NORTE VISTA / KING RANCH
FLOODPLAIN REDELINEATION
GILA RIVER
GOODYEAR, ARIZONA

LETTER OF MAP REVISION

Prepared for:

Spencer Management, Inc.
1186 So Fern Court
Gilbert, AZ 85296

SD 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

June 2007

NORTE VISTA / KING RANCH
FLOODPLAIN REDELINEATION
GILA RIVER
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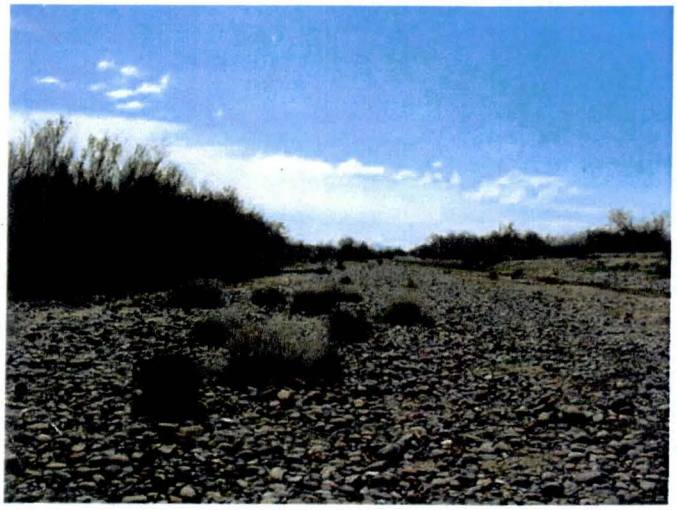

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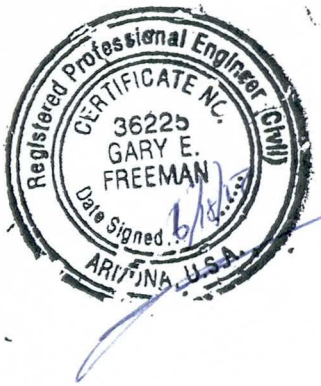

River Research & Design, Inc.
1345 E. Spur Ave
Gilbert, AZ 85296-1929

June 2007

2/7/13 Mona Returned the 2 reports borrowed from Stacey Lapp.

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GOODYEAR, ARIZONA

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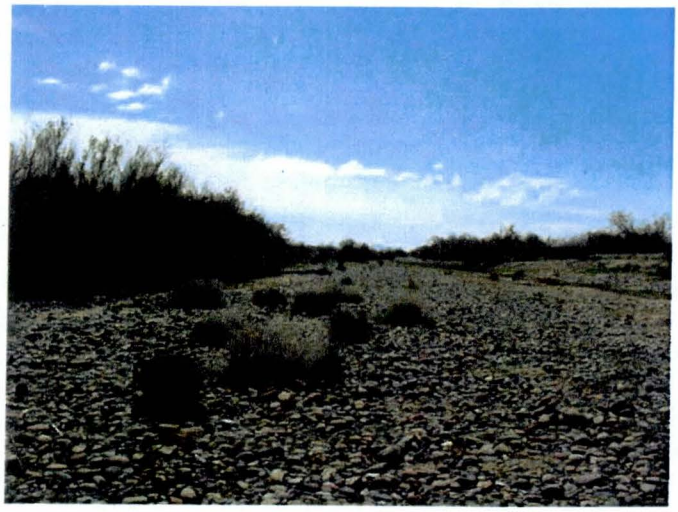

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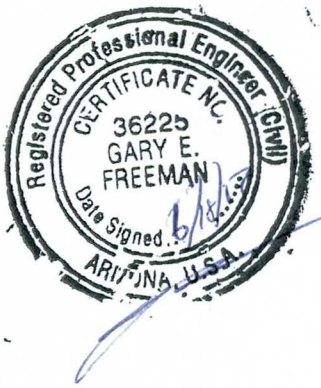

River Research & Design, Inc.
1345 E. Spur Ave
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June 2007

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1. Introduction

The current Gila River floodplain was delineated in 1993 immediately after the 1993 flood on the Gila River. New topography for portions of the area was obtained in 2005 as a part of the Gila River floodplain redelineation for the Cotton Lane Bridge and King Ranch development. Original plans were to obtain a CLOMR, make modifications to the channel and then obtain a LOMR for the entire reach. As the study progressed it became apparent that the area known as the Buckeye breakout on the north bank was no longer in the 100 year floodplain and could be removed from the floodplain without modification of the channel in this area. Land owners in the area were desirous to move forward with a LOMR to remove their property from the 100-year floodplain. This LOMR application modifies the Gila River floodplain from Estrella Parkway to Airport Road which is just west of Jackrabbit Trail and Tuthill Bridge. (See Figures 1 and 2)

A number of inter-related studies are being completed and several CLOMR/LOMR packages are expected to be submitted based, at least in part, on the data presented herein. Much of this data collection and study was funded by S. D. Construction, LLC (SDC) in conjunction with Sonterra Partners, LLC (Sonterra). The upstream Cotton Lane Bridge and channel project is being constructed as a cooperative effort between S. D. Construction, LLC, Maricopa County, the City of Goodyear and Estrella Mountain Ranch to provide improved access and better connectivity between the growing area south of the river and the more developed area north of the river and will be included in a later CLOMR application. An additional LOMR application was being prepared by the Flood Control District of Maricopa County with new mapping for the area known as the Buckeye breakout and continuing downstream from Jackrabbit Trail but has been combined into this submittal since the study areas had significant overlap. The following CLOMR/LOMR applications are anticipated in addition to this submittal. The firm or entity expected to be responsible for the submittals is shown in parenthesis.

1) CLOMR for King Ranch and Lakin developments including channel modifications and bank protection (River Research & Design)

2) CLOMR for Cotton Lane Bridge (River Research & Design)

The purposes of the 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. Data from the Stantec / Flood Control District of Maricopa County study have been incorporated to insure compatibility between the two studies. The two studies were closely coordinated by the Flood Control District. The final HEC-RAS model being submitted with this report combines the data from both studies.

1.1 Study Area

The study area is approximately 5 miles long and extends from the Estrella Parkway Bridge on the east (upstream) to Airport Road on the west. The study area is located in the jurisdictions of the City of Goodyear, Town of Buckeye and Maricopa County. The area modeled in both

hydraulic and sediment transport models extends approximately from the Agua Fria River confluence downstream to the west of Airport Road. Figure 1 shows the project vicinity and Figure 2 shows the aerial photograph and the location of the Norte Vista, King Ranch and Lakin Properties which are the proponents of this LOMR with the Flood Control District of Maricopa County. The Buckeye breakout will be discussed in more detail later but is the area to the north of the Norte Vista parcel.

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

No project is being presented in this LOMR application. The ultimate 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 Cotton Lane Bridge. The improvements to the channel and banks as well as the bridge are not a part of this LOMR application.

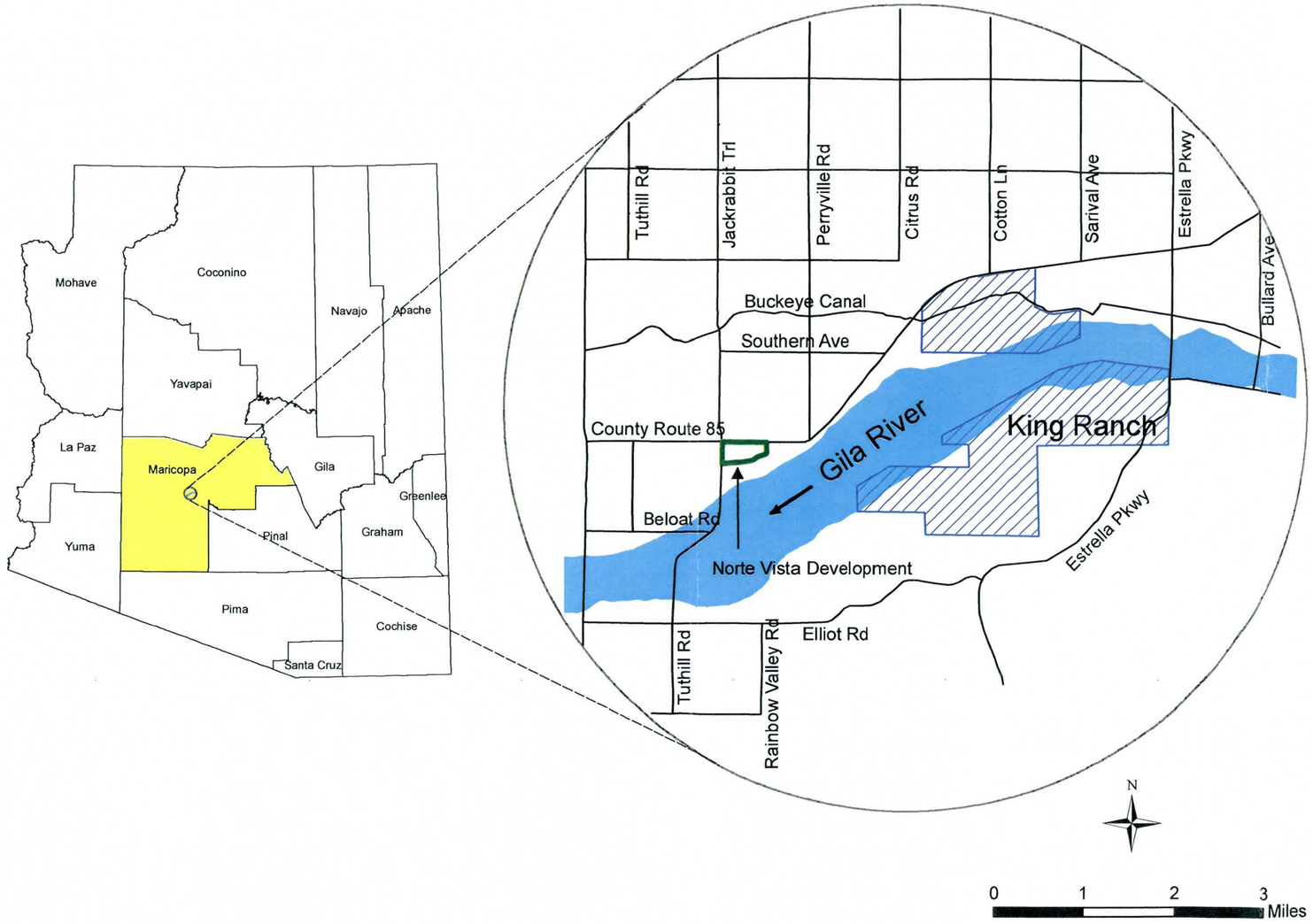


Figure 1. Project Vicinity Map

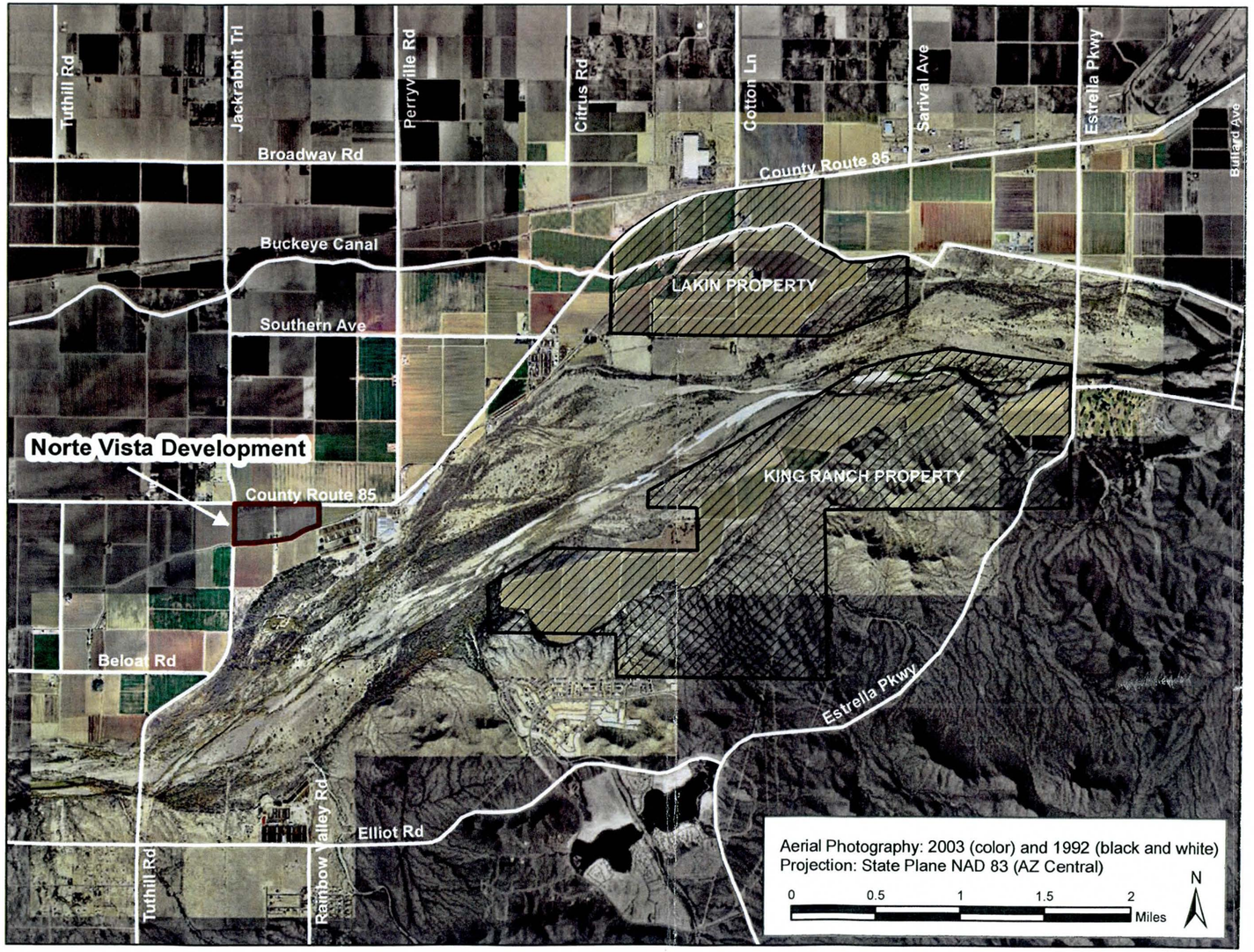


Figure 2. Area Map Showing Project Location and Surrounding Features. Lakin and King Ranch Properties are the subject of a separate CLOMR.

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, 2550G, 2510G, 2065H, 7070H	AZ	04013C	2550G	9/30/05

2. Flooding Source: Gila River

3. Project Name/Identifier: Vista Norte / 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: $0.00

☐ 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: Robert Wagoner	Company: SD Construction, LLC	
Mailing Address: 3340 N. 44th St Suite 3 Phoenix, AZ 85018	Daytime Telephone No.: 602 385-1545	Fax No.: 602 385-1524
	E-Mail Address: rw@sonterrapartners.com	
Signature of Requester (required): Robert R. Wagoner		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: Dave Ramirez, City Engineer		Telephone No.: (623) 882-7979
Community Name: City of Goodyear	Community Official's Signature (required):	Date:

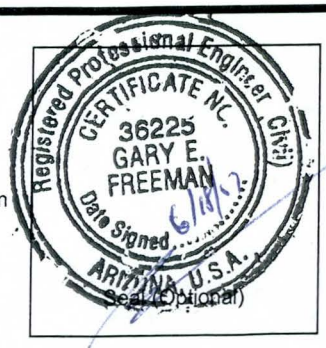
CERTIFICATION BY REGISTERED PROFESSIONAL ENGINEER AND/OR LAND SURVEYOR

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: 6/30/2009
Company Name: River Research & Design, Inc.	Telephone No.: 480-275-5077	Fax No.: 480-275-5870
Signature:		Date: 6/19/07

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



C. REVIEW FEE

Has the review fee for the appropriate request category been included? ☒ Yes Fee amount: $0.00

☐ 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: Troy Sepncer	Company: Spencer Management, LLC	
Mailing Address: 1186 So Fern Ct Gilbert, AZ 85296	Daytime Telephone No.: 480 202-8730	Fax No.:
	E-Mail Address: troys@cox.net	
Signature of Requester (required):		Date: 6/19/07

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: 6/30/2009
Company Name: River Research & Design, Inc.	Telephone No.: (480) 275-5077	Fax No.: (480) 275-5870
Signature:		Date: 6/19/2007

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

Form Name and (Number)	Required if ...
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☐ Riverine Structures Form (Form 3)	Channel is modified, addition/revision of bridge/culverts, addition/revision of levee/floodwall, addition/revision of dam
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☐ Coastal Structures Form (Form 5)	Addition/revision of coastal structure
☐ Alluvial Fan Flooding Form (Form 6)	Flood control measures on alluvial fans

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 Airport Rd	187.15	869.48	869.37
Upstream Limit	Gila River near Bullard Ave	195.09	912.92	912.57

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: reach2u	Floodway File Name: reach2u
Corrected Effective Model*	Natural File Name: reach2EfC	Floodway File Name:
Existing or Pre-Project Conditions Model	Natural File Name: ElRioR	Floodway File Name: ElRioR
Revised or Post-Project Conditions Model	Natural File Name:	Floodway File Name:
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.

3. Surveying and Mapping Information

Topography for the project area was obtained from a number of previous studies as well as new topography obtained for this study and others. New topography was obtained for the river channel from just upstream of Estrella Parkway Bridge to approximately the Airport Road Alignment (one mile west of Jackrabbit Trail and 0.75 miles west of the Tuthill Bridge). 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. The western channel and floodplain topography was obtained by the Flood Control District of the floodplain in the area of the Norte Vista property. This additional mapping is identified in Figure 3 as the "2006 El Rio Extension Mapping".

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. Other surveys to check the data are presented in the Stantec Report which is attached in Appendix A.

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.

4) Topography obtained by the Flood Control District of Maricopa County in 2006 for the active river channel that was not covered above in the vicinity of Tuthill Bridge and the floodplain north of the river.

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.

When the new CVL 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 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.

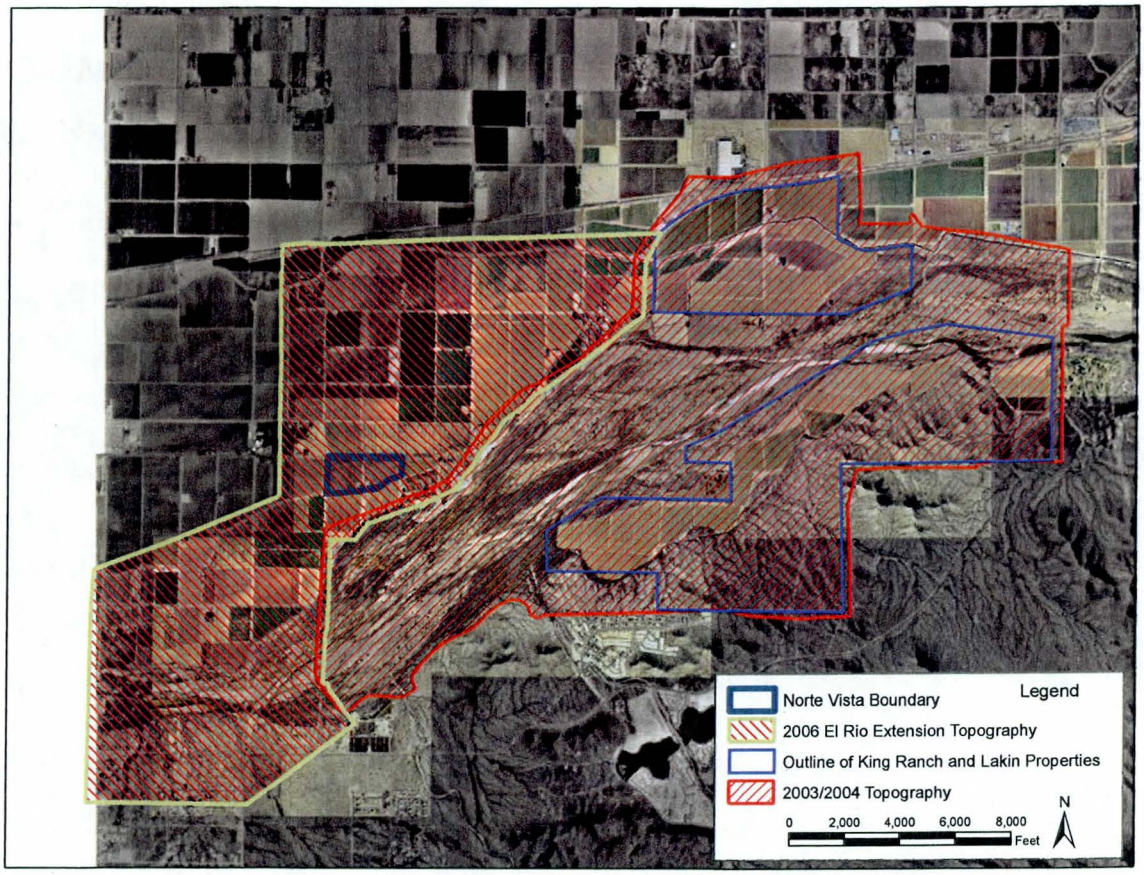

Figure 3. Updated Topography for King Ranch flown in 2003 and 2004 and for the El Rio Study in 2006. Areas outside the hatched area used the existing topography from the Baker FIS study (1999).

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, but not all, of the 6' to 8' difference in mapped channel 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.

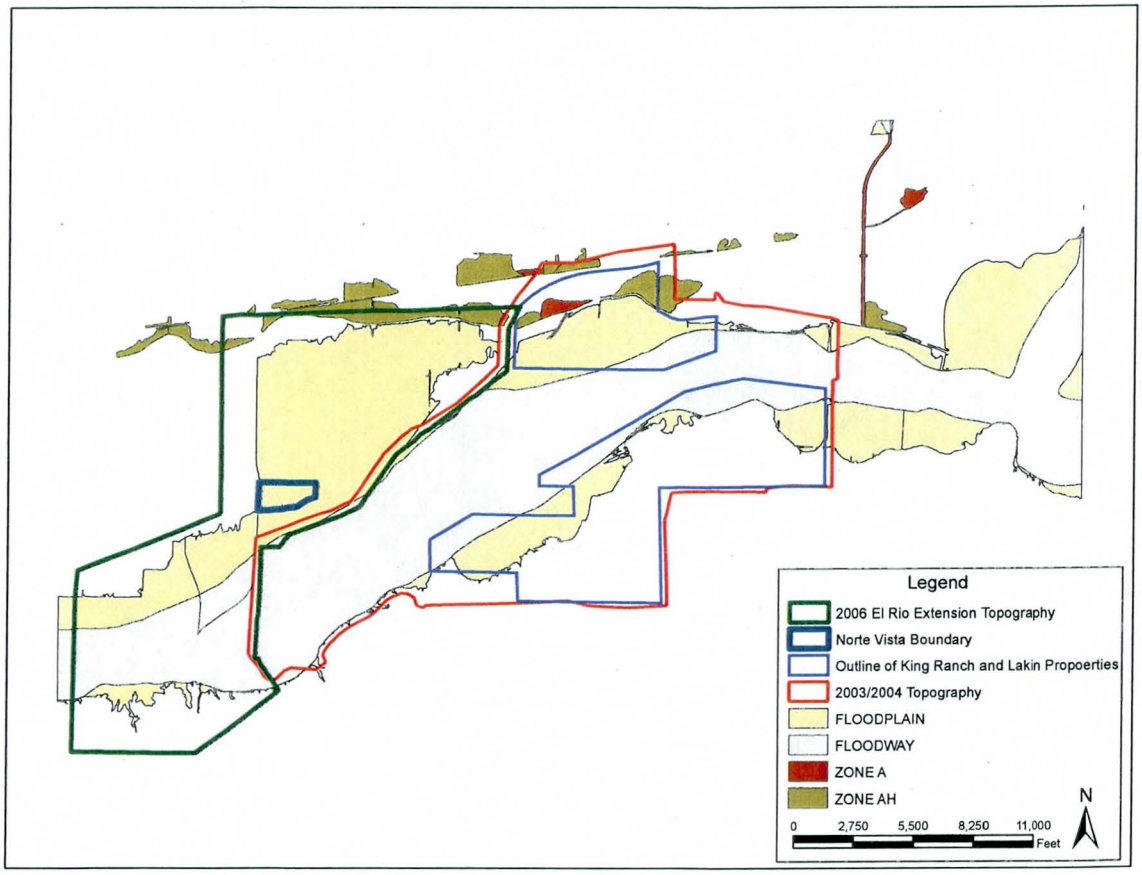

Figure 4. The Existing Floodplain, Floodway, and Limits of the 2003-2004 and 2006 New Topography.

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 2003 topography was compared to the February 1990 topography which was very similar. 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.

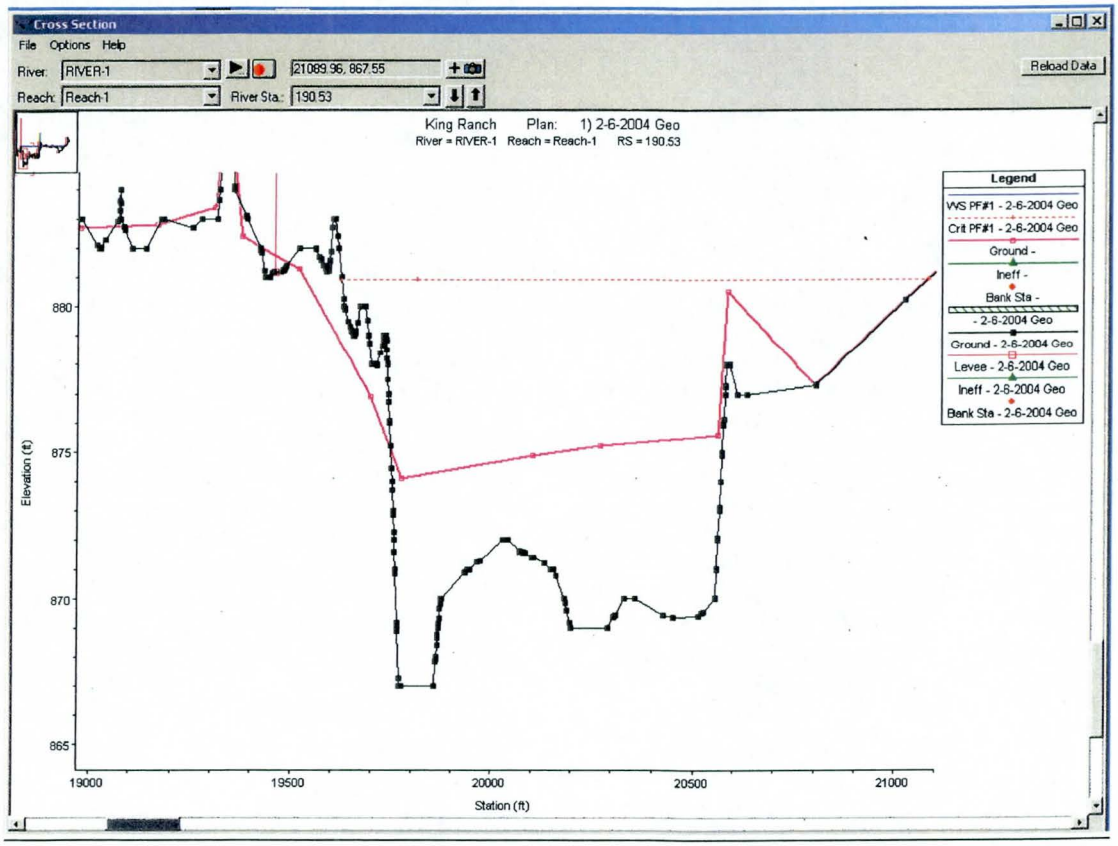

Figure 5. Typical Cross-section Detail for Main Channel. 2003 Topography shown in Black, FIS Topography shown in Magenta (with fewer points).

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.

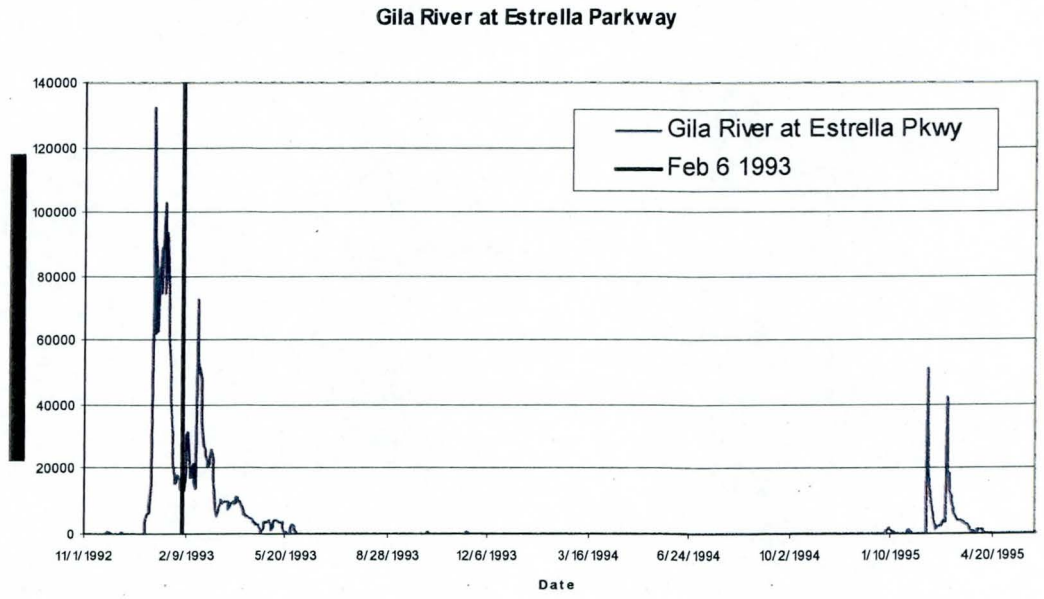

Figure 6. Daily average flows, Gila River at Estrella Parkway. Cause of Possible Changes in the Right Overbank

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.

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 the existing conditions for a reach from Estrella Parkway to the Airport Road alignment was performed. The effective conditions hydraulic analysis was rerun using the topographic information and U.S. Army Corps of Engineer's HEC-RAS, v. 3.1.3 model and data from the most recent FEMA FIS study. The results from the modeling indicated that the water surface elevations for the 100 year flood have changed significantly since the 1999 Baker study data was completed.

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 186.00. 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 187.06 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 model for the new existing conditions as well as the original FIS cross-sections.

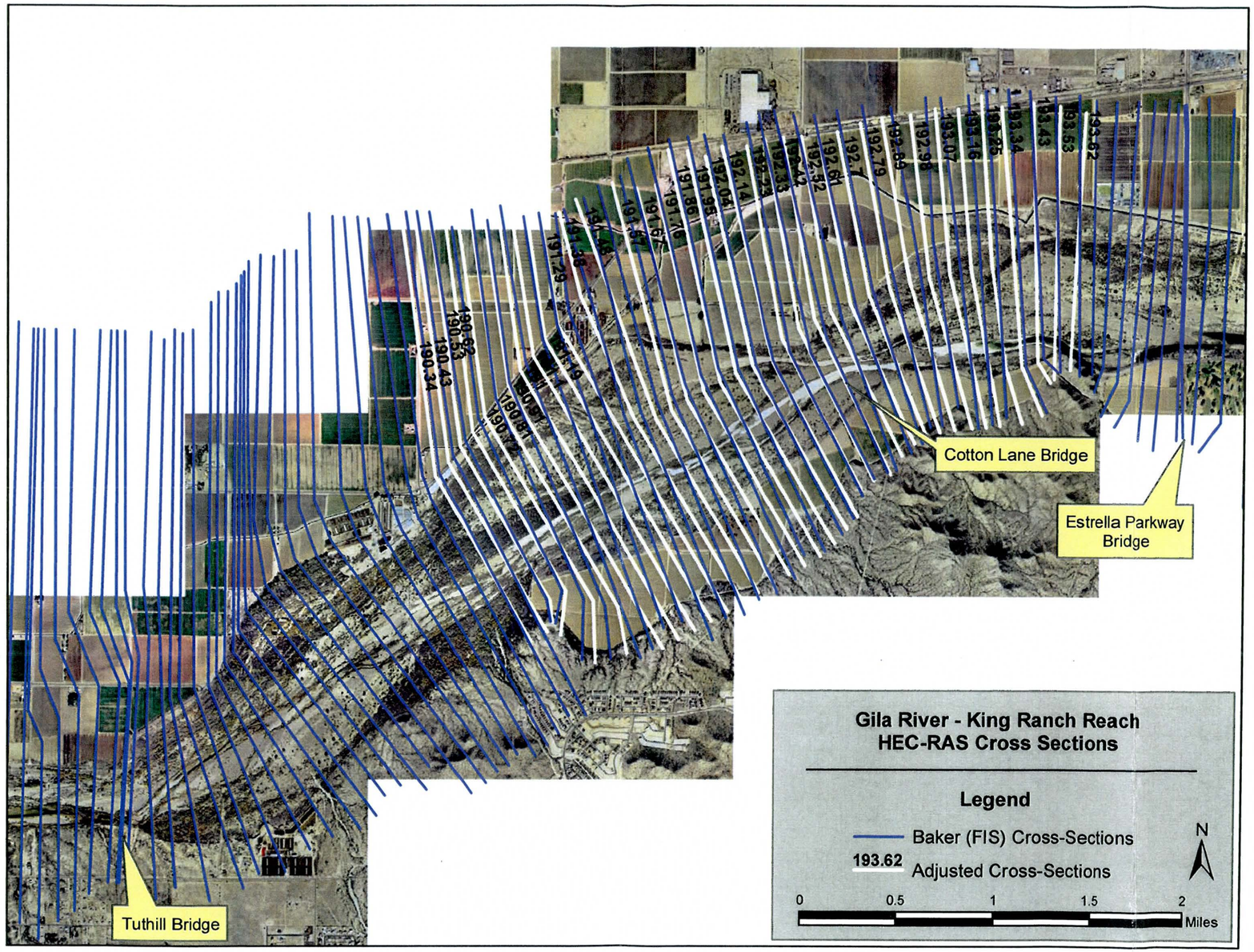

Figure 7. Original and Modified Cross Sections for the Study Reach. Original Cross Sections are shown in Blue and Modified Cross Section are shown in White.

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 11 maps plus the cover and index sheets. They are produced at a scale of 1" = 400' and include both the effective and existing floodplain and floodway lines for the project reach. The main sheets (3-11) have the effective and newly modeled existing floodplain and floodway shown.

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 photographs in Figure

9 and Figure 10 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 catalogs the photographs and describes the land use where the photographs were taken while the location waypoints are shown in Figures 9 and 10.

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.

Table 5. List of Photographs and Locations with Description of Land Use and Vegetation Density (Continued).

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 5 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

No future conditions analysis is included since this LOMR is based on a change in existing conditions rather than proposed modifications.

The n values used existing conditions vegetation were developed for the existing river conditions with approximately 14 years having passed since the 1993 flood event with no maintenance of vegetation. These values were also adjusted upwards and downwards 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 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 this floodplain redelineation study.

After extensive review it is felt that the n-values determined for the using the above procedures 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.

The only area of difference between the R2D and Stantec modeling efforts was an area just east of Tuthill Bridge in the northern edge of the channel. Stantec modeled the area as having an n value of 0.15 whereas R2D modeled the area with a lower n value. The higher Stantec value was used in the final model in an attempt to be conservative in the flood surface elevations.

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

	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 (ft)	-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	

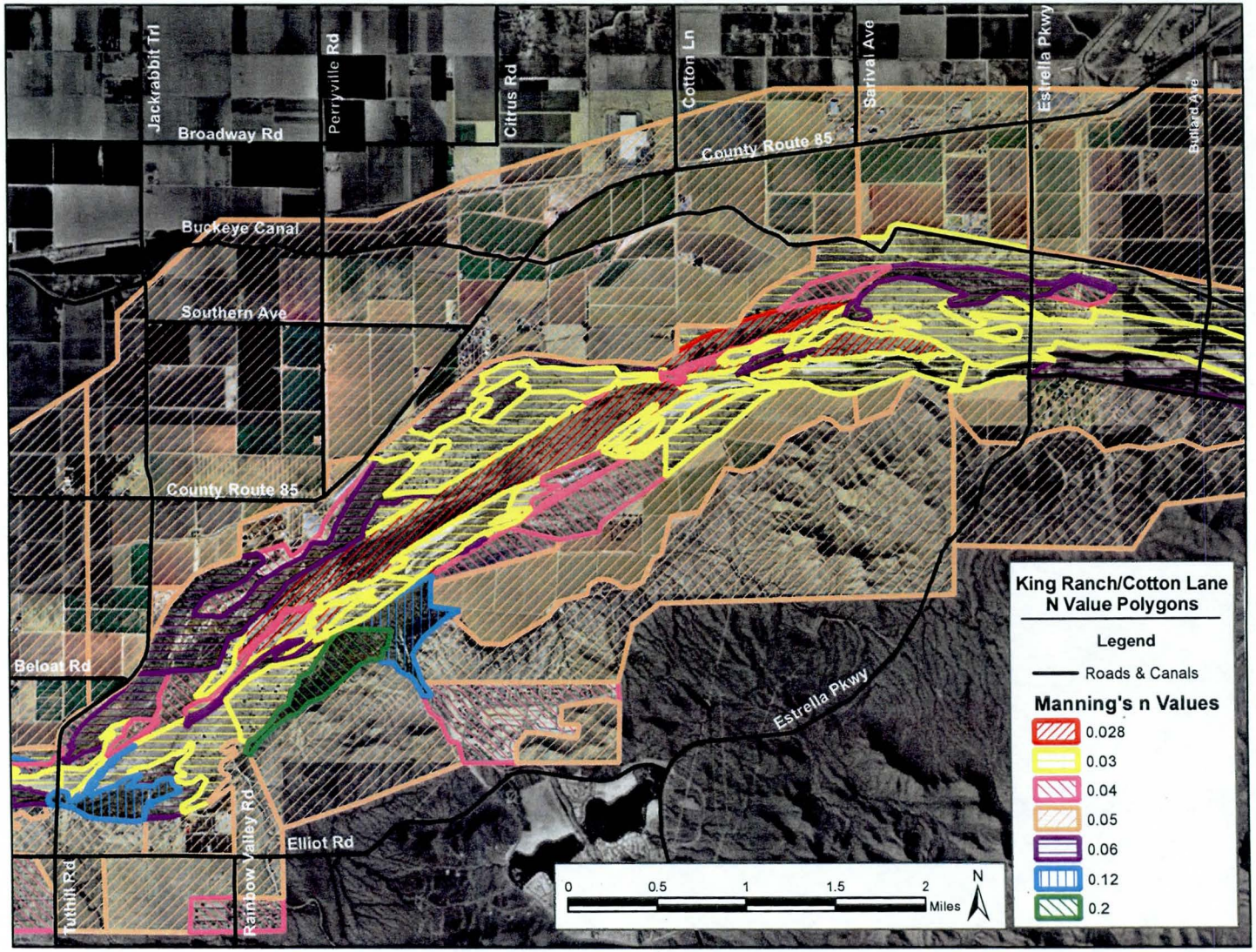

Figure 8. Overview of Selected Manning's n Values for the Cotton Lane Bridge Study Reach.

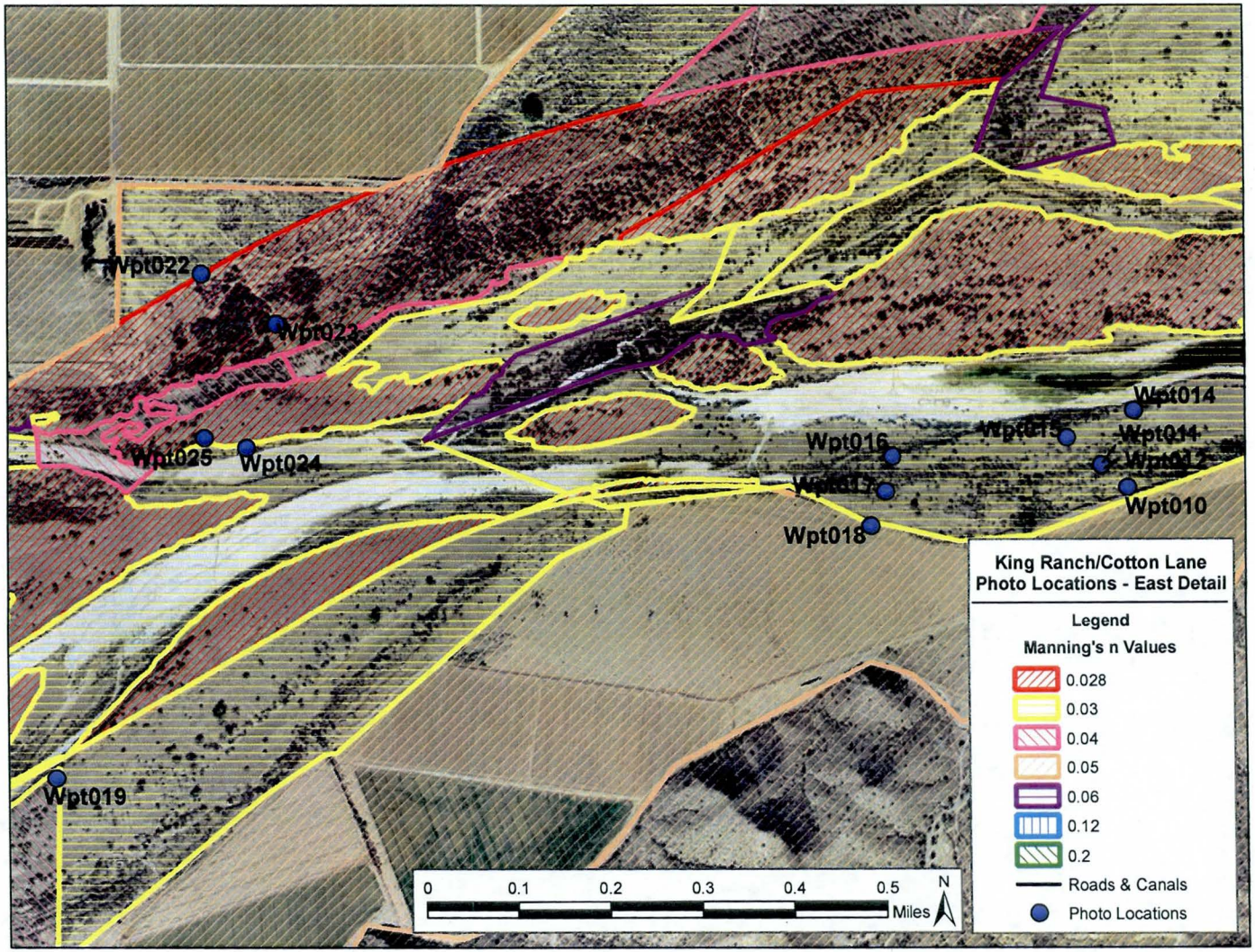

Figure 9. Cotton Lane Field Photo Locations and Associated n Values.

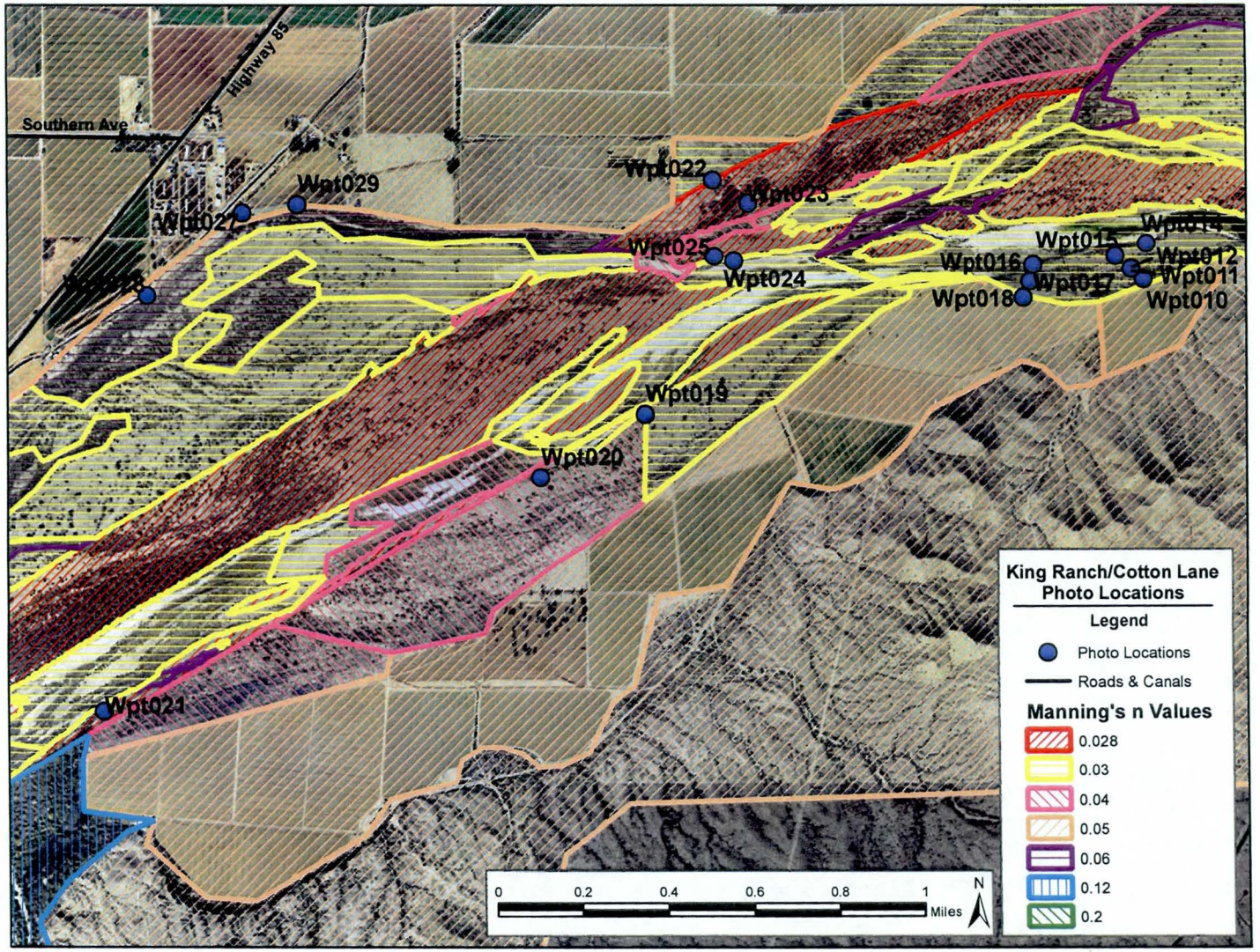

Figure 10. Cotton Lane Field Photo Locations for Central Portion of Study Area.

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. The Baker model has a reach near the Estrella Parkway bridge that used 0.3 for both the contraction and expansion coefficients and these were modified to be 0.1 and 0.3 respectively. The values are shown in the Appendix.

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 proposed for the King Ranch Development. 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.

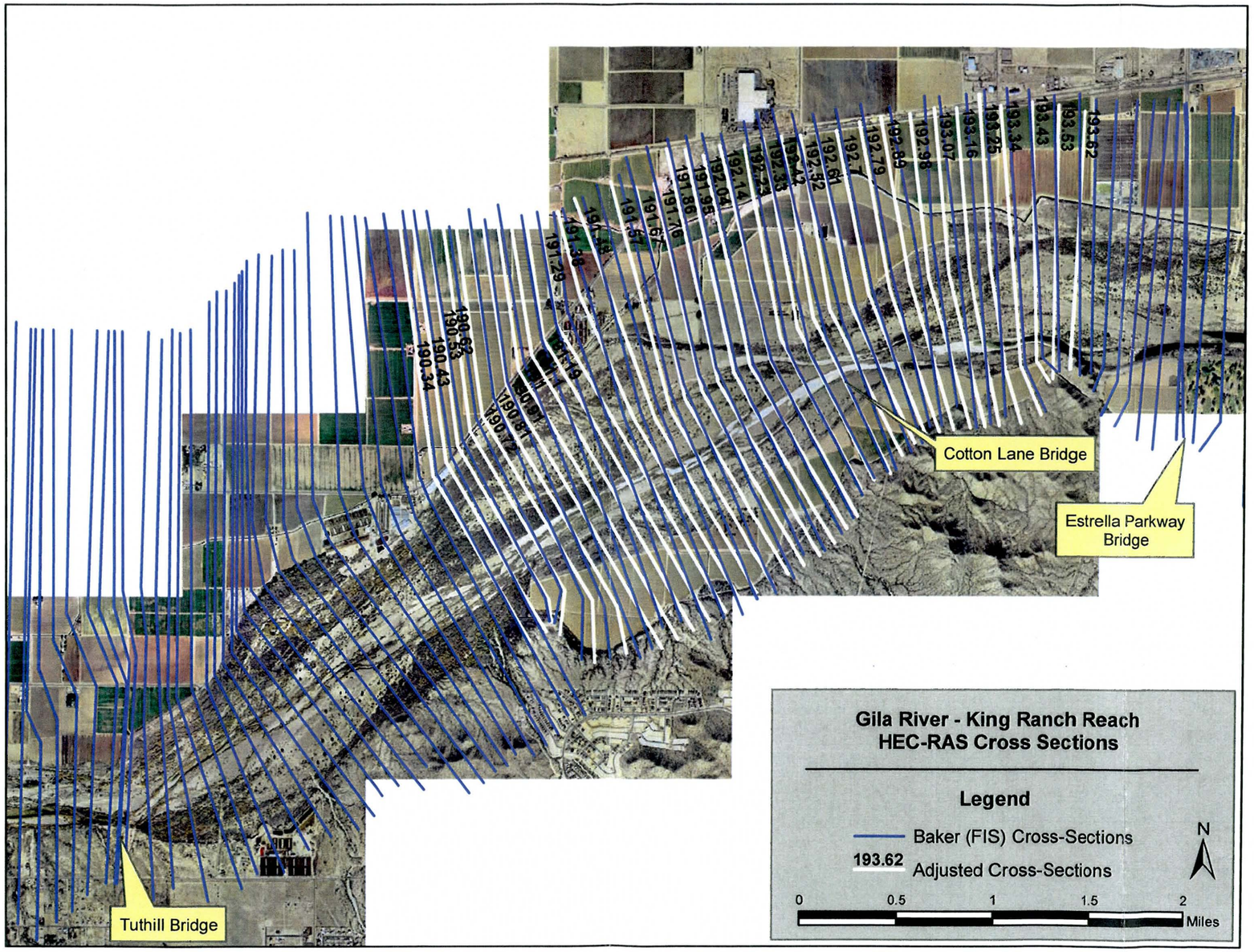

Figure 11. Cross-section cutlines used in HEC-RAS/HEC6-T models

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 but is a not 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 however the raised portion of the Tuthill-Jackrabbit roadway from the new floodplain boundary to the north end of the Tuthill bridge is above the 100 year water surface elevation and may function as a levee. This alternative was investigated and water was still below the ground elevation at the base of the canal just south side of the Norte Vista project. This indicates that the property is outside the 100 year floodplain for both conditions. If the road acts as a levee the WSE along the subject property is higher but is still contained by natural ground south of the subject property and canal as shown in Figures 12 and 13.

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. These areas are usually canals or other low areas cut off from the active floodplain by natural ground elevations.

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.

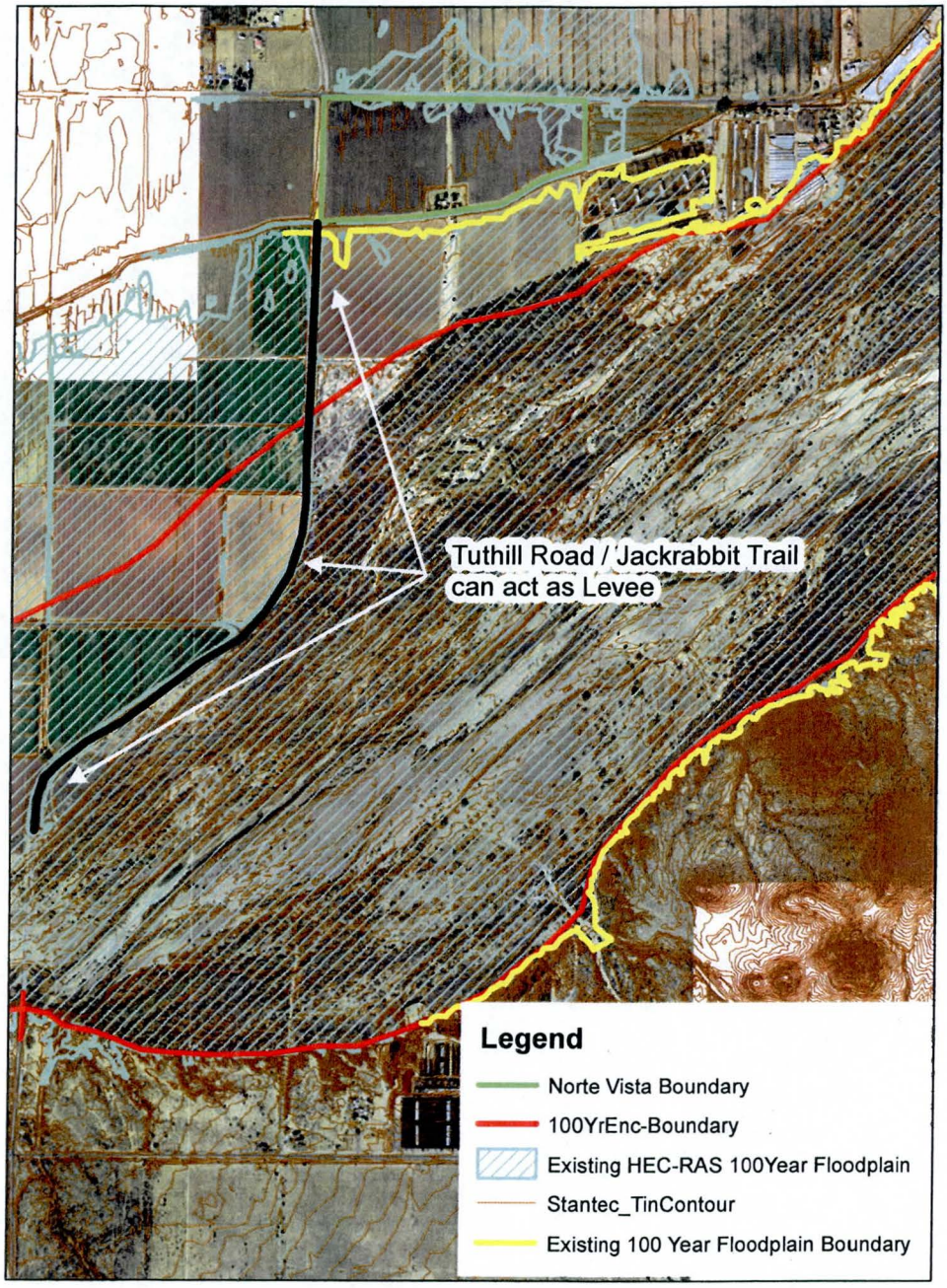

Figure 12. Norte Vista Area showing Existing Floodway, Floodplain and Portion of Jackrabbit Trail / Tuthill Road that can act as a Levee.

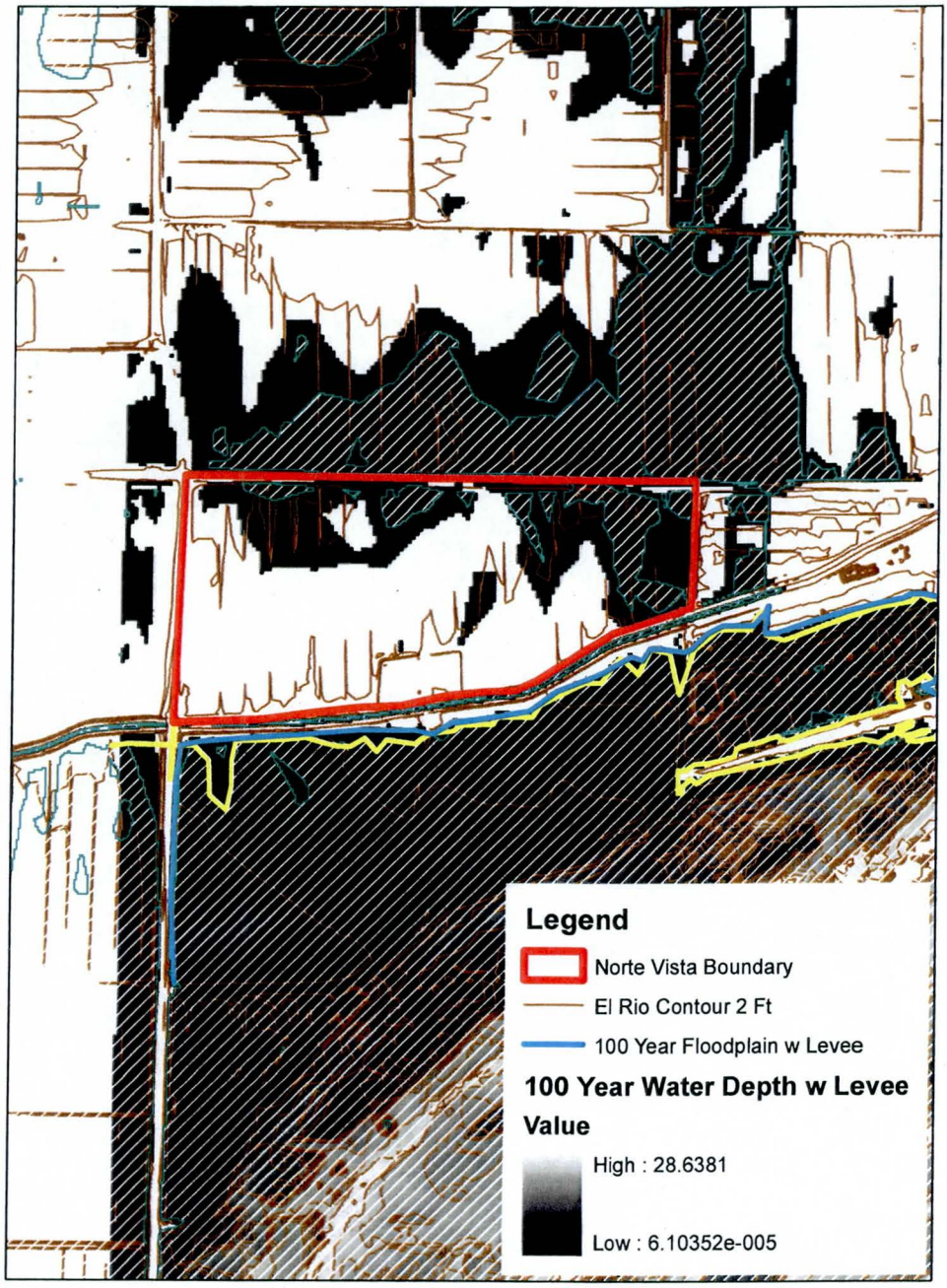

Figure 13. Comparison of Floodplain Boundaries with Jackrabbit Trail acting as levee.

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 14. The exiting conditions HEC-RAS model data is included in APPENDIX A-2 and the model is included on the enclosed CD.

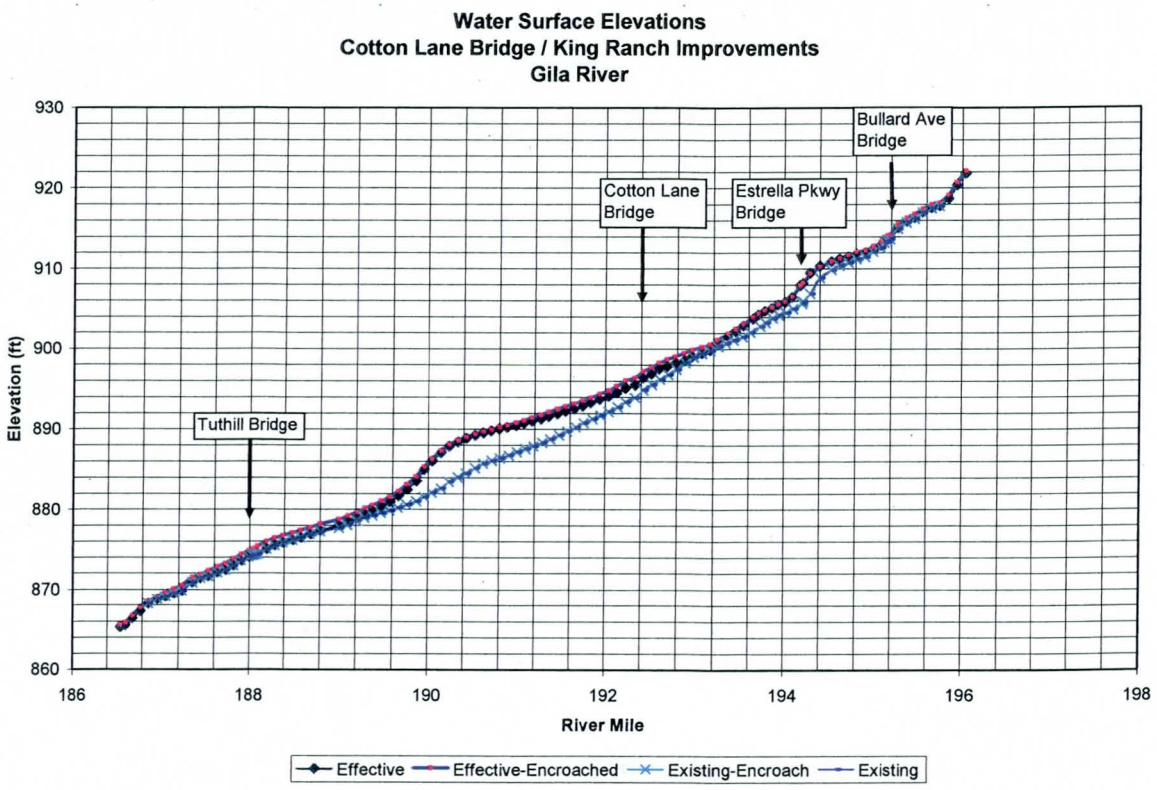

Figure 14. Floodway and Floodplain Elevations from Baker (1999) Study and Current Modeling

Figure 15 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.

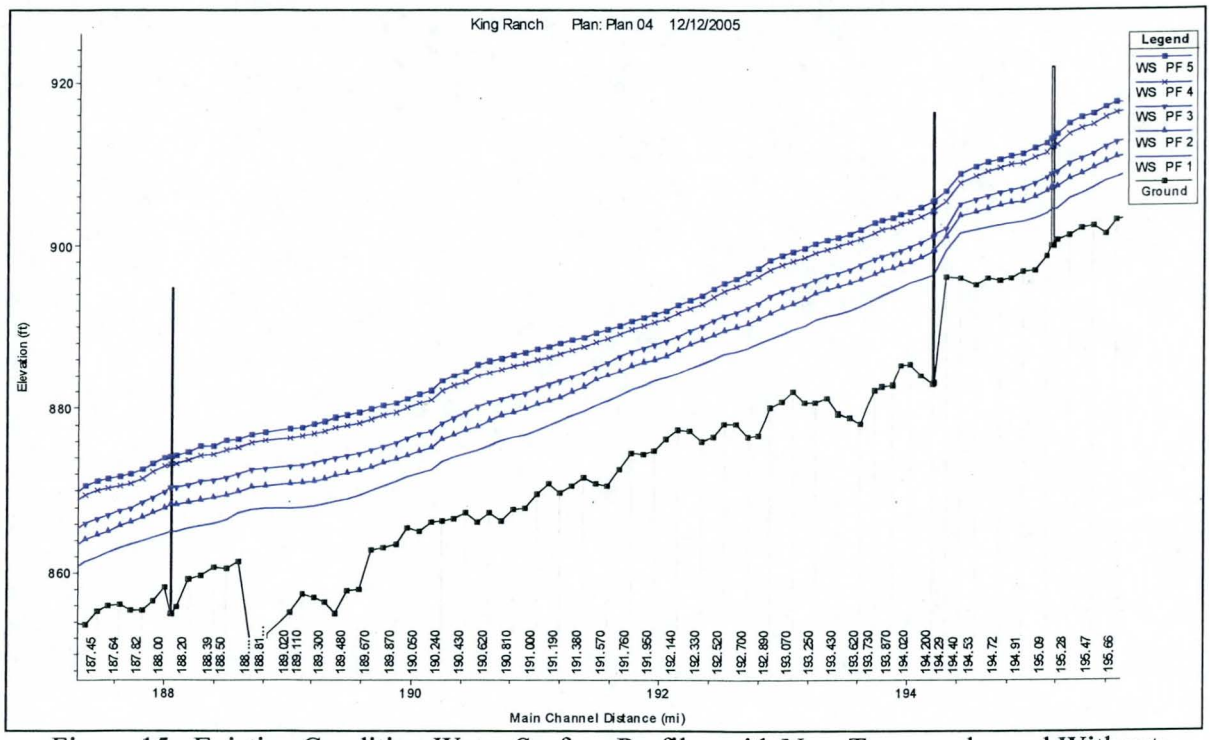

Figure 15. Existing Condition Water Surface Profiles with New Topography and Without Project.

The rapid change in thalweg elevation near the right side of Figure 15 (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 16. 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.

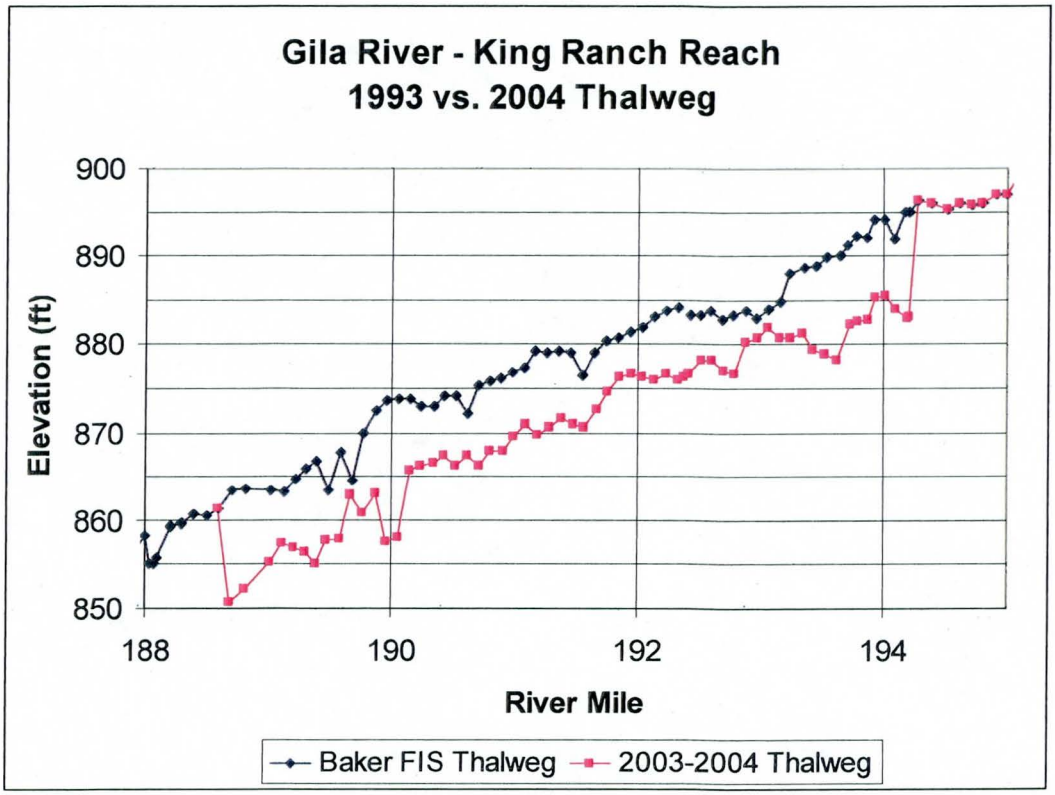

Figure 16. Difference in Thalweg Elevations between 1993 and 2003/2004 Surveys.

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 to 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

It can be noted that there is a large difference between the FIS and new 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 FIS topography was flown in 1993.

5.11.2 Verification of Results

The RAS results correspond closely to the 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 and New Existing Conditions Model June 21, 2007

Combined Stantec / R2D Existing Conditions Model

River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Delta	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude #
		(cfs)	(ft)	(ft)	WSE (ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	Channel
195.145		**Bullard Ave Bridge**										
TIE IN TO EFFECTIVE FLOODPLAIN												
195.13	Cor. Effect	227000	900	913.44		908.68	914.92	0.001418	9.84	23807.05	2248.43	0.49
195.13	Existing	227000	900	913.23	-0.21	908.68	914.76	0.001504	10.02	23345.57	2237.73	0.5
195.09	Cor. Effect	227000	898.8	912.85		909.24	914.51	0.00184	10.48	23074.76	3848.86	0.54
195.09	Existing	227000	898.8	912.57	-0.28	909.24	914.32	0.002001	10.76	22299.35	3657.99	0.57
195	Cor. Effect	227000	897	912.41		908.48	913.56	0.001376	8.86	27948.24	4577.61	0.47
195	Existing	227000	897	912.05	-0.36	908.48	913.29	0.001539	9.18	26683.25	4365.95	0.49
194.91	Cor. Effect	227000	896.9	911.92		907.63	912.88	0.001205	8.06	30748.51	5021.53	0.43
194.91	Existing	227000	896.9	911.43	-0.49	907.63	912.52	0.001445	8.56	28689.01	4973.5	0.47
194.81	Cor. Effect	227000	896	911.71		905.84	912.34	0.000684	6.6	37515.93	5264.84	0.34
194.81	Existing	227000	896	911.16	-0.55	905.84	911.88	0.000817	7	35130.51	5165.74	0.37
194.72	Cor. Effect	227000	895.7	911.36		905.79	912	0.000753	6.62	36744.11	5001.37	0.35
194.72	Existing	227000	895.7	910.72	-0.64	905.79	911.46	0.000926	7.07	34241.34	4705.38	0.38
194.62	Cor. Effect	227000	896	911.07		905.58	911.62	0.000666	6.13	38687.76	5461.49	0.32
194.62	Existing	227000	896	910.34	-0.73	905.58	910.99	0.000859	6.67	35666.16	5278.02	0.36
194.53	Cor. Effect	227000	895.2	910.71		905.21	911.27	0.00071	6.2	38432.97	6387.64	0.33
194.53	Existing	227000	895.2	909.83	-0.88	905.21	910.53	0.000967	6.87	34572.3	5319.66	0.38
194.4	Cor. Effect	227000	896	910.1		904.77	910.78	0.000786	6.78	36073.54	6537.2	0.35
194.4	Existing	227000	896	908.85	-1.25	904.77	909.76	0.00122	7.83	30954.36	5834.81	0.43
194.29	Cor. Effect	227000	896.2	909.25		904.97	910.17	0.001178	7.83	30026.48	5947.63	0.43
194.29	Existing	227000	896.2	906.81	-2.44	904.97	908.44	0.002932	10.41	22624.69	5080.08	0.65
194.21	Cor. Effect	227000	895	908.09		903.83	909.47	0.00154	9.43	24065.17	2139.48	0.5
194.21	Existing	227000	883.1	905.84	-2.25	902.06	907.36	0.001658	9.89	22970.87	2979.75	0.53
194.205		**Estrella Parkway Bridge**										
194.18	Cor. Effect	227000	895	907.9		903.83	909.33	0.00163	9.6	23651.1	2137.99	0.51
194.2	Existing	227000	882.97	905.54	-2.36	901.99	907.12	0.001784	10.1	22475.03	2480.1	0.55
194.09	Cor. Effect	227000	891.9	906.48		904.28	908.19	0.002976	10.48	21660.59	5496.29	0.64
194.1	Existing	227000	883.87	904.89	-1.59	901.14	906.2	0.001547	9.2	24796.13	4390.06	0.51
194.01	Cor. Effect	227000	894.1	905.82		902.59	906.93	0.001899	8.45	26850.71	5422.52	0.5
194.02	Existing	227000	885.49	904.35	-1.47	900.33	905.46	0.00138	8.45	26871.63	4253.57	0.47
193.93	Cor. Effect	227000	894.1	905.53		901.12	906.28	0.001111	6.96	32682.98	4960.39	0.4
193.94	Existing	227000	885.38	904.03	-1.5	899.39	904.93	0.001122	7.65	29970.23	4683.23	0.42
193.86	Cor. Effect	227000	892	905.11		900.74	905.85	0.001114	6.93	32753.66	4575.13	0.4
193.87	Existing	227000	882.8	903.69	-1.42	898.76	904.49	0.001007	7.26	32262.01	4427.13	0.39
193.78	Cor. Effect	227000	892.2	904.75		899.63	905.37	0.00097	6.33	35874.07	4101.57	0.35
193.79	Existing	227000	882.55	903.27	-1.48	898.23	904.02	0.001117	7.03	33925.36	4083.98	0.38
193.71	Cor. Effect	227000	891.3	904.3		899.46	905	0.001157	6.69	33916.43	3491.22	0.38
193.73	Existing	227000	882.18	902.83	-1.47	898.08	903.65	0.000975	7.39	32509.36	3422.12	0.4
193.65	Cor. Effect	227000	890	903.8		899.09	904.56	0.001228	7.01	32396.55	3334.06	0.39
193.62	Existing	227000	878.21	902.05	-1.75	897.98	903.03	0.001218	8.05	29855.05	3219.12	0.45
193.54	Cor. Effect	227000	889.8	902.93		898.88	903.82	0.001382	7.6	29965.48	3343.41	0.44
193.53	Existing	227000	878.96	901.51	-1.42	897.32	902.43	0.001137	7.82	30702.08	3344.27	0.43
193.45	Cor. Effect	227000	888.9	902.25		898.15	903.1	0.00162	7.43	30532.05	3530.86	0.43
193.43	Existing	227000	879.37	901.1	-1.15	896.46	901.89	0.000967	7.19	32988.75	3715.32	0.4
193.36	Cor. Effect	227000	888.7	901.61		897.59	902.41	0.001162	7.17	32169.06	3878.69	0.42
193.34	Existing	227000	881.18	900.75	-0.86	895.9	901.42	0.000841	6.64	34858.21	3883.49	0.37

Table 7. HEC-RAS Output for Effective and New Existing Conditions Model June 21, 2007

Combined Stantec / R2D Existing Conditions Model

River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Delta	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude #
		(cfs)	(ft)	(ft)	WSE (ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	Channel
193.24	Cor. Effect	227000	888	900.72		897.06	901.57	0.001645	7.39	31095.88	4150.34	0.46
193.25	Existing	227000	880.67	900.34	-0.38	895.48	900.97	0.001037	6.42	35888.74	4130.9	0.37
193.16	Cor. Effect	227000	884.8	899.83		896.56	900.78	0.002012	7.81	29367.2	4179.14	0.5
193.16	Existing	227000	880.66	899.83	0	895.44	900.5	0.000916	6.67	34876.11	4280.55	0.4
193.07	Cor. Effect	227000	883.9	899.45		893.82	900.06	0.000903	6.25	36849.99	4364.17	0.36
193.07	Existing	227000	881.99	899.45	0	894.72	900.07	0.000809	6.41	36863.37	4504.31	0.37
192.97	Cor. Effect	227000	883	899.04		893.61	899.58	0.000806	5.98	38933.65	5020.35	0.33
192.98	Existing	227000	880.71	899.02	-0.02	894.32	899.66	0.000871	6.51	36831.25	4501.19	0.37
192.88	Cor. Effect	227000	883.7	898.53		893.47	899.15	0.000925	6.43	37040.51	5456.69	0.35
192.89	Existing	227000	880.09	898.37	-0.16	894.01	899.12	0.001351	7.08	35406.87	5079.01	0.4
192.78	Cor. Effect	227000	883.3	898.14		892.61	898.73	0.000708	6.41	38896.72	6211.9	0.34
192.79	Existing	227000	876.81	897.48	-0.66	893.64	898.36	0.001733	7.77	33982.21	5344.82	0.44
192.69	Cor. Effect	227000	882.7	897.8		892.37	898.38	0.000677	6.53	39839.13	6880.82	0.33
192.7	Existing	227000	876.64	896.65	-1.15	892.33	897.59	0.00135	8.15	34668.83	5676.24	0.43
192.6	Cor. Effect	227000	883.7	897.49		892.8	897.99	0.000799	6.06	40747.94	6443.18	0.32
192.61	Existing	227000	878.15	896.06	-1.43	891.72	896.98	0.001156	8.23	35074.86	5867.25	0.43
192.51	Cor. Effect	227000	883.3	896.86		893.05	897.54	0.000955	7.21	36499.05	7531.22	0.39
192.52	Existing	227000	878.23	895.44	-1.42	890.81	896.39	0.001143	8.26	33829.27	6069.9	0.42
192.42	Cor. Effect	227000	883.2	896.36		892.68	897.03	0.001202	7.18	36197.95	7133.54	0.4
192.42	Existing	227000	876.63	894.76	-1.6	891.45	895.76	0.001342	8.73	31983.89	5805.89	0.46
192.33	Cor. Effect	227000	884.2	895.51		892.7	896.37	0.001428	8.1	33196.96	6171.26	0.47
192.33	Existing	227000	876.06	893.82	-1.69	890.83	895.01	0.00162	9.25	30200.71	5967.72	0.5
192.23	Cor. Effect	227000	883.7	895.12		891.34	895.67	0.001029	6.25	38851.23	6812.14	0.36
192.23	Existing	227000	876.72	893.24	-1.88	889.65	894.18	0.001411	8.12	33685.09	5890.23	0.44
192.13	Cor. Effect	227000	883.1	894.53		891.11	895.04	0.001305	5.62	39743.45	7677.65	0.34
192.14	Existing	227000	875.94	892.61	-1.92	889.42	893.48	0.001356	7.83	35378.34	6572.73	0.44
192.04	Cor. Effect	227000	882	894.07		890.72	894.52	0.000824	5.59	42424.03	7766.74	0.34
192.04	Existing	227000	876.36	892.06	-2.01	888.54	892.82	0.001176	7.2	38409.08	6336.14	0.41
191.94	Cor. Effect	227000	881.4	893.7		889.79	894.09	0.000797	5.07	45584.1	7948.92	0.3
191.95	Existing	227000	874.98	891.55	-2.15	887.6	892.25	0.001012	6.8	40187.71	6282.49	0.39
191.84	Cor. Effect	227000	880.8	893.24			893.64	0.000911	5.26	45223.06	7847.64	0.32
191.86	Existing	227000	874.43	891.08	-2.16	886.73	891.74	0.000978	6.44	40953.98	6189.44	0.37
191.75	Cor. Effect	227000	880.4	892.86		888.67	893.19	0.000796	4.82	49970.53	8659.98	0.29
191.76	Existing	227000	874.62	890.6	-2.26	886.58	891.22	0.001009	6.2	43226.16	6578.67	0.36
191.65	Cor. Effect	227000	879.1	892.5		887.65	892.8	0.000606	4.57	53249	9077.19	0.27
191.67	Existing	227000	872.6	890.03	-2.47	886.43	890.69	0.001104	6.22	42056.9	6300.26	0.38
191.55	Cor. Effect	227000	876.5	892.22		887.42	892.5	0.000677	4.39	54705.82	9150.76	0.26
191.57	Existing	227000	870.63	889.55	-2.67	885.66	890.16	0.000936	5.7	45028.5	6269.06	0.35
191.46	Cor. Effect	227000	879	891.88		887.33	892.16	0.000657	4.34	53804.05	8798.2	0.27
191.48	Existing	227000	870.63	889.1	-2.78	885.67	889.63	0.001143	6.14	41109.4	6197.89	0.39
191.36	Cor. Effect	227000	879.2	891.53		887.22	891.8	0.000745	4.16	54771.66	9220.32	0.26
191.38	Existing	227000	871.69	888.63	-2.9	884.7	889.09	0.000958	5.61	44256.73	6622.2	0.34
191.27	Cor. Effect	227000	879	891.23		886.23	891.46	0.00057	3.81	59113.2	9572.63	0.23
191.29	Existing	227000	870.63	888.21	-3.02	883.78	888.62	0.000855	5.31	46012.75	6935.29	0.32
191.17	Cor. Effect	227000	879.3	890.94		885.71	891.18	0.000553	3.96	58001.98	9540.22	0.23
191.19	Existing	227000	869.78	887.79	-3.15	882.89	888.21	0.000795	5.35	45676.42	7262.12	0.31
191.08	Cor. Effect	227000	877.3	890.65		885.43	890.9	0.000536	4.07	57635	9711.45	0.23

Table 7. HEC-RAS Output for Effective and New Existing Conditions Model June 21, 2007

Combined Stantec / R2D Existing Conditions Model

River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Delta	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude #
		(cfs)	(ft)	(ft)	WSE (ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	Channel
191.1	Existing	227000	870.88	887.44	-3.21	882.08	887.85	0.000644	5.25	46420.29	7374.02	0.3
190.99	Cor. Effect	227000	876.8	890.4		884.28	890.66	0.000469	4.2	57790.23	7494.27	0.23
191	Existing	227000	869.64	887.05	-3.35	881.88	887.51	0.000704	5.51	44116.21	7043.55	0.31
190.89	Cor. Effect	227000	876.2	890.18		883.88	890.41	0.000487	4.04	58720.39	10378.21	0.22
190.91	Existing	227000	867.98	886.63	-3.55	881.54	887.13	0.000804	5.71	42809.86	7269.76	0.32
190.8	Cor. Effect	227000	875.8	889.97		883.73	890.2	0.000447	3.9	60413.32	11719.18	0.21
190.81	Existing	227000	867.86	886.27	-3.7	881.12	886.75	0.000694	5.67	43515.63	7494.5	0.32
190.71	Cor. Effect	227000	875.3	889.76		883.41	889.98	0.000456	3.86	61067.79	11919.51	0.21
190.72	Existing	227000	866.3	885.93	-3.83	880.48	886.4	0.00069	5.6	44744.39	7567.59	0.31
190.62	Cor. Effect	227000	872.2	889.5		882.54	889.75	0.000472	3.97	57867.1	11205.91	0.2
190.62	Existing	227000	867.37	885.56	-3.94	880.08	886.04	0.000766	5.65	44095.21	6953.89	0.31
190.53	Cor. Effect	227000	874.1	889.2		882.19	889.47	0.000687	4.22	54383.1	11111.69	0.22
190.53	Existing	227000	866.16	885.1	-4.1	879.61	885.61	0.000919	5.83	41990.17	5568.45	0.32
190.43	Cor. Effect	227000	874.2	888.82		881.51	889.12	0.00075	4.47	54839.95	11248.1	0.23
190.43	Existing	227000	867.42	884.58	-4.24	878.92	885.15	0.000918	6.14	41389.8	5370.74	0.33
190.34	Cor. Effect	227000	873	888.35		881.37	888.65	0.001233	4.39	52085.64	11643.56	0.24
190.34	Existing	227000	866.61	884.11	-4.24	878.36	884.67	0.000991	6.12	42309.69	5453.74	0.33
190.24	Cor. Effect	227000	873	887.82		880.86	888.13	0.000861	4.46	51604.94	11847.98	0.24
190.24	Existing	227000	866.29	883.58	-4.24	877.78	884.13	0.001122	6.12	42974.58	5162.69	0.33
190.15	Cor. Effect	227000	873.8	887.01		882.2	887.5	0.002	5.62	41355.2	12521.23	0.34
190.15	Existing	227000	865.74	882.72	-4.29	878.04	883.49	0.001463	7.16	36946.05	4887.6	0.4
190.05	Cor. Effect	227000	873.8	885.99		881.79	886.56	0.001708	6.12	37817.95	12160.34	0.38
190.05	Existing	227000	858.06	882.1	-3.89	875.75	882.72	0.00139	6.47	42321.89	5183.88	0.35
189.96	Cor. Effect	227000	873.7	884.93		881.25	885.56	0.00254	6.41	35768.85	11879.18	0.4
189.96	Existing	227000	857.56	881.46	-3.47	875.66	882.06	0.00132	6.38	41646.34	5994.58	0.34
189.87	Cor. Effect	227000	872.5	883.54		880.41	884.24	0.002852	6.75	33882.41	11839.84	0.44
189.87	Existing	227000	862.94	880.8	-2.74	874.83	881.37	0.00151	6.23	42478.85	5961.75	0.34
189.77	Cor. Effect	227000	869.9	882.48		878.25	882.95	0.001848	5.49	41247.31	12202.15	0.34
189.77	Existing	227000	860.75	880.3	-2.18	873.42	880.71	0.000913	5.3	49580.35	9166.13	0.28
189.68	Cor. Effect	227000	864.6	881.65		877.27	882.1	0.001501	5.42	42378.98	12293.09	0.33
189.67	Existing	227000	862.77	879.81	-1.84	873.14	880.24	0.000896	5.4	48887.17	9148.01	0.28
189.58	Cor. Effect	227000	867.7	880.91		876.36	881.36	0.001514	5.53	42682.8	11905.5	0.34
189.58	Existing	227000	857.92	879.34	-1.57	872.76	879.76	0.001003	5.37	49366.23	9112.92	0.28
189.49	Cor. Effect	227000	863.4	880.32		875.29	880.7	0.001081	5.1	47016.49	10728.38	0.31
189.48	Existing	227000	857.85	878.93	-1.39	871.94	879.31	0.000783	5.11	50748.71	9789.47	0.26
189.39	Cor. Effect	227000	866.8	879.75		874.86	880.15	0.001145	5.29	46038.21	10705.65	0.32
189.39	Existing	227000	855.02	878.58	-1.17	871.32	878.95	0.000637	5.02	52034	10236.19	0.26
189.31	Cor. Effect	227000	865.8	879.34		874.2	879.7	0.001026	5.02	48027.75	10326.3	0.3
189.3	Existing	227000	856.36	878.25	-1.09	871.53	878.63	0.000843	5.1	50633.75	10089.01	0.27
189.22	Cor. Effect	227000	864.7	878.92		874.04	879.26	0.001017	4.89	48879.11	9433.39	0.29
189.21	Existing	227000	856.97	877.83	-1.09	870.89	878.18	0.000972	4.86	50889.97	9761.26	0.26
189.12	Cor. Effect	227000	863.1	878.47		873.77	878.81	0.001015	4.97	49123.61	9037.2	0.3
189.11	Existing	227000	857.4	877.35	-1.12	869.73	877.68	0.000955	4.62	52170.65	9434.89	0.25
189.02	Cor. Effect	227000	863.4	878		873.67	878.37	0.000958	5.15	49359.91	9413.65	0.32
189.02	Existing	227000	855.16	876.85	-1.15	868.98	877.19	0.000957	4.73	52162.66	9211.87	0.26
188.81	Cor. Effect	227000	863.5	877.31		871.67	877.6	0.000604	4.41	53904.1	8506.25	0.25
188.81	Existing	227000	852.25	876.09	-1.22	866.91	876.42	0.00053	4.64	52309.21	8415.25	0.23

Table 7. HEC-RAS Output for Effective and New Existing Conditions Model June 21, 2007

Combined Stantec / R2D Existing Conditions Model

River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Delta	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude #
		(cfs)	(ft)	(ft)	WSE (ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	Channel
188.7	Cor. Effect	227000	863.3	876.86		872.22	877.19	0.000909	4.79	49805.93	8743.5	0.28
188.69	Existing	227000	850.62	875.64	-1.22	868.19	876.02	0.000858	5.01	47656.55	8476.33	0.26
188.59	Cor. Effect	227000	861.4	876.44		871.17	876.76	0.000765	4.67	50873.55	7530.72	0.27
188.59	Existing	227000	852.76	875.22	-1.22	868.14	875.55	0.000835	4.74	50356.12	9087.3	0.26
188.5	Cor. Effect	227000	860.5	876.12		870.33	876.4	0.00069	4.44	53393.4	7597.74	0.24
188.5	Existing	227000	852.73	874.87	-1.25	867.21	875.19	0.00066	4.65	52281.7	9430.57	0.24
188.39	Cor. Effect	227000	860.7	875.81		868.98	876.11	0.000487	4.58	54047.77	7353.55	0.24
188.39	Existing	227000	852.73	874.5	-1.31	866.13	874.83	0.000632	4.77	51428.02	8574.63	0.24
188.29	Cor. Effect	227000	859.6	875.45		869.32	875.86	0.000472	5.41	47908.43	7326.69	0.28
188.29	Existing	227000	852.62	874.12	-1.33	866.08	874.49	0.000678	5.02	49349.5	7572.93	0.25
188.2	Cor. Effect	227000	859.3	875		868.81	875.54	0.000962	6.21	41666.16	7148.81	0.31
188.2	Existing	227000	852.5	873.79	-1.21	864.43	874.24	0.000384	5.54	46344.16	6831.61	0.25
188.1	Cor. Effect	227000	855.8	874.36		868.84	875.07	0.000862	7.28	37966.03	6595.49	0.36
188.1	Existing	227000	850.29	873.35	-1.01	864.63	873.92	0.001042	6.39	40505.92	6471.46	0.28
188.07	Cor. Effect	227000	855	874.27		866.15	874.91	0.000558	6.89	39209.3	5733.8	0.31
188.07	Existing	227000	849.32	872.98	-1.29	864.69	873.74	0.000644	7.34	35837.88	5491.49	0.32
188.055		**Tuthill Road Bridge**										
188.04	Cor. Effect	227000	855	874.21		866.15	874.88	0.000577	6.99	38249.08	5733.34	0.31
188.04	Existing	227000	849.15	872.95	-1.26	864.98	873.71	0.000686	7.43	37619.47	5982.72	0.33
188	Cor. Effect	227000	858.3	874.03		871.1	874.7	0.000857	7.29	37571.52	7288.17	0.39
188	Existing	227000	848.62	872.83	-1.2	866.6	873.5	0.000683	7.14	38490.64	6770	0.35
187.91	Cor. Effect	227000	856.5	873.54		870.77	874.24	0.00087	7.26	35901.3	5898.49	0.4
187.91	Existing	227000	848.62	872.48	-1.06	864.99	873.12	0.000748	6.79	38024.27	5679.51	0.35
187.82	Cor. Effect	227000	855.4	872.91		870.06	873.76	0.001124	7.77	32039.06	5367.22	0.46
187.82	Existing	227000	848.62	871.94	-0.97	864.07	872.55	0.002189	6.19	36262.91	5264.31	0.34
187.73	Cor. Effect	227000	855.4	872.38		869.18	873.23	0.001124	7.74	32553.39	7780.66	0.45
187.73	Existing	227000	848.62	871.3	-1.08	863.24	871.87	0.001018	6.17	37870.58	5318.3	0.33
187.64	Cor. Effect	227000	856.1	872.07		868.39	872.75	0.000847	6.99	36451.52	8098.67	0.38
187.64	Existing	227000	848.72	870.79	-1.28	864	871.47	0.000754	6.89	36026.82	4659.9	0.36
187.54	Cor. Effect	227000	855.9	871.57		867.67	872.34	0.000939	7.28	33186.02	8488.08	0.42
187.54	Existing	227000	849.28	870.51	-1.06	863.69	871.11	0.000716	6.4	37172.48	4371.62	0.34
187.45	Cor. Effect	227000	855.3	871.35		867	871.92	0.000722	6.45	38833.45	9340.2	0.36
187.45	Existing	227000	849.28	870.3	-1.05	863.05	870.78	0.00061	5.88	42067.25	5807.55	0.3
187.36	Cor. Effect	227000	853.7	870.83		866.53	871.53	0.000766	6.99	36029.66	9688.99	0.38
187.36	Existing	227000	847.91	869.92	-0.91	862.03	870.47	0.000613	6.12	40288.38	7304.78	0.31
187.24	Cor. Effect	227000	853.8	869.81		866.24	870.85	0.001547	8.48	30575.3	8205.17	0.47
187.24	Existing	227000	848.31	869.57	-0.24	861.17	870.07	0.000633	5.87	41963.38	7928.29	0.28
TIE IN TO EFFECTIVE FLOODPLAIN												
187.15	Cor. Effect	227000	853.2	869.48		864.95	870.16	0.000967	6.9	36063.86	8795.17	0.38
187.15	Existing	227000	846.94	869.37	-0.11	860.15	869.78	0.000475	5.33	46492.78	9771.91	0.26

6. Erosion and Sediment Transport

Since no changes are being proposed to this reach of the river in this LOMR, no sediment modeling was performed in support of this portion of the study.

