flow depth, area, wetted perimeter, and hydraulic radius for each subarea. The slope of each area is 0.0002, the fluid density is 1,000 kg/m^3, and the kinematic viscosity is 1.3E+06 m^2/s. The properties of the channel are summarized in Table A1 for ease of reference.

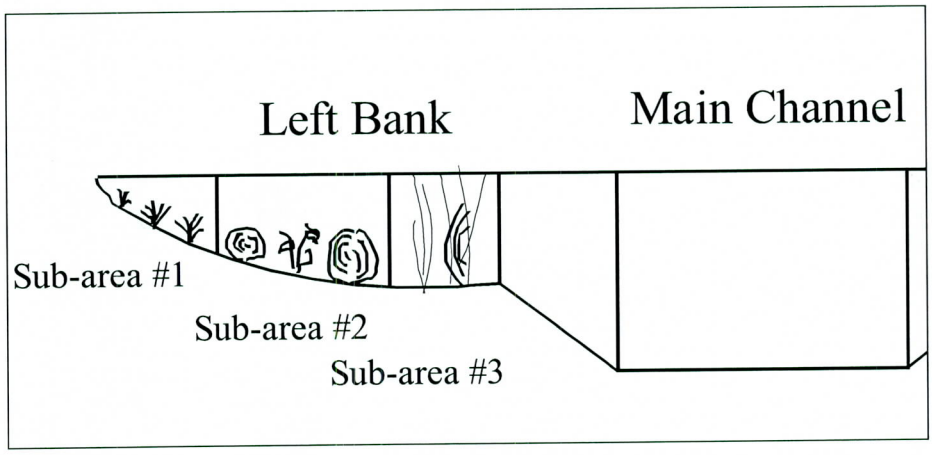

Figure A1. Left bank floodplain for example problem showing calculation subareas based on vegetation types

Table A1
Channel Properties for Example Problem

Channel Properties	Subarea 1	Subarea 2	Subarea 3	Overbank Total
S	0.0002	0.0002	0.0002	.0002
Y_o m	0.61	1.524	2.134	
Flow Area m^2	27.87	46.45	32.52	106.84
P m	31.39	31.09	15.85	78.33
R_h m	0.89	1.49	2.05	1.364

Table A2 lists the plant characteristics and properties for the shrubs in subareas 1 through 3. The stiffness modulus was measured in the field by applying Equation 33 for subarea 1, by using Equation 35 for weighted plant characteristic values for subarea 2, and by using the value for Pacific willows from Table 9 for subarea 3 multiplied by the $(H/D_s)^{1.5}$ value for the willows in subarea 3. The use of the value from Table 9 and the H/D parameter for the willows in subarea 3 provides an estimate of the actual E_s for the willows in the subarea that are different in size from those evaluated in the compilation of the data presented in Table 9.

Table A2 also lists the plant characteristics and shows the calculations to determine the weighted average characteristics to be used for the resistance calculations. This is done by multiplying the various plant characteristics by that plant's relative density on the floodplain in decimal form, H_1M_1/M_{total}, where the subscript 1 refers to plant type 1. These values are then summed for all three plant types to arrive at the weighted value for H. Thus, the equation for the weighted value becomes as follows:

$$H_{ave} = H_1 \frac{M_1}{M_{total}} + H_2 \frac{M_2}{M_{total}} + H_3 \frac{M_2}{M_{total}}$$

This averaging technique was verified using flume data from the Utah Water Research Laboratory Study and provides the correct average values for use in the equations presented herein.

Equation 23 was used to calculate V_*/V for the partially submerged vegetation in subarea 1 while Equation 21 was used for the fully submerged subareas 2 and 3. Manning's n values were calculated in the same way using Equation 24 for subarea 1 and Equation 22 for subareas 2 and 3.

The calculated Manning's n values for subareas 1 through 3 are 0.075, 0.088, and 0.127, respectively, while the V_*/V values are 0.240, 0.257, and 0.353, respectively. The values for the various subareas can then be used individually in a hydraulic model or composited to obtain a value for the entire channel. Methods described in the SAM User's Manual (Thomas et al. in preparation)[1] are recommended for compositing the subareas if that is necessary.

[1] References in this appendix are cited in the References section at the end of the main text.

Table A2
Plant Characteristics and Roughness Calculations for Subareas 1-3

Plant Characteristics	Sub area 1	Subarea 2				Subarea 3 (Pacific Willow)
		Plant Type 1	Plant Type 2	Plant Type 3	Weighted Values	
H m	0.91	0.2	0.71	0.99	0.59	1.83
H' m	0.76	0.2	0.51	0.81	0.49	1.52
We m	0.76	0.254	0.18	0.86	0.48	1.22
No. of Stems	4	2	6	1	2.20	4
D_s cm	1.27	0.64	0.64	1.2	0.86	1.3
A_s m^2 π D_s^2 / 4 x (no. of stems)	5.06E-04	6.43E-05	1.93E-04	1.13E-04	1.03E-04	5.31E-04
M (plants / m^2)	0.52	1.83	0.61	1.62	4.06	0.11
M / M total (%)		45.0	15.0	39.9	100.0	
H/D_s	72	31	111	82	64	141
F_{45}, N	8.08					
Es, N/m^2, Eq 33	1.75E+09					
Es, N/m^2, Eq 35	1.33E+09	3.15E+08	3.59E+09	1.49E+09	1.28E+09	6.56E+09
Es, N/m^2, Table 9 x $(H/D_s)^{1.5}$						8.85E+09
Vegetative Resistance						
Y_o / H	0.67				2.72	1.17
Submergence $P \leq 0.8H \leq$ Full	Partial				Full	Full
A_i or A_i^* (m^2)	0.35				0.24	1.85
$V_* = (gR_hS)^{1/2}$	4.18E-02				5.41E-02	6.34E-02
Es As / $\rho A_i V_*^2$	1449447				207582	630112
M A_i^*	0.182				0.964	0.204
$V_* R_h / \nu$	28608				61971	100009
V_*/V (Eq 23)	.130					
V_*/V (Eq 21)					0.380	0.350
Manning's n (Eq 22 or 24)	0.075 (Eq 24)				0.130 (Eq 22)	0.126

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14. ABSTRACT

Flume studies were conducted to determine hydraulic resistance of flexible plants that deform with turbulent flow. Both partially submerged and fully submerged plants were studied. The flexible stems and varying shapes of a plant leaf mass greatly complicate the understanding of resistance. The deformation of plant shape with flow precludes the use of constant blockage or plant density in predicting resistance. This study considers the effects on channel resistance for the variables of plant type, plant geometry, plant density, plant flexibility, and submerged and partially submerged plants. Regression equations were developed for determining the Manning's roughness coefficient.

15. SUBJECT TERMS

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Hydraulics
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Plant deformation

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APPENDIX B

General Documentation & Correspondence

B.1 Special Problem Reports - None

B.2 Contact (telephone) reports - None

B.3 Meeting minutes or reports - None

B.4 General Correspondence - None

B.5 Contract Documents - None

APPENDIX C

Survey Field Notes

C.1 Survey field notes for aerial mapping control

C.2 Survey field notes for hydrologic modeling

C.3 Survey field notes for hydraulic modeling

APPENDIX D

Hydrologic Analysis Supporting Documentation

D.1 Precipitation data - None

D.2 Physical parameter calculations - None

D.3 Hydrograph routing data - None

D.4 Reservoir routing data - None

D.5 Flow splits and diversions data - None

D.6 Hydrologic calculations - None

APPENDIX E

HYDRAULIC ANALYSIS SUPPORTING DOCUMENTATION

APPENDIX E.1

Field Photographs and Logs Report
Manning's n Value Field Assessments

Photos Waypoint 10 – South Overbank – Photos IMG_4293-4296 (L-R by Row) Very Low Density n=0.03 due to small area of shrubs

Waypoints 11-15 – Overbank Area Subject to Flow in 2005 (Photos IMG_4299-4301) n = 0.03 Very Low Density due to small area of shrubs.

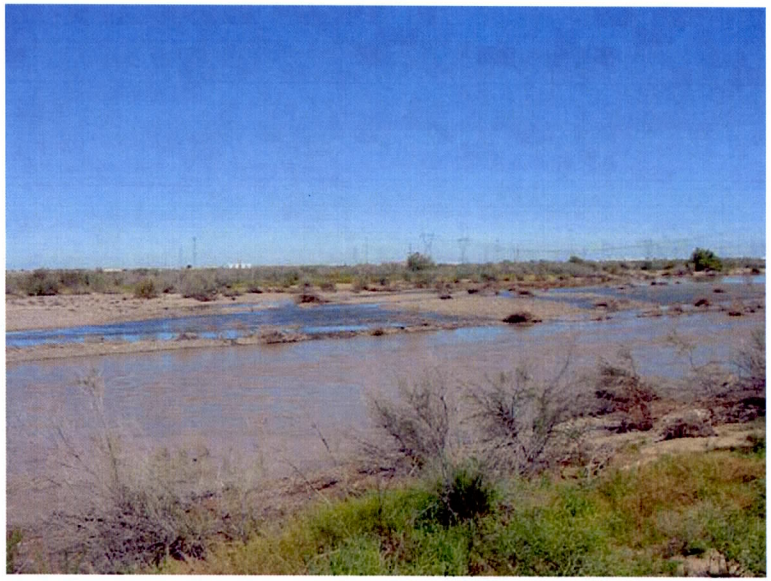
Waypoint 15 – Gila River – IMG_4302-4305 – n = 0.03

Waypoint 16 – Gila River Channel – Very Low Density Vegetation – IMG_4306-4309- n = 0.03

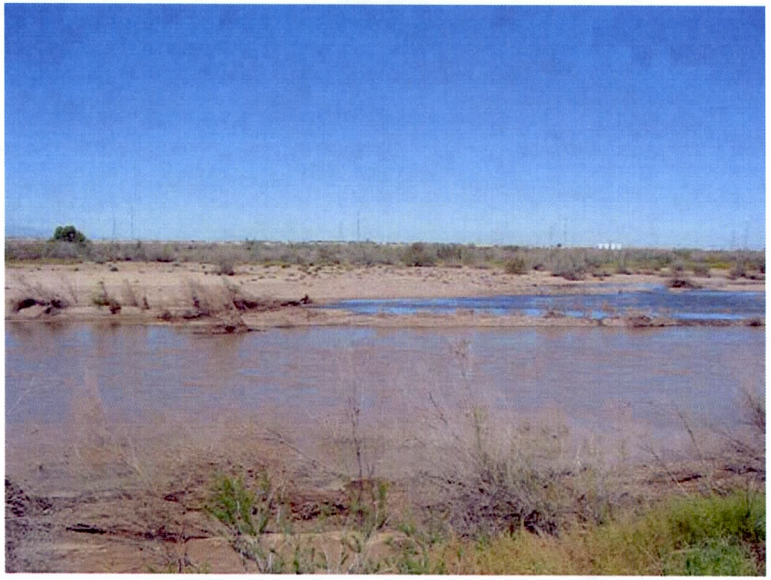
Waypoint 17 – Gila River Channel – IMG_4310-4313 Very Low Density – n = 0.03 due to limited area of vegetation

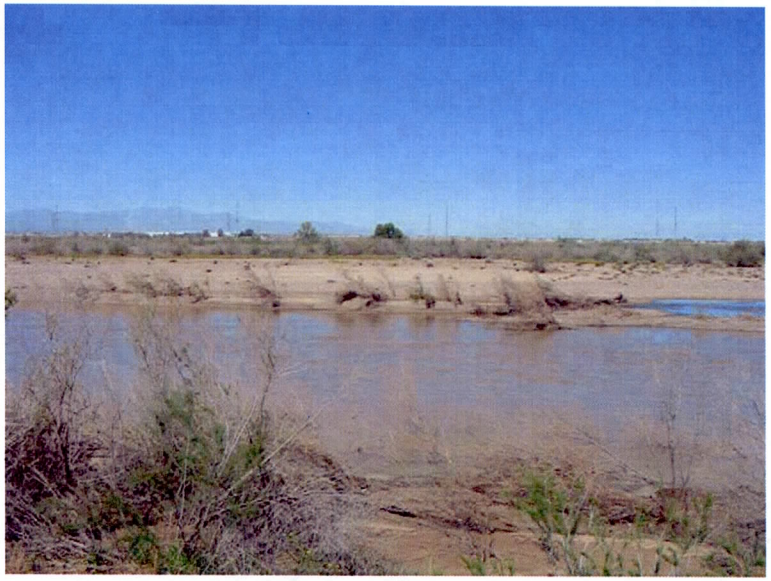
Waypoint 18 – Photos IMG_4314-4317 – Very Low Density / Farmland Interface – n = 0.03 – riverward area

Waypoint 18 – IMG_4318-4320 – n = 0.05 – assume crops during flood for worst case

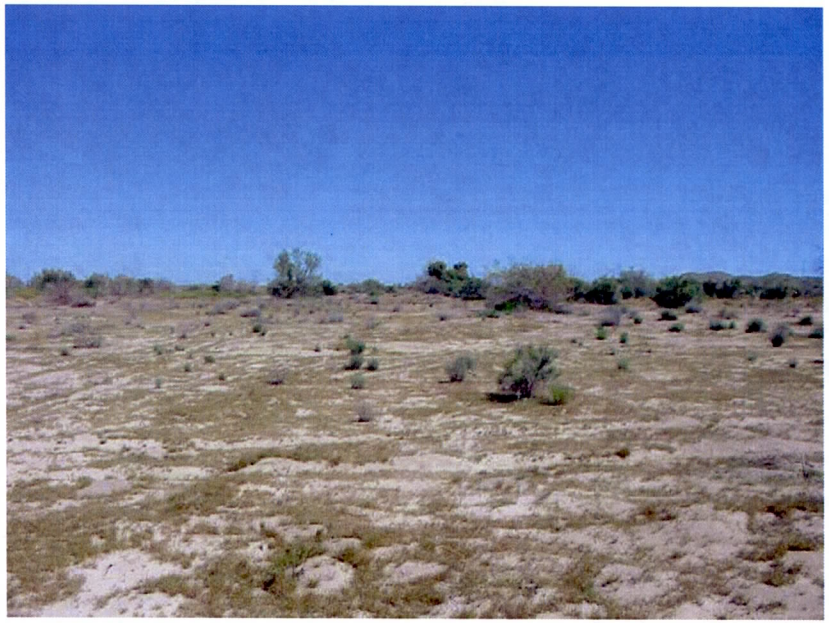


Waypoint 19 – Very Low Density – IMG_4321-4324 – n = 0.03 upstream and north





Waypoint 19 – IMG_4325-4328 Low Density – n = 0.03 northwest except lower right – n = 0.04



Waypoint 19 – IMG_4329-4332 – Very Low and Low Density Interface note higher density in distance n = 0.03 to 0.04

Waypoint 19 – Interface Between Very Low and Low Vegetation – IMG_4333-4336 n = 0.04

Waypoint 19-20 Photos 4337-4340 Low Density Vegetation – n = 0.04

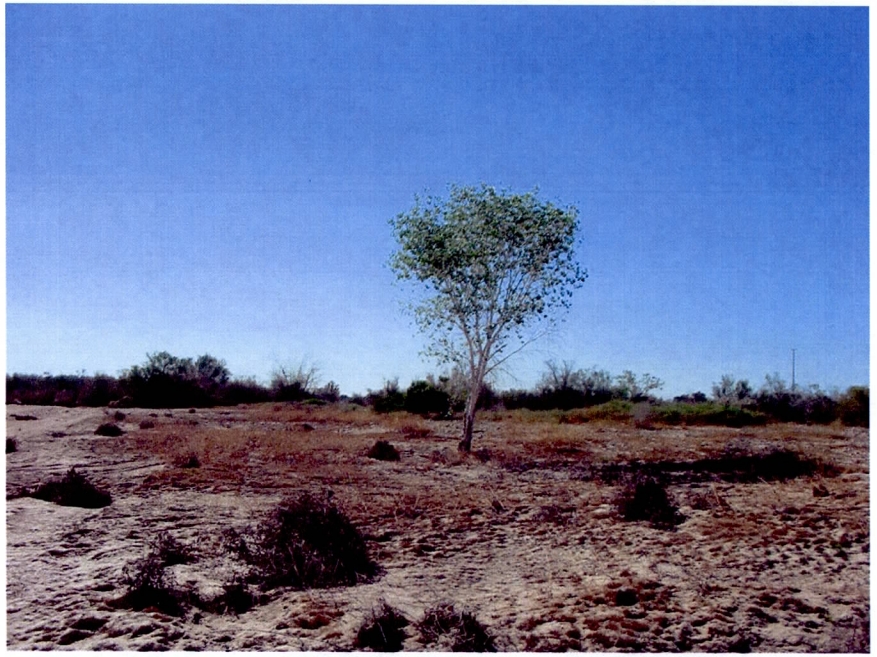
Waypoint 19-20 Photos 4341-4344 – Low Density Vegetation – n = 0.04

Waypoint 20 – Photos 4345-4347, 4349 Low Density Vegetation – n = 0.04

Waypoint 20 Photos 4350-4353 – Low Density Vegetation - n = 0.04

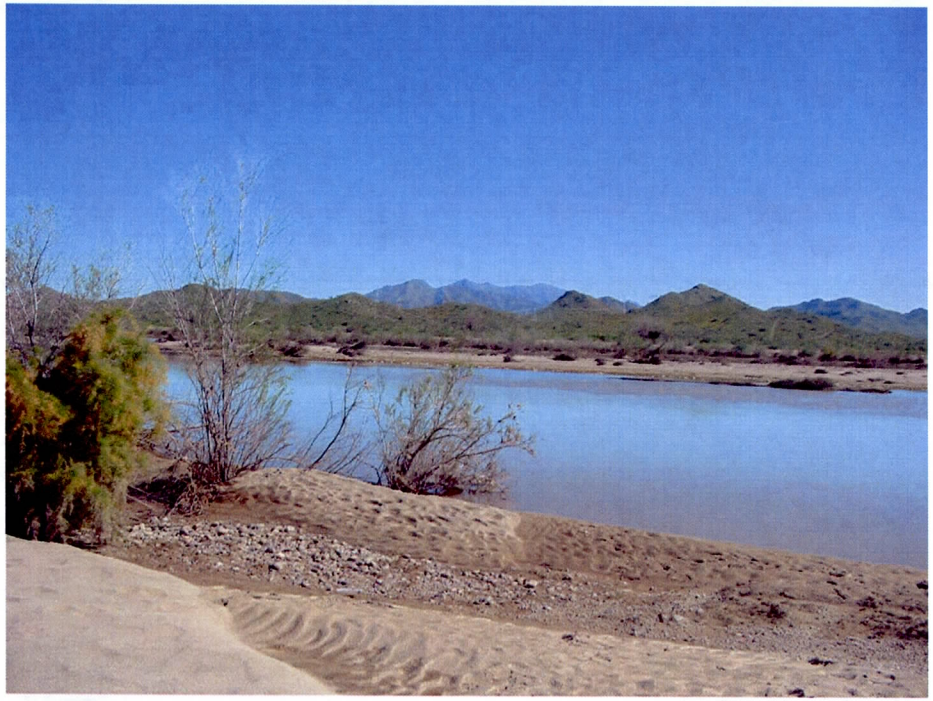
Waypoint 20 – Photos 4354-4357 – Boundary of Low Density Vegetation – n = 0.04

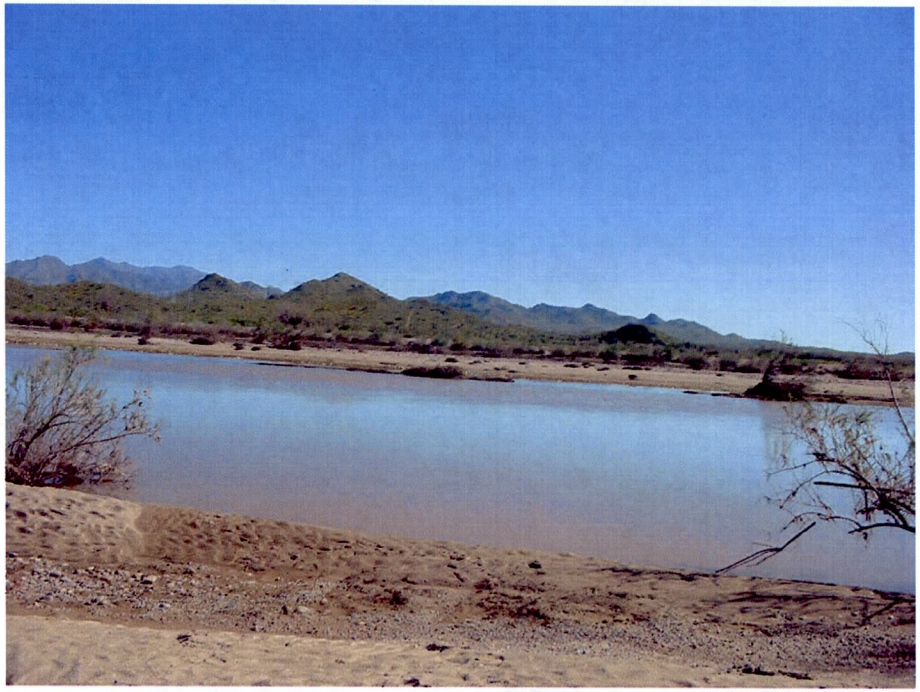
Waypoint 21 – Photo 4358-4361 Medium High Vegetation Density – n = 0.12 (background upper right and lower left)



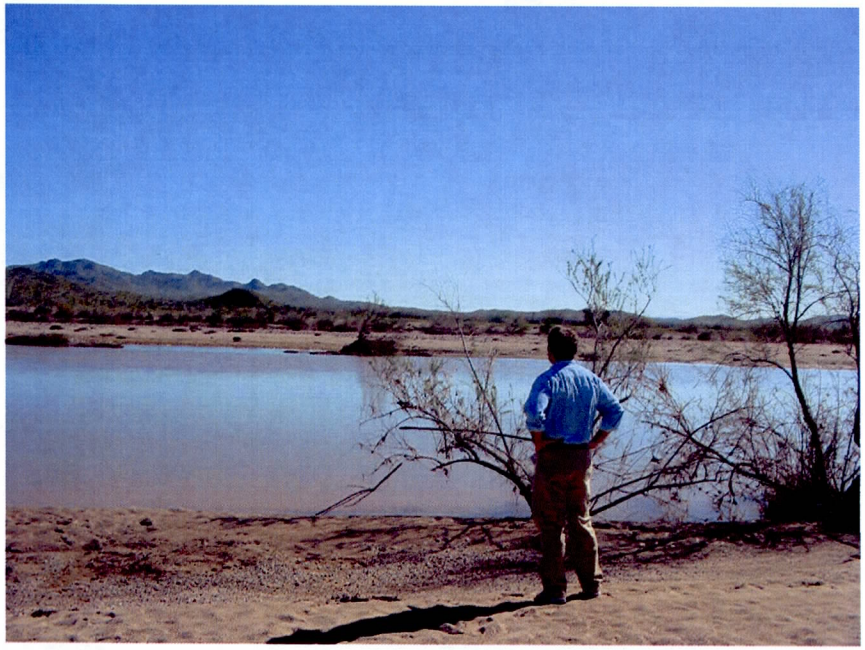
Waypoint 24 Photos 4365-4368 – Very Low Density Vegetation – n = 0.03

Waypoint 24 Photos 4369-4372 Very Low Density Vegetation n = 0.03



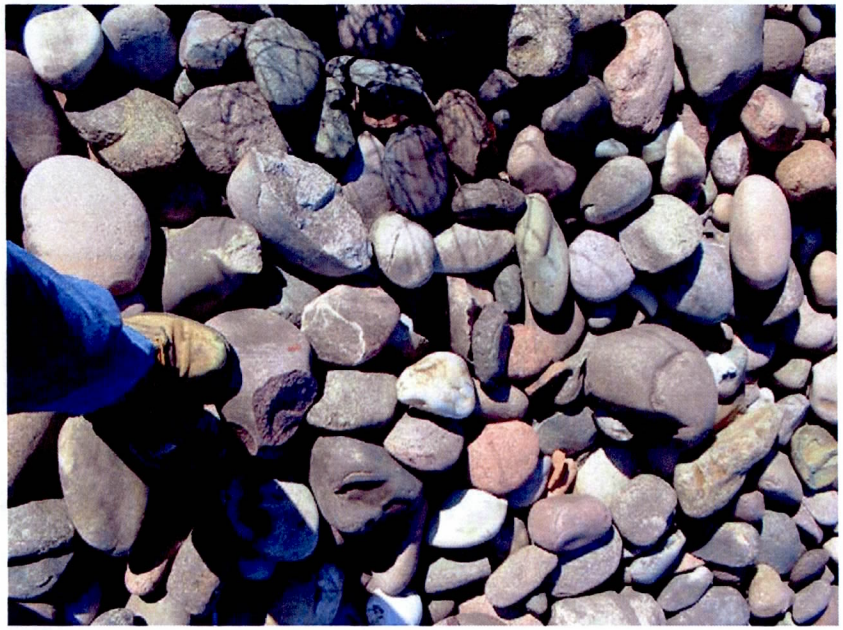


Waypoint 24 – Photos 4373-4376 – Main Channel – Very Low Density Vegetation - n = 0.03

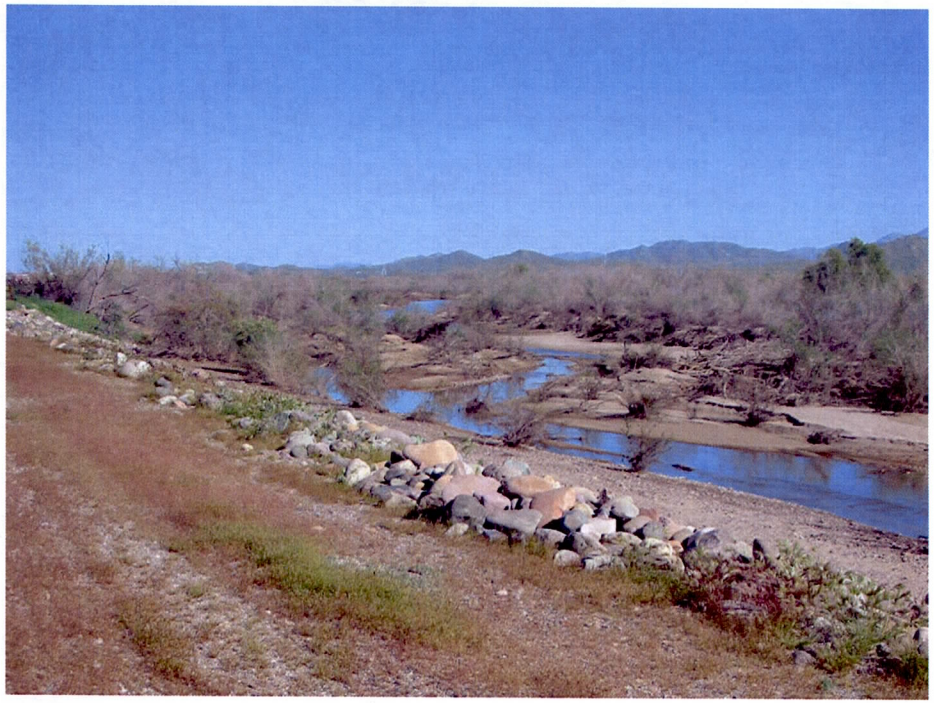


Waypoint 24 – Photos 4377-4380 Very Low Density – n = 0.03

Waypoint 28 – Photos 4383-4385 Protected north bank with Medium Dense Vegetation to left in channel – n = 0.06



Waypoint 27 - Photo 4386-4389 – Protected north bank with medium dense vegetation across channel - n = 0.06

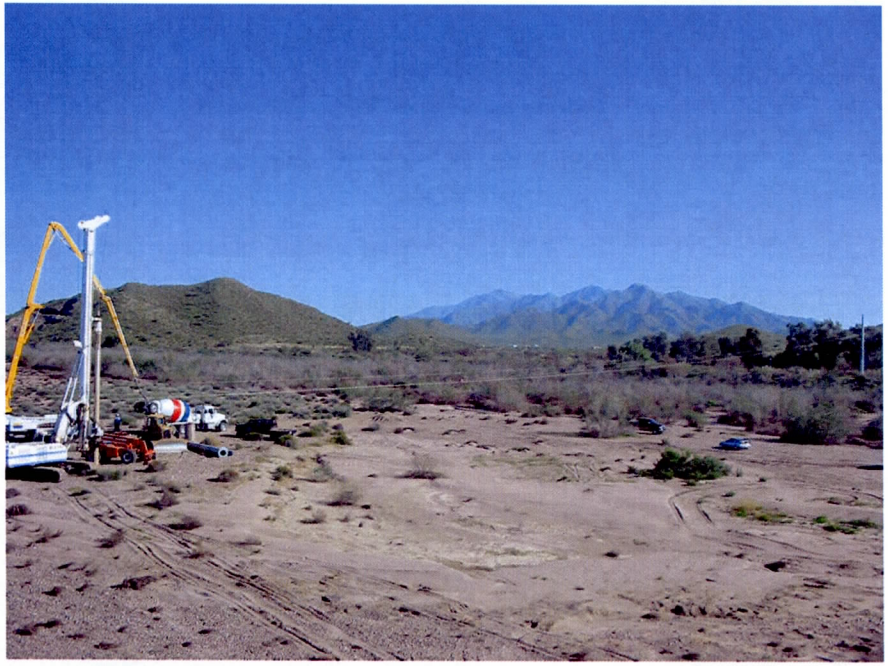


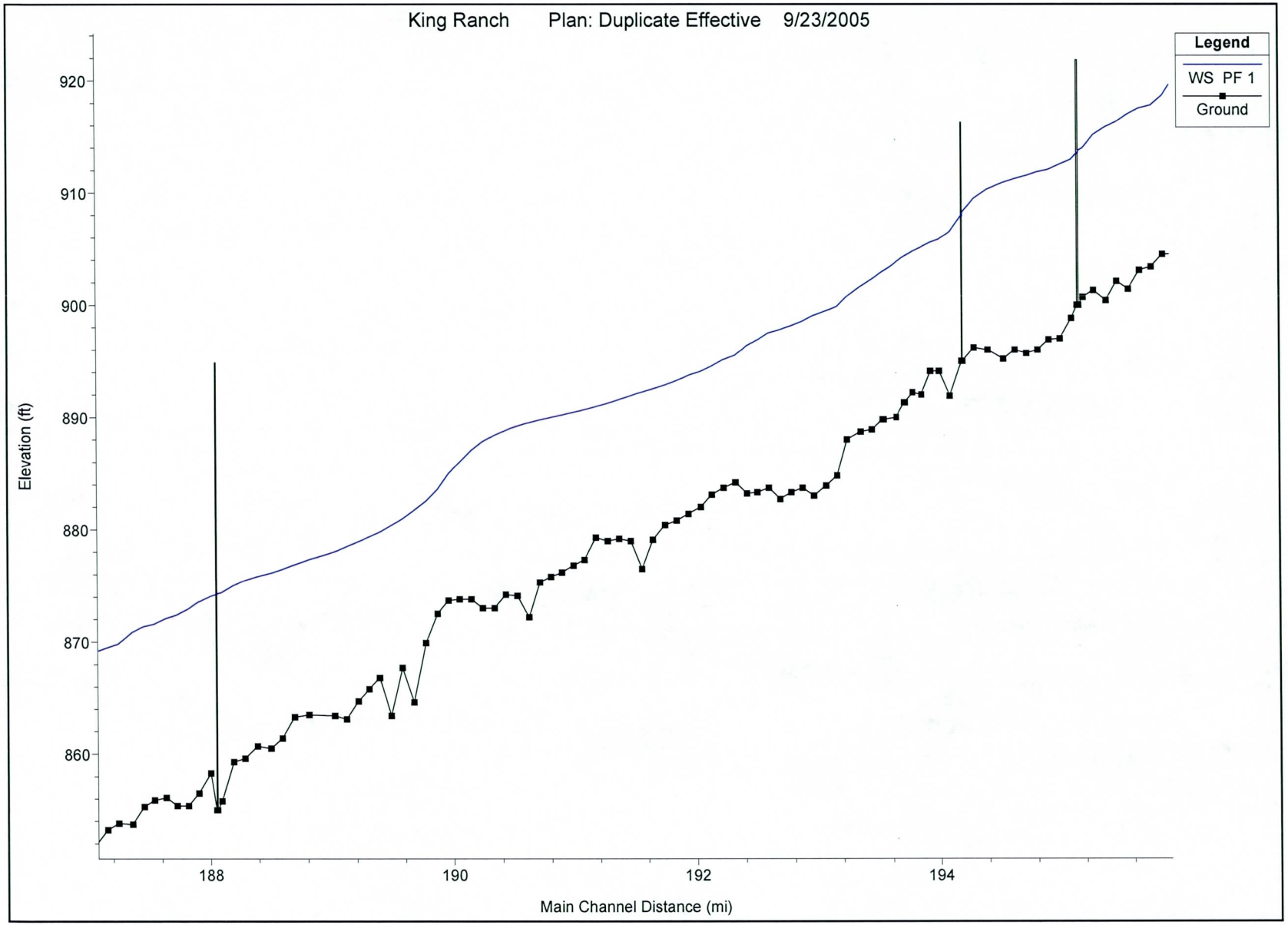
Waypoint 29 – Photos 4390-4391 East end of protected north bank – medium dense vegetation in channel – n = 0.06

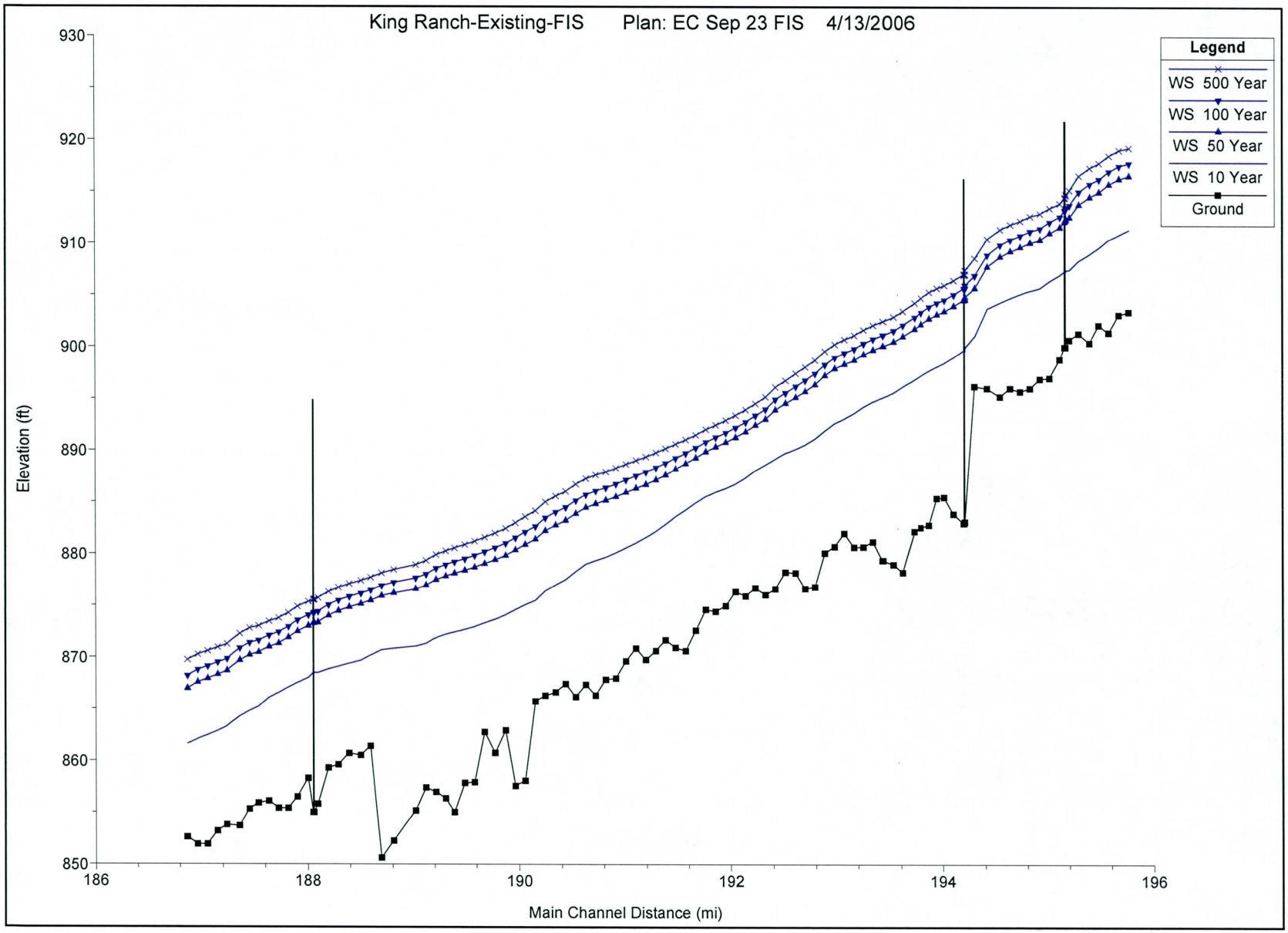
Channel at Bullard Avenue Looking Upstream (East) – Medium Vegetation Density (n = 0.06) Photos 4394-4397

Looking Upstream from Center of Bullard Ave Bridge (From North to East) - Low Density Vegetation (n = 0.03)

Bullard Avenue Bridge – looking east to south – Low density vegetation (n = 0.03) Photos 4403-4406




King Ranch Plan: Duplicate Effective 9/23/2005
Legend
WS PF 1
Ground
920
910
900
890
880
870
860
Elevation (ft)
188
190
192
194
Main Channel Distance (mi)


King Ranch-Existing-FIS Plan: EC Sep 23 FIS 4/13/2006
Legend
WS 500 Year
WS 100 Year
WS 50 Year
WS 10 Year
Ground
Elevation (ft)
930
920
910
900
890
880
870
860
850
186
188
190
192
194
196
Main Channel Distance (mi)

E.2 Cross Section Plots

E.2.1 Cross Section Plots

Effective Model

Existing Conditions

HEC-RAS River: Gila Reach: 1 Profile: PF 1

Reach	River Sta	Plan	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
1	195.75	EC FIS	227000.00	903.40	917.73	914.96	919.51	0.002168	11.22	22774.02	4473.94	0.59
1	195.75	Dupe Effec	227000.00	903.40	917.78	914.96	919.54	0.002135	11.17	22887.90	4484.18	0.58
1	195.66	EC FIS	227000.00	903.10	917.47	912.70	918.52	0.001162	8.46	28722.96	4347.24	0.43
1	195.66	Dupe Effec	227000.00	903.10	917.53	912.70	918.56	0.001143	8.42	28865.96	4371.39	0.43
1	195.56	EC FIS	227000.00	901.40	916.94	911.75	917.93	0.001156	8.12	28810.95	4106.66	0.42
1	195.56	Dupe Effec	227000.00	901.40	917.01	911.75	917.98	0.001135	8.07	28976.41	4114.54	0.42
1	195.47	EC FIS	227000.00	902.10	916.20	911.88	917.27	0.001385	8.43	27821.90	4362.31	0.45
1	195.47	Dupe Effec	227000.00	902.10	916.29	911.88	917.34	0.001347	8.36	28071.92	4377.25	0.45
1	195.38	EC FIS	227000.00	900.40	915.74	910.84	916.64	0.001098	7.82	30931.73	4013.89	0.41
1	195.38	Dupe Effec	227000.00	900.40	915.84	910.84	916.73	0.001064	7.74	31256.28	4074.60	0.40
1	195.28	EC FIS	227000.00	901.30	914.99	910.16	916.02	0.001115	8.39	29505.45	5073.02	0.43
1	195.28	Dupe Effec	227000.00	901.30	915.12	910.16	916.13	0.001069	8.27	29946.91	5149.13	0.42
1	195.19	EC FIS	227000.00	900.70	913.69	910.33	915.28	0.001884	10.39	23450.08	4198.92	0.55
1	195.19	Dupe Effec	227000.00	900.70	913.93	910.33	915.43	0.001746	10.13	24088.51	4217.69	0.53
1	195.16	EC FIS	227000.00	900.00	913.48	908.68	914.95	0.001407	9.81	23853.05	2341.51	0.48
1	195.16	Dupe Effec	227000.00	900.00	913.71	908.68	915.12	0.001320	9.62	24361.72	2345.16	0.47
1	195.15		Bridge									
1	195.13	EC FIS	227000.00	900.00	913.23	908.68	914.76	0.001503	10.02	23350.55	2237.84	0.50
1	195.13	Dupe Effec	227000.00	900.00	913.49	908.68	914.95	0.001400	9.80	23908.85	2250.79	0.48
1	195.09	EC FIS	227000.00	898.80	912.58	909.24	914.32	0.001998	10.76	22308.36	3660.31	0.56
1	195.09	Dupe Effec	227000.00	898.80	912.92	909.24	914.55	0.001800	10.41	23264.79	3870.46	0.54
1	195.00	EC FIS	227000.00	897.00	912.06	908.48	913.29	0.001537	9.17	26698.18	4368.53	0.49
1	195.00	Dupe Effec	227000.00	897.00	912.50	908.48	913.63	0.001335	8.77	28262.35	4603.73	0.46
1	194.91	EC FIS	227000.00	896.90	911.44	907.63	912.52	0.001442	8.55	28714.85	4973.81	0.47
1	194.91	Dupe Effec	227000.00	896.90	912.04	907.63	912.96	0.001156	7.95	31220.91	5049.35	0.43
1	194.81	EC FIS	227000.00	896.00	911.17	905.84	911.89	0.000815	7.00	35160.22	5168.10	0.37
1	194.81	Dupe Effec	227000.00	896.00	911.83	905.84	912.45	0.000657	6.51	38052.68	5295.65	0.33

HEC-RAS River: Gila Reach: 1 Profile: PF 1 (Continued)

Reach	River Sta	Plan	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
1	194.72	EC FIS	227000.00	895.70	910.73	905.79	911.47	0.000923	7.07	34273.66	4730.49	0.38
1	194.72	Dupe Effec	227000.00	895.70	911.49	905.79	912.12	0.000721	6.53	37296.60	5052.78	0.34
1	194.62	EC FIS	227000.00	896.00	910.35	905.58	911.00	0.000856	6.66	35706.64	5298.42	0.36
1	194.62	Dupe Effec	227000.00	896.00	911.22	905.58	911.75	0.000632	6.02	39329.16	5483.94	0.32
1	194.53	EC FIS	227000.00	895.20	909.84	905.21	910.54	0.000963	6.86	34624.42	5589.16	0.38
1	194.53	Dupe Effec	227000.00	895.20	910.88	905.21	911.43	0.000668	6.07	39262.35	6542.52	0.32
1	194.40	EC FIS	227000.00	896.00	908.87	904.77	909.78	0.001211	7.81	31032.90	5846.11	0.43
1	194.40	Dupe Effec	227000.00	896.00	910.30	904.77	910.94	0.000737	6.63	36874.39	6723.06	0.34
1	194.29	EC FIS	227000.00	896.20	906.89	904.97	908.48	0.002842	10.31	22847.51	5100.20	0.64
1	194.29	Dupe Effec	227000.00	896.20	909.44	904.97	910.32	0.001109	7.68	30593.88	5971.78	0.41
1	194.210	EC FIS	227000.00	883.10	905.94	902.06	907.43	0.001619	9.79	23180.12	2986.14	0.52
1	194.210	Dupe Effec	227000.00	895.00	908.21	903.83	909.56	0.001488	9.33	24317.26	2140.38	0.49
1	194.205		Bridge									
1	194.200	EC FIS	227000.00	882.97	905.65		907.20	0.001733	10.00	22708.96	2490.10	0.54
1	194.18	Dupe Effec	227000.00	895.00	907.96	903.83	909.38	0.001600	9.54	23788.79	2138.48	0.50
1	194.100	EC FIS	227000.00	883.87	905.03		906.30	0.001487	9.03	25152.53	4416.15	0.50
1	194.09	Dupe Effec	227000.00	891.90	906.48	904.28	908.19	0.002976	10.48	21660.59	5496.29	0.64
1	194.020	EC FIS	227000.00	885.49	904.53		905.60	0.001304	8.31	27334.51	4385.17	0.46
1	194.01	Dupe Effec	227000.00	894.10	905.82	902.59	906.93	0.001899	8.45	26850.71	5422.52	0.50
1	193.940	EC FIS	227000.00	885.38	904.24		905.09	0.001055	7.43	30577.74	4824.95	0.40
1	193.93	Dupe Effec	227000.00	894.10	905.53	901.12	906.28	0.001111	6.96	32682.98	4960.39	0.40
1	193.870	EC FIS	227000.00	882.80	903.85		904.60	0.001395	6.92	32789.38	4442.61	0.38
1	193.86	Dupe Effec	227000.00	892.00	905.11	900.74	905.85	0.001114	6.93	32753.66	4575.13	0.40
1	193.790	EC FIS	227000.00	882.55	903.30		903.99	0.001356	6.68	34001.67	4084.62	0.37

HEC-RAS River: Gila Reach: 1 Profile: PF 1 (Continued)

Reach	River Sta	Plan	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
1	193.78	Dupe Effec	227000.00	892.20	904.75	899.63	905.37	0.000970	6.33	35874.07	4101.57	0.35
1	193.730	EC FIS	227000.00	882.18	902.84		903.59	0.000969	6.98	32547.95	3422.17	0.40
1	193.71	Dupe Effec	227000.00	891.30	904.30	899.46	905.00	0.001157	6.69	33916.43	3491.22	0.38
1	193.65	Dupe Effec	227000.00	890.00	903.80	899.09	904.56	0.001228	7.01	32396.55	3334.06	0.39
1	193.620	EC FIS	227000.00	878.21	902.08		902.97	0.001205	7.58	29961.99	3219.71	0.43
1	193.54	Dupe Effec	227000.00	889.80	902.93	898.88	903.82	0.001382	7.60	29965.48	3343.41	0.44
1	193.530	EC FIS	227000.00	878.96	901.54		902.39	0.001126	7.39	30800.24	3345.84	0.42
1	193.45	Dupe Effec	227000.00	888.90	902.25	898.15	903.10	0.001620	7.43	30532.05	3530.86	0.43
1	193.430	EC FIS	227000.00	879.37	901.12		901.85	0.000961	6.90	33034.87	3717.42	0.39
1	193.36	Dupe Effec	227000.00	888.70	901.61	897.59	902.41	0.001162	7.17	32169.06	3878.69	0.42
1	193.340	EC FIS	227000.00	881.18	900.74		901.40	0.000849	6.56	34799.45	3882.87	0.37
1	193.250	EC FIS	227000.00	880.67	900.31		900.94	0.001057	6.43	35769.75	4130.63	0.37
1	193.24	Dupe Effec	227000.00	888.00	900.72	897.06	901.57	0.001645	7.39	31095.88	4150.34	0.46
1	193.160	EC FIS	227000.00	880.66	899.78		900.46	0.000935	6.65	34684.11	4280.19	0.40
1	193.160	Dupe Effec	227000.00	884.80	899.83	896.56	900.78	0.002012	7.81	29367.20	4179.14	0.50
1	193.070	EC FIS	227000.00	881.99	899.39		900.02	0.000833	6.41	36599.66	4501.91	0.38
1	193.070	Dupe Effec	227000.00	883.90	899.45	893.82	900.06	0.000903	6.25	36849.99	4364.17	0.36
1	192.980	EC FIS	227000.00	880.71	898.94		899.60	0.000904	6.55	36477.48	4492.52	0.37
1	192.97	Dupe Effec	227000.00	883.00	899.04	893.61	899.58	0.000806	5.98	38933.65	5020.35	0.33
1	192.890	EC FIS	227000.00	880.09	898.26		899.03	0.001424	7.17	34862.68	5006.47	0.41
1	192.88	Dupe Effec	227000.00	883.70	898.53	893.47	899.15	0.000925	6.43	37040.51	5456.69	0.35

HEC-RAS River: Gila Reach: 1 Profile: PF 1 (Continued)

Reach	River Sta	Plan	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
1	192.790	EC FIS	227000.00	876.81	897.40		898.32	0.001389	7.93	33573.02	5336.40	0.45
1	192.78	Dupe Effec	227000.00	883.30	898.14	892.61	898.73	0.000708	6.41	38896.72	6211.90	0.34
1	192.700	EC FIS	227000.00	876.64	896.74		897.64	0.001333	7.98	35145.32	5682.11	0.43
1	192.69	Dupe Effec	227000.00	882.70	897.80	892.37	898.38	0.000677	6.53	39839.13	6880.82	0.33
1	192.610	EC FIS	227000.00	878.15	896.15		897.03	0.001154	8.00	35546.89	5872.80	0.42
1	192.6	Dupe Effec	227000.00	883.70	897.49	892.80	897.99	0.000799	6.06	40747.94	6443.18	0.32
1	192.520	EC FIS	227000.00	878.23	895.53		896.44	0.001148	8.05	34239.52	6077.61	0.42
1	192.51	Dupe Effec	227000.00	883.30	896.86	893.05	897.54	0.000955	7.21	36499.05	7531.22	0.39
1	192.420	EC FIS	227000.00	876.63	894.89		895.82	0.001336	8.28	32561.57	5843.05	0.45
1	192.420	Dupe Effec	227000.00	883.20	896.36	892.68	897.03	0.001202	7.18	36197.95	7133.54	0.40
1	192.330	EC FIS	227000.00	876.06	893.94		895.05	0.001690	8.81	30701.01	6006.68	0.50
1	192.330	Dupe Effec	227000.00	884.20	895.51	892.70	896.37	0.001428	8.10	33196.96	6171.26	0.47
1	192.230	EC FIS	227000.00	876.72	893.34		894.21	0.001422	7.75	34065.29	5915.17	0.44
1	192.230	Dupe Effec	227000.00	883.70	895.12	891.34	895.67	0.001029	6.25	38851.23	6812.14	0.36
1	192.140	EC FIS	227000.00	875.94	892.70		893.51	0.001371	7.46	35753.43	6577.71	0.44
1	192.13	Dupe Effec	227000.00	883.10	894.53	891.11	895.04	0.001305	5.62	39743.45	7677.65	0.34
1	192.040	EC FIS	227000.00	876.36	892.15		892.84	0.001184	6.87	38705.71	6340.30	0.41
1	192.040	Dupe Effec	227000.00	882.00	894.07	890.72	894.52	0.000824	5.59	42424.03	7766.74	0.34
1	191.950	EC FIS	227000.00	874.98	891.68		892.27	0.000992	6.35	40579.67	6286.37	0.38
1	191.94	Dupe Effec	227000.00	881.40	893.70	889.79	894.09	0.000797	5.07	45584.10	7948.92	0.30
1	191.860	EC FIS	227000.00	874.43	891.23		891.77	0.000956	6.01	41392.52	6194.40	0.36
1	191.84	Dupe Effec	227000.00	880.80	893.24		893.64	0.000911	5.26	45223.06	7847.64	0.32
1	191.760	EC FIS	227000.00	874.62	890.77		891.25	0.001023	5.75	43691.46	6618.45	0.35

HEC-RAS River: Gila Reach: 1 Profile: PF 1 (Continued)

Reach	River Sta	Plan	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
1	191.75	Dupe Effec	227000.00	880.40	892.86	888.67	893.19	0.000796	4.82	49970.53	8659.98	0.29
1	191.670	EC FIS	227000.00	872.60	890.21		890.70	0.001196	5.76	42353.34	6318.40	0.36
1	191.65	Dupe Effec	227000.00	879.10	892.50	887.65	892.80	0.000606	4.57	53249.00	9077.19	0.27
1	191.570	EC FIS	227000.00	870.63	889.70		890.12	0.001047	5.33	44937.55	6254.95	0.34
1	191.55	Dupe Effec	227000.00	876.50	892.22	887.42	892.50	0.000677	4.39	54705.82	9150.76	0.26
1	191.480	EC FIS	227000.00	870.93	889.22		889.61	0.000939	5.10	45899.68	7187.75	0.32
1	191.46	Dupe Effec	227000.00	879.00	891.88	887.33	892.16	0.000657	4.34	53804.05	8798.20	0.27
1	191.380	EC FIS	227000.00	871.69	888.72		889.13	0.000974	5.18	44881.15	6649.49	0.34
1	191.36	Dupe Effec	227000.00	879.20	891.53	887.22	891.80	0.000745	4.16	54771.66	9220.32	0.26
1	191.290	EC FIS	227000.00	870.63	888.28		888.67	0.000858	4.99	46526.23	7388.01	0.31
1	191.27	Dupe Effec	227000.00	879.00	891.23	886.23	891.46	0.000570	3.81	59113.20	9572.63	0.23
1	191.190	EC FIS	227000.00	869.78	887.86		888.26	0.000787	5.05	46198.18	7861.27	0.30
1	191.17	Dupe Effec	227000.00	879.30	890.94	885.71	891.18	0.000553	3.96	58001.98	9540.22	0.23
1	191.100	EC FIS	227000.00	870.88	887.51		887.91	0.000629	5.09	46885.33	7293.46	0.29
1	191.08	Dupe Effec	227000.00	877.30	890.65	885.43	890.90	0.000536	4.07	57635.00	9711.45	0.23
1	191.000	EC FIS	227000.00	869.64	887.13		887.57	0.000686	5.41	44628.57	7582.72	0.31
1	190.99	Dupe Effec	227000.00	876.80	890.40	884.28	890.66	0.000469	4.20	57790.23	7494.27	0.23
1	190.910	EC FIS	227000.00	867.98	886.72		887.20	0.000782	5.65	43346.07	7999.37	0.32
1	190.89	Dupe Effec	227000.00	876.20	890.18	883.88	890.41	0.000487	4.04	58720.39	10378.21	0.22
1	190.810	EC FIS	227000.00	867.86	886.37		886.84	0.000669	5.59	44158.22	8364.90	0.31

HEC-RAS River: Gila Reach: 1 Profile: PF 1 (Continued)

Reach	River Sta	Plan	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
1	190.8	Dupe Effec	227000.00	875.80	889.97	883.73	890.20	0.000447	3.90	60413.32	11719.18	0.21
1	190.720	EC FIS	227000.00	866.30	886.05		886.50	0.000661	5.50	45458.39	8348.21	0.30
1	190.71	Dupe Effec	227000.00	875.30	889.76	883.41	889.98	0.000456	3.86	61067.79	11919.51	0.21
1	190.620	EC FIS	227000.00	867.37	885.69		886.15	0.000739	5.55	44852.69	7726.17	0.30
1	190.620	Dupe Effec	227000.00	872.20	889.50	882.54	889.75	0.000472	3.97	57867.10	11205.91	0.20
1	190.530	EC FIS	227000.00	866.16	885.12		885.61	0.001724	5.68	42071.69	6517.66	0.32
1	190.530	Dupe Effec	227000.00	874.10	889.20	882.19	889.47	0.000687	4.22	54383.10	11111.69	0.22
1	190.430	EC FIS	227000.00	867.42	884.46		884.98	0.000953	5.82	40797.63	5841.82	0.33
1	190.430	Dupe Effec	227000.00	874.20	888.82	881.51	889.12	0.000750	4.47	54839.95	11248.10	0.23
1	190.340	EC FIS	227000.00	866.61	884.00		884.46	0.001034	5.43	41834.49	5720.86	0.32
1	190.340	Dupe Effec	227000.00	873.00	888.35	881.37	888.65	0.001233	4.39	52085.64	11643.56	0.24
1	190.240	EC FIS	227000.00	866.29	883.45		883.89	0.001198	5.36	42387.94	5596.41	0.31
1	190.240	Dupe Effec	227000.00	873.00	887.82	880.86	888.13	0.000861	4.46	51604.94	11847.98	0.24
1	190.150	EC FIS	227000.00	865.74	882.61		883.22	0.001518	6.24	36446.58	5097.66	0.38
1	190.150	Dupe Effec	227000.00	873.80	887.01	882.20	887.50	0.002000	5.62	41355.20	12521.23	0.34
1	190.050	EC FIS	227000.00	858.06	882.07		882.52	0.001089	5.38	42196.50	5755.81	0.30
1	190.050	Dupe Effec	227000.00	873.80	885.99	881.79	886.56	0.001708	6.12	37817.95	12160.34	0.38
1	189.960	EC FIS	227000.00	857.56	881.52		881.98	0.001179	5.43	41782.05	5173.45	0.30
1	189.960	Dupe Effec	227000.00	873.70	884.93	881.25	885.56	0.002540	6.41	35768.85	11879.18	0.40
1	189.870	EC FIS	227000.00	862.94	880.98		881.41	0.001119	5.28	43407.35	9106.03	0.30
1	189.870	Dupe Effec	227000.00	872.50	883.54	880.41	884.24	0.002852	6.75	33882.41	11839.84	0.44
1	189.770	EC FIS	227000.00	860.75	880.56		880.89	0.000778	4.64	50356.75	10644.73	0.25
1	189.770	Dupe Effec	227000.00	869.90	882.48	878.25	882.95	0.001848	5.49	41247.31	12202.15	0.34
1	189.68	Dupe Effec	227000.00	864.60	881.65	877.27	882.10	0.001501	5.42	42378.98	12293.09	0.33
1	189.670	EC FIS	227000.00	862.77	880.16		880.48	0.000779	4.56	51568.92	10427.07	0.25
1	189.580	EC FIS	227000.00	857.92	879.80		880.11	0.000701	4.53	52684.95	9175.34	0.24

HEC-RAS River: Gila Reach: 1 Profile: PF 1 (Continued)

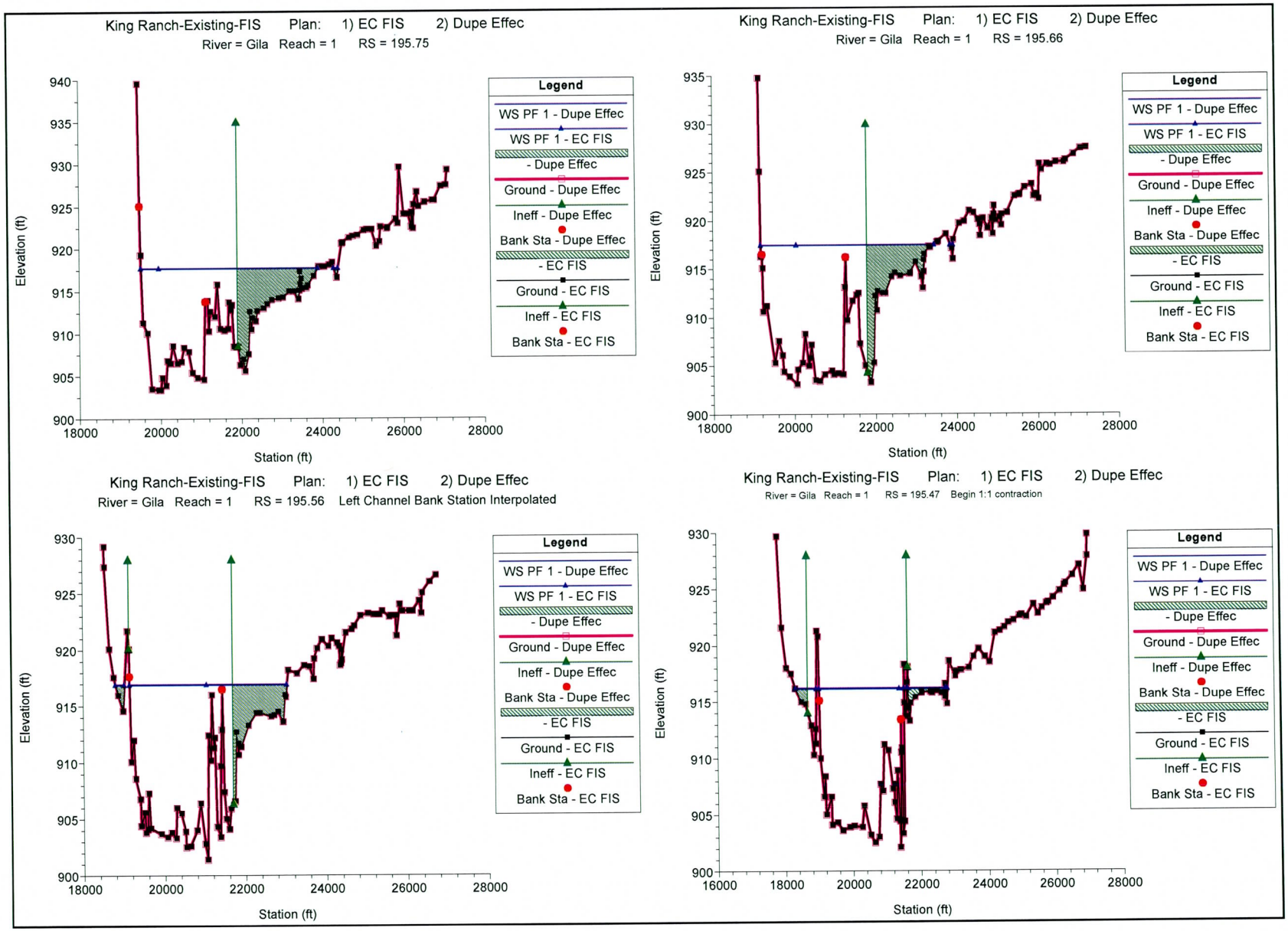
Reach	River Sta	Plan	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
1	189.580	Dupe Effec	227000.00	867.70	880.91	876.36	881.36	0.001514	5.53	42682.80	11905.50	0.34
1	189.49	Dupe Effec	227000.00	863.40	880.32	875.29	880.70	0.001081	5.10	47016.49	10728.38	0.31
1	189.480	EC FIS	227000.00	857.85	879.48		879.77	0.000636	4.42	54786.62	8934.14	0.23
1	189.390	EC FIS	227000.00	855.02	879.18		879.47	0.000545	4.45	55398.39	9977.68	0.23
1	189.390	Dupe Effec	227000.00	866.80	879.75	874.86	880.15	0.001145	5.29	46038.21	10705.65	0.32
1	189.31	Dupe Effec	227000.00	865.80	879.34	874.20	879.70	0.001026	5.02	48027.75	10326.30	0.30
1	189.300	EC FIS	227000.00	856.36	878.90		879.21	0.000638	4.59	54138.75	9775.70	0.24
1	189.22	Dupe Effec	227000.00	864.70	878.92	874.04	879.26	0.001017	4.89	48879.11	9433.39	0.29
1	189.210	EC FIS	227000.00	856.97	878.54		878.80	0.001059	4.32	56990.95	9083.98	0.23
1	189.12	Dupe Effec	227000.00	863.10	878.47	873.77	878.81	0.001015	4.97	49123.61	9037.20	0.30
1	189.110	EC FIS	227000.00	857.40	877.99		878.25	0.001099	4.28	57377.02	8474.79	0.22
1	189.020	EC FIS	227000.00	855.16	877.62		877.89	0.000495	4.30	58870.63	8955.39	0.23
1	189.020	Dupe Effec	227000.00	863.40	878.00	873.67	878.37	0.000958	5.15	49359.91	9413.65	0.32
1	188.810	EC FIS	227000.00	852.24	877.19		877.43	0.000348	4.09	62725.53	8318.66	0.20
1	188.810	Dupe Effec	227000.00	863.50	877.31	871.67	877.60	0.000604	4.41	53904.10	8506.25	0.25
1	188.7	Dupe Effec	227000.00	863.30	876.86	872.22	877.19	0.000909	4.79	49805.93	8743.50	0.28
1	188.690	EC FIS	227000.00	850.62	876.87		877.15	0.000700	4.35	59160.10	8930.40	0.21
1	188.59	EC FIS	227000.00	861.40	876.44	871.17	876.76	0.000765	4.67	50873.55	7530.72	0.27
1	188.59	Dupe Effec	227000.00	861.40	876.44	871.17	876.76	0.000765	4.67	50873.55	7530.72	0.27
1	188.5	EC FIS	227000.00	860.50	876.12	870.33	876.40	0.000690	4.44	53393.40	7597.74	0.24
1	188.5	Dupe Effec	227000.00	860.50	876.12	870.33	876.40	0.000690	4.44	53393.40	7597.74	0.24
1	188.39	EC FIS	227000.00	860.70	875.81	868.98	876.11	0.000487	4.58	54047.77	7353.55	0.24
1	188.39	Dupe Effec	227000.00	860.70	875.81	868.98	876.11	0.000487	4.58	54047.77	7353.55	0.24
1	188.29	EC FIS	227000.00	859.60	875.45	869.32	875.86	0.000472	5.41	47908.43	7326.69	0.28

HEC-RAS River: Gila Reach: 1 Profile: PF 1 (Continued)

Reach	River Sta	Plan	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
1	188.29	Dupe Effec	227000.00	859.60	875.45	869.32	875.86	0.000472	5.41	47908.43	7326.69	0.28
1	188.2	EC FIS	227000.00	859.30	875.00	868.81	875.54	0.000962	6.21	41665.74	7148.81	0.31
1	188.2	Dupe Effec	227000.00	859.30	875.00	868.81	875.54	0.000962	6.21	41666.16	7148.81	0.31
1	188.1	EC FIS	227000.00	855.80	874.36	868.84	875.07	0.000862	7.28	37965.66	6595.48	0.36
1	188.1	Dupe Effec	227000.00	855.80	874.36	868.84	875.07	0.000862	7.28	37966.03	6595.49	0.36
1	188.07	EC FIS	227000.00	855.00	874.27	866.15	874.91	0.000558	6.89	39208.98	5733.80	0.31
1	188.07	Dupe Effec	227000.00	855.00	874.27	866.15	874.91	0.000558	6.89	39209.29	5733.80	0.31
1	188.055		Bridge									
1	188.04	EC FIS	227000.00	855.00	874.21	866.15	874.88	0.000577	6.99	38248.79	5733.34	0.31
1	188.04	Dupe Effec	227000.00	855.00	874.21	866.15	874.88	0.000577	6.99	38249.08	5733.34	0.31
1	188	EC FIS	227000.00	858.30	874.03	871.10	874.70	0.000857	7.29	37571.17	7288.16	0.39
1	188	Dupe Effec	227000.00	858.30	874.03	871.10	874.70	0.000857	7.29	37571.52	7288.17	0.39
1	187.91	EC FIS	227000.00	856.50	873.54	870.77	874.24	0.000870	7.26	35900.98	5898.48	0.40
1	187.91	Dupe Effec	227000.00	856.50	873.54	870.77	874.24	0.000870	7.26	35901.30	5898.49	0.40
1	187.82	EC FIS	227000.00	855.40	872.91	870.06	873.76	0.001124	7.77	32038.47	5367.10	0.46
1	187.82	Dupe Effec	227000.00	855.40	872.91	870.06	873.76	0.001124	7.77	32039.06	5367.22	0.46
1	187.73	EC FIS	227000.00	855.40	872.38	869.18	873.23	0.001125	7.74	32552.54	7779.96	0.45
1	187.73	Dupe Effec	227000.00	855.40	872.38	869.18	873.23	0.001124	7.74	32553.39	7780.66	0.45
1	187.64	EC FIS	227000.00	856.10	872.07	868.39	872.75	0.000847	6.99	36450.42	8097.85	0.38
1	187.64	Dupe Effec	227000.00	856.10	872.07	868.39	872.75	0.000847	6.99	36451.52	8098.67	0.38
1	187.54	EC FIS	227000.00	855.90	871.57	867.67	872.34	0.000939	7.28	33184.70	8486.68	0.42
1	187.54	Dupe Effec	227000.00	855.90	871.57	867.67	872.34	0.000939	7.28	33186.02	8488.08	0.42
1	187.45	EC FIS	227000.00	855.30	871.35	867.00	871.92	0.000722	6.45	38831.71	9337.40	0.36
1	187.45	Dupe Effec	227000.00	855.30	871.35	867.00	871.92	0.000722	6.45	38833.45	9340.20	0.36
1	187.36	EC FIS	227000.00	853.70	870.83	866.53	871.53	0.000766	6.99	36027.79	9688.24	0.38
1	187.36	Dupe Effec	227000.00	853.70	870.83	866.53	871.53	0.000766	6.99	36029.66	9688.99	0.38
1	187.24	EC FIS	227000.00	853.80	869.81	866.24	870.85	0.001548	8.48	30572.47	8203.42	0.47

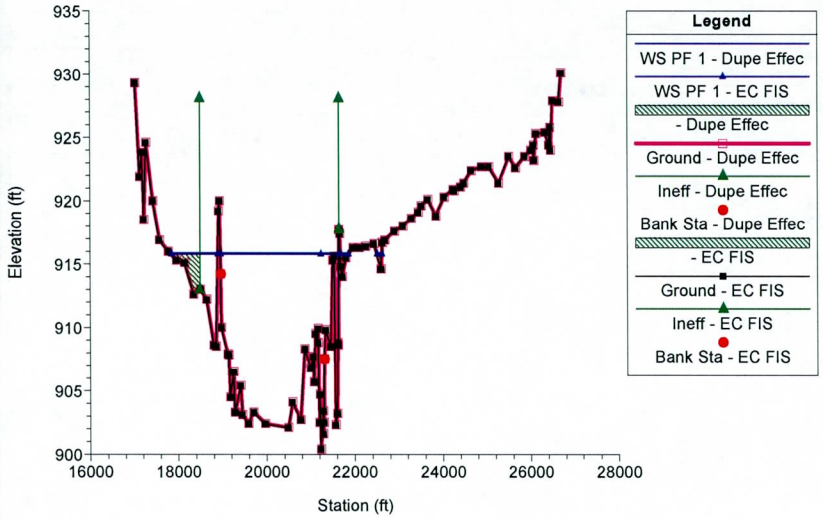
HEC-RAS River: Gila Reach: 1 Profile: PF 1 (Continued)

Reach	River Sta	Plan	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
1	187.24	Dupe Effec	227000.00	853.80	869.81	866.24	870.85	0.001547	8.48	30575.30	8205.17	0.47
1	187.15	EC FIS	227000.00	853.20	869.48	864.95	870.16	0.000967	6.90	36060.30	8790.41	0.38
1	187.15	Dupe Effec	227000.00	853.20	869.48	864.95	870.16	0.000967	6.90	36063.86	8795.17	0.38
1	187.06	EC FIS	227000.00	851.90	869.09	864.37	869.68	0.000821	6.34	37393.59	8893.03	0.35
1	187.06	Dupe Effec	227000.00	851.90	869.09	864.37	869.69	0.000821	6.34	37397.82	8895.22	0.35
1	186.97	EC FIS	227000.00	851.90	868.75	864.00	869.29	0.000764	5.99	38631.88	9763.17	0.35
1	186.97	Dupe Effec	227000.00	851.90	868.75	864.00	869.29	0.000764	5.98	38636.68	9764.51	0.35
1	186.87	EC FIS	227000.00	852.60	868.18	863.60	868.83	0.001045	6.65	35918.05	11022.50	0.38
1	186.87	Dupe Effec	227000.00	852.60	868.18	863.60	868.83	0.001044	6.65	35925.27	11028.66	0.38


King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 195.75
Elevation (ft)
Station (ft)
Legend
WS PF 1 - Dupe Effec
WS PF 1 - EC FIS
- Dupe Effec
Ground - Dupe Effec
Ineff - Dupe Effec
Bank Sta - Dupe Effec
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 195.66
Elevation (ft)
Station (ft)
Legend
WS PF 1 - Dupe Effec
WS PF 1 - EC FIS
- Dupe Effec
Ground - Dupe Effec
Ineff - Dupe Effec
Bank Sta - Dupe Effec
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 195.56 Left Channel Bank Station Interpolated
Elevation (ft)
Station (ft)
Legend
WS PF 1 - Dupe Effec
WS PF 1 - EC FIS
- Dupe Effec
Ground - Dupe Effec
Ineff - Dupe Effec
Bank Sta - Dupe Effec
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 195.47 Begin 1:1 contraction
Elevation (ft)
Station (ft)
Legend
WS PF 1 - Dupe Effec
WS PF 1 - EC FIS
- Dupe Effec
Ground - Dupe Effec
Ineff - Dupe Effec
Bank Sta - Dupe Effec
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS

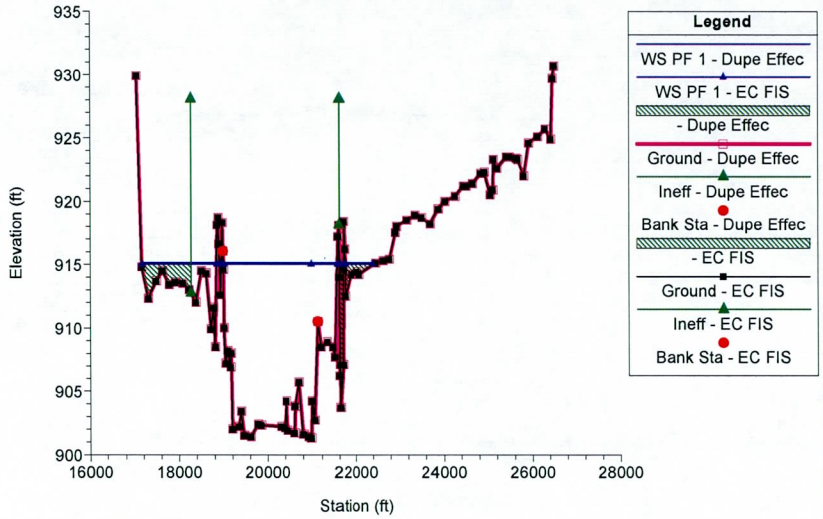
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec

River = Gila Reach = 1 RS = 195.38



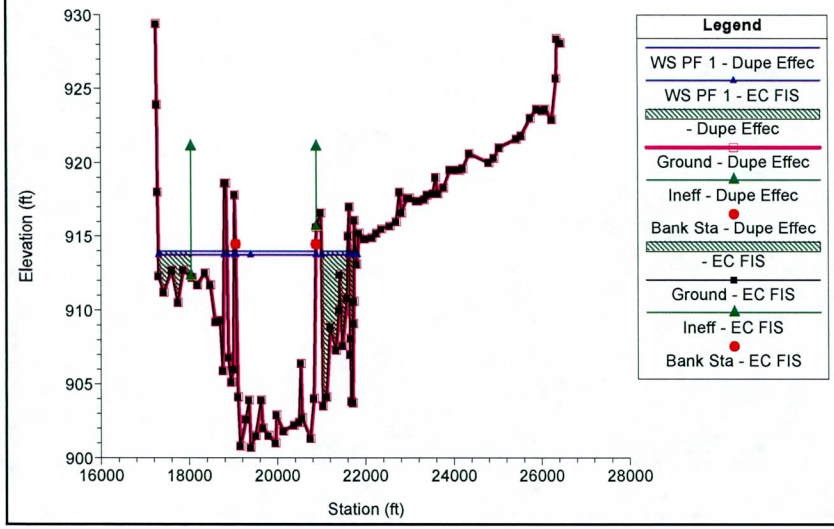
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec

River = Gila Reach = 1 RS = 195.28 Left Channel Bank Station Interpolated



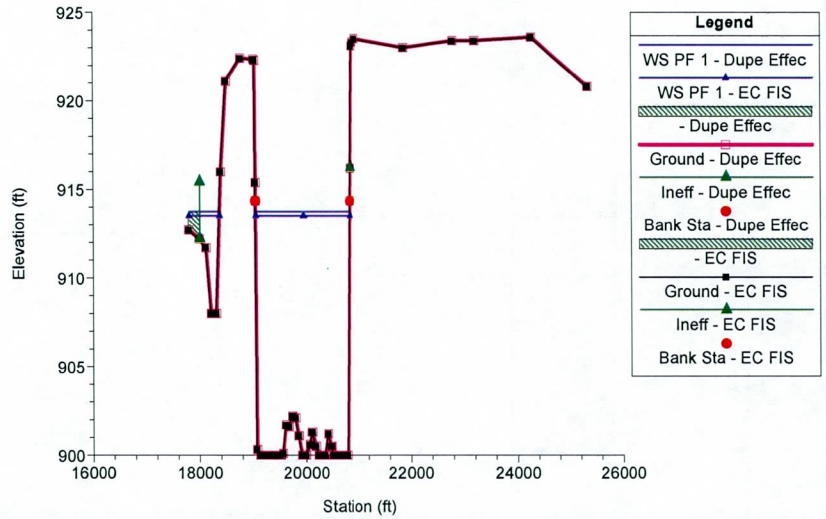
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec

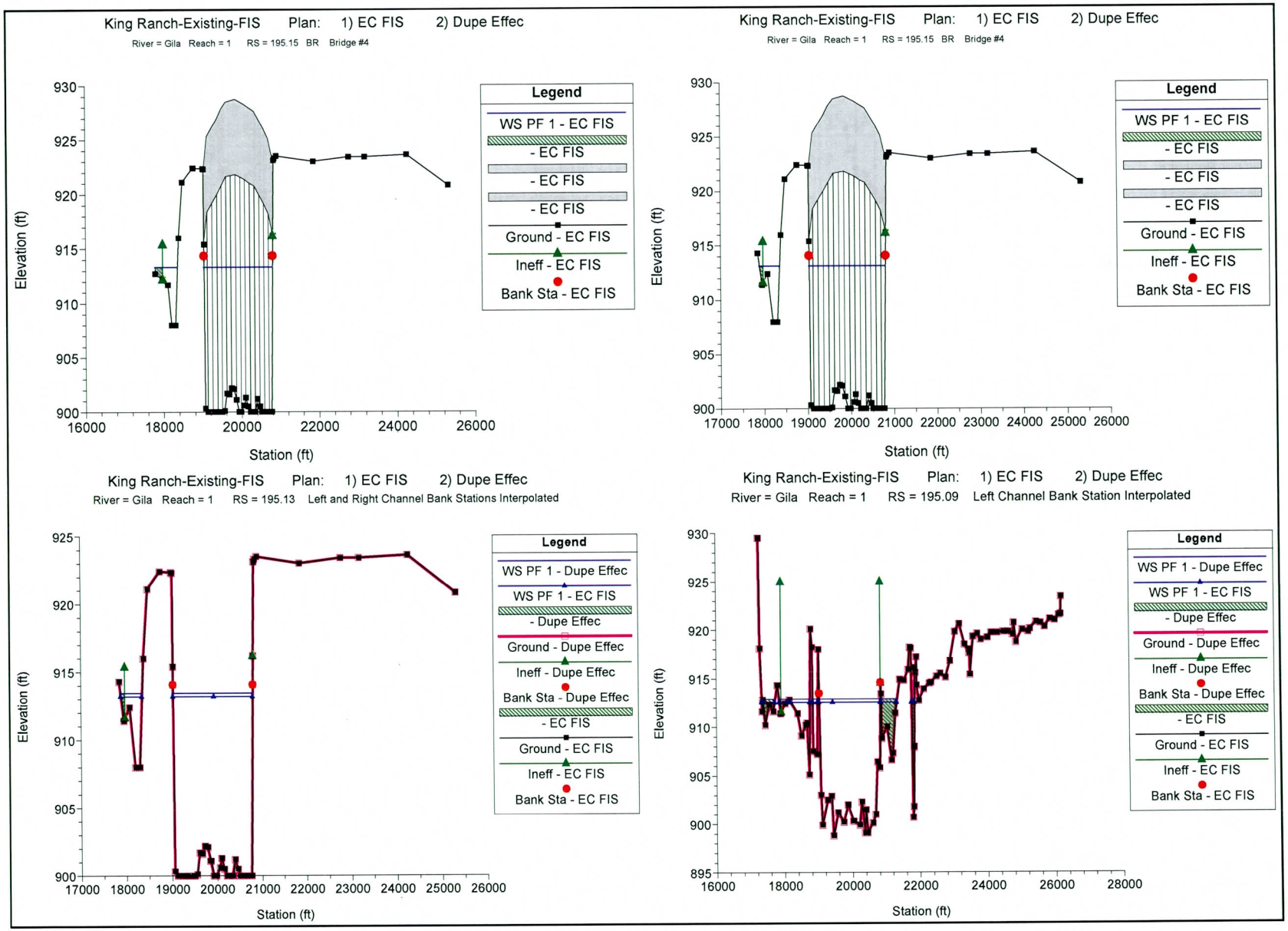
River = Gila Reach = 1 RS = 195.19 Left and Right Channel Bank Stations Interpolated

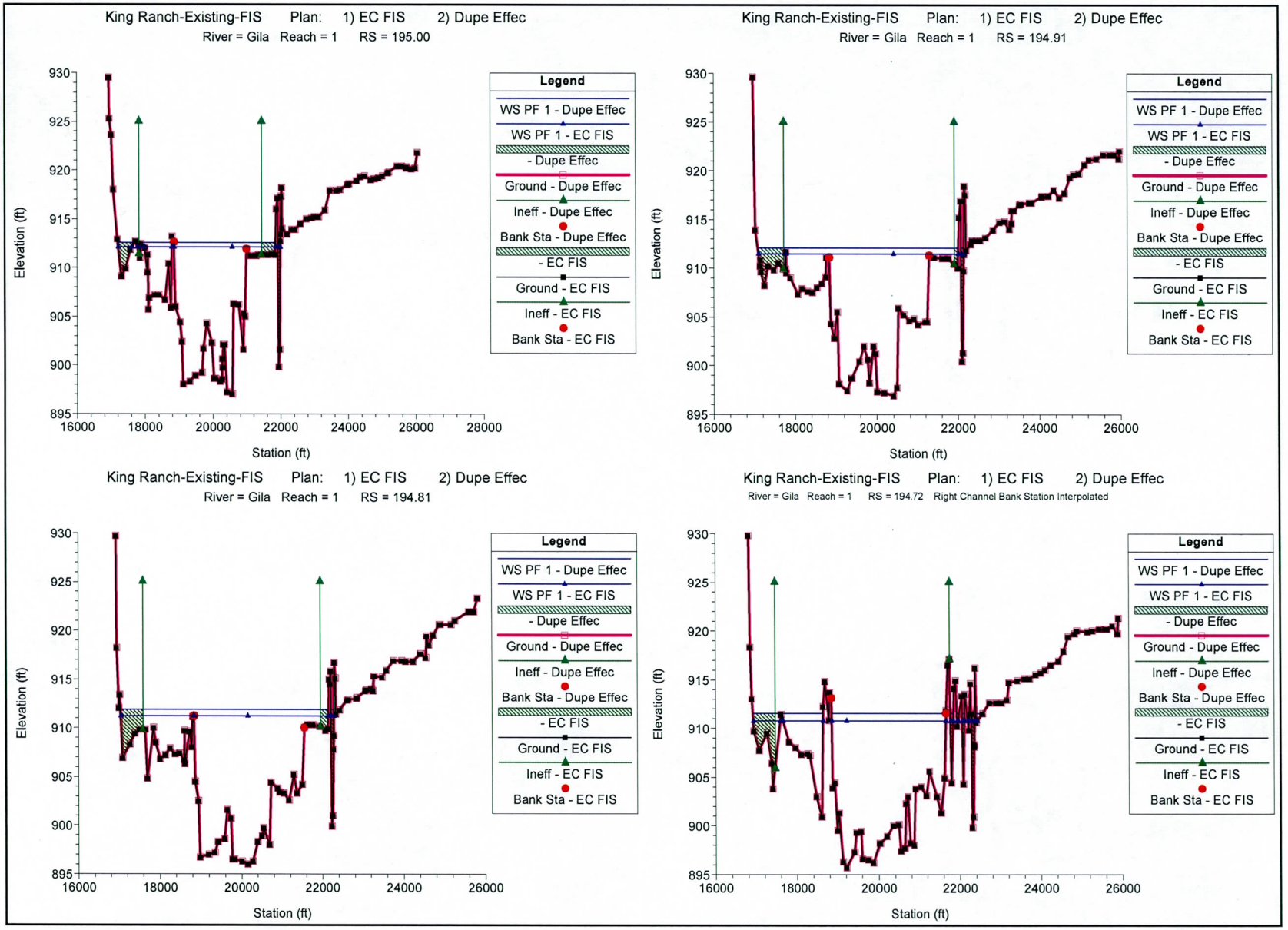


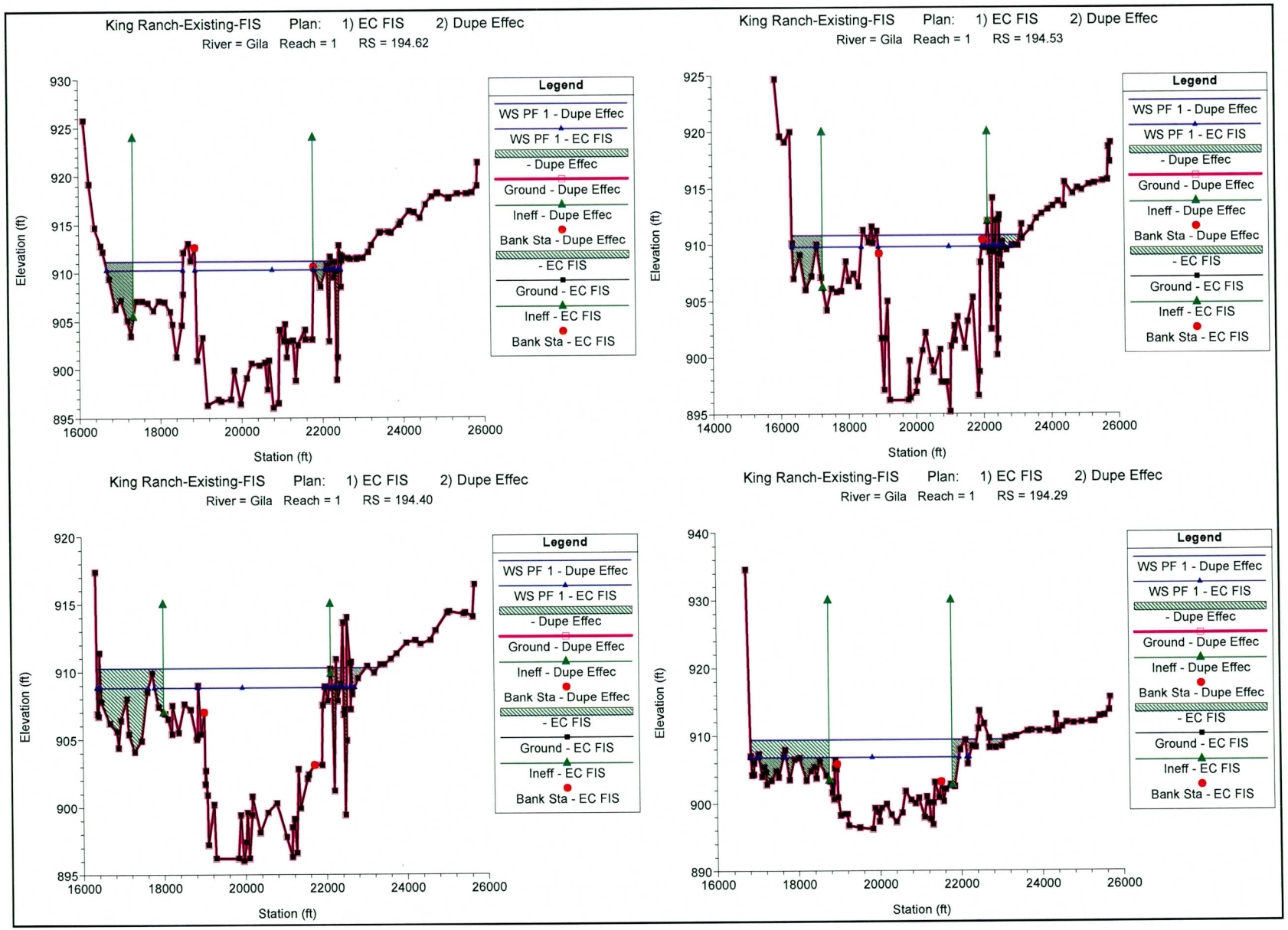
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec

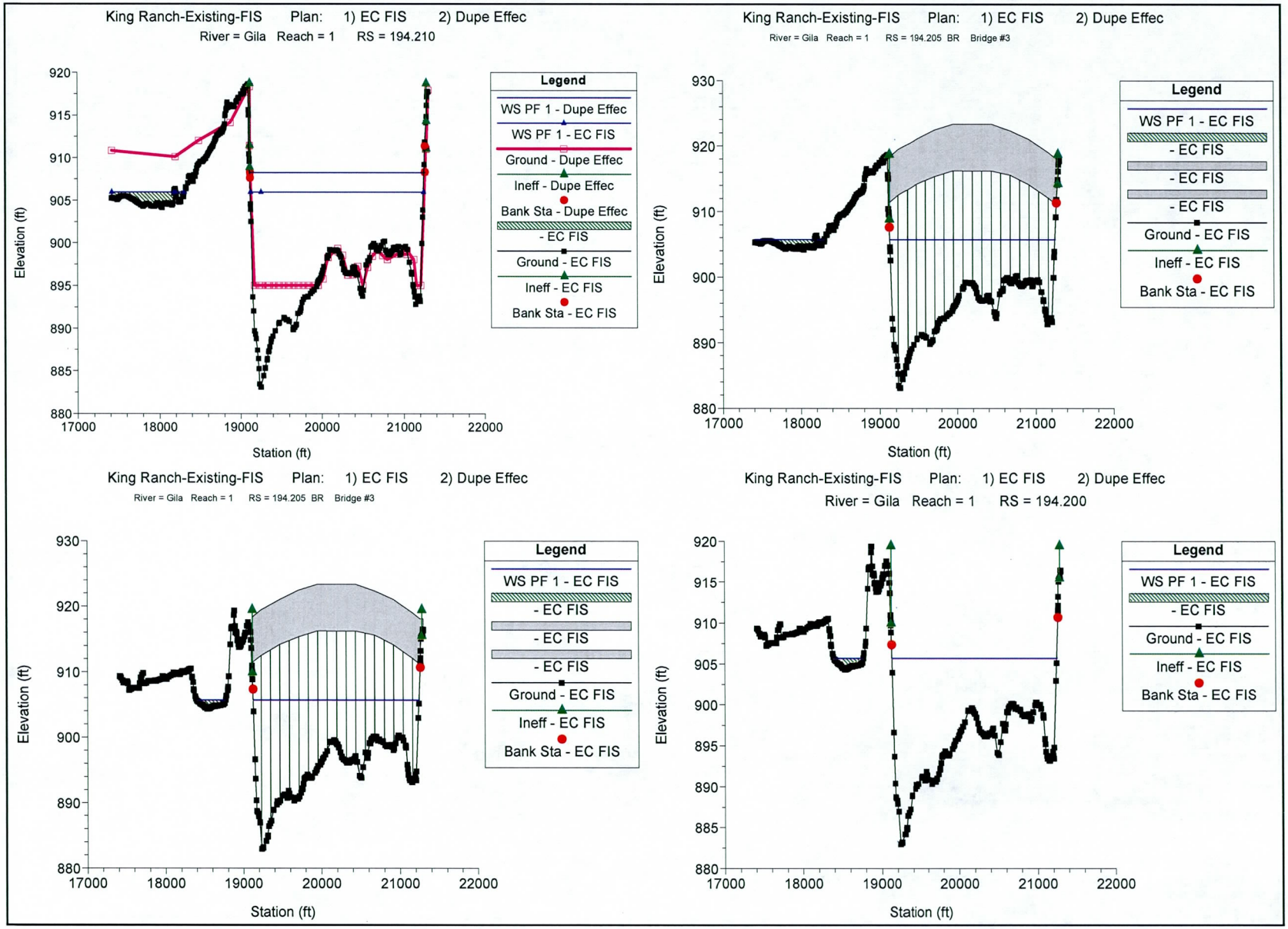
River = Gila Reach = 1 RS = 195.16 APPROX. ALIGNMENT OF BULLARD AVE. BRIDGE

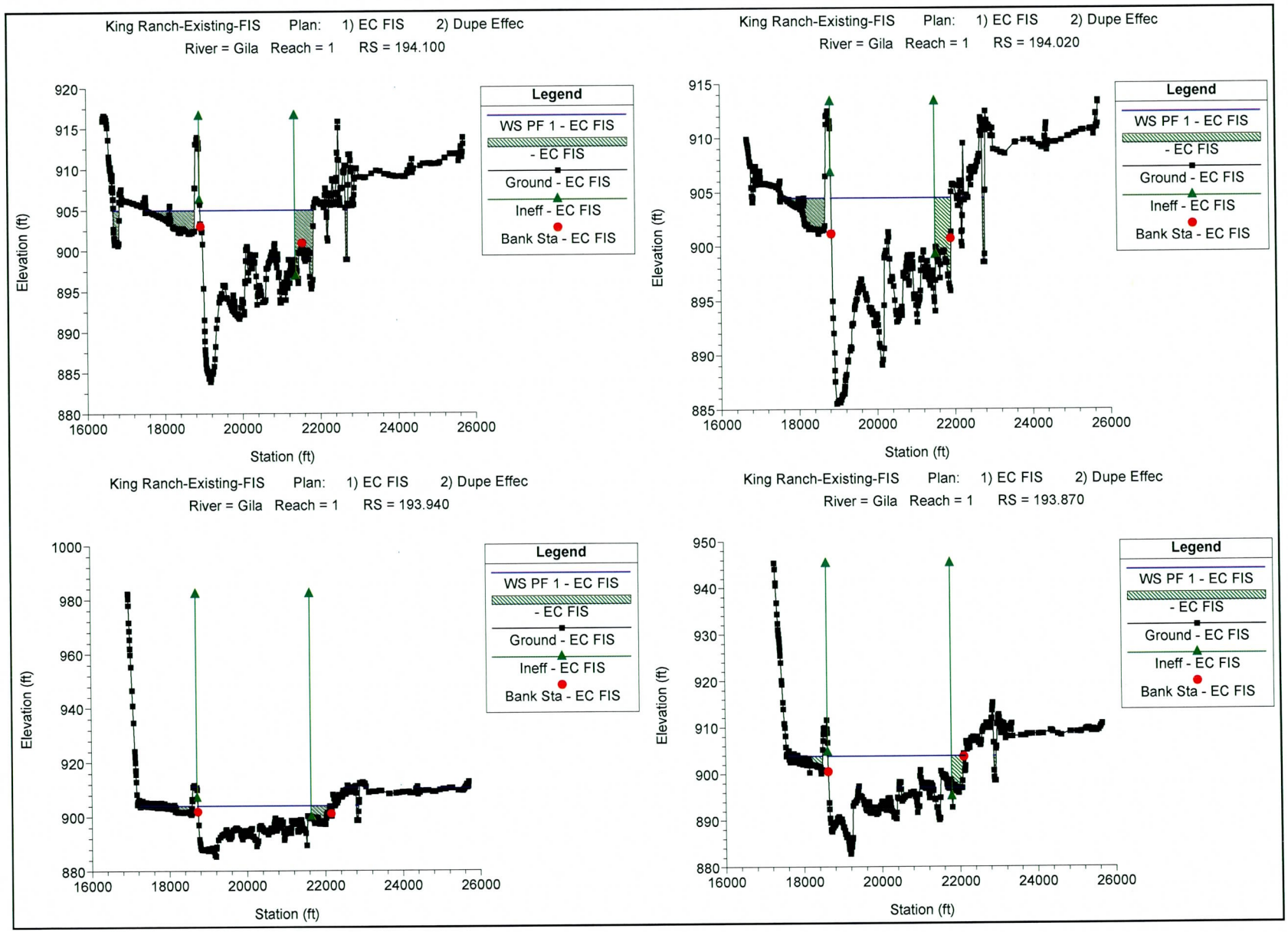


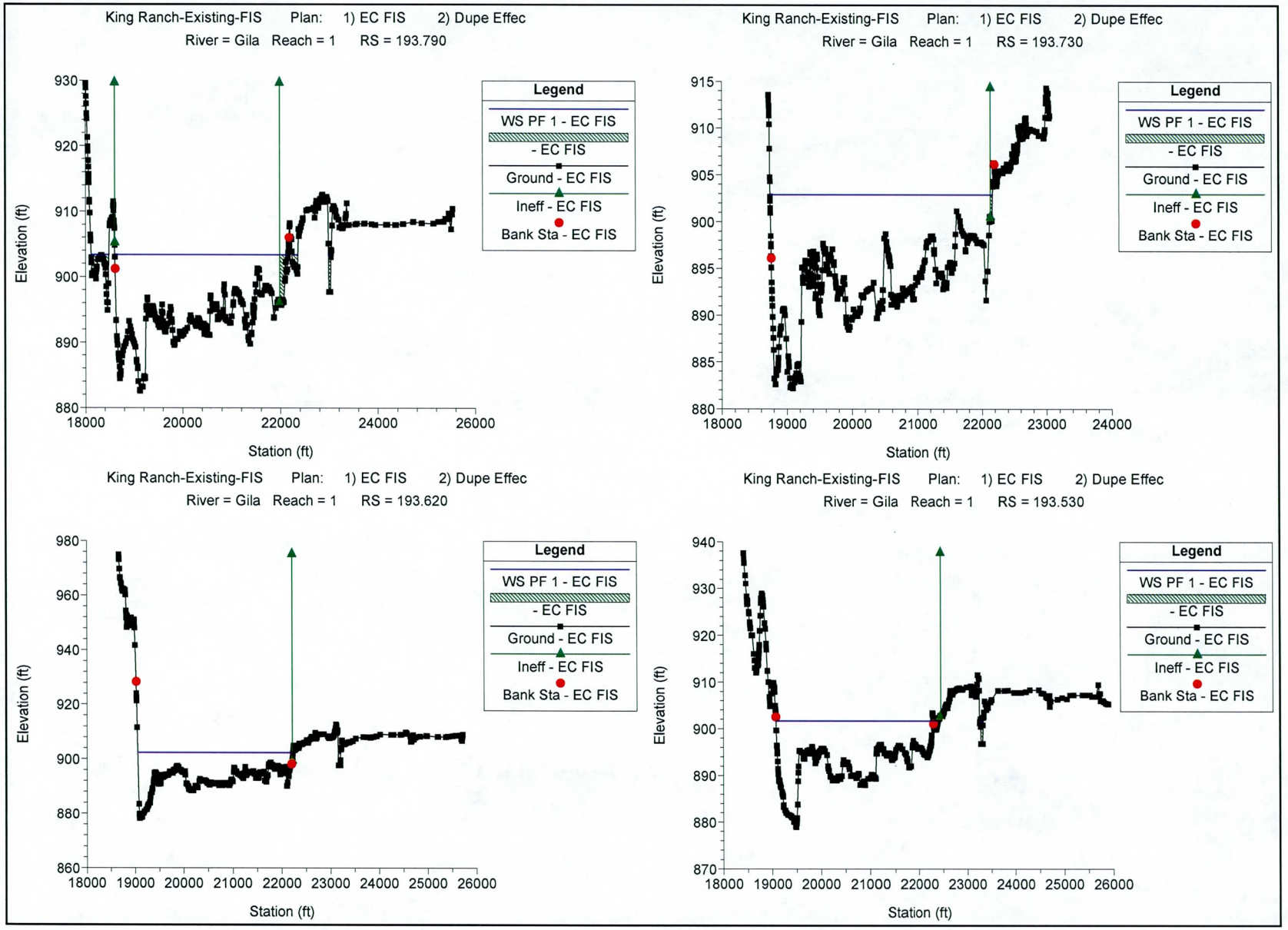

King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 195.15 BR Bridge #4
Elevation (ft)
Station (ft)
Legend
WS PF 1 - EC FIS
- EC FIS
- EC FIS
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 195.15 BR Bridge #4
Elevation (ft)
Station (ft)
Legend
WS PF 1 - EC FIS
- EC FIS
- EC FIS
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 195.13 Left and Right Channel Bank Stations Interpolated
Elevation (ft)
Station (ft)
Legend
WS PF 1 - Dupe Effec
WS PF 1 - EC FIS
- Dupe Effec
Ground - Dupe Effec
Ineff - Dupe Effec
Bank Sta - Dupe Effec
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 195.09 Left Channel Bank Station Interpolated
Elevation (ft)
Station (ft)
Legend
WS PF 1 - Dupe Effec
WS PF 1 - EC FIS
- Dupe Effec
Ground - Dupe Effec
Ineff - Dupe Effec
Bank Sta - Dupe Effec
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS

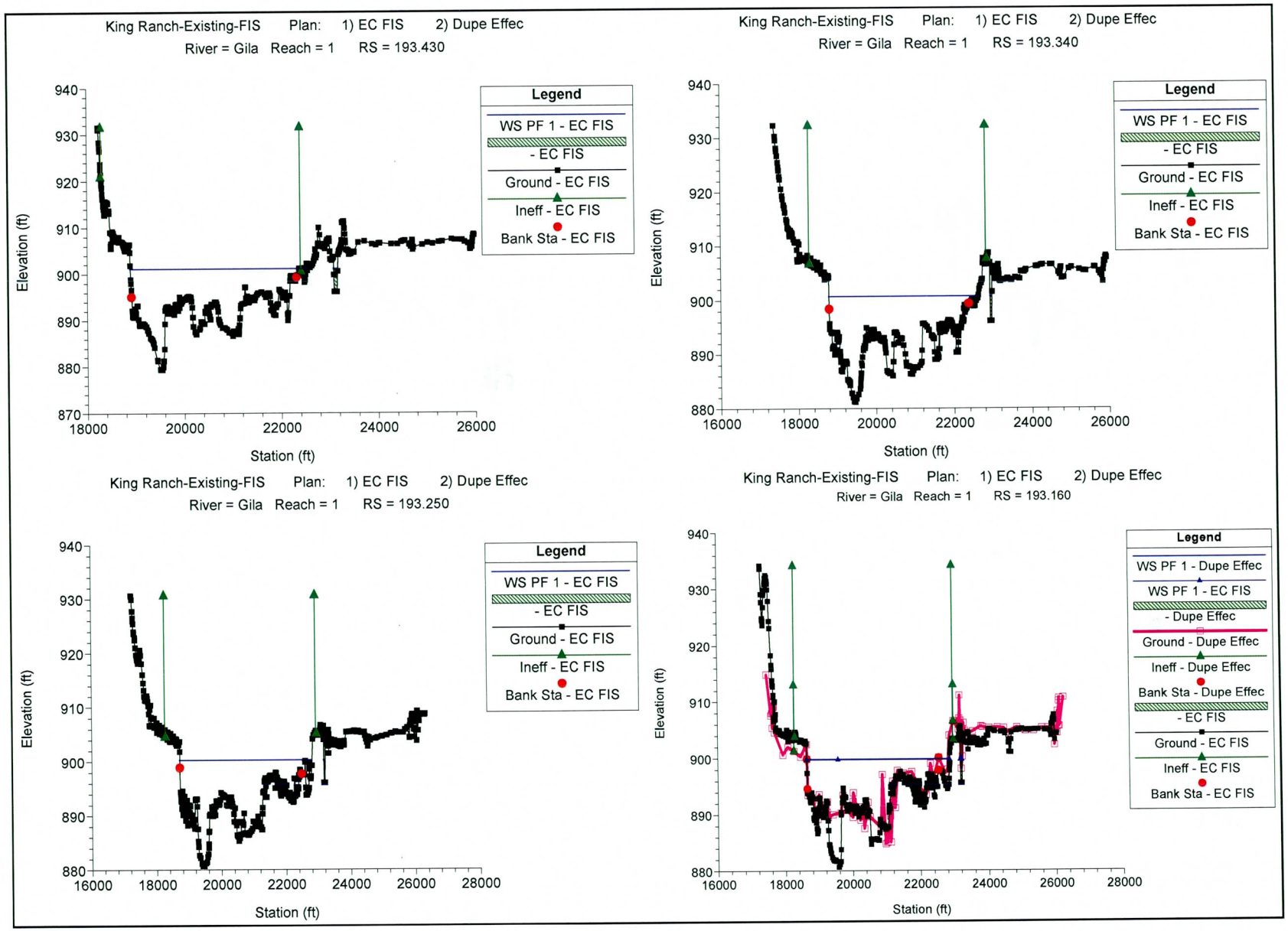

King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 195.00
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 194.91
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 194.81
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 194.72 Right Channel Bank Station Interpolated
Elevation (ft)
Station (ft)
Legend
WS PF 1 - Dupe Effec
WS PF 1 - EC FIS
- Dupe Effec
Ground - Dupe Effec
Ineff - Dupe Effec
Bank Sta - Dupe Effec
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS

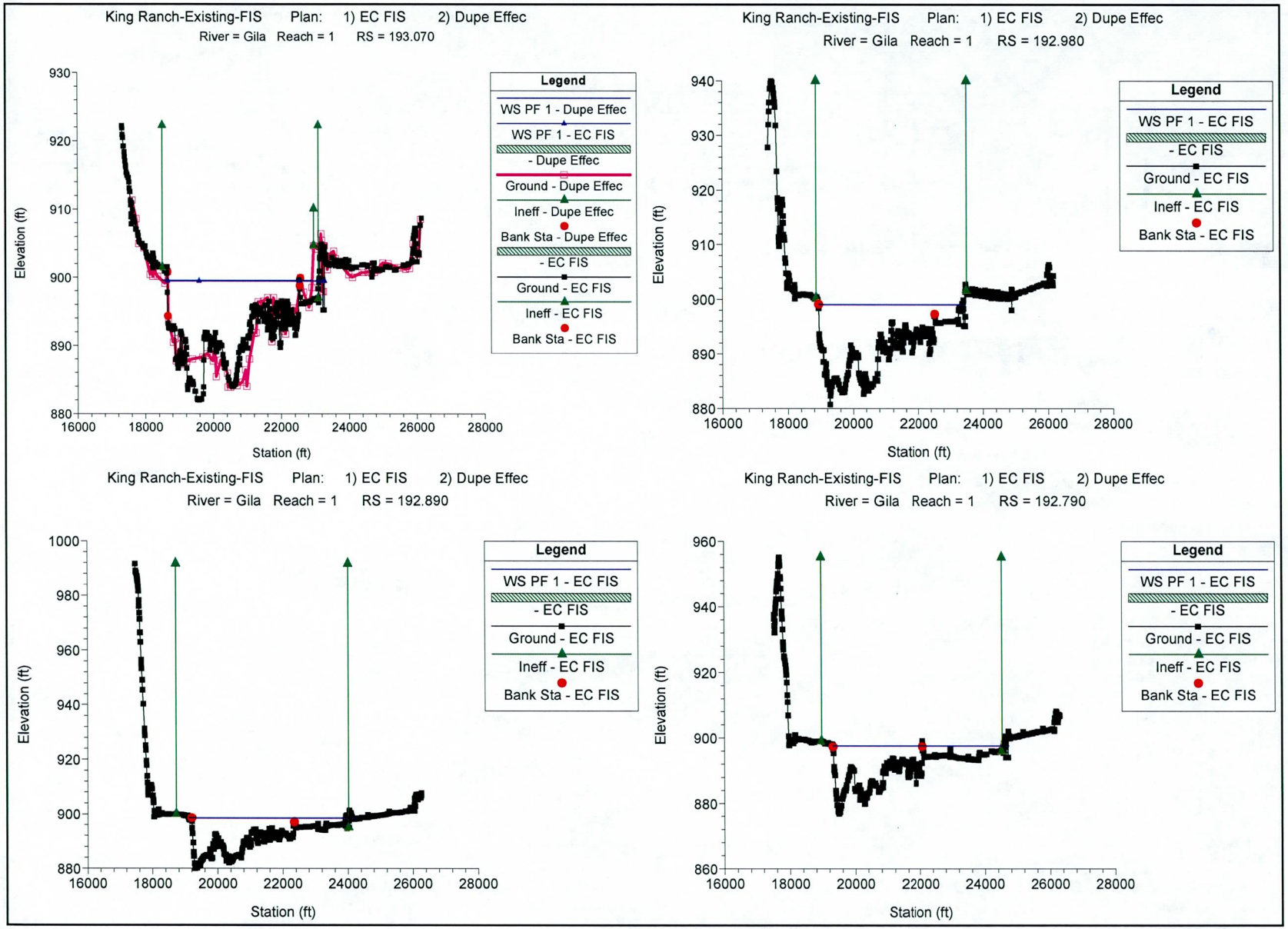

King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 194.62
Elevation (ft)
Station (ft)
Legend
WS PF 1 - Dupe Effec
WS PF 1 - EC FIS
- Dupe Effec
Ground - Dupe Effec
Ineff - Dupe Effec
Bank Sta - Dupe Effec
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 194.53
Elevation (ft)
Station (ft)
Legend
WS PF 1 - Dupe Effec
WS PF 1 - EC FIS
- Dupe Effec
Ground - Dupe Effec
Ineff - Dupe Effec
Bank Sta - Dupe Effec
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 194.40
Elevation (ft)
Station (ft)
Legend
WS PF 1 - Dupe Effec
WS PF 1 - EC FIS
- Dupe Effec
Ground - Dupe Effec
Ineff - Dupe Effec
Bank Sta - Dupe Effec
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 194.29
Elevation (ft)
Station (ft)
Legend
WS PF 1 - Dupe Effec
WS PF 1 - EC FIS
- Dupe Effec
Ground - Dupe Effec
Ineff - Dupe Effec
Bank Sta - Dupe Effec
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS

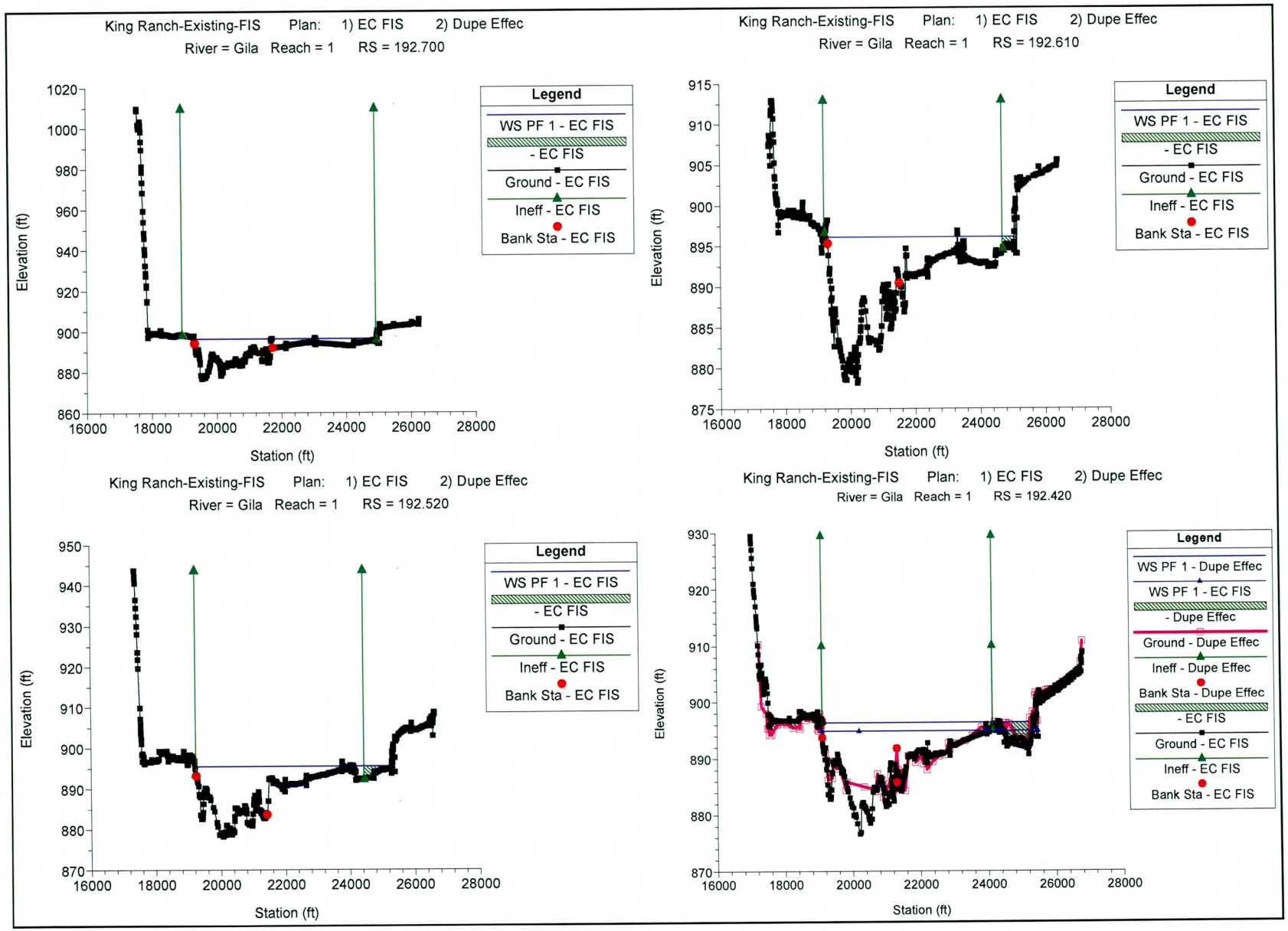

King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 194.210
Elevation (ft)
Station (ft)
Legend
WS PF 1 - Dupe Effec
WS PF 1 - EC FIS
Ground - Dupe Effec
Ineff - Dupe Effec
Bank Sta - Dupe Effec
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 194.205 BR Bridge #3
Elevation (ft)
Station (ft)
Legend
WS PF 1 - EC FIS
- EC FIS
- EC FIS
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 194.205 BR Bridge #3
Elevation (ft)
Station (ft)
Legend
WS PF 1 - EC FIS
- EC FIS
- EC FIS
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 194.200
Elevation (ft)
Station (ft)
Legend
WS PF 1 - EC FIS
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS

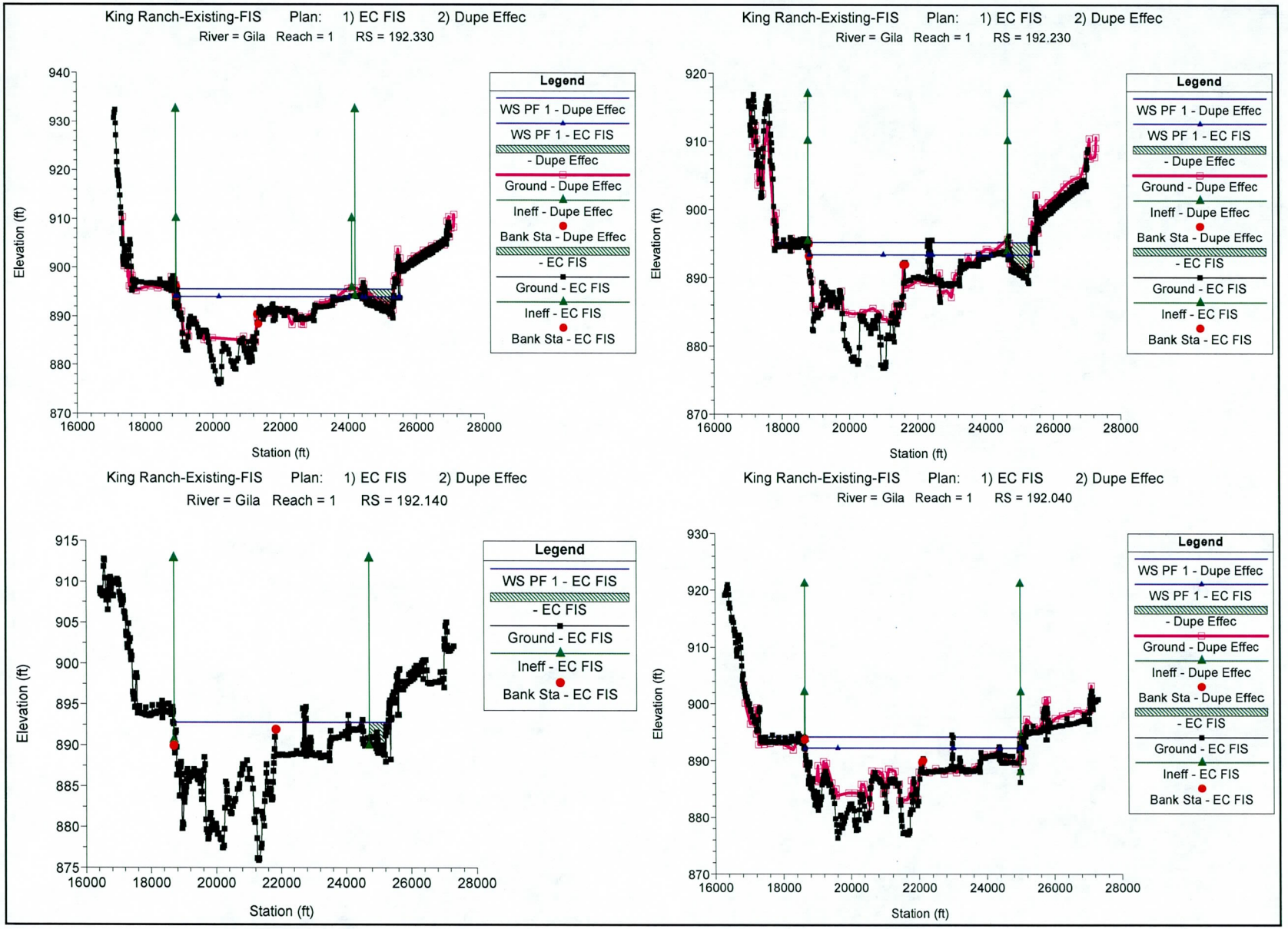

King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 194.100
Elevation (ft)
Station (ft)
Legend
WS PF 1 - EC FIS
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 194.020
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 193.940
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 193.870

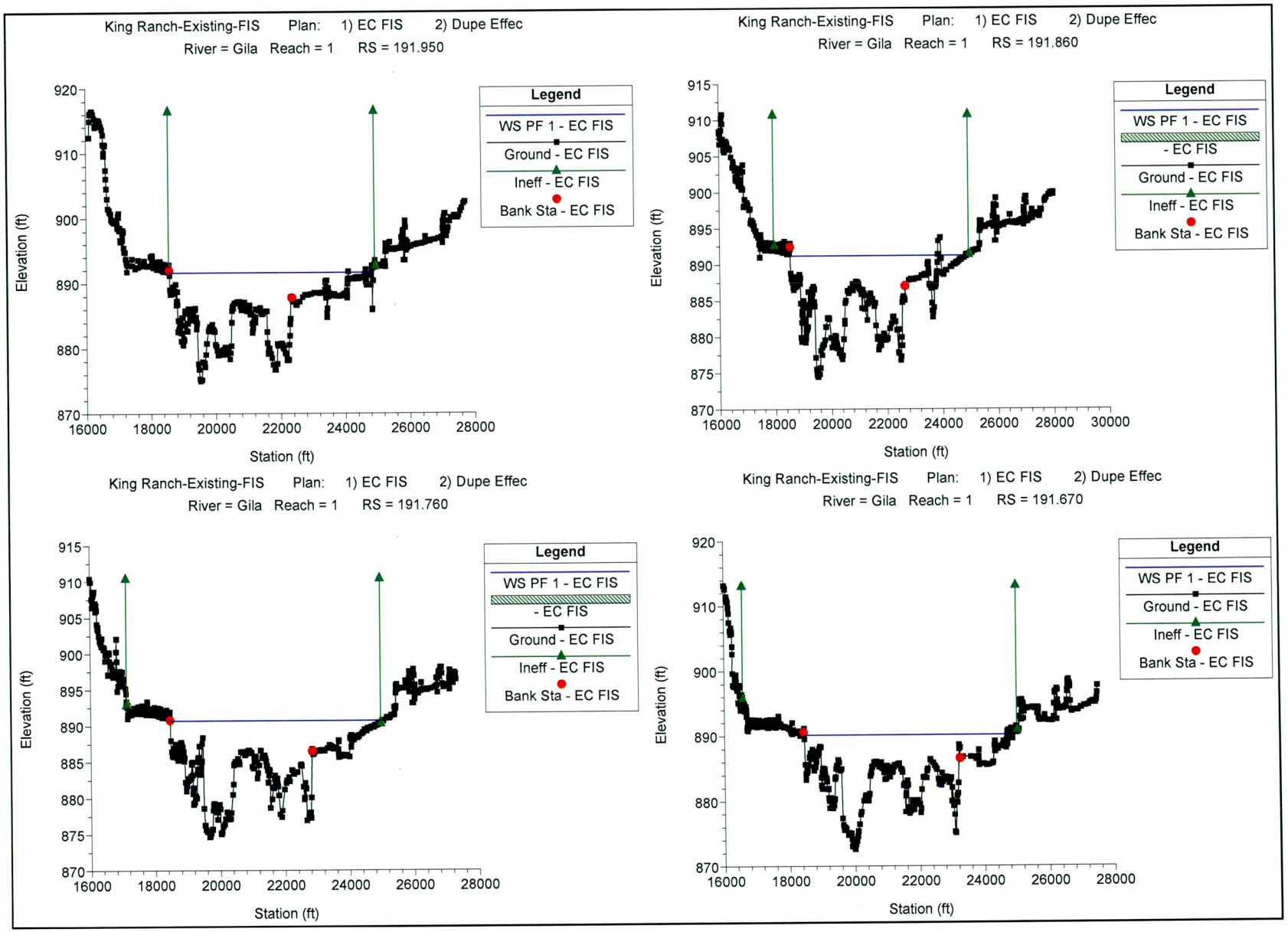

King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 193.790
Legend
WS PF 1 - EC FIS
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
Elevation (ft)
Station (ft)
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 193.730
Legend
WS PF 1 - EC FIS
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
Elevation (ft)
Station (ft)
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 193.620
Legend
WS PF 1 - EC FIS
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
Elevation (ft)
Station (ft)
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 193.530
Legend
WS PF 1 - EC FIS
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
Elevation (ft)
Station (ft)

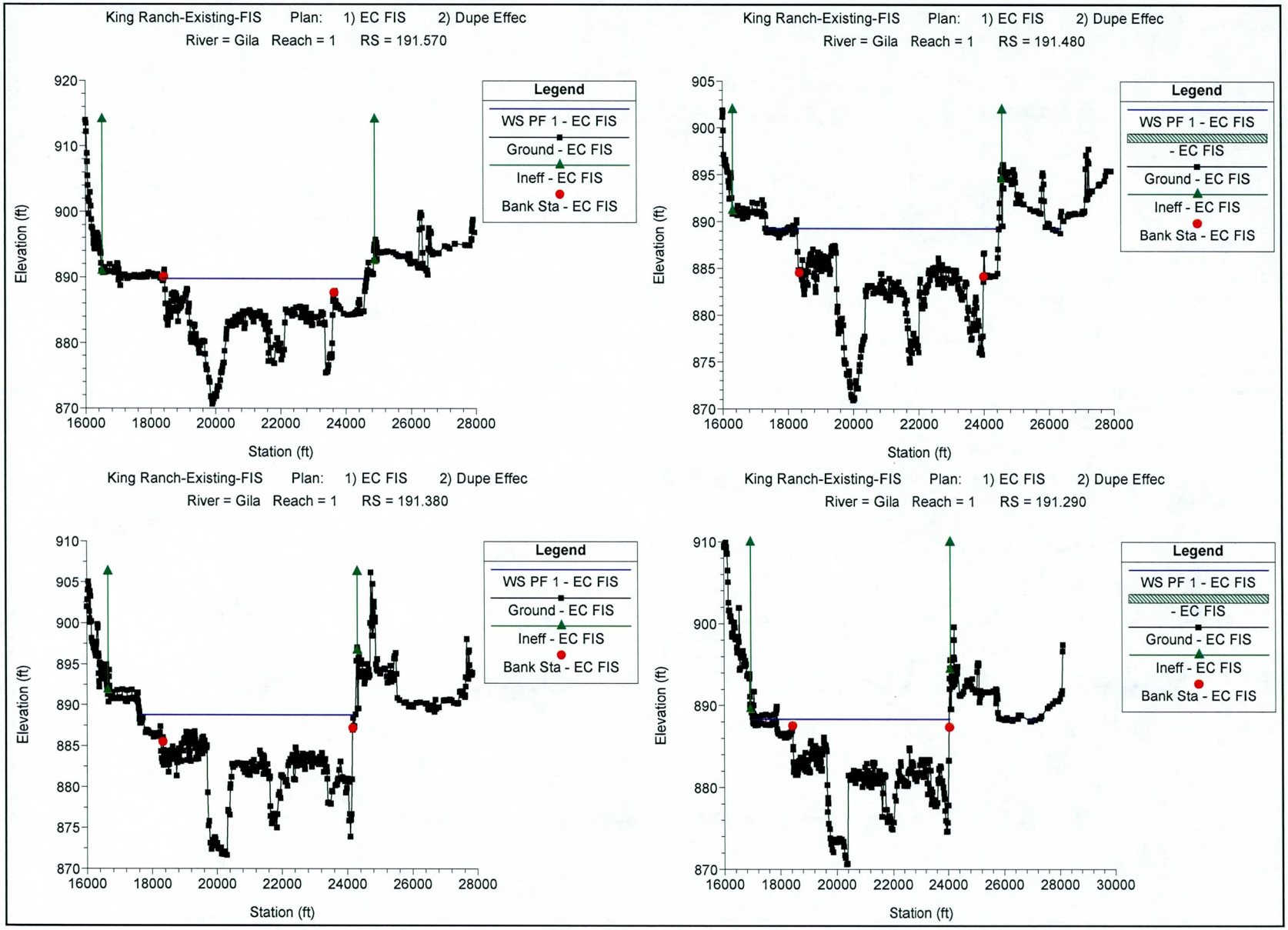

King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 193.430
Legend
WS PF 1 - EC FIS
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
Elevation (ft)
Station (ft)
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 193.340
Legend
WS PF 1 - EC FIS
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
Elevation (ft)
Station (ft)
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 193.250
Legend
WS PF 1 - EC FIS
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
Elevation (ft)
Station (ft)
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 193.160
Legend
WS PF 1 - Dupe Effec
WS PF 1 - EC FIS
- Dupe Effec
Ground - Dupe Effec
Ineff - Dupe Effec
Bank Sta - Dupe Effec
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
Elevation (ft)
Station (ft)

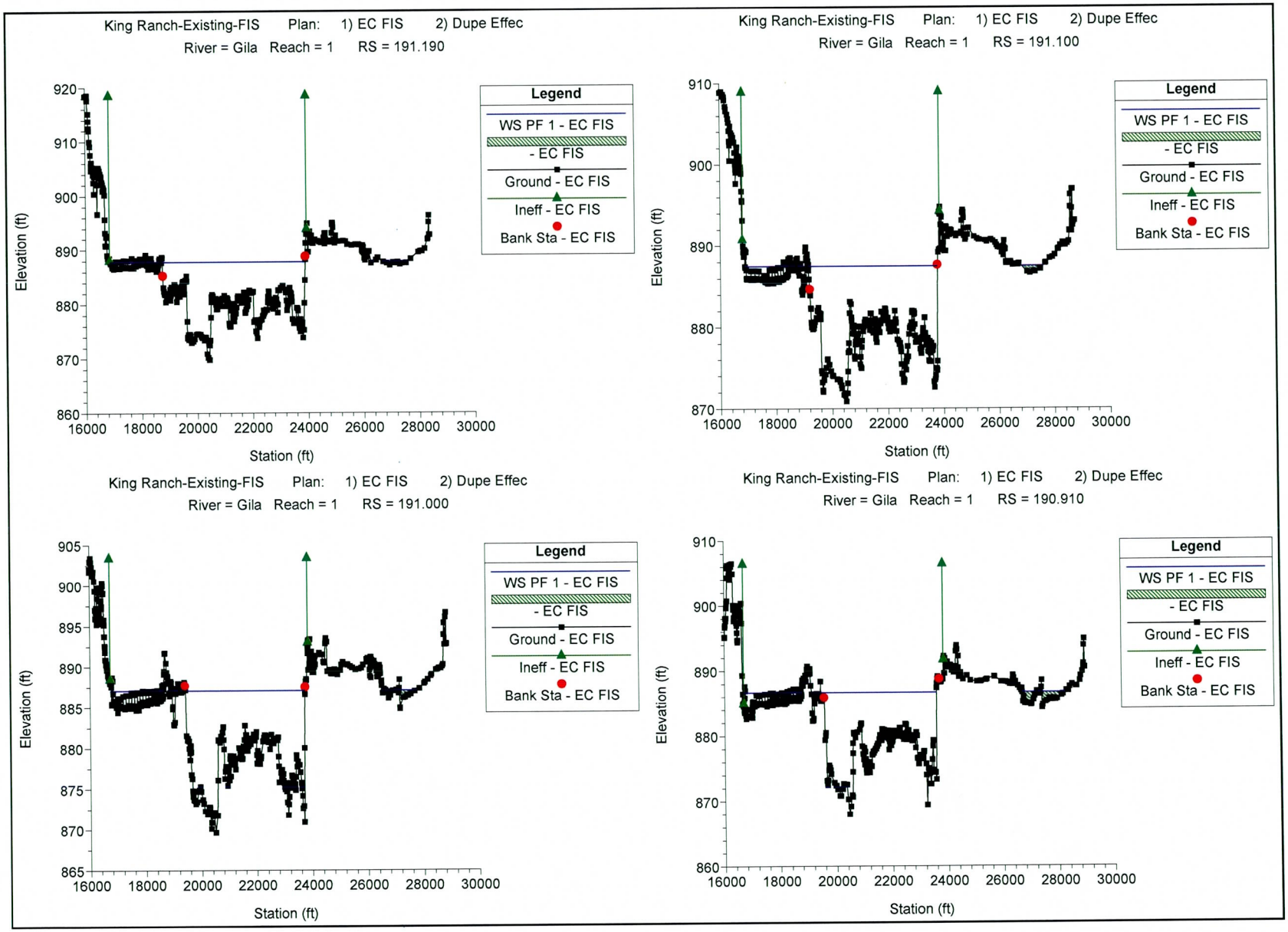

King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 193.070
Legend
WS PF 1 - Dupe Effec
WS PF 1 - EC FIS
- Dupe Effec
Ground - Dupe Effec
Ineff - Dupe Effec
Bank Sta - Dupe Effec
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
Elevation (ft)
Station (ft)
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 192.980
Legend
WS PF 1 - EC FIS
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
Elevation (ft)
Station (ft)
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 192.890
Legend
WS PF 1 - EC FIS
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
Elevation (ft)
Station (ft)
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 192.790
Legend
WS PF 1 - EC FIS
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
Elevation (ft)
Station (ft)

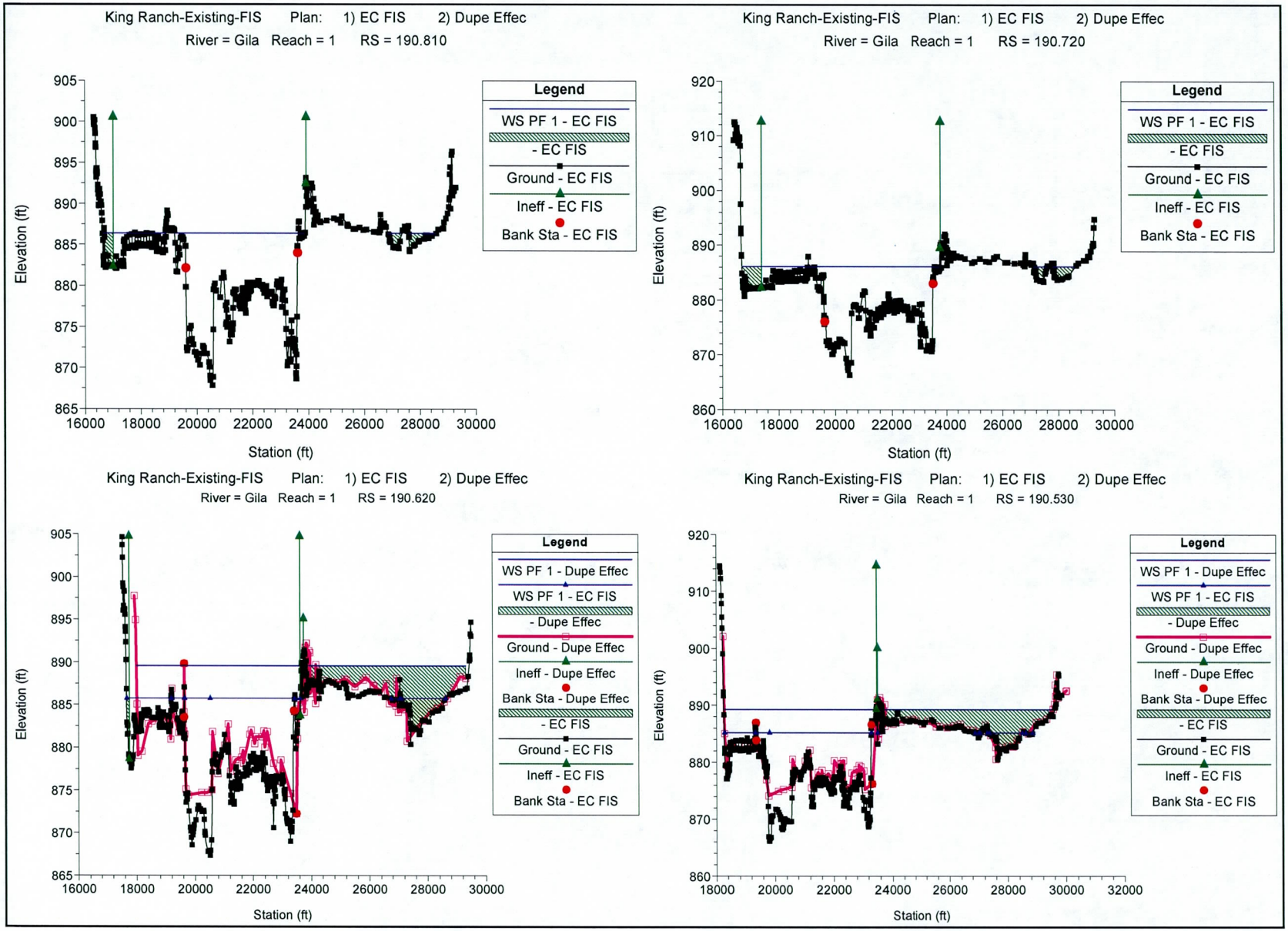

King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 192.700
Elevation (ft)
Station (ft)
Legend
WS PF 1 - EC FIS
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 192.610
Elevation (ft)
Station (ft)
Legend
WS PF 1 - EC FIS
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 192.520
Elevation (ft)
Station (ft)
Legend
WS PF 1 - EC FIS
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 192.420
Elevation (ft)
Station (ft)
Legend
WS PF 1 - Dupe Effec
WS PF 1 - EC FIS
- Dupe Effec
Ground - Dupe Effec
Ineff - Dupe Effec
Bank Sta - Dupe Effec
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS


King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 192.330
Elevation (ft)
Station (ft)
Legend
WS PF 1 - Dupe Effec
WS PF 1 - EC FIS
- Dupe Effec
Ground - Dupe Effec
Ineff - Dupe Effec
Bank Sta - Dupe Effec
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 192.230
Elevation (ft)
Station (ft)
Legend
WS PF 1 - Dupe Effec
WS PF 1 - EC FIS
- Dupe Effec
Ground - Dupe Effec
Ineff - Dupe Effec
Bank Sta - Dupe Effec
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 192.140
Elevation (ft)
Station (ft)
Legend
WS PF 1 - EC FIS
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 192.040
Elevation (ft)
Station (ft)
Legend
WS PF 1 - Dupe Effec
WS PF 1 - EC FIS
- Dupe Effec
Ground - Dupe Effec
Ineff - Dupe Effec
Bank Sta - Dupe Effec
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS


King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 191.950
Legend
WS PF 1 - EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
Elevation (ft)
Station (ft)
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 191.860
Legend
WS PF 1 - EC FIS
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
Elevation (ft)
Station (ft)
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 191.760
Legend
WS PF 1 - EC FIS
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
Elevation (ft)
Station (ft)
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 191.670
Legend
WS PF 1 - EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
Elevation (ft)
Station (ft)


King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 191.570
Legend
WS PF 1 - EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
Elevation (ft)
Station (ft)
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 191.480
Legend
WS PF 1 - EC FIS
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
Elevation (ft)
Station (ft)
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 191.380
Legend
WS PF 1 - EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
Elevation (ft)
Station (ft)
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 191.290
Legend
WS PF 1 - EC FIS
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
Elevation (ft)
Station (ft)


King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 191.190
Legend
WS PF 1 - EC FIS
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
Elevation (ft)
Station (ft)
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 191.100
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 191.000
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 190.910


King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 190.810
Elevation (ft)
Station (ft)
Legend
WS PF 1 - EC FIS
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 190.720
Elevation (ft)
Station (ft)
Legend
WS PF 1 - EC FIS
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 190.620
Elevation (ft)
Station (ft)
Legend
WS PF 1 - Dupe Effec
WS PF 1 - EC FIS
- Dupe Effec
Ground - Dupe Effec
Ineff - Dupe Effec
Bank Sta - Dupe Effec
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 190.530
Elevation (ft)
Station (ft)
Legend
WS PF 1 - Dupe Effec
WS PF 1 - EC FIS
- Dupe Effec
Ground - Dupe Effec
Ineff - Dupe Effec
Bank Sta - Dupe Effec
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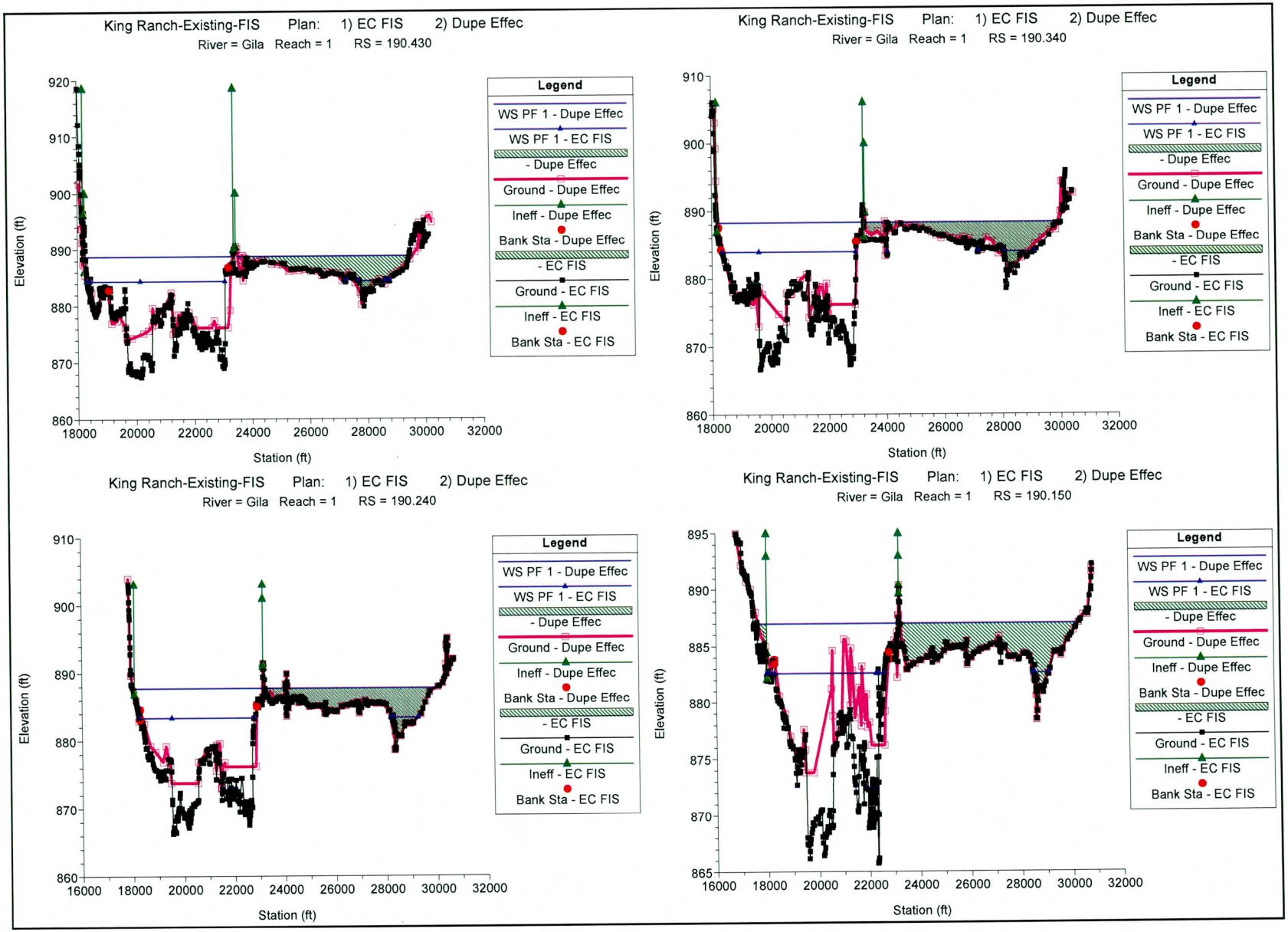
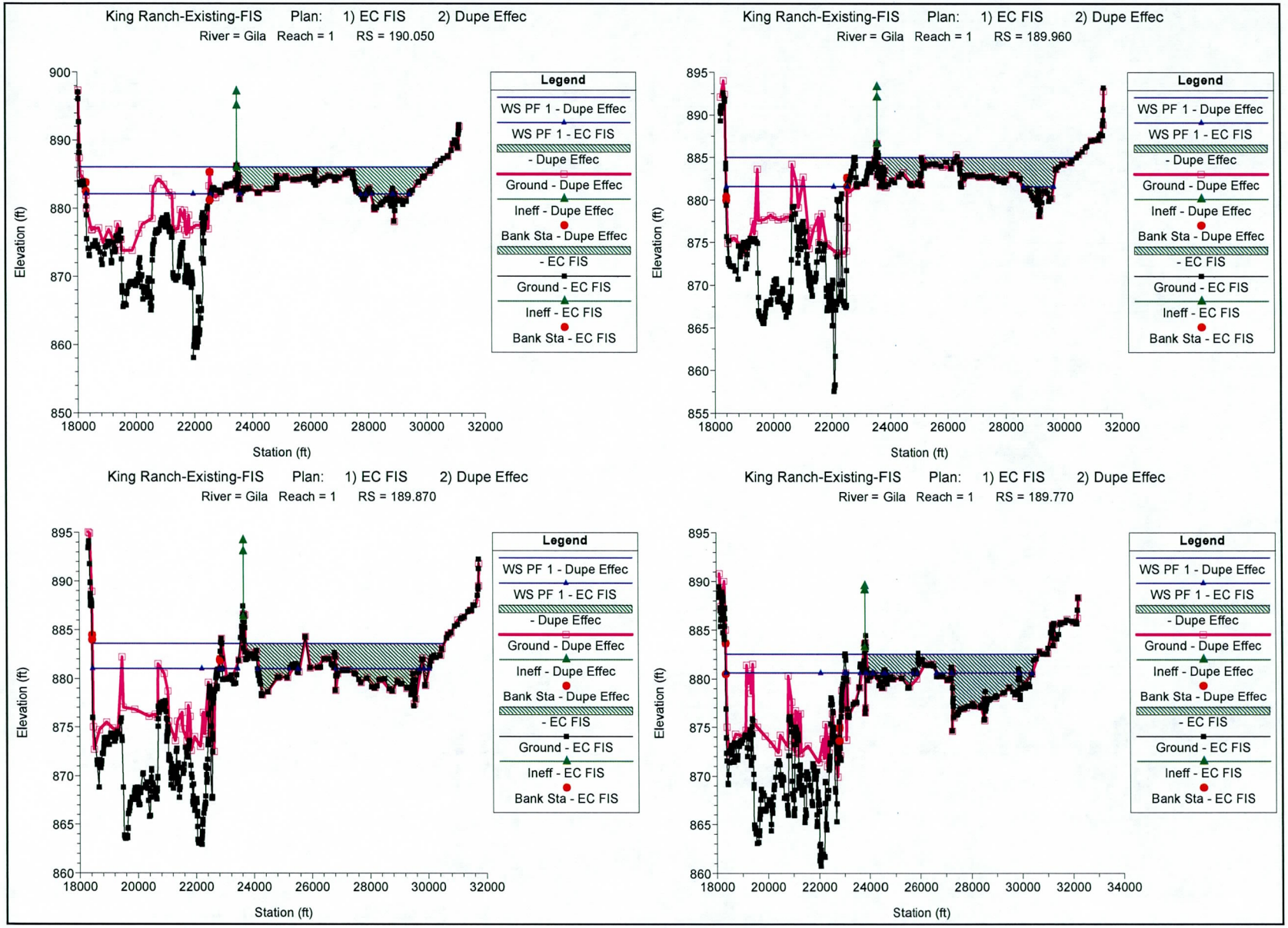
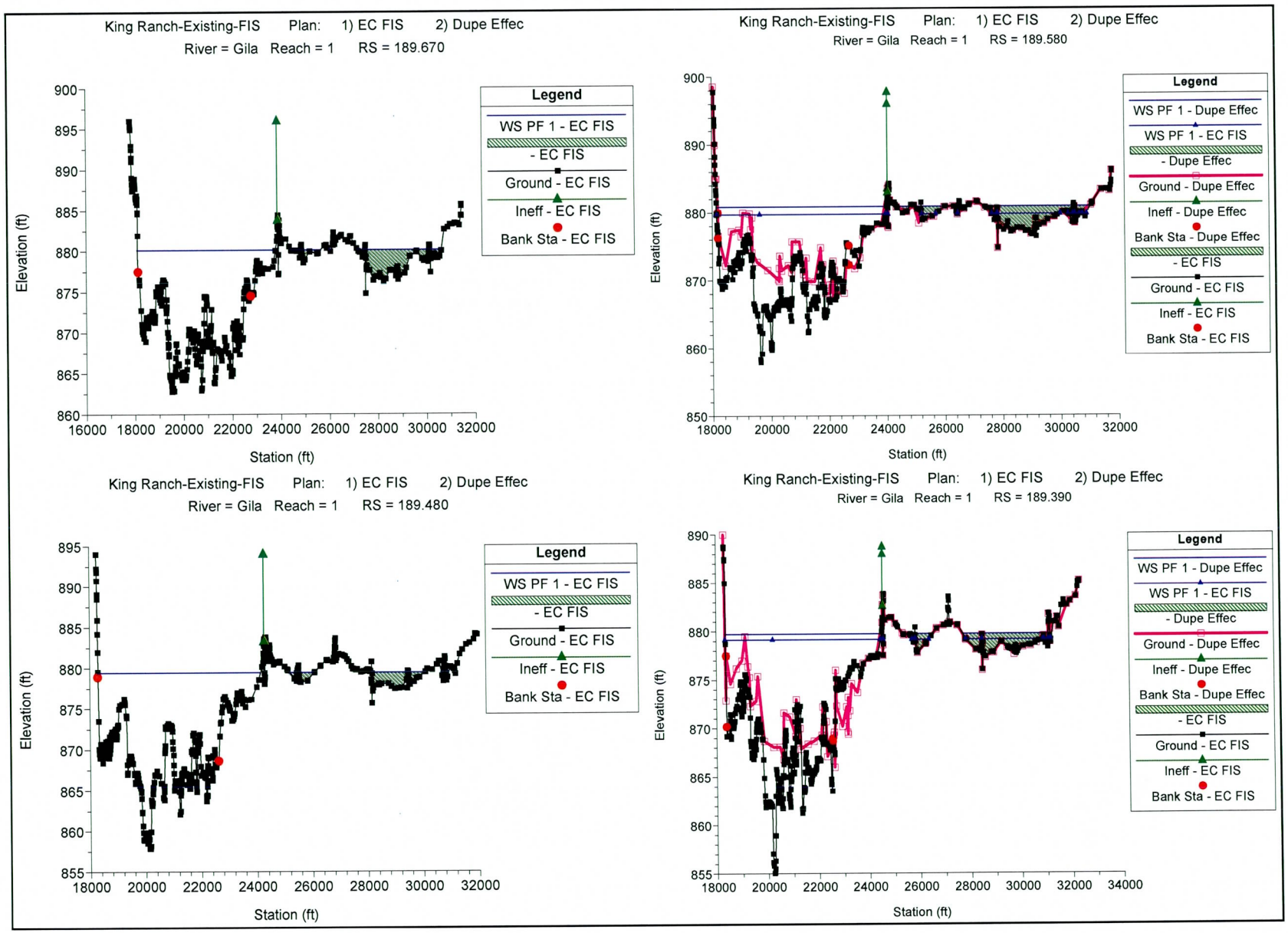
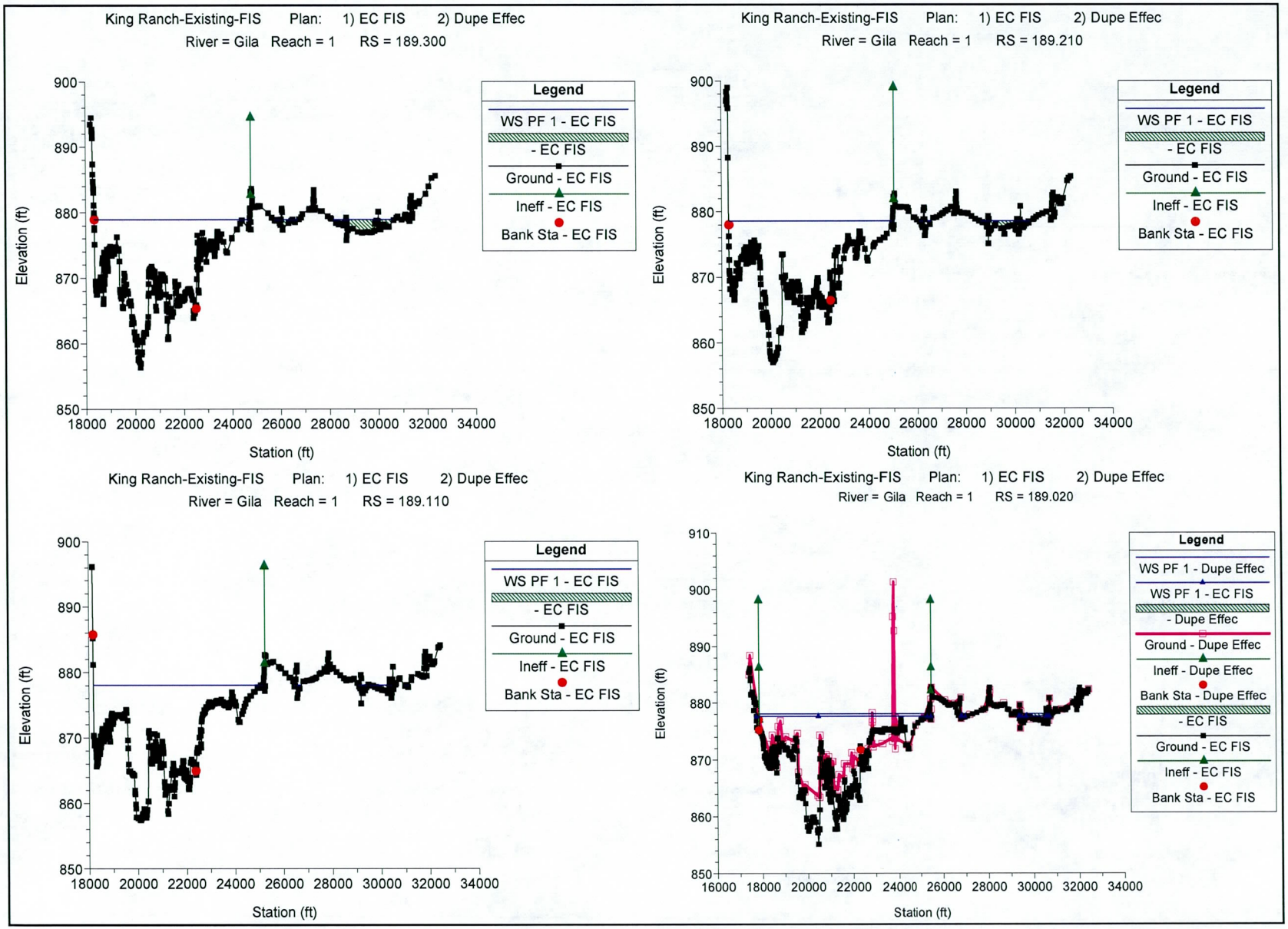
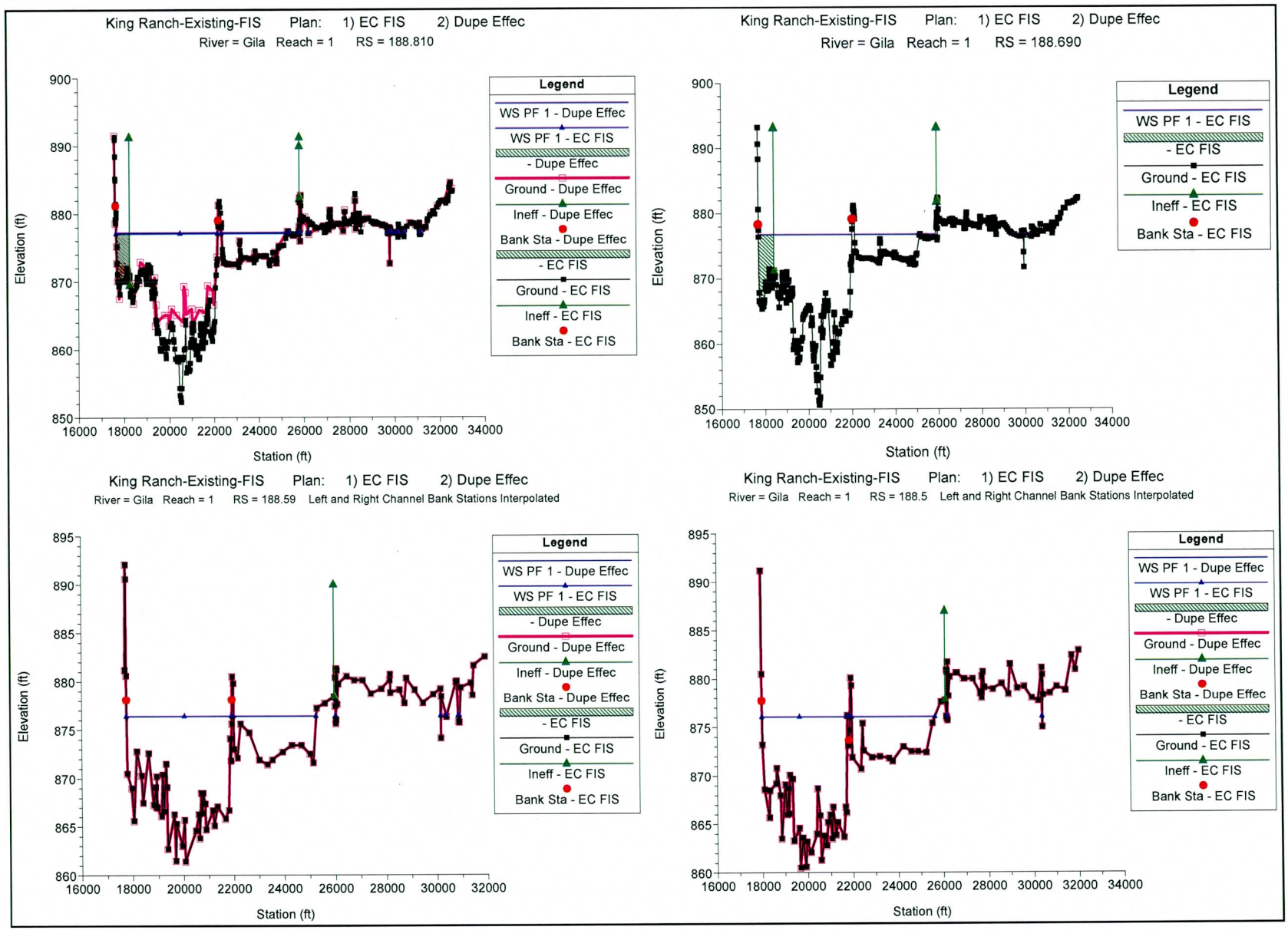
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS

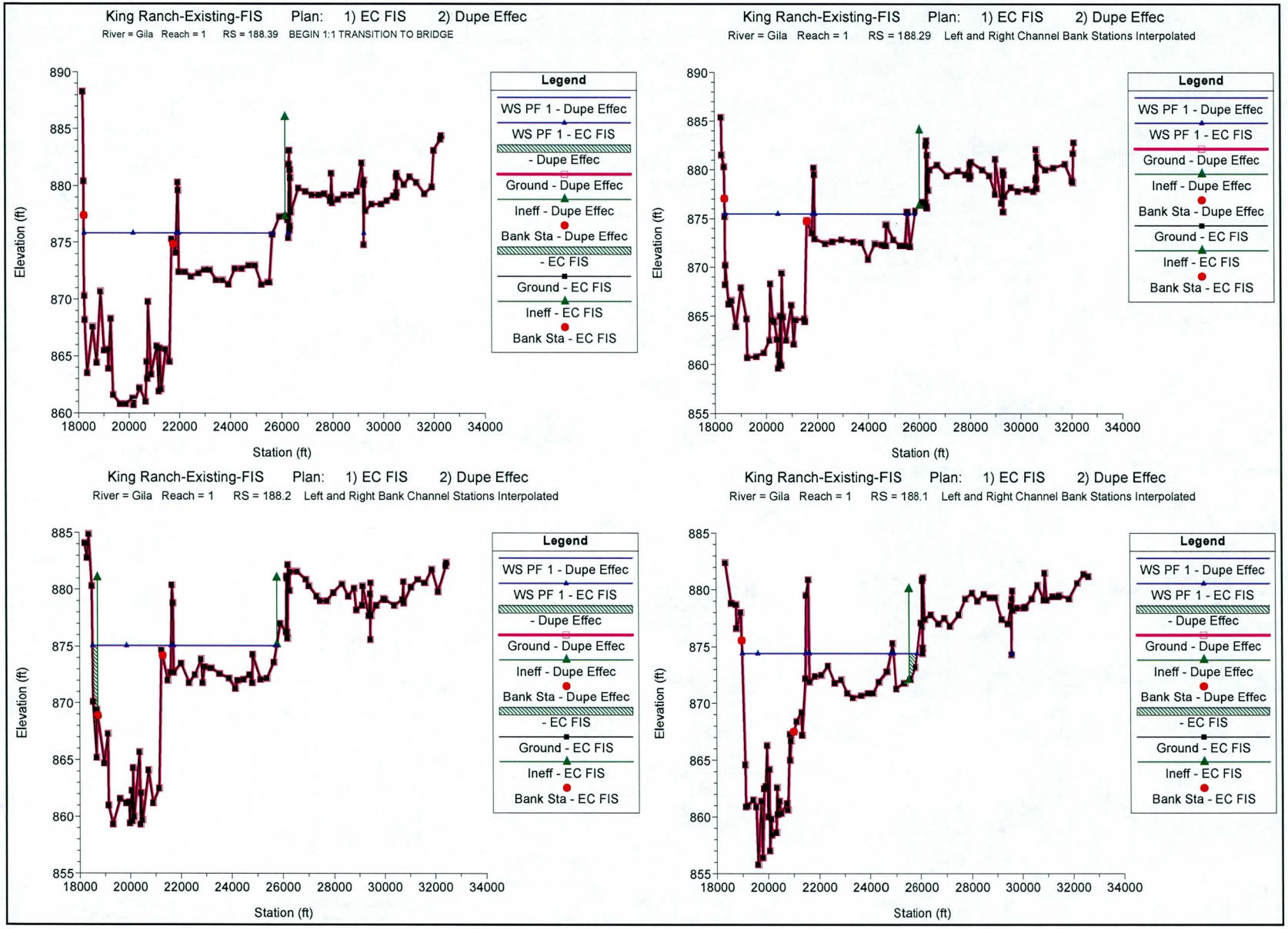

King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 190.430
Elevation (ft)
Station (ft)
Legend
WS PF 1 - Dupe Effec
WS PF 1 - EC FIS
- Dupe Effec
Ground - Dupe Effec
Ineff - Dupe Effec
Bank Sta - Dupe Effec
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 190.340
Elevation (ft)
Station (ft)
Legend
WS PF 1 - Dupe Effec
WS PF 1 - EC FIS
- Dupe Effec
Ground - Dupe Effec
Ineff - Dupe Effec
Bank Sta - Dupe Effec
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 190.240
Elevation (ft)
Station (ft)
Legend
WS PF 1 - Dupe Effec
WS PF 1 - EC FIS
- Dupe Effec
Ground - Dupe Effec
Ineff - Dupe Effec
Bank Sta - Dupe Effec
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 190.150
Elevation (ft)
Station (ft)
Legend
WS PF 1 - Dupe Effec
WS PF 1 - EC FIS
- Dupe Effec
Ground - Dupe Effec
Ineff - Dupe Effec
Bank Sta - Dupe Effec
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS


King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 190.050
Elevation (ft)
Station (ft)
Legend
WS PF 1 - Dupe Effec
WS PF 1 - EC FIS
- Dupe Effec
Ground - Dupe Effec
Ineff - Dupe Effec
Bank Sta - Dupe Effec
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 189.960
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 189.870
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 189.770


King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 189.670
Elevation (ft)
Station (ft)
Legend
WS PF 1 - EC FIS
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 189.580
Elevation (ft)
Station (ft)
Legend
WS PF 1 - Dupe Effec
WS PF 1 - EC FIS
- Dupe Effec
Ground - Dupe Effec
Ineff - Dupe Effec
Bank Sta - Dupe Effec
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 189.480
Elevation (ft)
Station (ft)
Legend
WS PF 1 - EC FIS
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 189.390
Elevation (ft)
Station (ft)
Legend
WS PF 1 - Dupe Effec
WS PF 1 - EC FIS
- Dupe Effec
Ground - Dupe Effec
Ineff - Dupe Effec
Bank Sta - Dupe Effec
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS

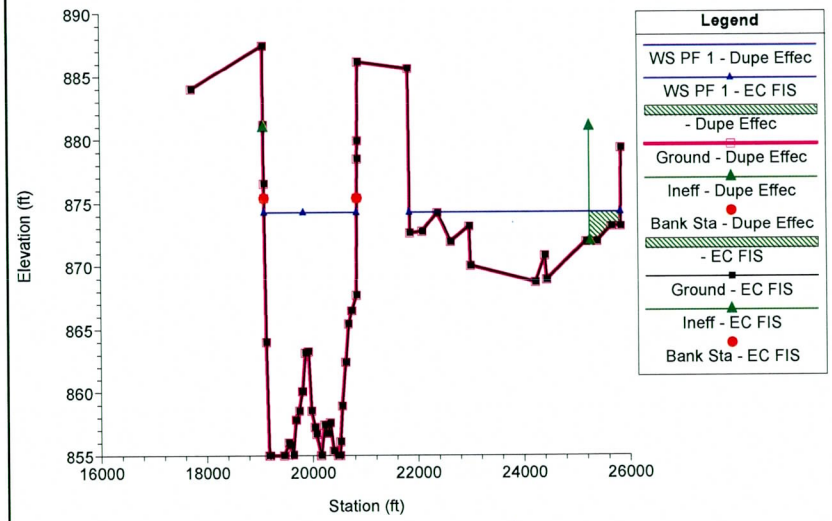

King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 189.300
Elevation (ft)
Station (ft)
Legend
WS PF 1 - EC FIS
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 189.210
Elevation (ft)
Station (ft)
Legend
WS PF 1 - EC FIS
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 189.110
Elevation (ft)
Station (ft)
Legend
WS PF 1 - EC FIS
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 189.020
Elevation (ft)
Station (ft)
Legend
WS PF 1 - Dupe Effec
WS PF 1 - EC FIS
- Dupe Effec
Ground - Dupe Effec
Ineff - Dupe Effec
Bank Sta - Dupe Effec
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS


King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 188.810
Legend
WS PF 1 - Dupe Effec
WS PF 1 - EC FIS
- Dupe Effec
Ground - Dupe Effec
Ineff - Dupe Effec
Bank Sta - Dupe Effec
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
Elevation (ft)
Station (ft)
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 188.690
Legend
WS PF 1 - EC FIS
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
Elevation (ft)
Station (ft)
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 188.59 Left and Right Channel Bank Stations Interpolated
Legend
WS PF 1 - Dupe Effec
WS PF 1 - EC FIS
- Dupe Effec
Ground - Dupe Effec
Ineff - Dupe Effec
Bank Sta - Dupe Effec
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
Elevation (ft)
Station (ft)
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 188.5 Left and Right Channel Bank Stations Interpolated
Legend
WS PF 1 - Dupe Effec
WS PF 1 - EC FIS
- Dupe Effec
Ground - Dupe Effec
Ineff - Dupe Effec
Bank Sta - Dupe Effec
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
Elevation (ft)
Station (ft)


King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 188.39 BEGIN 1:1 TRANSITION TO BRIDGE
Elevation (ft)
Station (ft)
Legend
WS PF 1 - Dupe Effec
WS PF 1 - EC FIS
- Dupe Effec
Ground - Dupe Effec
Ineff - Dupe Effec
Bank Sta - Dupe Effec
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 188.29 Left and Right Channel Bank Stations Interpolated
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 188.2 Left and Right Bank Channel Stations Interpolated
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 188.1 Left and Right Channel Bank Stations Interpolated

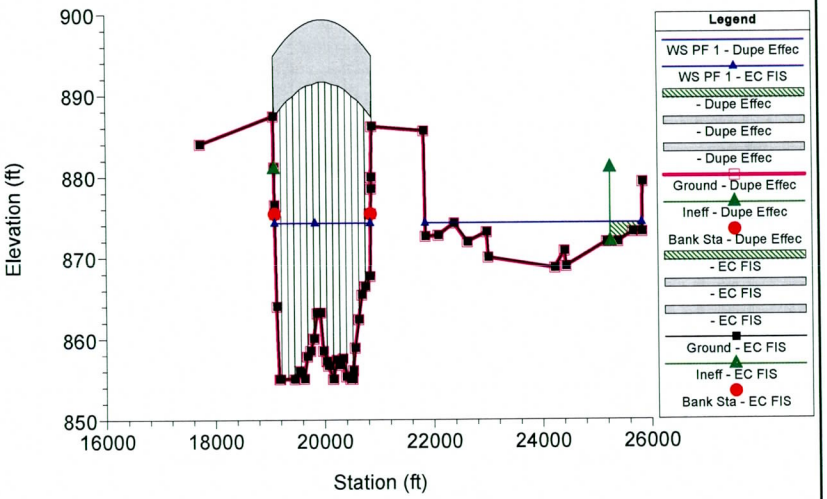
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec

River = Gila Reach = 1 RS = 188.07 Left and Right Channel Bank Stations Interpolated



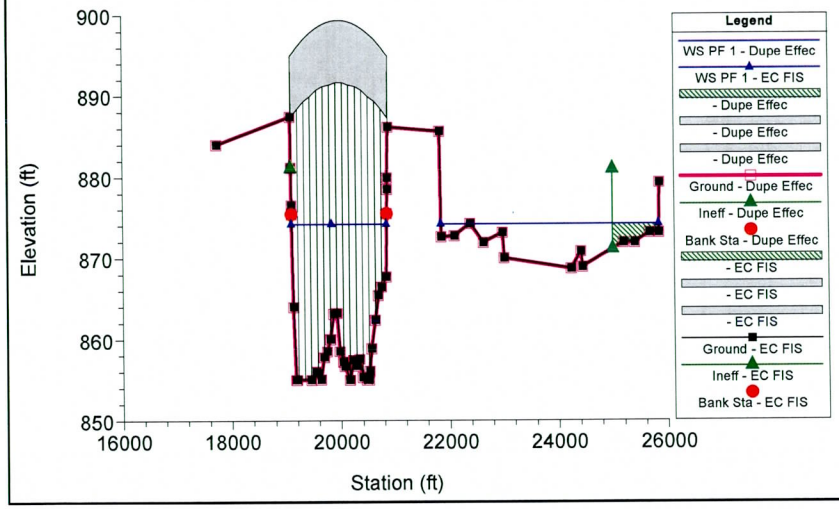
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec

River = Gila Reach = 1 RS = 188.055 BR Bridge #2 (Tuthill)



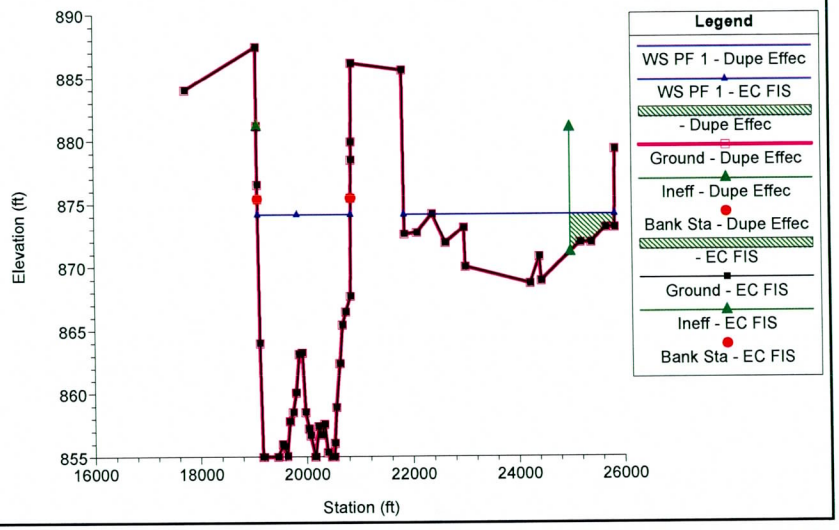
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec

River = Gila Reach = 1 RS = 188.055 BR Bridge #2 (Tuthill)



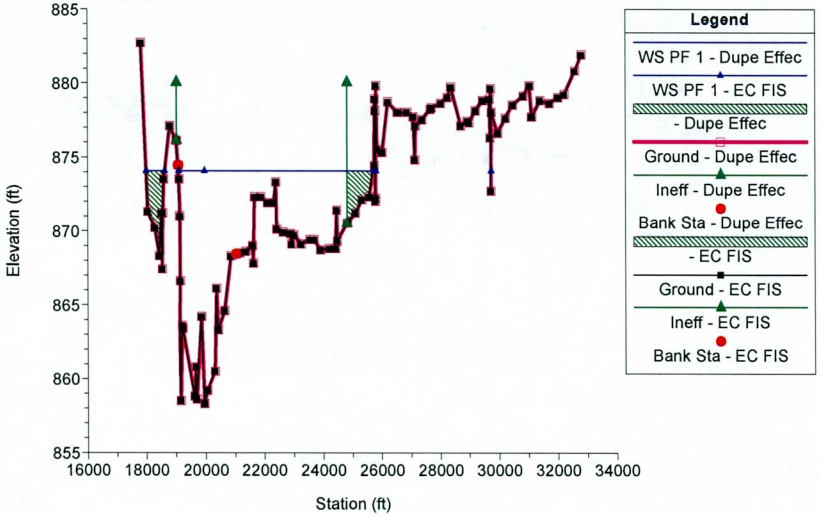
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec

River = Gila Reach = 1 RS = 188.04 Left and Right Channel Bank Stations Interpolated



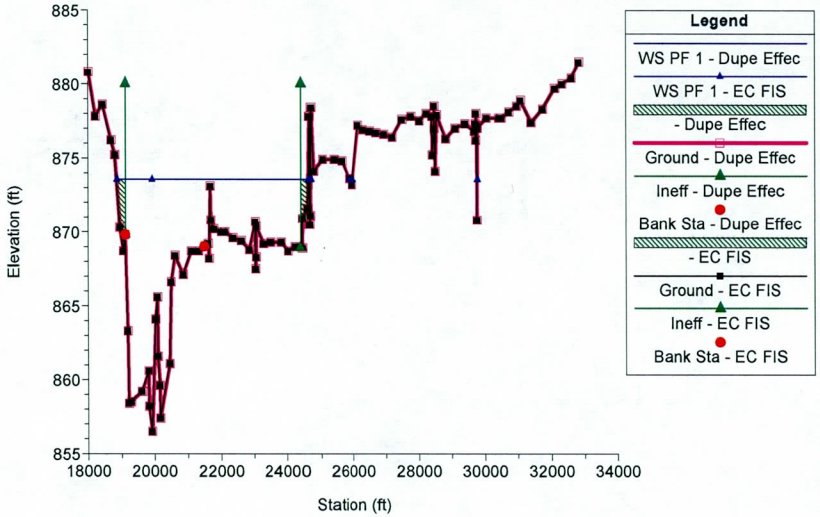
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec

River = Gila Reach = 1 RS = 188 Left and Right Bank Channel Station Interpolated



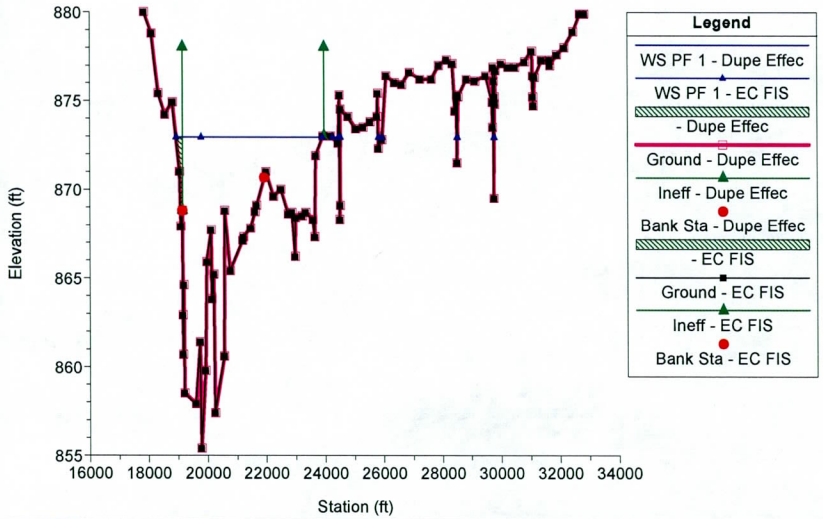
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec

River = Gila Reach = 1 RS = 187.91 Right Bank Channel Station Interpolated



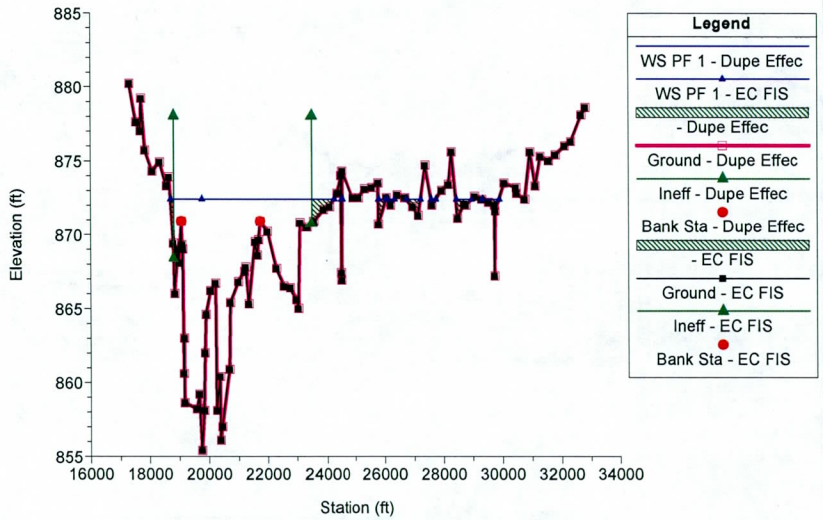
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec

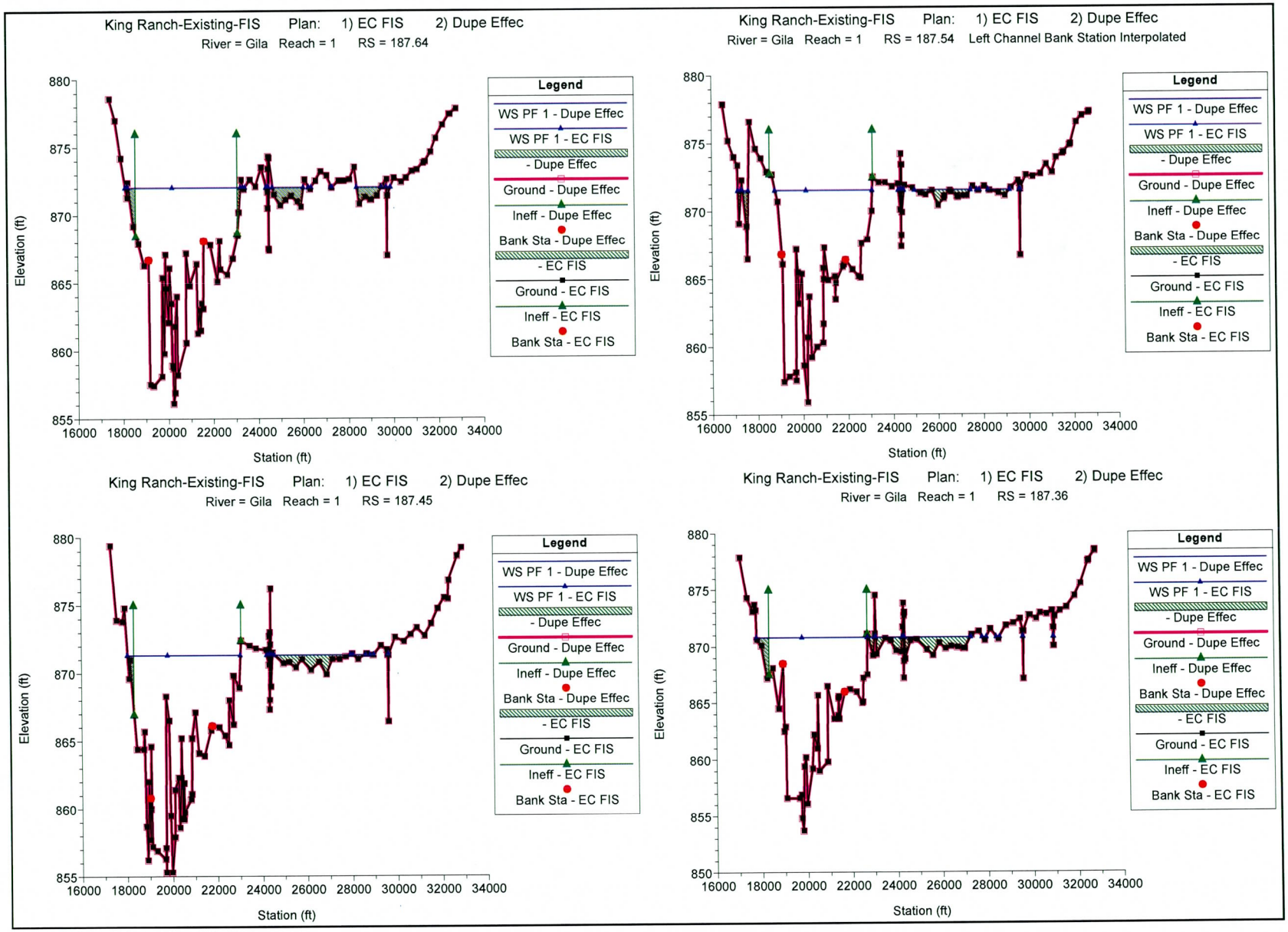
River = Gila Reach = 1 RS = 187.82 Right Bank Channel Station Interpolated

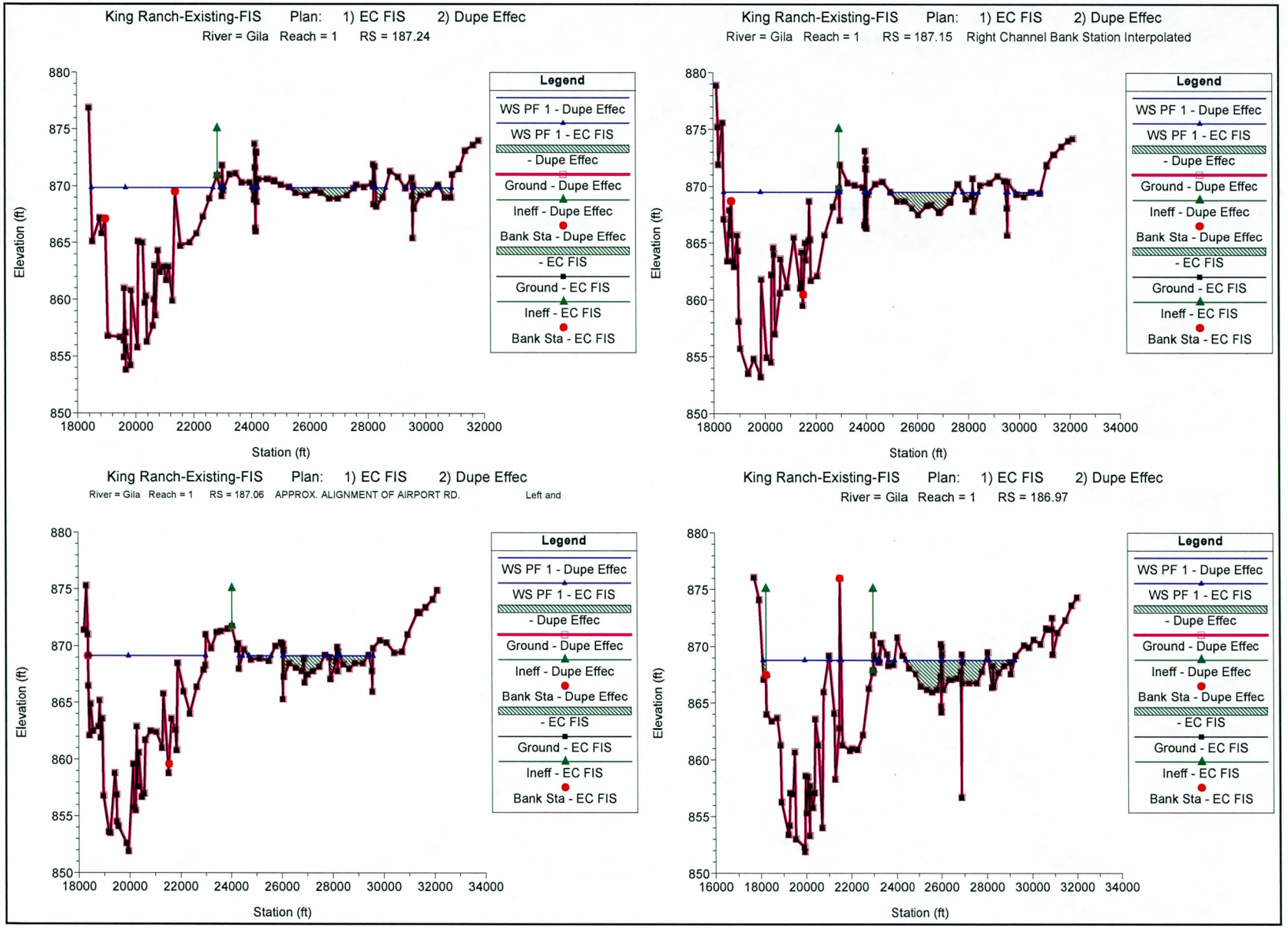


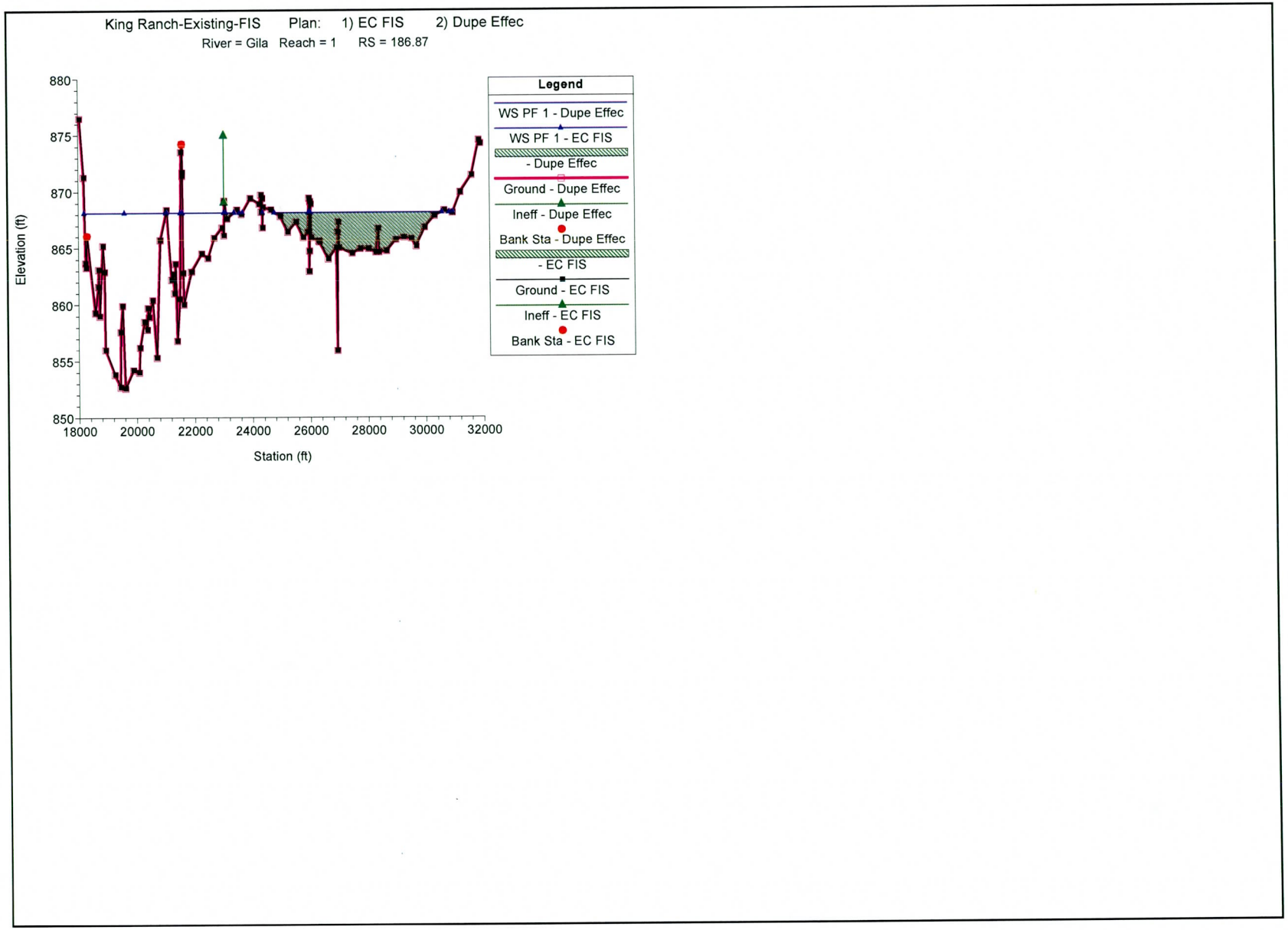
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec

River = Gila Reach = 1 RS = 187.73



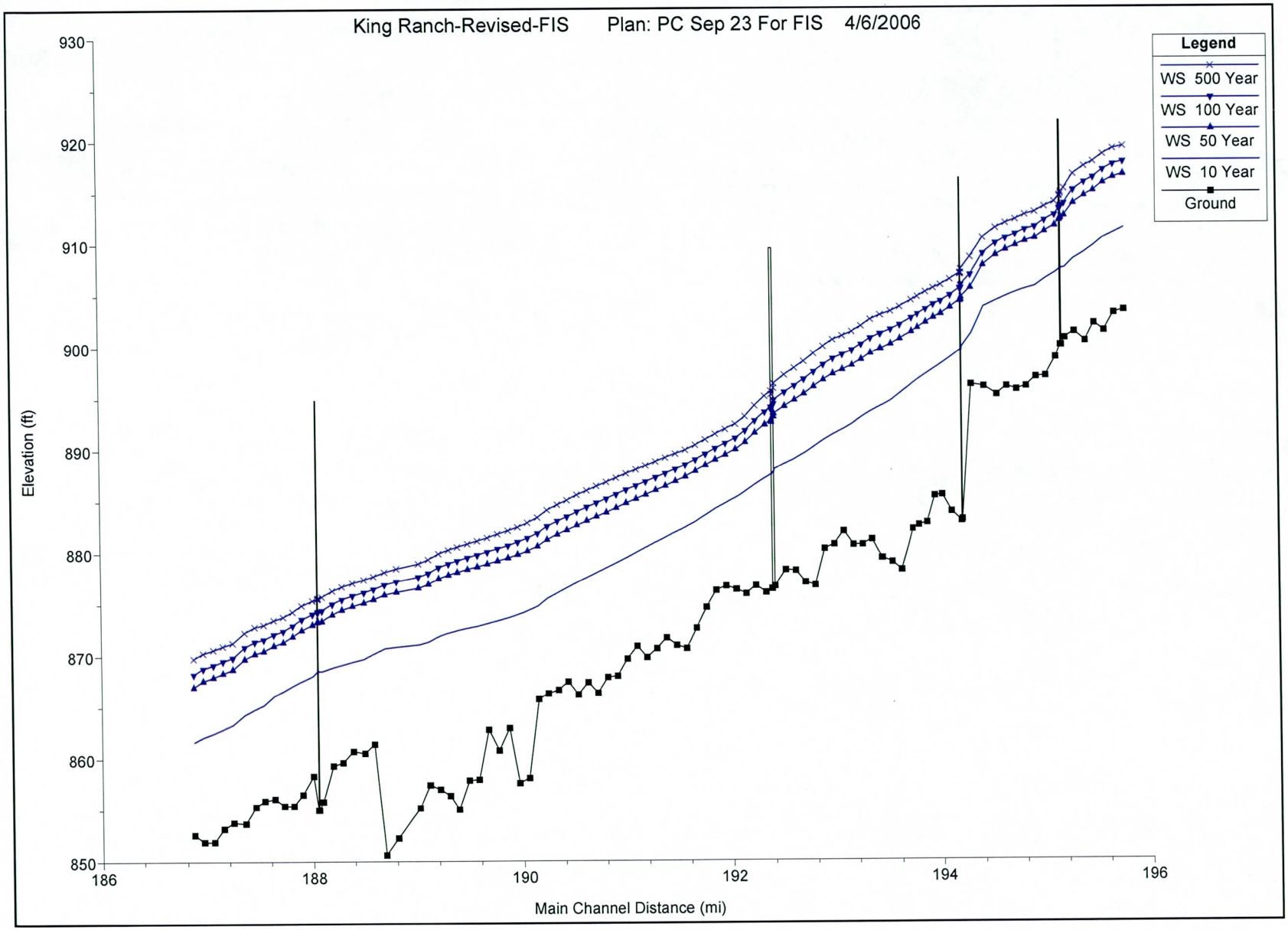

King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 187.64
Elevation (ft)
Station (ft)
Legend
WS PF 1 - Dupe Effec
WS PF 1 - EC FIS
- Dupe Effec
Ground - Dupe Effec
Ineff - Dupe Effec
Bank Sta - Dupe Effec
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 187.54 Left Channel Bank Station Interpolated
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 187.45
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 187.36


King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 187.24
Elevation (ft)
Station (ft)
Legend
WS PF 1 - Dupe Effec
WS PF 1 - EC FIS
- Dupe Effec
Ground - Dupe Effec
Ineff - Dupe Effec
Bank Sta - Dupe Effec
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 187.15 Right Channel Bank Station Interpolated
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 187.06 APPROX. ALIGNMENT OF AIRPORT RD. Left and
King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 186.97


King Ranch-Existing-FIS Plan: 1) EC FIS 2) Dupe Effec
River = Gila Reach = 1 RS = 186.87
Elevation (ft)
880
875
870
865
860
855
850
18000
20000
22000
24000
26000
28000
30000
32000
Station (ft)
Legend
WS PF 1 - Dupe Effec
WS PF 1 - EC FIS
- Dupe Effec
Ground - Dupe Effec
Ineff - Dupe Effec
Bank Sta - Dupe Effec
- EC FIS
Ground - EC FIS
Ineff - EC FIS
Bank Sta - EC FIS

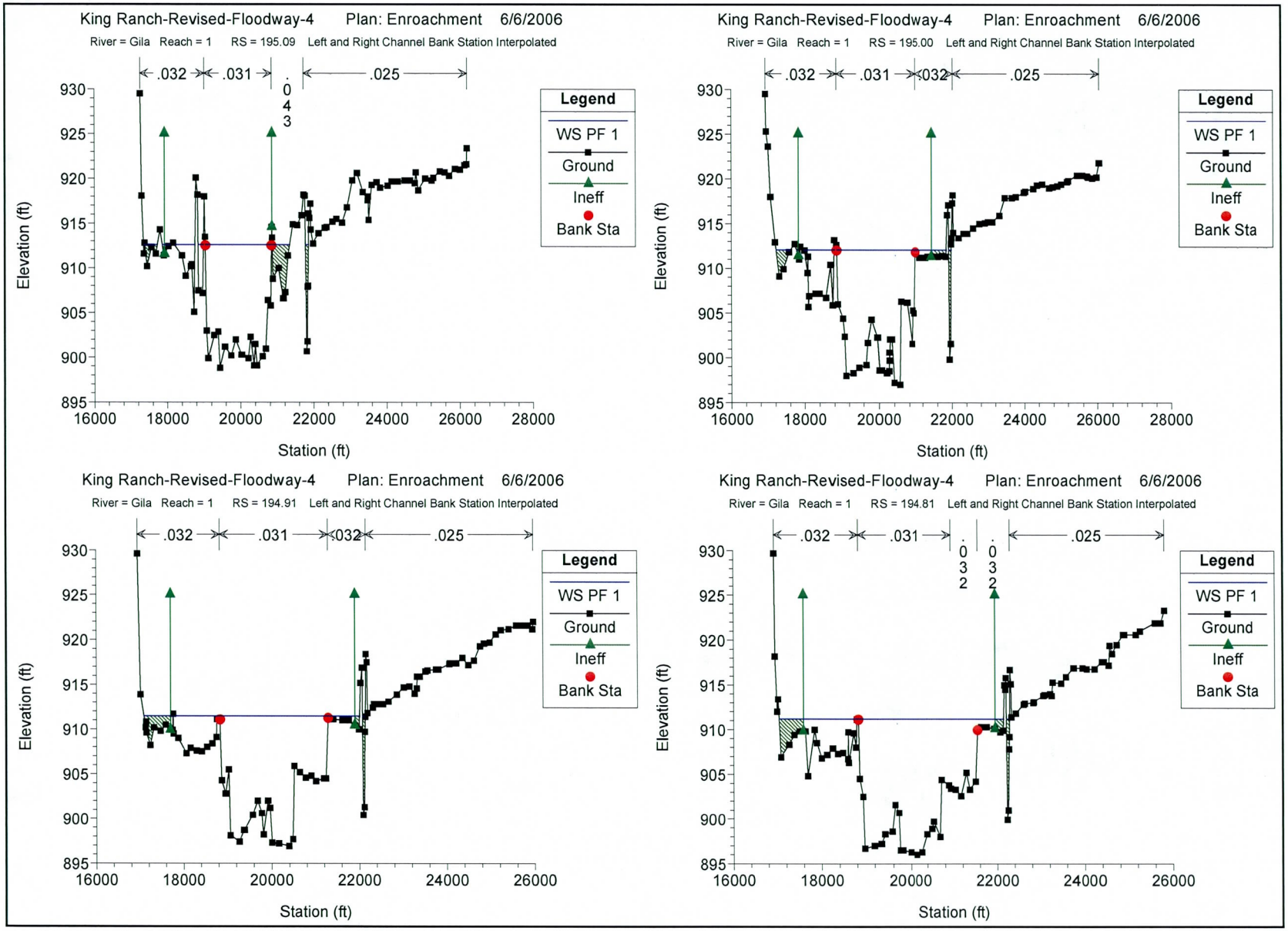
E.2.2 Cross Section Plots

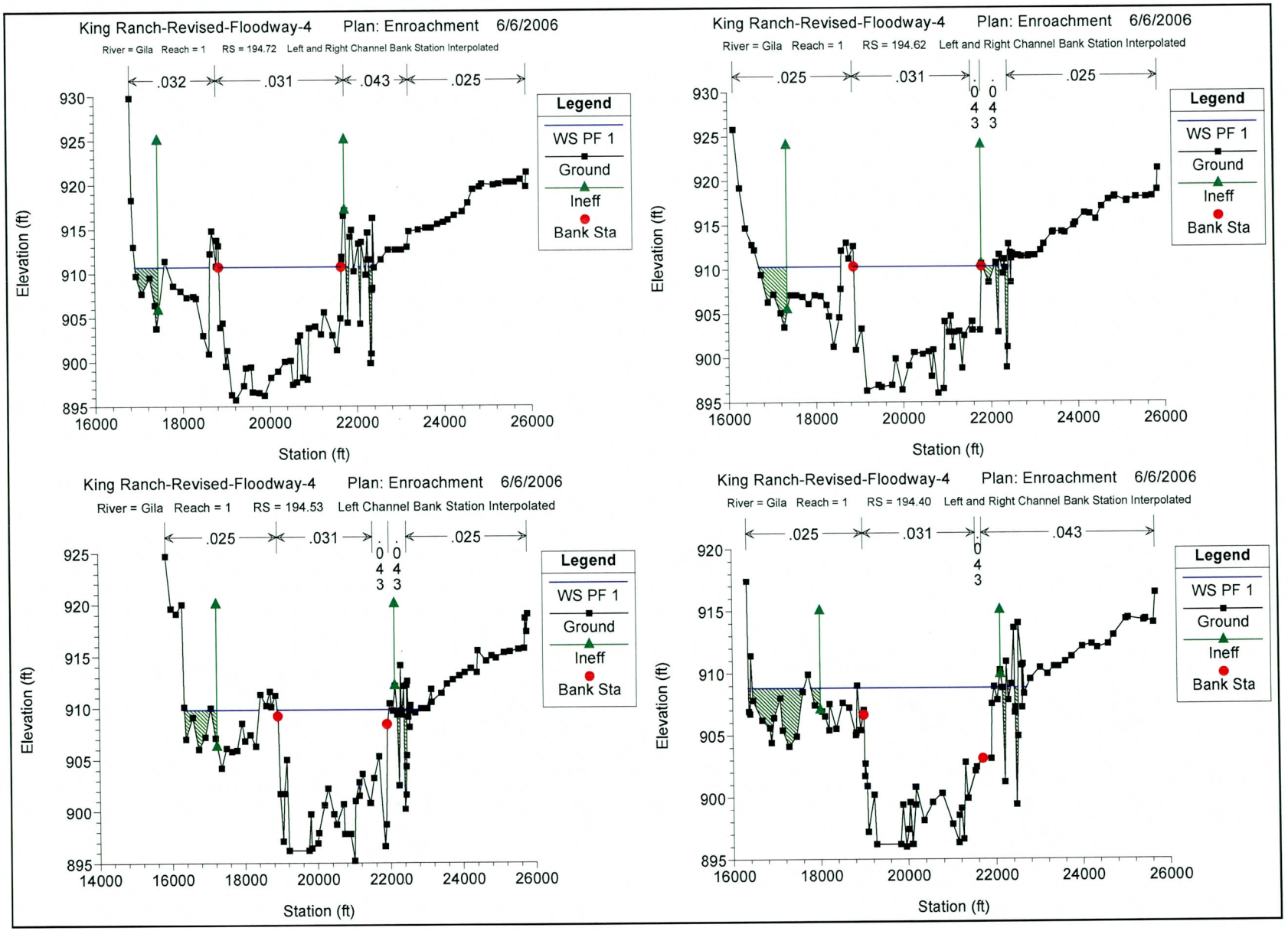
Revised Conditions

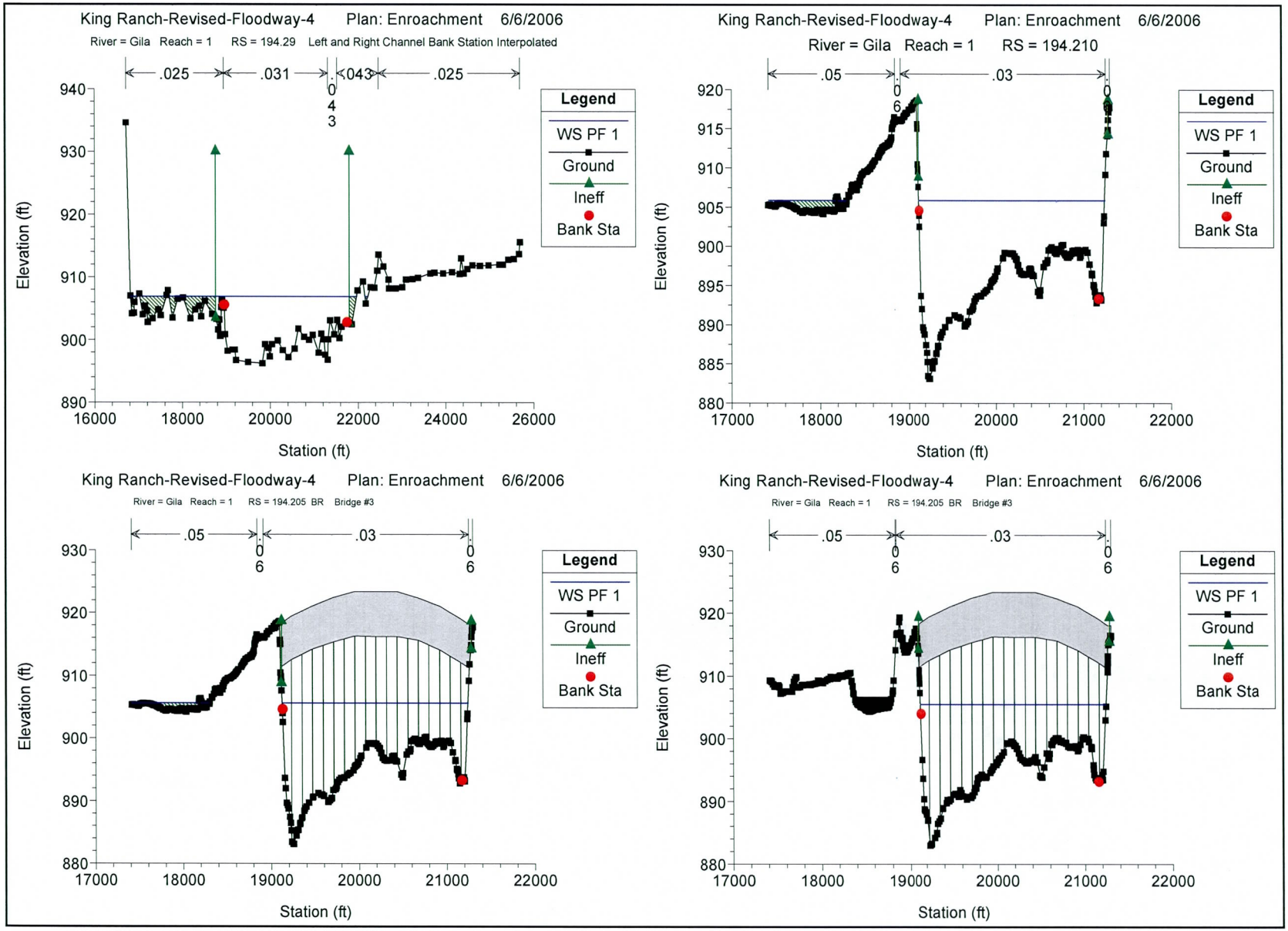

King Ranch-Revised-FIS Plan: PC Sep 23 For FIS 4/6/2006
Legend
WS 500 Year
WS 100 Year
WS 50 Year
WS 10 Year
Ground
Elevation (ft)
930
920
910
900
890
880
870
860
850
186
188
190
192
194
196
Main Channel Distance (mi)

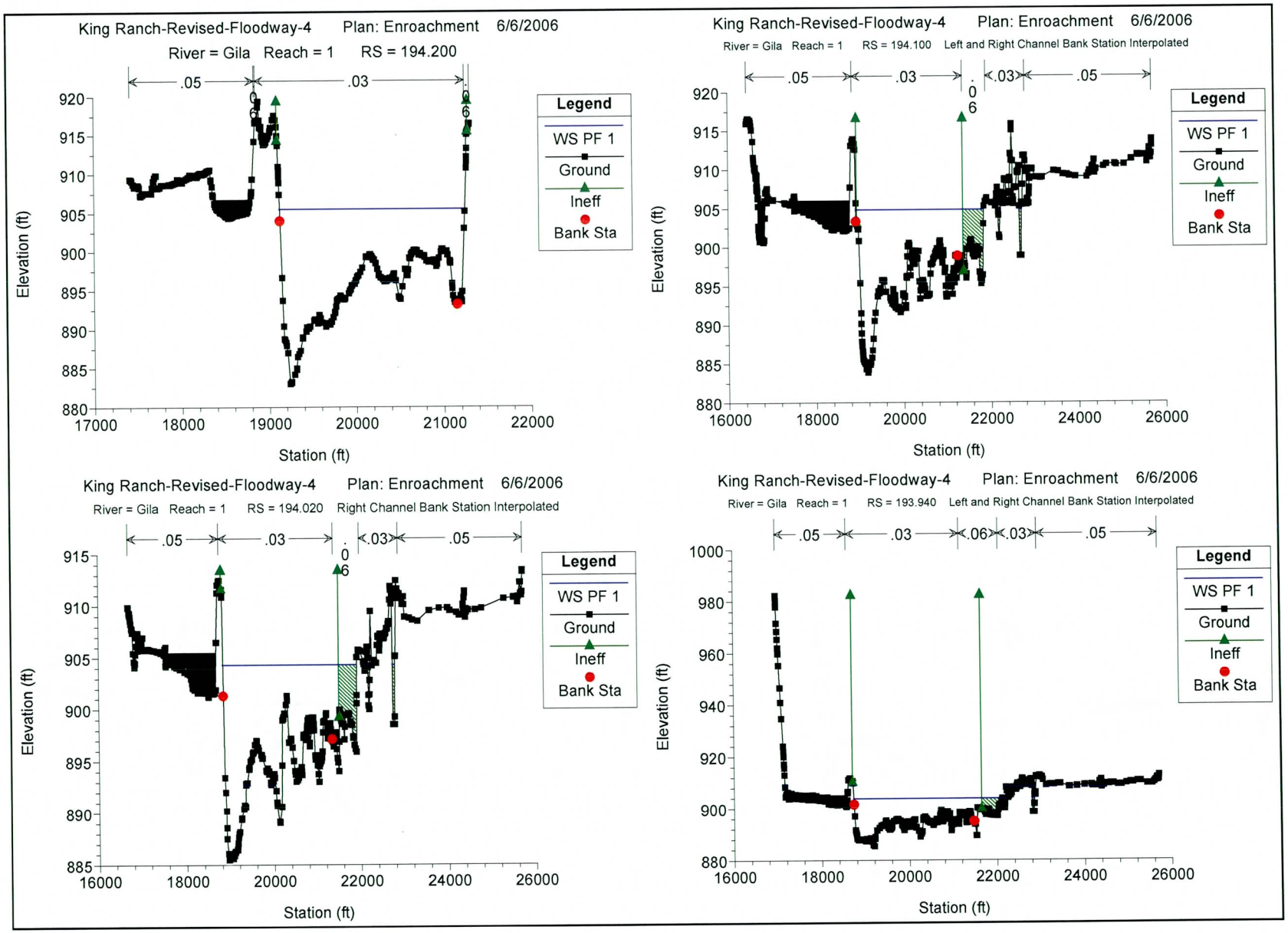
HEC-RAS Plan: Encroached River: Gila Reach: 1 Profile: PF 1

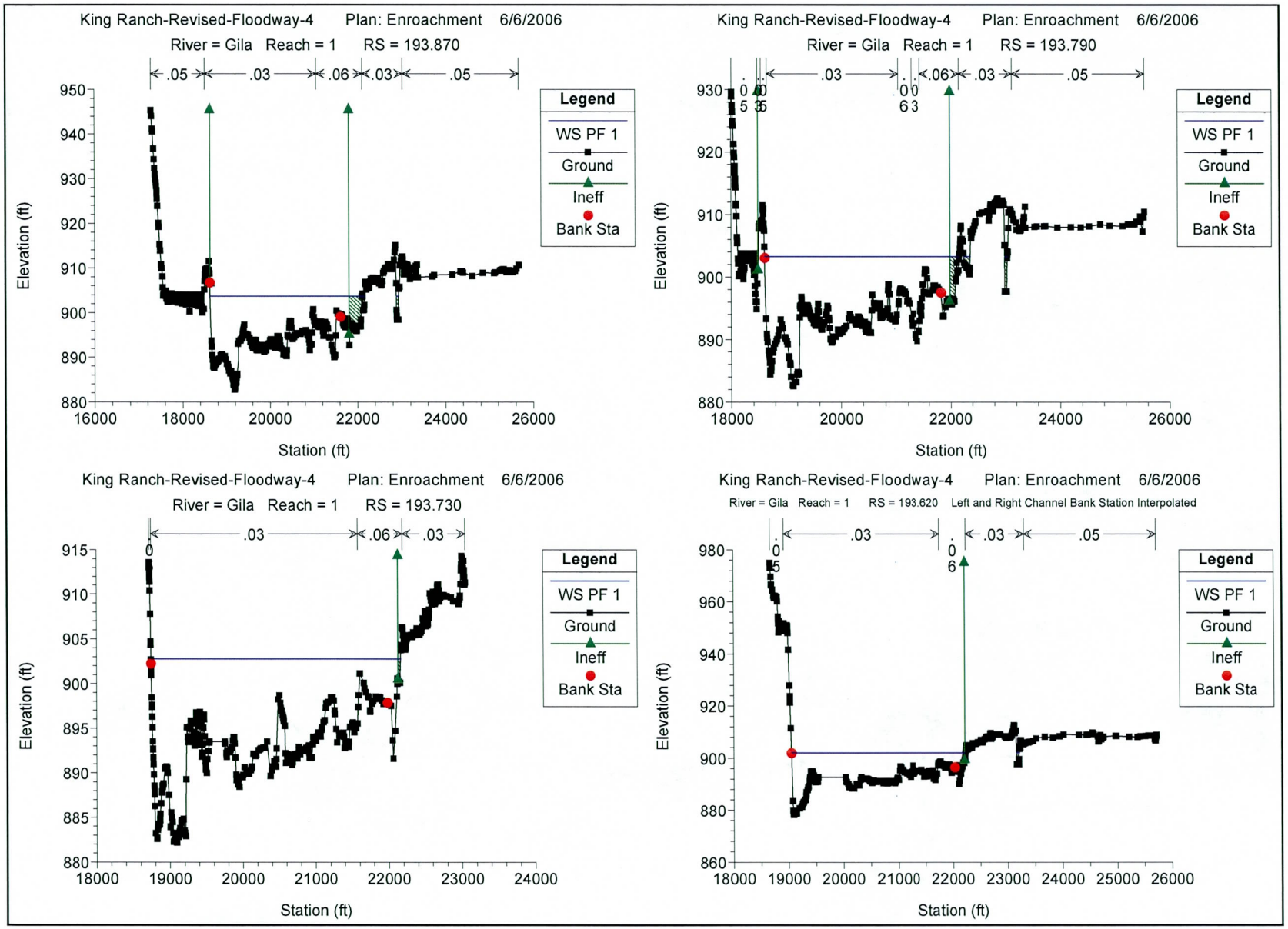
Reach	River Sta	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
		(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
1	195.09	227000.00	898.80	912.57	909.24	914.32	0.002001	10.76	22293.30	3656.43	0.57
1	195.00	227000.00	897.00	912.05	908.49	913.29	0.001540	9.18	26675.47	4364.60	0.49
1	194.91	227000.00	896.90	911.43	907.63	912.51	0.001446	8.56	28677.74	4973.36	0.47
1	194.81	227000.00	896.00	911.16	905.84	911.88	0.000818	7.00	35118.30	5164.77	0.37
1	194.72	227000.00	895.70	910.72	905.79	911.46	0.000927	7.08	34228.41	4725.73	0.38
1	194.62	227000.00	896.00	910.33	905.57	910.99	0.000861	6.67	35650.46	5294.07	0.36
1	194.53	227000.00	895.20	909.82	905.21	910.53	0.000963	6.89	34550.00	5571.13	0.38
1	194.40	227000.00	896.00	908.85	904.77	909.76	0.001220	7.83	30952.59	5834.55	0.43
1	194.29	227000.00	896.20	906.81	904.97	908.44	0.002932	10.41	22623.04	5079.93	0.65
1	194.210	227000.00	883.10	905.84	902.06	907.36	0.001660	9.89	22969.06	2979.70	0.53
1	194.205	Bridge									
1	194.200	227000.00	882.97	905.54	901.99	907.12	0.001785	10.10	22472.19	2117.26	0.55
1	194.100	227000.00	883.87	904.88	901.13	906.19	0.001565	9.17	24765.32	3014.25	0.51
1	194.020	227000.00	885.49	904.34	900.33	905.45	0.001387	8.46	26835.07	3215.48	0.47
1	193.940	227000.00	885.38	904.02	899.40	904.92	0.001126	7.58	29956.84	3507.09	0.42
1	193.870	227000.00	882.80	903.70	898.77	904.47	0.001010	7.02	32317.08	3573.40	0.39
1	193.790	227000.00	882.55	903.24	898.25	903.95	0.001372	6.73	33826.84	3717.02	0.37
1	193.730	227000.00	882.18	902.72	897.93	903.48	0.001317	7.03	32639.32	3421.62	0.40
1	193.620	227000.00	878.21	901.93	897.55	902.79	0.001092	7.51	30757.47	3218.46	0.42
1	193.530	227000.00	878.96	901.49	896.73	902.27	0.000946	7.10	32216.98	3319.36	0.39
1	193.430	227000.00	879.37	901.08	896.02	901.82	0.000885	6.88	33182.05	3565.70	0.38
1	193.340	227000.00	881.18	900.66	895.21	901.41	0.000820	6.98	32690.88	3675.54	0.37
1	193.250	227000.00	880.67	900.05	894.47	900.93	0.001183	7.54	30109.36	2637.22	0.39
1	193.160	227000.00	880.66	899.49	894.10	900.41	0.000963	7.72	29424.64	2539.44	0.40
1	193.070	227000.00	881.99	899.08	893.35	899.96	0.000881	7.50	30247.00	2538.03	0.38
1	192.980	227000.00	880.71	898.69	892.52	899.51	0.000904	7.28	31189.38	2521.54	0.36
1	192.890	227000.00	880.29	898.09	892.19	899.02	0.001053	7.74	29320.36	2381.65	0.39
1	192.790	227000.00	876.74	897.40	891.76	898.43	0.001312	8.17	27792.78	2265.15	0.41
1	192.700	227000.00	877.01	896.68	891.15	897.77	0.001376	8.41	26999.82	2194.89	0.42
1	192.610	227000.00	878.15	896.06	890.41	897.16	0.001206	8.43	26932.69	2156.06	0.42
1	192.520	227000.00	878.23	895.42	889.84	896.55	0.001209	8.52	26637.11	2133.56	0.42
1	192.41	227000.00	876.67	894.65	889.52	895.86	0.001302	8.83	25704.92	2147.49	0.45
1	192.39	Bridge									
1	192.38	227000.00	876.41	893.98	889.30	895.28	0.001443	9.17	24753.31	2144.55	0.47
1	192.330	227000.00	876.06	893.52	888.89	894.84	0.001471	9.20	24665.93	2851.47	0.48
1	192.230	227000.00	876.72	892.68	888.24	894.04	0.001749	9.34	24293.64	3055.32	0.49
1	192.140	227000.00	875.94	891.71	887.75	893.13	0.001893	9.56	23751.93	3297.97	0.51
1	192.040	227000.00	876.36	891.06	886.85	892.21	0.001550	8.60	26396.70	3671.07	0.47
1	191.950	227000.00	876.68	890.52	885.96	891.45	0.001238	7.80	29573.75	3987.16	0.43
1	191.860	227000.00	876.27	890.05	885.29	890.84	0.001057	7.16	32085.39	4306.03	0.39
1	191.760	227000.00	874.62	889.52	885.02	890.29	0.001121	7.04	32590.99	4514.06	0.40
1	191.670	227000.00	872.60	888.99	884.41	889.69	0.001188	6.74	33741.53	5162.56	0.39
1	191.570	227000.00	870.63	888.50	883.35	889.10	0.001046	6.21	36535.39	5065.55	0.37
1	191.480	227000.00	870.93	888.09	882.78	888.60	0.000879	5.71	39791.98	5545.91	0.34
1	191.380	227000.00	871.69	887.67	882.49	888.17	0.000822	5.67	40716.73	6150.25	0.34
1	191.290	227000.00	870.63	887.28	881.98	887.74	0.000837	5.46	41582.00	5890.63	0.32
1	191.190	227000.00	869.78	886.85	881.32	887.32	0.000873	5.50	41486.89	5263.42	0.32
1	191.100	227000.00	870.88	886.46	880.92	886.92	0.000707	5.43	41874.25	4764.65	0.31
1	191.000	227000.00	869.64	886.10	880.28	886.56	0.000725	5.45	41632.96	4424.70	0.31
1	190.910	227000.00	867.98	885.66	880.17	886.16	0.000868	5.71	39776.48	4946.74	0.32
1	190.810	227000.00	867.86	885.25	879.57	885.75	0.000781	5.65	40207.38	4700.58	0.32
1	190.720	227000.00	866.30	884.88	879.07	885.36	0.000754	5.55	40921.00	4965.37	0.31
1	190.620	227000.00	867.37	884.49	878.51	884.97	0.000807	5.52	41334.29	5151.48	0.30
1	190.530	227000.00	866.16	883.96	877.87	884.43	0.001456	5.55	40922.51	4531.19	0.30
1	190.430	227000.00	867.42	883.34	877.12	883.85	0.000945	5.73	39593.25	4121.85	0.31
1	190.340	227000.00	866.61	882.90	876.54	883.36	0.000967	5.46	41552.79	4995.83	0.29
1	190.240	227000.00	866.29	882.37	876.03	882.83	0.001114	5.45	41656.73	4852.75	0.29
1	190.150	227000.00	865.74	881.66	876.05	882.22	0.001342	6.02	37695.06	4656.45	0.33
1	190.050	227000.00	858.06	881.17	874.35	881.63	0.000919	5.44	41711.88	5055.07	0.29
1	189.960	227000.00	857.56	880.76	874.21	881.21	0.000826	5.34	42565.66	4707.40	0.29
1	189.870	227000.00	862.94	880.39	873.61	880.79	0.000817	5.07	45018.30	8082.38	0.27
1	189.770	227000.00	860.75	880.07	872.72	880.38	0.000654	4.56	51391.65	9558.24	0.24
1	189.670	227000.00	862.77	879.72	872.39	880.04	0.000690	4.56	51402.32	9169.72	0.24
1	189.580	227000.00	857.92	879.40	872.00	879.70	0.000623	4.51	53120.89	8605.12	0.24
1	189.480	227000.00	857.85	879.10	871.42	879.40	0.000595	4.45	54919.66	8453.95	0.23
1	189.390	227000.00	855.02	878.77	871.26	879.10	0.000598	4.63	53336.20	9144.26	0.24
1	189.300	227000.00	856.36	878.45	871.42	878.80	0.000733	4.83	51323.42	8652.06	0.26
1	189.210	227000.00	856.97	878.11	870.93	878.43	0.000740	4.69	54184.91	8481.39	0.25
1	189.110	227000.00	857.40	877.79	869.75	878.09	0.000601	4.50	56004.50	7944.71	0.23
1	189.020	227000.00	855.16	877.52	869.00	877.80	0.000511	4.35	58129.04	8839.55	0.23
1	188.810	227000.00	852.24	877.07	866.90	877.33	0.000358	4.14	61905.59	7986.71	0.20
1	188.690	227000.00	850.62	876.79	867.82	877.08	0.000483	4.43	58559.81	8830.76	0.21
1	188.59	227000.00	861.40	876.44	871.17	876.76	0.000764	4.67	50872.18	7530.67	0.27

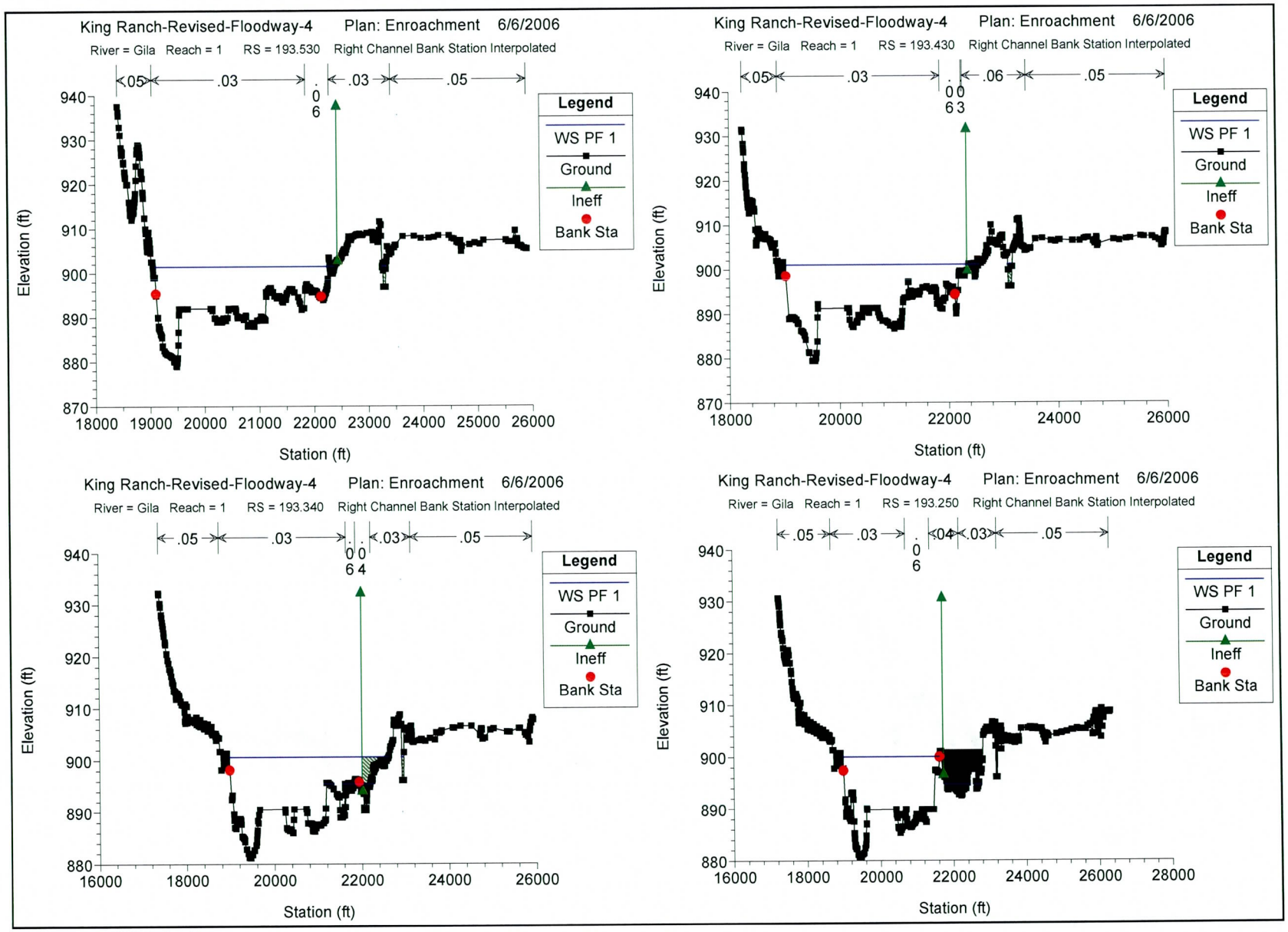

King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 195.09 Left and Right Channel Bank Station Interpolated
.032
.031
.043
.025
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 195.00 Left and Right Channel Bank Station Interpolated
.032
.031
.032
.025
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 194.91 Left and Right Channel Bank Station Interpolated
.032
.031
.032
.025
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 194.81 Left and Right Channel Bank Station Interpolated
.032
.031
.032
.032
.025
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)