7. Draft FIS Report Data

7.1 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 8.

Table 8. 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

7.2 Floodway Data

The encroached floodway surcharge data is shown in Table 9 along with the tie in cross sections and water surface elevations for both the floodway and floodplain.

Table 9. Floodway and Floodplain Water Surface Elevations and Encroachment Depths.

King Ranch / Cotton Lane Bridge CLOMR

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	Effective Model					Existing		
	River Sta	W.S. Elev (ft)	Profile Delta WSE (ft)	Delta WSE Exist-Eff (ft)		River Sta	Stantec W.S. Elev (ft)	FW-FP Profile Delta WSE (ft)
FP	195.09	912.92		-0.35	TIE IN	195.09	912.57	
FW	195.09	913.3	0.37	-0.34		195.09	912.96	0.38
FP	195	912.5		-0.45		195	912.05	
FW	195	912.75	0.25	-0.44		195	912.31	0.26
FP	194.91	912.04		-0.61		194.91	911.43	
FW	194.91	912.26	0.23	-0.55		194.91	911.71	0.28
FP	194.81	911.83		-0.67		194.81	911.16	
FW	194.81	912.05	0.22	-0.61		194.81	911.44	0.29
FP	194.72	911.49		-0.77		194.72	910.72	
FW	194.72	911.67	0.18	-0.71		194.72	910.96	0.25
FP	194.62	911.22		-0.88		194.62	910.34	
FW	194.62	911.28	0.06	-0.83		194.62	910.45	0.12
FP	194.53	910.88		-1.05		194.53	909.83	
FW	194.53	910.9	0.01	-0.97		194.53	909.93	0.11
FP	194.4	910.3		-1.45		194.4	908.85	
FW	194.4	910.25	-0.05	-1.32		194.4	908.93	0.11
FP	194.29	909.44		-2.63		194.29	906.81	
FW	194.29	909.38	-0.06	-2.44		194.29	906.94	0.18
FP	194.21	908.21		-2.37		194.21	905.84	
FW	194.21	908.23	0.02	-2.15		194.21	906.08	0.31
FP	194.195 BI	907.98		-2.43		194.205 BI	905.55	
FW	194.195 BI	908	0.02	-2.19		194.205 BI	905.81	0.26
		Estrella Parkway						
FP	194.195 BI	907.86		-2.41		194.205 BI	905.45	
FW	194.195 BI	907.88	0.02	-2.3		194.205 BI	905.58	0.12
FP	194.18	907.96		-2.42		194.2	905.54	
FW	194.18	907.98	0.02	-2.26		194.2	905.72	0.18
FP	194.09	906.48		-1.59		194.1	904.89	
FW	194.09	906.54	0.05	-1.41		194.1	905.13	0.24
FP	194.01	905.82		-1.47		194.02	904.35	
FW	194.01	905.9	0.08	-1.24		194.02	904.66	0.3
FP	193.93	905.53		-1.5		193.94	904.03	
FW	193.93	905.61	0.08	-1.25		193.94	904.36	0.33
FP	193.86	905.11		-1.42		193.87	903.69	
FW	193.86	905.21	0.1	-1.17		193.87	904.04	0.35
FP	193.78	904.75		-1.48		193.79	903.27	
FW	193.78	904.86	0.11	-1.24		193.79	903.62	0.35
FP	193.71	904.31		-1.48		193.73	902.83	
FW	193.71	904.44	0.13	-1.22		193.73	903.22	0.39
FP	193.65	903.8		-1.75		193.62	902.05	
FW	193.65	903.96	0.16	-1.48		193.62	902.48	0.43
FP	193.54	902.93		-1.42		193.53	901.51	
FW	193.54	903.14	0.22	-1.2		193.53	901.94	0.42
FP	193.45	902.25		-1.15		193.43	901.1	
FW	193.45	902.53	0.28	-0.93		193.43	901.6	0.49
FP	193.36	901.61		-0.86		193.34	900.75	
FW	193.36	901.95	0.33	-0.62		193.34	901.33	0.57
FP	193.24	900.72		-0.38		193.25	900.34	
FW	193.24	901.21	0.49	-0.26		193.25	900.95	0.61

Table 9. Floodway and Floodplain Water Surface Elevations and Encroachment Depths.

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	Effective Model				Existing		
	River Sta	W.S. Elev (ft)	Profile Delta WSE (ft)	Delta WSE Exist-Eff (ft)	River Sta	Stantec W.S. Elev (ft)	FW-FP Profile Delta WSE (ft)
FP	193.16	899.83		0	193.16	899.83	
FW	193.16	900.56	0.72	-0.02	193.16	900.54	0.7
FP	193.07	899.45		0	193.07	899.45	
FW	193.07	900.27	0.82	-0.03	193.07	900.24	0.78
FP	192.97	899.04		-0.02	192.98	899.02	
FW	192.97	899.92	0.88	-0.08	192.98	899.84	0.81
FP	192.88	898.53		-0.16	192.89	898.37	
FW	192.88	899.48	0.95	-0.2	192.89	899.28	0.89
FP	192.78	898.14		-0.66	192.79	897.48	
FW	192.78	899.03	0.9	-0.57	192.79	898.46	0.96
FP	192.69	897.8		-1.15	192.7	896.65	
FW	192.69	898.67	0.87	-1.01	192.7	897.66	1
FP	192.6	897.49		-1.43	192.61	896.06	
FW	192.6	898.24	0.75	-1.18	192.61	897.06	1
FP	192.51	896.86		-1.41	192.52	895.45	
FW	192.51	897.67	0.82	-1.22	192.52	896.45	1
FP	192.42	896.36		-1.59	192.42	894.77	
FW	192.42	897.21	0.85	-1.44	192.42	895.77	1
		Future Cotton Lane Bridge					
FP	192.33	895.51		-1.67	192.33	893.84	
FW	192.33	896.36	0.85	-1.52	192.33	894.84	1
FP	192.23	895.12		-1.85	192.23	893.27	
FW	192.23	896.01	0.89	-1.83	192.23	894.18	0.91
FP	192.13	894.53		-1.89	192.14	892.64	
FW	192.13	895.34	0.82	-1.96	192.14	893.38	0.73
FP	192.04	894.07		-1.96	192.04	892.11	
FW	192.04	894.81	0.74	-2.08	192.04	892.73	0.62
FP	191.94	893.7		-2.08	191.95	891.62	
FW	191.94	894.41	0.71	-2.21	191.95	892.2	0.59
FP	191.84	893.24		-2.09	191.86	891.15	
FW	191.84	893.93	0.69	-2.18	191.86	891.75	0.59
FP	191.75	892.86		-2.17	191.76	890.69	
FW	191.75	893.5	0.64	-2.32	191.76	891.18	0.49
FP	191.65	892.5		-2.34	191.67	890.16	
FW	191.65	893.14	0.64	-2.61	191.67	890.53	0.37
FP	191.55	892.22		-2.51	191.57	889.71	
FW	191.55	892.83	0.61	-2.84	191.57	889.99	0.26
FP	191.46	891.88		-2.78	191.48	889.1	
FW	191.46	892.5	0.61	-3.11	191.48	889.39	0.3
FP	191.36	891.53		-2.9	191.38	888.63	
FW	191.36	892.11	0.58	-3.2	191.38	888.91	0.27
FP	191.27	891.23		-3.02	191.29	888.21	
FW	191.27	891.78	0.55	-3.36	191.29	888.42	0.23
FP	191.17	890.94		-3.15	191.19	887.79	
FW	191.17	891.41	0.48	-3.43	191.19	887.98	0.2
FP	191.08	890.65		-3.21	191.1	887.44	
FW	191.08	891.05	0.39	-3.41	191.1	887.64	0.21
FP	190.99	890.4		-3.35	191	887.05	
FW	190.99	890.77	0.37	-3.5	191	887.27	0.23

Table 9. Floodway and Floodplain Water Surface Elevations and Encroachment Depths.

King Ranch / Cotton Lane Bridge CLOMR

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	Effective Model				Existing		
	River Sta	W.S. Elev (ft)	Profile Delta WSE (ft)	Delta WSE Exist-Eff (ft)	River Sta	Stantec W.S. Elev (ft)	FW-FP Profile Delta WSE (ft)
FP	190.89	890.18		-3.55	190.91	886.63	
FW	190.89	890.48	0.3	-3.61	190.91	886.87	0.25
FP	190.8	889.97		-3.7	190.81	886.27	
FW	190.8	890.2	0.23	-3.7	190.81	886.5	0.25
FP	190.71	889.76		-3.83	190.72	885.93	
FW	190.71	889.91	0.14	-3.77	190.72	886.14	0.23
FP	190.62	889.5		-3.94	190.62	885.56	
FW	190.62	889.66	0.15	-3.91	190.62	885.75	0.21
FP	190.53	889.2		-4.1	190.53	885.1	
FW	190.53	889.37	0.17	-4.1	190.53	885.27	0.19
FP	190.43	888.82		-4.24	190.43	884.58	
FW	190.43	889.01	0.19	-4.27	190.43	884.74	0.19
FP	190.34	888.35		-4.24	190.34	884.11	
FW	190.34	888.57	0.22	-4.32	190.34	884.25	0.18
FP	190.24	887.82		-4.24	190.24	883.58	
FW	190.24	888.07	0.24	-4.36	190.24	883.71	0.17
FP	190.15	887.02		-4.3	190.15	882.72	
FW	190.15	887.28	0.27	-4.4	190.15	882.88	0.21
FP	190.05	885.99		-3.89	190.05	882.1	
FW	190.05	886.27	0.28	-4.02	190.05	882.25	0.22
FP	189.96	884.93		-3.47	189.96	881.46	
FW	189.96	885.28	0.35	-3.65	189.96	881.63	0.3
FP	189.87	883.54		-2.74	189.87	880.8	
FW	189.87	884.09	0.55	-3.08	189.87	881.01	0.37
FP	189.77	882.48		-2.18	189.77	880.3	
FW	189.77	883.1	0.62	-2.6	189.77	880.5	0.41
FP	189.68	881.65		-1.84	189.67	879.81	
FW	189.68	882.27	0.61	-2.22	189.67	880.05	0.46
FP	189.58	880.91		-1.57	189.58	879.34	
FW	189.58	881.56	0.66	-1.96	189.58	879.6	0.49
FP	189.49	880.32		-1.39	189.48	878.93	
FW	189.49	881.02	0.7	-1.8	189.48	879.22	0.54
FP	189.39	879.75		-1.17	189.39	878.58	
FW	189.39	880.52	0.77	-1.62	189.39	878.9	0.58
FP	189.31	879.34		-1.09	189.3	878.25	
FW	189.31	880.13	0.79	-1.54	189.3	878.59	0.63
FP	189.22	878.92		-1.09	189.21	877.83	
FW	189.22	879.66	0.74	-1.45	189.21	878.21	0.67
FP	189.12	878.47		-1.12	189.11	877.35	
FW	189.12	879.17	0.71	-1.38	189.11	877.79	0.72
FP	189.02	878		-1.15	189.02	876.85	
FW	189.02	878.73	0.72	-1.36	189.02	877.37	0.78
FP	188.81	877.31		-1.22	188.81	876.09	
FW	188.81	878.12	0.8	-1.39	188.81	876.73	0.84
FP	188.7	876.86		-1.22	188.69	875.64	
FW	188.7	877.7	0.84	-1.34	188.69	876.36	0.88
FP	188.59	876.44		-1.22	188.59	875.22	
FW	188.59	877.33	0.89	-1.31	188.59	876.02	0.8

Table 9. Floodway and Floodplain Water Surface Elevations and Encroachment Depths.

King Ranch / Cotton Lane Bridge CLOMR

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	Effective Model				Existing		
	River Sta	W.S. Elev (ft)	Profile Delta WSE (ft)	Delta WSE Exist-Eff (ft)	River Sta	Stantec W.S. Elev (ft)	FW-FP Profile Delta WSE (ft)
FP	188.5	876.12		-1.25	188.5	874.87	
FW	188.5	877.02	0.9	-1.3	188.5	875.72	0.85
FP	188.39	875.81		-1.31	188.39	874.5	
FW	188.39	876.71	0.9	-1.31	188.39	875.4	0.9
FP	188.29	875.45		-1.33	188.29	874.12	
FW	188.29	876.37	0.92	-1.29	188.29	875.08	0.96
FP	188.2	875		-1.21	188.2	873.79	
FW	188.2	875.95	0.95	-1.16	188.2	874.79	1
FP	188.1	874.36		-1.01	188.1	873.35	
FW	188.1	875.36	1	-1.01	188.1	874.35	1
FP	188.07	874.27		-1.29	188.07	872.98	
FW	188.07	875.08	0.81	-1.16	188.07	873.92	0.94
FP	188.055	874.27		-1.3	188.055	872.97	
FW		875.01	0.74	-1.14		873.87	0.9
		Tuthill Bridge					
FP	188.055	874.22		-1.28	188.055	872.94	
FW		874.97	0.75	-1.2		873.77	0.83
FP	188.04	874.21		-1.26	188.04	872.95	
FW	188.04	875	0.79	-1.19	188.04	873.81	0.86
FP	188	874.03		-1.2	188	872.83	
FW	188	874.79	0.76	-1.1	188	873.69	0.86
FP	187.91	873.54		-1.06	187.91	872.48	
FW	187.91	874.32	0.78	-0.98	187.91	873.34	0.86
FP	187.82	872.91		-0.97	187.82	871.94	
FW	187.82	873.8	0.89	-1	187.82	872.8	0.86
FP	187.73	872.38		-1.08	187.73	871.3	
FW	187.73	873.21	0.83	-1.11	187.73	872.1	0.8
FP	187.64	872.07		-1.28	187.64	870.79	
FW	187.64	872.8	0.73	-1.23	187.64	871.57	0.78
FP	187.54	871.57		-1.06	187.54	870.51	
FW	187.54	872.29	0.72	-1.03	187.54	871.26	0.75
FP	187.45	871.35		-1.05	187.45	870.3	
FW	187.45	871.81	0.46	-0.87	187.45	870.94	0.64
FP	187.36	870.83		-0.91	187.36	869.92	
FW	187.36	871.42	0.59	-0.78	187.36	870.64	0.72
FP	187.24	869.81		-0.24	187.24	869.57	
FW	187.24	870.44	0.63	-0.22	187.24	870.22	0.65
FP	187.15	869.48		-0.11 TIE IN	187.15	869.37	
FW	187.15	870.04	0.56	-0.05	187.15	869.99	0.62

7.3 Annotated Flood Insurance Rate Maps

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

7.4 Flood Profiles

Flood Profiles are shown in Figure 17. Floodplain elevations on the work maps treat the Jackrabbit/Tuthill Road embankment as non-existent for floodplain and floodway elevations. The difference between the results treating the road as a levee and as non-existent do not impact the horizontal location floodplain lines more than a few dozen feet and while noticeable the line is still away from the base of the canal upstream of the road embankment along the Norte Vista property.

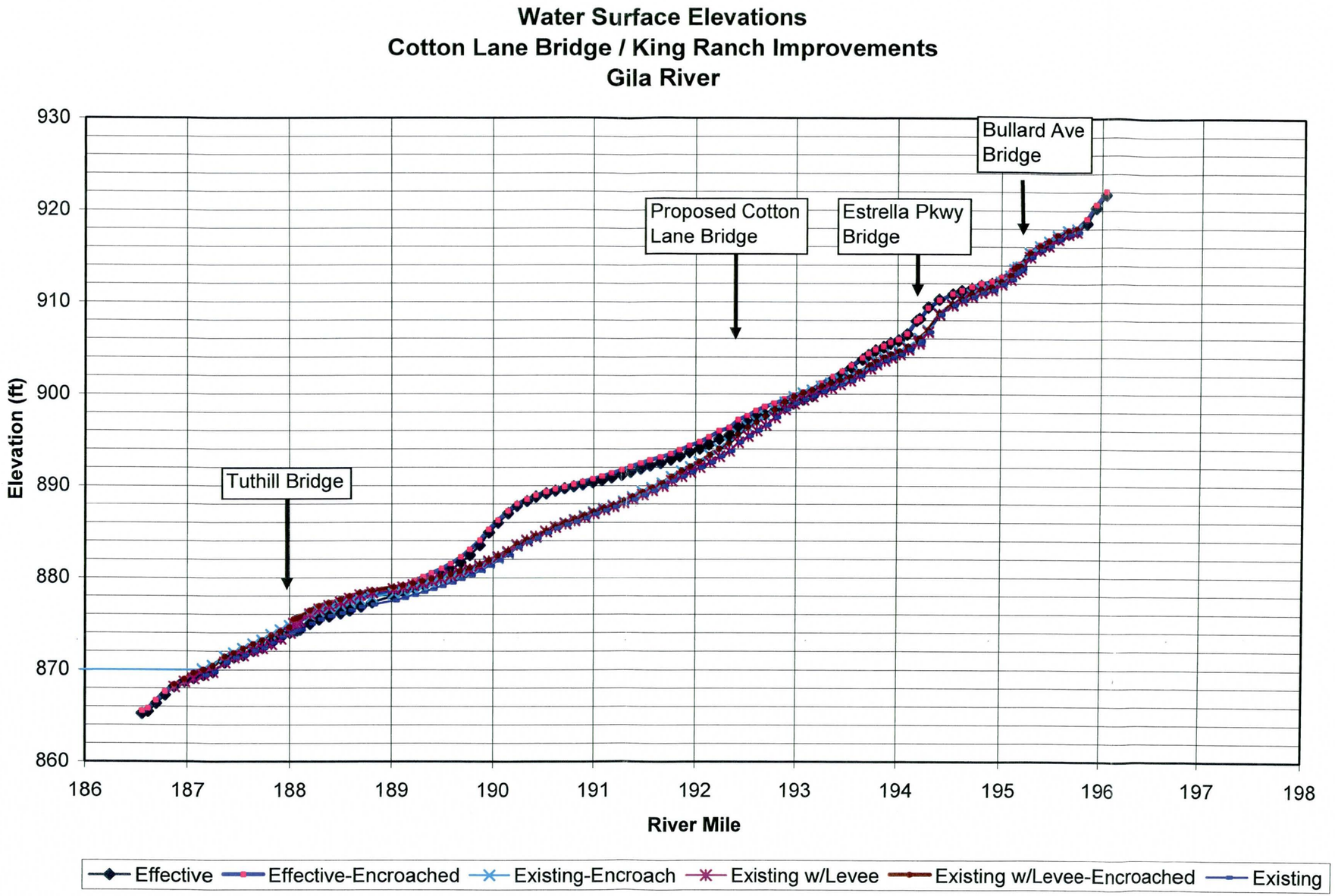

Figure 17. Floodplain and Floodway Profiles for Effective and Existing Conditions.

List of Appendices

A References

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A.2 Referenced Documents

B General Documentation and Correspondence

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B.2 Contact (telephone) Reports

B.3 Meeting Minutes or 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

References

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

2. Salt-Gila River Floodplain Delineation Restudy, (FDS), Michael Baker Jr., Inc. for Maricopa County Flood Control District-FCD, 1999

3. HEC-RAS, River Analysis System, v. 3.1.3. U.S. Army Corps of Engineers Hydrologic Engineering Center, Davis, CA, 2004.

4. PED Hydraulic Design of Tres Rios North Levee, Maricopa County, WEST Consultants for U.S. Army Corps of Engineeers, Los Angeles District, 2004.

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

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

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

8. Freeman, Rahmeyer, and Copeland, 2000. Determination of resistance due to shrubs and woody vegetation. Technical Report, ERDC/CHL TR-00-25, Engineering Research and Development Center, US Army Corps of Engineers, Vicksburg, Mississippi.

A.2 Data Referenced documents

ERDC/CHL TR-00-25

Coastal and Hydraulics Laboratory

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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

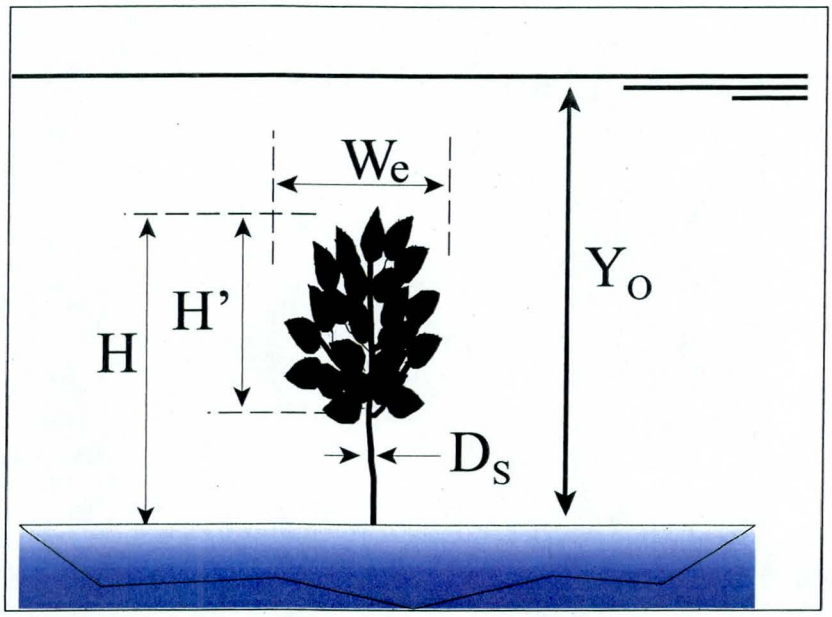

Figure 1. Plant dimension definitions for submerged plants

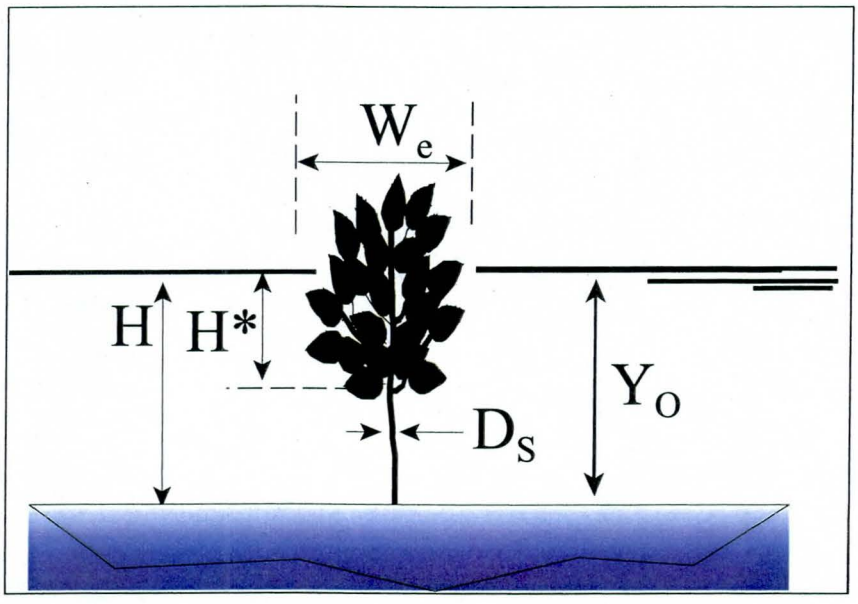

Figure 2. Plant dimension definitions for partially submerged plants

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:

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

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.

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

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.

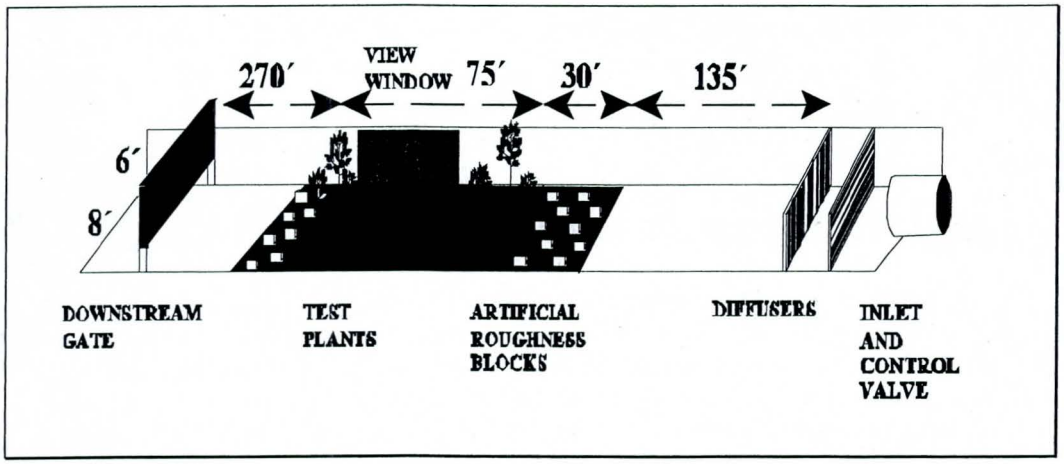

Figure 3. Layout of large flume for plant roughness experiments (To convert feet to meters, multiply by 0.3048)

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.)

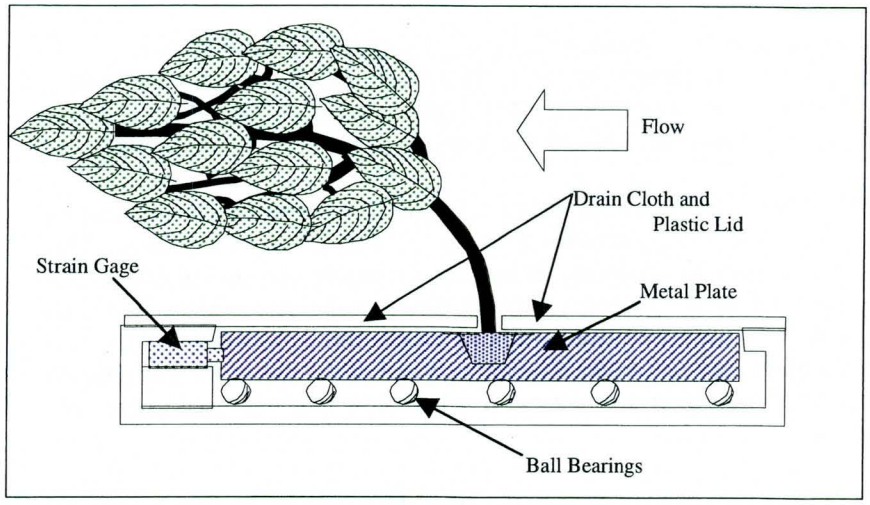

Figure 4. Experimental setup to measure plant drag

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

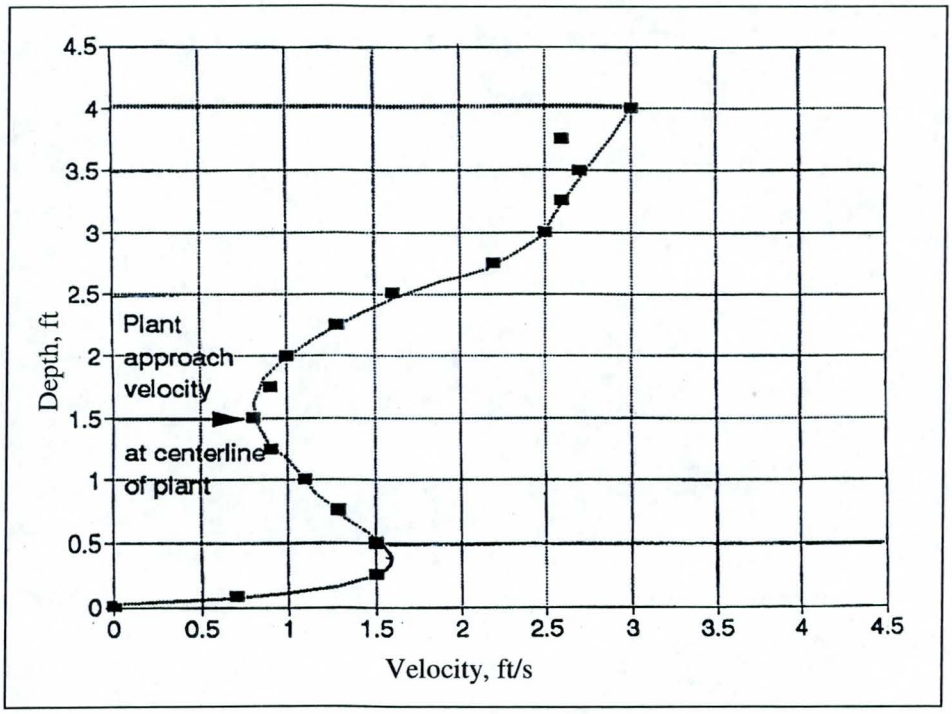

Figure 5. Example velocity profile for an experimental run with dogwoods (To convert feet to meters, multiply by 0.3048)

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.

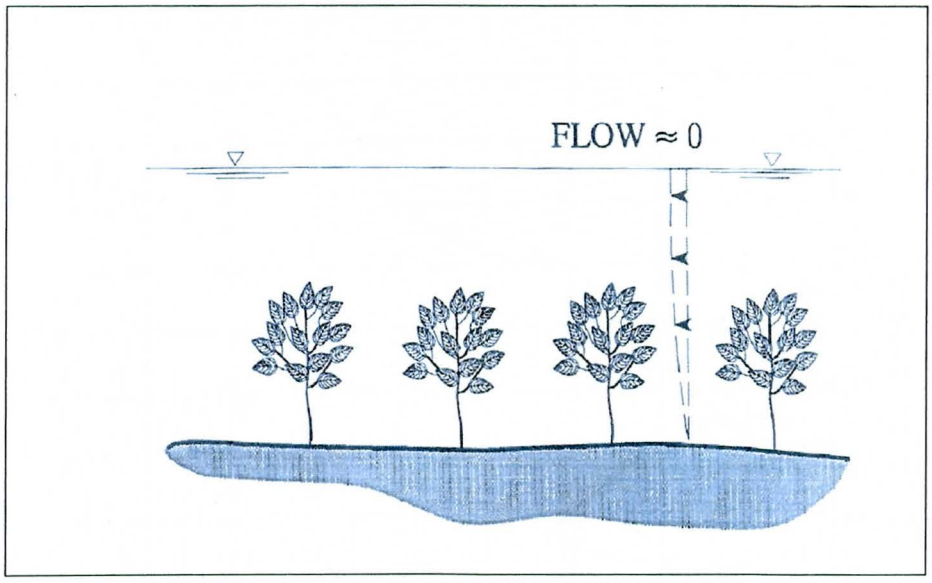

Figure 6. Plants at zero flow

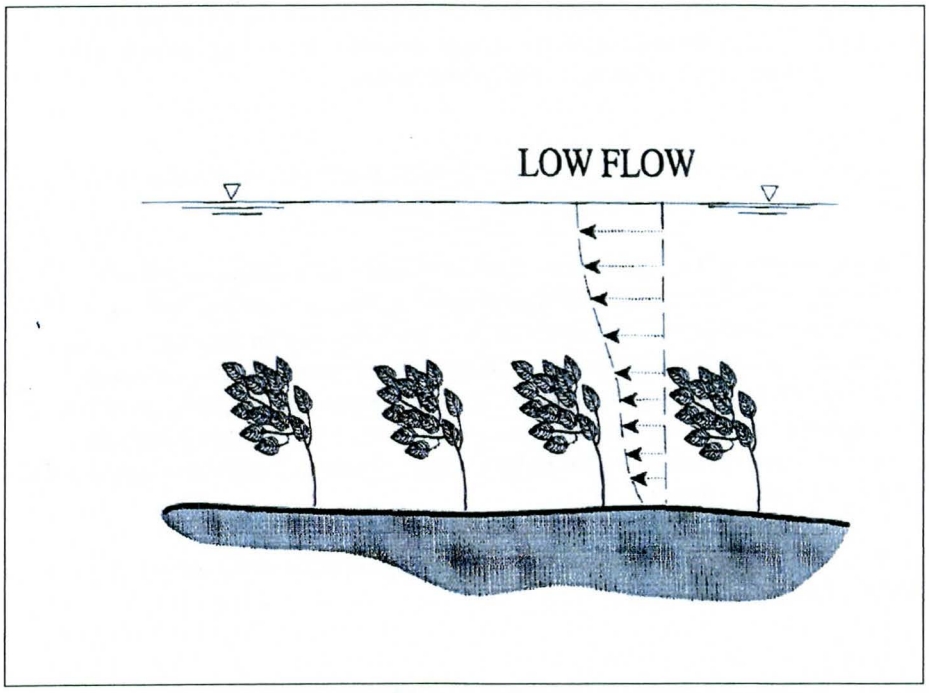

Figure 7. Plants at low flow

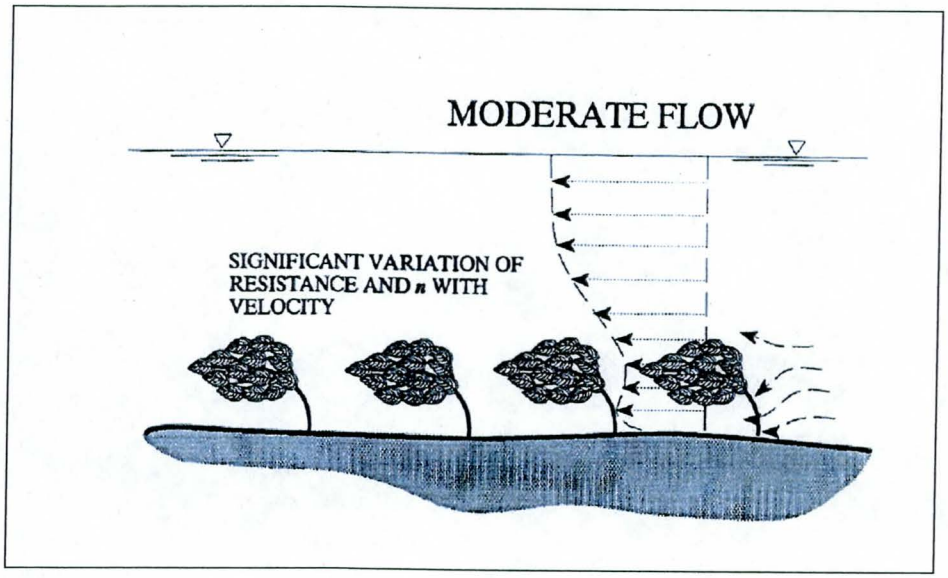

Figure 8. Plants at moderate flow

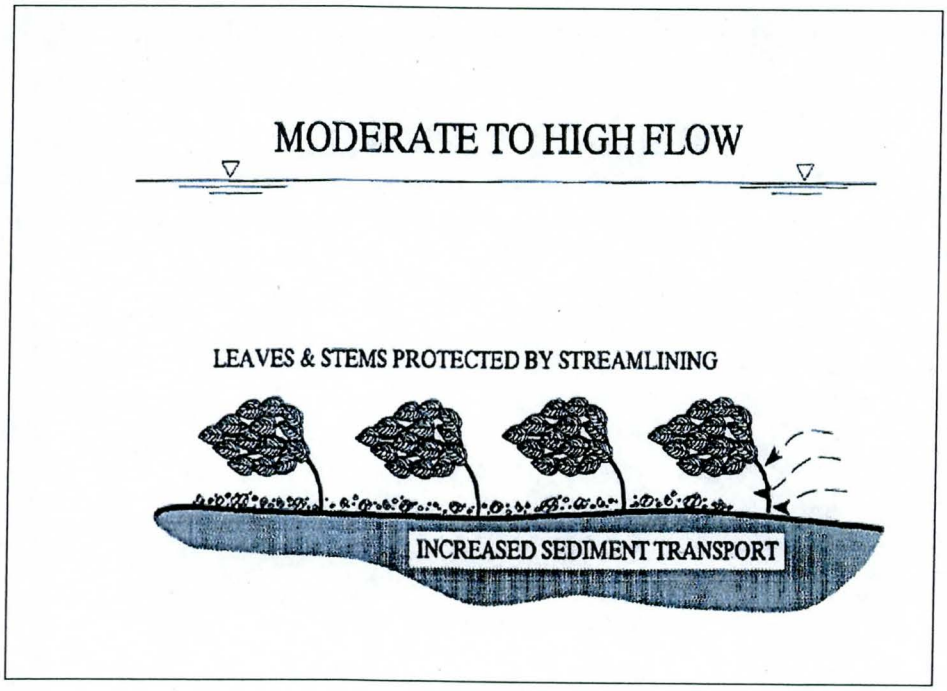

Figure 9. Plants with sediment transport

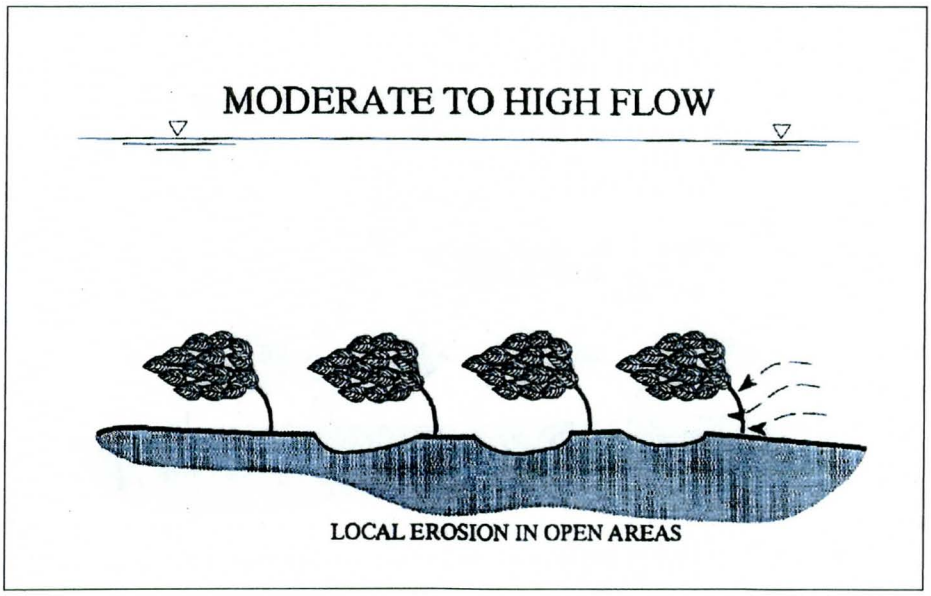

Figure 10. Plants with local erosion

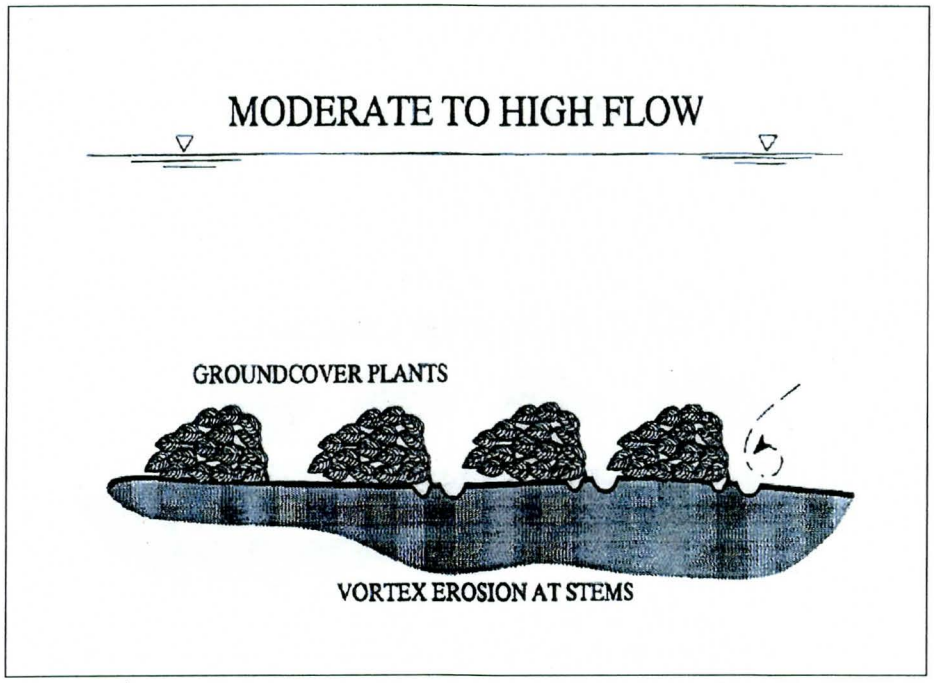

Figure 11. Plants with stem erosion

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

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.

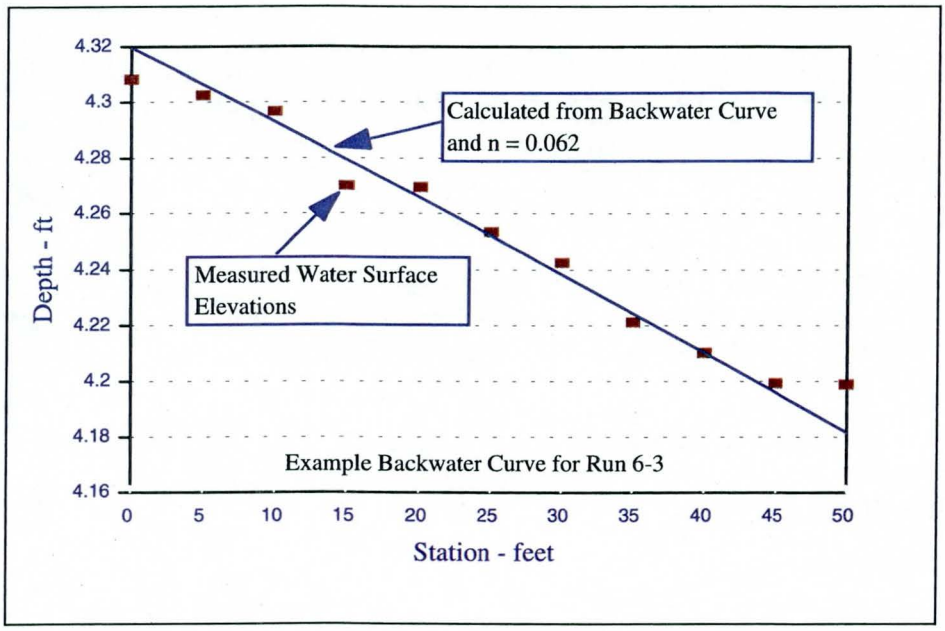

Figure 12. Typical backwater curve for experimental runs (To convert feet to meters, multiply by 0.3048)

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.

$$\sqrt{f} = \frac{n\sqrt{8g}}{K_n R_h^{1/6}} \quad (10)$$

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).

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

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.

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

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.

$$\frac{R_b}{f_b} = \frac{R_w}{f_w} = \frac{R_h}{f} \quad (13)$$

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.

$$n_{veg} = n_b - n_o \quad (14)$$

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.

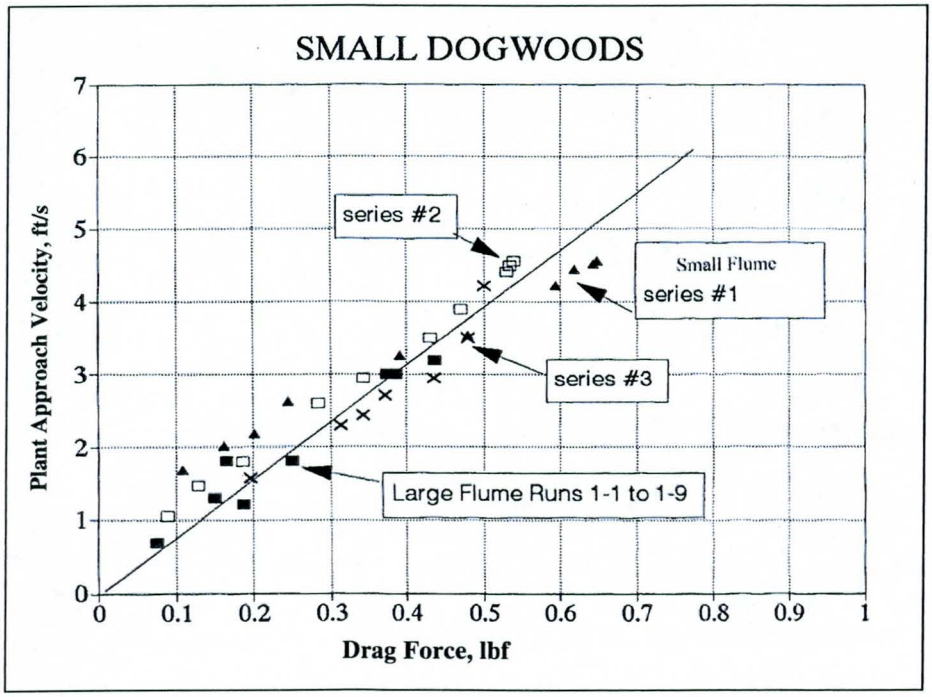

Figure 13. Plant approach velocity versus drag force (To convert feet to meters, multiply by 0.3048) [To convert pounds (force) to newtons, multiply by 4.448222]

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.

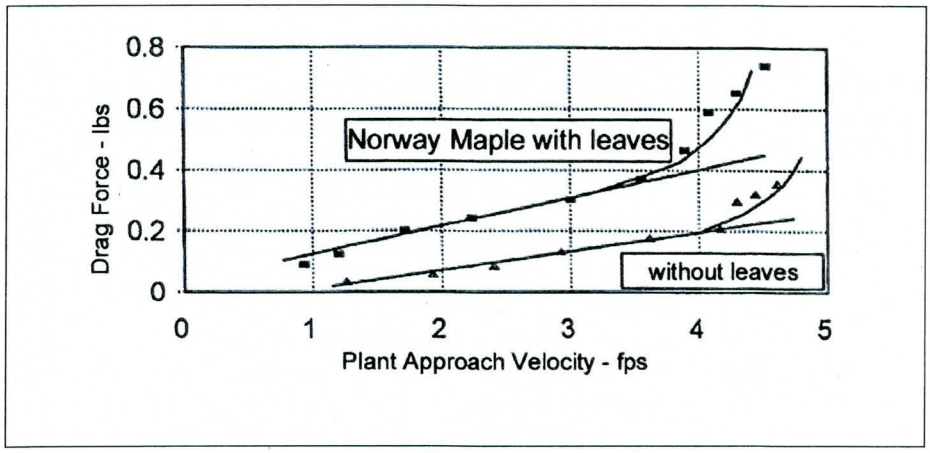

Figure 14. Drag force versus velocity (To convert feet to meters, multiply by 0.3048) [To convert pounds (force) to newtons, multiply by 4.448222]

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.

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

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.

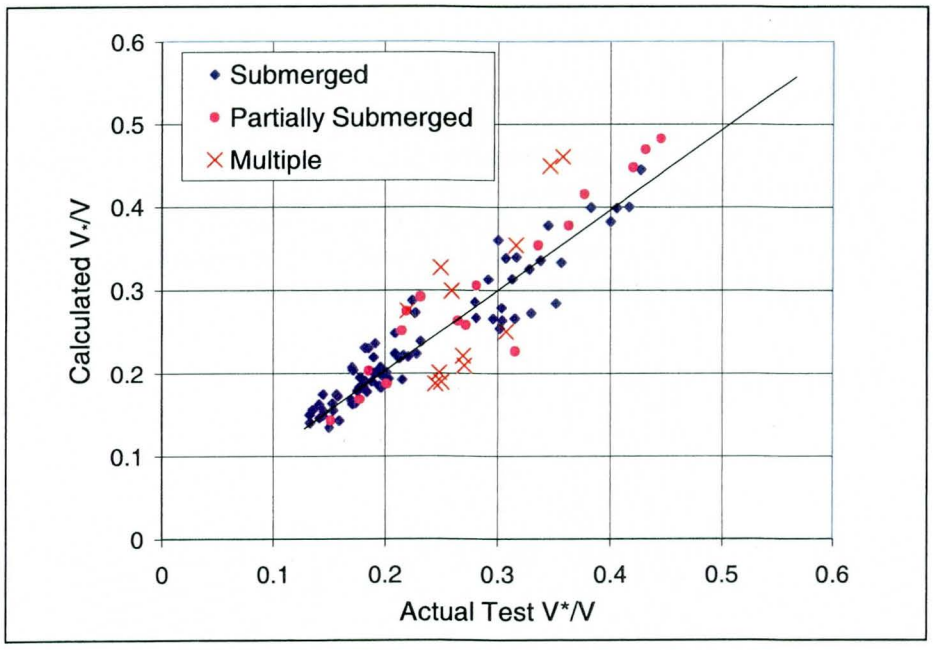

Figure 15. Comparison of calculated versus actual resistance V_*/V

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.

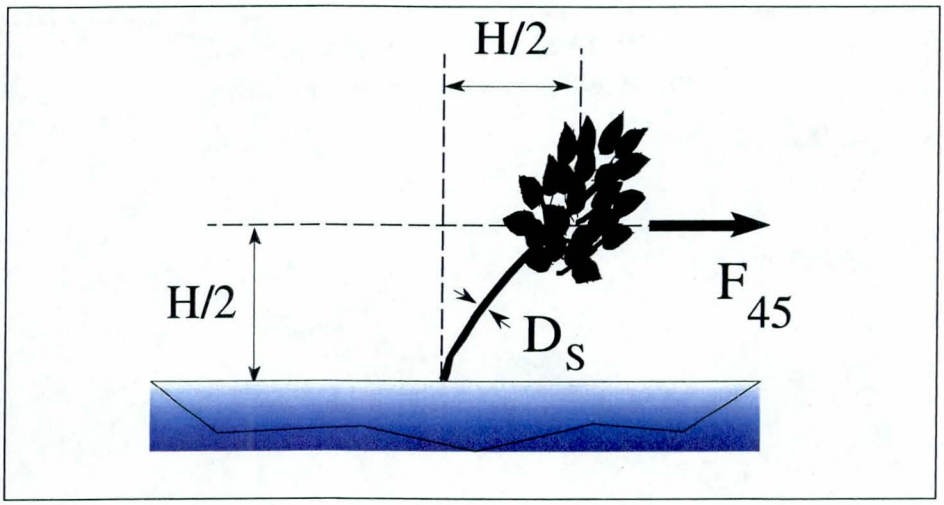

Figure 16. Methodology for measurement of plant stiffness for calculation of E_s in the field for plants with effective height of leaf mass approximately equal to the plant height

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

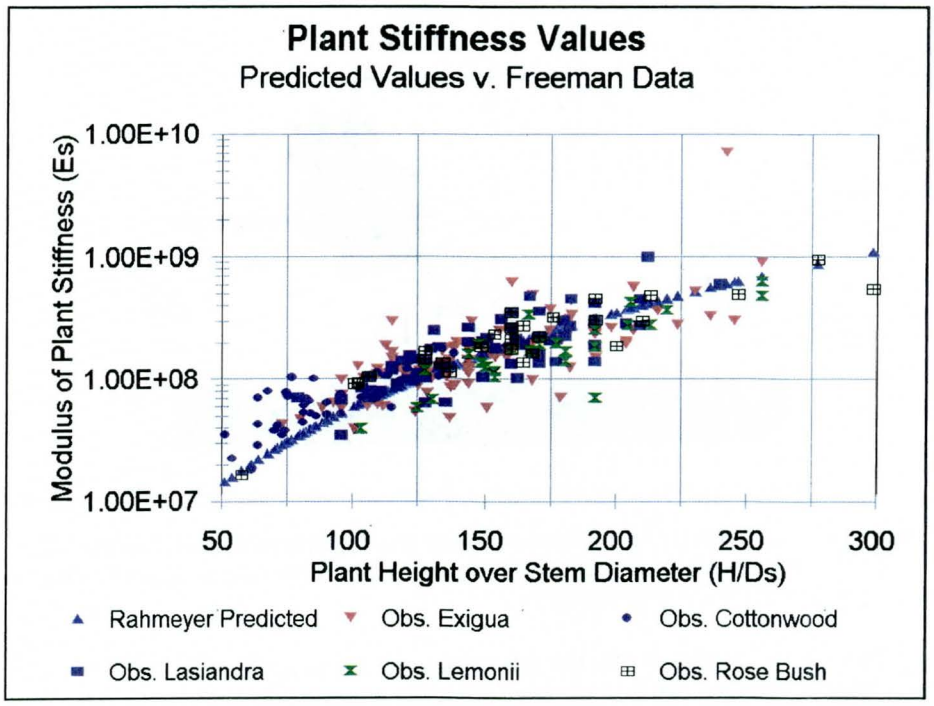

Figure 17. Measured versus calculated plant stiffness modulus, E_s

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.

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

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

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.

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

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*, $N/m^2 x 10^8$
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

		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.

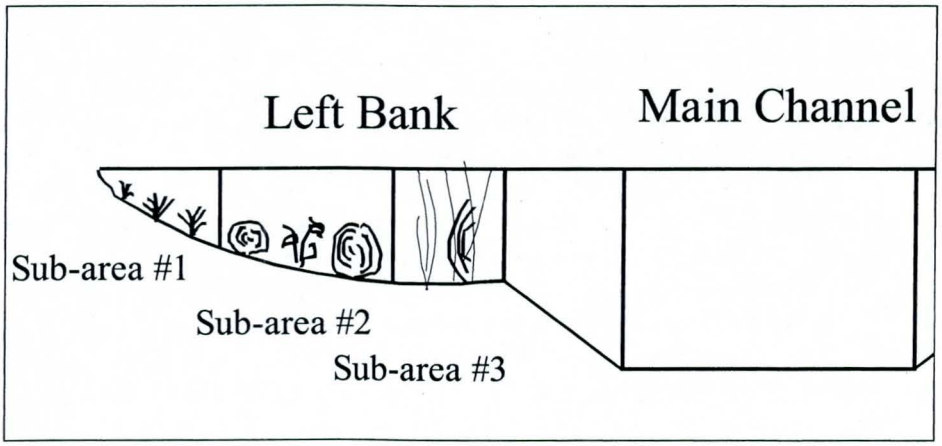

Figure A1. Left bank floodplain for example problem showing calculation subareas based on vegetation types

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

REPORT DOCUMENTATION PAGE

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October 2000	Final Report	

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Determination of Resistance Due to Shrubs and Woody Vegetation

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5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

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

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13. SUPPLEMENTARY NOTES

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

Drag force
Hydraulic roughness
Hydraulics
Vegetation resistance
Plant deformation

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
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Gila River Floodplain Redelineation Study
Maricopa County

Technical Data Notebook

PREPARED FOR:

FLOOD CONTROL DISTRICT OF MARICOPA COUNTY
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June 2007

STANTEC CONSULTING Inc.
Project No.18200453

Contract FCD 2006C013

Flood Control District of Maricopa County

Stantec

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- Work Study Maps
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1.0 Introduction

1.1 PURPOSE

This document contains the results and supporting computations for a hydraulic analyses and floodplain delineation conducted for a reach of the Gila River located in Maricopa County, Arizona. The overall study reach, approximately 8.2 miles in length, commences at the Airport Road crossing of the Gila River (approximately cross section 186.97) and extends up stream to the Bullard Avenue crossing of the Gila River (approximately cross section 195.13). Between approximately cross sections 189.02 and 191.0 the extent of the floodplain and associated base flood elevations mapped as part of the *Salt-Gila River Floodplain Delineation Restudy* (Effective study), prepared by Michael Baker Jr. (1999) was based on existing physical features (canals and roadway) functioning as a levee (with levee model) and then not as a levee (without levee model, base water surface elevations are higher than physical features and levee failure was assumed). Revised hydraulic models through the subject reach of the Gila River were developed as part of the *El Rio Watercourse Master Plan*, (*ERWMP)* prepared by Stantec (2006) and by developers for the *Norte Vista / King Ranch Floodplain Redelineation, Gila River* (Norte Vista / King Ranch) prepared by River Research & Design, Inc. (2007). In the preparation of the models developed for the Norte Vista / King Ranch projects it was discovered that that there were differences between recent topographic data and the topographic data used to develop the Effective model. Results of hydraulic models developed for the Norte Vista / King Ranch projects and the *ERWMP* (which uses topographic data from the Norte Vista / King Ranch projects) indicate that the water surface elevations in the vicinity of the levee area are lower. The Flood Control District of Maricopa County (FCDMC) obtained new topographic data through and downstream of the levee reach. The new topographic data combined with topographic data from the Norte Vista / King Ranch is used to evaluate the hydraulic conditions of the study reach.

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1.2 LOCATION

The overall reach of the Gila River Floodplain Redelineation Study extends from approximately Airport Road (Township 1 South, Range 2 West, Section 7) to the Bullard Avenue Bridge (Township 1 North, Range 1 West, Sections 29 and 32). It includes the communities of Goodyear and Buckeye and unincorporated Maricopa County. Figure 1.1 depicts the Effective floodplain and floodway boundaries, study reach and hydraulic cross sections.

1.3 ANALYSIS METHODOLOGY

The hydraulics of the study is executed using the methodology contained in the Drainage Design Manual for Maricopa County, Arizona, Volume II, Hydraulics (1995). The hydraulic modeling is accomplished using the US Army Corps of Engineers (COE) computer program HEC-RAS, version 3.1.3 (COE 2005).

1.4 ORGANIZATION OF REPORT

This report is generally structured in a Technical Data Notebook format in accordance with Arizona Department of Water Resources requirements of State Standard SS1-97 and State Standard SSA1-97.

1.5 AUTHORITY FOR STUDY

Pursuant to Arizona revised Statues 48-3609.01 the FCDMC is authorized to conduct watercourse master plans for river reaches within Maricopa County. Stantec Consulting Inc. was awarded the contract (FCD 2006C013).

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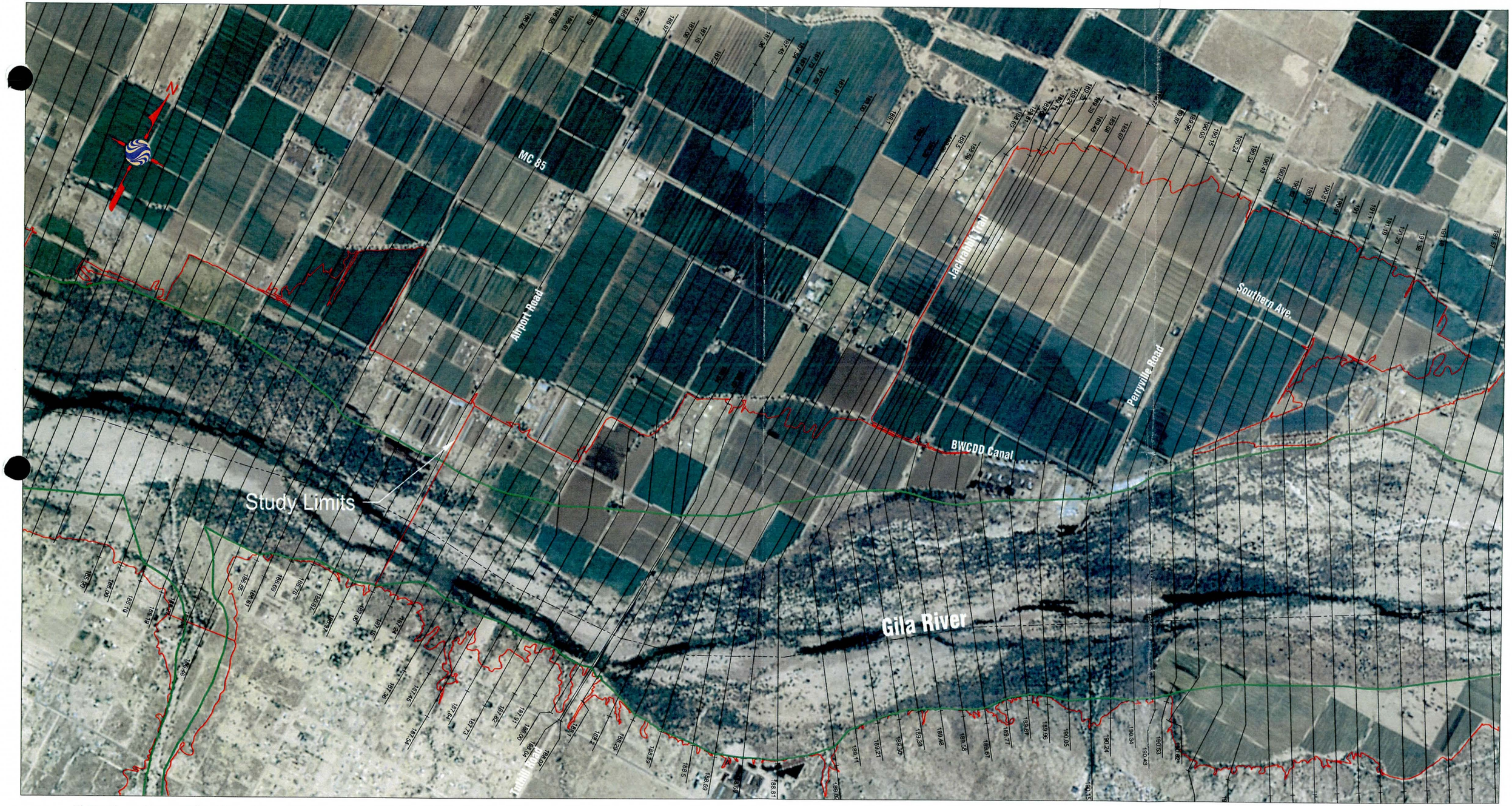

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Fax. 602.431.9562
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Legend

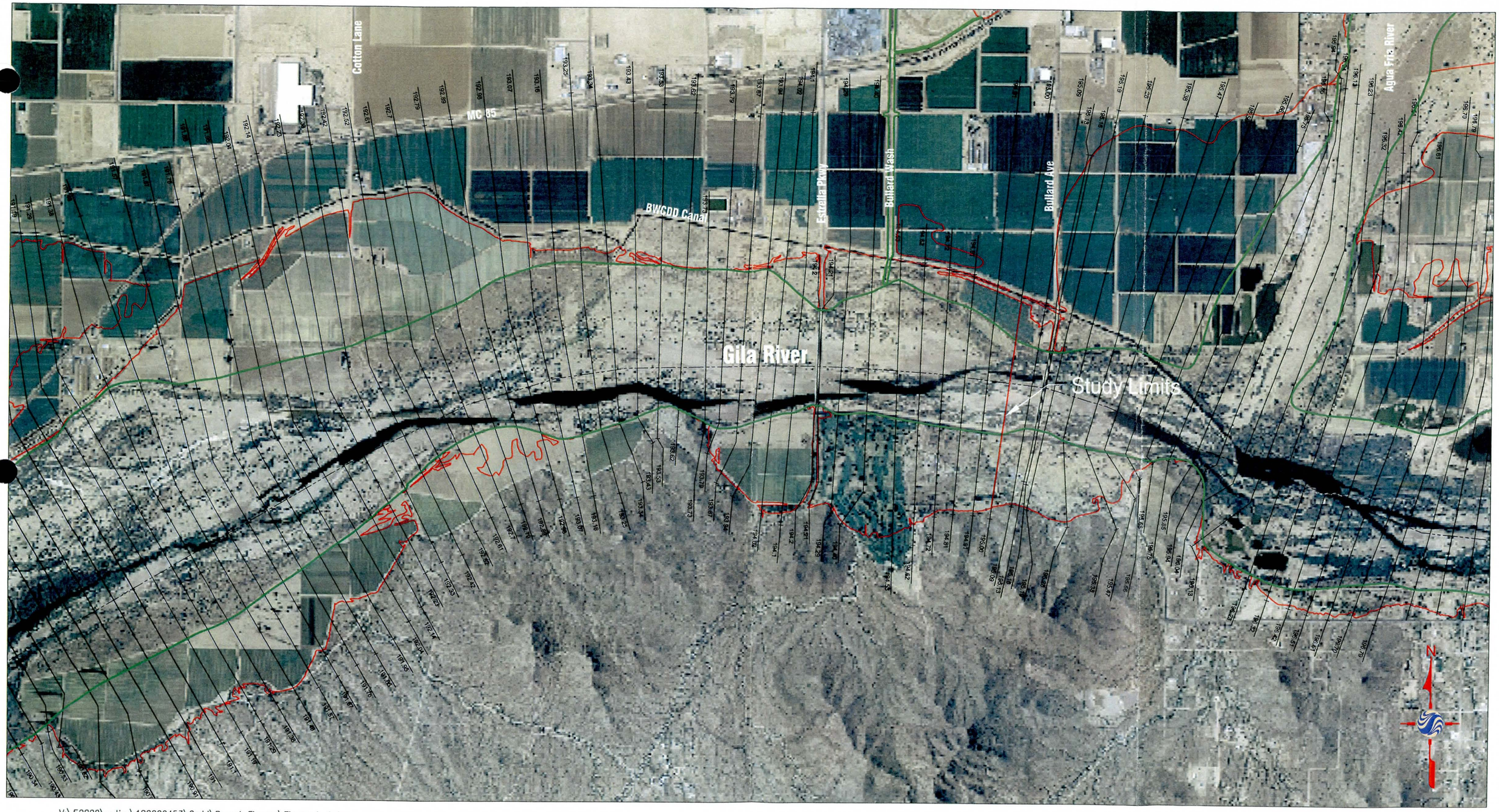
- Effective Floodway
- Effective Floodplain
- Cross Sections
- Center Line

0 2000' 3000' 4000'
1In=2000Ft

Client/Project
Flood Control District of Maricopa County
Gila River Floodplain Redelineation Study
FCD No. 2006C013, PCN No. 014.34.01

Figure No.
1.1 Sheet 1

Title
Site Plan



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Legend

- Effective Floodway
- Effective Floodplain
- Cross Sections
- Center Line

1in=2000ft 0 2000' 3000' 4000'

Client/Project
Flood Control District of Maricopa County
Gila River Floodplain Redelineation Study
FCD No. 2006C013, PCN No. 014.34.01

Figure No.
1.1 Sheet 2

Title
Site Plan

2.0 ADWR/FEMA FORMS

2.1 STUDY DOCUMENTATION ABSTRACT FOR FEMA SUBMITTALS

Study Documentation Abstract for FEMA Submittals	Initial Study		Restudy		CLOMR		LOMR	x	Other	

Section 2.1: Study Documentation Abstract for FEMA Submittals		
2.1.1	Date Study Accepted	
2.1.2	Study Contractor Contact(s) Address Phone Internal Reference Number	Stantec Consulting Inc. Pat Ellison, PE 8211 South 48th Street Phoenix, Arizona 85044 (602) 438-2200 FAX: (602) 431-9562 182000453
2.1.3	FEMA Technical Review Contractor Contact(s) Address Phone Internal Reference Number	
2.1.4	FEMA Regional Review Phone	
2.1.5	State Technical Reviewer Phone	
2.1.6	Local Technical Reviewer Phone	Flood Control District of Maricopa County John Hathaway, (602) 506-0503
2.1.7	Reach Description	The study will result in a redelineation of the 100-year floodplain and floodway along the Gila River between Airport Road and Bullard Avenue.
2.1.8	USGS Quad Sheet(s) with original photo date & latest photo revision date	Avondale SW Topo dated 7/1/1979, aerial dated 4/18/1979 Perryville Topo dated 7/1/1979, aerial dated 9/6/1992
2.19	Unique Conditions and Problems	All unique conditions and problems are listed in Section 5.7.
2.1.10	Coordination of Q's Discharges (Agency, Date, Comments)	Not applicable.

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2.2 FEMA FORMS

See proceeding pages.

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U.S. DEPARTMENT OF HOMELAND SECURITY - FEDERAL EMERGENCY MANAGEMENT AGENCY

OVERVIEW & CONCURRENCE FORM

O.M.B No. 1660-0016
Expires: August 31, 2007

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A. REQUESTED RESPONSE FROM DHS-FEMA

This request is for a (check one):

☐ CLOMR: A letter from DHS-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 DHS-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	City of Katy	TX	480301	0005D	02/08/83
480287	Harris County	TX	48201C	0220G	09/28/90
040046	Goodyear, City of	AZ	04013C2550G	2550	09/30/2005
040039	Buckeye, Town of		04013C2530G	2550	
040037	Maricopa County		04013C2510G	2510	
			04013C2070H	2070	
			04013C2065H	2065	

2. Flooding Source: Gila River

3. Project Name/Identifier: Gila River Redelineation Study

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

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C. REVIEW FEE

Has the review fee for the appropriate request category been included?	☐ Yes	Fee amount: $_____
	☐ No, Attach Explanation	

Please see the DHS-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: John Hathaway, PE	Company: Flood Control Dist. of Maricopa County	
Mailing Address: 2801 West Durango St. Phoenix AZ 85009	Daytime Telephone No.: (602) 506-0503	Fax No.: (602) 506-4601
	E-Mail Address: joh@mail.maricopa.gov	
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:		Telephone No.:
Community Name:	Community Official's Signature (required):	Date:

DRAFT

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: Patrick J. Ellison	License No.: State of Arizona - 31680	Expiration Date: 09/30/2009
Company Name: Stantec Consulting Inc.	Telephone No.: (602) 438-2200	Fax No.: (602) 431-9562
Signature: See Section 3.1		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)

C. REVIEW FEE

Has the review fee for the appropriate request category been included?	☐ Yes	Fee amount: $_____
	☐ No, Attach Explanation	

Please see the DHS-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: John Hathaway, PE	Company: Flood Control Dist. of Maricopa County	
Mailing Address: 2801 West Durango St. Phoenix AZ 85009	Daytime Telephone No.: (602) 506-0503	Fax No.: (602) 506-4601
	E-Mail Address: joh@mail.maricopa.gov	
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:		Telephone No.:
Community Name:	Community Official's Signature (required):	Date:

DRAFT

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Certifier's Name:	License No.:	Expiration Date:
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☐ Coastal Structures Form (Form 5)	Addition/revision of coastal structure
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Seal (Optional)

C. REVIEW FEE

Has the review fee for the appropriate request category been included?	☐ Yes	Fee amount: $_____
	☐ No, Attach Explanation	

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

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Signature of Requester (required):		Date:

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Community Official's Name and Title:		Telephone No.:
Community Name:	Community Official's Signature (required):	Date:

DRAFT

CERTIFICATION BY REGISTERED PROFESSIONAL ENGINEER AND/OR LAND SURVEYOR

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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
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☐ 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)

U.S. DEPARTMENT OF HOMELAND SECURITY - FEDERAL EMERGENCY MANAGEMENT AGENCY

RIVERINE HYDROLOGY & HYDRAULICS FORM

O.M.B No. 1660-0016
Expires: August 31, 2007

PAPERWORK REDUCTION ACT

Public reporting burden for this form is estimated to average 3.25 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, U.S. Department of Homeland Security, Federal Emergency Management Agency, 500 C Street, SW, Washington DC 20472, Paperwork Reduction Project (1660-0016). 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 DHS-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	Airport Road	187.06	869.09	869.25
Upstream Limit	Bullard Avenue	195.00	912.50	912.05

2. Hydraulic Method Used

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

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B. HYDRAULICS (CONTINUED)

3. Pre-Submittal Review of Hydraulic Models

DHS-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 ☒ Diskette Submitted

	Natural Run	Floodway Run	Datum
Duplicate Effective Model*	File Name: ERWMP.prj Plan Name: FEMA FP/FW w/ & w/o levees	File Name: same Plan Name: same	NAD83
Corrected Effective Model*	File Name: gilarvr.prj Plan Name: Redelineation w/ & w/o levee	File Name: same Plan Name: same	NAD83
Existing or Pre-Project Conditions Model	File Name: Plan Name:	File Name: Plan Name:	____
Revised or Post-Project Conditions Model	File Name: Plan Name:	File Name: Plan Name:	____
Other - (attach description)	File Name: Plan Name:	File Name: Plan 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 DHS-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.

☐ Annotated FIRM and/or FBFM Included ☒ Digital Mapping (GIS/CADD) Data Submitted (Recommended)

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 or without 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/CLOMR 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/CLOMR requests, does this request have the potential to impact an endangered species? ☐ Yes ☒ No

If Yes, please submit documentation from the community to show that they have complied with Sections 9 and 10 of the Endangered Species Act (ESA). Section 9 of the ESA prohibits anyone from "taking" or harming an endangered species. If an action might harm an endangered species, a permit is required from U.S. Fish and Wildlife Service or National Marine Fisheries Service under Section 10 of the ESA.

For actions authorized, funded, or being carried out by Federal or State agencies, please submit documentation from the agency showing its compliance with Section 7(a)(2) of the ESA.

5. 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.

* Not inclusive of all applicable regulatory requirements. For details, see 44 CFR parts 60 and 65.

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3.0 MAPPING AND SURVEY INFORMATION

3.1 FIELD SURVEY INFORMATION

Field surveys were conducted by various consultants for the FCDMC during May 2005, June 2005, August 2005 and March 2007 to compare previous mapping and new topography in the area. The surveyed cross sections, 187.24, 188.10 189.21, 189.87, 190.91, 191.67, 192.14, 192.42, 193.34 and 193.94 are shown on Figure 3.1. Graphs comparing the Effective HEC-RAS model cross sections, Corrected Effective HEC-RAS model cross sections and survey data are shown on Figures 3.2 through 3.12. The graphs show a reasonable correlation, within mapping limits, between the Corrected Effective topography and the survey data. There are significant differences, up to eight feet in some areas, between the Effective model and the Corrected Effective model. This difference is further discussed in Section 3.2 Mapping.

DRAFT

V:\52820\active\182000453\Cadd\Report Figures\Figure 3-1.dwg
2007-06-19 04:16PM By: amlynch

April, 2007
182000453

ORIGINAL SHEET - ANSI B

Stantec Consulting Inc.
8211 South 48th Street
Phoenix AZ U.S.A.
85044
Tel. 602.438.2200
Fax. 602.431.9562
www.stantec.com

Legend

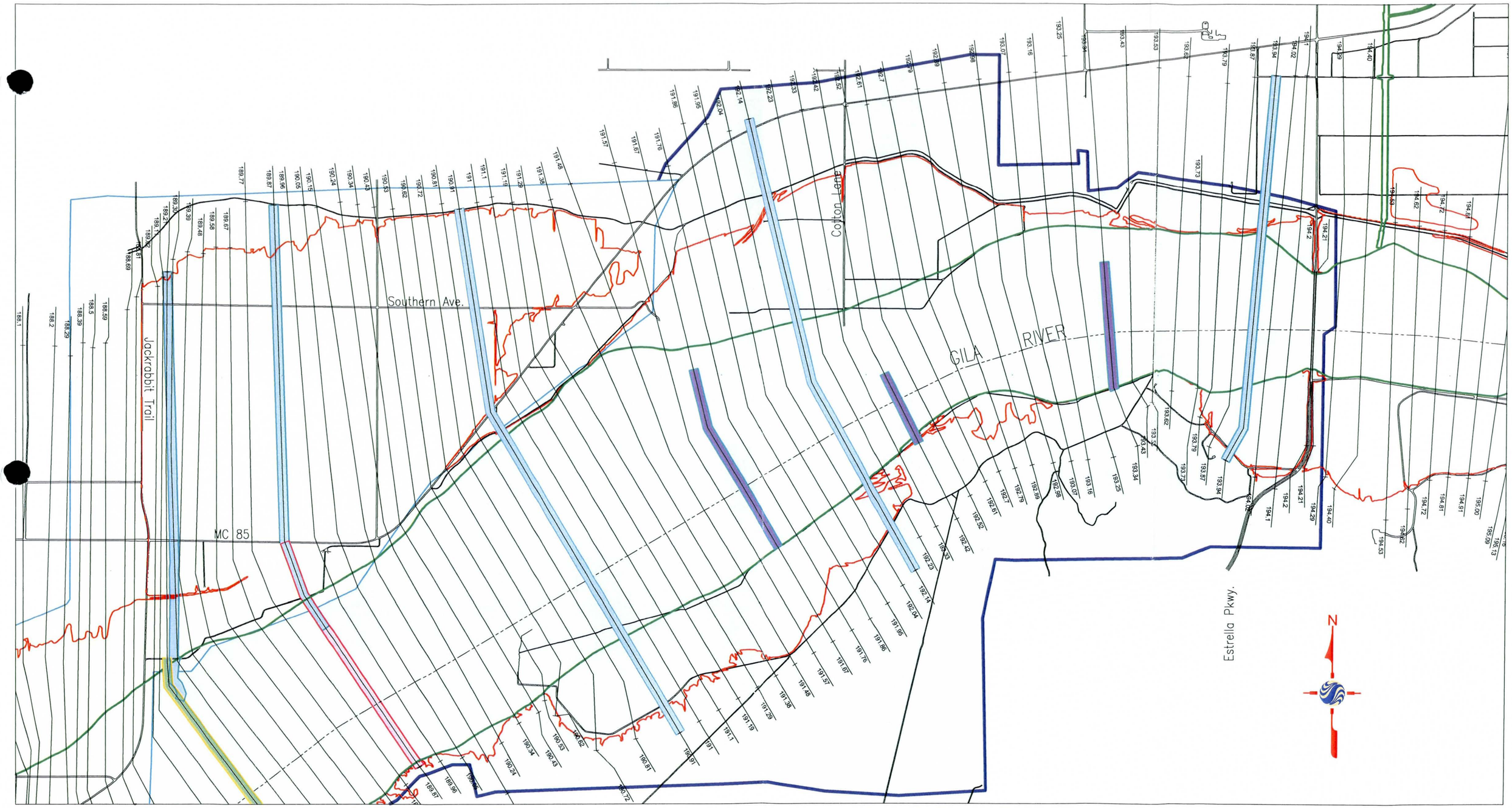
- Baseline
- Effective Floodway
- Effective Floodplain
- Existing Conditions Cross Sections
- King Ranch Topography Boundary
- FCDMC Topography Boundary
- May 2005 Survey Location
- June 2005 Survey Location
- August 2005 Survey Location
- March 2007 Survey Location

1in=2000ft 0 2000' 3000' 4000'

Client/Project
Flood Control District of Maricopa County
Gila River Floodplain Redelineation Study
FCD No. 2006C013, PCN No. 014.34.01

Figure No.
3.1 Sheet 1

Title
Field Survey Location



V:\52820\active\182000453\Cadd\Report Figures\Figure 3-1.dwg
2007-06-19 04:16PM By: amlynch

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Legend

- Baseline
- Effective Floodway
- Effective Floodplain
- Existing Conditions Cross Sections
- King Ranch Topography Boundary
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0 2000' 3000' 4000'
1in=2000ft

Client/Project
Flood Control District of Maricopa County
Gila River Floodplain Redelineation Study
FCD No. 2006C013, PCN No. 014.34.01

Figure No.
3.1 Sheet 2

Title
Field Survey Location

Figure 3.2
Survey Data Compared to HEC-RAS Models - XS 187.24

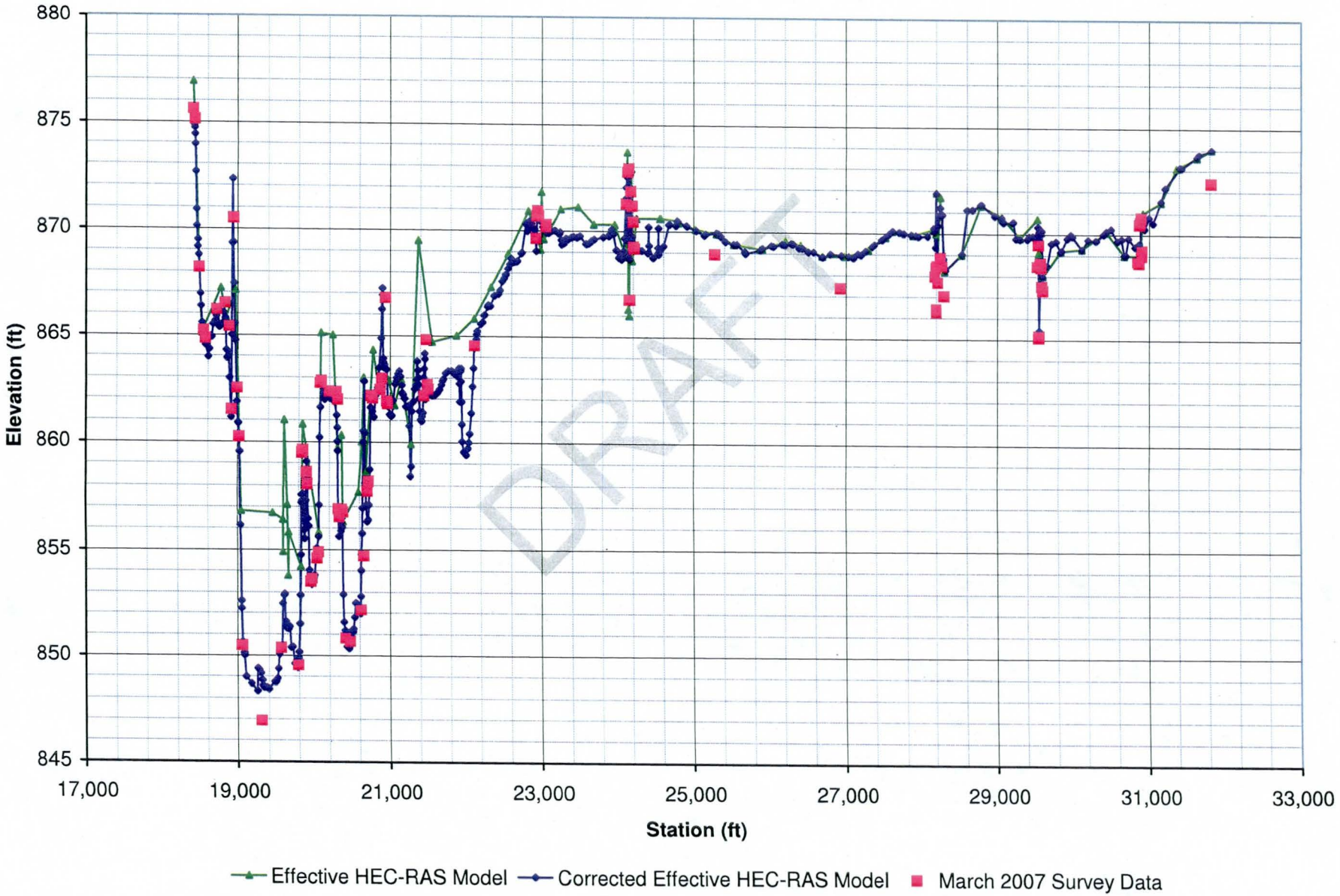

Figure 3.3
Survey Data Compared to HEC-RAS Models - XS 188.10

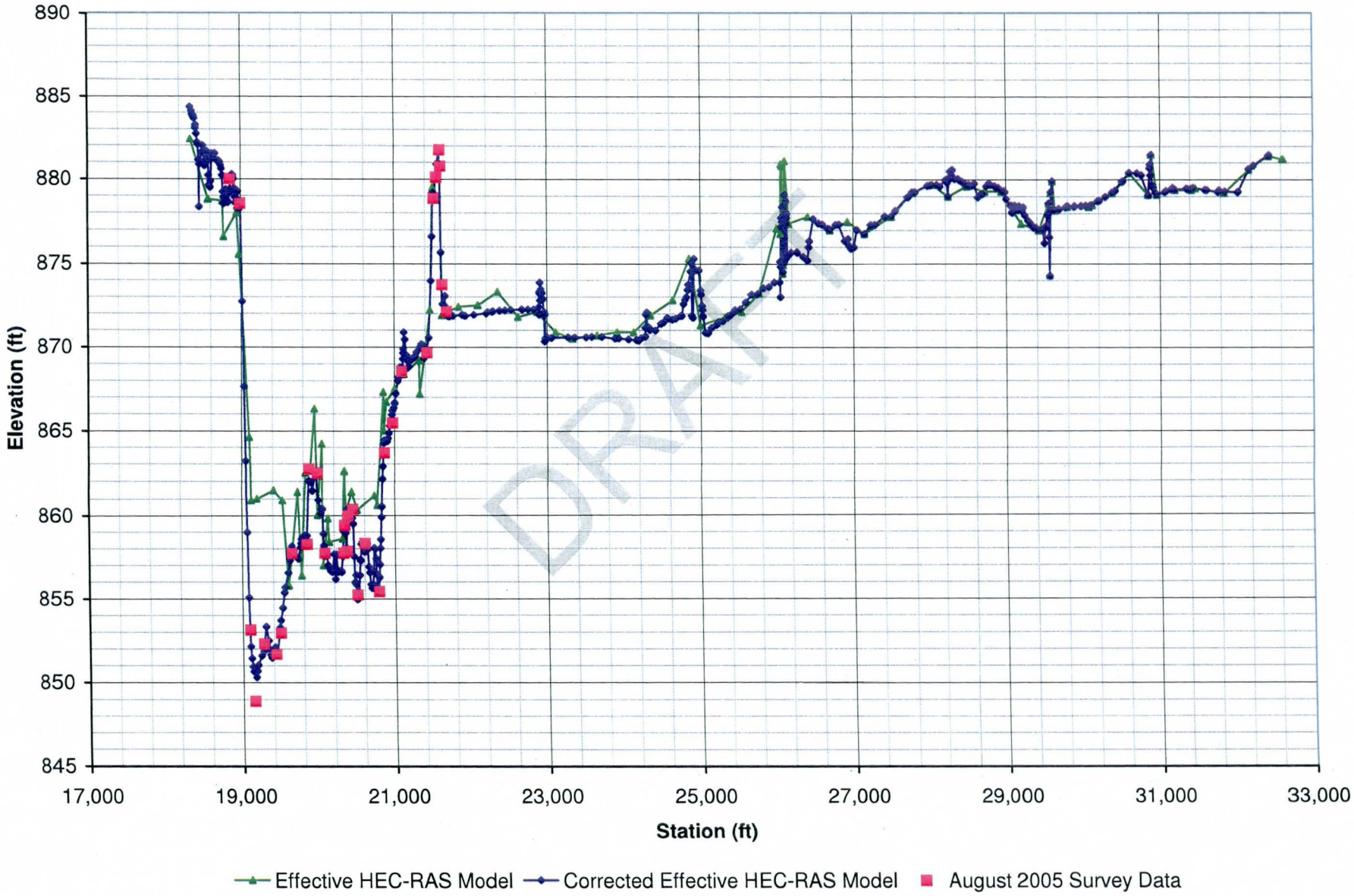

Figure 3.4
Survey Data Compared to HEC-RAS Models - XS 189.21

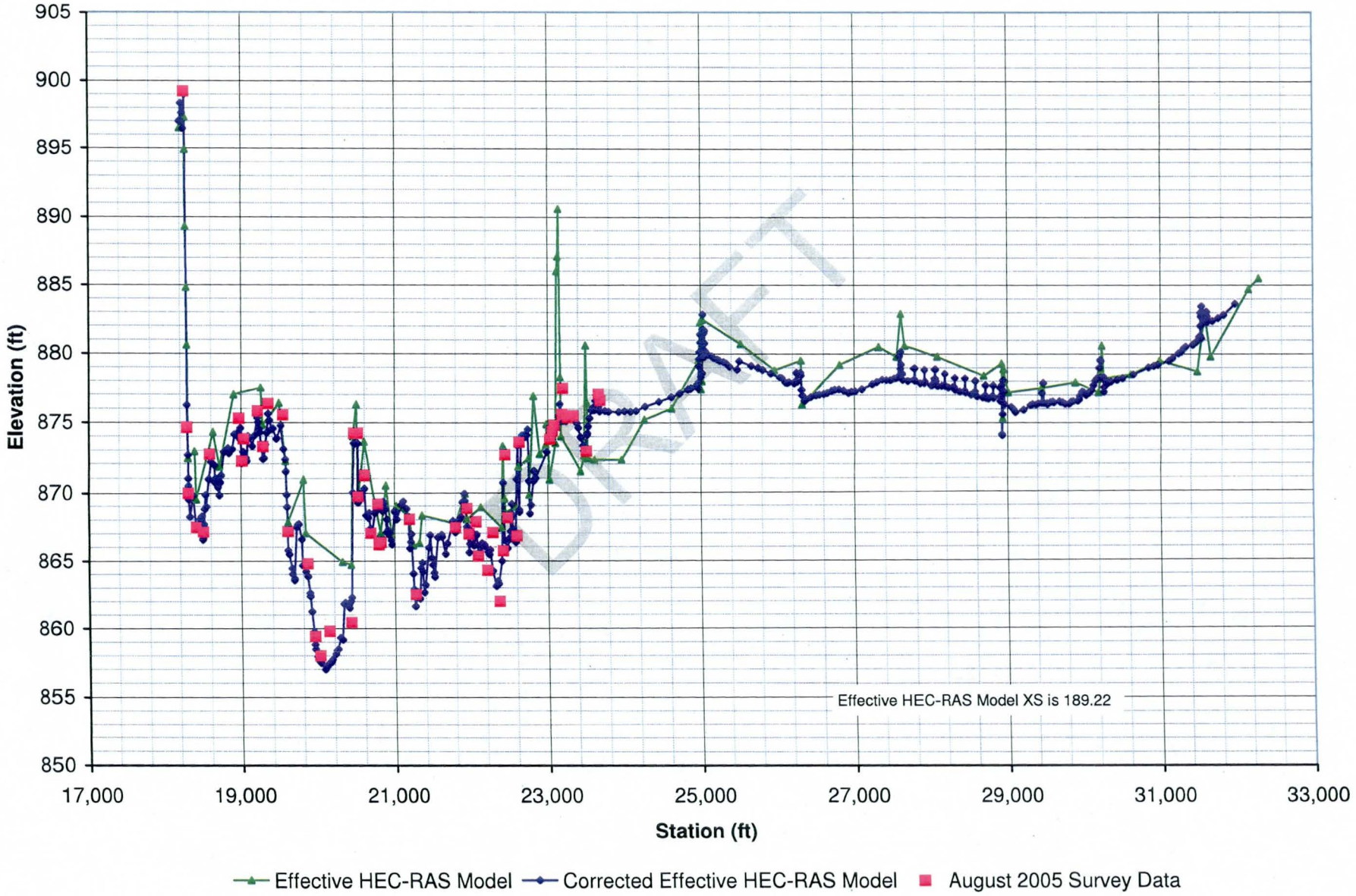

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Figure 3.5
Survey Line between XS 189.21 and 189.30
Extracted Survey Line Data compared to Survey Data

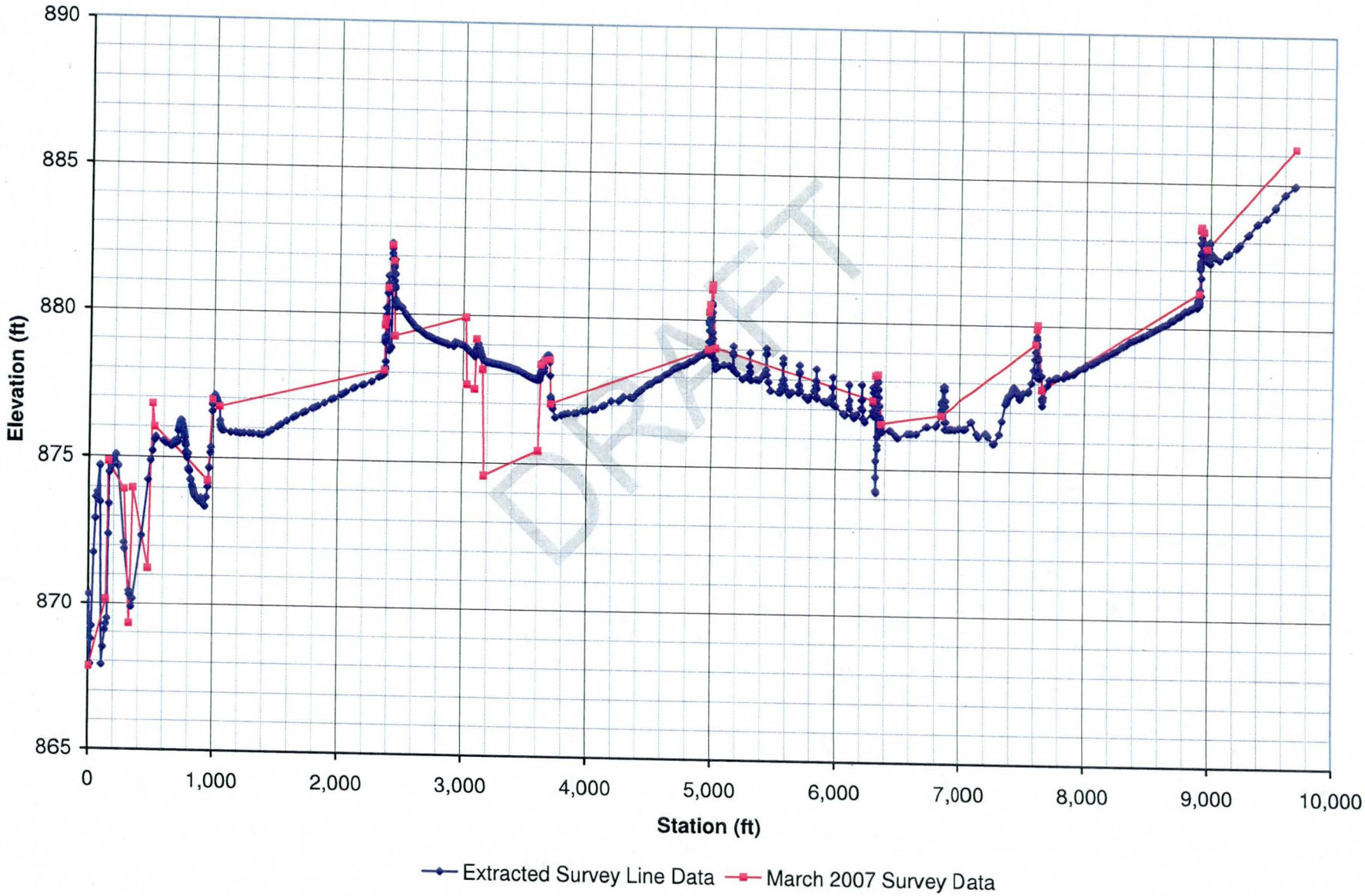

Figure 3.6
Survey Data Compared to HEC-RAS Models - XS 189.87

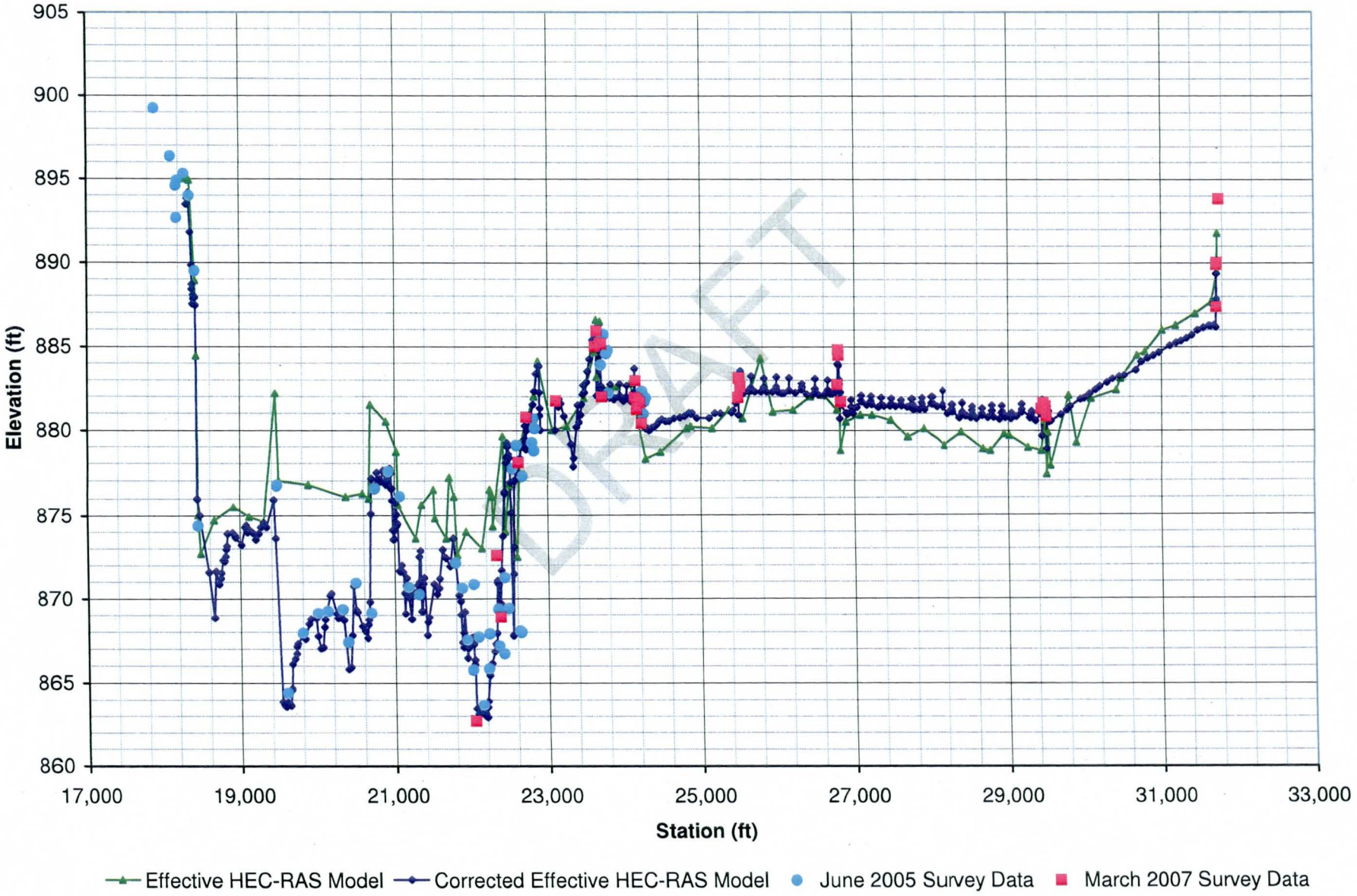

Figure 3.7
Survey Data Compared to HEC-RAS Models - XS 190.91

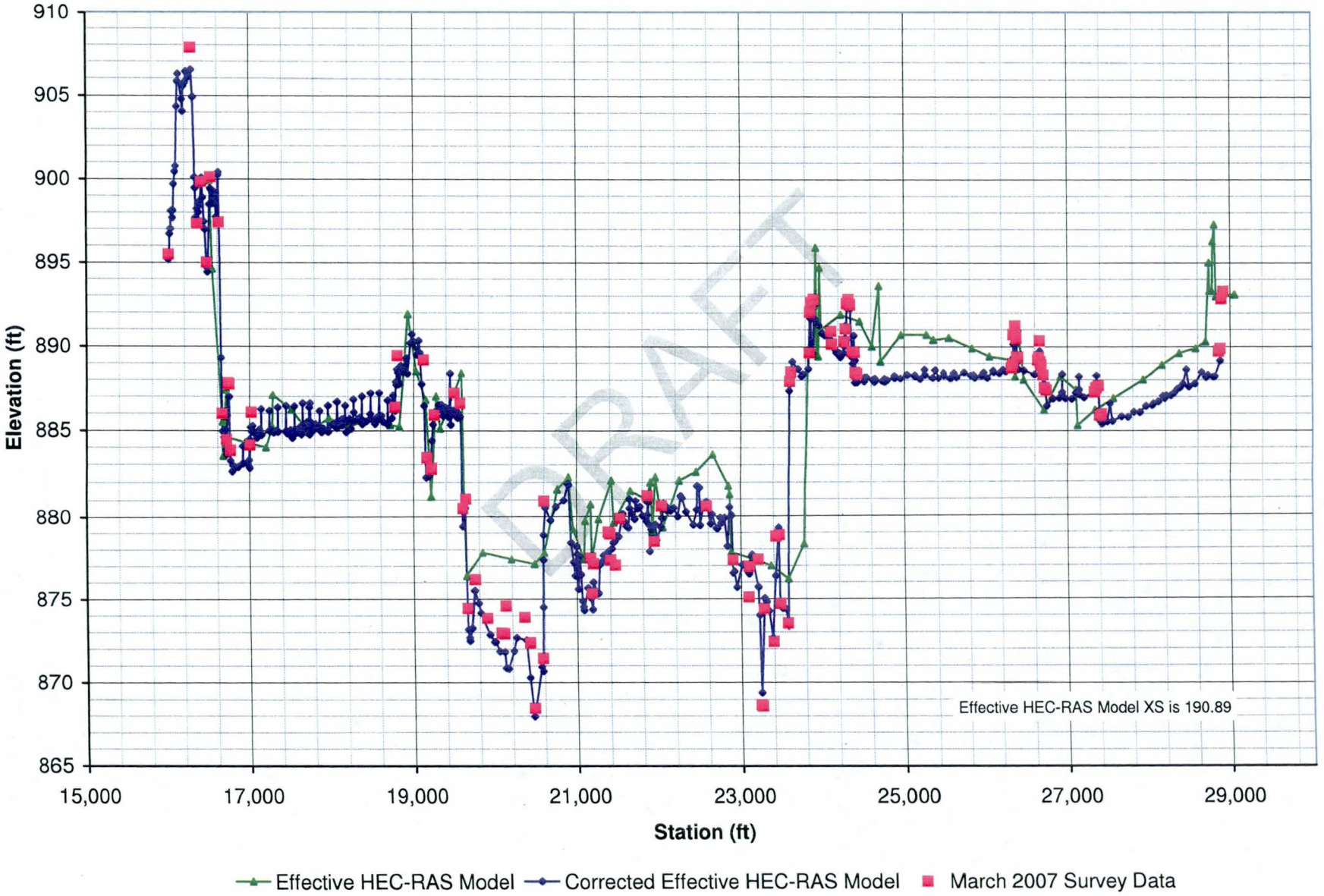

Figure 3.8
Survey Data Compared to HEC-RAS Models - XS 191.67

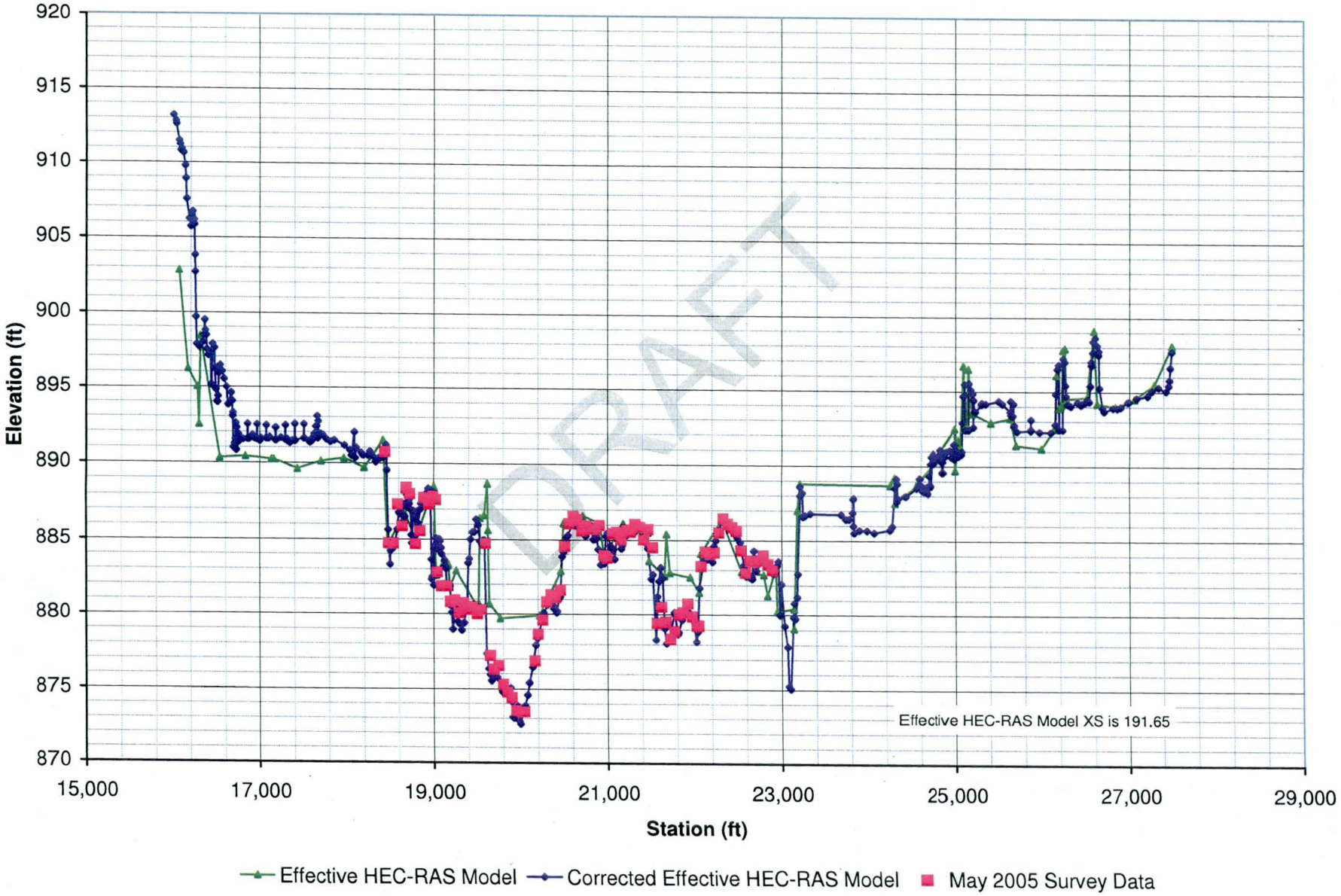

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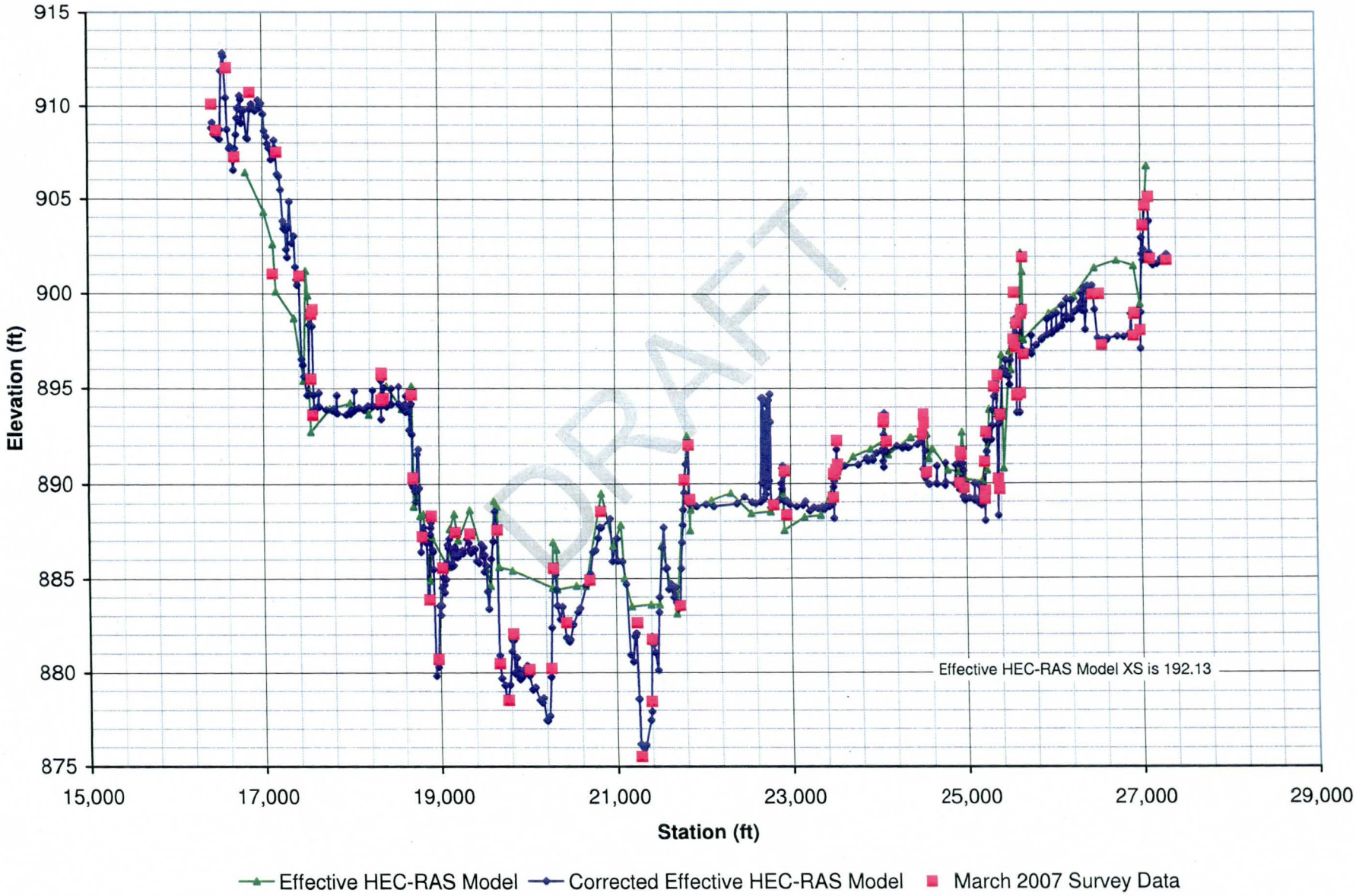
Figure 3.9
Survey Data Compared to HEC-RAS Models - XS 192.14



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Firgure 3.10
Survey Data Compared to HEC-RAS Models - XS 192.42

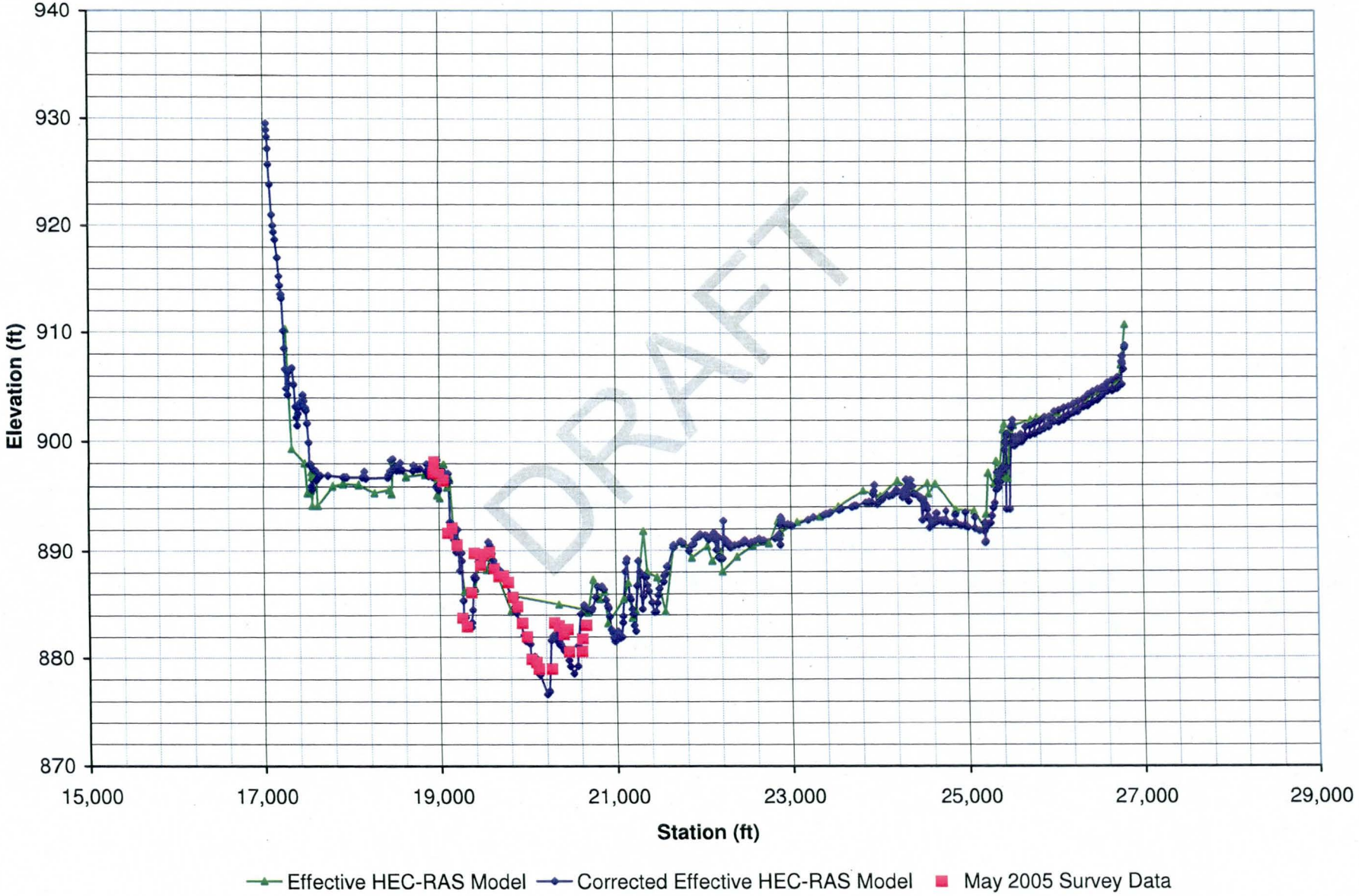


Figure 3.11
Survey Data Compared to HEC-RAS Models - XS 193.34

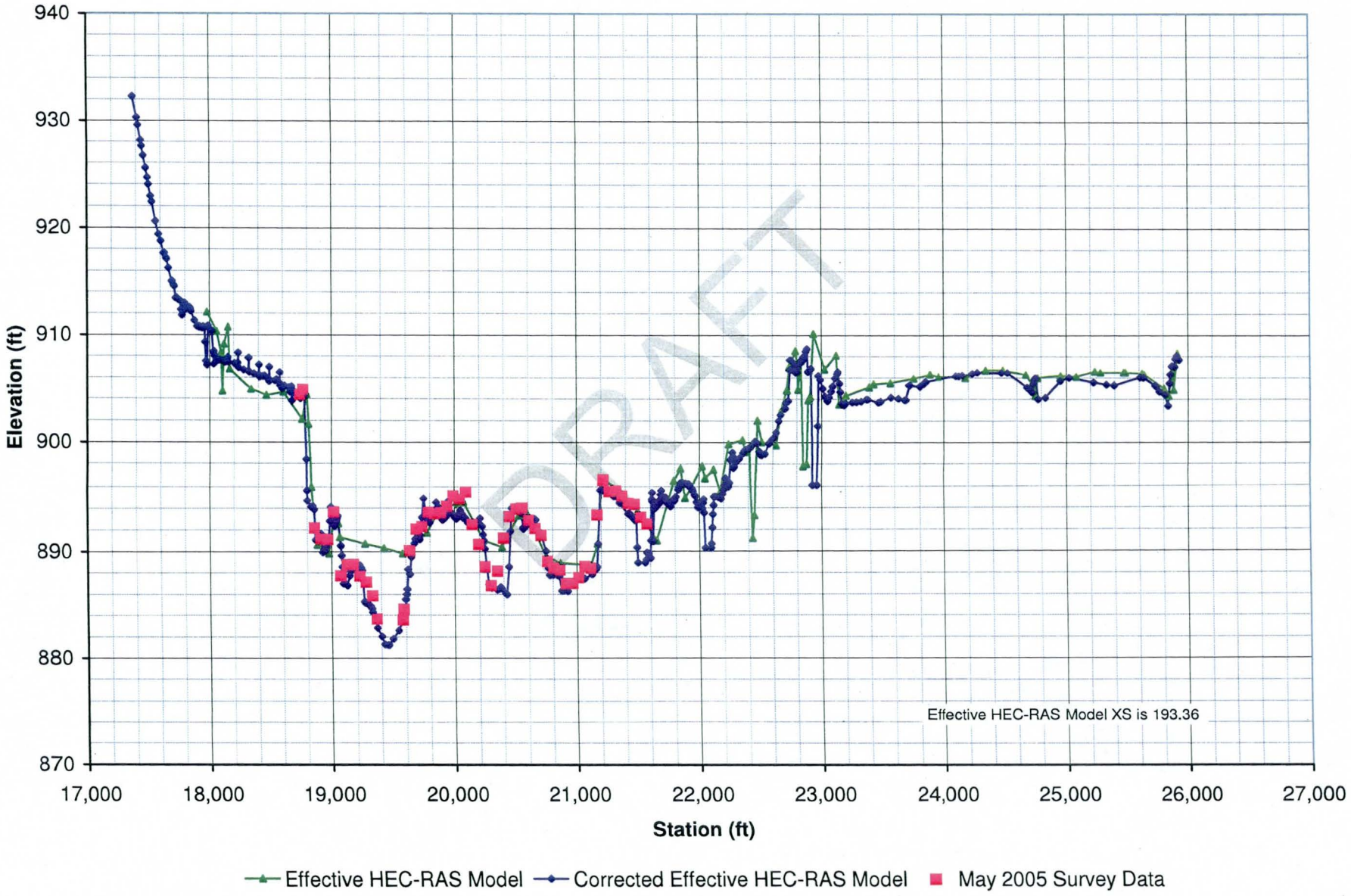
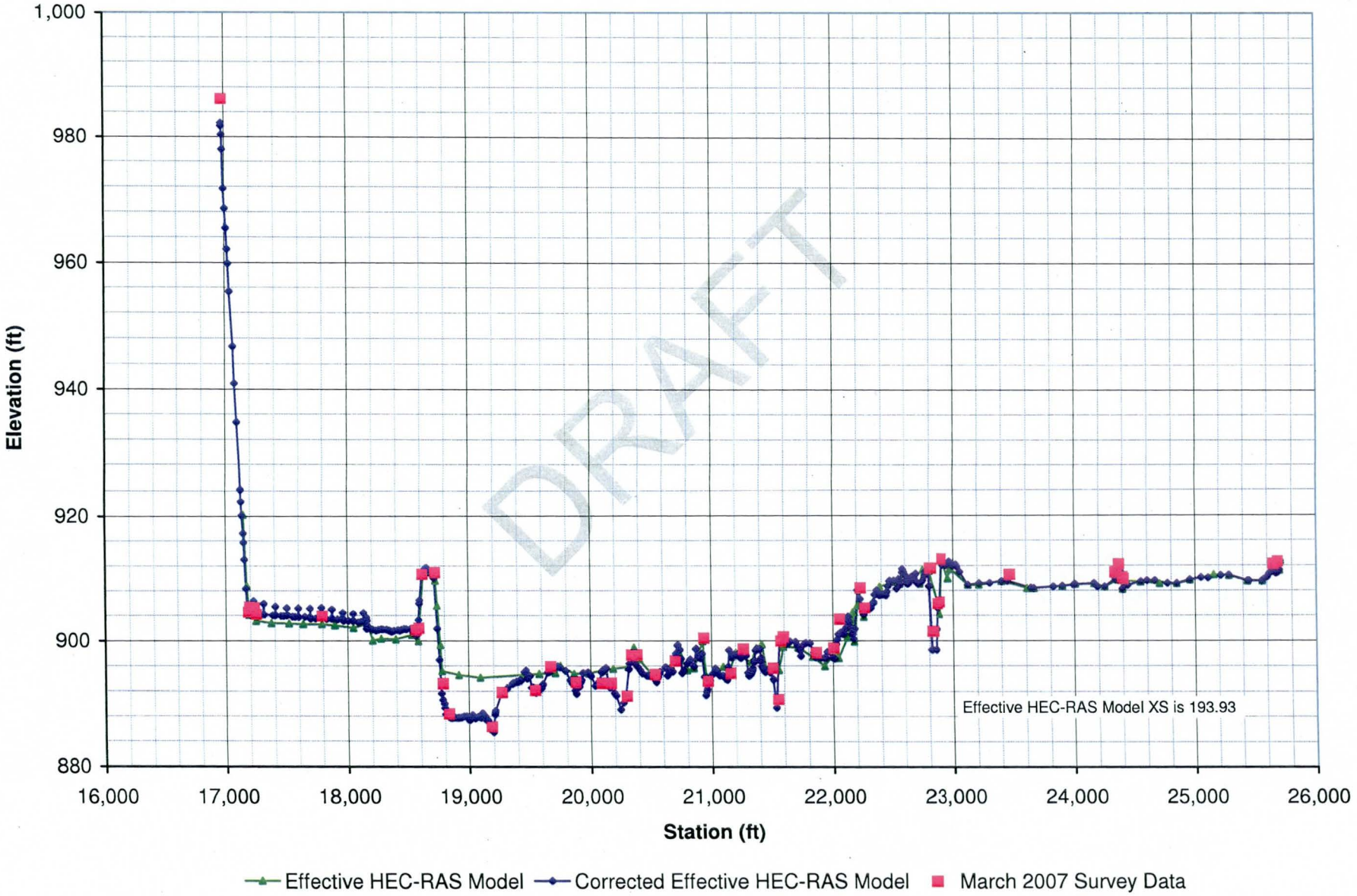


Figure 3.12
Survey Data Compared to HEC-RAS Models - XS 193.94



3.2 MAPPING

Mapping for this project consists of the following sources.

- Effective Model (Michael Baker, Jr. 1999)
- Norte Vista / King Ranch Floodplain Redelineation by River Research & Design, Inc. (2007)
- Mapping prepared for this project (2006)

Figure 3.1 shows the location of the three sources. The following section provides a description of each of the sources and map control used for the study.

3.2.1 Salt-Gila River Floodplain Delineation Restudy

The mapping, covering the study area, was developed for the Effective study and was completed by Michael Baker, Jr. and McLain Harbers Co., Inc. (Michael Baker, Jr., 1999). The study area was first flown on 14 November 1991. During the end of 1992 and early 1993 a flood with a peak discharge 130,000 cfs occurred with the largest runoff volume recorded on the Gila River. The channel and part of the adjacent overbanks were reflown on 6 February 1993. The contour interval was four feet. The horizontal datum is NAD83 State Plane Coordinate System (AZ Central Zone, International Feet) and the vertical datum is NGVD 29. The topography was provided by the FCDMC.

3.2.2 Norte Vista / King Ranch Floodplain Redelineation

The mapping, covering the area between cross sections 188.69 and 194.29, was developed for the Norte Vista / King Ranch project (River Research & Design, Inc., 2007). The area was flown by Kenney Aerial Mapping, Inc during 2003 and 2004. Ground control survey was provided by Coe & Van Loo Consultants, Inc. The contour interval varied between one foot in the overbanks and two feet in the channel. The horizontal datum was based on the Norte Vista / King Ranch project and the vertical datum was NGVD 29. The project was projected to the same horizontal coordinate system as the Effective study using ArcView v3.2.

3.2.3 FCDMC Topography

The mapping, covering the study area between cross sections 187.06 and 191.38, was developed for this project. The area was flown by Vertical Mapping Resources, Inc. during March 13, 2006. Ground control survey was provided by RBF Consulting, Inc. The contour interval is two feet. The horizontal datum NAD83 State Plane Coordinate System (AZ Central Zone, International Feet) and the vertical datum is NGVD 88. To adjust NAVD 88 data to NGVD 29 a vertical adjustment factor was determined using the National Geodetic Survey program VERTCON accessed at http://www.ngs.noaa.gov/cgi-bin/VERTCON/vert_con.prl (August, 2001). Four latitude/longitude pairs were selected from within the re-mapped area, and the results are summarized in the table below. A vertical datum shift of 2.1 feet was used to adjust NAVD 88 data to NGVD 29.

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Table 3.1 Datum Adjustments

Latitude 1 (N)	Longitude 2 (W)	Datum shift (NAVD 88 minus NGVD 29) 3 (ft)
33.35	112.49	2.096
33.36	112.50	2.100
33.38	112.48	2.106
33.39	112.45	2.103
	Average	**2.101**

3.2.4 Comparison of Topographic Mapping

Figures 3.2 through 3.12 show a comparison of the Effective study and Corrected Effective study. In some locations the Corrected Effective study channel invert is as much as eight feet deeper. When the area was reflown for the Effective study 6 February 1993 there was still water in the channel from the flood event. The USGS gage data shows a discharge of 13,200 cfs on 6 February 1993 and 13,300 cfs for 7 February 1993. The water surface elevation in the main channel was mapped rather than the channel invert.

Figure 3.13 shows a comparison of the Effective study and Corrected Effective study thalweg. There are two locations were there is a sudden change in the thalweg near cross sections 194.12 and 186.97. This is due to the transition between new topography and the topography used for the Effective study. Also, the water elevations for the Effective and Corrected Effective models are shown.

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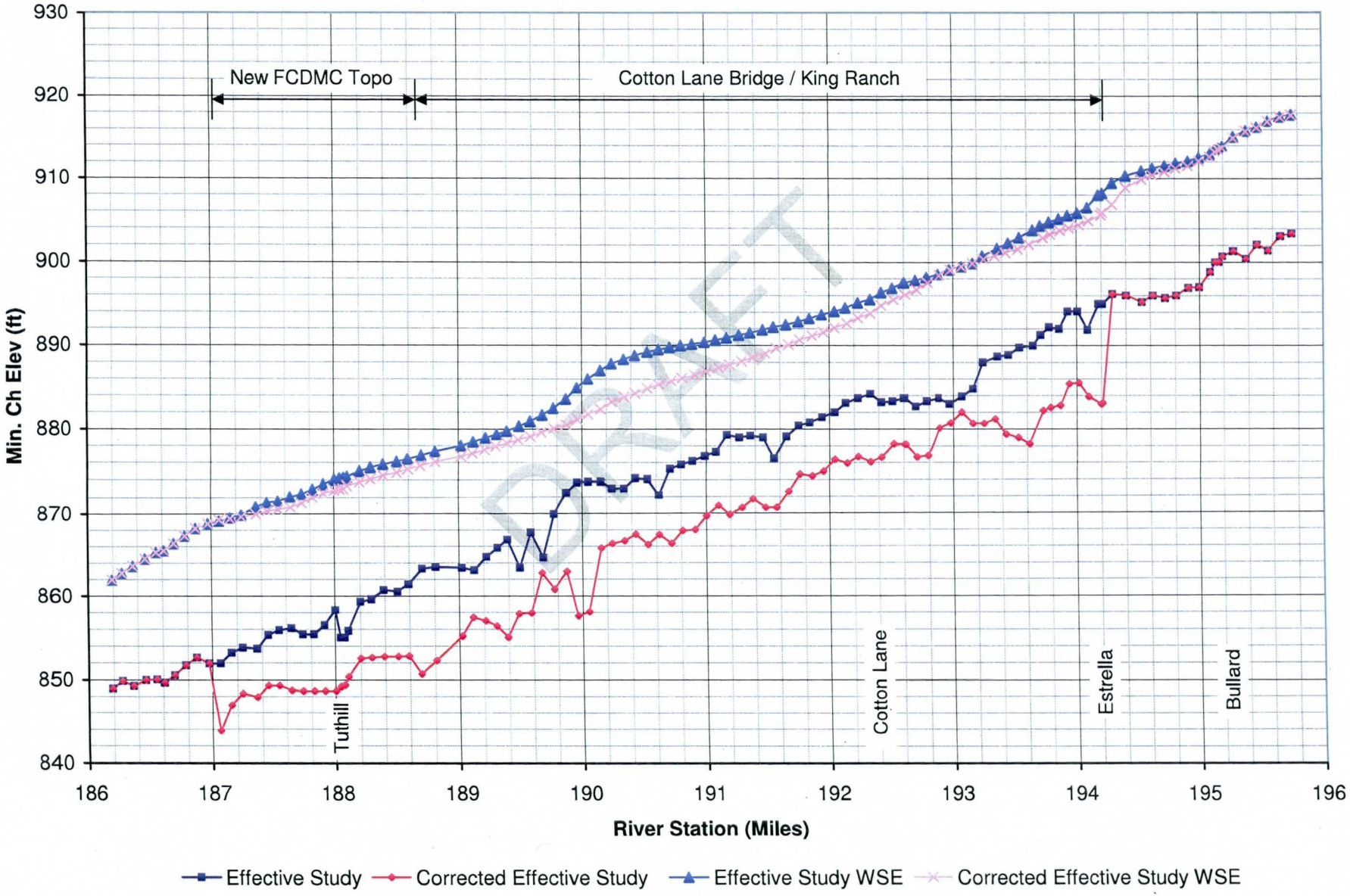
Figure 3.13
Comparison Between Effective and Corrected Effective Studies



4.0 HYDROLOGY

This study does not include changes to the hydrology. Peak discharges used in the hydraulic analysis were taken from the March 1996 U.S. Army Corps of Engineers report for the modifications to Roosevelt Dam entitled *Gila River Basin, Arizona, Section 7 Study for Modified Roosevelt Dam, Arizona, Hydrologic Evaluation of Water Control Plans, Salt River Project to Gila River at Gillespie Dam.*

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5.0 HYDRAULICS

5.1 METHOD DESCRIPTION

Baseline hydraulic data for the Corrected Effective study was obtained from the Effective model and the Norte Vista / King Ranch Projects. The Effective study was authorized in 1992 by the FCDMC and extends from 1.4 miles downstream of State Route 85 on the Gila River to the Granite Reef Dam on the Salt River. The HEC-RAS model for this study includes cross sections between 178.61 (approximately 3.4 miles downstream of State Route 85) and 199.07 (approximately four miles upstream of Estrella Parkway).

Aerial mapping was developed for the Norte Vista / King Ranch Project and is documented in the report *Norte Vista / King Ranch Floodplain Redelineation, Gila River, Goodyear, Arizona, Letter of Map Revision*, dated June 2007 by River Research & Design, Inc. This mapping covers the area between cross sections 188.69 and 194.29. Aerial mapping developed for this project covers the area between 187.06 and 191.38.

5.2 WORK STUDY MAPS

Floodplain delineation maps prepared for this study depict Corrected Effective floodplain and floodway boundaries, hydraulic cross section locations and alignments (see Exhibit Maps). Copies of the Work Maps reduced to 11" x 17" sheets are provided in the Exhibit Map Section Work Maps at 24" x 36" sheets size with a 1" = 400' scale are provided under separate cover. Work Maps depict where this study matches the Effective study mapping. Work maps for this study match the same sheet layout and page numbering so that sheets from the Effective study could be replaced with this study. The cover sheet shows the sheets effected by this study.

5.3 PARAMETER ESTIMATION

5.3.1 Roughness Coefficients

Roughness coefficients for the Gila River Floodplain Redelineation study were obtained from three sources. For cross sections upstream of 195.75 and downstream of 186.87 values from the Effective study were used (Michael Baker, Jr., 1994). Manning's n-values were estimated using circa 1991 and 1993 aerial photography, ground photographs and video and the 1 inch = 400 foot, 4 foot contour interval mapping. Ground photographs and videos were taken during field reconnaissance trips on 9 April and 18 November 1992 and 6 May and 16 June 1993.

For cross sections between 190.05 and 195.75 the n-values were obtained from the Norte Vista/ King Ranch project. For information regarding the method used to estimate the roughness coefficient see the report prepared by River Research & Design, Inc included on a CD in Appendix E. A figure showing the overview of the selected Manning's roughness coefficients is also included in Appendix E.

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For cross sections between 187.06 and 190.05 n-values were developed as part of this study for the channel. The n-values from the Effective model were used for the overbank areas. The Manning's roughness coefficients developed for the Effective Study were reviewed and, if necessary, were revised to reflect existing conditions of the Gila River. The following sections present the methodology and results of the investigation.

5.3.1.1 Methodology

In order to estimate Manning's n-values for portions of the study reach of the Gila River physical characteristics were identified through field observations and examination of ground and aerial photographs as well as examination of topographic mapping. The discerning characteristics recorded are channel size and shape, bed material, vegetation density; the presence of meanders or channel bends and the presence or absence of channel obstructions. Physical characteristics of the channel reach were viewed on foot during field reconnaissance and each sub-reach was photographed at representative locations.

Manning's n-values were estimated using the methods set forth in the US Geological Survey (USGS) publication *Estimated Manning's n-Values for Stream Channels and Flood Plains in Maricopa County Arizona (USGS, 1991)*. The method cited in the USGS publication and the method used for this study involved the selection of an initial Manning's n-value based upon the channel bed material and then the adjustment of that value for channel irregularities, effects of obstructions, vegetation and channel cross sectional variations. If the channel has sufficient meander to increase roughness, then the sum of the base n-value plus subsequent adjustments is multiplied by a meander value, *m*.

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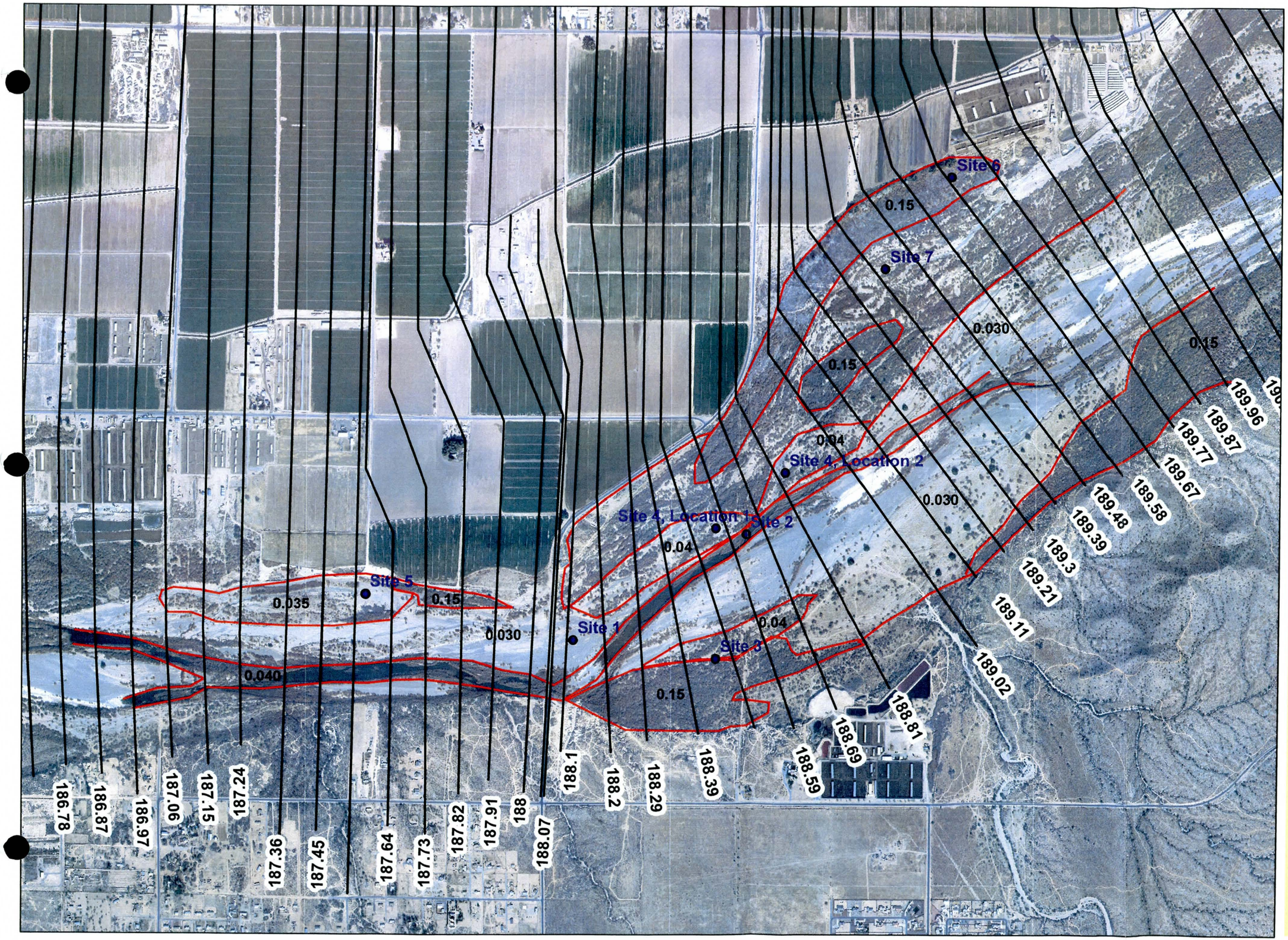

Flood Control District of Maricopa County
2801 W. Durango St.
Phoenix, AZ 85009

Consultants:

Stantec Consulting Inc.
8211 S. 48th St.
Phoenix, AZ 85044

Legend

- Data Collection Points
- Cross-Section Location
- Manning's n-Value Boundary

Manning's n-Value Distribution Map
Figure 5.1

N

0 305 610 1,220 Feet

1 inch = 1200 feet

Title:

GILA RIVER FLOODPLAIN REDELINEATION STUDY

Produced by:
RKJ

Date:
21 Aug 2006

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The main flow conveyance area (the area between the bank stations) of the Gila River is characterized with multiple channels (see Figure 5.1). Vegetation occurs adjacent to the channels generally along the side slopes of each of the channels. A composite n-value is estimated for vegetated channel segments that is representative of the vegetated side slopes and the non-vegetated bottom width. The difference between the composite n-value and the base n-value is then coded as the channel vegetation adjustment in the calculation sheets. Composite n-values are estimated for a typical channel section using Equation 6-17 from *Open Channel Hydraulics, Chow (1959).* That equation is:

$$nc = \left[\frac{\left(P_1 n_1^{1.5} + P_2 n_2^{1.5} + P_3 n_3^{1.5} \right)}{P} \right]^{2/3}$$

where:

P = total wetted perimeter of the channel;

P_1 = wetted perimeter of the channel bottom;

$P_{2,3}$ = wetted perimeter of the channel side slopes;

n_1 = Manning's n-value of the channel bottom; and

$n_{2,3}$ = Manning's n-value of the channel side slopes.

nc = composite n-value

The typical channel section estimated for a channel is based on inspection of the cross section plots, aerial photographs and field visits. The typical section is determined to be trapezoidal with 1:1 (horizontal to vertical) side slopes with channel bottom widths of up to 200 feet. Average depths of flow for the estimation of the wetted perimeter are approximately 21 feet. A channel side slope n-value of 0.050 is used along with the base n-value estimated for each watercourse reach to determine a composite n-value.

5.3.1.2 Summary of Manning's Roughness Coefficients

Calculation sheets developed to estimate Manning's n-values are provided in Appendix E. Manning's n-value estimated for the river reach from cross sections 187.06 to 190.05 are:

- Areas of dense vegetation (minor open areas no localized channels) = 0.15
- Areas of medium-dense vegetation (some open areas with localized channels) = 0.065
- Areas where the open area is at least 50 percent of the define n-value area = 0.040
- Channels with dense vegetation adjacent and along side slopes = 0.040
- Areas of light vegetation coverage = 0.035

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- Clear areas with minor vegetation = 0.030

Manning's n-values estimated in this study for the river reach between cross sections 187.06 to 190.05 are consistent with Manning's n-values estimated for the Effective Study. Figure 5.1 shows the n-value distribution between cross sections 187.06 and 190.05.

5.3.2 Expansion and Contraction Coefficients

The contraction and expansion coefficients for the study area were obtained from two sources. For cross sections between 186.87 and 195.75 the coefficients were obtain from the Norte Vista/ King Ranch Project. Contraction and expansion coefficients for the main channel and the Tuthill Bridge were set to 0.1 and 0.3, respectively, which is consistent with the Effective study. For cross sections upstream of 195.75 and downstream of 186.87 coefficients were obtained from the Effective study.

5.4 CROSS SECTION DESCRIPTION

A HEC-RAS model was used to develop the Corrected Effective floodplain and floodway boundaries. Three sources were used to develop the model and are shown on Figure 3.1. The Effective study HEC-RAS model, obtained from the FCDMC, covers the area between cross sections 178.61 and 199.07. Norte Vista / King Ranch Project HEC-RAS model obtained from River Research & Design, Inc. replaced the Effective study area between cross sections 194.29 and 191.48 and between 191.38 and 188.69 in the channel only. Between cross sections 187.06 and 188.59 and between 188.69 and 191.38 in the right overbank only new topography developed for this study replaced the Effective study area. Cross sectional geometry was developed from the new topography using a triangulated irregular network (TIN).

A TIN was developed from digital terrain models using the 3D Analyst extension of ArcView GIS v3.2 from the following sources.

- Effective mapping obtained from the FCDMC
- Norte Vista / King Ranch Project obtained from River Research & Design, Inc.
- New Topography obtained from the FCDMC

Contours, shown on the work maps, were developed from the TIN. The cross sectional alignments were provided by River Research & Design, Inc. The cross section numbering is expressed in river miles above Painted Rock Dam. Cross section stationing is from left to right looking downstream with the location of the hydraulic baseline set to station 20,000. The cross sectional alignments were adjusted slightly from the Effective study to better represent existing conditions. The following is a summary of differences between the Norte Vista / King Ranch and Effective study cross sectional data for the area between 194.29 and 188.69.

- Cross sections were modified slightly to better represent flows in the proposed channel between cross sections 193.73 and 190.24. See the figure located in Appendix E.3.

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- The hydraulic baseline was modified slightly to stay within the channel. This resulted in a cross sectional station difference of 0.01 miles for the realigned cross sections.

Further information regarding the cross section modifications can be found in the TDN by River Research & Design, Inc.

5.5 MODELING CONSIDERATIONS

5.5.1 Hydraulic Jump and Drop Analysis

There are no drop structures or physical conditions that would develop a hydraulic jump within the study reach.

5.5.2 Bridges and Culverts

There are four bridges in the reach of the Gila River between RM 178.91 to 199.07 and are summarized in Table 5-1. Bridge data needed to code HEC-RAS models was obtained from the Effective HEC-RAS model.

Table 5.1 Summary of Bridges

Location	Cross Section	Type of Structure	Modeling Method	Source of Data
1	2	3	4	5
State Route 85	180.025	Bridge	Energy (Standard Step) in HEC-RAS	Effective Study
Tuthill Road	188.055	Bridge	Energy (Standard Step) in HEC-RAS	Effective Study
Estrella Road	194.205	Bridge	Energy (Standard Step) in HEC-RAS	Effective Study
Bullard Avenue	195.15	Bridge	Energy (Standard Step) in HEC-RAS	Effective Study

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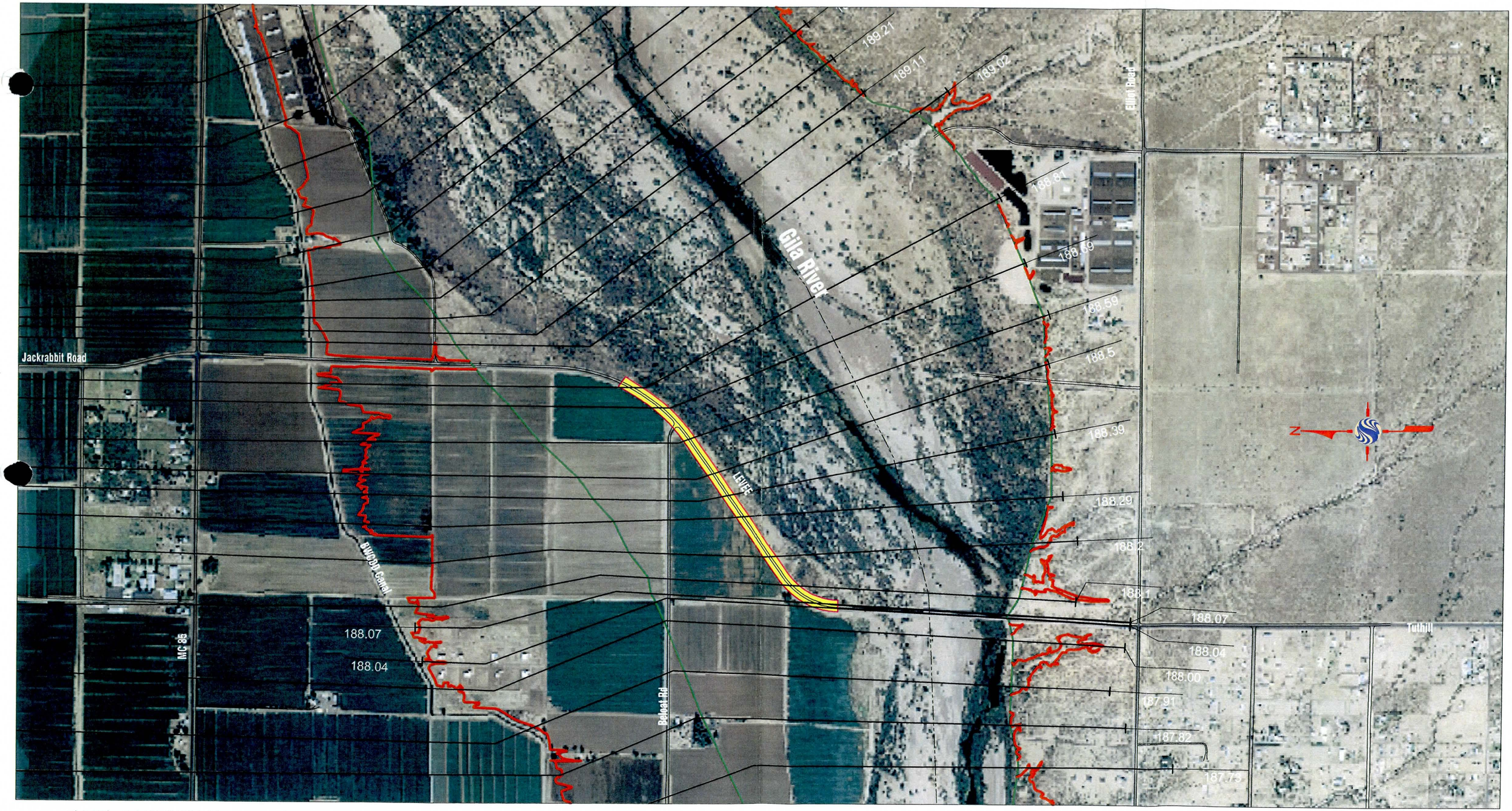
5.5.3 Levees and Dikes

There are no engineered levees in the project but the area upstream of Tuthill bridge may function as a levee as shown on Figure 5.2. Two HEC-RAS models were built to investigate the effects of the levee, "with levee" and "without levee". The "with levee" model includes using the levee option in HEC-RAS between cross sections 188.81 and 188.07 at the location of the roadway. This model investigates the effects if the roadway embankment does not fail during the 100-year event resulting in a higher water surface elevation in the main channel of the Gila River. The "without levee" assumes the roadway embankment would fail and water could enter the area on the west side of the roadway. This model shows a lower water surface elevation in the main channel but a wider floodplain. Base Flood Elevation (BFE) lines on the work study maps for the "with levee" model were drawn between the roadway embankment and the south bank. BFE lines for the "without levee" model were drawn between the north bank and the roadway embankment. The floodplain elevations shown on the maps are from the "without levee" model. The floodway encroachment stations and elevations for both models are the same.



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2007-06-19 04:38PM By: amlynch

April, 2007
182000453

ORIGINAL SHEET - ANSI B

Stantec Consulting Inc.
8211 South 48th Street
Phoenix AZ U.S.A.
85044
Tel. 602.438.2200
Fax. 602.431.9562
www.stantec.com

Legend

- Corrected Effective Floodway
- Corrected Effective Floodplain
- Cross Sections
- Baseline
- Levee

1in=1000ft 0 1000' 1500' 2000'

Client/Project
Flood Control District of Maricopa County
Gila River Floodplain Redelineation Study
FCD No. 2006C013, PCN No. 014.34.01

Figure No.
5.2

Title
Levee Located Near Tuthill Bridge

5.5.4 Islands and Flow Splits

No flow splits were identified through restudy reach. Islands were included within the 100-year floodplain.

5.5.5 Ineffective Flow Areas

The ineffective flow area option of the HEC-RAS computer program is used to model ineffective flow areas. Typical ineffective flow areas are located upstream and downstream of bridges, backwater areas in the floodplain and within topographic depressions in which runoff is ponded and there is no apparent conveyance from one cross-section to another. Ineffective flow areas were also utilized in the Effective HEC-RAS model to define non-conveyance areas behind canals and roadways that function as levees.

5.5.6 Supercritical Flow

There are no areas of supercritical flow within the study reach.

5.6 FLOODWAY MODELING

Floodway encroachments were obtained from two sources. The Effective study encroachments were used upstream of cross section 195.75 and downstream of cross section 186.87. Between cross sections 195.75 and 186.87 encroachment stations from the Norte Vista / King Ranch HEC-RAS model were used. The model was checked to make sure the rise in water surface elevation between the floodplain and the floodway model was less than a foot rise.

5.7 PROBLEMS ENCOUNTERED DURING THE STUDY

5.7.1 Tie-In to Existing Floodplain Delineations

This study ties into the Effective study at upstream and downstream ends at cross sections 195.00 and 187.06 (Baker, 1999). Table 5.2 shows a comparison between the water surface elevation and top width for the Effective and Corrected Effective study. It also ties into the Bullard Wash between cross sections 194.91 and 194.40.

Table 5.2 Comparison at Tie-in Locations

River Sta (miles)	Water Surface Elevation		Top Width	
	Effective (ft)	Corrected Effective (ft)	Effective (ft)	Corrected Effective (ft)
1	2	3	4	5
195.00	912.50	912.05	4,603.60	4,365.95
187.06	869.09	869.25	4621	4630

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5.7.2 Effects of New Topography

As stated in previous sections new topography was obtained for the area between Airport Road (cross section 187.06) and Bullard Avenue (cross section 195.00). The new topography was used to update the HEC-RAS model. Water surface elevations decreased in some area as much as four feet. At the tie-ins between the new and existing topography there is a sudden change in the thalweg.

5.7.3 HEC-RAS Warning and Error Messages

The HEC-RAS models ("with levee" and "without levee") execute with out errors for both the floodplain and floodway profiles. However, the model does report several different warning messages. In general, the majority of these messages are to be expected given the hydraulic characteristic of the Gila River.

5.7.4 CHECKRAS Warning Messages

Warning messages from CHECKRAS in the Corrected Effective study area (187.06 and 195.00) were reviewed. The areas upstream of cross section 195.00 and downstream of cross section 187.06 are in Effective Study area. The reports from CHECKRAS are included in Appendix E.

NT Check – Several warnings were noted for the Manning's roughness values that were less than 0.035 in the overbank area. This warning is not applicable for this situation since majority of the overbank area is farm fields. For an explanation of the Manning's roughness determination see the report by River Research & Design, Inc. Several warnings were noted for contraction/expansion coefficients. These values were obtained from work completed by River Research & Design, Inc.

Cross Section Check – Several warnings were noted for overbank distances longer than channel distances. This warning is not applicable for this situation since the overbank area has wide shallow flooding in the farm fields. Another warning was concerning the decrease in discharge in the downstream direction. This warning is not applicable for this situation since the values were obtained from the March 1996 U.S. Army Corps of Engineers report for the modifications to Roosevelt Dam entitled *Gila River Basin, Arizona, Section 7 Study for Modified Roosevelt Dam, Arizona, Hydrologic Evaluation of Water Control Plans, Salt River Project to Gila River at Gillespie Dam.*

Structure Check – Warnings were noted for the Estrella and Tuthill Bridges within the study area. The bridge data including cross section spacing and alignments, ineffective flow and encroachment stations were provided as part of the Effective Model.

Floodway Check – Several warnings were noted regarding the location of the floodway encroachment station. The location of the floodway was provided by River Research & Design, Inc. except for one cross section, 191.29. At this cross section the encroachment station was moved from 24,029.92 to 23,940.6 to smooth the floodway limits.

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5.8 CALIBRATION

No calibration procedures were attempted in this study. The mapped floodplain limits were inspected for reasonableness and found to be appropriate.

5.9 FINAL RESULTS

Print outs from the HEC-RAS models for each of the Corrected Effective models ("with levee" and "without levee") are provided in Appendix E on the CD as a Portable Document Format (PDF). Summary output for the floodplain profiles are provided in Tables 5.3 through 5.6. Results are reported for the reach of the Gila River commencing at cross section 187.06 to 195.00. The HEC-RAS model data files, both input and output, are provided digitally on CD in Appendix E.

5.9.1 Verification of Results

The results seem reasonable. In the areas with the Effective topography the Effective and Corrected Effective floodplains correspond closely.

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Table 5.3 Summary of HEC-RAS Model Results for Corrected Effective Model – Without Levee

River Sta (miles)	Peak Discharge (cfs)	Min. Channel Elev (ft)	Water Surface Elevation (ft)	Critical Water Surface (ft)	Energy Gradeline Elevation (ft)	Slope (ft/ft)	Average Velocity (ft/s)	Flow Area (ft^2)	Top Width (ft)	Froude # Channel	Station where Water Surface meets Existing Ground Left (ft)	Right (ft)
1	2	3	4	5	6	7	8	9	10	11	12	13
195.00	227,000	897.00	912.05	908.48	913.29	0.001539	8.51	26,683.25	4,365.95	0.49	17,213.10	21,979.16
194.91	227,000	896.90	911.43	907.63	912.52	0.001445	7.91	28,689.01	4,973.50	0.47	17,089.49	22,135.55
194.81	227,000	896.00	911.16	905.84	911.88	0.000817	6.46	35,130.51	5,165.74	0.37	17,036.21	22,281.86
194.72	227,000	895.70	910.72	905.79	911.46	0.000926	6.63	34,241.34	4,705.38	0.38	16,914.04	22,396.20
194.62	227,000	896.00	910.34	905.58	910.99	0.000859	6.36	35,666.16	5,278.02	0.36	16,692.66	22,404.24
194.53	227,000	895.20	909.83	905.21	910.53	0.000967	6.57	34,572.30	5,319.66	0.38	16,349.91	22,503.40
194.40	227,000	896.00	908.85	904.77	909.76	0.00122	7.33	30,954.36	5,834.81	0.43	16,361.12	22,727.92
194.29	227,000	896.20	906.81	904.97	908.44	0.002932	10.03	22,624.69	5,080.08	0.65	16,825.07	22,215.02
194.21	227,000	883.10	905.84	902.06	907.36	0.001658	9.88	22,970.87	2,979.75	0.53	17,414.00	21,242.21
194.21	Bridge											
194.20	227,000	882.97	905.54	901.99	907.12	0.001784	10.10	22,475.03	2,480.10	0.55	18,403.47	21,241.86
194.10	227,000	883.87	904.89	901.14	906.20	0.001547	9.15	24,796.13	4,390.06	0.51	16,687.87	22,709.57
194.02	227,000	885.49	904.35	900.33	905.46	0.00138	8.45	26,871.63	4,253.57	0.47	16,821.56	22,783.06
193.94	227,000	885.38	904.03	899.39	904.93	0.001122	7.57	29,970.23	4,683.23	0.42	17,244.50	22,857.77
193.87	227,000	882.80	903.69	898.76	904.49	0.001007	7.04	32,262.01	4,427.13	0.39	17,628.36	22,935.67
193.79	227,000	882.55	903.27	898.23	904.02	0.001117	6.69	33,925.36	4,083.98	0.38	18,117.93	23,032.46
193.73	227,000	882.18	902.83	898.08	903.65	0.000975	6.98	32,509.36	3,422.12	0.40	18,740.59	22,162.71
193.62	227,000	878.21	902.05	897.98	903.03	0.001218	7.60	29,855.05	3,219.12	0.45	19,051.18	23,203.45
193.53	227,000	878.96	901.51	897.32	902.43	0.001137	7.39	30,702.08	3,344.27	0.43	19,072.85	23,317.95
193.43	227,000	879.37	901.10	896.46	901.89	0.000967	6.88	32,988.75	3,715.32	0.40	18,888.26	23,165.00
193.34	227,000	881.18	900.75	895.90	901.42	0.000841	6.51	34,858.21	3,883.49	0.37	18,786.64	22,969.17
193.25	227,000	880.67	900.34	895.48	900.97	0.001037	6.33	35,888.74	4,130.90	0.37	18,721.88	23,214.23
193.16	227,000	880.66	899.83	895.44	900.50	0.000916	6.51	34,876.11	4,280.55	0.40	18,634.94	23,229.60
193.07	227,000	881.99	899.45	894.72	900.07	0.000809	6.16	36,863.37	4,504.31	0.37	18,643.94	23,273.04
192.98	227,000	880.71	899.02	894.32	899.66	0.000871	6.16	36,831.25	4,501.19	0.37	18,928.59	24,878.79

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Table 5.3 Summary of HEC-RAS Model Results for Corrected Effective Model – Without Levee - Continued

River Sta (miles) 1	Peak Discharge (cfs) 2	Min. Channel Elev (ft) 3	Water Surface Elevation (ft) 4	Critical Water Surface (ft) 5	Energy Gradeline Elevation (ft) 6	Slope (ft/ft) 7	Average Velocity (ft/s) 8	Flow Area (ft^2) 9	Top Width (ft) 10	Froude # Channel 11	Station where Water Surface meets Existing Ground Left (ft) 12	Right (ft) 13
192.89	227,000	880.09	898.37	894.01	899.12	0.001351	6.41	35,406.87	5,079.01	0.40	19,110.72	24,351.63
192.79	227,000	876.81	897.48	893.64	898.36	0.001733	6.68	33,982.21	5,344.82	0.44	19,297.34	24,708.11
192.70	227,000	876.64	896.65	892.33	897.59	0.00135	6.55	34,668.83	5,676.24	0.43	19,297.82	25,035.08
192.61	227,000	878.15	896.06	891.72	896.98	0.001156	6.47	35,074.86	5,867.25	0.43	19,101.56	25,156.22
192.52	227,000	878.23	895.45	890.81	896.39	0.001143	6.71	33,829.27	6,069.90	0.42	19,204.28	25,385.55
192.42	227,000	876.63	894.77	891.45	895.76	0.001342	7.10	31,983.89	5,805.89	0.46	19,106.59	25,487.08
192.33	227,000	876.06	893.84	890.83	895.01	0.00162	7.52	30,200.71	5,967.72	0.50	18,871.84	25,520.52
192.23	227,000	876.72	893.27	889.65	894.18	0.001411	6.74	33,685.09	5,890.23	0.44	18,795.19	25,321.78
192.14	227,000	875.94	892.64	889.42	893.48	0.001356	6.42	35,378.34	6,572.73	0.44	18,684.32	25,373.57
192.04	227,000	876.36	892.11	888.54	892.82	0.001176	5.91	38,409.08	6,336.14	0.41	18,630.83	25,016.40
191.95	227,000	874.98	891.62	887.60	892.25	0.001012	5.65	40,187.71	6,282.49	0.39	18,576.79	24,885.82
191.86	227,000	874.43	891.15	886.73	891.74	0.000978	5.54	40,953.98	6,189.44	0.37	17,438.13	24,845.81
191.76	227,000	874.62	890.69	886.58	891.22	0.001009	5.25	43,226.16	6,578.67	0.36	18,475.45	25,072.07
191.67	227,000	872.60	890.16	886.43	890.69	0.001104	5.40	42,056.90	6,300.26	0.38	18,318.96	24,867.01
191.57	227,000	870.63	889.71	885.66	890.16	0.000936	5.04	45,028.50	6,269.06	0.35	17,002.99	24,646.26
191.48	227,000	870.63	889.10	885.67	889.63	0.001143	5.52	41,109.40	6,197.89	0.39	17,050.00	24,617.42
191.38	227,000	871.69	888.63	884.70	889.09	0.000958	5.13	44,256.73	6,622.20	0.34	17,595.11	24,224.63
191.29	227,000	870.63	888.21	883.78	888.62	0.000855	4.93	46,012.75	6,935.29	0.32	17,006.06	24,046.09
191.19	227,000	869.78	887.79	882.89	888.21	0.000795	4.97	45,676.42	7,262.12	0.31	16,883.88	27,498.55
191.10	227,000	870.88	887.44	882.08	887.85	0.000644	4.89	46,420.29	7,374.02	0.30	16,881.09	27,953.45
191.00	227,000	869.64	887.05	881.88	887.51	0.000704	5.15	44,116.21	7,043.55	0.31	16,775.67	27,827.01
190.91	227,000	867.98	886.63	881.54	887.13	0.000804	5.30	42,809.86	7,269.76	0.32	16,652.40	28,081.31
190.81	227,000	867.86	886.27	881.12	886.75	0.000694	5.22	43,515.63	7,494.50	0.32	16,638.51	28,250.70
190.72	227,000	866.30	885.93	880.48	886.40	0.00069	5.07	44,744.39	7,567.59	0.31	16,683.06	28,421.51
190.62	227,000	867.37	885.56	880.08	886.04	0.000766	5.15	44,095.21	6,953.89	0.31	17,649.36	28,443.75
190.53	227,000	866.16	885.10	879.61	885.61	0.000919	5.41	41,990.17	5,568.45	0.32	18,270.27	28,203.83
190.43	227,000	867.42	884.58	878.92	885.15	0.000918	5.48	41,389.80	5,370.74	0.33	18,311.10	28,498.54

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Table 5.3 Summary of HEC-RAS Model Results for Corrected Effective Model – Without Levee - Continued

River Sta (miles) 1	Peak Discharge (cfs) 2	Min. Channel Elev (ft) 3	Water Surface Elevation (ft) 4	Critical Water Surface (ft) 5	Energy Gradeline Elevation (ft) 6	Slope (ft/ft) 7	Average Velocity (ft/s) 8	Flow Area (ft^2) 9	Top Width (ft) 10	Froude # Channel 11	Station where Water Surface meets Existing Ground Left (ft) 12	Right (ft) 13
190.34	227,000	866.61	884.11	878.36	884.67	0.000991	5.37	42,309.69	5,453.74	0.33	18,344.86	28,948.38
190.24	227,000	866.29	883.58	877.78	884.13	0.001122	5.28	42,974.58	5,162.69	0.33	18,253.82	28,926.73
190.15	227,000	865.74	882.72	878.04	883.49	0.001463	6.14	36,946.05	4,887.60	0.40	17,970.61	28,963.16
190.05	227,000	858.06	882.10	875.75	882.72	0.00139	5.36	42,321.89	5,183.88	0.35	18,286.64	29,166.69
189.96	227,000	857.56	881.46	875.66	882.06	0.00132	5.45	41,646.34	5,994.58	0.34	18,389.61	29,395.48
189.87	227,000	862.94	880.80	874.83	881.37	0.00151	5.34	42,478.85	5,961.75	0.34	18,431.87	29,647.96
189.77	227,000	860.75	880.30	873.42	880.71	0.000913	4.58	49,580.35	9,166.13	0.28	18,347.91	29,847.25
189.67	227,000	862.77	879.81	873.14	880.24	0.000896	4.64	48,887.17	9,148.01	0.28	18,141.59	29,581.68
189.58	227,000	857.92	879.34	872.76	879.76	0.001003	4.60	49,366.23	9,112.92	0.28	18,149.62	29,598.80
189.48	227,000	857.85	878.93	871.94	879.31	0.000783	4.47	50,748.71	9,789.47	0.26	18,302.26	29,726.47
189.39	227,000	855.02	878.58	871.32	878.95	0.000637	4.36	52,034.00	10,236.19	0.26	18,355.89	30,031.79
189.30	227,000	856.36	878.25	871.53	878.63	0.000843	4.48	50,633.75	10,089.01	0.27	18,348.35	30,114.57
189.21	227,000	856.97	877.83	870.89	878.18	0.000972	4.46	50,889.97	9,761.26	0.26	18,287.88	30,317.45
189.11	227,000	857.40	877.35	869.73	877.68	0.000955	4.35	52,170.65	9,434.89	0.25	18,185.10	30,515.60
189.02	227,000	855.16	876.85	868.98	877.19	0.000957	4.35	52,162.66	9,211.87	0.26	17,733.98	30,025.99
188.81	227,000	852.25	876.09	866.91	876.42	0.00053	4.34	52,309.21	8,415.25	0.23	17,691.77	30,189.43
188.69	227,000	850.62	875.64	868.19	876.02	0.000858	4.76	47,656.55	8,476.33	0.26	17,710.53	30,337.22
188.59	227,000	852.76	875.22	868.14	875.55	0.000835	4.51	50,356.12	9,087.30	0.26	17,774.44	30,541.09
188.50	227,000	852.73	874.87	867.21	875.19	0.00066	4.34	52,281.70	9,430.57	0.24	17,981.43	30,715.02
188.39	227,000	852.73	874.50	866.13	874.83	0.000632	4.41	51,428.02	8,574.63	0.24	18,228.35	31,750.69
188.29	227,000	852.62	874.12	866.08	874.49	0.000678	4.60	49,349.50	7,572.93	0.25	18,374.89	26,275.88
188.20	227,000	852.50	873.79	864.43	874.24	0.000384	4.90	46,344.16	6,831.61	0.25	18,525.04	25,469.41
188.10	227,000	850.29	873.35	864.63	873.92	0.001042	5.60	40,505.92	6,471.46	0.28	19,005.20	26,045.80
188.07	227,000	849.32	872.98	864.69	873.74	0.000644	6.33	35,837.88	5,491.49	0.32	19,114.55	25,797.52
188.06	Bridge											
188.04	227,000	849.15	872.95	864.98	873.71	0.000686	6.03	37,619.47	5,982.72	0.33	19,126.97	25,838.95
188.00	227,000	848.62	872.83	866.60	873.50	0.000683	5.90	38,490.64	6,770.00	0.35	18,047.96	29,716.11

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Table 5.4 Summary of HEC-RAS model results for Corrected Effective Model – With Levee

River Sta (miles)	Peak Discharge (cfs)	Min. Channel Elev (ft)	Water Surface Elevation (ft)	Critical Water Surface (ft)	Energy Gradeline Elevation (ft)	Slope (ft/ft)	Average Velocity (ft/s)	Flow Area (ft^2)	Top Width (ft)	Froude # Channel	Station where Water Surface meets Existing Ground Left (ft)	Right (ft)
1	2	3	4	5	6	7	8	9	10	11	12	13
195.00	227,000	897.00	912.05	908.48	913.29	0.001539	8.51	26,683.25	4,365.95	0.49	17,213.10	21,979.16
194.91	227,000	896.90	911.43	907.63	912.52	0.001445	7.91	28,689.01	4,973.50	0.47	17,089.49	22,135.55
194.81	227,000	896.00	911.16	905.84	911.88	0.000817	6.46	35,130.51	5,165.74	0.37	17,036.21	22,281.86
194.72	227,000	895.70	910.72	905.79	911.46	0.000926	6.63	34,241.34	4,705.38	0.38	16,914.04	22,396.20
194.62	227,000	896.00	910.34	905.58	910.99	0.000859	6.36	35,666.16	5,278.02	0.36	16,692.66	22,404.24
194.53	227,000	895.20	909.83	905.21	910.53	0.000967	6.57	34,572.30	5,319.66	0.38	16,349.91	22,503.40
194.40	227,000	896.00	908.85	904.77	909.76	0.00122	7.33	30,954.36	5,834.81	0.43	16,361.12	22,727.92
194.29	227,000	896.20	906.81	904.97	908.44	0.002932	10.03	22,624.69	5,080.08	0.65	16,825.07	22,215.02
194.21	227,000	883.10	905.84	902.06	907.36	0.001658	9.88	22,970.87	2,979.75	0.53	17,414.00	21,242.21
194.21	Bridge											
194.20	227,000	882.97	905.54	901.99	907.12	0.001784	10.10	22,475.03	2,480.10	0.55	18,403.47	21,241.86
194.10	227,000	883.87	904.89	901.14	906.20	0.001547	9.15	24,796.13	4,390.06	0.51	16,687.87	22,709.57
194.02	227,000	885.49	904.35	900.33	905.46	0.00138	8.45	26,871.63	4,253.57	0.47	16,821.56	22,783.06
193.94	227,000	885.38	904.03	899.39	904.93	0.001122	7.57	29,970.23	4,683.23	0.42	17,244.50	22,857.77
193.87	227,000	882.80	903.69	898.76	904.49	0.001007	7.04	32,262.01	4,427.13	0.39	17,628.36	22,935.67
193.79	227,000	882.55	903.27	898.23	904.02	0.001117	6.69	33,925.36	4,083.98	0.38	18,117.93	23,032.46
193.73	227,000	882.18	902.83	898.08	903.65	0.000975	6.98	32,509.36	3,422.12	0.40	18,740.59	22,162.71
193.62	227,000	878.21	902.05	897.98	903.03	0.001218	7.60	29,855.05	3,219.12	0.45	19,051.18	23,203.45
193.53	227,000	878.96	901.51	897.32	902.43	0.001137	7.39	30,702.08	3,344.27	0.43	19,072.85	23,317.95
193.43	227,000	879.37	901.10	896.46	901.89	0.000967	6.88	32,988.75	3,715.32	0.40	18,888.26	23,165.00
193.34	227,000	881.18	900.75	895.90	901.42	0.000841	6.51	34,858.21	3,883.49	0.37	18,786.64	22,969.17
193.25	227,000	880.67	900.34	895.48	900.97	0.001037	6.33	35,888.74	4,130.90	0.37	18,721.88	23,214.23
193.16	227,000	880.66	899.83	895.44	900.50	0.000916	6.51	34,876.11	4,280.55	0.40	18,634.94	23,229.60
193.07	227,000	881.99	899.45	894.72	900.07	0.000809	6.16	36,863.37	4,504.31	0.37	18,643.94	23,273.04
192.98	227,000	880.71	899.02	894.32	899.66	0.000871	6.16	36,831.25	4,501.19	0.37	18,928.59	24,878.79
192.89	227,000	880.09	898.38	894.01	899.12	0.001351	6.41	35,407.17	5,079.04	0.40	19,110.72	24,351.65
192.79	227,000	876.81	897.48	893.64	898.36	0.001733	6.68	33,982.84	5,344.83	0.44	19,297.34	24,708.11

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Table 5.4 Summary of HEC-RAS model results for Corrected Effective Model – With Levee - Continued

River Sta (miles) 1	Peak Discharge (cfs) 2	Min. Channel Elev (ft) 3	Water Surface Elevation (ft) 4	Critical Water Surface (ft) 5	Energy Gradeline Elevation (ft) 6	Slope (ft/ft) 7	Average Velocity (ft/s) 8	Flow Area (ft^2) 9	Top Width (ft) 10	Froude # Channel 11	Station where Water Surface meets Existing Ground Left (ft) 12	Right (ft) 13
192.70	227,000	876.64	896.65	892.33	897.59	0.00135	6.55	34,669.86	5,676.25	0.43	19,297.82	25,035.08
192.61	227,000	878.15	896.06	891.72	896.98	0.001156	6.47	35,076.17	5,867.31	0.43	19,101.56	25,156.22
192.52	227,000	878.23	895.45	890.81	896.39	0.001143	6.71	33,830.84	6,069.92	0.42	19,204.28	25,385.55
192.42	227,000	876.63	894.77	891.45	895.76	0.001342	7.10	31,985.99	5,806.00	0.46	19,106.59	25,487.08
192.33	227,000	876.06	893.84	890.83	895.01	0.00162	7.52	30,204.42	5,967.96	0.50	18,871.84	25,520.53
192.23	227,000	876.72	893.27	889.65	894.18	0.001411	6.74	33,690.27	5,890.57	0.44	18,795.18	25,321.78
192.14	227,000	875.94	892.65	889.42	893.49	0.001356	6.41	35,386.34	6,572.84	0.44	18,684.31	25,373.57
192.04	227,000	876.36	892.11	888.54	892.82	0.001175	5.91	38,420.22	6,336.29	0.41	18,630.82	25,016.40
191.95	227,000	874.98	891.62	887.60	892.25	0.001012	5.65	40,201.91	6,282.63	0.39	18,576.78	24,885.84
191.86	227,000	874.43	891.16	886.73	891.74	0.000977	5.54	40,971.36	6,189.63	0.37	17,438.12	24,845.93
191.76	227,000	874.62	890.70	886.58	891.23	0.001007	5.25	43,249.20	6,580.90	0.36	18,475.43	25,073.13
191.67	227,000	872.60	890.16	886.43	890.70	0.001102	5.39	42,086.52	6,301.87	0.38	18,318.56	24,867.06
191.57	227,000	870.63	889.72	885.66	890.17	0.000934	5.04	45,065.23	6,269.60	0.35	17,002.95	24,646.30
191.48	227,000	870.63	889.11	885.67	889.64	0.001139	5.52	41,158.40	6,198.30	0.39	17,049.93	24,617.58
191.38	227,000	871.69	888.64	884.70	889.10	0.000954	5.12	44,323.43	6,622.81	0.34	17,595.04	24,225.03
191.29	227,000	870.63	888.22	883.78	888.63	0.000851	4.92	46,096.99	6,940.78	0.32	17,005.88	26,810.34
191.19	227,000	869.78	887.80	882.89	888.22	0.000791	4.96	45,774.61	7,291.09	0.31	16,883.09	27,499.30
191.10	227,000	870.88	887.45	882.08	887.86	0.00064	4.88	46,527.02	7,399.87	0.29	16,879.79	27,955.04
191.00	227,000	869.64	887.07	881.88	887.53	0.000699	5.13	44,238.78	7,094.44	0.31	16,775.61	27,832.51
190.91	227,000	867.98	886.66	881.54	887.15	0.000797	5.28	42,959.39	7,289.59	0.32	16,652.29	28,093.86
190.81	227,000	867.86	886.29	881.12	886.78	0.000687	5.20	43,687.60	7,508.56	0.32	16,638.12	28,256.26
190.72	227,000	866.30	885.96	880.48	886.43	0.000683	5.05	44,933.98	7,587.64	0.31	16,682.91	28,431.77
190.62	227,000	867.37	885.60	880.08	886.07	0.000758	5.12	44,295.21	6,972.56	0.31	17,649.25	28,456.82
190.53	227,000	866.16	885.14	879.61	885.65	0.000908	5.38	42,190.26	5,578.30	0.32	18,270.12	28,212.20
190.43	227,000	867.42	884.63	878.92	885.19	0.000905	5.45	41,614.54	5,387.65	0.33	18,310.23	28,509.69
190.34	227,000	866.61	884.16	878.36	884.72	0.000975	5.33	42,562.21	5,479.48	0.33	18,341.08	28,968.92
190.24	227,000	866.29	883.64	877.78	884.19	0.001101	5.25	43,268.70	5,199.53	0.32	18,251.78	28,949.85

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Table 5.4 Summary of HEC-RAS model results for Corrected Effective Model – With Levee - Continued

River Sta (miles) 1	Peak Discharge (cfs) 2	Min. Channel Elev (ft) 3	Water Surface Elevation (ft) 4	Critical Water Surface (ft) 5	Energy Gradeline Elevation (ft) 6	Slope (ft/ft) 7	Average Velocity (ft/s) 8	Flow Area (ft^2) 9	Top Width (ft) 10	Froude # Channel 11	Station where Water Surface meets Existing Ground Left (ft) 12	Right (ft) 13
190.15	227,000	865.74	882.81	878.04	883.56	0.001425	6.08	37,334.23	4,956.47	0.40	17,968.53	29,000.13
190.05	227,000	858.06	882.21	875.75	882.81	0.001343	5.31	42,780.71	5,261.21	0.34	18,286.34	29,203.30
189.96	227,000	857.56	881.59	875.66	882.18	0.001265	5.38	42,229.57	6,536.82	0.34	18,389.13	29,440.20
189.87	227,000	862.94	880.96	874.83	881.52	0.001428	5.24	43,281.57	6,755.60	0.33	18,431.65	29,703.88
189.77	227,000	860.75	880.50	873.42	880.89	0.00086	4.49	50,605.32	9,306.16	0.27	18,347.32	29,847.54
189.67	227,000	862.77	880.05	873.14	880.46	0.000834	4.52	50,187.91	9,813.96	0.27	18,140.48	29,638.38
189.58	227,000	857.92	879.62	872.76	880.01	0.000923	4.45	50,956.63	9,701.33	0.27	18,146.94	29,668.14
189.48	227,000	857.85	879.24	871.94	879.60	0.000714	4.32	52,561.29	10,574.77	0.25	18,301.41	29,789.85
189.39	227,000	855.02	878.93	871.32	879.27	0.000573	4.19	54,170.92	10,785.96	0.24	18,354.88	30,127.14
189.30	227,000	856.36	878.64	871.53	878.98	0.000741	4.27	53,127.78	10,931.44	0.25	18,346.86	30,440.31
189.21	227,000	856.97	878.28	870.89	878.59	0.000829	4.21	53,907.23	11,005.62	0.25	18,287.40	30,551.21
189.11	227,000	857.40	877.89	869.73	878.17	0.000792	4.06	55,888.54	10,687.93	0.23	18,184.42	30,604.26
189.02	227,000	855.16	877.48	868.98	877.77	0.000763	3.99	56,912.14	10,451.10	0.23	17,731.04	30,746.05
188.81	227,000	852.25	876.82	866.93	877.13	0.000465	4.48	50,700.16	4,505.57	0.22	17,687.25	22,192.81
188.69	227,000	850.62	876.35	868.19	876.75	0.000818	5.04	45,031.98	4,322.39	0.25	17,709.00	22,031.38
188.59	227,000	852.76	875.94	868.11	876.30	0.000804	4.78	47,516.23	4,162.48	0.25	17,772.54	21,935.01
188.50	227,000	852.73	875.58	867.21	875.94	0.000663	4.78	47,514.37	3,902.26	0.24	17,980.17	21,882.43
188.39	227,000	852.73	875.18	866.13	875.56	0.00064	4.89	46,378.54	3,654.09	0.24	18,227.44	21,881.53
188.29	227,000	852.62	874.78	866.08	875.20	0.000692	5.13	44,251.17	3,437.05	0.25	18,372.54	21,809.59
188.20	227,000	852.50	874.46	864.43	874.95	0.000372	5.50	41,245.39	3,092.77	0.25	18,521.90	21,614.67
188.10	227,000	850.29	873.90	864.63	874.61	0.001134	6.53	34,785.36	2,472.08	0.30	19,003.22	21,475.29
188.07	227,000	849.32	873.40	864.69	874.40	0.000748	8.04	28,226.02	1,737.01	0.35	19,113.74	20,850.75
188.06	Bridge											
188.04	227,000	849.15	873.24	864.98	874.32	0.000844	8.34	27,217.43	1,727.07	0.37	19,126.39	20,853.46
188.00	227,000	848.62	873.14	866.60	874.06	0.000826	7.10	31,982.38	6,875.28	0.38	18,043.04	29,717.02
187.91	227,000	848.62	872.72	864.99	873.58	0.000917	7.17	31,666.71	5,730.82	0.39	18,918.70	29,754.53
187.82	227,000	848.62	872.05	864.07	872.87	0.003013	7.27	31,206.89	5,308.34	0.40	19,023.22	29,751.28

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Table 5.5 Summary of Results for the Floodway Profile

River Station (miles)	Water Surface Elevation (WSE) Floodplain (ft)	Water Surface Elevation (WSE) Floodway (ft)	Energy Grade Line (EGL) Floodplain (ft)	Energy Grade Line (EGL) Floodway (ft)	Surcharge WSE (ft)	Surcharge EGL (ft)	Floodway Encroachment Station Left (ft)	Floodway Encroachment Station Right (ft)
1	2	3	4	5	6	7	8	9
195.00	912.05	912.31	913.29	913.76	0.26	0.47	18,846.60	20,978.00
194.91	911.43	911.71	912.52	912.92	0.28	0.40	18,830.00	21,286.90
194.81	911.16	911.44	911.88	912.26	0.28	0.38	18,830.90	21,544.50
194.72	910.72	910.96	911.46	911.81	0.24	0.35	18,832.60	21,653.16
194.62	910.34	910.45	910.99	911.30	0.11	0.31	18,871.40	21,793.50
194.53	909.83	909.93	910.53	910.76	0.10	0.23	18,928.90	22,150.00
194.40	908.85	908.93	909.76	909.93	0.08	0.17	19,006.60	22,130.00
194.29	906.81	906.94	908.44	908.59	0.13	0.15	18,945.40	21,792.00
194.21	905.84	906.08	907.36	907.53	0.24	0.17	19,100.00	21,372.61
194.20	905.54	905.72	907.12	907.25	0.18	0.13	19,120.00	21,372.61
194.10	904.89	905.13	906.20	906.38	0.24	0.18	18,875.00	21,370.00
194.02	904.35	904.66	905.46	905.70	0.31	0.24	18,835.00	21,520.00
193.94	904.03	904.36	904.93	905.22	0.33	0.29	18,720.00	21,560.00
193.87	903.69	904.04	904.49	904.83	0.35	0.34	18,620.00	21,520.00
193.79	903.27	903.62	904.02	904.39	0.35	0.37	18,600.00	21,530.00
193.73	902.83	903.22	903.65	904.05	0.39	0.40	18,730.00	21,605.00
193.62	902.05	902.48	903.03	903.46	0.43	0.43	19,045.00	21,760.00
193.53	901.51	901.94	902.43	902.92	0.43	0.49	19,161.00	21,870.00
193.43	901.10	901.60	901.89	902.38	0.50	0.49	18,971.00	21,960.00
193.34	900.75	901.33	901.42	901.95	0.58	0.53	18,870.00	22,270.00
193.25	900.34	900.95	900.97	901.56	0.61	0.59	18,810.00	22,440.00
193.16	899.83	900.54	900.50	901.16	0.71	0.66	18,737.81	22,520.00
193.07	899.45	900.24	900.07	900.80	0.79	0.73	18,740.00	22,520.00
192.98	899.02	899.84	899.66	900.46	0.82	0.80	19,085.00	22,510.00
192.89	898.37	899.28	899.12	900.00	0.91	0.88	19,205.00	22,325.00
192.79	897.48	898.46	898.36	899.36	0.98	1.00	19,300.00	22,200.00
192.70	896.65	897.66	897.59	898.69	1.00	1.10	19,419.00	21,870.00
192.61	896.06	897.06	896.98	898.12	1.00	1.14	19,526.00	22,020.00
192.52	895.45	896.45	896.39	897.55	1.00	1.16	19,575.00	21,980.00
192.42	894.77	895.77	895.76	896.94	1.00	1.18	19,525.00	22,080.00
192.33	893.84	894.84	895.01	896.21	1.00	1.20	19,395.00	22,040.00

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Table 5.5 Summary of Results for the Floodway Profile - Continued

River Station (miles)	Water Surface Elevation (WSE) Floodplain (ft)	Water Surface Elevation (WSE) Floodway (ft)	Energy Grade Line (EGL) Floodplain (ft)	Energy Grade Line (EGL) Floodway (ft)	Surcharge WSE (ft)	Surcharge EGL (ft)	Floodway Encroachment Station Left (ft)	Floodway Encroachment Station Right (ft)
1	2	3	4	5	6	7	8	9
192.23	893.27	894.18	894.18	895.39	0.91	1.21	19,430.00	22,075.00
192.14	892.64	893.38	893.48	894.61	0.74	1.13	19,430.00	22,180.00
192.04	892.11	892.73	892.82	893.79	0.62	0.97	19,380.00	22,300.00
191.95	891.62	892.20	892.25	893.09	0.58	0.84	19,360.00	22,403.38
191.86	891.15	891.75	891.74	892.49	0.60	0.75	19,355.00	22,645.22
191.76	890.69	891.18	891.22	891.94	0.49	0.72	19,470.00	22,931.35
191.67	890.16	890.53	890.69	891.30	0.37	0.61	19,580.00	23,282.85
191.57	889.71	889.99	890.16	890.64	0.28	0.48	19,580.00	23,692.43
191.48	889.10	889.39	889.63	890.04	0.29	0.41	19,450.00	24,047.05
191.38	888.63	888.91	889.09	889.44	0.28	0.35	19,550.00	24,139.79
191.29	888.21	888.42	888.62	888.94	0.21	0.32	19,540.00	23,940.60
191.19	887.79	887.98	888.21	888.47	0.19	0.26	19,550.00	23,839.95
191.10	887.44	887.64	887.85	888.08	0.20	0.23	19,520.00	23,771.65
191.00	887.05	887.27	887.51	887.74	0.22	0.23	19,540.83	23,708.25
190.91	886.63	886.87	887.13	887.37	0.24	0.24	19,576.00	23,601.15
190.81	886.27	886.50	886.75	887.01	0.23	0.26	19,600.00	23,581.48
190.72	885.93	886.14	886.40	886.65	0.21	0.25	19,650.00	23,478.12
190.62	885.56	885.75	886.04	886.27	0.19	0.23	19,632.00	23,374.73
190.53	885.10	885.27	885.61	885.83	0.17	0.22	19,600.00	23,238.24
190.43	884.58	884.74	885.15	885.35	0.16	0.20	19,616.00	23,044.14
190.34	884.11	884.25	884.67	884.86	0.14	0.19	19,347.00	22,888.90
190.24	883.58	883.71	884.13	884.30	0.13	0.17	19,147.00	22,712.72
190.15	882.72	882.88	883.49	883.65	0.16	0.16	19,000.00	22,595.26
190.05	882.10	882.25	882.72	882.89	0.15	0.17	18,789.00	22,512.15
189.96	881.46	881.63	882.06	882.24	0.17	0.18	18,618.00	22,534.77
189.87	880.80	881.01	881.37	881.57	0.21	0.20	18,525.00	22,773.88
189.77	880.30	880.50	880.71	880.93	0.20	0.22	18,395.73	22,800.00
189.67	879.81	880.05	880.24	880.47	0.24	0.23	18,198.71	22,770.00
189.58	879.34	879.60	879.76	880.01	0.26	0.25	18,273.51	22,950.00
189.48	878.93	879.22	879.31	879.59	0.29	0.28	18,383.43	23,200.00
189.39	878.58	878.90	878.95	879.25	0.32	0.30	18,428.59	23,350.00
189.30	878.25	878.59	878.63	878.95	0.34	0.32	18,393.23	23,390.00
189.21	877.83	878.21	878.18	878.54	0.38	0.36	18,313.06	23,480.00

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Table 5.5 Summary of Results for the Floodway Profile - Continued

River Station	Water Surface Elevation (WSE)		Energy Grade Line (EGL)		Surcharge		Floodway Encroachment Station	
	Floodplain	Floodway	Floodplain	Floodway	WSE	EGL	Left	Right
(miles)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)
1	2	3	4	5	6	7	8	9
189.11	877.35	877.79	877.68	878.10	0.44	0.42	18,196.96	23,580.00
189.02	876.85	877.37	877.19	877.67	0.52	0.48	17,826.77	23,700.00
188.81	876.09	876.73	876.42	877.03	0.64	0.61	17,654.80	23,780.00
188.69	875.64	876.36	876.02	876.69	0.72	0.67	17,705.12	23,720.00
188.59	875.22	876.02	875.55	876.31	0.80	0.76	17,764.80	23,640.00
188.50	874.87	875.72	875.19	876.01	0.85	0.82	17,985.99	23,450.00
188.39	874.50	875.40	874.83	875.71	0.90	0.88	18,219.99	23,400.00
188.29	874.12	875.08	874.49	875.42	0.96	0.93	18,370.74	23,300.00
188.20	873.79	874.79	874.24	875.21	1.00	0.97	18,700.00	23,250.00
188.10	873.35	874.35	873.92	874.93	1.00	1.01	18,969.12	23,100.00
188.07	872.98	873.92	873.74	874.75	0.94	1.01	19,107.54	23,150.00
188.04	872.95	873.81	873.71	874.70	0.86	0.99	19,107.51	23,100.00
188.00	872.83	873.69	873.50	874.49	0.86	0.99	19,064.73	23,010.00
187.91	872.48	873.34	873.12	874.09	0.86	0.97	19,105.10	22,800.00
187.82	871.94	872.80	872.55	873.50	0.86	0.95	19,134.40	22,580.00
187.73	871.30	872.10	871.87	872.76	0.80	0.89	19,064.30	22,350.00
187.64	870.79	871.57	871.47	872.33	0.78	0.86	19,149.80	22,110.00
187.54	870.51	871.26	871.11	871.94	0.75	0.83	19,070.00	22,000.00
187.45	870.30	870.94	870.78	871.62	0.64	0.84	19,030.10	21,860.00
187.36	869.92	870.64	870.47	871.27	0.72	0.80	18,951.60	21,674.60
187.24	869.57	870.22	870.07	870.86	0.65	0.79	18,963.00	21,500.00
187.15	869.37	869.99	869.78	870.52	0.62	0.74	18,686.60	21,500.00
187.06	869.25	869.81	869.54	870.24	0.56	0.70	18,358.98	21,542.00

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Table 5.6 Summary of HEC-RAS Model Results for Bridges

River Station (miles) 1	Road Name	Water Surface Elevation (ft) 2	Energy Grade Line Elevation (ft) 3	Peak Discharge (cfs) 4	Discharge Through Structure (cfs) 5	Discharge Over Weir (cfs) 6	Velocity (ft/s) 7	Friction Loss (ft) 8	Contraction Coefficients 9	Expansion Coefficients 10
188.055	Tuthill	872.97	873.74	227,000	227,000	0	6.51	0.03	0.1	0.3
194.205	Estrella	905.55	907.29	227,000	227,000	0	10.59	0.09	0.3	0.3

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6.0 EROSION AND SEDIMENT TRANSPORT

Erosion and sediment transport was not conducted as part of this study. This LOMR is based on topographic changes and no new structures are part of the revision.