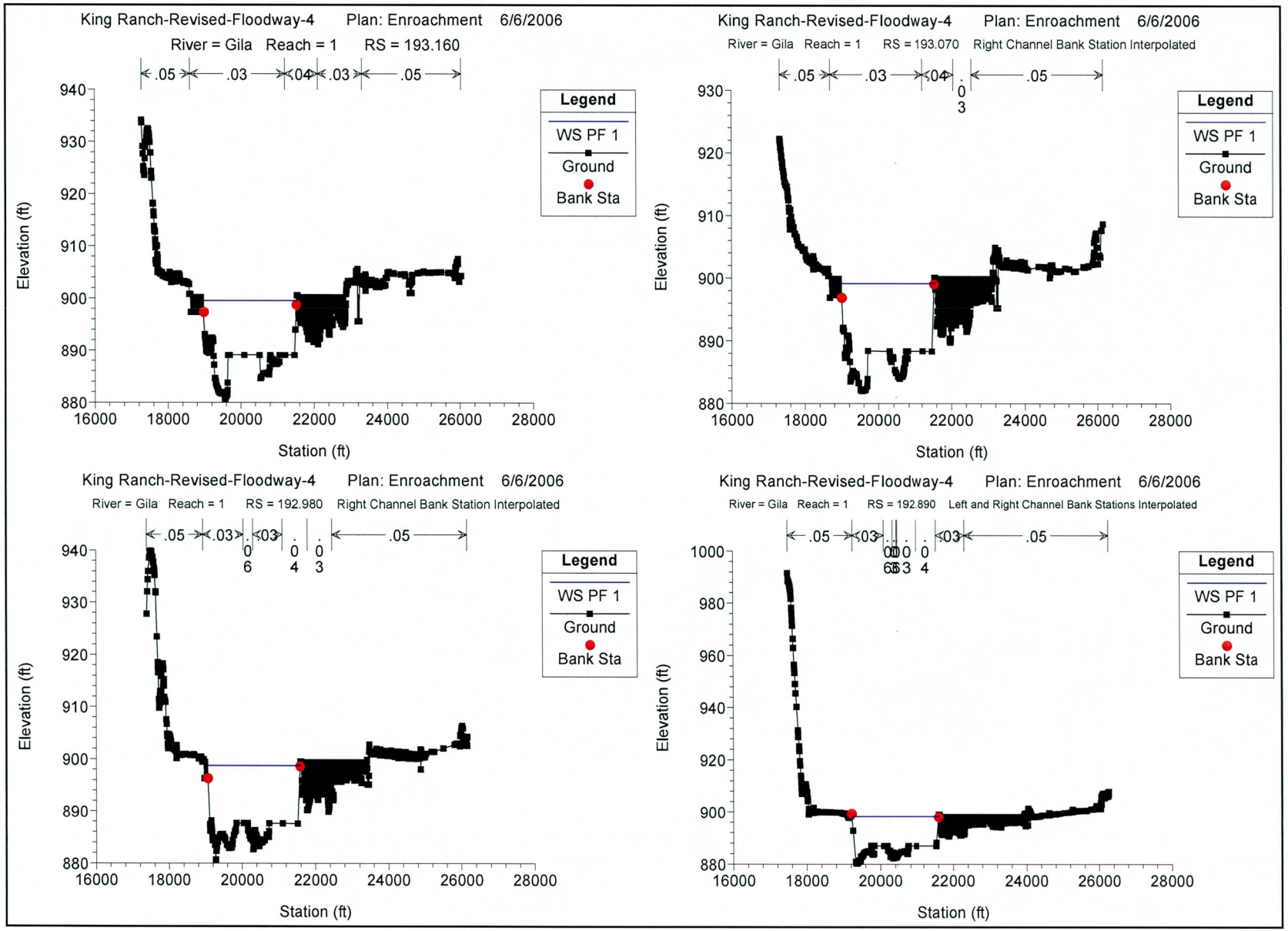

King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 194.72 Left and Right Channel Bank Station Interpolated
.032
.031
.043
.025
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 194.62 Left and Right Channel Bank Station Interpolated
.025
.031
.043
.043
.025
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 194.53 Left Channel Bank Station Interpolated
.025
.031
.043
.043
.025
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 194.40 Left and Right Channel Bank Station Interpolated
.025
.031
.043
.043
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)

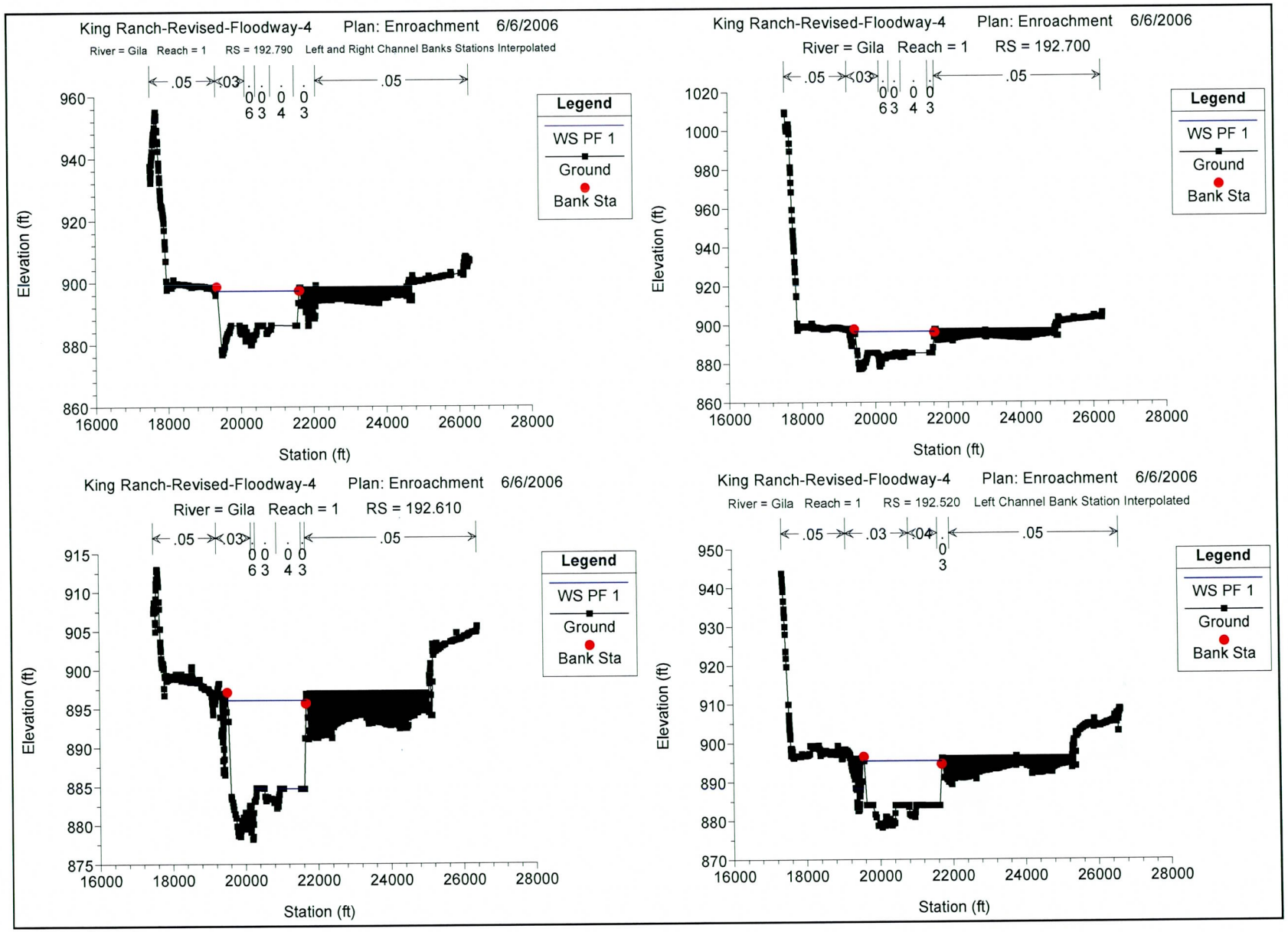

King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 194.29 Left and Right Channel Bank Station Interpolated
.025
.031
.043
.025
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 194.210
.05
.03
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 194.205 BR Bridge #3
.05
.03
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 194.205 BR Bridge #3
.05
.03
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)

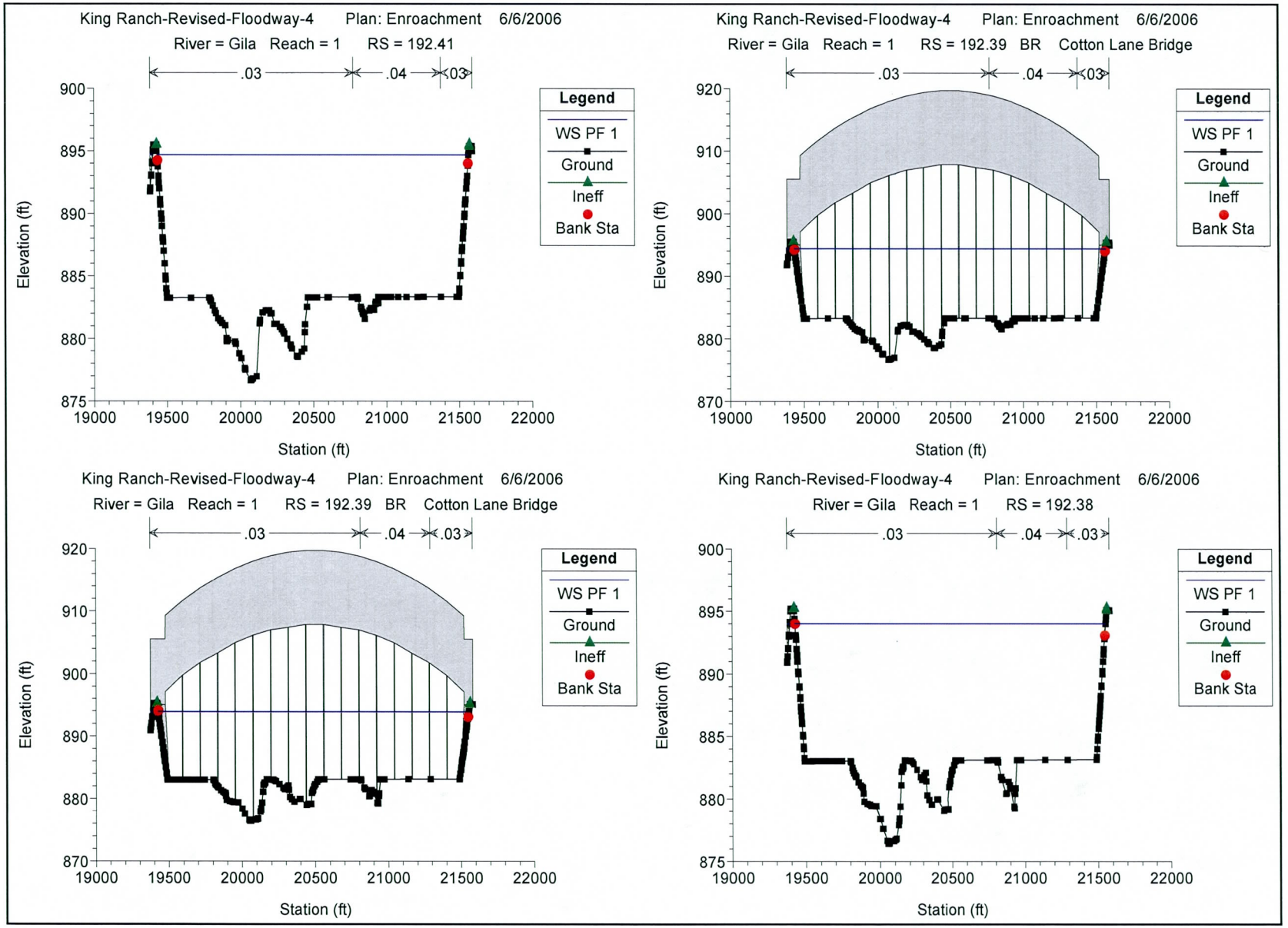

King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 194.200
.05
.03
.06
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 194.100 Left and Right Channel Bank Station Interpolated
.05
.03
.03
.05
.06
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 194.020 Right Channel Bank Station Interpolated
.05
.03
.03
.05
.06
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 193.940 Left and Right Channel Bank Station Interpolated
.05
.03
.06
.03
.05
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)

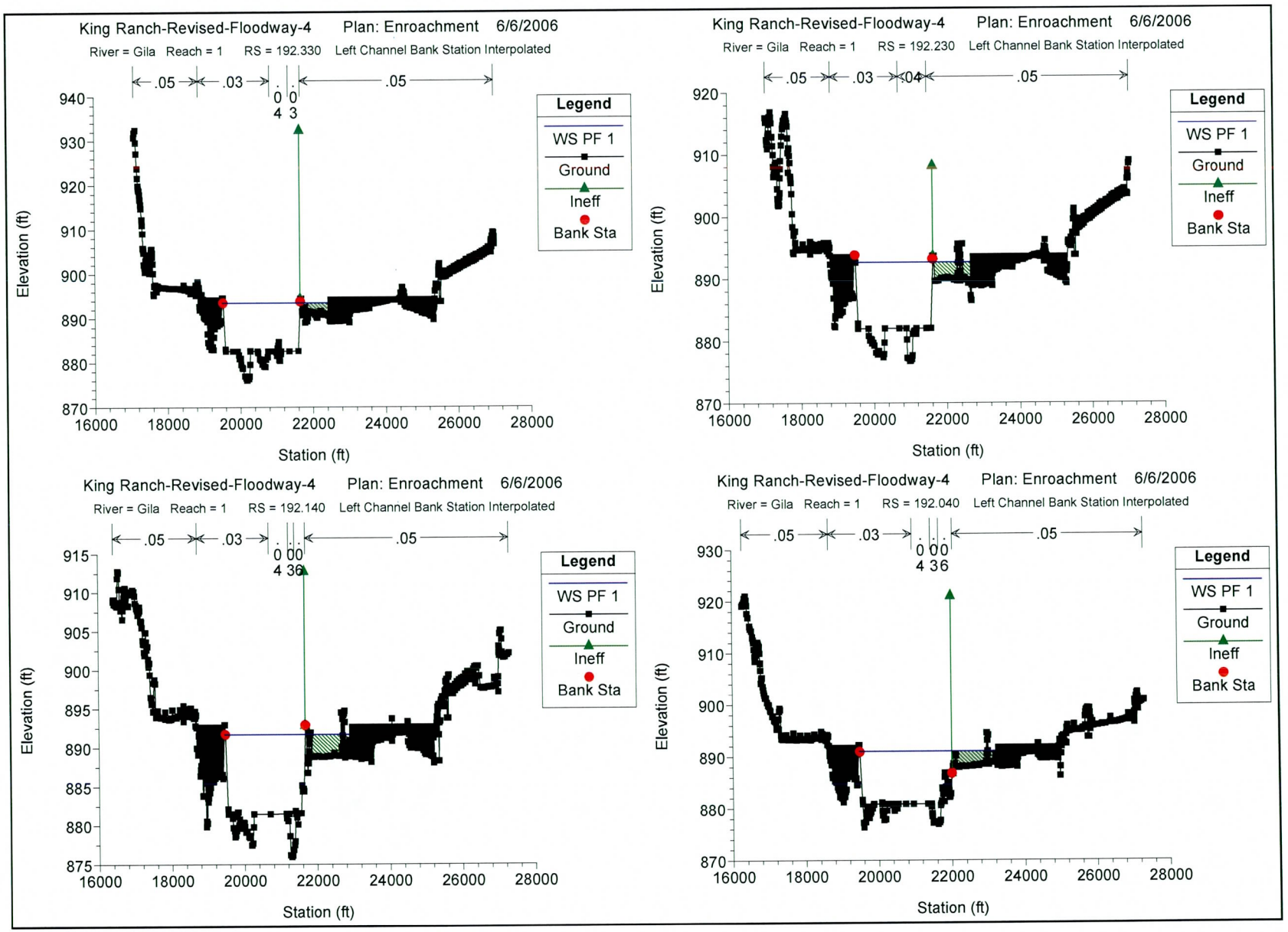

King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 193.870
.05 .03 .06 .03 .05
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 193.790
.03 .06 .03 .05
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 193.730
.03 .06 .03
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 193.620 Left and Right Channel Bank Station Interpolated
.03 .03 .05
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)

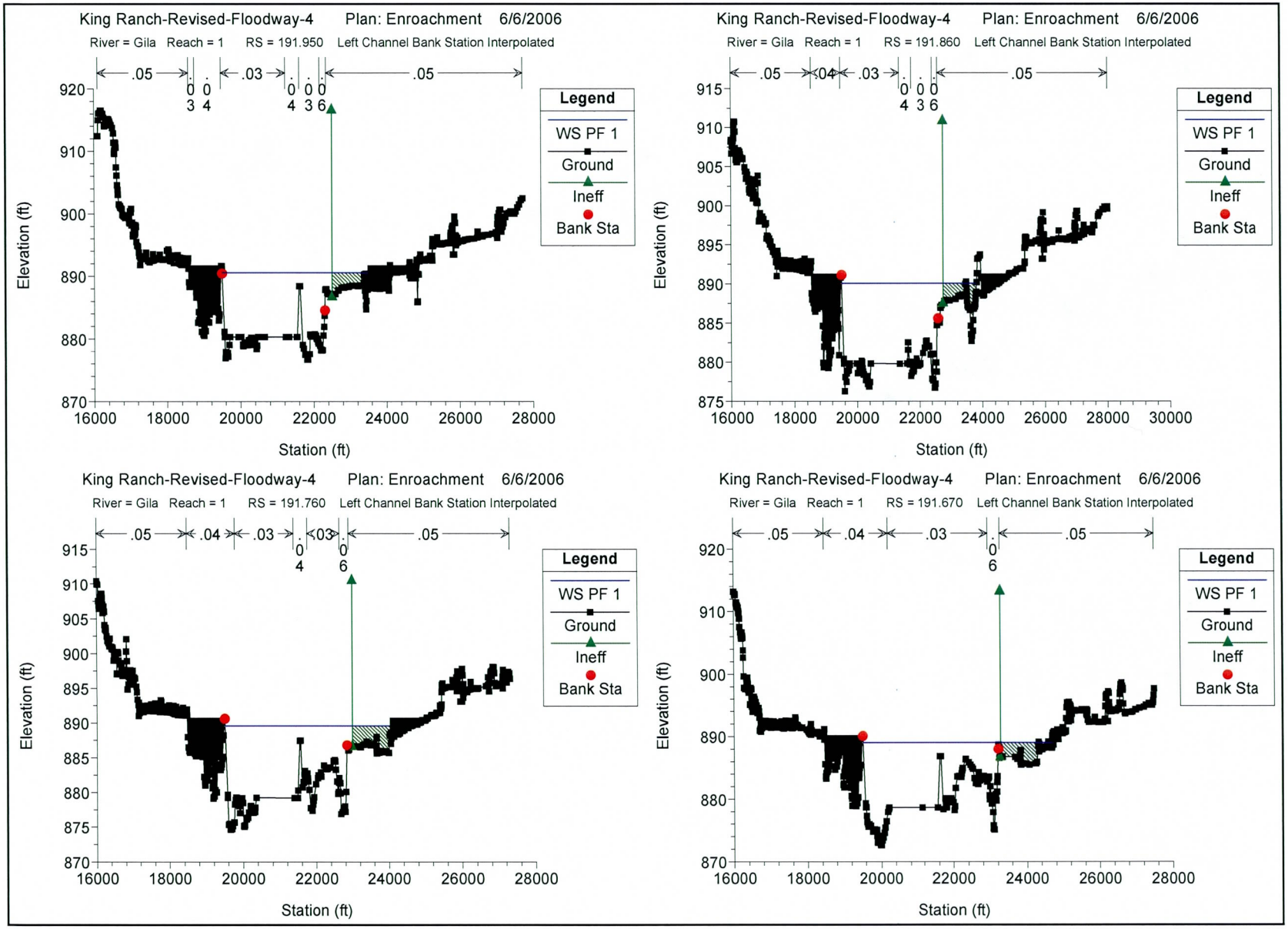

King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 193.530 Right Channel Bank Station Interpolated
.05 .03 .06 .03 .05
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 193.430 Right Channel Bank Station Interpolated
.05 .03 .00 .06 .05
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 193.340 Right Channel Bank Station Interpolated
.05 .03 .00 .03 .05
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 193.250 Right Channel Bank Station Interpolated
.05 .03 .06 .04 .03 .05
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)

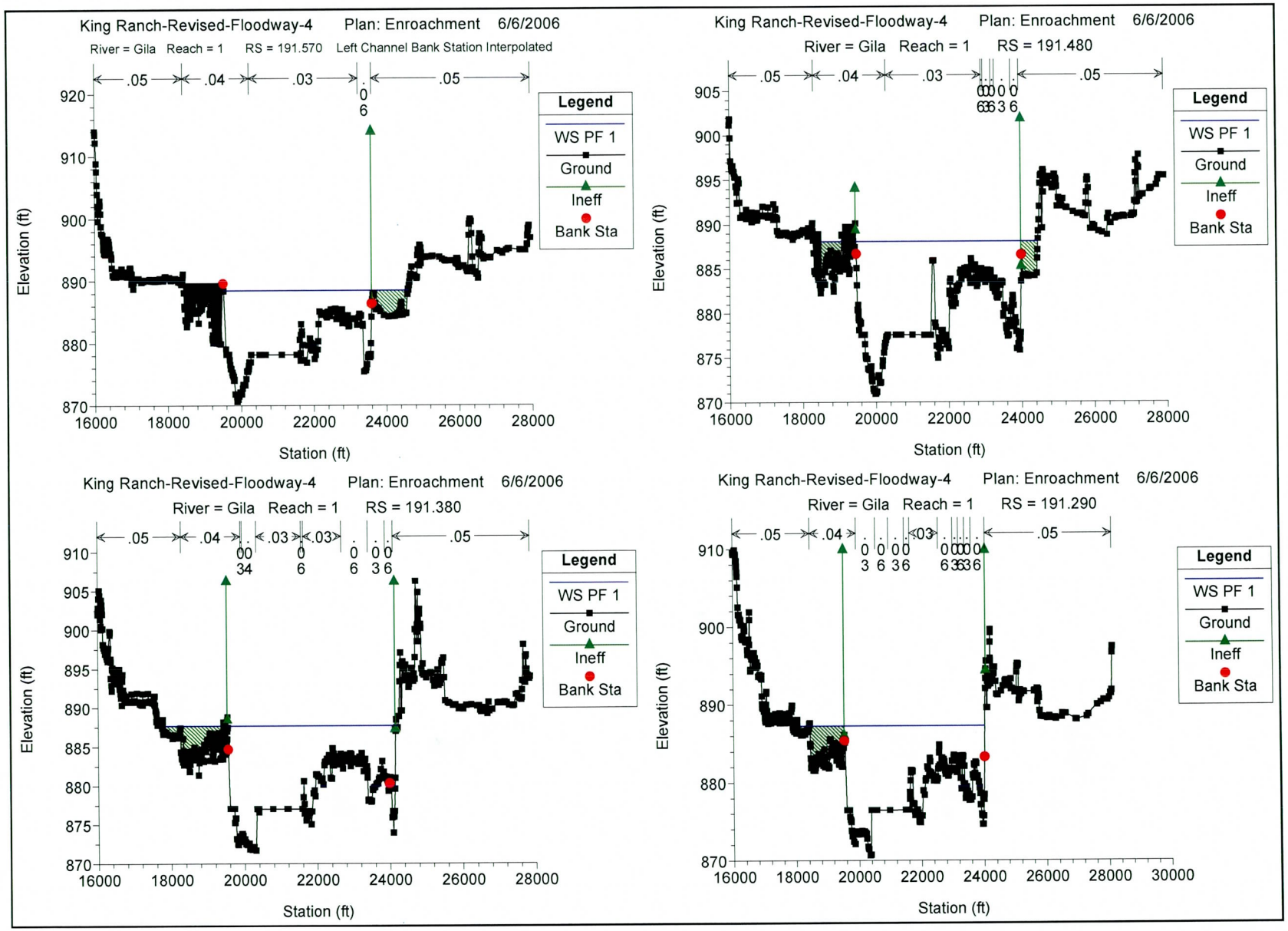

King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 193.160
.05 .03 .04 .03 .05
Legend
WS PF 1
Ground
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 193.070 Right Channel Bank Station Interpolated
.05 .03 .04 .05
Legend
WS PF 1
Ground
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 192.980 Right Channel Bank Station Interpolated
.05 .03 .05
Legend
WS PF 1
Ground
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 192.890 Left and Right Channel Bank Stations Interpolated
.05 .03 .05
Legend
WS PF 1
Ground
Bank Sta
Elevation (ft)
Station (ft)

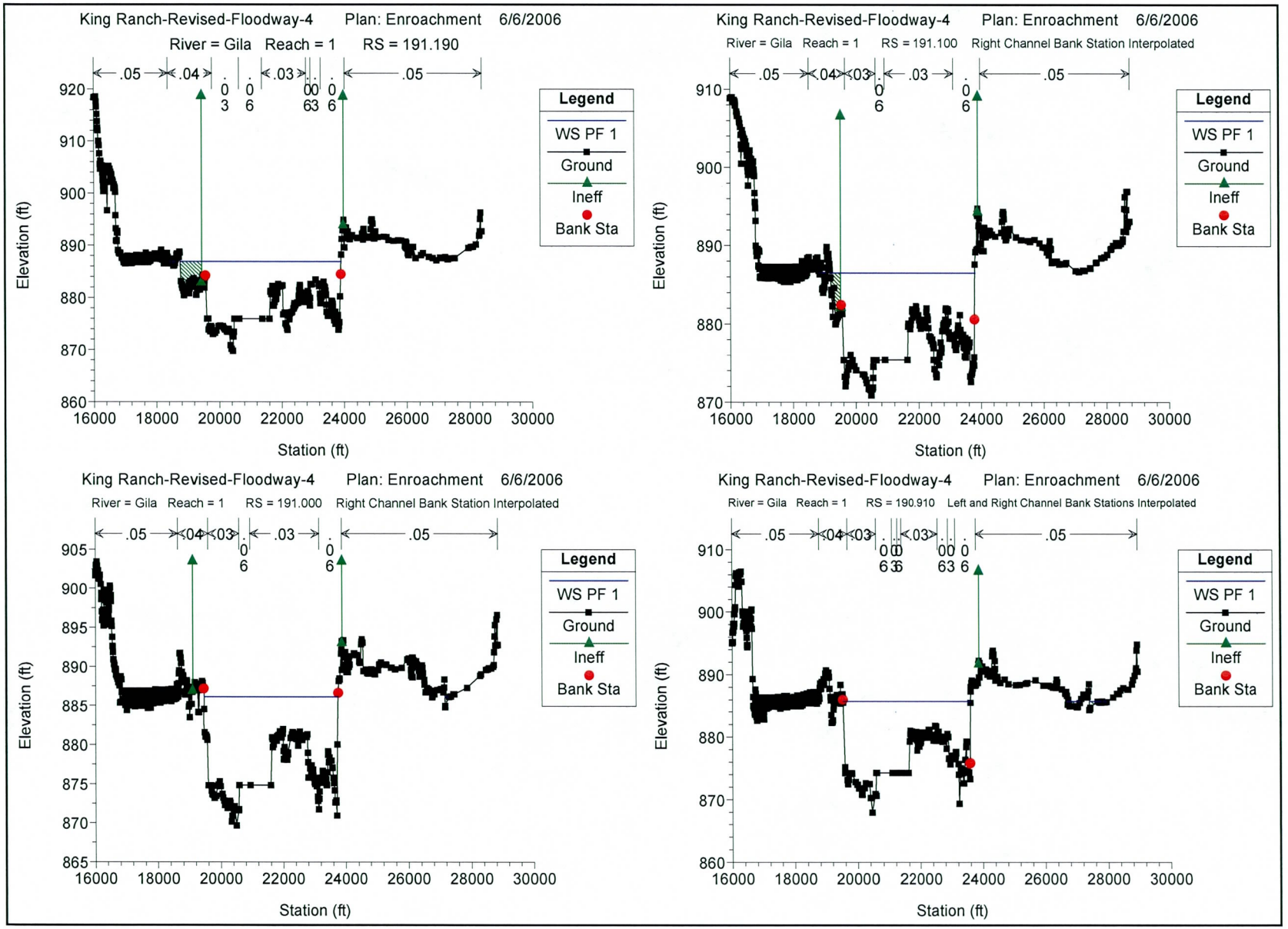

King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 192.790 Left and Right Channel Banks Stations Interpolated
.05 .03 .05
0 0 0 0 0
6 3 4 3
Legend
WS PF 1
Ground
Bank Sta
Elevation (ft)
960
940
920
900
880
860
16000 18000 20000 22000 24000 26000 28000
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 192.700
.05 .03 .05
0 0 0 0 0
6 3 4 3
Legend
WS PF 1
Ground
Bank Sta
Elevation (ft)
1020
1000
980
960
940
920
900
880
860
16000 18000 20000 22000 24000 26000 28000
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 192.610
.05 .03 .05
0 0 0 0
6 3 4 3
Legend
WS PF 1
Ground
Bank Sta
Elevation (ft)
915
910
905
900
895
890
885
880
875
16000 18000 20000 22000 24000 26000 28000
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 192.520 Left Channel Bank Station Interpolated
.05 .03 .04 .05
0
3
Legend
WS PF 1
Ground
Bank Sta
Elevation (ft)
950
940
930
920
910
900
890
880
870
16000 18000 20000 22000 24000 26000 28000
Station (ft)

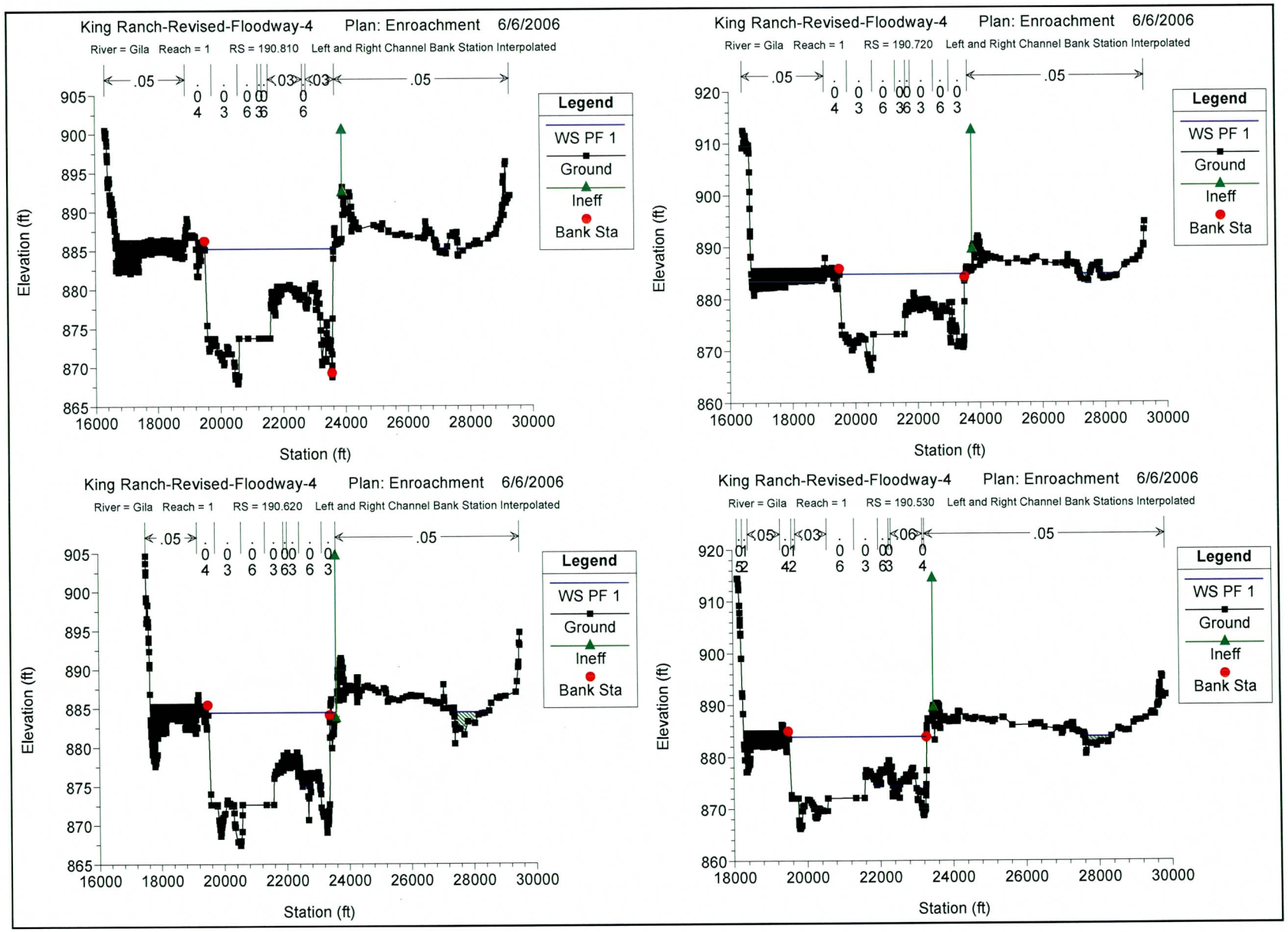

King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 192.41
.03
.04
.03
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 192.39 BR Cotton Lane Bridge
.03
.04
.03
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 192.39 BR Cotton Lane Bridge
.03
.04
.03
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 192.38
.03
.04
.03
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)

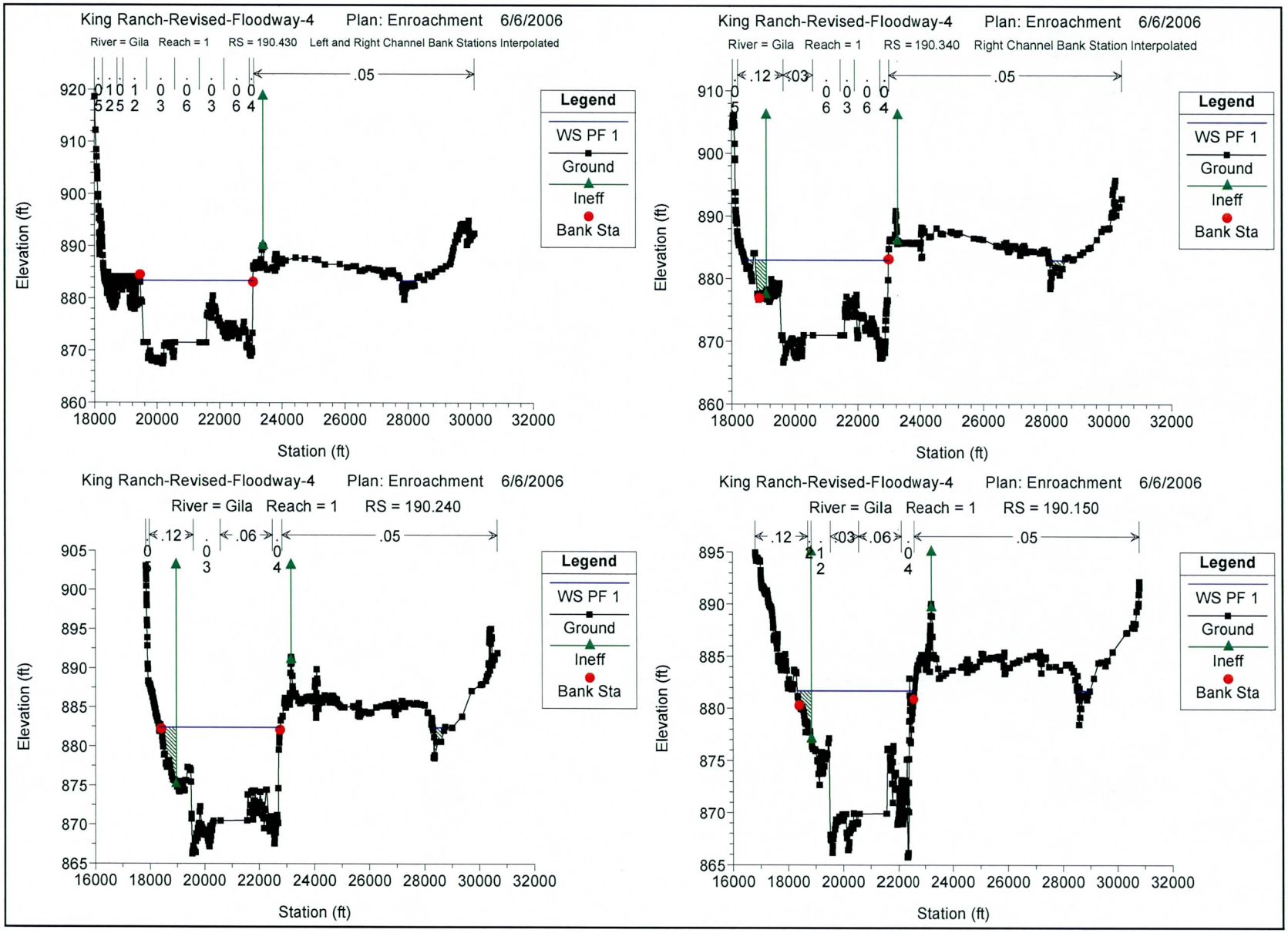

King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 192.330 Left Channel Bank Station Interpolated
.05 .03 .05
0 0
4 3
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
940 930 920 910 900 890 880 870
16000 18000 20000 22000 24000 26000 28000
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 192.230 Left Channel Bank Station Interpolated
.05 .03 .04 .05
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
920 910 900 890 880 870
16000 18000 20000 22000 24000 26000 28000
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 192.140 Left Channel Bank Station Interpolated
.05 .03 .05
0 00
4 36
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
915 910 905 900 895 890 885 880 875
16000 18000 20000 22000 24000 26000 28000
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 192.040 Left Channel Bank Station Interpolated
.05 .03 .05
0 00
4 36
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
930 920 910 900 890 880 870
16000 18000 20000 22000 24000 26000 28000
Station (ft)

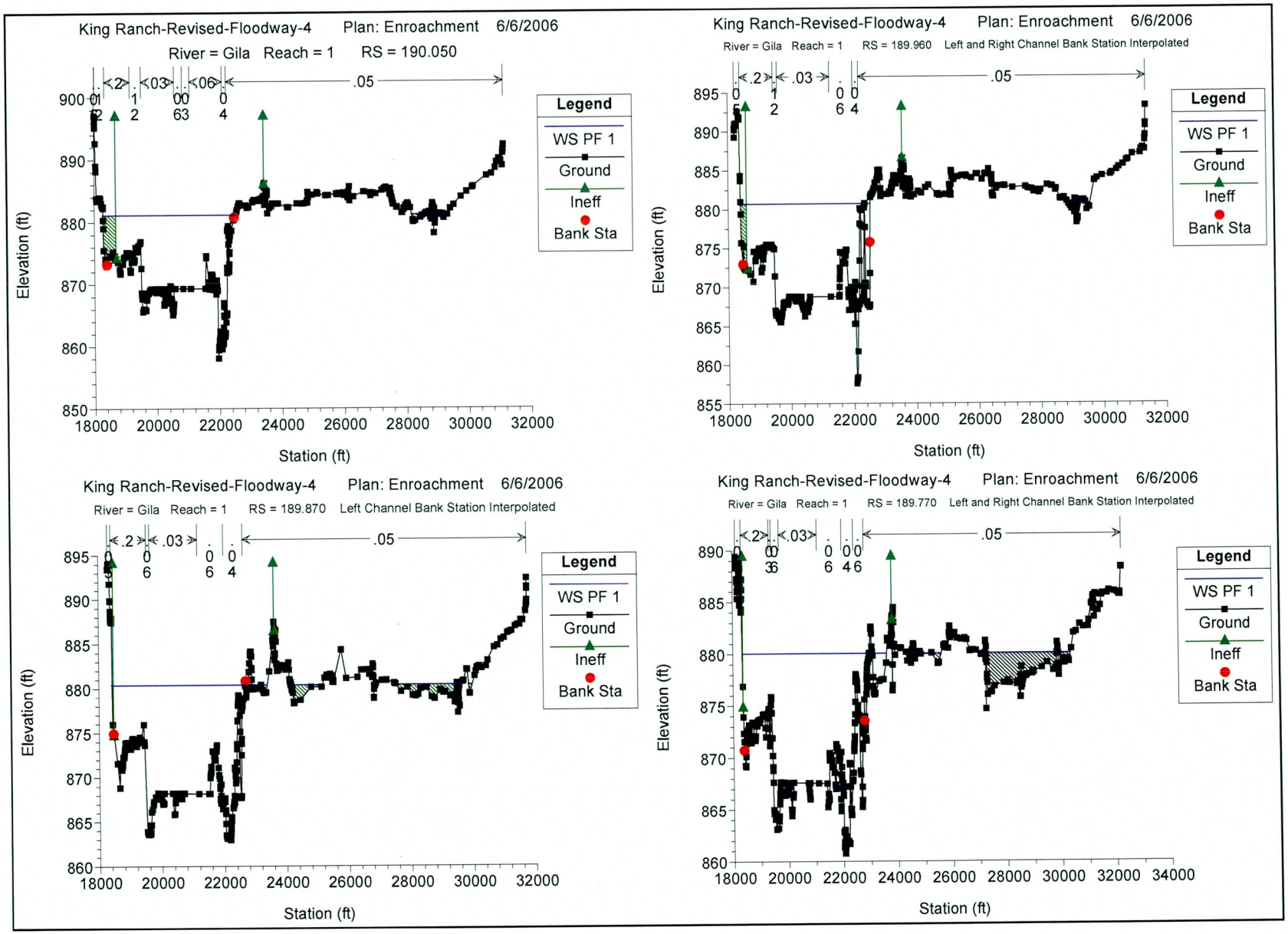

King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 191.950 Left Channel Bank Station Interpolated
.05 .03 .05
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 191.860 Left Channel Bank Station Interpolated
.05 .04 .03 .05
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 191.760 Left Channel Bank Station Interpolated
.05 .04 .03 .03 .05
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 191.670 Left Channel Bank Station Interpolated
.05 .04 .03 .05
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)

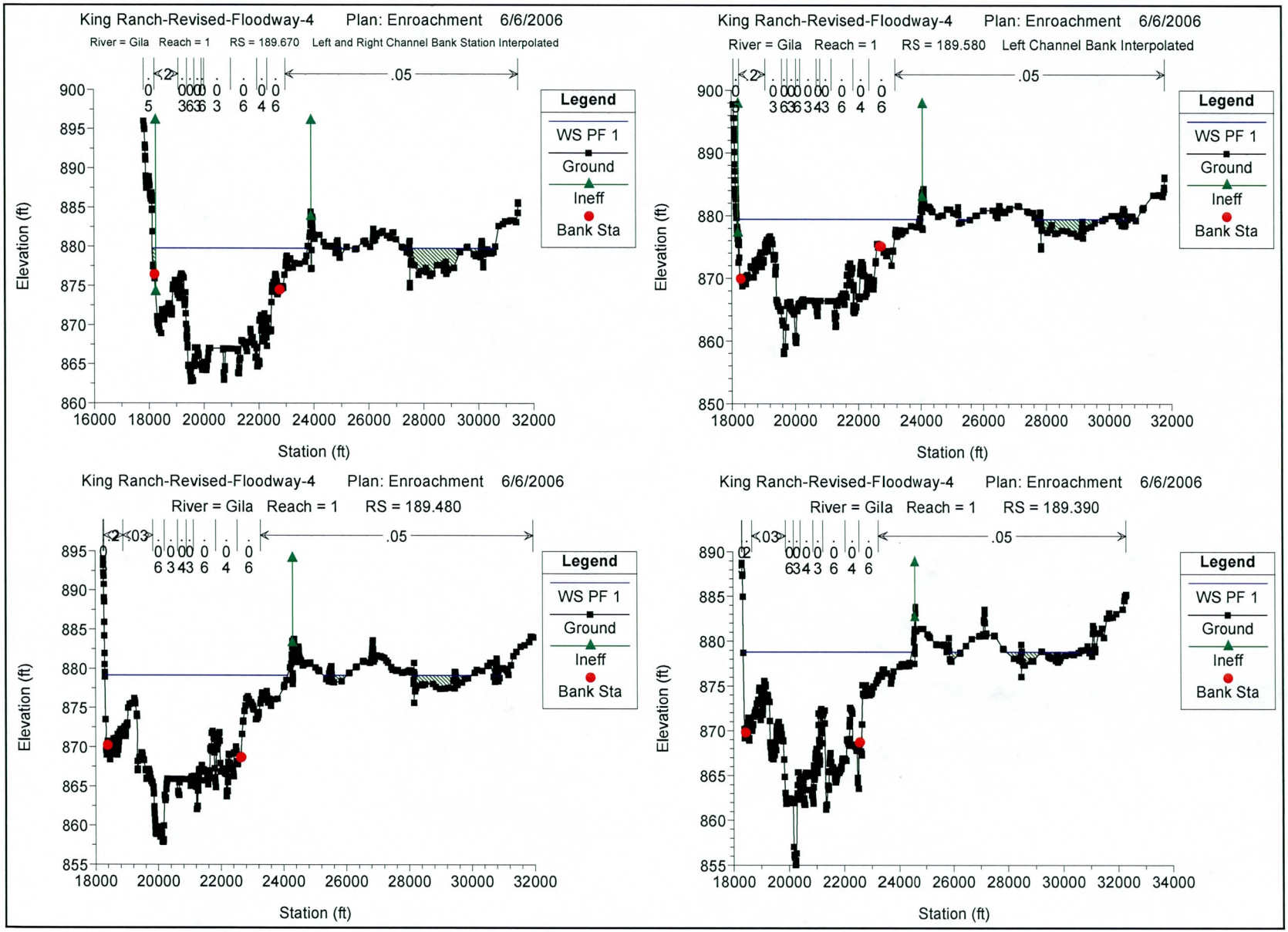

King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 191.570 Left Channel Bank Station Interpolated
.05 .04 .03 .05
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 191.480
.05 .04 .03 .05
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 191.380
.05 .04 .03 .03 .05
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 191.290
.05 .04 .03 .05
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)

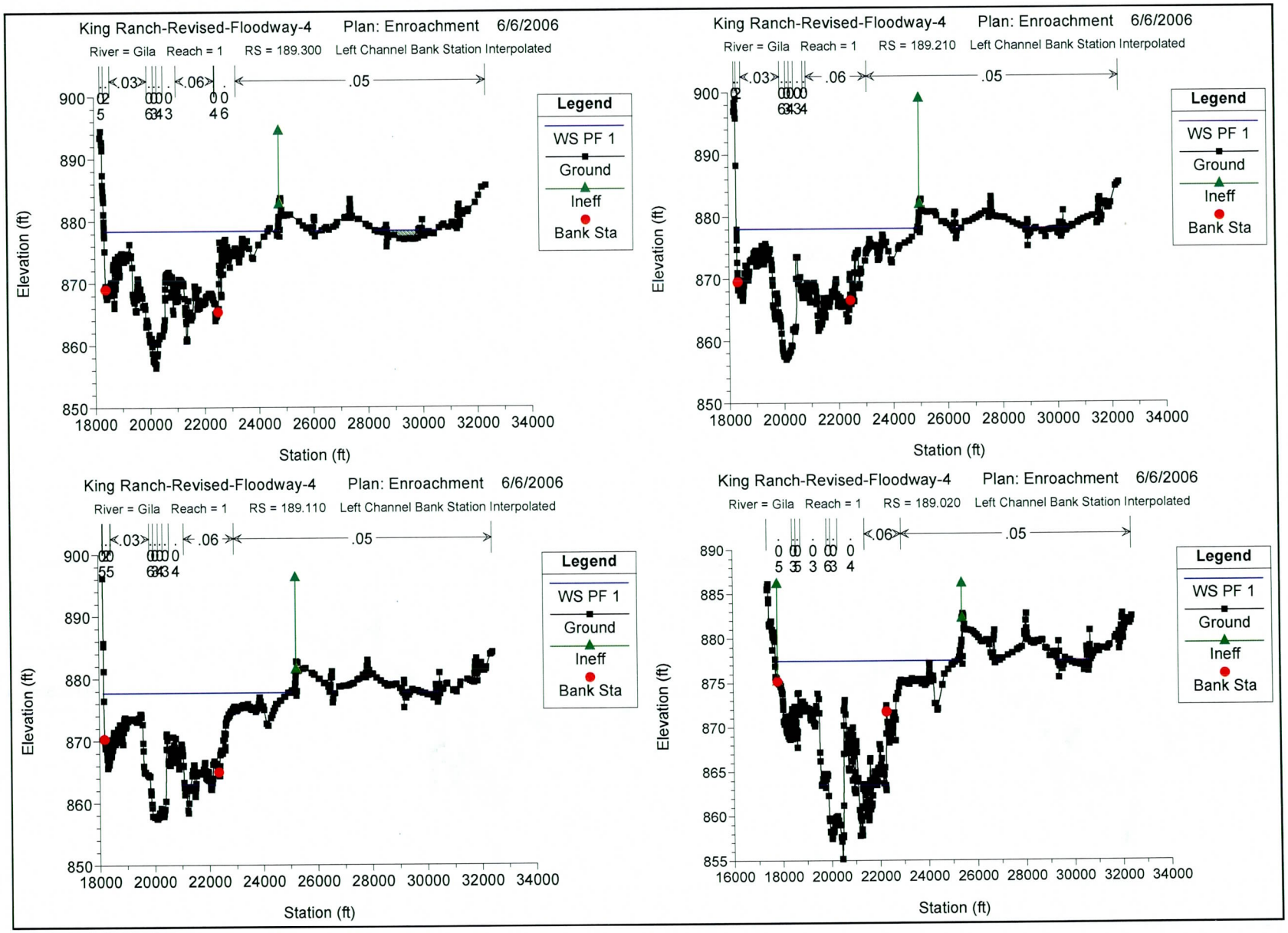

King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 191.190
.05 .04 .03 .05
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 191.100 Right Channel Bank Station Interpolated
.05 .04 .03 .03 .05
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 191.000 Right Channel Bank Station Interpolated
.05 .04 .03 .03 .05
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 190.910 Left and Right Channel Bank Stations Interpolated
.05 .04 .03 .03 .05
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)

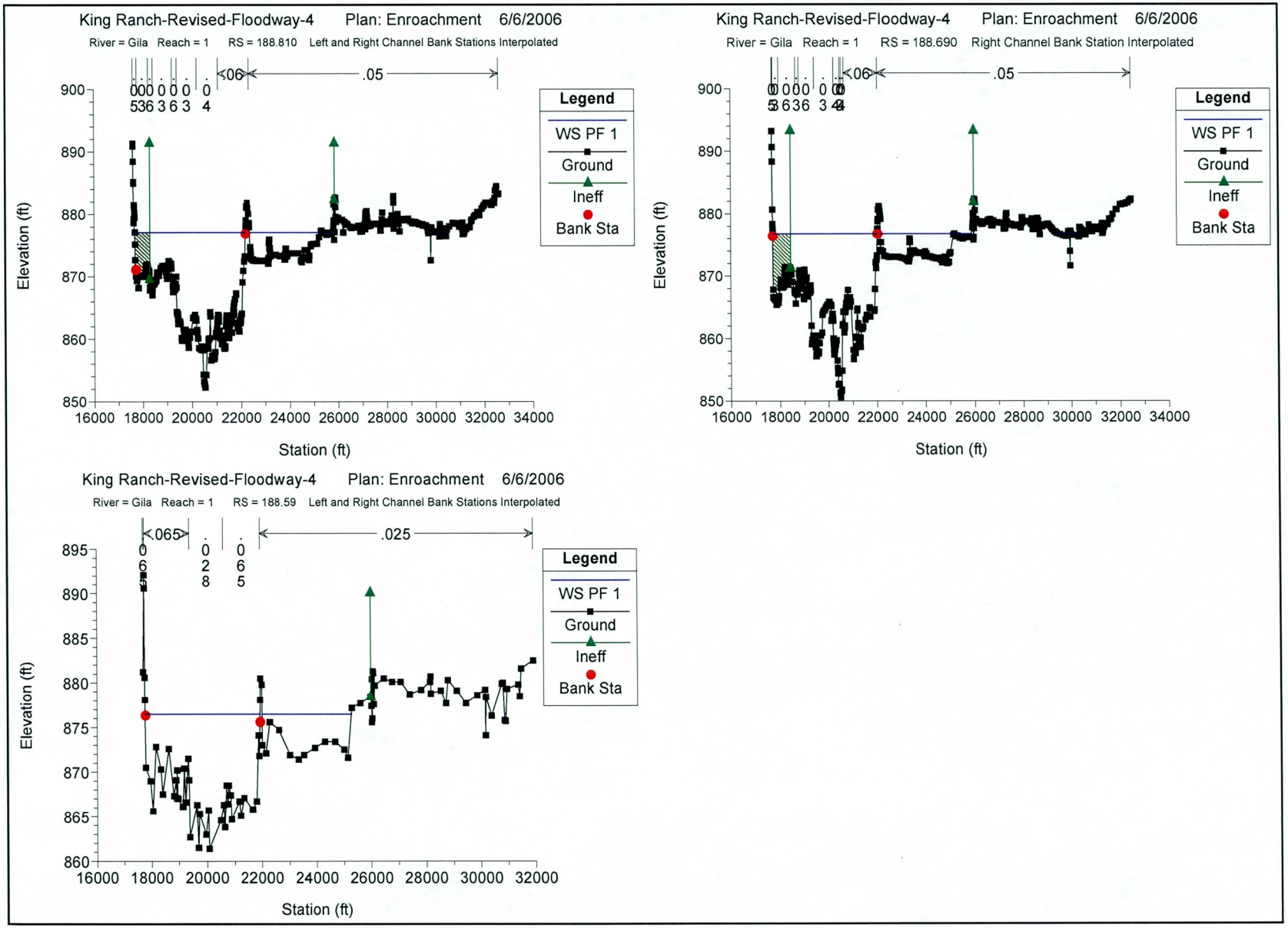

King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 190.810 Left and Right Channel Bank Station Interpolated
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 190.720 Left and Right Channel Bank Station Interpolated
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 190.620 Left and Right Channel Bank Station Interpolated
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 190.530 Left and Right Channel Bank Stations Interpolated
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)


King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 190.430 Left and Right Channel Bank Stations Interpolated
.05
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 190.340 Right Channel Bank Station Interpolated
.12
.03
.05
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 190.240
.12
.06
.05
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 190.150
.12
.03
.06
.05
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)


King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 190.050
.2
.03
.06
.05
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 189.960 Left and Right Channel Bank Station Interpolated
.2
.03
.05
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 189.870 Left Channel Bank Station Interpolated
.2
.03
.05
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 189.770 Left and Right Channel Bank Station Interpolated
.2
.03
.05
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)


King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 189.670 Left and Right Channel Bank Station Interpolated
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 189.580 Left Channel Bank Interpolated
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 189.480
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 189.390
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)


King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 189.300 Left Channel Bank Station Interpolated
.03
.06
.05
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 189.210 Left Channel Bank Station Interpolated
.03
.06
.05
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 189.110 Left Channel Bank Station Interpolated
.03
.06
.05
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 189.020 Left Channel Bank Station Interpolated
.06
.05
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)


King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 188.810 Left and Right Channel Bank Stations Interpolated
.06
.05
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 188.690 Right Channel Bank Station Interpolated
.06
.05
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
King Ranch-Revised-Floodway-4 Plan: Enroachment 6/6/2006
River = Gila Reach = 1 RS = 188.59 Left and Right Channel Bank Stations Interpolated
.065
.025
Legend
WS PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)

E.3 Expansion and Contraction Coefficients

Existing Conditions Model

Edit Contraction/Expansion Coefficients

	River Stati	Contractior	Expansion
1	195.75	0.1	0.3
2	195.66	0.1	0.3
3	195.56	0.1	0.3
4	195.47	0.1	0.3
5	195.38	0.1	0.3
6	195.28	0.1	0.3
7	195.19	0.1	0.3
8	195.16	0.1	0.3
9	195.15	Bridge	
10	195.13	0.1	0.3
11	195.09	0.1	0.3
12	195	0.1	0.3
13	194.91	0.1	0.3
14	194.81	0.1	0.3
15	194.72	0.1	0.3
16	194.62	0.1	0.3
17	194.53	0.1	0.3
18	194.4	0.1	0.3
19	194.29	0.1	0.3
20	194.21	0.1	0.3
21	194.205	Bridge	
22	194.2	0.1	0.3
23	194.1	0.1	0.3
24	194.02	0.1	0.3
25	193.94	0.1	0.3
26	193.87	0.1	0.3
27	193.79	0.1	0.3
28	193.73	0.1	0.3
29	193.62	0.1	0.3
30	193.53	0.1	0.3
31	193.43	0.1	0.3
32	193.34	0.1	0.3
33	193.25	0.1	0.3
34	193.16	0.1	0.3
35	193.07	0.1	0.3
36	192.98	0.1	0.3
37	192.89	0.1	0.3
38	192.79	0.1	0.3
39	192.7	0.1	0.3
40	192.61	0.1	0.3
41	192.52	0.1	0.3
42	192.42	0.1	0.3
43	192.33	0.1	0.3
44	192.23	0.1	0.3
45	192.14	0.1	0.3
46	192.04	0.1	0.3
47	191.95	0.1	0.3
48	191.86	0.1	0.3
49	191.76	0.1	0.3
50	191.67	0.1	0.3

Proposed Conditions Model

Edit Contraction/Expansion Coefficients

	River Stati	Contractior	Expansion
1	195.75	0.1	0.3
2	195.66	0.1	0.3
3	195.56	0.1	0.3
4	195.47	0.1	0.3
5	195.38	0.1	0.3
6	195.28	0.1	0.3
7	195.19	0.1	0.3
8	195.16	0.1	0.3
9	195.15	Bridge	
10	195.13	0.1	0.3
11	195.09	0.1	0.3
12	195	0.1	0.3
13	194.91	0.1	0.3
14	194.81	0.1	0.3
15	194.72	0.1	0.3
16	194.62	0.1	0.3
17	194.53	0.1	0.3
18	194.4	0.1	0.3
19	194.29	0.1	0.3
20	194.21	0.1	0.3
21	194.205	Bridge	
22	194.2	0.1	0.3
23	194.1	0.1	0.3
24	194.02	0.1	0.3
25	193.94	0.1	0.3
26	193.87	0.1	0.3
27	193.79	0.1	0.3
28	193.73	0.1	0.3
29	193.62	0.1	0.3
30	193.53	0.1	0.3
31	193.43	0.1	0.3
32	193.34	0.1	0.3
33	193.25	0.1	0.3
34	193.16	0.1	0.3
35	193.07	0.1	0.3
36	192.98	0.1	0.3
37	192.89	0.1	0.3
38	192.79	0.1	0.3
39	192.7	0.1	0.3
40	192.61	0.1	0.3
41	192.52	0.1	0.3
42	192.41	0.1	0.3
43	192.39	Bridge	
44	192.38	0.1	0.3
45	192.33	0.1	0.3
46	192.23	0.1	0.3
47	192.14	0.1	0.3
48	192.04	0.1	0.3
49	191.95	0.1	0.3
50	191.86	0.1	0.3
51	191.76	0.1	0.3
52	191.67	0.1	0.3

51	191.57	0.1	0.3
52	191.48	0.1	0.3
53	191.38	0.1	0.3
54	191.29	0.1	0.3
55	191.19	0.1	0.3
56	191.1	0.1	0.3
57	191	0.1	0.3
58	190.91	0.1	0.3
59	190.81	0.1	0.3
60	190.72	0.1	0.3
61	190.62	0.1	0.3
62	190.53	0.1	0.3
63	190.43	0.1	0.3
64	190.34	0.1	0.3
65	190.24	0.1	0.3
66	190.15	0.1	0.3
67	190.05	0.1	0.3
68	189.96	0.1	0.3
69	189.87	0.1	0.3
70	189.77	0.1	0.3
71	189.67	0.1	0.3
72	189.58	0.1	0.3
73	189.48	0.1	0.3
74	189.39	0.1	0.3
75	189.3	0.1	0.3
76	189.21	0.1	0.3
77	189.11	0.1	0.3
78	189.02	0.1	0.3
79	188.81	0.1	0.3
80	188.69	0.1	0.3
81	188.59	0.1	0.3
82	188.5	0.1	0.3
83	188.39	0.1	0.3
84	188.29	0.1	0.3
85	188.2	0.1	0.3
86	188.1	0.1	0.3
87	188.07	0.1	0.3
88	188.055 Bridge		
89	188.04	0.1	0.3
90	188	0.1	0.3
91	187.91	0.1	0.3
92	187.82	0.1	0.3
93	187.73	0.1	0.3
94	187.64	0.1	0.3
95	187.54	0.1	0.3
96	187.45	0.1	0.3
97	187.36	0.1	0.3
98	187.24	0.1	0.3
99	187.15	0.1	0.3
100	187.06	0.1	0.3
101	186.97	0.1	0.3
102	186.87	0.1	0.3

53	191.57	0.1	0.3
54	191.48	0.1	0.3
55	191.38	0.1	0.3
56	191.29	0.1	0.3
57	191.19	0.1	0.3
58	191.1	0.1	0.3
59	191	0.1	0.3
60	190.91	0.1	0.3
61	190.81	0.1	0.3
62	190.72	0.1	0.3
63	190.62	0.1	0.3
64	190.53	0.1	0.3
65	190.43	0.1	0.3
66	190.34	0.1	0.3
67	190.24	0.1	0.3
68	190.15	0.1	0.3
69	190.05	0.1	0.3
70	189.96	0.1	0.3
71	189.87	0.1	0.3
72	189.77	0.1	0.3
73	189.67	0.1	0.3
74	189.58	0.1	0.3
75	189.48	0.1	0.3
76	189.39	0.1	0.3
77	189.3	0.1	0.3
78	189.21	0.1	0.3
79	189.11	0.1	0.3
80	189.02	0.1	0.3
81	188.81	0.1	0.3
82	188.69	0.1	0.3
83	188.59	0.1	0.3
84	188.5	0.1	0.3
85	188.39	0.1	0.3
86	188.29	0.1	0.3
87	188.2	0.1	0.3
88	188.1	0.1	0.3
89	188.07	0.1	0.3
90	188.055 Bridge		
91	188.04	0.1	0.3
92	188	0.1	0.3
93	187.91	0.1	0.3
94	187.82	0.1	0.3
95	187.73	0.1	0.3
96	187.64	0.1	0.3
97	187.54	0.1	0.3
98	187.45	0.1	0.3
99	187.36	0.1	0.3
100	187.24	0.1	0.3
101	187.15	0.1	0.3
102	187.06	0.1	0.3
103	186.97	0.1	0.3
104	186.87	0.1	0.3

E.4 Analysis of Structures

Structures were Analyzed Using Standard HEC-RAS Bridge Routines

E.5 Hydraulic Calculations

APPENDIX F

Sediment Transport HEC-6T Model Results

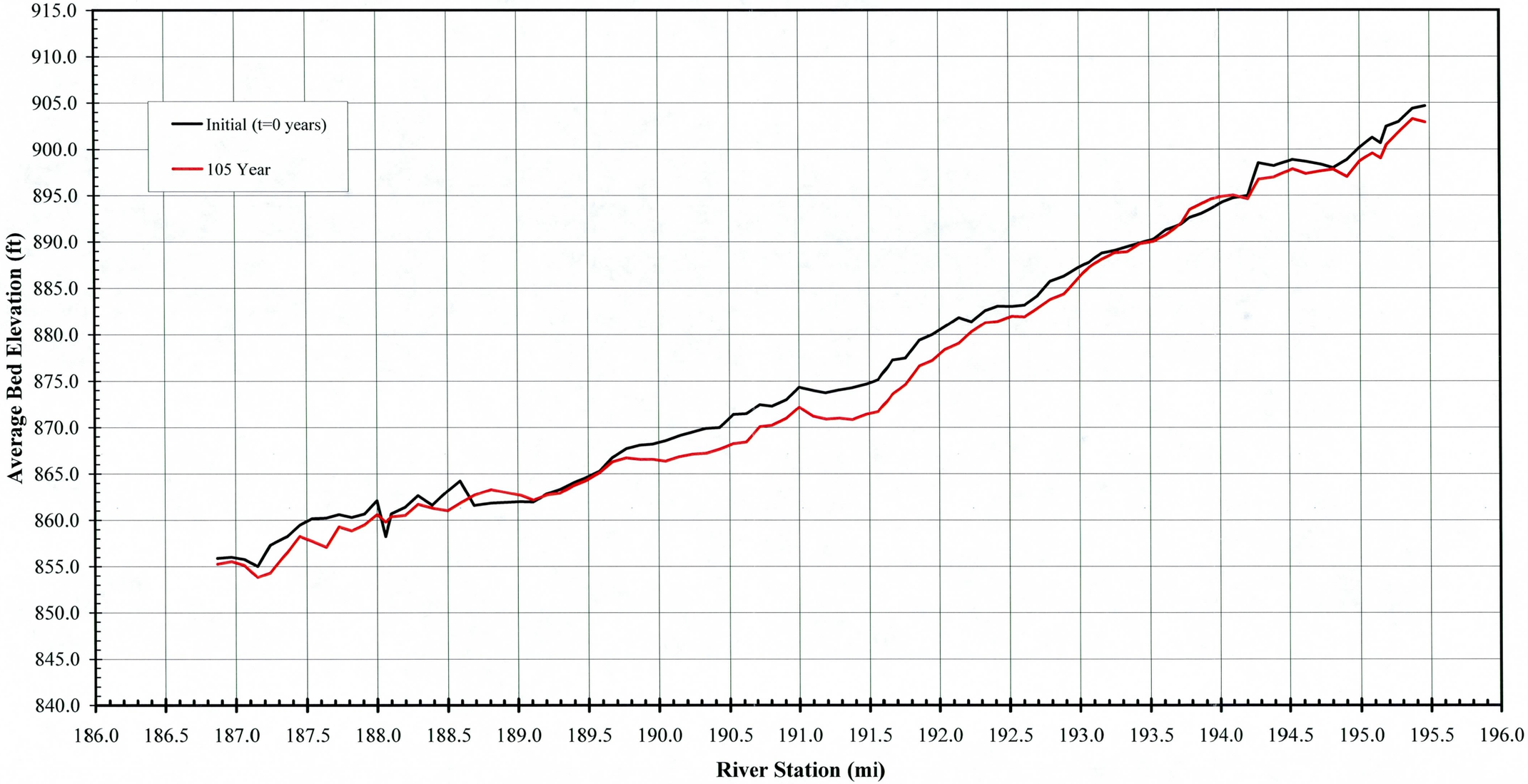
APPENDIX F

SECTION 1

Sediment Transport HEC-6T Model Results

EXISTING CONDITIONS

King Ranch
Average Bed Elevations for the 105-Year Simulation (1898-1993)
Existing Conditions with New Topography, Stantec Sediment Load, and WEST Gradation
Revised October 2005



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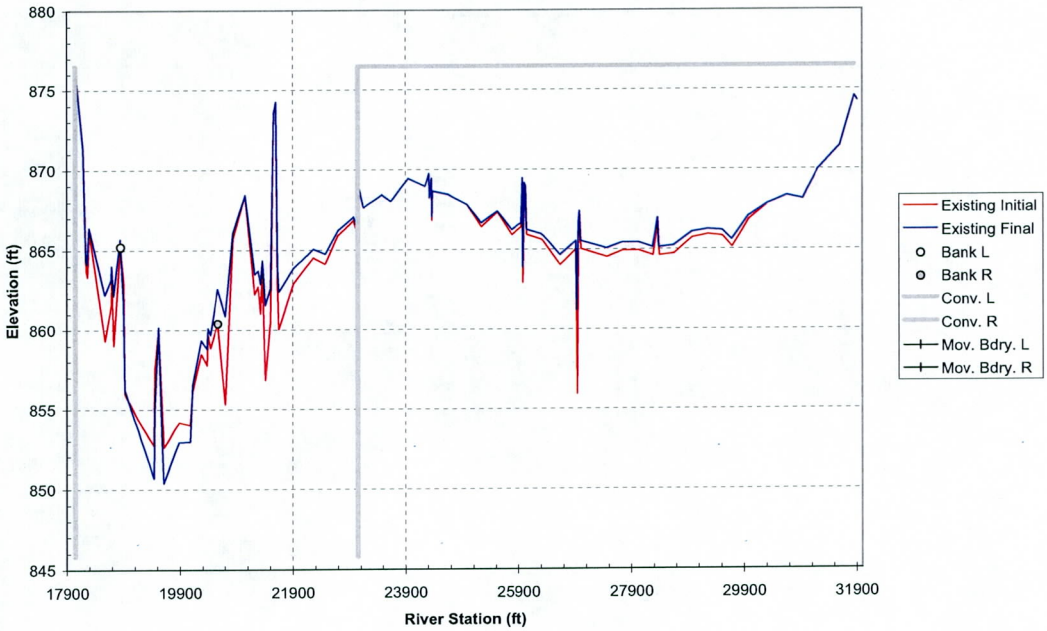

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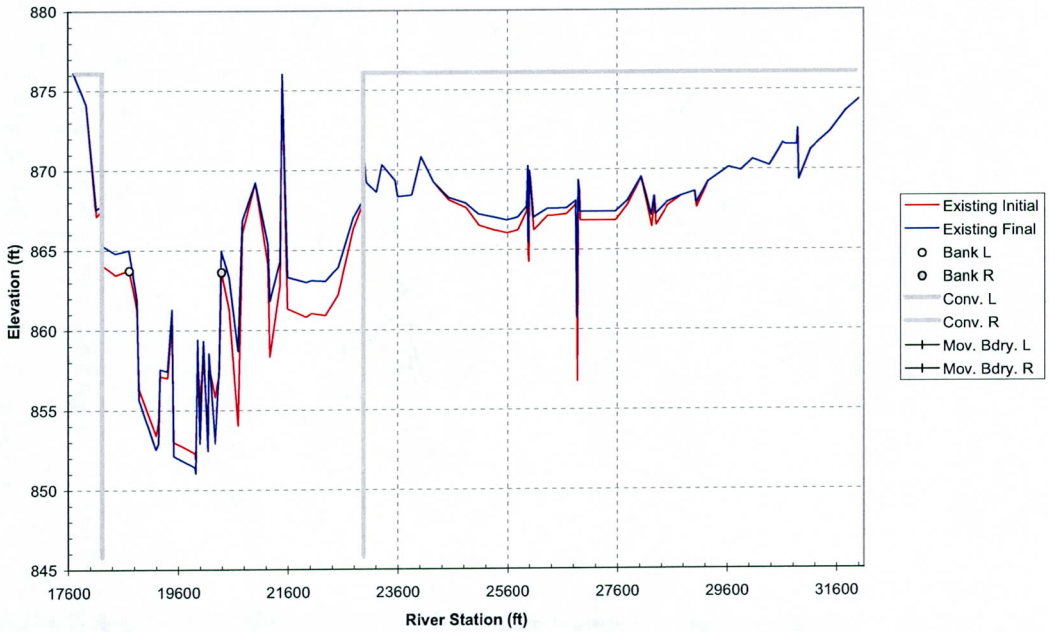

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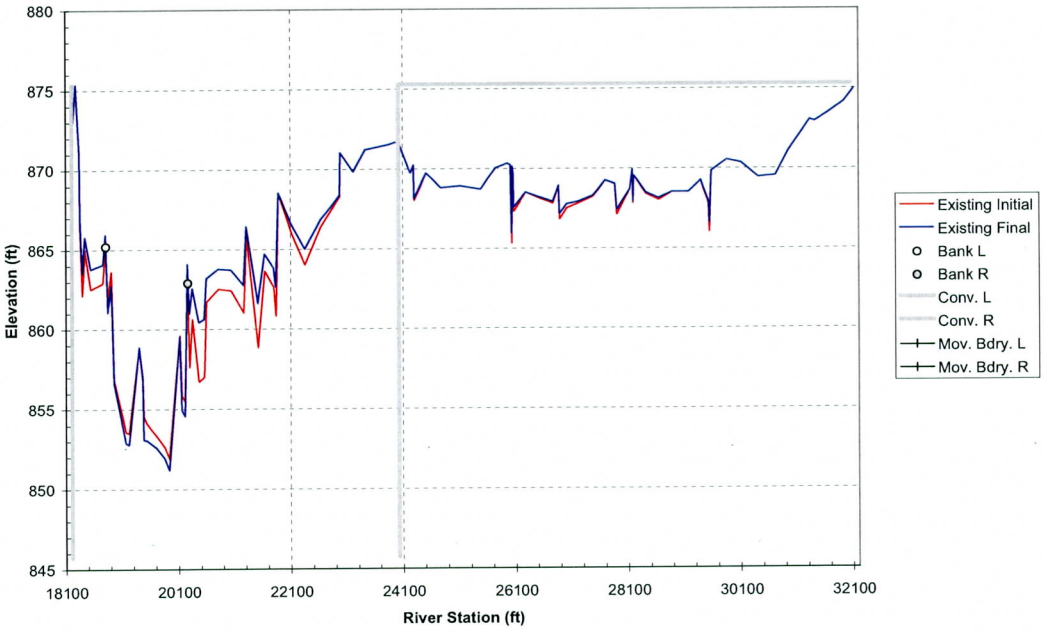

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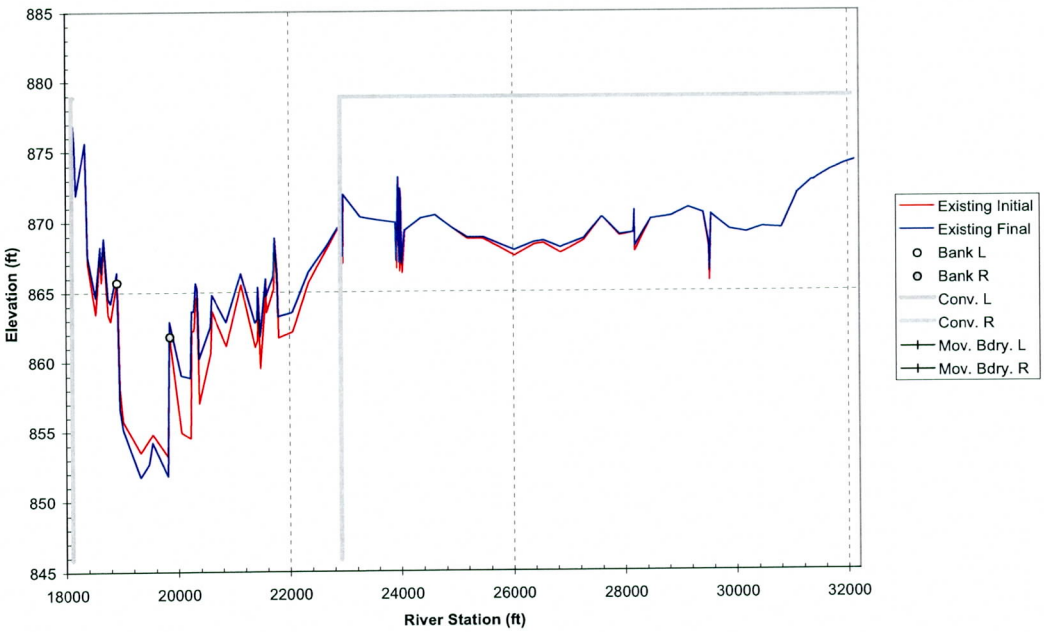

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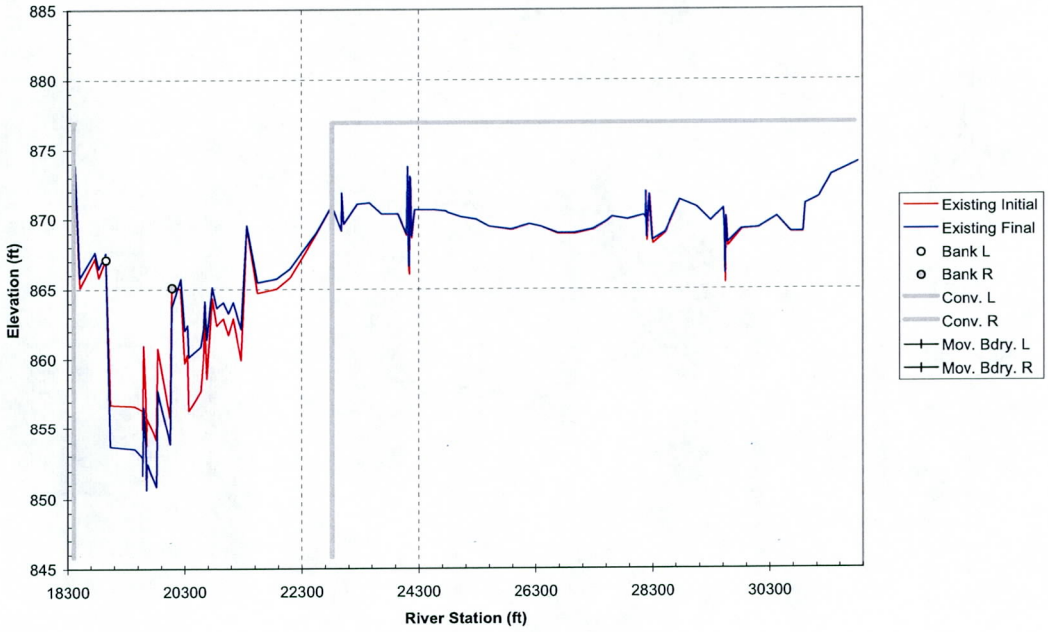

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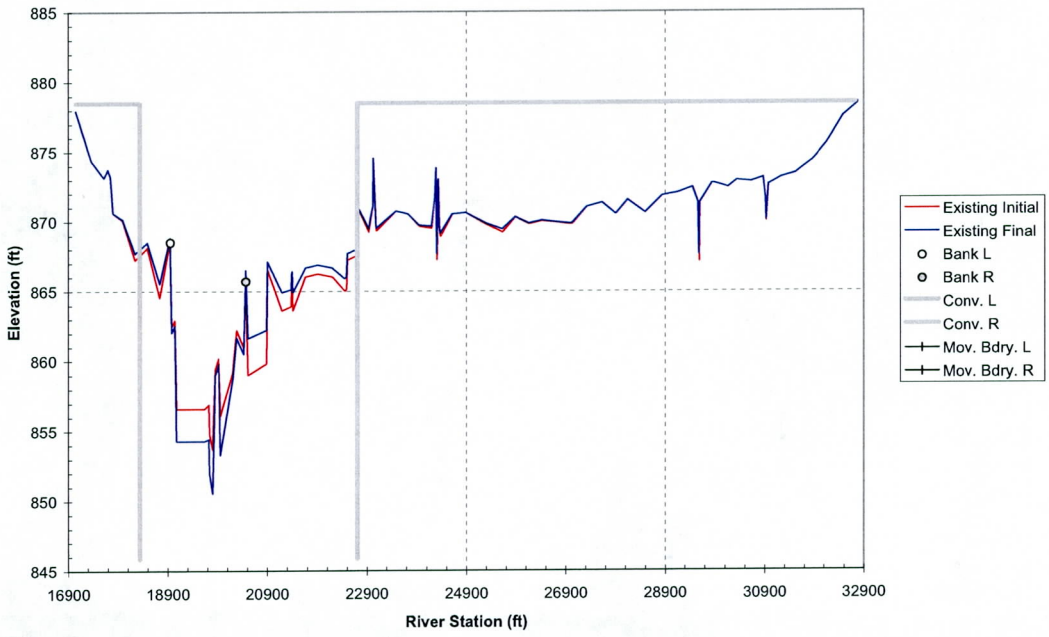

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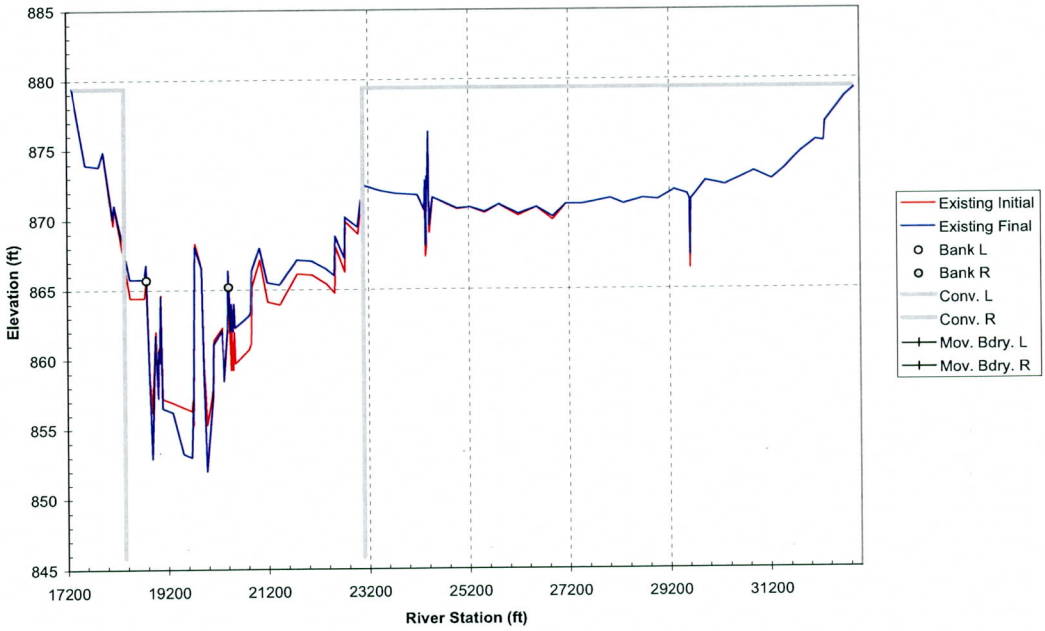

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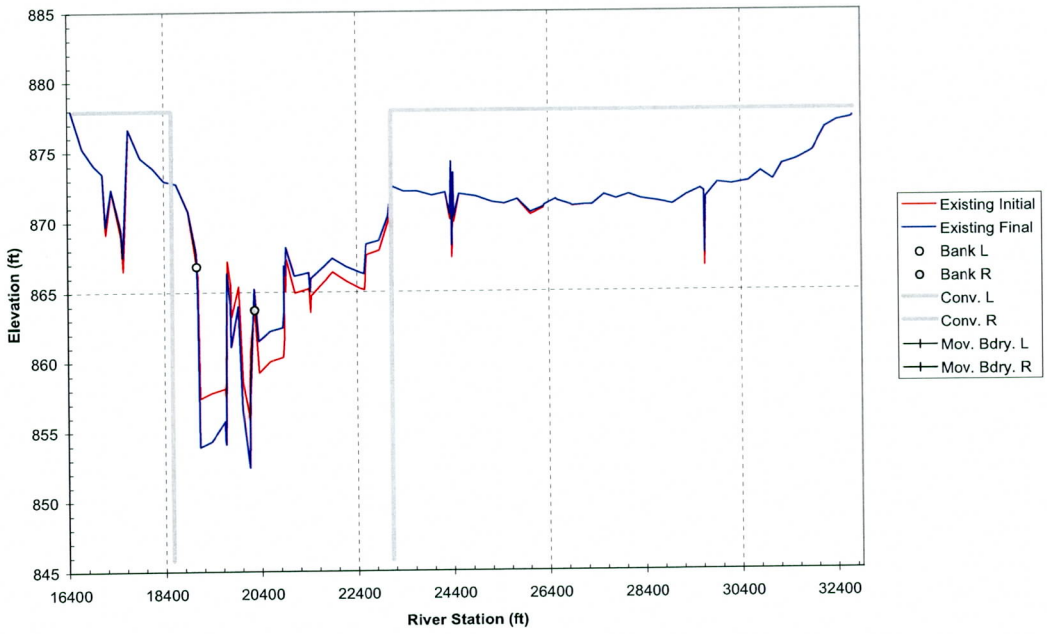

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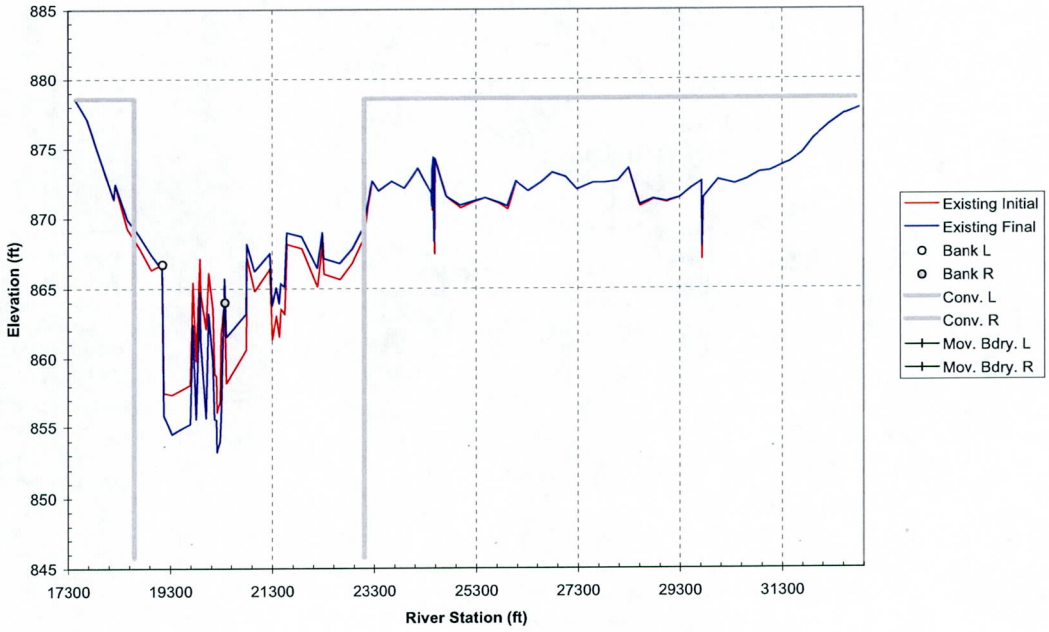

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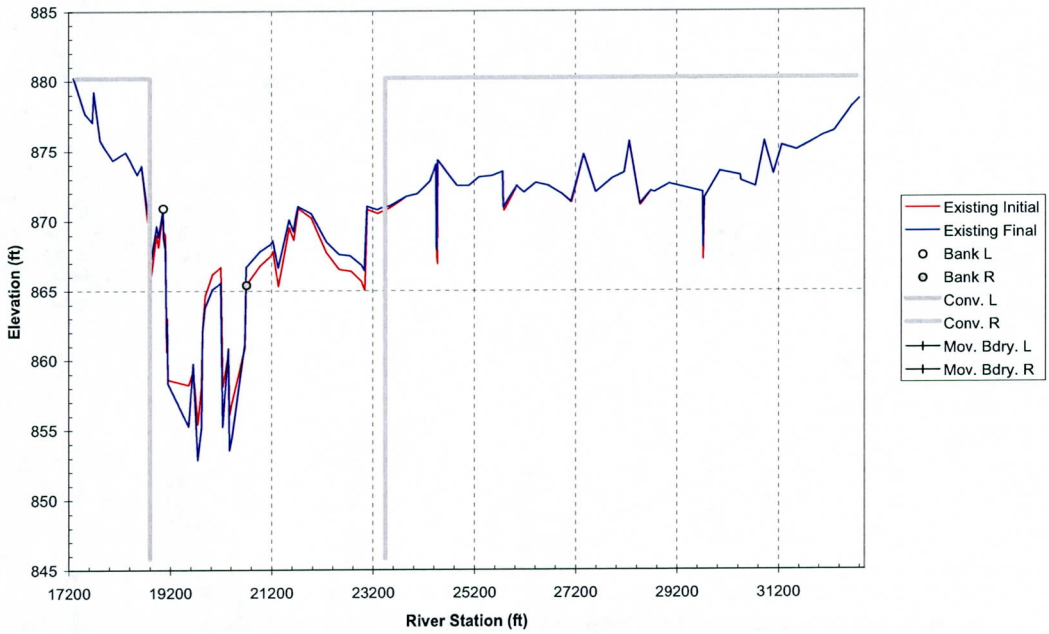

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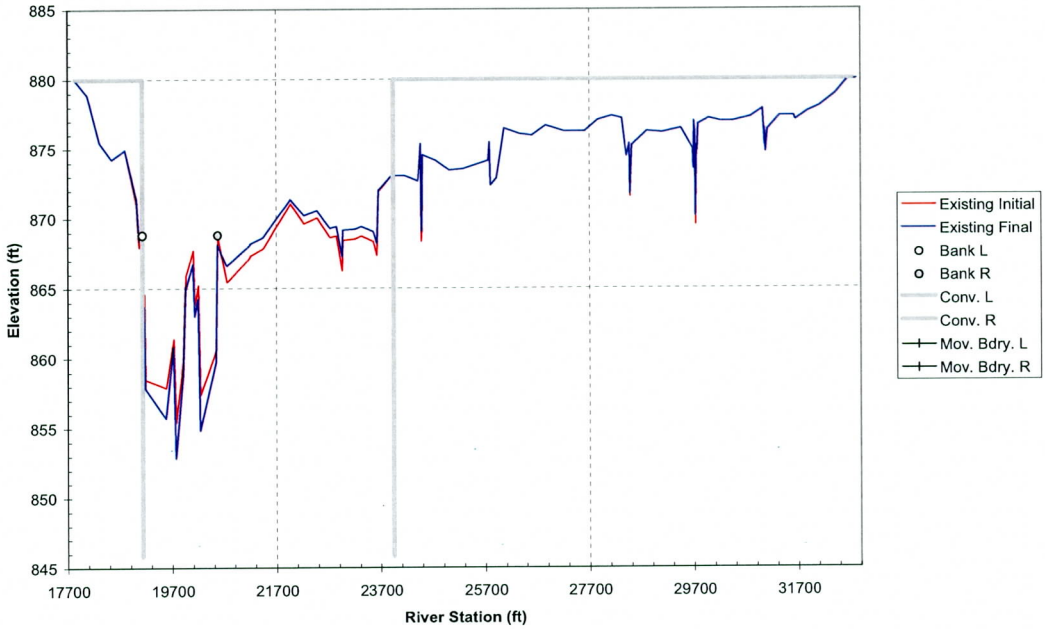

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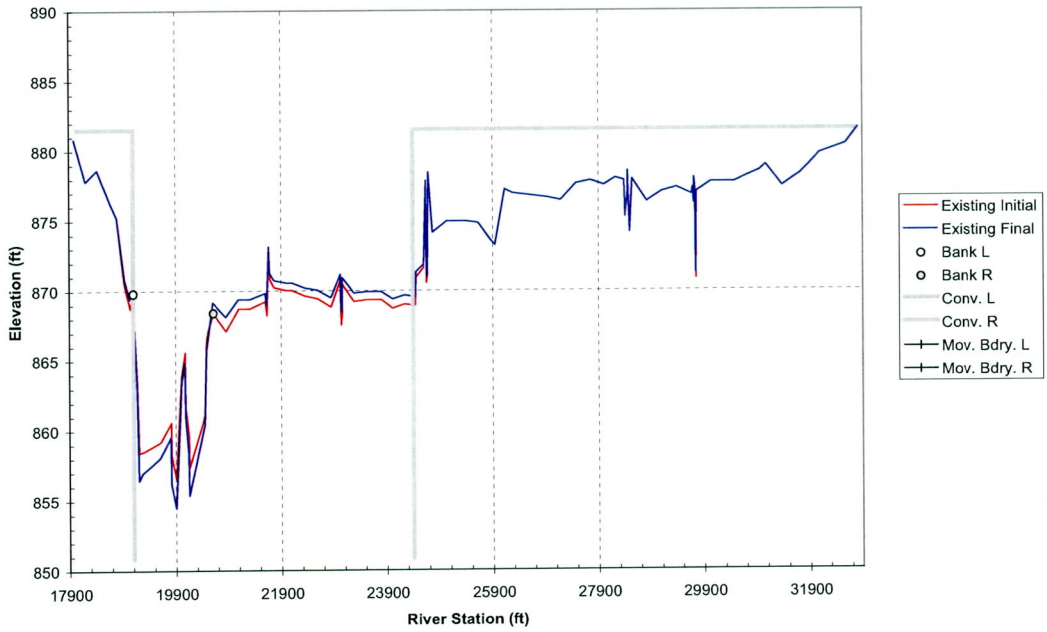

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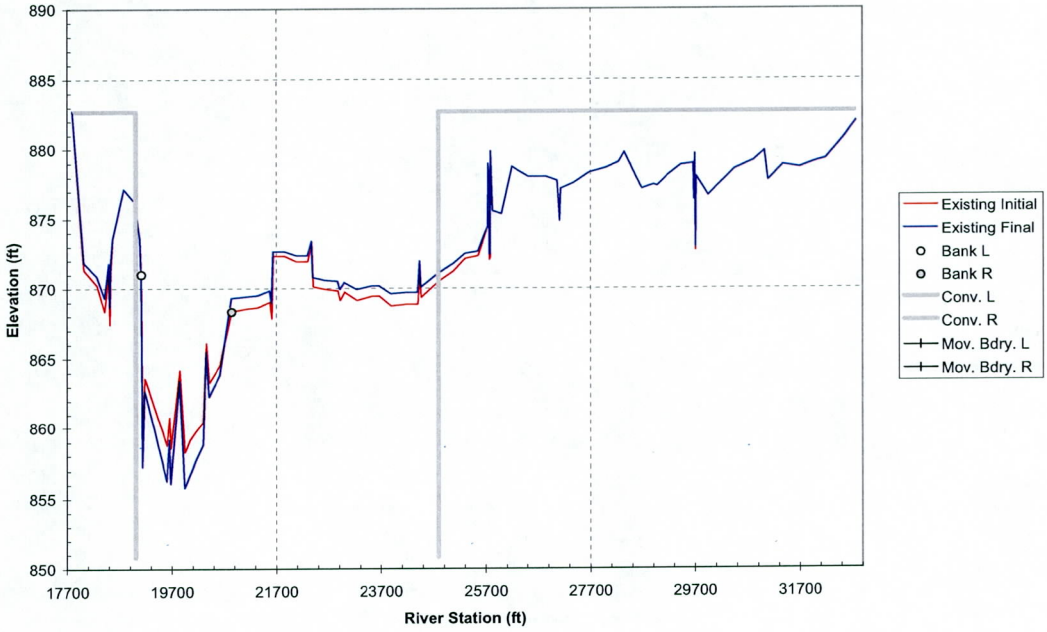

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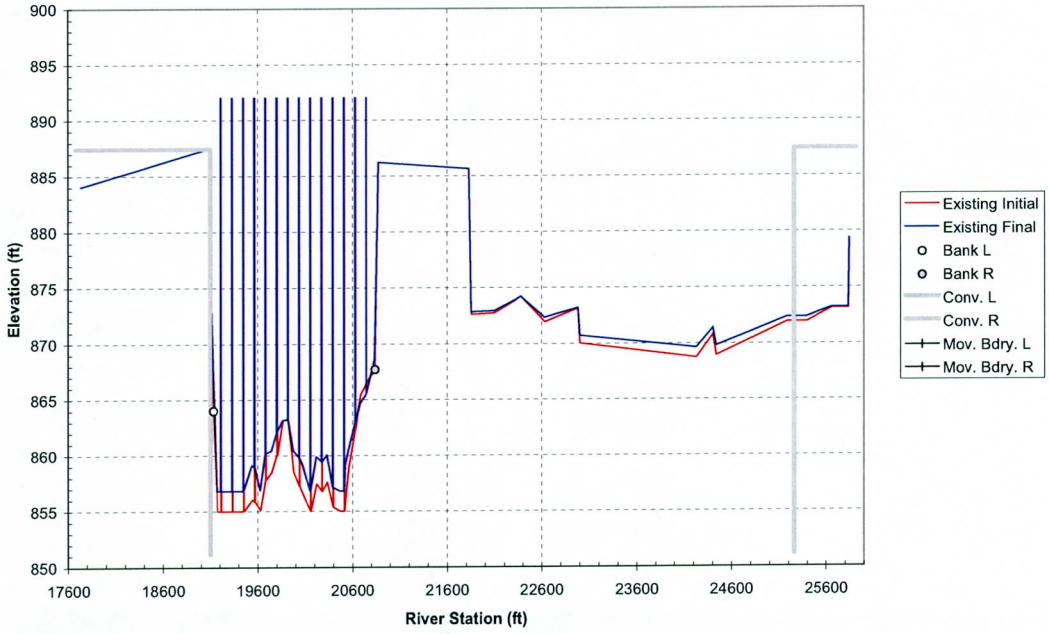

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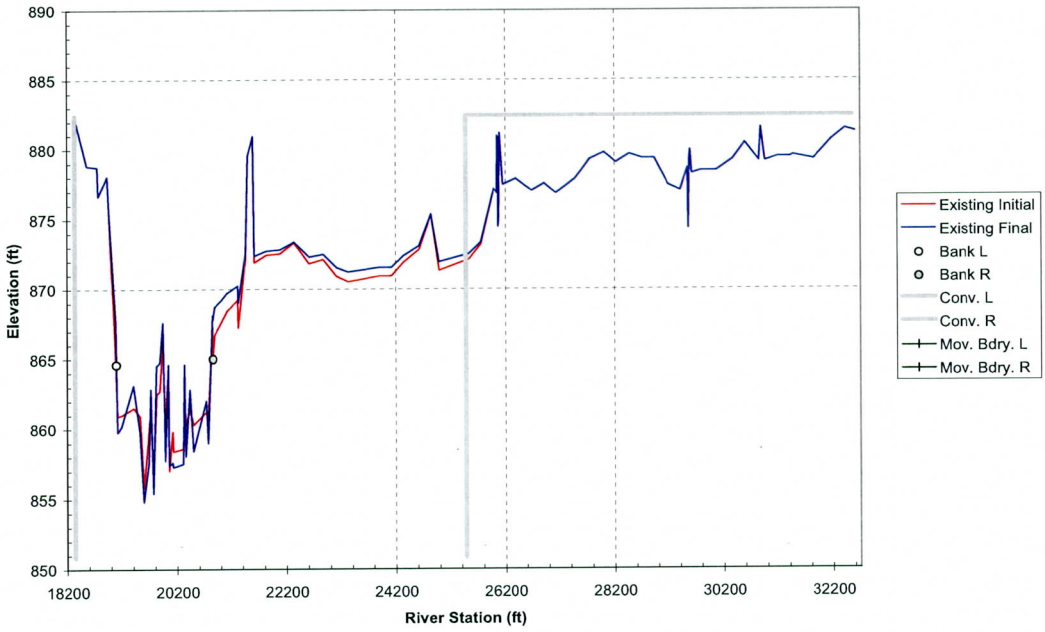

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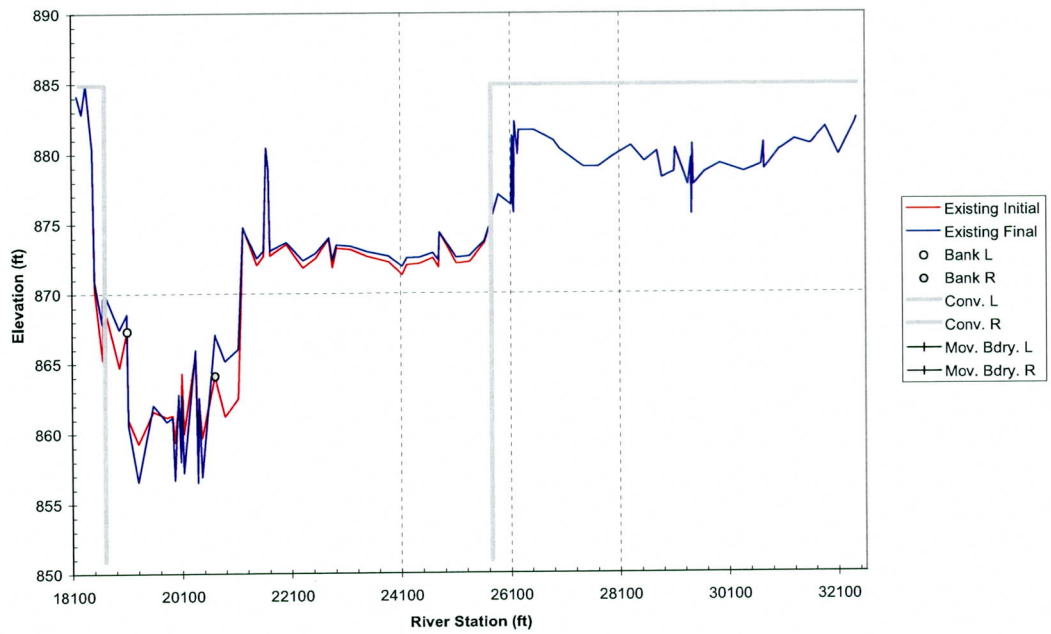

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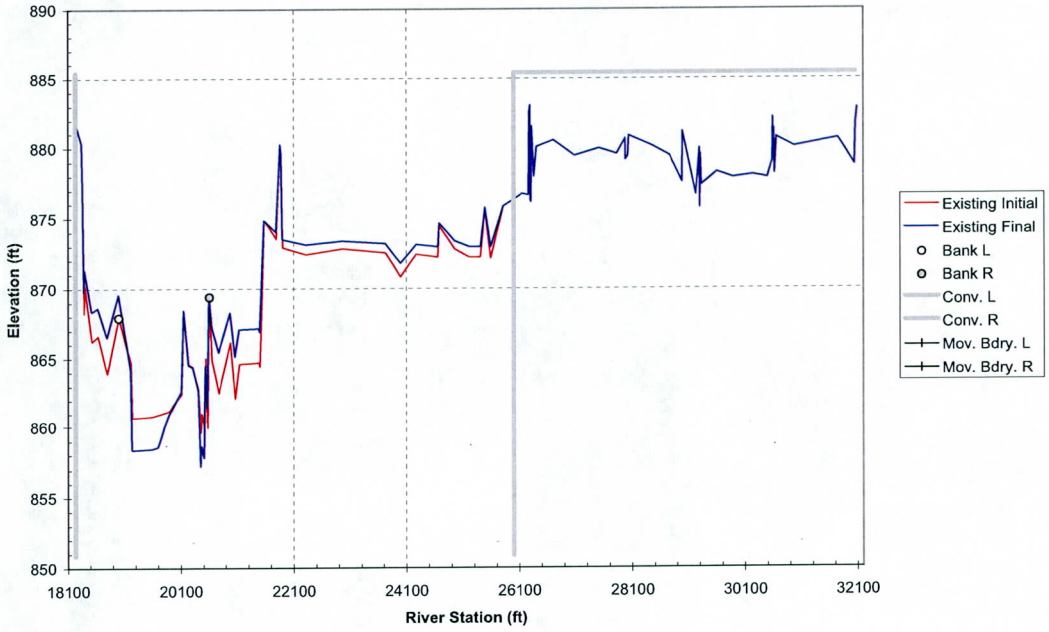

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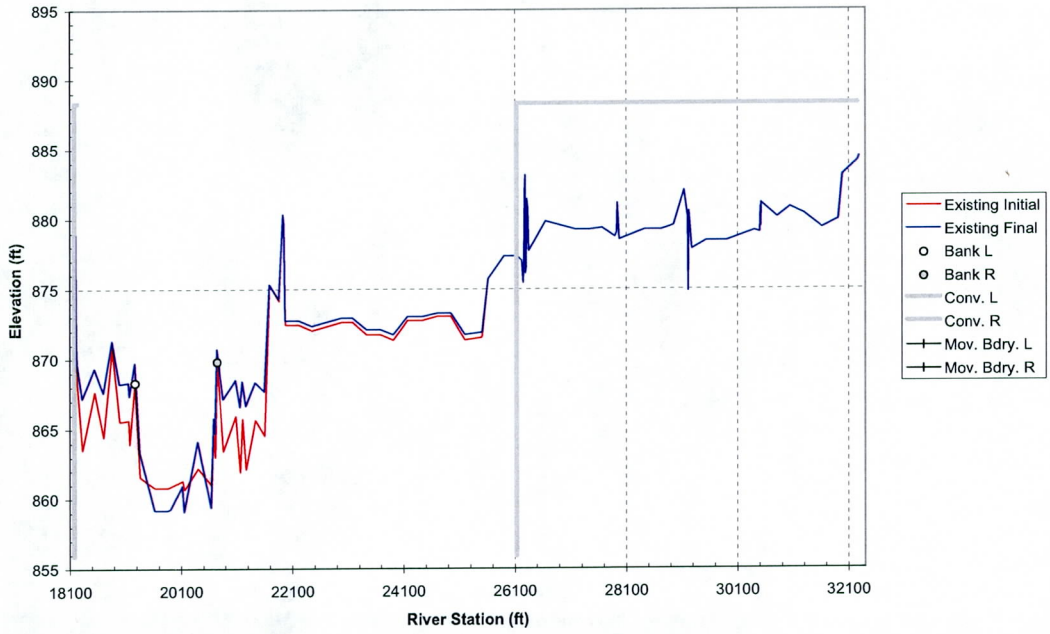

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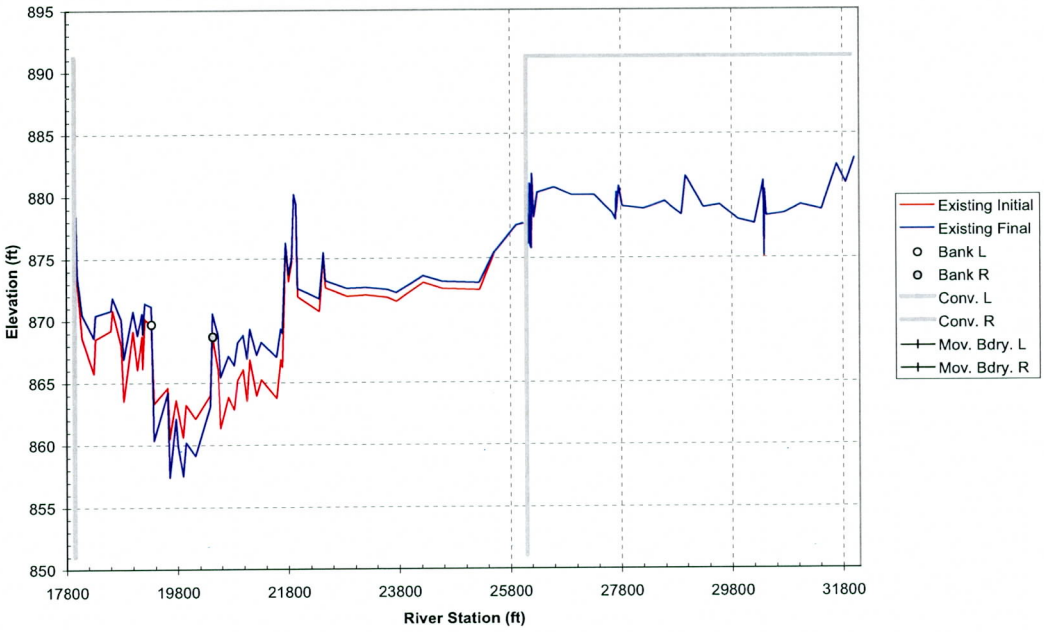

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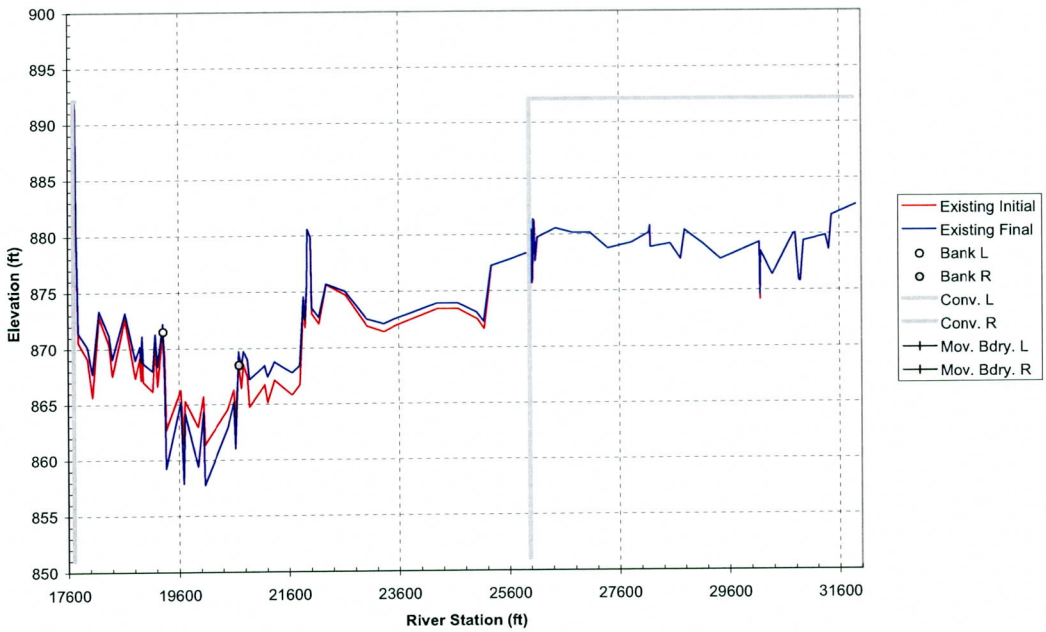

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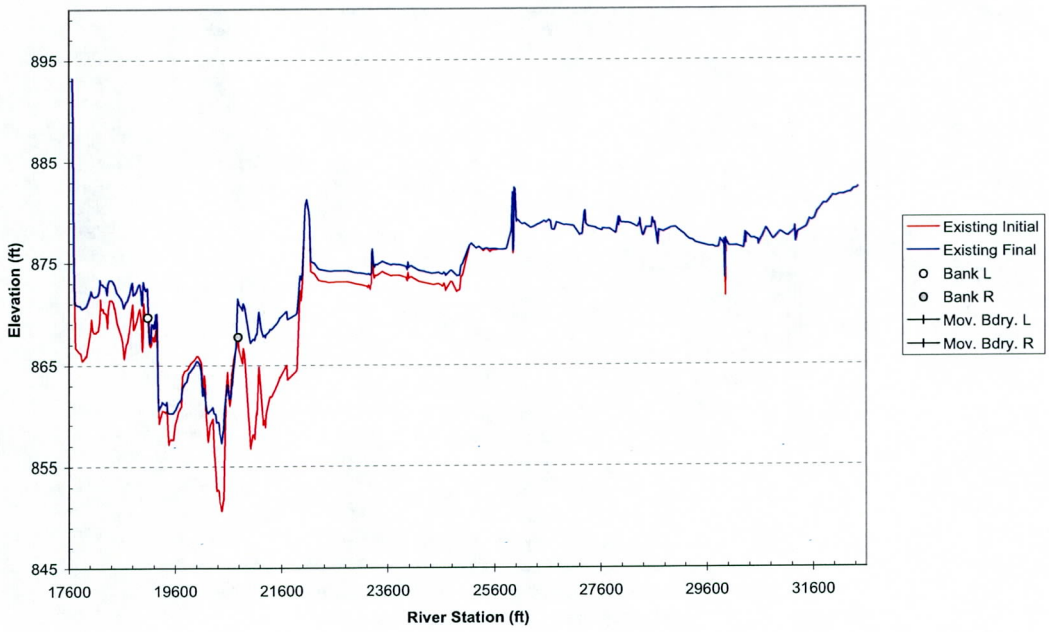

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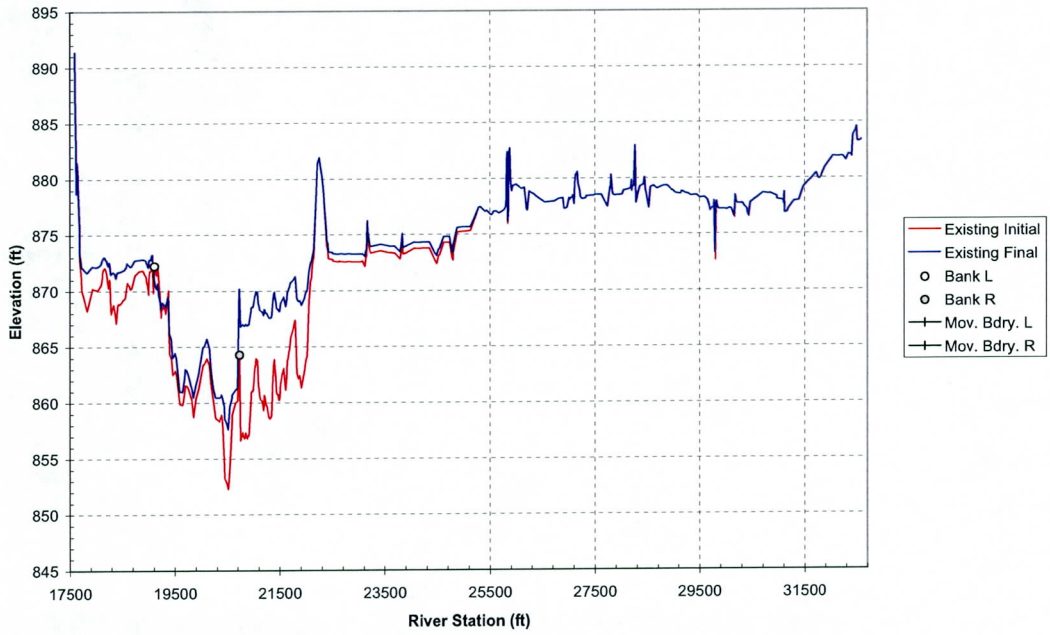

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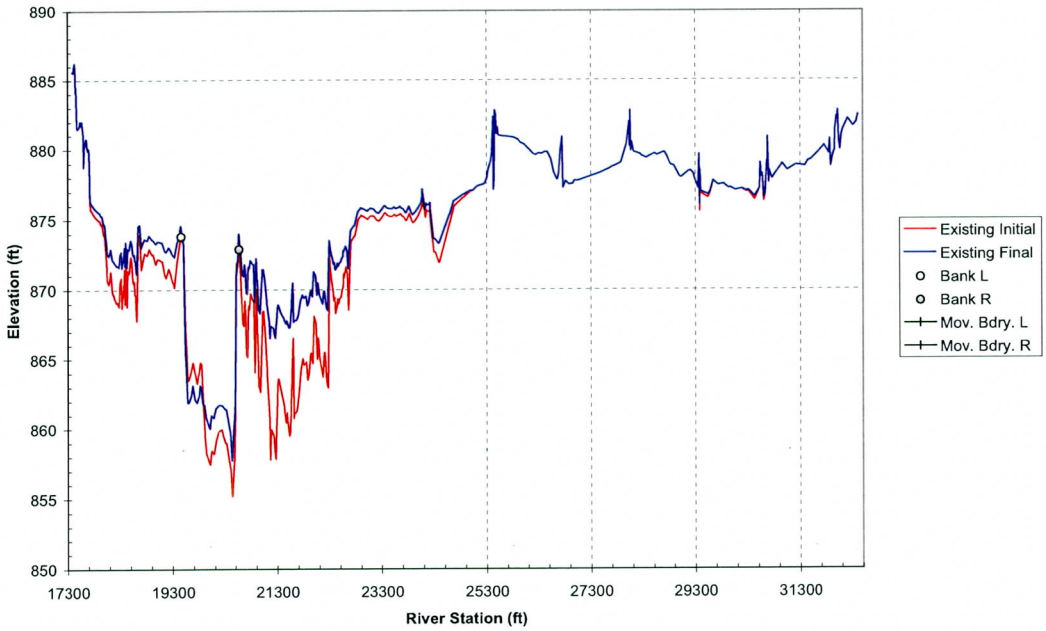