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7.0 DRAFT FIS REPORT DATA

7.1 SUMMARY OF DISCHARGES

Peak discharges used in the hydraulic analysis were taken from the US Army Corps of Engineers report for the modifications to Roosevelt Dam entitled *Gila River Basin, Arizona, Section 7 Study for Modified Roosevelt Dam, Arizona, Hydrologic Evaluation of Water Control Plans, Salt River Project to Gila River at Gillespie Dam* (USACE 1996). The peak discharges, along with the previous Effective model discharges are listed in Table 7.1. Value of 227,000 cfs was utilized in this study.

Table 7.1 Summary of Discharges

Location	River Station miles	100-Year Peak Discharge	
		Effective cfs	Revised cfs
1	2	3	4
Granite Reef Dam (Salt River)	237.59	245,000	175,000
Gilbert Road (Salt River)	213.55	230,000	172,000
Tempe Bridge (Salt River)	221.24	215,000	169,000
Central Avenue (Salt River)	213.24	200,000	166,000
67th Avenue (Salt River)	205.40	190,000	164,000
Below Confluence with Gila River	199.82	250,000	227,000
Below Confluence with Waterman Wash (Gila River)	186.10	245,000	210,000

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7.2 FLOODWAY DATA

Table 7.2 shows the floodplain and floodway elevation for each cross section.

Table 7.2 Floodway Data Table

Floodway Source		Floodway				Base Flood Elevations			
Cross Section	FEMA Cross Section	Distance[1] (ft)	Width (ft)	Area (sq ft)	Mean Velocity (fps)	Regulatory[2] (ft)	Without Floodway (ft)	With Floodway (ft)	Increase (ft)
1	2	3	4	5	6	7	8	9	10
187.06		20.727	3,180.85	43,137.12	5.26	869.25	869.25	869.81	0.6
187.15		20.817	2,813.40	38,719.92	5.86	869.37	869.37	869.99	0.6
187.24		20.907	2,537.00	35,499.68	6.39	869.57	869.57	870.22	0.7
187.36	AO	21.027	2,723.00	35,571.88	6.38	869.92	869.92	870.64	0.7
187.45		21.117	2,829.90	34,262.61	6.63	870.30	870.30	870.94	0.6
187.54		21.207	2,930.00	34,356.64	6.61	870.51	870.51	871.26	0.8
187.64		21.307	2,960.20	32,746.32	6.93	870.79	870.79	871.57	0.8
187.73		21.397	3,285.70	34,997.05	6.49	871.30	871.30	872.10	0.8
187.82	AP	21.487	3,445.60	33,798.66	6.72	871.94	871.94	872.80	0.9
187.91		21.577	3,694.90	33,942.63	6.69	872.48	872.48	873.34	0.9
188		21.667	3,938.15	34,135.01	6.65	872.83	872.83	873.69	0.9
188.04		21.707	3,576.03	32,702.59	6.94	873.24/872.95	872.95	873.81	0.9
188.07		21.737	3,514.82	32,874.23	6.91	873.18/872.94	872.98	873.92	0.9
188.1	AQ	21.767	3,968.97	39,382.12	5.76	873.31/872.97	873.35	874.35	1.0
188.2		21.867	4,463.38	46,564.61	4.87	873.40/872.98	873.79	874.79	1.0
188.29		21.957	4,848.57	49,740.31	4.56	873.90/873.35	874.12	875.08	1.0
188.39		22.057	5,096.99	51,993.57	4.37	874.46/873.79	874.50	875.40	0.9
188.5		22.167	5,396.09	53,422.39	4.25	874.78/874.12	874.87	875.72	0.9
188.59	AR	22.257	5,795.56	52,784.22	4.30	875.18/874.50	875.22	876.02	0.8
188.69		22.357	5,894.45	54,934.63	4.55	875.58/874.87	875.64	876.36	0.7
188.81		22.477	5,934.24	58,152.82	4.16	875.94/875.22	876.09	876.73	0.6
189.02		22.687	5,873.23	53,727.31	4.23	876.85	876.85	877.37	0.5
189.11	AS	22.777	5,383.04	52,548.89	4.32	877.35	877.35	877.79	0.4
189.21		22.877	5,166.94	50,434.81	4.50	877.83	877.83	878.21	0.4
189.3		22.967	4,996.77	49,978.16	4.54	878.25	878.25	878.59	0.3
189.39		23.057	4,921.41	51,498.57	4.41	878.58	878.58	878.90	0.3

[1] – Miles above Crest of Gillespie Dam

[2] – River Side / Land Side

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Table 7.2 Floodway Data Table – Continued

Floodway Source		Floodway				Base Flood Elevations			
Cross Section	FEMA Cross Section	Distance[1] (ft)	Width (ft)	Area (sq ft)	Mean Velocity (fps)	Regulatory[2] (ft)	Without Floodway (ft)	With Floodway (ft)	Increase (ft)
1	2	3	4	5	6	7	8	9	10
189.48		23.147	4,816.57	50,068.18	4.53	878.93	878.93	879.22	0.3
189.58	AT	23.247	4,676.49	48,176.87	4.71	879.34	879.34	879.60	0.3
189.67		23.337	4,571.29	48,173.70	4.71	879.81	879.81	880.05	0.2
189.77		23.437	4,404.27	47,402.15	4.79	880.30	880.30	880.50	0.2
189.87		23.537	4,248.88	42,480.21	5.34	880.80	880.80	881.01	0.2
189.96		23.627	3,916.77	40,398.55	5.62	881.46	881.46	881.63	0.2
190.05	AU	23.717	3,723.15	38,959.18	5.83	882.10	882.10	882.25	0.2
190.15		23.817	3,595.12	34,522.28	6.58	882.72	882.72	882.88	0.2
190.24		23.907	3,565.72	38,239.38	5.94	883.58	883.58	883.71	0.1
190.34		24.007	3,541.90	37,188.40	6.10	884.11	884.11	884.25	0.1
190.43		24.097	3,428.14	36,391.29	6.24	884.58	884.58	884.74	0.2
190.53	AV	24.197	3,638.24	37,712.66	6.02	885.10	885.10	885.27	0.2
190.62		24.287	3,739.20	39,054.57	5.81	885.56	885.56	885.75	0.2
190.72		24.387	3,828.12	39,458.01	5.75	885.93	885.93	886.14	0.2
190.81		24.477	3,981.48	39,859.01	5.70	886.27	886.27	886.50	0.2
190.91	AW	24.577	4,021.62	39,877.47	5.69	886.63	886.63	886.87	0.2
191.00		24.667	4,167.42	41,052.07	5.53	887.05	887.05	887.27	0.2
191.10		24.767	4,251.65	42,402.99	5.35	887.44	887.44	887.64	0.2
191.19		24.857	4,289.95	40,367.71	5.62	887.79	887.79	887.98	0.2
191.29		24.957	4,400.60	39,124.73	5.80	888.21	888.21	888.42	0.2
191.38		25.047	4,589.79	38,853.73	5.84	888.63	888.63	888.91	0.3
191.48	AX	25.147	4,597.05	35,634.14	6.37	889.10	889.10	889.39	0.3
191.57		25.237	4,112.43	35,266.24	6.44	889.71	889.71	889.99	0.3
191.67		25.337	3,702.85	32,387.00	7.01	890.16	890.16	890.53	0.4
189.48		23.147	4,816.57	50,068.18	4.53	878.93	878.93	879.22	0.3
189.58	AT	23.247	4,676.49	48,176.87	4.71	879.34	879.34	879.60	0.3

[1] – Miles above Crest of Gillespie Dam

[2] – River Side / Land Side

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Table 7.2 Floodway Data Table – Continued

Floodway Cross Section	Source FEMA Cross Section	Floodway				Base Flood Elevations			
		Distance[1] (ft)	Width (ft)	Area (sq ft)	Mean Velocity (fps)	Regulatory[2] (ft)	Without Floodway (ft)	With Floodway (ft)	Increase (ft)
1	2	3	4	5	6	7	8	9	10
191.76		25.427	3,461.35	32,853.38	6.91	890.69	890.69	891.18	0.5
191.86		25.527	3,290.22	32,717.89	6.94	891.15	891.15	891.75	0.6
191.95	AY	25.617	3,043.38	30,348.74	7.48	891.62	891.62	892.20	0.6
192.04		25.707	2,920.00	28,083.83	8.08	892.11	892.11	892.73	0.6
192.14		25.807	2,750.00	26,449.95	8.58	892.64	892.64	893.38	0.7
192.23		25.897	2,645.00	26,803.39	8.47	893.27	893.27	894.18	0.9
192.33		25.997	2,645.00	25,348.05	8.96	893.84	893.84	894.84	1.0
192.42	AZ	26.087	2,555.00	26,950.88	8.42	894.77	894.77	895.77	1.0
192.52		26.187	2,405.00	27,699.88	8.19	895.45	895.45	896.45	1.0
192.61		26.277	2,494.00	28,362.23	8.00	896.06	896.06	897.06	1.0
192.7		26.367	2,451.00	28,244.67	8.04	896.65	896.65	897.66	1.0
192.79		26.457	2,896.16	30,074.16	7.55	897.48	897.48	898.46	1.0
192.89	BA	26.557	3,120.00	33,356.22	6.81	898.37	898.37	899.28	0.9
192.98		26.647	3,425.00	35,920.08	6.32	899.02	899.02	899.84	0.8
193.07		26.737	3,780.00	37,679.81	6.02	899.45	899.45	900.24	0.8
193.16		26.827	3,782.19	35,788.05	6.34	899.83	899.83	900.54	0.7
193.25		26.917	3,630.00	36,300.51	6.25	900.34	900.34	900.95	0.6
193.34	BB	27.007	3,400.00	35,785.75	6.34	900.75	900.75	901.33	0.6
193.43		27.097	2,989.00	32,098.27	7.07	901.10	901.10	901.60	0.5
193.53		27.197	2,709.00	28,633.76	7.93	901.51	901.51	901.94	0.4
193.62		27.287	2,709.38	28,529.53	7.96	902.05	902.05	902.48	0.4
193.73		27.397	2,864.85	31,086.59	7.30	902.83	902.83	903.22	0.4
193.79	BC	27.457	2,924.53	32,354.68	7.02	903.27	903.27	903.62	0.4
193.87		27.537	2,895.87	31,845.04	7.13	903.69	903.69	904.04	0.4
191.76		25.427	3,461.35	32,853.38	6.91	890.69	890.69	891.18	0.5
191.86		25.527	3,290.22	32,717.89	6.94	891.15	891.15	891.75	0.6

[1] – Miles above Crest of Gillespie Dam

[2] – River Side / Land Side

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Table 7.2 Floodway Data Table – Continued

Floodway Source Cross Section	FEMA Cross Section	Floodway				Base Flood Elevations			
		Distance[1] (ft)	Width (ft)	Area (sq ft)	Mean Velocity (fps)	Regulatory[2] (ft)	Without Floodway (ft)	With Floodway (ft)	Increase (ft)
1	2	3	4	5	6	7	8	9	10
193.94		27.607	2,827.10	30,545.71	7.43	904.03	904.03	904.36	0.3
194.02		27.687	2,680.98	27,725.13	8.20	904.35	904.35	904.66	0.3
194.10		27.767	2,446.93	25,342.79	8.96	904.89	904.89	905.13	0.2
194.20	BD	27.867	2,118.38	22,869.41	9.93	905.54	905.54	905.72	0.2
194.21		27.877	2,122.63	23,474.40	9.67	905.84	905.84	906.08	0.2
194.29		27.957	2,846.60	22,371.72	10.15	906.81	906.81	906.94	0.1
194.4		28.067	3,076.50	28,945.08	7.84	908.85	908.85	908.93	0.1
194.53		28.197	3,084.99	30,985.22	7.33	909.83	909.83	909.93	0.1
194.62	BE	28.287	2,913.55	30,615.61	7.41	910.34	910.34	910.45	0.1
194.72		28.387	2,810.16	30,702.45	7.39	910.72	910.72	910.96	0.2
194.81		28.477	2,713.60	31,332.75	7.24	911.16	911.16	911.44	0.3
194.91		28.577	2,456.90	25,713.63	8.83	911.43	911.43	911.71	0.3
195		28.667	2,129.68	23,535.42	9.65	912.05	912.05	912.31	0.3

[1] – Miles above Crest of Gillespie Dam
[2] – River Side / Land Side

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7.3 ANNOTATED FLOOD INSURANCE RATE MAPS

Annotated FIRM panels are included in Exhibit Maps.

7.4 FLOOD PROFILES

The flood profiles are included in Exhibit Maps.

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APPENDIX A: REFERENCES

References

The following references were utilized in the evaluations for this study:

Chow, 1959, Open-Channel Hydraulics.

Michael Baker Jr., 1994, Salt -Gila Floodplain Delineation Restudy, "n" Value Report, Dated 1994.

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National Geodetic Survey, 2001, National Geodetic Survey Program VERTCON accessed at http://www.ngs.noaa.gov/cgi-bin/VERTCAN/vert com.prl, Dated August 2001.

River Research & Design, Inc., 2007, Norte Vista / King Ranch Floodplain Redelineation, Gila River, Dated June 2007.

Stantec Consulting Inc., 2006, El Rio Watercourse Master Plan, Sedimentation Analysis Book 1- El Rio Existing Condition Sedimentation Analysis, Dated March 2006.

USACE, 1996, Gila River Basin, Arizona, Section 7 Study for Modified Roosevelt Dam, Arizona, Hydrologic Evaluation of Water Control Plans, Salt River Project to Gila River at Gillespie Dam, U.S. Army Corps of Engineers, Dated March 1996.

USACE, 2005, US Army Corps of Engineers, Hydrologic Engineering Center River Analysis System (HEC-RAS) Version 3.1.3, May 2005.

USGS, 1991, Estimated Manning's n-Values for Stream Channels and Flood Plains in Maricopa County Arizona.

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APPENDIX B: GENERAL DOCUMENTATION & CORRESPONDENCE

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APPENDIX C: SURVEY FIELD NOTES

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APPENDIX D: HYDROLOGIC ANALYSIS SUPPORTING DOCUMENTATION

E.1 Manning's Roughness Coefficients from the Norte Vista / King Ranch Study

E.2 Manning's Roughness Coefficient Calculation Sheets for Cross Sections Between 187.06 and 190.05

E.3 Comparison of Cross Section Alignments Between Effective and Corrected Effective Models

E.4 CD with Project Data

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APPENDIX E: HYDRAULIC ANALYSIS SUPPORTING DOCUMENTATION

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APPENDIX E.1: MANNING'S ROUGHNESS COEFFICIENTS FROM THE NORTE VISTA / KING RANCH STUDY

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 11 maps plus the cover and index sheets. They are produced at a scale of 1" = 400' and include both the effective and existing floodplain and floodway lines for the project reach. The main sheets (3-11) have the effective and newly modeled existing floodplain and floodway shown.

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

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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.

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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.

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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 photographs in Figure

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9 and Figure 10 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 catalogs the photographs and describes the land use where the photographs were taken while the location waypoints are shown in Figures 9 and 10.

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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

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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.

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Table 5. List of Photographs and Locations with Description of Land Use and Vegetation Density (Continued).

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)

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Table 5 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

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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

No future conditions analysis is included since this LOMR is based on a change in existing conditions rather than proposed modifications.

The n values used existing conditions vegetation were developed for the existing river conditions with approximately 14 years having passed since the 1993 flood event with no maintenance of vegetation. These values were also adjusted upwards and downwards 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 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 this floodplain redelineation study.

After extensive review it is felt that the n-values determined for the using the above procedures 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.

The only area of difference between the R2D and Stantec modeling efforts was an area just east of Tuthill Bridge in the northern edge of the channel. Stantec modeled the area as having an n value of 0.15 whereas R2D modeled the area with a lower n value. The higher Stantec value was used in the final model in an attempt to be conservative in the flood surface elevations.

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

	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 (ft)	-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

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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	

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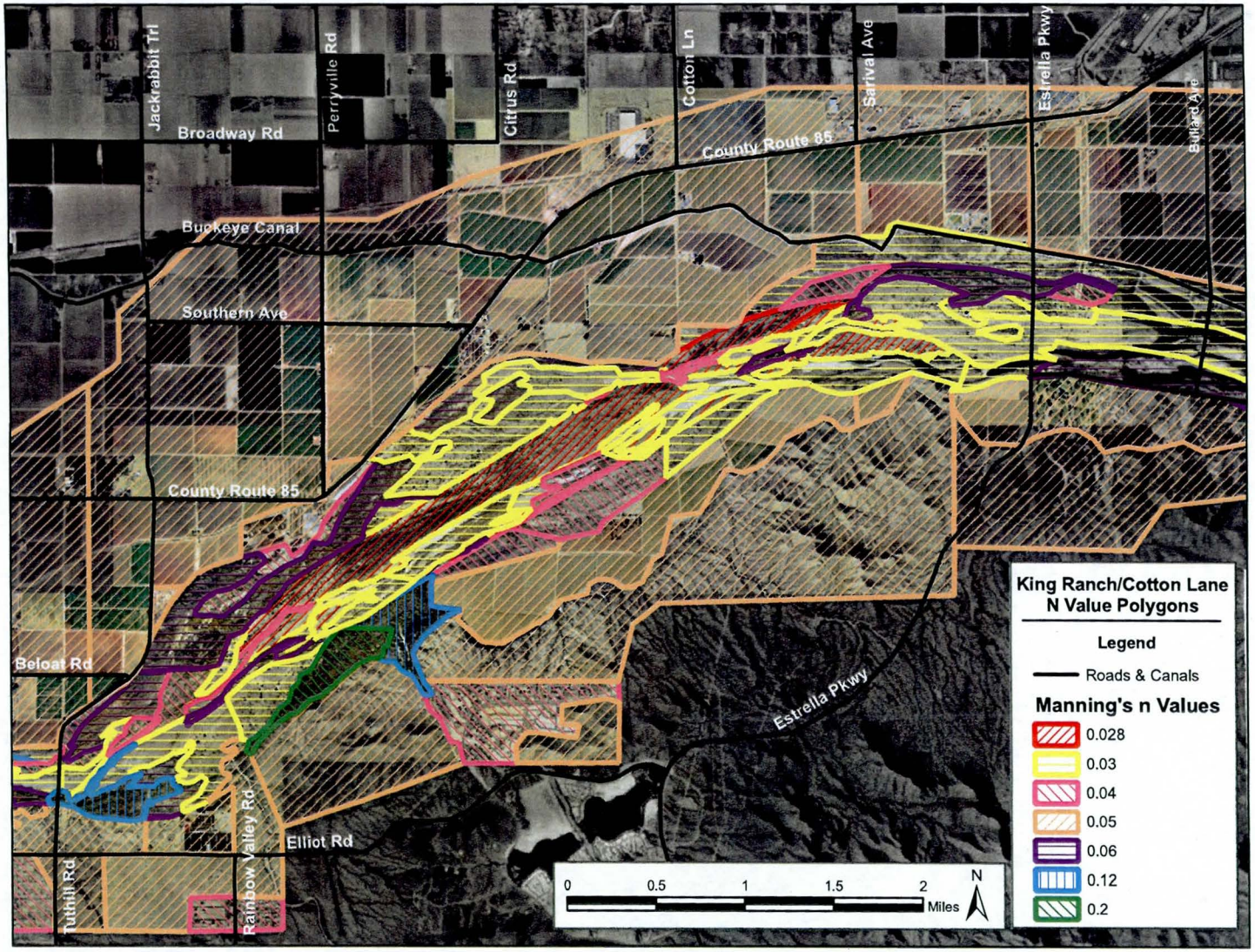

Figure 8. Overview of Selected Manning's n Values for the Cotton Lane Bridge Study Reach.

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APPENDIX E.2: MANNING'S ROUGHNESS COEFFICIENT CALCULATION SHEETS FOR CROSS SECTIONS BETWEEN 187.06 AND 190.05

Determination of Manning's n-value by the FCDMC method

Project: Gila River Floodplain Redelineation Study
Stream: Gila River
Reach: RM 187.06 to RM 190.05 By: NDB & PJE Date: 2-Aug-06
Photo Location Site 1

Channel Conditions		Manning's n Adjustment		Left Overbank	Main Channel	Right Overbank
Channel Bed Material	Concrete	n_0	0.012 - 0.018			
	Rock Cut		0.025			
	Firm Soil		0.025 - 0.032			
	Fine Sand		0.023 - 0.026			
	Coarse Sand		0.026 - 0.035		0.030	
	Gravel		0.028 - 0.035			
	Cobble		0.030 - 0.050			
	Boulder		0.040 - 0.070			
Degree of Irregularity	Smooth	n_1	0.000		0.000	
	Minor		0.001 - 0.005			
	Moderate		0.006 - 0.010			
	Severe		0.011 - 0.020			
Effects of Obstructions	Negligable	n_2	0.000 - 0.004		0.000	0.000
	Minor		0.005 - 0.015			
	Appreciable		0.020 - 0.030			
	Severe		0.040 - 0.060			
Vegetation	Small	n_3	0.002 - 0.010		0.000	
	Medium		0.010 - 0.025			
	Large		0.025 - 0.050			
	Very Large		0.050 - 0.100			
Variations in Channel Cross Section	Gradual	n_4	0.000		0.000	0.000
	Alternating (occasionally)		0.001 - 0.005			
	Alternating (frequently)		0.010 - 0.015			
Degree of Meandering	Minor	m	1.00	1.000	1.000	1.000
	Appreciable		1.15			
	Severe		1.30			
$n = (n_0 + n_1 + n_2 + n_3 + n_4)m$				0.000	0.030	0.000
Round values to the nearest 0.005:				**0.000**	**0.030**	**0.000**
Photograph No.: 1, 2, 3						

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Determination of Manning's n-value by the FCDMC method

Project: Gila River Floodplain Redelineation Study
Stream: Gila River
Reach: RM 187.06 to RM 190.05 By: NDB & PJE Date: 2-Aug-06
Photo Location Site 2

Channel Conditions		Manning's n Adjustment		Left Overbank	Main Channel	Right Overbank
Channel Bed Material	Concrete	n_0	0.012 - 0.018			
	Rock Cut		0.025			
	Firm Soil		0.025 - 0.032			
	Fine Sand		0.023 - 0.026			
	Coarse Sand		0.026 - 0.035		0.030	
	Gravel		0.028 - 0.035			
	Cobble		0.030 - 0.050			
	Boulder		0.040 - 0.070			
Degree of Irregularity	Smooth	n_1	0.000			
	Minor		0.001 - 0.005		0.003	
	Moderate		0.006 - 0.010			
	Severe		0.011 - 0.020			
Effects of Obstructions	Negligable	n_2	0.000 - 0.004		0.000	
	Minor		0.005 - 0.015			
	Appreciable		0.020 - 0.030			
	Severe		0.040 - 0.060			
Vegetation	Small	n_3	0.002 - 0.010			
	Medium		0.010 - 0.025			
	Large		0.025 - 0.050	0.050		0.050
	Very Large		0.050 - 0.100			
Variations in Channel Cross Section	Gradual	n_4	0.000		0.000	
	Alternating (occasionally)		0.001 - 0.005			
	Alternating (frequently)		0.010 - 0.015			
Degree of Meandering	Minor	m	1.00	1.000	1.000	1.000
	Appreciable		1.15			
	Severe		1.30			
$n = (n_0 + n_1 + n_2 + n_3 + n_4)m$				0.050	0.033	0.050
Round values to the nearest 0.005:				**Composit Value**	**0.040**	**0.000**
Photograph No.: 4,5,6						

Determination of Manning's n-value by the FCDMC method

Project: Gila River Floodplain Redelineation Study
Stream: Gila River
Reach: RM 187.06 to RM 190.05 By: NDB & PJE Date: 2-Aug-06
Photo Location Site 3

Channel Conditions		Manning's n Adjustment		Left Overbank	Main Channel	Right Overbank
Channel Bed Material	Concrete	n_0	0.012 - 0.018			
	Rock Cut		0.025			
	Firm Soil		0.025 - 0.032			
	Fine Sand		0.023 - 0.026		0.025	
	Coarse Sand		0.026 - 0.035			
	Gravel		0.028 - 0.035			
	Cobble		0.030 - 0.050			
	Boulder		0.040 - 0.070			
Degree of Irregularity	Smooth	n_1	0.000			
	Minor		0.001 - 0.005			
	Moderate		0.006 - 0.010			
	Severe		0.011 - 0.020		0.015	
Effects of Obstructions	Negligable	n_2	0.000 - 0.004			
	Minor		0.005 - 0.015			
	Appreciable		0.020 - 0.030		0.025	
	Severe		0.040 - 0.060			
Vegetation	Small	n_3	0.002 - 0.010			
	Medium		0.010 - 0.025			
	Large		0.025 - 0.050		0.050	
	Very Large		0.050 - 0.100			
Variations in Channel Cross Section	Gradual	n_4	0.000			
	Alternating (occasionally)		0.001 - 0.005			
	Alternating (frequently)		0.010 - 0.015		0.015	
Degree of Meandering	Minor	m	1.00	1.000	1.000	1.000
	Appreciable		1.15			
	Severe		1.30			
$n = (n_0 + n_1 + n_2 + n_3 + n_4)m$				0.000	0.130	0.000
Round values to the nearest 0.005:				**0.000**	**0.150**	**0.000**
Photograph No.: 7,8,9						

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Determination of Manning's n-value by the FCDMC method

Project: Gila River Floodplain Redelineation Study
Stream: Gila River
Reach: RM 187.06 to RM 190.05 By: NDB & PJE Date: 2-Aug-06
Photo Location Site 4 Location 1

Channel Conditions		Manning's n Adjustment		Left Overbank	Main Channel	Right Overbank
Channel Bed Material	Concrete	n_0	0.012 - 0.018			
	Rock Cut		0.025			
	Firm Soil		0.025 - 0.032			
	Fine Sand		0.023 - 0.026			
	Coarse Sand		0.026 - 0.035		0.030	
	Gravel		0.028 - 0.035			
	Cobble		0.030 - 0.050			
	Boulder		0.040 - 0.070			
Degree of Irregularity	Smooth	n_1	0.000		0.000	
	Minor		0.001 - 0.005			
	Moderate		0.006 - 0.010			
	Severe		0.011 - 0.020			
Effects of Obstructions	Negligable	n_2	0.000 - 0.004			
	Minor		0.005 - 0.015			
	Appreciable		0.020 - 0.030			
	Severe		0.040 - 0.060			
Vegetation	Small	n_3	0.002 - 0.010			
	Medium		0.010 - 0.025		0.010	
	Large		0.025 - 0.050			
	Very Large		0.050 - 0.100			
Variations in Channel Cross Section	Gradual	n_4	0.000		0.000	0.000
	Alternating (occasionally)		0.001 - 0.005			
	Alternating (frequently)		0.010 - 0.015			
Degree of Meandering	Minor	m	1.00	1.000	1.000	1.000
	Appreciable		1.15			
	Severe		1.30			
$n = (n_0 + n_1 + n_2 + n_3 + n_4)m$				0.000	0.040	0.000
Round values to the nearest 0.005:				**0.000**	**0.040**	**0.000**
Photograph No.: 10,11,12						

DRAFT

Determination of Manning's n-value by the FCDMC method

Project: Gila River Floodplain Redelineation Study
Stream: Gila River
Reach: RM 187.06 to RM 190.05 By: NDB & PJE Date: 2-Aug-06
Photo Location Site 4 Location 2

Channel Conditions		Manning's n Adjustment		Left Overbank	Main Channel	Right Overbank
Channel Bed Material	Concrete	n_0	0.012 - 0.018			
	Rock Cut		0.025			
	Firm Soil		0.025 - 0.032			
	Fine Sand		0.023 - 0.026			
	Coarse Sand		0.026 - 0.035			
	Gravel		0.028 - 0.035		0.030	
	Cobble		0.030 - 0.050			
	Boulder		0.040 - 0.070			
Degree of Irregularity	Smooth	n_1	0.000		0.000	
	Minor		0.001 - 0.005			
	Moderate		0.006 - 0.010			
	Severe		0.011 - 0.020			
Effects of Obstructions	Negligable	n_2	0.000 - 0.004		0.000	
	Minor		0.005 - 0.015			
	Appreciable		0.020 - 0.030			
	Severe		0.040 - 0.060			
Vegetation	Small	n_3	0.002 - 0.010			
	Medium		0.010 - 0.025		0.010	
	Large		0.025 - 0.050			
	Very Large		0.050 - 0.100			
Variations in Channel Cross Section	Gradual	n_4	0.000		0.000	0.000
	Alternating (occasionally)		0.001 - 0.005			
	Alternating (frequently)		0.010 - 0.015			
Degree of Meandering	Minor	m	1.00	1.000	1.000	1.000
	Appreciable		1.15			
	Severe		1.30			
$n = (n_0 + n_1 + n_2 + n_3 + n_4)m$				0.000	0.040	0.000
Round values to the nearest 0.005:				**0.000**	**0.040**	**0.000**
Photograph No.: 13,14,15						

DRAFT

Determination of Manning's n-value by the FCDMC method

Project: Gila River Floodplain Redelineation Study
Stream: Gila River
Reach: RM 187.06 to RM 190.05 By: NDB & PJE Date: 2-Aug-06
Photo Location Site 5

Channel Conditions		Manning's n Adjustment		Left Overbank	Main Channel	Right Overbank
Channel Bed Material	Concrete	n_0	0.012 - 0.018			
	Rock Cut		0.025			
	Firm Soil		0.025 - 0.032			
	Fine Sand		0.023 - 0.026			
	Coarse Sand		0.026 - 0.035		0.030	
	Gravel		0.028 - 0.035			
	Cobble		0.030 - 0.050			
	Boulder		0.040 - 0.070			
Degree of Irregularity	Smooth	n_1	0.000		0.000	0.000
	Minor		0.001 - 0.005			
	Moderate		0.006 - 0.010			
	Severe		0.011 - 0.020			
Effects of Obstructions	Negligable	n_2	0.000 - 0.004		0.000	0.000
	Minor		0.005 - 0.015			
	Appreciable		0.020 - 0.030			
	Severe		0.040 - 0.060			
Vegetation	Small	n_3	0.002 - 0.010		0.006	
	Medium		0.010 - 0.025			
	Large		0.025 - 0.050			
	Very Large		0.050 - 0.100			
Variations in Channel Cross Section	Gradual	n_4	0.000		0.000	0.000
	Alternating (occasionally)		0.001 - 0.005			
	Alternating (frequently)		0.010 - 0.015			
Degree of Meandering	Minor	m	1.00	1.000	1.000	1.000
	Appreciable		1.15			
	Severe		1.30			
$n = (n_0 + n_1 + n_2 + n_3 + n_4)m$				0.000	0.036	0.000
Round values to the nearest 0.005:				**0.000**	**0.035**	**0.000**
Photograph No.:16,17,18						

DRAFT

Determination of Manning's n-value by the FCDMC method

Project: Gila River Floodplain Redelineation Study
Stream: Gila River
Reach: RM 187.06 to RM 190.05 By: NDB & PJE Date: 2-Aug-06
Photo Location Site 6

Channel Conditions		Manning's n Adjustment		Left Overbank	Main Channel	Right Overbank
Channel Bed Material	Concrete	n_0	0.012 - 0.018			
	Rock Cut		0.025			
	Firm Soil		0.025 - 0.032			
	Fine Sand		0.023 - 0.026		0.025	
	Coarse Sand		0.026 - 0.035			
	Gravel		0.028 - 0.035			
	Cobble		0.030 - 0.050			
	Boulder		0.040 - 0.070			
Degree of Irregularity	Smooth	n_1	0.000			
	Minor		0.001 - 0.005			
	Moderate		0.006 - 0.010			
	Severe		0.011 - 0.020		0.015	
Effects of Obstructions	Negligable	n_2	0.000 - 0.004			
	Minor		0.005 - 0.015			
	Appreciable		0.020 - 0.030		0.025	
	Severe		0.040 - 0.060			
Vegetation	Small	n_3	0.002 - 0.010			
	Medium		0.010 - 0.025			
	Large		0.025 - 0.050		0.050	
	Very Large		0.050 - 0.100			
Variations in Channel Cross Section	Gradual	n_4	0.000			
	Alternating (occasionally)		0.001 - 0.005			
	Alternating (frequently)		0.010 - 0.015		0.015	
Degree of Meandering	Minor	m	1.00	1.000	1.000	1.000
	Appreciable		1.15			
	Severe		1.30			
$n = (n_0 + n_1 + n_2 + n_3 + n_4)m$				0.000	0.130	0.000
Round values to the nearest 0.005:				**0.000**	**0.150**	**0.000**
Photograph No.: 19,20,21						

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Determination of Manning's n-value by the FCDMC method

Project: Gila River Floodplain Redelineation Study
Stream: Gila River
Reach: RM 187.06 to RM 190.05 By: NDB & PJE Date: 2-Aug-06
Photo Location Site 7

Channel Conditions		Manning's n Adjustment		Left Overbank	Main Channel	Right Overbank
Channel Bed Material	Concrete	n_0	0.012 - 0.018			
	Rock Cut		0.025			
	Firm Soil		0.025 - 0.032			
	Fine Sand		0.023 - 0.026			
	Coarse Sand		0.026 - 0.035		0.030	
	Gravel		0.028 - 0.035			
	Cobble		0.030 - 0.050			
	Boulder		0.040 - 0.070			
Degree of Irregularity	Smooth	n_1	0.000			
	Minor		0.001 - 0.005			
	Moderate		0.006 - 0.010			
	Severe		0.011 - 0.020			
Effects of Obstructions	Negligable	n_2	0.000 - 0.004			
	Minor		0.005 - 0.015		0.010	
	Appreciable		0.020 - 0.030			
	Severe		0.040 - 0.060			
Vegetation	Small	n_3	0.002 - 0.010			
	Medium		0.010 - 0.025		0.025	
	Large		0.025 - 0.050			
	Very Large		0.050 - 0.100			
Variations in Channel Cross Section	Gradual	n_4	0.000		0.000	
	Alternating (occasionally)		0.001 - 0.005			
	Alternating (frequently)		0.010 - 0.015			
Degree of Meandering	Minor	m	1.00	1.000	1.000	1.000
	Appreciable		1.15			
	Severe		1.30			
$n = (n_0 + n_1 + n_2 + n_3 + n_4)m$				0.000	0.065	0.000
Round values to the nearest 0.005:				**0.000**	**0.065**	**0.000**
Photograph No.: 22,23, 24						

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Project: Gila River Floodplain Redelineation Study
Stream: Gila River
Reach: RM 187.06 to RM 190.05

Estimate composite "n" value for braided channel sections.

Given

Depth =	21
Bottom Width =	200
Side Slopes___:1 =	1

		Subarea 1	Channel	Subarea2	Total
Area	A	220.5	4200	220.5	4641
Wetted Perimeter	P	29.698485	200	29.69848481	259.39697
Hydraulic Radius	R	7.4246212	21	7.424621202	17.891497
Estimated Manning's "n" value	n	0.05	0.033	0.05	
	K	24957.275	1441034.7	24957.27462	1490949.2

$$nc = \left[\frac{\left(P_1 n_1^{1.5} + P_2 n_2^{1.5} + P_3 n_3^{1.5} \right)}{P} \right]^{2/3}$$

$P_1 n_1$	$P_2 n_2$	$P_3 n_3$	P	nc	Round "n" value up to nearest 0.005
0.332	1.199	0.332	259.397	0.037	0.04

nc = composite "n" value

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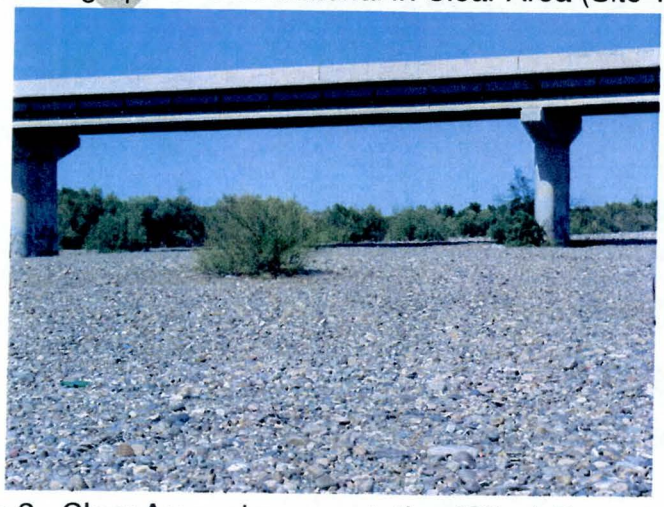
Photograph 1 Clear Area minor vegetation (Site 1 Upstream View)

Photograph 2 Bed material in Clear Area (Site 1)



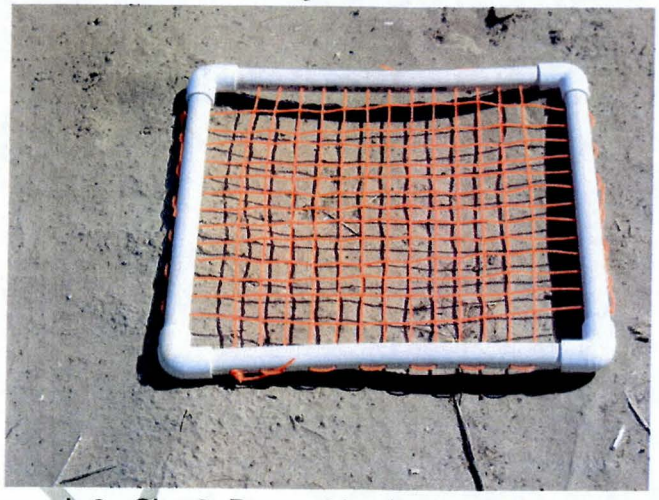
Photograph 3 Clear Area minor vegetation (Site 1 Downstream View)

Photograph 4 Site 2, Channels with dense vegetation on side slopes

Photograph 5 Site 2, Bed material of channels with dense vegetation on side slopes.

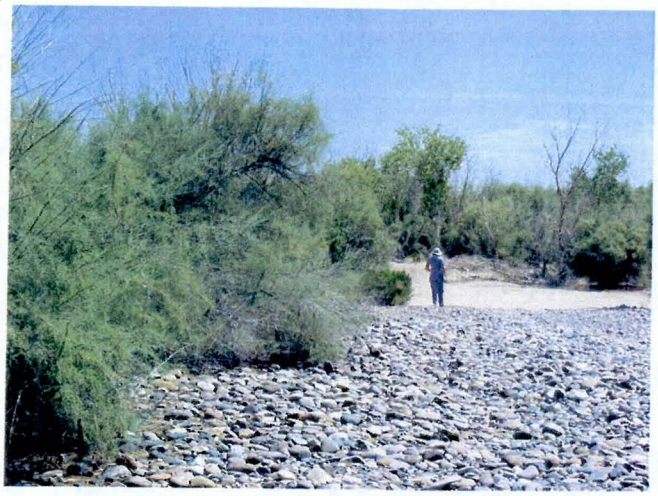
Photograph 6 Site 2, Channels with dense vegetation on side slopes.

Photograph 7 Site 3, Dense Vegetation Area viewed from open area.



Photograph 8 Site 3, Dense Vegetation Area bed material.

Photograph 9 Site 3, Dense Vegetation Area viewed from open area.



Photograph 10 Site 4, Location 1 example of a 0.040 n value area

Photograph 11 Site 4, Location 1 example of bed material in a 0.040 n value area

Photograph 12 Site 4, Location 1 example of a0.040 n value area

Photograph 13 Site 4, Location 2, example .040 n value area

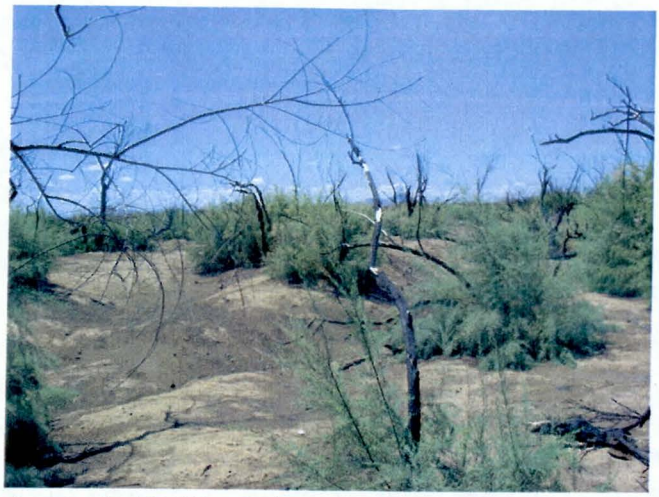
Photograph 14 Site 4, Location2, example of bed material in an .040 n value area

Photograph 15 Site 4, Location 2, example .040 n value area

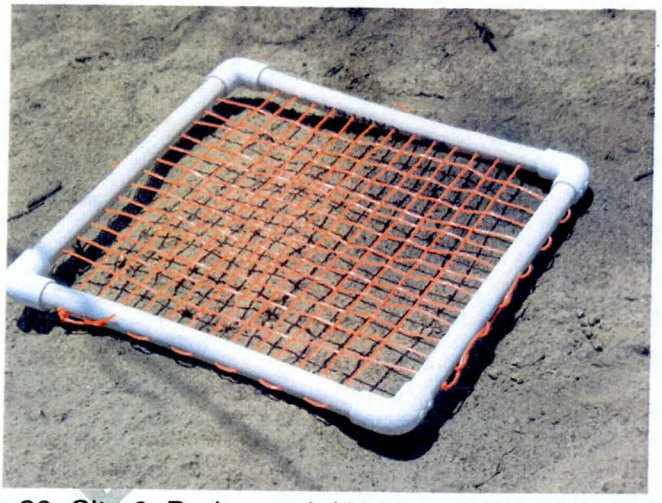
Photograph 16 Site 5, example of a 0.035 n value area

Photograph 17 Site 5, example of bed material in a 0.035 n value area

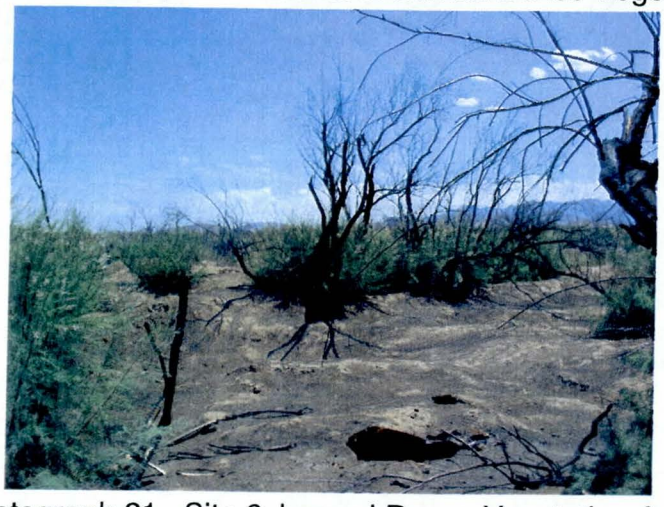
Photograph 18 Site 5, example of a 0.035 n value area



Photograph 19 Site 6, burned Dense Vegetation Area



Photograph 20 Site 6, Bed material in burned Dense Vegetation Area



Photograph 21 Site 6, burned Dense Vegetation Area

Photograph 22 Site 7, example of a 0.065 n value area

Photograph 23 Site 7, example of a 0.065 n value area

Photograph 24 Site 7, example of a 0.065 n value area, note build up of debris at base of vegetation

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APPENDIX E.3: COMPARISON OF CROSS SECTION ALIGNMENTS BETWEEN EFFECTIVE AND CORRECTED EFFECTIVE MODELS

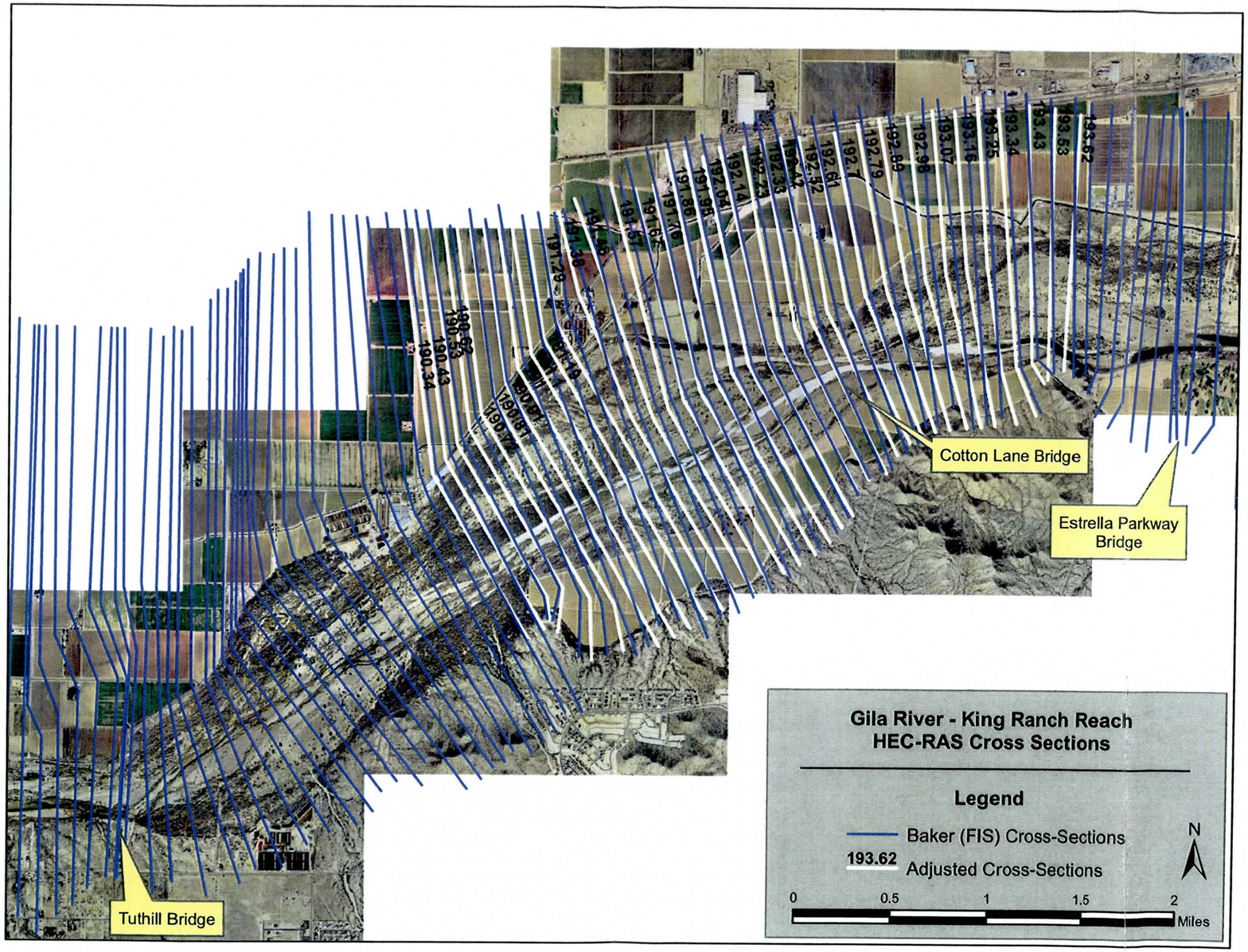

Figure 7. Original and Modified Cross Sections for the Study Reach. Original Cross Sections are shown in Blue and Modified Cross Section are shown inWhite.

The CD contains the following:

- Corrected Effective HEC-RAS model
- CHECKRAS reports as PDF
- Printouts of the input and output files of the Corrected Effective HEC-RAS model as PDF
- Copy of the *Norte Vista / King Ranch Floodplain Redelineation, Gila River*, Dated June 2007 by River Research & Design, Inc.

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APPENDIX E.4: CD WITH PROJECT DATA

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EXHIBIT MAPS

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

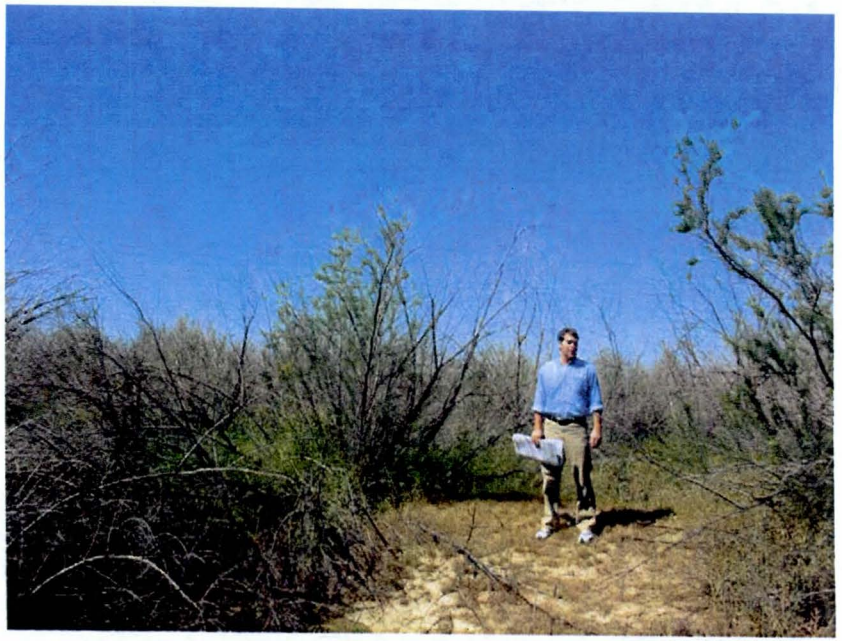
APPENDIX E

HYDRAULIC ANALYSIS SUPPORTING DOCUMENTATION

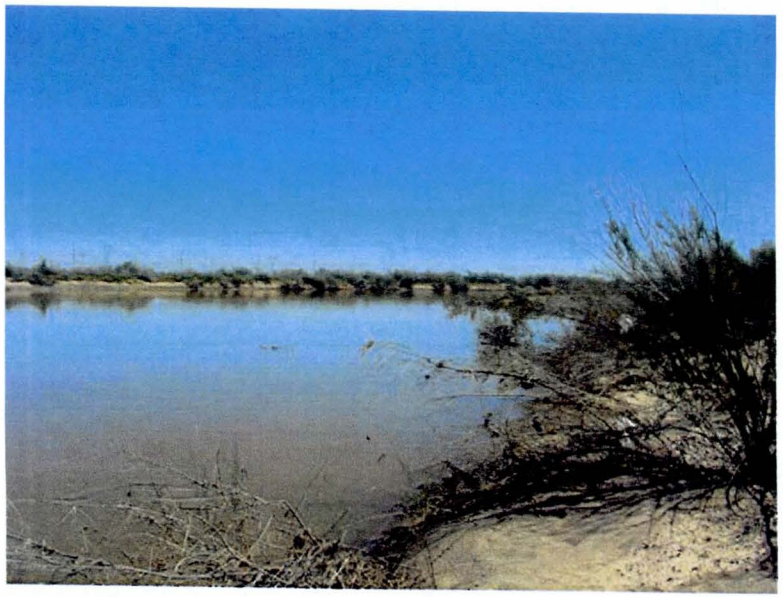
APPENDIX E.1

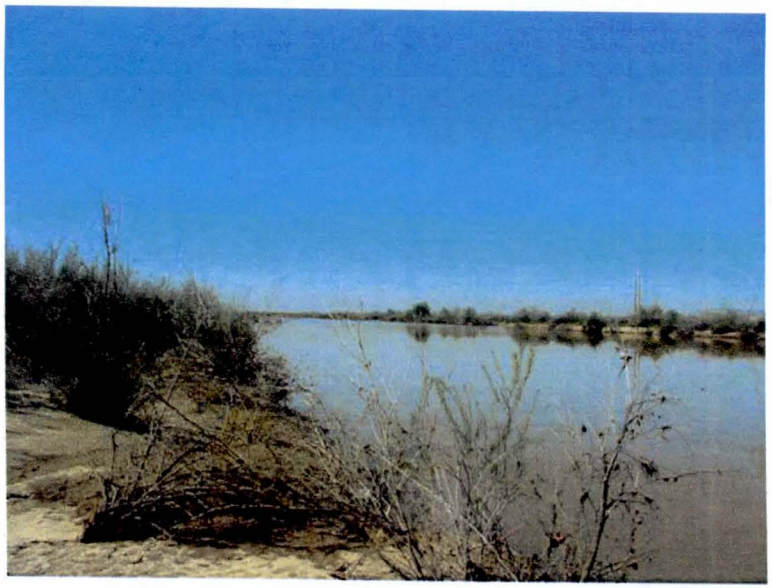
Field Photographs and Logs Report
Manning's n Value Field Assessments

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



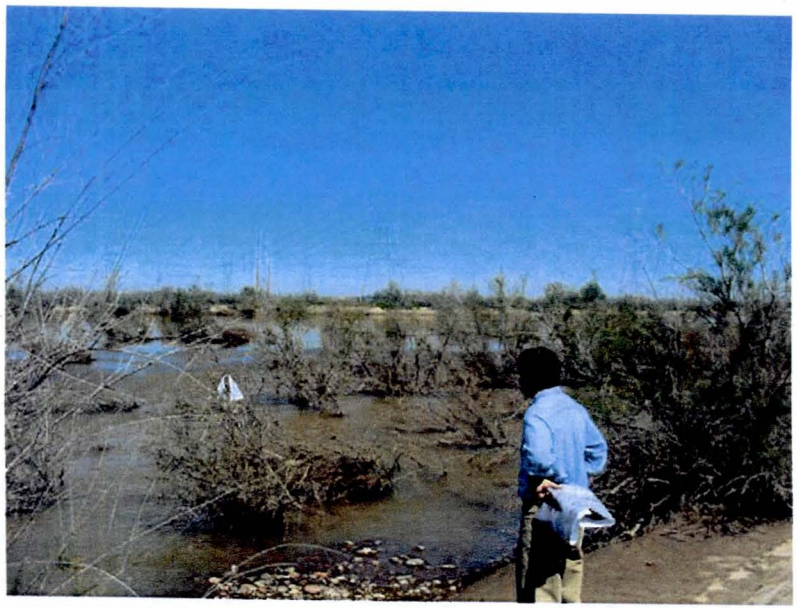
Waypoints 11-15 – Overbank Area Subject to Flow in 2005 (Photos IMG_4299-4301) n = 0.03 Very Low Density due to small area of shrubs.

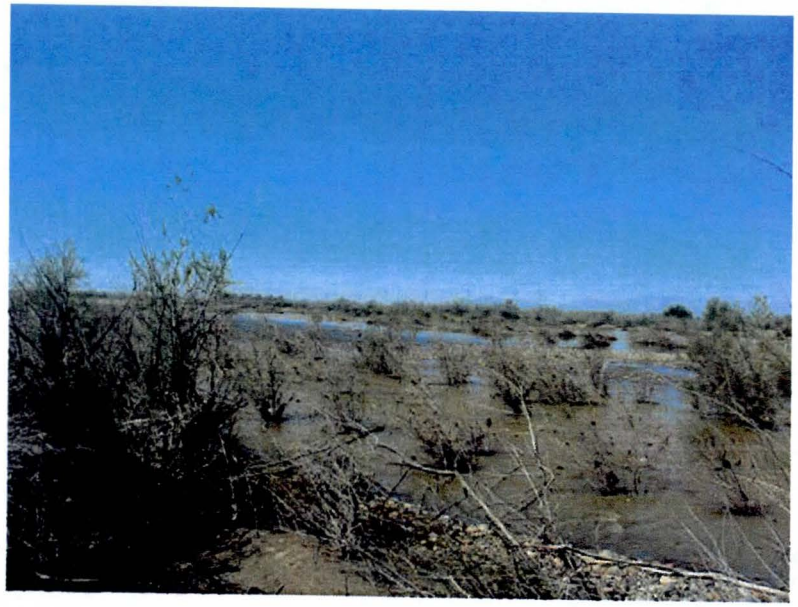




Waypoint 15 – Gila River – IMG_4302-4305 – n = 0.03

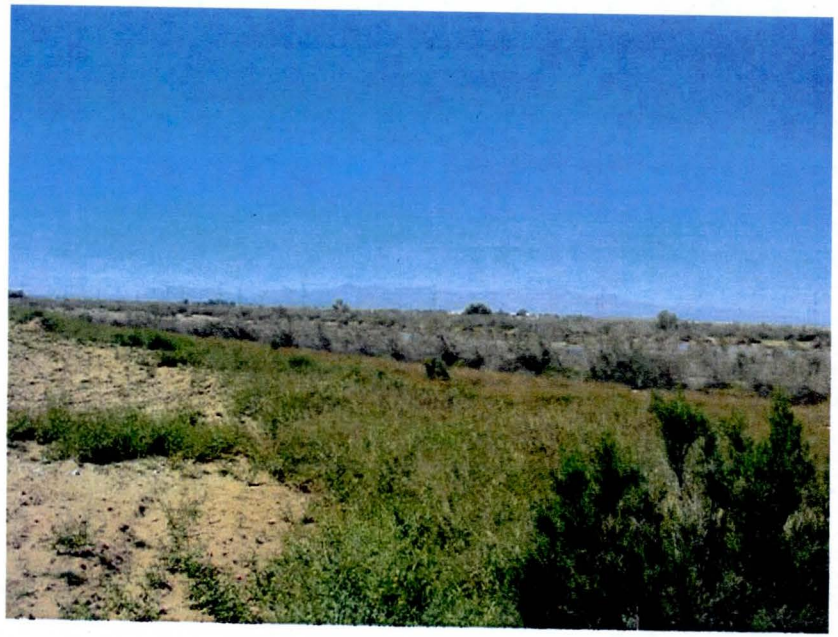
Waypoint 16 – Gila River Channel – Very Low Density Vegetation – IMG_4306-4309- n = 0.03



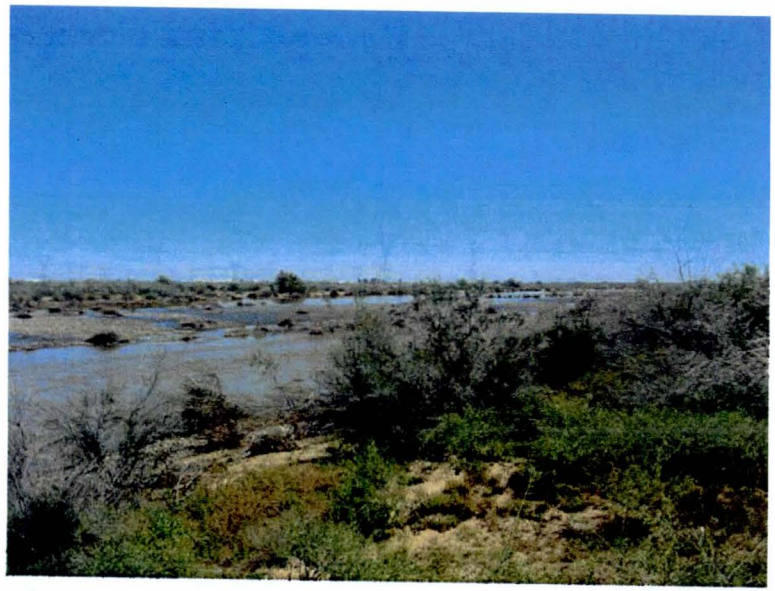


Waypoint 17 – Gila River Channel – IMG_4310-4313 Very Low Density – n = 0.03 due to limited area of vegetation

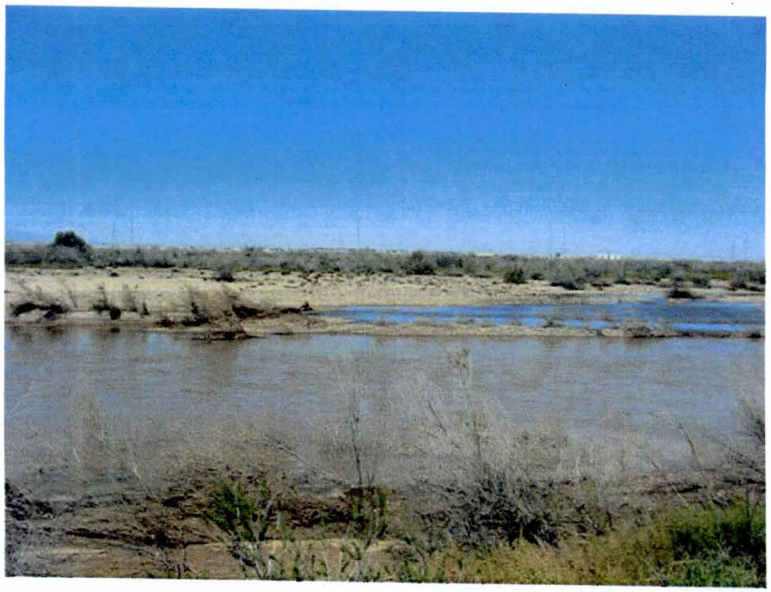
Waypoint 18 – Photos IMG_4314-4317 – Very Low Density / Farmland Interface – n = 0.03 – riverward area

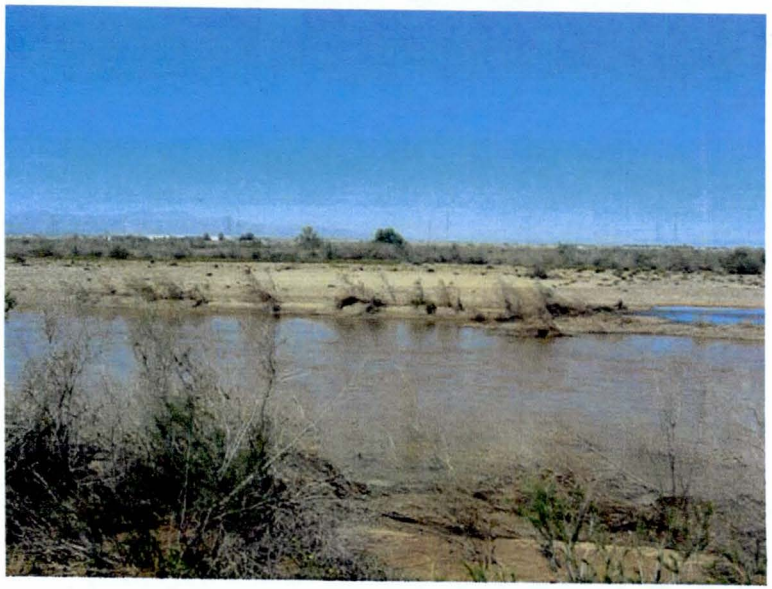


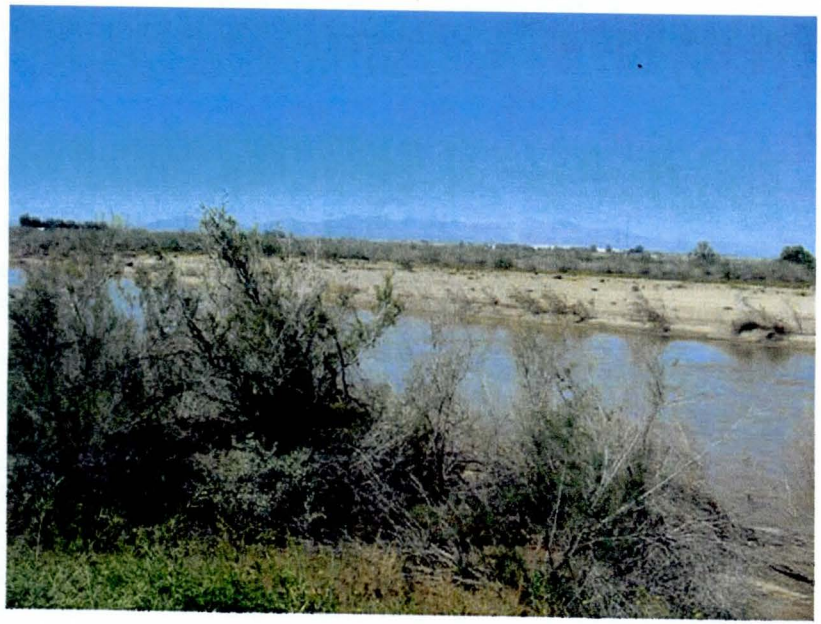
Waypoint 18 – IMG_4318-4320 – n = 0.05 – assume crops during flood for worst case

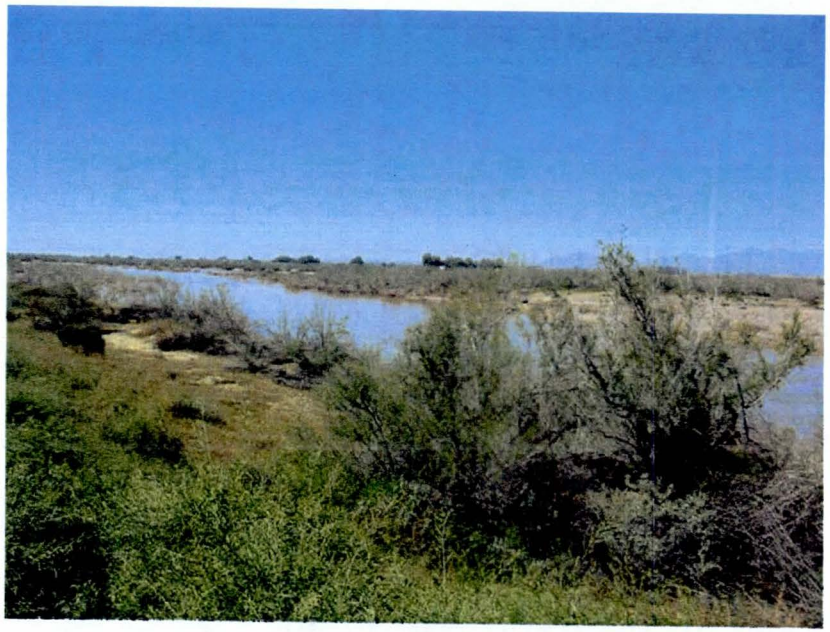


Waypoint 19 – Very Low Density – IMG_4321-4324 – n = 0.03 upstream and north



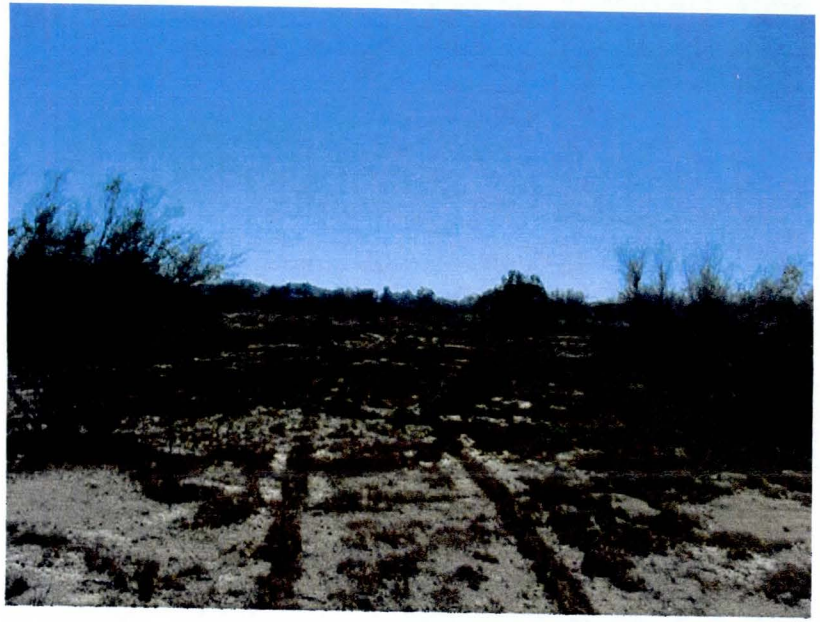




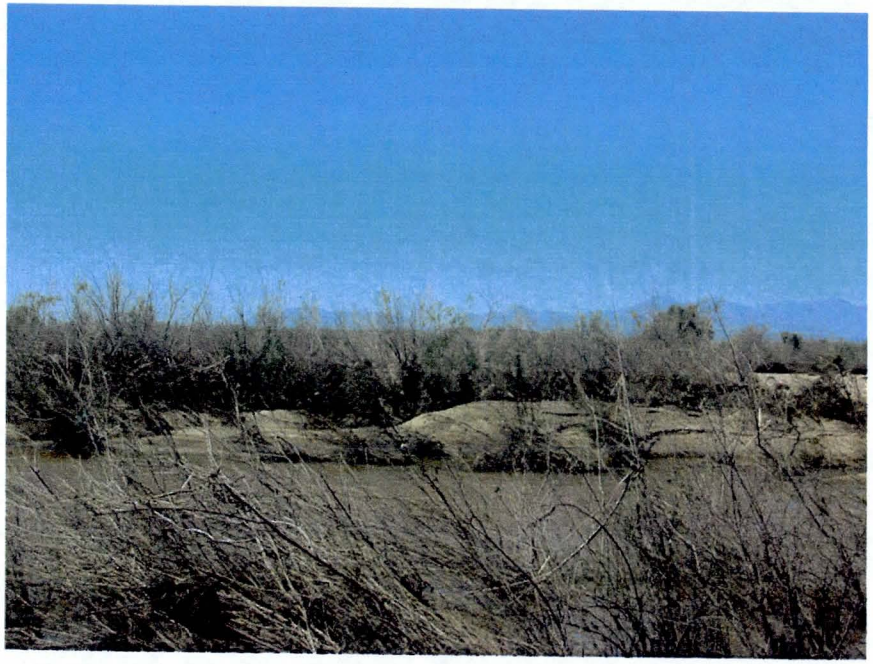


Waypoint 19 – IMG_4325-4328 Low Density – n = 0.03 northwest except lower right – n = 0.04

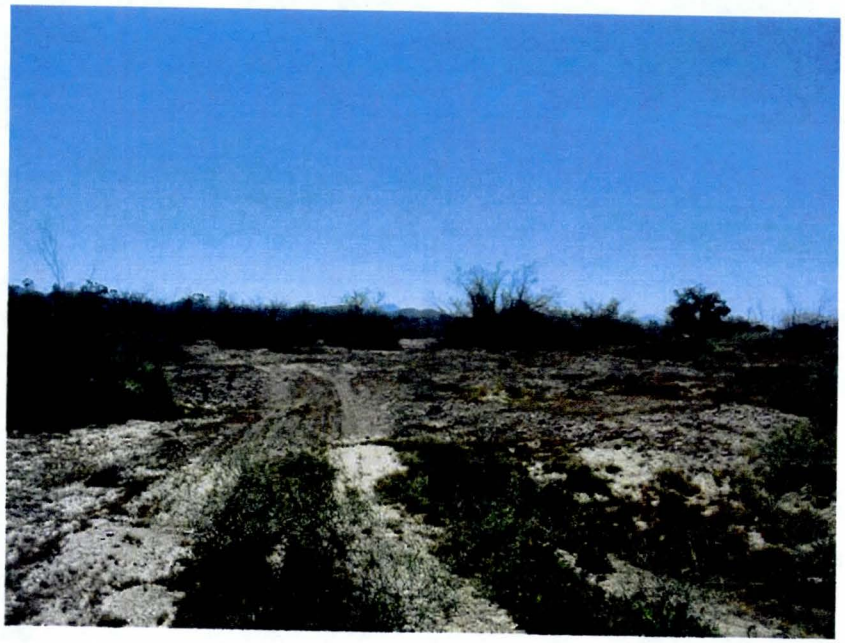
Waypoint 19 – IMG_4329-4332 – Very Low and Low Density Interface note higher density in distance n = 0.03 to 0.04



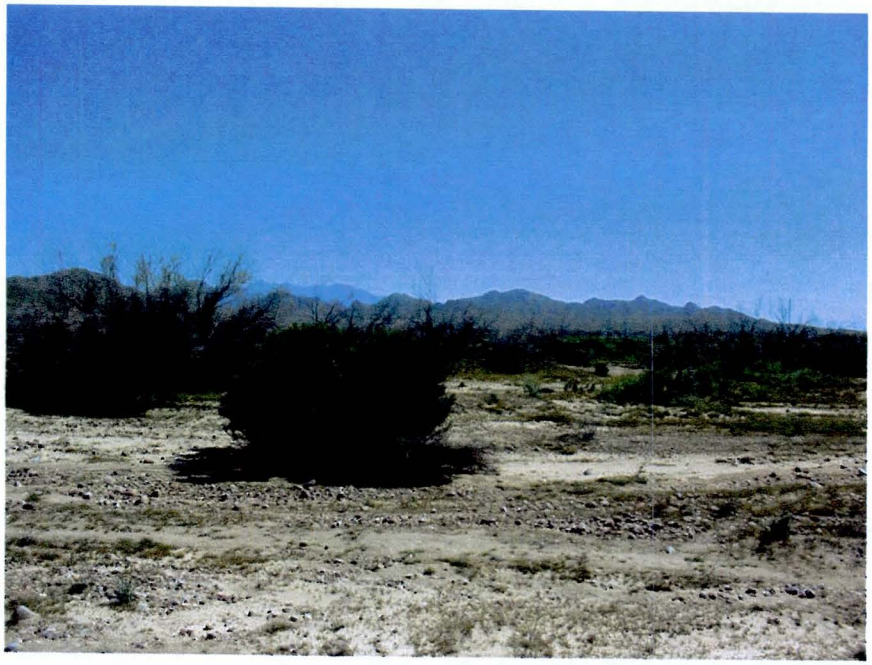
Waypoint 19 – Interface Between Very Low and Low Vegetation – IMG_4333-4336 n = 0.04



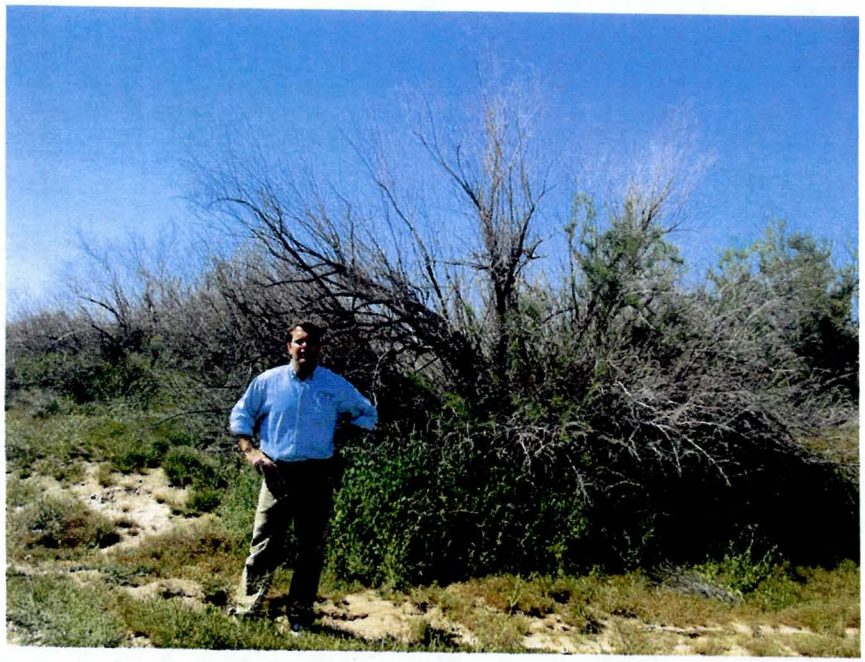
Waypoint 19-20 Photos 4337-4340 Low Density Vegetation – n = 0.04



Waypoint 19-20 Photos 4341-4344 – Low Density Vegetation – n = 0.04

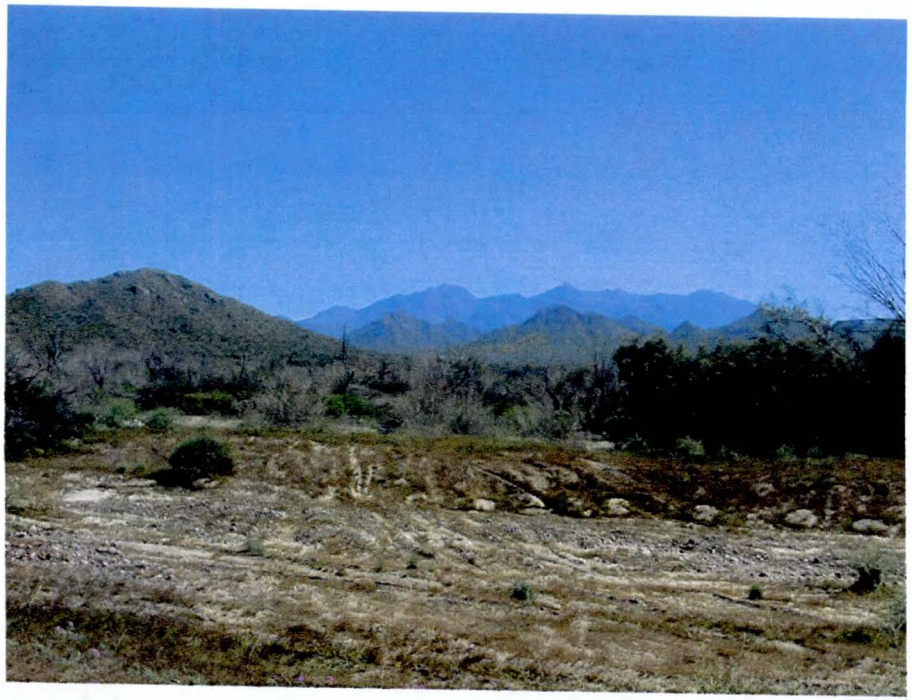


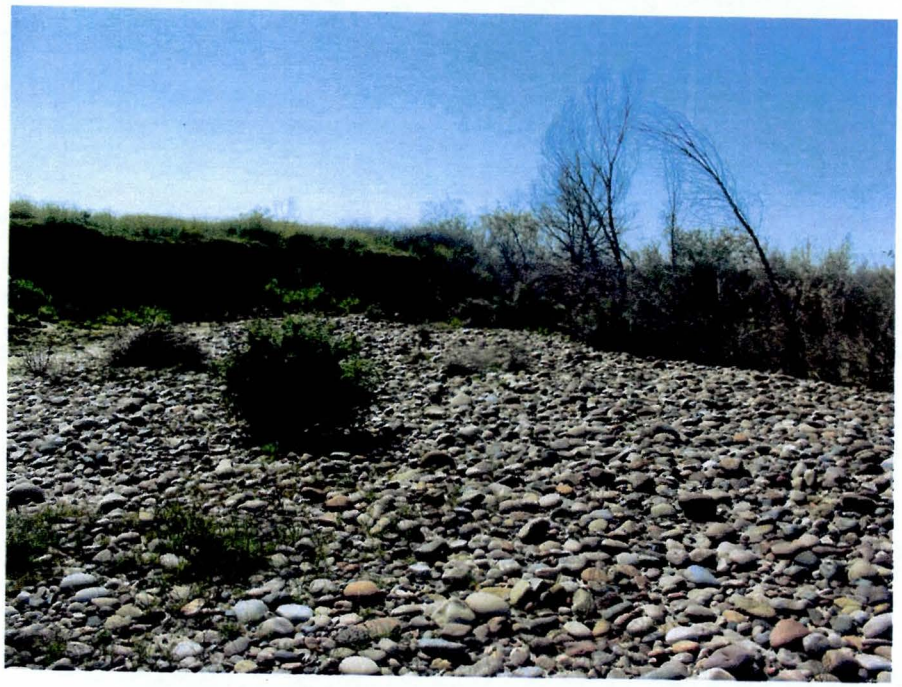
Waypoint 20 – Photos 4345-4347, 4349 Low Density Vegetation – n = 0.04



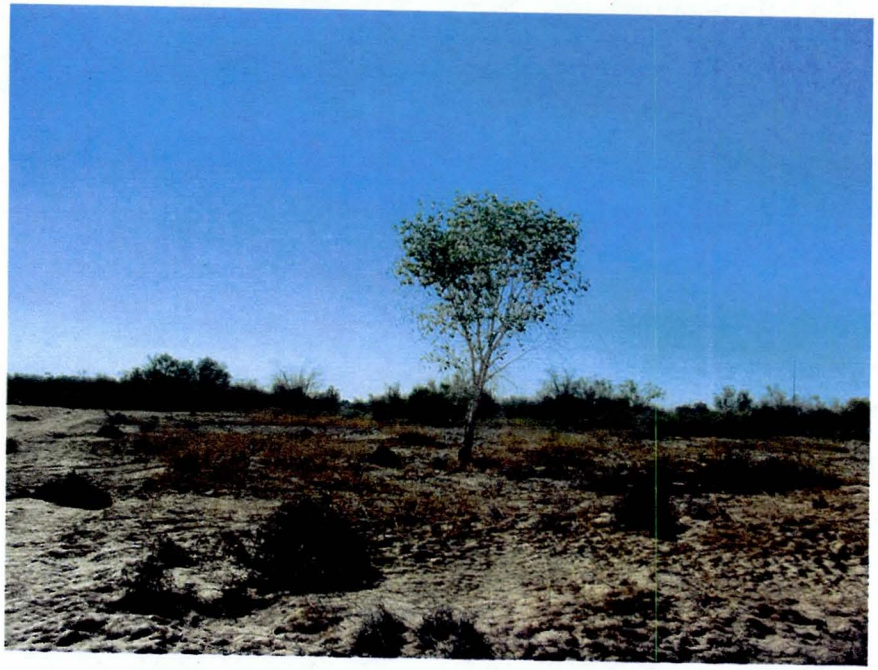
Waypoint 20 Photos 4350-4353 – Low Density Vegetation - n = 0.04