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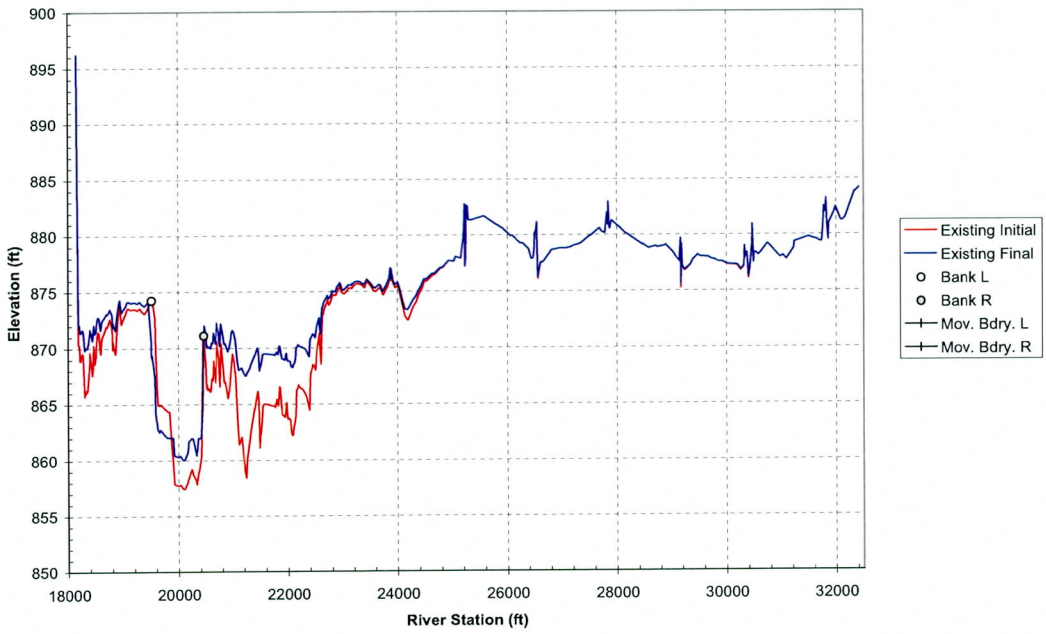

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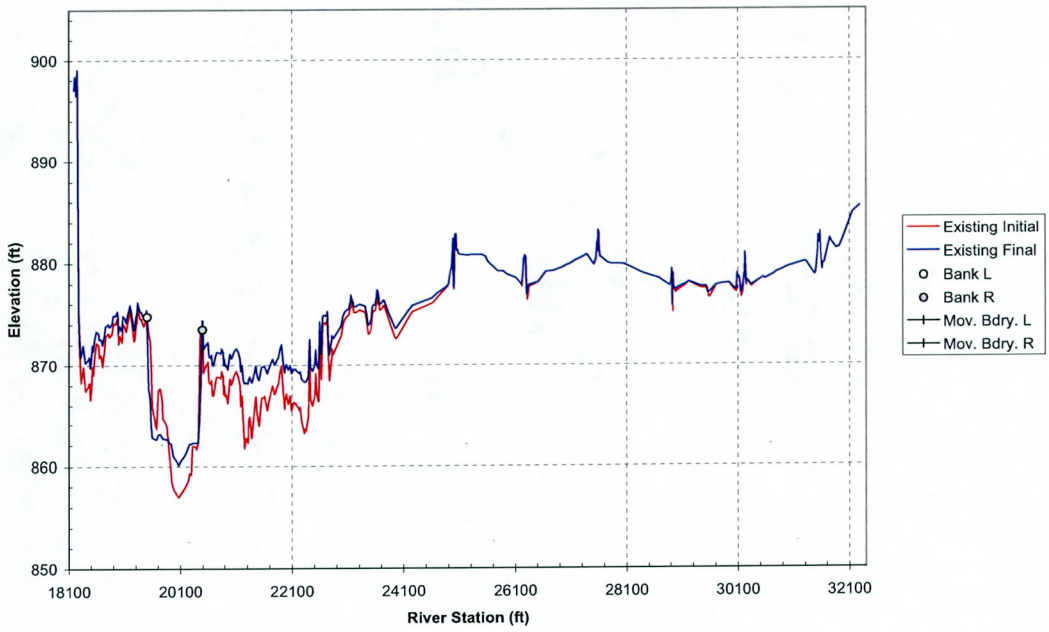

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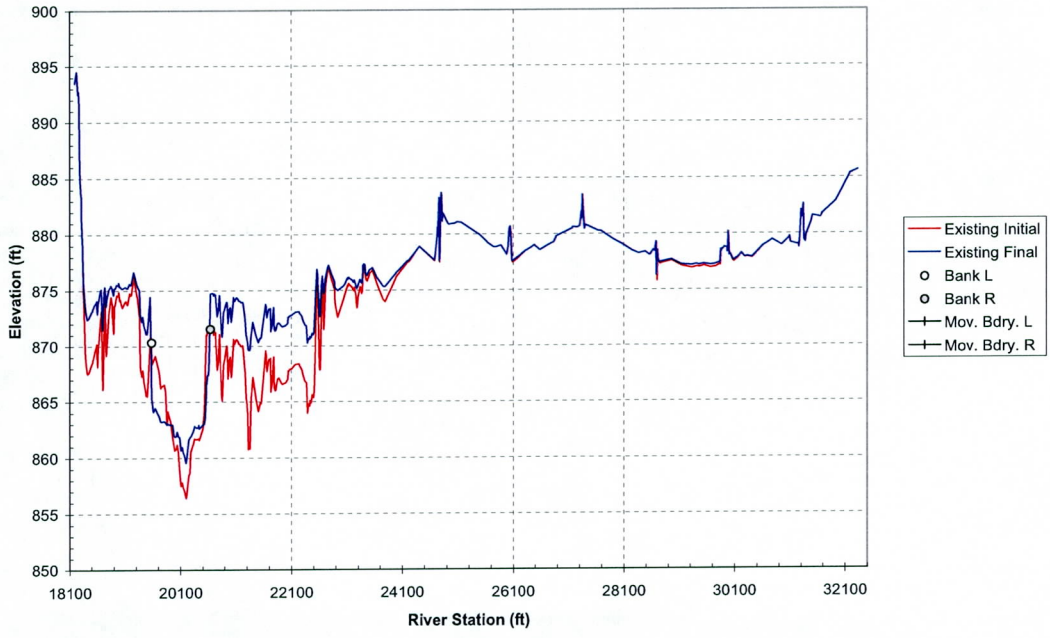

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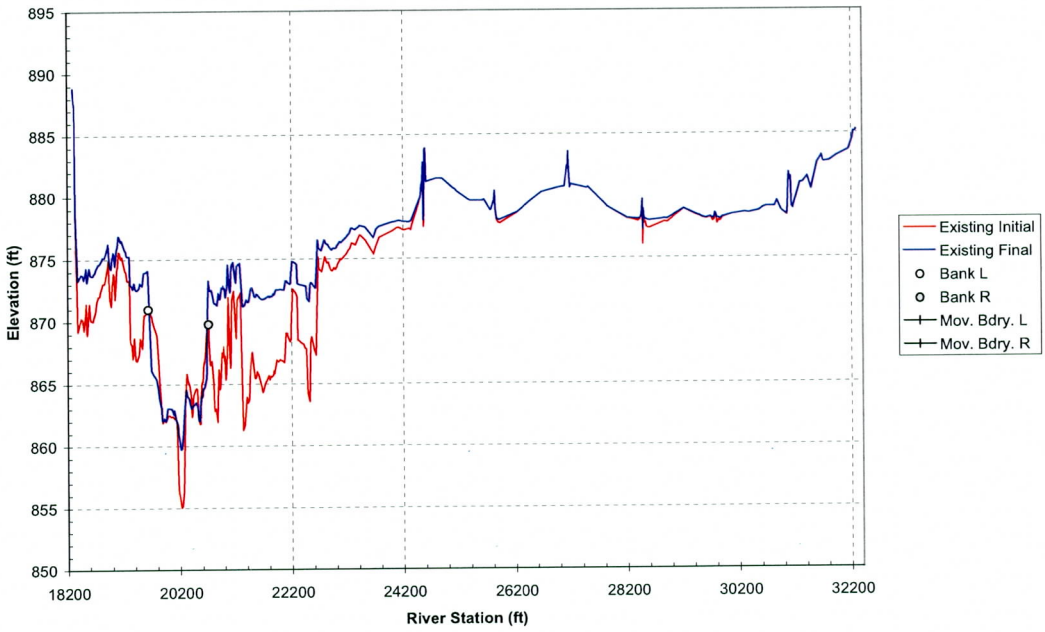

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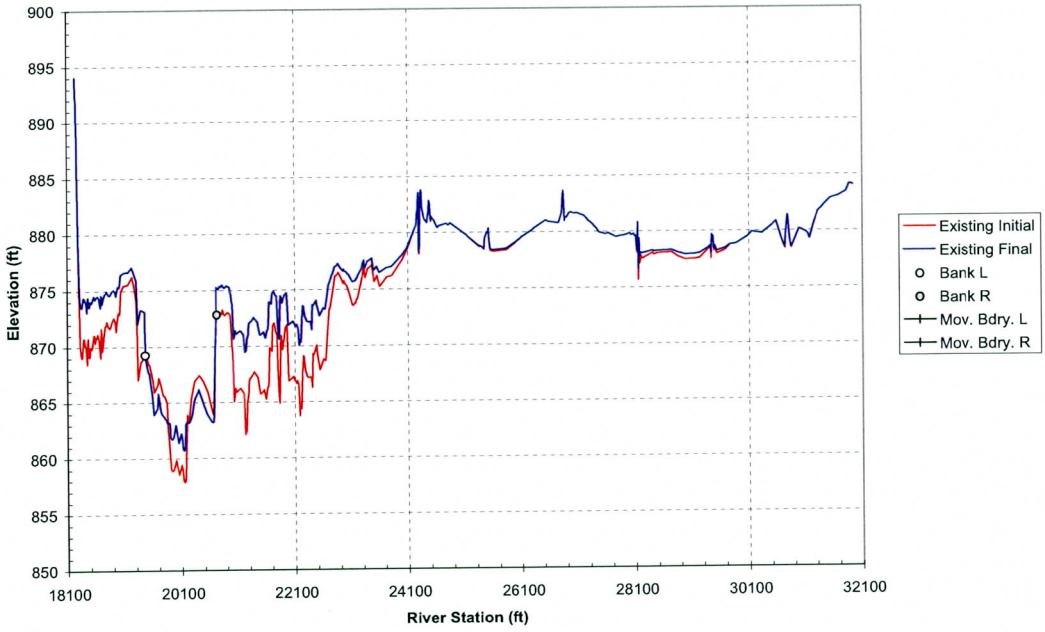

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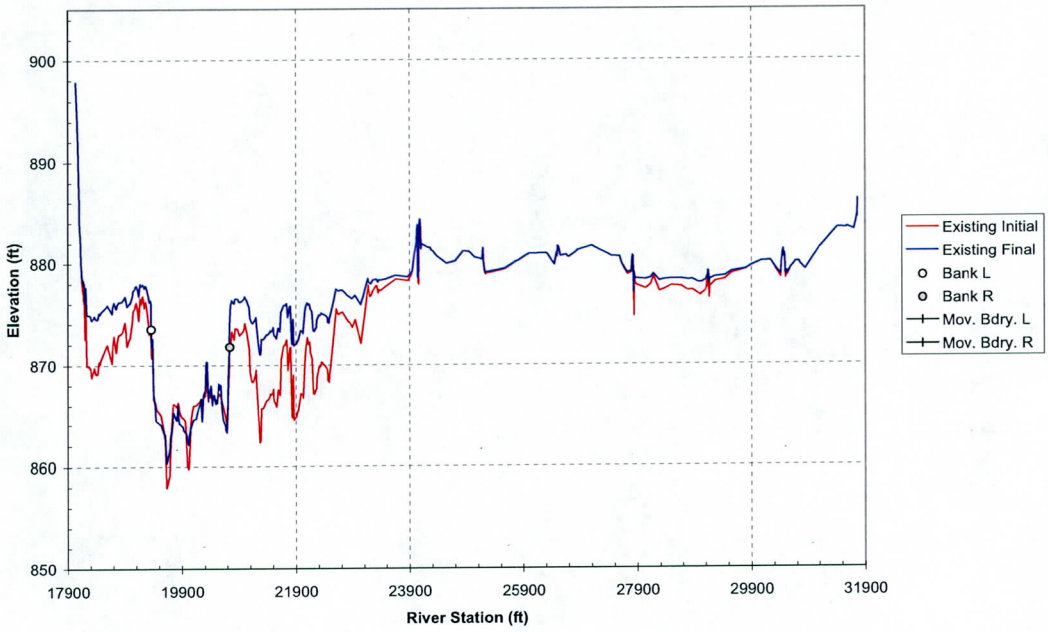

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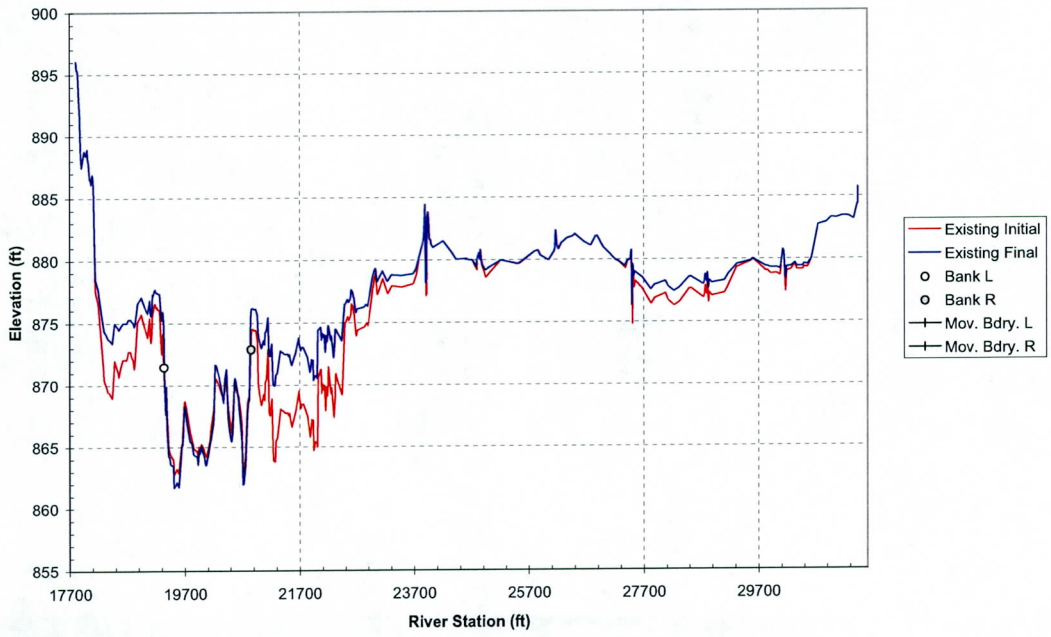

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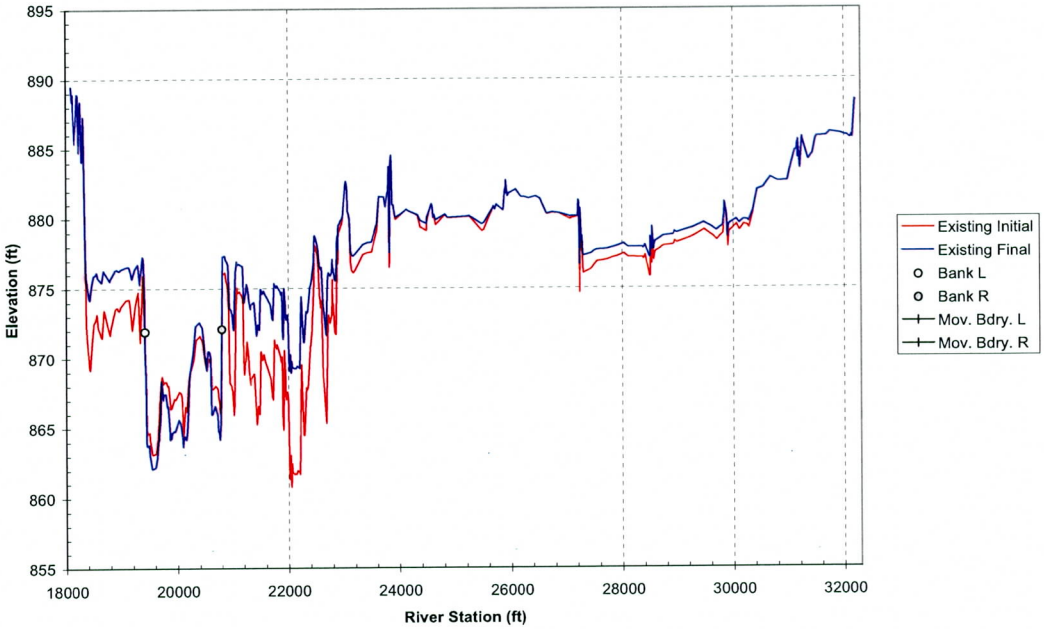

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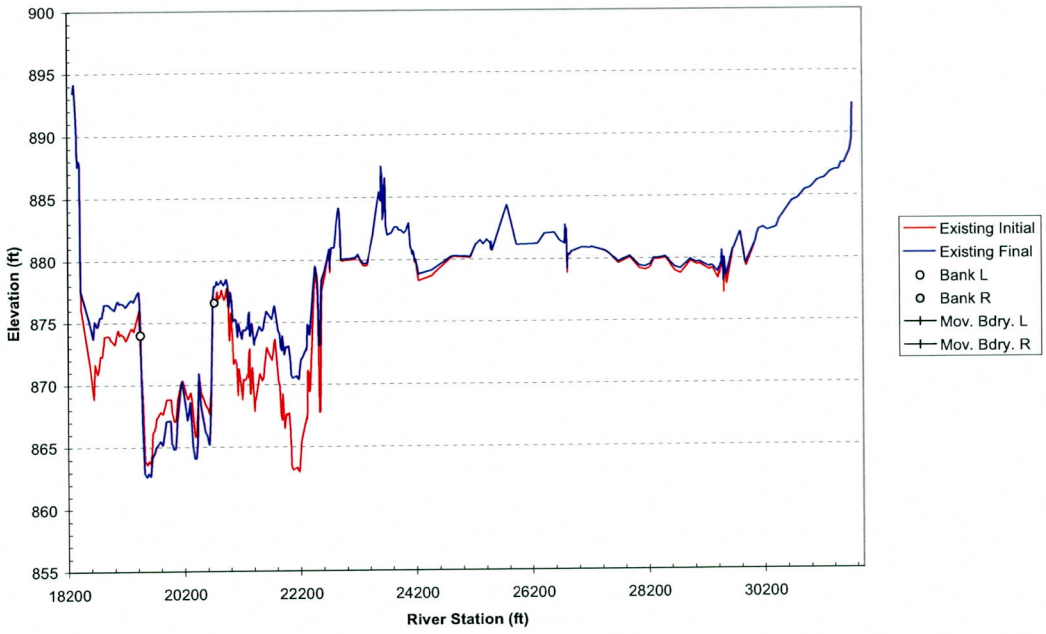

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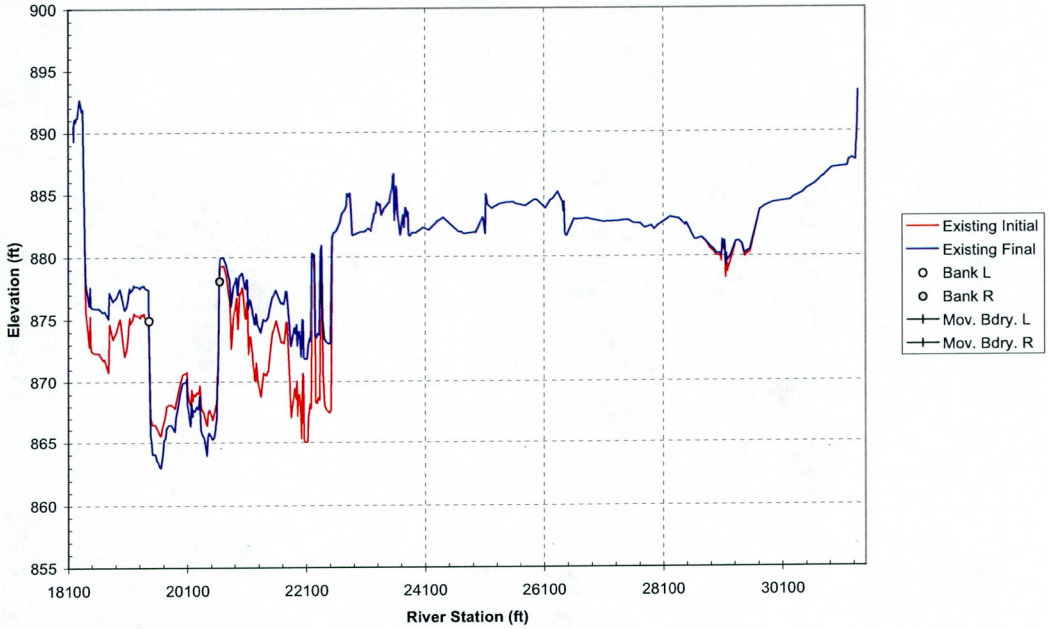

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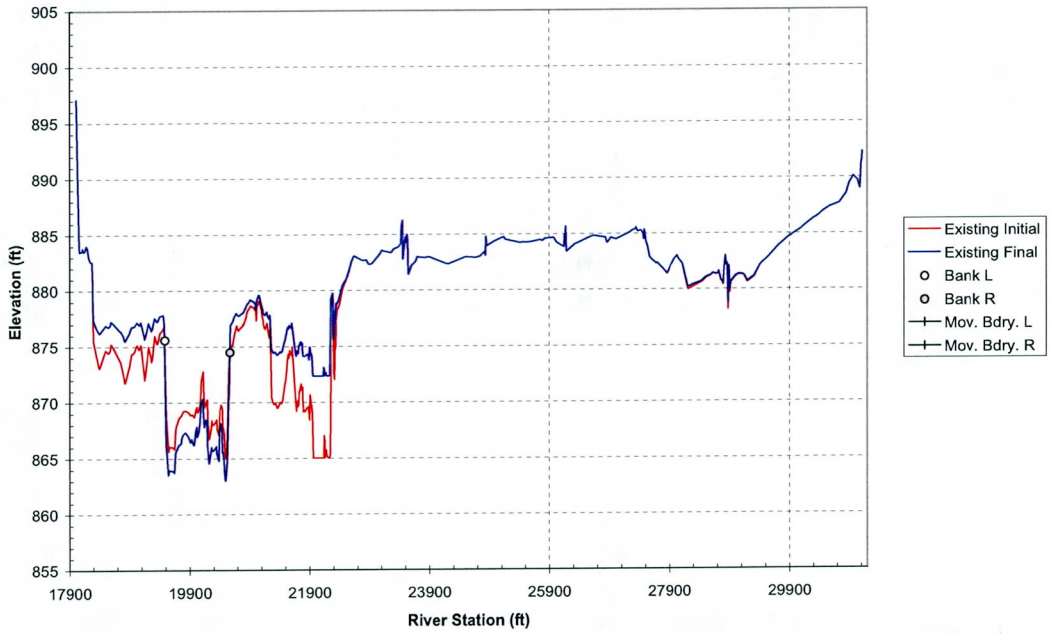

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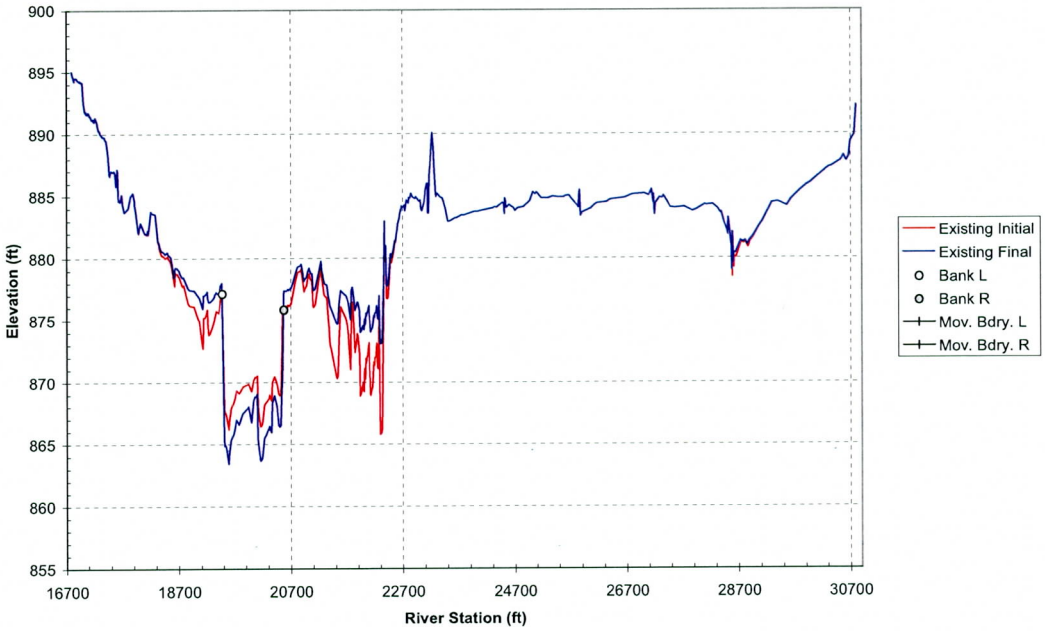

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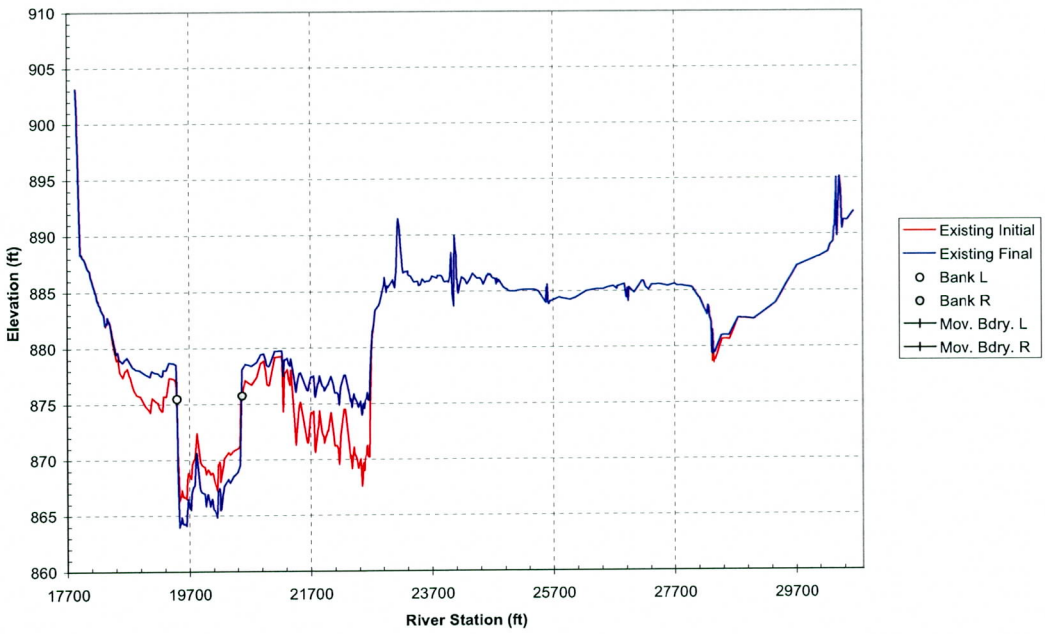

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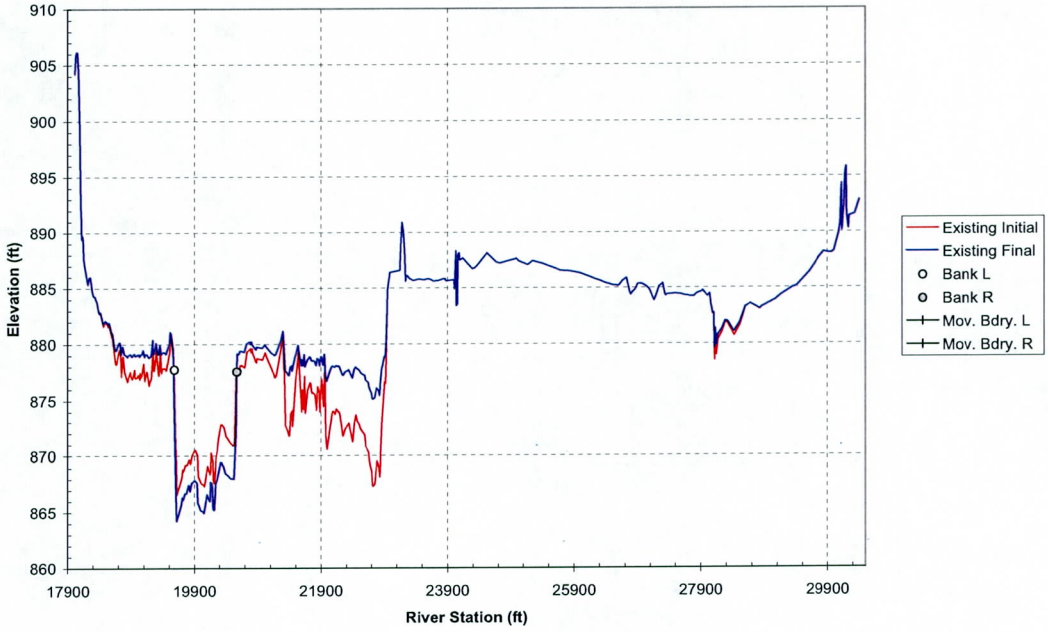

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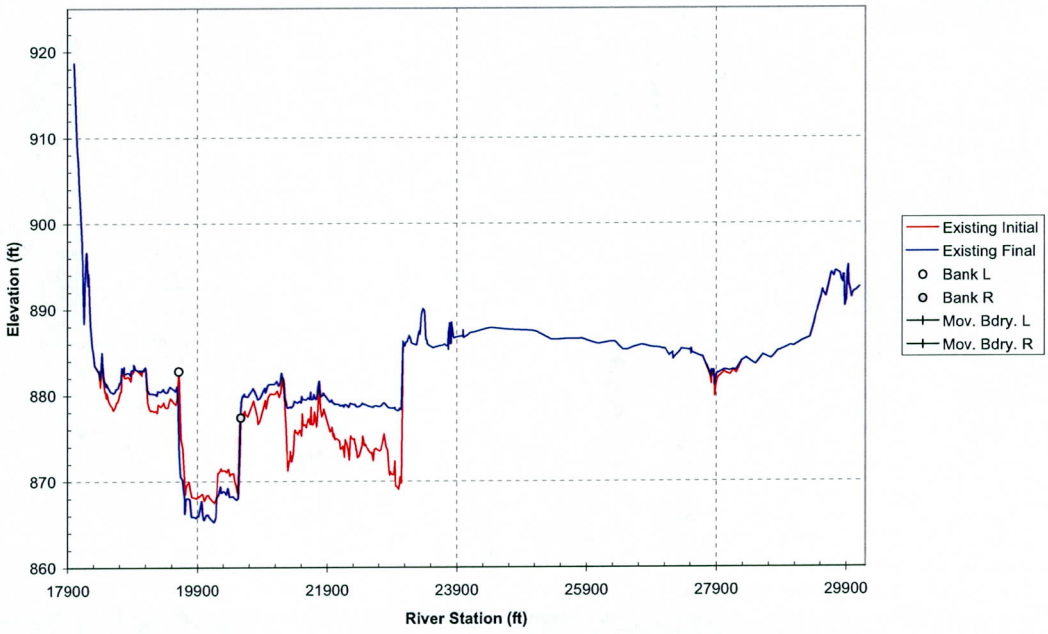

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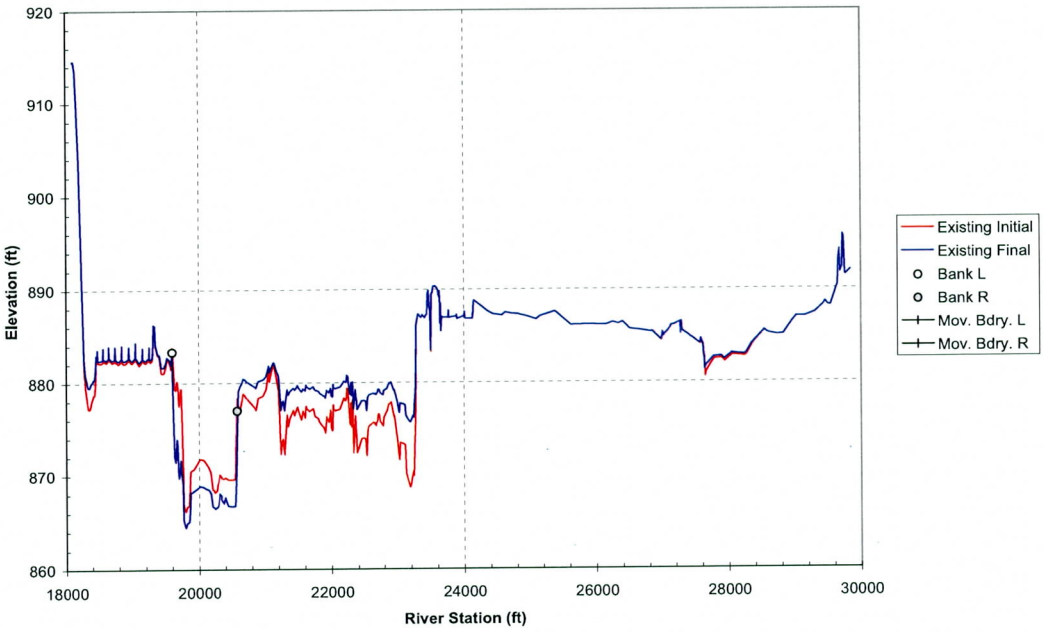

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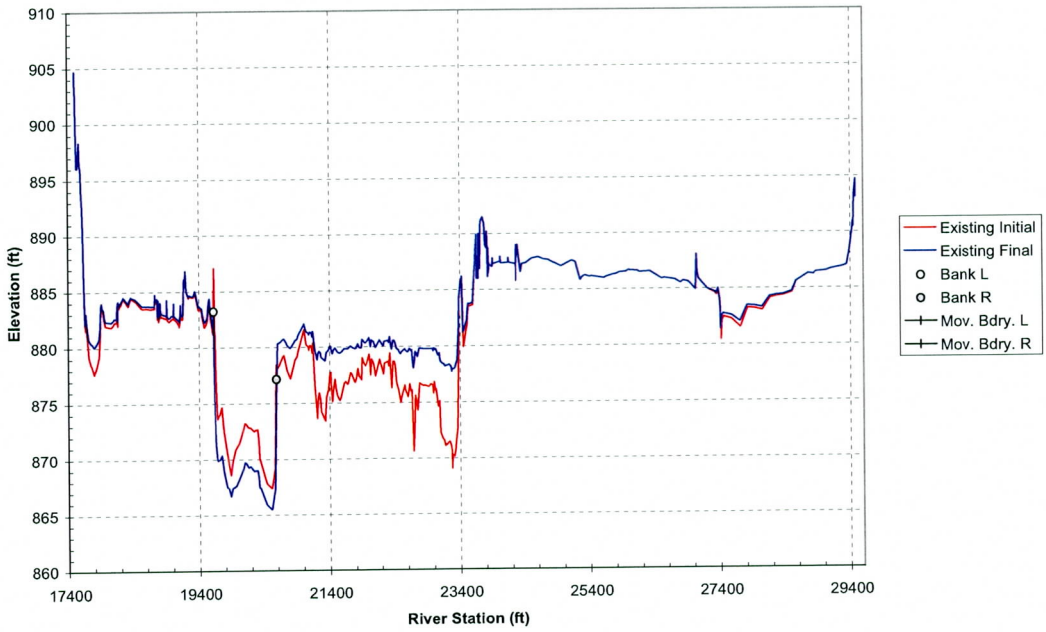

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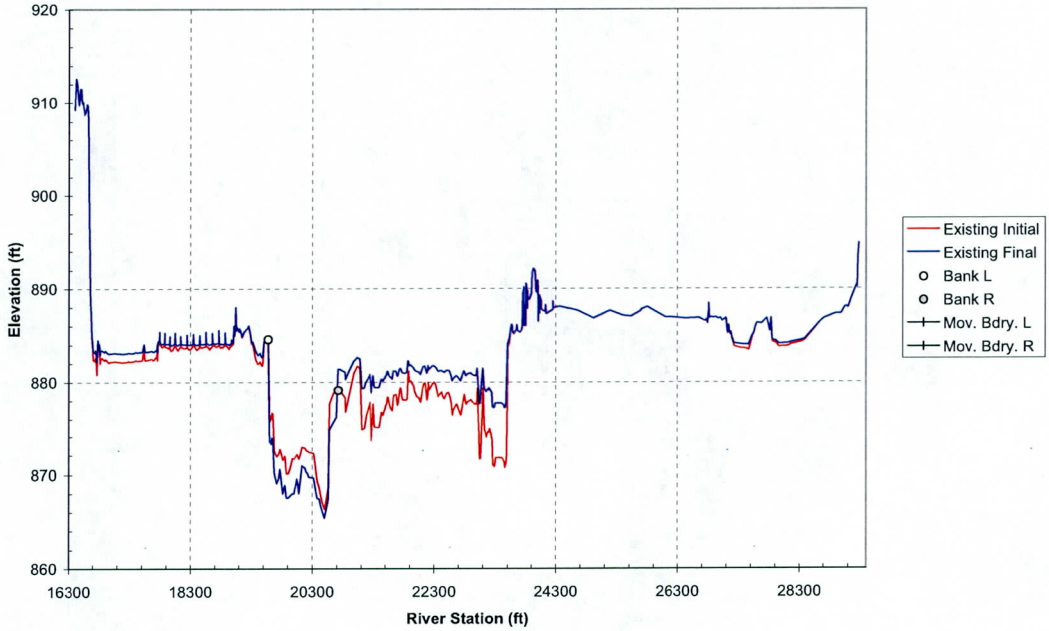

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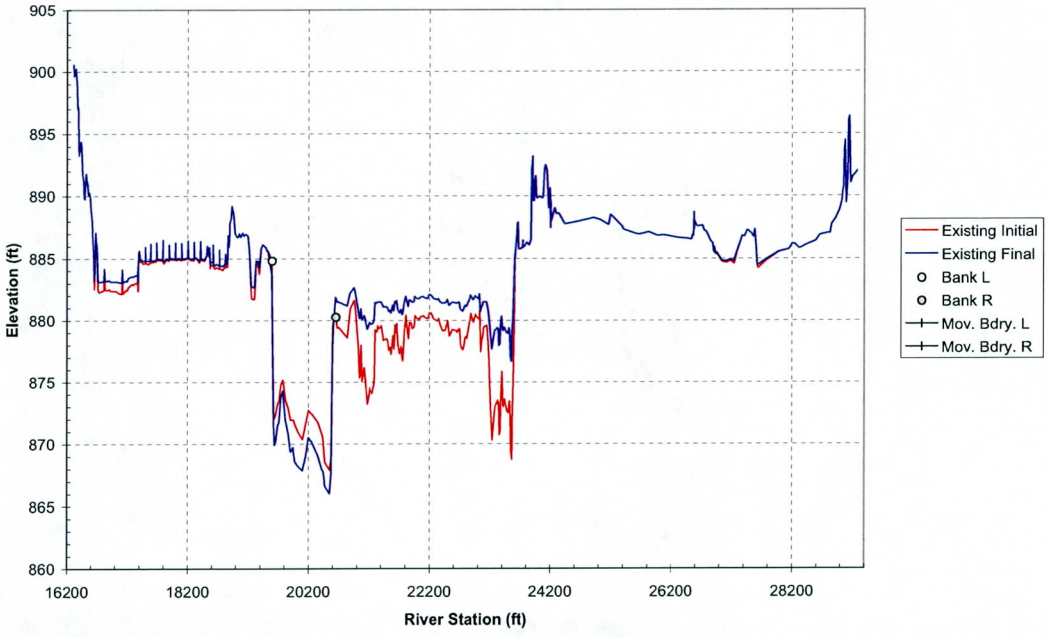

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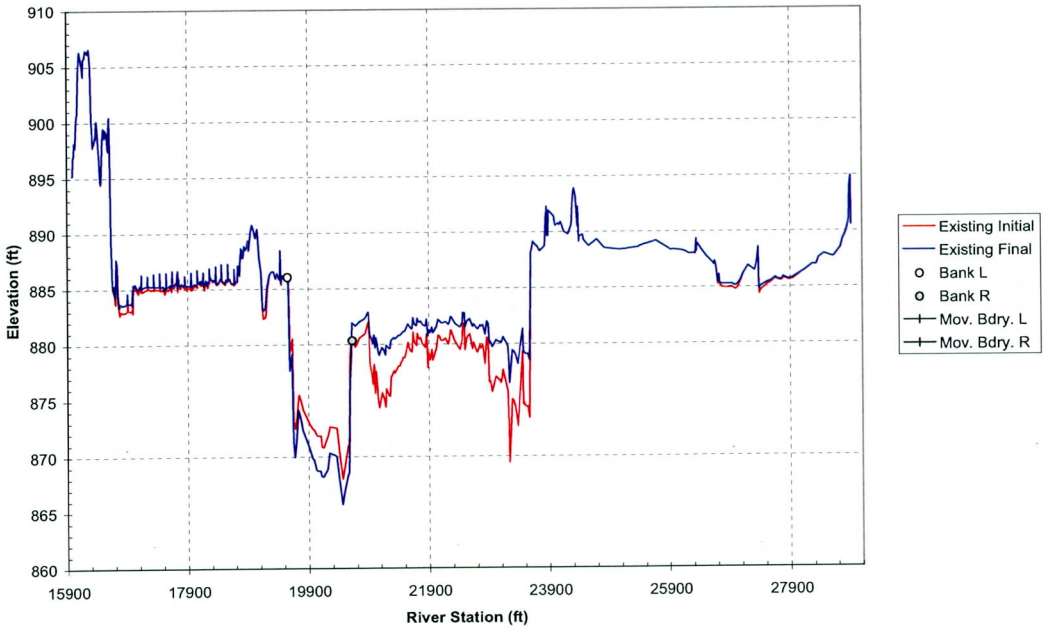

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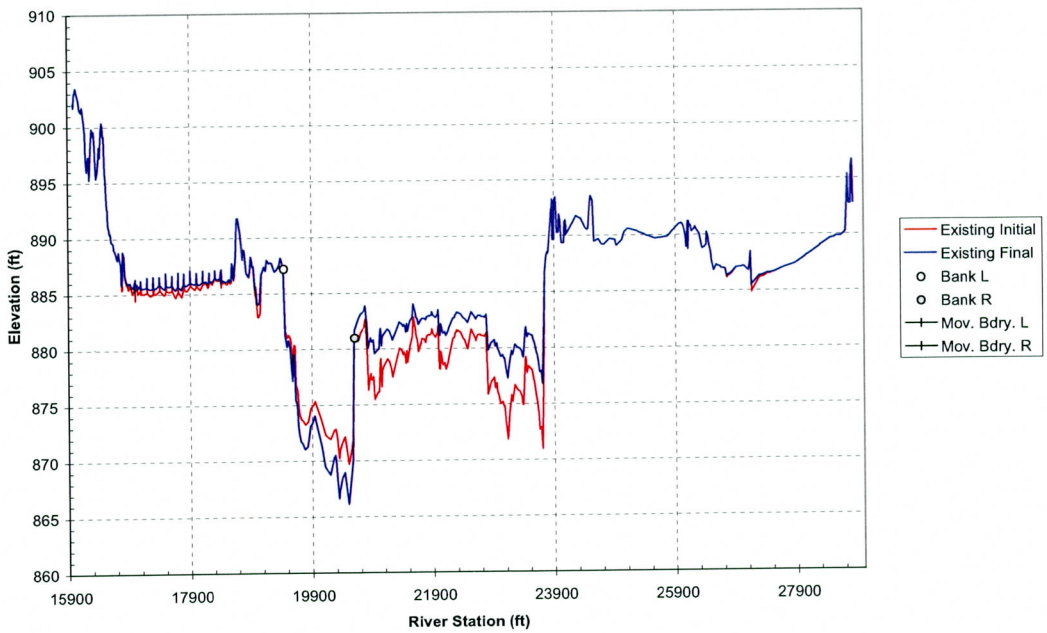

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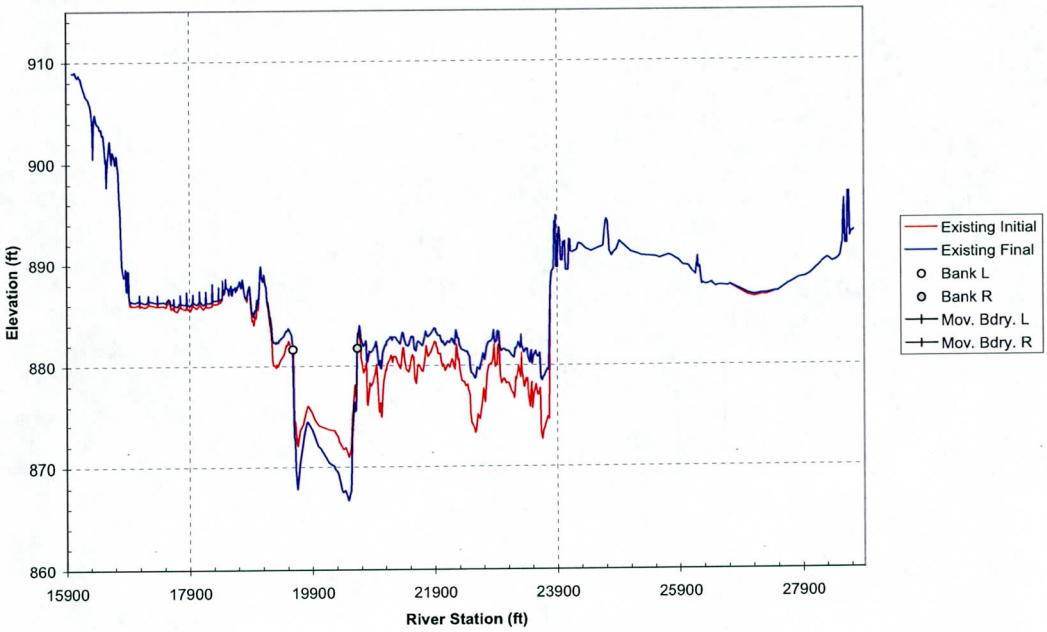

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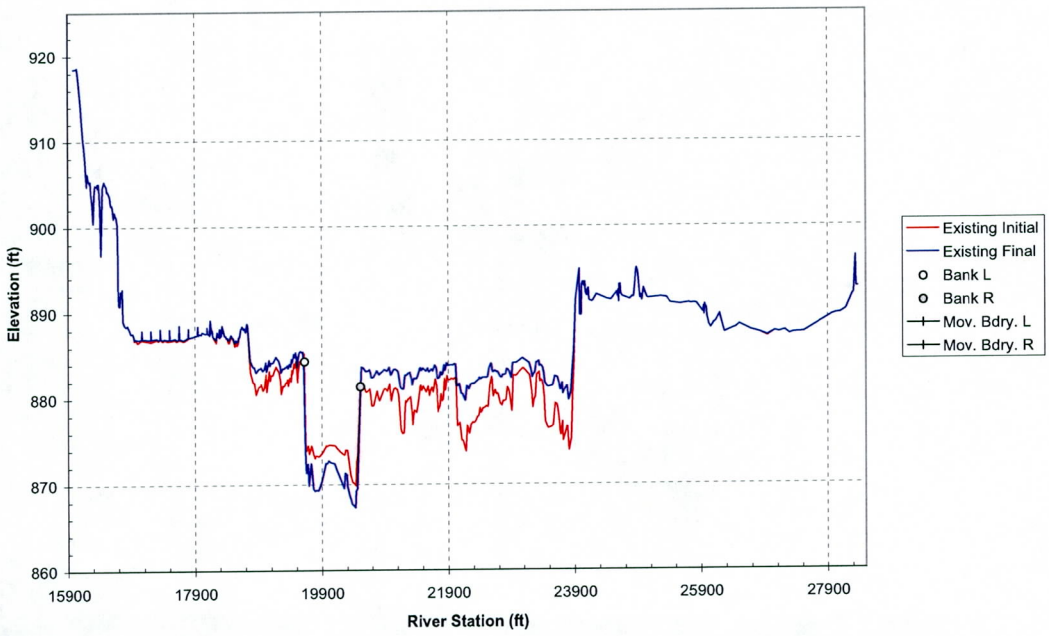

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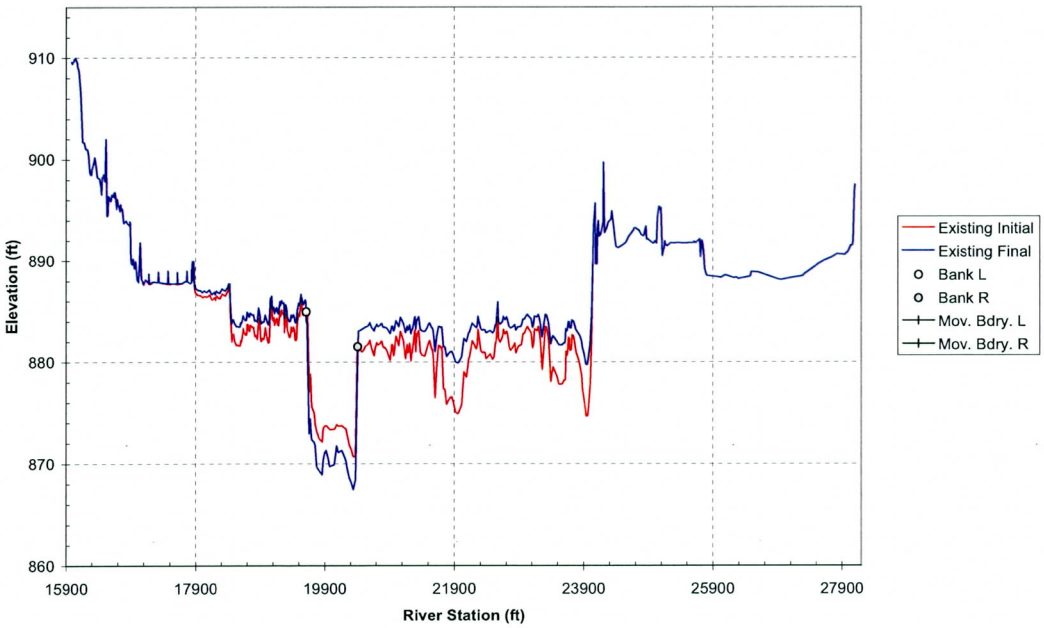

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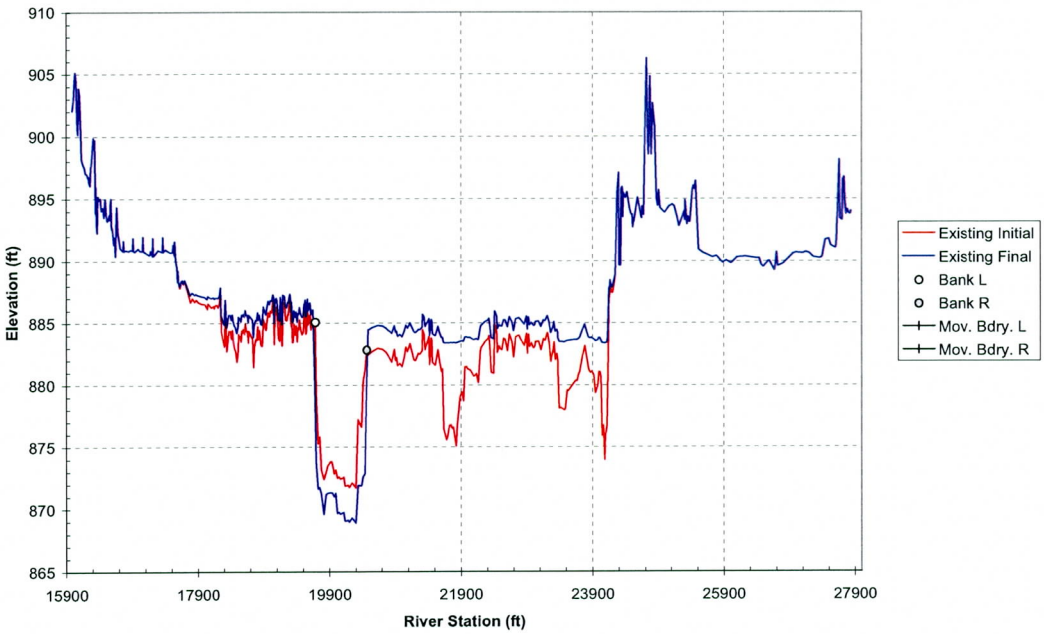

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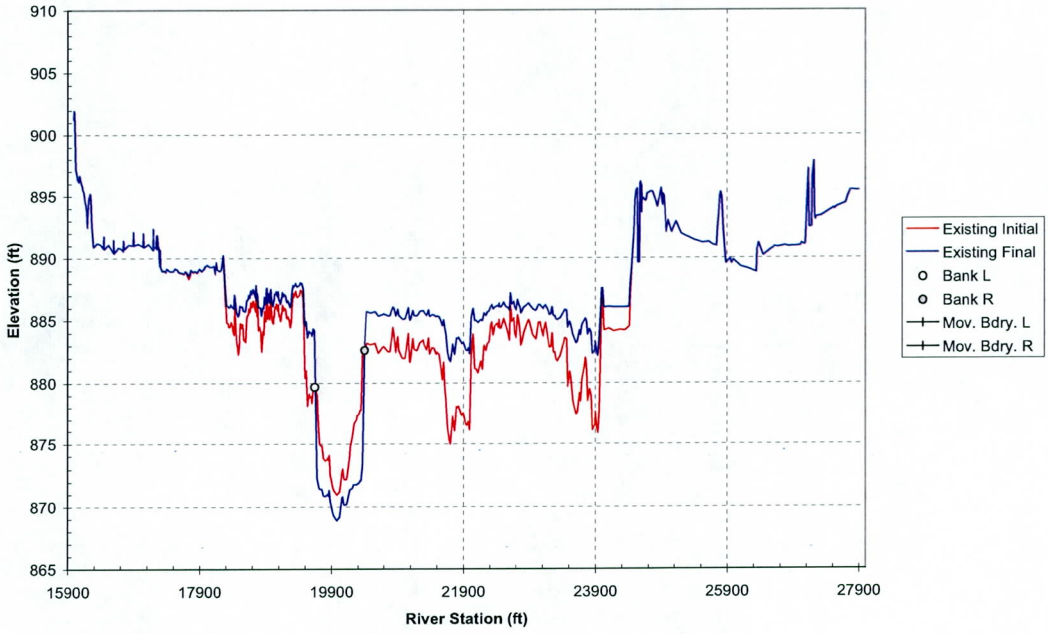

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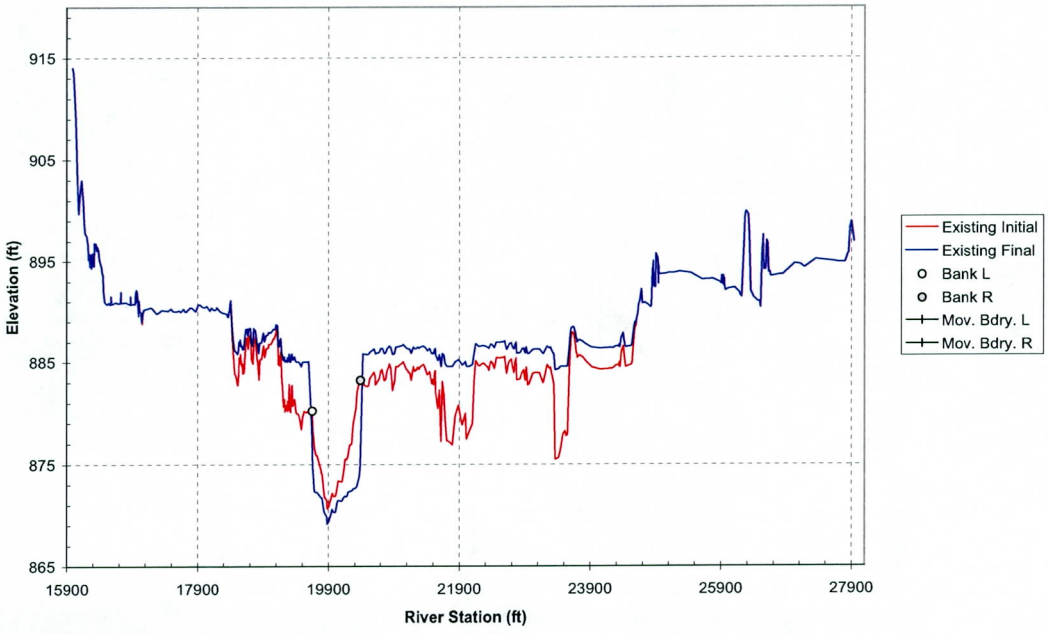

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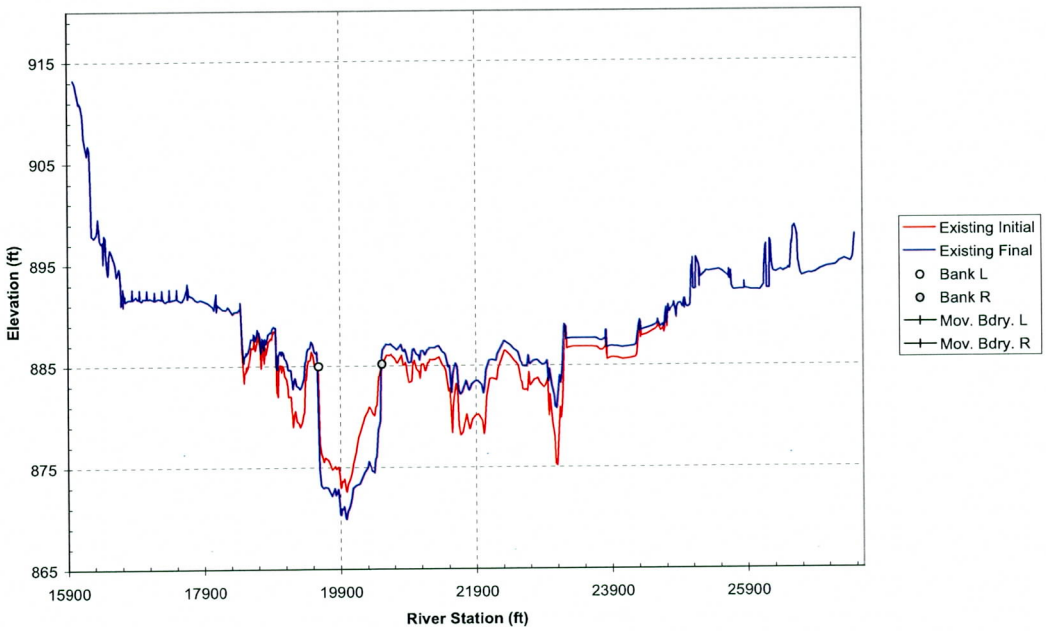

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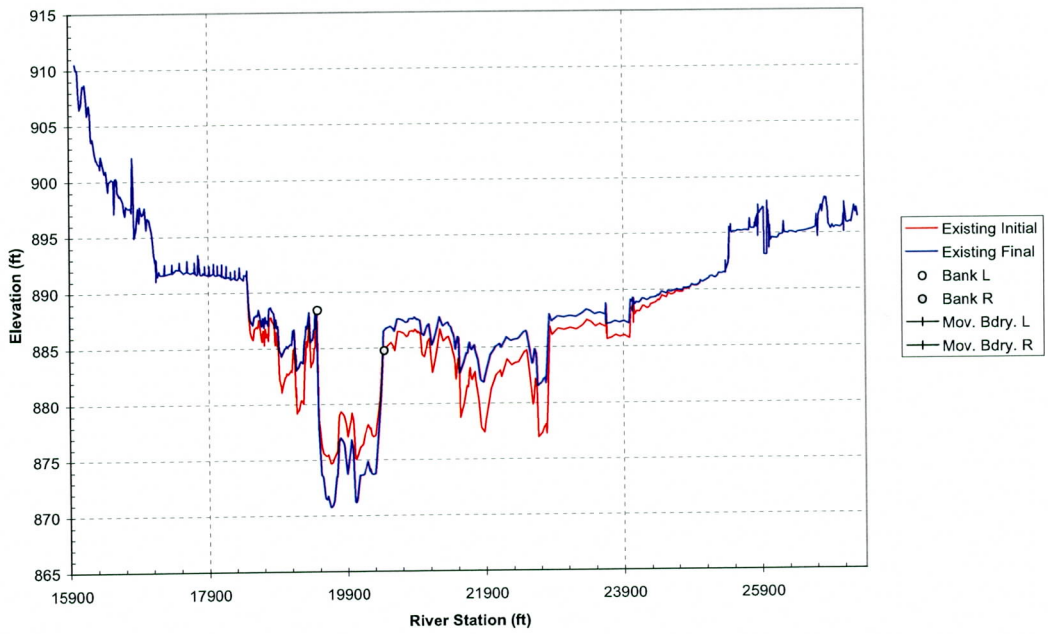

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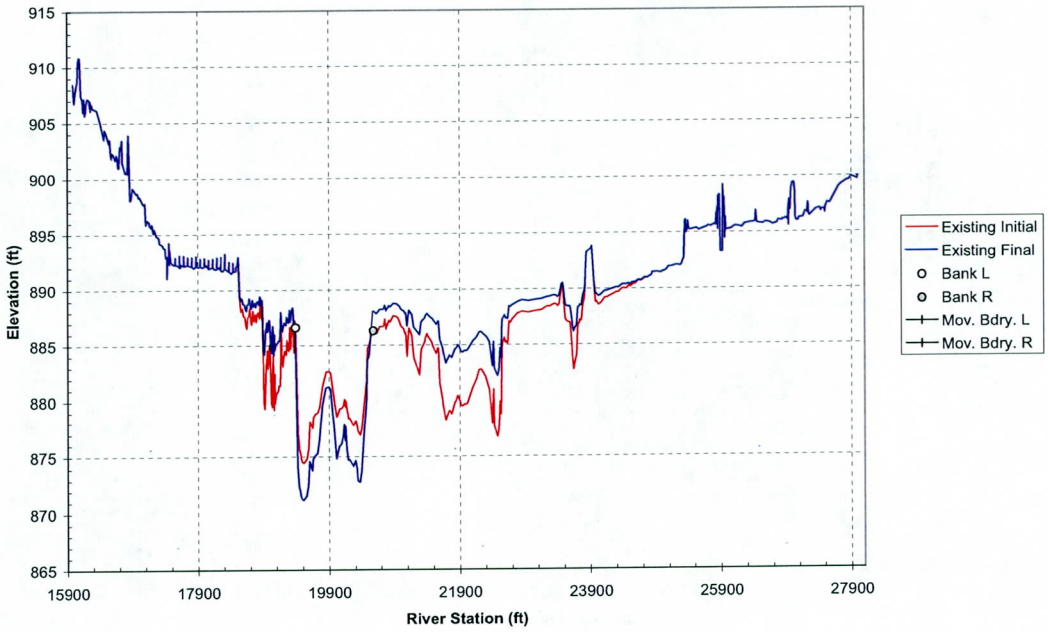

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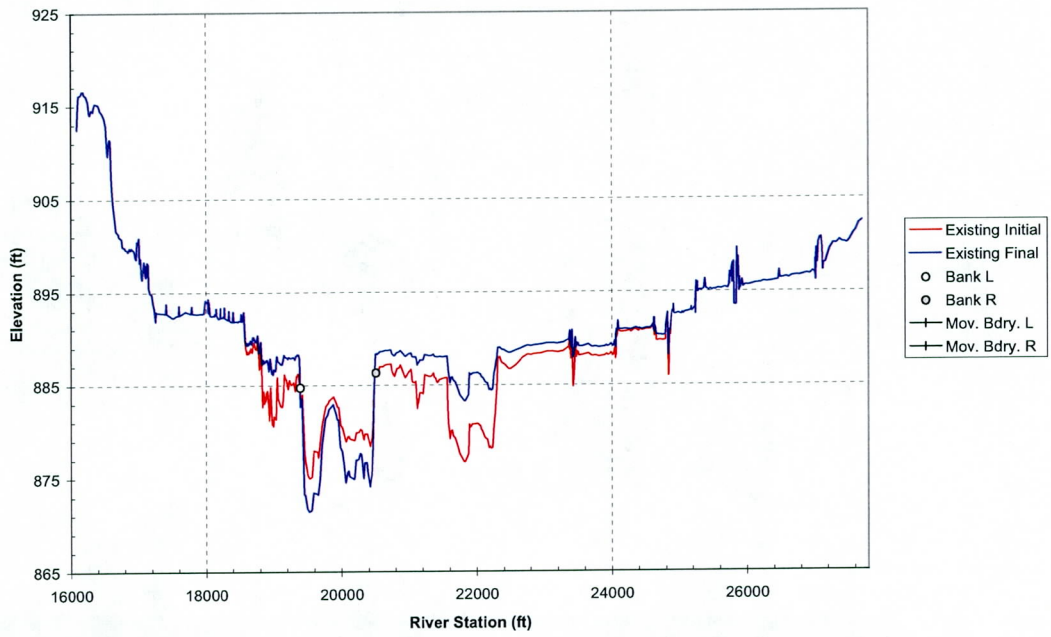

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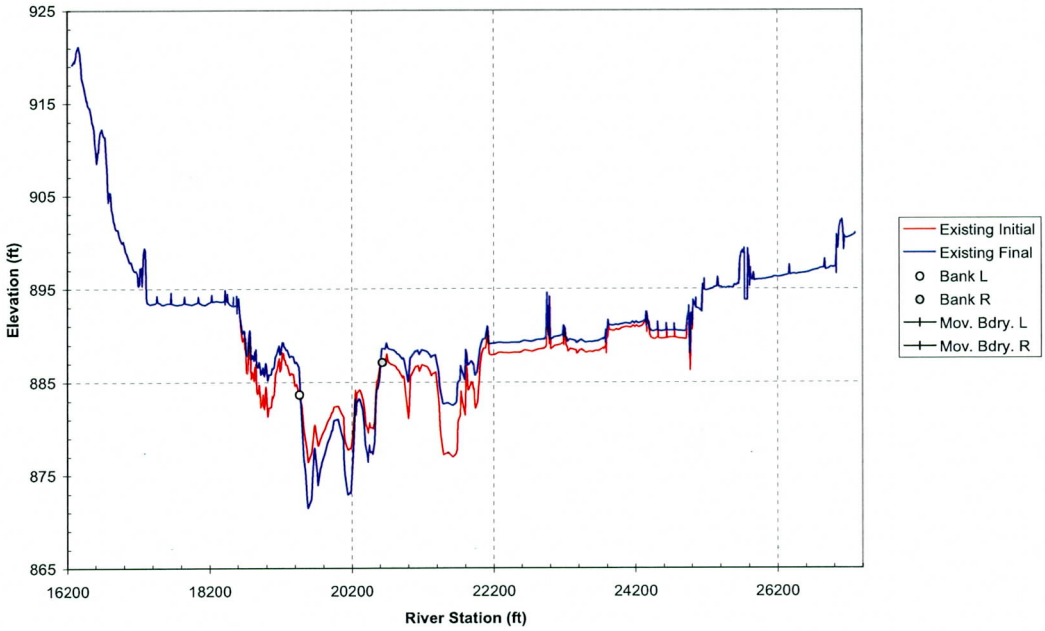

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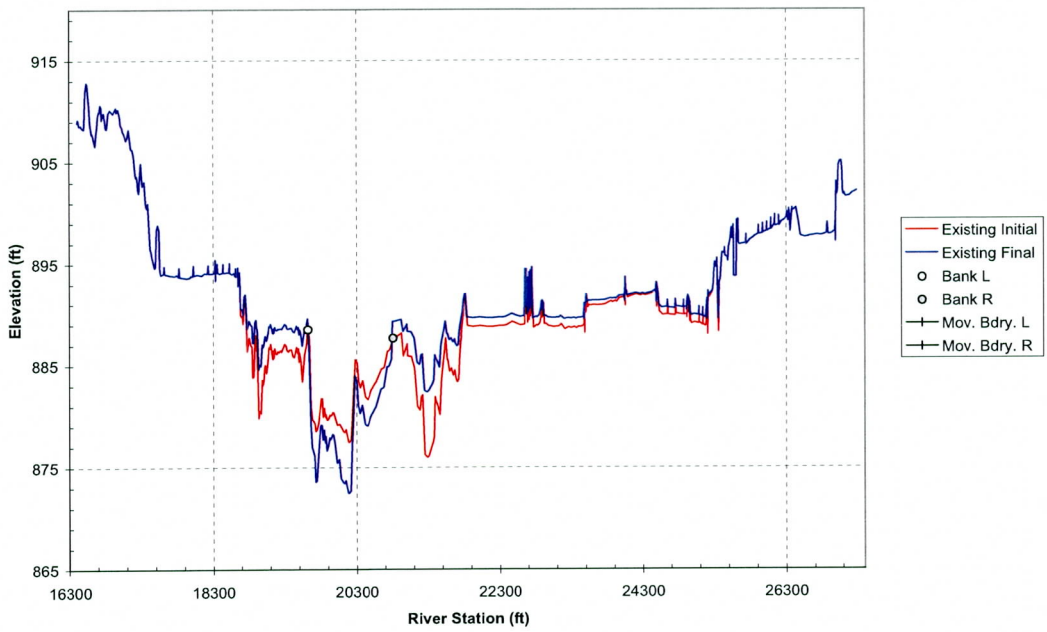

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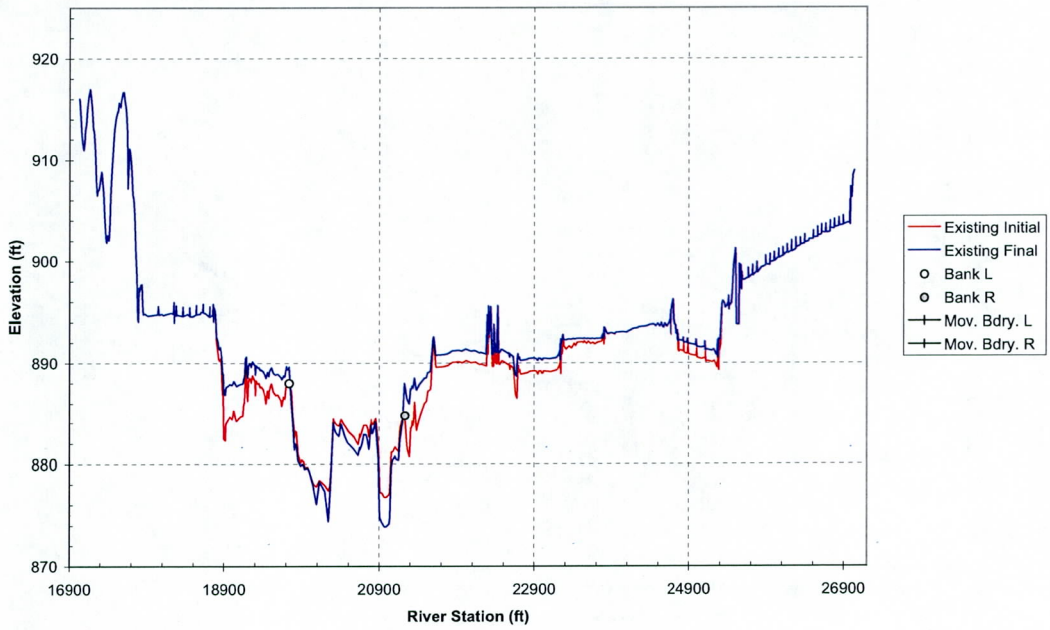

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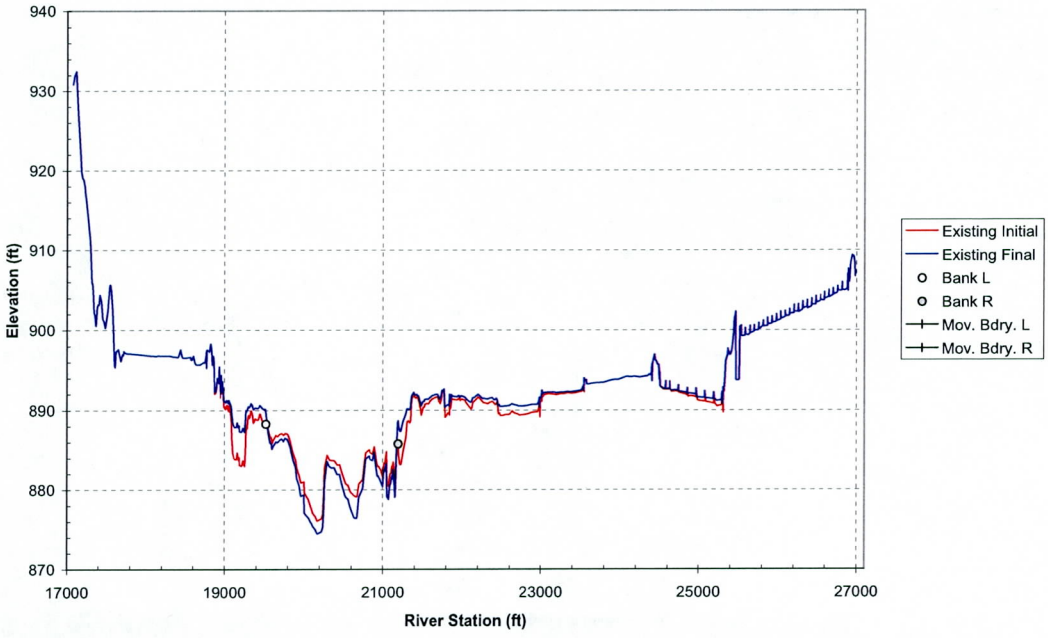

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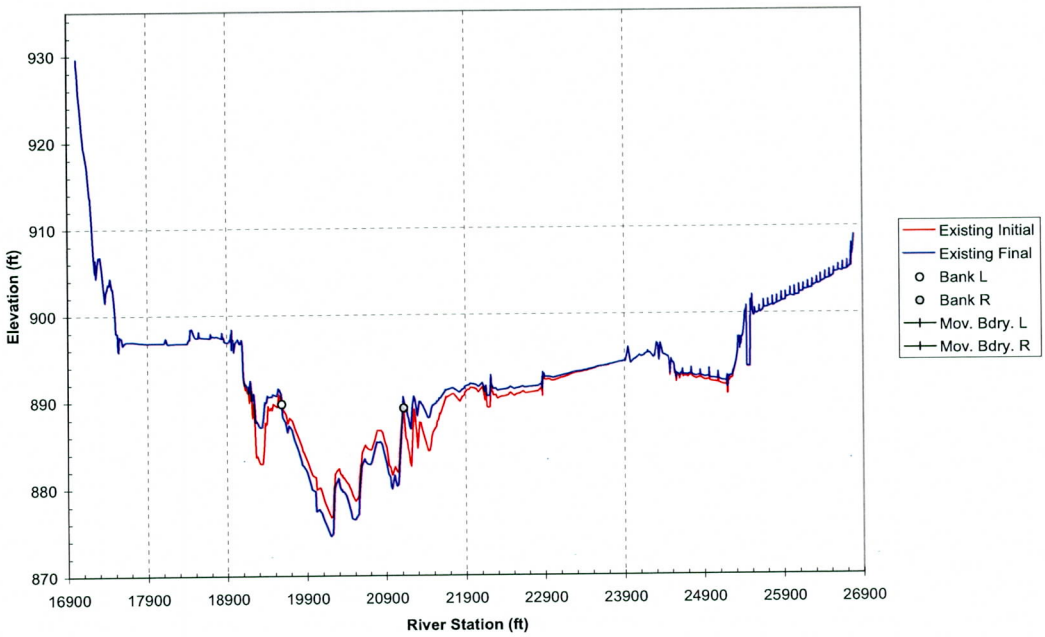

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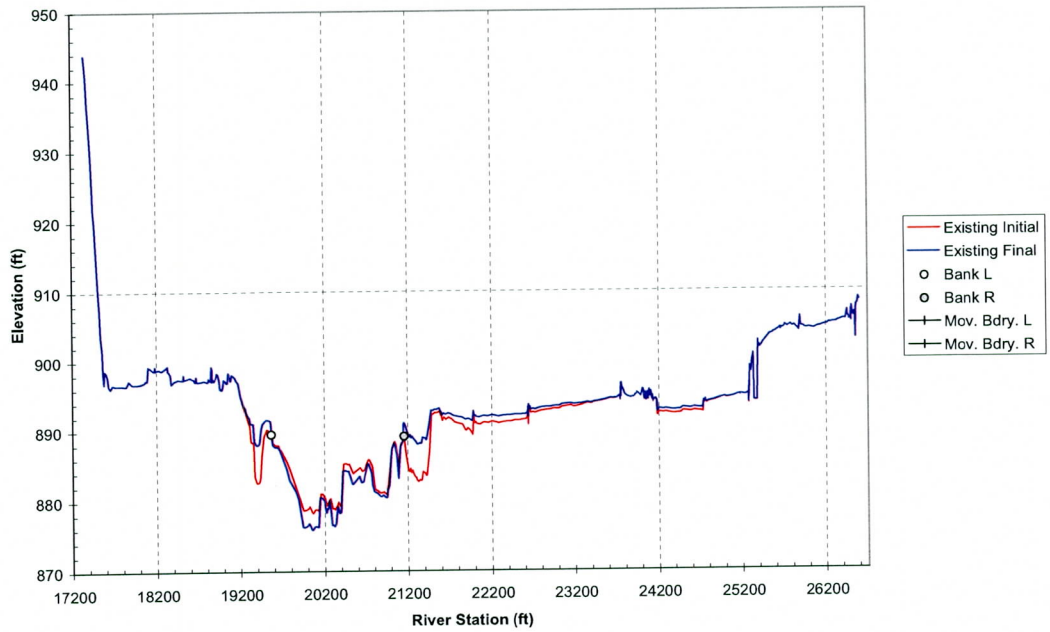

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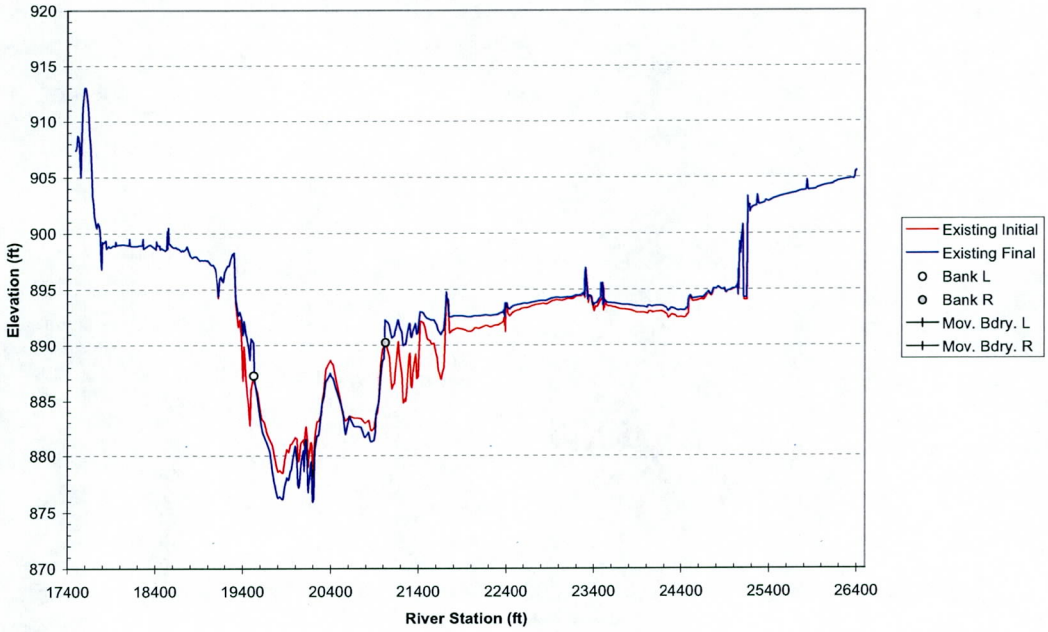

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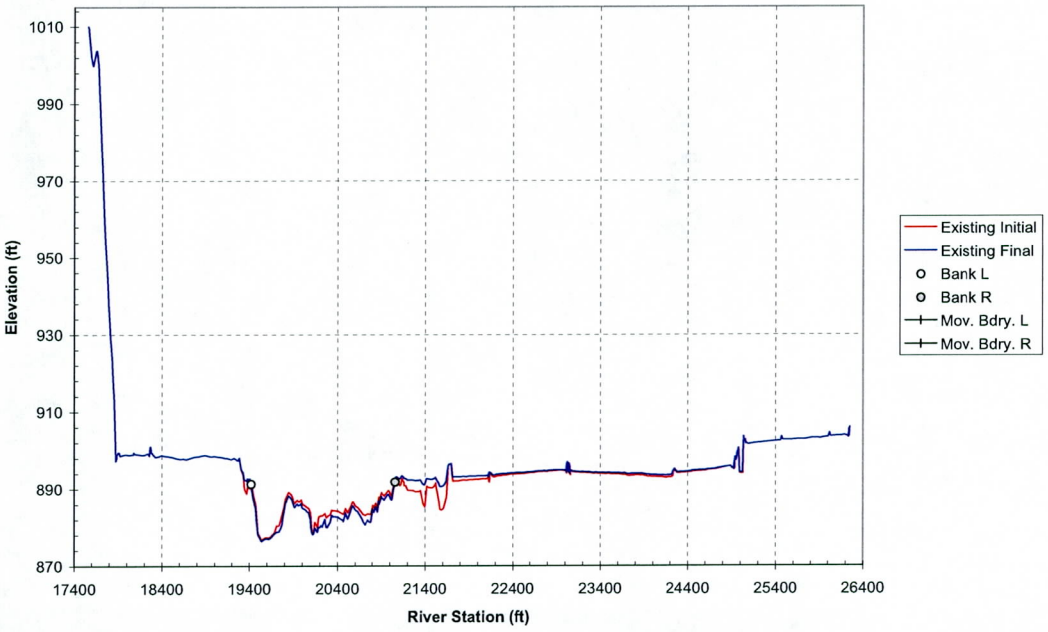

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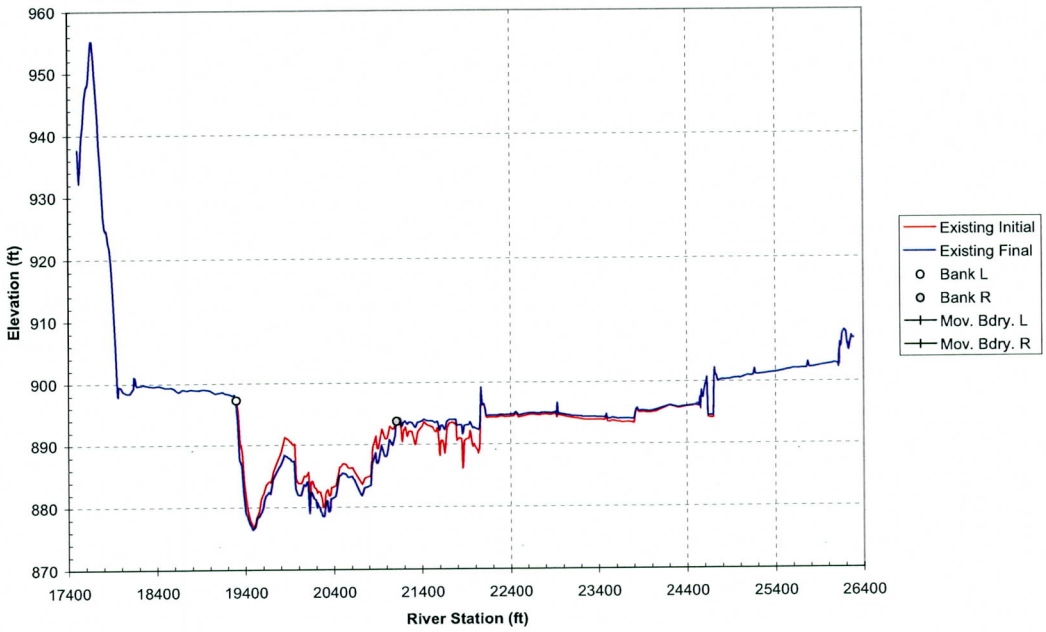

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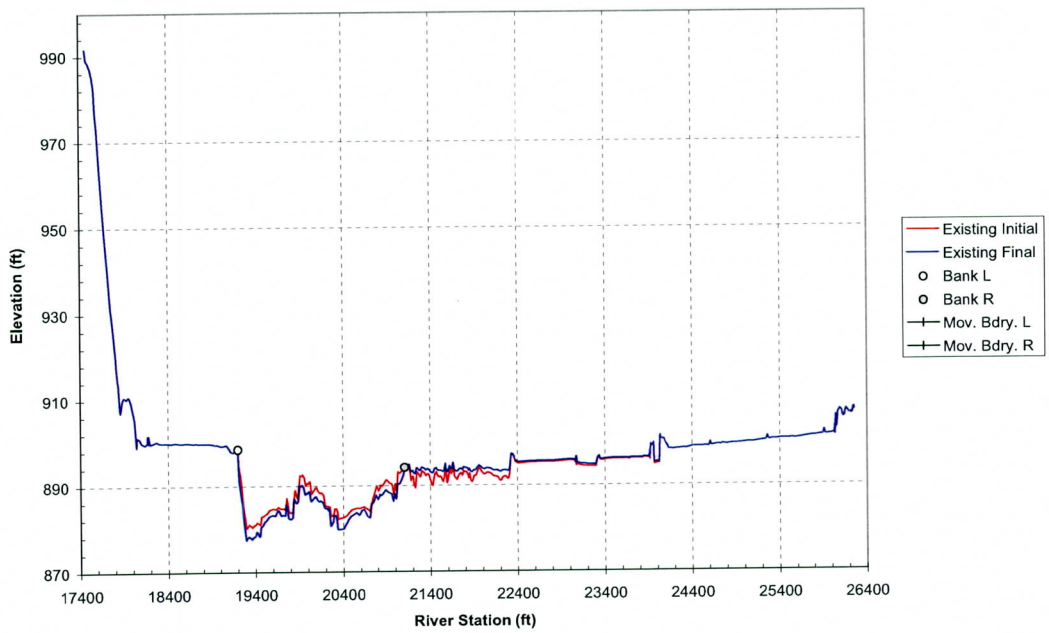

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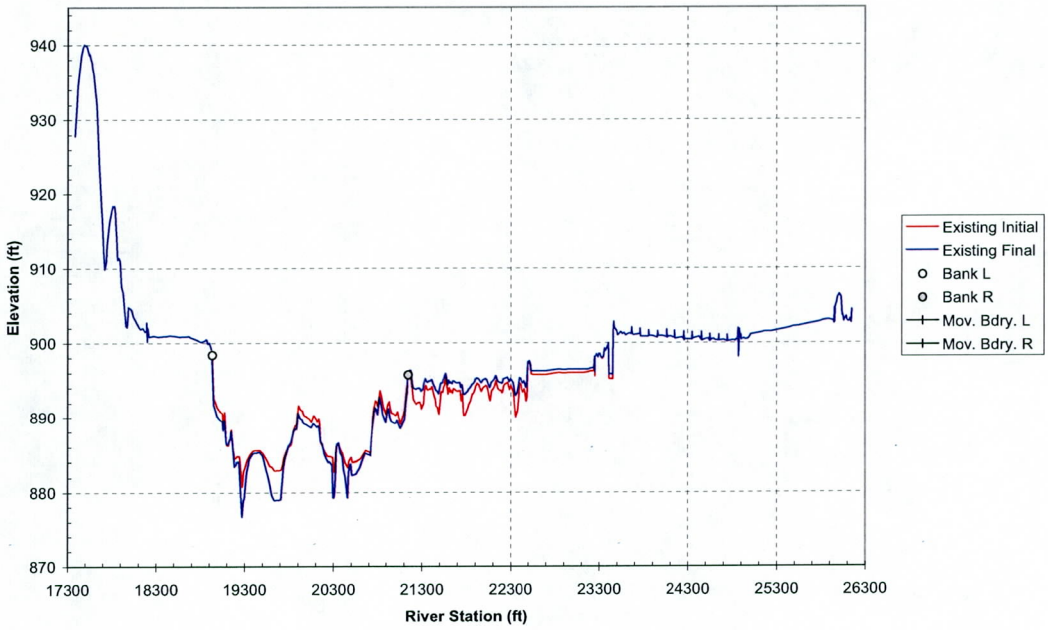

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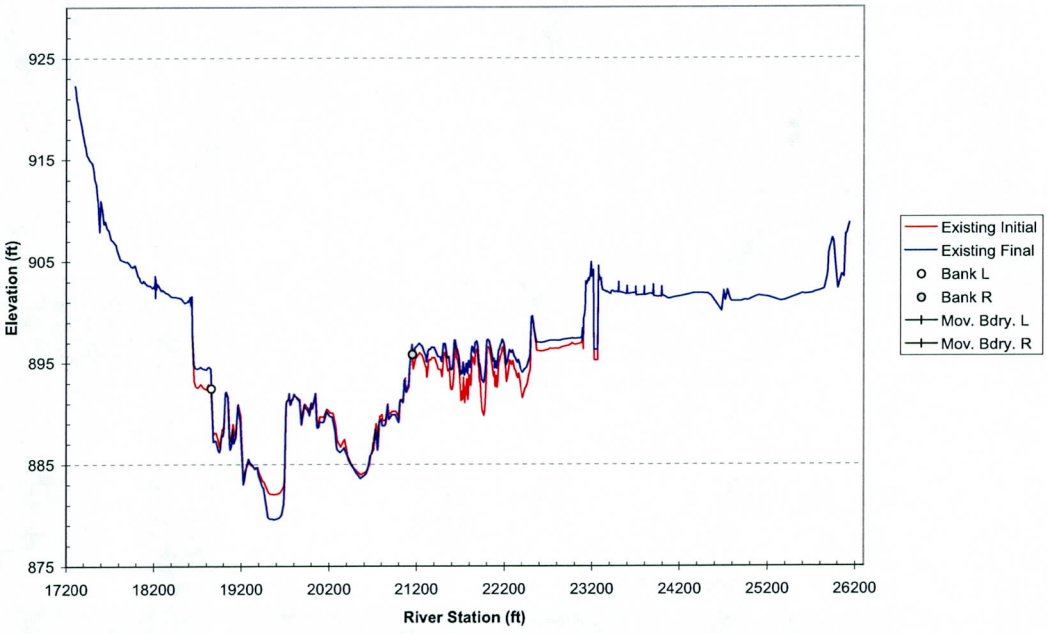

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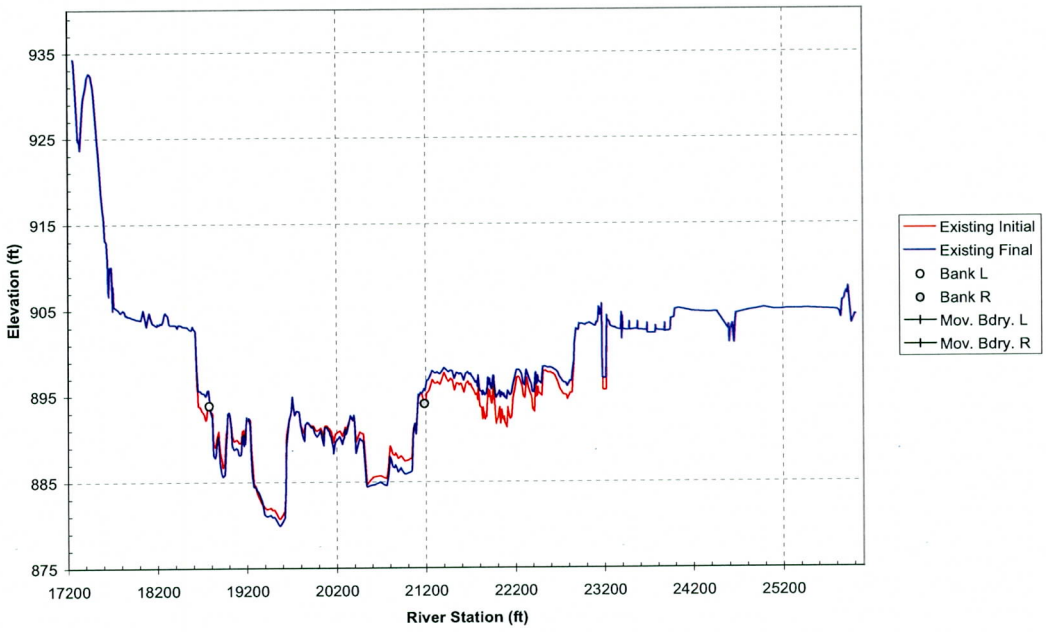

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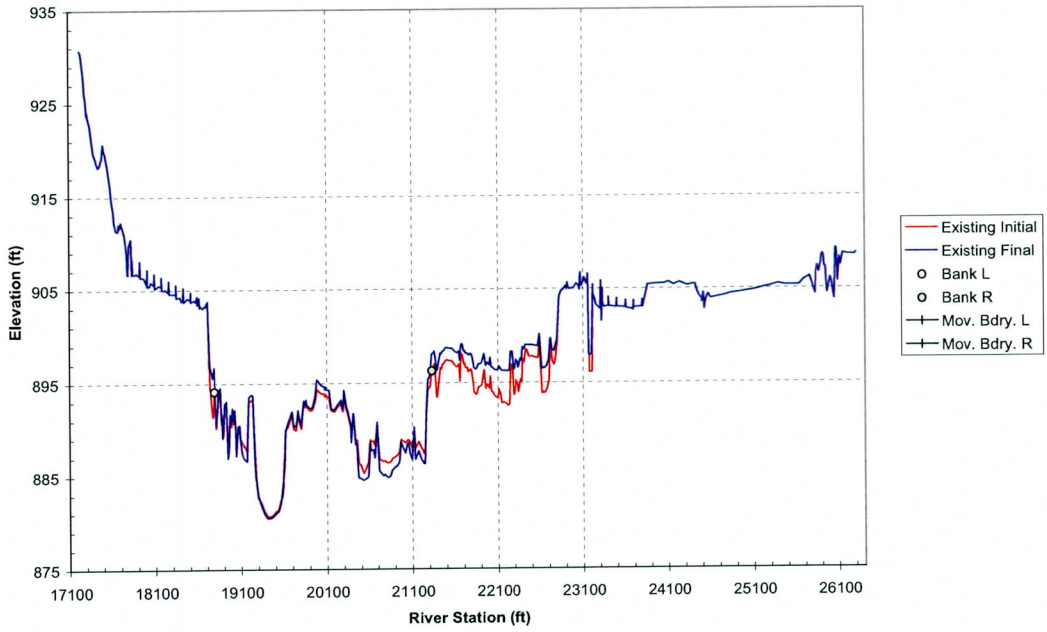

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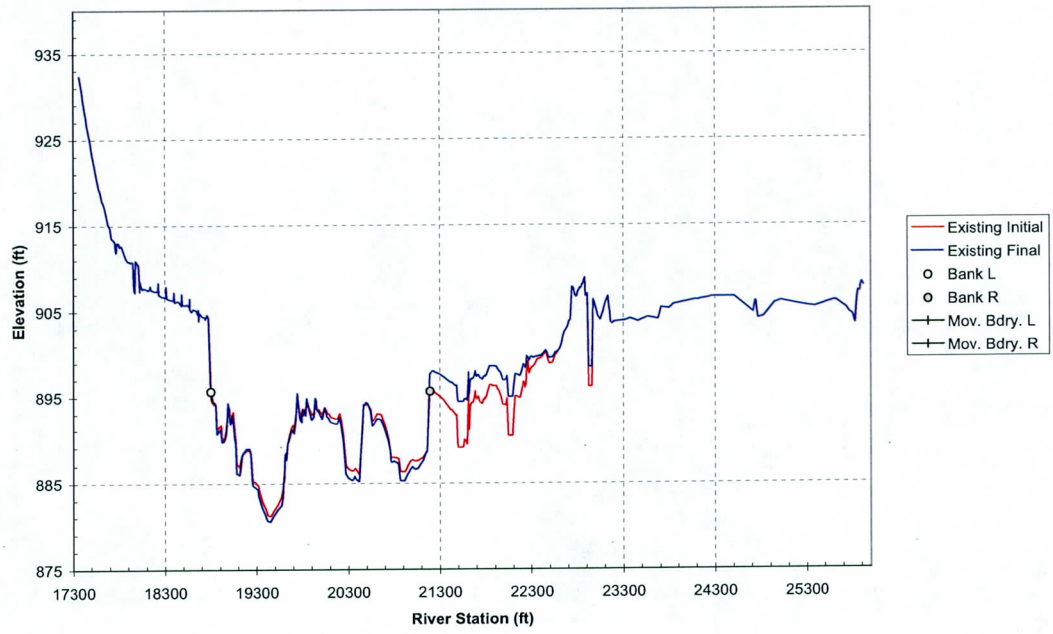

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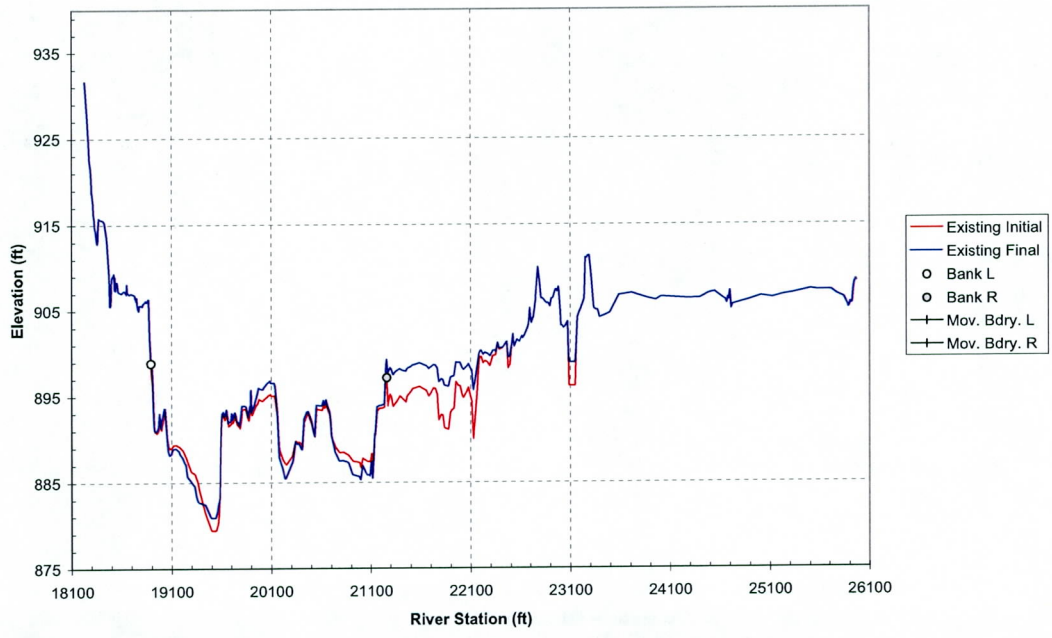

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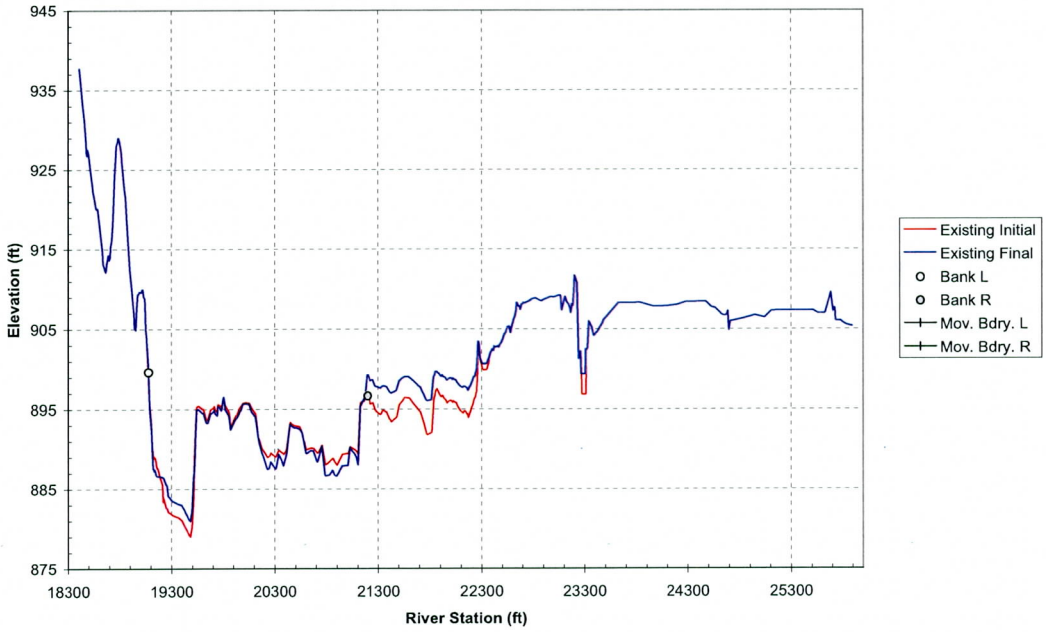

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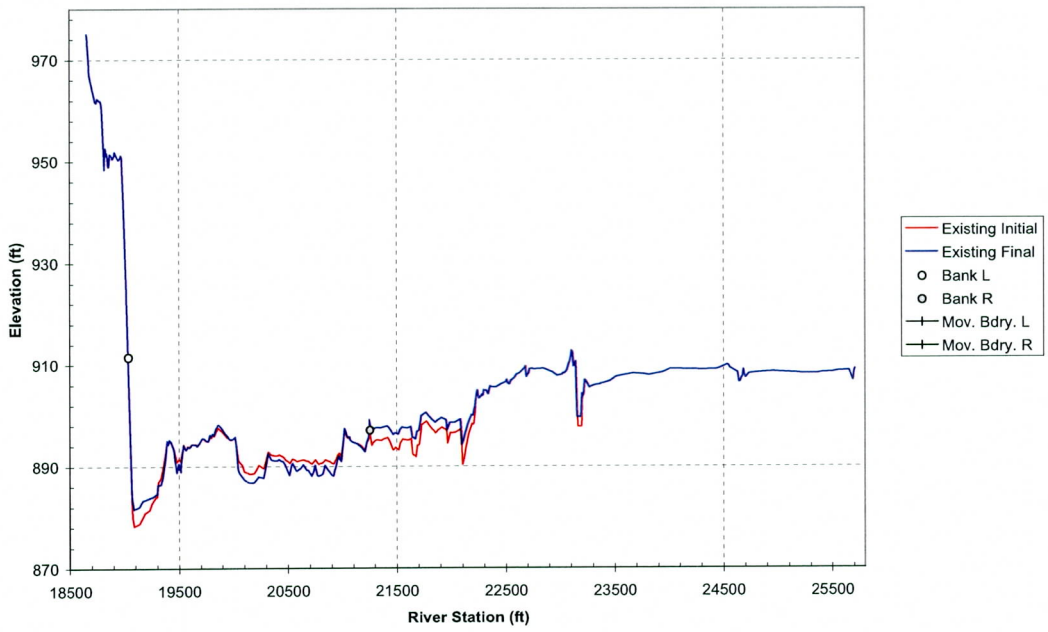

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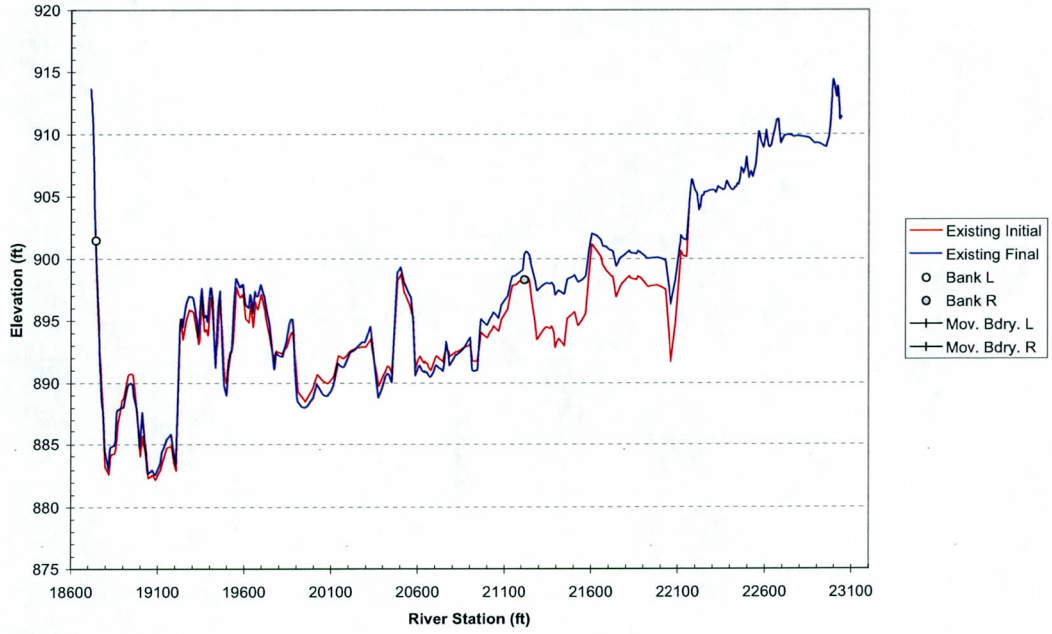

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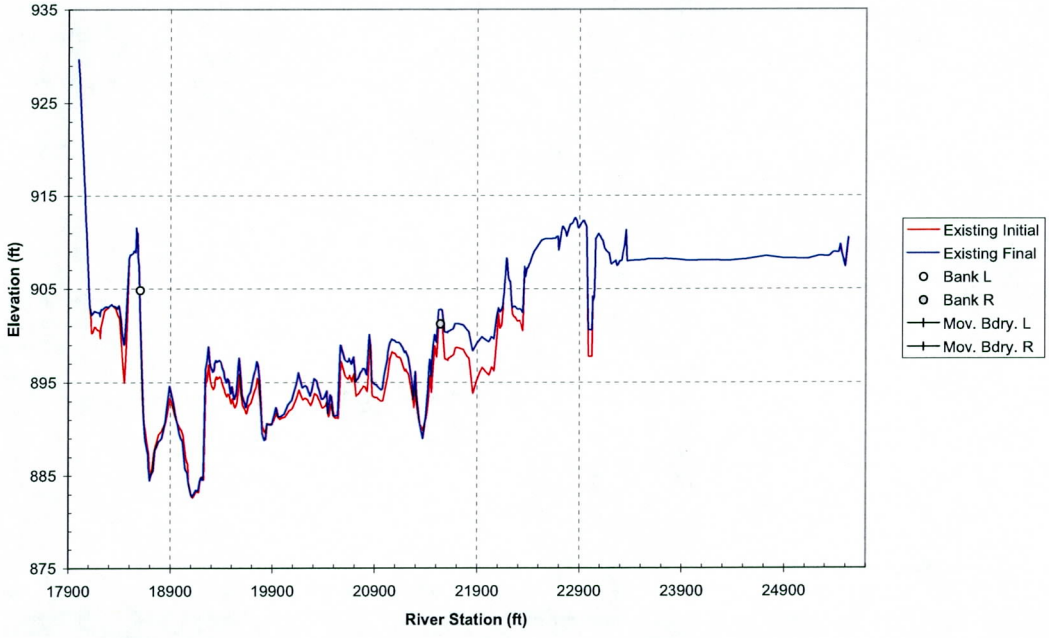

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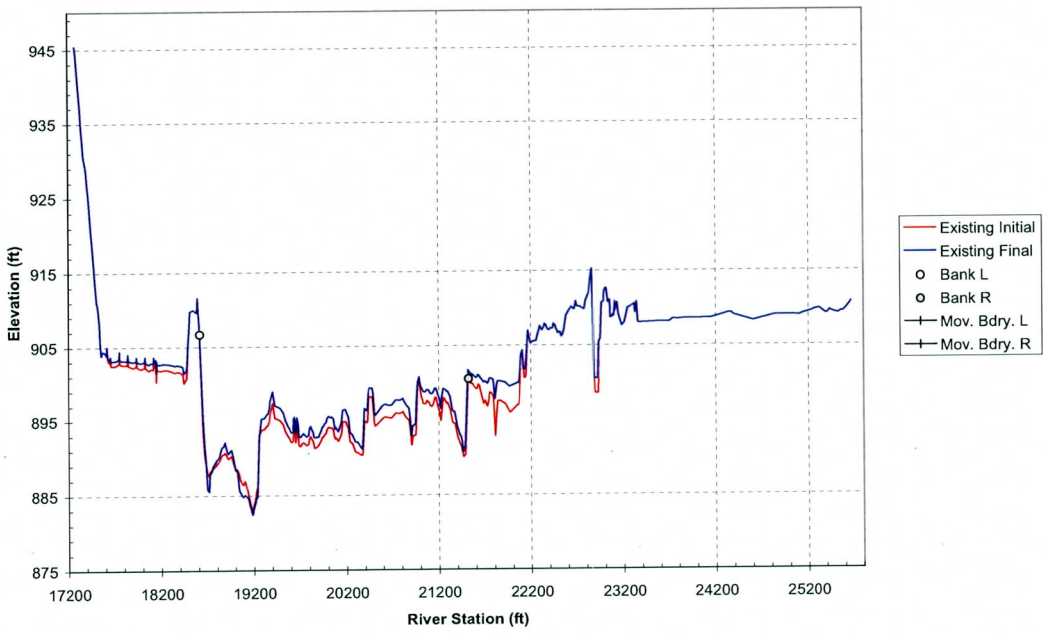

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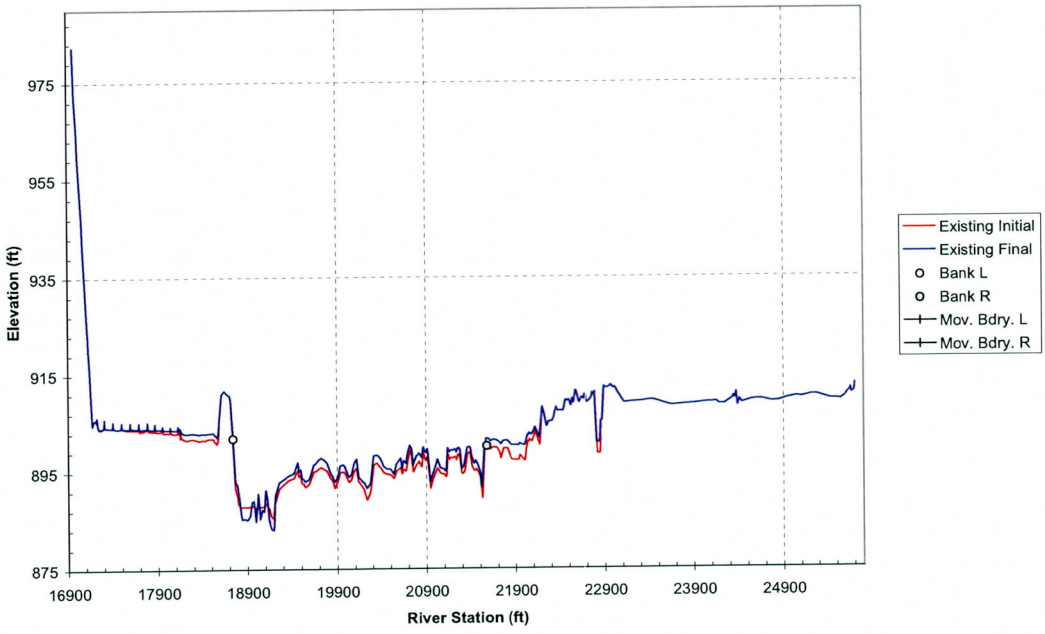

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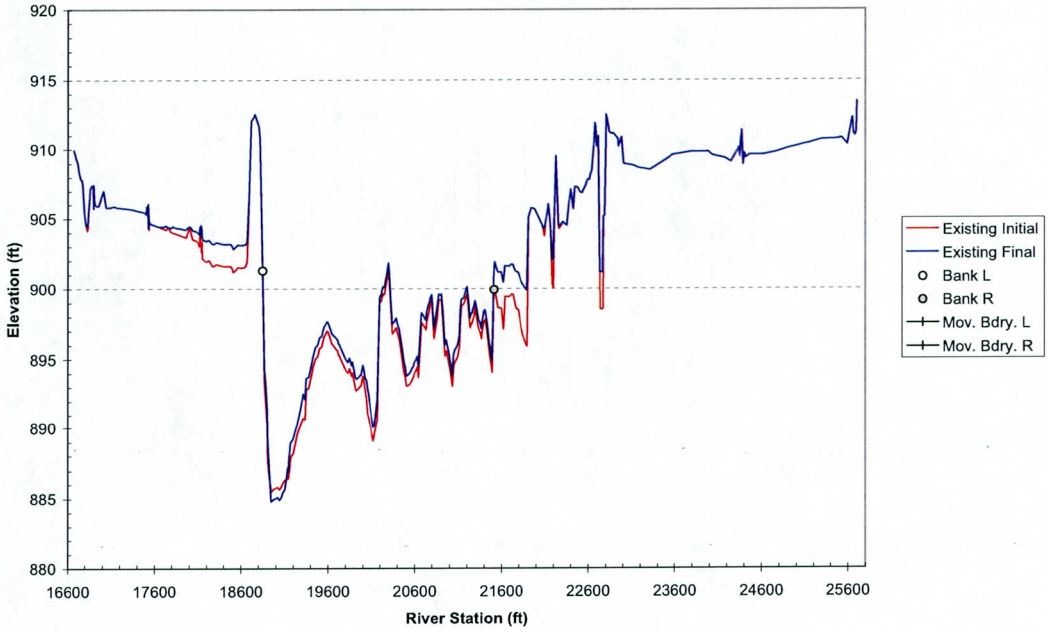

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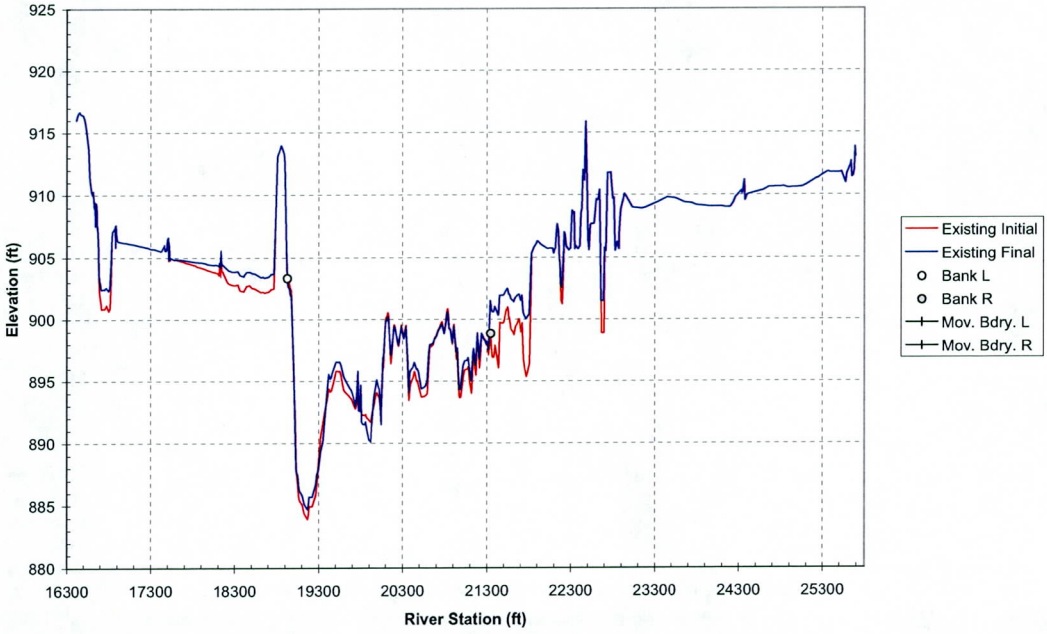

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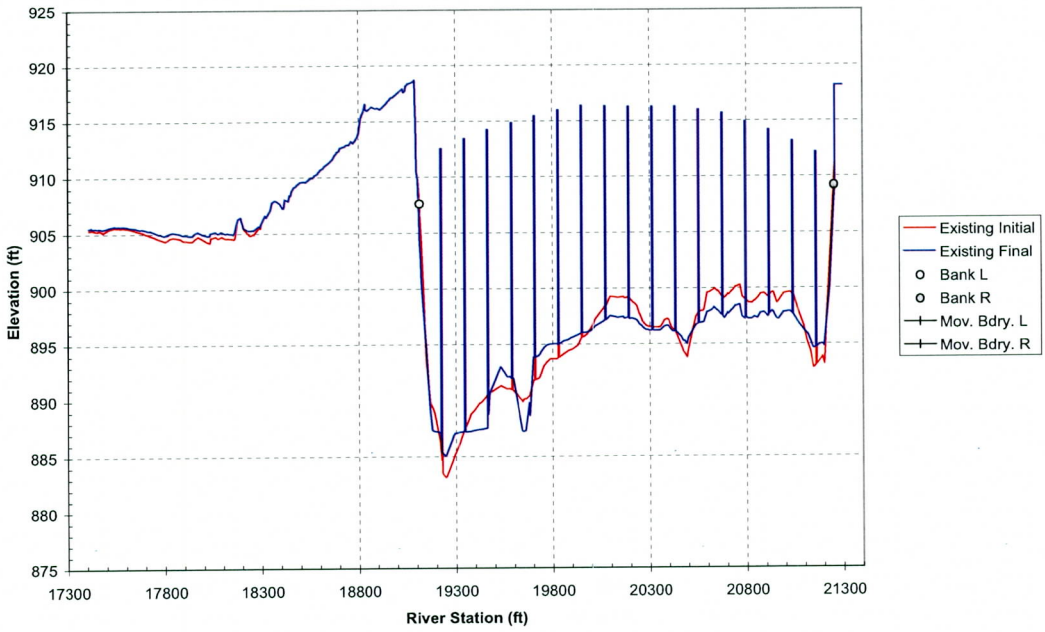

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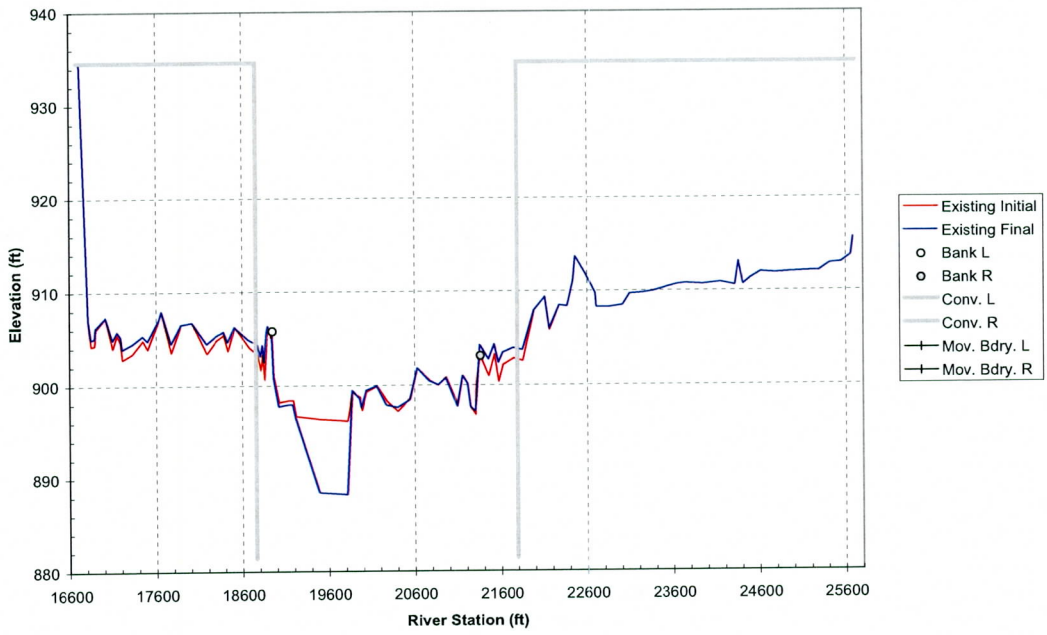

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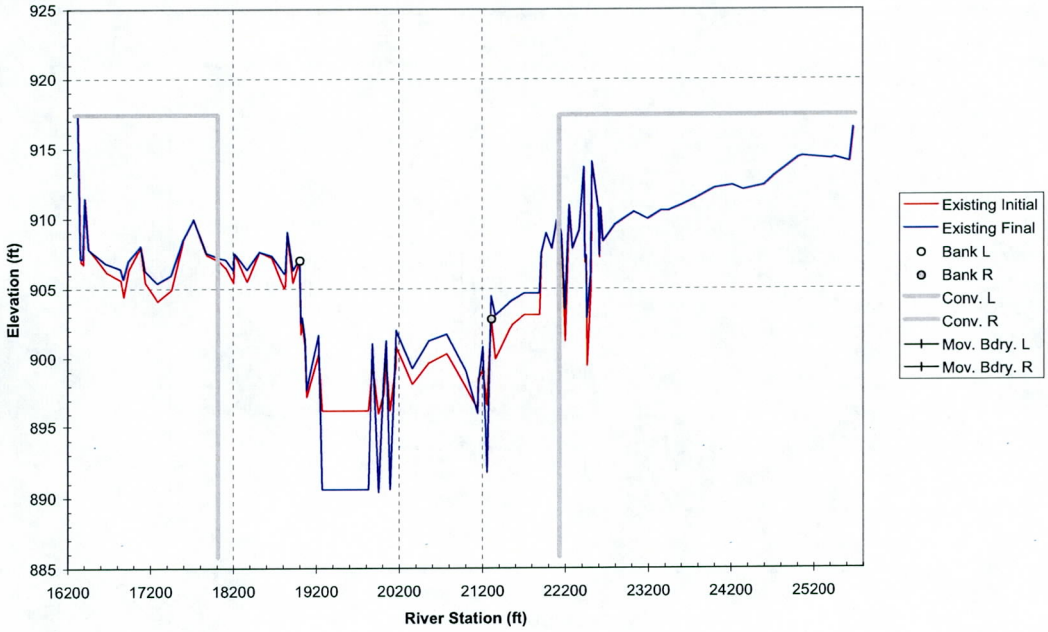

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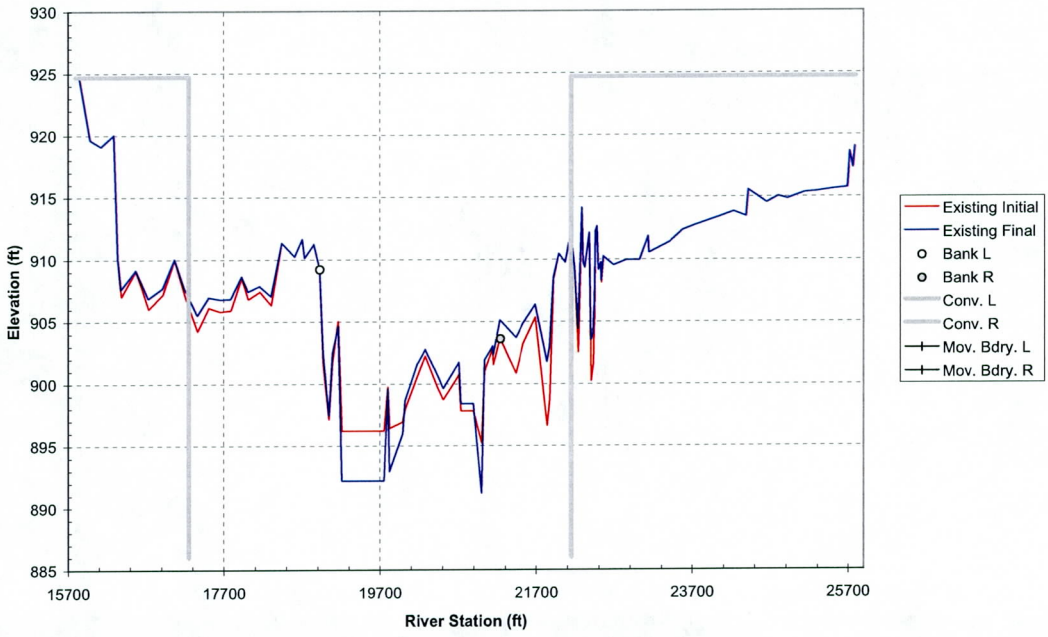

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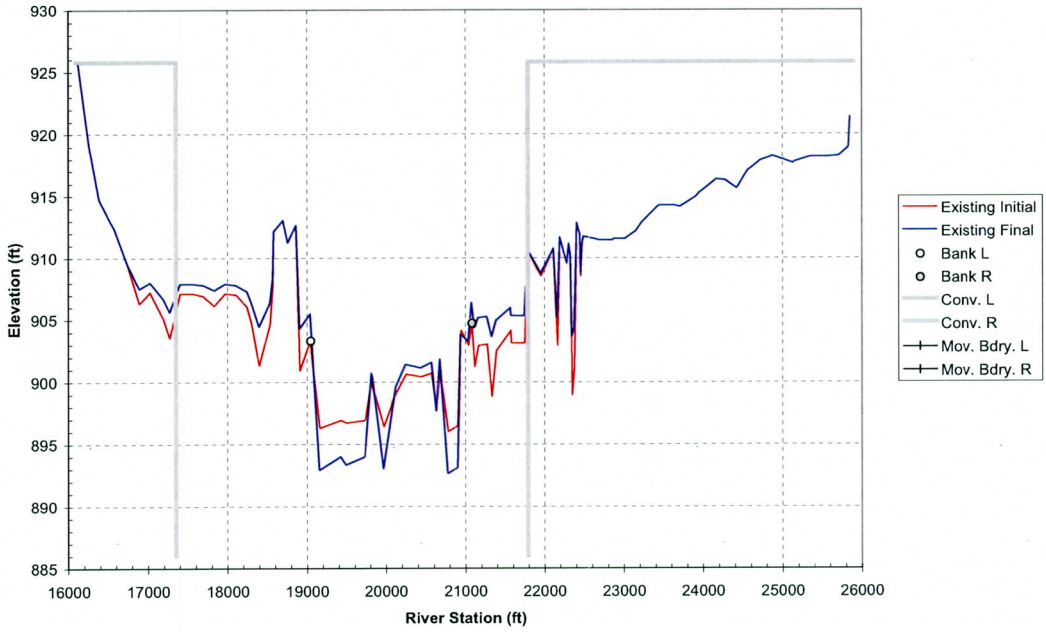

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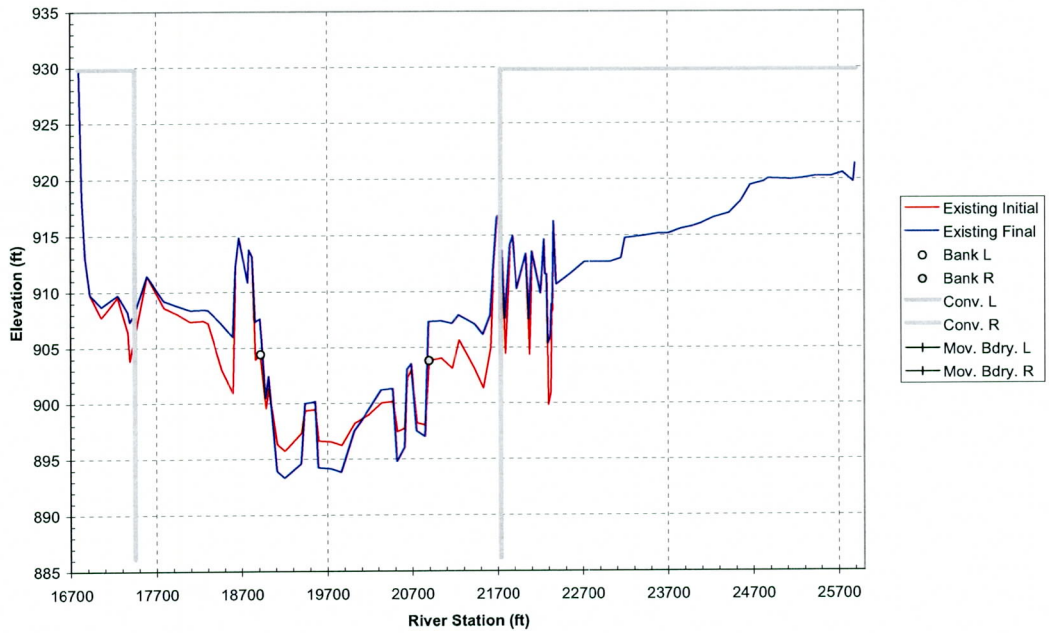

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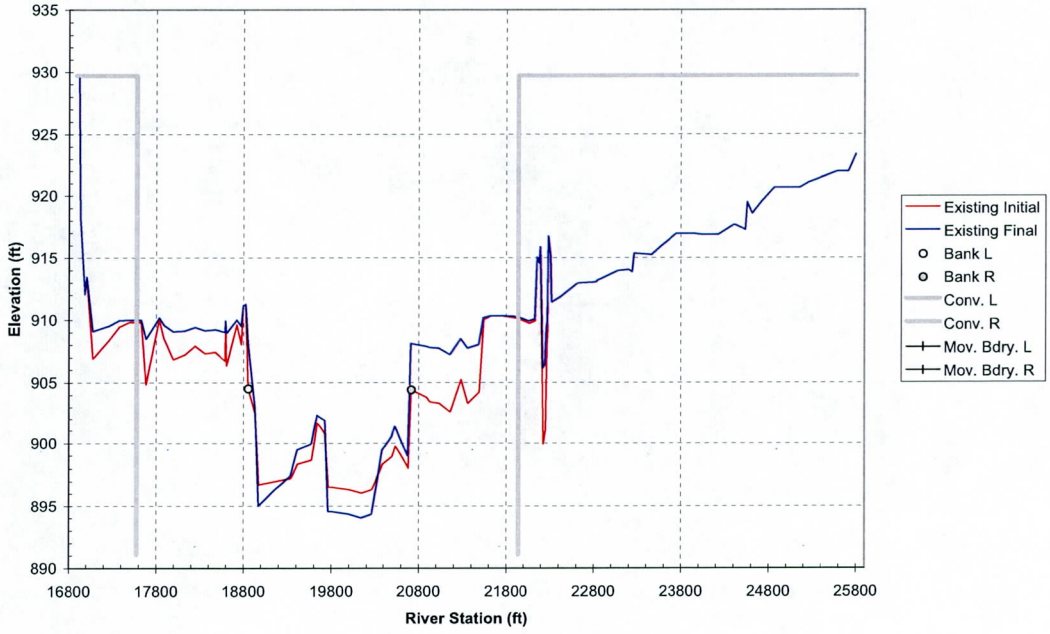

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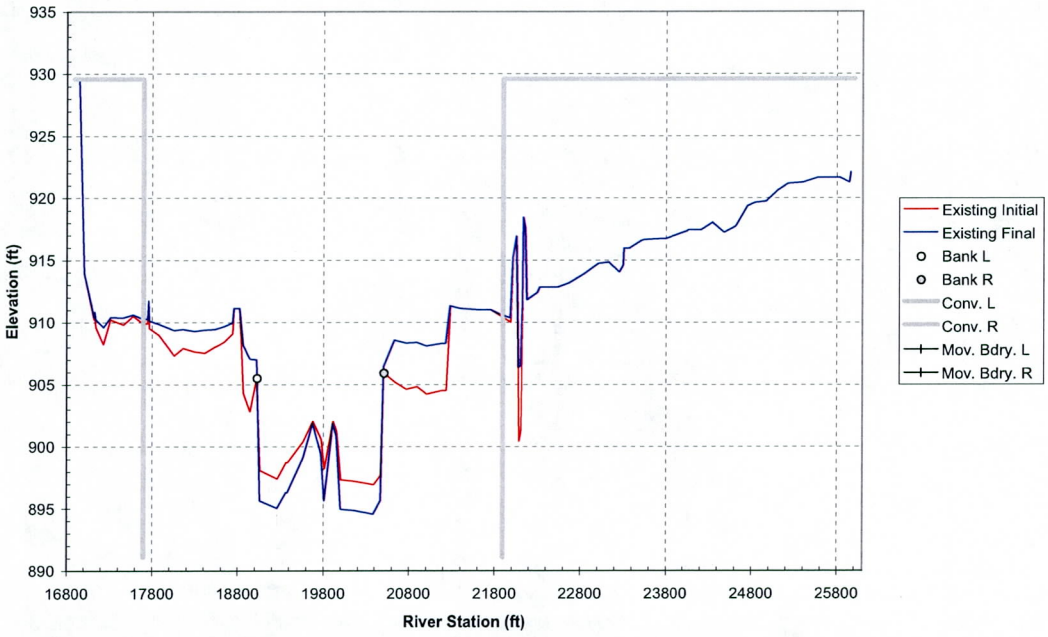

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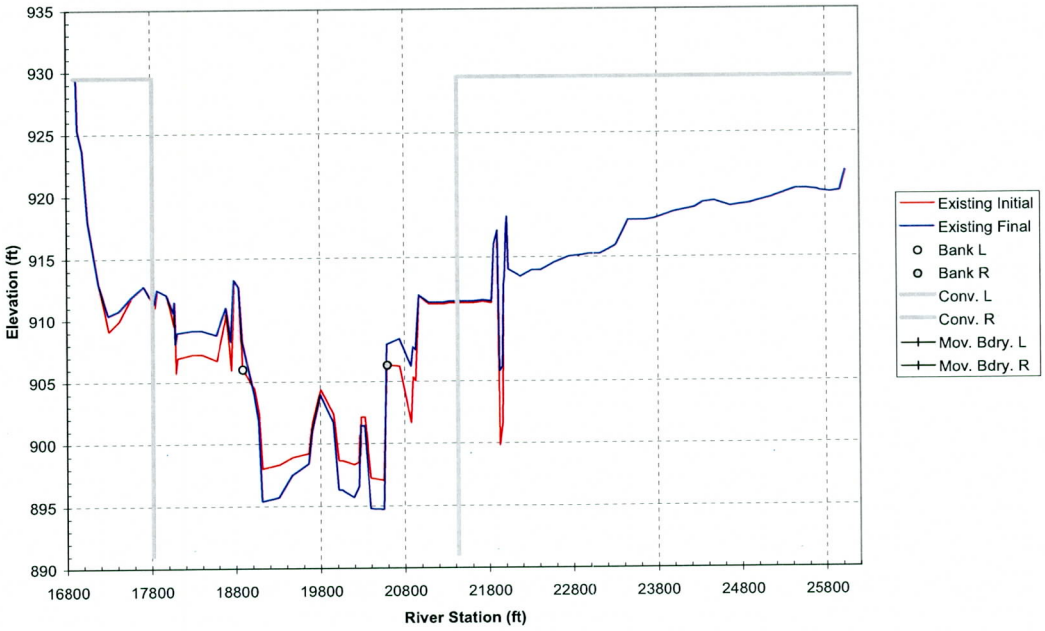

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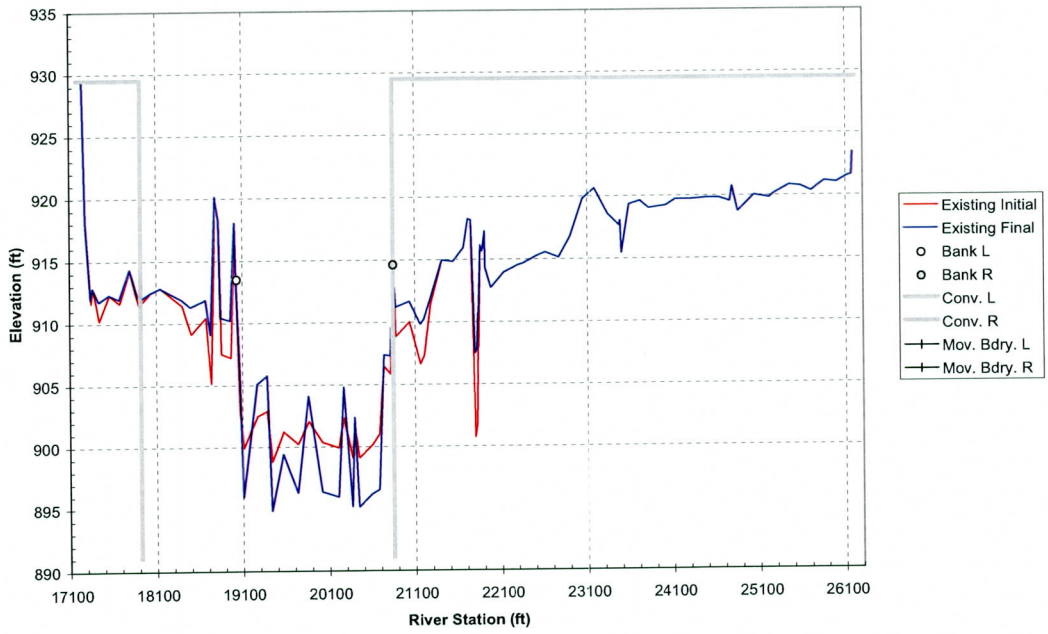

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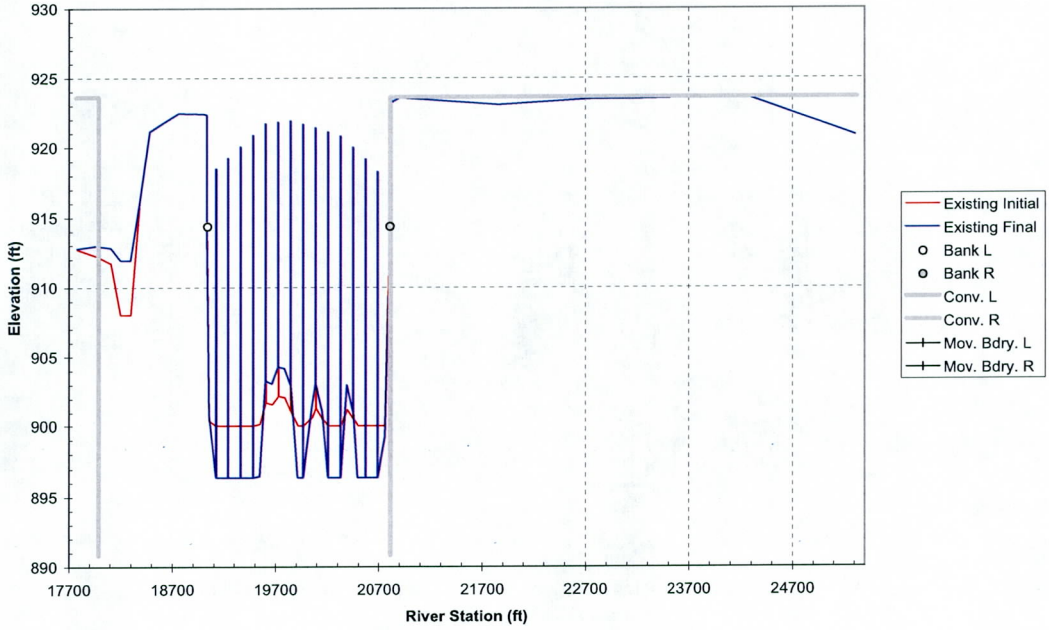

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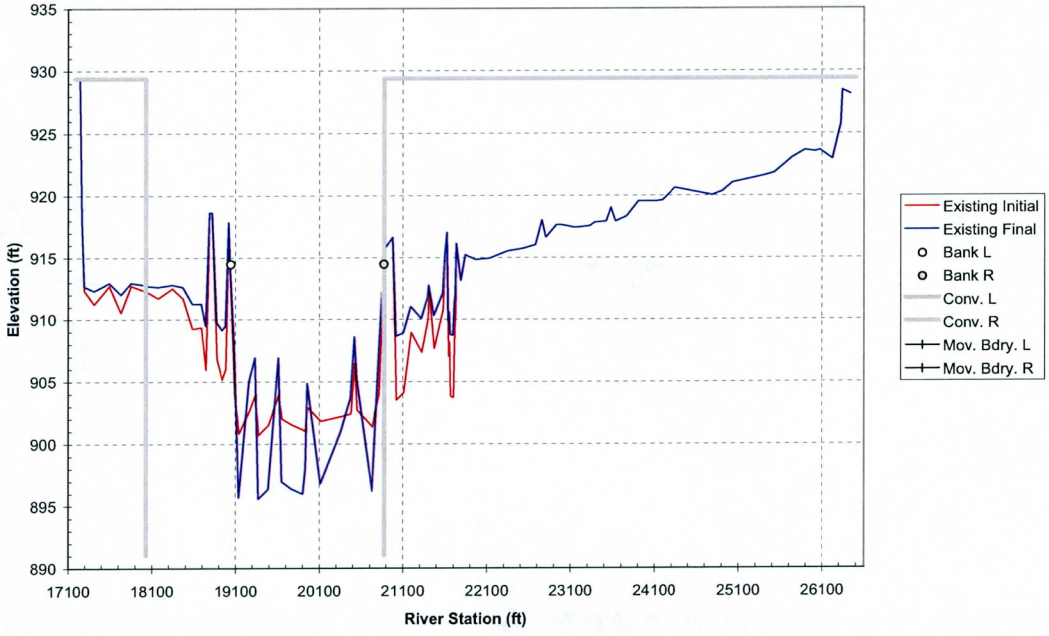

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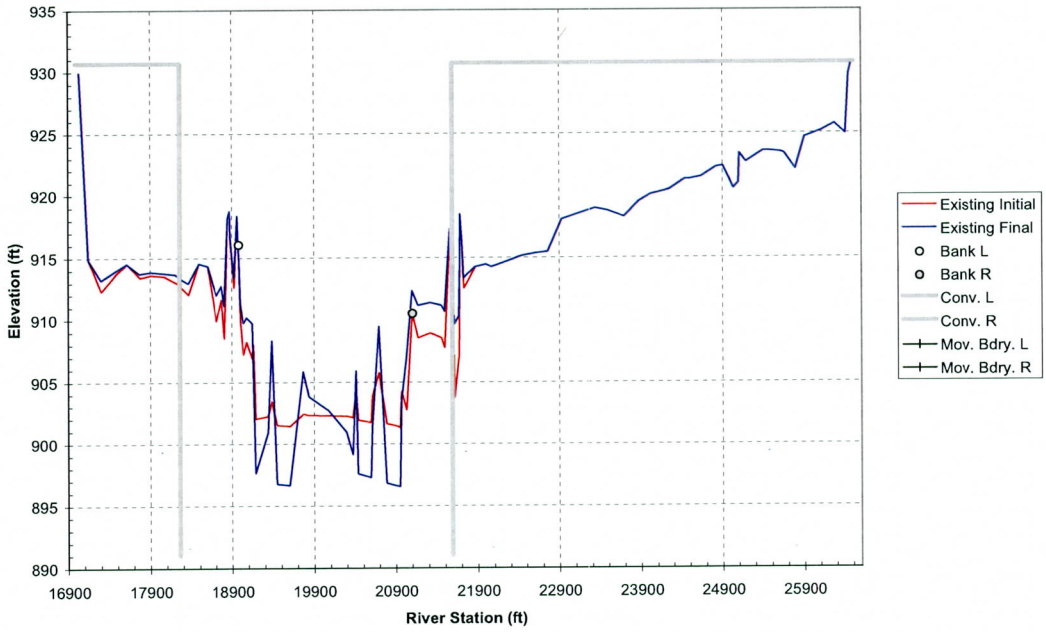

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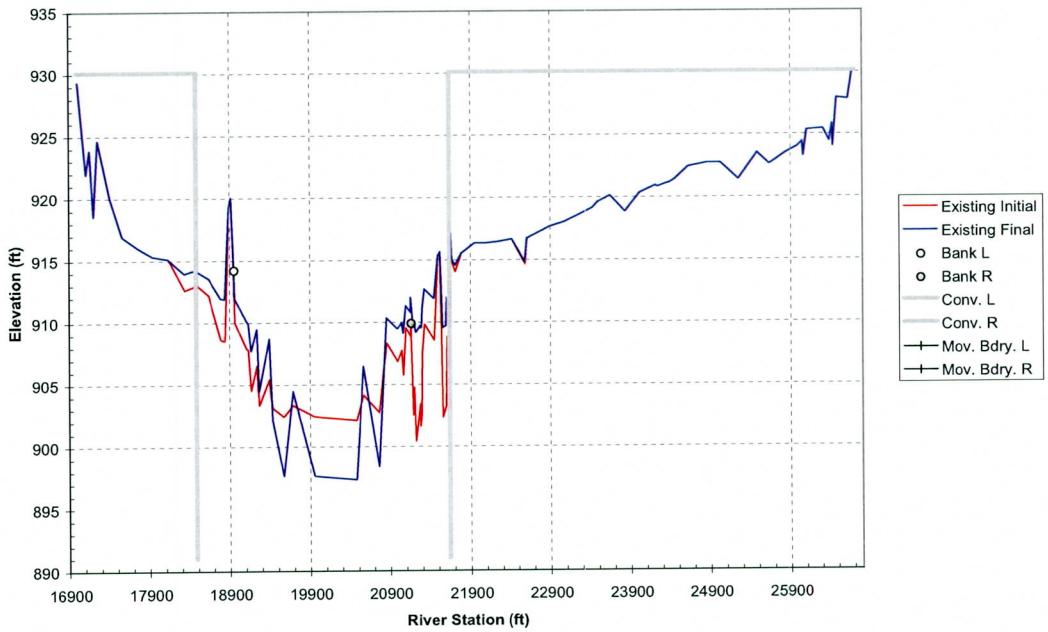

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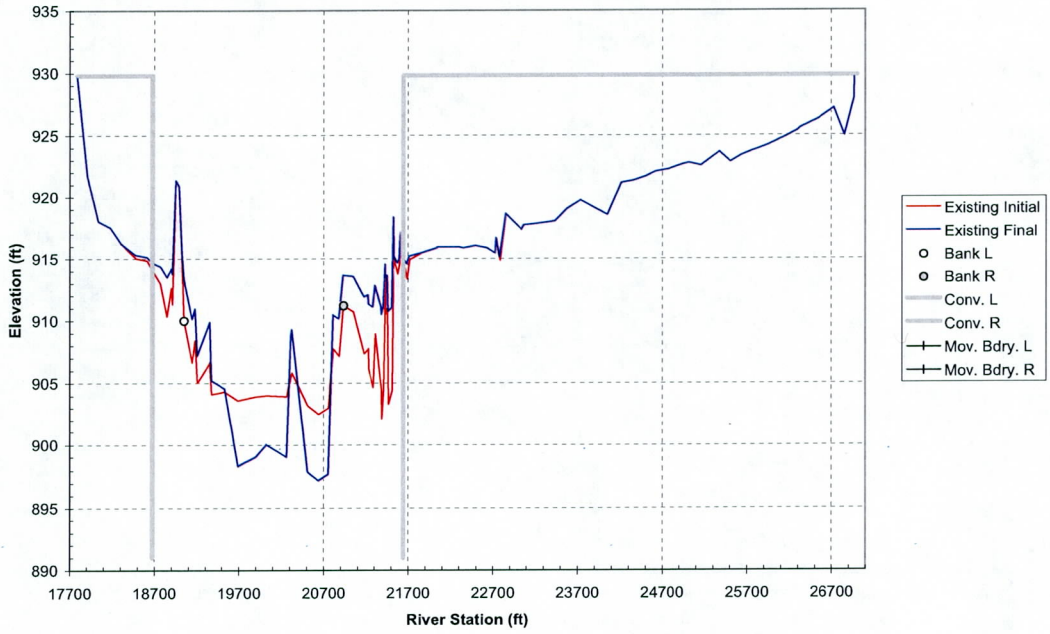

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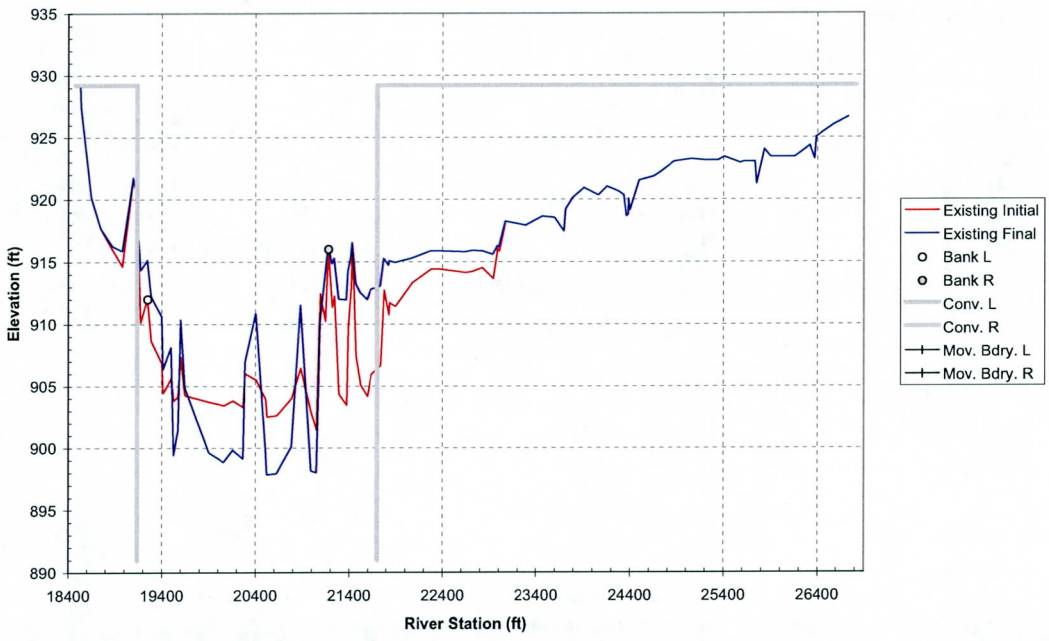

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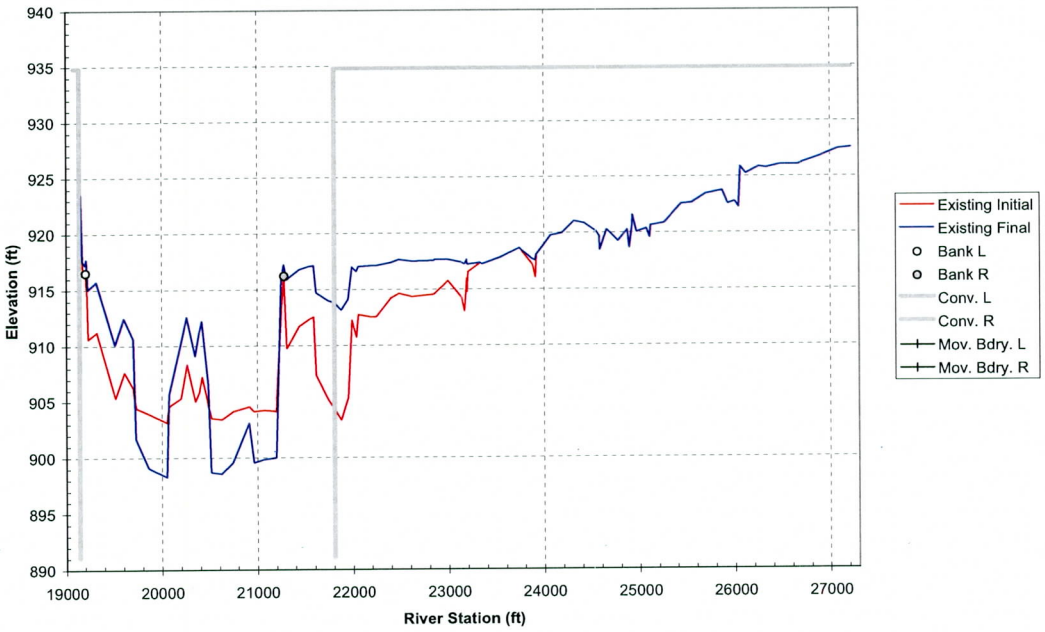

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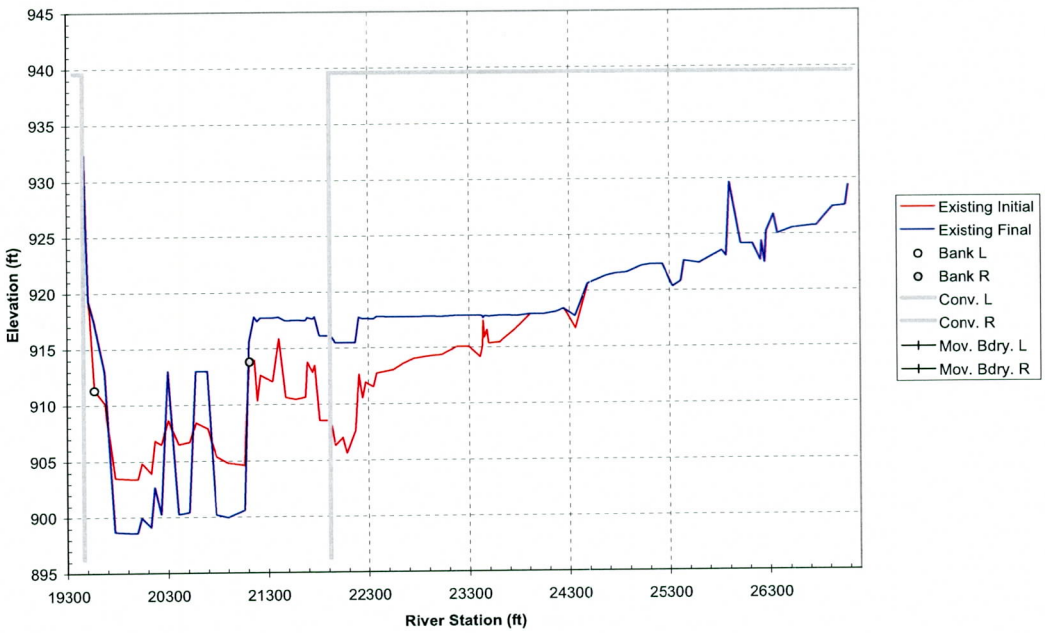


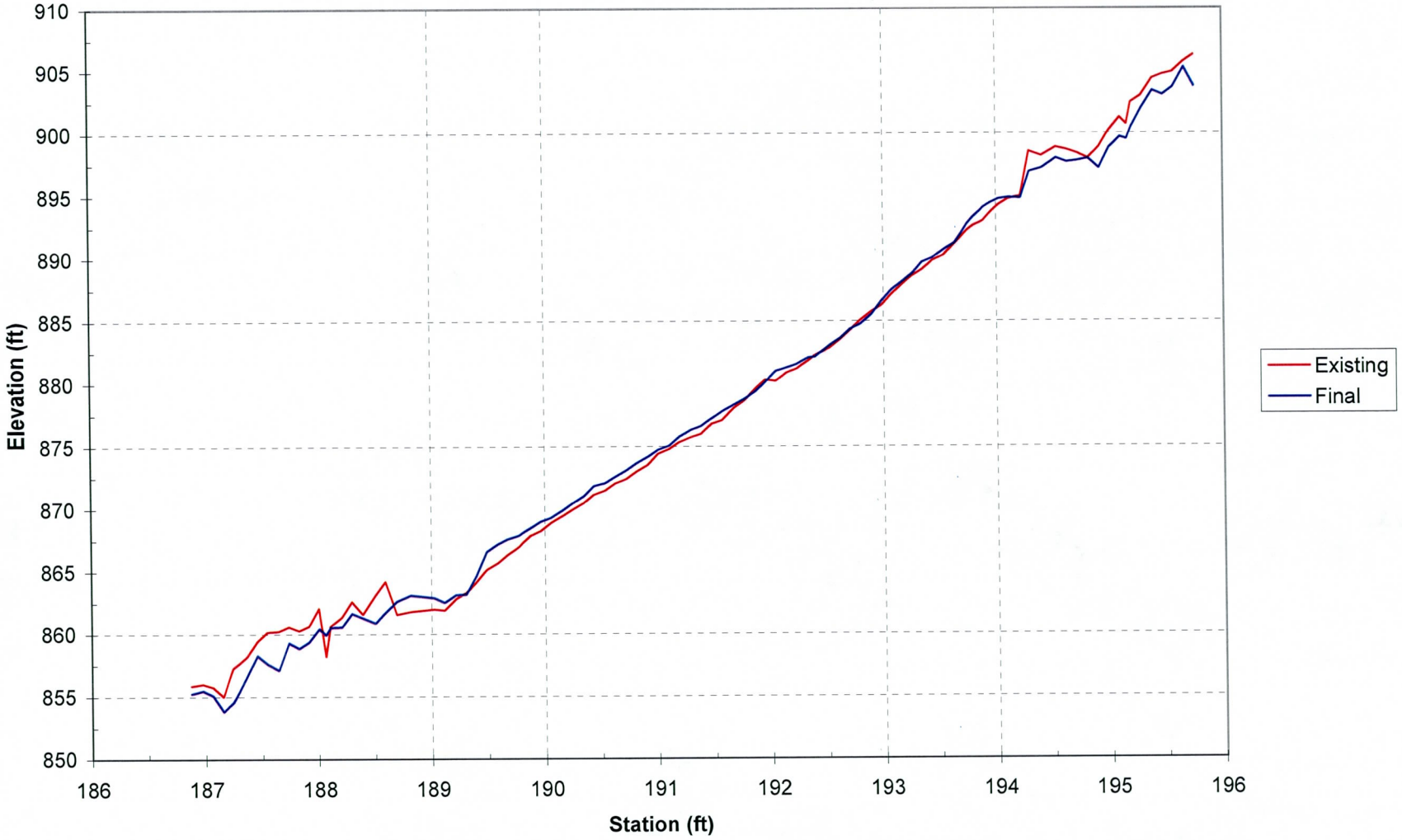
APPENDIX F

SECTION 2

Sediment Transport HEC-6T Model Results

PROPOSED CONDITIONS

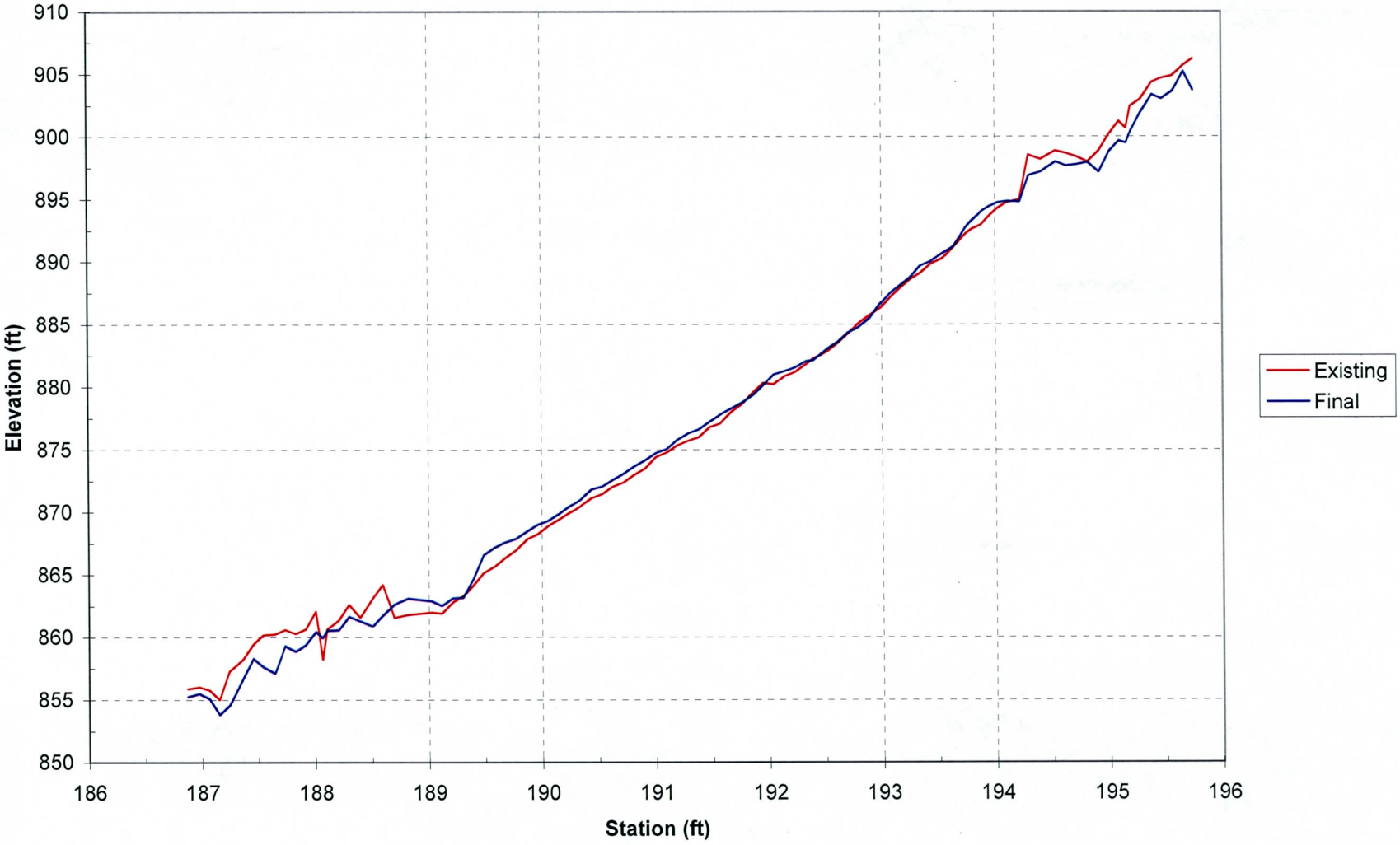
Bed Profile



105 Year Sediment Run

Proposed Conditions

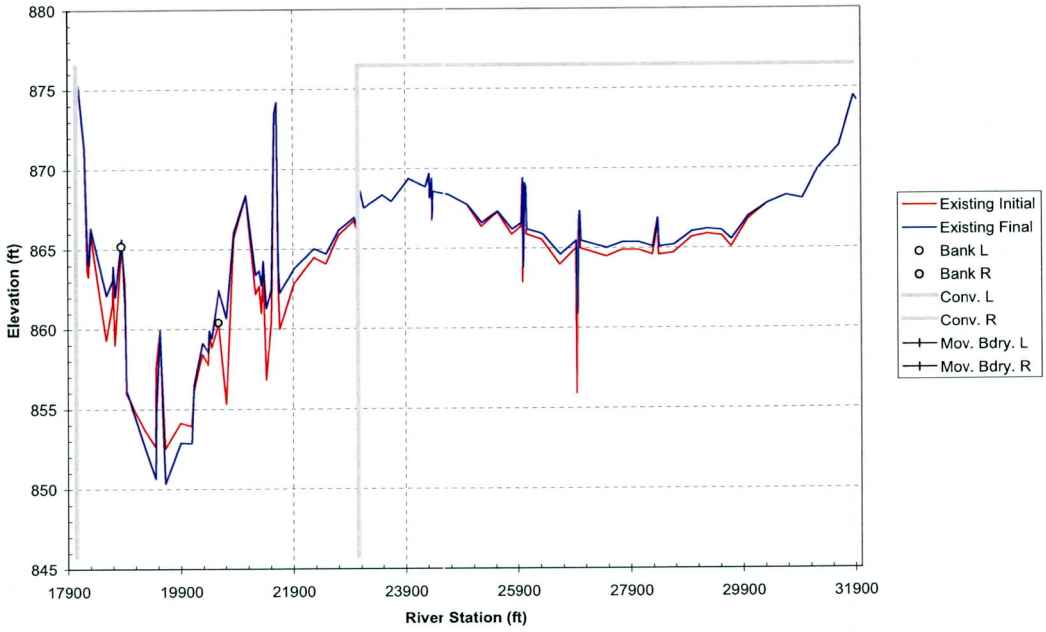
Bed Profile



105 Year Sediment Run

Proposed Conditions

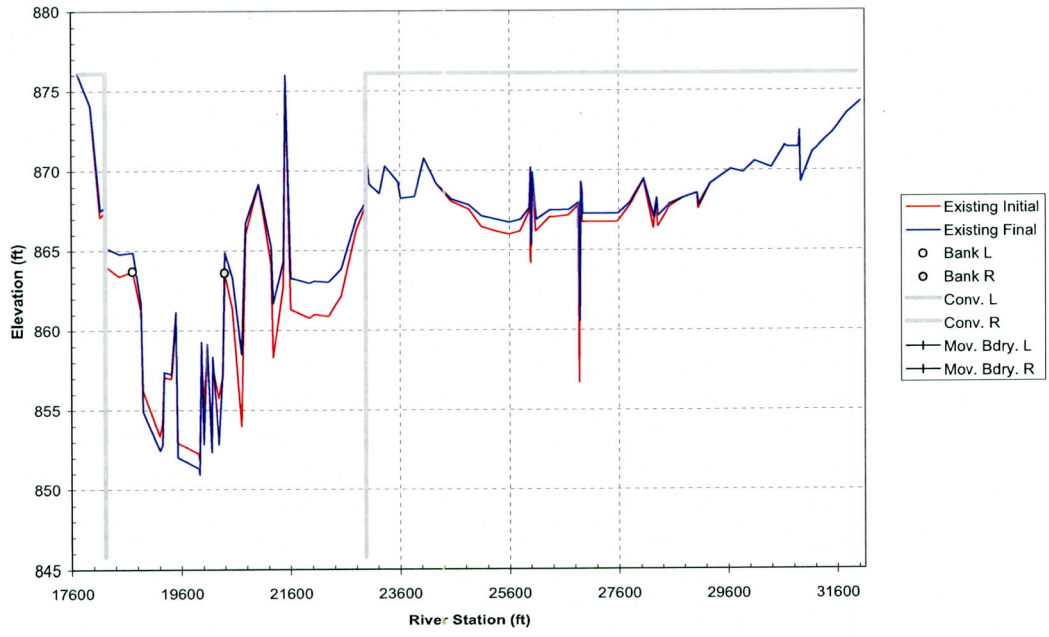
Cross Section 186.87



105 Year Run

Proposed Conditions

Cross Section 186.97



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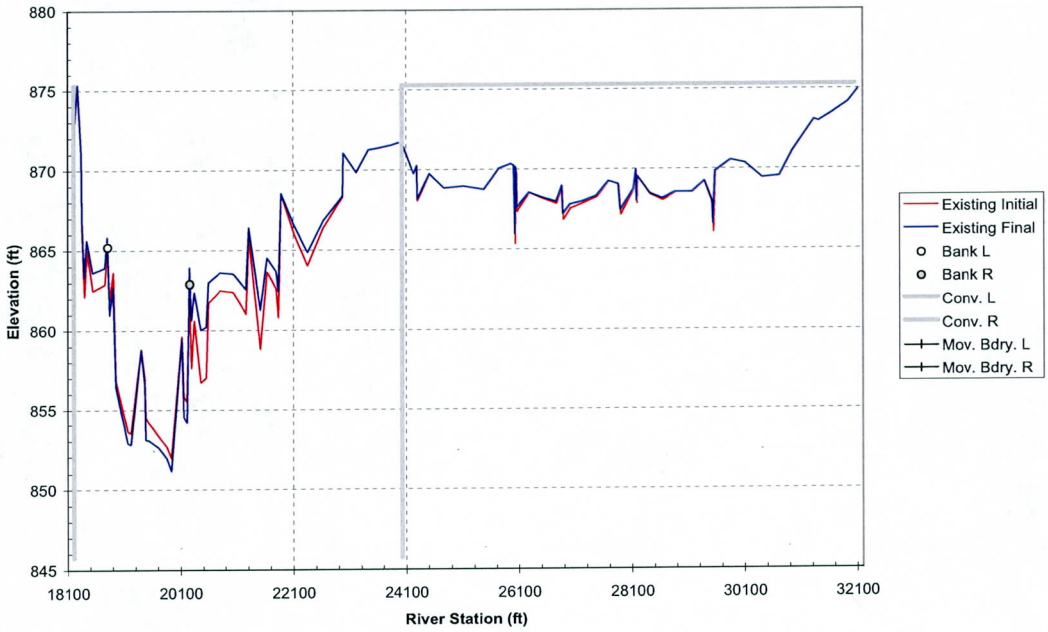

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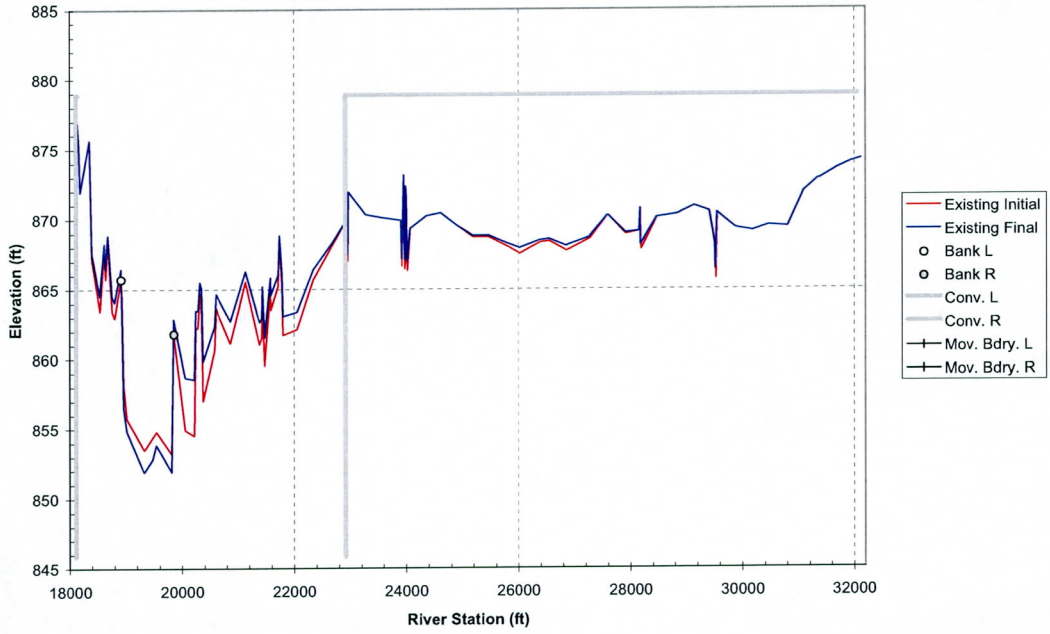

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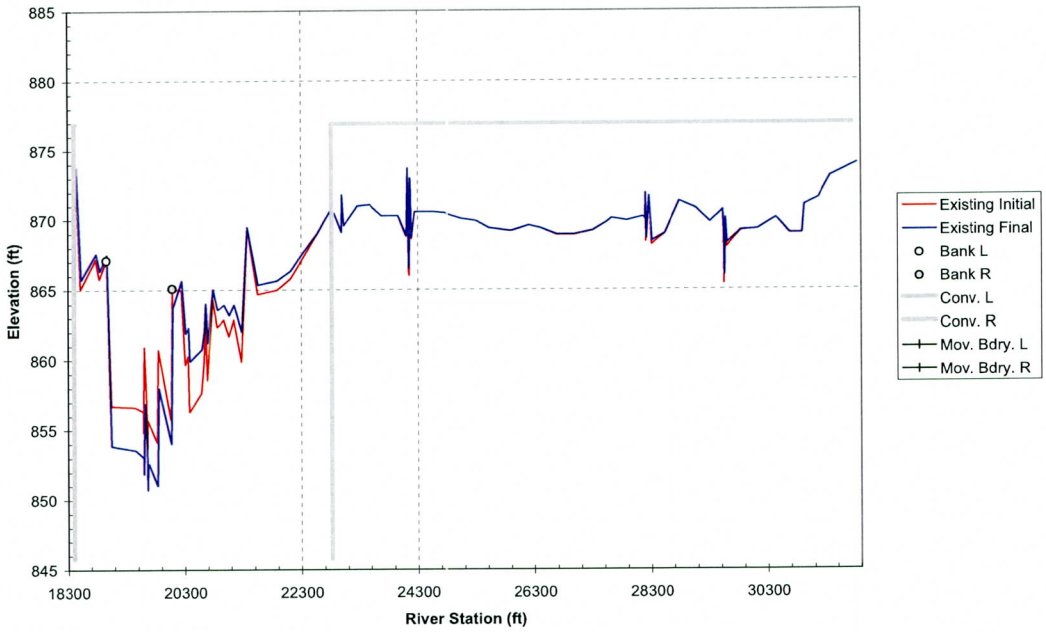

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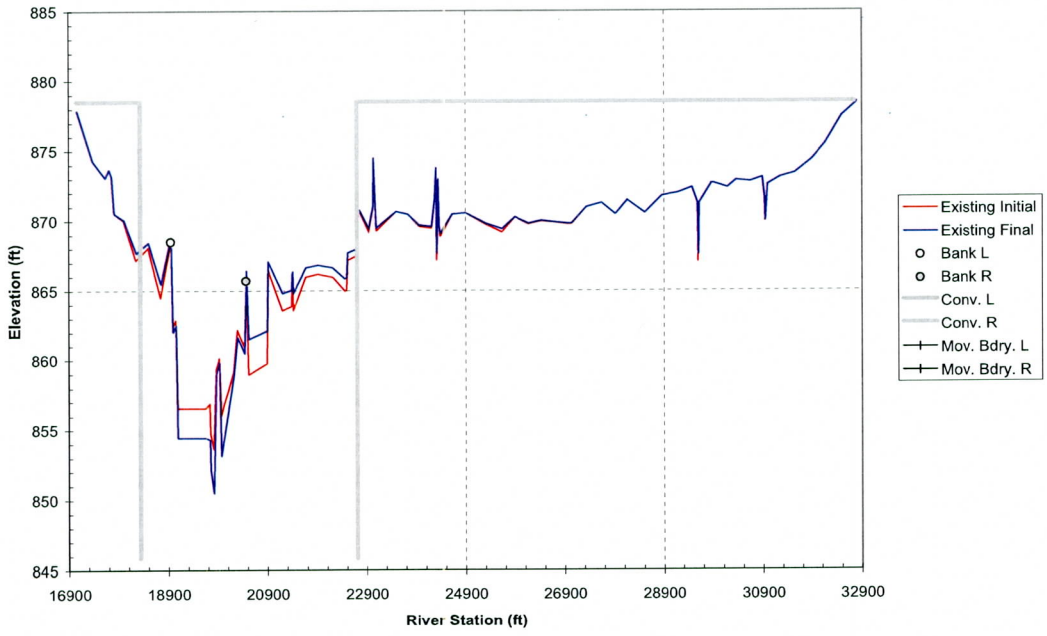

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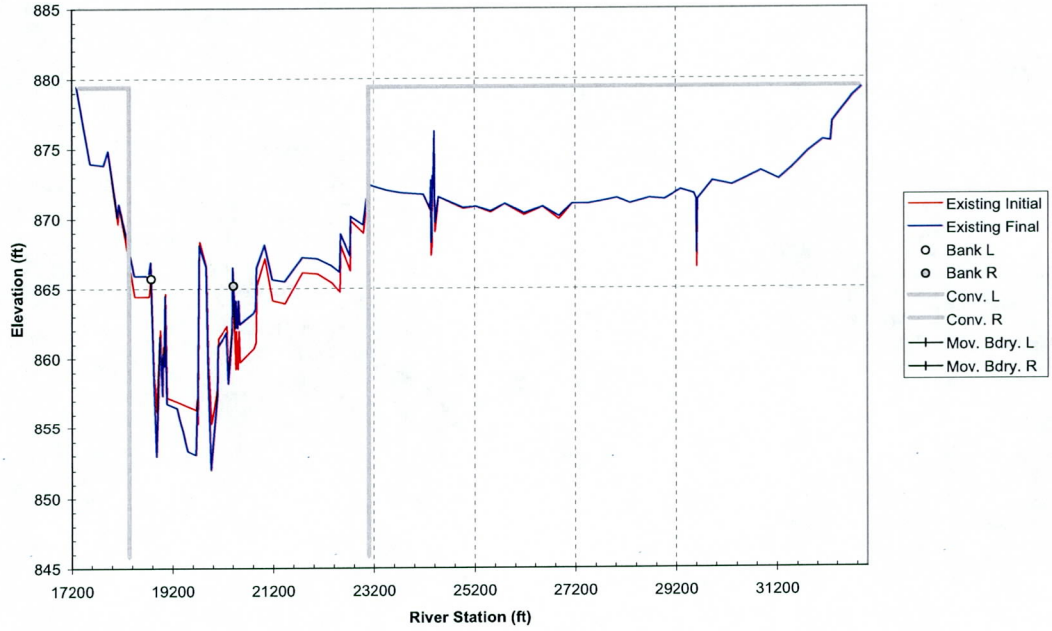

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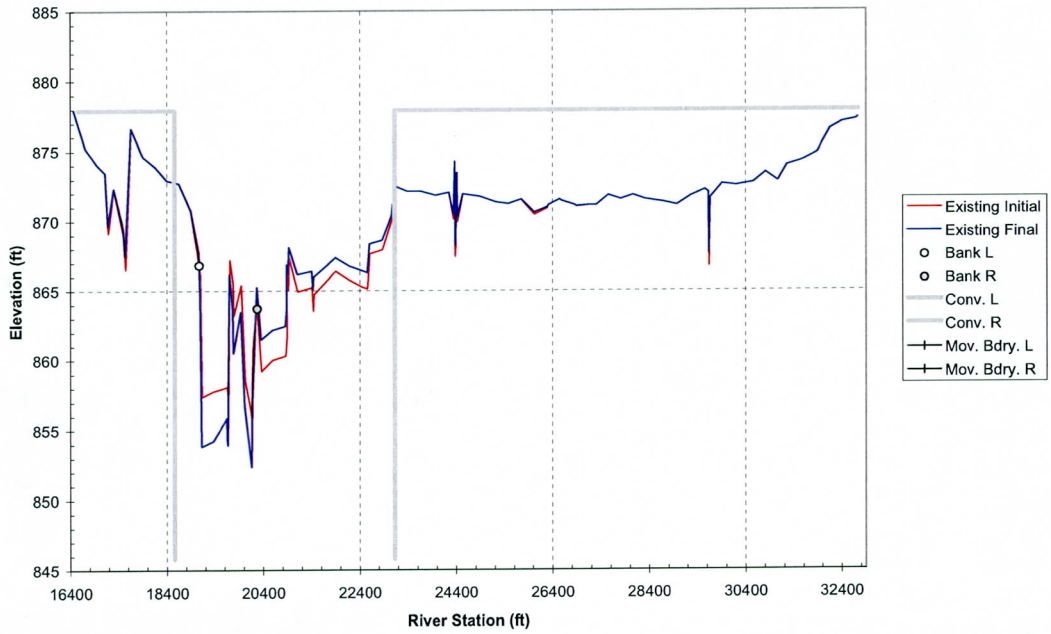

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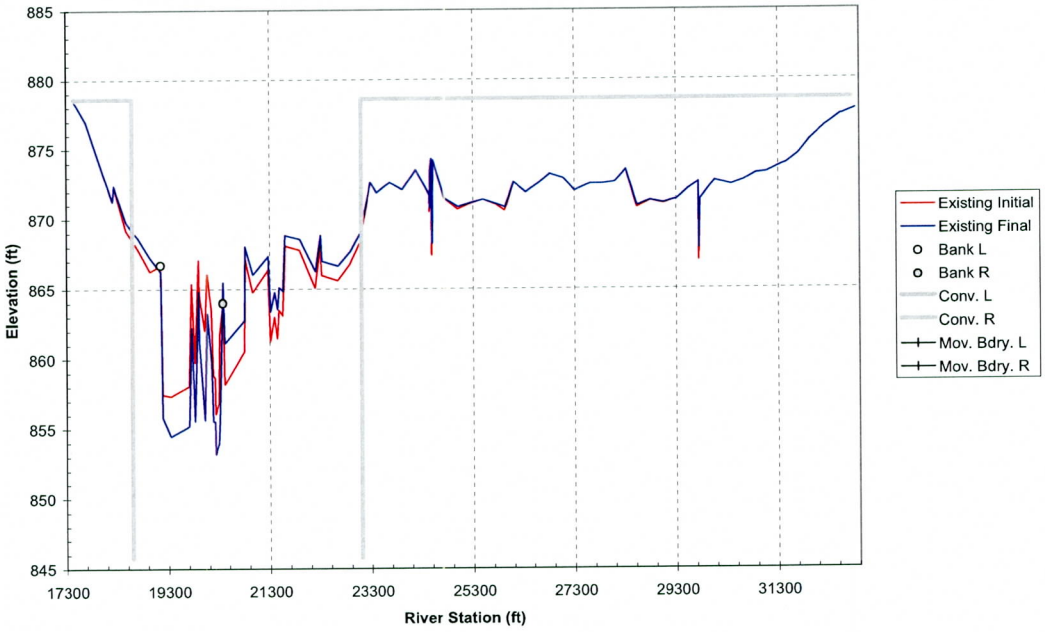
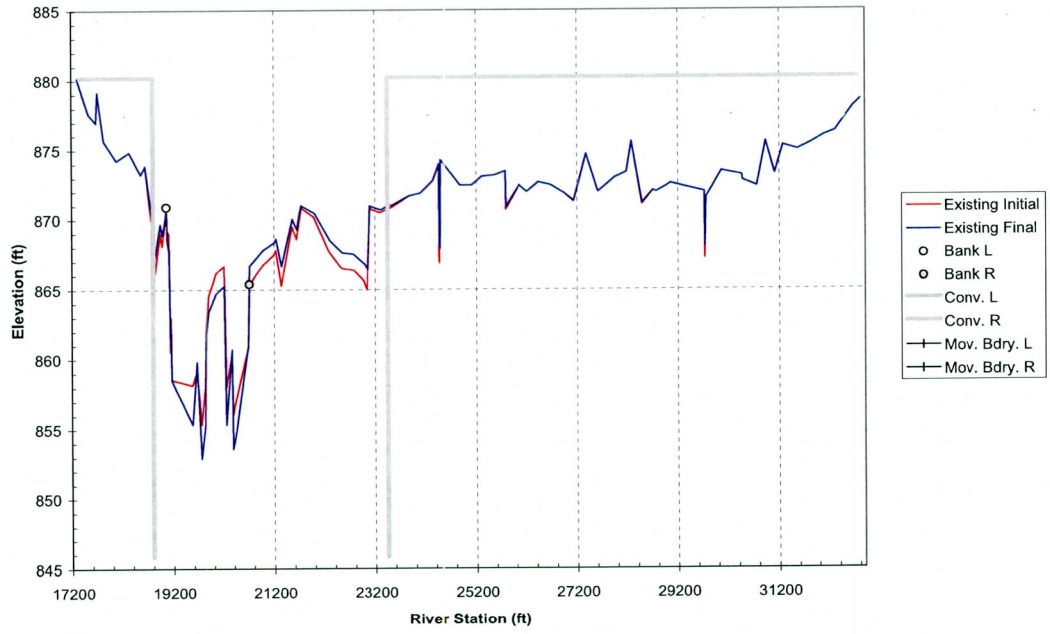


Cross Section 187.73



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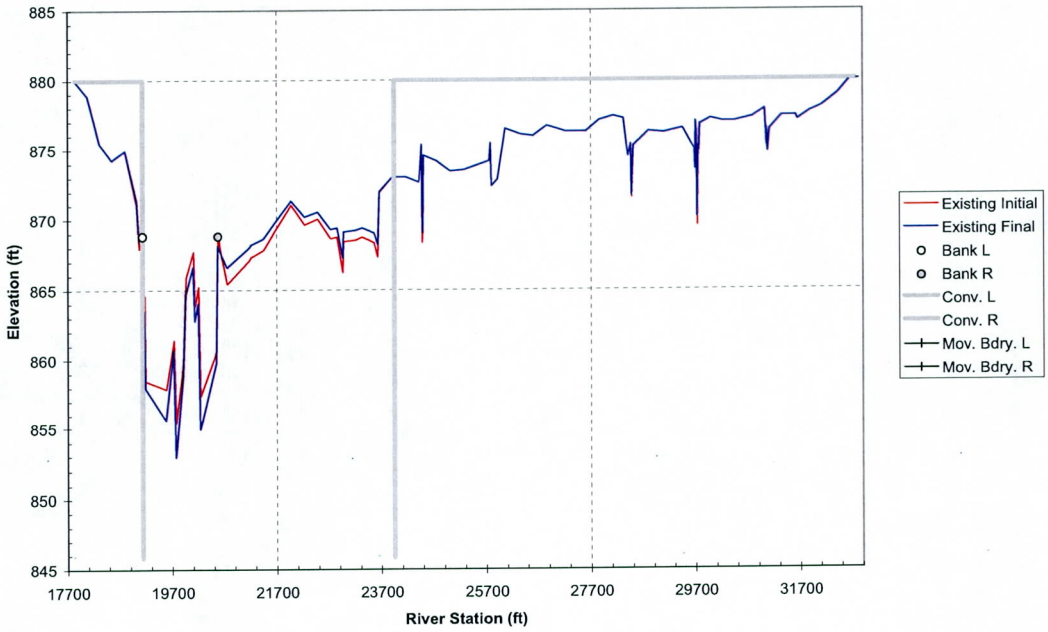

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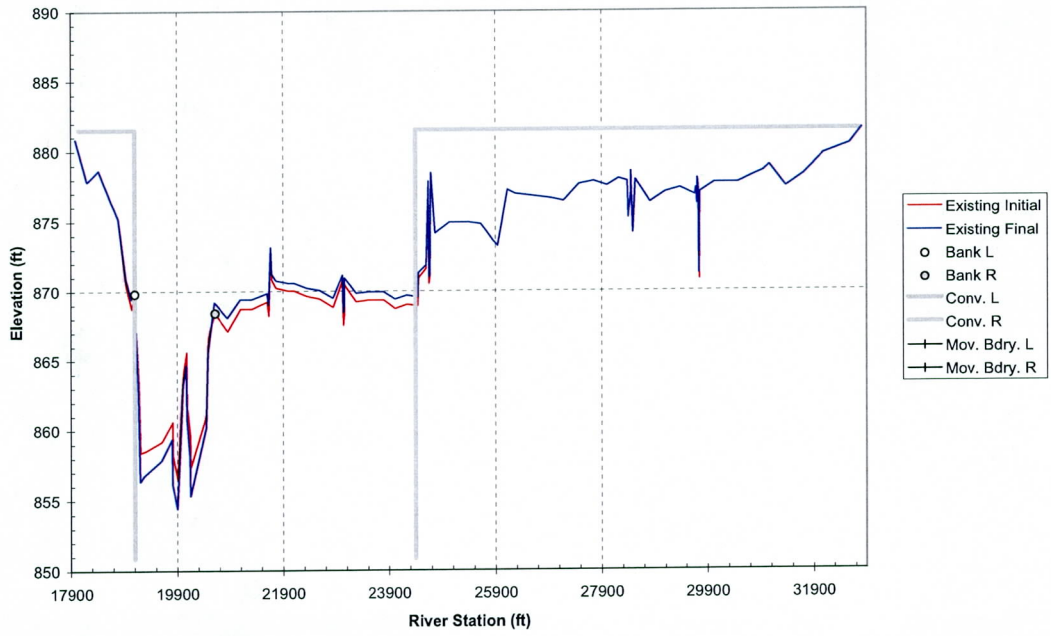

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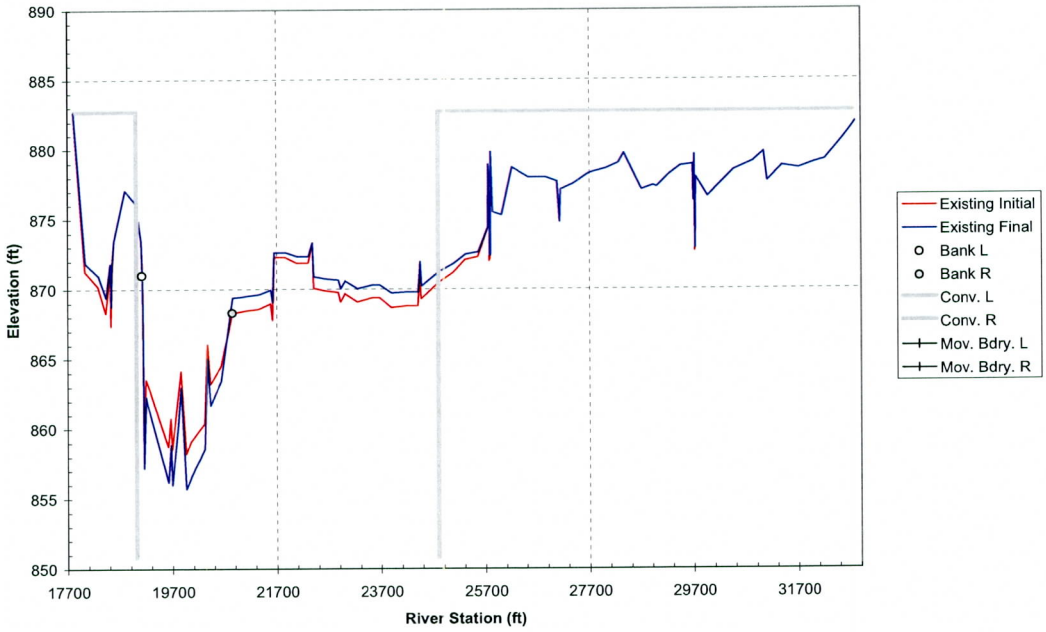

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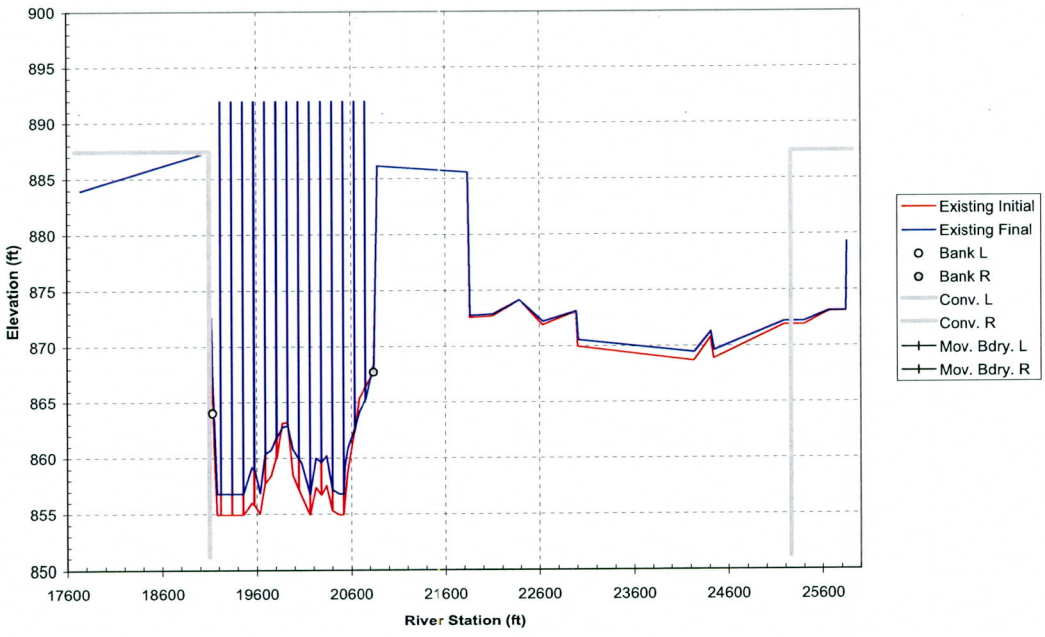

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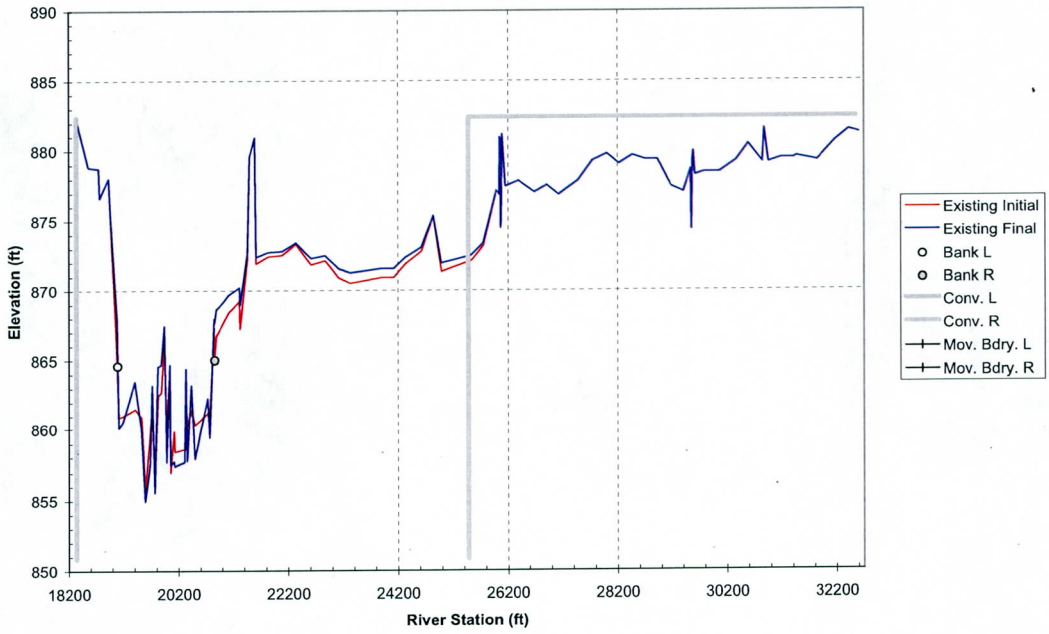

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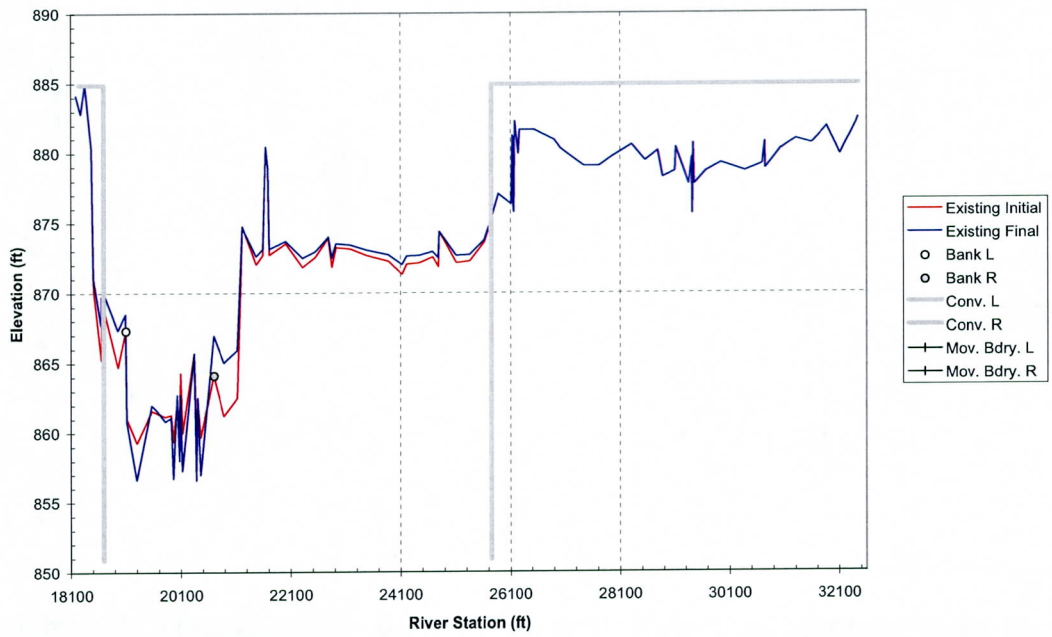

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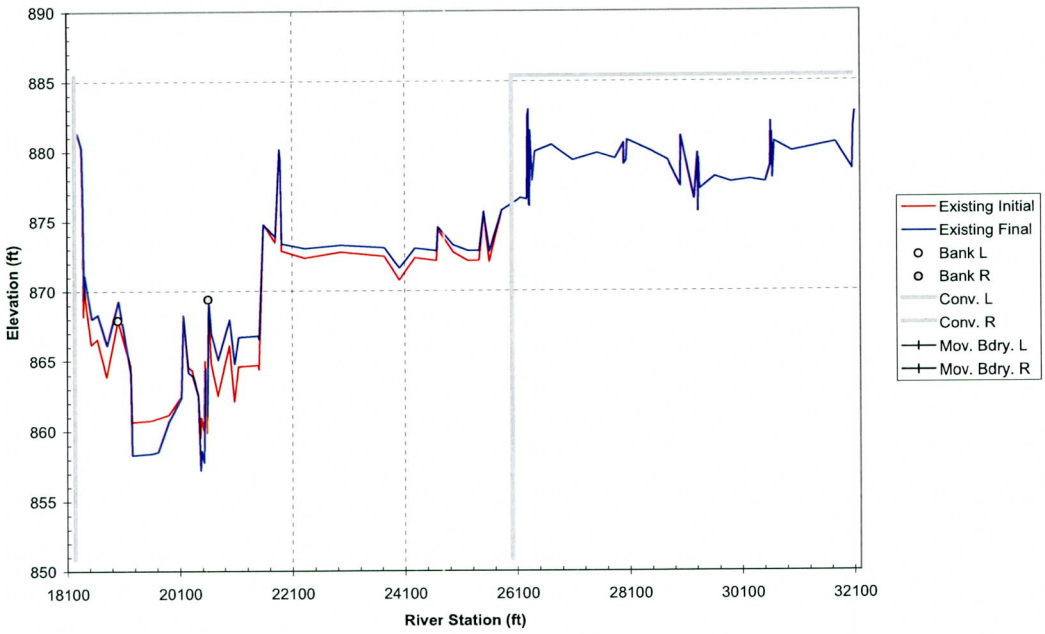
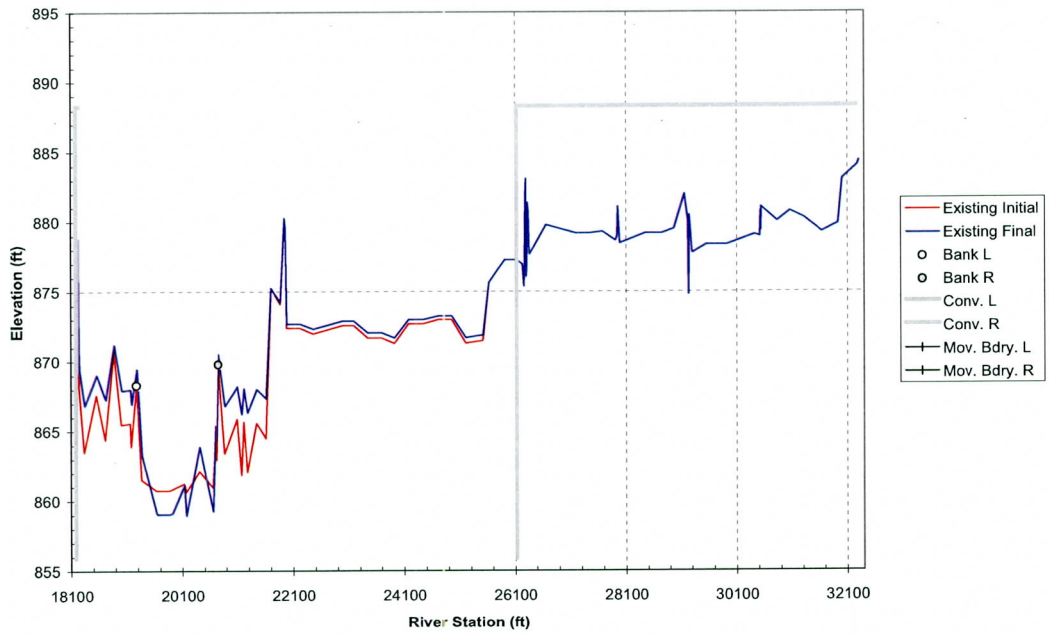


Cross Section 188.39



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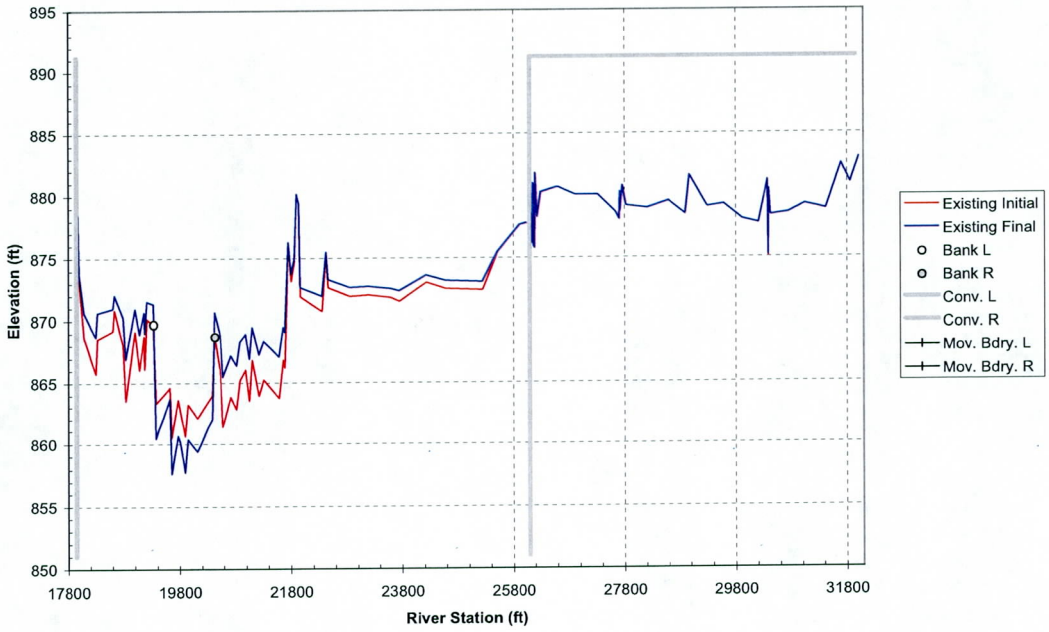

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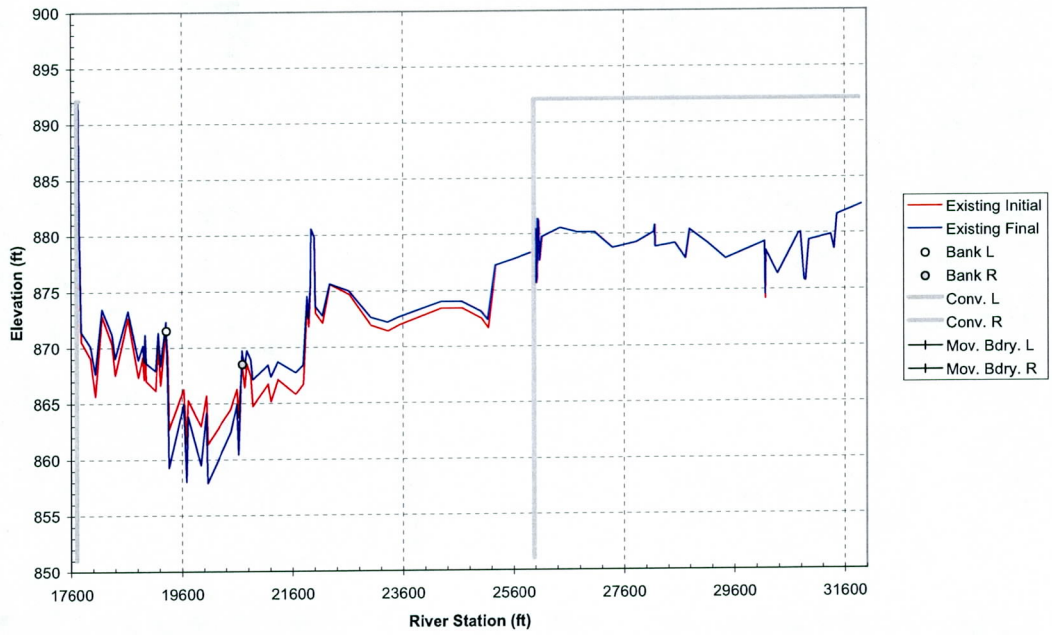

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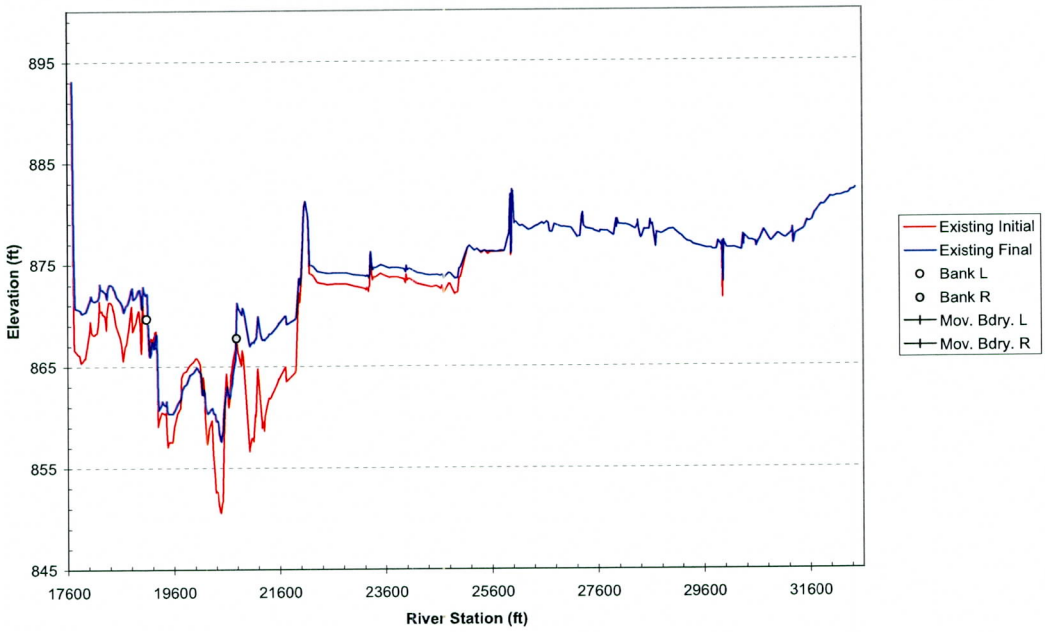

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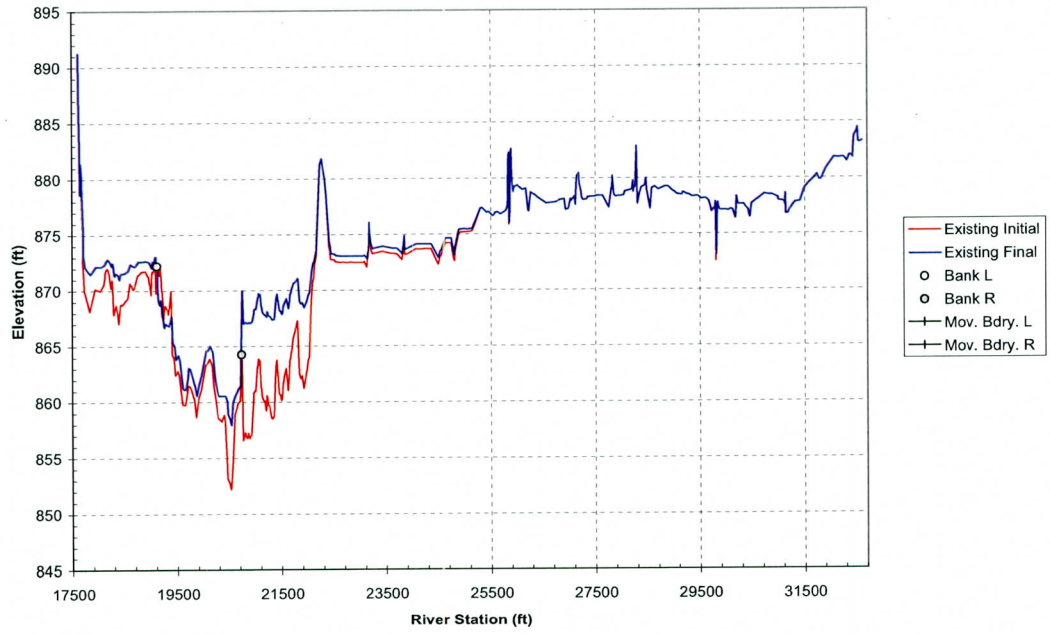

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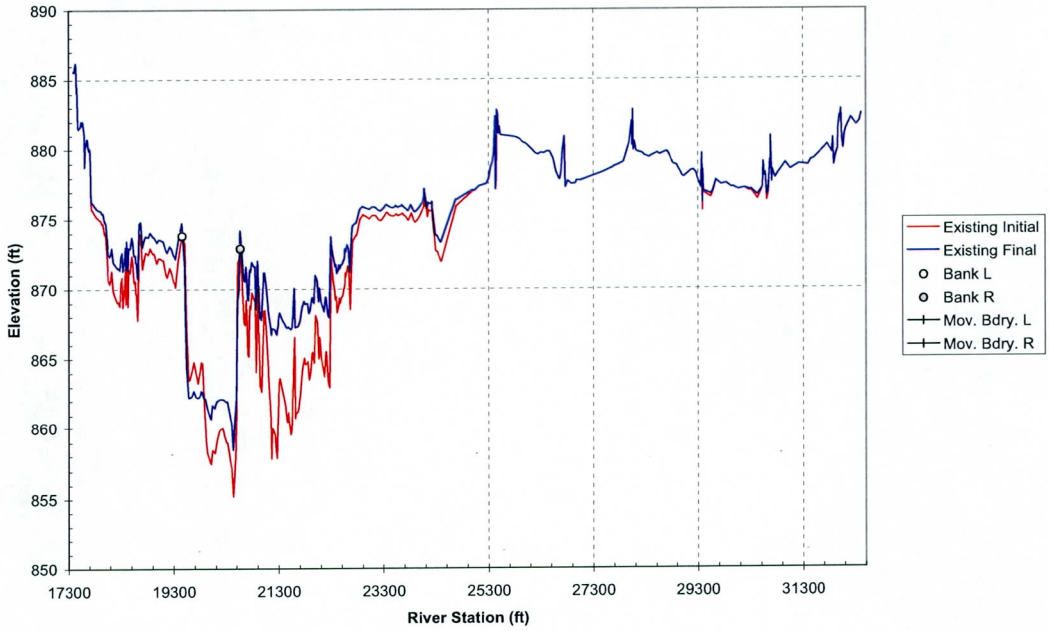

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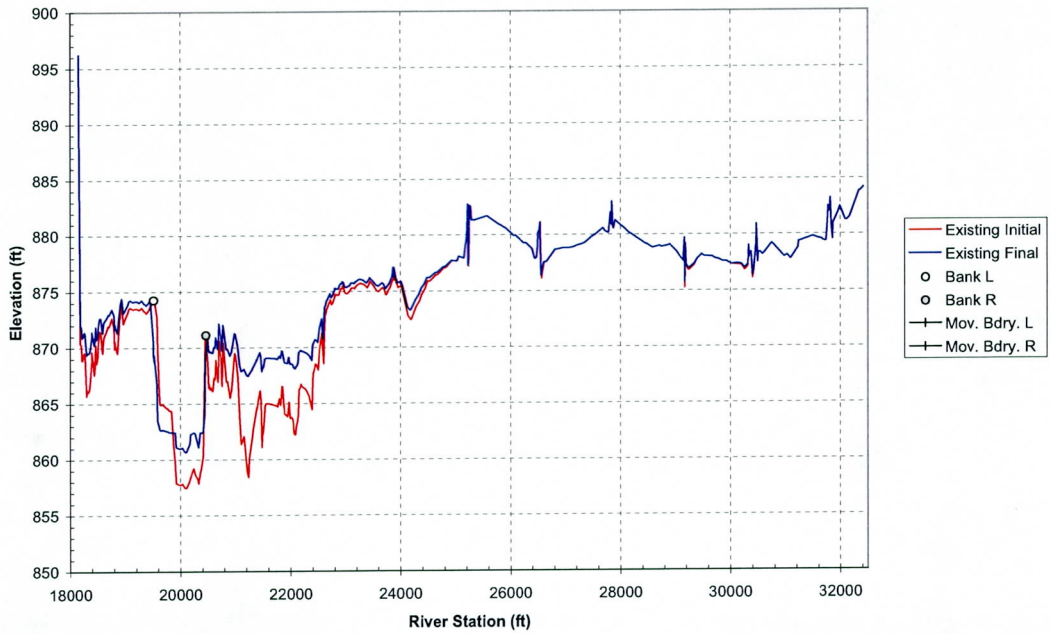

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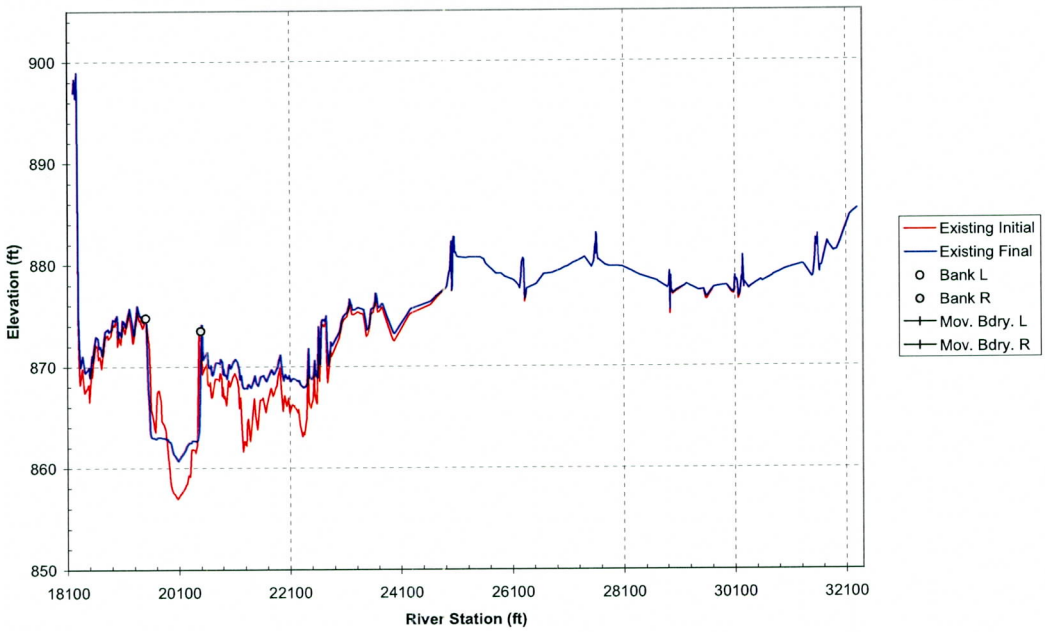

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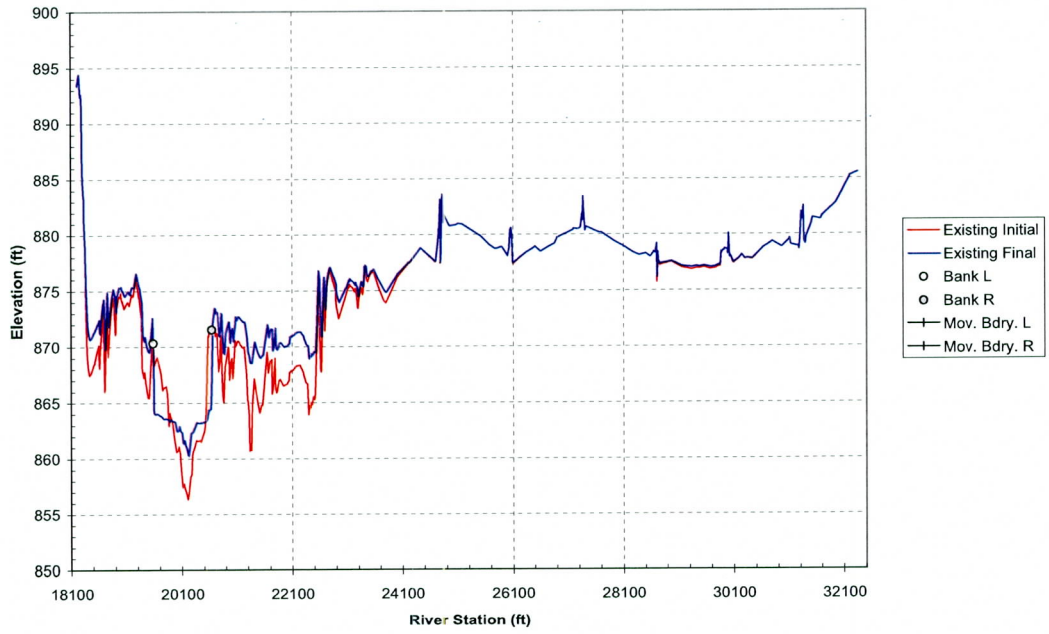

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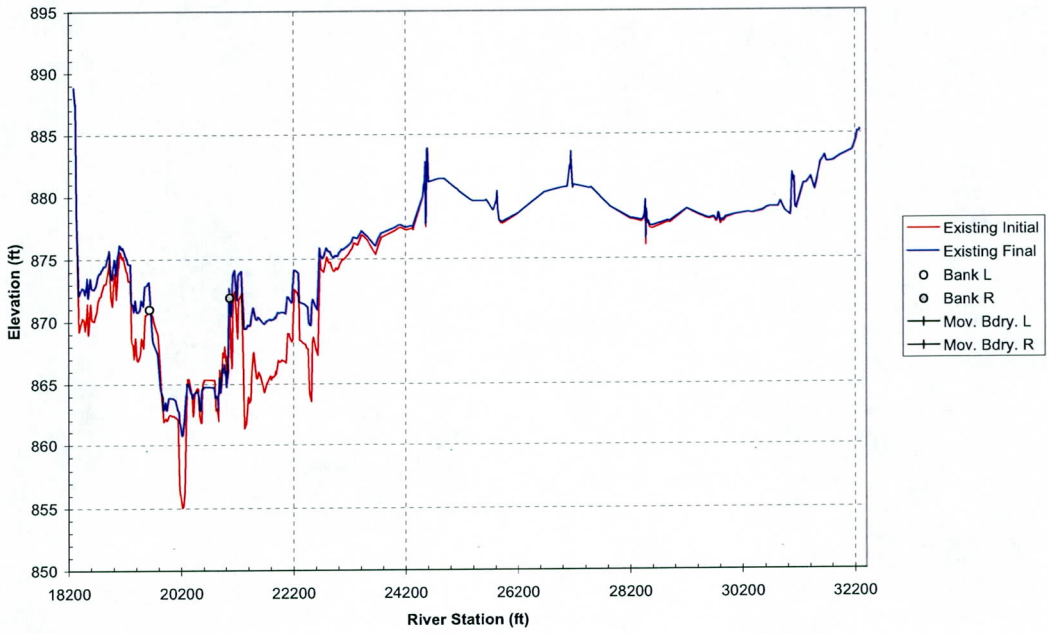

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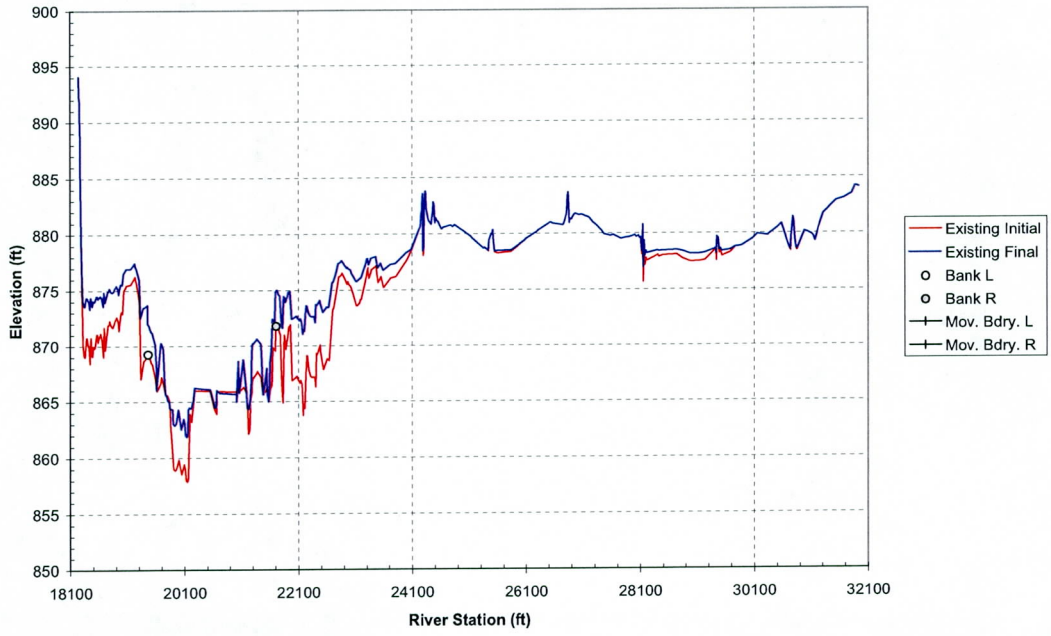

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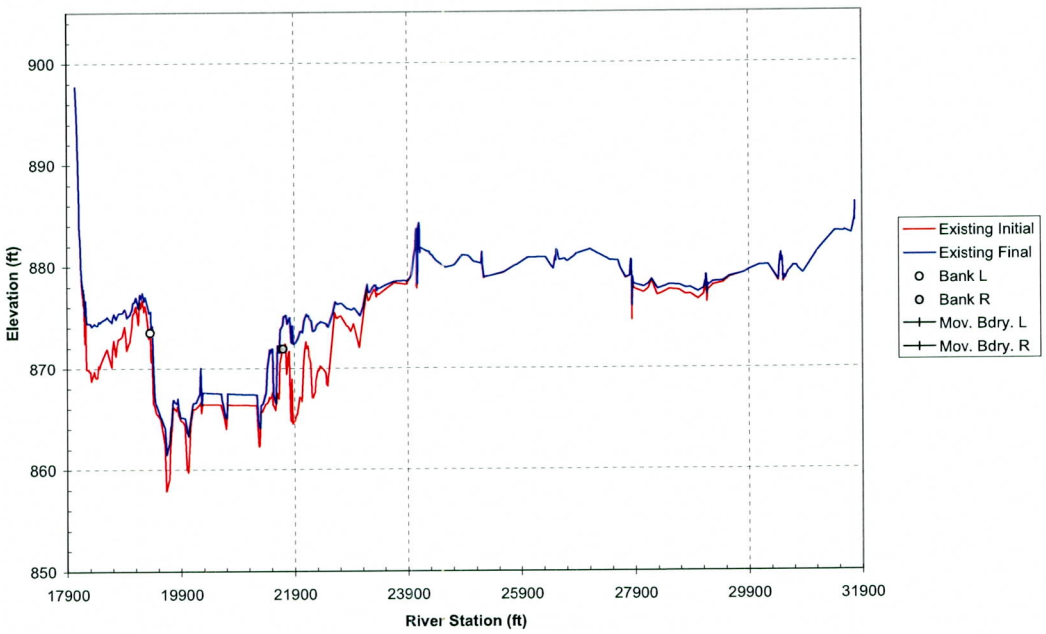

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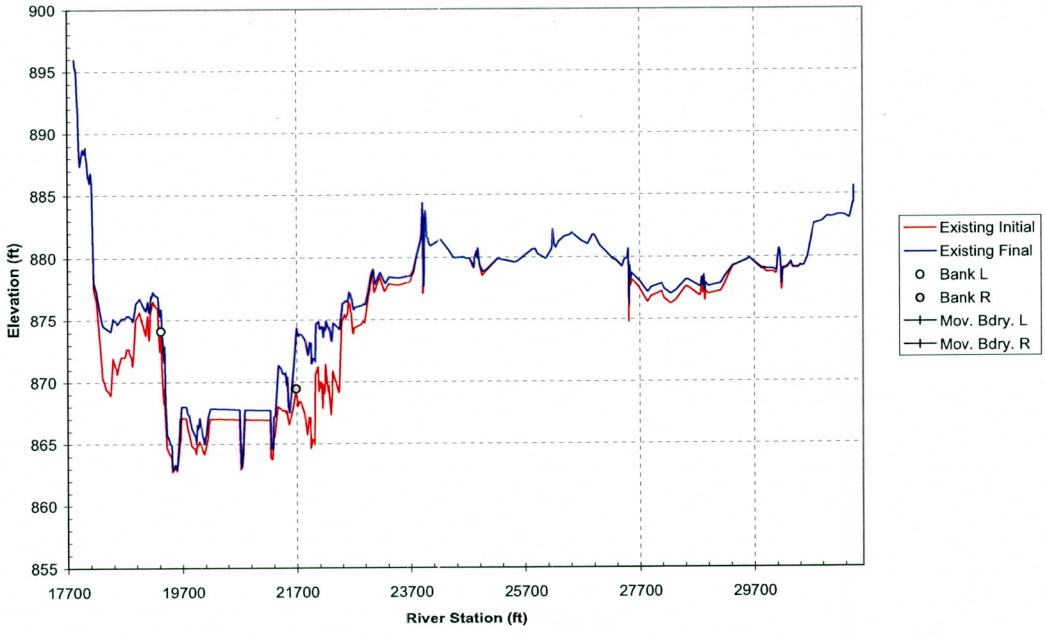