Waypoint 20 – Photos 4354-4357 – Boundary of Low Density Vegetation – n = 0.04



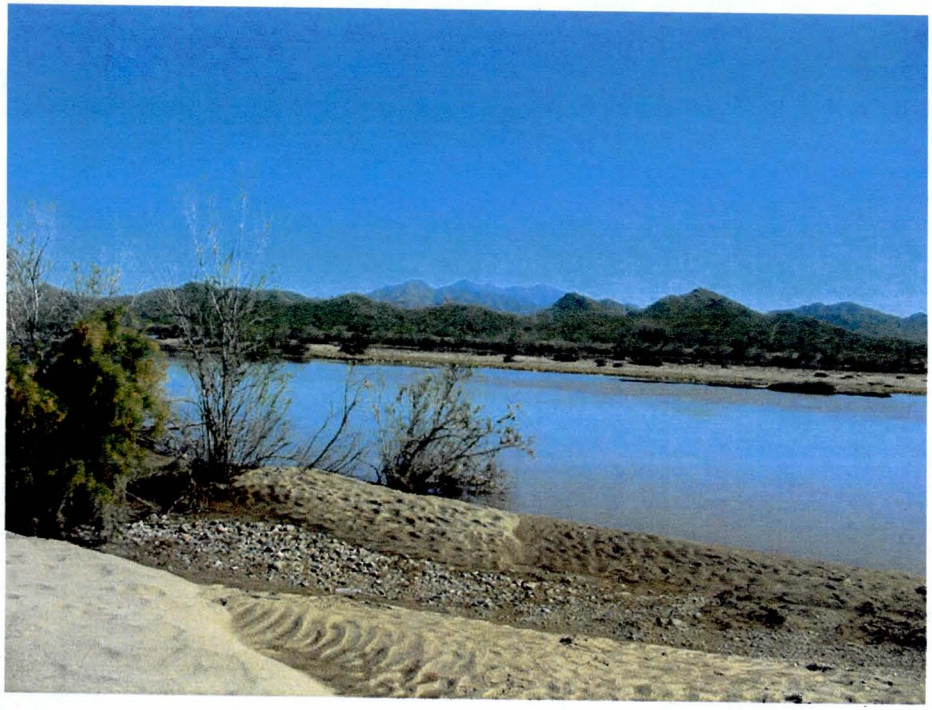


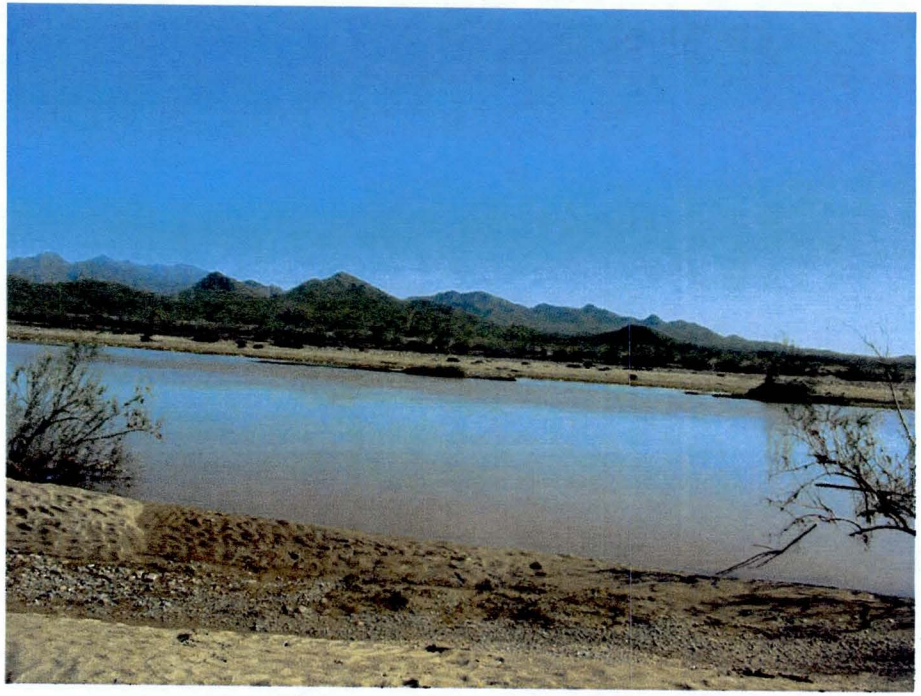
Waypoint 21 – Photo 4358-4361 Medium High Vegetation Density – n = 0.12 (background upper right and lower left)



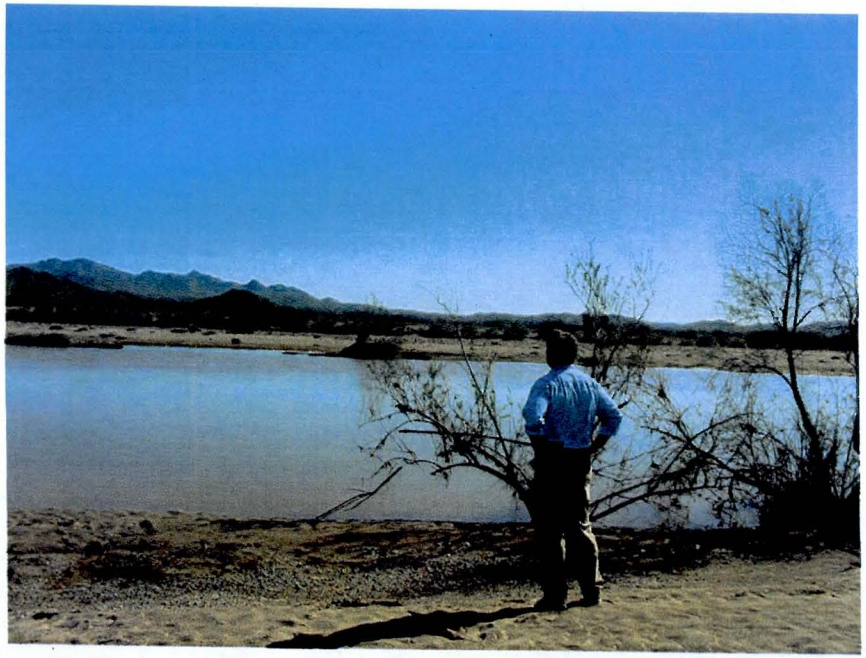
Waypoint 24 Photos 4365-4368 – Very Low Density Vegetation – n = 0.03

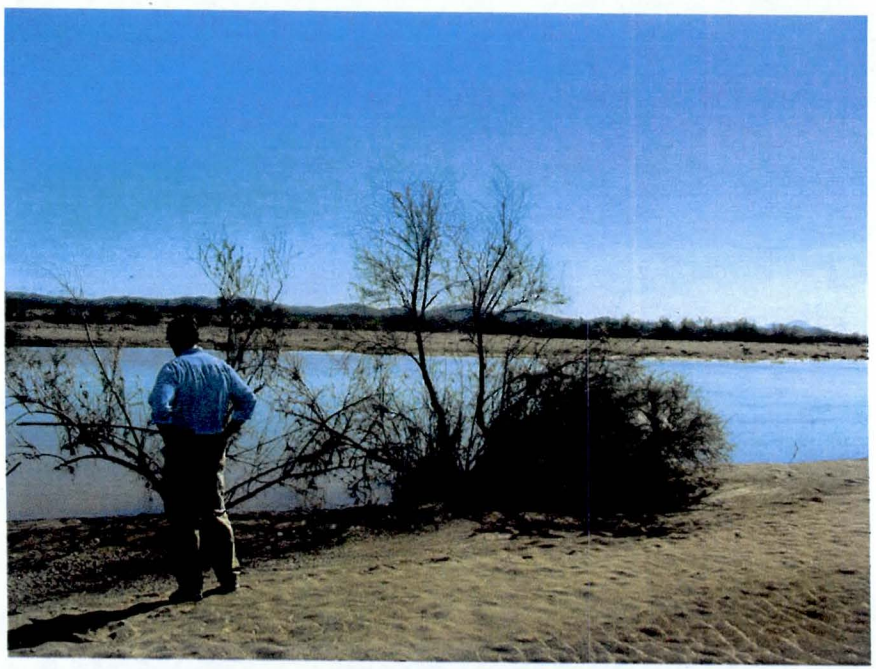
Waypoint 24 Photos 4369-4372 Very Low Density Vegetation n = 0.03



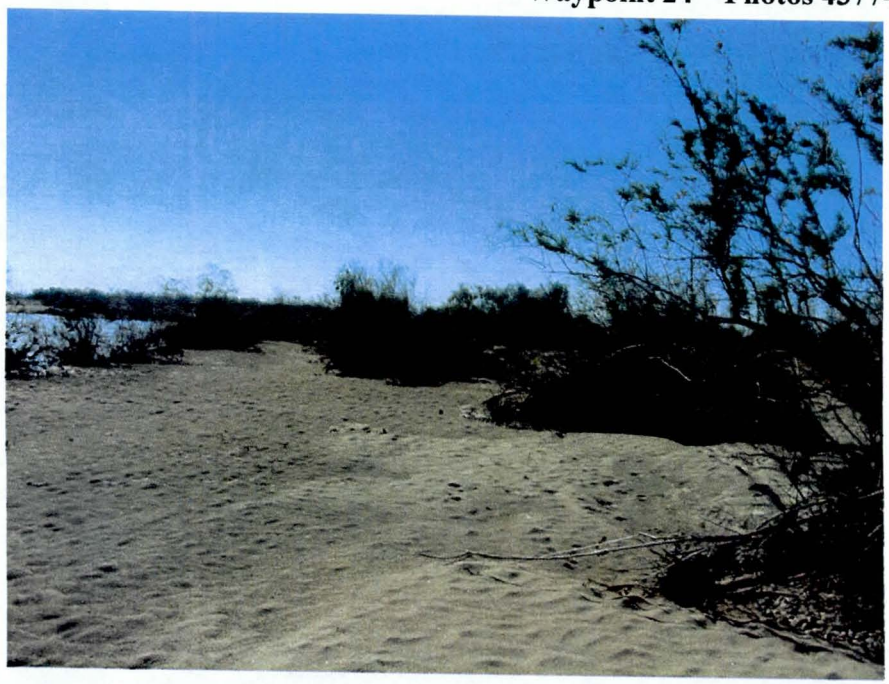


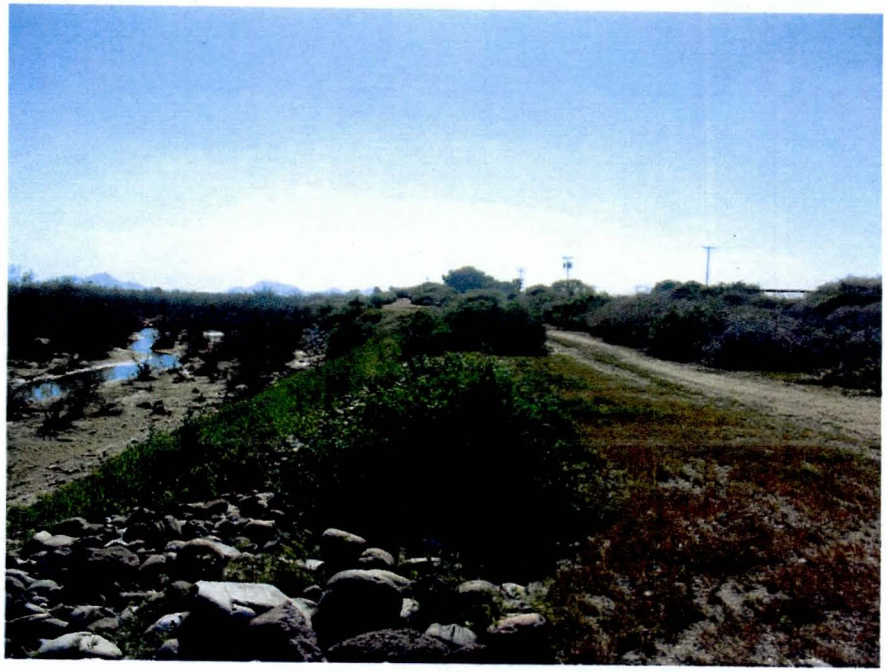
Waypoint 24 – Photos 4373-4376 – Main Channel – Very Low Density Vegetation - n = 0.03



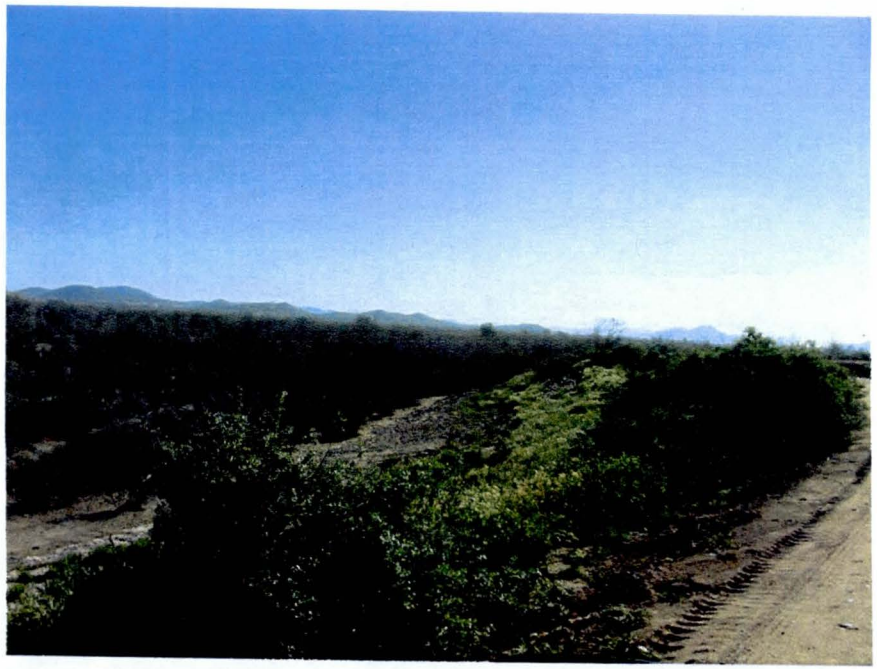


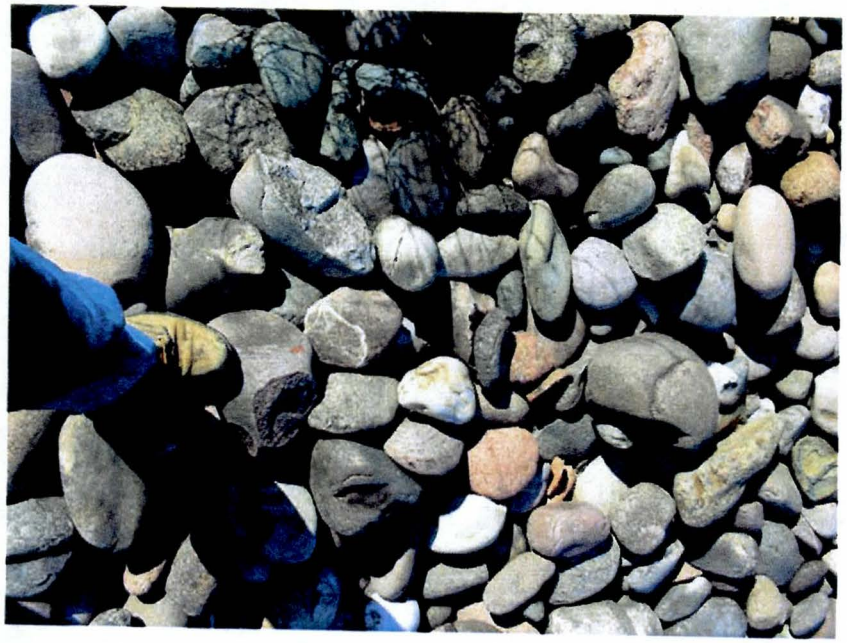
Waypoint 24 – Photos 4377-4380 Very Low Density – n = 0.03



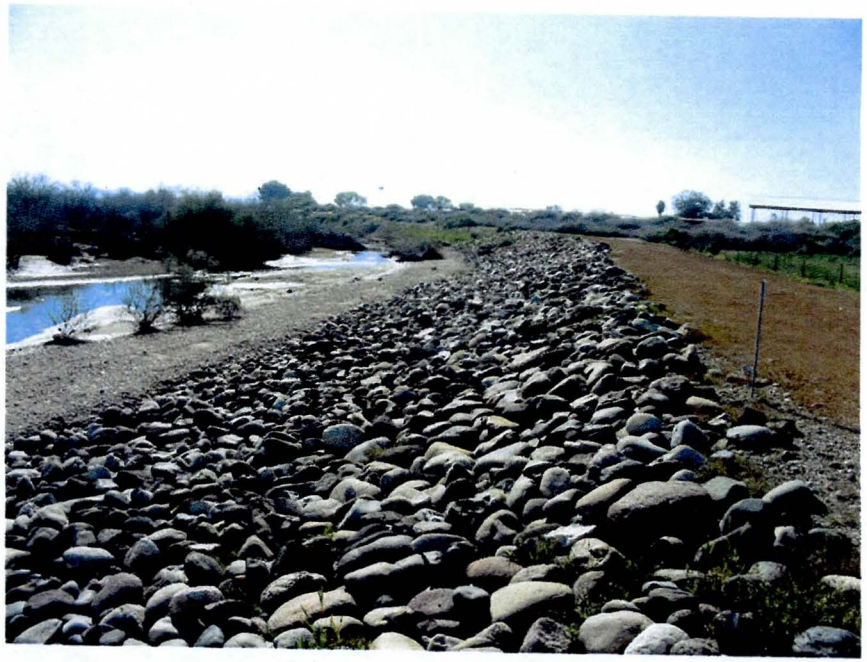


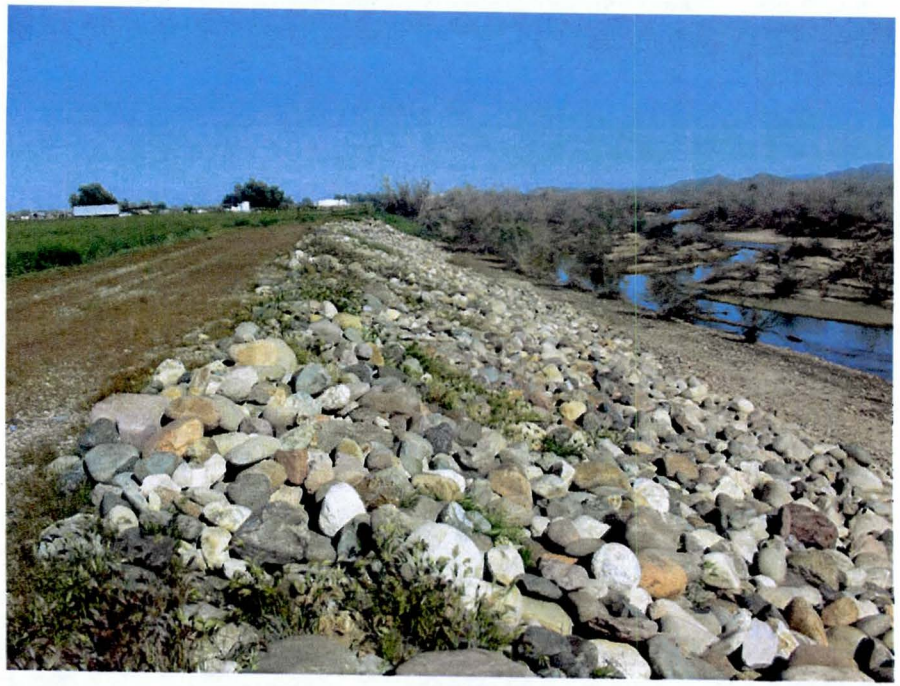
Waypoint 28 – Photos 4383-4385 Protected north bank with Medium Dense Vegetation to left in channel – n = 0.06



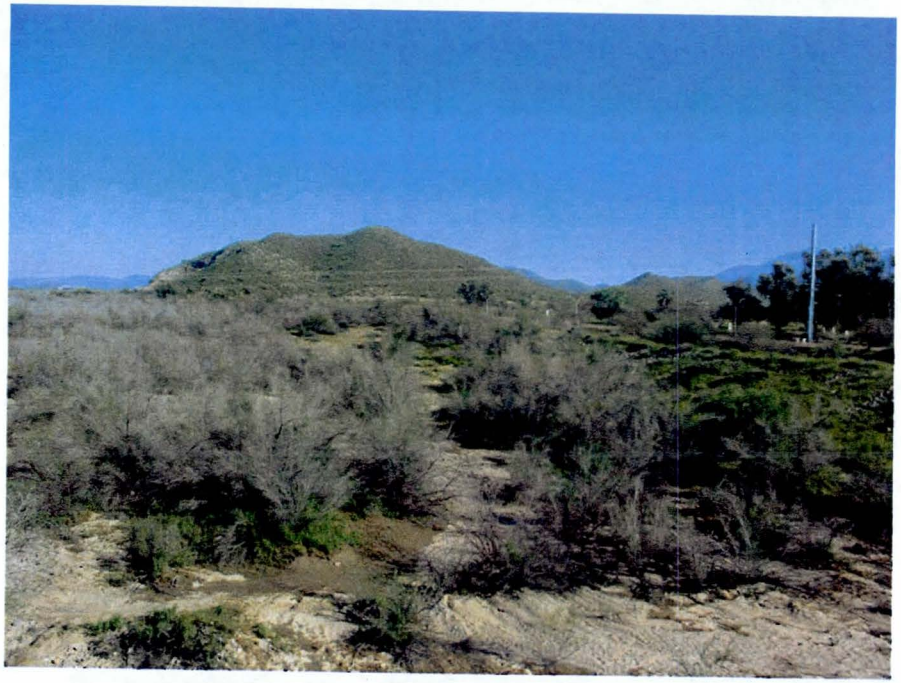


Waypoint 27 - Photo 4386-4389 – Protected north bank with medium dense vegetation across channel - n = 0.06

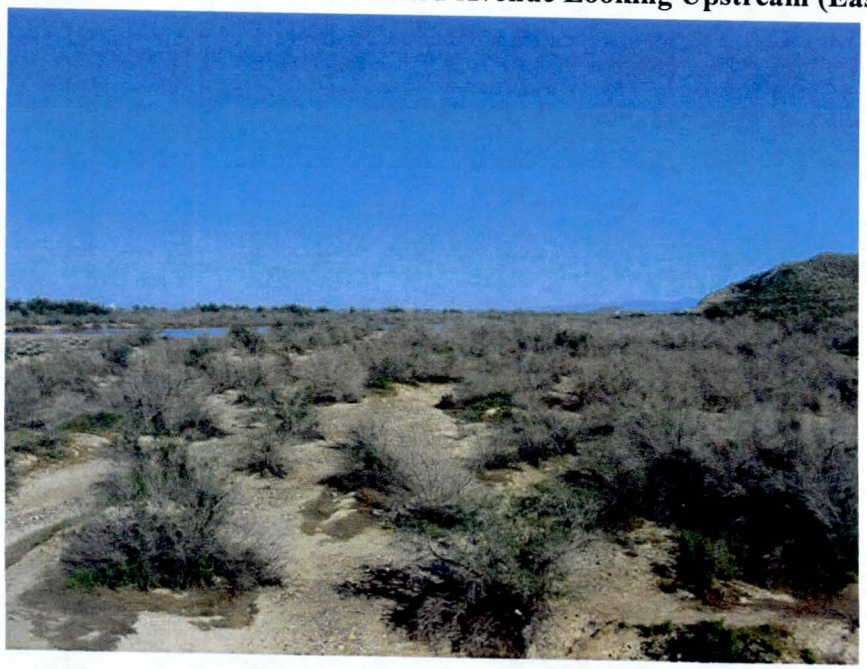




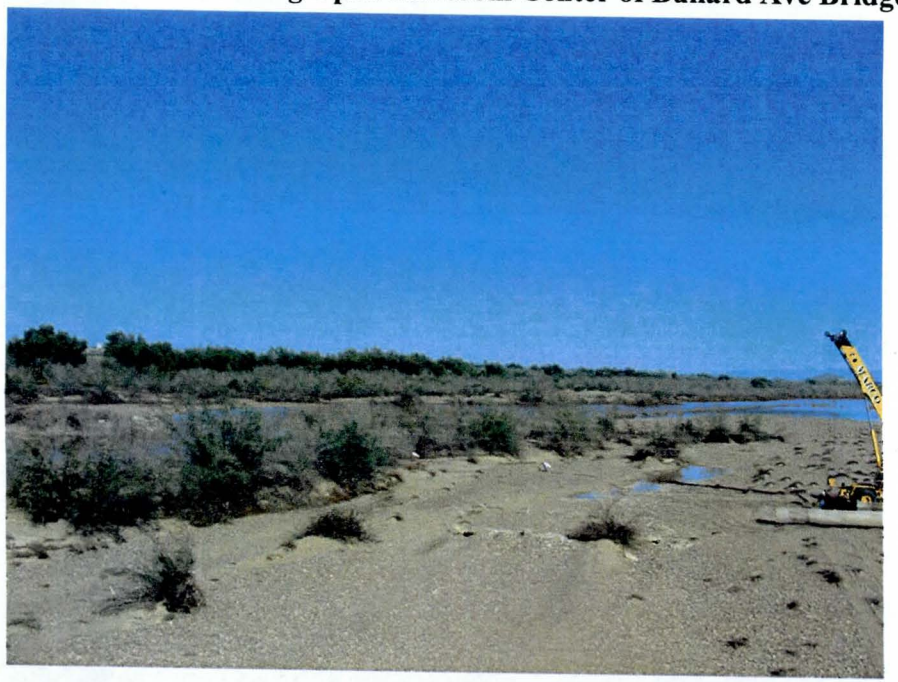
Waypoint 29 – Photos 4390-4391 East end of protected north bank – medium dense vegetation in channel – n = 0.06



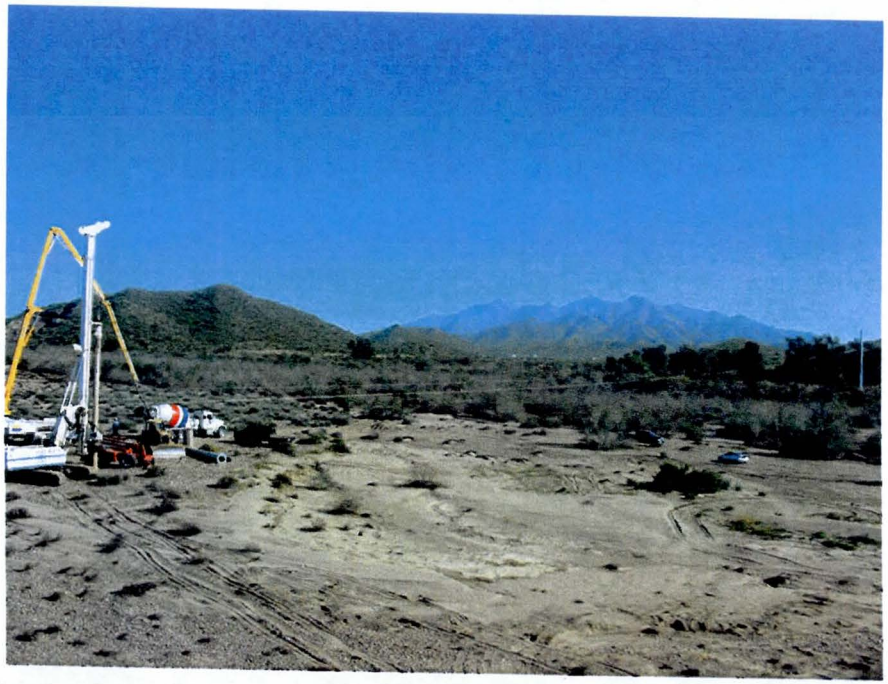
Channel at Bullard Avenue Looking Upstream (East) – Medium Vegetation Density (n = 0.06) Photos 4394-4397

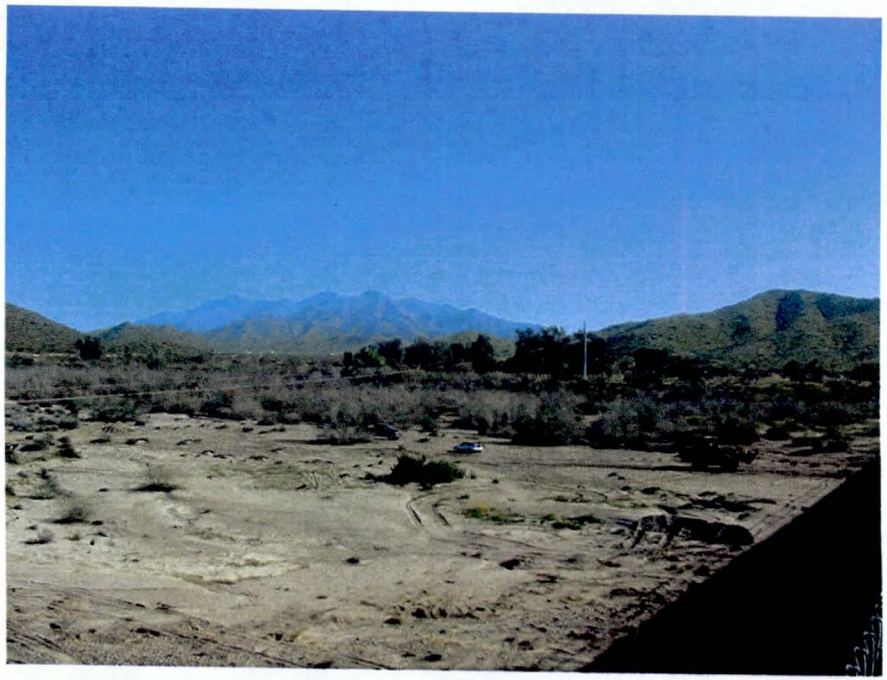


Looking Upstream from Center of Bullard Ave Bridge (From North to East) - Low Density Vegetation (n = 0.03)



Bullard Avenue Bridge – looking east to south – Low density vegetation (n = 0.03) Photos 4403-4406





E.2 Cross Section Plots

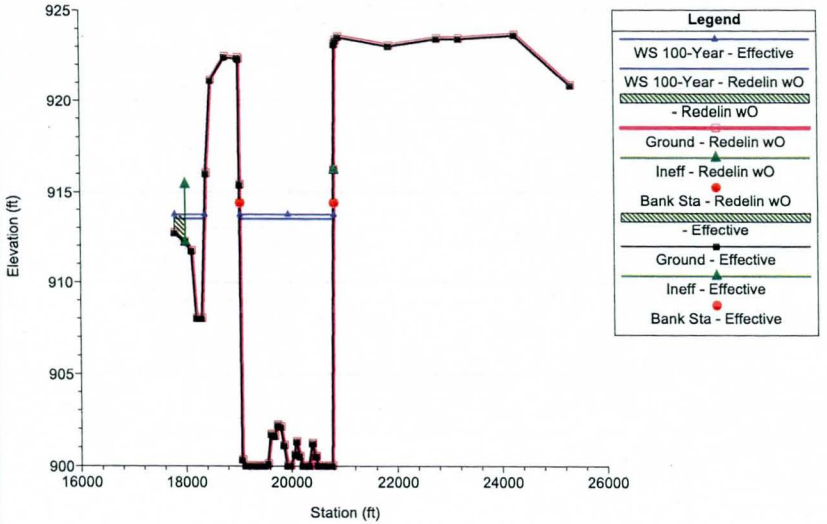
E.2.1 Cross Section Plots

Effective Model

Existing Conditions

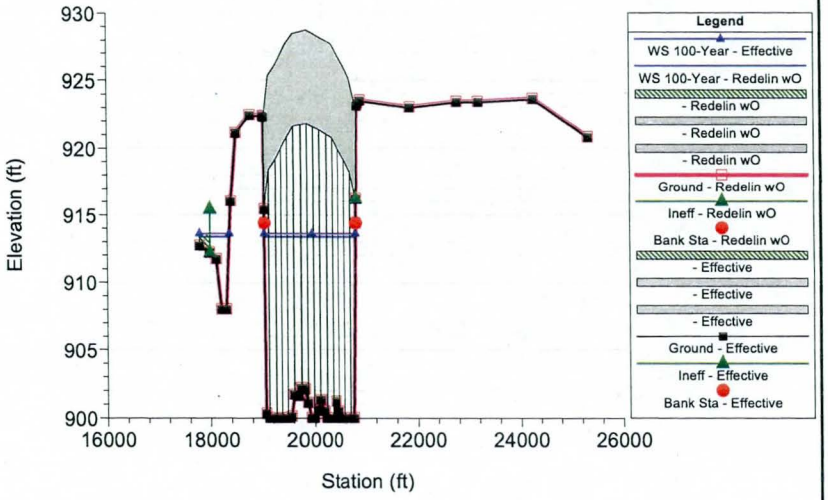
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO

River = Gila River Reach = El Rio WMP RS = 195.16 APPROX. ALIGNMENT OF BULLARD AVE. BRIDGE



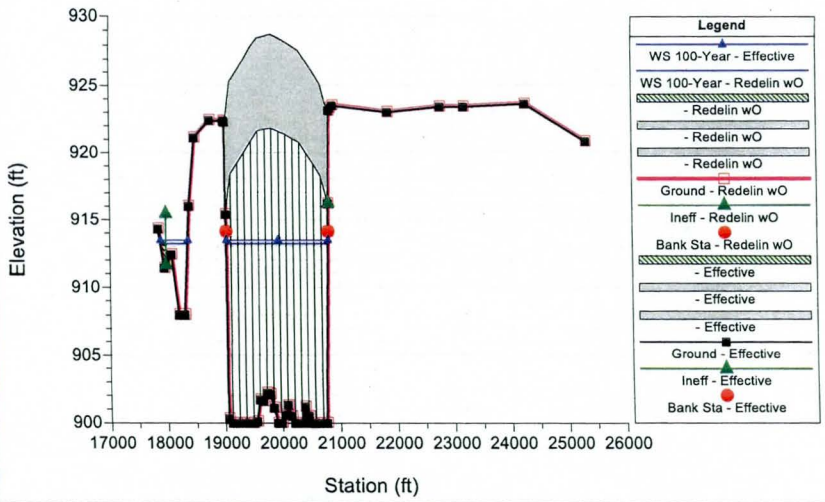
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO

River = Gila River Reach = El Rio WMP RS = 195.15 BR Bridge #4



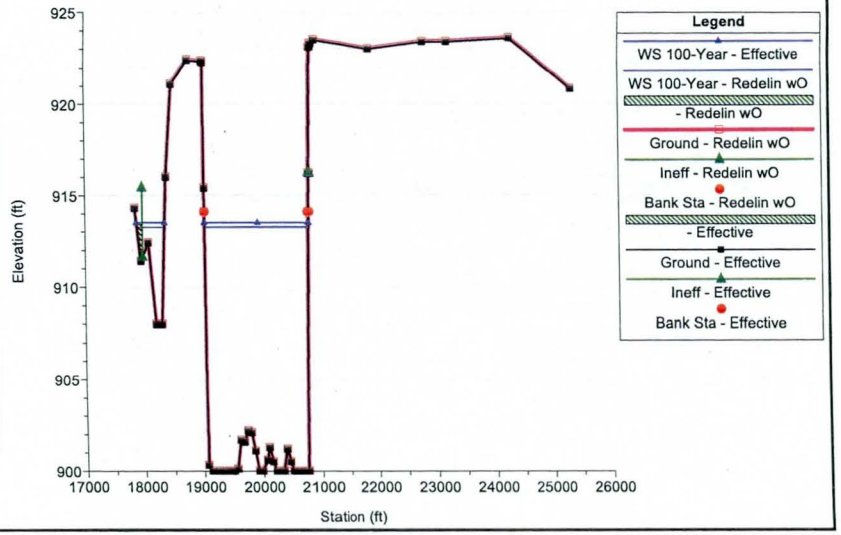
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO

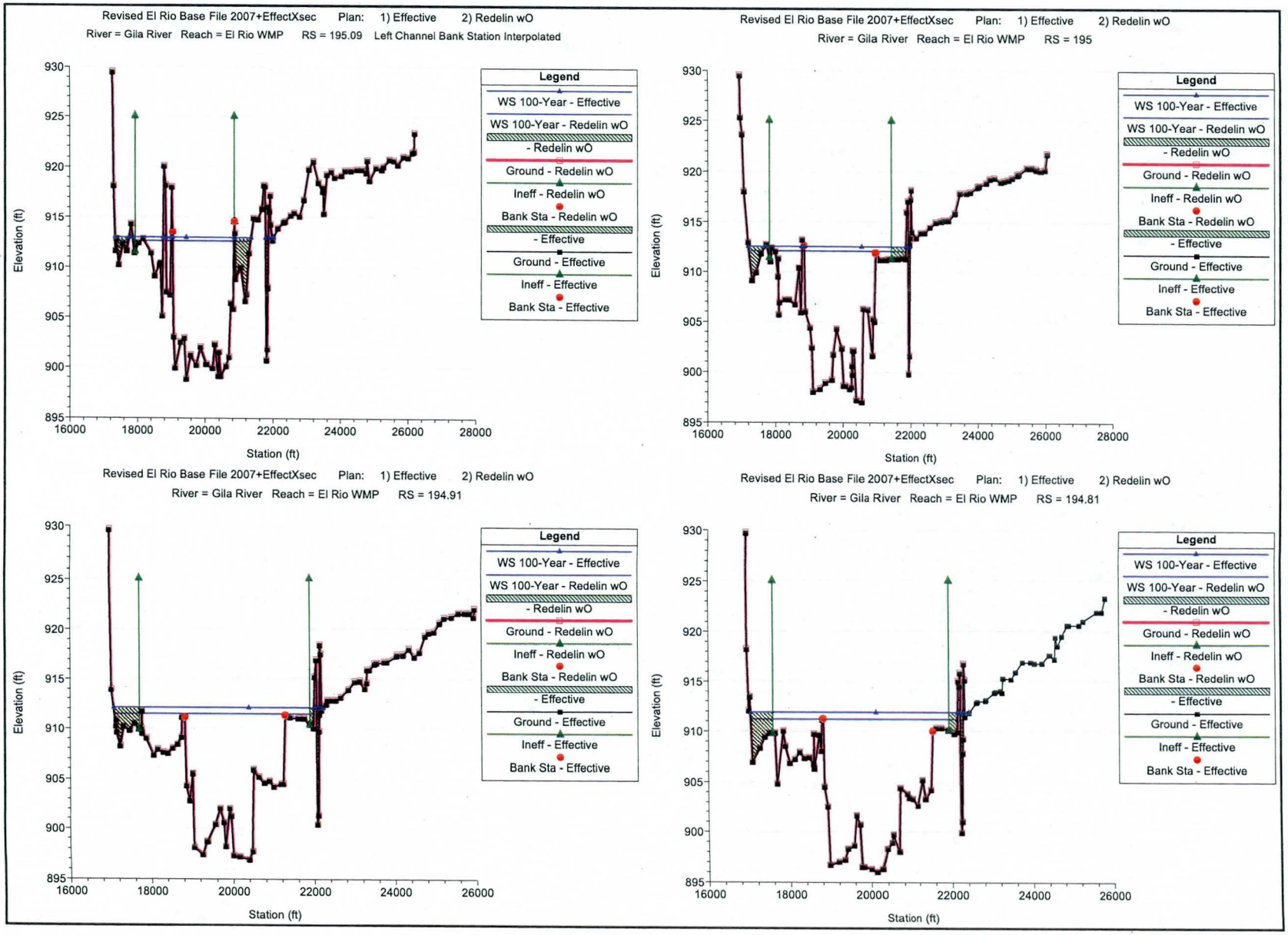
River = Gila River Reach = El Rio WMP RS = 195.15 BR Bridge #4

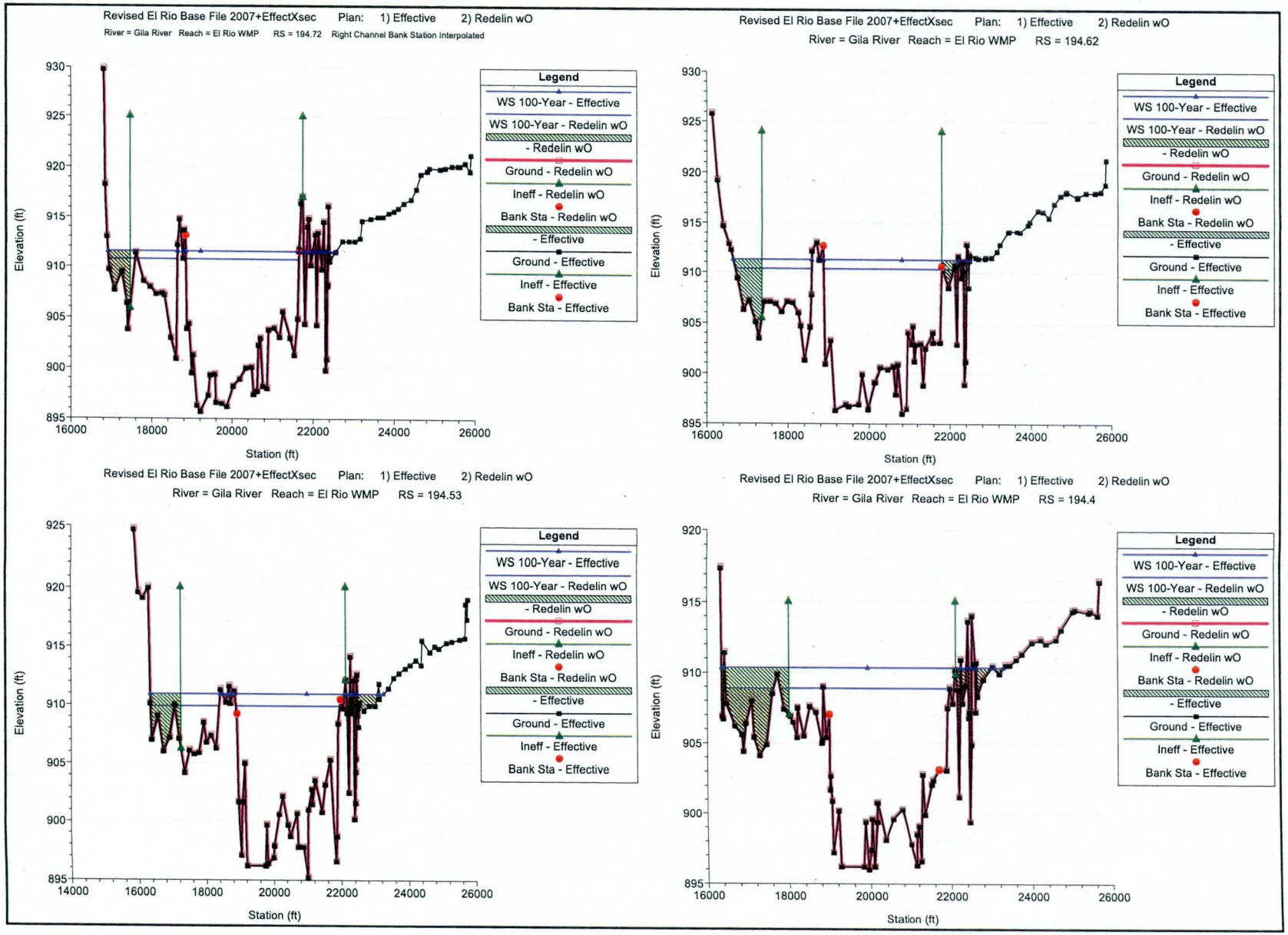


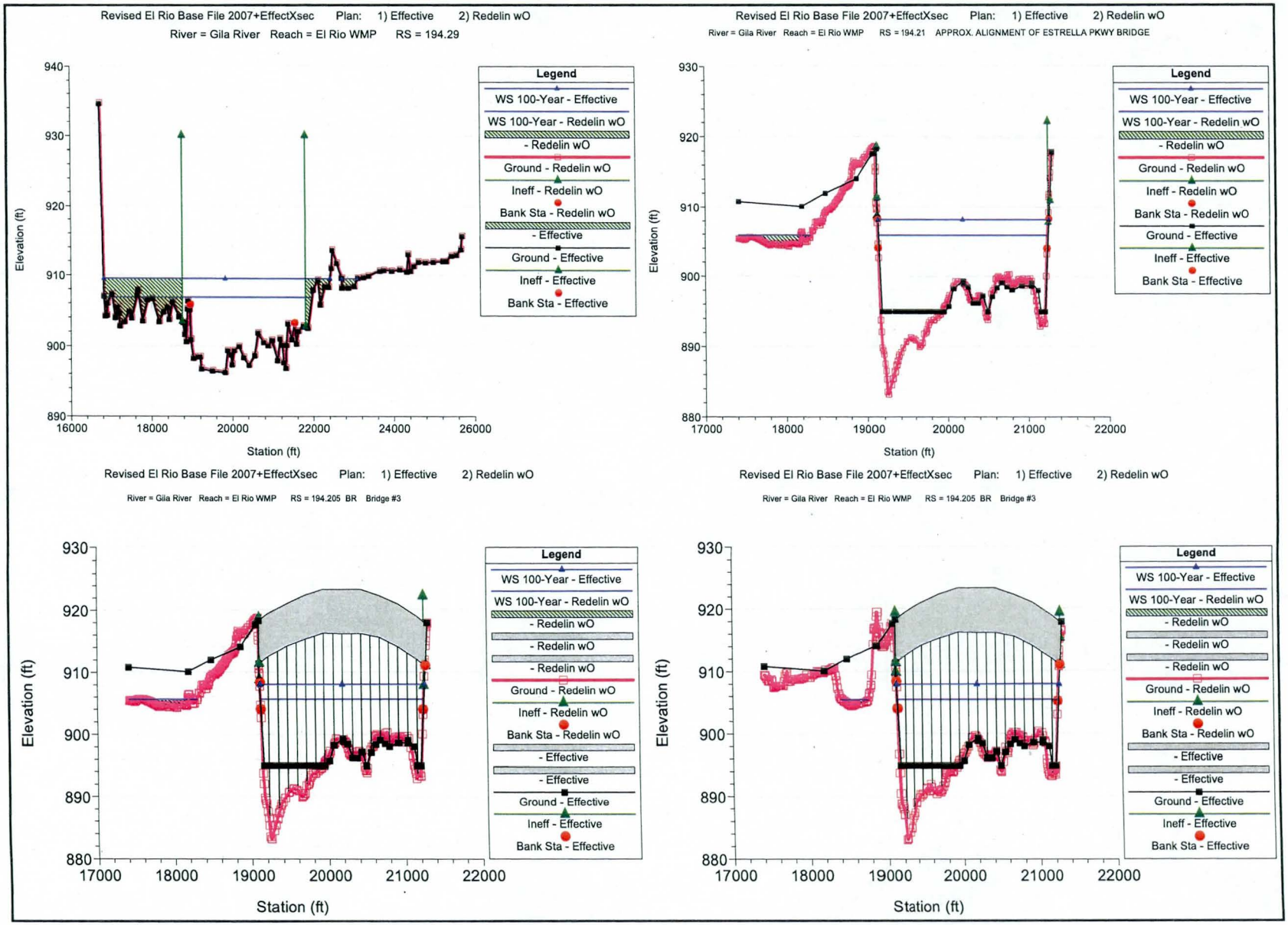
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO

River = Gila River Reach = El Rio WMP RS = 195.13 Left and Right Channel Bank Stations Interpolated



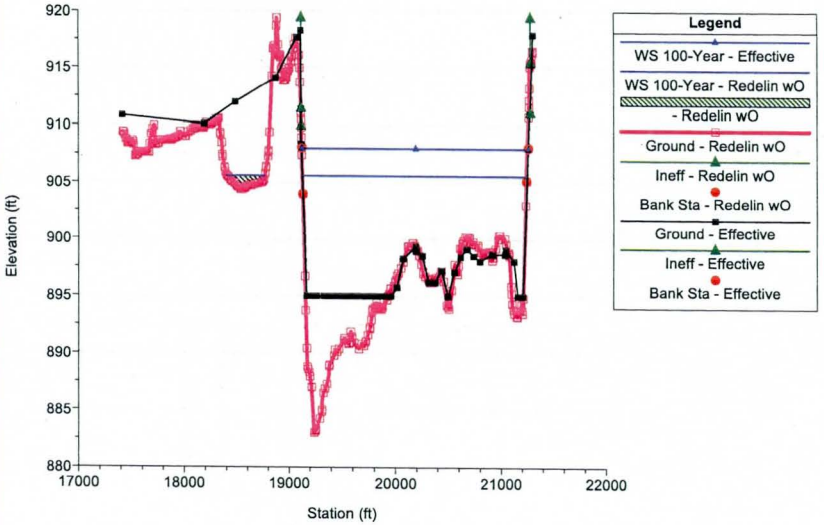

Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 195.09 Left Channel Bank Station Interpolated
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 195
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 194.91
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 194.81
Legend
WS 100-Year - Effective
WS 100-Year - Redelin wO
- Redelin wO
Ground - Redelin wO
Ineff - Redelin wO
Bank Sta - Redelin wO
- Effective
Ground - Effective
Ineff - Effective
Bank Sta - Effective
Elevation (ft)
Station (ft)
930
925
920
915
910
905
900
895
16000
18000
20000
22000
24000
26000
28000


Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 194.72 Right Channel Bank Station Interpolated
Elevation (ft)
Station (ft)
Legend
WS 100-Year - Effective
WS 100-Year - Redelin wO
- Redelin wO
Ground - Redelin wO
Ineff - Redelin wO
Bank Sta - Redelin wO
- Effective
Ground - Effective
Ineff - Effective
Bank Sta - Effective
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 194.62
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 194.53
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 194.4


Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 194.29
Elevation (ft)
Station (ft)
Legend
WS 100-Year - Effective
WS 100-Year - Redelin wO
- Redelin wO
Ground - Redelin wO
Ineff - Redelin wO
Bank Sta - Redelin wO
- Effective
Ground - Effective
Ineff - Effective
Bank Sta - Effective
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 194.21 APPROX. ALIGNMENT OF ESTRELLA PKWY BRIDGE
Elevation (ft)
Station (ft)
Legend
WS 100-Year - Effective
WS 100-Year - Redelin wO
- Redelin wO
Ground - Redelin wO
Ineff - Redelin wO
Bank Sta - Redelin wO
Ground - Effective
Ineff - Effective
Bank Sta - Effective
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 194.205 BR Bridge #3
Elevation (ft)
Station (ft)
Legend
WS 100-Year - Effective
WS 100-Year - Redelin wO
- Redelin wO
- Redelin wO
- Redelin wO
Ground - Redelin wO
Ineff - Redelin wO
Bank Sta - Redelin wO
- Effective
- Effective
Ground - Effective
Ineff - Effective
Bank Sta - Effective
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 194.205 BR Bridge #3
Elevation (ft)
Station (ft)
Legend
WS 100-Year - Effective
WS 100-Year - Redelin wO
- Redelin wO
- Redelin wO
- Redelin wO
Ground - Redelin wO
Ineff - Redelin wO
Bank Sta - Redelin wO
- Effective
- Effective
Ground - Effective
Ineff - Effective
Bank Sta - Effective

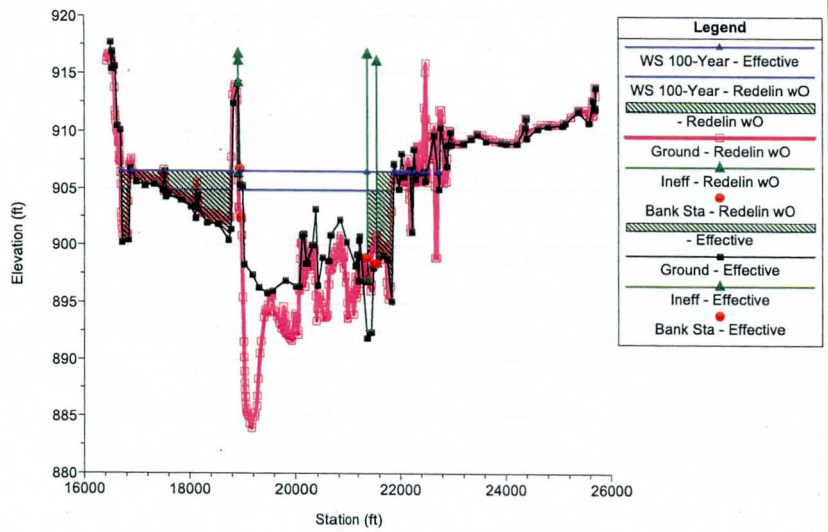
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO

River = Gila River Reach = El Rio WMP RS = 194.2 Left and Right Channel Bank Stations Interpolated



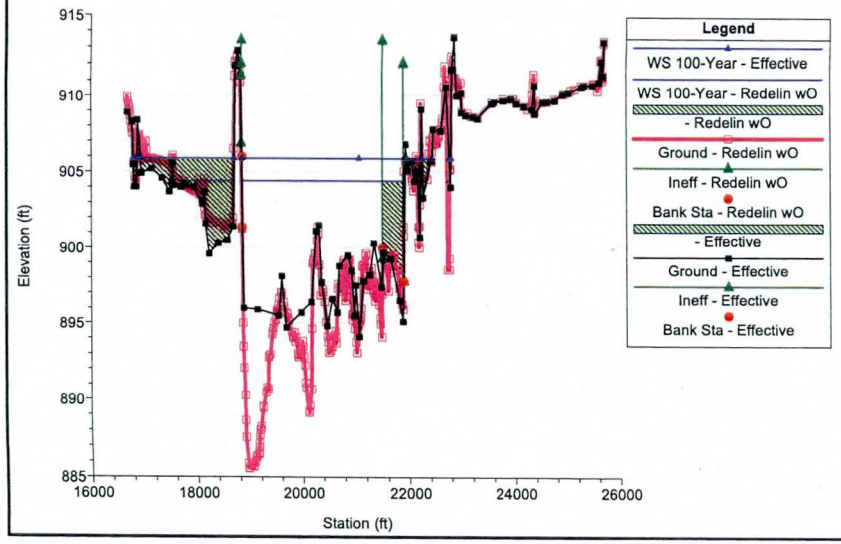
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO

River = Gila River Reach = El Rio WMP RS = 194.10 Left and Right Channel Bank Stations Interpolated



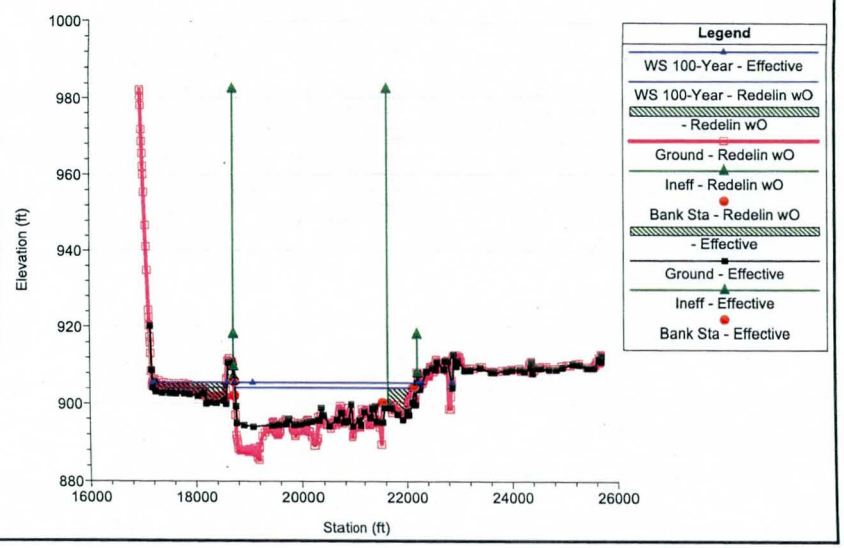
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO

River = Gila River Reach = El Rio WMP RS = 194.02 Left and Right Channel Bank Stations Interpolated



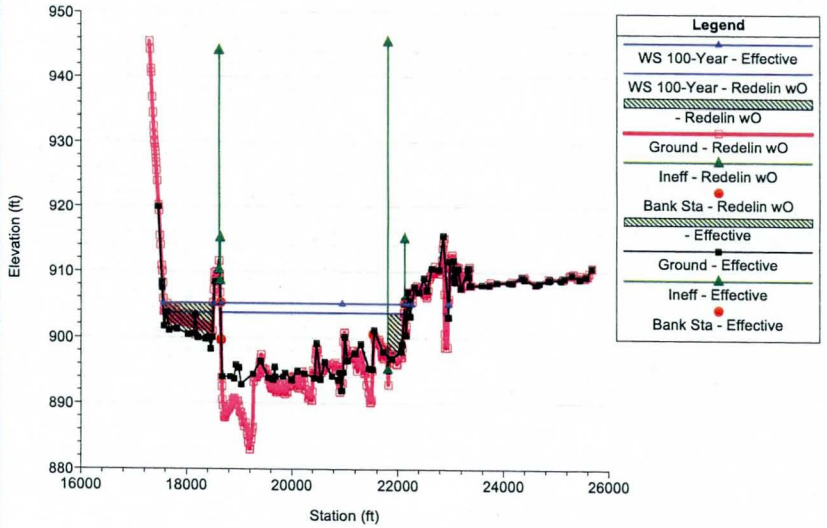
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO

River = Gila River Reach = El Rio WMP RS = 193.94 Left and Right Channel Bank Stations Interpolated



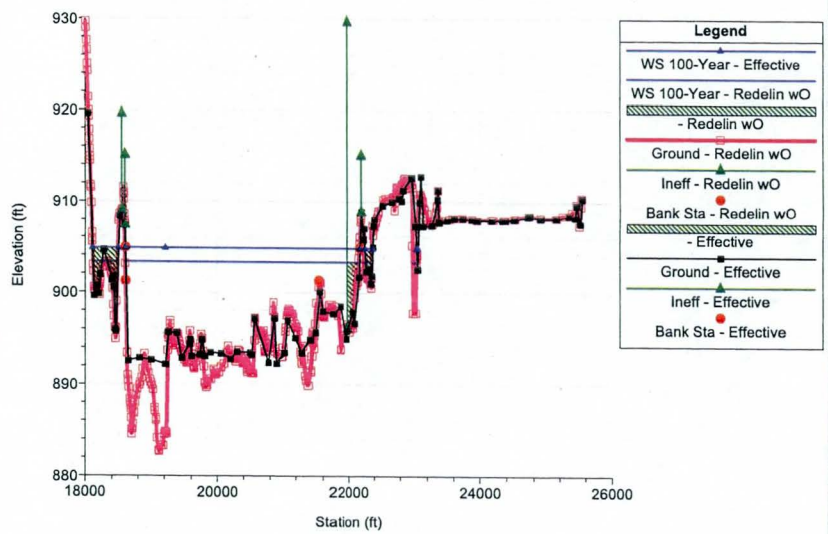
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO

River = Gila River Reach = El Rio WMP RS = 193.87 Left and Right Channel Bank Stations Interpolated



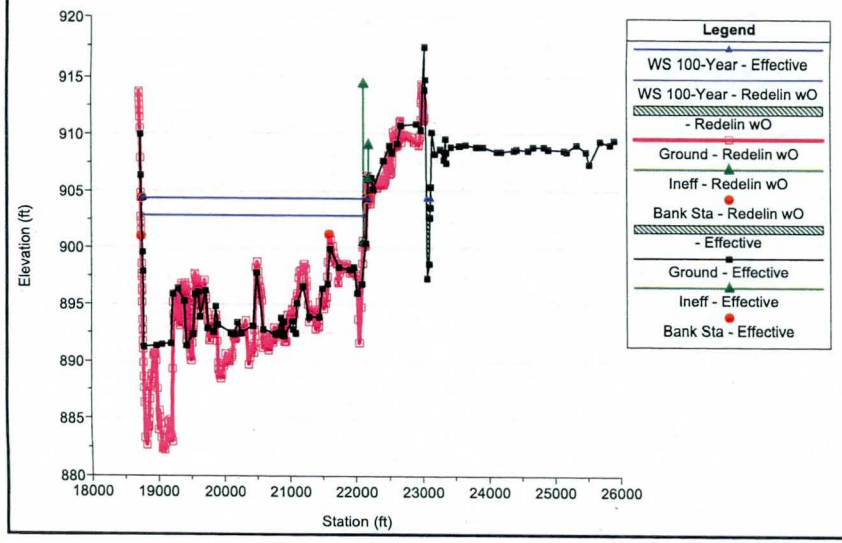
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO

River = Gila River Reach = El Rio WMP RS = 193.79 Left and Right Channel Bank Stations Interpolated



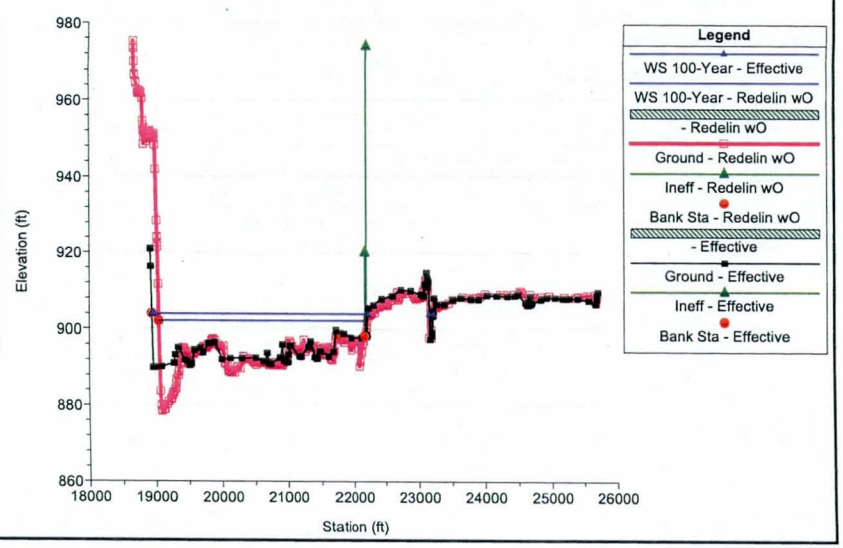
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO

River = Gila River Reach = El Rio WMP RS = 193.73 Left and Right Channel Bank Stations Interpolated



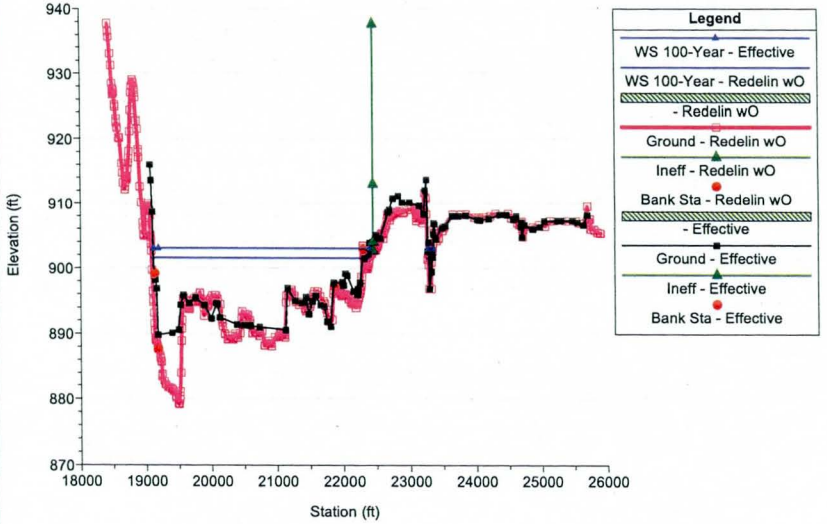
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO

River = Gila River Reach = El Rio WMP RS = 193.62 Left and Right Channel Bank Stations Interpolated



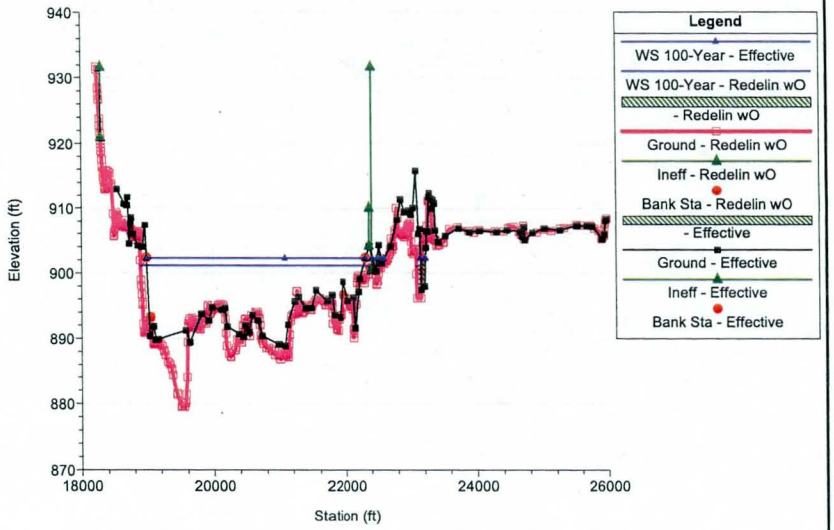
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO

River = Gila River Reach = El Rio WMP RS = 193.53



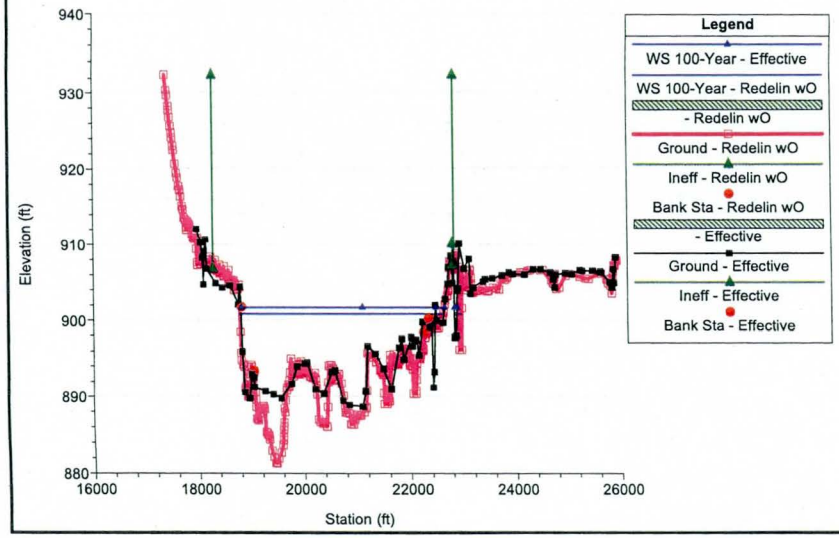
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO

River = Gila River Reach = El Rio WMP RS = 193.43 Left and Right Channel Bank Stations Interpolated



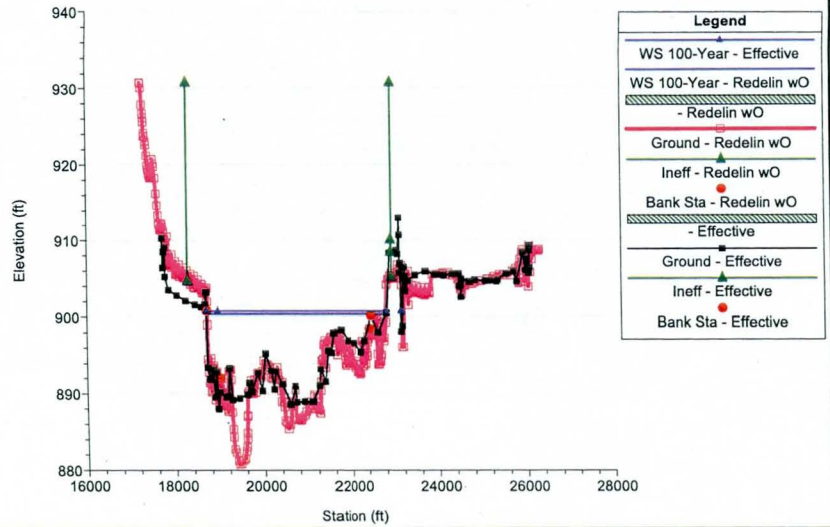
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO

River = Gila River Reach = El Rio WMP RS = 193.34 Left Channel Bank Station Interpolated



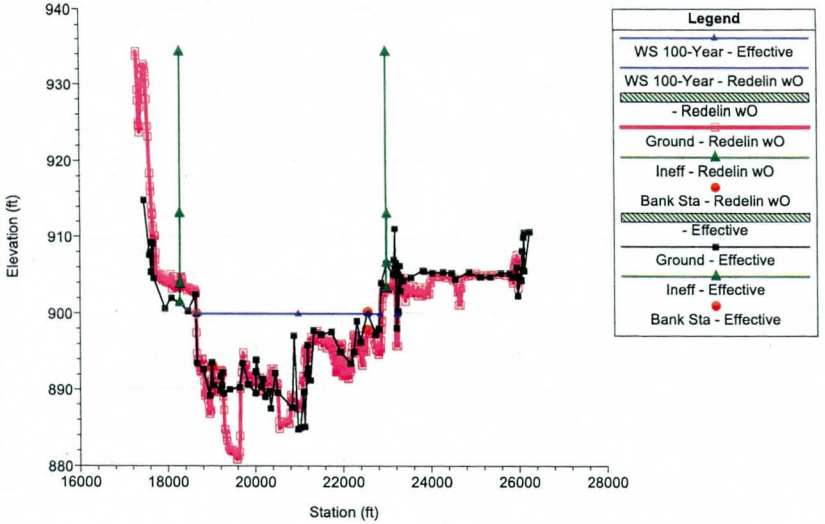
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO

River = Gila River Reach = El Rio WMP RS = 193.25 Left Channel Bank Station Interpolated



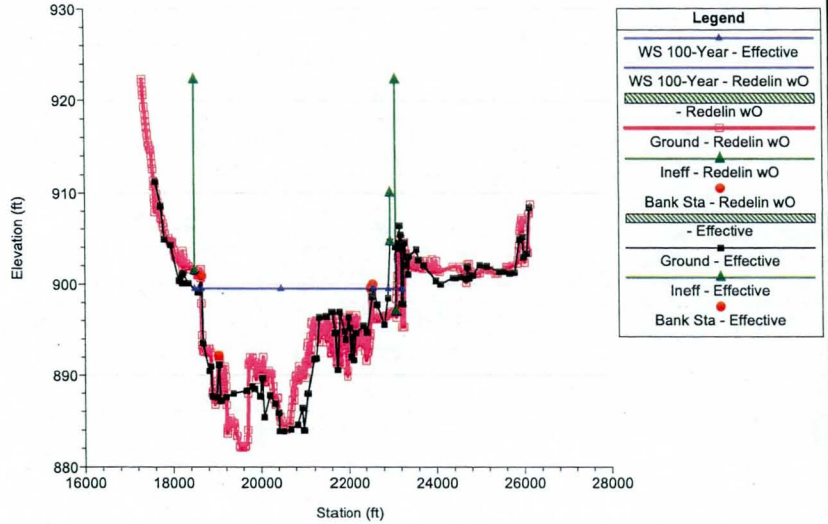
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO

River = Gila River Reach = El Rio WMP RS = 193.16 Left Channel Bank Station Interpolated



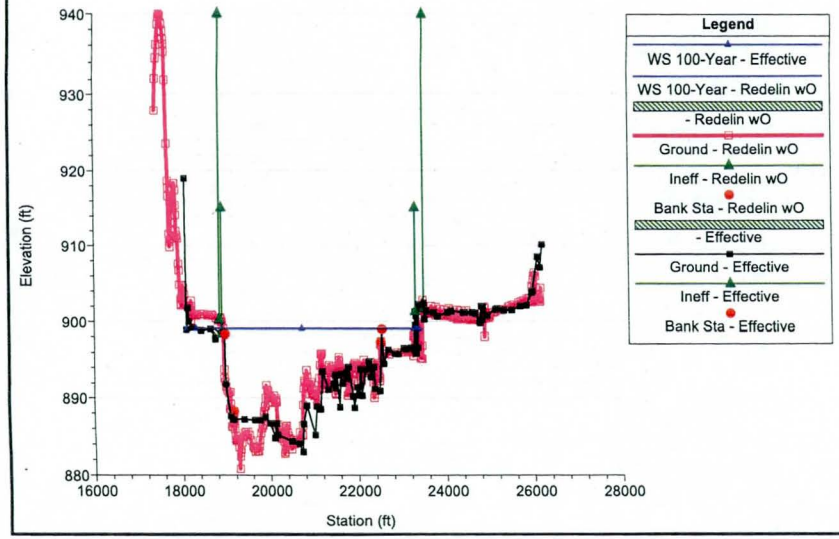
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO

River = Gila River Reach = El Rio WMP RS = 193.07



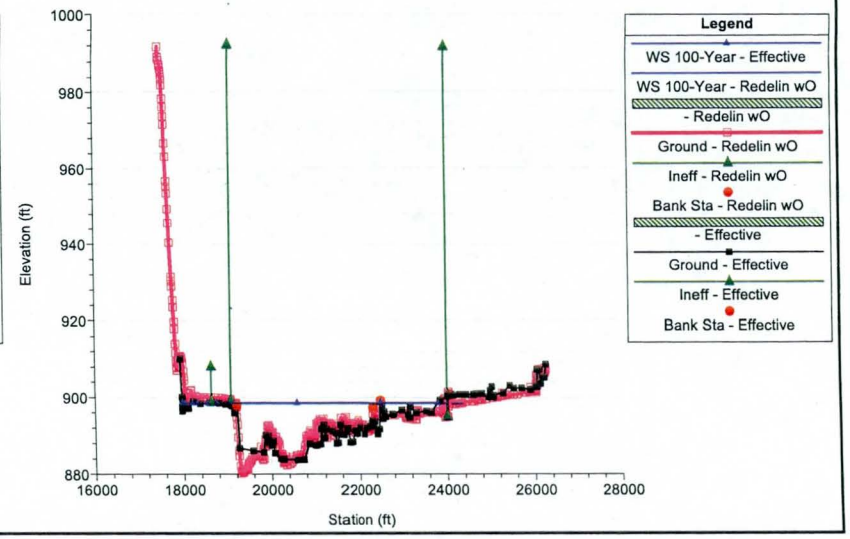
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO

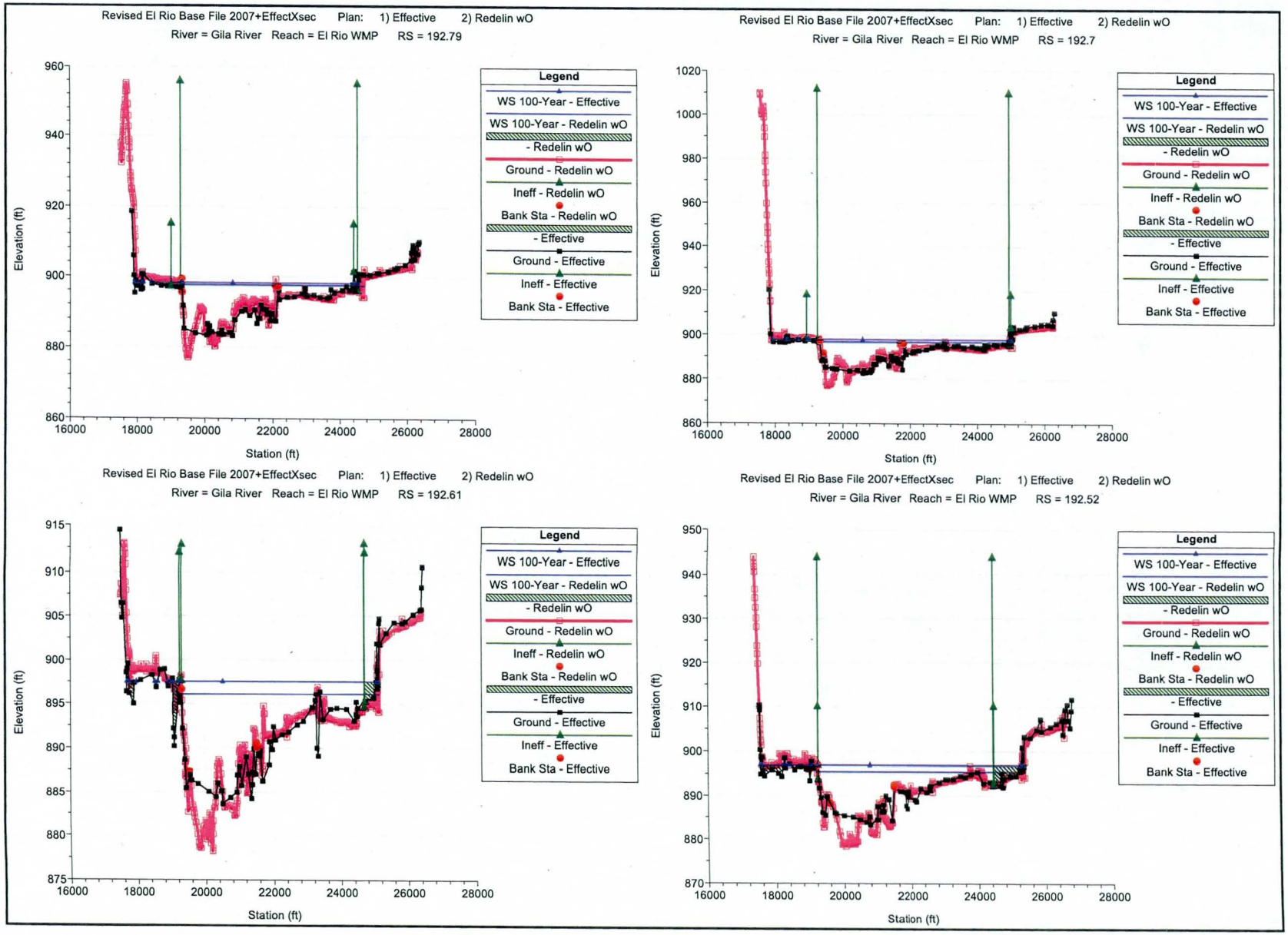
River = Gila River Reach = El Rio WMP RS = 192.98



Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO

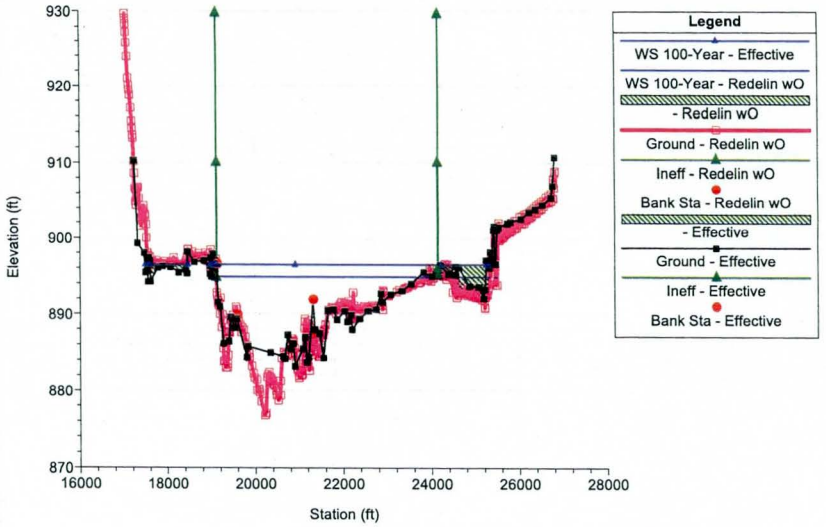
River = Gila River Reach = El Rio WMP RS = 192.89




Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 192.79
Elevation (ft)
Station (ft)
Legend
WS 100-Year - Effective
WS 100-Year - Redelin wO
- Redelin wO
Ground - Redelin wO
Ineff - Redelin wO
Bank Sta - Redelin wO
- Effective
Ground - Effective
Ineff - Effective
Bank Sta - Effective
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 192.7
Elevation (ft)
Station (ft)
Legend
WS 100-Year - Effective
WS 100-Year - Redelin wO
- Redelin wO
Ground - Redelin wO
Ineff - Redelin wO
Bank Sta - Redelin wO
- Effective
Ground - Effective
Ineff - Effective
Bank Sta - Effective
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 192.61
Elevation (ft)
Station (ft)
Legend
WS 100-Year - Effective
WS 100-Year - Redelin wO
- Redelin wO
Ground - Redelin wO
Ineff - Redelin wO
Bank Sta - Redelin wO
- Effective
Ground - Effective
Ineff - Effective
Bank Sta - Effective
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 192.52
Elevation (ft)
Station (ft)
Legend
WS 100-Year - Effective
WS 100-Year - Redelin wO
- Redelin wO
Ground - Redelin wO
Ineff - Redelin wO
Bank Sta - Redelin wO
- Effective
Ground - Effective
Ineff - Effective
Bank Sta - Effective

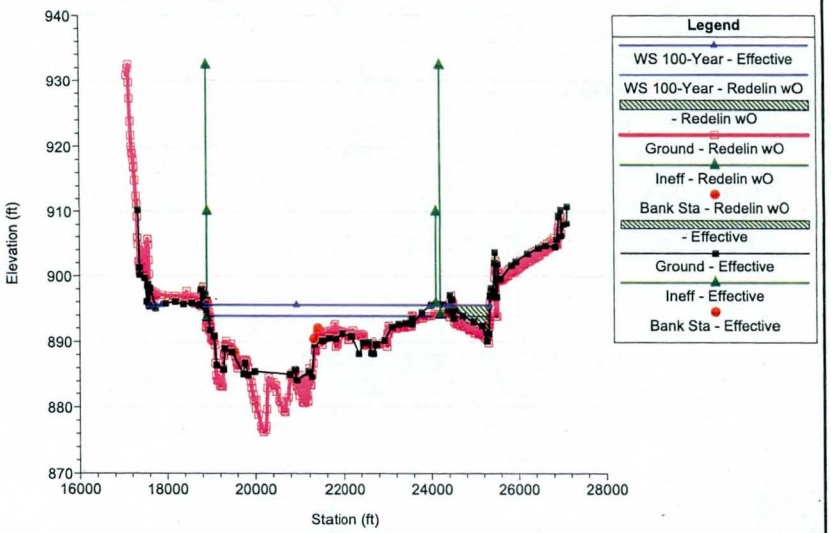
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO

River = Gila River Reach = El Rio WMP RS = 192.42 Left Bank Channel Station Interpolated



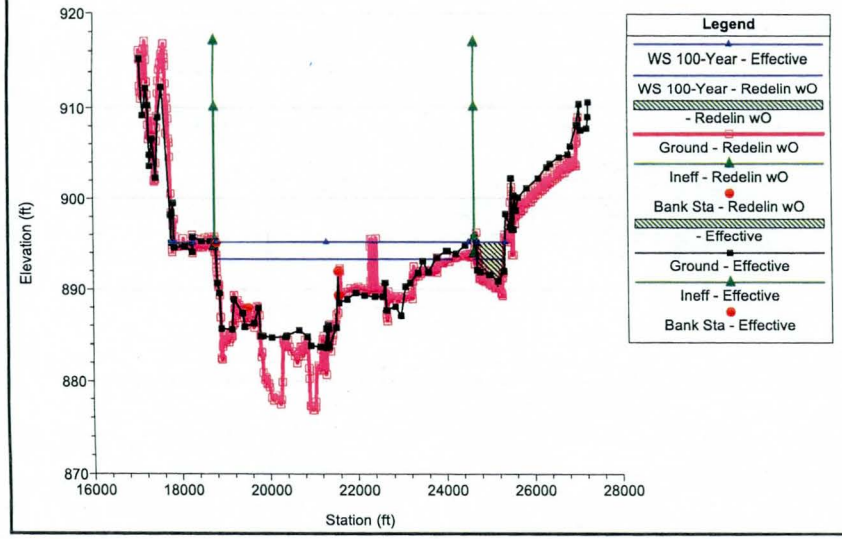
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO

River = Gila River Reach = El Rio WMP RS = 192.33 Left Bank Channel Station Interpolated



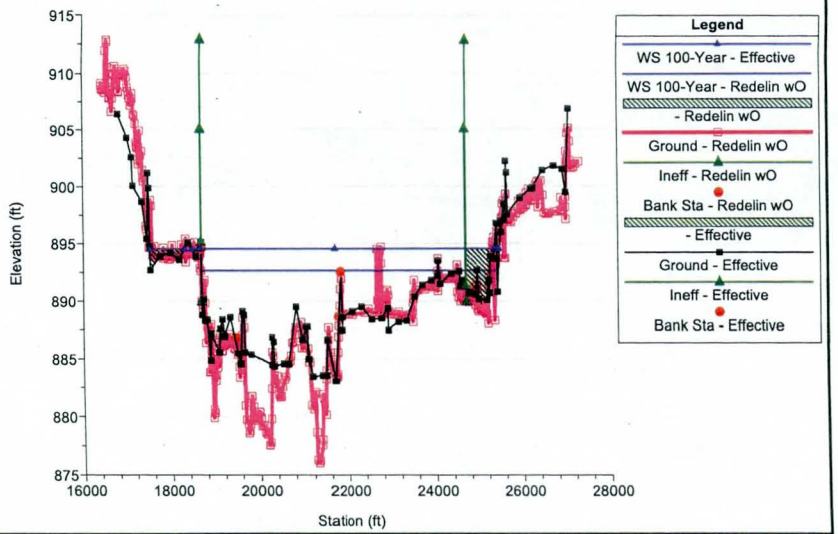
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO

River = Gila River Reach = El Rio WMP RS = 192.23 CROSSES COTTON LN. ALIGNMENT AT CENTERLINE OF 100 YR FLOW

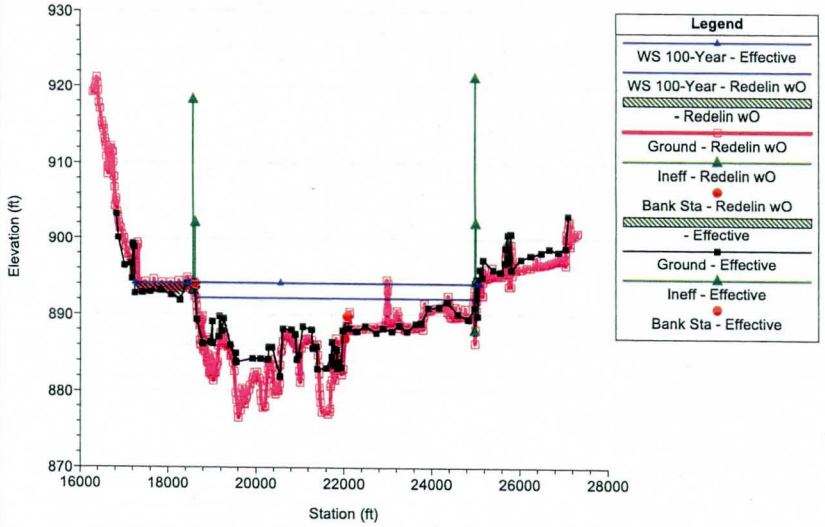


Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO

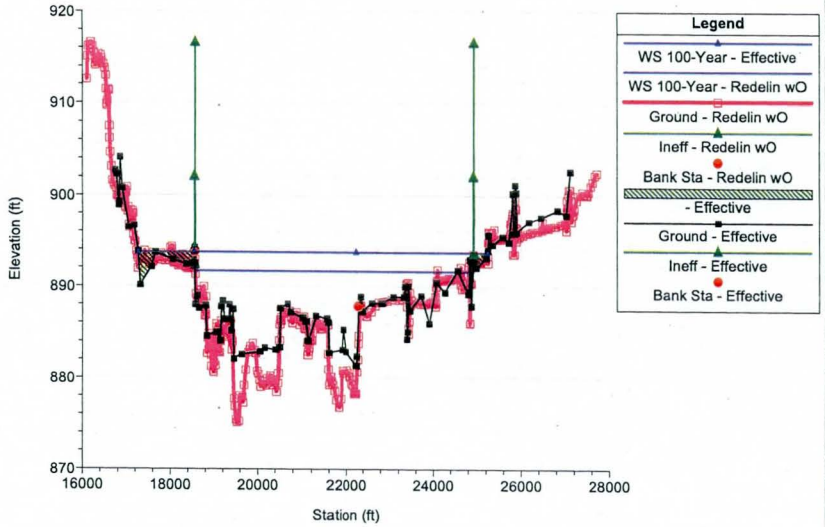
River = Gila River Reach = El Rio WMP RS = 192.14 Left Channel Bank Station Interpolated



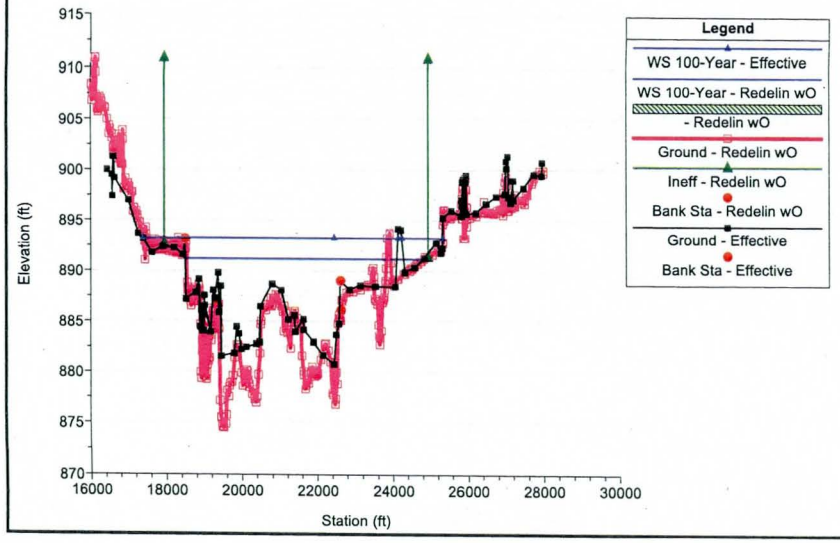
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 192.04



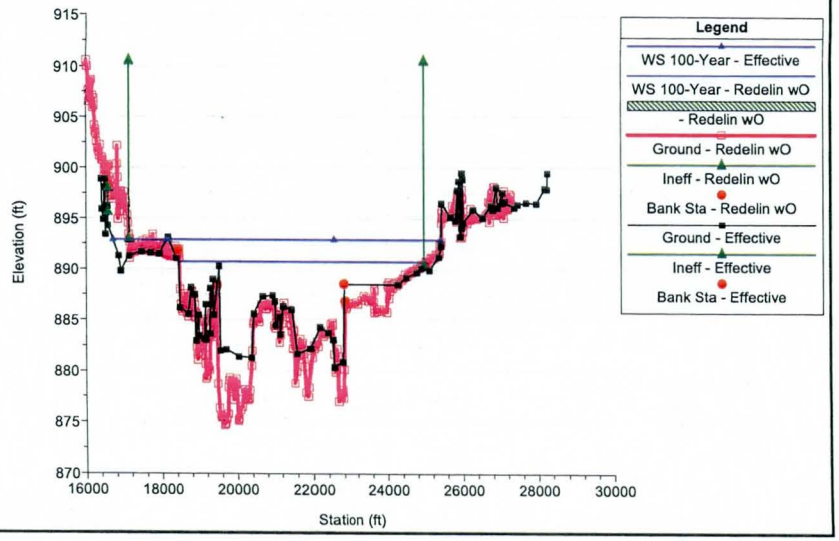
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 191.95 Left Channel Bank Station Interpolated