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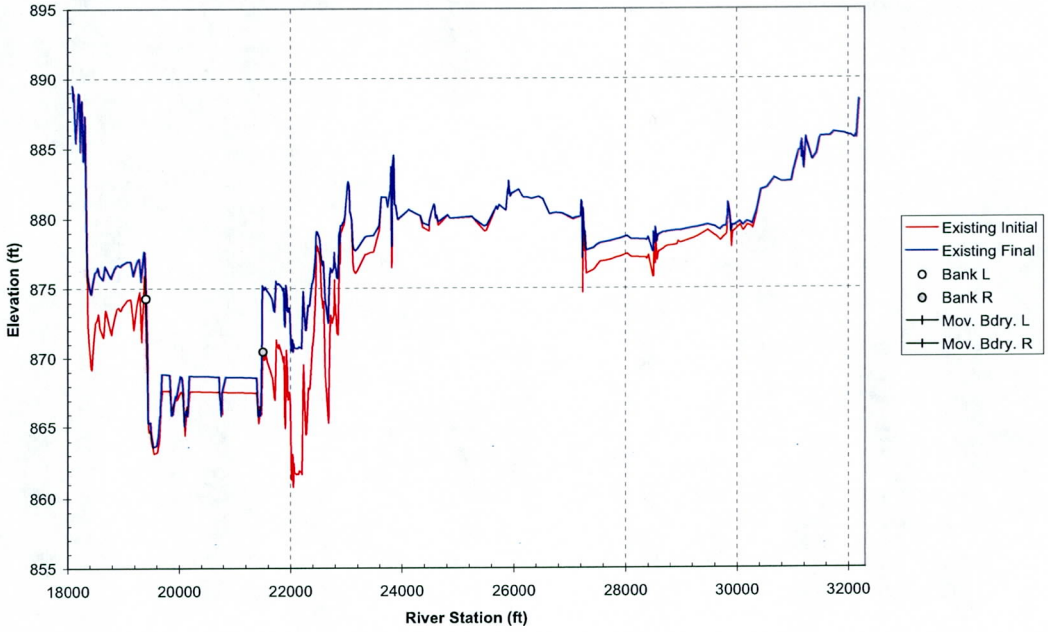

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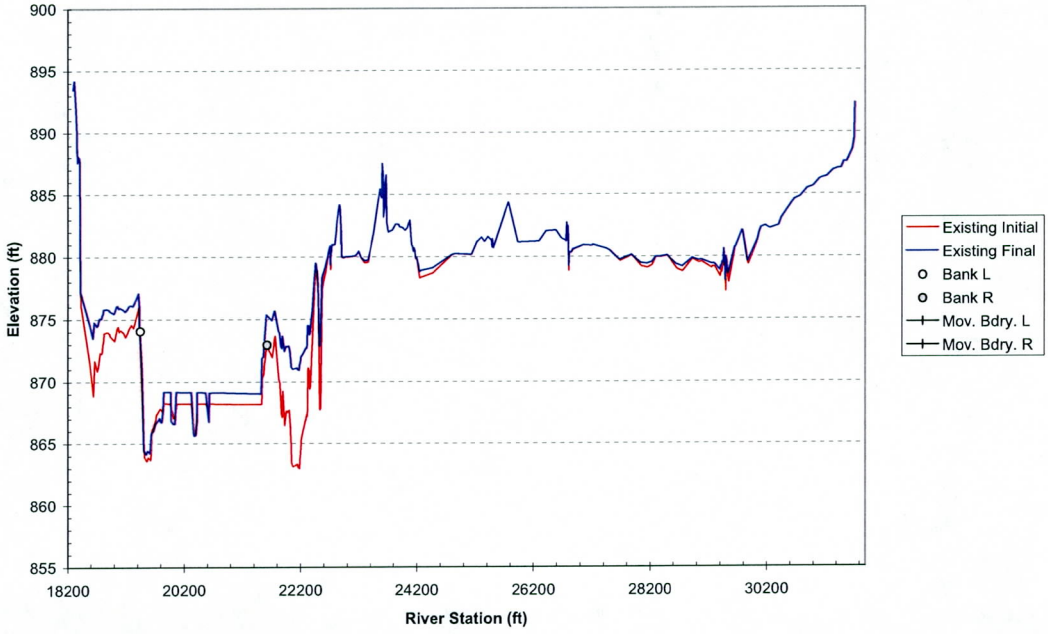

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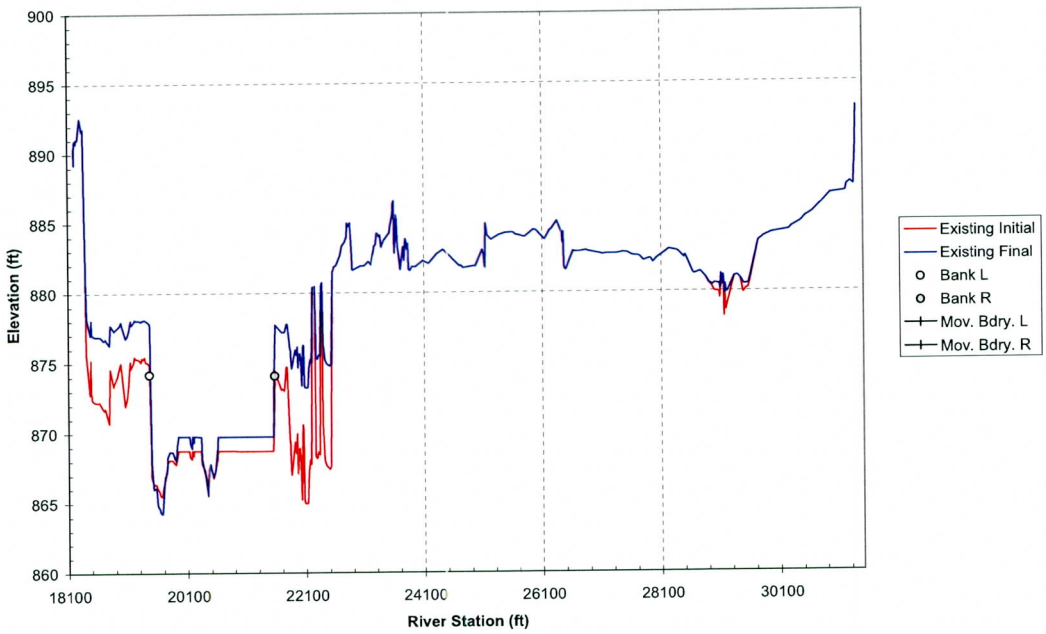

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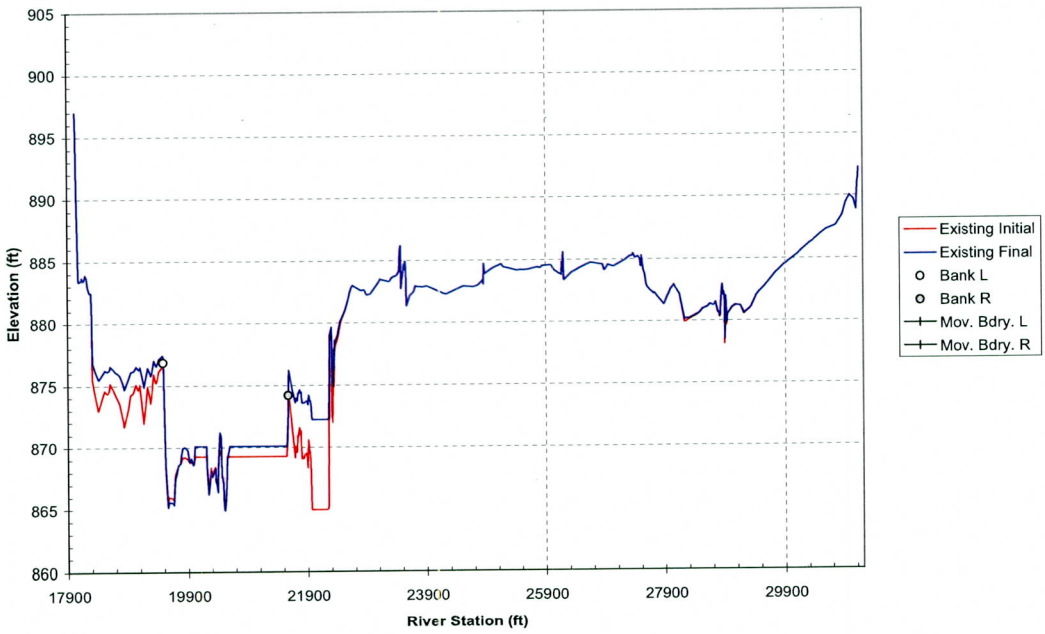
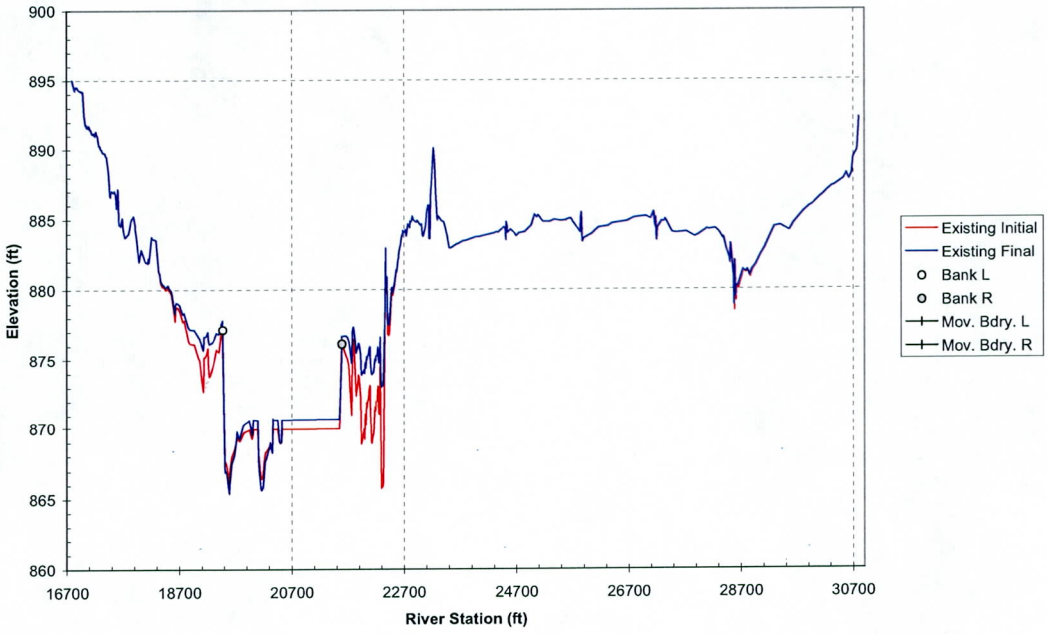


Cross Section 190.15



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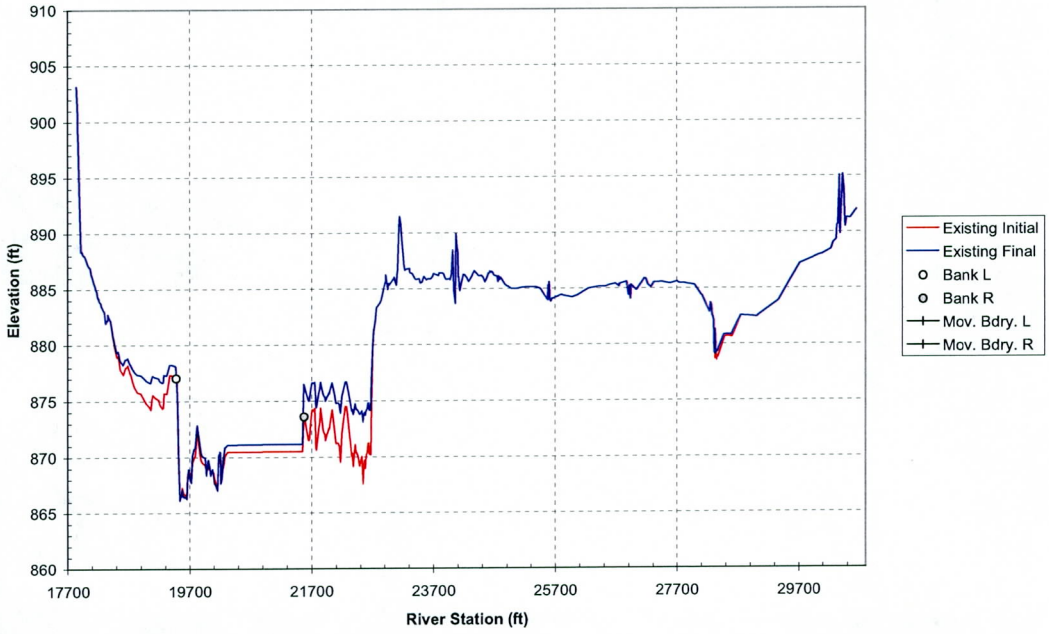

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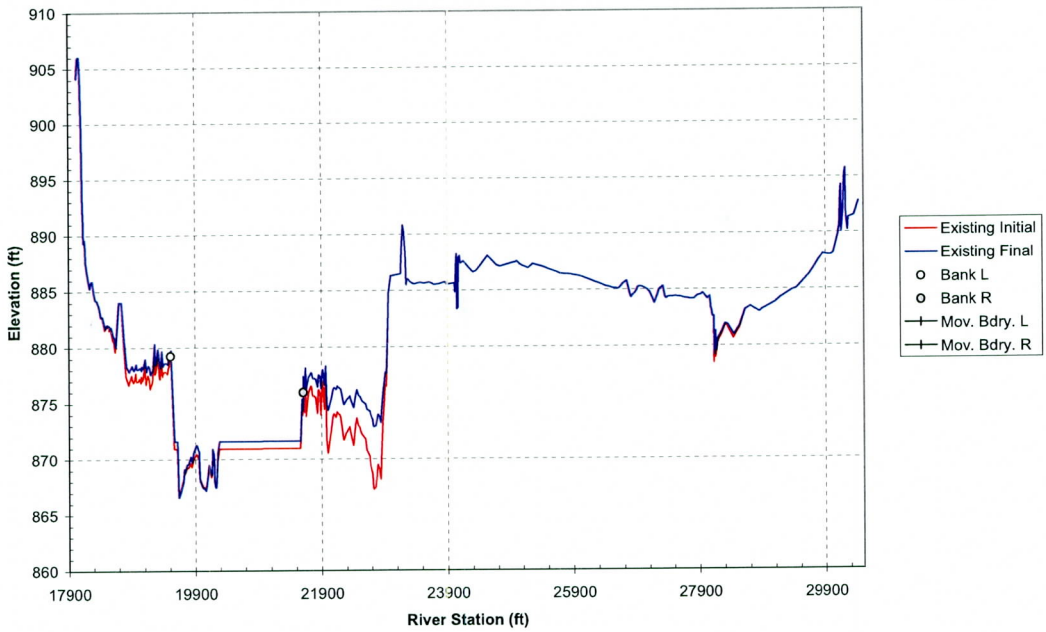

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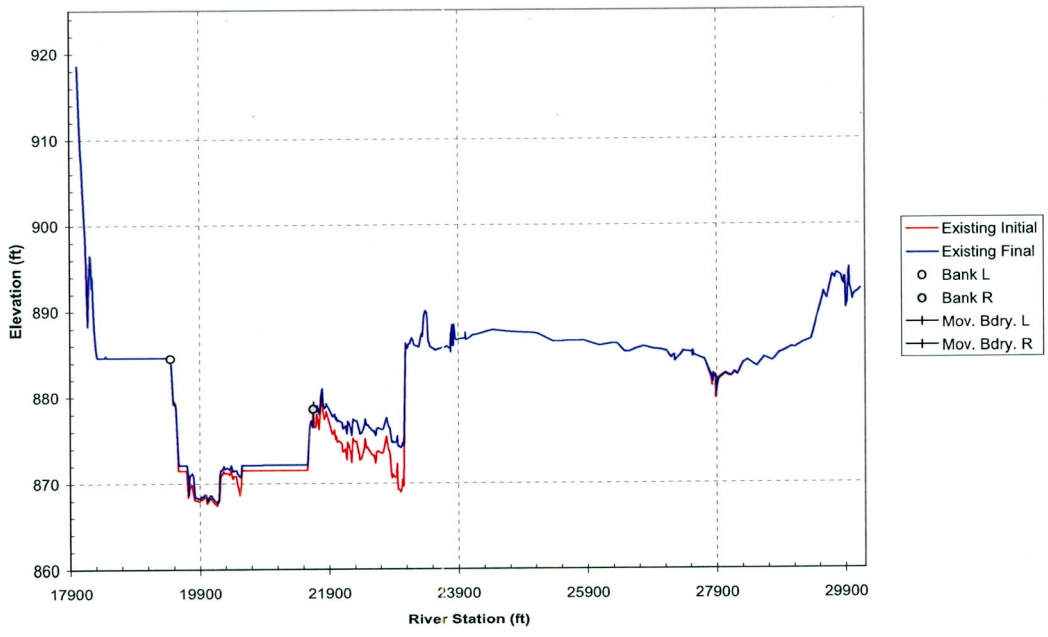

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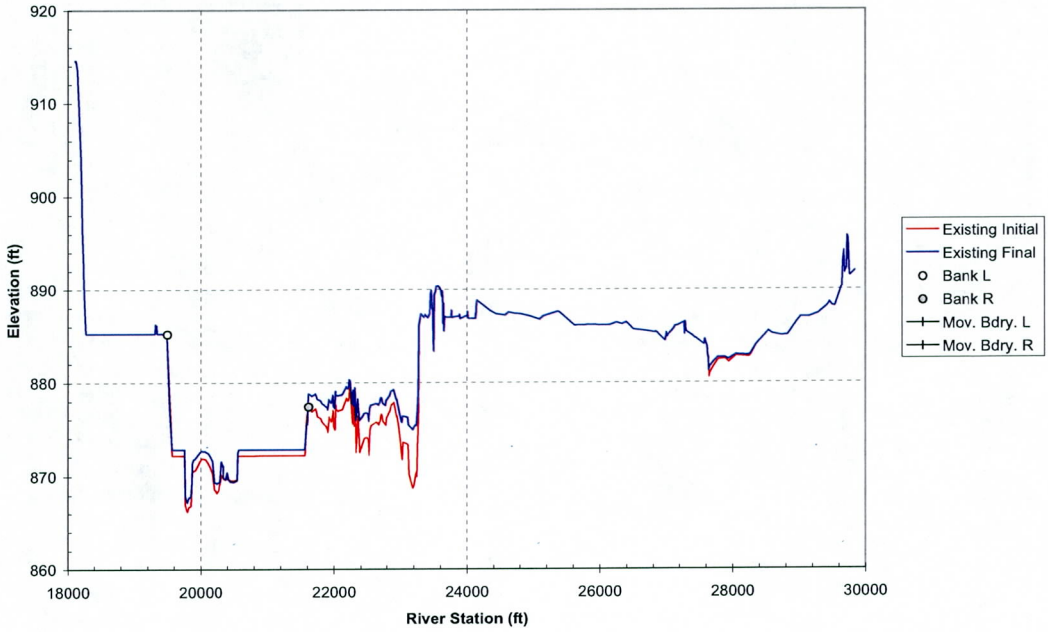

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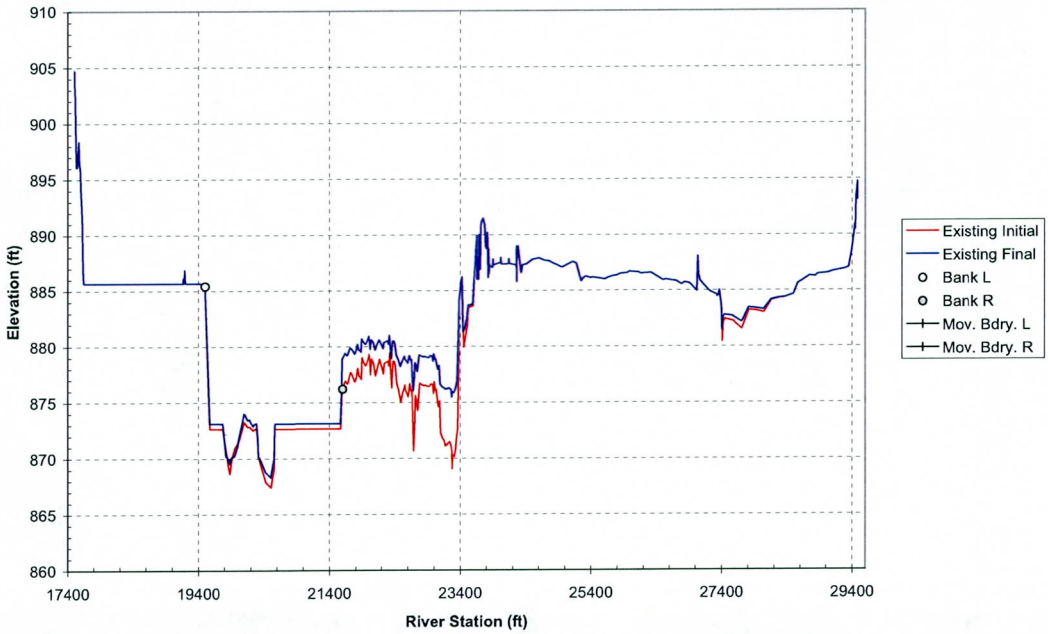

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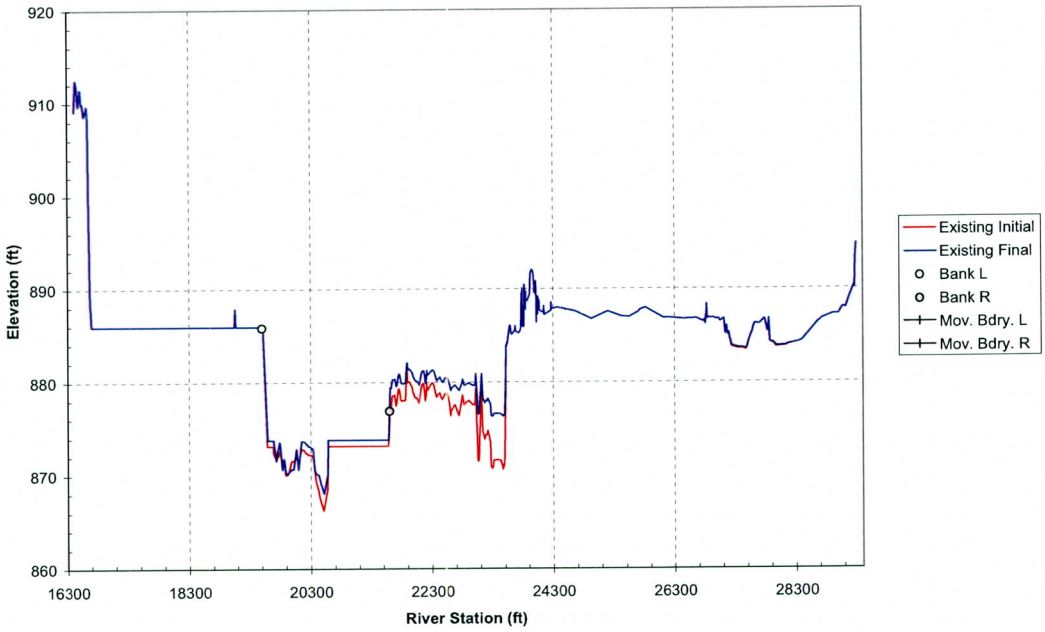

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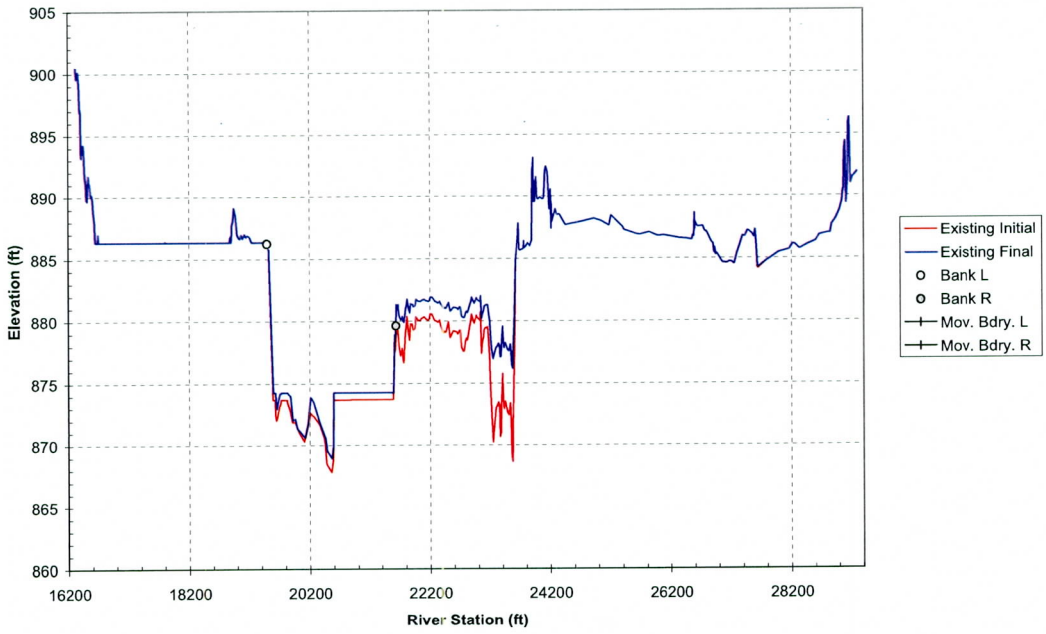

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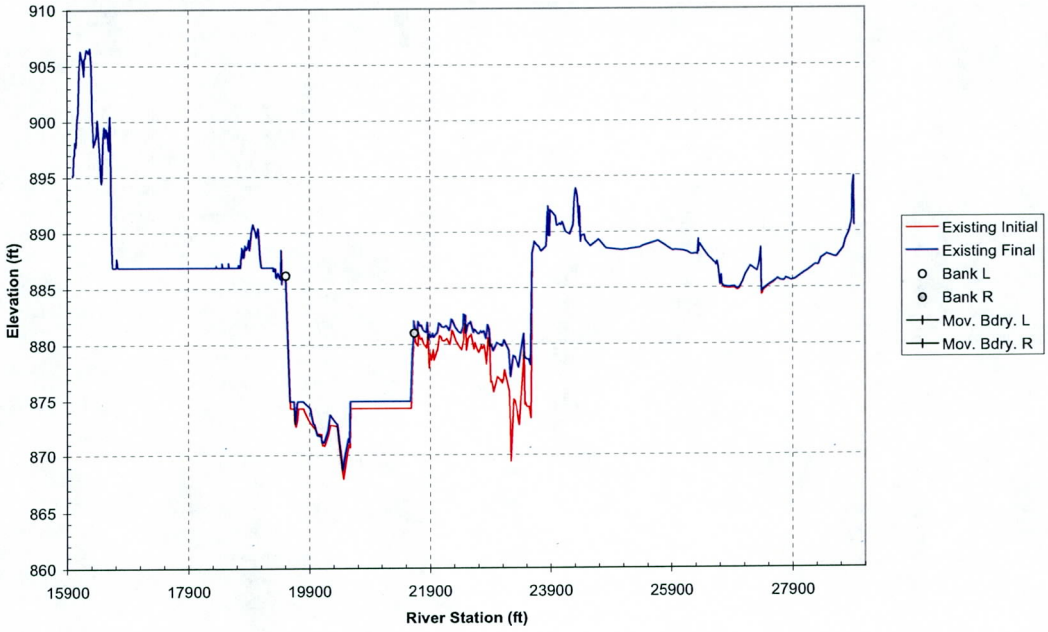

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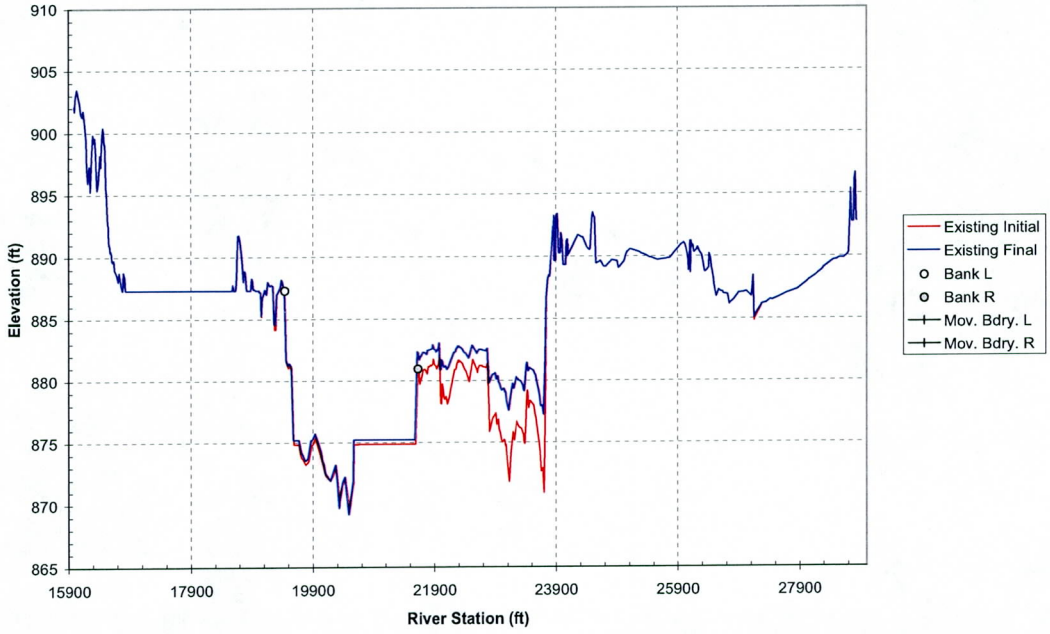

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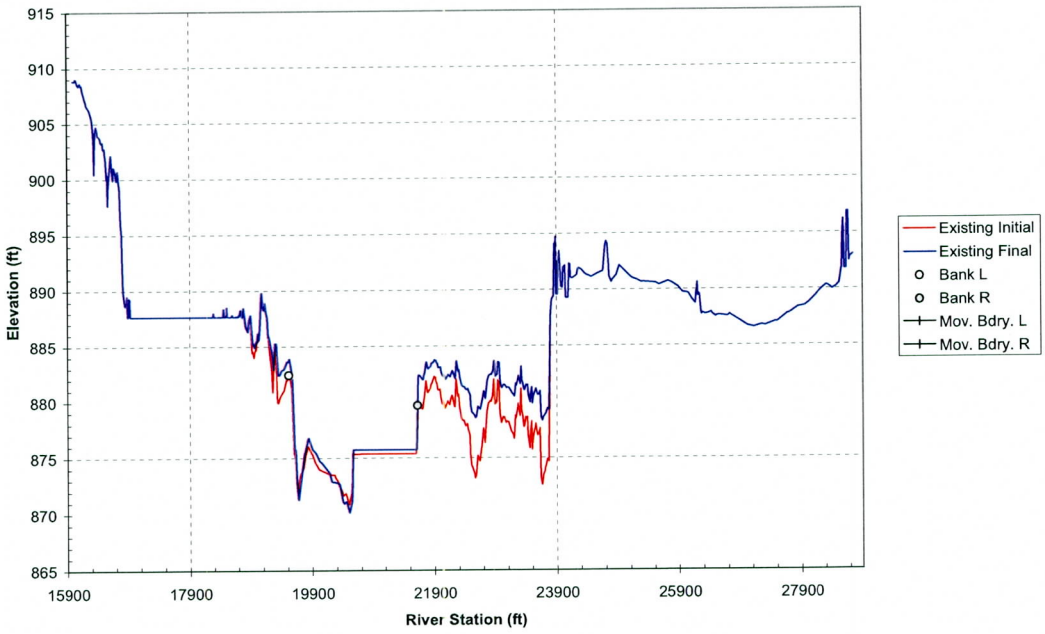

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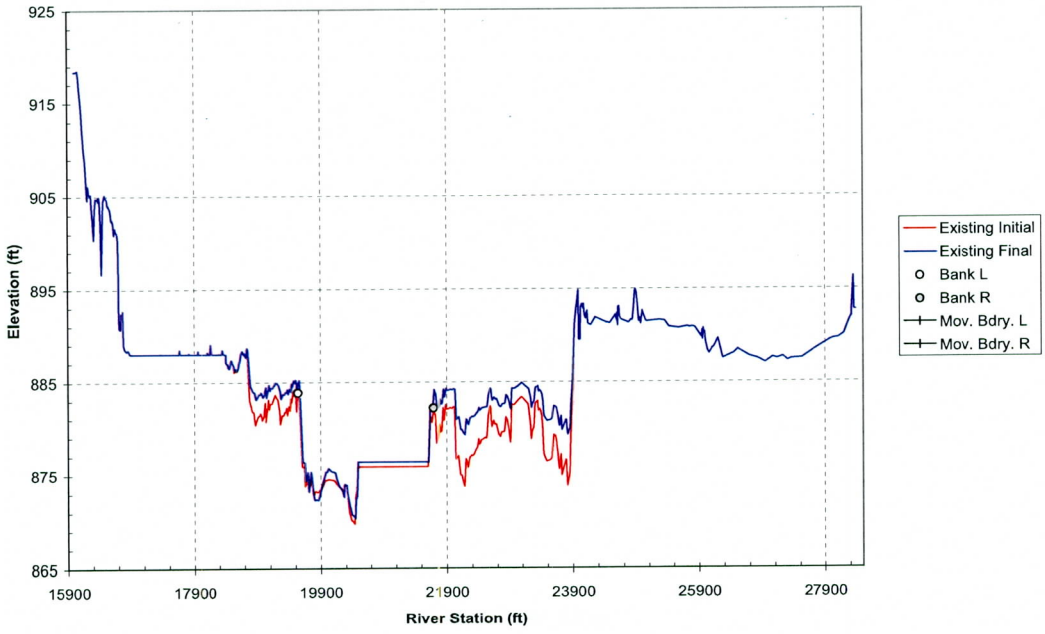

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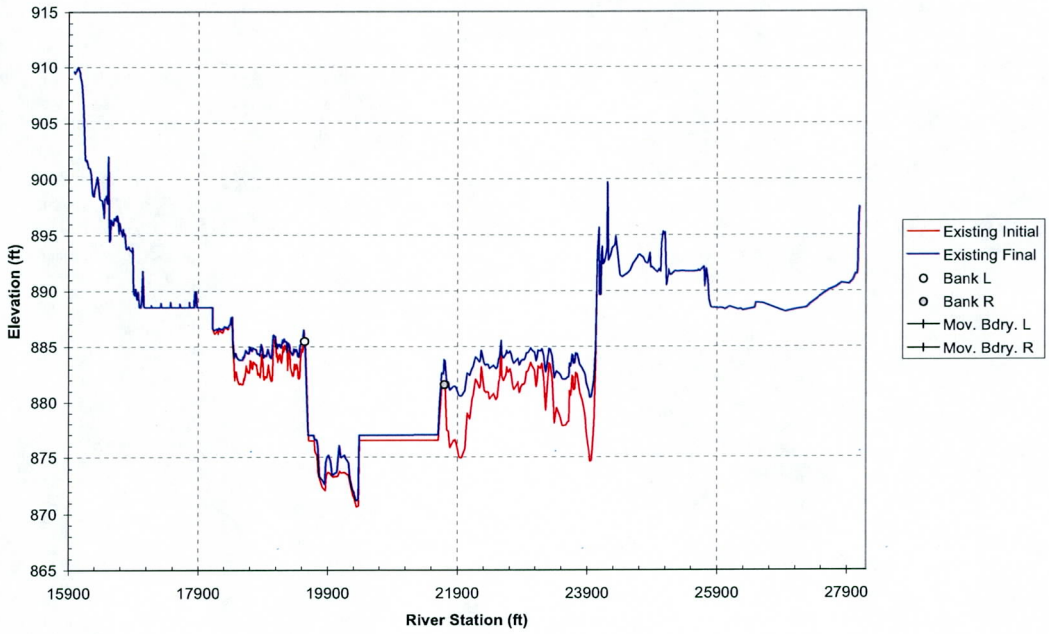

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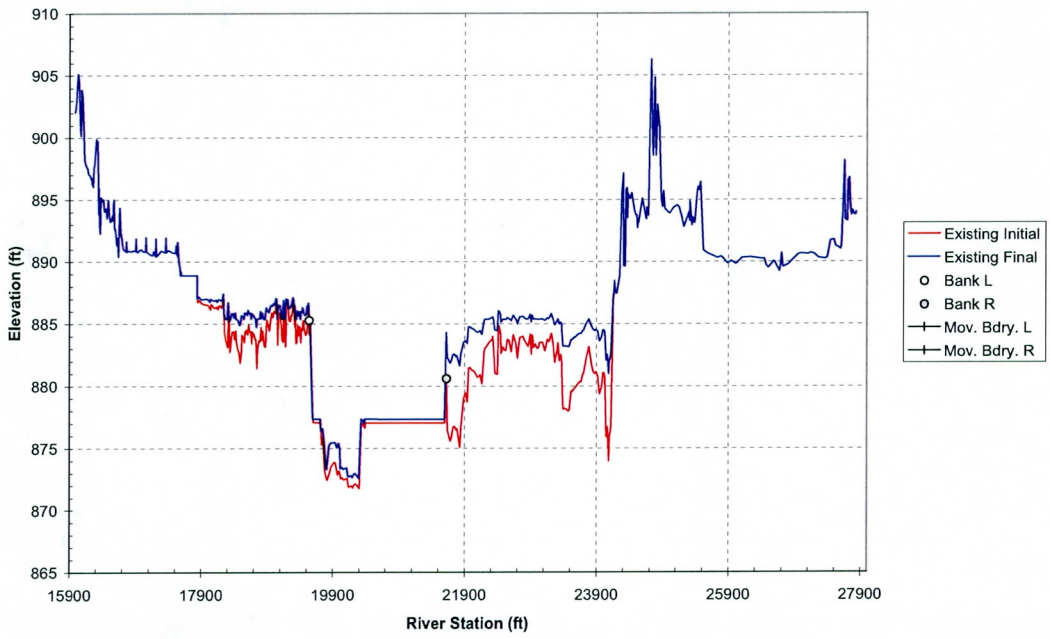

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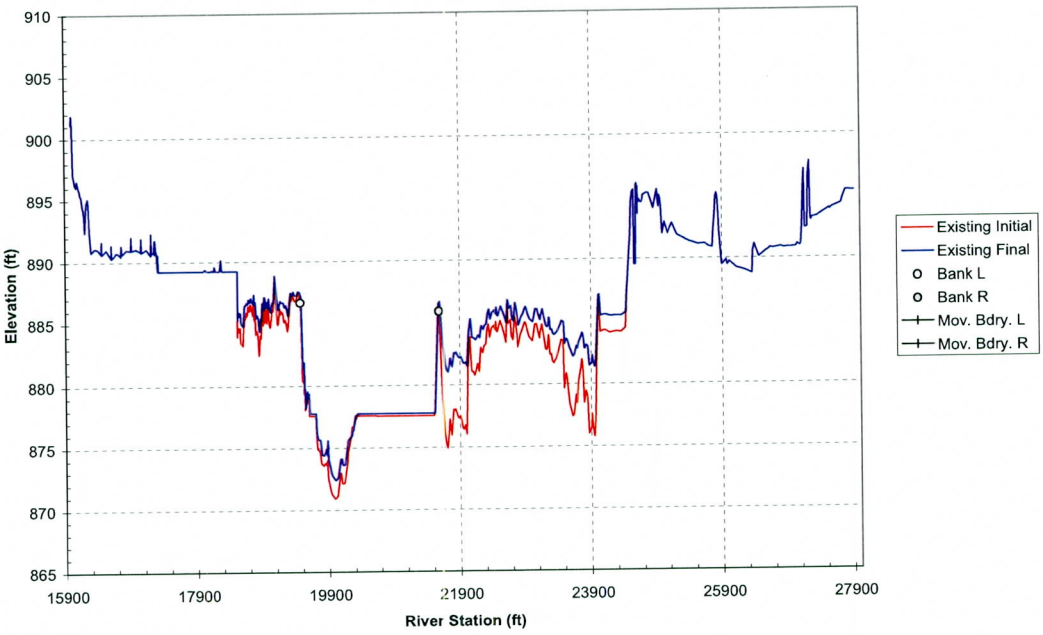

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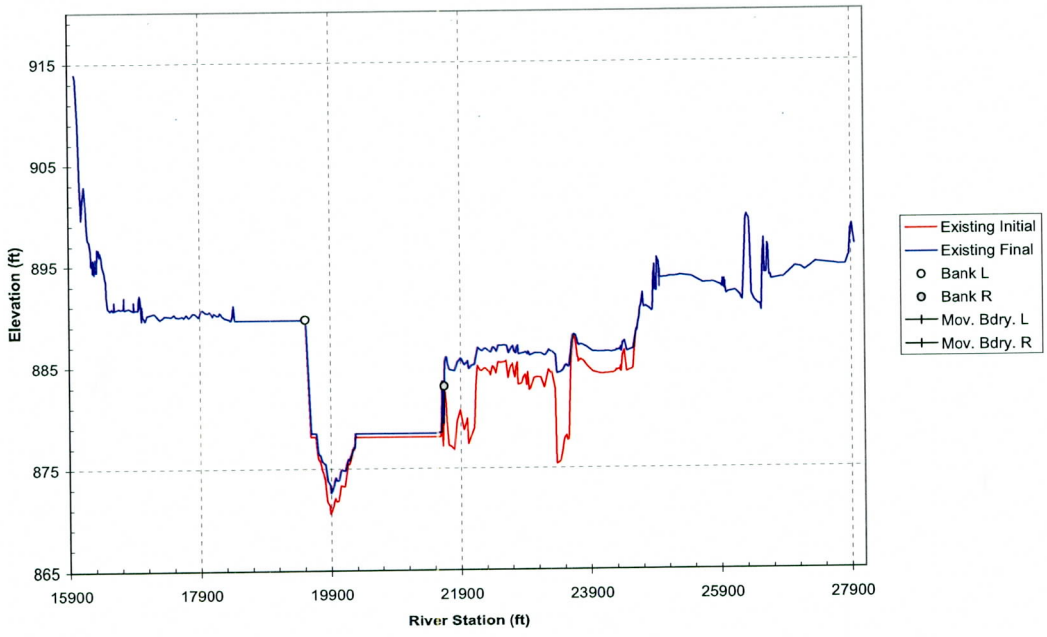

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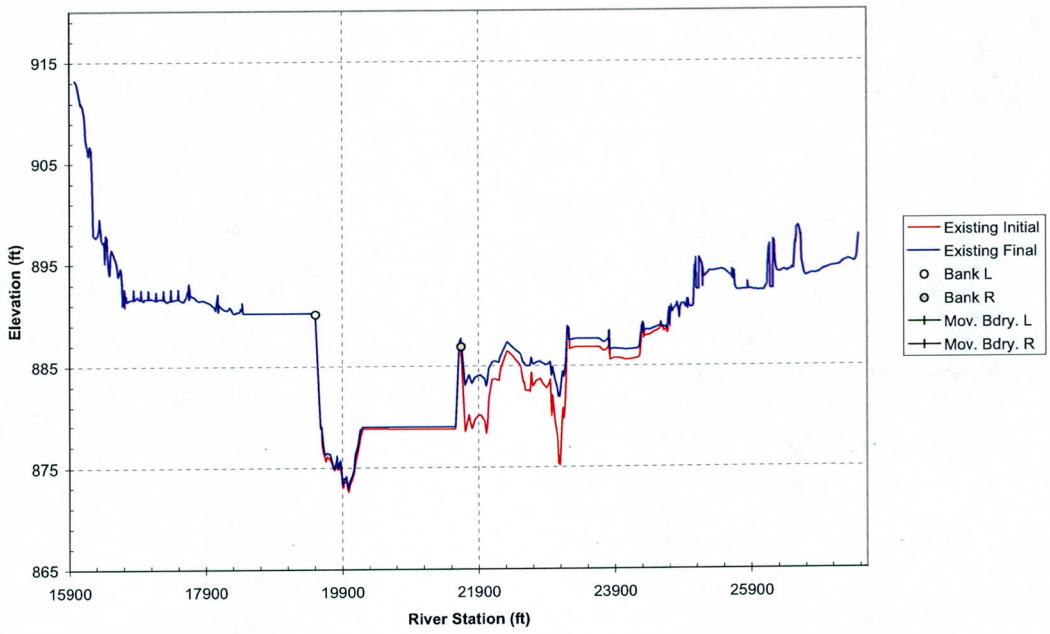

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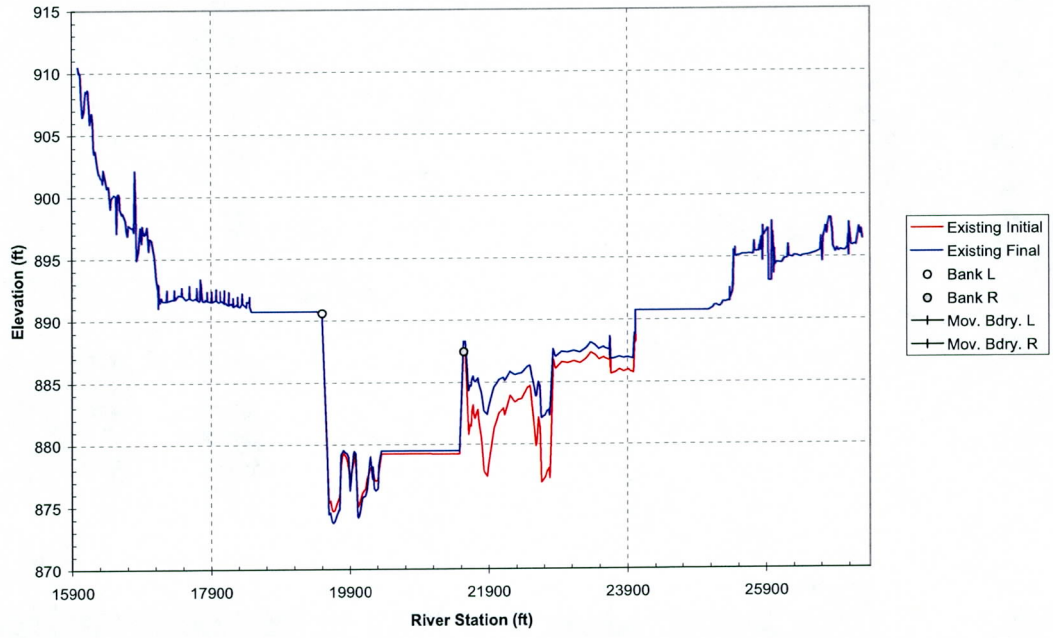

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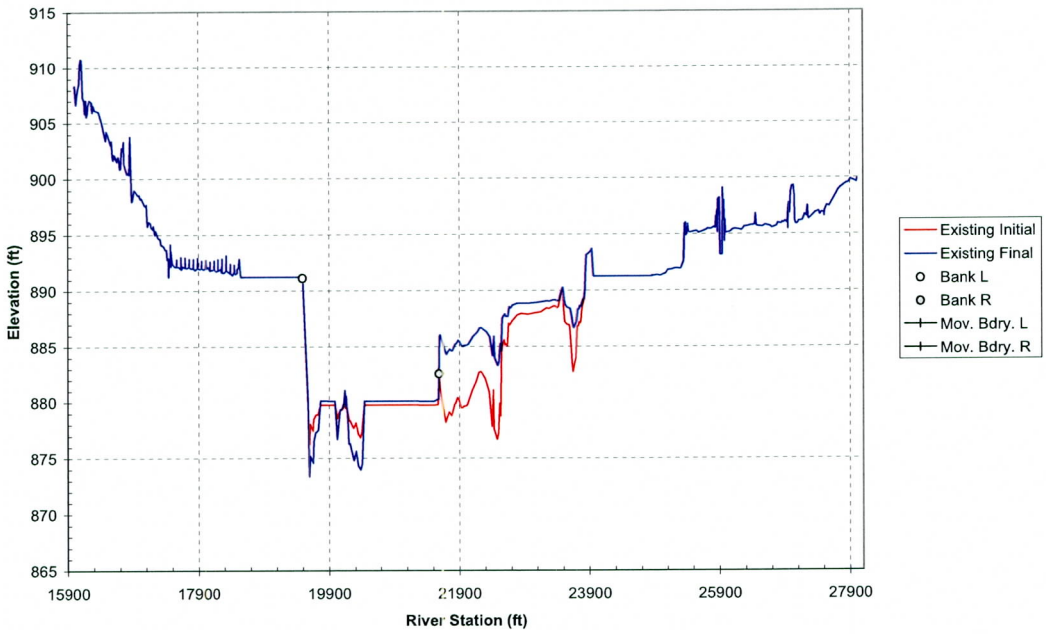

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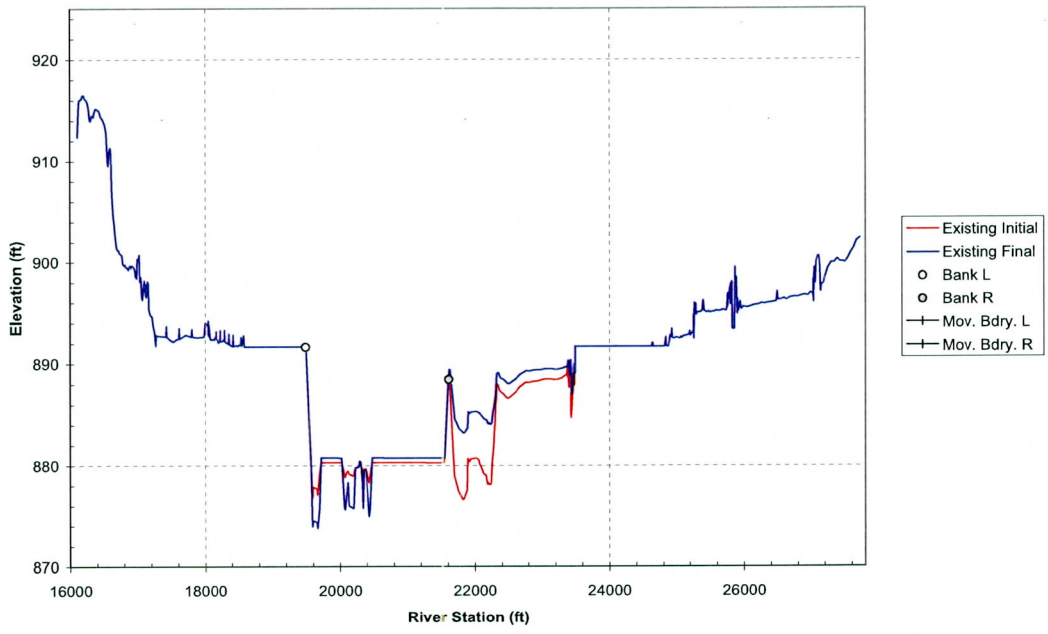

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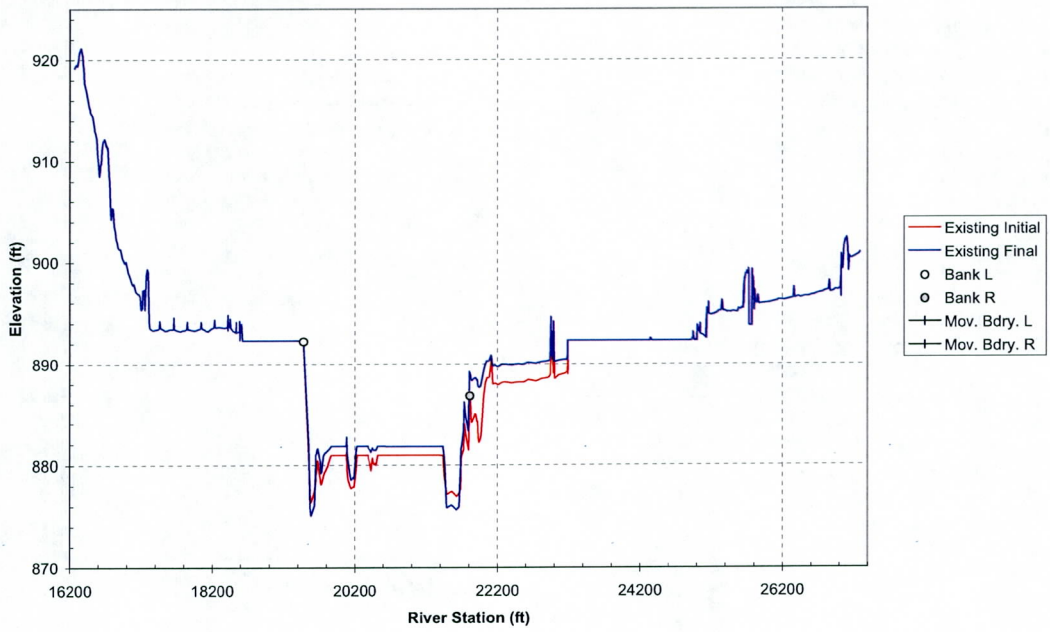

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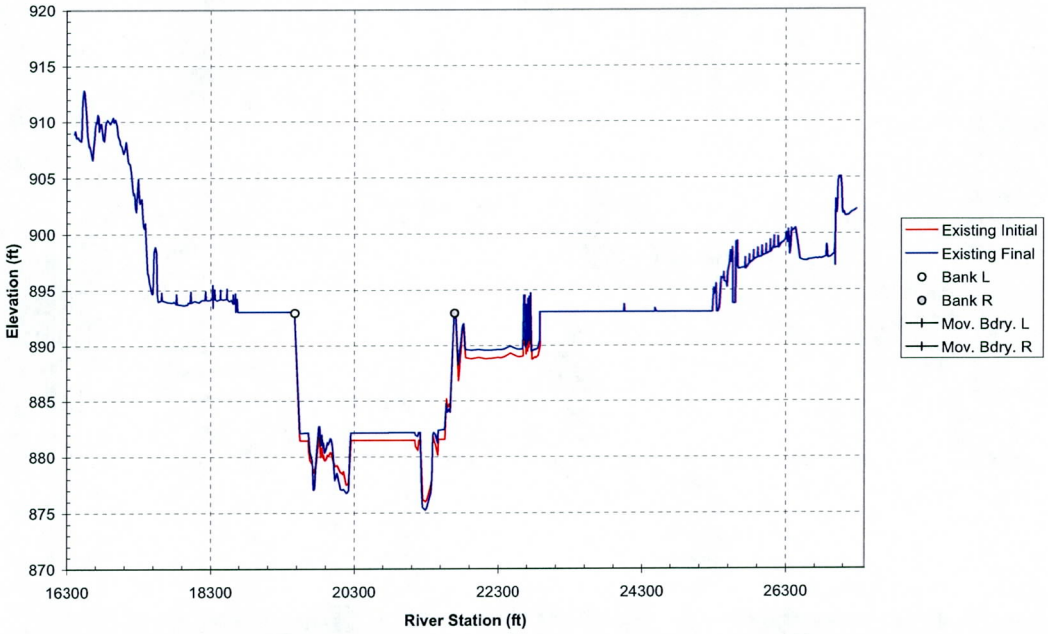

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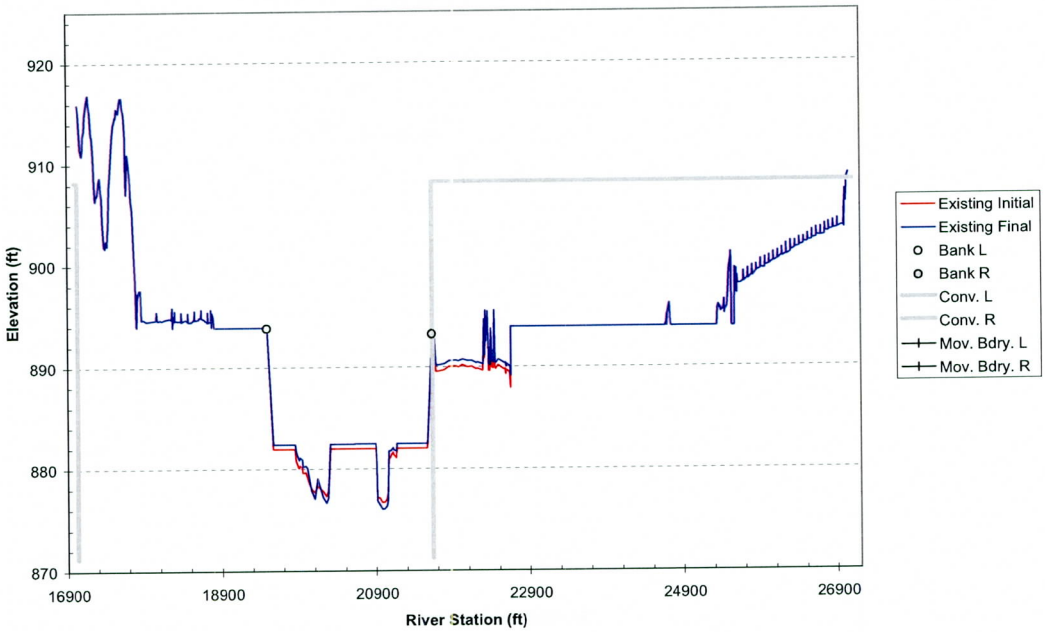

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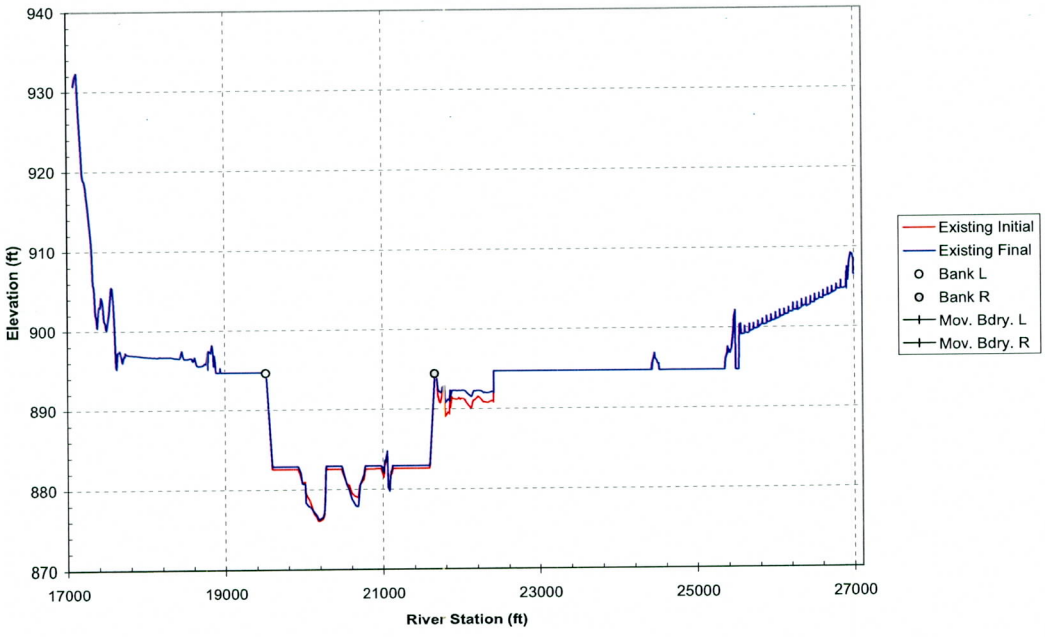

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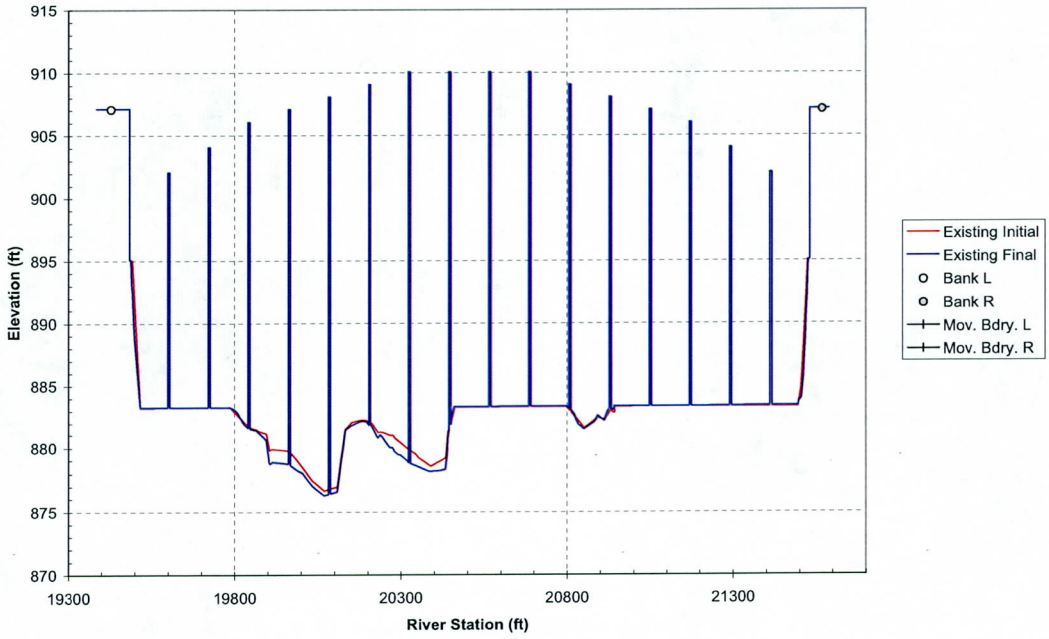

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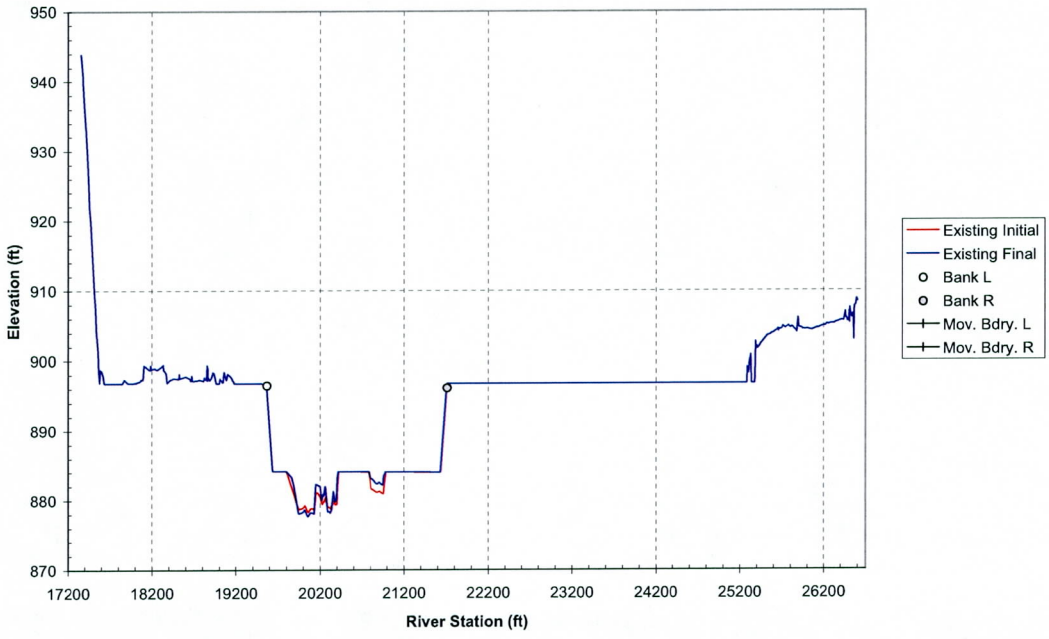

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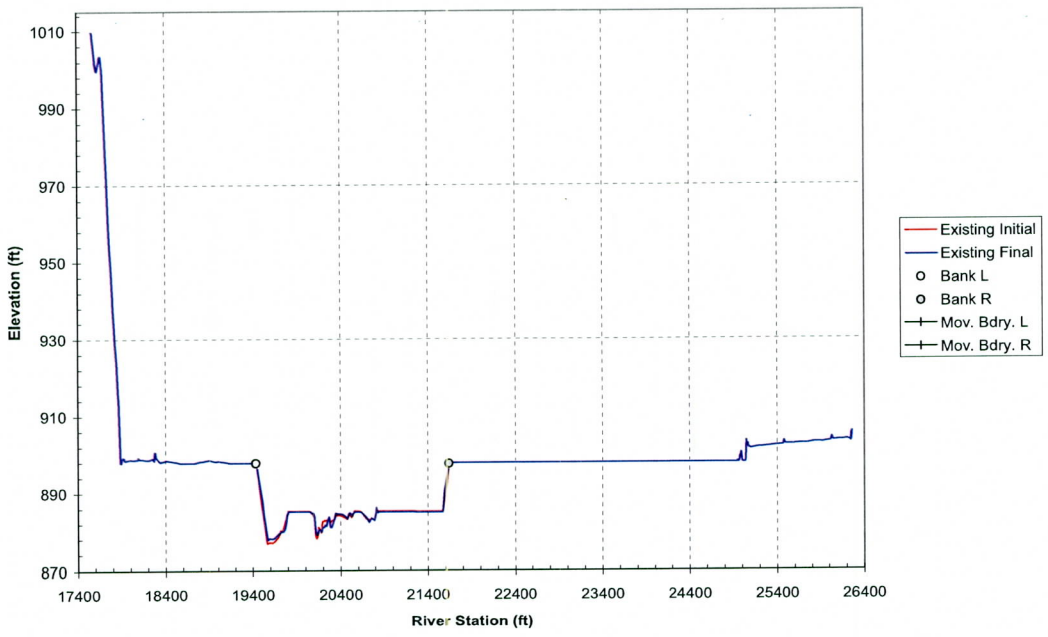

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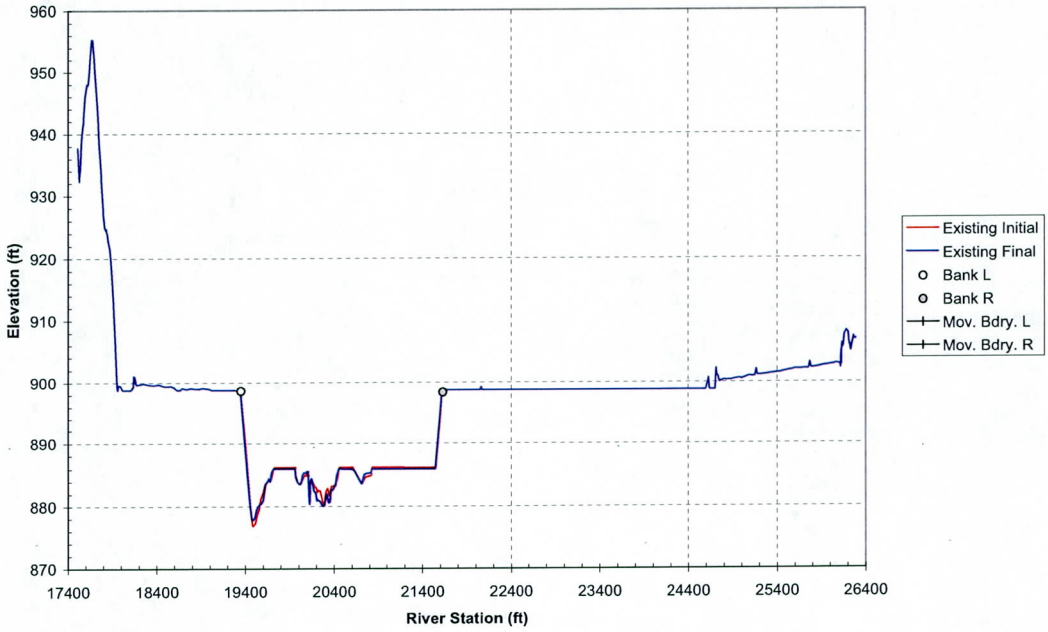

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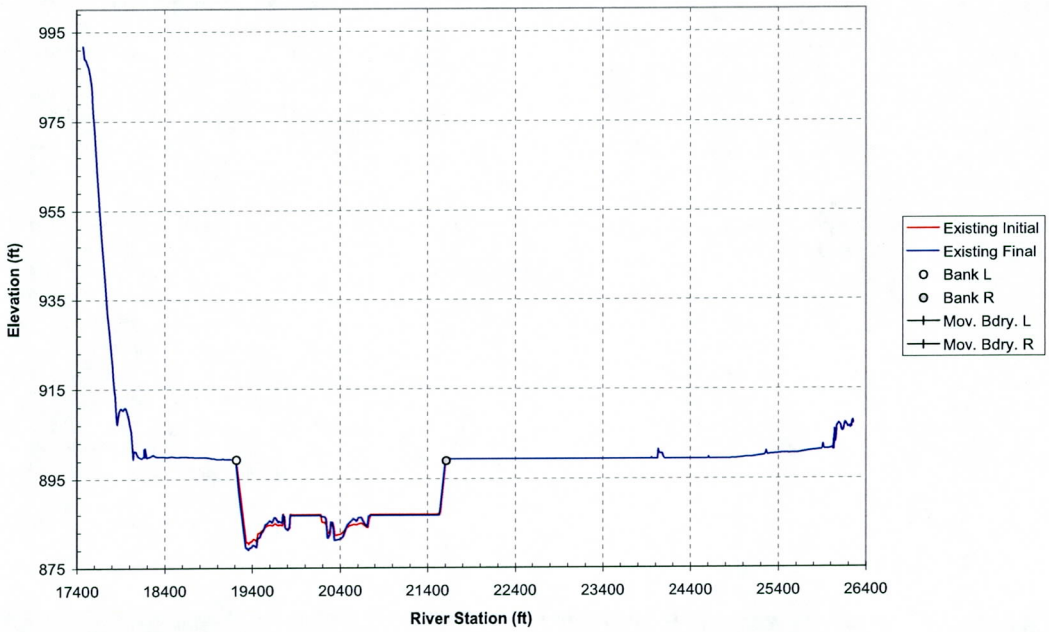

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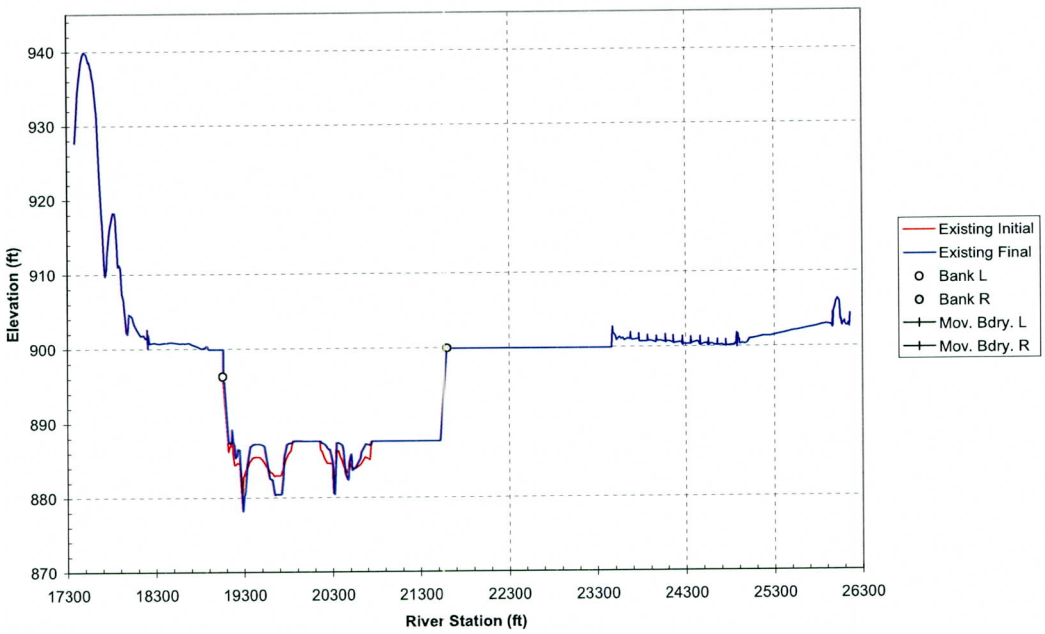

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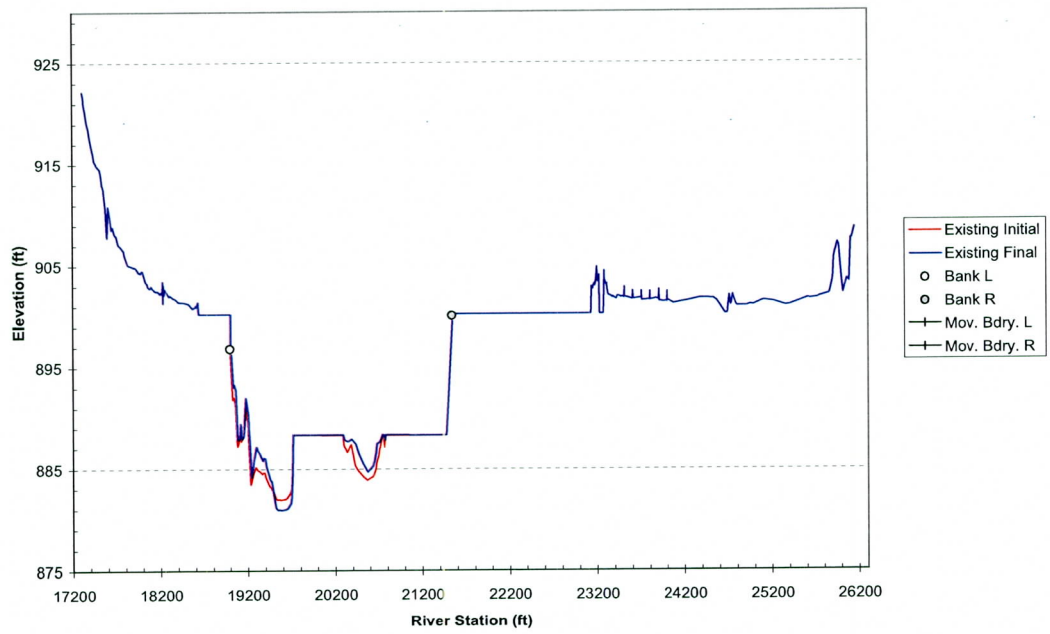

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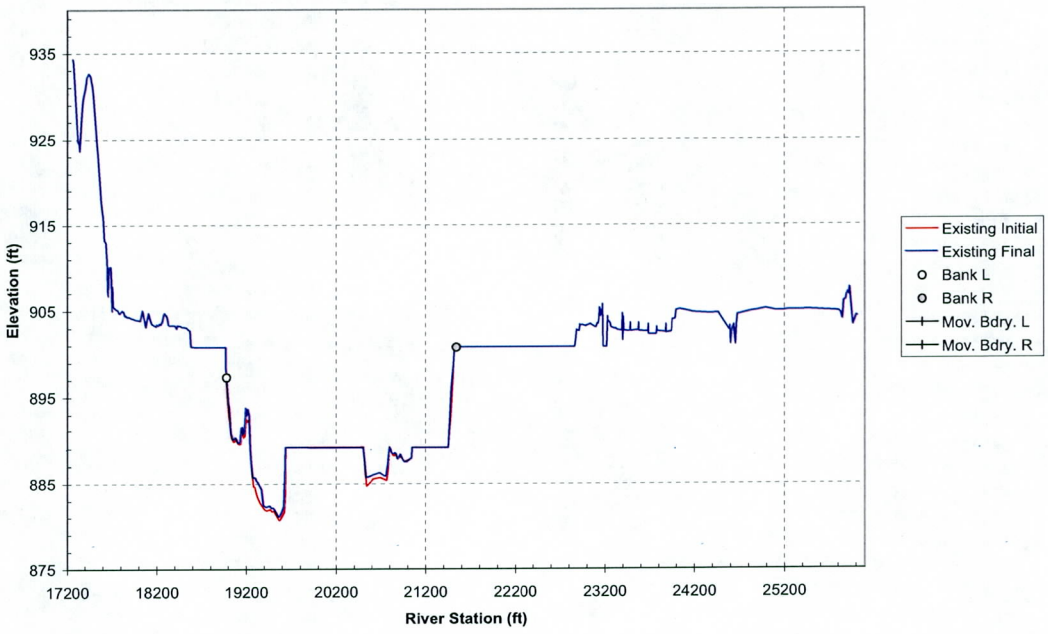

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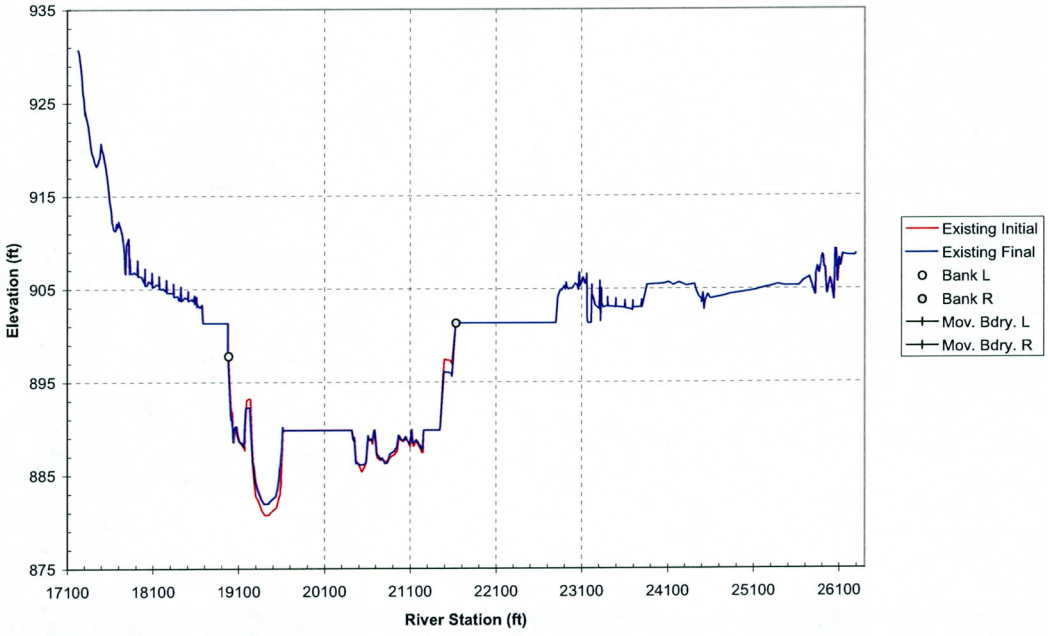

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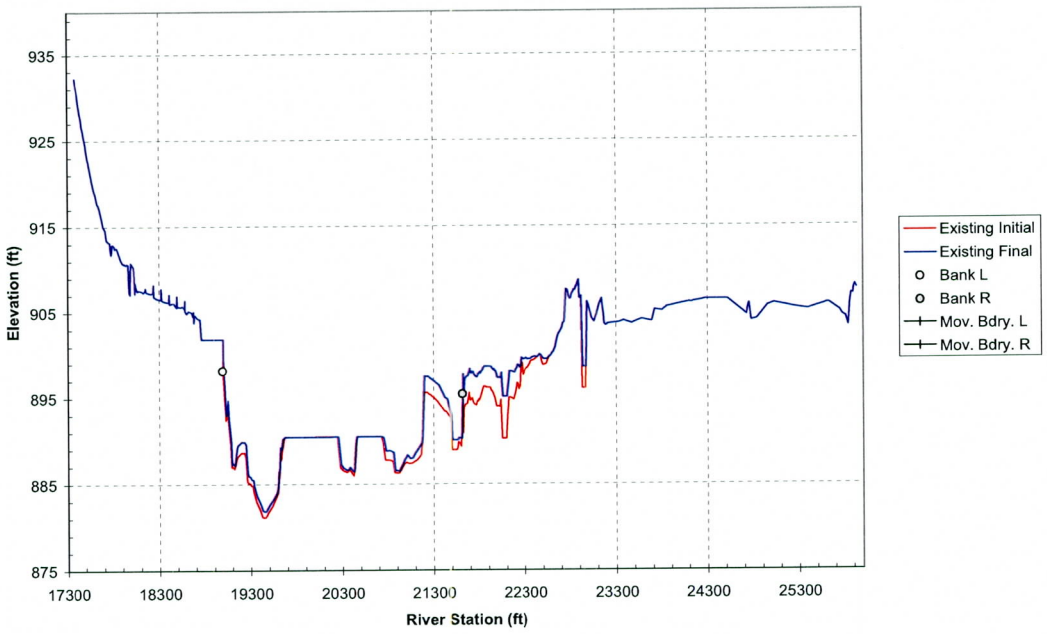

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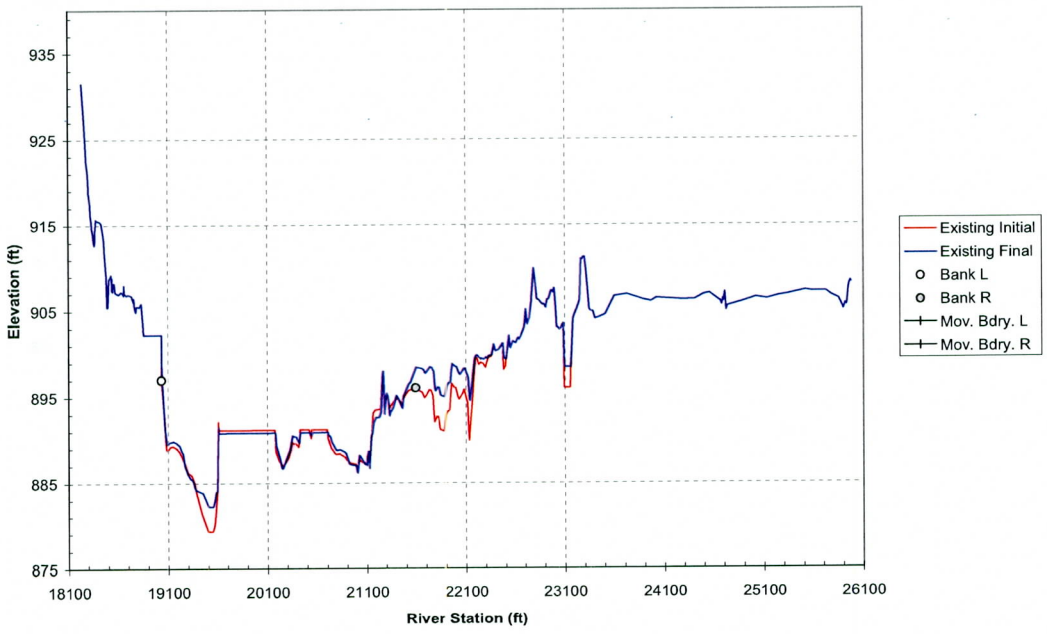

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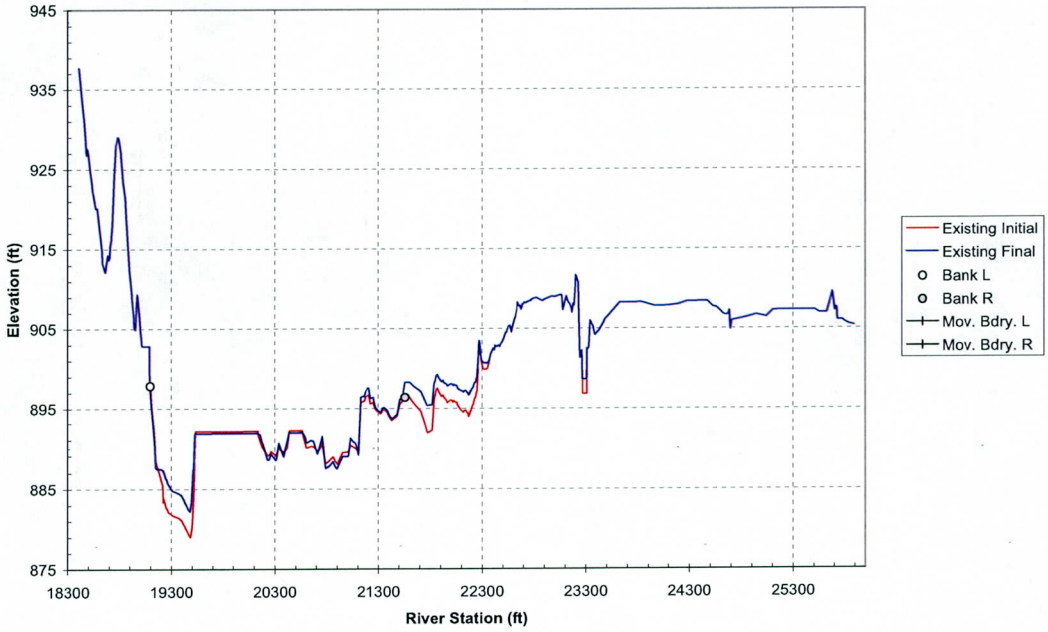

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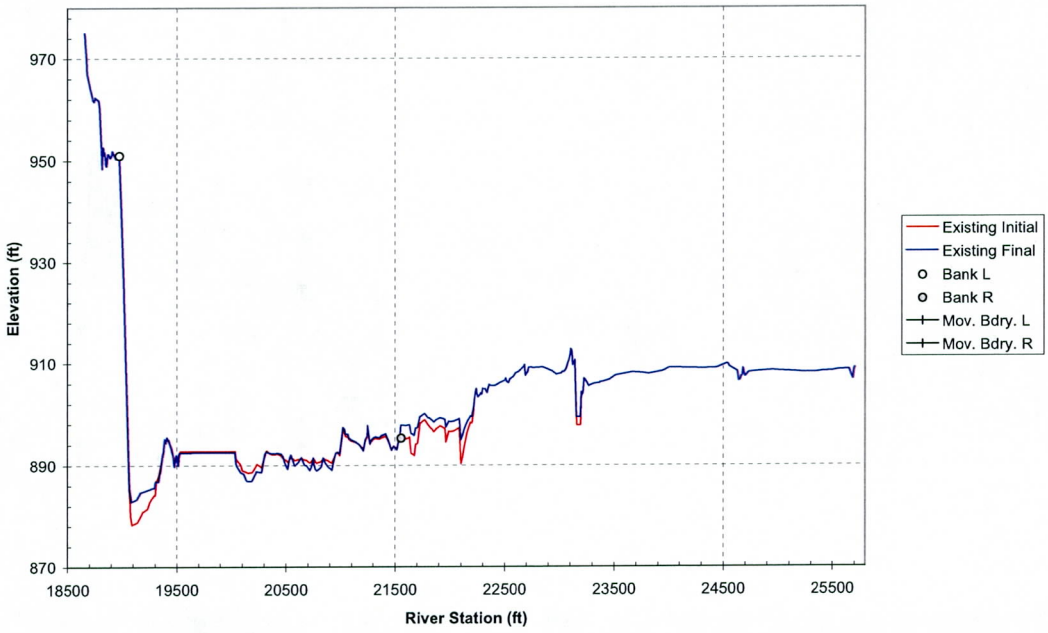

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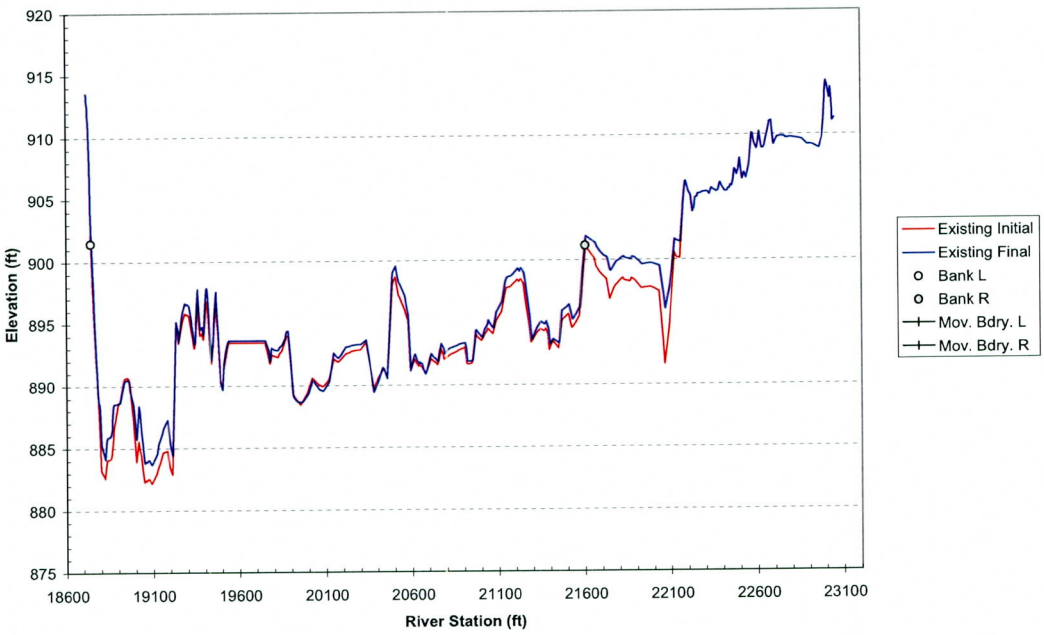

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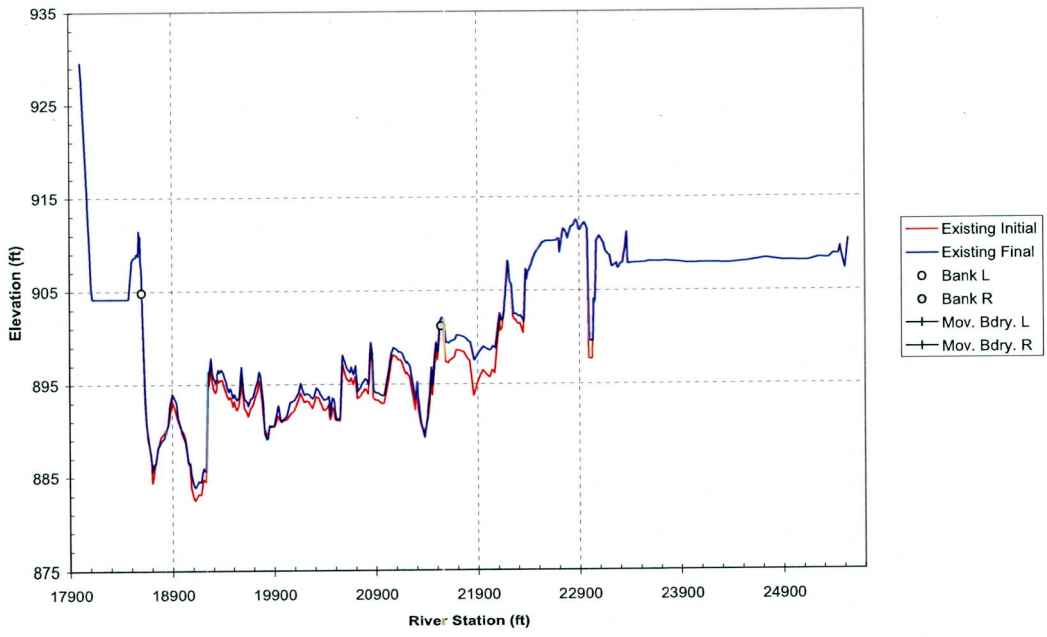

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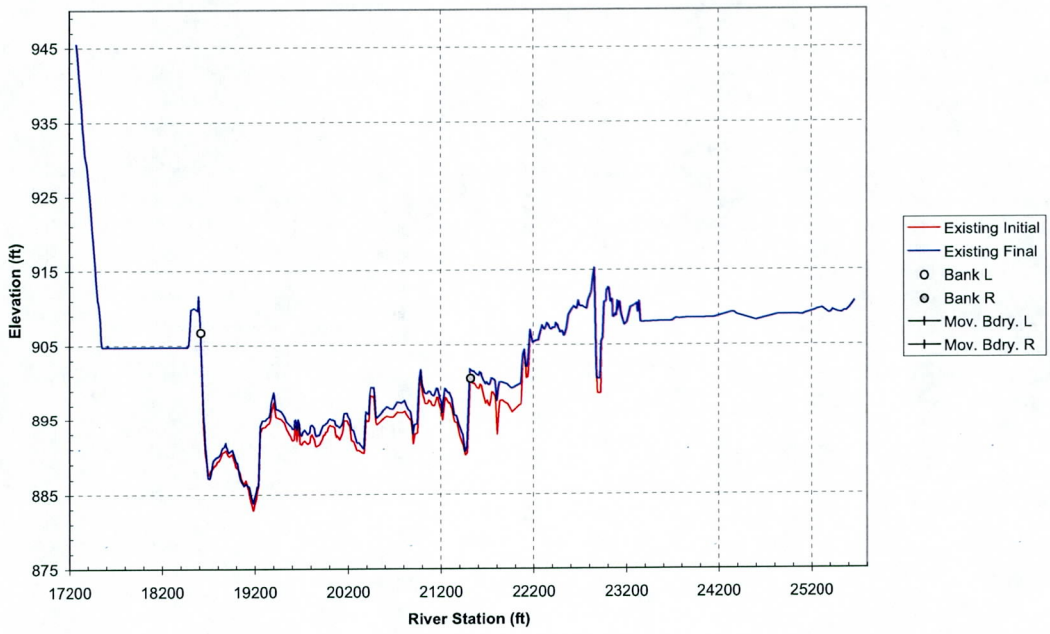

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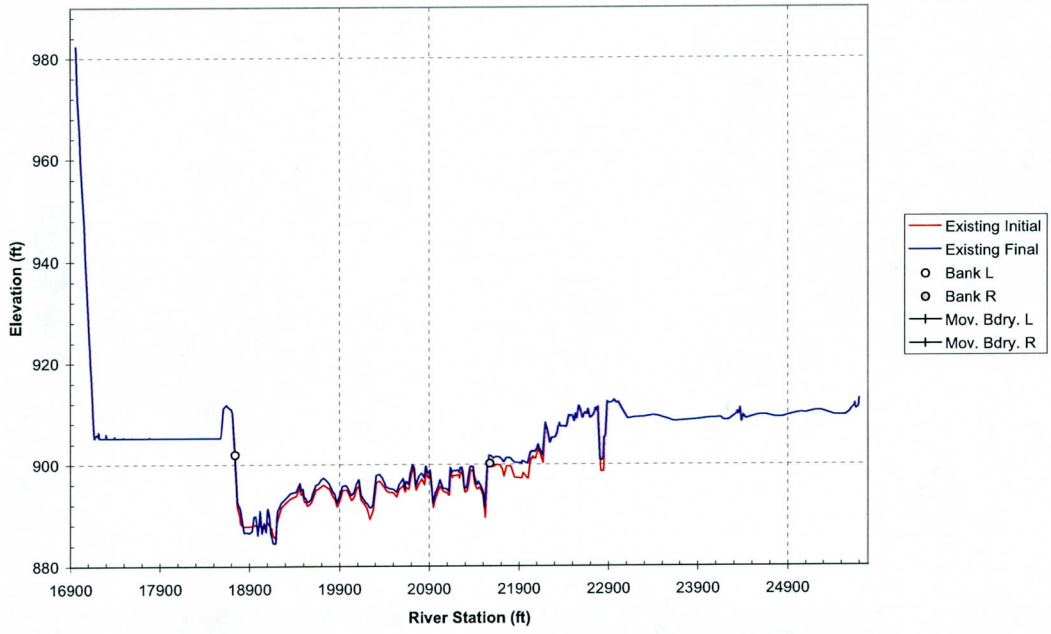

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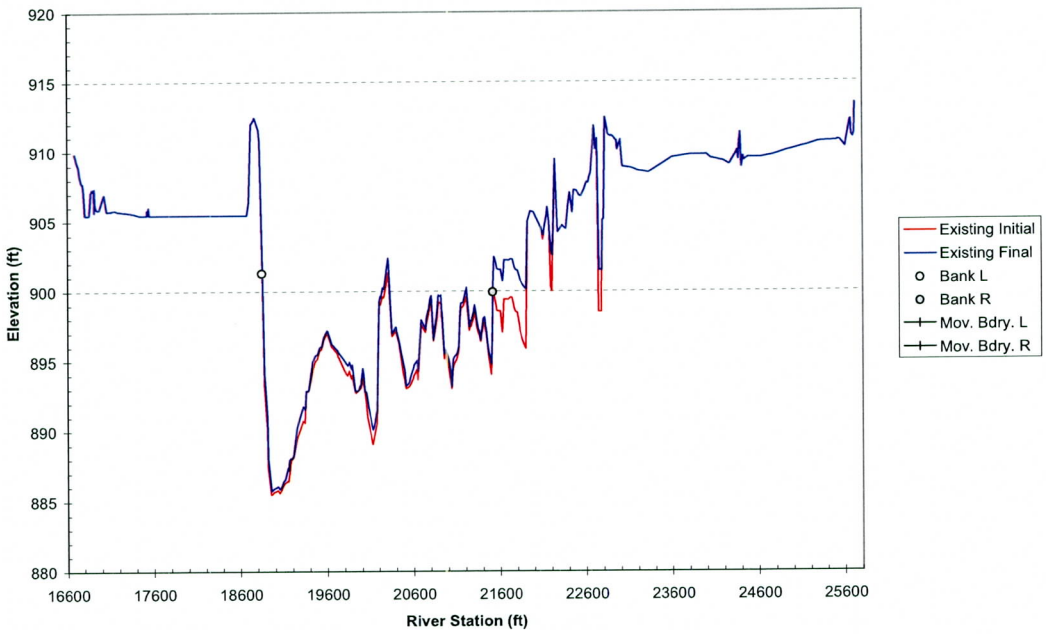

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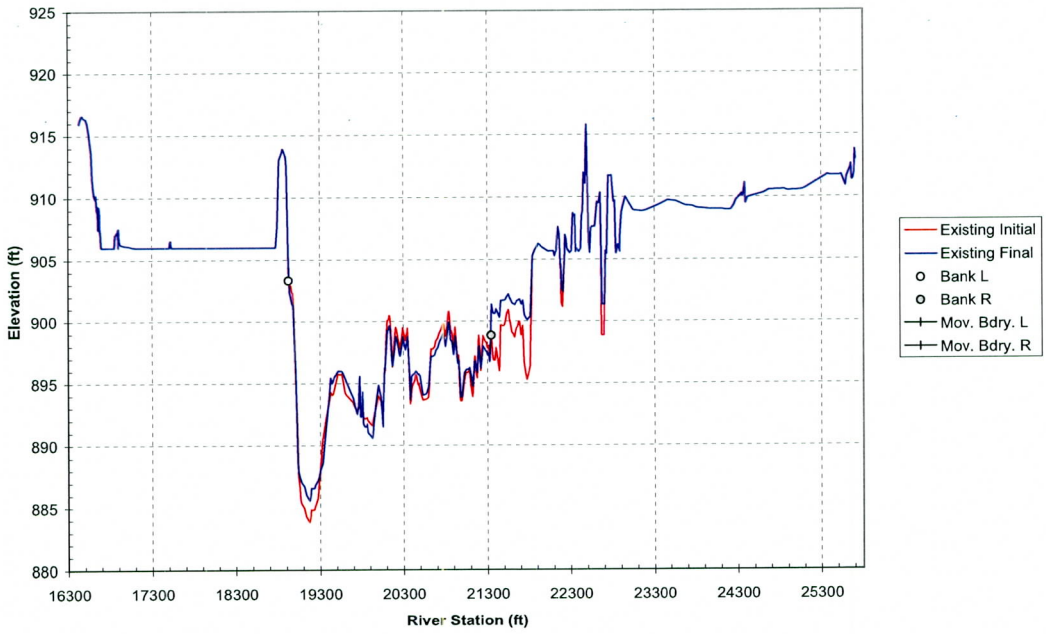

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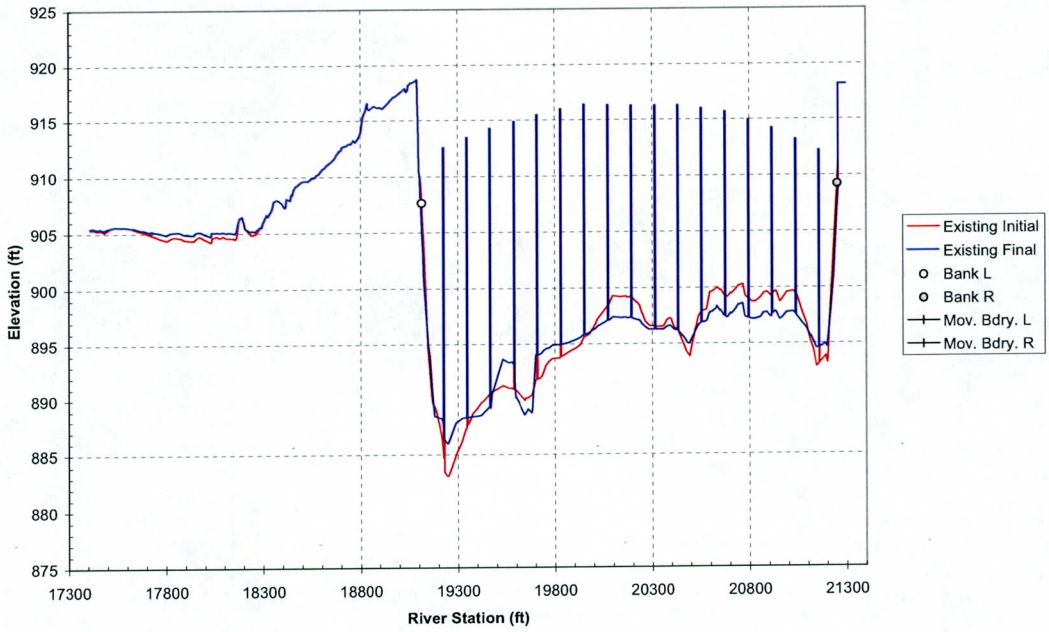

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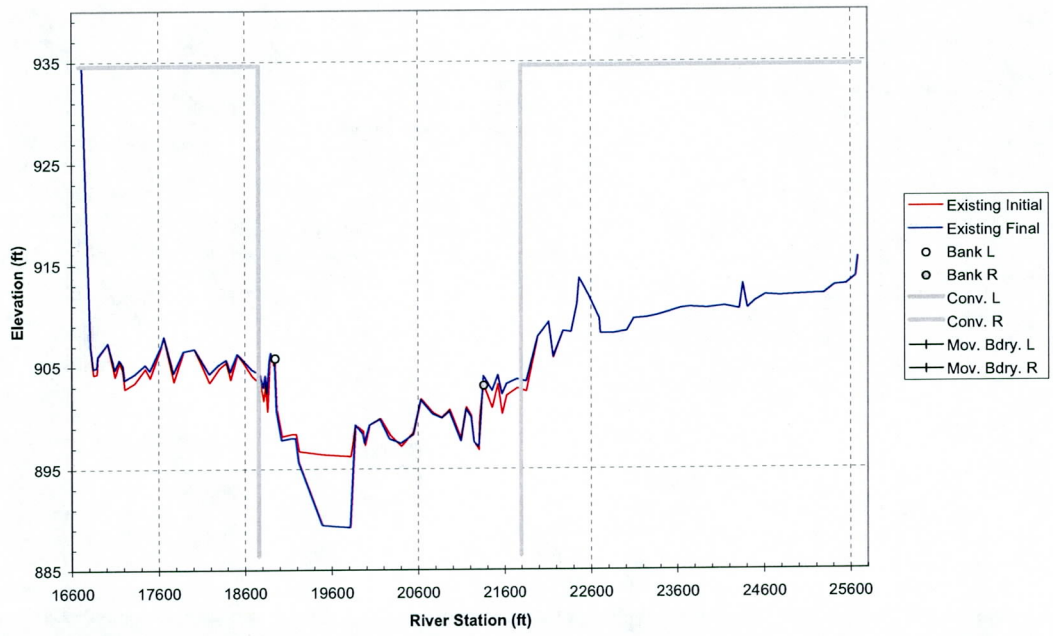

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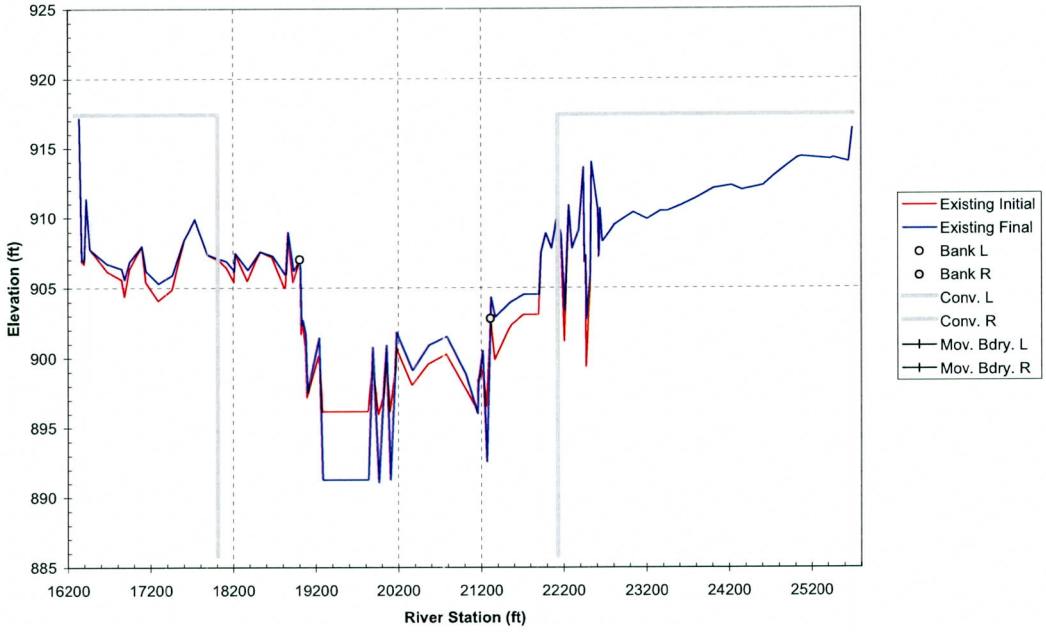

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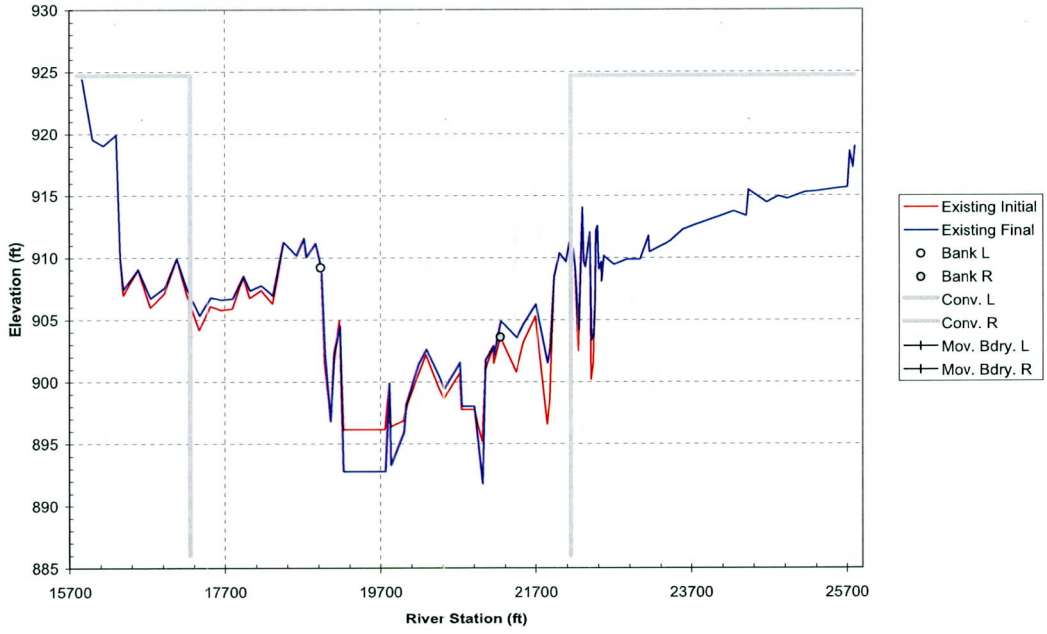

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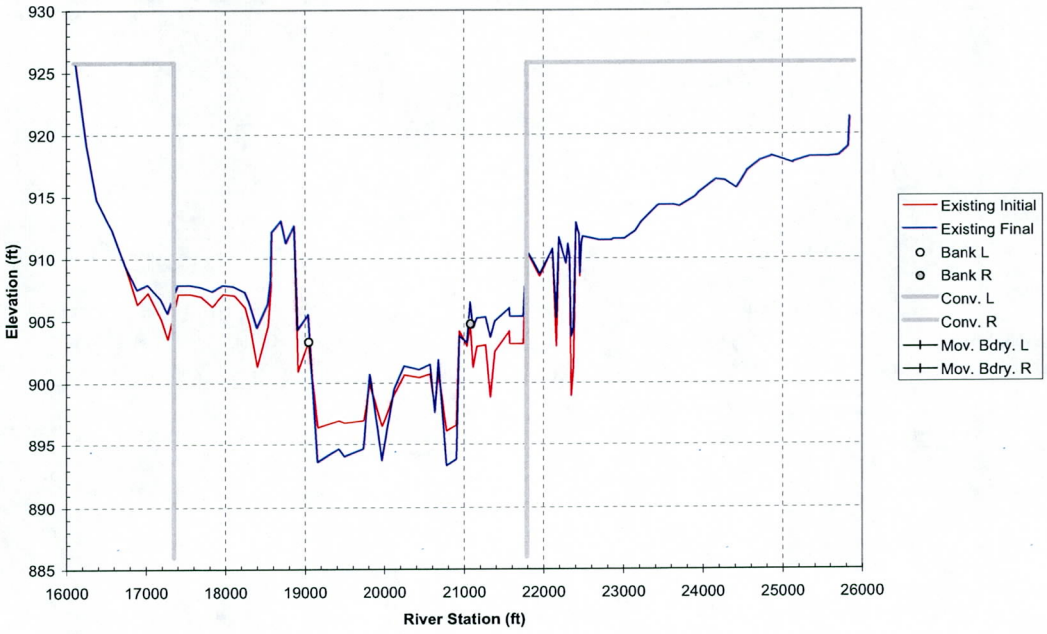

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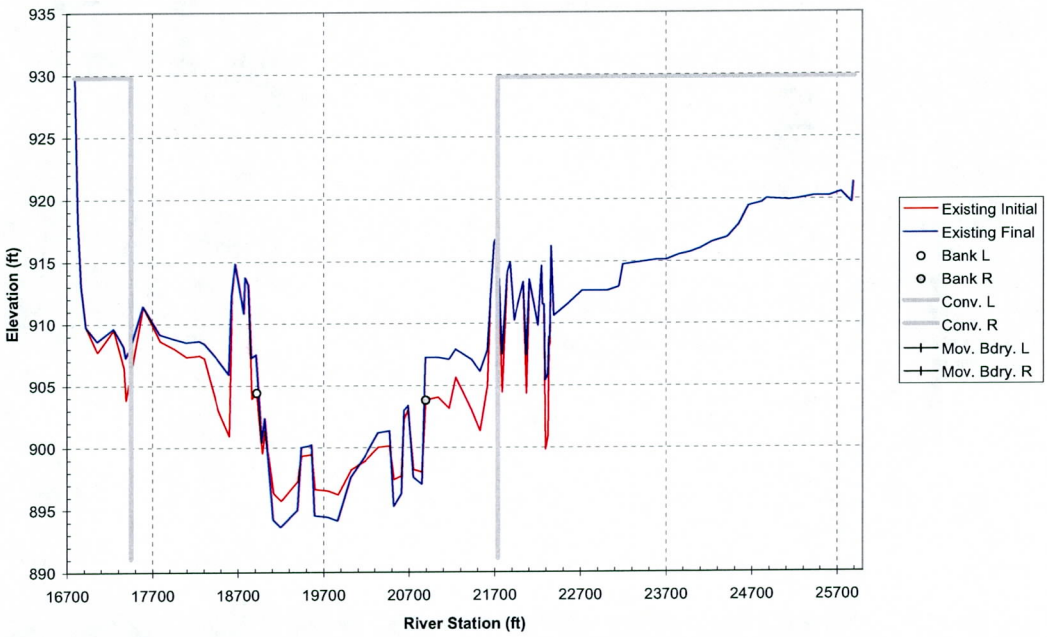

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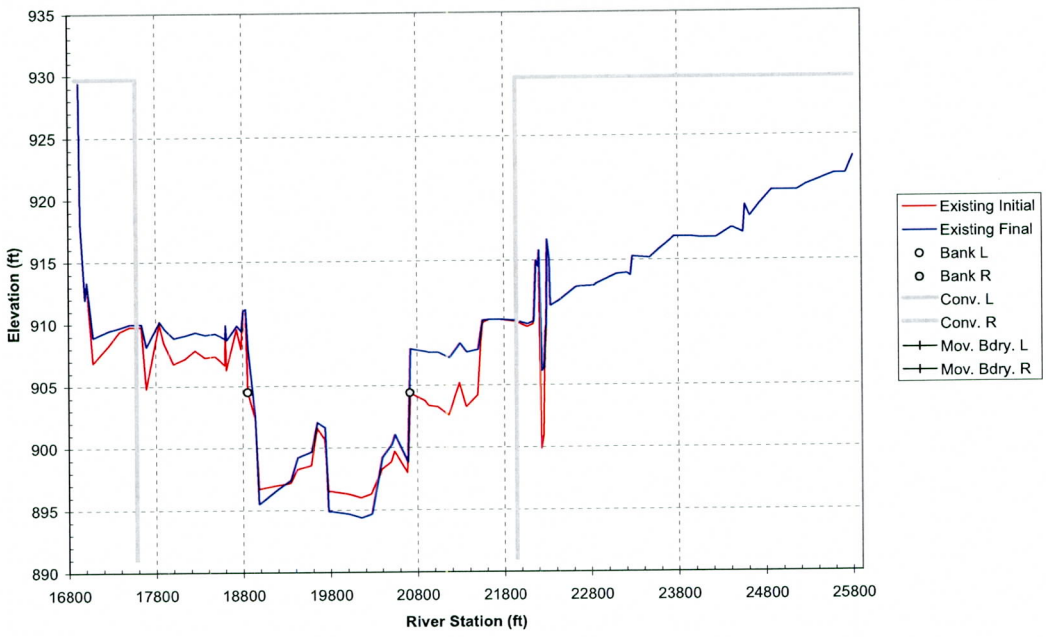

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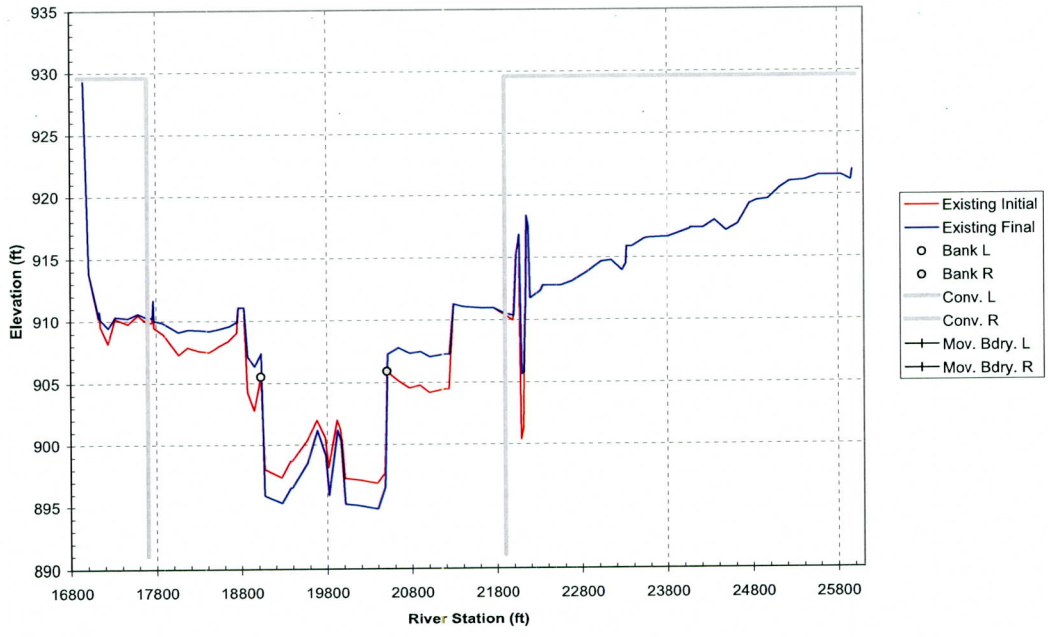

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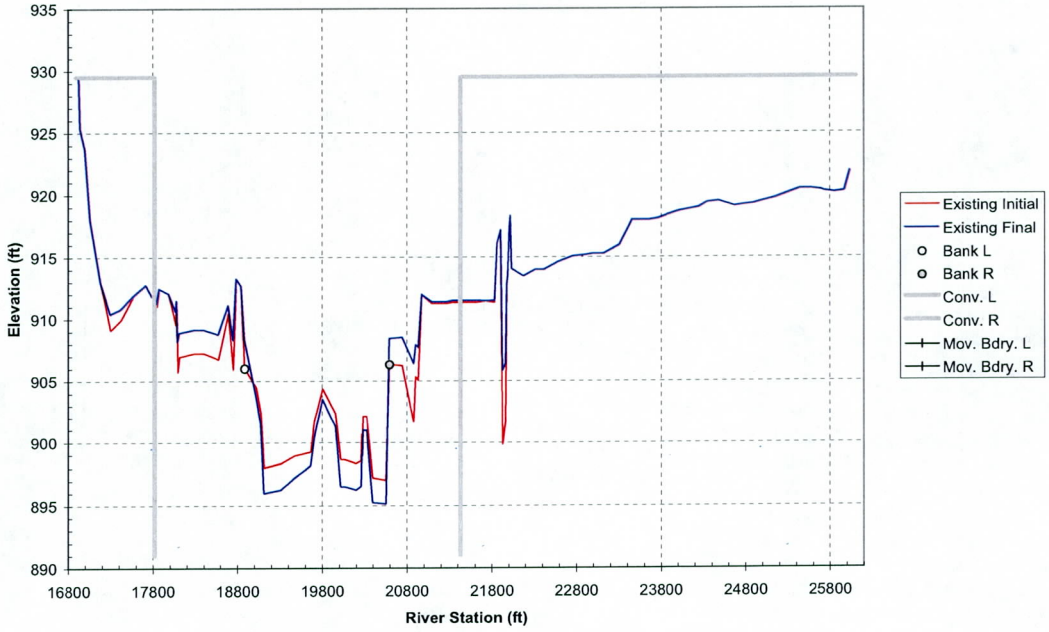

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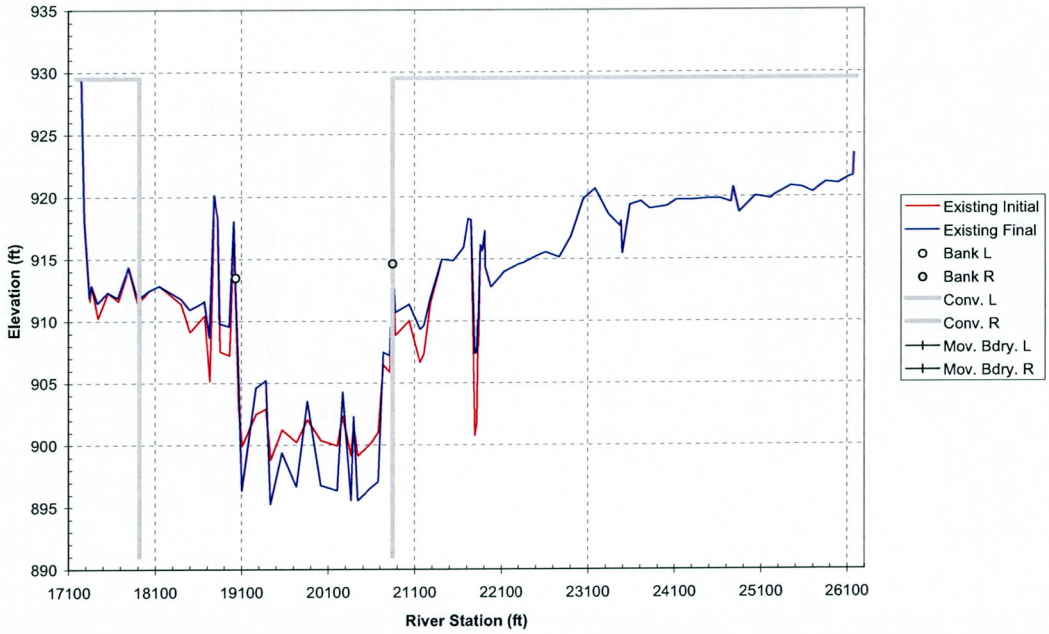

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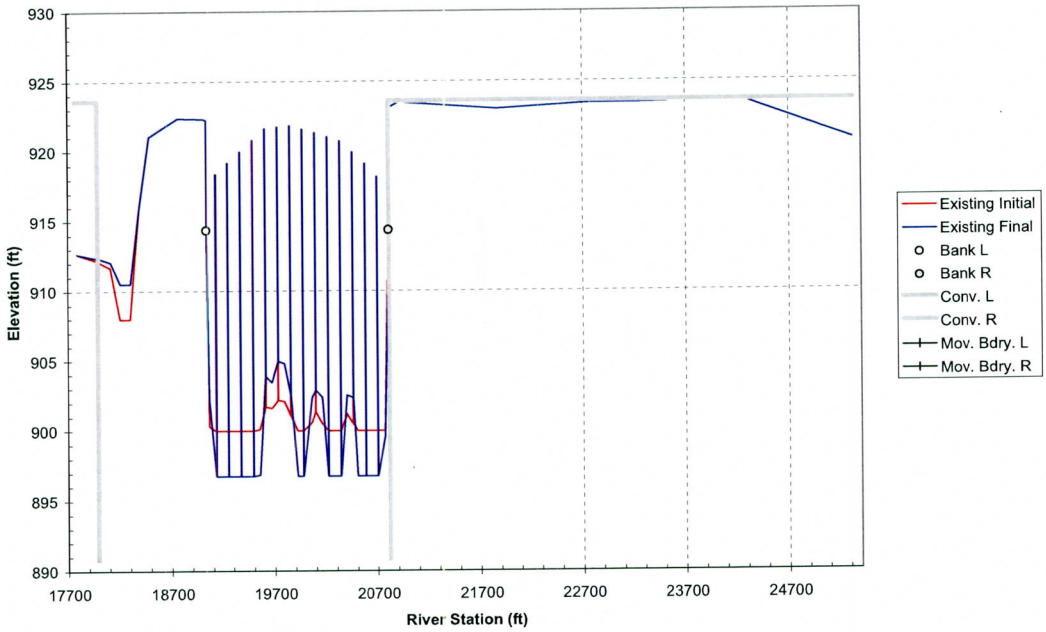

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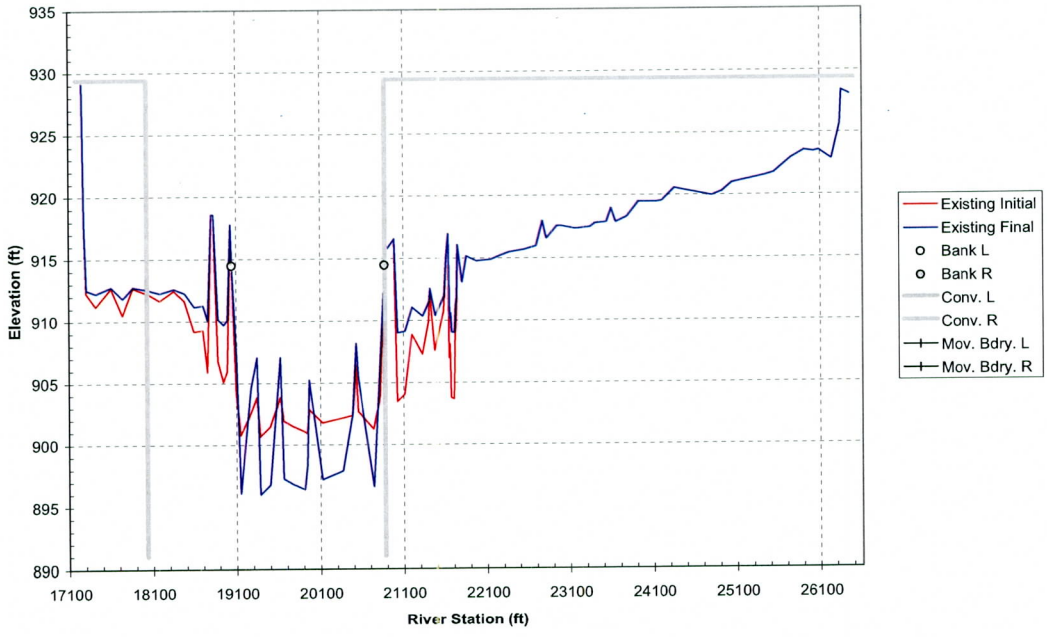

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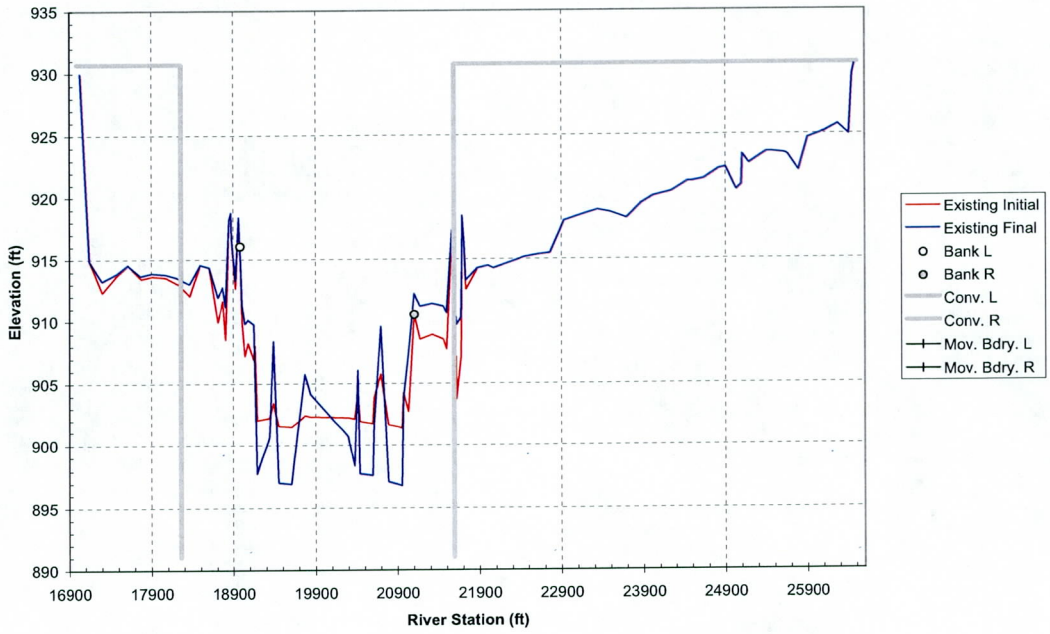

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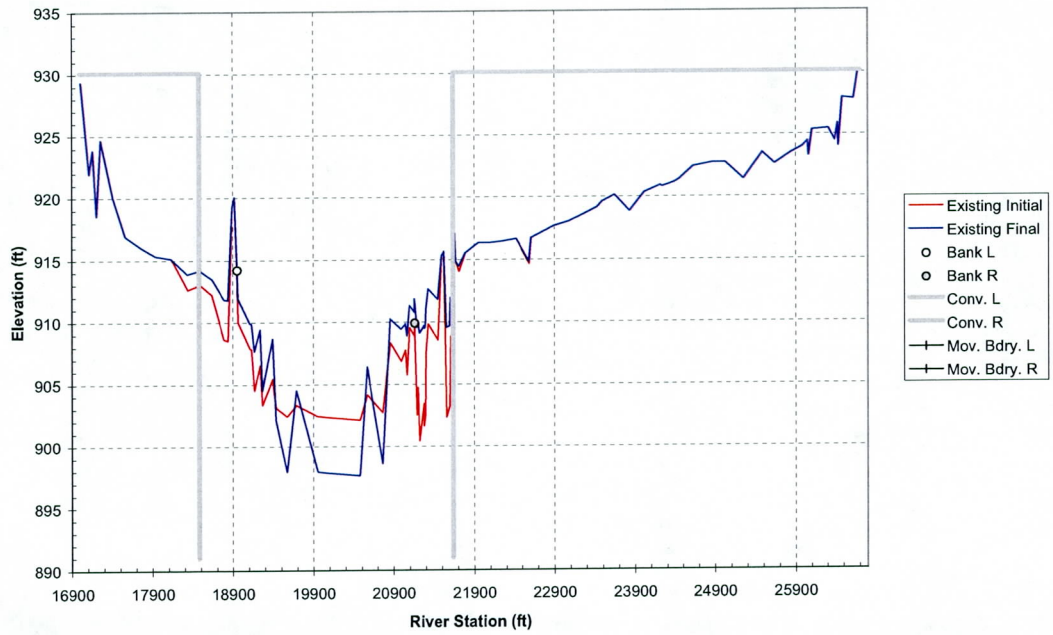
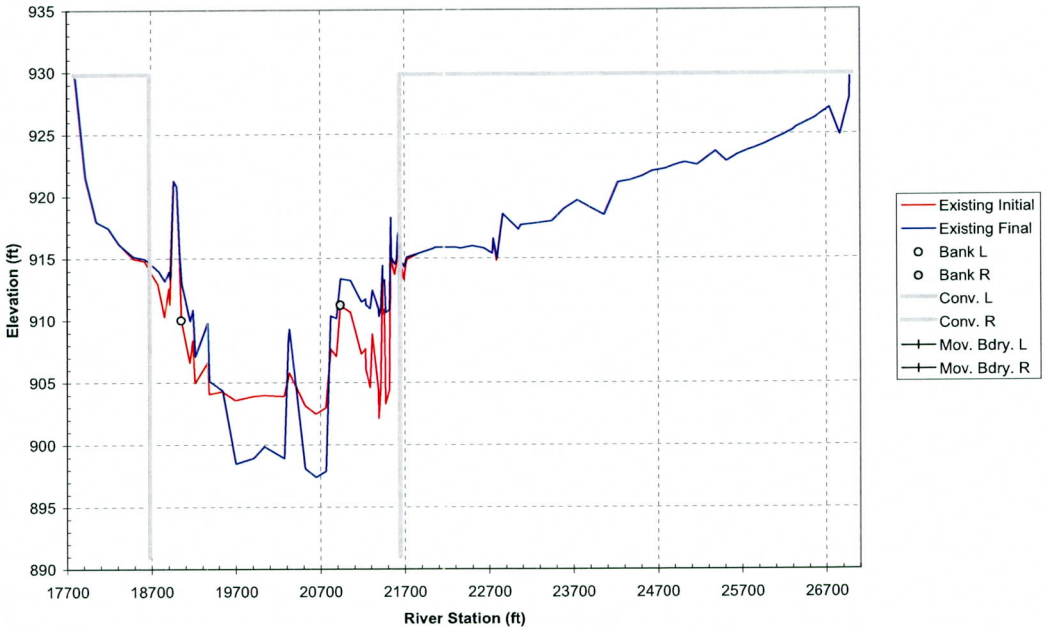
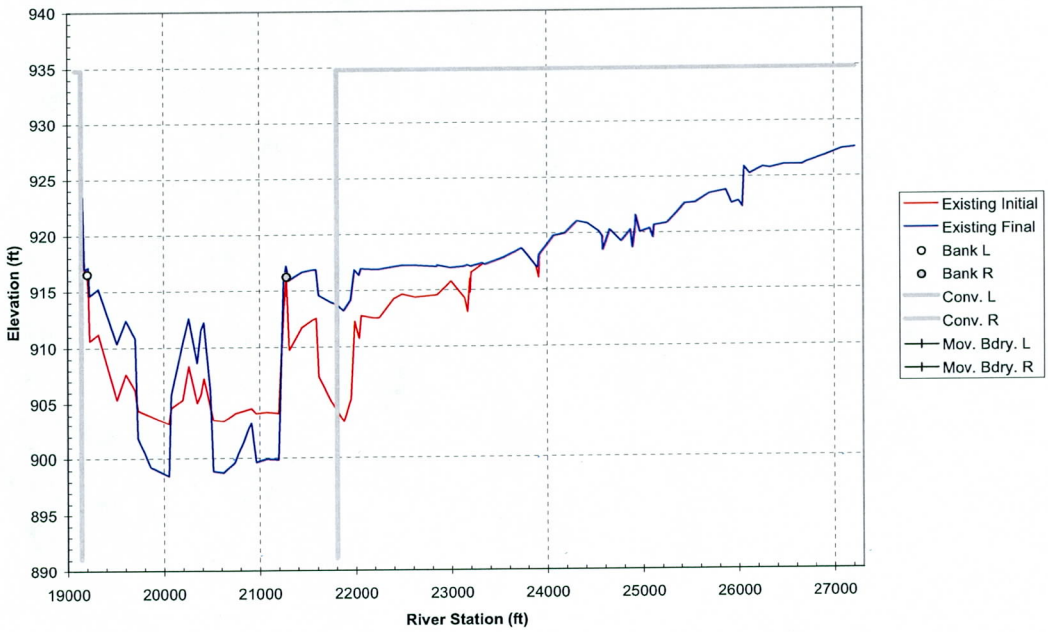


Cross Section 195.47

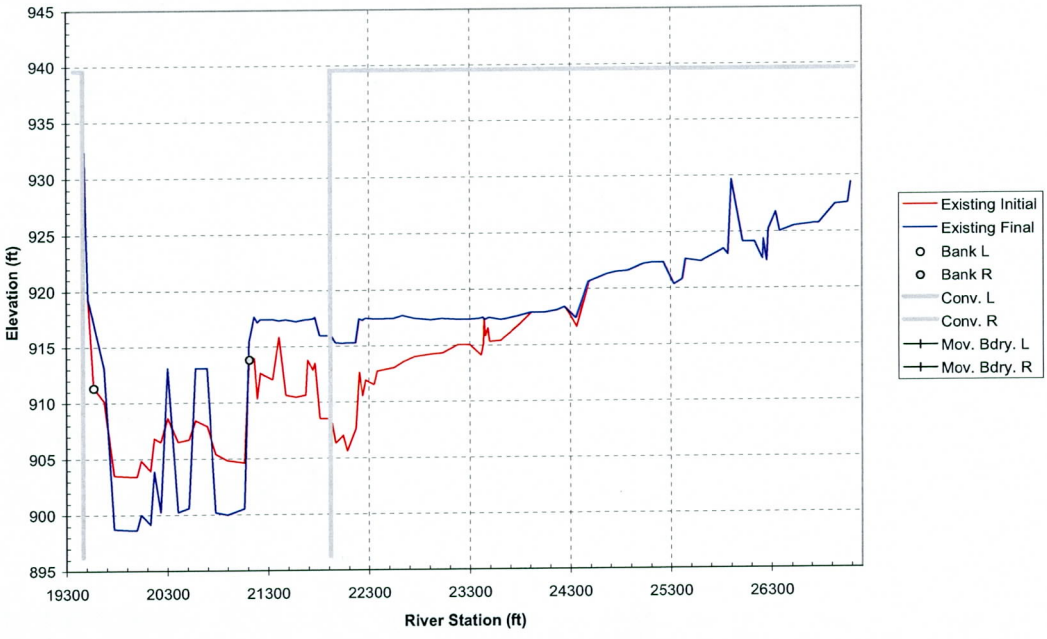


Cross Section 195.56

Cross Section 195.66



Cross Section 195.75



APPENDIX F

SECTION 3

SCOUR CALCULATIONS

SCOUR CALCULATIONS

The scour along the banks and at the Cotton Lane Bridge were calculated using standard formulas from engineering practice. These values have been calculated using formulas that have been applied in the Phoenix metropolitan area and have been reviewed by the Flood Control District of Maricopa County. The methods recommended by the U.S. Bureau of Reclamation have been applied and equations that give similar results in the mid- to upper mid-range of scour values have been used. The following pages give the equations, values used and results for the scour calculations.

Maximum Scour Depths for Gila River at Cotton Lane Bridge

6/5/2006

River Mile	Beginning Bed Elev	Min Bed Elevation	Max Scour (ft)	End Bed Elevation	End Scour (ft)
194.21	883.1	883.1	0	884.48	1.38
Estrella Parkway Bridge					
194.1	883.87	883.9	0.03	884.36	0.49
194.02	885.49	884.4	-1.09	884.42	-1.07
193.94	885.38	882.88	-2.5	882.9	-2.48
193.87	882.8	882	-0.8	882.08	-0.72
193.79	882.55	882.17	-0.38	882.41	-0.14
193.73	882.18	882.18	0	882.24	0.06
193.62	878.21	878.21	0	881.61	3.4
193.53	878.96	878.96	0	881.02	2.06
193.43	879.37	879.23	-0.14	881.02	1.65
193.34	881.18	880.71	-0.47	880.72	-0.46
193.25	880.67	880.58	-0.09	880.85	0.18
193.16	880.66	879.91	-0.75	879.94	-0.72
193.07	881.99	879.95	-2.04	879.97	-2.02
192.98	880.71	877.32	-3.39	877.38	-3.33
192.89	880.29	878.49	-1.8	878.51	-1.78
192.79	876.74	876.73	-0.01	877.4	0.66
192.7	877.01	877.01	0	877.87	0.86
192.61	878.15	877.28	-0.87	877.34	-0.81
192.52	878.23	877.52	-0.71	877.53	-0.7
Cotton lane Bridge					
192.39	876.67	873.92	-2.75	876.31	-0.36
192.33	876.06	875.41	-0.65	876.38	0.32
192.23	876.72	875.85	-0.87	876.09	-0.63
192.14	875.94	875.02	-0.92	875.12	-0.82
192.04	876.36	874.93	-1.43	874.94	-1.42
191.95	876.88	873.58	-3.3	873.61	-3.27
191.86	876.27	873.18	-3.09	873.2	-3.07
191.76	874.62	873.45	-1.17	873.5	-1.12
191.67	872.6	872.37	-0.23	872.73	0.13
191.57	870.63	870.63	0	872.23	1.6
191.48	870.93	870.89	-0.04	872.13	1.2
191.38	871.69	871.66	-0.03	872.11	0.42
191.29	870.63	870.53	-0.1	870.93	0.3
191.19	869.78	869.63	-0.15	870.28	0.5
191.1	870.88	870.01	-0.87	870.13	-0.75
191	869.64	869	-0.64	869.26	-0.38
190.91	867.98	867.65	-0.33	868.8	0.82
190.81	867.86	867.83	-0.03	869.11	1.25
190.72	866.3	866.3	0	868.51	2.21
190.62	867.37	867.28	-0.09	868.61	1.24
190.53	866.16	866.16	0	867.43	1.27
190.43	867.42	866.93	-0.49	868	0.58

	Reach 1	
	Max Scour (ft)	End Scour (ft)
	-3.39	-3.33
	Reach 2	
	Max Scour (ft)	End Scour (ft)
	-3.3	-3.27
	Reach 3	
	Max Scour (ft)	End Scour (ft)
	-0.87	-0.75

Calculation of General Scour Depths - English Units (ft)

June 5, 2006

Gila River / Cotton Lane Bridge - w/Protected South Bank - 500 Year Flood Flow = 285,000 cfs

Gila River - King Ranch/Cotton Lane Bridge
Cotton Lane Bridge Section
Method not Applicable

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Stream Values

Incised / Bankfull Q cfs	Qi	285000
Incised / Bankfull Width	Wi	2140
Incised / Bankfull q cfs/ft	qi	133.18
Depth of Incision	di	10
Competent Veloc.(Fig 12 p.41 cohensionle	Vc	7
(Table 8 for cohesive soils)		
Design Q (Channel)		285000
Design Channel Width		2140
Design Flow / Width	qf	133.18
Average Depth / Hydraulic Depth	dm	14.2
Maximum Depth	Ymax	24
Average Velocity	Vm	10.6
Bend Radius of Curvature (ft)	Rc	4210
Neill's m - 0.67 Sand to 0.85 Coarse Gravel	m	0.85
D50 - mm		6
D85 - mm		35
D90 - mm		50
Slope		0.0012
Froude Number for Channel		0.51
USBR - Lacey Z - Straight Reach	Zl	0.25
Neill Z (p. 36 USBR) Straight Reach	Zn	0.5
Blench Z (p. 36 USBR) Straight Rch	Zb	0.6
Blench "zero bed factor" (p35)	Fbo	2.8

Using All Equations

Average Scour Depth	6.3
Bend Scour - Moderate Bend	8.5
Bend Scour - Severe Bend	9.2

Total Scour Depth Calculations — **Meth. Used**

Average of Similar Values	4.2	3,4
Bend Scour Average	9.5	4 (Moderate)
Long Term Scour (HEC-6T 105 Yrs) (Max	3.4	
Bed Form Scour (See Tab) (BF)	1.6	
Low Flow Incisement (LFI)	2	
Safety Factor x (LT+BF+BS+LFI)	1.3	
Recommended Toe Down / with Bend	21.5	

Recommended Toe Down -No Bend	**14.5 Feet**

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Methodology Adapted from "Computing Degradation and Local Scour", US Bureau of Reclamation, Ernest L. Pemberton and Joseph M. Lara, January 1984

Zeller Equation from the Flood Control District of Maricopa County Drainage Design Manual - Hydraulics, September 2003 (Draft)

Thanks to those who have reviewed this spreadsheet and pointed out inconsistencies and suggested improvements!

		Scour Depth	Scour in Bends: Moderate Bend	Severe Bend	Right Angle Bend	Vertical Wall
1	**Neill - Incised** — ds = Z *df; df = di*(qf/qi)^m; di = 10, qf = 133.18, m = 0.85, df = 10.0, Zn = 0.5	5.0	Don't Use			
	Includes Bend Scour: qi = 133.18; Moderate Bend 0.6; Severe Bend 0.70		6.0	7		
2	**Neill - Competent Velocity - Sand or Coarser Material** — ds = dm((Vm/Vc)-1); dm = 14.2, Vm = 10.6, Vc = 7, ds = 7.3	7.3	7.3	7.3		
3	**USBR - D90 Method** — 50% of Average Flow Depth (dm); ds = Z*dm; Z = 0.25, dm = 14.2, ds = 3.6	3.6				
4	**Lacey - Zero Bed Sediment Transport Assumed** — ds = Z*dm; dm=0.47*(Q/f)^1/3; dm = 0.47, Q = 285000, dm = 19.0, Z = 0.25	4.8				
	Includes Bend Scour: f = 4.3; Mod Bend 0.5; Sharp Bend 0.6; Right Angle Bend 1; Vertical Rock Bank or Wall 1.25		9.5	11.4	19.0	23.8
	Dm = D50 = 6; f = 1.76 * Dm^0.5 = 4.3					
5	**Blench - Zero Bed Factor** — ds = Z*dfo; dfo = qf ^(2/3) / Fbo^(1/3); qf = 133.18, Fbo = 2.8, dfo = 18.5, Z = 0.6	11.1	11.1	11.1		
	Includes Bend Scour: Right Angle Bend 1.25				12.0	
6	**Abbot - SW Streams** — 0.5 < d50 < 0.7 Design Assumption; ds = K * (qi)^0.24; K = 2.45; qi = 133.18, ds = 7.9	Don't Use 7.9				
7	**Zeller Equation - General Scour - Minor Watercourses** — IGNORE IF NEGATIVE! Z = Ymax * [0.0685 * v^0.8 / (yh^0.4 * Se^0.3) - 1]	OK				
	Zgeneral = 24 [(0.0685 * V^0.8) / (14.2^0.4 * 0.0012^0.3) - 1] = 4.3 (Ymax = 24, V = 10.6, Yh = 14.2, Se = 0.0012)	4.3				
	Average Bend Scour Values		8.5	9.2	15.5	23.8

Use Proper Bend Scour Value in B29 for Calculations at Left - Not Necessarily This Average!!!

Applicability of Neill Incised Eqn

No	dm < df	19.0 dm
No	dm < df < dfo	10.0 df
OK	df < dfo	18.5 dfo
	dfo calculated below (under eqn 5)	

Middle Section			Recommended Toe Down
USBR Calcs			
Straight Bank	14.5	ft	**14.5**
With Bend	21.5	ft	**21.5**
Corps Calcs			
Outer Bend	19.4	ft	**19.4**

Table LR

Method	Neill	Lacey	Blench
Straight	0.5	0.25	0.6
Moderate Bend	0.6	0.5	0.6
Severe Bend	0.7	0.75	0.6
Right Angle Bend		1	1.25
Vertical Rock Bank		1.25	

Final Design Calculations - Section 1 (Bridge Section)

King Ranch - Cotton Lane Bridge - Near Bridge Reach
Bedform Scour Depths

Zbedform = 0.5 Dh

Hydraulic Depth	14.2
Froude Number	0.51

Simons and Senturk (1992)

Dune Height (Dh) **Applicable when Fr <1.0**

Dh = 0.066 * Yh^1.21

		Yh			
Dh =	0.066		14.2 ^ 1.21	=	**1.6**

Antidune Height **Applicable when Fr > 0.7**

Dh = 0.28 * pi * Yh * Fr^2

Dh =	0.28	3.14	14.2 *	0.51 ^2	=	**3.2**

Bedform Height	**1.6**	**Fr =**	**0.51**

Based on Methodology Presented in Flood Control District of Maricopa County Drainage Design Manual, September 2003 (Draft)

Calculation of General Scour Depths - English Units (ft)

June 5, 2006

Gila River / Cotton Lane Bridge - w/Protected South Bank - 500 Year Flood Flow = 285,000 cfs

Gila River - King Ranch/Cotton Lane Bridge
Cotton Lane Bridge Section
Method not Applicable

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Stream Values

Incised / Bankfull Q cfs	Qi	285000
Incised / Bankfull Width	Wi	3150
Incised / Bankfull q cfs/ft	qi	90.48
Depth of Incision	di	10
Competent Veloc.(Fig 12 p.41 cohensionle	Vc	7
(Table 8 for cohesive soils)		
Design Q (Channel)		285000
Design Channel Width		3150
Design Flow / Width	qf	90.48
Average Depth / Hydraulic Depth	dm	11
Maximum Depth	Ymax	19.26
Average Velocity	Vm	8.8
Bend Radius of Curvature (ft)	Rc	4210
Neill's m - 0.67 Sand to 0.85 Coarse Gravel	m	0.85
D50 - mm		6
D85 - mm		35
D90 - mm		50
Slope		0.0012
Froude Number for Channel		0.44
USBR - Lacey Z - Straight Reach	Zl	0.25
Neill Z (p. 36 USBR) Straight Reach	Zn	0.5
Blench Z (p. 36 USBR) Straight Rch	Zb	0.6
Blench "zero bed factor" (p35)	Fbo	2.8

Using All Equations

Average Scour Depth	4.8
Average Scour Depth - Moderate Bend	6.7
Average Scour Depth - Severe Bend	7.5

Total Scour Depth Calculations — **Meth. Used**

Average of Similar Values	3.8	3,4
Bend Scour Average	9.0	Moderate Bend
Long Term Scour (HEC-6T 105 Yrs) (Max	3.3	
Bed Form Scour (See Tab) (BF)	1.2	
Low Flow Incisement (LFI)	2	
Safety Factor x (LT+BF+BS+LFI)	1.3	
Recommended Toe Down / with Bend	20.2	

Recommended Toe Down -No Bend	13.3 Feet

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Methodology Adapted from "Computing Degradation and Local Scour", US Bureau of Reclamation, Ernest L. Pemberton and Joseph M. Lara, January 1984
Zeller Equation from the Flood Control District of Maricopa County Drainage Design Manual - Hydraulics, September 2003 (Draft)
Thanks to those who have reviewed this spreadsheet and pointed out inconsistencies and suggested improvements!

		Scour Depth	Scour in Bends: Moderate Bend	Severe Bend	Right Angle Bend	Vertical Wall
1	**Neill - Incised** — ds = Z *df — df = di*(qf/qi)^m — di = 10, qf = 90.48, m = 0.85, df = 10.0, Zn = 0.5	5.0	Don't Use			
	Includes Bend Scour — qi = 90.48 — Moderate Bend 0.6		6.0			
	Severe Bend 0.70			7		
2	**Neill - Competent Velocity - Sand or Coarser Material** — ds = dm((Vm/Vc)-1) — dm = 11, Vm = 8.8, Vc = 7, ds = 2.8	2.8	2.8	2.8		
3	**USBR - D90 Method** — 50% of Average Flow Depth (dm) — ds = Z*dm — Z = 0.25, dm = 11, ds = 2.8	2.8				
4	**Lacey - Zero Bed Sediment Transport Assumed** — ds = Z*dm — dm=0.47*(Q/f)^1/3 — dm = 0.47, Q = 285000, ^ 0.3333, dm = 19.0, Z = 0.25	4.8				
	Includes Bend Scour — f = 4.3 — Mod Bend 0.5		9.5			
	Sharp Bend 0.6			11.4		
	Right Angle Bend 1				19.0	
	Vertical Rock Bank or Wall 1.25					23.8
	f = 1.76 * Dm = D50 6 ^ 0.5 = f 4.3					
5	**Blench - Zero Bed Factor** — ds = Z*dfo — dfo = qf ^(2/3) / Fbo^(1/3) — qf = 90.48, ^ 0.67, dfo = 14.3, Z = 0.6	8.6	8.6	8.6		
	Includes Bend Scour — Fbo = 2.8 ^ 0.3333 — Right Angle Bend 1.25				9.3	
6	**Abbot - SW Streams** — 0.5 < d50 < 0.7 — Design Assumption — ds = K * (qi)^0.24 — K = 2.45 — qi = 90.48, ^ 0.24, ds = 7.2	Don't Use 7.2				
7	**Zeller Equation - General Scour - Minor Watercourses** — IGNORE IF NEGATIVE! — Z = Ymax * [0.0685 * v^0.8 / (yh^0.4 * Se^0.3) - 1]					
	Zgeneral = 19.26 [(0.0685 * V 8.8 ^ 0.8) -1] = — (Yh 11 ^0.4 * Se 0.0012 ^0.3)	OK 2.4				
	Average Bend Scour Values		6.7	7.5	14.1	23.8

Use Proper Bend Scour Value in B29 for Calculations at Left - Not Necessarily This Average!!!

Applicability of Neill Incised Eqn

No	dm < df	19.0 dm
No	dm < df < dfo	10.0 df
OK	df < dfo	14.3 dfo
	dfo calculated below (under eqn 5)	

Middle Section — Recommended Toe Down

USBR Calcs			
Straight Bank	13.3	ft	13.5
With Bend	20.2	ft	20.5
Corps Calcs			
Outer Bend	26.9	ft	26.9

Table LR

Method	Neill	Lacey	Blench
Straight	0.5	0.25	0.6
Moderate Bend	0.6	0.5	0.6
Severe Bend	0.7	0.75	0.6
Right Angle Bend		1	1.25
Vertical Rock Bank		1.25	

Final Design Calculations - Section 2 (West of Cotton Lane Bridge)

King Ranch - Cotton Lane Bridge - Middle Reach - Expansion Reach
Bedform Scour Depths

Zbedform = 0.5 Dh

Hydraulic Depth	11
Froude Number	0.44

Simons and Senturk (1992)

Dune Height (Dh) **Applicable when Fr <1.0**

Dh = 0.066 * Yh^1.21

Yh

Dh = 0.066 11 ^ 1.21 = **1.2**

Antidune Height **Applicable when Fr > 0.7**

Dh = 0.28 * pi * Yh * Fr^2

Dh = 0.28 3.14 11 * 0.44 ^2 = **1.9**

Bedform Height	**1.2**	**Fr =**	**0.44**

Based on Methodology Presented in Flood Control District of Maricopa County Drainage Design Manual, September 2003 (Draft)

Final Design Calculations - June 2006

Section 2 - West of Cotton Lane Bridge - Expansion Reach

Calculation of General Scour Depths - English Units (ft)

June 5, 2006

Gila River / Cotton Lane Bridge - w/Protected South Bank - 500 Year Flood Flow = 285,000 cfs

Gila River - King Ranch/Cotton Lane Bridge
Cotton Lane Bridge Section
Method not Applicable

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Stream Values

Incised / Bankfull Q cfs	Qi	285000
Incised / Bankfull Width	Wi	4150
Incised / Bankfull q cfs/ft	qi	68.67
Depth of Incision	di	10
Competent Veloc.(Fig 12 p.41 cohensionle	Vc	7
(Table 8 for cohesive soils)		
Design Q (Channel)		285000
Design Channel Width		4150
Design Flow / Width	qf	68.67
Average Depth / Hydraulic Depth	dm	12.6
Maximum Depth	Ymax	20.1
Average Velocity	Vm	6.3
Bend Radius of Curvature (ft)	Rc	4210
Neill's m - 0.67 Sand to 0.85 Coarse Gravel	m	0.85
D50 - mm		6
D85 - mm		35
D90 - mm		50
Slope		0.0012
Froude Number for Channel		0.35
USBR - Lacey Z - Straight Reach	Zl	0.25
Neill Z (p. 36 USBR) Straight Reach	Zn	0.5
Blench Z (p. 36 USBR) Straight Rch	Zb	0.6
Blench "zero bed factor" (p35)	Fbo	2.8

	Scour Depth	Scour in Bends: Moderate Bend	Severe Bend	Right Angle Bend	Vertical Wall
1 Neill - Incised					
df = di*(qf/qi)^m : 10 x (68.67 / 68.67) ^ 0.85 = 10.0 ; ds = Z*df ; Z = 0.5	5.0	Don't Use			
Includes Bend Scour: qi; Moderate Bend 0.6; Severe Bend 0.70		6.0	7		
2 Neill - Competent Velocity - Sand or Coarser Material					
ds = dm((Vm/Vc)-1) : 12.6 x (6.3 / 7) - 1) = -1.3	-1.3	-1.3	-1.3		
3 USBR - D90 Method 50% of Average Flow Depth (dm)					
ds = Z*dm : 0.25 x 12.6 = 3.2	3.2				
4 Lacey - Zero Bed Sediment Transport Assumed					
dm=0.47*(Q/f)^1/3 : 0.47 x (285000) ^ 0.3333 = 19.0 ; ds = Z*dm ; Z = 0.25	4.8				
Includes Bend Scour: f = 4.3; Mod Bend 0.5; Sharp Bend 0.6; Right Angle Bend 1; Vertical Rock Bank or Wall 1.25		9.5	11.4	19.0	23.8
f = 1.76 * Dm = D50 (6) ^ 0.5 = 4.3					
5 Blench - Zero Bed Factor					
dfo = qf ^(2/3) / Fbo^(1/3) : qf 68.67 ^ 0.67 = dfo 11.9 ; ds = Z*dfo ; Z = 0.6	7.1	7.1	7.1		
Includes Bend Scour: Fbo 2.8 ^ 0.3333; Right Angle Bend 1.25				7.7	
6 Abbot - SW Streams 0.5 < d50 < 0.7 Design Assumption					
ds = K * (qi)^0.24 : 2.45 * qi 68.67 ^ 0.24 = ds 6.8 ; K = 2.45	Don't Use 6.8				
7 Zeller Equation - General Scour - Minor Watercourses IGNORE IF NEGATIVE!					
Z = Ymax * [0.0685 * v^0.8 / (yh^0.4 * Se^0.3) - 1]					
Zgeneral = 20.1 [(Ymax 0.0685 6.3 ^ V 0.8) -1] = (Yh 12.6 ^0.4 Se 0.0012 ^0.3)	Don't Use -3.7				
Average Bend Scour Values		5.3	6.1	13.4	23.8

Use Proper Bend Scour Value in B29 for Calculations at Left - Not Necessarily This Average!!!

Applicability of Neill Incised Eqn

No	dm < df	19.0 dm
No	dm < df < dfo	10.0 df
OK	df < dfo	11.9 dfo
	dfo calculated below (under eqn 5)	

Using All Equations

Average Scour Depth	3.1
Average Scour Depth - Moderate Bend	5.3
Average Scour Depth - Severe Bene	6.1

Total Scour Depth Calculations		Meth. Used
Average of Similar Values	4.0	3, 4
Bend Scour Average (Moderate Bend)	8.3	4, 5
Long Term Scour (HEC-6T 105 Yrs)	0.9	
Bed Form Scour (See Tab) (BF)	1.4	
Low Flow Incisement (LFI)	2	
Safety Factor x (LT+BF+BS+LFI)	1.3	
Recommended Toe Down / with Bend	16.4	

Recommended Toe Down -No Bend	10.7 Feet

Middle Section			Recommended Toe Down
USBR Calcs			
Straight Bank	10.7	ft	11
With Bend	16.4	ft	16.5
Corps Calcs			
Outer Bend	37.4	ft	

Table LR

Method	Neill	Lacey	Blench
Straight	0.5	0.25	0.6
Moderate Bend	0.6	0.5	0.6
Severe Bend	0.7	0.75	0.6
Right Angle Bend		1	1.25
Vertical Rock Bank		1.25	

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Zeller Equation from the Flood Control District of Maricopa County Drainage Design Manual - Hydraulics, September 2003 (Draft)

Thanks to those who have reviewed this spreadsheet and pointed out inconsistencies and suggested improvements!

Final Design Calculations - Section 3 (West End of King Ranch)

King Ranch - Cotton Lane Bridge - Middle Reach - Expansion Reach
Bedform Scour Depths

Zbedform = 0.5 Dh

Hydraulic Depth	12.6
Froude Number	0.35

Simons and Senturk (1992)

Dune Height (Dh) **Applicable when Fr <1.0**

Dh = 0.066 * Yh^1.21

		Yh		
Dh =	0.066	12.6 ^ 1.21	=	**1.4**

Antidune Height **Applicable when Fr > 0.7**

Dh = 0.28 * pi * Yh * Fr^2

Dh =	0.28	3.14	12.6 *	0.35 ^2	=	**1.4**

Bedform Height	**1.4**	**Fr =**	**0.35**

Based on Methodology Presented in Flood Control District of Maricopa County Drainage Design Manual, September 2003 (Draft)

Final Design Calculations - June 2006

Section 3 - West of Cotton Lane Bridge - West End of King Ranch

Cotton Lane Bridge - Pier Scour Calculations

Scour Summary of Calculations

Leo Kreymborg, P.E.

16-Feb-06

Pier Scour (5 foot columns)	100-year	500-year	Notes
General Scour	1.1	1.1	Both are Zeller General Scour at 192.41 from n=0.025 in channel model
Long Term Scour	1.5	1.5	
30% factor of safety on subtotal	0.8	0.8	
Subtotal	3.4	3.4	
Local Pier Scour	19.7	20.7	
Total Scour	23.1	24.1	

Left and Right Abutment Scour	100-year	500-year	Notes
General Scour	1.1	see note below	Zeller General Scour at 192.41 from n=0.025 in channel model
Long Term Scour	1.5	see note below	
Dune Scour	3	see note below	1/6 of Maximum Depth at 192.41
Factor of Safety, 30%	1.7	see note below	
Total Scour	7.3	27.3	for 500-year flood, use pier scour calculation for 5-foot piers

500-year pier scour

y_1	19.6	Flow depth directly upstream of pier	from cross-section 192.41 Channel Maximum Depth (n=0.025 in channel model)
K_1	1.1	Correction Factor for pier nose shape	Square Nose Including Debris, Table 6.1 HEC-18
K_2	1.0	Correction Factor for angle of attack	0 angle of attack, Table 6.2
K_3	1.1	Correction Factor for bed condition	Table 6.3 Plane bed and antidune flow
K_4	1.0	Correction Factor for armoring	Several samples do not have D95 > 20mm, so no armoring is assumed
a	9.0	Pier width (5 feet + 4 feet debris)	8 feet
Fr_1	0.47	Froude number directly upstream of pier	from cross-section 192.42, Channel Froude number
V_1	9.77	Mean channel velocity (not used)	Channel velocity from 192.42
g	32.2	(not used)	

$y_s = a * 2.0 * K_1 * K_2 * K_3 * K_4 * (y_1/a)^{0.35} * Fr_1^{0.43}$

$y_s = 20.67115$

Summary of Scour Values for Vane Dikes June 29, 2006

Using Pier Scour Equations from WEST

500-year pier scour

y_1	13.9	Flow depth directly upstream of pier	from cross-section 192.41 Channel Maximum Depth (n=0.025 in char
K_1	1.0	Correction Factor for pier nose shape	Round Nose Not Including Debris, Table 6.1 HEC-18
K_2	1.0	Correction Factor for angle of attack	15 degree angle of attack, Table 6.2 - L/a = 500/20 = 25
K_3	1.1	Correction Factor for bed condition	Table 6.3 Plane bed and antidune flow
K_4	1.0	Correction Factor for armoring	Several samples do not have D95 > 20mm, so no armoring is assum
a	30.0	Pier width - No Direct Correlation	Varies from 9 ft at crest to 93 ft at bed
Fr_1	0.43	Froude number directly upstream of pier	from cross-section 191.95, Channel Froude number
V_1	7.8	Mean channel velocity (not used)	Channel velocity from 191.95
g	32.2	(not used)	

$y_s = a * 2.0 * K_1 * K_2 * K_3 * K_4 * (y_1/a)^{0.35} * Fr_1^{0.43}$

$y_s = 35.07503$

Method	Scour Depth
Pier Scour - 20 ft width	27
Pier Scour - 30 ft width	35
Guide Dike Calculations (USBR - See Section 2)	
Lacey - Using Worst Value	33.33
Blench - Using Worst Value	25
Average Value	30.08

	River Mile	Water Surface Elevation	Top of Vane Dike	ank Elevati FW+1.0 ft	Thalweg Elevation	Vane Dikes		
						Toe Elevation	Total Height	Distance to Toe*
						30		
Reach 2	191.95	890.70	887.50	891.70	876.88	846.88	40.62	121.86
	191.86	890.19	887.00	891.19	876.27	846.27	40.73	122.19
	191.76	889.66	886.50	890.66	874.62	844.62	41.88	125.64
	191.67	889.10	886.00	890.10	872.6	842.60	43.40	130.2
	191.57	888.58	885.50	889.58	870.63	840.63	44.87	134.61
Reach 3	191.48	888.13	885.00	889.13	870.93	840.93	44.07	132.21

ChannelPro-RiprapSize-12-Outer

King Ranch Riprap Sizing - North/Outer Bank

PROGRAM OUTPUT FOR A CHANNEL WITH A KNOWN LOCAL
DEPTH AVERAGED VELOCITY, BENDWAY
INPUT PARAMETERS

SPECIFIC WEIGHT OF STONE,PCF	155.0
MINIMUM CENTER LINE BEND RADIUS,FT	5000.0
WATER SURFACE WIDTH,FT	2100.0
LOCAL FLOW DEPTH,FT	20.0
CHANNEL SIDE SLOPE,1 VER: 4.00 HORZ	
LOCAL DEPTH AVG VELOCITY,FPS	10.00
SIDE SLOPE CORRECTION FACTOR K1	1.00
CORRECTION FOR VELOCITY PROFILE IN BEND	1.21
RIPRAP DESIGN SAFETY FACTOR	1.10

SELECTED STABLE GRADATIONS
ETL GRADATION

NAME	COMPUTED D30 FT	D30(MIN) FT	D100(MAX) IN	D85/D15	N=THICKNESS/ D100(MAX)	CT	THICKNESS IN
1		.37	9.00	1.70	NOT STABLE		
2	.48	.48	12.00	1.70	1.00	1.00	12.0

D100(MAX) IN	LIMITS OF STONE WEIGHT,LB FOR PERCENT LIGHTER BY WEIGHT						D30(MIN) FT	D90(MIN) FT
	100		50		15			
12.00	81	32	24	16	12	5	.48	.70

EQUIVALENT SPHERICAL DIAMETERS IN INCHES

D100(MAX)	D100(MIN)	D50(MAX)	D50(MIN)	D15(MAX)	D15(MIN)
12.0	8.8	8.0	7.0	6.3	4.8

King Ranch Riprap Sizes South Bank

PROGRAM OUTPUT FOR A CHANNEL WITH A KNOWN LOCAL
DEPTH AVERAGED VELOCITY, STRAIGHT REACH
INPUT PARAMETERS

SPECIFIC WEIGHT OF STONE,PCF	155.0
LOCAL FLOW DEPTH,FT	10.0
CHANNEL SIDE SLOPE,1 VER: 4.00 HORZ	
LOCAL DEPTH AVG VELOCITY,FPS	10.00
SIDE SLOPE CORRECTION FACTOR K1	1.00
CORRECTION FOR VELOCITY PROFILE IN BEND	1.00
RIPRAP DESIGN SAFETY FACTOR	1.10

SELECTED STABLE GRADATIONS
ETL GRADATION

NAME	COMPUTED D30 FT	D30(MIN) FT	D100(MAX) IN	D85/D15	N=THICKNESS/ D100(MAX)	CT	THICKNESS IN
1		.37	9.00	1.70	NOT STABLE		
2	.47	.48	12.00	1.70	1.00	1.00	12.0

D100(MAX) LIMITS OF STONE WEIGHT,LB D30(MIN) D90(MIN)

ChannelPro-RiprapSize-12-Outer

IN	FOR PERCENT LIGHTER BY WEIGHT						FT	FT
	100		50		15			
12.00	81	32	24	16	12	5	.48	.70

EQUIVALENT SPHERICAL DIAMETERS IN INCHES

D100(MAX)	D100(MIN)	D50(MAX)	D50(MIN)	D15(MAX)	D15(MIN)
12.0	8.8	8.0	7.0	6.3	4.8

APPENDIX G

CHECK-RAS OUTPUT

The CHECK-RAS report was reviewed and no critical errors were found. The report files are found on the enclosed CD with the models for further review if desired. This was done to conserve both paper and storage space.

EXHIBIT MAPS

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7 JUN 2006
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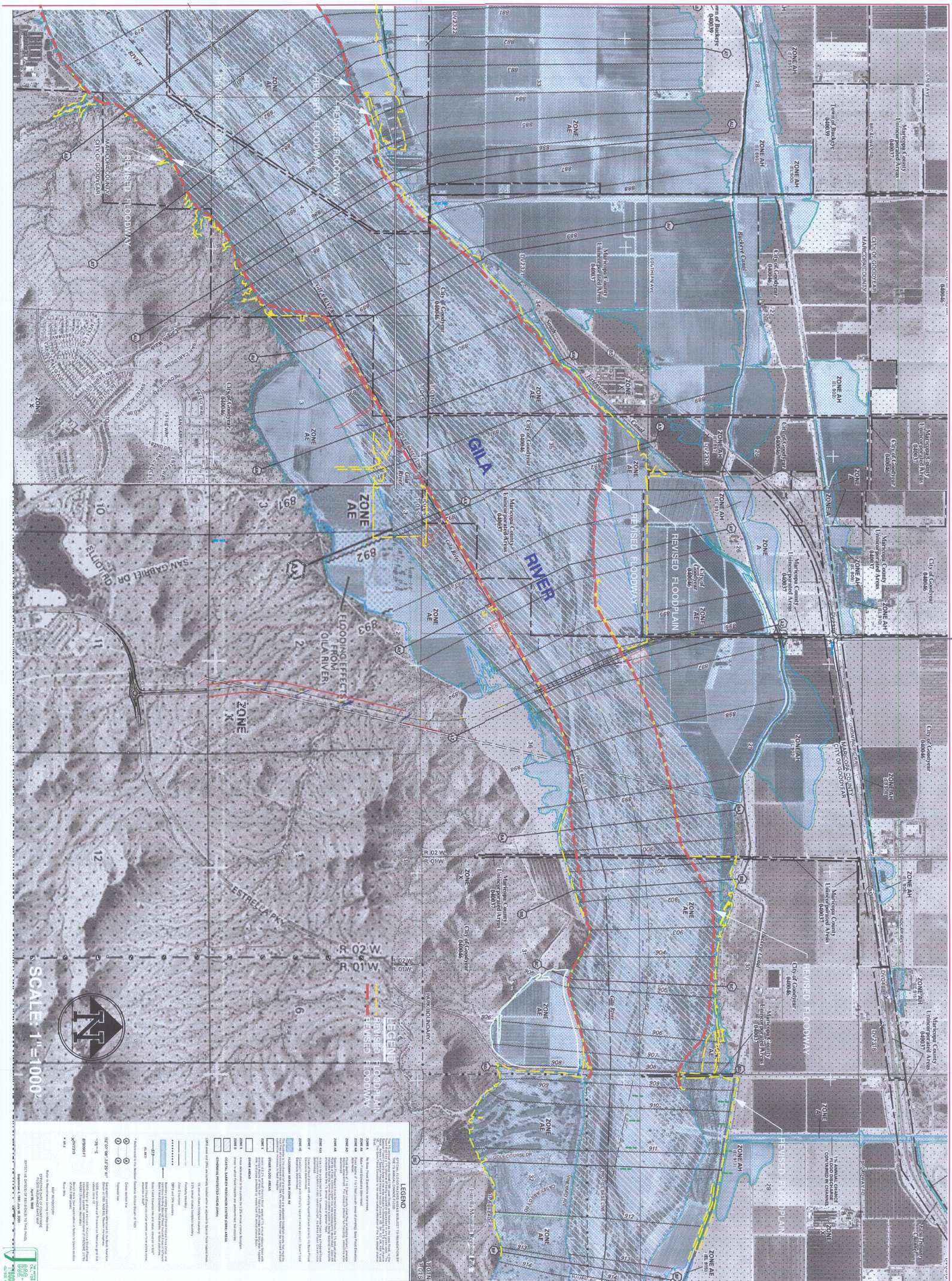


EXHIBIT

GILA RIVER FLOODPLAIN

COTTON LANE BRIDGE/KING RANCH FLOODPLAIN REDELINEATION

CVL Contract GARY FREEMAN
CVL Project #: 800001
DESIGN DATE JAN 12, 2006

NO.	REVISION	DATE
	90% SUBMITTAL	02-17-06
	FINAL SUBMITTAL	06-23-06

Coe & Van Loo Consultants, Inc.
River Research & Design, Inc.

CVL
4550 North 12th Street
Phoenix, Arizona 85014
Telephone 602-264-6831
http://www.cvlci.com

GILA RIVER IMPROVEMENT

FOR COTTON LANE BRIDGE

CITY OF GOODYEAR GENERAL NOTES FOR CONSTRUCTION

A. ALL CONSTRUCTION SHALL CONFORM WITH THE LATEST MAG STANDARD DETAILS AND SPECIFICATIONS AND THE CITY'S SUPPLEMENTAL DETAILS AND SPECIFICATIONS.

B. THIS SET OF PLANS HAS BEEN REVIEWED FOR COMPLIANCE WITH CITY REQUIREMENTS PRIOR TO ISSUANCE OF CONSTRUCTION PERMITS. HOWEVER, SUCH REVIEW SHALL NOT PREVENT THE CITY FROM REQUIRING CORRECTION OF ERRORS IN PLANS FOUND TO BE IN VIOLATION OF ANY LAW OR ORDINANCE.

C. THE CITY DOES NOT WARRANT ANY QUANTITIES SHOWN ON THESE PLANS.

D. THE CITY APPROVAL IS FOR GENERAL LAYOUT IN THE RIGHT-OF-WAY ONLY. THIS APPROVAL IS VALID FOR A PERIOD OF SIX MONTHS. CONSTRUCTION PERMITS SHALL BE OBTAINED DURING THIS PERIOD OR THE PLANS SHALL BE OBTAINED DURING THIS PERIOD OR THE PLANS SHALL BE RESUBMITTED FOR REVIEW AND APPROVAL.

E. AN APPROVED SET OF PLANS SHALL BE AVAILABLE ON THE JOB SITE AT ALL TIMES.

F. THE CITY SHALL BE NOTIFIED 24 HOURS PRIOR TO ANY CONSTRUCTION WORK AND INSPECTION (932-1637). CONSTRUCTION WORK CONCEALED WITHOUT INSPECTION BY THE CITY SHALL BE SUBJECT TO EXPOSURE AT THE CONTRACTOR'S EXPENSE.

G. RIGHT-OF-WAY IMPROVEMENTS SHALL NOT BE ACCEPTED UNTIL "AS-BUILT" PLANS HAVE BEEN SUBMITTED AND APPROVED BY THE CITY. (SEE "AS BUILT" REQUIREMENTS)

H. THE DEVELOPER IS RESPONSIBLE FOR THE REMOVAL OR RELOCATION OF ALL OBSTRUCTIONS WITHIN THE RIGHT-OF-WAY PRIOR TO STARTING NEW CONSTRUCTION.

I. THE DEVELOPER IS RESPONSIBLE FOR ARRANGING THE RELOCATION AND ASSOCIATED COSTS OF ALL UTILITIES. A UTILITY RELOCATION SCHEDULE SHALL BE SUBMITTED PRIOR TO THE ISSUANCE OF PERMITS.

J. THE DEVELOPER IS RESPONSIBLE FOR OBTAINING OR DEDICATING ALL REQUIRED RIGHTS-OF-WAY AND EASEMENTS TO THE CITY PRIOR TO ISSUANCE OF PERMITS.

K. THE CONTRACTOR SHALL CONTACT BLUE STAKE (602-263-1100) 48 HOURS PRIOR TO CONSTRUCTION.

L. THE CONTRACTOR SHALL BARRICADE CONSTRUCTION SITES AT ALL TIMES PER THE CITY OF PHOENIX TRAFFIC BARRICADE MANUAL. WHEN REQUIRED BY THE CITY, A TRAFFIC CONTROL PLAN SHALL BE SUBMITTED FOR APPROVAL IN ADVANCE OF CONSTRUCTION.

M. THE CONTRACTOR MAY OBTAIN A FIRE HYDRANT METER FOR CONSTRUCTION WATER FROM THE FINANCE DEPARTMENT. THIS METER SHOULD BE ORDERED TWO WORKING DAYS PRIOR TO THE START OF CONSTRUCTION. THE UNLAWFUL REMOVAL OF WATER FROM A FIRE HYDRANT IS A VIOLATION OF THE MUNICIPAL CODE, PUNISHABLE BY FINE AND/OR IMPRISONMENT.

N. PRIVATE ON-SITE WATER AND SEWER LINES SHALL BE CONSTRUCTED IN ACCORDANCE WITH THE UNIFORM PLUMBING CODE AS ADOPTED BY THE CITY.

ENGINEER NOTES

1. THESE PLANS ARE NOT TO BE USED FOR CONSTRUCTION PURPOSES UNLESS THE APPROVAL BLOCK HAS BEEN SIGNED BY THE APPROPRIATE AGENCIES. ALL WORK SHALL CONFORM TO THE CURRENT MARICOPA ASSOCIATION OF GOVERNMENTS (M.A.G.) SPECIFICATIONS AND STANDARD DETAILS TOGETHER WITH THE SUPPLEMENT OF THE APPROPRIATE AGENCY AND ADOT STANDARD DRAWING WHERE NOTED ON PLANS.
2. THE CONTRACTOR SHALL MAKE NO CLAIM AGAINST THE OWNER OR THE ENGINEER REGARDING ALLEGED INACCURACY OF CONSTRUCTION STAKES SET BY THE ENGINEER UNLESS ALL SURVEY STAKES SET BY THE ENGINEER ARE MAINTAINED INTACT AND CAN BE VERIFIED AS TO THEIR ORIGIN. IF, IN THE OPINION OF THE ENGINEER, THE STAKES ARE NOT MAINTAINED INTACT AND CANNOT BE VERIFIED AS TO THEIR ORIGIN, ANY REMEDIAL WORK REQUIRED TO CORRECT ANY ITEM OR IMPROPER CONSTRUCTION WORK IN THIS DEVELOPMENT SHALL BE PERFORMED AT THE SOLE EXPENSE OF THE RESPONSIBLE CONTRACTOR OR SUBCONTRACTOR.
3. NOTHING CONTAINED IN THE CONTRACT DOCUMENTS SHALL CREATE, NOR SHALL BE CONSTRUED TO CREATE, ANY CONTRACTUAL RELATIONSHIP BETWEEN THE ENGINEER AND THE CONTRACTOR OR ANY SUBCONTRACTOR.
4. THE ENGINEER IS NOT RESPONSIBLE FOR CONSTRUCTION MEANS, METHODS, TECHNIQUES, SEQUENCES OR PROCEDURES OR FOR SAFETY PRECAUTIONS OR PROGRAMS UTILIZED IN CONNECTION WITH THE WORK. THE ENGINEER IS NOT RESPONSIBLE FOR THE CONTRACTOR'S FAILURE TO CARRY OUT THE WORK IN ACCORDANCE WITH THE CONTRACT DOCUMENTS NOR ANY COSTS INCURRED, WHETHER INITIAL OR ADDITIONAL, TO CORRECT, MODIFY, OR ALTER ANY CONSTRUCTION COMPLETED CONTRARY TO THE CONTRACT DOCUMENTS.
5. ALL COMPACTION SHALL COMPLY WITH M.A.G. SPECS SECTION 601.
6. THE ENGINEER WILL MAKE FIELD RECORD DRAWING MEASUREMENTS OF THE WORK UPON NOTIFICATION BY THE CONTRACTOR THAT THE WORK IS COMPLETE AND READY FOR RECORD DRAWING SURVEY.
7. A THOROUGH ATTEMPT HAS BEEN MADE TO SHOW THE LOCATIONS OF ALL UNDERGROUND OBSTRUCTIONS AND UTILITY LINES IN THE WORK AREA. HOWEVER, THE CONTRACTOR SHALL BE RESPONSIBLE FOR ANY DAMAGE TO OBSTRUCTIONS AND UTILITY LINES ENCOUNTERED DURING CONSTRUCTION AND SHALL DETERMINE THE EXACT LOCATION OF UTILITIES IN THE AREA.
8. ALL EARTHWORK CONSTRUCTION SHALL CONFORM TO THE LATEST M.A.G. STANDARD DETAILS AND/OR SPECIFICATIONS INCLUDING ANY SUPPLEMENTS THERETO AND THE SOILS REPORT PREPARED BY: PSI ENGINEERING, CONSULTING TESTING
9. DATA FOR EARTHWORK CALCULATIONS IS PROVIDED IN THE SOILS REPORT AND (IF APPLICABLE) ANY SUPPLEMENTS THERETO.
10. OWNER/CONTRACTOR IS RESPONSIBLE FOR SURVEY VERIFICATION OF EXISTING HORIZONTAL AND VERTICAL CONDITIONS PRIOR TO START OF CONSTRUCTION. A DEVIATION IN EXISTING CONDITIONS MUST BE BROUGHT TO THE ATTENTION OF COE & VAN LOO BEFORE CONSTRUCTION STARTS.
11. COE & VAN LOO WILL NOT BE RESPONSIBLE FOR REMOVAL, REPLACEMENT, OR OTHER MODIFICATIONS THAT MAY BE REQUIRED AS A RESULT OF EXISTING CONDITIONS NOT PROPERLY VERIFIED AND CONFIRMED.
12. SHOULD AN ERROR BE FOUND IN THE HORIZONTAL & VERTICAL CONDITIONS, COE & VAN LOO WILL BE NOTIFIED AND CONSTRUCTION WILL NOT PROCEED UNTIL REVISIONS/MODIFICATIONS HAVE BEEN PREPARED AND SUBMITTED BY COE & VAN LOO.
13. IN THE EVENT THAT COLLAPSING SOILS ARE ENCOUNTERED, OVEREXCAVATION REMOVAL AND REPLACEMENT WITH COMPACTED FILL SHALL BE REQUIRED.
14. QUANTITIES FOR CONSTRUCTION PURPOSES SHALL BE PROVIDED BY THE CONTRACTOR. ESTIMATED QUANTITIES SHOWN ARE FOR AGENCY REVIEW ONLY.

FLOOD CONTROL DISTRICT NOTES

1. ALL CONSTRUCTION WITHIN FLOOD CONTROL DISTRICT (DISTRICT) RIGHTS-OF-WAY JURISDICTION SHALL CONFORM TO THE LATEST MARICOPA ASSOCIATION OF GOVERNMENTS' (MAG) SPECIFICATIONS, UNLESS THE STRUCTURE INVOLVED IS A DAM. IF THE STRUCTURE IS A DAM, SPECIAL PERMIT REQUIREMENTS WILL APPLY. DAM SHALL MEAN A STRUCTURE THAT IS UNDER THE JURISDICTION OF THE ARIZONA DEPARTMENT OF WATER RESOURCES AND IS DEFINED IN ARIZONA REVISED STATUTES 45-1201.

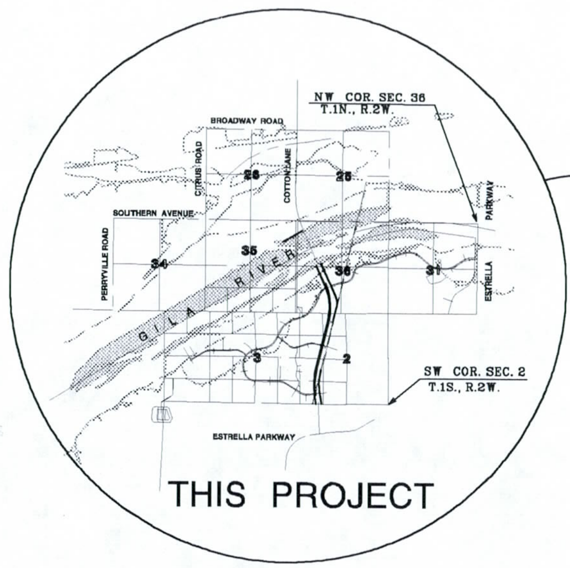
2. CONTRACTOR MUST OBTAIN NECESSARY DISTRICT PERMIT PRIOR TO COMMENCEMENT OF CONSTRUCTION WITHIN DISTRICT RIGHT-OF-WAY AND MAINTAIN A COPY OF THE PERMIT ON THE PROJECT SITE AT ALL TIMES.

3. NOTIFY THE DISTRICT'S PERMITS INSPECTOR AT (602) 506-4727 OR (602) 506-4723 AT LEAST 48 HOURS PRIOR TO ANY WORK BEING PERFORMED IN THE DISTRICT'S RIGHT-OF-WAY

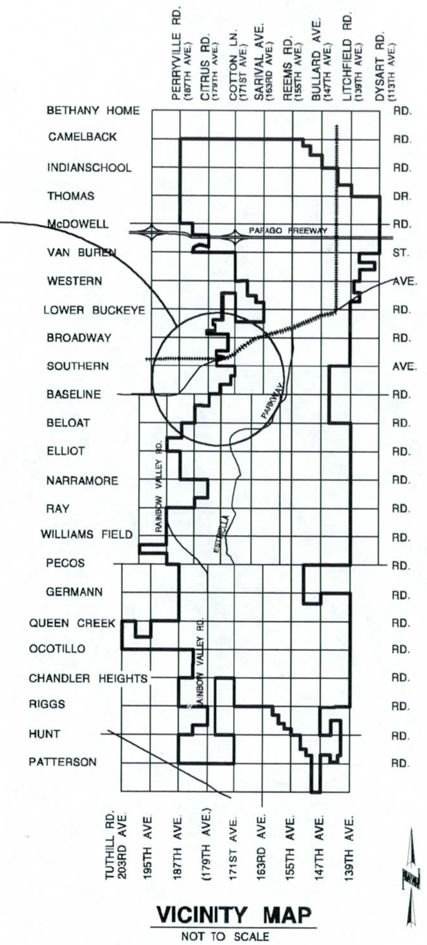
4. CONTRACTOR PERFORMING EXCAVATION OPERATIONS IS RESPONSIBLE FOR LOCATING AND PROTECTING ALL UNDERGROUND UTILITIES.

5. ALL COMPACTION AND BACKFILL WITHIN THE DISTRICT'S RIGHT-OF-WAY SHALL CONFORM TO THE LATEST MAG SPECIFICATIONS UNLESS STIPULATED OTHERWISE IN THE DISTRICT'S PERMIT.

6. ANY DAMAGE TO DISTRICT'S STRUCTURES, EQUIPMENT, MATERIALS, VEGETATION, AND/OR PROPERTY SHALL BE REPLACED AND/OR REPAIRED IN-KIND TO THE SATISFACTION OF THE DISTRICT.



A PORTION OF SECTIONS 25, 31, 34, 35 & 36, TOWNSHIP 1 NORTH, RANGE 2 WEST AND SECTIONS 2, 3, 4 & 5, TOWNSHIP 1 SOUTH, RANGE 2 WEST, GILA AND SALT RIVER MERIDIAN, MARICOPA COUNTY, GOODYEAR, ARIZONA



VICINITY MAP
NOT TO SCALE

SHEET INDEX

1 ....COVER SHEET
2 ....SHEET INDEX & VICINITY MAP
3 ....OVERVIEW MAP & LEGEND
4-21 ....100 SCALE PLAN VIEWS
22-24 ....CROSS SECTIONS
25 ....DETAILS

EXISTING UTILITIES:
W.A.P.A. (HIGH KV VOLTAGE OVERHEAD TOWERS)
APS (OVERHEAD ELEC)
SOUTHWEST (HIGH PRESSURE GAS LINE)

CITY OF GOODYEAR GENERAL NOTES FOR GRADING AND DRAINAGE CONSTRUCTION

A. AN ON-SITE GRADING PERMIT IS REQUIRED.

B. A SEPARATE PERMIT IS NECESSARY FOR ANY OFF-SITE CONSTRUCTION.

C. THE CITY SHALL BE NOTIFIED 24 HOURS BEFORE ANY ON-SITE CONSTRUCTION BEGINS (623-932-1637).

D. THE GRADING CONTRACTOR SHALL DESIGNATE THE LOCATION FOR WASTING SPOIL MATERIALS AND A LETTER FROM THE OWNER GIVING PERMISSION FOR SAID DISPOSAL PRIOR TO STARTING ON-SITE CONSTRUCTION.

E. THE CONTRACTOR IS RESPONSIBLE FOR LOCATING AND CONFIRMING DEPTH OF ALL THE EXISTING UTILITY LINES. IN THE EVENT OF ANY CONFLICT WITH UNDERGROUND UTILITIES, THE CONTRACTOR SHOULD CONTACT THE CITY AND DESIGNER

F. YOU ARE HEREBY ADVISED THAT NO PERSON SHALL USE ANY MECHANICAL EQUIPMENT FOR LAND LEVELING OR CLEARING, ROAD CONSTRUCTION, TRENCHING, EXCAVATING, DEMOLITION, OR ENGAGE IN ANY EARTHMOVING ACTIVITY WITHOUT FIRST OBTAINING A PERMIT FROM AIR POLLUTION CONTROL, MARICOPA COUNTY DEPARTMENT OF HEALTH SERVICES, 2406 S. 24TH ST. #E204, PHOENIX, AZ 85006, PHONE: 506-6666. (THIS NOTICE IS ISSUED PURSUANT TO A.R.S. 36-779.07, NOTICE OF BUILDING AGENCIES.)

CITY OF GOODYEAR

REVIEW AND RECOMMENDED APPROVAL BY:

FIRE DEPT.		GRADING & DRAINAGE	
LANDSCAPE & PLANNING		WATER & SEWER	
TRAFFIC		PAVING	

APPROVED BY:

PROJECT REVIEW SR. ENGINEER   DATE

OWNER:

EP - THE KING L.L.C.
AN ARIZONA LIMITED LIABILITY COMPANY
3040 N. 44TH STREET, SUITE 4
PHOENIX, AZ 85018
PH: (602) 385-1544
FAX: (602) 385-1524
CONTACT: DAVID E. CORNWALL

DEVELOPER:

DIAMOND CREEK DEVELOPMENT
3040 N. 44TH STREET, SUITE 4
PHOENIX, AZ 85018
PH: (602) 385-1544
FAX: (602) 385-1524
CONTACT: DAVID E. CORNWALL

ENGINEER

COE & VAN LOO CONSULTANTS
4550 N. 12TH ST.
PHOENIX, ARIZONA 85014
PH.: (602) 264-6831
CONTACT: BRIAN HENSLEY

BENCHMARK

NGS CONTROL DESIGNATION:
4ACI, PID:AJ3819
3-1/4" MARICOPA COUNTY D.O.T.
BRASS CAP STAMPED
4ACII-1999 SET IN ROCK OUTCROP
SOUTH OF TRAILHEAD
AND CASEY ABBOT ROAD.
ELEVATION 924.74
(NGVD29 VERTICAL DATUM)

THE VERTICAL EQUATION TO TIE INTO THE CITY OF GOODYEAR'S DATUM IS AS FOLLOWS:
BRASS CAP IN HANDHOLE AT LOWER BUCKEYE AND ESTRELLA PARKWAY
ELEVATION 952.06 (CITY OF GOODYEAR DATUM)
ELEVATION 953.76 (CVL)
ELEVATION DIFFERENCE OF +1.70'
CITY OF GOODYEAR +1.70 = KING RANCH

BASIS OF BEARING

THE BASIS OF BEARING FOR THIS PROJECT IS N89°33'36"W BETWEEN THE NORTH QUARTER CORNER OF SECTION 2, TOWNSHIP 1 SOUTH, RANGE 2 WEST AND THE SOUTH QUARTER CORNER OF SECTION 36, TOWNSHIP 1 NORTH, RANGE 2 WEST ACCORDING TO BOOK 643 OF MAPS, PAGE 5, MARICOPA COUNTY RECORDS.

SUBMITTED:

"I HEREBY CERTIFY THAT THIS DESIGN IS BASED ON ACCURATE FIELD DATA WHICH HAS BEEN CHECKED IN THE FIELD PRIOR TO SUBMISSION FOR CITY APPROVAL."

BY: ______________________ ________
REGISTERED CIVIL ENGINEER   DATE

AS-BUILT CERTIFICATION

I HEREBY CERTIFY THAT THE "AS - BUILT" INFORMATION AS SHOWN HEREON WAS OBTAINED UNDER MY DIRECT SUPERVISION AND IS CORRECT AND COMPLETE TO THE BEST OF MY KNOWLEDGE AND BELIEF.

BY: ______________________
REGISTERED LAND SURVEYOR   (SEAL)

______________________ ________
REGISTRATION NUMBER   DATE

REVIEWED BY: ______________________
FIELD ENGINEERING

THE QUANTITIES SHOWN ARE AN ESTIMATE ONLY THE CONTRACTOR SHALL BE RESPONSIBLE FOR VERIFYING ALL QUANTITIES BEFORE BIDDING.

ESTIMATED QUANTITIES

DESCRIPTION	UNITS	TOTAL
EARTHWORK -- CHANNEL		
CUT	CY	4,259,343
FILL	CY	476,649
EARTHWORK -- COTTON LANE		
CUT	CY	154,146
FILL	CY	88,554
SOIL CEMENT	CY	
TEMPORARY CONST. CHAIN-LINK FENCING	LF	

99% NOT FOR CONSTRUCTION

Two working days before you dig CALL FOR THE BLUE STAKES
602-263-1100
1-800-STAKE-IT
(OUTSIDE MARICOPA COUNTY)

NO.	REVISION	DATE
	90% SUBMITTAL	02-17-06
	95% SUBMITTAL	06-23-06
	99% SUBMITTAL	09-25-06

CVL
4550 North 12th Street
Phoenix, Arizona 85014
Telephone 602-264-6831
http://www.cvlci.com

Coe & Van Loo Consultants, Inc.
River Research & Design, Inc.

COVER SHEET

GILA RIVER IMPROVEMENT PLANS
(FOR COTTON LANE BRIDGE)

SHEET 1 OF 26
CVL Contact: GARY FREEMAN
CVL Project #: 800001
DESIGN DATE: JAN.12, 2006

KevinK
25 SEP 2006
14:00:09
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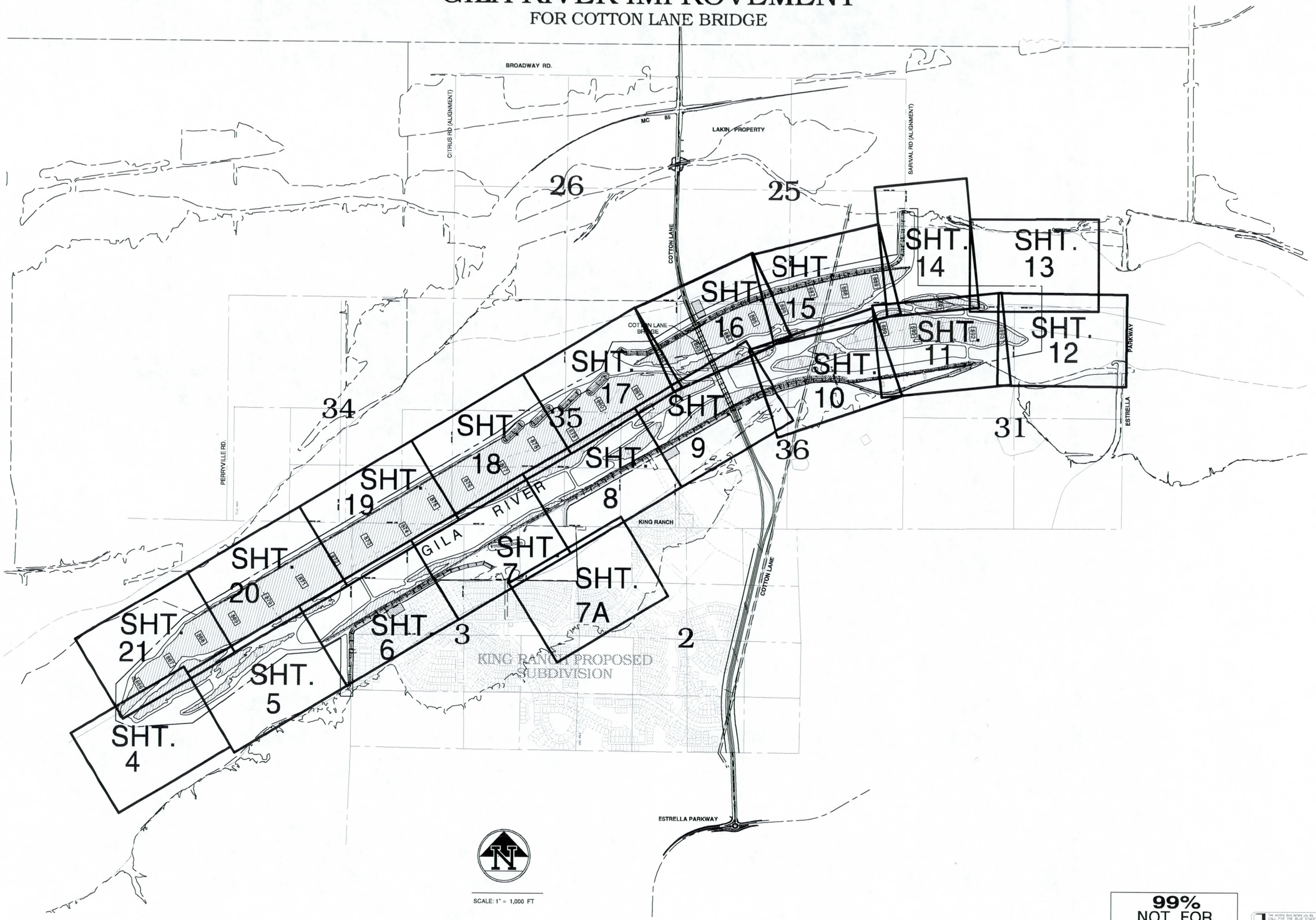
GILA RIVER IMPROVEMENT
FOR COTTON LANE BRIDGE



SCALE: 1" = 1,000 FT

99%
NOT FOR CONSTRUCTION

CVL
4550 North 12th Street
Phoenix, Arizona 85014
Telephone 602-264-6831
http://www.cvlci.com

NO.	REVISION	DATE
	90% SUBMITTAL	02-17-06
	95% SUBMITTAL	06-23-06
	99% SUBMITTAL	09-26-06

Coe & Van Loo Consultants, Inc.
River Research & Design, Inc.

SHEET INDEX AND VICINITY MAP

GILA RIVER IMPROVEMENT PLANS
(FOR COTTON LANE BRIDGE)

Two working days before you dig
CALL FOR THE BLUE STAKES
602-263-1100
1-800-STAKE-IT
(OUTSIDE MARICOPA COUNTY)

SHEET
2 OF 26

CVL Contact: GARY FREEMAN
CVL Project #: 800001
DESIGN DATE: JAN.12, 2006

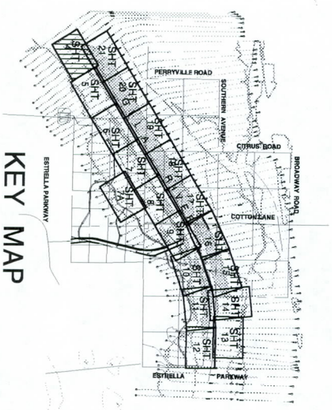
KevinK
25 SEP 2006
13:59:24
n:\800001\land\g.airvarsct01.dgn

Kev:nK
25 SEP 2006
14:08:03
n:\800001\landfg\ariver\cd100s04.dgn

GRADING CONSTRUCTION NOTES:

1. USACE JURISDICTIONAL BOUNDARY
2. EXIST. FP
3. EXIST. FW
4. PROPOSED SOIL CEMENT PROTECTION. SEE PLANS FOR QUANTITIES
5. RIPRAP UPPER BANK
6. CHANNEL BANK SLOPE 6'HORIZ TO 1'VERT MAX.
7. REVISED FLOODPLAIN
8. REVISED FLOODWAY
9. TEMPORARY STAGING AREA
10. TEMPORARY HAUL ROADS OUTSIDE BUFFERS (60 FT WIDE)
11. CONSTRUCTION ZONE BOUNDARY (NO ACCESS ALLOWED BEYOND THIS AREA)
12. EXCAVATION AREA
13. EXISTING CHANNEL TO REMAIN UNDISTURBED

KEY MAP



FP 877.79
189.11 FW 878.51

FP 878.11
189.21 FW 878.78

FP 878.45
189.30 FW 879.07

F.P. 878.77
189.39 FW 879.35

FP 879.1
189.48 FW 879.63

FP 879.4
189.58 FW 879.89

FP 879.72
189.67 FW 880.19

CONSTRUCTION ℄

835+00

840+00

845+00

850+00

855+00

FLOW

TEMP. CONSTRUCTION EASEMENT

BUFFER ZONE APPROX. 50' TYP.

866

867

SEE SHT 21

SEE SHT 5

99% NOT FOR CONSTRUCTION

SCALE: 1" = 100'
100' 50' 0 100'

ARIZONA BLUE STAKE, INC.
602-263-1100
1-800-STAKE-IT
OUTSIDE MARICOPA COUNTY

GILA RIVER IMPROVEMENT PLANS
(FOR COTTON LANE BRIDGE)

GILA RIVER

NO.	REVISION	DATE
	90% SUBMITTAL	02-17-06
	95% SUBMITTAL	06-23-06
	99% SUBMITTAL	09-25-06

Coe & Van Loo Consultants, Inc.
River Research & Design, Inc.

CVL
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Telephone 602-264-6831
http://www.cvlci.com

SHEET 4 OF 26

DSN. Checked: BARRY FREEMAN
DR. Project #: 800001
DESIGN DATE: JAN 12, 2006

Kev.nK
25 SEP 2006
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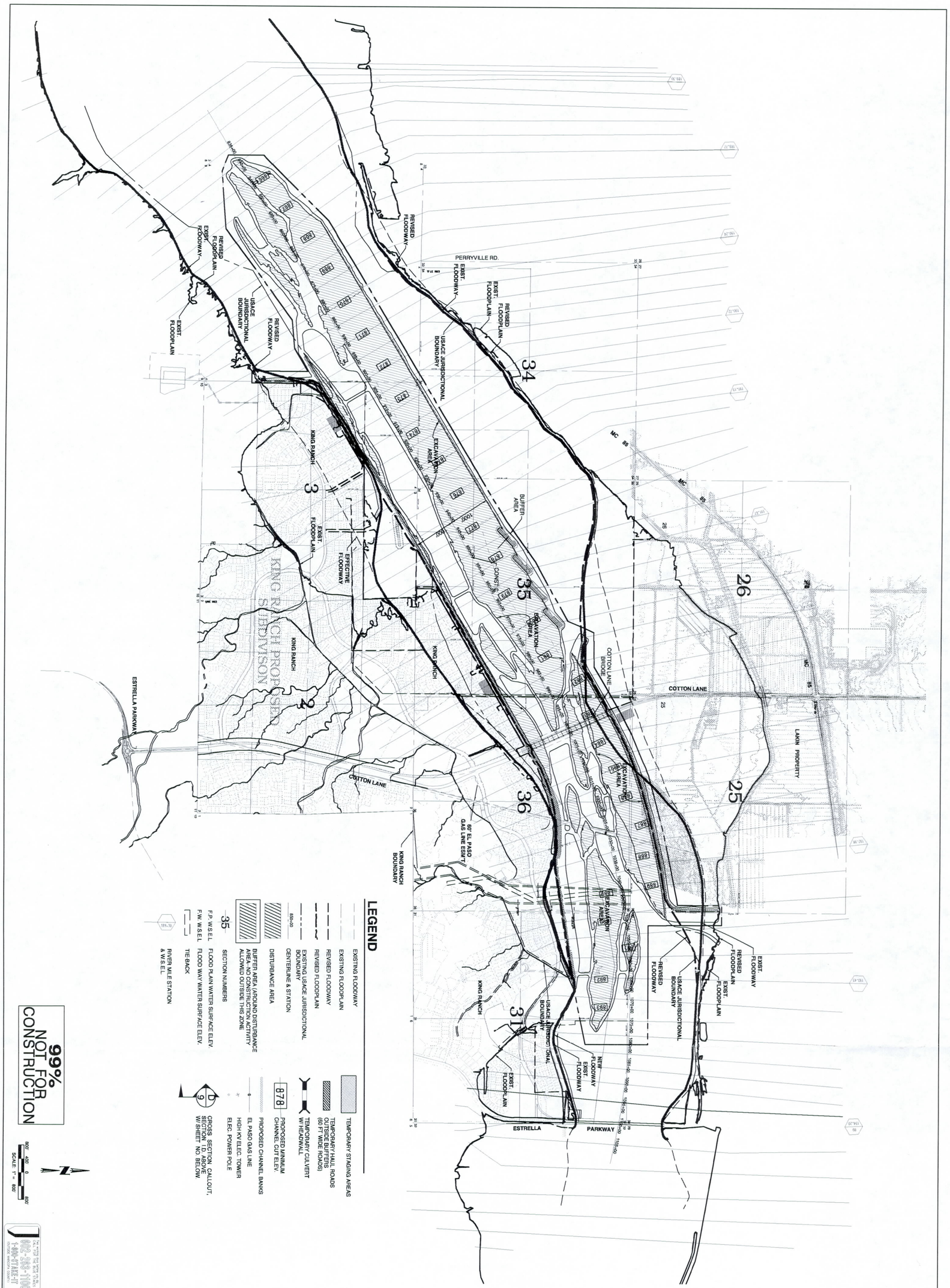

LEGEND

- EXISTING FLOODWAY
- EXISTING FLOODPLAIN
- REVISED FLOODWAY
- REVISED FLOODPLAIN
- EXISTING USACE JURISDICTIONAL BOUNDARY
- 850+00 CENTERLINE & STATION
- DISTURBANCE AREA
- BUFFER AREA (AROUND DISTURBANCE AREA- NO CONSTRUCTION ACTIVITY ALLOWED OUTSIDE THIS ZONE)
- 35 SECTION NUMBERS
- F.P. W.S.E.L. FLOOD PLAIN WATER SURFACE ELEV.
- F.W. W.S.E.L. FLOOD WAY WATER SURFACE ELEV.
- TIE BACK
- 589.70 RIVER MILE STATION & W.S.E.L.
- TEMPORARY STAGING AREAS
- TEMPORARY HAUL ROADS OUTSIDE BUFFERS (60 FT WIDE ROADS)
- TEMPORARY CULVERT W/ HEADWALL
- 878 PROPOSED MINIMUM CHANNEL CUT ELEV.
- PROPOSED CHANNEL BANKS
- EL PASO GAS LINE
- HIGH KV ELEC. TOWER
- ELEC. POWER POLE
- D 9 CROSS SECTION, CALLOUT, SECTION NUMBER W/ SHEET NO. BELOW.

99% NOT FOR CONSTRUCTION

SCALE 1" = 800'

CALL BLUE STAKE, INC. 602-263-1100 1-800-STAKE-IT

SHEET	3 OF 26
DR. Checked	BOUTON
DR. Project Mgr.	FREEMAN
DESIGN DATE	JAN. 13, 2006

OVERVIEW MAP & LEGEND

GILA RIVER

NO.	REVISION	DATE
	90% SUBMITTAL	02-17-06
	95% SUBMITTAL	06-23-06
	99% SUBMITTAL	09-25-06

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SEE SHT 21

SEE SHT 20

860+00 865+00 870+00 875+00 880+00 885+00

CONSTRUCTION ℄

FLOW

BUFFER ZONE
APPROX. 50'
TYP.

TEMP. CONSTRUCTION
EASEMENT

SEE SHT 4

SEE SHT 6

FP 880.07
FW 880.5
189.17

FP 880.39
FW 880.81
189.87

FP 880.76
FW 881.14
189.96

FP 881.17
FW 881.5
190.05

FP 881.66
FW 882.15
190.15

FP 882.37
FW 882.6
190.24

GRADING CONSTRUCTION NOTES:

1. USACE JURISDICTIONAL BOUNDARY
2. EXIST. FP
3. EXIST. FW
4. PROPOSED SOIL CEMENT PROTECTION, SEE PLANS FOR QUANTITIES
5. RIPRAP UPPER BANK
6. CHANNEL BANK SLOPE 6' HORIZ. TO 1' VERT. MAX.
7. REVISED FLOODPLAIN
8. REVISED FLOODWAY
9. TEMPORARY STAGING AREA
10. TEMPORARY HAUL ROADS OUTSIDE BUFFERS (60 FT WIDE)
11. CONSTRUCTION ZONE BOUNDARY (-NO ACCESS ALLOWED BEYOND THIS AREA)
12. EXCAVATION AREA
13. EXISTING CHANNEL TO REMAIN UNDISTURBED

KEY MAP

99%
NOT FOR
CONSTRUCTION

100' 50' 0 100'
SCALE: 1" = 100'

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GILA RIVER IMPROVEMENT PLANS
(FOR COTTON LANE BRIDGE)

GILA RIVER

Kev:nK
25 SEP 2006
14:09:31
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Two working days before you dig
CALL FOR THE BLUE STAKES
602-263-1100
1-800-STAKE-IT
OUTSIDE MARICOPA COUNTY

SHEET
5 OF 26

CVL Contact: GARY FREEMAN
CVL Project #: 800001
DESIGN DATE: JAN.12, 2006

SEE SHT 20

SEE SHT 19

890+00 895+00 900+00 905+00 910+00 915+00

871 872 873

12 11 10 13

FLOW

1175.60'

SECTION LINE

CONSTRUCTION ℄

5% MAX GRADE RECOMMENDED
(CONTRACTOR DISCRETION)

APPROX. 50'
TYP.

END 6:1 & BEGIN 2:1
SOIL CEMENT PROTECTION

BOTTOM SOIL
CEMENT PROTECTION

TOP OF SOIL
CEMENT PROTECTION

6 4 5 12

A 28

A 25

SEE SHT 5

TEMP. CONSTRUCTION
EASEMENT

1 4 11 7

KING RANCH
PROPERTY LINE

8 6 3

FP 883.34
FW 883.58

FP 883.96
FW 884.1

FP 884.49
FW 884.61

FP 884.88
FW 884.99

FP 885.25
FW 885.35

FP 882.9
FW 883.1

9

SEE MASS GRADING
PLANS PREPARED BY
CVL CONSULT. ENGRS.
PROJECT# 800001

KING RANCH
RETENTION BASINS
& CHANNELS

KING RANCH
PROPOSED SUBDIVISION
(FILL AREA)

BUFFER ZONE
APPROX. 50'
TYP.

SEE SHT 7

KING RANCH
PROPERTY LINE

TEMP. CONSTRUCTION
EASEMENT

KING RANCH
PROPERTY LINE

GRADING CONSTRUCTION NOTES:

1. USACE JURISDICTIONAL BOUNDARY
2. EXIST. FP
3. EXIST. FW
4. PROPOSED SOIL CEMENT PROTECTION, SEE PLANS FOR QUANTITIES
5. RIPRAP UPPER BANK
6. CHANNEL BANK SLOPE 6'HORIZ. TO 1'VERT. MAX.
7. REVISED FLOODPLAIN
8. REVISED FLOODWAY
9. TEMPORARY STAGING AREA
10. TEMPORARY HAUL ROADS OUTSIDE BUFFERS (60 FT WIDE)
11. CONSTRUCTION ZONE BOUNDARY (–NO ACCESS ALLOWED BEYOND THIS AREA)
12. EXCAVATION AREA
13. EXISTING CHANNEL TO REMAIN UNDISTURBED

KEY MAP

BROADWAY ROAD, COTTON LANE, SOUTHERN AVENUE, PERRYVILLE ROAD, ESTRELLA PARKWAY, SHT. 1 – SHT. 21

100' 50' 0 100'
SCALE: 1" = 100'

99%
NOT FOR CONSTRUCTION

811 BLUE STAKE, INC.
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1-800-STAKE-IT
OUTSIDE MARICOPA COUNTY

SHEET 6 OF 26
CVL Contact: GARY FREEMAN
CVL Project #: 800001
DESIGN DATE: JAN.12, 2006

GILA RIVER IMPROVEMENT PLANS
(FOR COTTON LANE BRIDGE)

GILA RIVER

NO.	REVISION	DATE
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	95% SUBMITTAL	06-23-06
	99% SUBMITTAL	09-25-06

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SEE SHT 19

SEE SHT 18

920+00 925+00 930+00 935+00 940+00 945+00

CONSTRUCTION ℄

SECTION LINE

FLOW

TOP OF SOIL CEMENT PROTECTION

BUFFER ZONE APPROX. 50' TYP.

END 6:1 & BEGIN 2:1 SOIL CEMENT PROTECTION

BOTTOM SOIL CEMENT PROTECTION

874 875 876 877

SEE SHT 6

SEE SHT 8

KING RANCH PROPERTY LINE

TEMP. CONSTRUCTION EASEMENT

KING RANCH DRAINAGE CHANNELS

PROPOSED SUBDIVISION KING RANCH

SEE MASS GRADING PLANS PREPARED BY CVL CONSULT. ENGRS. PROJECT# 800001

VANE DIKE SEE DTL. SHT. 25

FILL

SEE MITIGATION PLANS BY OTHERS

FP 885.66 FW 885.75 (100.91)

FP 886.1 FW 886.18 (101.00)

FP 886.46 FW 886.54 (101.10)

FP 886.85 FW 886.91 (101.29)

FP 887.28 FW 887.34 (101.29)

FP 887.67 FW 887.73 (101.39)

GRADING CONSTRUCTION NOTES:

1. USACE JURISDICTIONAL BOUNDARY
2. EXIST. FP
3. EXIST. FW
4. PROPOSED SOIL CEMENT PROTECTION SEE PLANS FOR QUANTITIES
5. RIPRAP UPPER BANK
6. CHANNEL BANK SLOPE 6' HORIZ. TO 1' VERT. MAX.
7. REVISED FLOODPLAIN
8. REVISED FLOODWAY
9. TEMPORARY STAGING AREA
10. TEMPORARY HAUL ROADS OUTSIDE BUFFERS (60 FT WIDE)
11. CONSTRUCTION ZONE BOUNDARY (–NO ACCESS ALLOWED BEYOND THIS AREA)
12. EXCAVATION AREA
13. EXISTING CHANNEL TO REMAIN UNDISTURBED

BROADWAY ROAD, SOUTHERN AVENUE, CLIFFORD ROAD, COTTONLANE, PERRYVILLE ROAD, ESTRELLA PARKWAY, SHT. 1 – SHT. 20

KEY MAP

SCALE: 1"= 40' HORIZ
SCALE: 1"= 4' VERT.

40' 20' 0 40'

100' 50' 0 100'

SCALE: 1" = 100'

99% NOT FOR CONSTRUCTION

Kev.nK
25 SEP 2006
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n:\800001\land\gila\river\sct100d07.dgn

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	99% SUBMITTAL	09-25-06

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GILA RIVER IMPROVEMENT PLANS
(FOR COTTON LANE BRIDGE)

GILA RIVER

Tell us where you dig
CALL FOR THIS BLUE STAKES
602-263-1100
1-800-STAKE-IT
OUTSIDE MARICOPA COUNTY

SHEET 7 OF 26
CVL Contact: GARY FREEMAN
CVL Project #: 800001
DESIGN DATE: JAN 12, 2006

SEE SHT 7

SEE SHT 8

3

7

KING RANCH
PROPERTY LINE

LIMIT OF
DETAILED
STUDY

TEMP. CONSTRUCTION
EASEMENT

SEE CVL MASS
GRADING PLANS
PROJECT # 800001

2

KING RANCH
RETENTION BASINS
& DRAINAGE CHANNELS

KING RANCH
PROPOSED SUBDIVISION

FP 886.85
FW 886.91

FP 887.28
FW 887.34

FP 887.67
FW 887.73

FP 888.09
FW 888.14

FP 888.50
FW 888.54

FP 888.99
FW 889.02

1

191.19

191.29

191.38

191.48

191.57

191.67

GRADING CONSTRUCTION NOTES:

1	USACE JURISDICTIONAL BOUNDARY	8	REVISED FLOODWAY
2	EXIST. FP	9	TEMPORARY STAGING AREA
3	EXIST. FW	10	TEMPORARY HAUL ROADS OUTSIDE BUFFERS (60 FT WIDE)
4	PROPOSED SOIL CEMENT PROTECTION, SEE PLANS FOR QUANTITIES	11	CONSTRUCTION ZONE BOUNDARY (–NO ACCESS ALLOWED BEYOND THIS AREA)
5	RIPRAP UPPER BANK	12	EXCAVATION AREA
6	CHANNEL BANK SLOPE 6'HORIZ. TO 1'VERT. MAX.	13	EXISTING CHANNEL TO REMAIN UNDISTURBED
7	REVISED FLOODPLAIN		

BROADWAY ROAD
COTTON LANE
SOUTHERN AVENUE
PERRYVILLE ROAD
ESTRELLA PARKWAY
ESTRELLA
SHT. 1 … SHT. 26

KEY MAP

N

100' 50' 0 100'
SCALE: 1" = 100'

99%
NOT FOR
CONSTRUCTION

Kev:nK
29 SEP 2006
15:12:27
n:\800001\landig.ai\vr\sht10\s07a.dgn

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	95% SUBMITTAL	06-23-06
	99% SUBMITTAL	09-25-06

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GILA RIVER IMPROVEMENT PLANS
(FOR COTTON LANE BRIDGE)

GILA RIVER

Arizona law requires you to call before you dig. CALL FOR THE BLUE STAKES
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1-800-STAKE-IT
(OUTSIDE MARICOPA COUNTY)

SHEET
7A OF 26
CVL Contact: GARY FREEMAN
CVL Project #: 800001
DESIGN DATE: JAN 12, 2005

SEE SHT 18

SEE SHT 17

950+00 955+00 960+00 965+00 970+00 975+00

878 879 880

SECTION LINE

CONSTRUCTION ℄

BUFFER ZONE APPROX. 50' TYP.

FLOW

60' TYP.

END 6:1 & BEGIN 2:1 SOIL CEMENT PROTECTION

BOTTOM SOIL CEMENT PROTECTION

TOP OF SOIL CEMENT PROTECTION

KING RANCH PROPERTY LINE

TEMP. CONSTRUCTION EASEMENT

KING RANCH RETENTION BASINS & DRAINAGE CHANNELS

KING RANCH SUBDIVISION FILL AREA

SEE MASS GRADING PLANS PREPARED BY CVL CONSULT. ENGRS. PROJECT# 800001

FP 888.09 FW 888.14

FP 888.5 FW 888.54

FP 888.99 FW 889.02

FP 889.52 FW 889.54

FP 890.05 FW 890.07

FP 890.52 FW 890.54

RET BOT 86.0

RET BOT 86.5

404 WASH

SEE SHT 7

SEE SHT 7A

SEE SHT 9

GRADING CONSTRUCTION NOTES:

1. USACE JURISDICTIONAL BOUNDARY
2. EXIST. FP
3. EXIST. FW
4. PROPOSED SOIL CEMENT PROTECTION, SEE PLANS FOR QUANTITIES
5. RIPRAP UPPER BANK
6. CHANNEL BANK SLOPE 6' HORIZ. TO 1' VERT. MAX.
7. REVISED FLOODPLAIN
8. REVISED FLOODWAY
9. TEMPORARY STAGING AREA
10. TEMPORARY HAUL ROADS OUTSIDE BUFFERS (60 FT WIDE)
11. CONSTRUCTION ZONE BOUNDARY (–NO ACCESS ALLOWED BEYOND THIS AREA)
12. EXCAVATION AREA
13. EXISTING CHANNEL TO REMAIN UNDISTURBED

KEY MAP

BROADWAY ROAD, COTTON LANE, SOUTHERN AVENUE, PERRYVILLE ROAD, ESTRELLA PARKWAY, SHT. 1 through SHT. 21

100' 50' 0 100'

SCALE: 1" = 100'

99% NOT FOR CONSTRUCTION

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25 SEP 2006
15:36:54
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	95% SUBMITTAL	06-23-06
	99% SUBMITTAL	09-25-06

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GILA RIVER IMPROVEMENT PLANS
(FOR COTTON LANE BRIDGE)

GILA RIVER

SHEET 8 OF 26

CVL Contact: GARY FREEMAN

CVL Project #: 800001

DESIGN DATE: JAN 12, 2006

SEE SHT 17

SEE SHT 16

980+00 985+00 990+00 995+00 1000+00 1005+00

881 882 883 884

ELECTRIC POLES & 80' EASEMENT

CONSTRUCTION ℄

SECTION LINE

FLOW

BUFFER ZONE APPROX. 50' TYP.

COTTON LANE PROPOSED BRIDGE (PREPARED BY BAKER ENGINEERS)

FP 893.98 FW 893.99

FP 894.65 FW 894.64

300' BRIDGE CONSTRUCTION EASEMENT

END 6:1 & BEGIN 2:1 SOIL CEMENT PROTECTION

14' MAINTENANCE TRAIL TYP. EACH SIDE OF BRIDGE SEE DETAIL SHT. 26

BOTTOM SOIL CEMENT PROTECTION

TOP OF SOIL CEMENT PROTECTION

SEE SHT 8

SEE SHT 10

TEMP. CONST. EASEMENT

KING RANCH RETENTION BASINS & DRAINAGE CHANNELS

KING RANCH PROPERTY LINE

SEE MASS GRADING PLANS PREPARED BY CVL CONSULT. ENGRS. PROJECT# 800001

FP 891.06 FW 891.09

FP 891.71 FW 891.74

FP 892.68 FW 892.7

FP 893.52 FW 893.53

FP 895.42 FW 895.43

KING RANCH PROPOSED SUBDIVISION

GRADING CONSTRUCTION NOTES:

1. USACE JURISDICTIONAL BOUNDARY
2. EXIST. FP
3. EXIST. FW
4. PROPOSED SOIL CEMENT PROTECTION SEE PLANS FOR QUANTITIES
5. RIPRAP UPPER BANK
6. CHANNEL BANK SLOPE 6'HORIZ. TO 1'VERT. MAX.
7. REVISED FLOODPLAIN
8. REVISED FLOODWAY
9. TEMPORARY STAGING AREA
10. TEMPORARY HAUL ROADS OUTSIDE BUFFERS (60 FT WIDE)
11. CONSTRUCTION ZONE BOUNDARY (-NO ACCESS ALLOWED BEYOND THIS AREA)
12. EXCAVATION AREA
13. EXISTING CHANNEL TO REMAIN UNDISTURBED

KEY MAP

BROADWAY ROAD, COTTON LANE, SOUTHERN AVENUE, PERRYVILLE ROAD, ESTRELLA PARKWAY, SHT. 1 – SHT. 21

99% NOT FOR CONSTRUCTION

100' 50' 0 100'

SCALE: 1" = 100'

Blue Stake, Inc. 602-263-1100 1-800-STAKE-IT (OUTSIDE MARICOPA COUNTY)

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	99% SUBMITTAL	09-25-06

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River Research & Design, Inc.

GILA RIVER IMPROVEMENT PLANS
(FOR COTTON LANE BRIDGE)

GILA RIVER

SHEET 9 OF 26

CVL Contact: GARY FREEMAN

CVL Project #: 800001

DESIGN DATE: JAN 12, 2006

Kevin K
25 SEP 2006
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SEE SHT 16

SEE SHT 15

SEE SHT 9

SEE SHT 11

1010+00 1015+00 1020+00 1025+00 1030+00 1035+00

885 886 887 888

CONSTRUCTION ℄

KING RANCH PROPERTY LINE

BUFFER ZONE APPROX. 50' TYP.

APPROX. 50' TYP.

60' TYP.

FLOW

END 6:1 & BEGIN 2:1 SOIL CEMENT PROTECTION

BOTTOM SOIL CEMENT PROTECTION

S.R.P. 100' ELEC. EASM'T

30' A.P.S R.O.W. EASM'T

BORE LOCATION #3 PIPE ELEV.= 898.70

TEMP. CONSTRUCTION EASEMENT

60' GAS EASM'T PER BOOK 81 MISC. PAGE 33 MCR

CAUTION HIGH-PRESSURE GAS LINE FIELD VERIFY (SEE DTL SHT 25)

TOP OF SOIL CEMENT PROTECTION

FUTURE MITIGATION AREA

HIGH KV ELEC. TOWER

TRANSMISSION LINE EASM'T 33'

FP 896.06 FW 896.06

FP 896.68 FW 896.68

FP 897.09 FW 897.09

FP 898.09 FW 898.09

FP 898.69 FW 898.69

FP 899.08 FW 899.09

KING RANCH PROPOSED SUBDIVISION

GRADING CONSTRUCTION NOTES:

1. USACE JURISDICTIONAL BOUNDARY
2. EXIST. FP
3. EXIST. FW
4. PROPOSED SOIL CEMENT PROTECTION SEE PLANS FOR QUANTITIES
5. RIPRAP UPPER BANK
6. CHANNEL BANK SLOPE 6' HORIZ. TO 1' VERT. MAX. REVISED FLOODPLAIN
8. REVISED FLOODWAY
9. TEMPORARY STAGING AREA
10. TEMPORARY HAUL ROADS OUTSIDE BUFFERS (60 FT WIDE)
11. CONSTRUCTION ZONE BOUNDARY (-NO ACCESS ALLOWED BEYOND THIS AREA)
12. EXCAVATION AREA
13. EXISTING CHANNEL TO REMAIN UNDISTURBED

100' 50' 0 100'

SCALE: 1" = 100'

KEY MAP

BROADWAY ROAD, COTTON LANE, SOUTHERN AVENUE, PERRYVILLE ROAD, ESTRELLA PARKWAY, ESTRELLA PARKWAY, SHT 1 – SHT 26

99% NOT FOR CONSTRUCTION

Kev.mK
29 SEP 2006
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	99% SUBMITTAL	09-25-06

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River Research & Design, Inc.

GILA RIVER IMPROVEMENT PLANS
(FOR COTTON LANE BRIDGE)

GILA RIVER

SHEET 10 OF 26

CVL Contact: GARY FREEMAN
CVL Project #: 800001
DESIGN DATE: JAN.12, 2006

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SEE SHT 14

SEE SHT 10

SEE SHT 12

1040+00 1045+00 1050+00 1055+00 1060+00 1065+00 1070+0

889 890 891 892 893 897 898

FP 899.49 FW 899.49

FP 900.05 FW 900.05

FP 900.66 FW 900.64

FP 901.08 FW 901.07

FP 901.49 FW 901.48

FP 901.93 FW 901.93

CONSTRUCTION ℄

60' TYP.

SECTION LINE

FLOW

HIGH KV ELEC. TOWER

HIGH KV ELEC. TOWER

A.P.S. R.O.W. EASM'T 30'

HIGHWAY PURPOSES ESM'T--WIDTH VARIES DKT. 3320, PG. 524

S.R.P. 100' ELEC. EASM'T

APS TRANSMISSION LINE EASM'T 33'

APPROX. 50' TYP.

60' TYP.