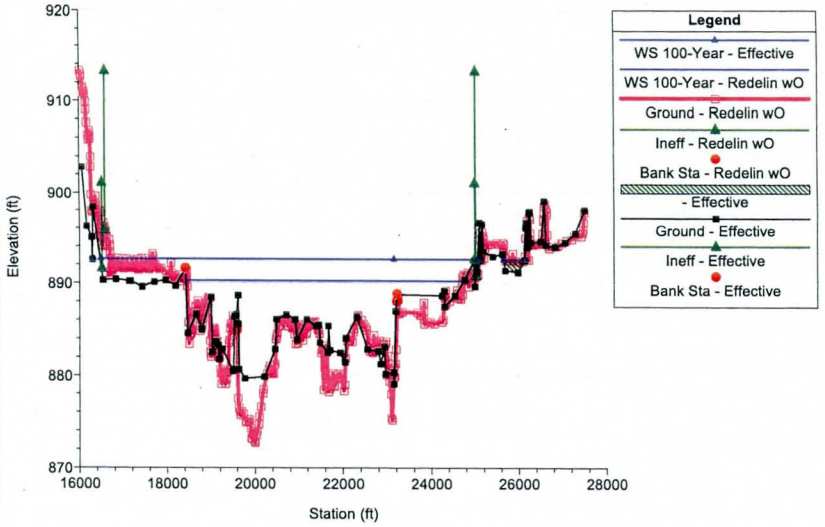
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 191.86



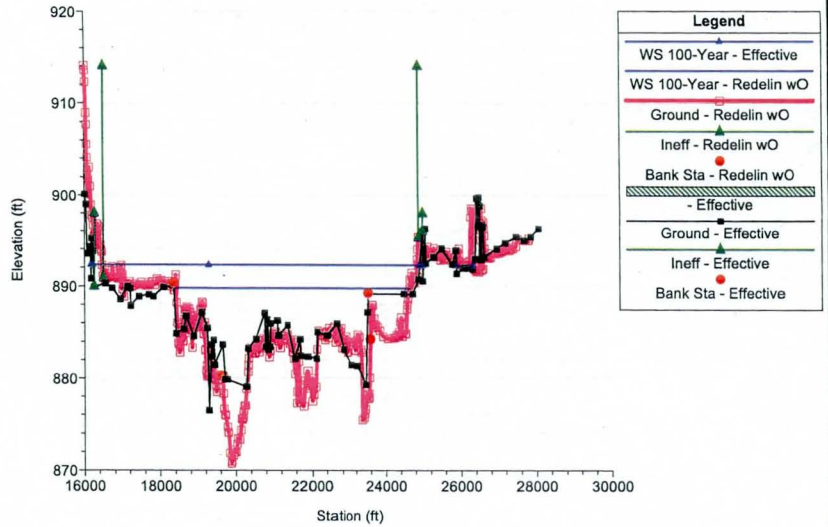
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 191.76



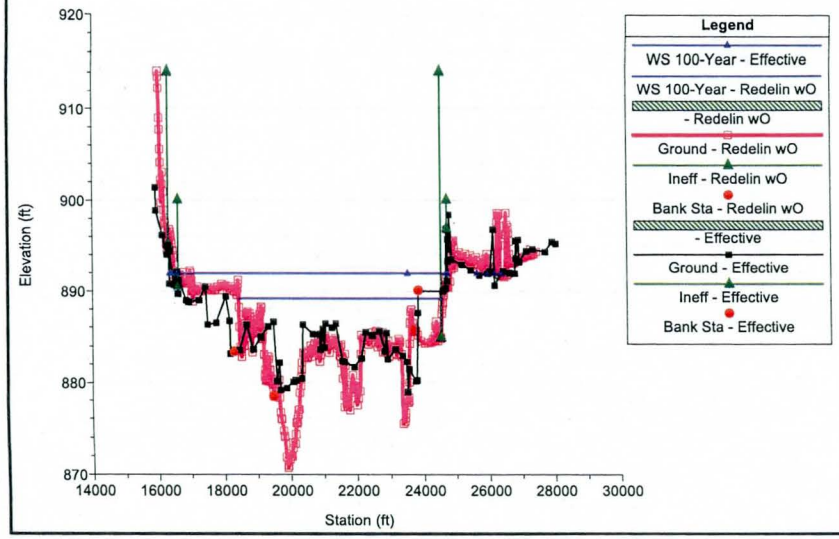
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 191.67



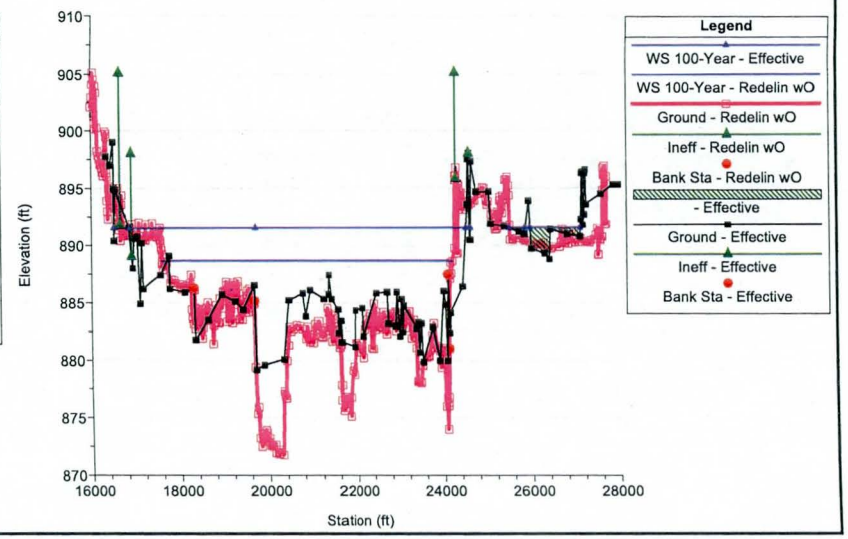
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 191.57

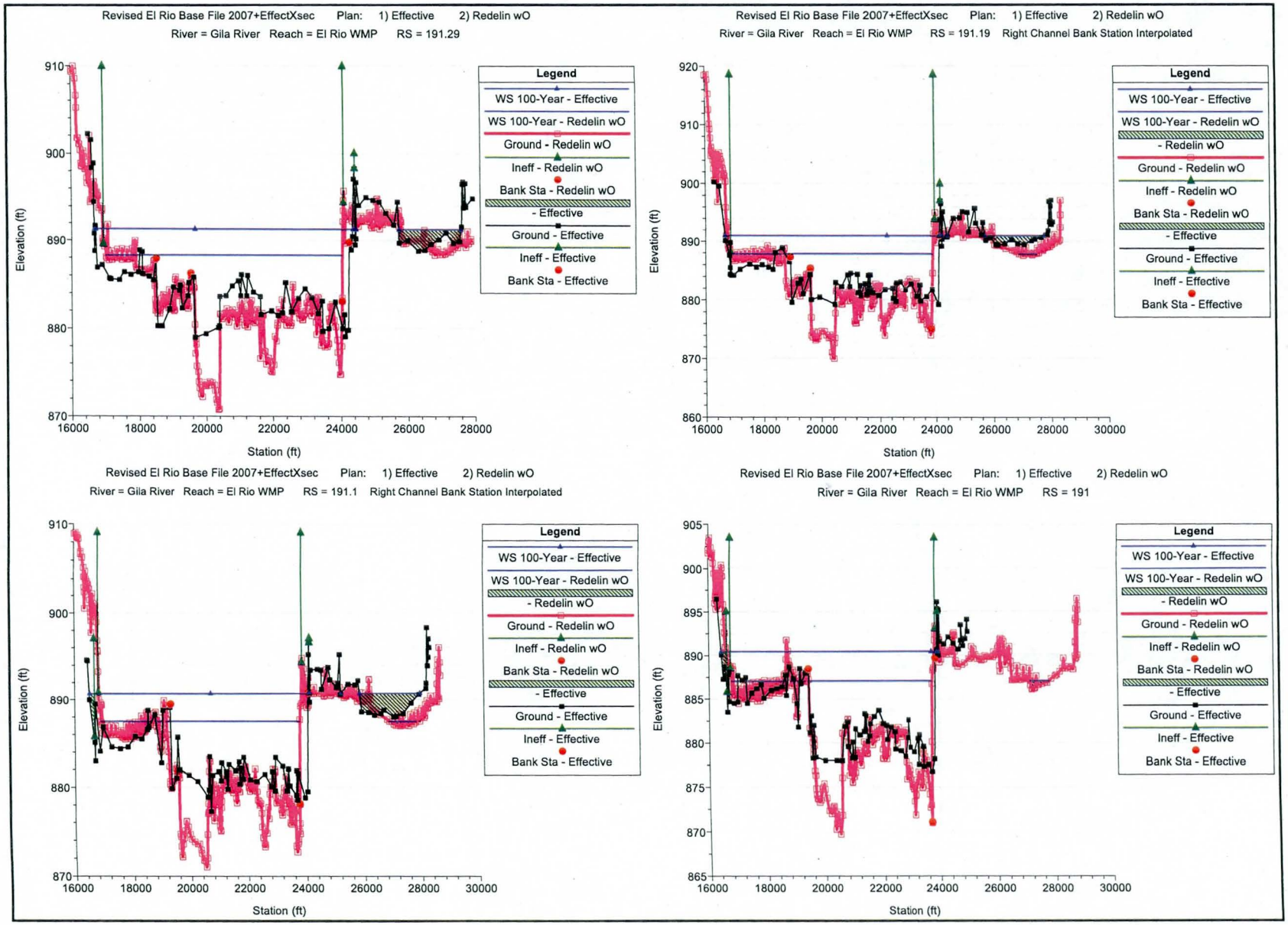


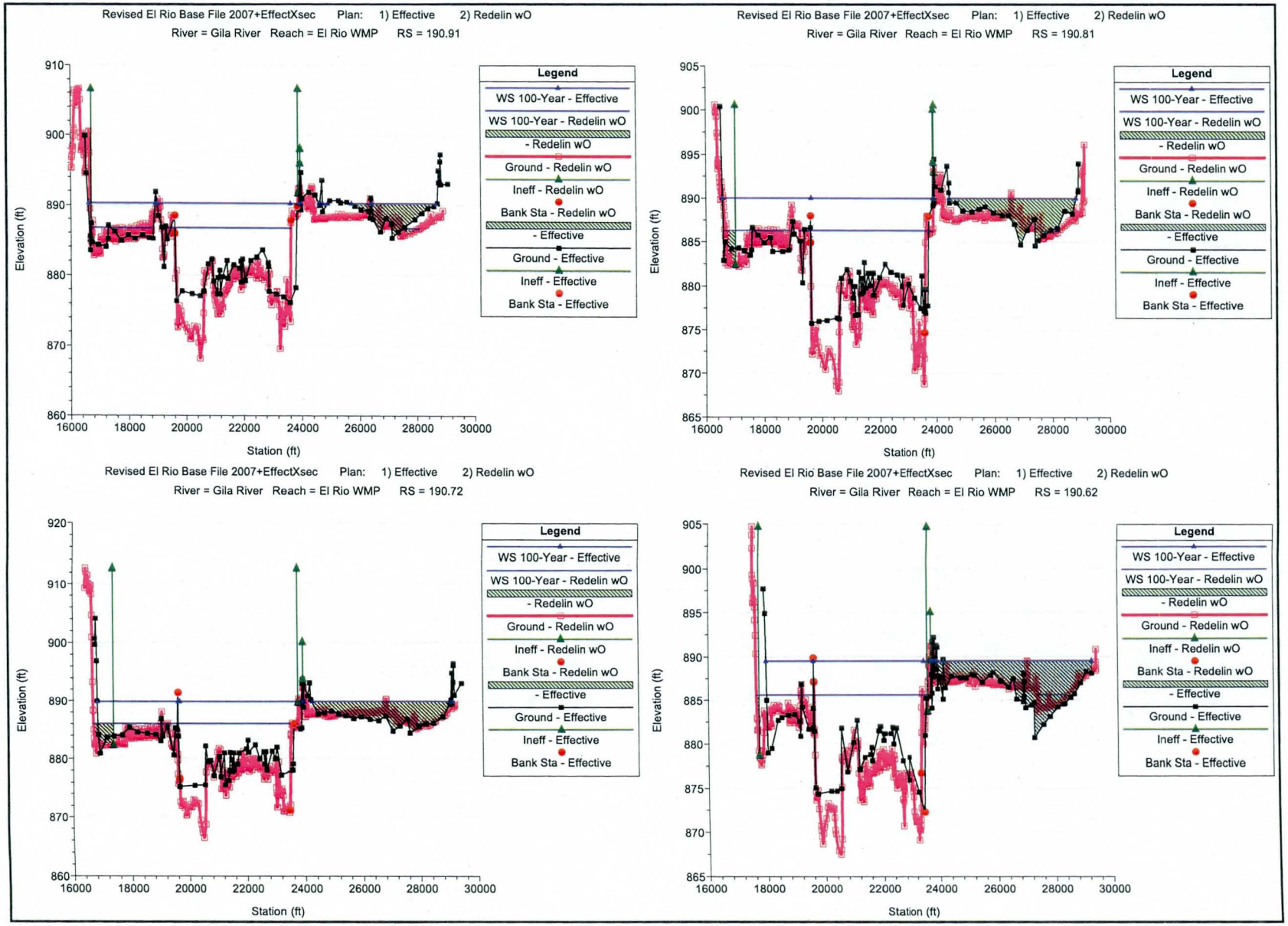
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 191.48

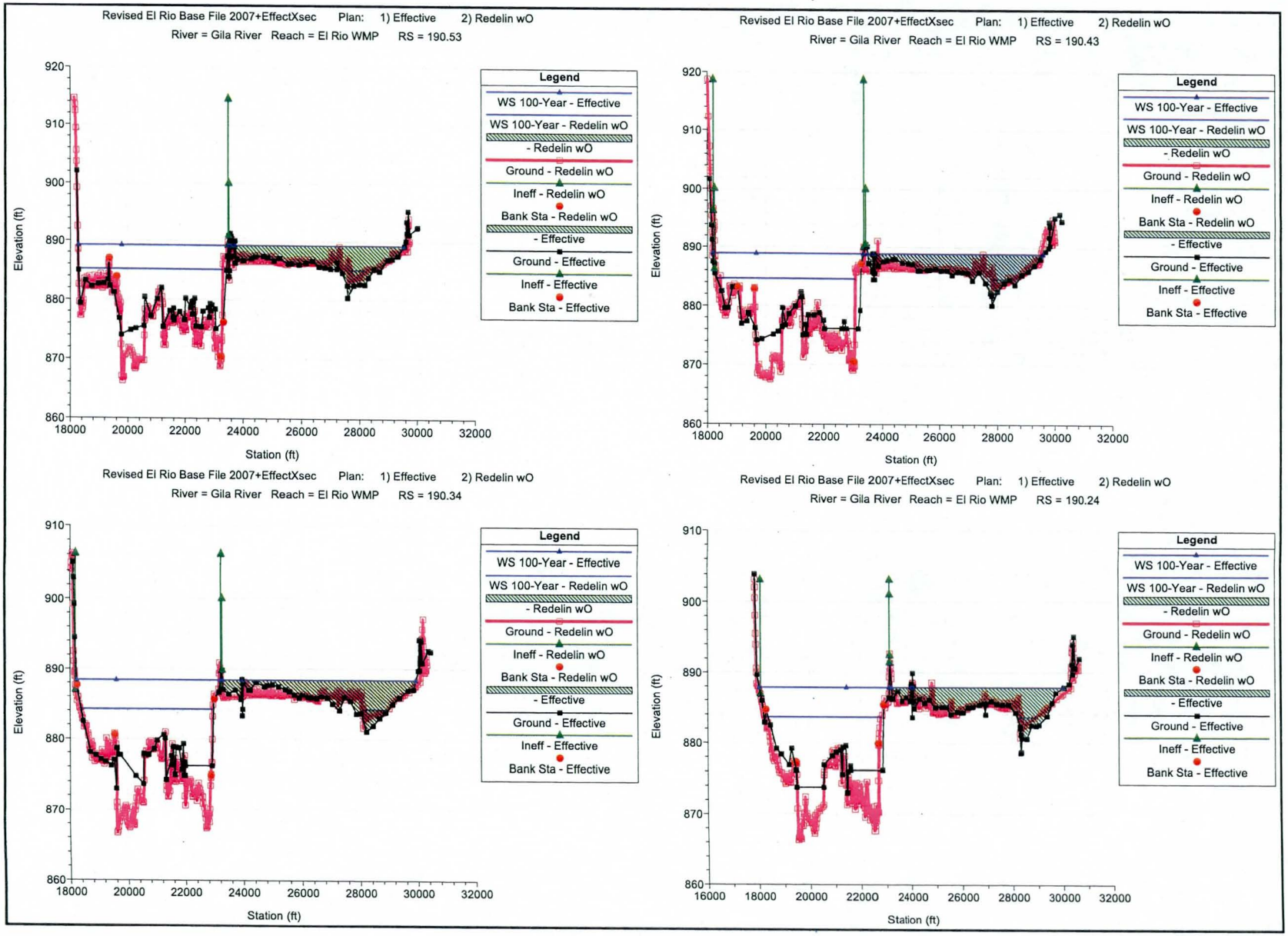


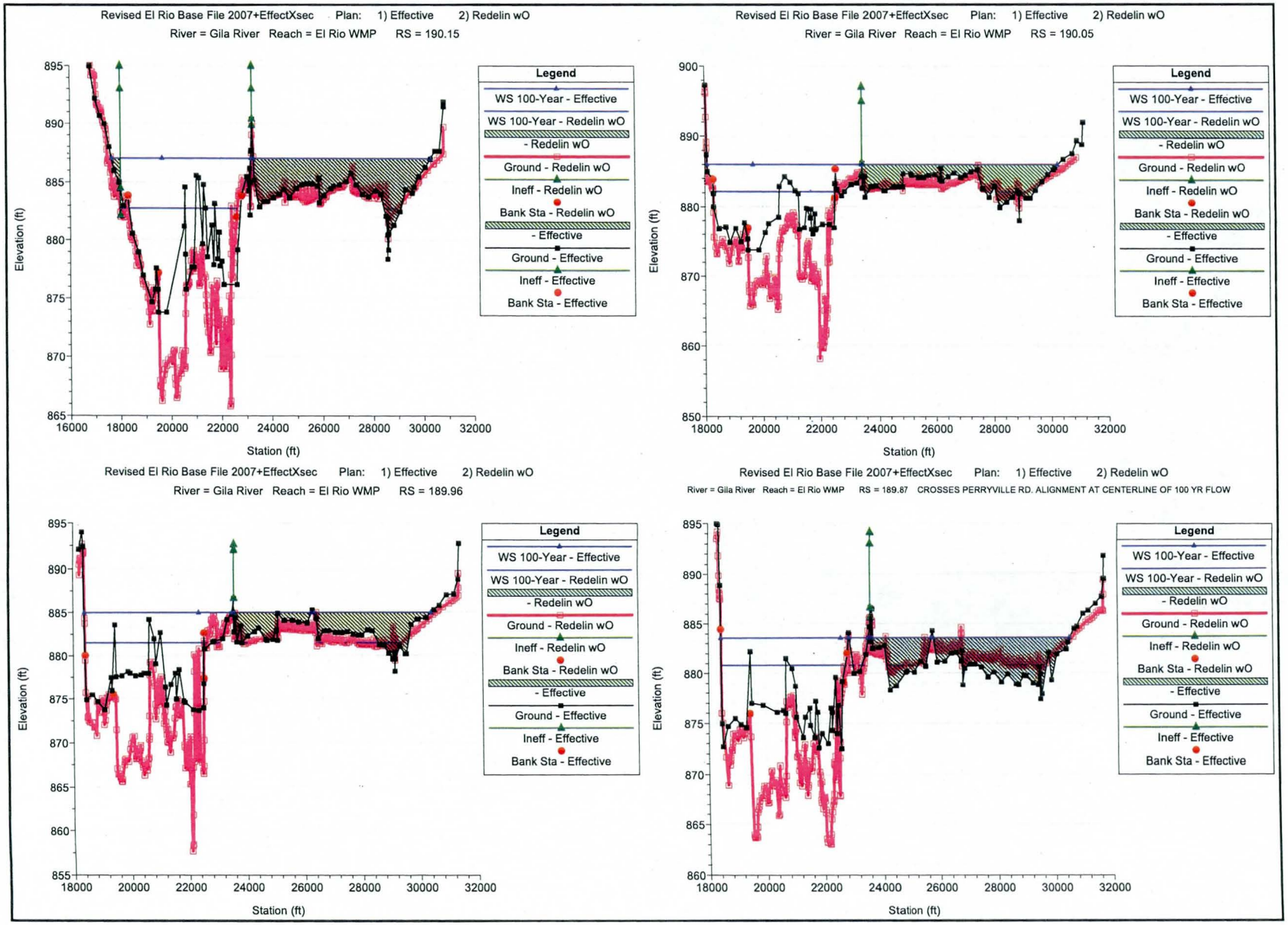
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 191.38




Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 191.29
Elevation (ft)
Station (ft)
Legend
WS 100-Year - Effective
WS 100-Year - Redelin wO
Ground - Redelin wO
Ineff - Redelin wO
Bank Sta - Redelin wO
- Effective
Ground - Effective
Ineff - Effective
Bank Sta - Effective
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 191.19 Right Channel Bank Station Interpolated
Elevation (ft)
Station (ft)
Legend
WS 100-Year - Effective
WS 100-Year - Redelin wO
- Redelin wO
Ground - Redelin wO
Ineff - Redelin wO
Bank Sta - Redelin wO
- Effective
Ground - Effective
Ineff - Effective
Bank Sta - Effective
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 191.1 Right Channel Bank Station Interpolated
Elevation (ft)
Station (ft)
Legend
WS 100-Year - Effective
WS 100-Year - Redelin wO
- Redelin wO
Ground - Redelin wO
Ineff - Redelin wO
Bank Sta - Redelin wO
- Effective
Ground - Effective
Ineff - Effective
Bank Sta - Effective
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 191
Elevation (ft)
Station (ft)
Legend
WS 100-Year - Effective
WS 100-Year - Redelin wO
- Redelin wO
Ground - Redelin wO
Ineff - Redelin wO
Bank Sta - Redelin wO
- Effective
Ground - Effective
Ineff - Effective
Bank Sta - Effective

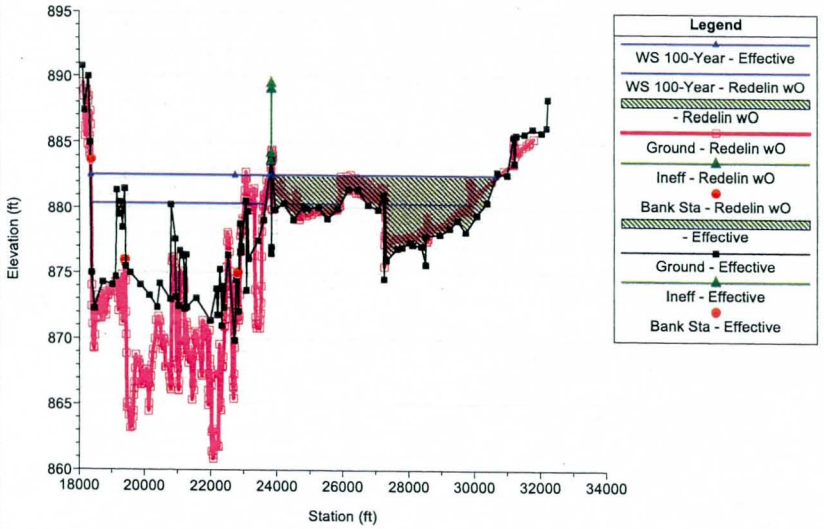

Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 190.91
Elevation (ft)
Station (ft)
Legend
WS 100-Year - Effective
WS 100-Year - Redelin wO
- Redelin wO
Ground - Redelin wO
Ineff - Redelin wO
Bank Sta - Redelin wO
- Effective
Ground - Effective
Ineff - Effective
Bank Sta - Effective
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 190.81
Elevation (ft)
Station (ft)
Legend
WS 100-Year - Effective
WS 100-Year - Redelin wO
- Redelin wO
Ground - Redelin wO
Ineff - Redelin wO
Bank Sta - Redelin wO
- Effective
Ground - Effective
Ineff - Effective
Bank Sta - Effective
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 190.72
Elevation (ft)
Station (ft)
Legend
WS 100-Year - Effective
WS 100-Year - Redelin wO
- Redelin wO
Ground - Redelin wO
Ineff - Redelin wO
Bank Sta - Redelin wO
- Effective
Ground - Effective
Ineff - Effective
Bank Sta - Effective
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 190.62
Elevation (ft)
Station (ft)
Legend
WS 100-Year - Effective
WS 100-Year - Redelin wO
- Redelin wO
Ground - Redelin wO
Ineff - Redelin wO
Bank Sta - Redelin wO
- Effective
Ground - Effective
Ineff - Effective
Bank Sta - Effective


Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 190.53
Elevation (ft)
Station (ft)
Legend
WS 100-Year - Effective
WS 100-Year - Redelin wO
- Redelin wO
Ground - Redelin wO
Ineff - Redelin wO
Bank Sta - Redelin wO
- Effective
Ground - Effective
Ineff - Effective
Bank Sta - Effective
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 190.43
Elevation (ft)
Station (ft)
Legend
WS 100-Year - Effective
WS 100-Year - Redelin wO
- Redelin wO
Ground - Redelin wO
Ineff - Redelin wO
Bank Sta - Redelin wO
- Effective
Ground - Effective
Ineff - Effective
Bank Sta - Effective
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 190.34
Elevation (ft)
Station (ft)
Legend
WS 100-Year - Effective
WS 100-Year - Redelin wO
- Redelin wO
Ground - Redelin wO
Ineff - Redelin wO
Bank Sta - Redelin wO
- Effective
Ground - Effective
Ineff - Effective
Bank Sta - Effective
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 190.24
Elevation (ft)
Station (ft)
Legend
WS 100-Year - Effective
WS 100-Year - Redelin wO
- Redelin wO
Ground - Redelin wO
Ineff - Redelin wO
Bank Sta - Redelin wO
- Effective
Ground - Effective
Ineff - Effective
Bank Sta - Effective


Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 190.15
Elevation (ft)
Station (ft)
Legend
WS 100-Year - Effective
WS 100-Year - Redelin wO
- Redelin wO
Ground - Redelin wO
Ineff - Redelin wO
Bank Sta - Redelin wO
- Effective
Ground - Effective
Ineff - Effective
Bank Sta - Effective
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 190.05
Elevation (ft)
Station (ft)
Legend
WS 100-Year - Effective
WS 100-Year - Redelin wO
- Redelin wO
Ground - Redelin wO
Ineff - Redelin wO
Bank Sta - Redelin wO
- Effective
Ground - Effective
Ineff - Effective
Bank Sta - Effective
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 189.96
Elevation (ft)
Station (ft)
Legend
WS 100-Year - Effective
WS 100-Year - Redelin wO
- Redelin wO
Ground - Redelin wO
Ineff - Redelin wO
Bank Sta - Redelin wO
- Effective
Ground - Effective
Ineff - Effective
Bank Sta - Effective
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 189.87 CROSSES PERRYVILLE RD. ALIGNMENT AT CENTERLINE OF 100 YR FLOW
Elevation (ft)
Station (ft)
Legend
WS 100-Year - Effective
WS 100-Year - Redelin wO
- Redelin wO
Ground - Redelin wO
Ineff - Redelin wO
Bank Sta - Redelin wO
- Effective
Ground - Effective
Ineff - Effective
Bank Sta - Effective

Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO

River = Gila River Reach = El Rio WMP RS = 189.77 Left and Right Channel Bank Stations Interpolated



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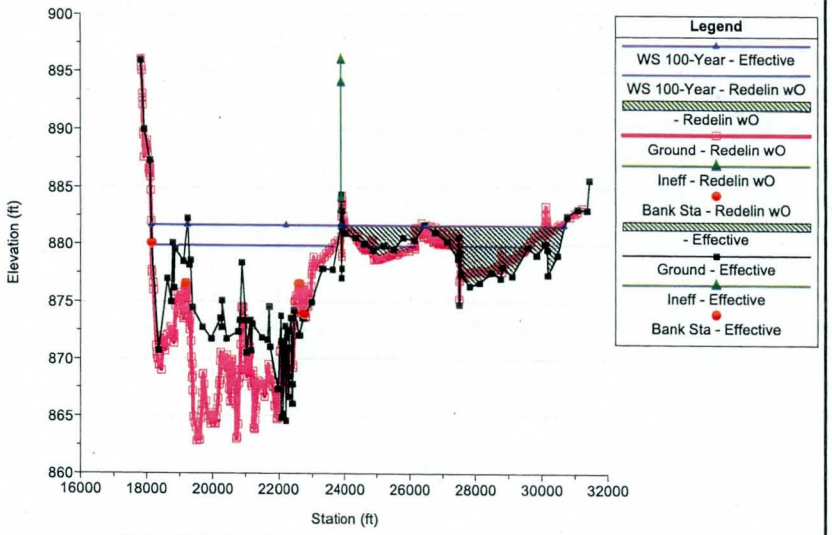
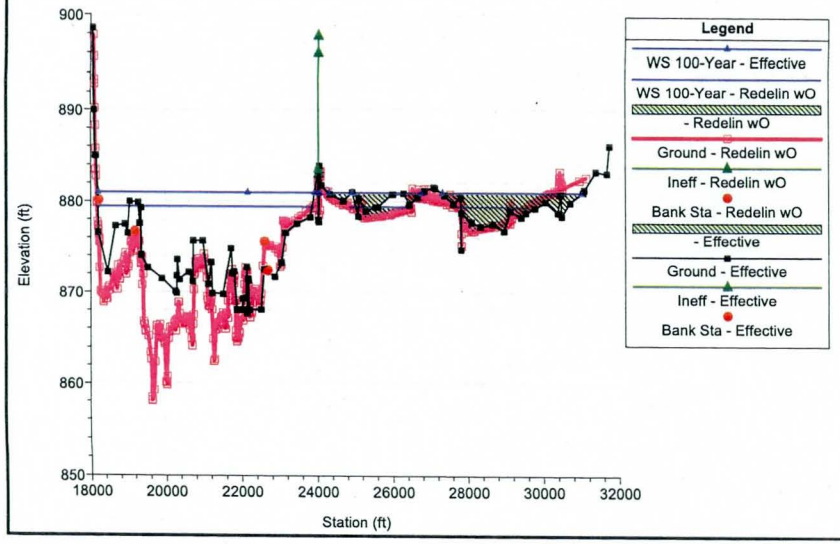
River = Gila River Reach = El Rio WMP RS = 189.67 Right Bank Channel Station Interpolated



Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO

River = Gila River Reach = El Rio WMP RS = 189.58



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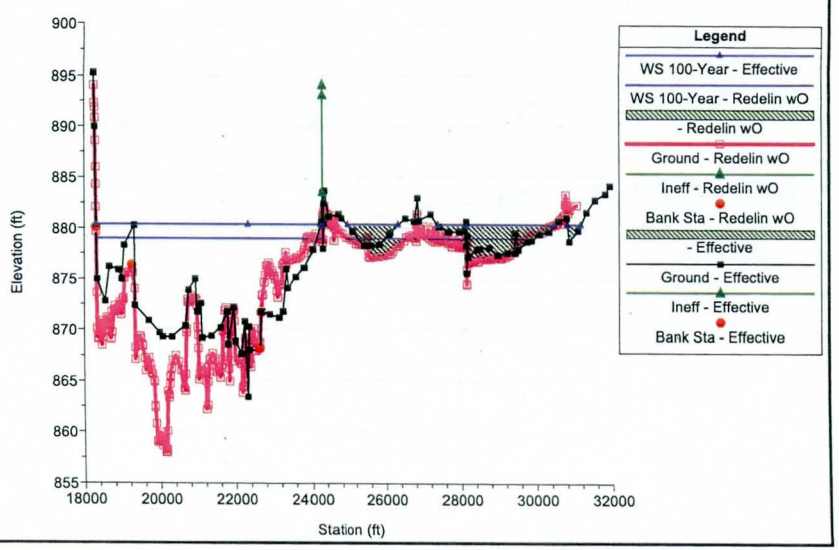
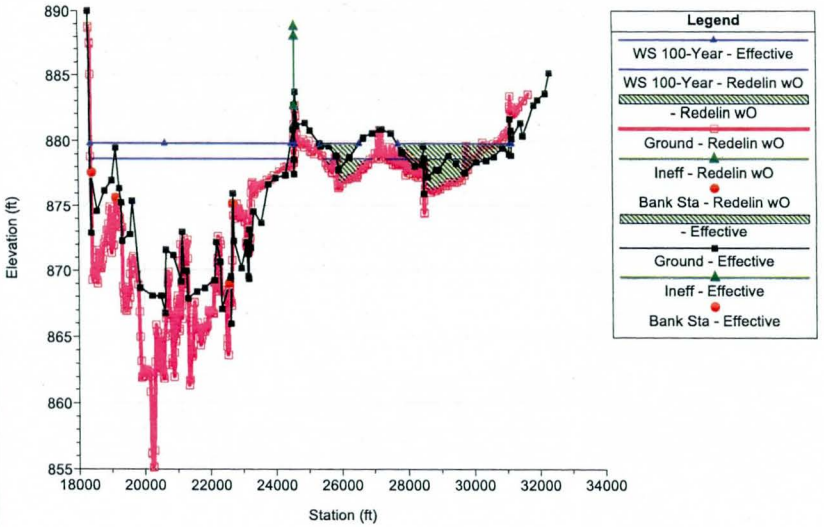
River = Gila River Reach = El Rio WMP RS = 189.48



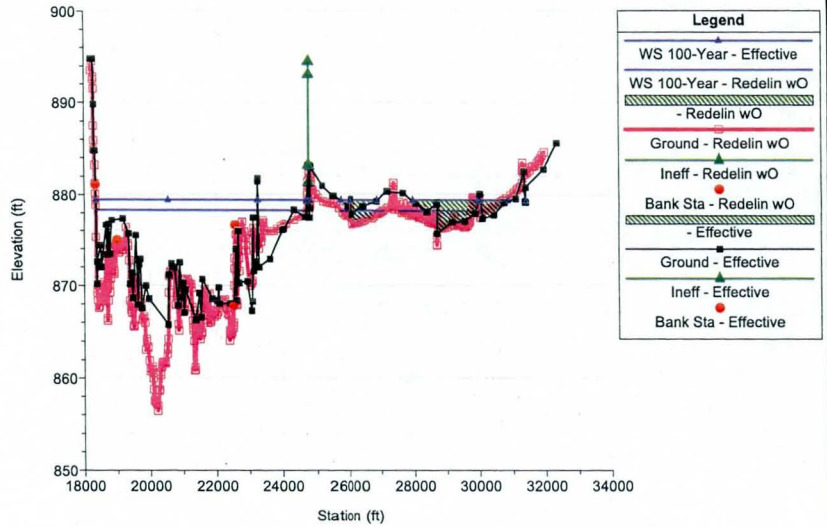
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO

River = Gila River Reach = El Rio WMP RS = 189.39 Right Bank Channel Station Interpolated



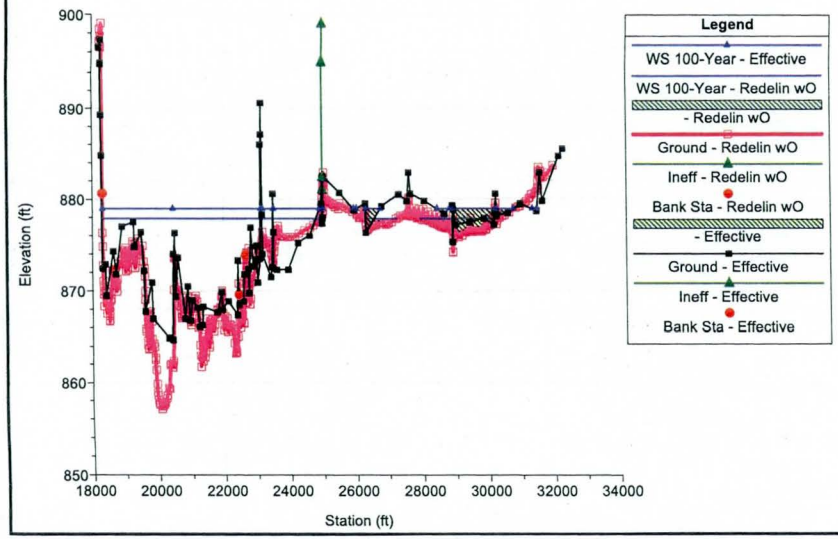
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO

River = Gila River Reach = El Rio WMP RS = 189.3 Left and Right Channel Bank Stations Interpolated



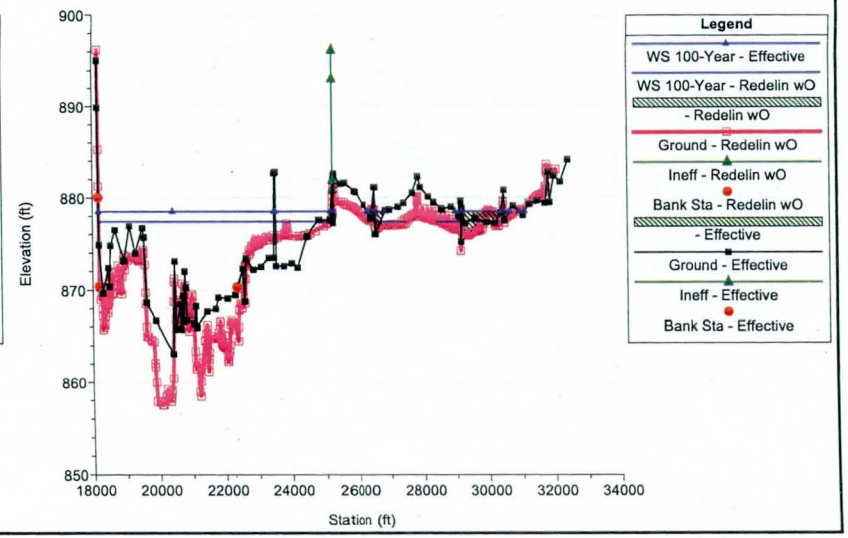
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO

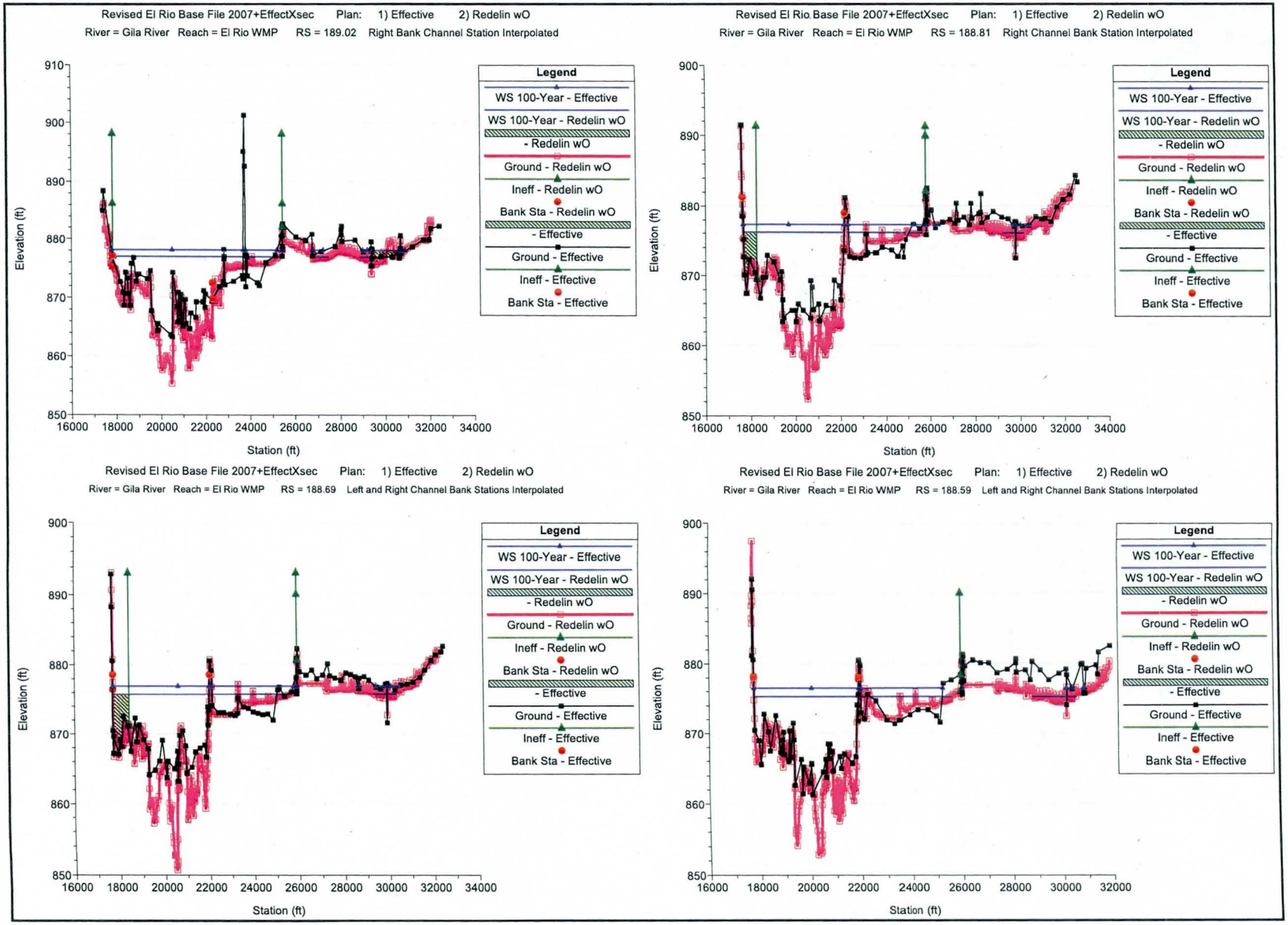
River = Gila River Reach = El Rio WMP RS = 189.21 Left and Right Channel Bank Stations Interpolated



Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO

River = Gila River Reach = El Rio WMP RS = 189.11 Right Bank Channel Station Interpolated

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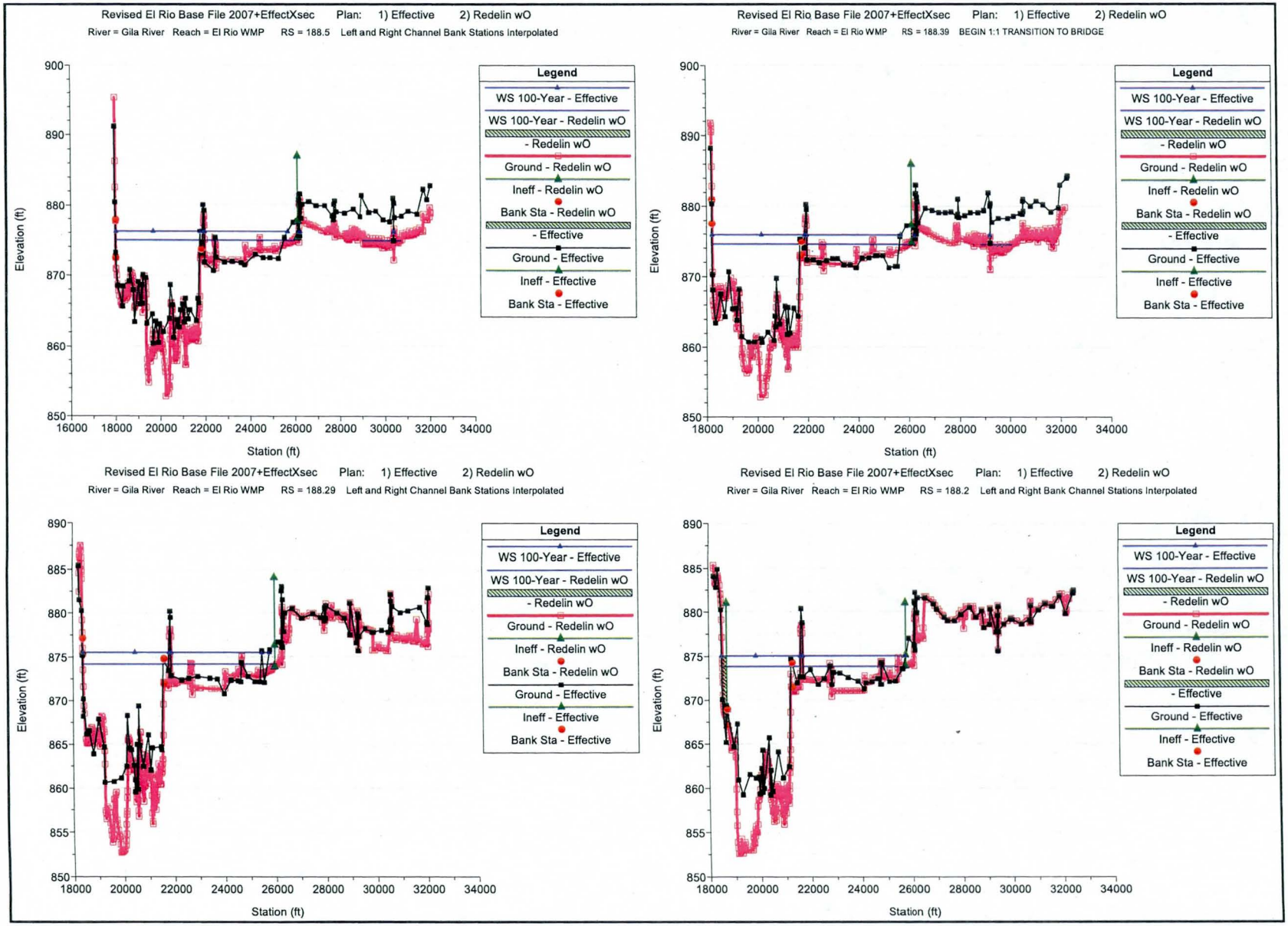
River = Gila River Reach = El Rio WMP RS = 189.02 Right Bank Channel Station Interpolated
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 188.81 Right Channel Bank Station Interpolated
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 188.69 Left and Right Channel Bank Stations Interpolated
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 188.59 Left and Right Channel Bank Stations Interpolated
Elevation (ft)
Station (ft)
Legend
WS 100-Year - Effective
WS 100-Year - Redelin wO
- Redelin wO
Ground - Redelin wO
Ineff - Redelin wO
Bank Sta - Redelin wO
- Effective
Ground - Effective
Ineff - Effective
Bank Sta - Effective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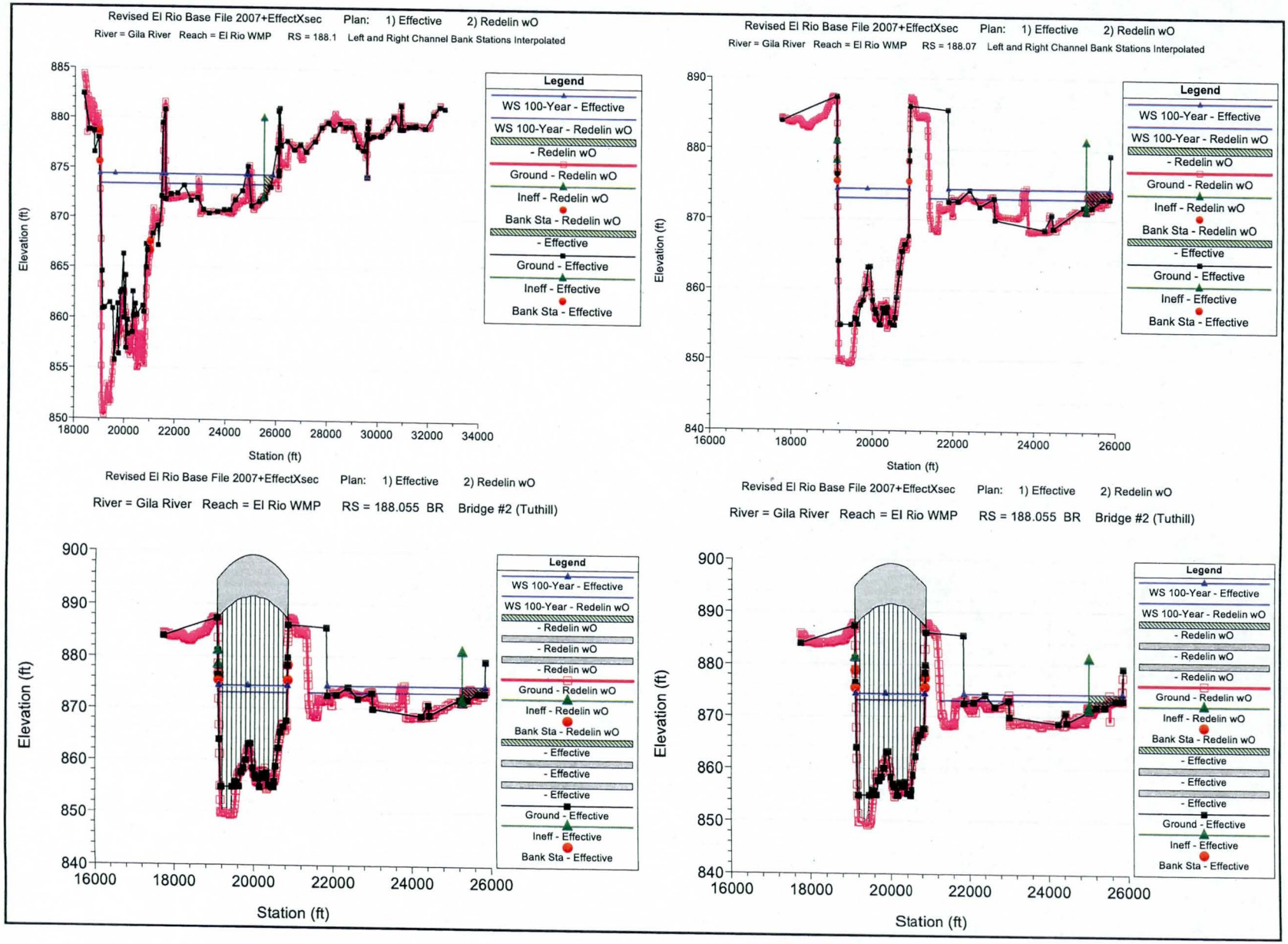
River = Gila River Reach = El Rio WMP RS = 188.5 Left and Right Channel Bank Stations Interpolated
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 188.39 BEGIN 1:1 TRANSITION TO BRIDGE
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 188.29 Left and Right Channel Bank Stations Interpolated
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 188.2 Left and Right Bank Channel Stations Interpolated
Legend
WS 100-Year - Effective
WS 100-Year - Redelin wO
- Redelin wO
Ground - Redelin wO
Ineff - Redelin wO
Bank Sta - Redelin wO
- Effective
Ground - Effective
Ineff - Effective
Bank Sta - Effective
Elevation (ft)
Station (ft)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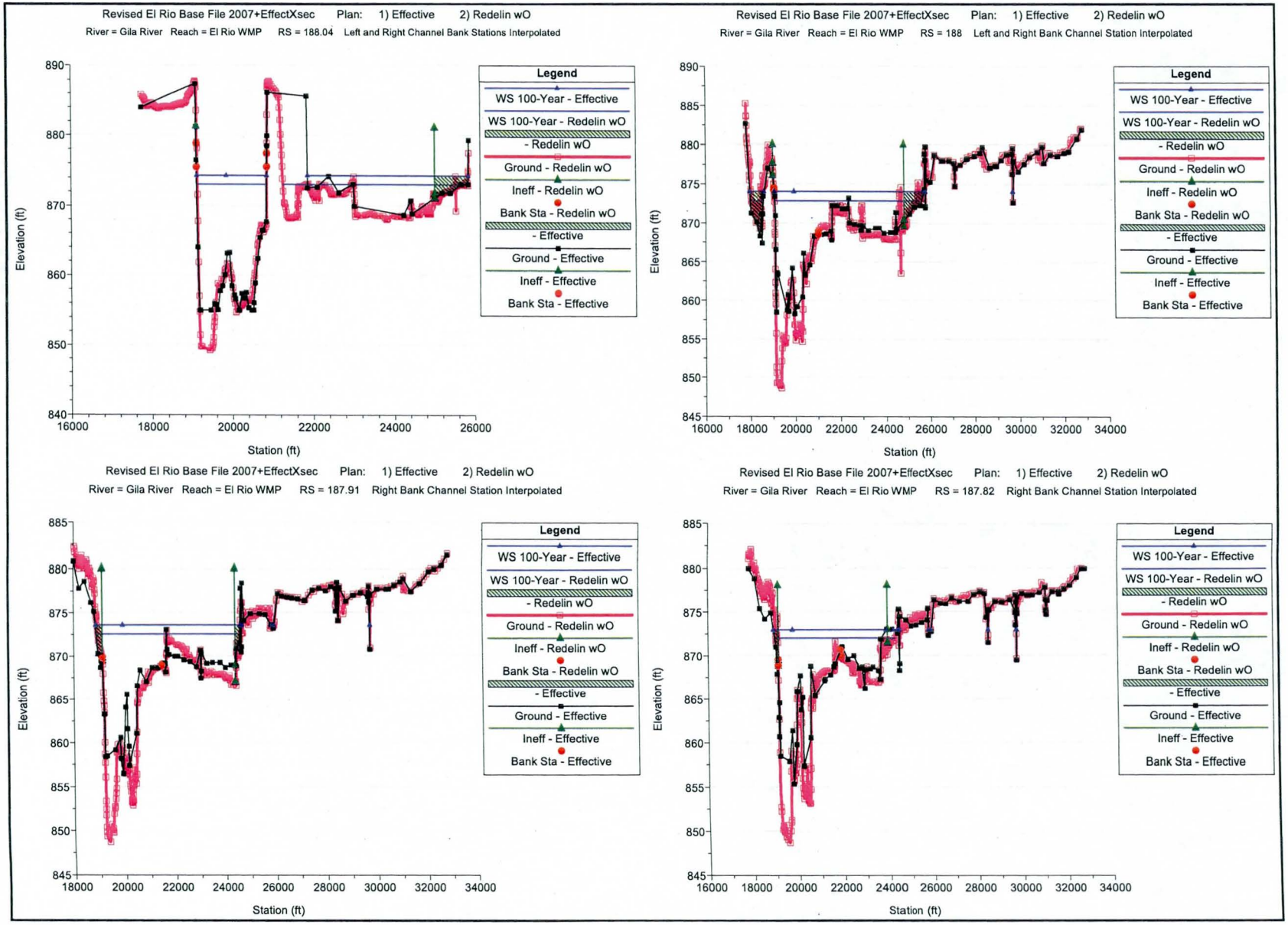
River = Gila River Reach = El Rio WMP RS = 188.1 Left and Right Channel Bank Stations Interpolated
Elevation (ft)
Station (ft)
Legend
WS 100-Year - Effective
WS 100-Year - Redelin wO
- Redelin wO
Ground - Redelin wO
Ineff - Redelin wO
Bank Sta - Redelin wO
- Effective
Ground - Effective
Ineff - Effective
Bank Sta - Effective
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 188.07 Left and Right Channel Bank Stations Interpolated
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 188.055 BR Bridge #2 (Tuthill)
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 188.055 BR Bridge #2 (Tuthill)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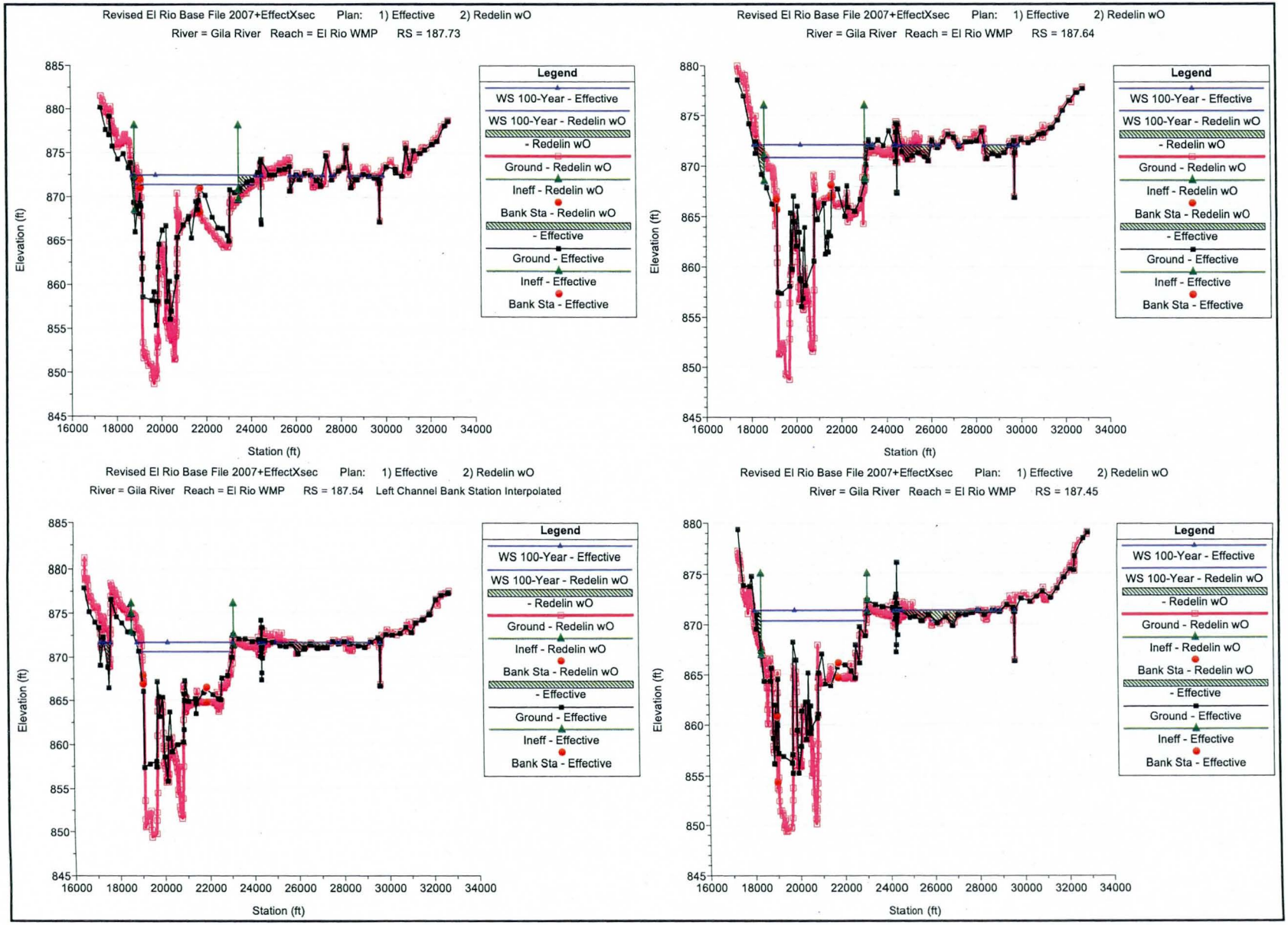
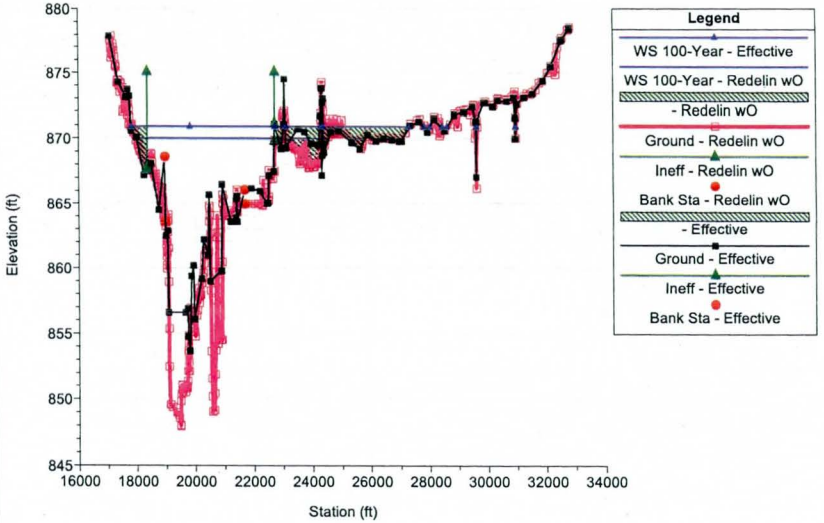
River = Gila River Reach = El Rio WMP RS = 188.04 Left and Right Channel Bank Stations Interpolated
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 188 Left and Right Bank Channel Station Interpolated
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 187.91 Right Bank Channel Station Interpolated
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 187.82 Right Bank Channel Station Interpolated
Elevation (ft)
Station (ft)
Legend
WS 100-Year - Effective
WS 100-Year - Redelin wO
- Redelin wO
Ground - Redelin wO
Ineff - Redelin wO
Bank Sta - Redelin wO
- Effective
Ground - Effective
Ineff - Effective
Bank Sta - Effective


Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 187.73
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 187.64
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 187.54 Left Channel Bank Station Interpolated
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO
River = Gila River Reach = El Rio WMP RS = 187.45
Legend
WS 100-Year - Effective
WS 100-Year - Redelin wO
- Redelin wO
Ground - Redelin wO
Ineff - Redelin wO
Bank Sta - Redelin wO
- Effective
Ground - Effective
Ineff - Effective
Bank Sta - Effective
Elevation (ft)
Station (ft)

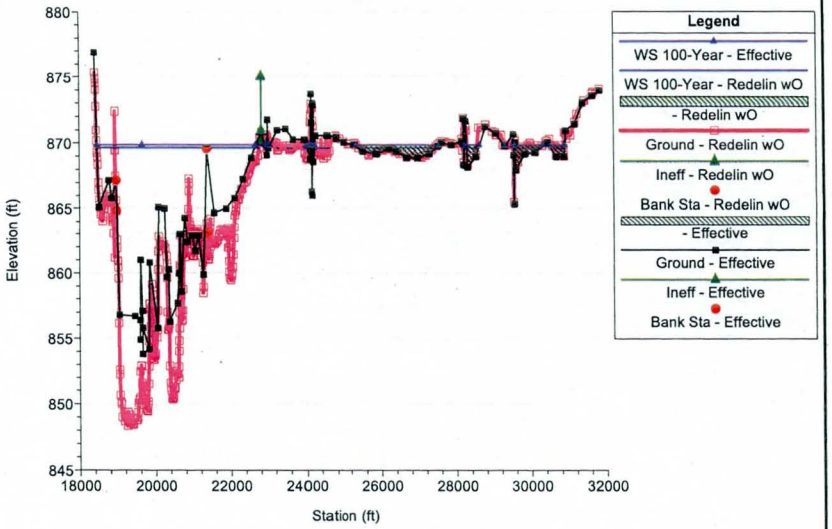
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO

River = Gila River Reach = El Rio WMP RS = 187.36



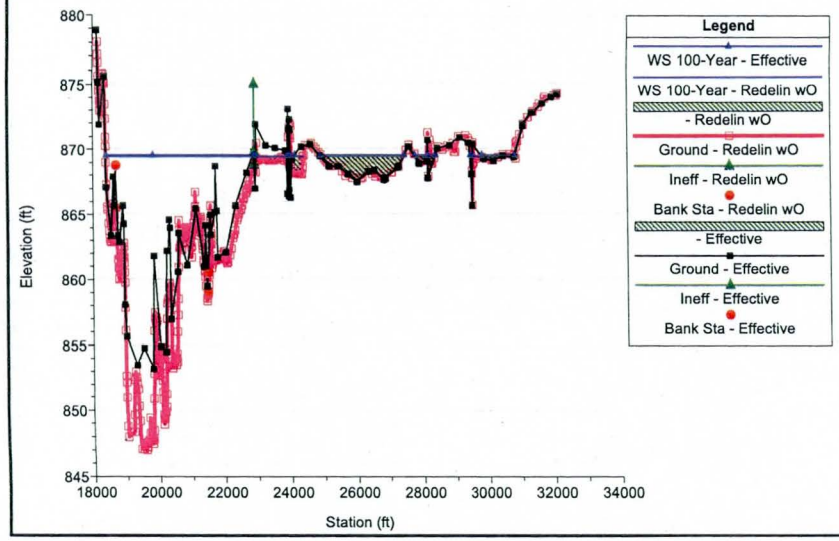
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO

River = Gila River Reach = El Rio WMP RS = 187.24



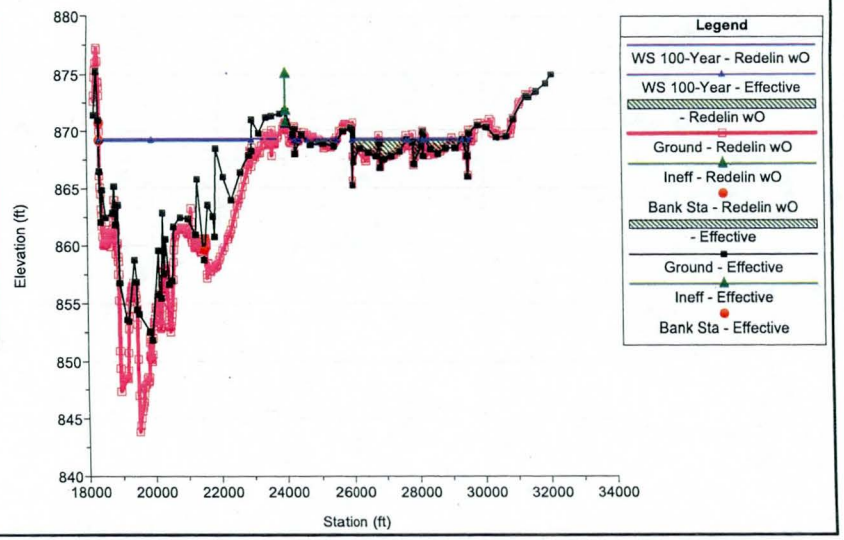
Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO

River = Gila River Reach = El Rio WMP RS = 187.15 Right Channel Bank Station Interpolated



Revised El Rio Base File 2007+EffectXsec Plan: 1) Effective 2) Redelin wO

River = Gila River Reach = El Rio WMP RS = 187.06 APPROX. ALIGNMENT OF AIRPORT RD. Left and



E.3 Expansion and Contraction Coefficients

Table of Contraction and Expansion Coefficients for Gila River
King Ranch / Norte Vista LOMR
Differences Highlighted in Yellow

River Mile	Effective Model Baker (1996)			Existing Conditions R2D (2007)	
	Contraction	Expansion		Contraction	Expansion
195.75	0.1	0.3		0.1	0.3
195.66	0.1	0.3		0.1	0.3
195.56	0.1	0.3		0.1	0.3
195.47	0.1	0.3		0.1	0.3
195.38	0.1	0.3		0.1	0.3
195.28	0.1	0.3		0.1	0.3
195.19	0.1	0.3		0.1	0.3
195.16	0.1	0.3		0.1	0.3
195.15	Bridge			Bridge	
195.13	0.1	0.3		0.1	0.3
195.09	0.1	0.3		0.1	0.3
195	0.1	0.3		0.1	0.3
194.91	0.1	0.3		0.1	0.3
194.81	0.1	0.3		0.1	0.3
194.72	0.1	0.3		0.1	0.3
194.62	0.1	0.3		0.1	0.3
194.53	0.3	0.3		0.1	0.3
194.4	0.3	0.3		0.1	0.3
194.29	0.3	0.3		0.1	0.3
194.21	0.3	0.3		0.1	0.3
194.205	Bridge			Bridge	
194.2	0.3	0.3		0.1	0.3
194.1	0.3	0.3		0.1	0.3
194.02	0.3	0.3		0.1	0.3
193.94	0.3	0.3		0.1	0.3
193.87	0.1	0.3		0.1	0.3
193.79	0.1	0.3		0.1	0.3
193.73	0.1	0.3		0.1	0.3
193.62	0.1	0.3		0.1	0.3
193.53	0.1	0.3		0.1	0.3
193.43	0.1	0.3		0.1	0.3
193.34	0.1	0.3		0.1	0.3
193.25	0.1	0.3		0.1	0.3
193.16	0.1	0.3		0.1	0.3
193.07	0.1	0.3		0.1	0.3
192.98	0.1	0.3		0.1	0.3
192.89	0.1	0.3		0.1	0.3
192.79	0.1	0.3		0.1	0.3
192.7	0.1	0.3		0.1	0.3
192.61	0.1	0.3		0.1	0.3
192.52	0.1	0.3		0.1	0.3
192.42	0.1	0.3		0.1	0.3
192.33	0.1	0.3		0.1	0.3
192.23	0.1	0.3		0.1	0.3
192.14	0.1	0.3		0.1	0.3
192.04	0.1	0.3		0.1	0.3
191.95	0.1	0.3		0.1	0.3

191.86	0.1	0.3		0.1	0.3
191.76	0.1	0.3		0.1	0.3
191.67	0.1	0.3		0.1	0.3
191.57	0.1	0.3		0.1	0.3
191.48	0.1	0.3		0.1	0.3
191.38	0.1	0.3		0.1	0.3
191.29	0.1	0.3		0.1	0.3
191.19	0.1	0.3		0.1	0.3
191.1	0.1	0.3		0.1	0.3
191	0.1	0.3		0.1	0.3
190.91	0.1	0.3		0.1	0.3
190.81	0.1	0.3		0.1	0.3
190.72	0.1	0.3		0.1	0.3
190.62	0.1	0.3		0.1	0.3
190.53	0.1	0.3		0.1	0.3
190.43	0.1	0.3		0.1	0.3
190.34	0.1	0.3		0.1	0.3
190.24	0.1	0.3		0.1	0.3
190.15	0.1	0.3		0.1	0.3
190.05	0.1	0.3		0.1	0.3
189.96	0.1	0.3		0.1	0.3
189.87	0.1	0.3		0.1	0.3
189.77	0.1	0.3		0.1	0.3
189.67	0.1	0.3		0.1	0.3
189.58	0.1	0.3		0.1	0.3
189.48	0.1	0.3		0.1	0.3
189.39	0.1	0.3		0.1	0.3
189.3	0.1	0.3		0.1	0.3
189.21	0.1	0.3		0.1	0.3
189.11	0.1	0.3		0.1	0.3
189.02	0.1	0.3		0.1	0.3
188.81	0.1	0.3		0.1	0.3
188.69	0.1	0.3		0.1	0.3
188.59	0.1	0.3		0.1	0.3
188.5	0.1	0.3		0.1	0.3
188.39	0.1	0.3		0.1	0.3
188.29	0.1	0.3		0.1	0.3
188.2	0.1	0.3		0.1	0.3
188.1	0.1	0.3		0.1	0.3
188.07	0.1	0.3		0.1	0.3
188.055	Bridge			Bridge	
188.04	0.1	0.3		0.1	0.3
188	0.1	0.3		0.1	0.3
187.91	0.1	0.3		0.1	0.3
187.82	0.1	0.3		0.1	0.3
187.73	0.1	0.3		0.1	0.3
187.64	0.1	0.3		0.1	0.3
187.54	0.1	0.3		0.1	0.3
187.45	0.1	0.3		0.1	0.3
187.36	0.1	0.3		0.1	0.3
187.24	0.1	0.3		0.1	0.3
187.15	0.1	0.3		0.1	0.3
187.06	0.1	0.3		0.1	0.3
186.97	0.1	0.3		0.1	0.3
186.87	0.1	0.3		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

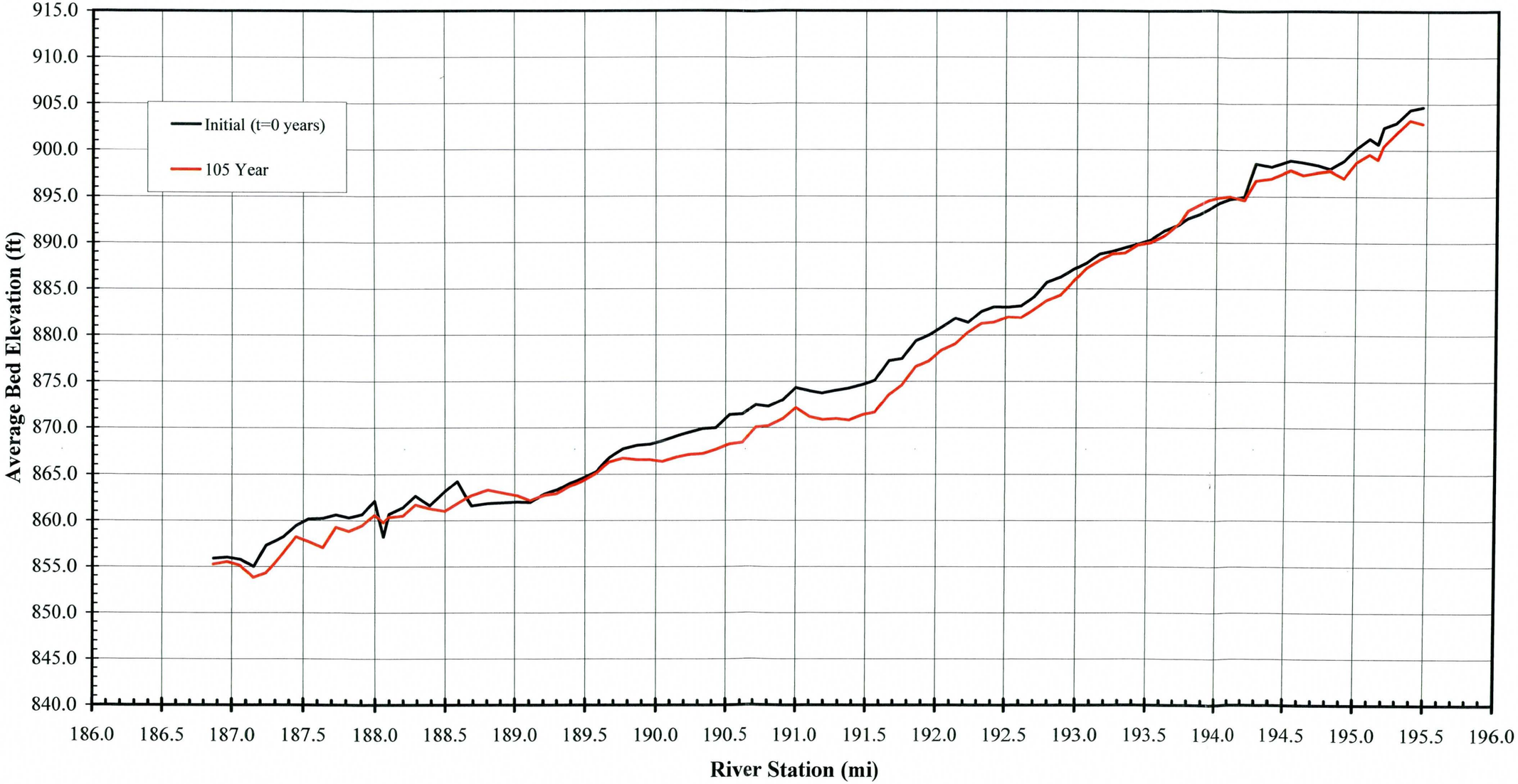
APPENDIX F

SECTION 1

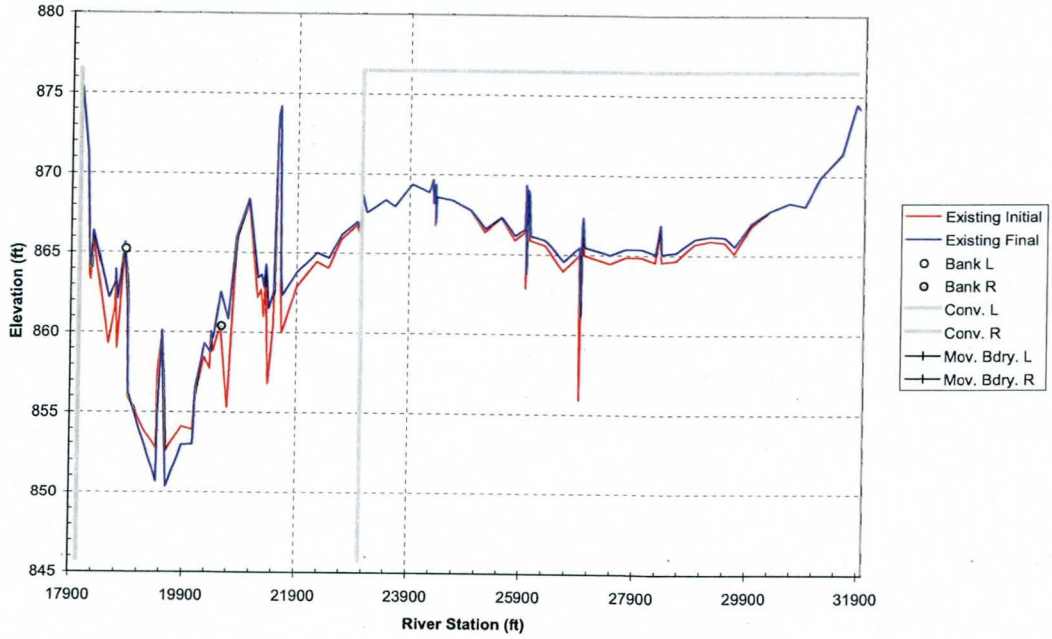
Sediment Transport HEC-6T Model Results

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



Cross Section 186.87



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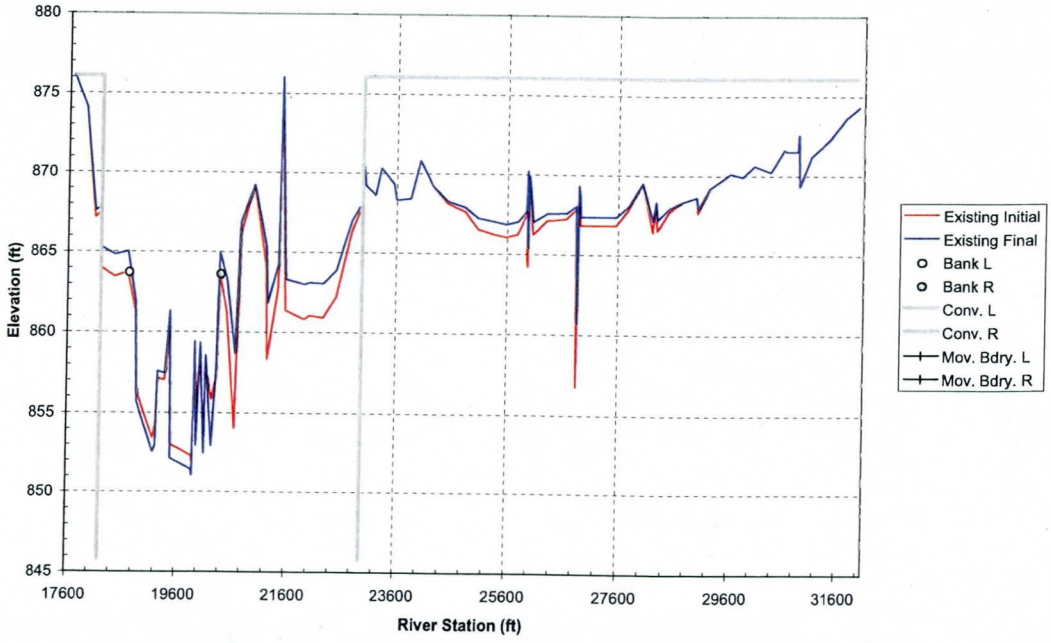
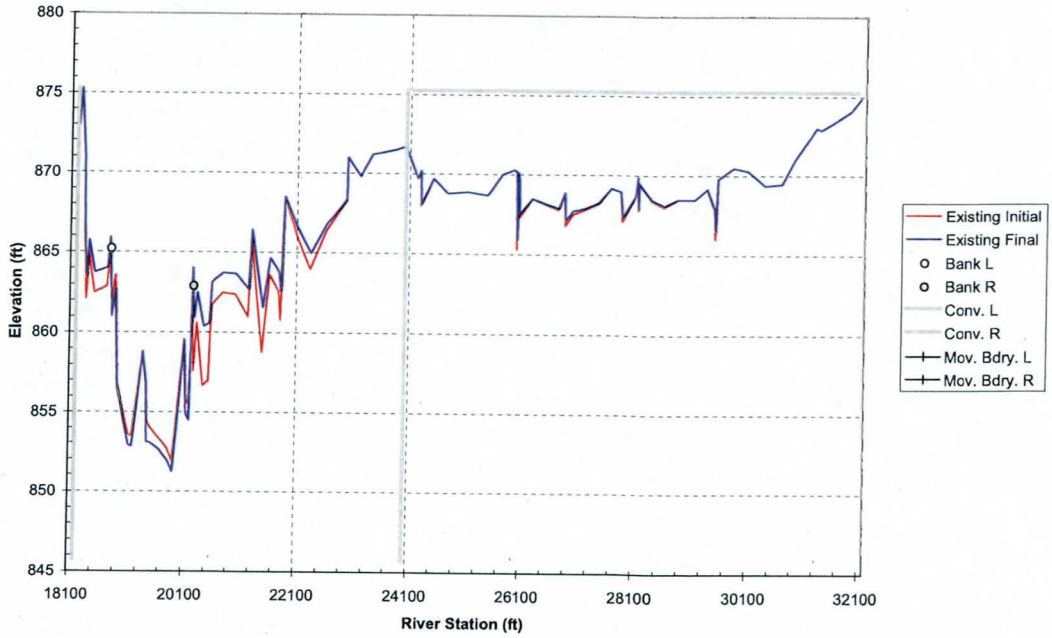


Cross Section 187.06



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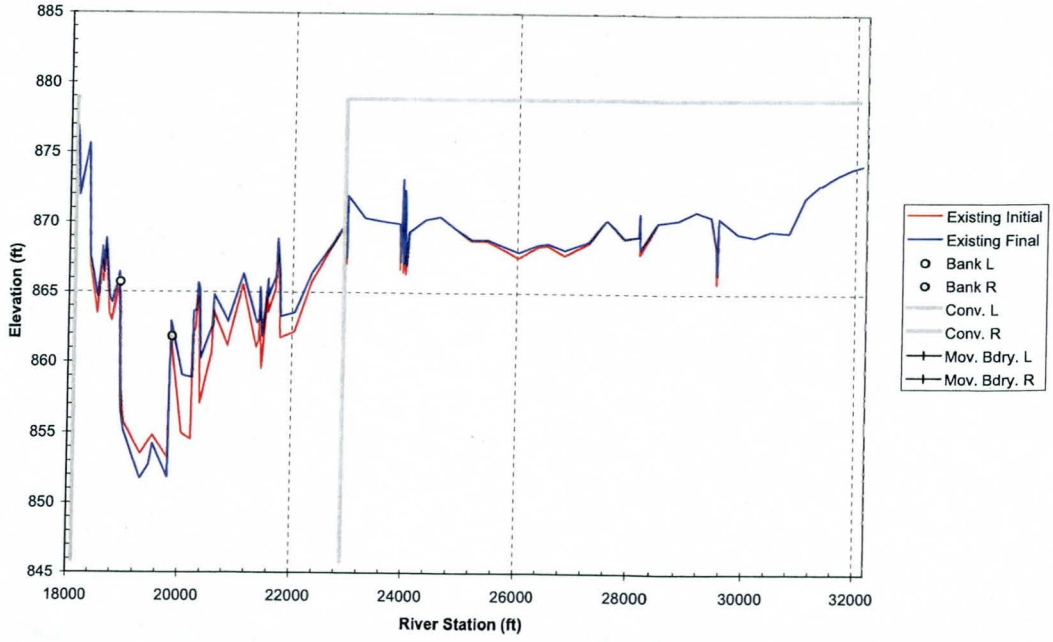

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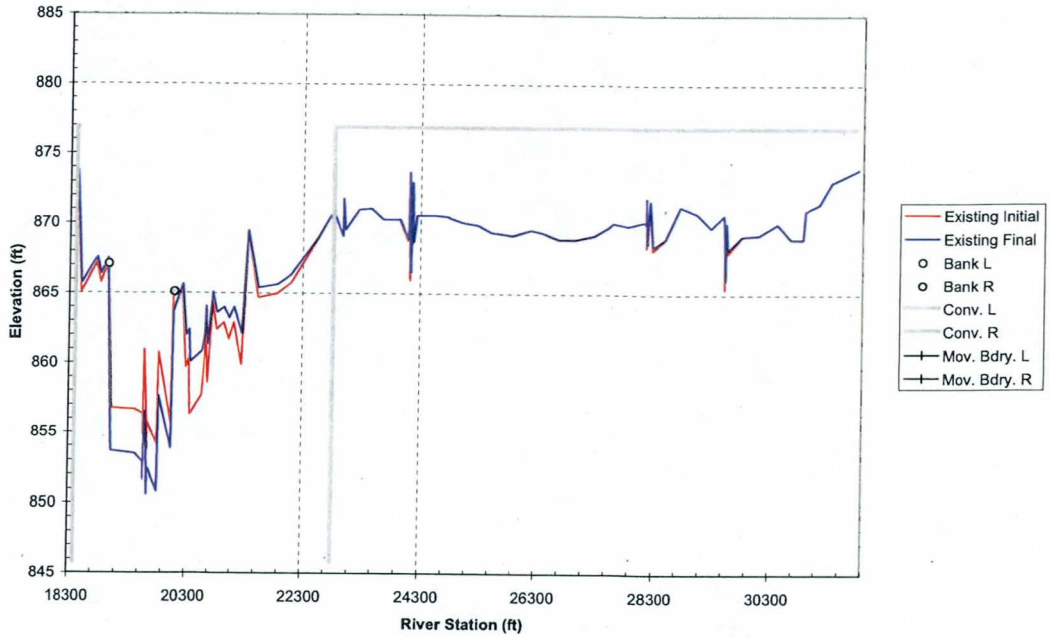

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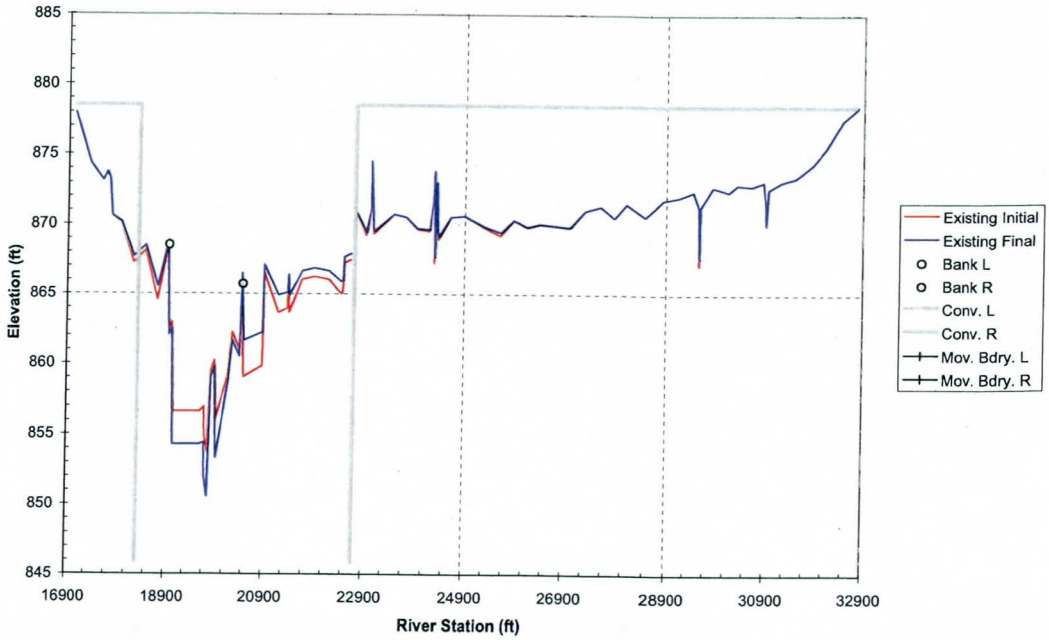

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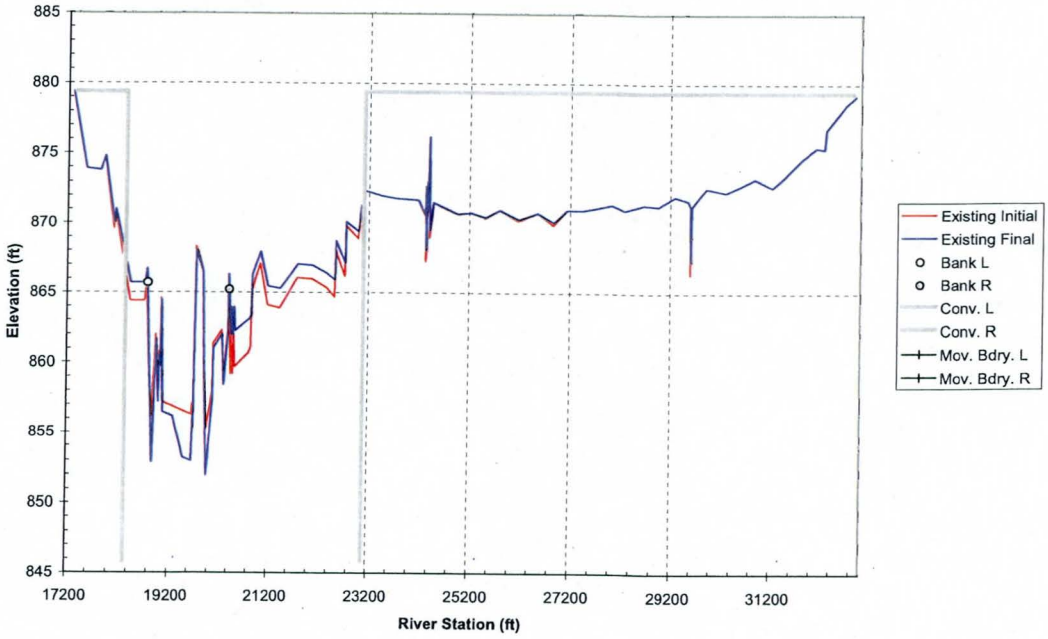

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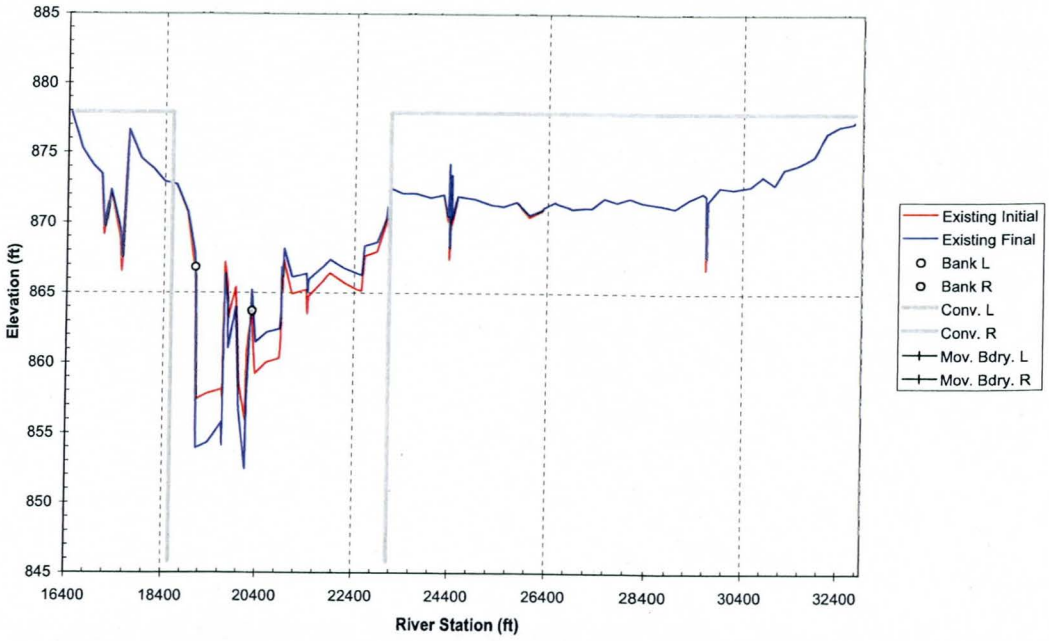

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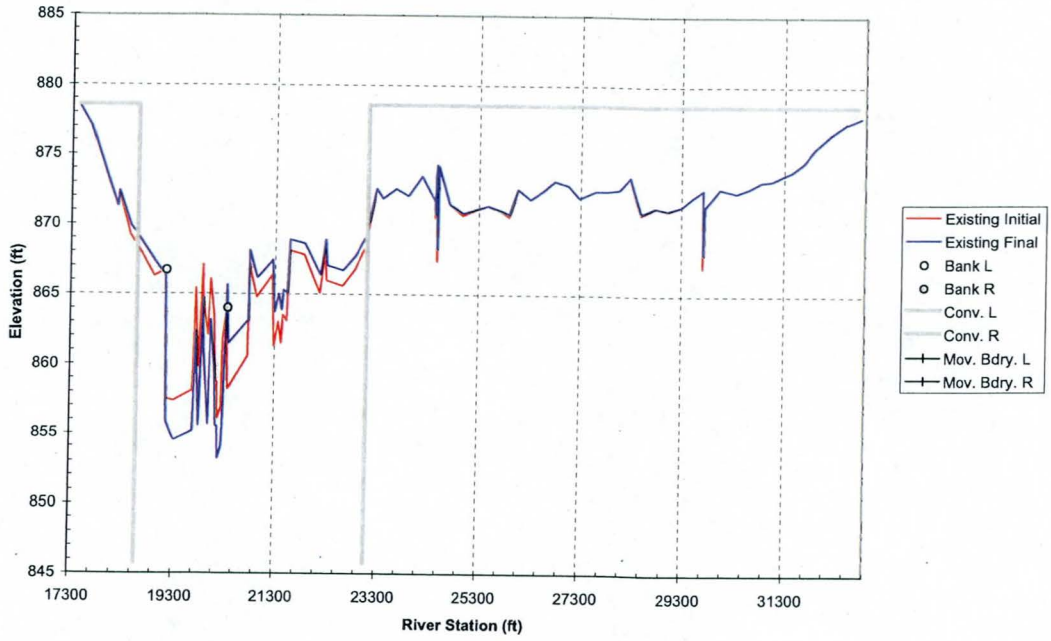

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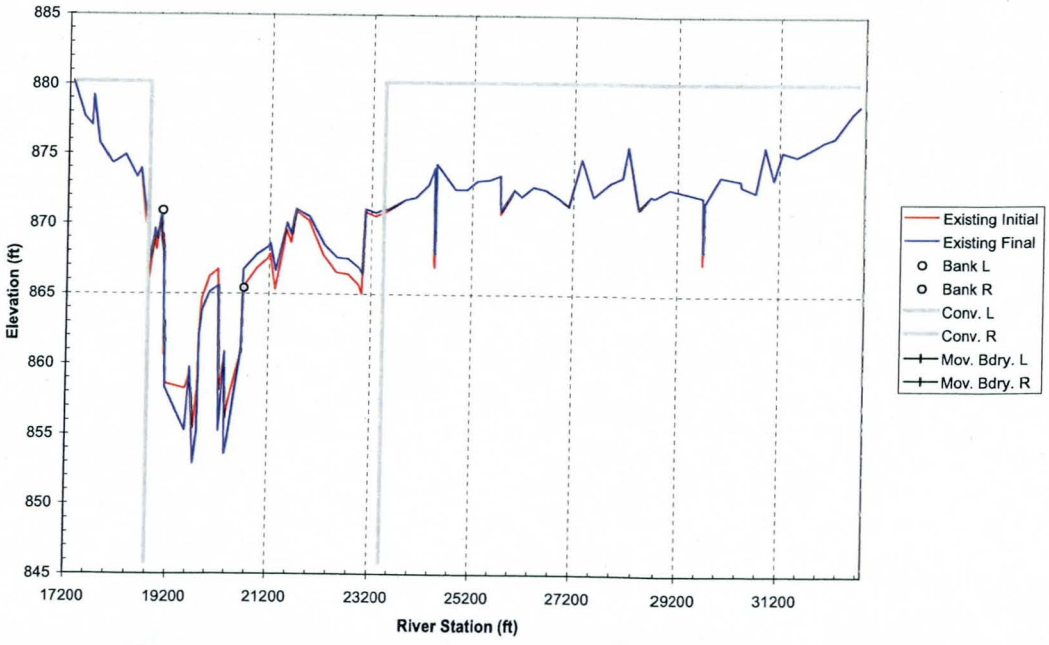

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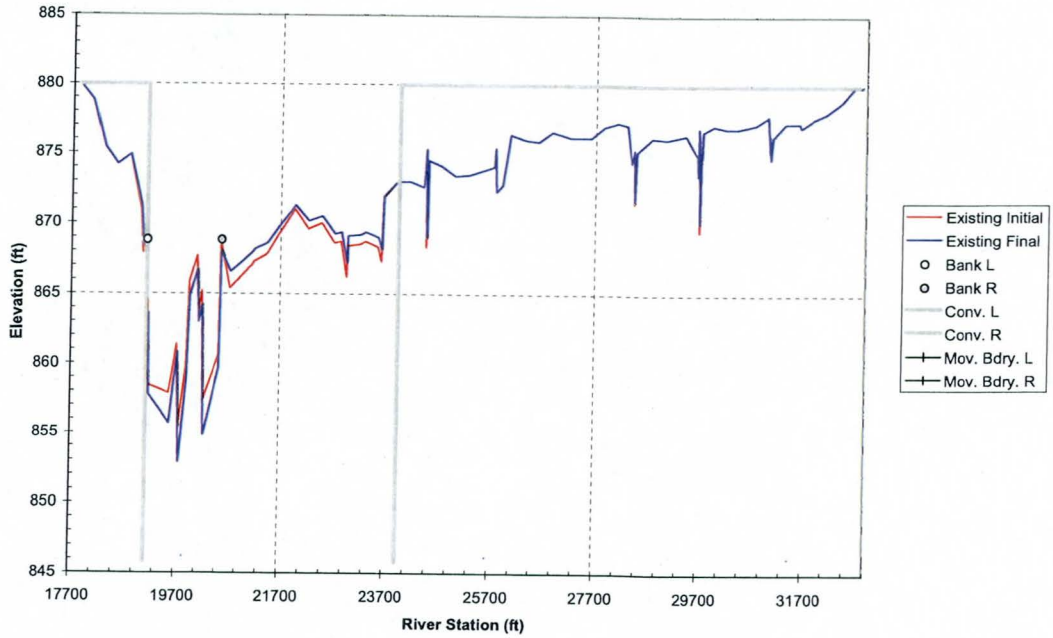

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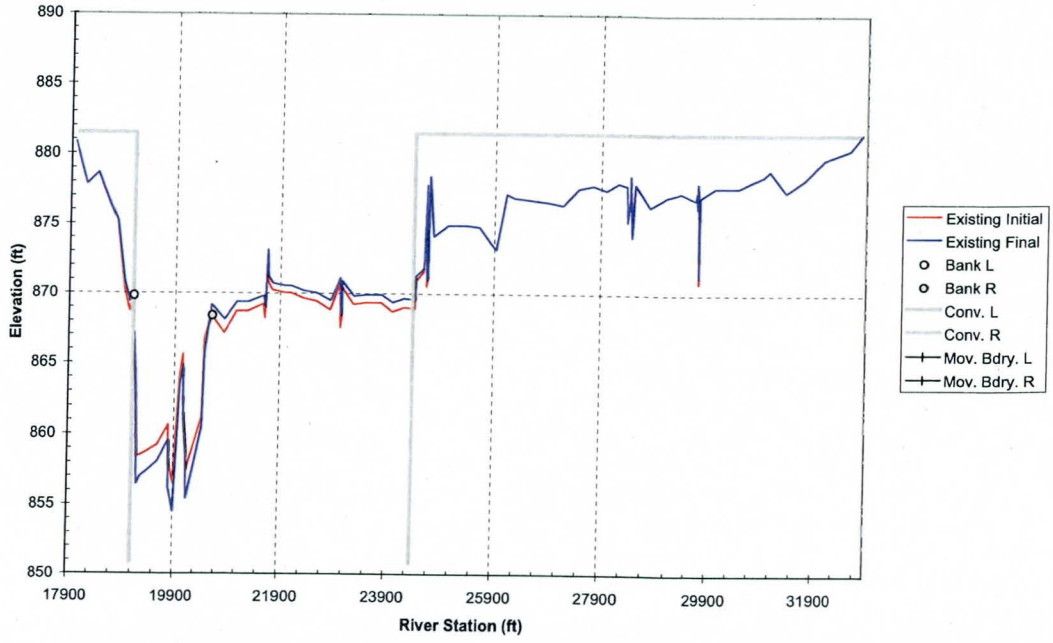

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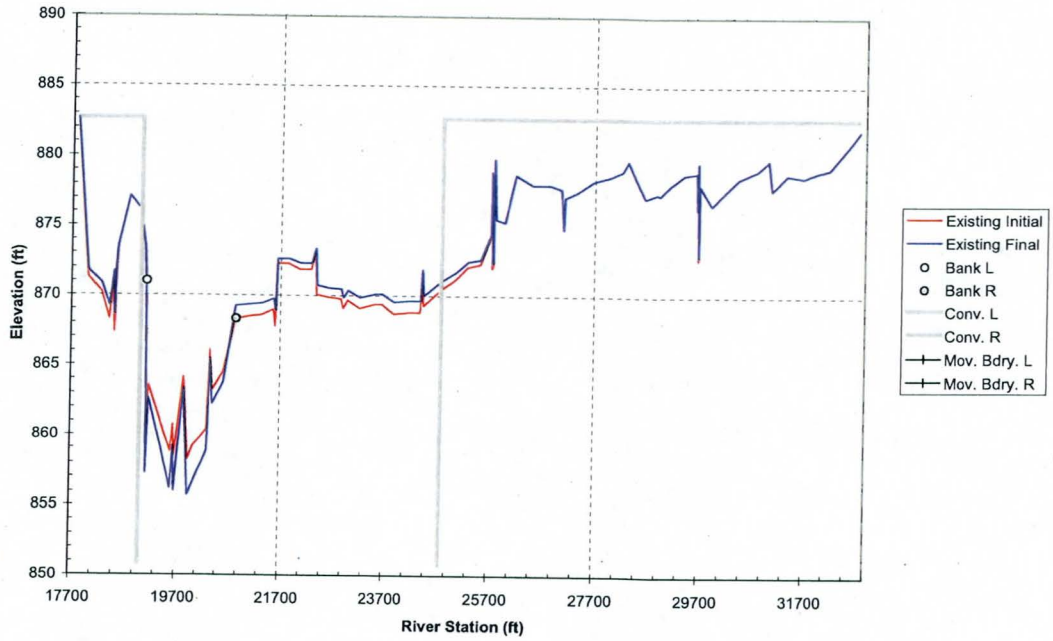

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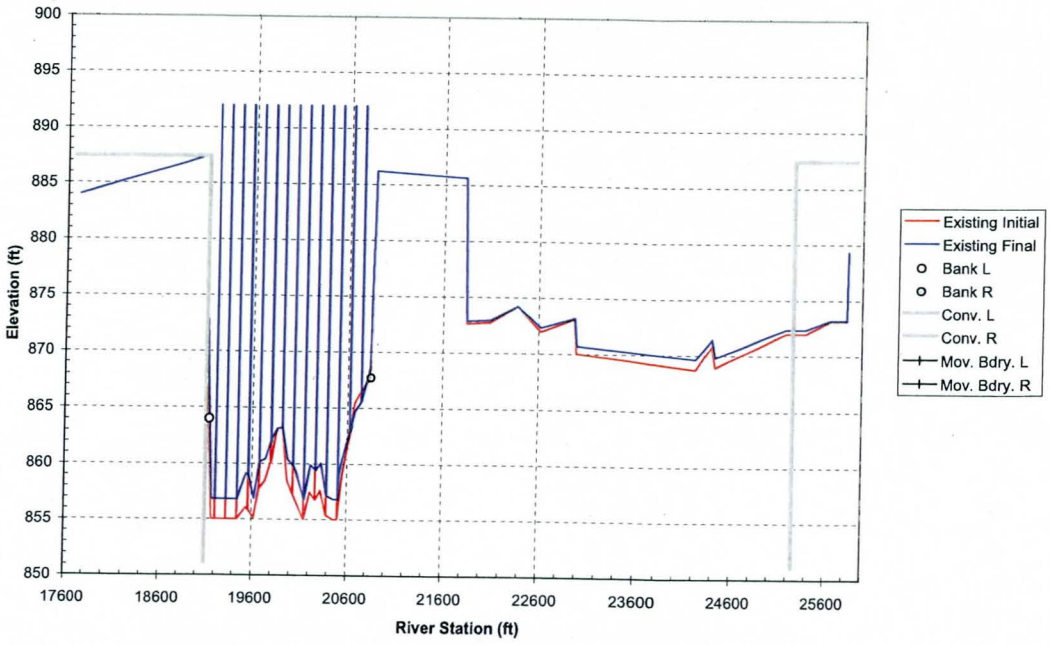

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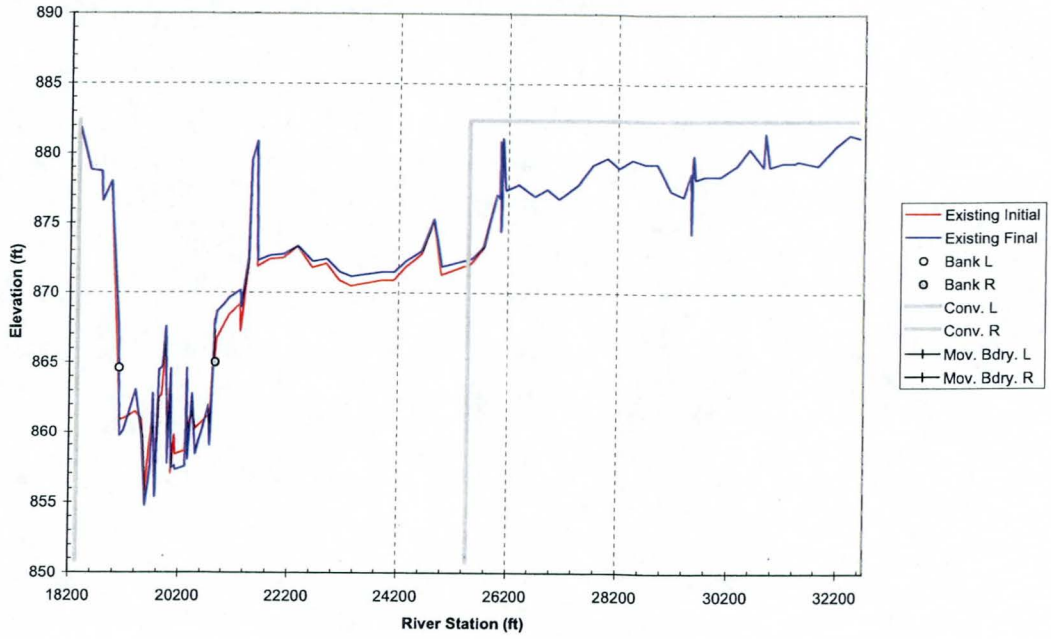

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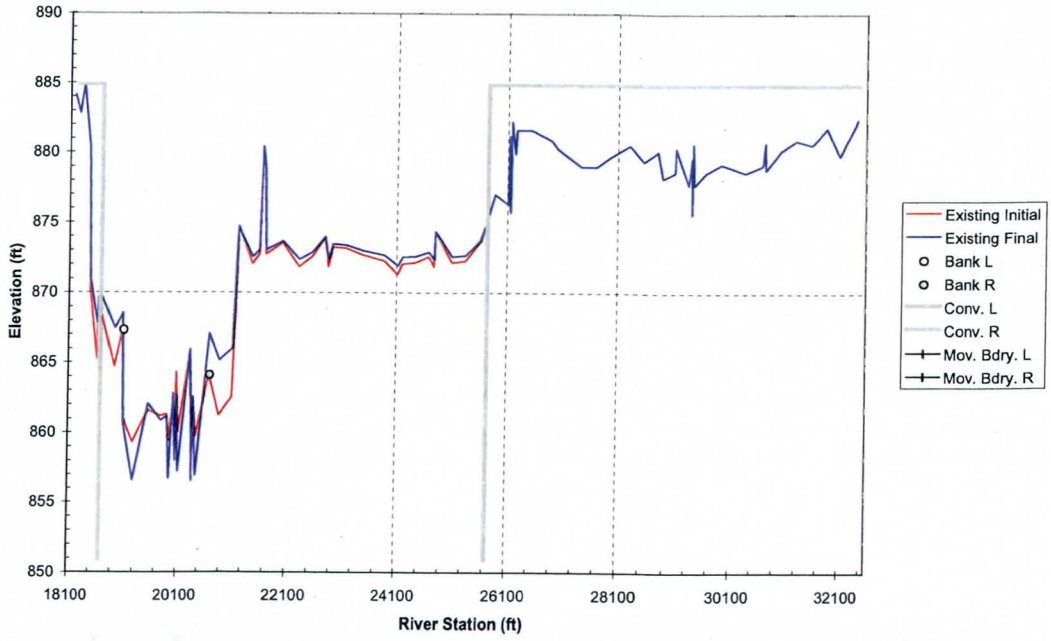

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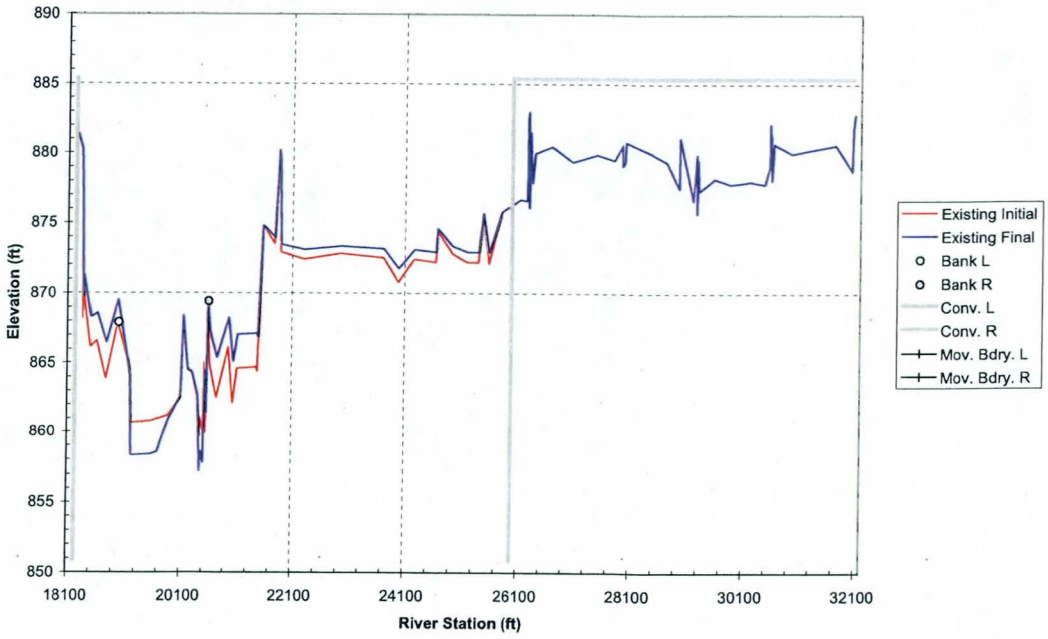

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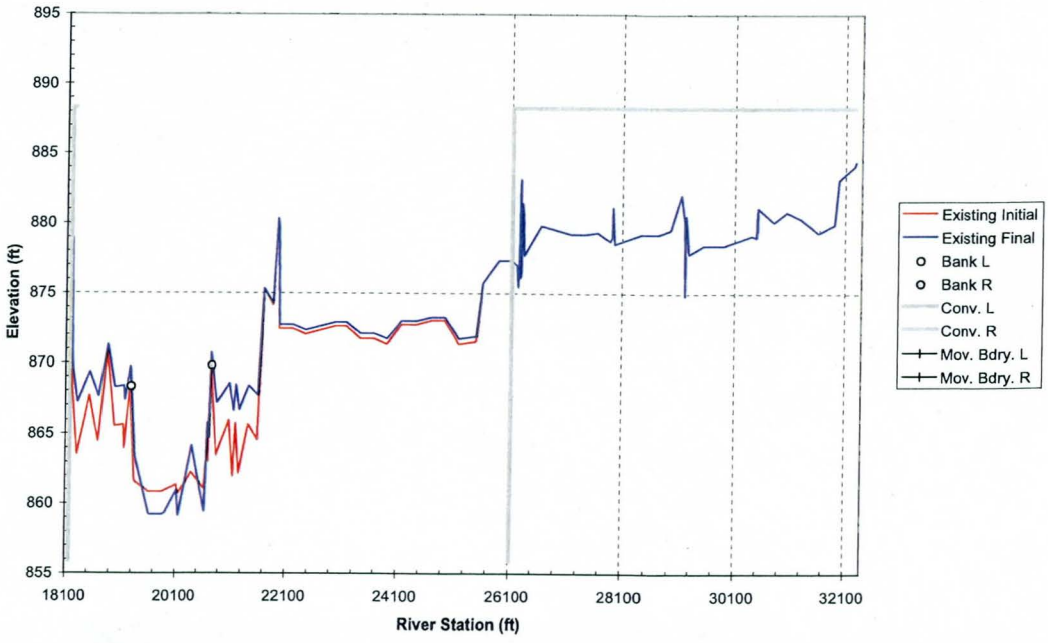

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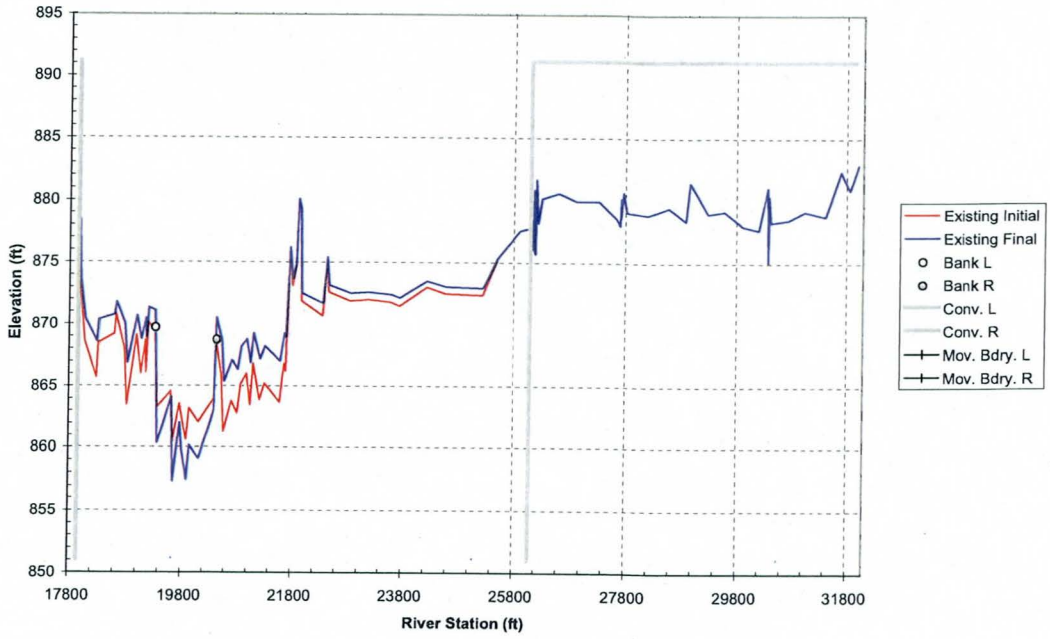

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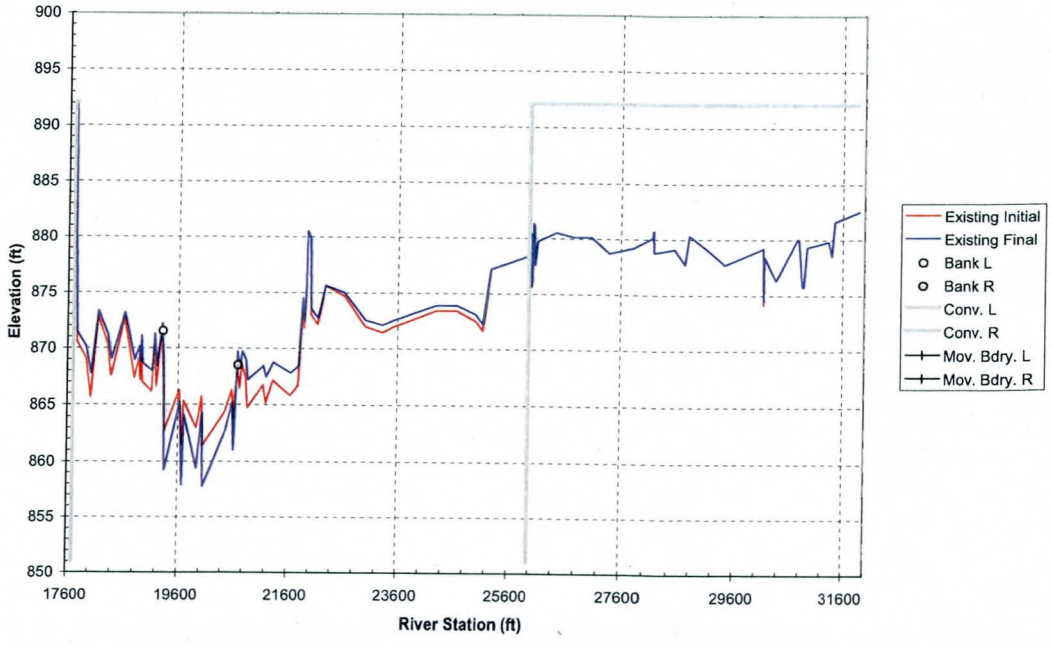

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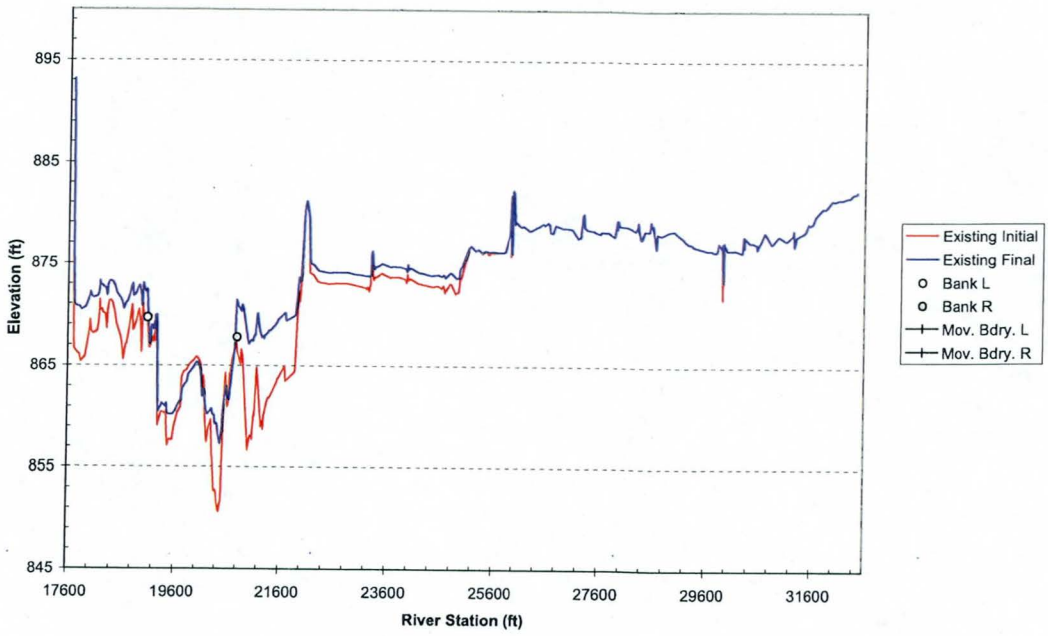

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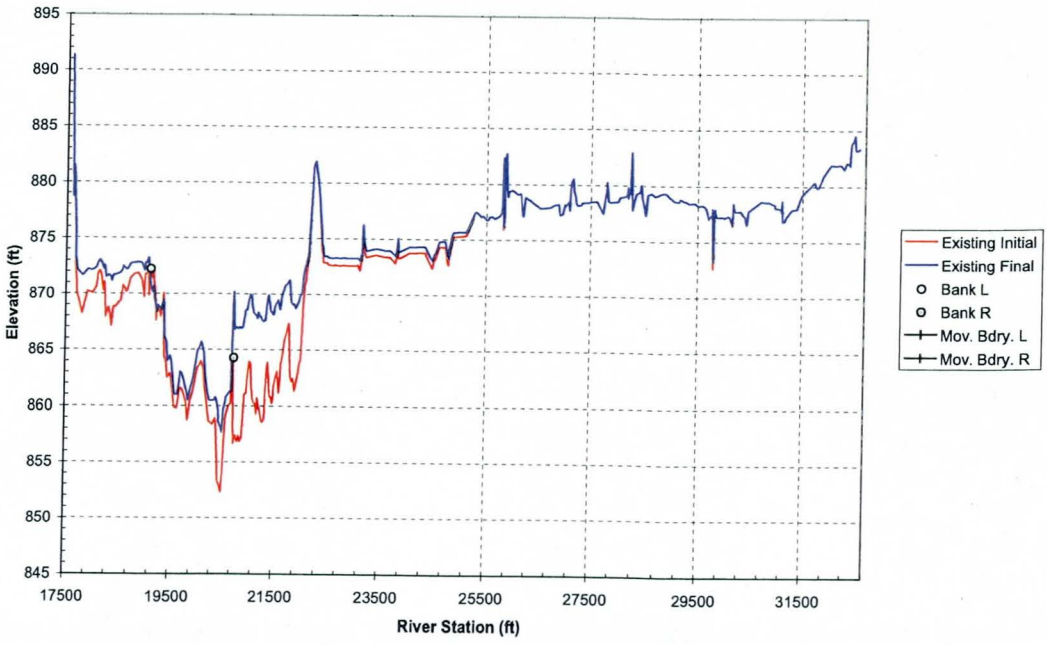

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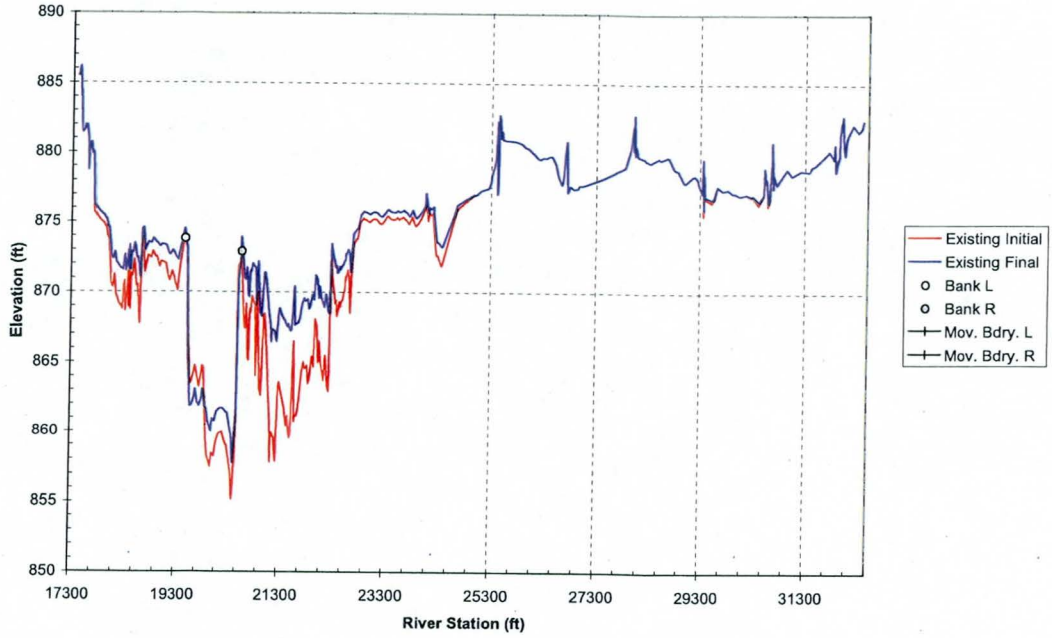

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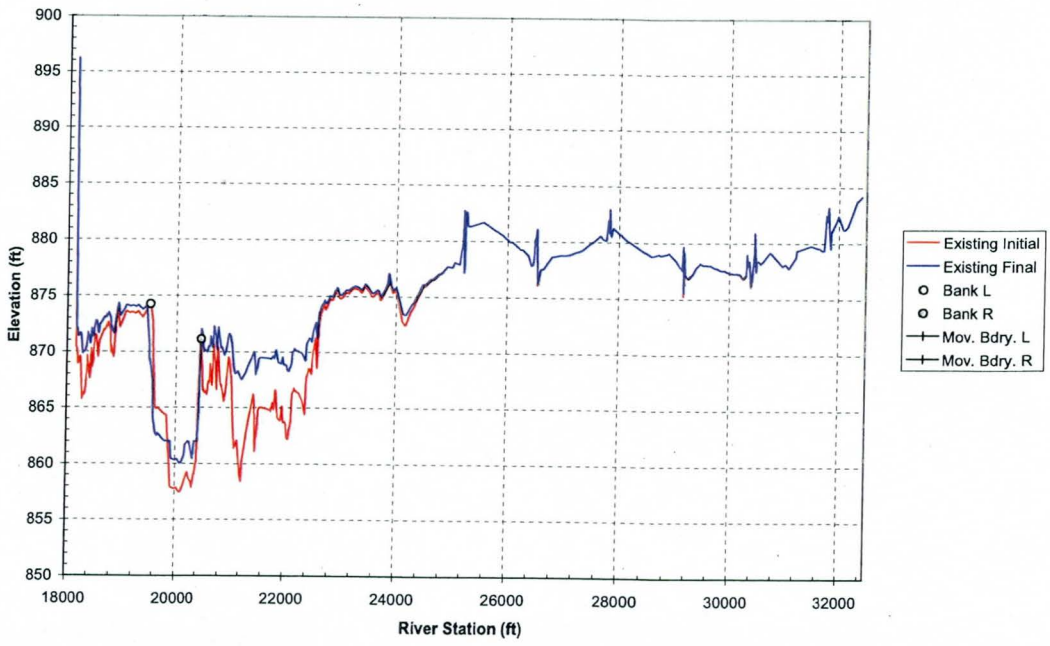

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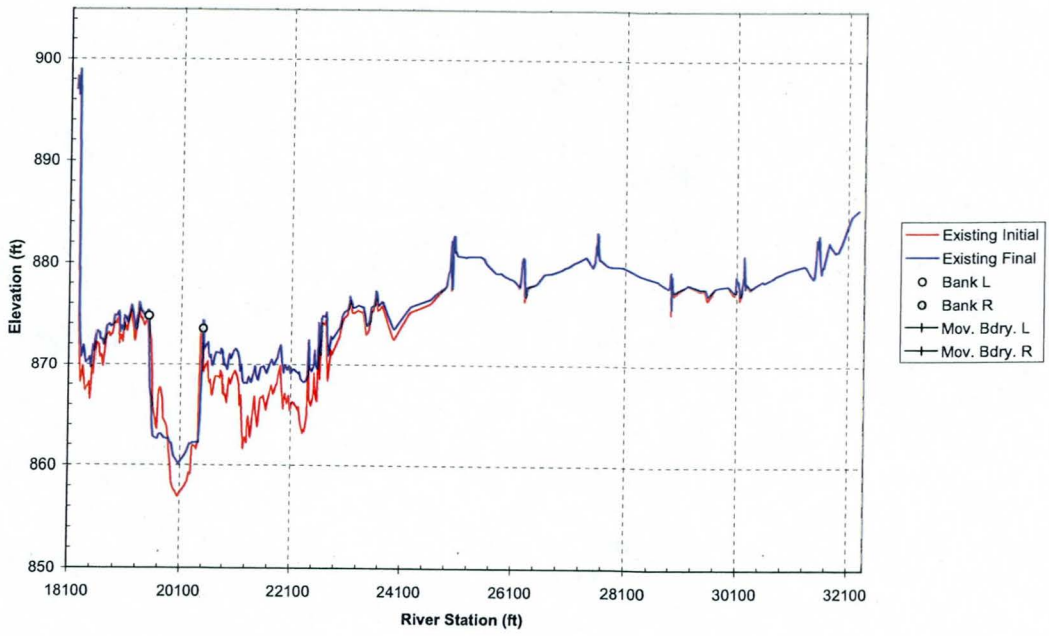

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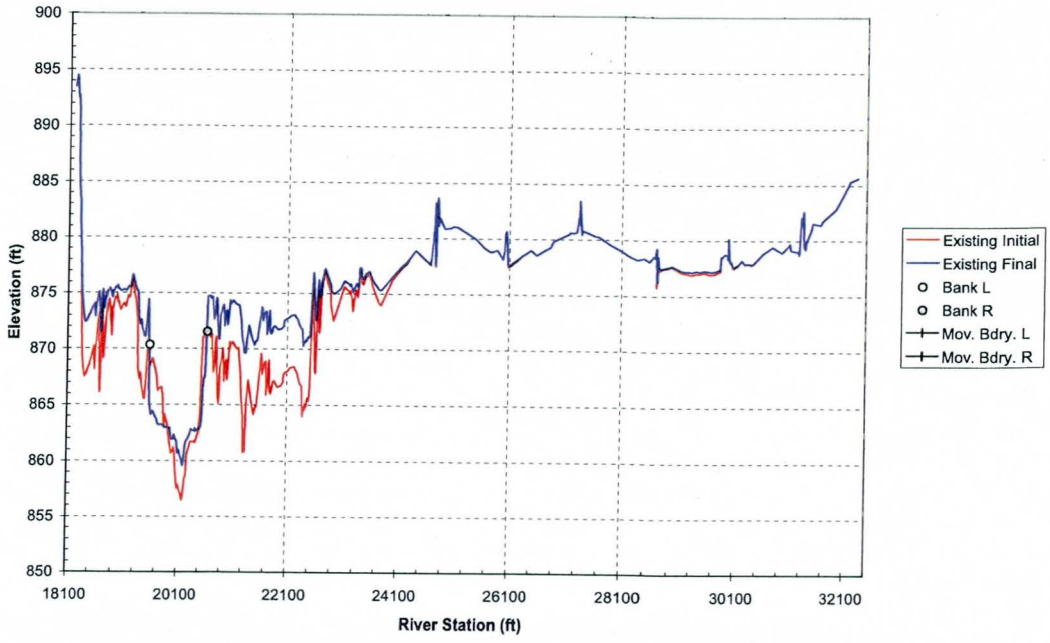

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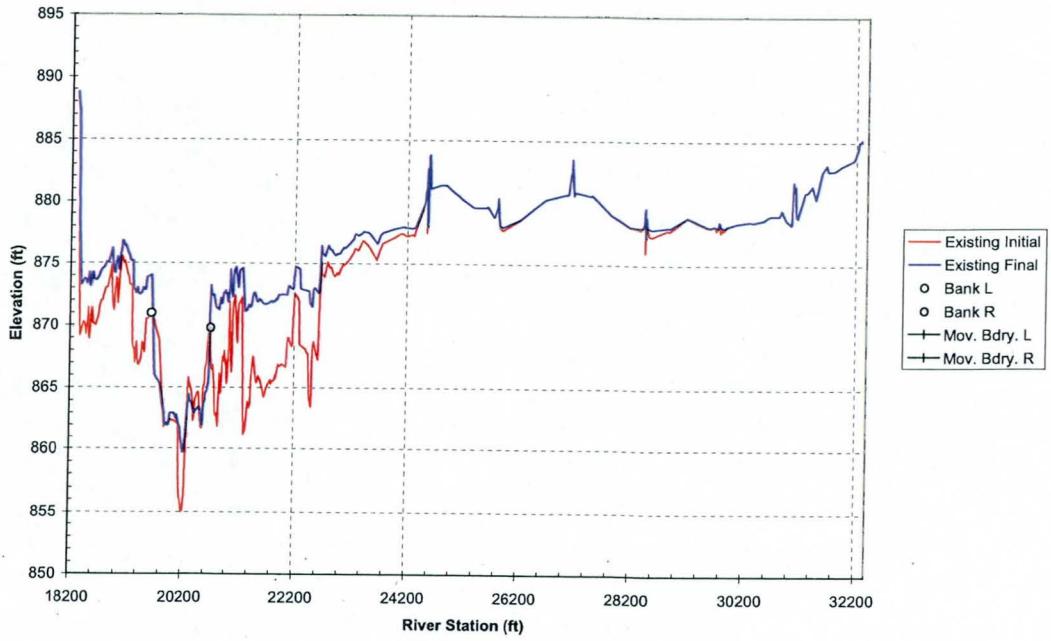

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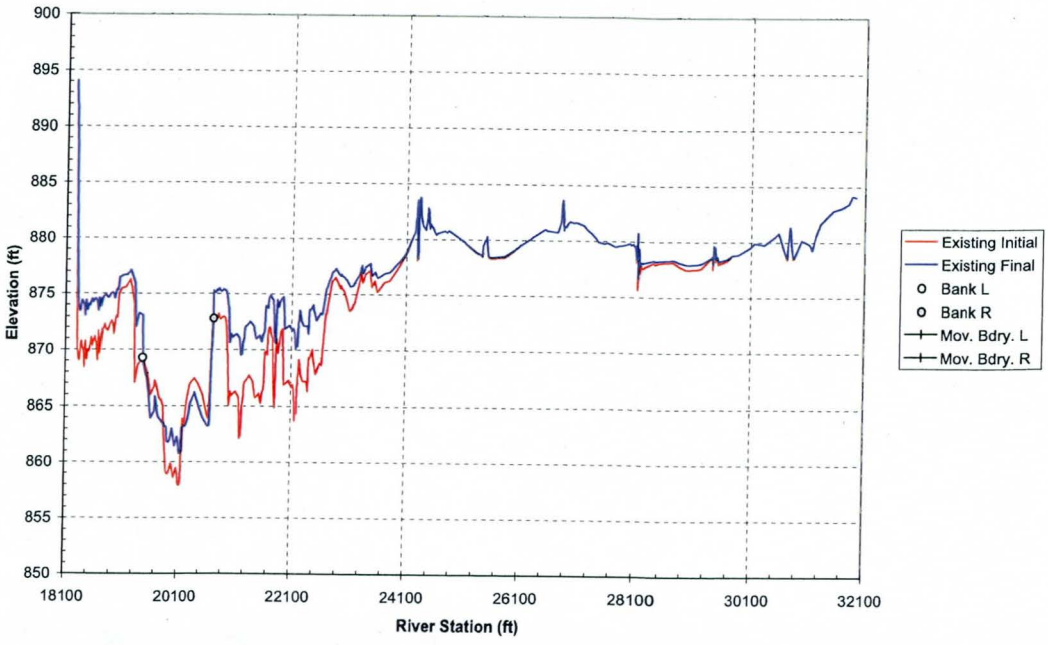

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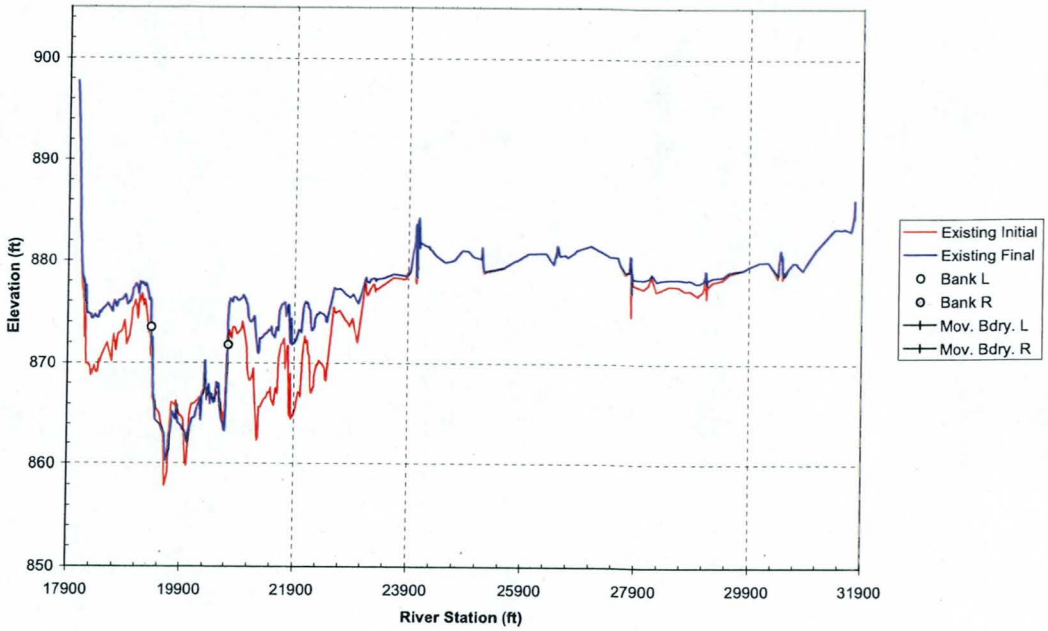

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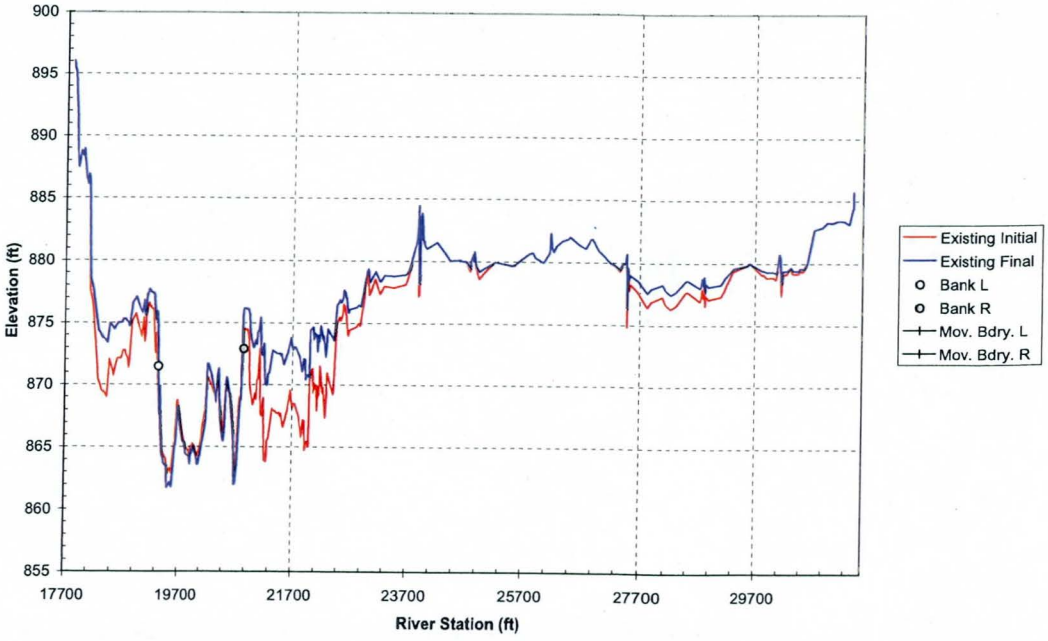

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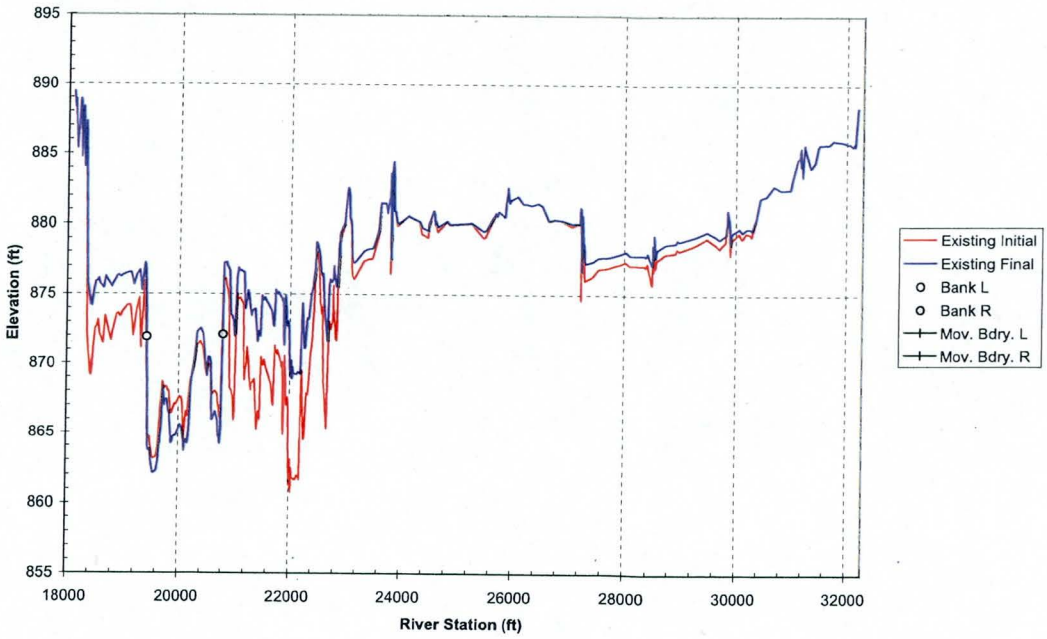

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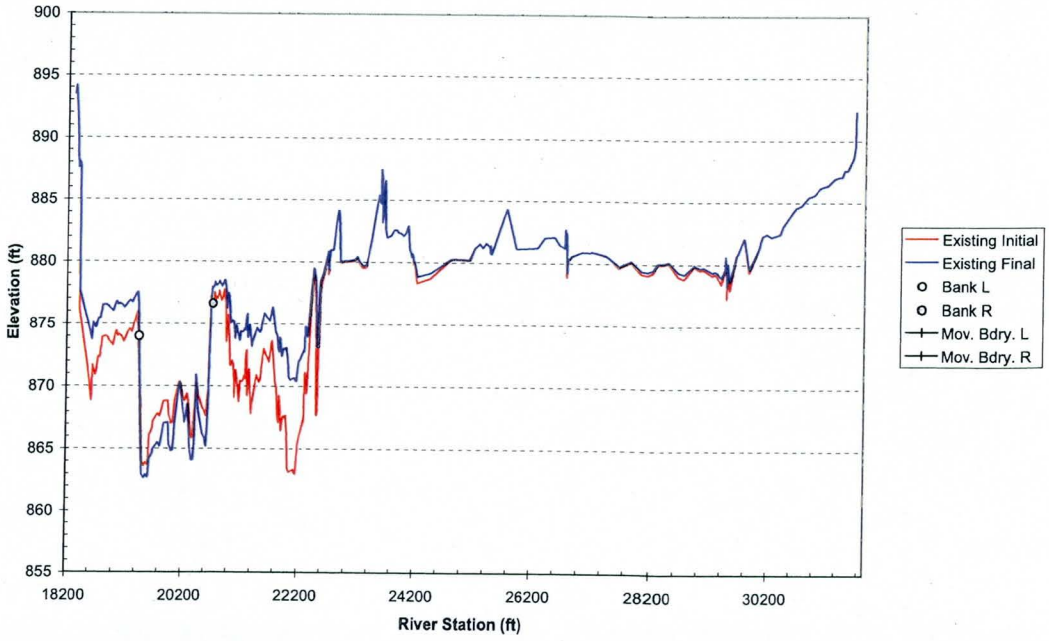

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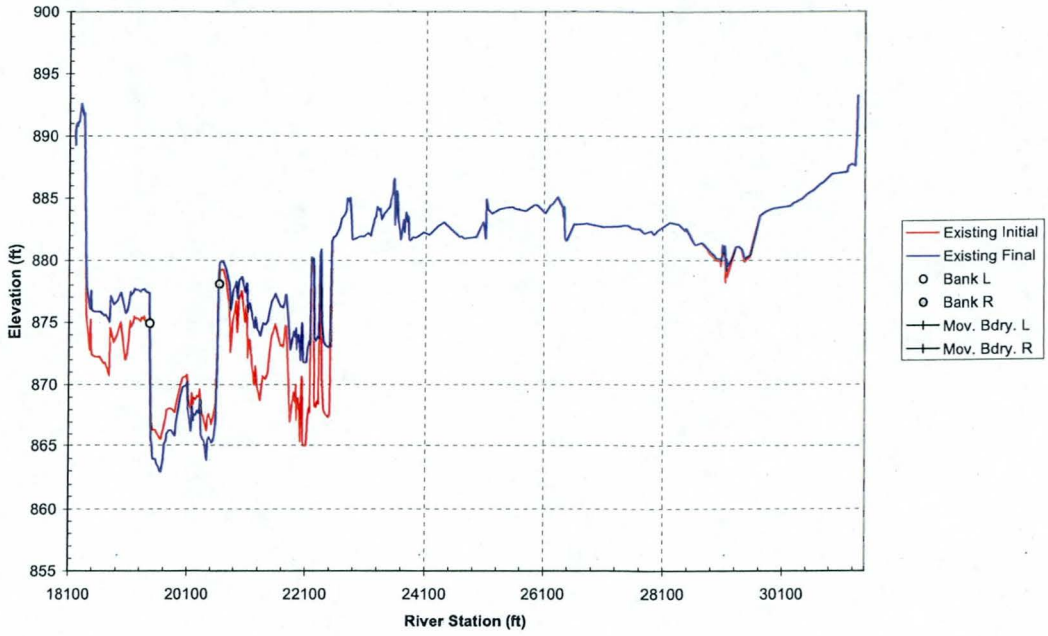

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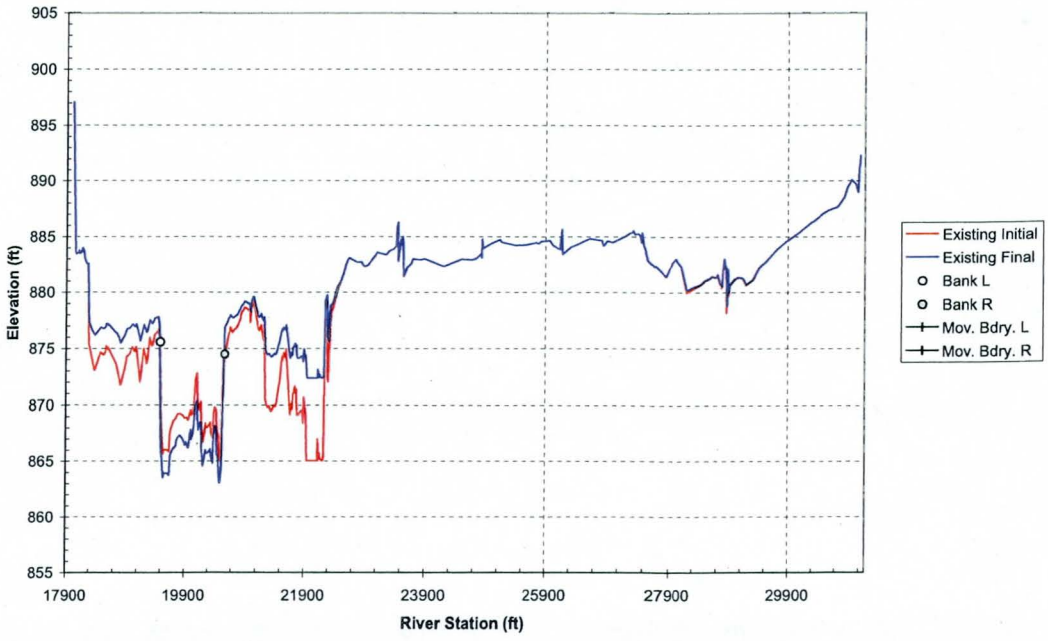

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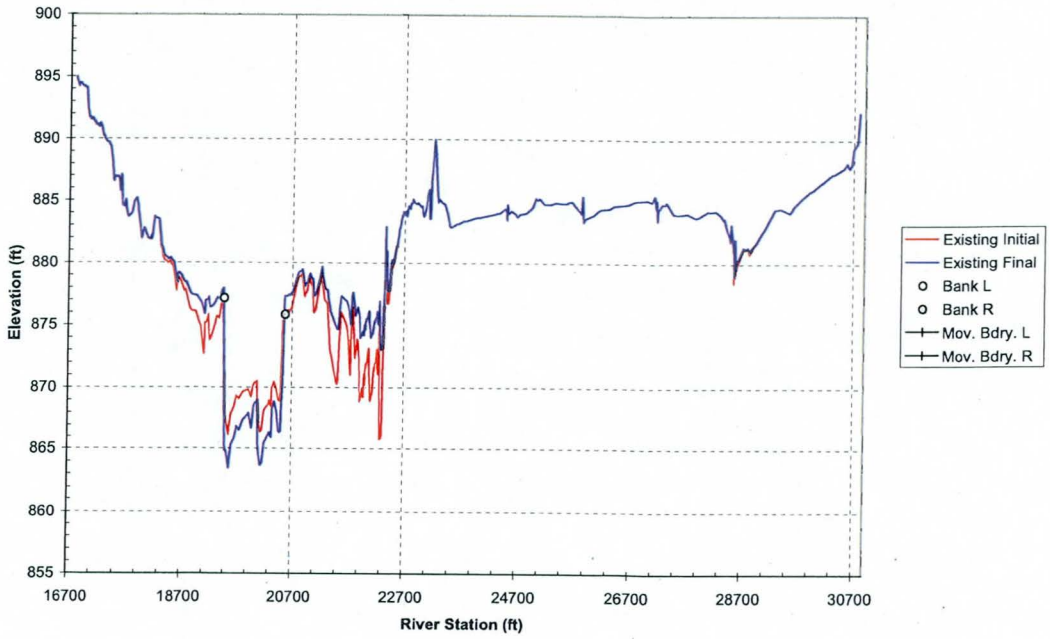

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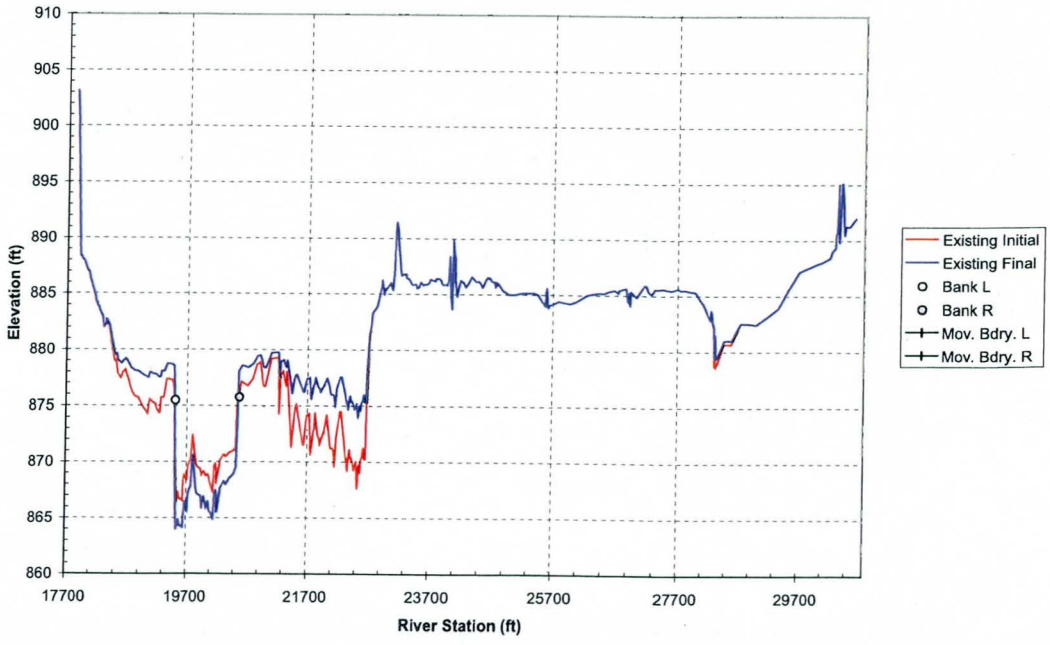

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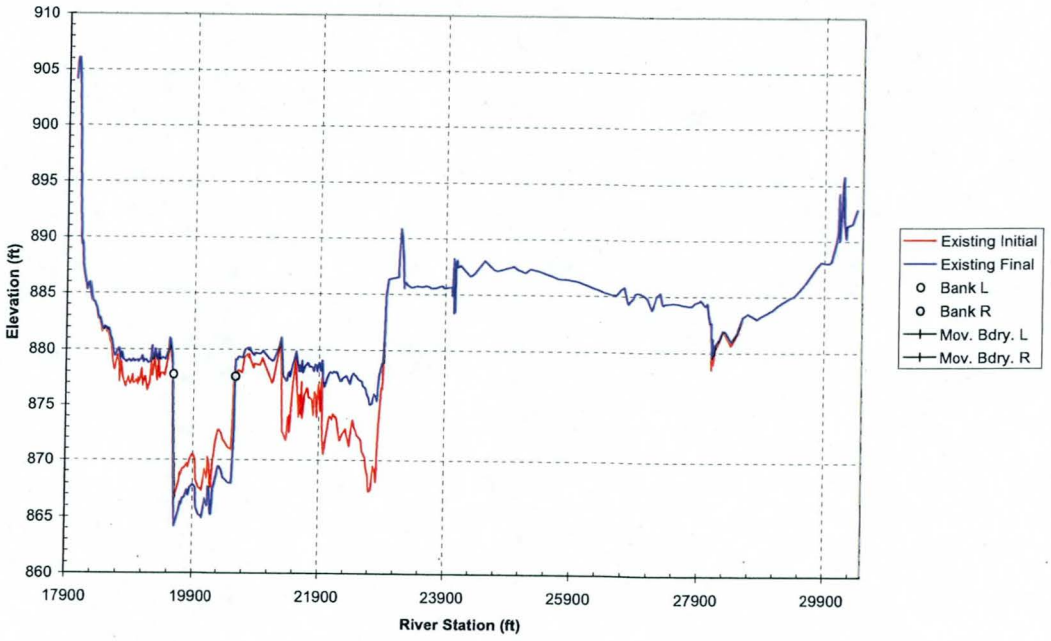

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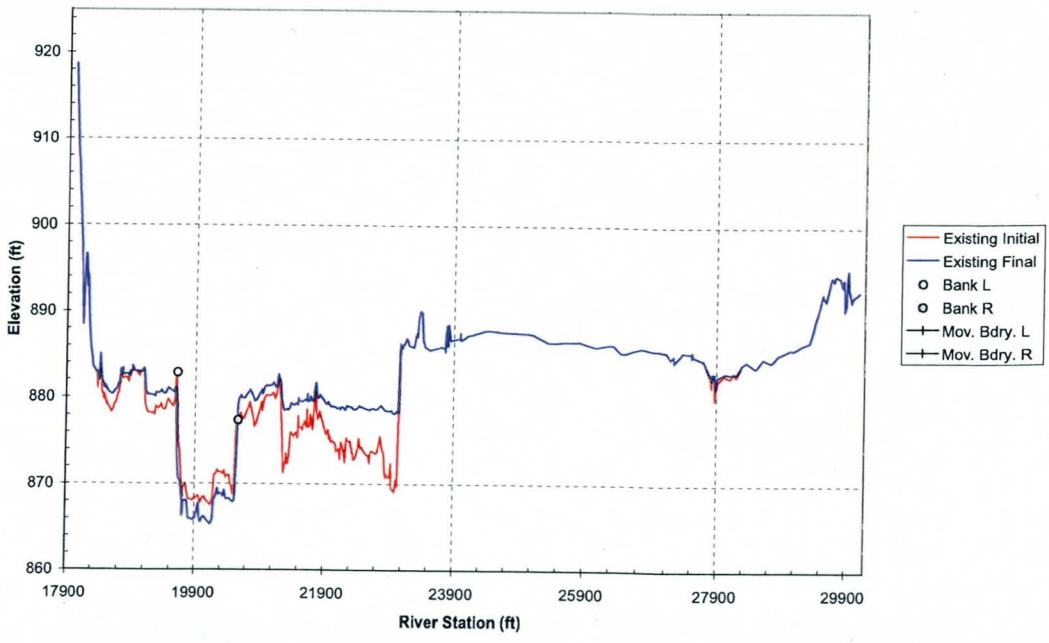

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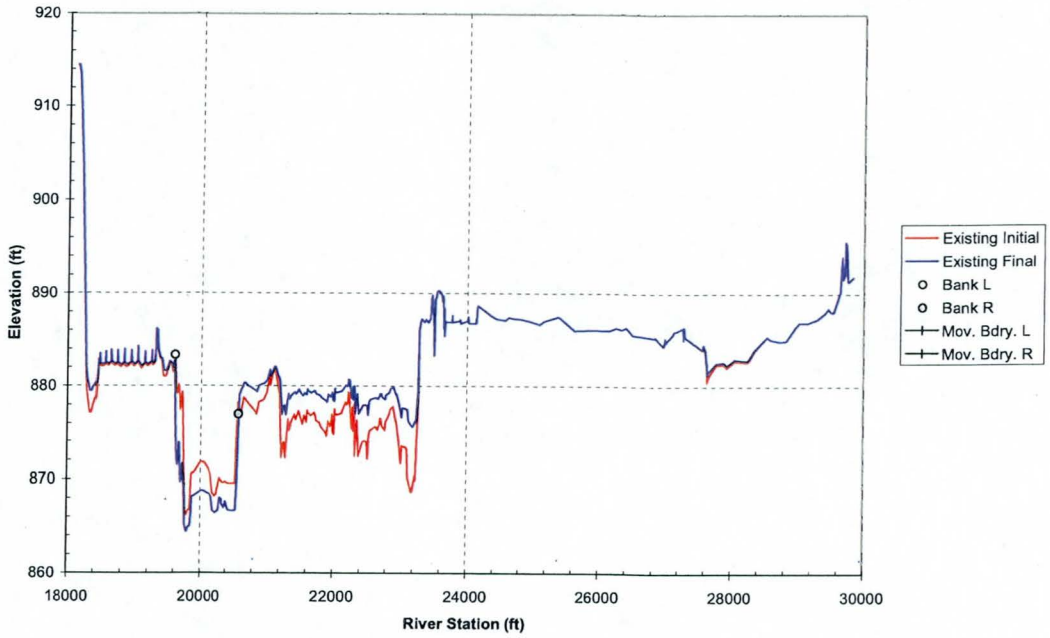

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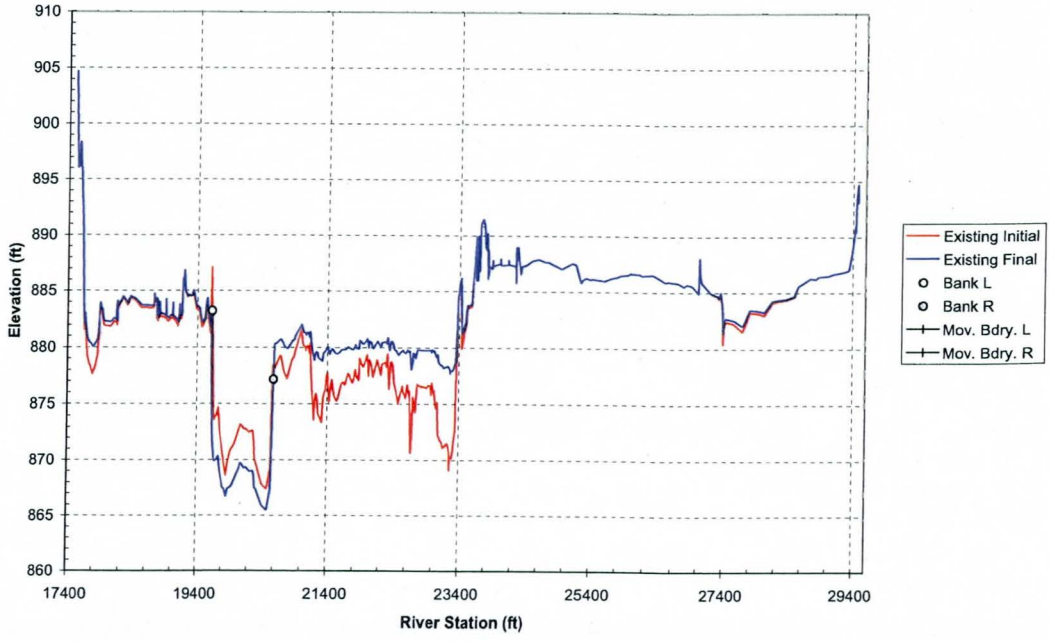

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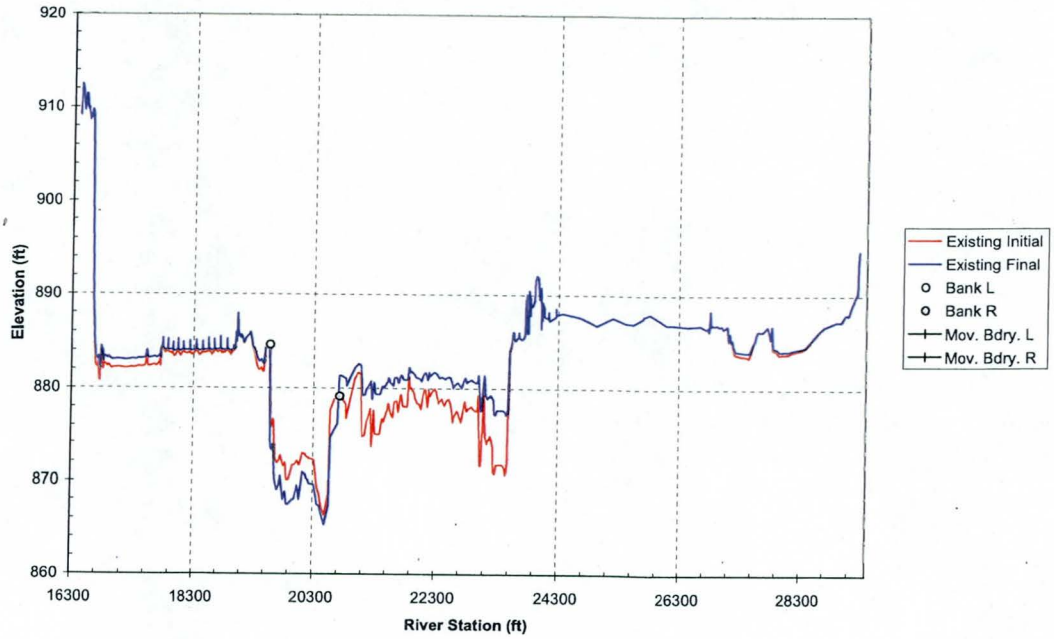

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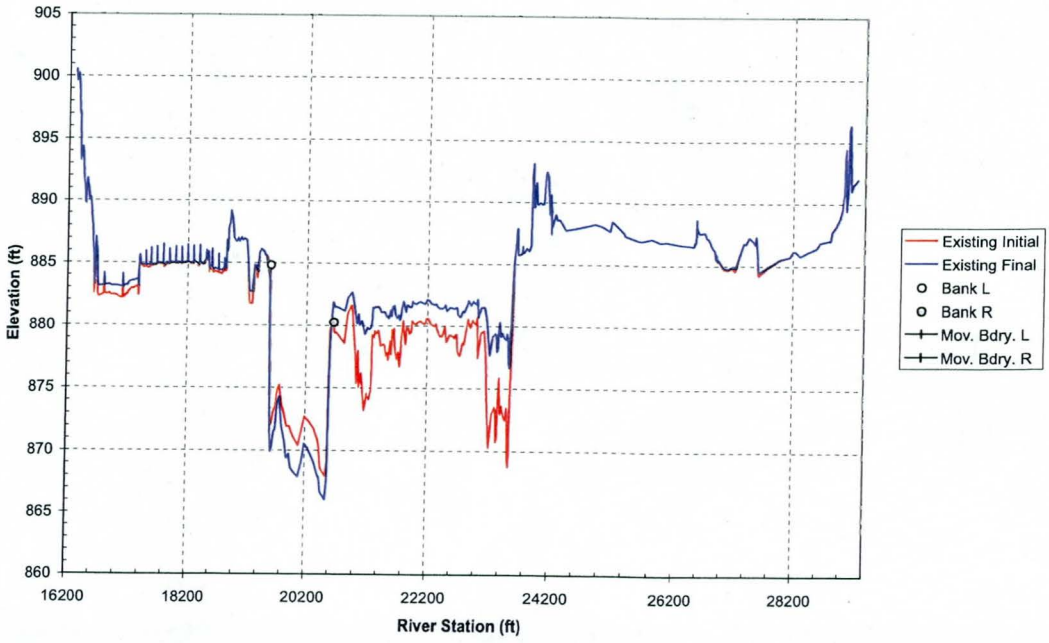

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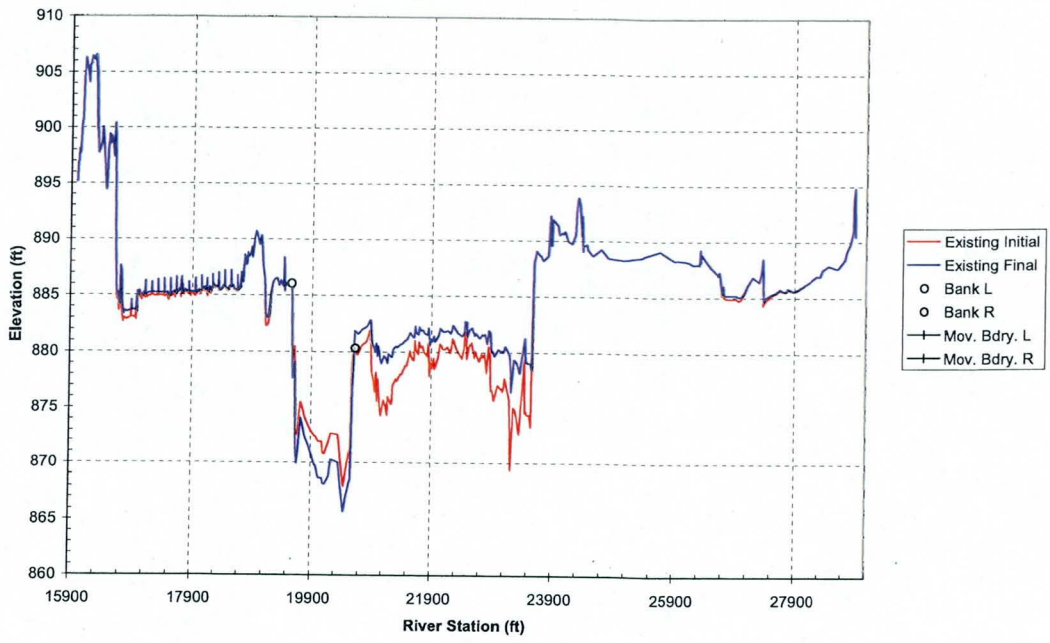

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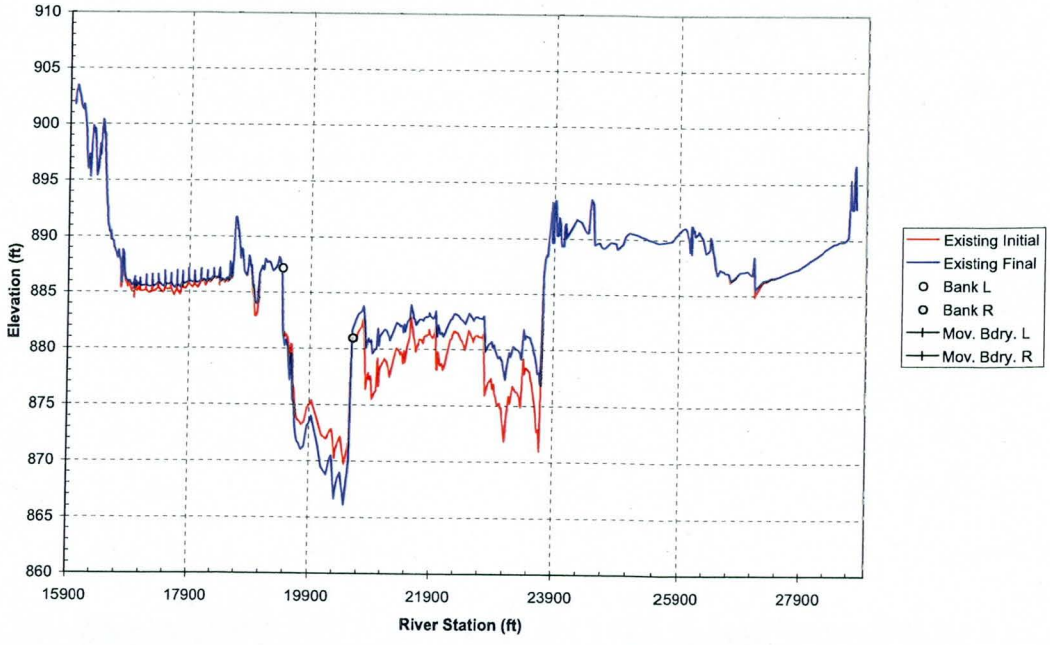

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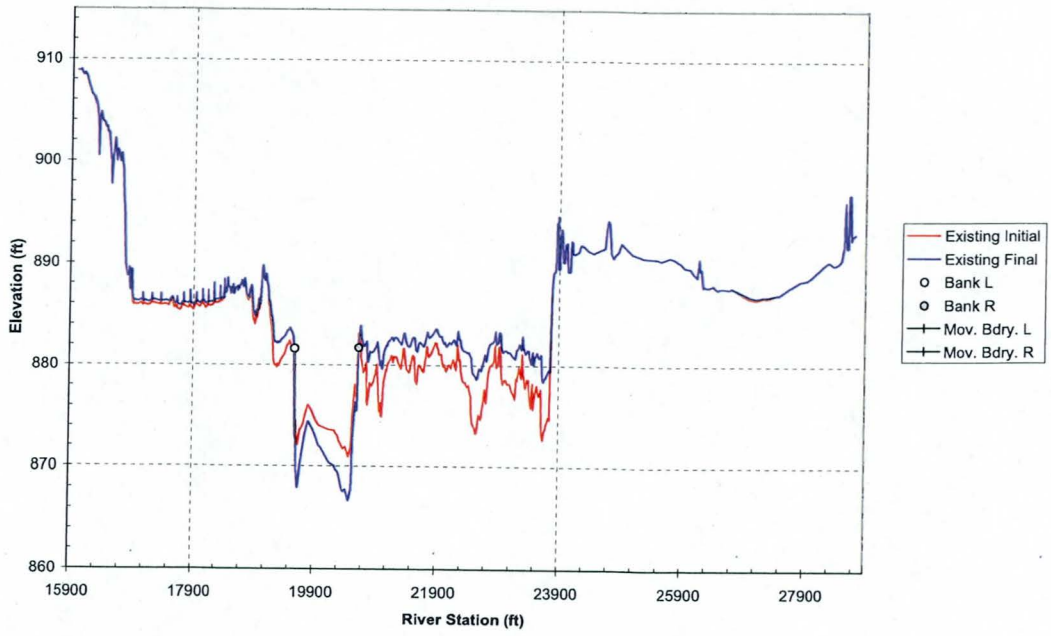

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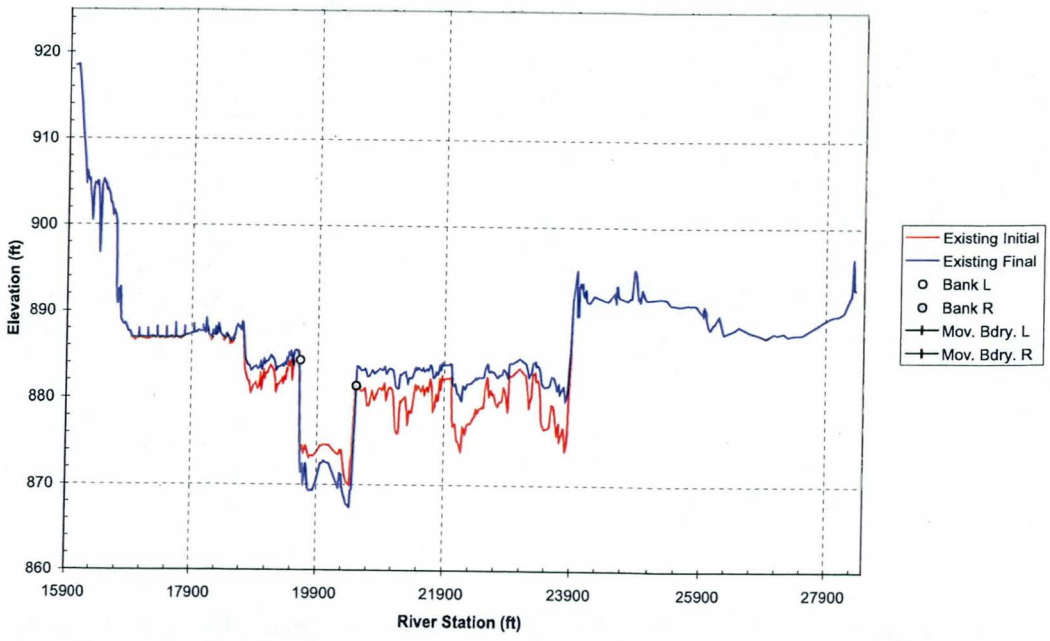

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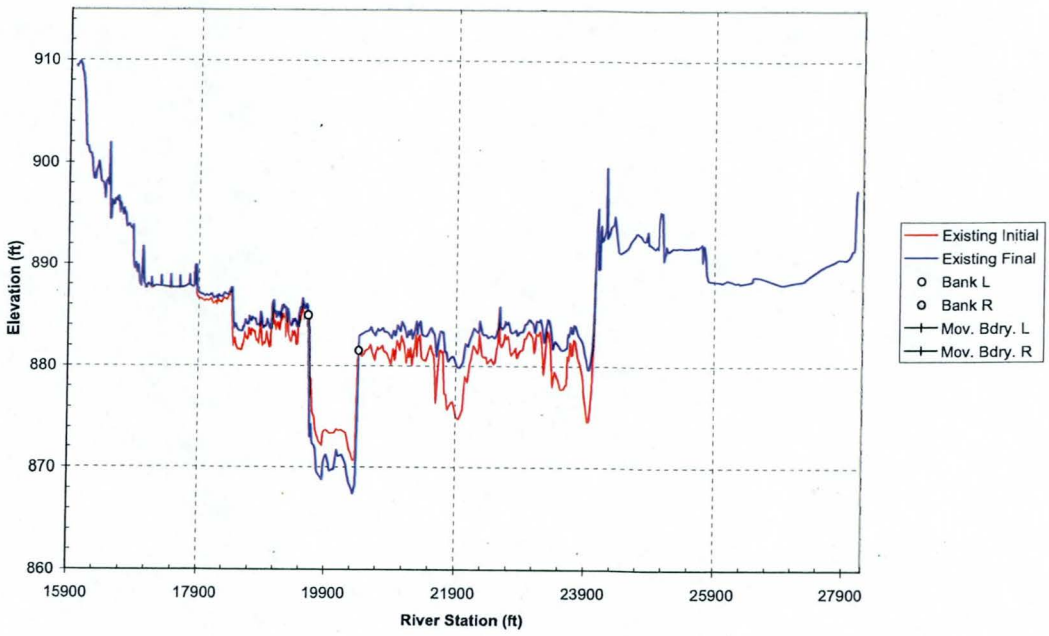

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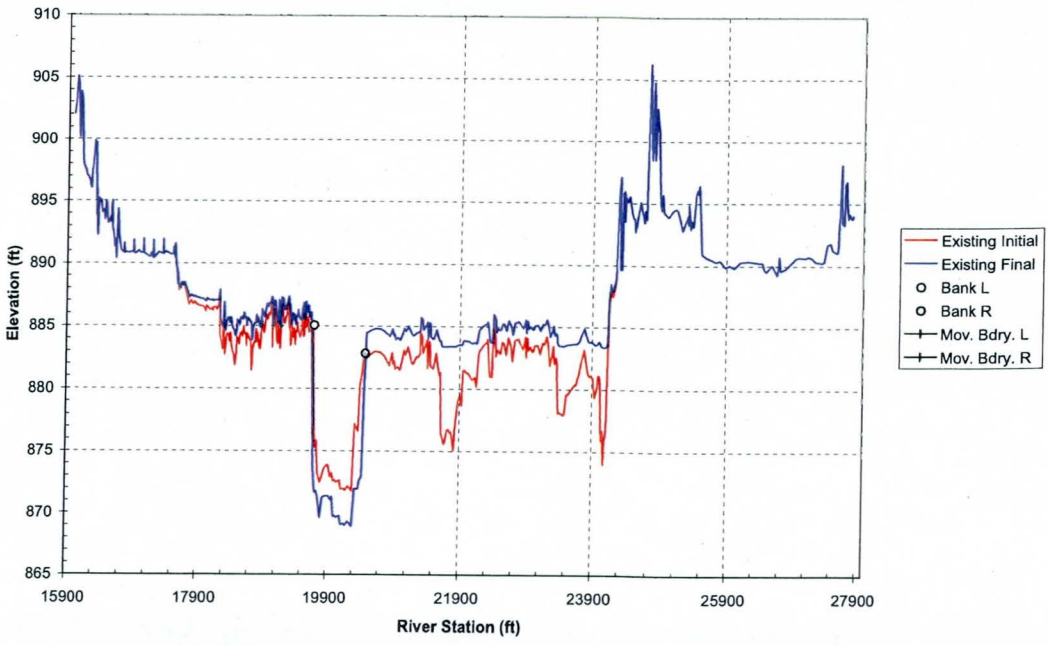

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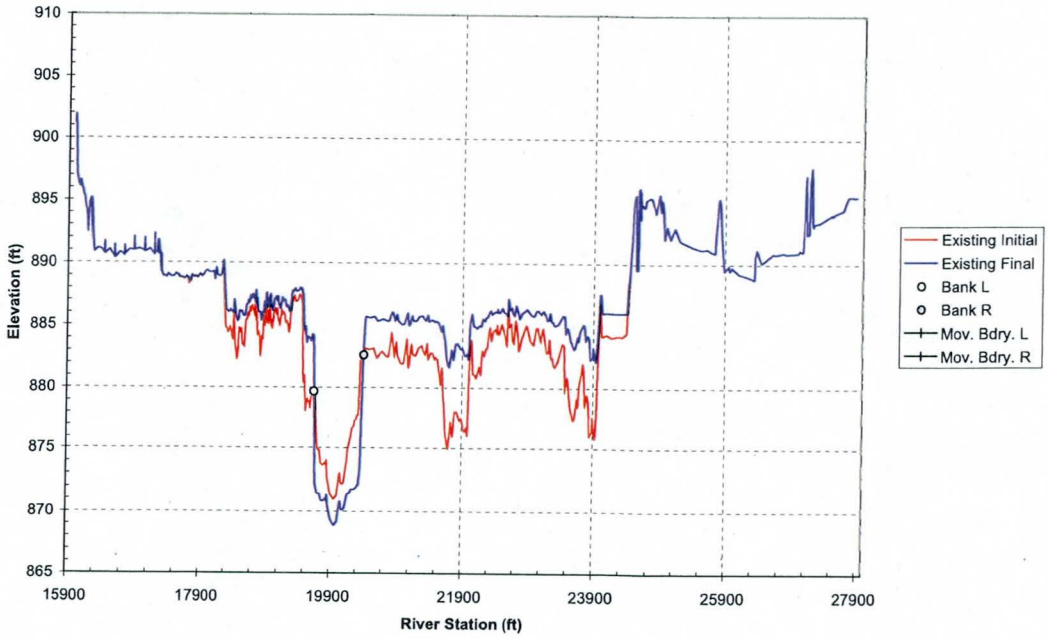

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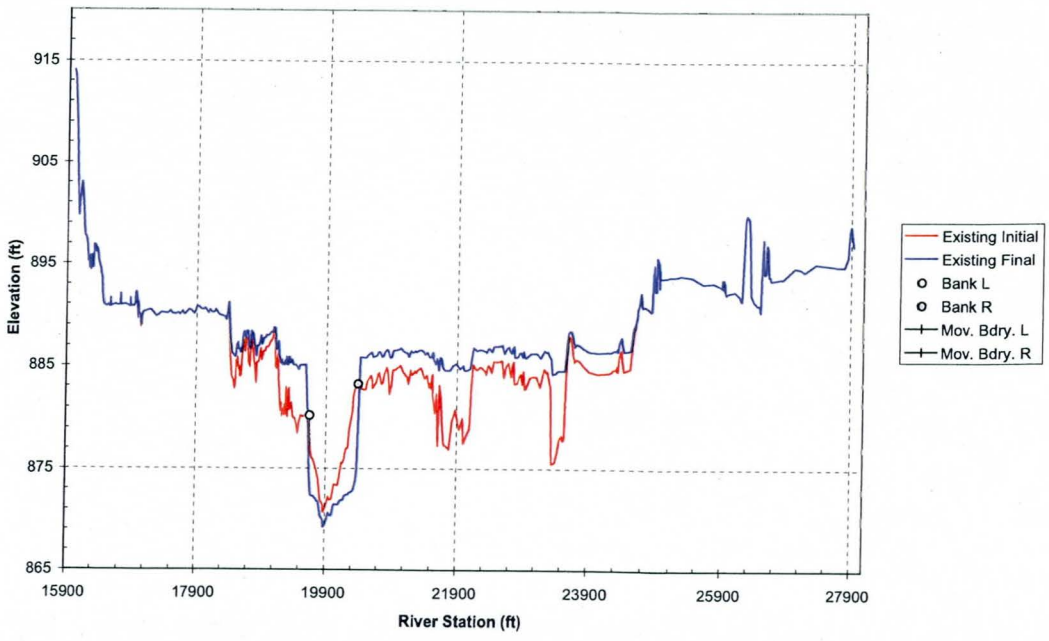