END 6:1 & BEGIN 2:1 SOIL CEMENT PROTECTION

BOTTOM SOIL CEMENT PROTECTION

TOP OF SOIL CEMENT PROTECTION

TRANSITION SOIL CEMENT SMOOTHLY INTO ROCK OUTCROPPING

TEMP. CONSTRUCTION EASEMENT

KING RANCH PROPOSED SUBDIVISION

100' 50' 0 100'

SCALE: 1" = 100'

GRADING CONSTRUCTION NOTES:

1. USACE JURISDICTIONAL BOUNDARY
2. EXIST. FP
3. EXIST. FW
4. PROPOSED SOIL CEMENT PROTECTION SEE PLANS FOR QUANTITIES
5. RIPRAP UPPER BANK
6. CHANNEL BANK SLOPE 6'HORIZ. TO 1'VERT. MAX.
7. REVISED FLOODPLAIN
8. REVISED FLOODWAY
9. TEMPORARY STAGING AREA
10. TEMPORARY HAUL ROADS OUTSIDE BUFFERS (60 FT WIDE)
11. CONSTRUCTION ZONE BOUNDARY (-NO ACCESS ALLOWED BEYOND THIS AREA)
12. EXCAVATION AREA
13. EXISTING CHANNEL TO REMAIN UNDISTURBED

KEY MAP

BROADWAY ROAD, COTTON LANE, SOUTHERN AVENUE, PERRYVILLE ROAD, ESTRELLA PARKWAY, SHT. 14, SHT. 13, SHT. 12, SHT. 15, SHT. 16, SHT. 17, SHT. 18, SHT. 19, SHT. 9, SHT. 8, SHT. 7A, SHT. 20, SHT. 6, SHT. 5, SHT. 21, SHT. 4, SHT.

99% NOT FOR CONSTRUCTION

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Coe & Van Loo Consultants, Inc.
River Research & Design, Inc.

GILA RIVER IMPROVEMENT PLANS
(FOR COTTON LANE BRIDGE)

GILA RIVER

SHEET 11 OF 26
CVL Contact: GARY FREEMAN
CVL Project #: 800001
DESIGN DATE: JAN 12, 2006

602-263-1100
1-800-STAKE-IT
OUTSIDE MARICOPA COUNTY

Kevin K
25 SEP 2006
16:11:22
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SEE SHT 13

1070+00 1075+00 1080+00 1085+00 1090+00 1095+00 1100+

NE SECTION LINE

CONSTRUCTION ℄

KING RANCH PROPERTY LINE

FLOW

SEE SHT 11

SECTION LINE

APPROX. 50' TYP.

TEMP. CONSTRUCTION EASEMENT

FP 902.72 FW 902.75

FP 903.24 FW 903.25

FP 903.70 FW 903.71

FP 904.02 FW 904.03

FP 904.34 FW 904.34

FP 904.88 FW 904.93

12 11 13 7 1 8 3 7

99% NOT FOR CONSTRUCTION

N

100' 50' 0 100'

SCALE: 1" = 100'

GRADING CONSTRUCTION NOTES:

1. USACE JURISDICTIONAL BOUNDARY
2. EXIST. FP
3. EXIST. FW
4. PROPOSED SOIL CEMENT PROTECTION, SEE PLANS FOR QUANTITIES
5. RIPRAP UPPER BANK
6. CHANNEL BANK SLOPE 6'HORIZ. TO 1'VERT. MAX.
7. REVISED FLOODPLAIN
8. REVISED FLOODWAY
9. TEMPORARY STAGING AREA
10. TEMPORARY HAUL ROADS OUTSIDE BUFFERS (60 FT WIDE)
11. CONSTRUCTION ZONE BOUNDARY (–NO ACCESS ALLOWED BEYOND THIS AREA)
12. EXCAVATION AREA
13. EXISTING CHANNEL TO REMAIN UNDISTURBED

BROADWAY ROAD
COTTON LANE
SOUTHERN AVENUE
PEORIA AVENUE
ESTRELLA PARKWAY
SHT 1 – SHT 21

KEY MAP

Blue Stake, Inc. 602-263-1100 1-800-STAKE-IT (OUTSIDE MARICOPA COUNTY)

CVL
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Phoenix, Arizona 85014
Telephone 602-264-6831
http://www.cvlci.com

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	99% SUBMITTAL	09-25-06

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River Research & Design, Inc.

GILA RIVER IMPROVEMENT PLANS
(FOR COTTON LANE BRIDGE)

GILA RIVER

SHEET 12 OF 26

CVL Contact: GARY FREEMAN

CVL Project #: 800001

DESIGN DATE: JAN.12, 2006

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25 SEP 2006
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SEE SHT 14

FP 901.49
FW 901.48

FP 901.93
FW 901.93

FP 902.72
FW 902.75

FP 903.24
FW 903.25

FP 903.70
FW 903.71

FP 904.02
FW 904.03

FP 904.34
FW 904.34

GRADING CONSTRUCTION NOTES:

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13. EXISTING CHANNEL TO REMAIN UNDISTURBED

KEY MAP

TEMP. CONSTRUCTION EASEMENT

FLOW

BUFFER ZONE APPROX. 50' TYP.

CONSTRUCTION ℄

1065+00
1070+00
1075+00
1080+00
1085+00
1090+00

SECTION LINE
SECTION LINE

SEE SHT 12

SCALE: 1" = 100'

99% NOT FOR CONSTRUCTION

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River Research & Design, Inc.

GILA RIVER IMPROVEMENT PLANS
(FOR COTTON LANE BRIDGE)

GILA RIVER

SHEET 13 OF 26
CVL Contact: GARY FREEMAN
CVL Project #: 800001
DESIGN DATE: JAN.12, 2006

Two working days before you dig CALL FOR THE BLUE STAKES 602-263-1100 1-800-STAKE-IT (OUTSIDE MARICOPA COUNTY)

SEE SHT 13

GRADING CONSTRUCTION NOTES:

1. USACE JURISDICTIONAL BOUNDARY
2. EXIST. FP
3. EXIST. FW
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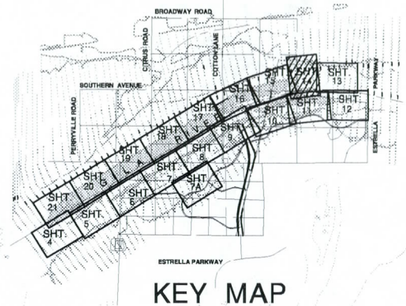
99% NOT FOR CONSTRUCTION



KEY MAP

FP 901.08
193.43 FW 901.07

FP 900.66
193.34 FW 900.64

FP 900.05
193.25 FW 900.05

SECTION LINE

892

891

1060+00

1055+00

1050+00

1045+00

CONSTRUCTION ℄

END 6:1 & BEGIN 2:1 SOIL CEMENT PROTECTION

FLOW

BOTTOM SOIL CEMENT PROTECTION

TEMP. CONSTRUCTION EASEMENT

BUFFER ZONE APPROX. 50' TYP.

60' TYP.

ELEC. POLE

FILL

TRANSMISSION LINE EASM'T 33'

S.R.P. 100' ELEC. EASM'T

SEE SHT 11

SEE SHT 15

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GILA RIVER IMPROVEMENT PLANS
(FOR COTTON LANE BRIDGE)

GILA RIVER

SHEET 14 OF 26
CVL Contact: GARY FREEMAN
CVL Project #: 800001
DESIGN DATE: JAN.12, 2006

THE MINING RULE REQUIRES NOTICE TO BE GIVEN TO ALL OF THE BLUE STAKES
602-263-1100
1-800-STAKE-IT
OUTSIDE MARICOPA COUNTY

GRADING CONSTRUCTION NOTES:

1. USACE JURISDICTIONAL BOUNDARY
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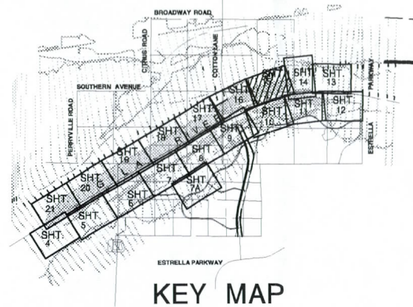

KEY MAP

100' 50' 0 100'
SCALE: 1" = 100'

99%
NOT FOR CONSTRUCTION

SEE SHT 16

SEE SHT 14

AREA OF PROPOSED FILL

TEMP. CONSTRUCTION EASEMENT

TOP OF SOIL CEMENT PROTECTION

END 6:1--BEGIN 2:1 SOIL CEMENT PROTECTION

BOTTOM SOIL CEMENT PROTECTION

CAUTION
HIGH-PRESSURE GAS LINE
SEE DTL. SHT. 25

FLOW

SECTION LINE

60' TYP.

60' GAS EASEMENT PER BOOK 81 MISC. PAGE 33 MCR

CONSTRUCTION ℄

APPROX. 50' TYP.

R.O.W. EASM'T 30'

TRANSMISSION LINE EASM'T 33'

S.R.P. 100' ELEC. EASM'T

886 887 888 889

FP 896.68 FW 896.68
FP 897.4 FW 897.4
FP 898.09 FW 898.09
FP 898.69 FW 898.69
FP 899.08 FW 899.09
FP 899.49 FW 899.49

1020+00 1025+00 1030+00 1035+00 1040+00 1045+00

192.79 192.89 192.98 193.07 193.16

SEE SHT 10

Kev.nK
25 SEP 2006
16:38:55
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GILA RIVER IMPROVEMENT PLANS
(FOR COTTON LANE BRIDGE)

GILA RIVER

BLUE STAKE, INC.
602-263-1100
1-800-STAKE-IT
(OUTSIDE MARICOPA COUNTY)

SHEET 15 OF 26
CVL Contact: GARY FREEMAN
CVL Project #: 800001
DESIGN DATE: JAN.12, 2006

99% NOT FOR CONSTRUCTION

SCALE: 1" = 100'

GRADING CONSTRUCTION NOTES:

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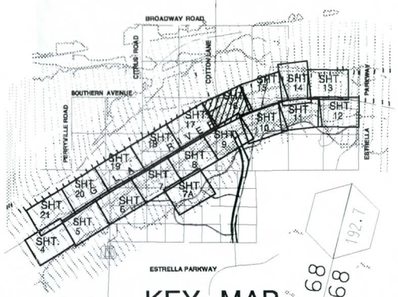

KEY MAP

FP 892.68
FW 892.7
192.33
SECTION LINE
FP 893.52
FW 893.53
SECTION LINE
FP 895.42
FW 895.43
194.52
192.67
FP 896.06
FW 896.06
FP 896.68
FW 896.68
192.7

AREA OF PROPOSED FILL

CONSTRUCT 4:1 SLOPE ON L;ANDWARD SIDE

TEMP. CONSTRUCTION EASEMENT

BUFFER ZONE APPROX. 50' TYP.

300' R/W

C 26

C 26

TOP OF SOIL CEMENT PROTECTION

MAINTENANCE ROAD/TRAIL (TYP. BOTH SIDES--SEE DTL SHT. 26)

END 6:1 & BEGIN 2:1 SOIL CEMENT PROTECTION

BOTTOM SOIL CEMENT PROTECTION

SEE SHT 17

SEE SHT 15

882

888

884

885

883

COTTON LANE PROPOSED BRIDGE (PREPARED BY BAKER ENGINEERS)

FLOW

CONSTRUCTION ℄

300' BRIDGE CONSTRUCTION EASEMENT

BUFFER ZONE APPROX. 50' TYP.

990+00

995+00

1000+00

1005+00

1010+00

1015+00

60' TYP.

SEE SHT 9

SEE SHT 10

KevinK
25 SEP 2006
16:45:32
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GILA RIVER IMPROVEMENT PLANS
(FOR COTTON LANE BRIDGE)

GILA RIVER

SHEET 16 OF 26
CVL Contact: GARY FREEMAN
CVL Project #: 800001
DESIGN DATE: JAN.12, 2006

Call two working days before you dig
CALL FOR THE BLUE STAKES
602-263-1100
1-800-STAKE-IT
OUTSIDE MARICOPA COUNTY

GRADING CONSTRUCTION NOTES:

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12. EXCAVATION AREA
13. EXISTING CHANNEL TO REMAIN UNDISTURBED

SCALE: 1" = 100'

KEY MAP

FP 888.99
FW 889.02
191.67

FP 889.52
FW 889.54
191.16

FP 890.05
FW 890.07
191.86

FP 890.52
FW 890.54
191.95

FP 891.06
FW 891.09
192.04

FP 891.71
FW 891.74
192.14

SECTION LINE

TEMP. CONSTRUCTION EASEMENT

END 6:1 & BEGIN 2:1 SOIL CEMENT PROTECTION

BOTTOM SOIL CEMENT PROTECTION

TOP OF SOIL CEMENT PROTECTION

10 YR WSEL

VANE DIKE TYP. (SEE DTL SHT. 25)

A 25

SEE SHT 18

SEE SHT 16

879

880

881

882

FLOW

CONSTRUCTION ℄

BUFFER ZONE APPROX. 50' TYP.

965+00

970+00

975+00

980+00

985+00

990+00

SEE SHT 8

SEE SHT 9

99%
NOT FOR CONSTRUCTION

Kev:nK
25 SEP 2006
17:02:53
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GILA RIVER IMPROVEMENT PLANS
(FOR COTTON LANE BRIDGE)

GILA RIVER

17 SHEET OF 26

CVL Contact: GARY FREEMAN
CVL Project #: 800001
DESIGN DATE: JAN.12, 2006

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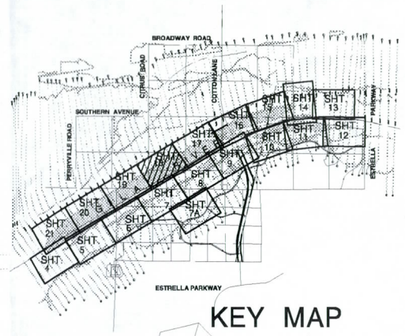
100' 50' 0 100'
SCALE: 1" = 100'



KEY MAP

FP 886.46
FW 886.54
191.10

FP 886.85
FW 886.91
191.19

FP 887.28
FW 887.34
191.29

FP 887.67
FW 887.73
191.38

FP 888.09
FW 888.14
191.48

FP 888.5
FW 888.54
191.51

SECTION LINE

SEE SHT 19

TEMP. CONSTRUCTION EASEMENT

BUFFER ZONE APPROX. 50' TYP.

11

EXCAVATION ONLY

6

VANE DIKE SEE (A/25) TYP.

SEE SHT 17

876

877

878

12

FLOW

CONSTRUCTION ℄

30+00 935+00 940+00 945+00 950+00 955+00 960+00

11

SEE SHT 7

SEE SHT 8

99% NOT FOR CONSTRUCTION

Kevin K
25 SEP 2006
17:07:46
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GILA RIVER IMPROVEMENT PLANS
(FOR COTTON LANE BRIDGE)

GILA RIVER

SHEET 18 OF 26

CVL Contact: GARY FREEMAN
CVL Project #: 800001
DESIGN DATE: JAN 12, 2006

2 working days before you dig CALL FOR THE BLUE STAKES 602-263-1100 1-800-STAKE-IT (OUTSIDE MARICOPA COUNTY)

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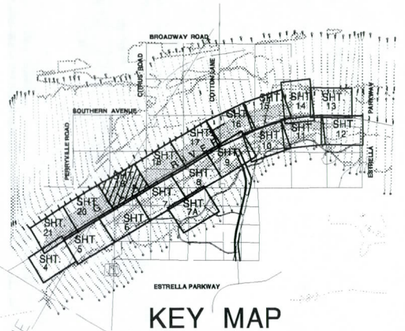
100' 50' 0 100'
SCALE: 1" = 100'



KEY MAP

FP 883.96 FW 884.1 (190.53)
FP 884.49 FW 884.61 (190.62)
FP 884.88 FW 884.99 (190.72)
FP 885.25 FW 885.35 (190.81)
FP 885.66 FW 885.75 (190.91)
FP 886.1 FW 886.18 (191.00)

SECTION LINE

TEMP. CONSTRUCTION EASEMENT
BUFFER ZONE APPROX. 50' TYP.
EXCAVATION ONLY
FLOW
CONSTRUCTION ℄

872 873 874 875

900+00 905+00 910+00 915+00 920+00 925+00

SEE SHT 20
SEE SHT 18
SEE SHT 6
SEE SHT 7

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GILA RIVER IMPROVEMENT PLANS
(FOR COTTON LANE BRIDGE)

GILA RIVER

SHEET 19 OF 26
CVL Contact: GARY FREEMAN
CVL Project #: 800001
DESIGN DATE: JAN 12, 2006

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25 SEP 2006
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GRADING CONSTRUCTION NOTES:

1. USACE JURISDICTIONAL BOUNDARY
2. EXIST. FP
3. EXIST. FW
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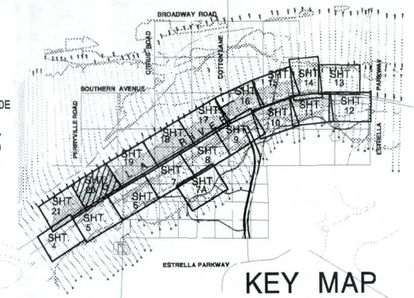

KEY MAP

FP 880.76 189.96
FW 881.14

FP 881.17 190.05
FW 881.5

FP 881.66 190.15
FW 882.15

FP 882.37 190.24
FW 882.6

FP 882.9 190.34
FW 883.1

FP 883.34 190.43
FW 883.52

TEMP. CONSTRUCTION EASEMENT

BUFFER ZONE APPROX. 50' TYP.

EXCAVATION ONLY

FLOW

CONSTRUCTION ℄

869 870 871

870+00 875+00 880+00 885+00 890+00 895+00

SEE SHT 21

SEE SHT 19

SEE SHT 5

SEE SHT 6

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Telephone 602-264-6831
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	99% SUBMITTAL	09-25-06

Coe & Van Loo Consultants, Inc.
River Research & Design, Inc.

GILA RIVER IMPROVEMENT PLANS
(FOR COTTON LANE BRIDGE)

GILA RIVER

SHEET 20 OF 26
CVL Contact: GARY FREEMAN
CVL Project #: 800001
DESIGN DATE: JAN.12, 2006

KevinK
25 SEP 2005
17:14:45
n:\80000\landfg.ai\river\sct100x20.dgn

GRADING CONSTRUCTION NOTES:

1. USACE JURISDICTIONAL BOUNDARY
2. EXIST. FP
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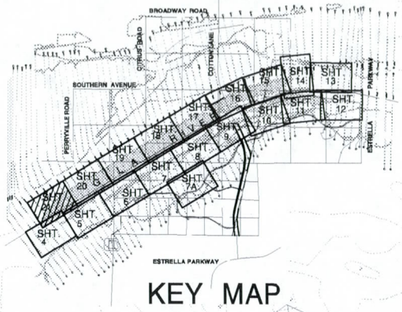

KEY MAP

FP 879.1
FW 879.63
189.48

FP 878.77
FW 879.35
189.39

FP 879.4
FW 879.89
189.58

FP 879.72
FW 880.19
189.67

FP 880.07
FW 880.5
189.77

FP 880.39
FW 880.81
189.87

100' 50' 0 100'
SCALE: 1" = 100'

TEMP. CONSTRUCTION EASEMENT

BUFFER ZONE APPROX. 50' TYP.

FLOW

EXCAVATION ONLY

CONSTRUCTION ℄

840+00 845+00 850+00 855+00 860+00 865+00

866 867 867 868 868

SEE SHT 4

SEE SHT 5

SEE SHT 20

99% NOT FOR CONSTRUCTION

Kev:nK
25 SEP 2006
17:23:13
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	95% SUBMITTAL	06-23-06
	99% SUBMITTAL	09-25-06

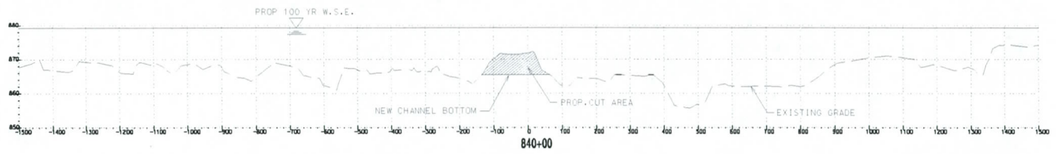
Coe & Van Loo Consultants, Inc.
River Research & Design, Inc.

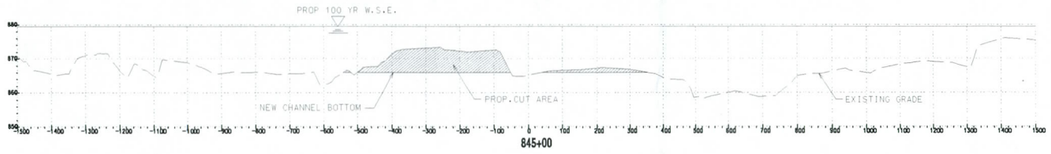
GILA RIVER IMPROVEMENT PLANS
(FOR COTTON LANE BRIDGE)

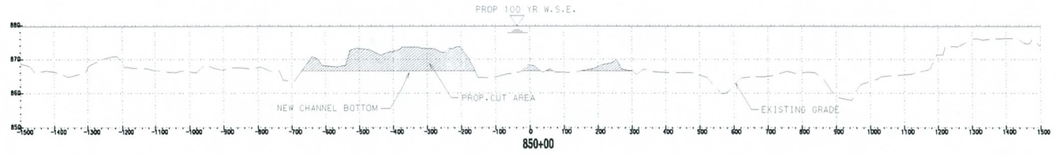
GILA RIVER

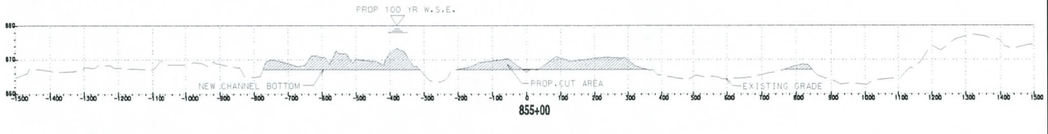
BLUE STAKE, INC.
ALL FOR THE BLUE STAKES
602-263-1100
1-800-STAKE-IT
OUTSIDE MARICOPA COUNTY

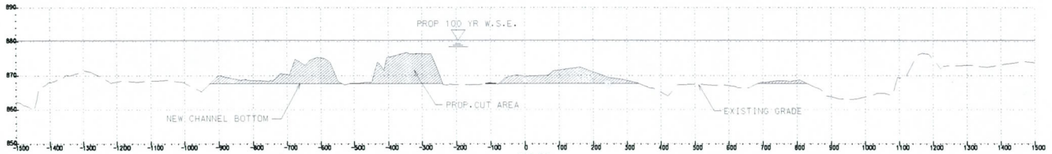
SHEET 21 OF 26
CVL Contact: GARY FREEMAN
CVL Project #: 800001
DESIGN DATE: JAN 12, 2006

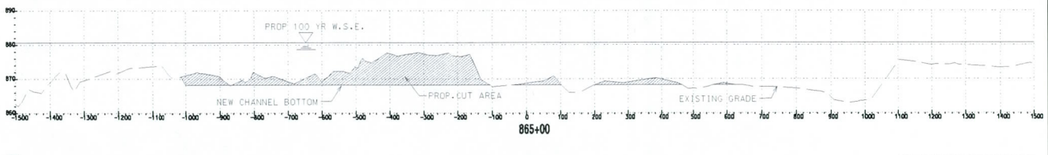


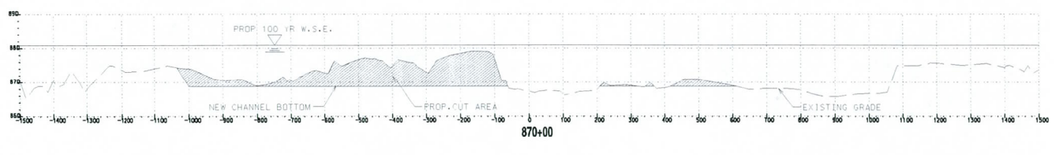


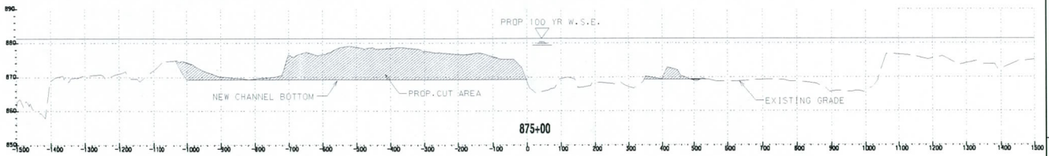


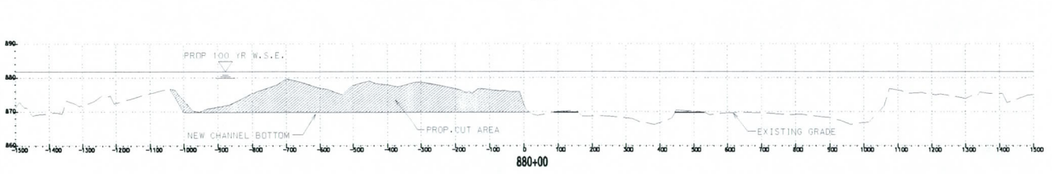


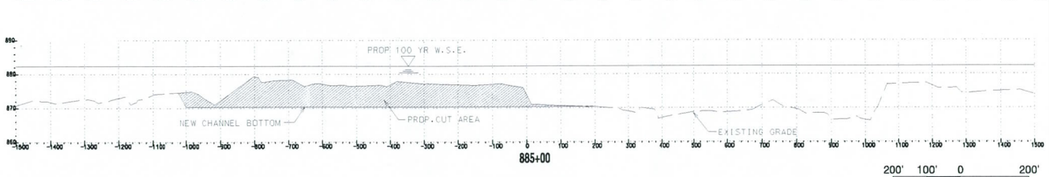






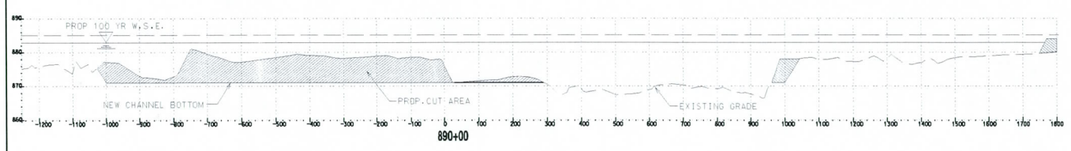


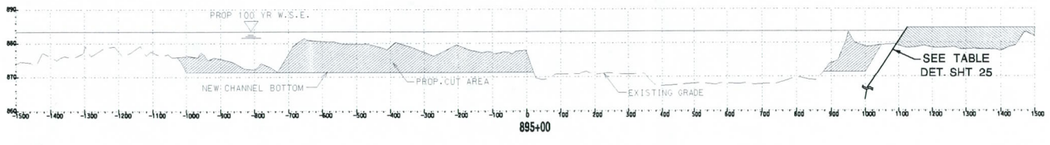


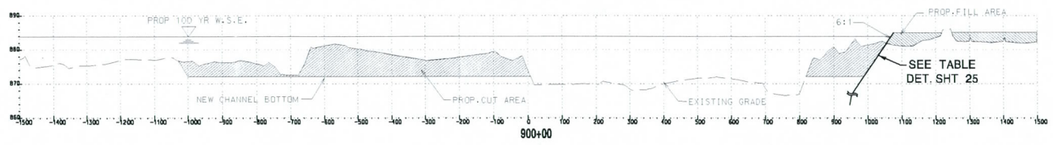


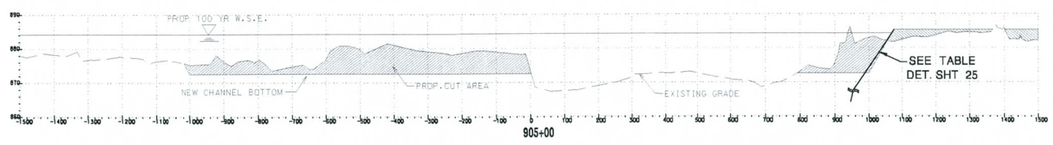
200' 100' 0 200'

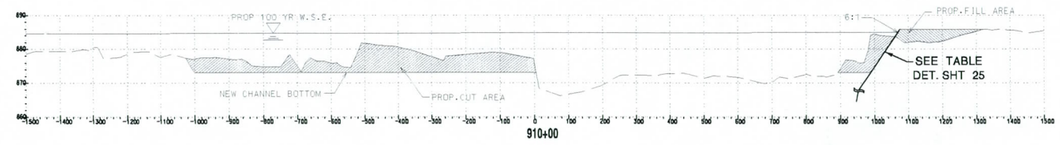
SCALE: 1"= 200 ' HORIZ.
SCALE: 1"= 20 ' VERT.

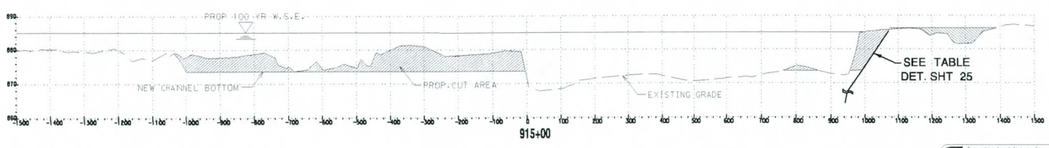












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CROSS SECTIONS

GILA RIVER

SHEET
22 OF 26

CVL Contact: GARY FREEMAN
CVL Project #: 800001
DESIGN DATE: JAN.12, 2006

Kevin K
25 SEP 2006
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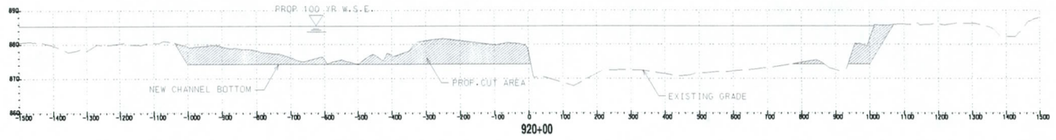

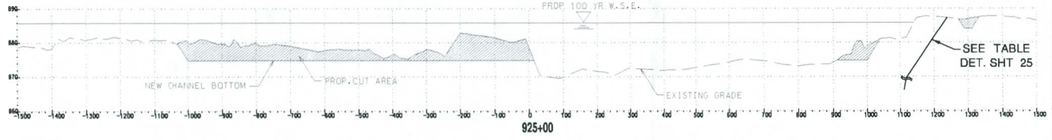

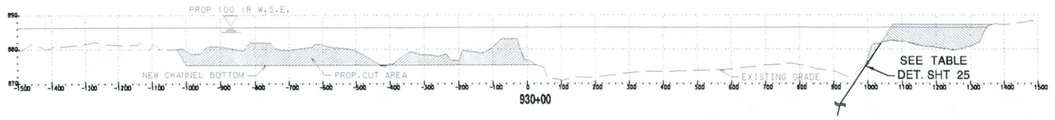

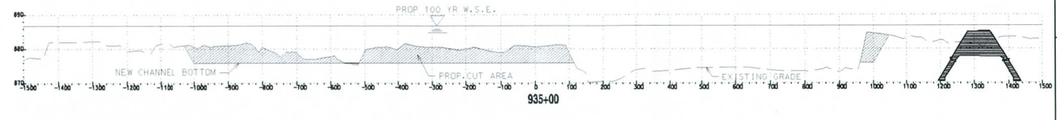

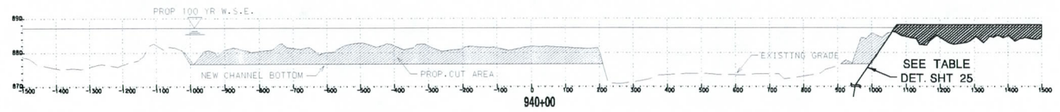

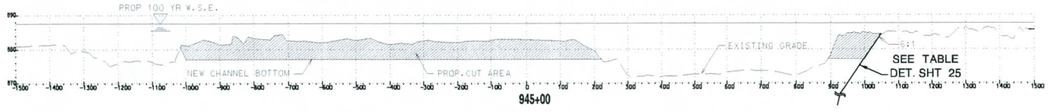

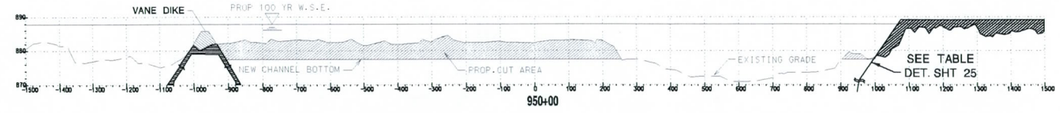

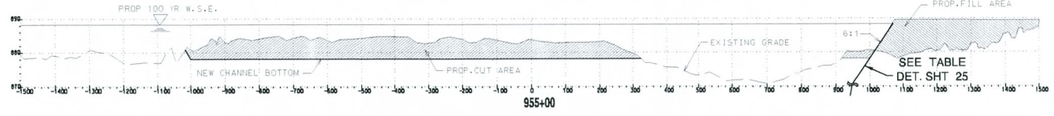

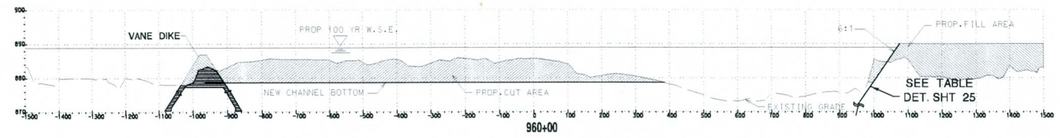

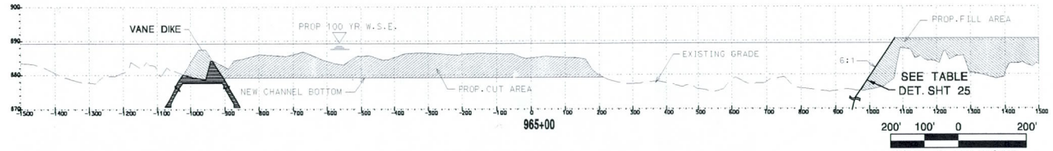

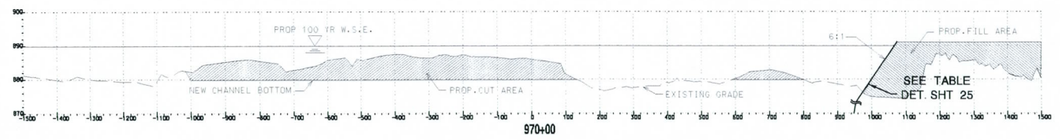

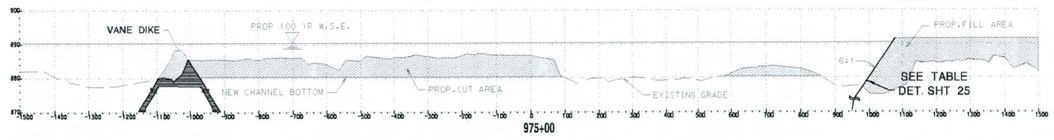

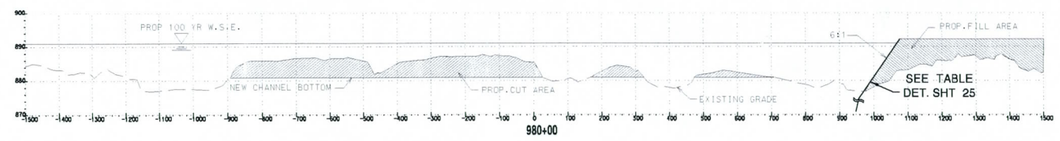

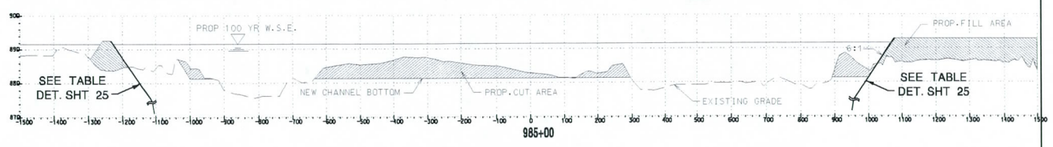

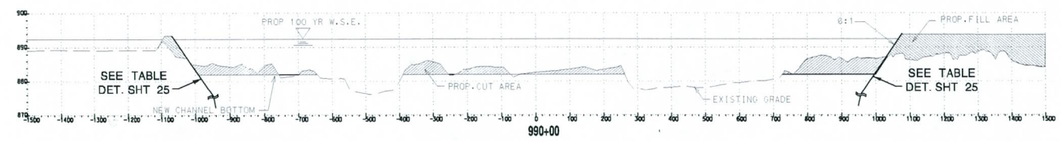

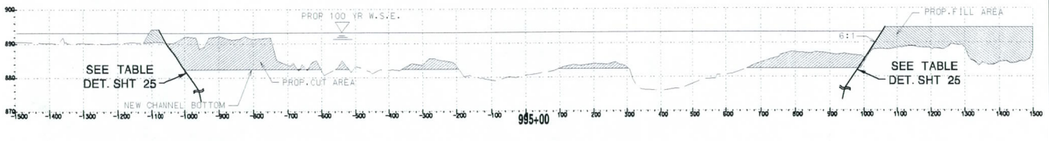

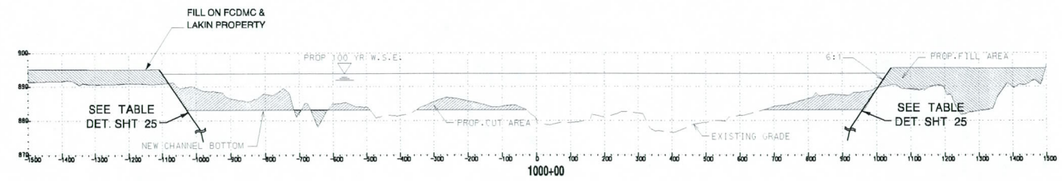

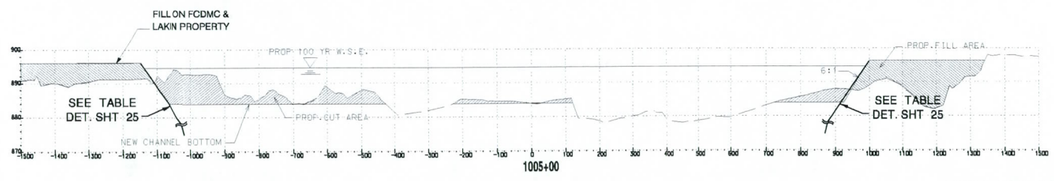

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CVL Contact: GARY FREEMAN
CVL Project #: 800001
DESIGN DATE: JAN.12, 2006

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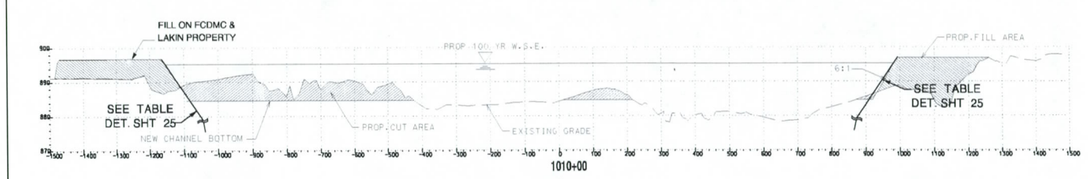

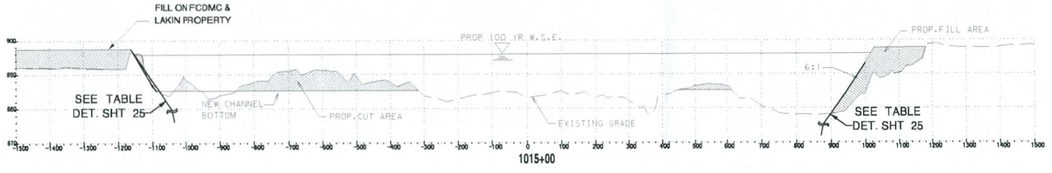

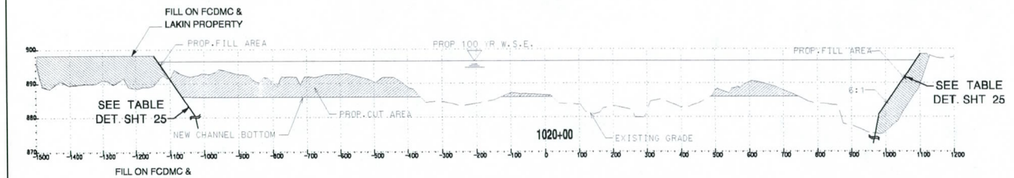

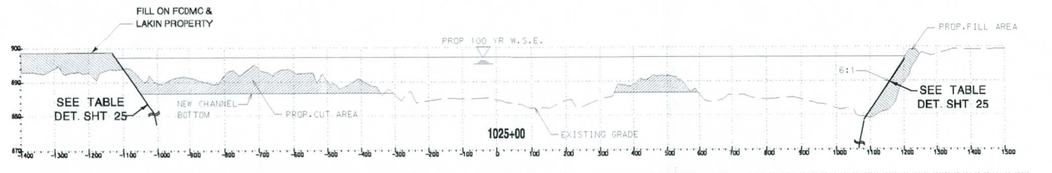

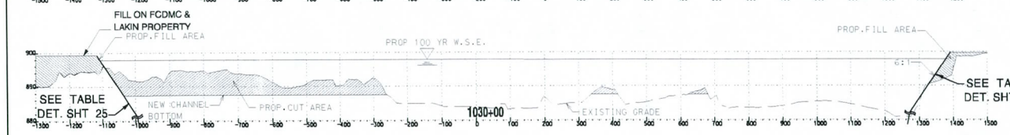

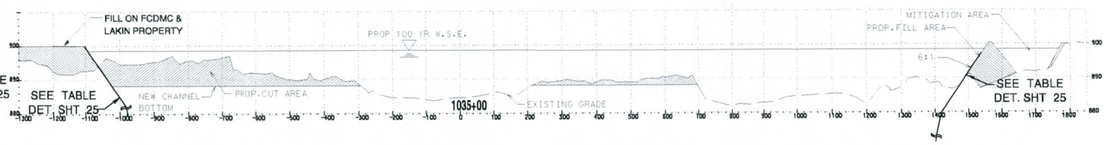

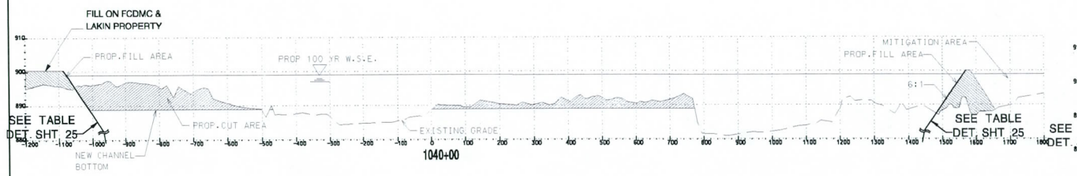

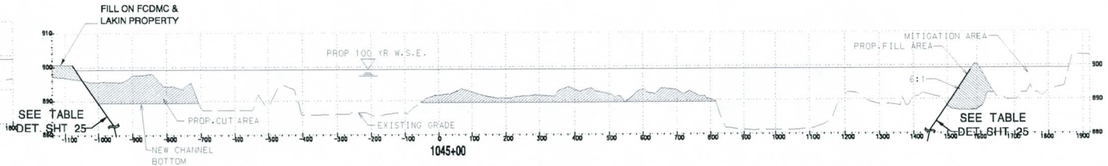

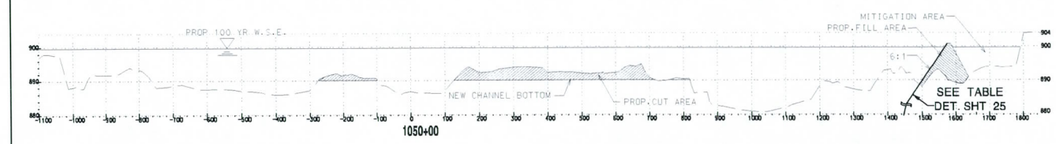

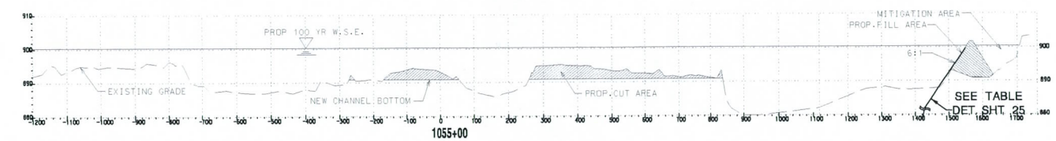

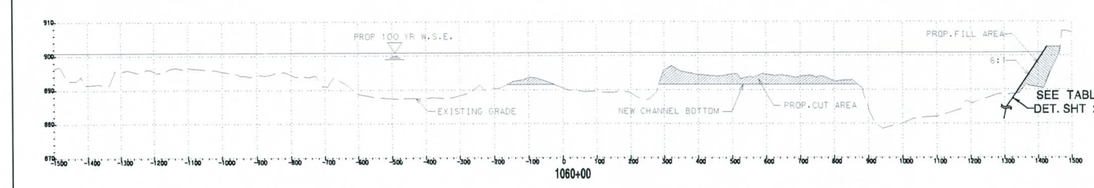

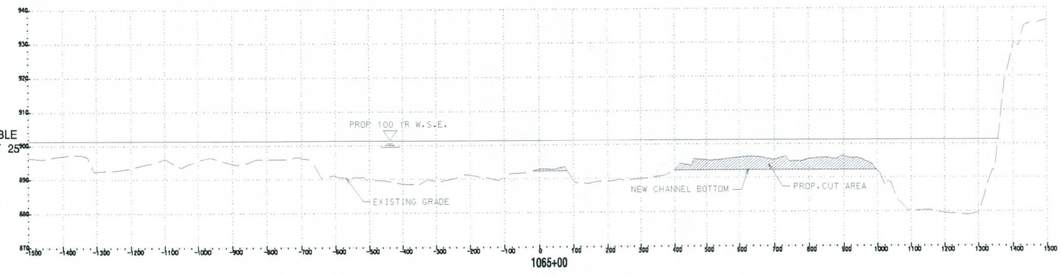

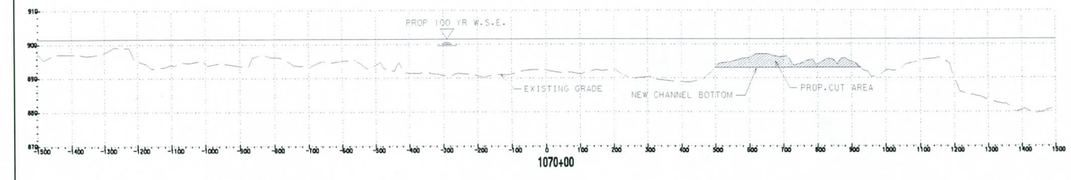

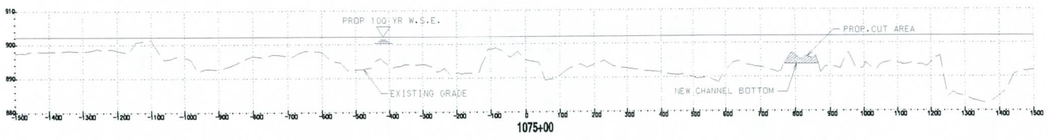

200' 100' 0 200'
SCALE: 1"= 200 'HORIZ.
SCALE: 1"= 20 'VERT.

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GILA RIVER

SHEET 24 OF 26

CVL Contact: GARY FREEMAN
CVL Project #: 800001
DESIGN DATE: JAN.12, 2006

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25 SEP 2006
18:47:20
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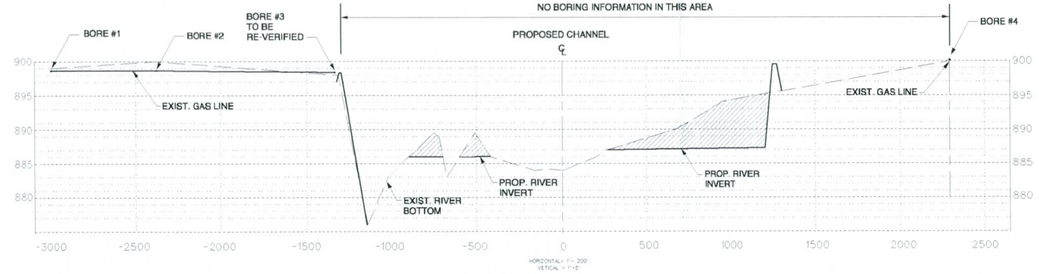
SOIL CEMENT TOE DOWN CALCULATIONS

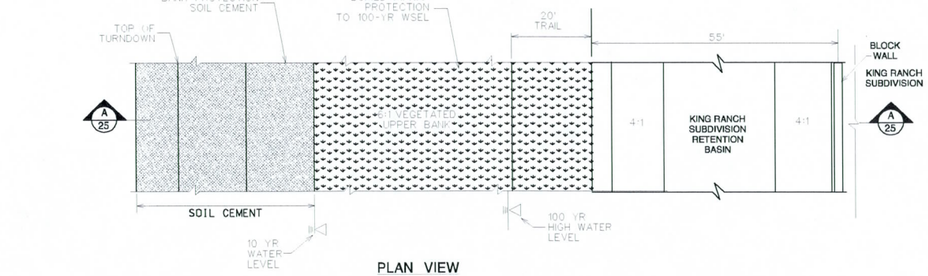
BANK PROTECTION DEPTHS AND DISTANCES FROM TOP OF BANK

	River Mile	Riprap Bank Elev.	Turn Down Total		South Bank					North Bank			
		Elevation*	Elevation	Height	to Turn Dwn Toe*	Distance	Total	Toe Down	Turn Dwn	Total	to Turn Dwn Toe*	Distance	Total
		EW+1.0 ft					Distance**	Elevation	Elevation	Height			Distance**
	193.63	901.92	902.92	864.92	877.92	38.00	69.68	5	68.68	867.40	870.40	58.82	166.24	40	234.92
	193.43	901.01	902.01	863.84	876.84	38.01	116.70	28	88.70	866.18	870.18	49.94	165.64	40	203.64
	193.14	900.66	901.66	863.38	876.38	38.28	151.74	28	123.74	851.81	879.81	45.75	154.74	40	283.74
	192.95	900.06	901.06	863.04	876.04	37.92	149.91	28	121.91	851.63	879.63	45.48	153.64	40	280.64
	192.81	899.90	900.90	862.91	875.91	37.93	146.49	28	118.49	851.29	879.29	45.08	152.52	40	192.92
	192.81	899.01	900.01	862.46	875.46	37.65	147.50	28	119.50	851.83	879.83	45.83	153.15	40	193.15
	192.49	896.71	899.71	862.16	874.16	37.84	147.19	28	119.19	850.81	874.81	48.96	149.40	40	197.40
	192.89	898.13	899.13	861.84	874.84	37.32	146.62	28	118.62	850.64	874.64	48.98	147.48	40	196.48
Reach 1	192.74	897.46	898.46	861.60	874.60	36.96	143.61	28	115.61	850.74	874.74	48.26	145.38	40	193.38
	192.78	896.74	897.74	861.16	874.16	36.66	141.11	28	113.11	849.93	874.93	47.74	142.92	40	190.92
	192.61	896.13	897.16	860.84	873.84	36.21	139.48	28	111.48	849.78	873.78	47.43	140.65	40	188.65
	192.53	896.58	896.58	860.58	873.58	35.92	137.67	28	109.67	848.93	873.43	47.51	138.43	40	187.42
		Sutton Low Bridge	848.18	883.18	872.18	24.00	Flat Path***	64.34		848.18	883.18	48.24	Flat Path***	63.34	
	192.39	894.10	895.10	860.61	872.61	34.49	134.49	28	107.88	846.72	872.04	45.66	134.32	40	181.36
	192.39	893.67	894.67	859.90	872.34	34.74	138.17	28	106.45	846.86	872.06	45.81	138.66	40	178.86
	192.32	893.88	894.88	859.93	872.93	34.95	127.15	28	103.78	848.58	872.58	45.35	127.53	40	176.50
	192.14	892.91	893.91	859.54	871.54	34.37	127.05	28	103.30	848.24	871.74	44.74	124.98	40	172.33
	192.03	893.26	894.26	858.92	871.42	33.26	127.85	28	148.85	847.93	870.93	44.26	121.76	40	169.74
	191.95	890.78	891.78	858.63	871.63	33.07	128.43	28	146.43				Horizontal Distances		
	191.88	890.19	891.19	858.33	871.33	32.87	115.91	28	145.91						
Reach 2	191.78	889.64	890.64	857.98	870.98	32.66	118.49	28	144.88						
	191.67	889.10	890.10	857.67	870.67	32.43	116.71	28	143.71						
	191.67	888.58	889.58	857.33	870.33	32.25	115.60	28	141.60						
	191.49	888.13	889.13	857.03	870.03	32.10	114.67	28	140.67	Bank Toe Dwn Depths at Abutments to be Deepened					
	191.38	887.73	888.73	856.68	869.68	32.05	114.38	28	140.38	to Account For Bridge Requirements					
	191.11	887.43	888.43	856.51	869.51	31.92	113.75	28	139.75	South Bank Deepened to 26.1 Below Thalweg (+1.0 ft)					
	191.19	886.93	887.93	856.01	869.01	31.99	113.49	28	139.49	North bank Deepened to 26.9 Below Thalweg (+1.0 ft)					
Reach 3	191.18	886.88	887.88	856.73	868.73	31.82	112.97	28	138.97						
	191.06	886.28	887.28	856.38	868.38	31.81	112.93	28	138.93						
	190.97	885.78	886.78	856.01	868.01	31.71	111.75	28	139.75						
	190.81	885.39	886.39	854.73	867.73	31.65	111.56	28	137.96						
	190.73	885.84	886.84	854.43	867.43	31.82	111.57	28	137.71						
	190.67	884.57	885.57	854.08	867.08	31.69	111.42	28	137.64						
	190.62	884.13	885.13	853.77	866.77	31.46	110.35	28	136.38						
	190.43	883.69	884.69	853.43	866.43	31.40	108.56	28	124.98						
	190.24	883.19	884.19	853.20	866.18	31.07	108.42	28	124.42						

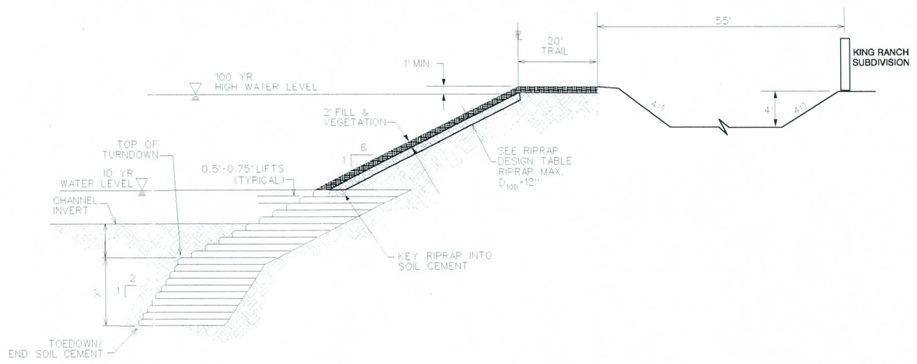
* Horizontal Distance from Turn Down to Toe
** Total Horizontal Distance from Top Bank to Toe
*** Turn Down Starts at River Side Edge of Path. This may require hand rails if erosion occurs.
All Slopes are 2h:1v For turn downs except under bridge where slope is 1.0h:1v to clear piers with Toe and avoid scour holes
Slopes to transition from 2h:1v, or 1.0h:1v, from 400 feet on each side of bridge.
Turn down alignment and elevation also transitions linearly from 400 feet on each side of bridge to bridge values



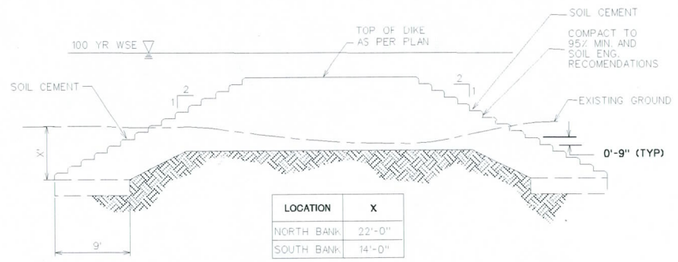
GAS PIPELINE PROFILE
(LOOKING DOWNSTREAM)



PLAN VIEW
N.T.S.



A
6&9
TYPICAL
SECTION THROUGH
VEGETATED UPPER BANK
N.T.S.



LOCATION	X
NORTH BANK	22'-0"
SOUTH BANK	14'-0"

A
17
VANE DIKE
TYPICAL N.T.S.

CVL
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Phoenix, Arizona 85014
Telephone 602-264-6831
http://www.cvlci.com

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	95% SUBMITTAL	06-23-06
	99% SUBMITTAL	09-25-06

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DETAILS

GILA RIVER

99%
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OR 800-782-5348
1-800-STAKE-IT
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SHEET
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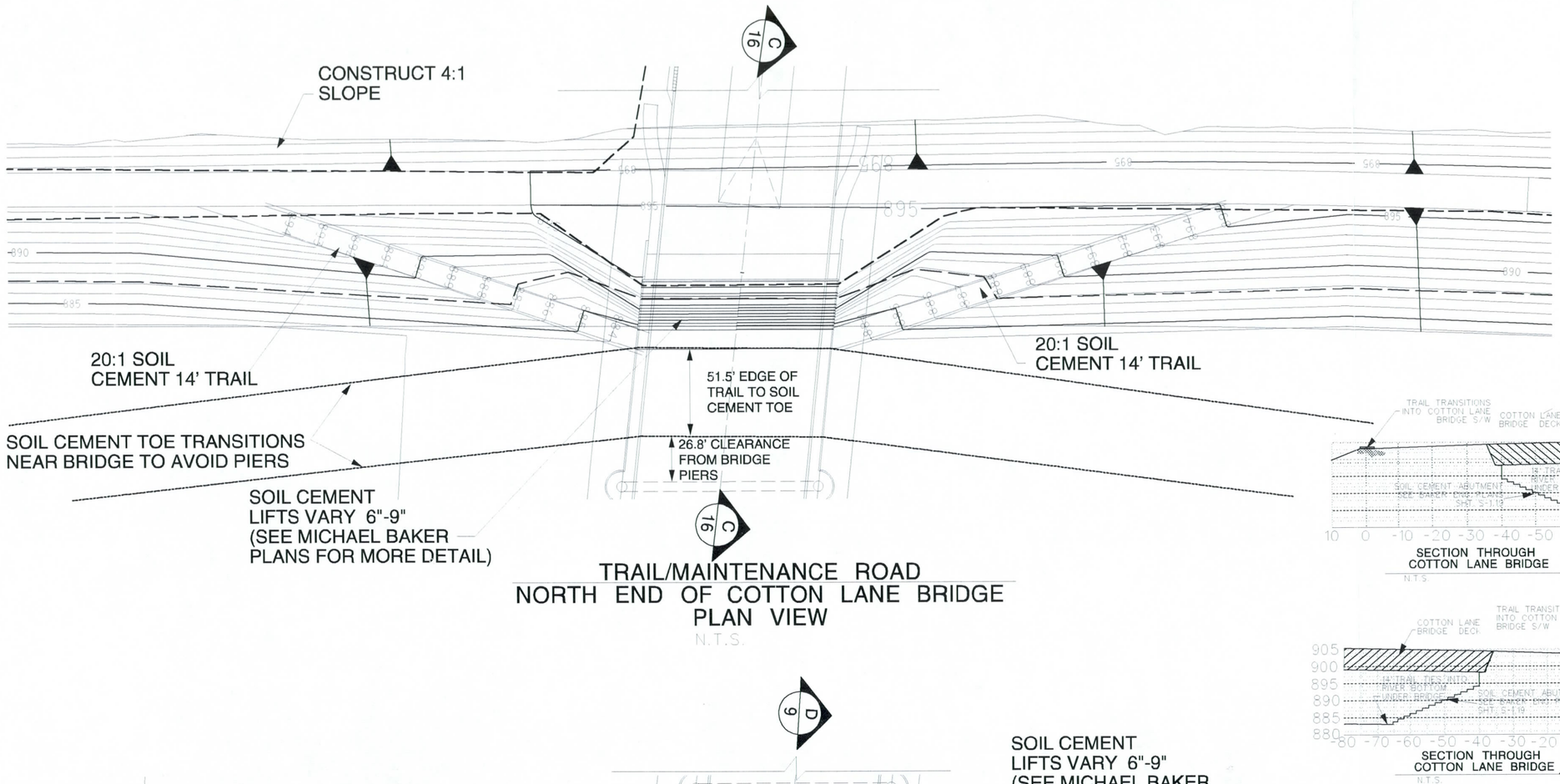
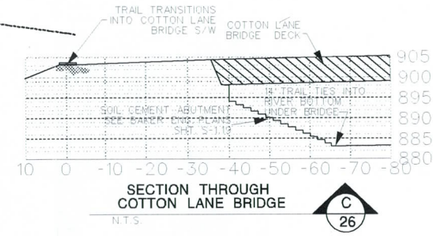
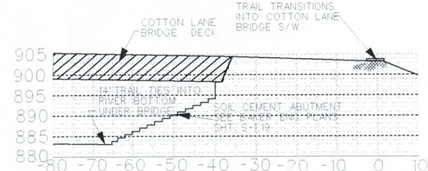
CVL Contact: GARY FREEMAN
CVL Project #: 800001
CVL File #:



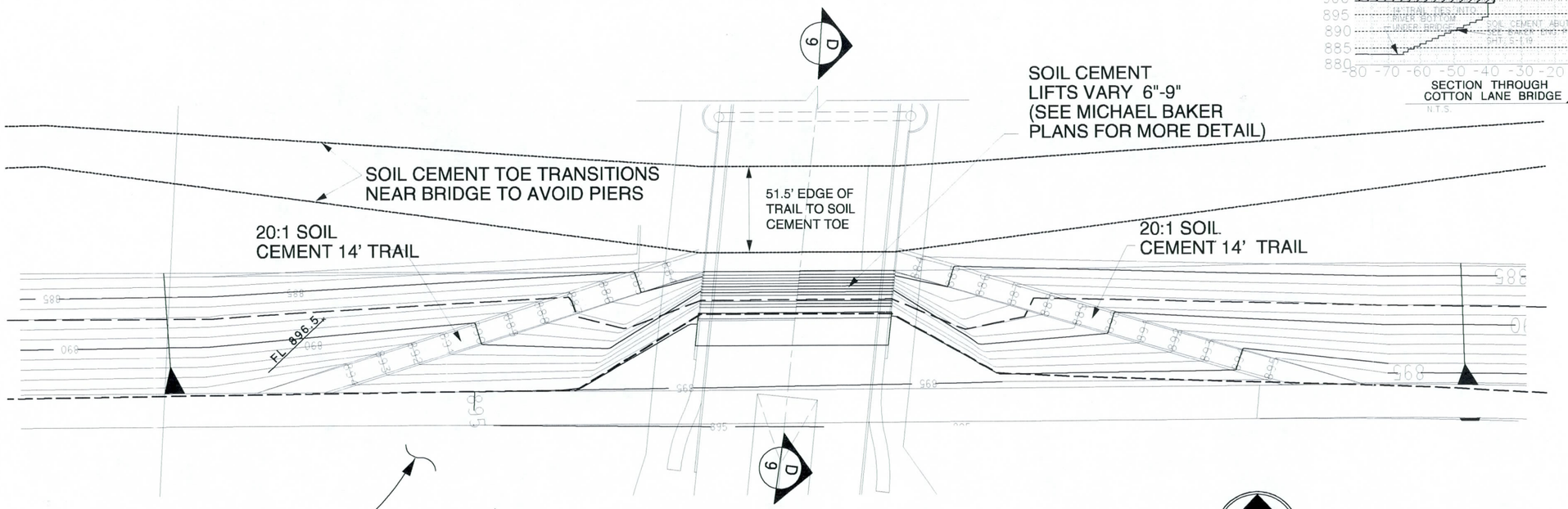
TRAIL/MAINTENANCE ROAD
NORTH END OF COTTON LANE BRIDGE
PLAN VIEW
N.T.S.



SECTION THROUGH
COTTON LANE BRIDGE
N.T.S.
C
26



SECTION THROUGH
COTTON LANE BRIDGE
N.T.S.
D
26



TRAIL/MAINTENANCE ROAD
SOUTH END OF COTTON LANE BRIDGE
PLAN VIEW
N.T.S.

FUTURE LAKE, LANDSCAPE
MONUMENT & INTEGRATED
TRAIL SYSTEM FOR
KING RANCH ENTRANCE

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COTTON LANE MAINTENANCE/RECREATIONAL
TRAIL DETAILS

GILA RIVER

SHEET
26 OF 26

CVL Contact: GARY FREEMAN
CVL Project #: 800001
CVL File #:

Two working days before you dig, CALL FOR THE BLUE STAKE, 602-263-1100, 1-800-STAKE-IT (OUTSIDE MARICOPA COUNTY)

n:\800001-land-gilariver-sddetails2

MARICOPA COUNTY
DEPARTMENT OF TRANSPORTATION

PLANS FOR THE CONSTRUCTION OF
COTTON LANE – MC 85 TO ESTRELLA PARKWAY

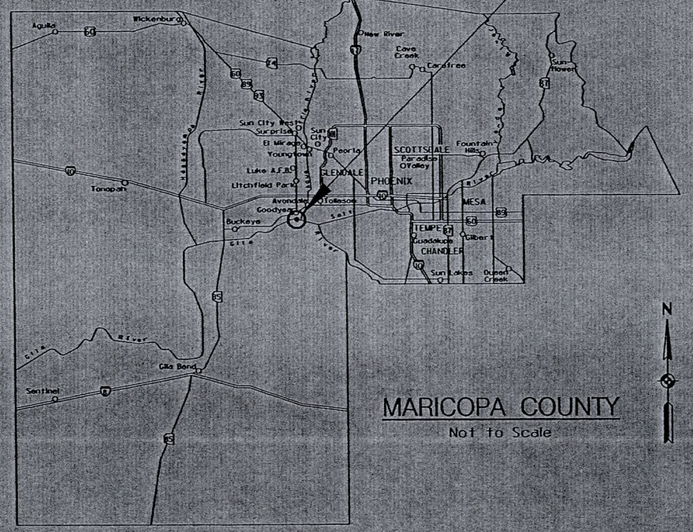
PROJECT NO. TT-180

06/21/2006

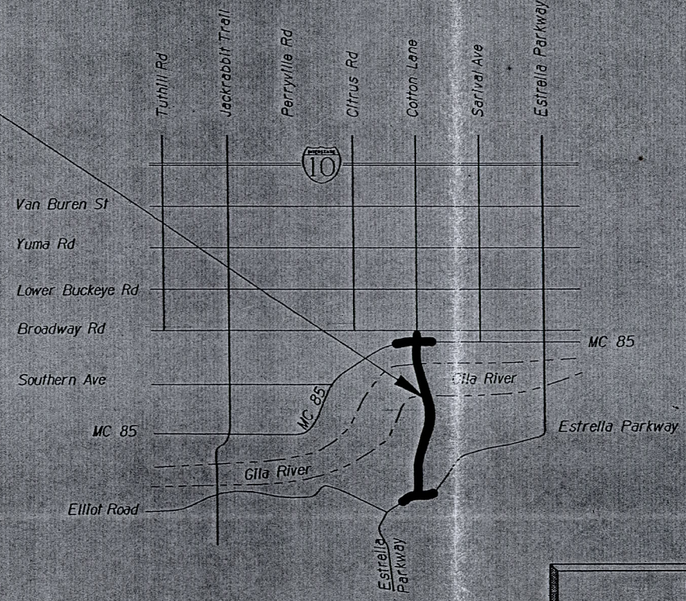
02:42:52 PM

T:*Cotton Lane*Goodyear_CL\cover.dgn

PROJECT NO. TT-180



MARICOPA COUNTY
Not to Scale



VICINITY MAP
Not to Scale

100% SUBMITTAL
JUNE 28, 2006

Baker

IN COOPERATION WITH:
CITY OF GOODYEAR

MARICOPA COUNTY DEPARTMENT OF TRANSPORTATION

ISSUED FOR PUBLIC BIDDING BY:

PROJECT MANAGER _____ DATE _____

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DISTRICT 2	DON STAPLEY
DISTRICT 3	ANDREW W. KUNASEK
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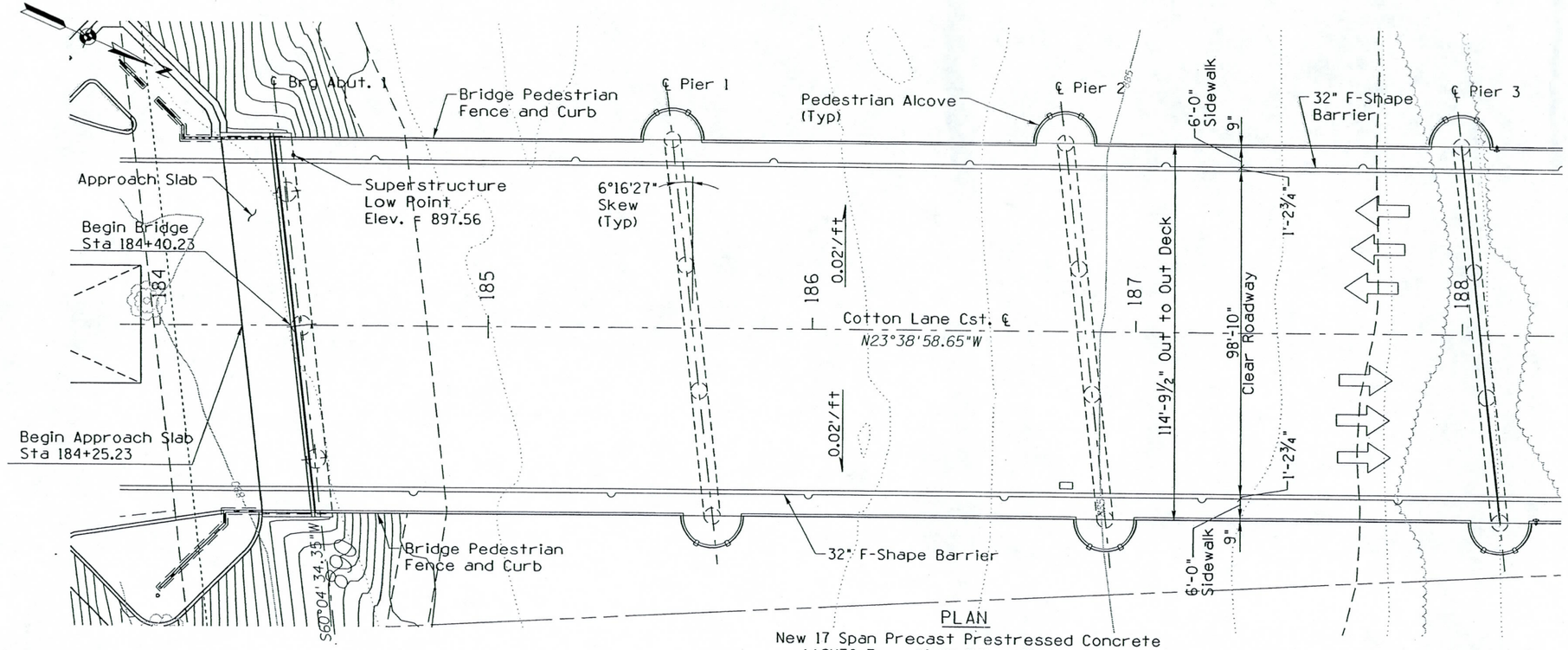
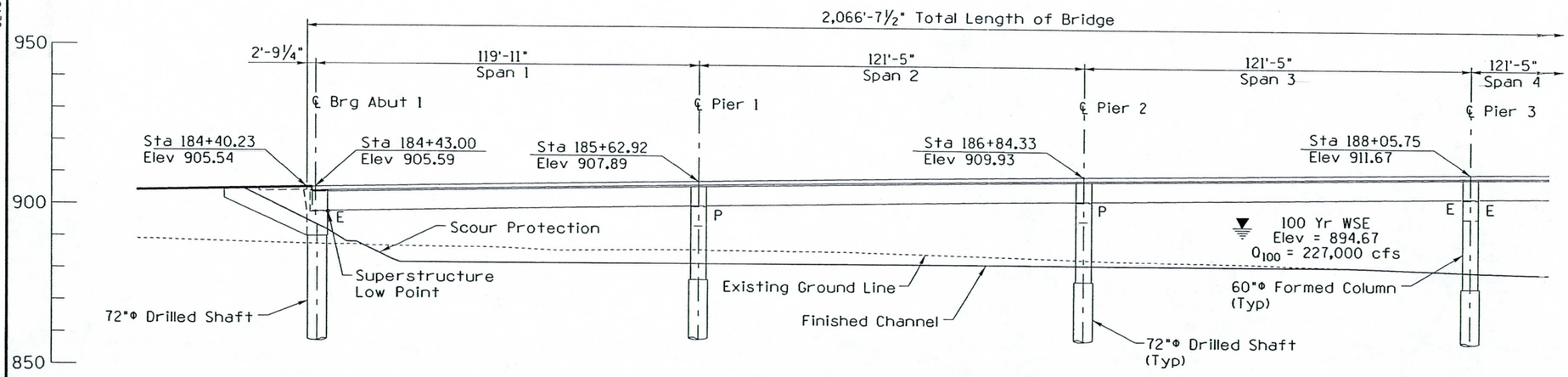


PLAN

New 17 Span Precast Prestressed Concrete
AASHTO Type VI Modified Girder Bridge
Scale: 1" = 20'-0"



SECTION ALONG CST. ℄

Elevations indicated are given at the
Cotton Lane Cst ℄
Scale: 1" = 20'-0"

F.H.W.A. REGION	STATE	PROJECT NO.	SHEET NO.	TOTAL SHEETS	RECORD DRAWING
9	AZ	TT-180	333	556	

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S-1.07	STRUCTURE PAYMENT LIMITS & QUAN.
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S-1.48	SCREED ELEVATIONS - 3(SPANS 6, 7, & 8)
S-1.49	SCREED ELEVATIONS - 4(SPANS 9, 10 & 11)
S-1.50	SCREED ELEVATIONS - 5(SPANS 12, 13 & 14)
S-1.51	SCREED ELEVATIONS - 6(SPANS 15, 16 & 17)
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S-1.53	DIP WATER LINE PROFILE ON BRIDGE
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S-1.55	PEDESTRIAN FENCE DETAILS - 1
S-1.56	PEDESTRIAN FENCE DETAILS - 2

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MARICOPA COUNTY
DEPARTMENT OF TRANSPORTATION
ENGINEERING DIVISION

COTTON LANE
MC 85 TO ESTRELLA PARKWAY
PROJECT NO. TT-180

100%
PRELIMINARY
NOT FOR CONSTRUCTION

	BY	DATE
DESIGNED	D.J. LAWSON	06/06
DRAWN	C.R. SMITH	06/06
CHECKED	T. E. QUILLMAN	06/06

GILA RIVER BRIDGE
LOCATION PLAN - 1

SHEET S-1.01 OF 56

Baker

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F.H.W.A. REGION	STATE	PROJECT NO.	SHEET NO.	TOTAL SHEETS	RECORD DRAWING
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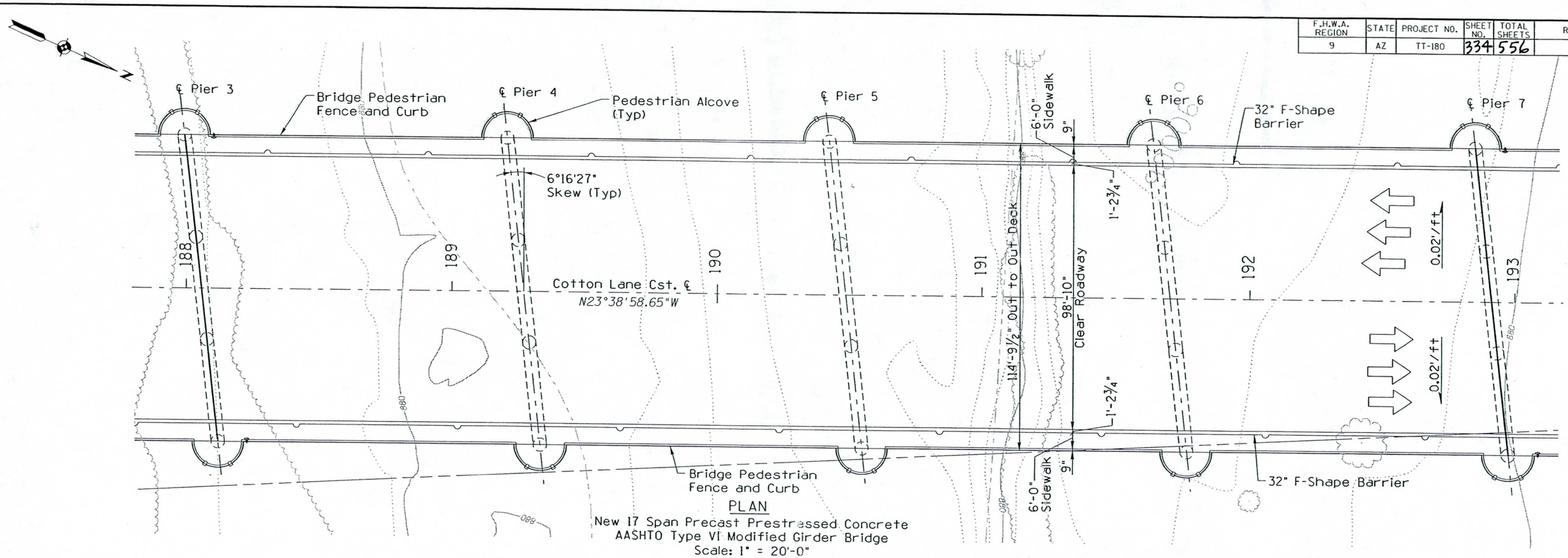
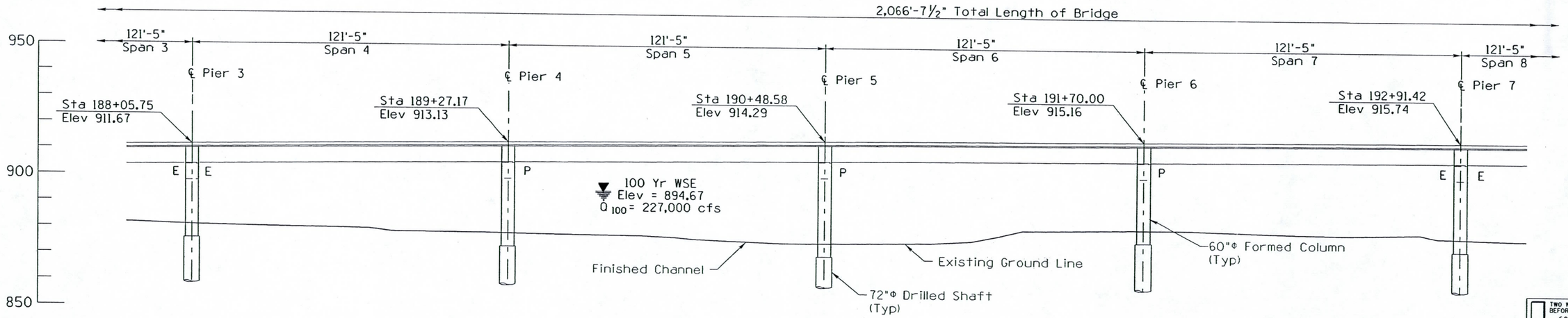


PLAN

New 17 Span Precast Prestressed Concrete
AASHTO Type VI Modified Girder Bridge
Scale: 1" = 20'-0"



SECTION ALONG CST. ℄

Elevations indicated are given at the
Cotton Lane Cst ℄
Scale: 1" = 20'-0"

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BLUE STAKE

NO.	REVISION	BY	DATE
3			
2			
1			

MARICOPA COUNTY
DEPARTMENT OF TRANSPORTATION
ENGINEERING DIVISION

COTTON LANE
MC 85 TO ESTRELLA PARKWAY
PROJECT NO. TT-180

100%
PRELIMINARY
NOT FOR CONSTRUCTION

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DRAWN	C.R. SMITH	06/06
CHECKED	C. MATTY	06/06

GILA RIVER BRIDGE
LOCATION PLAN - 2

SHEET S-1.02 OF 56

Baker

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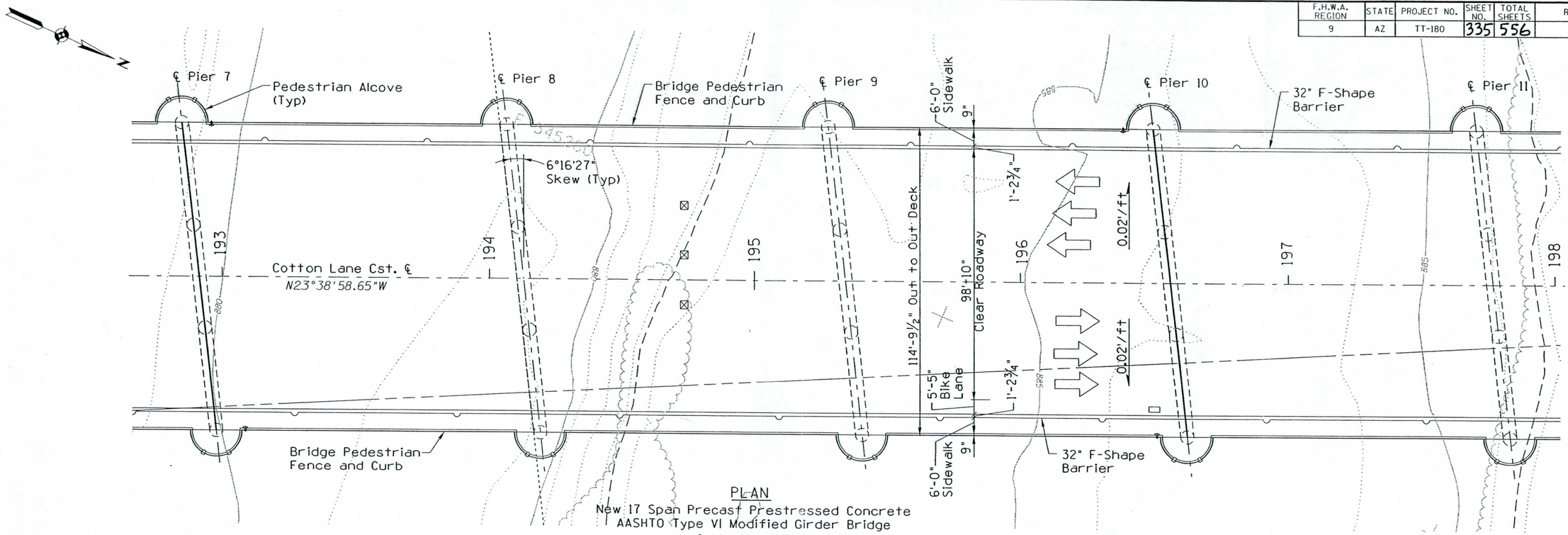
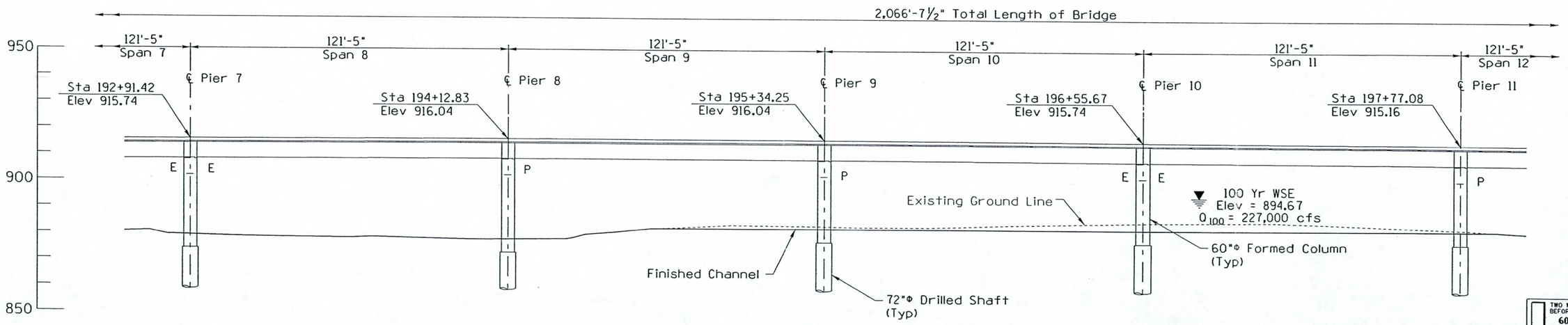


PLAN

New 17 Span Precast Prestressed Concrete
AASHTO Type VI Modified Girder Bridge
Scale: 1" = 20'-0"



SECTION ALONG CST. ℄

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NO.	REVISION	BY	DATE
3			
2			
1			

MARICOPA COUNTY
DEPARTMENT OF TRANSPORTATION
ENGINEERING DIVISION

COTTON LANE
MC 85 TO ESTRELLA PARKWAY
PROJECT NO. TT-180

100%
PRELIMINARY
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CHECKED	T. E. QUILLMAN	06/06

GILA RIVER BRIDGE
LOCATION PLAN - 3

SHEET S-1.03 OF 56

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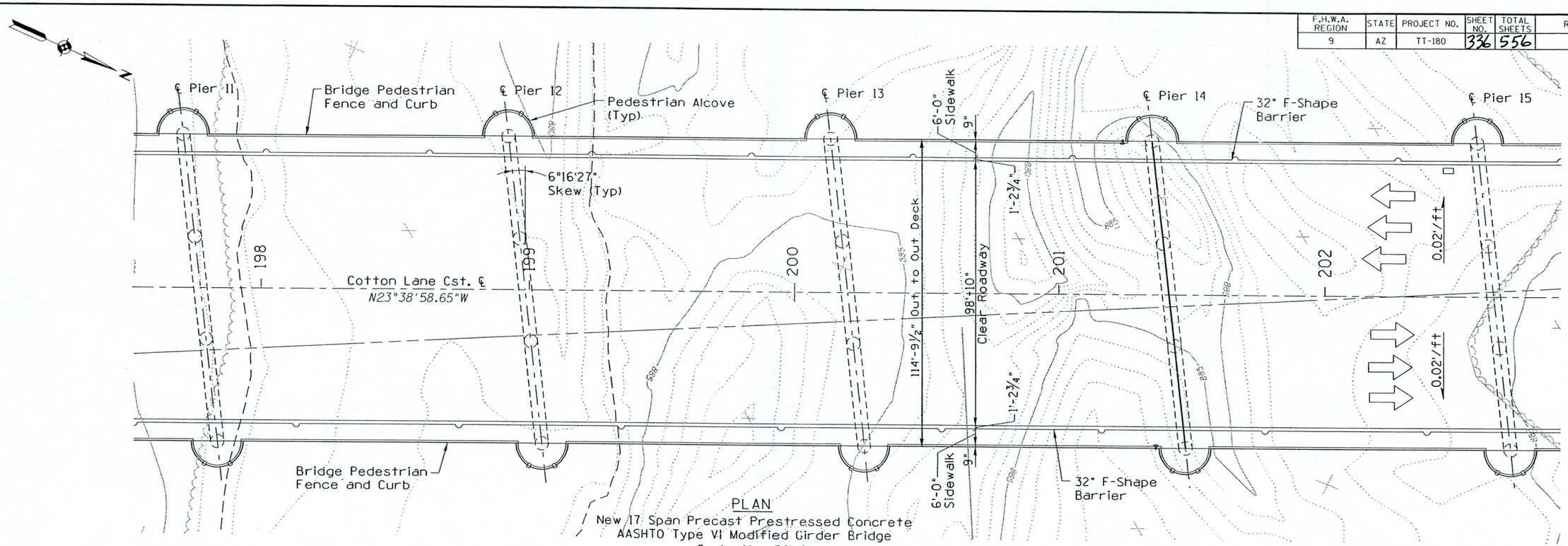
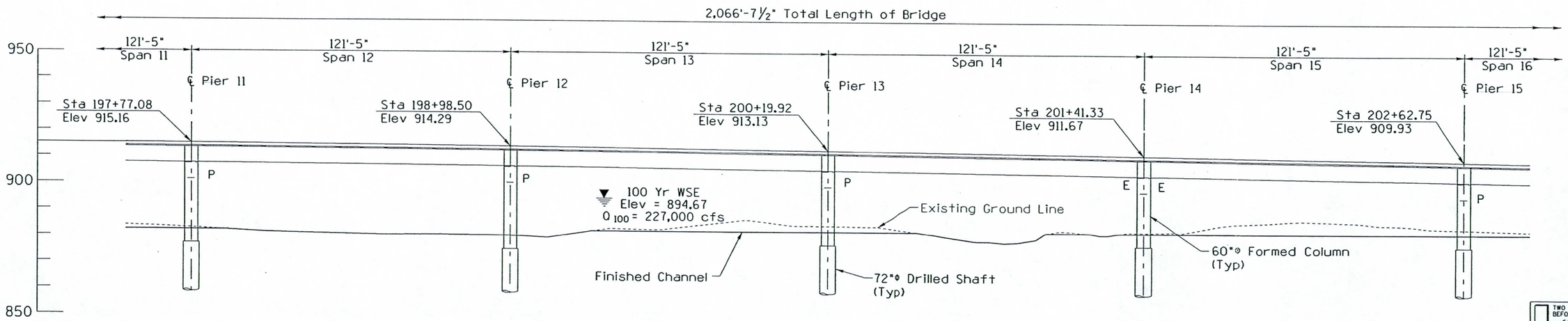
9	AZ	TT-180	336	556	



PLAN

New 17 Span Precast Prestressed Concrete AASHTO Type VI Modified Girder Bridge
Scale: 1" = 20'-0"



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NO.	REVISION	BY	DATE
3			
2			
1			

MARICOPA COUNTY
DEPARTMENT OF TRANSPORTATION
ENGINEERING DIVISION

COTTON LANE
MC 85 TO ESTRELLA PARKWAY
PROJECT NO. TT-180

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PRELIMINARY
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DRAWN	C. R. SMITH	06/06
CHECKED	C. MATTY	06/06

GILA RIVER BRIDGE
LOCATION PLAN - 4

SHEET S-1.04 OF 56

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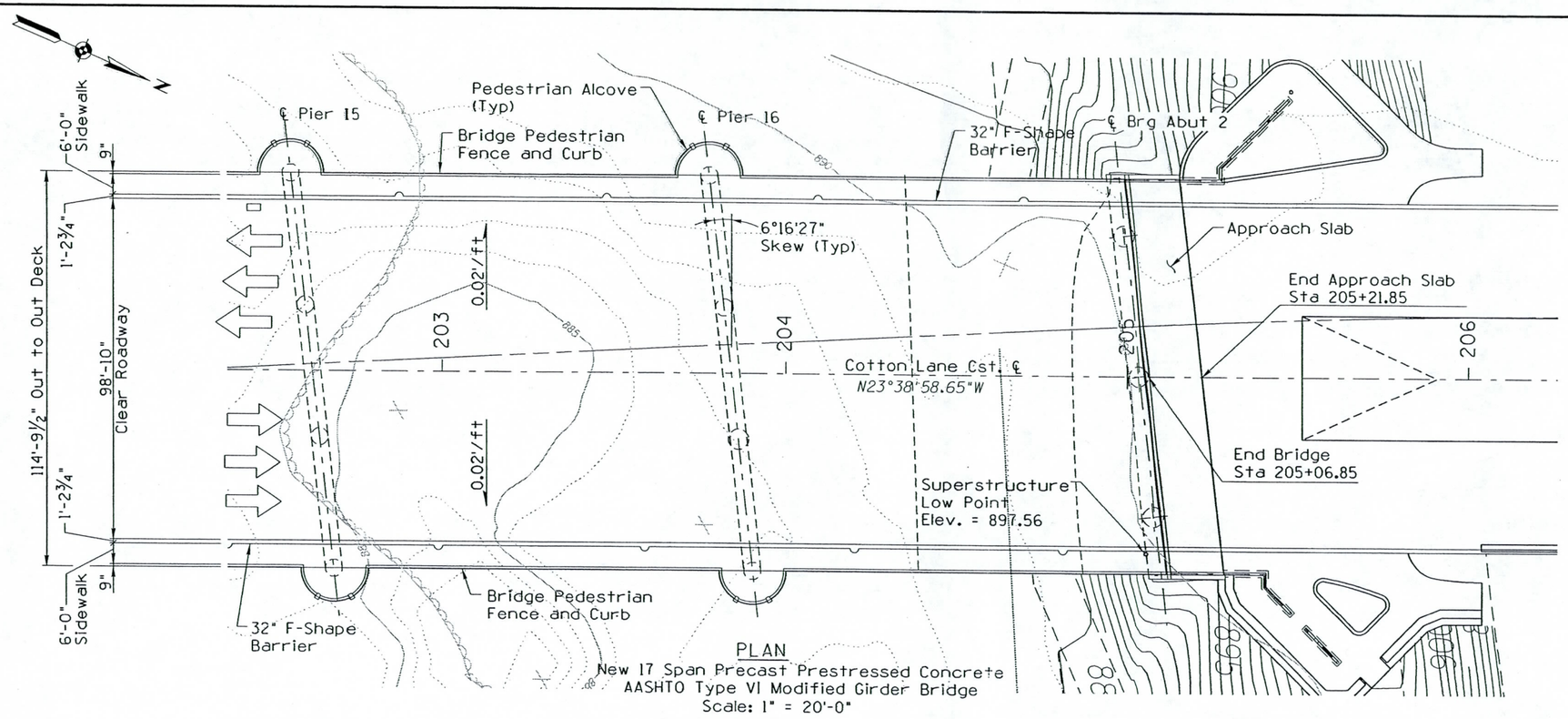
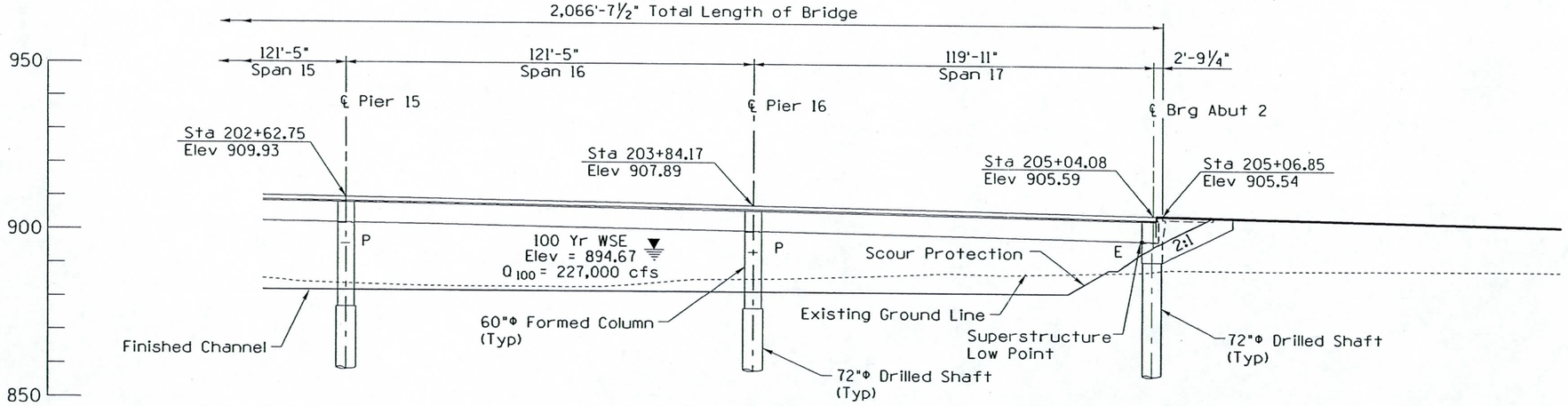
F.H.W.A. REGION	STATE	PROJECT NO.	SHEET NO.	TOTAL SHEETS	RECORD DRAWING
9	AZ	TT-180	337	556	





SECTION ALONG CST. ℄
Elevations indicated are given at the Cotton Lane Cst ℄
Scale: 1" = 20'-0"

TWO WORKING DAYS BEFORE YOU DIG, CALL 602-263-1100 BLUE STAKE

NO.	REVISION	BY	DATE
3			
2			
1			

MARICOPA COUNTY
DEPARTMENT OF TRANSPORTATION
ENGINEERING DIVISION

COTTON LANE
MC 85 TO ESTRELLA PARKWAY
PROJECT NO. TT-180

100%
PRELIMINARY
NOT FOR CONSTRUCTION

	BY	DATE
DESIGNED	D. J. LAWSON	06/06
DRAWN	C. R. SMITH	06/06
CHECKED	C. MATTY	06/06

GILA RIVER BRIDGE
LOCATION PLAN - 5

SHEET S-1.05 OF 56

Baker

06/21/2006
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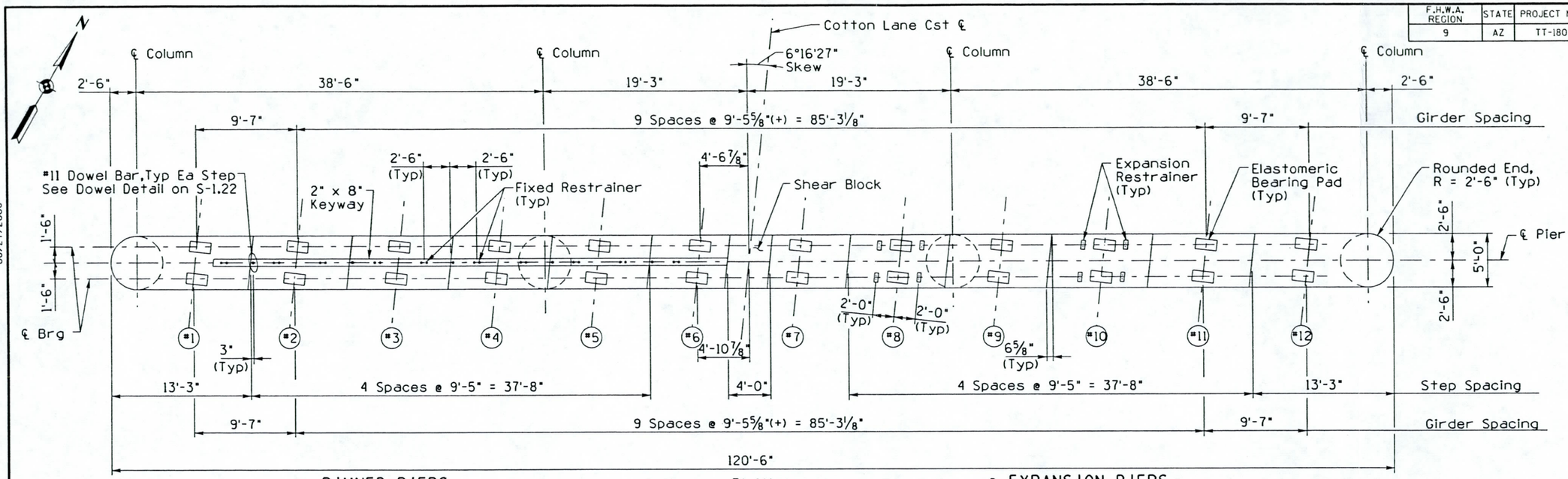
t:*cotton lane*cadd*s_cl_genpl_05.dgn

F.H.W.A. REGION	STATE	PROJECT NO.	SHEET NO.	TOTAL SHEETS	RECORD DRAWING
9	AZ	TT-180	352	556	

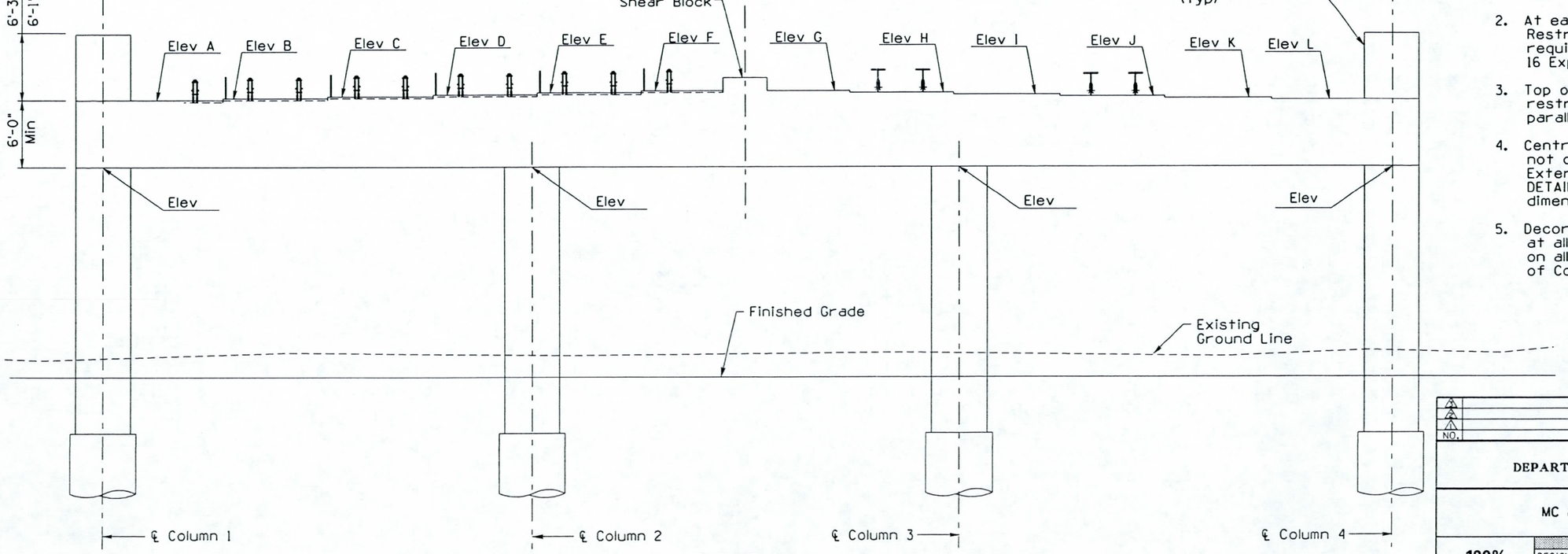


@ PINNED PIERS

PLAN

Scale: 3/16" = 1'-0"

@ EXPANSION PIERS



ELEVATION

Scale: 3/16" = 1'-0"

NOTES:

1. See 'PIER DETAILS - 1' sheet for column & girder bearing seat elevations and for column reinforcing details. See 'PIER DETAILS - 2' sheet for pier cap reinforcing details.
2. At each pinned pier, 20 Fixed Restrainers and 10-#11 Dowel Bars required. At each expansion pier, 16 Expansion Restrainers required.
3. Top of pier steps & expansion restrainers shall be oriented parallel w/ Girders.
4. Centriod of Bearing Pad does not coincide with centriod for Exterior Girders, See 'BEARING DETAILS' sheet for offset dimension.
5. Decorative concrete stain required at all Piers. Provide stain all around on all columns, beginning at Bottom of Column up to Elev 893.50.

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COTTON LANE
MC 85 TO ESTRELLA PARKWAY
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CHECKED	C. MATTY	06/06

GILA RIVER BRIDGE
TYP PIER PLAN & ELEVATION

SHEET S-1.20 OF 56

Baker

06/21/2006
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F.H.W.A. REGION	STATE	PROJECT NO.	SHEET NO.	TOTAL SHEETS	RECORD DRAWING
9	AZ	TT-180	353	556	

06/22/2006

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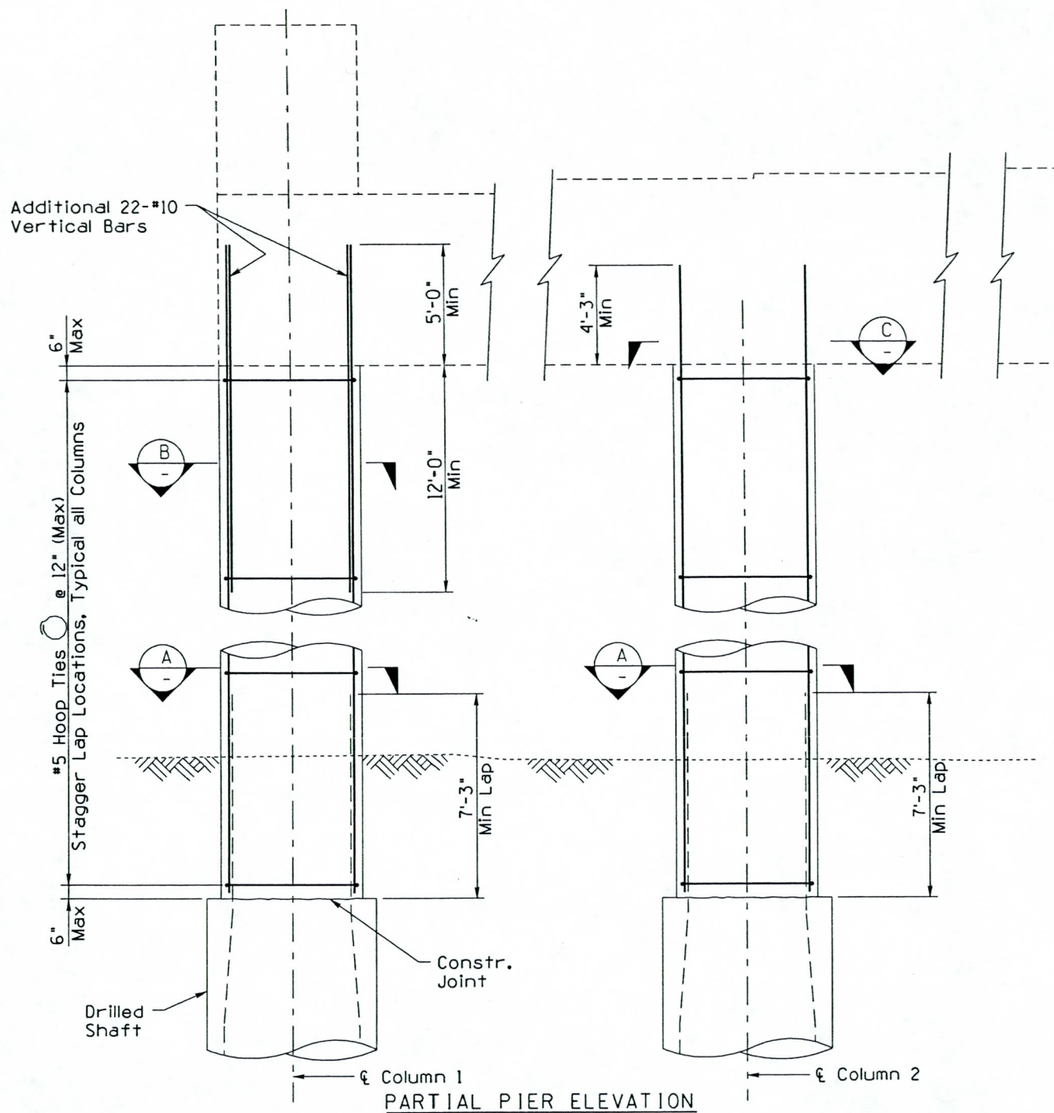
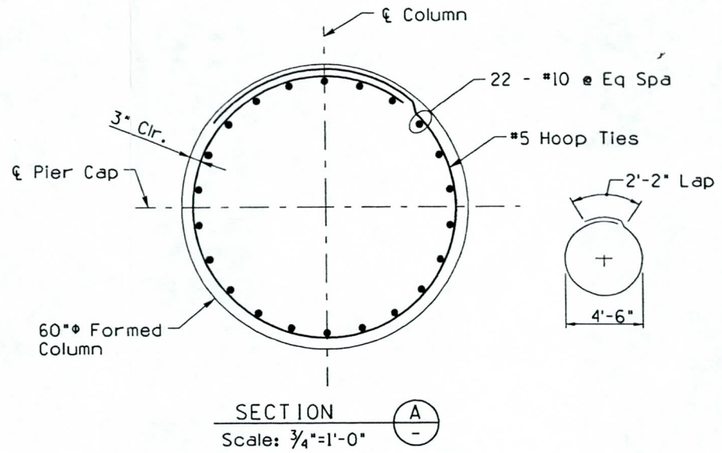
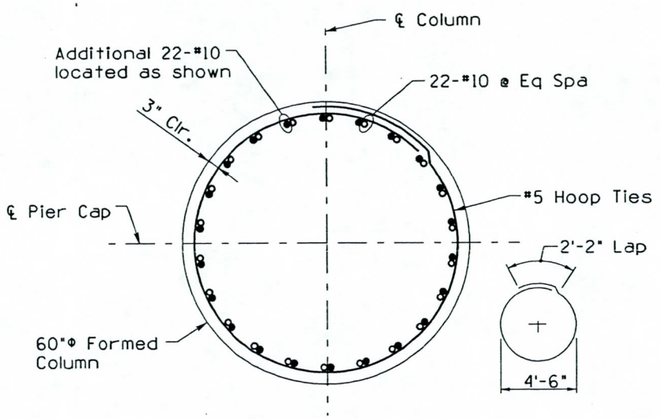


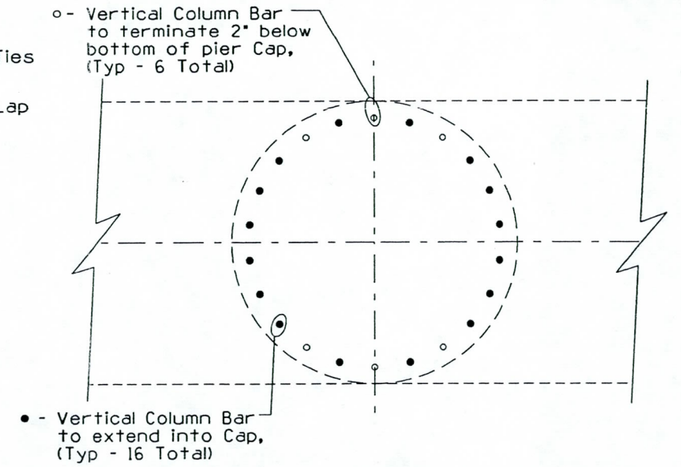
PARTIAL PIER ELEVATION
Scale: 3/8"=1'-0"



SECTION (A)
Scale: 3/4"=1'-0"



SECTION (B)
(COLUMNS #1 & #4)
Scale: 3/4"=1'-0"



SECTION (C)
(COLUMNS #2 & #3)
Scale: 3/4"=1'-0"

PIER DATA

LOCATION	COLUMN ELEVS. TOP	COLUMN ELEVS. BOTTOM	COLUMN HEIGHT	TOP OF CAP ELEVS. A	B	C	D	E	F	G	H	I	J	K	L
Pier 1	893.57	878.07	15'-6"	899.57	899.79	899.99	900.20	900.41	900.61	900.63	900.46	900.29	900.12	899.95	899.77
Pier 2	895.62	878.12	17'-6"	901.62	901.84	902.04	902.25	902.45	902.65	902.67	902.50	902.33	902.15	901.98	901.80
Pier 3	897.22	876.22	21'-0"	903.22	903.43	903.63	903.83	904.04	904.24	904.25	904.08	903.90	903.73	903.55	903.37
Pier 4	898.90	874.40	24'-6"	904.90	905.11	905.31	905.51	905.71	905.91	905.92	905.74	905.56	905.39	905.21	905.02
Pier 5	900.09	871.34	28'-9"	906.09	906.30	906.50	906.69	906.89	907.09	907.10	906.92	906.74	906.56	906.38	906.18
Pier 6	900.98	877.23	23'-9"	906.98	907.18	907.38	907.57	907.77	907.96	907.97	907.79	907.60	907.42	907.24	907.04
Pier 7	901.36	875.11	26'-3"	907.36	907.57	907.76	907.95	908.14	908.34	908.34	908.16	907.97	907.79	907.60	907.40
Pier 8	901.88	873.13	28'-9"	907.88	908.08	908.27	908.46	908.65	908.84	908.84	908.65	908.46	908.28	908.09	907.89
Pier 9	901.88	878.13	23'-9"	907.89	908.09	908.28	908.46	908.65	908.84	908.84	908.65	908.46	908.27	908.08	907.88
Pier 10	901.36	877.61	23'-9"	907.40	907.60	907.79	907.97	908.15	908.34	908.34	908.14	907.95	907.76	907.57	907.36
Pier 11	900.98	877.98	23'-0"	907.04	907.24	907.42	907.60	907.79	907.97	907.96	907.77	907.57	907.38	907.18	906.98
Pier 12	900.09	876.34	23'-9"	906.18	906.38	906.56	906.74	906.92	907.10	907.09	906.89	906.69	906.50	906.30	906.09
Pier 13	898.90	877.90	21'-0"	905.02	905.21	905.39	905.56	905.74	905.92	905.91	905.71	905.51	905.31	905.11	904.90
Pier 14	897.22	878.22	19'-0"	903.37	903.55	903.73	903.90	904.08	904.25	904.24	904.04	903.83	903.63	903.43	903.22
Pier 15	895.62	878.12	17'-6"	901.80	901.98	902.15	902.33	902.50	902.67	902.65	902.45	902.25	902.04	901.84	901.62
Pier 16	893.57	878.07	15'-6"	899.77	899.95	900.12	900.29	900.46	900.63	900.61	900.41	900.20	899.99	899.79	899.57

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GILA RIVER BRIDGE
PIER DETAILS - 1

SHEET S-1.21 OF 56

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