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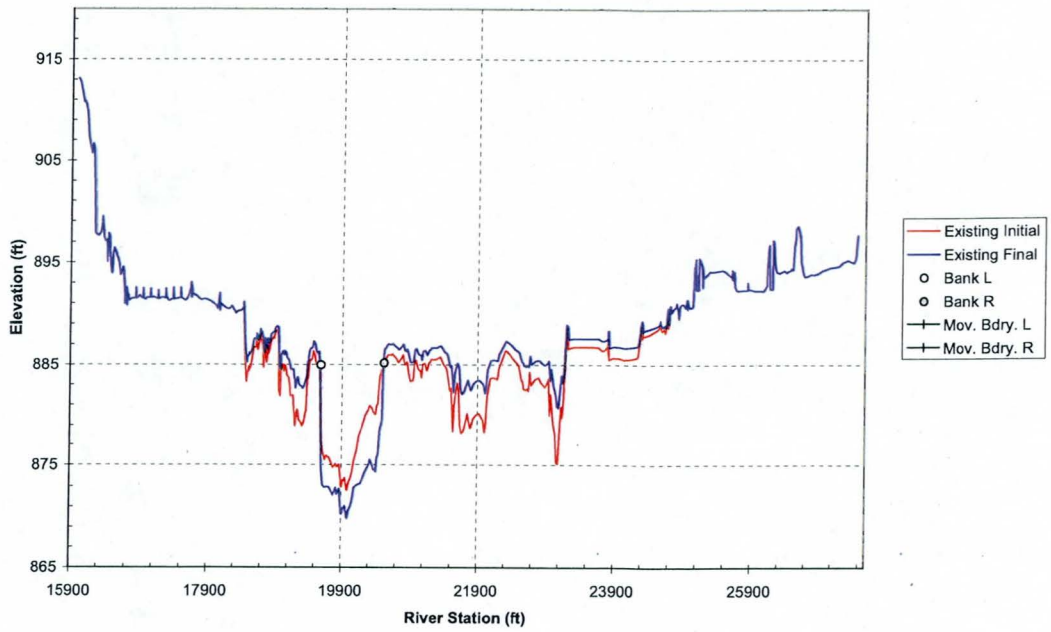

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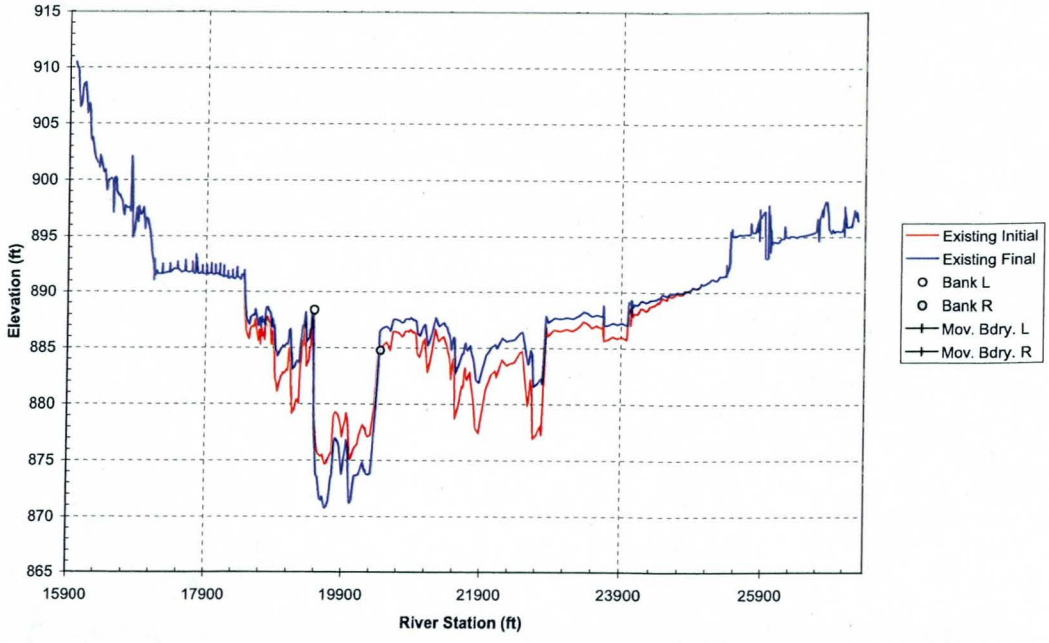

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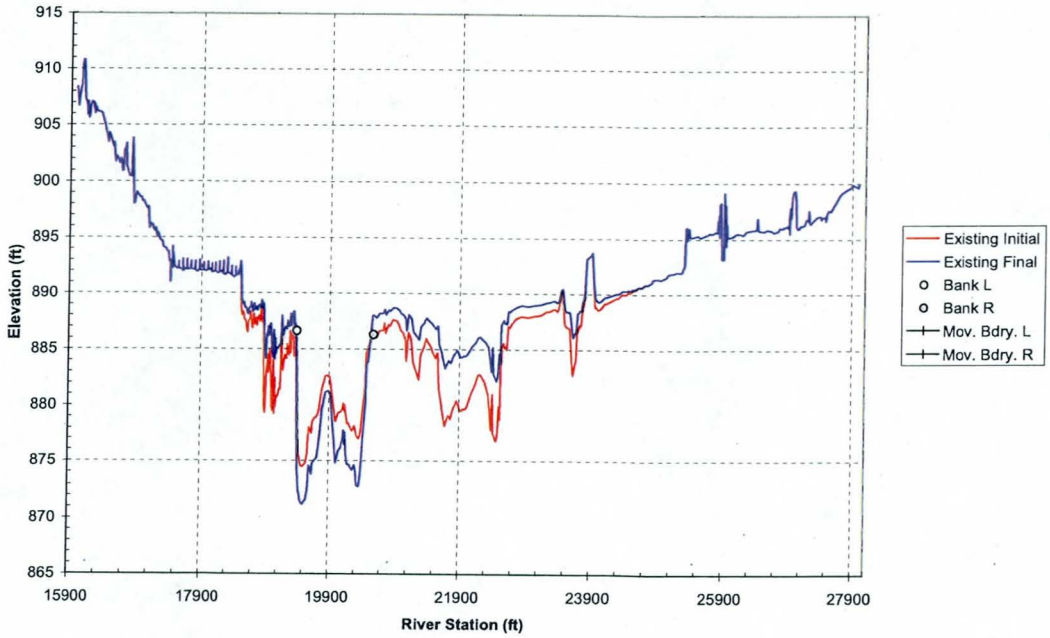

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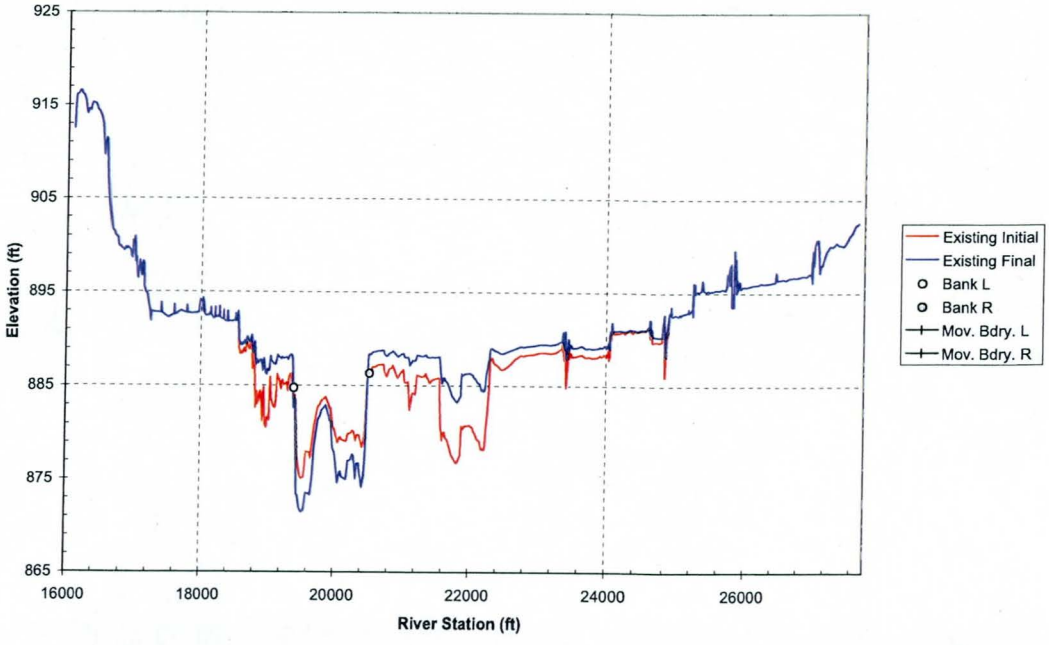

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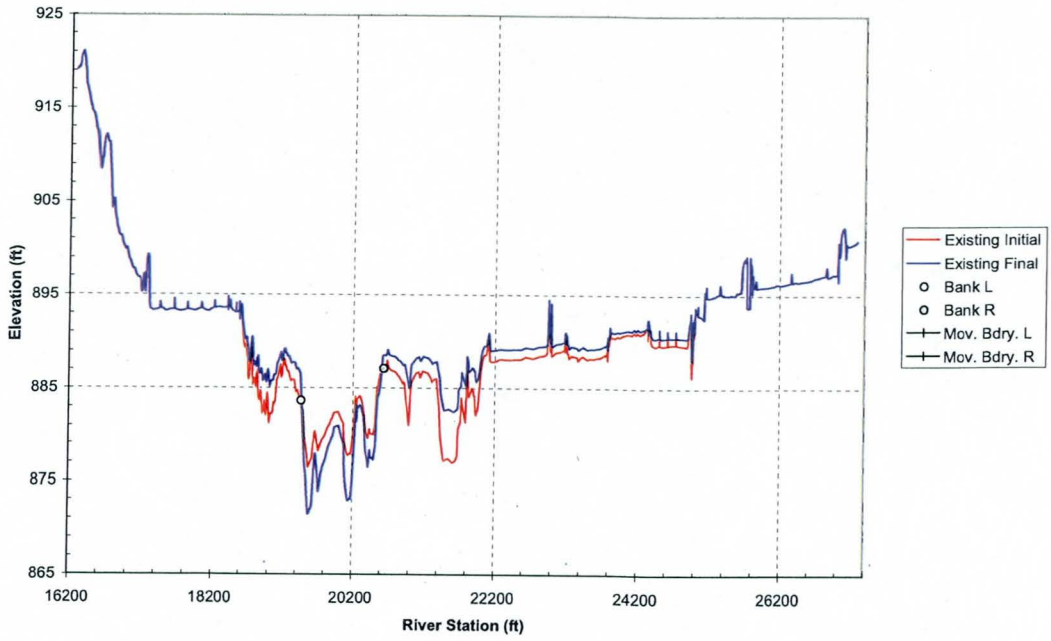

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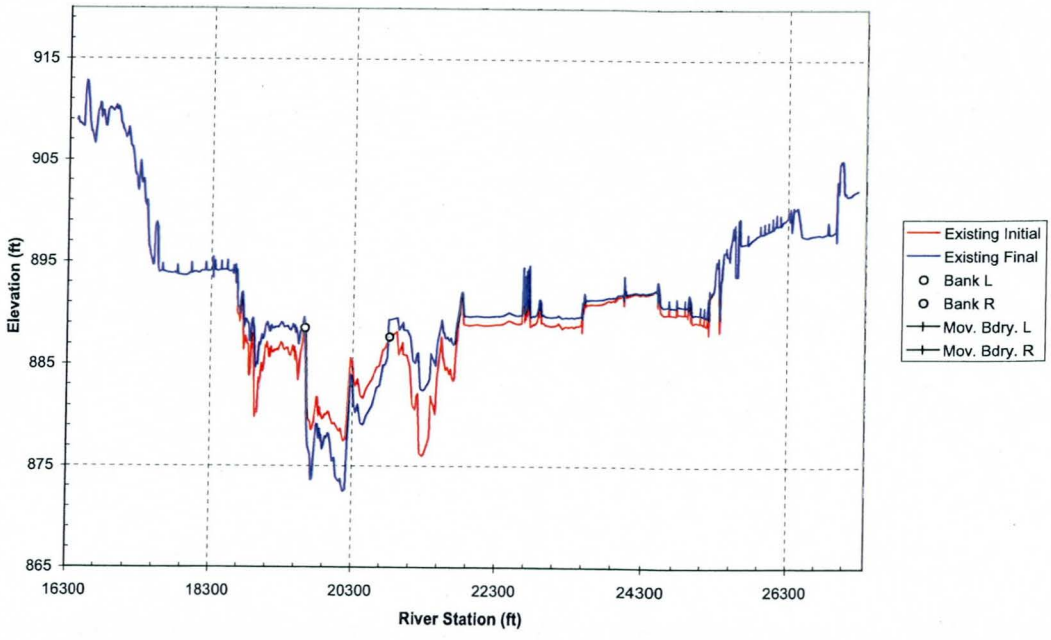

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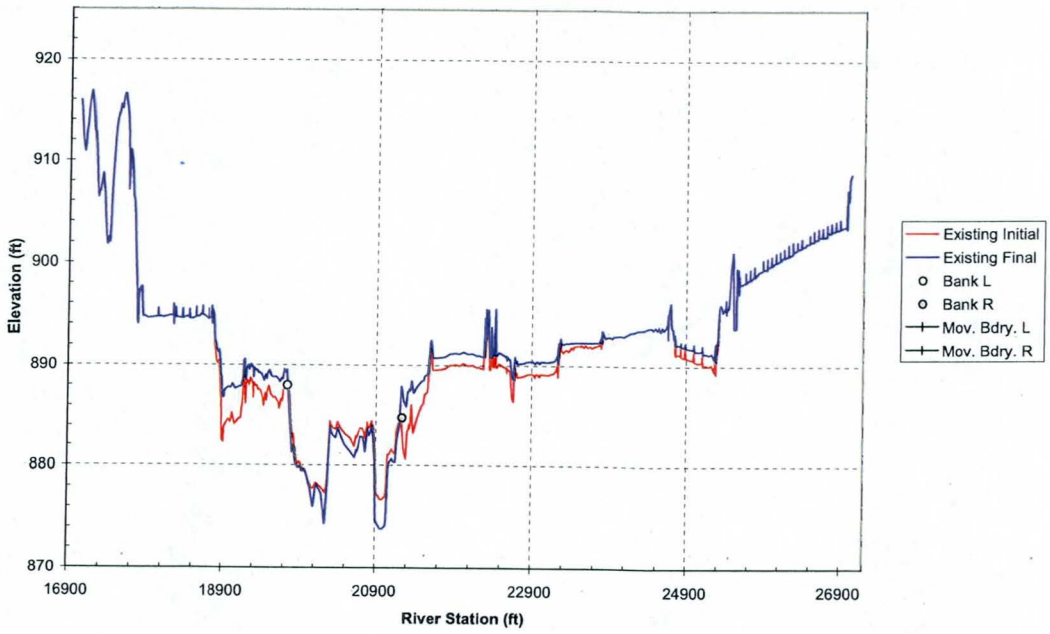

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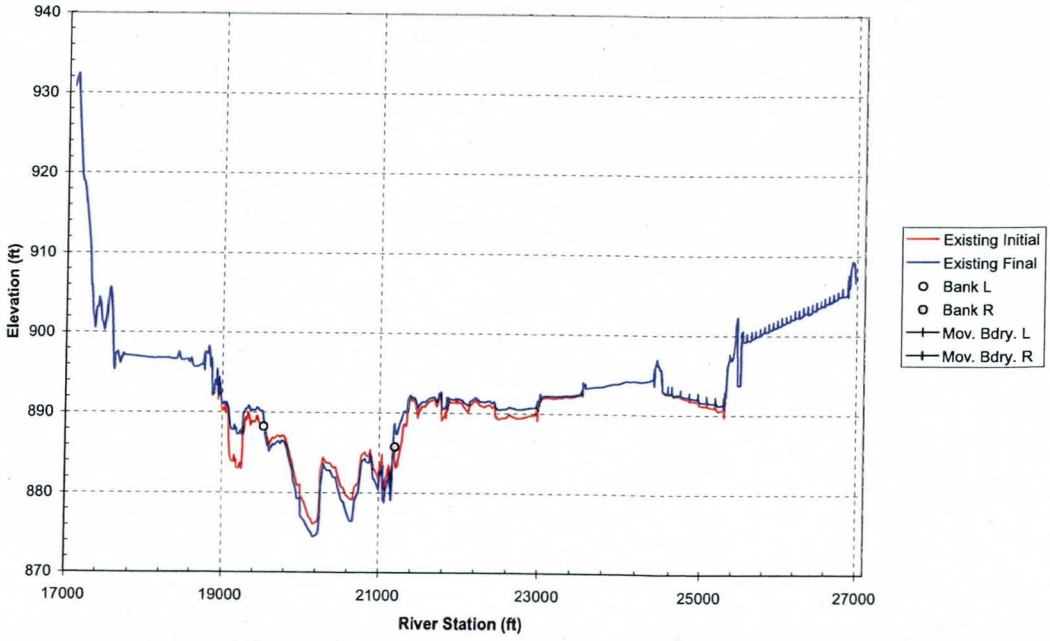

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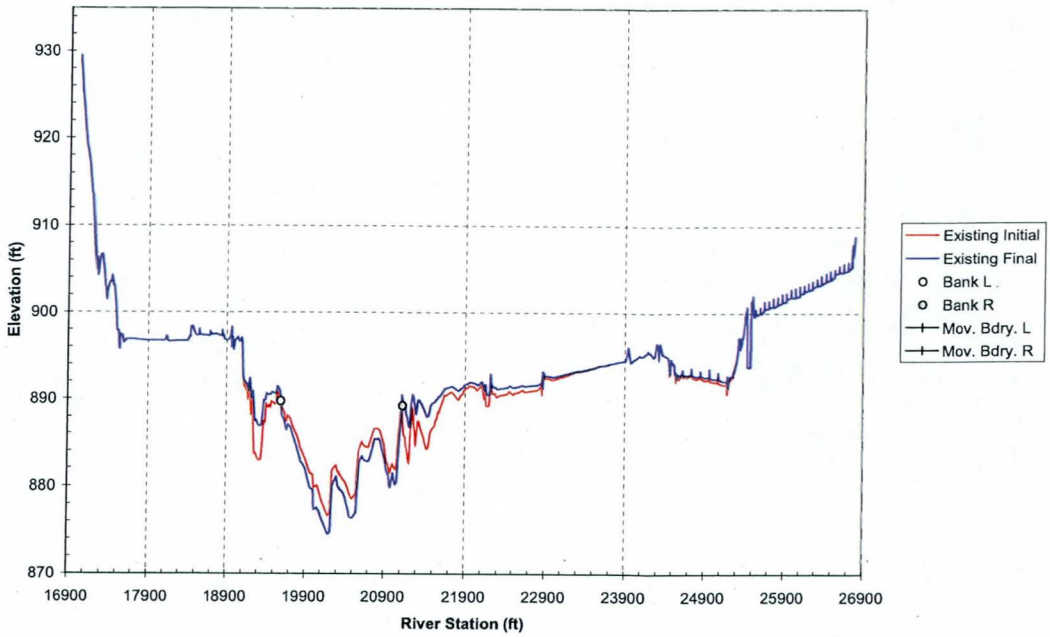

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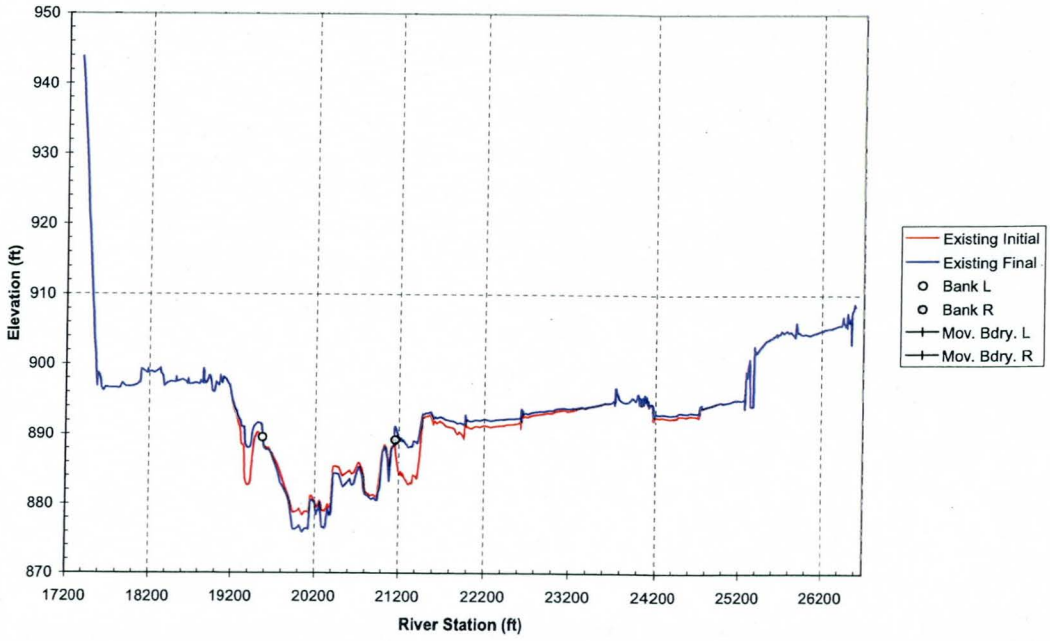

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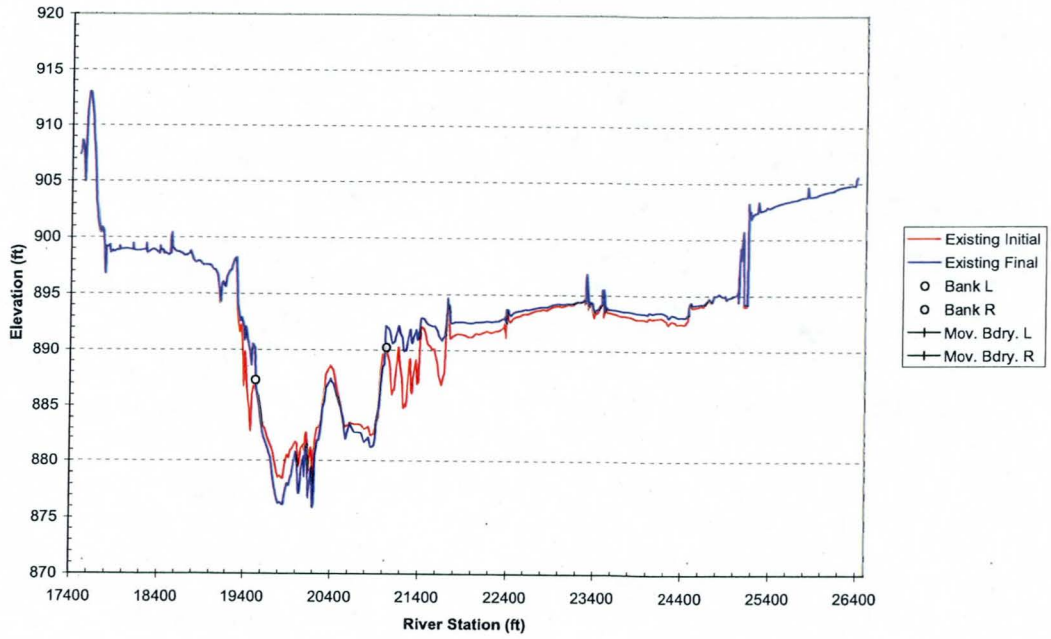

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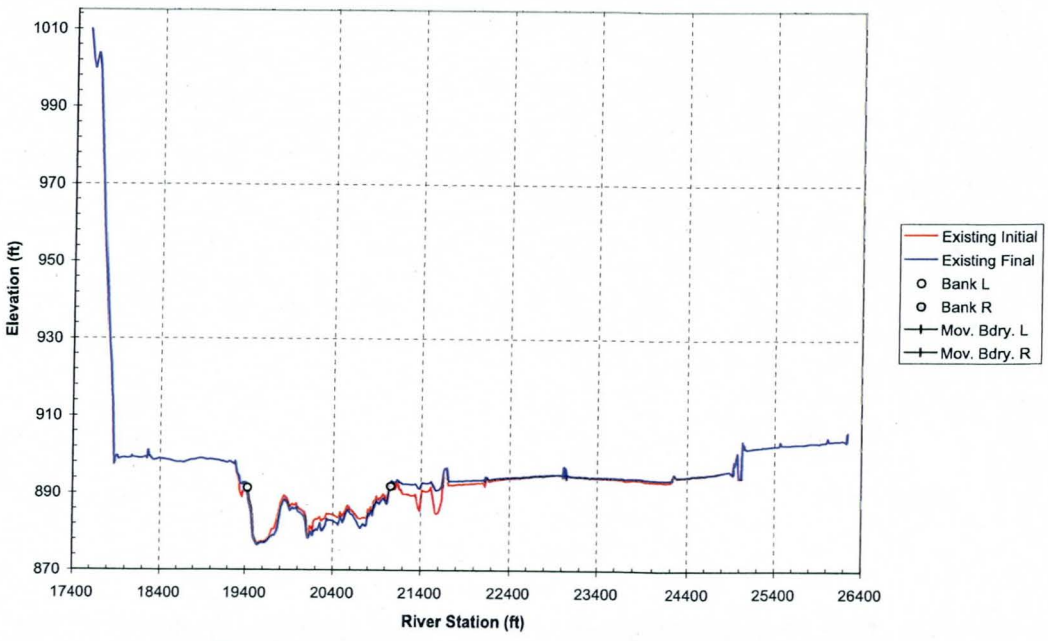

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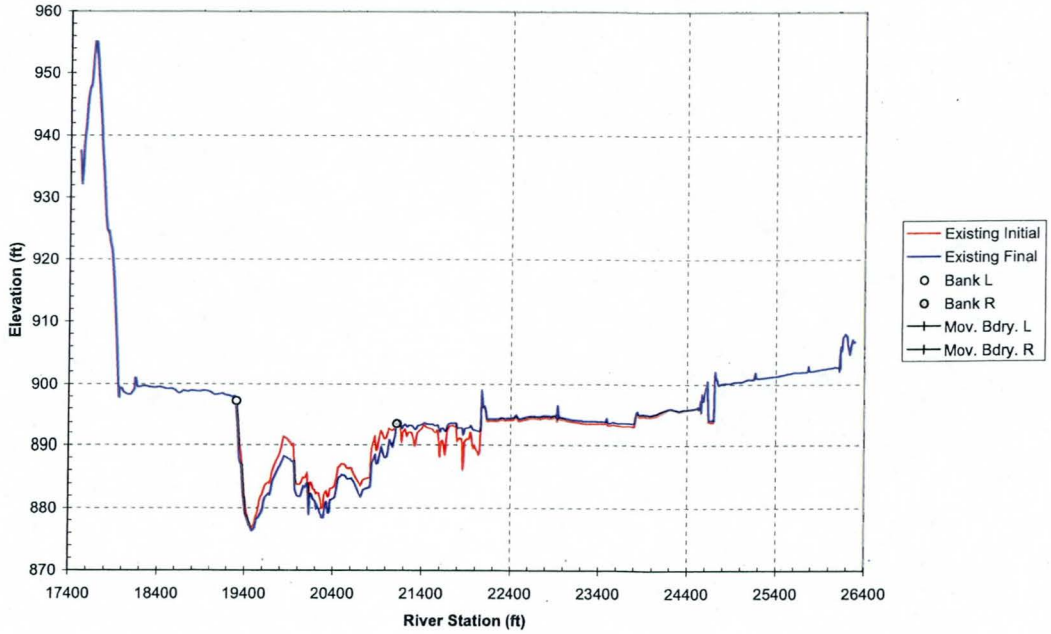

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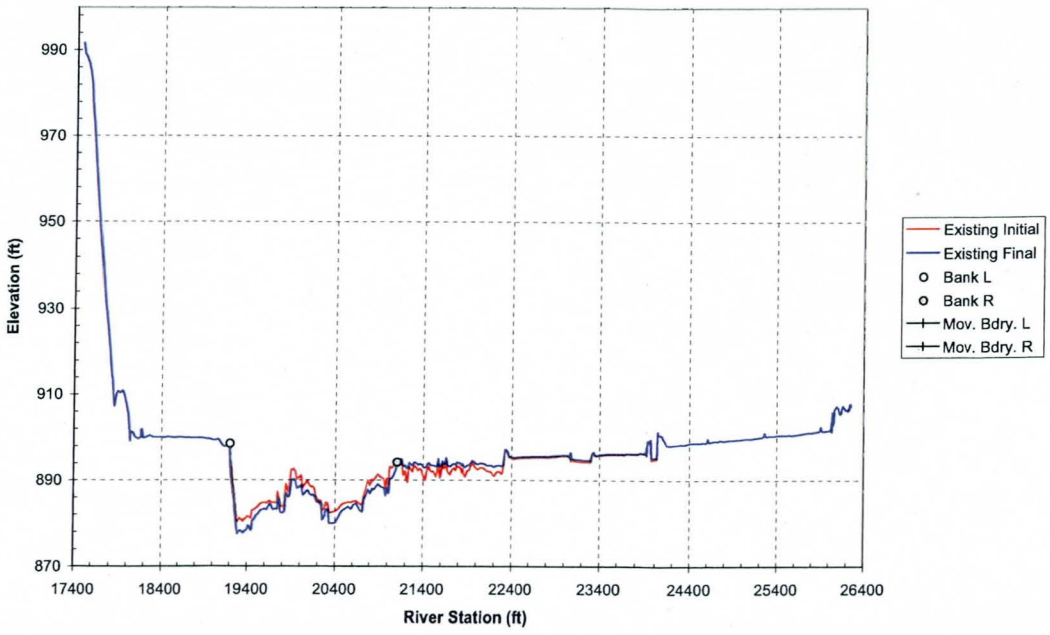

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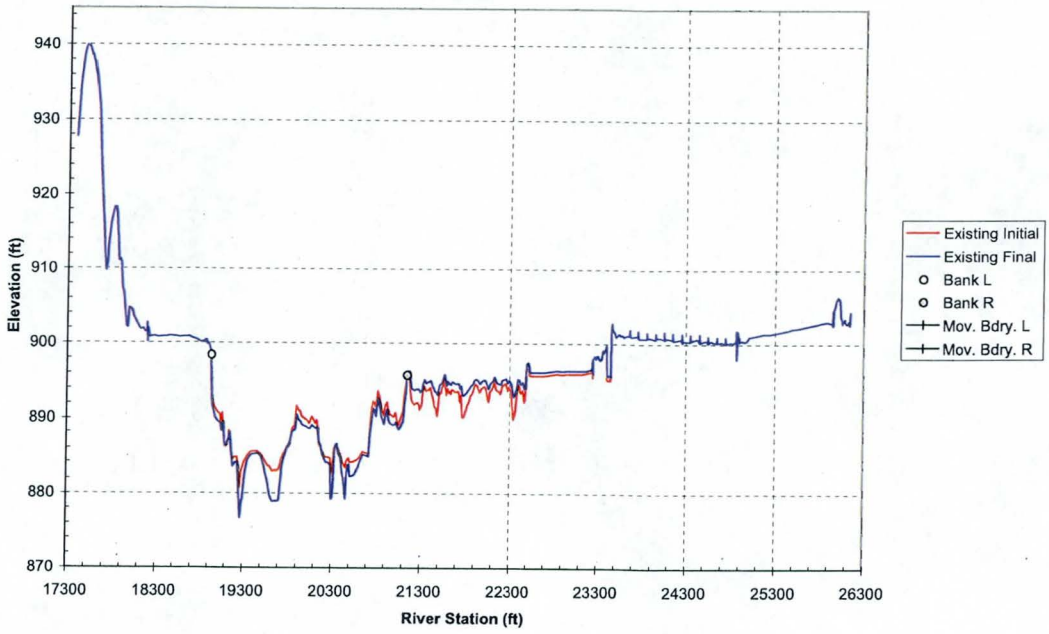
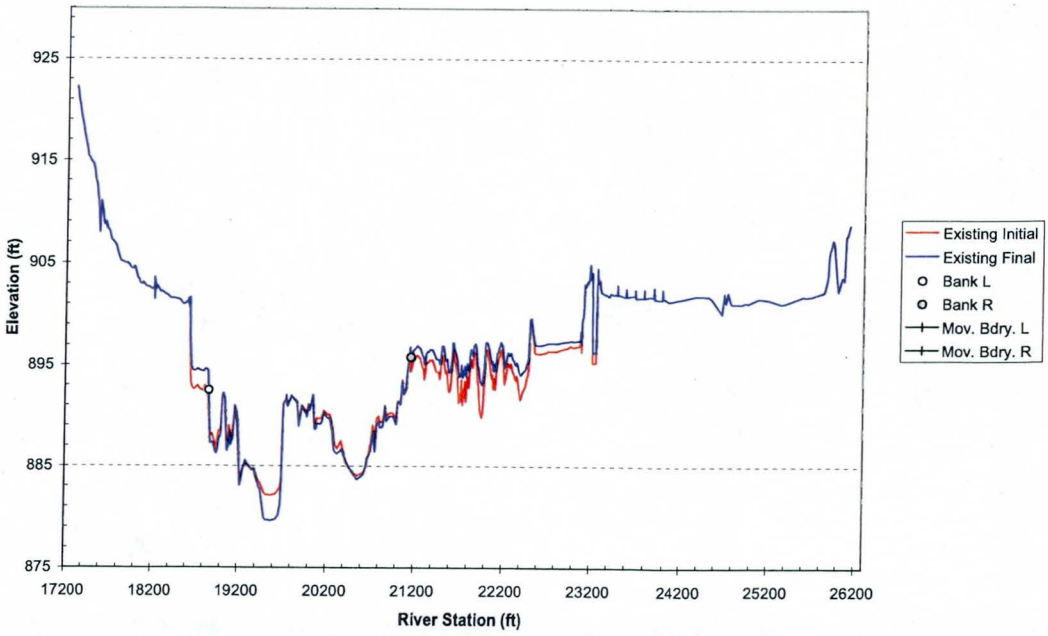


Cross Section 193.07



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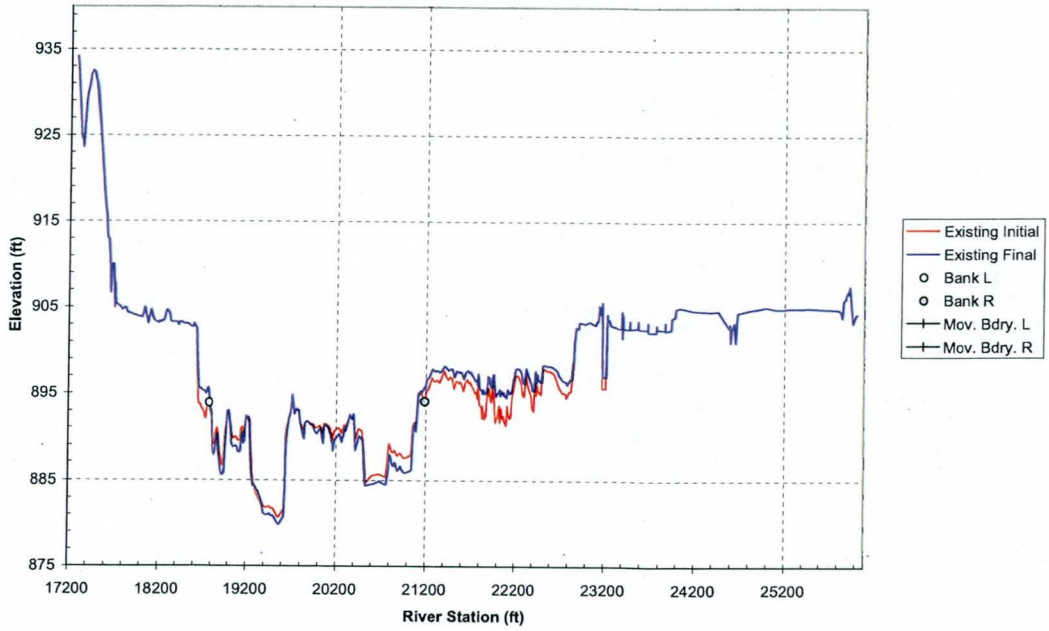

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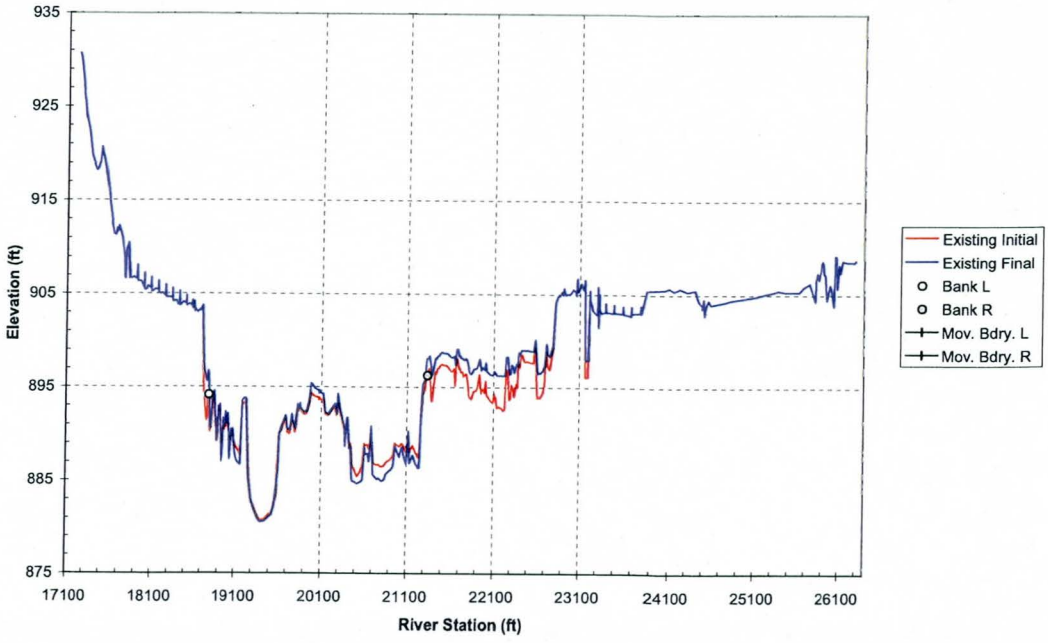

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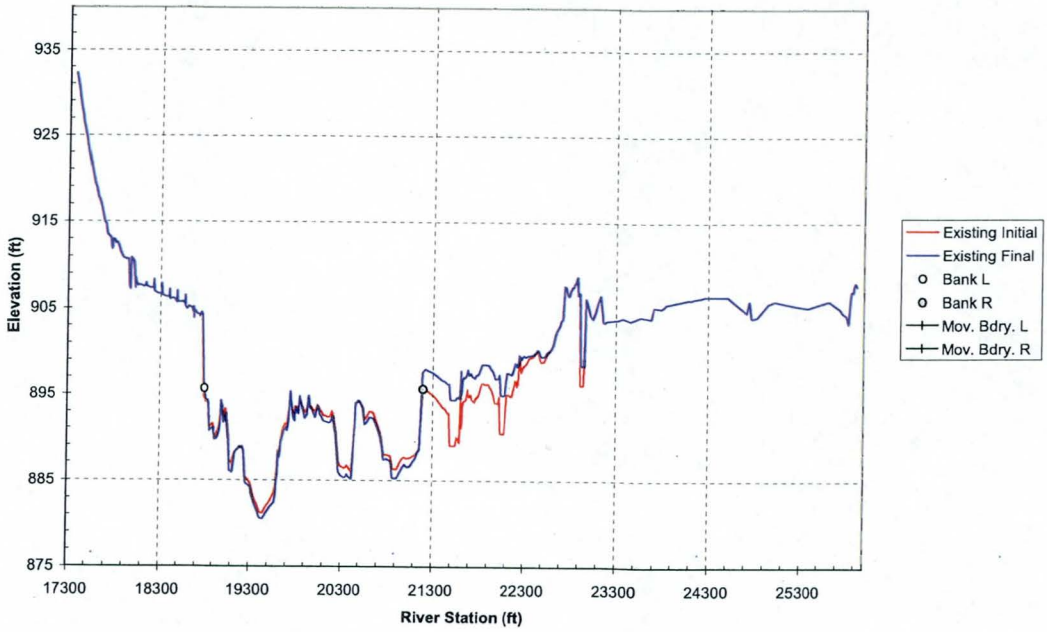

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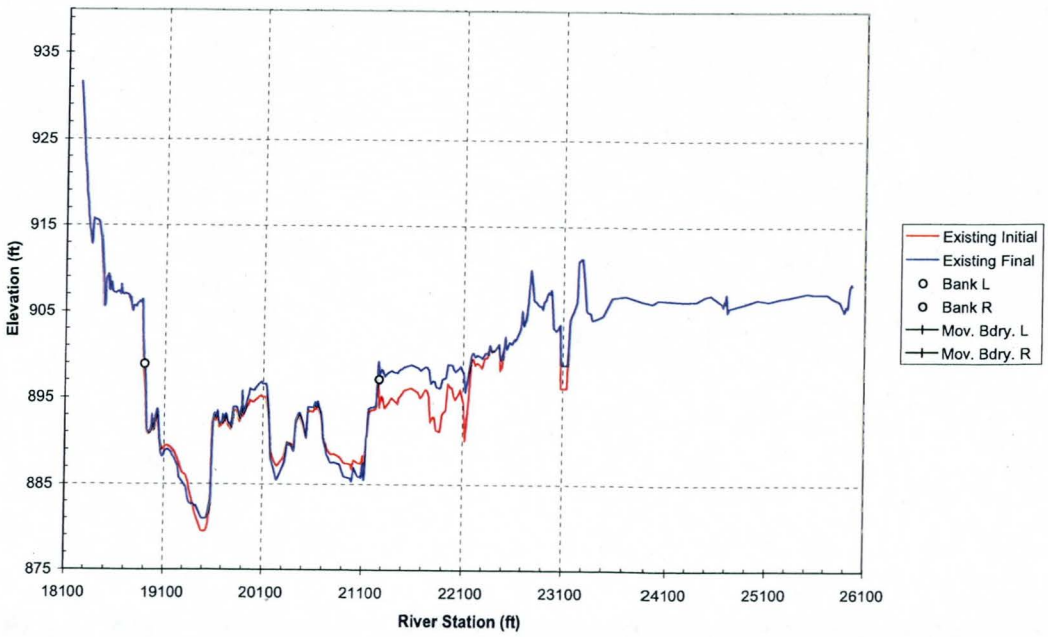
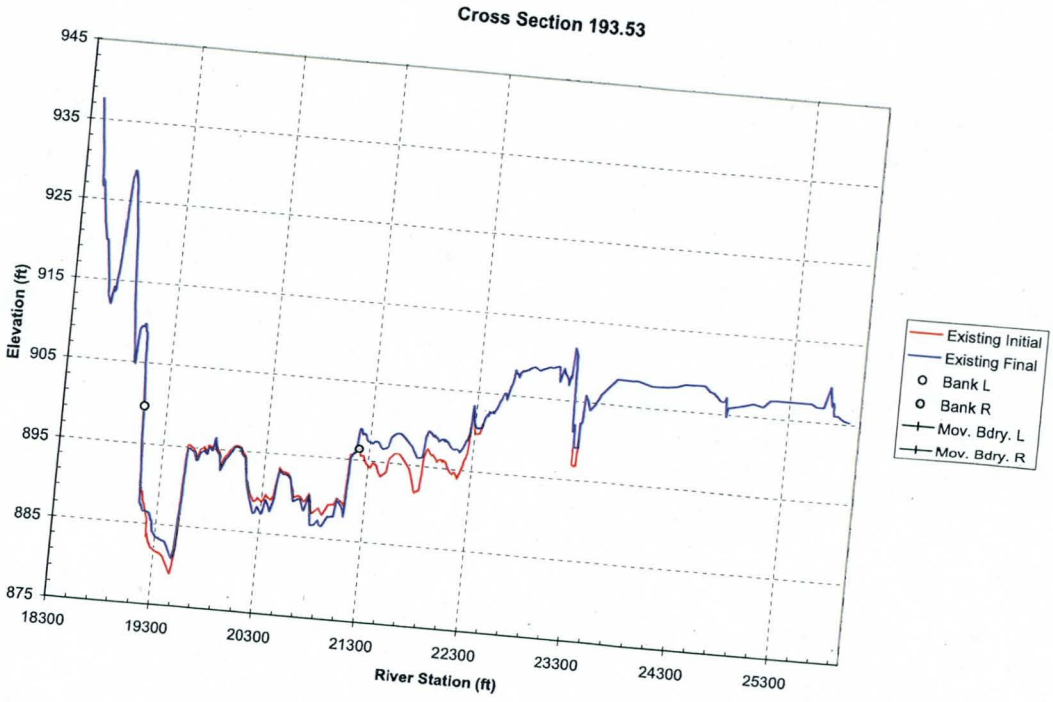
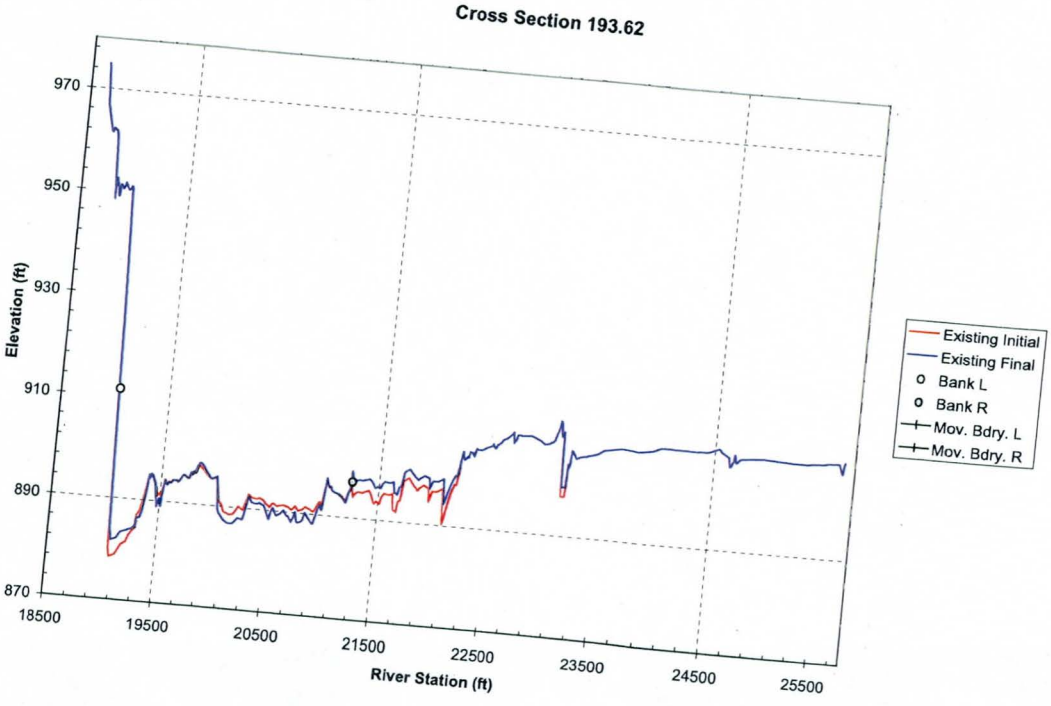
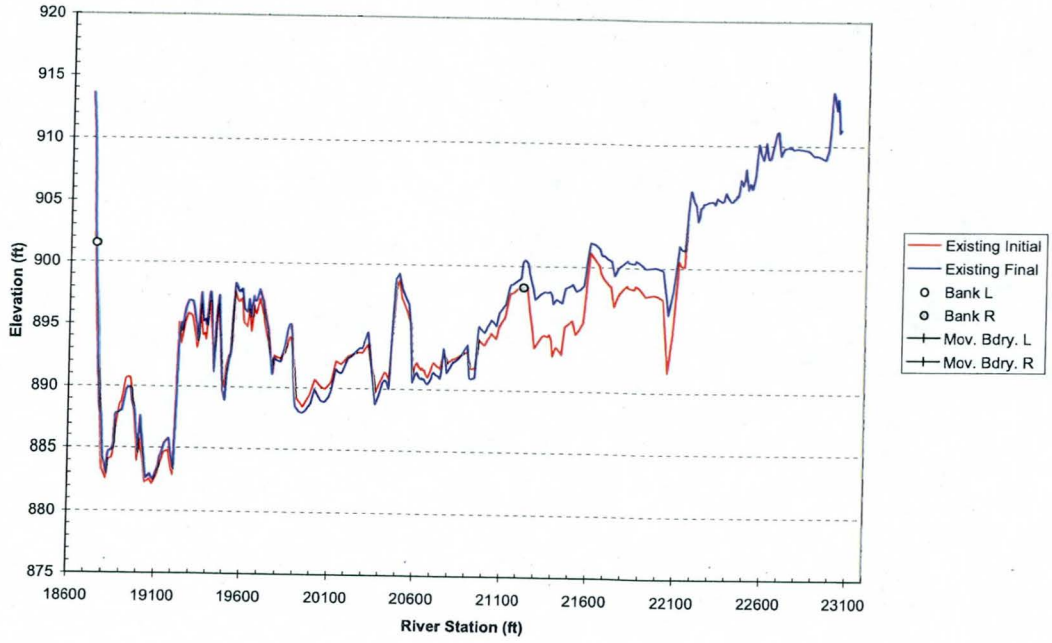



Cross Section 193.53
945
935
925
915
905
895
885
875
Elevation (ft)
18300
19300
20300
21300
22300
23300
24300
25300
River Station (ft)
Existing Initial
Existing Final
Bank L
Bank R
Mov. Bdry. L
Mov. Bdry. R


Cross Section 193.62
970
950
930
910
890
870
Elevation (ft)
18500
19500
20500
21500
22500
23500
24500
25500
River Station (ft)
Existing Initial
Existing Final
Bank L
Bank R
Mov. Bdry. L
Mov. Bdry. R

Cross Section 193.73



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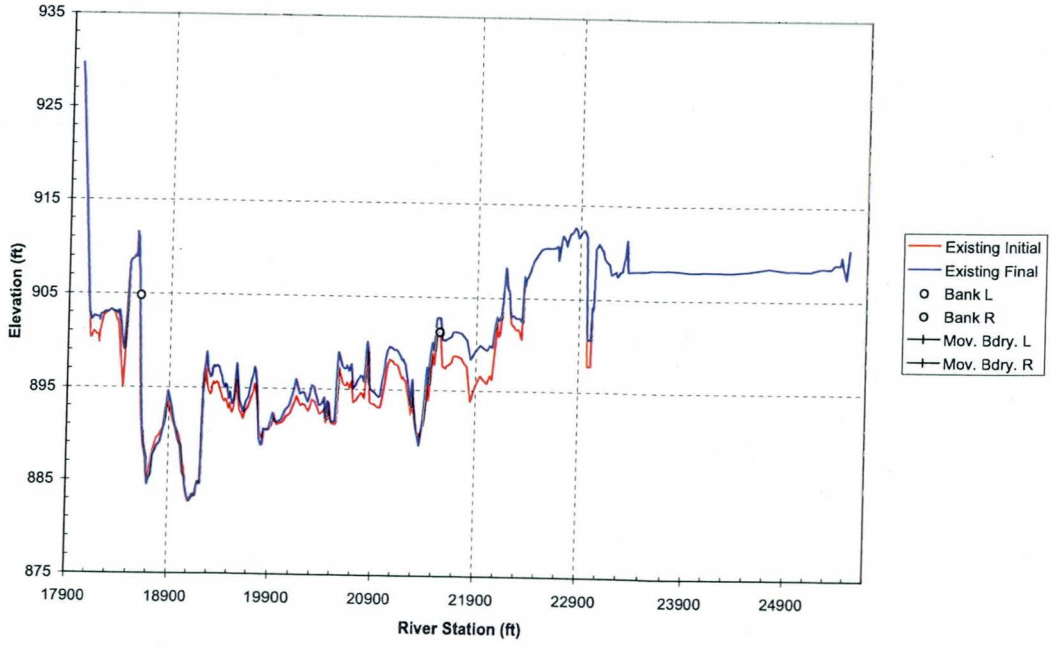
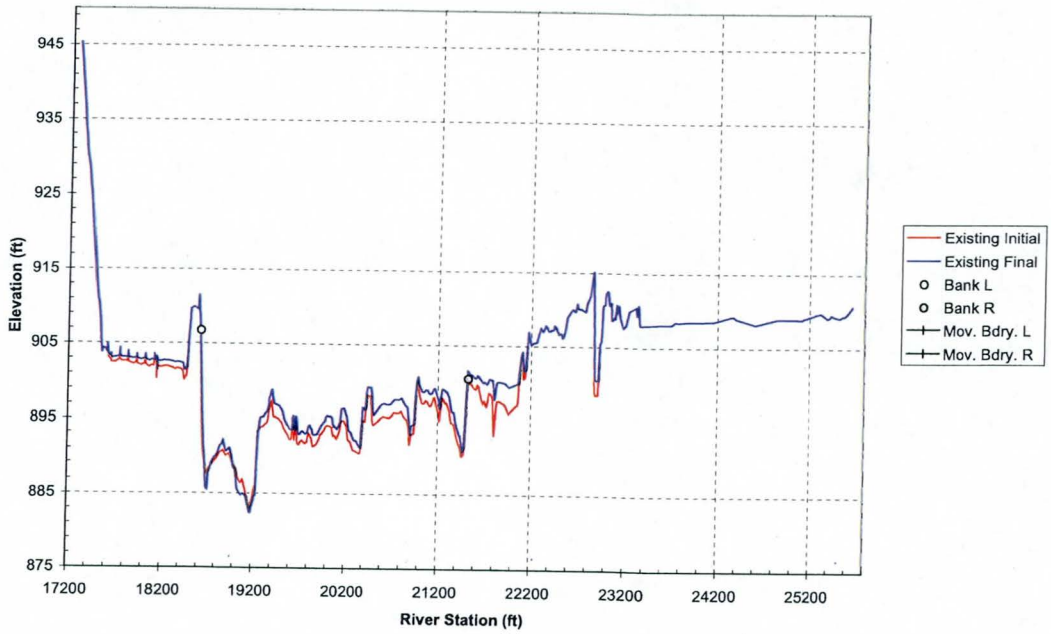
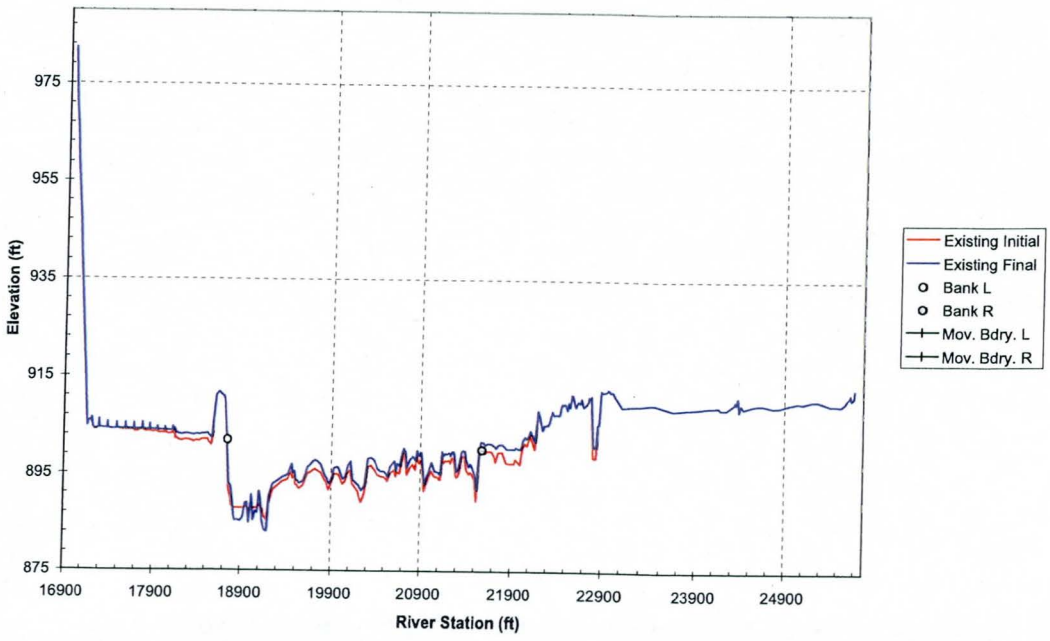


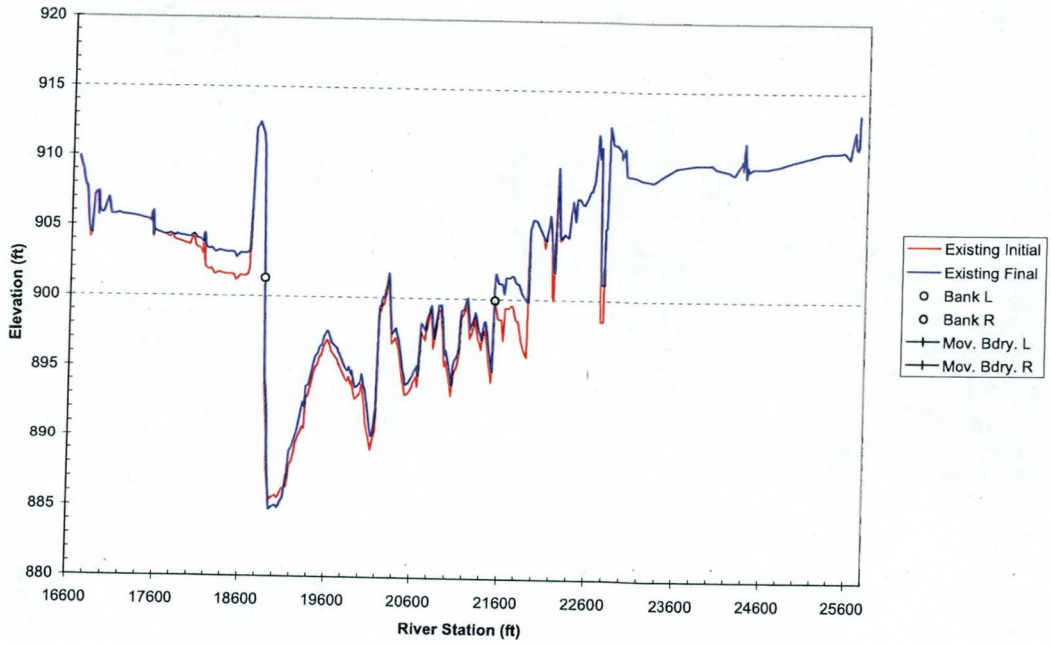
Cross Section 193.87



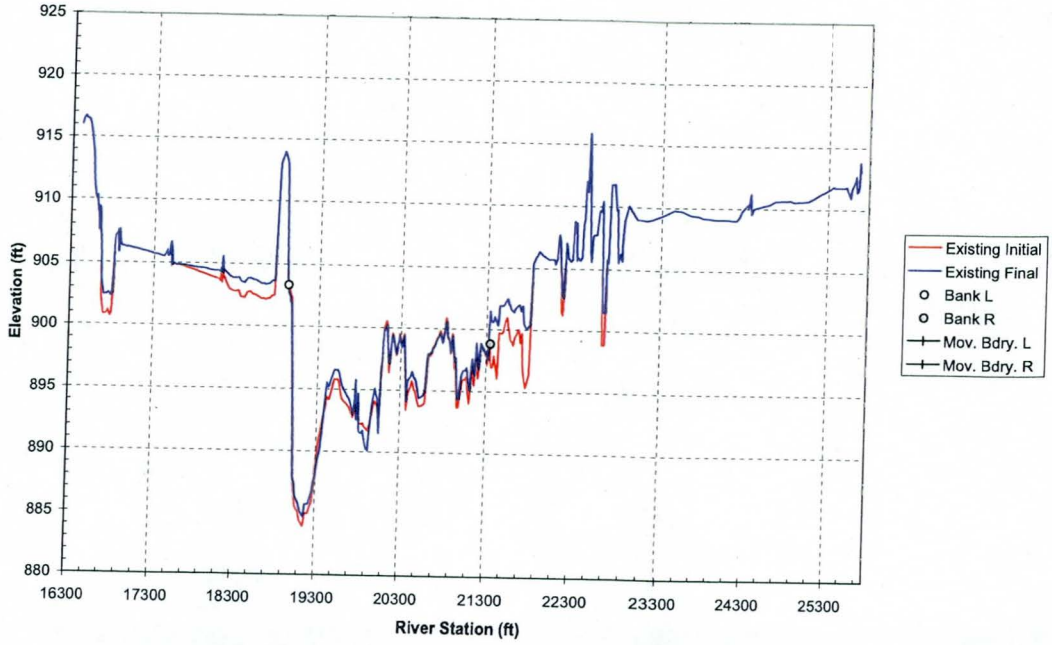
Cross Section 193.94



Cross Section 194.02



Cross Section 194.1



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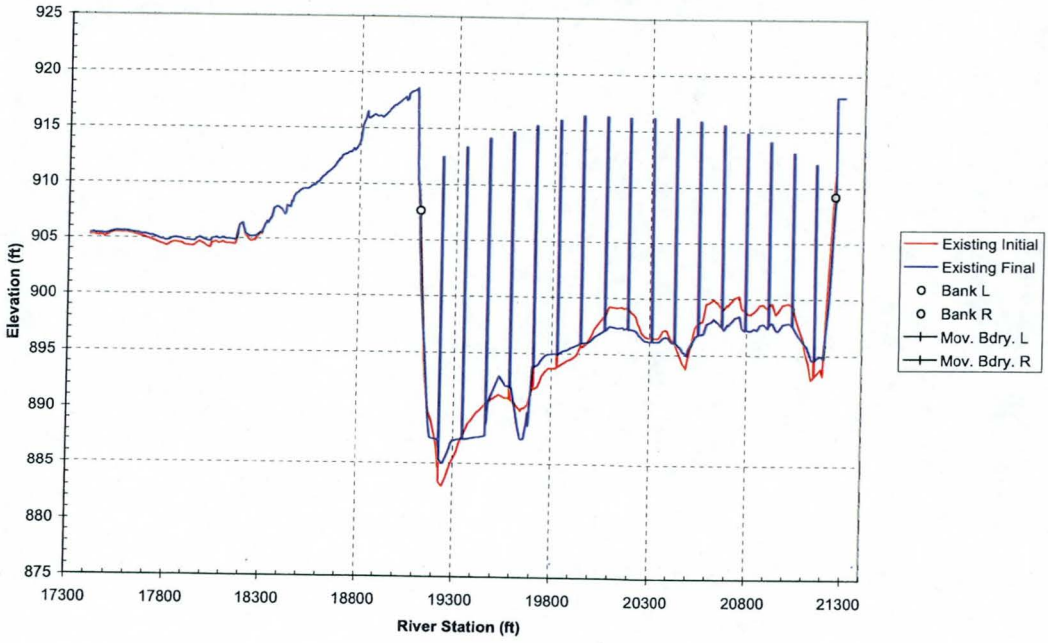
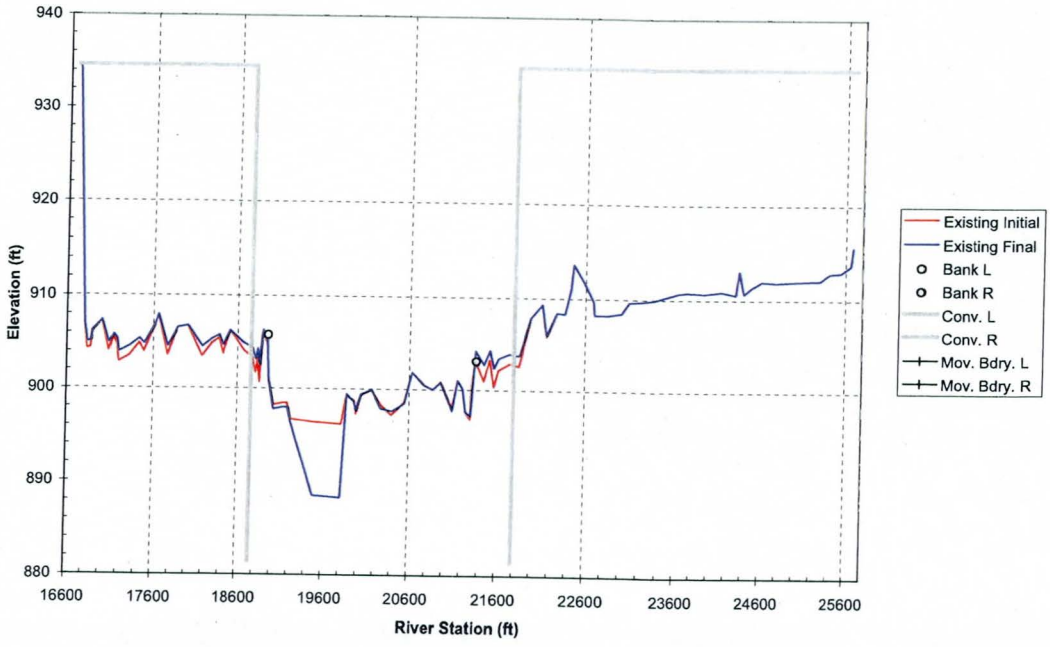
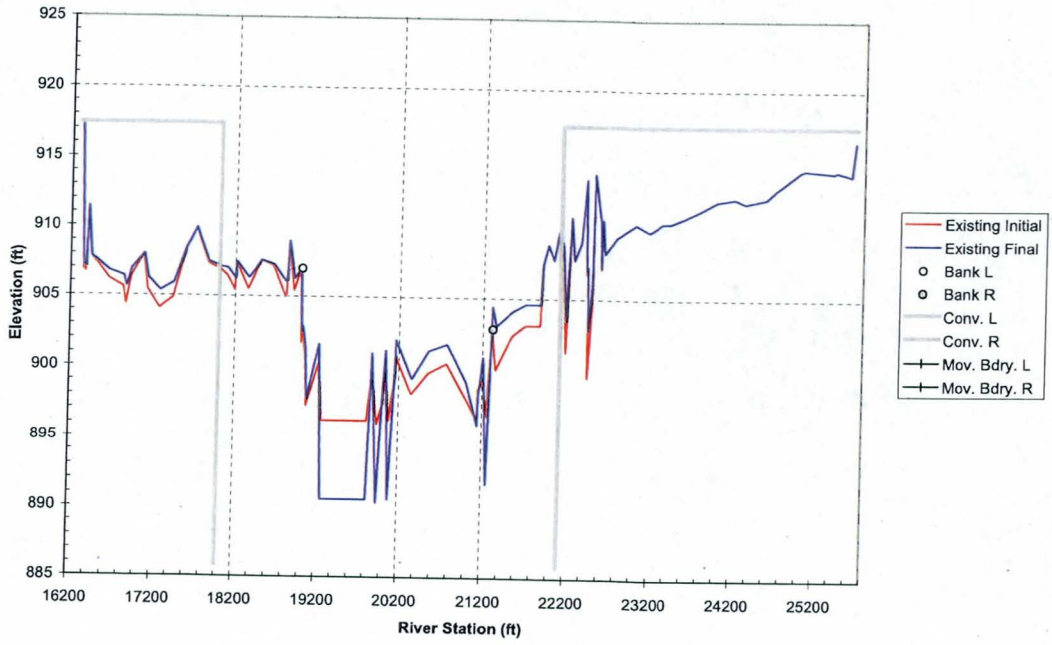


Cross Section 194.29



Cross Section 194.40



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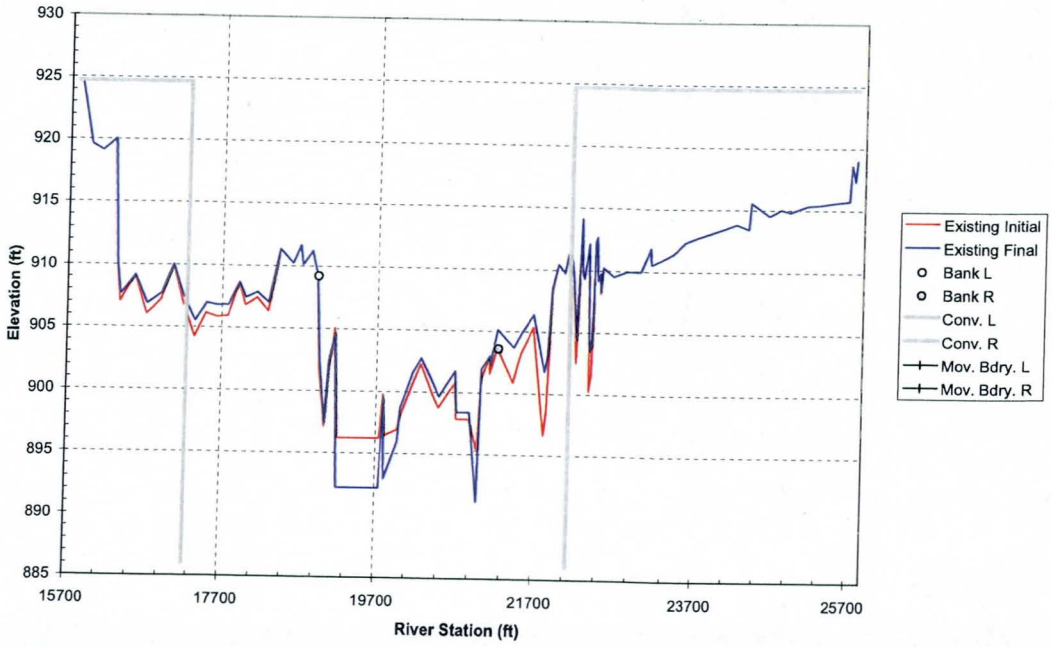
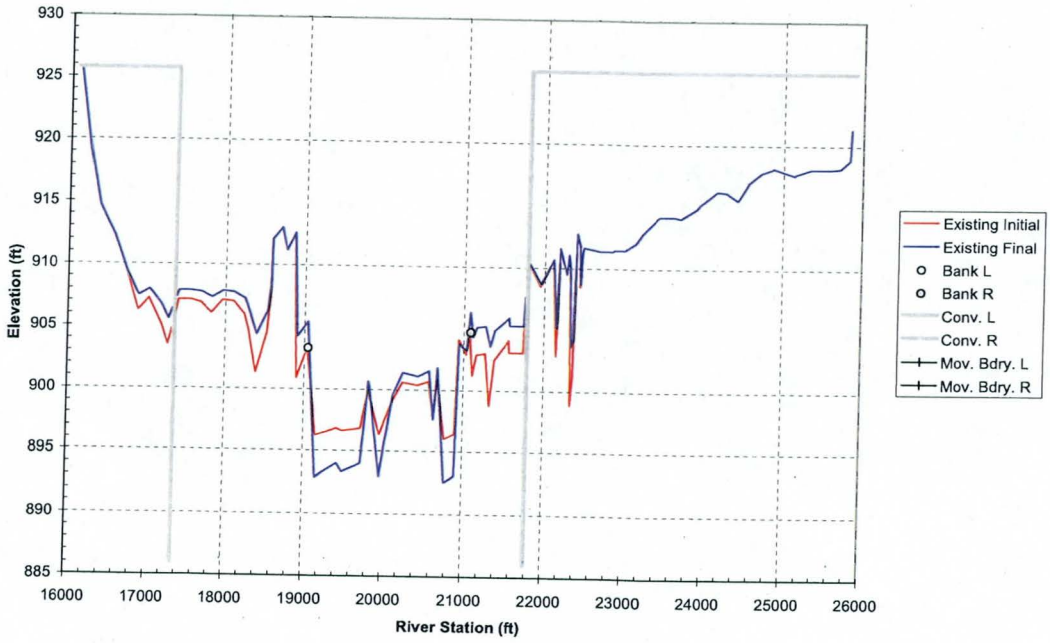
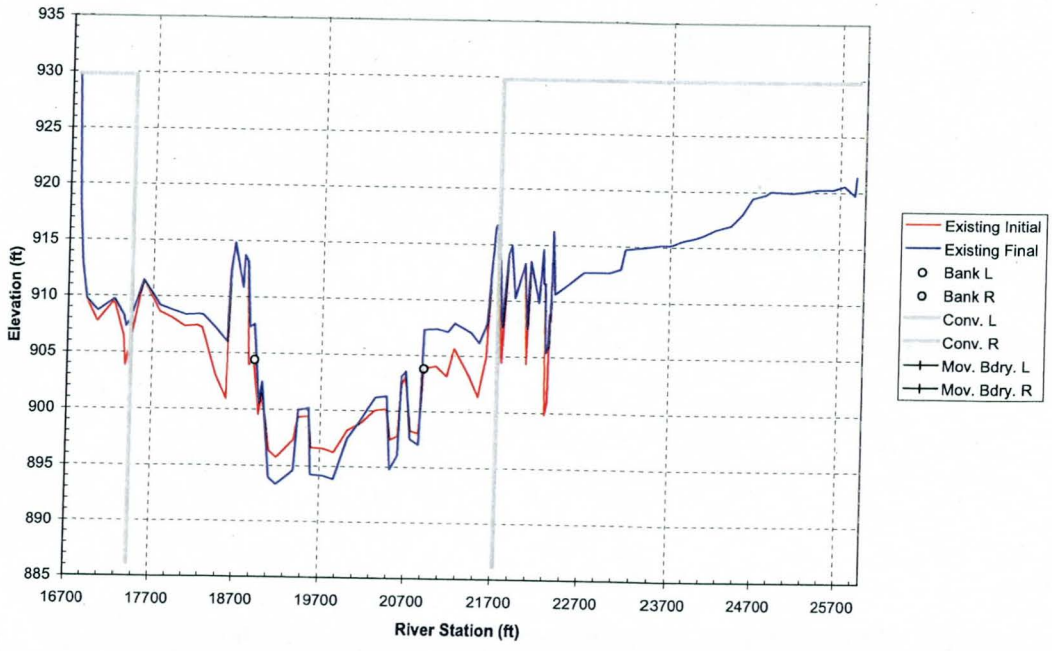


Cross Section 194.62



Cross Section 194.72



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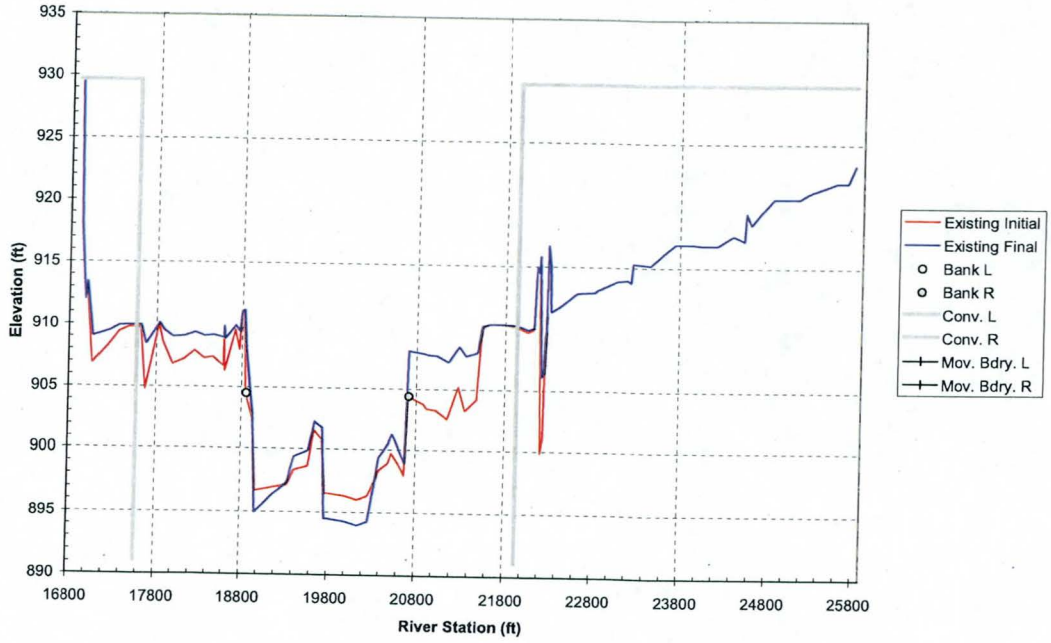

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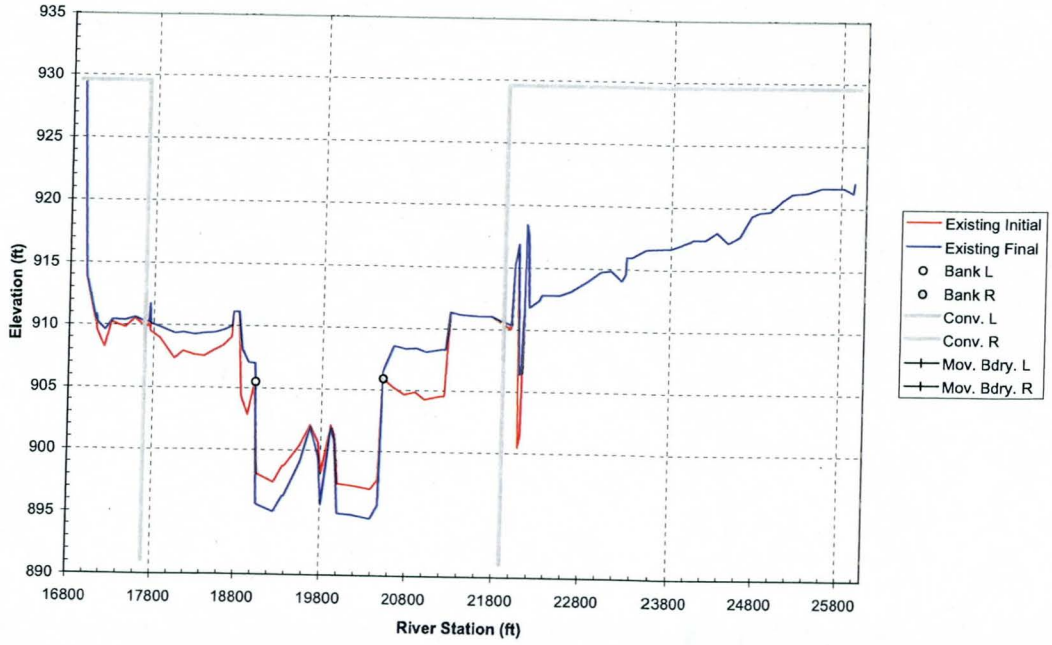

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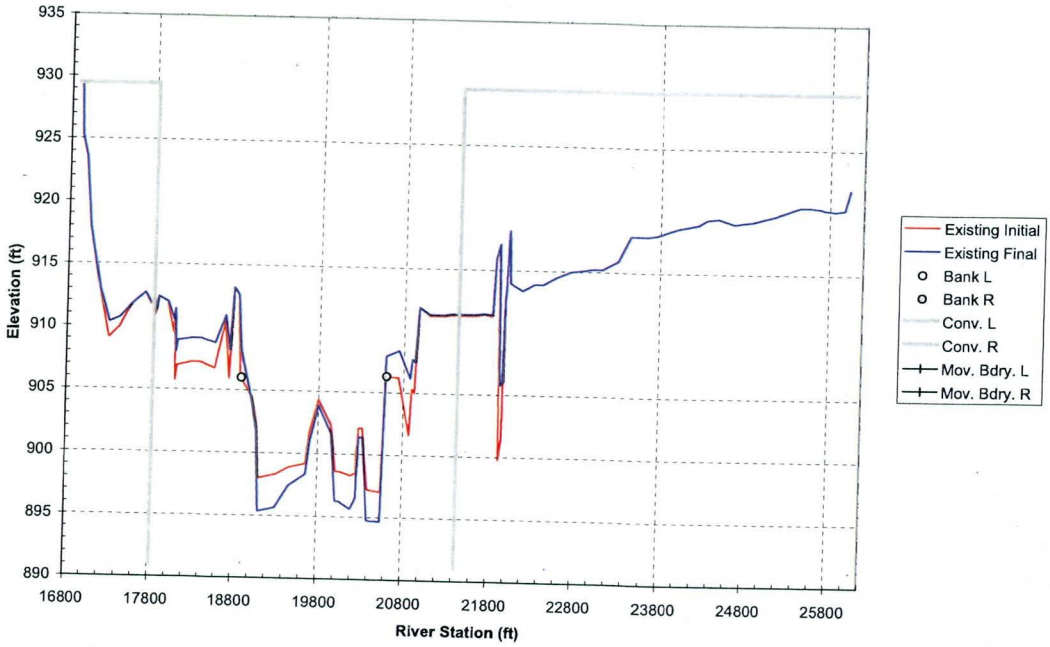

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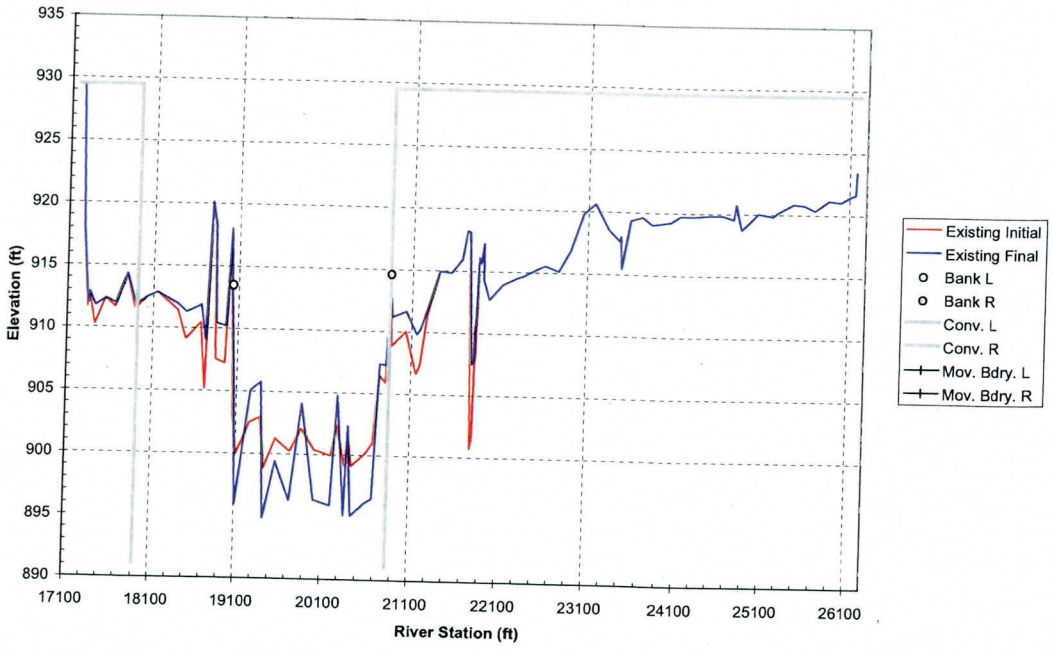

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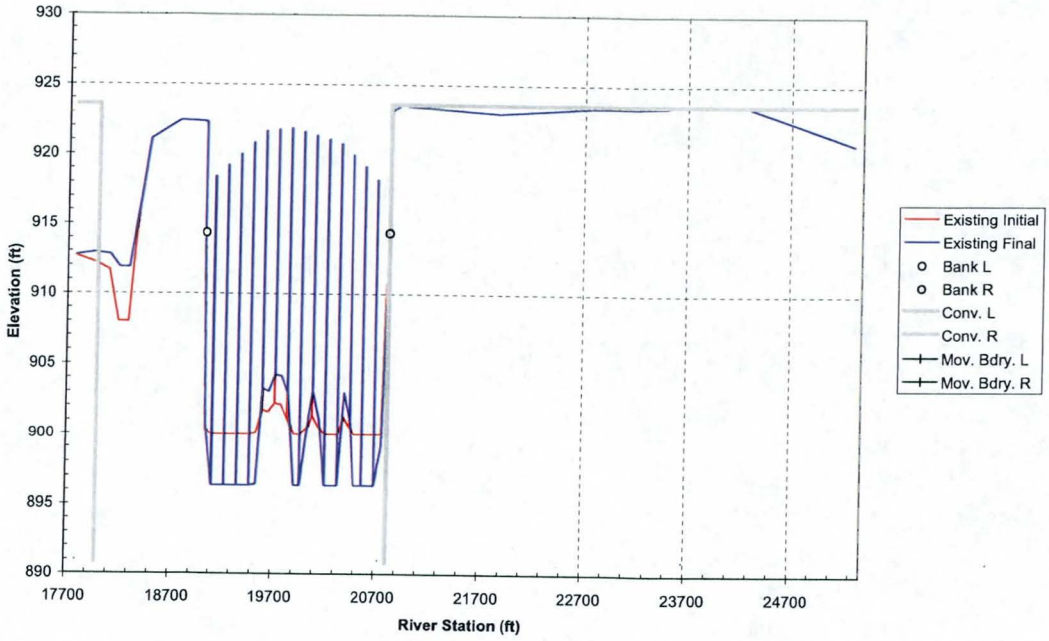

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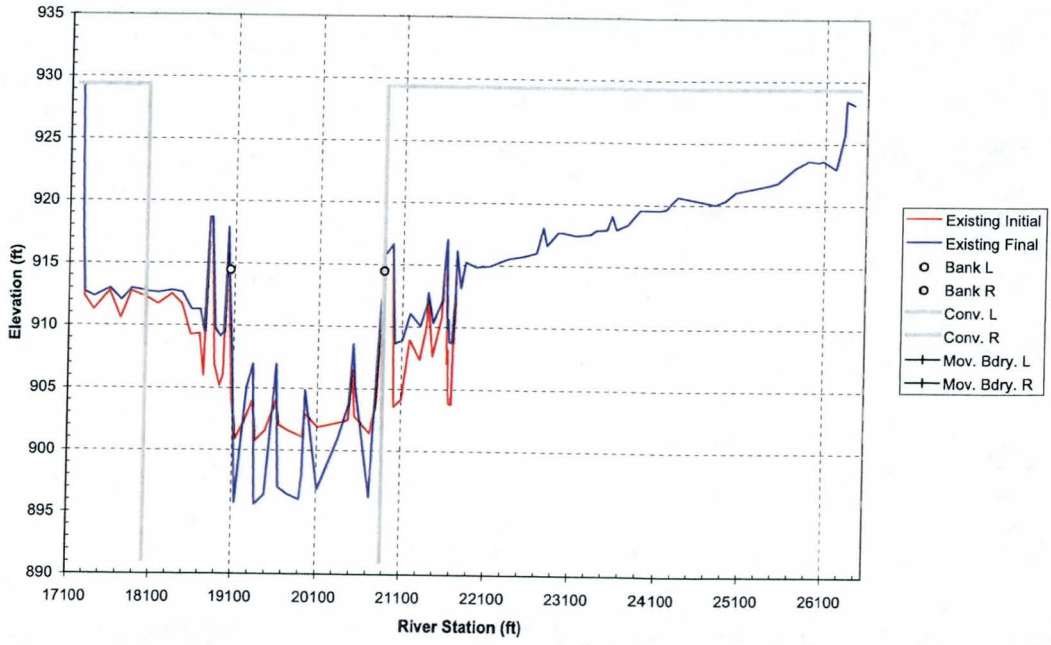

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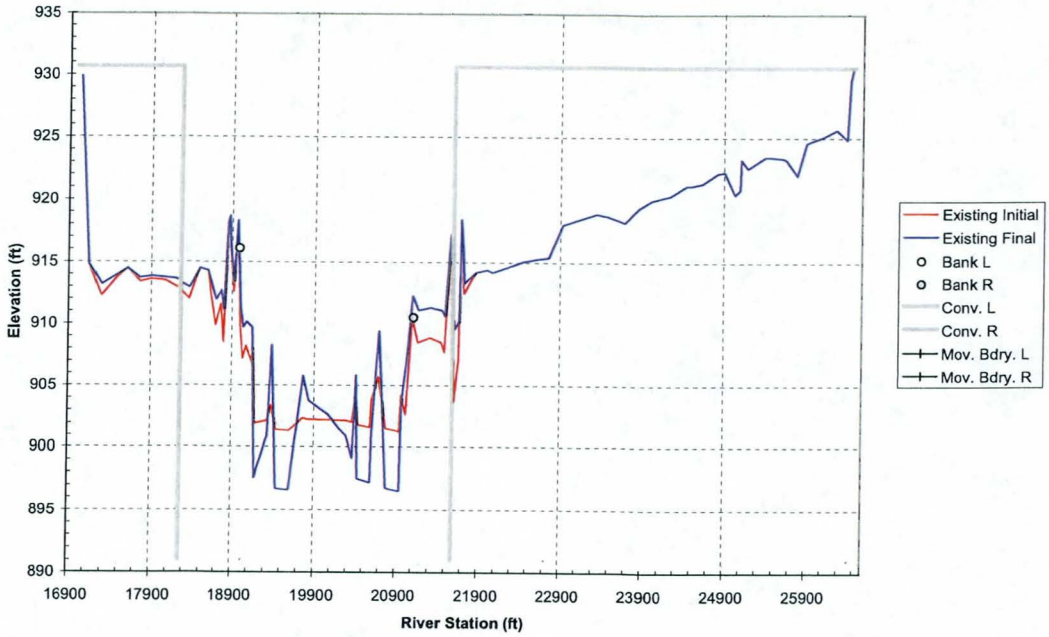

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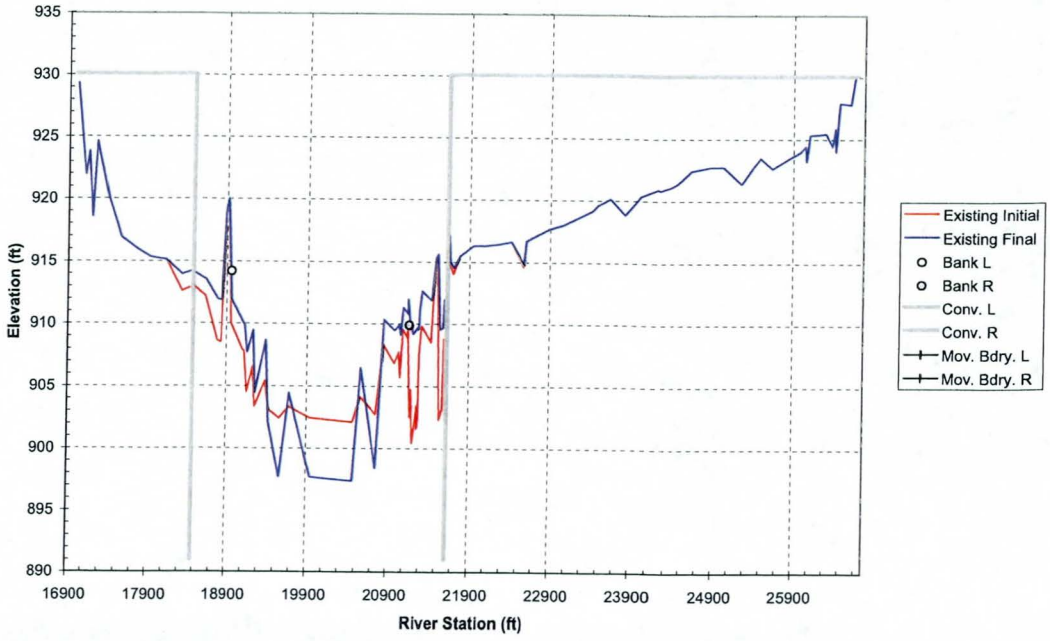

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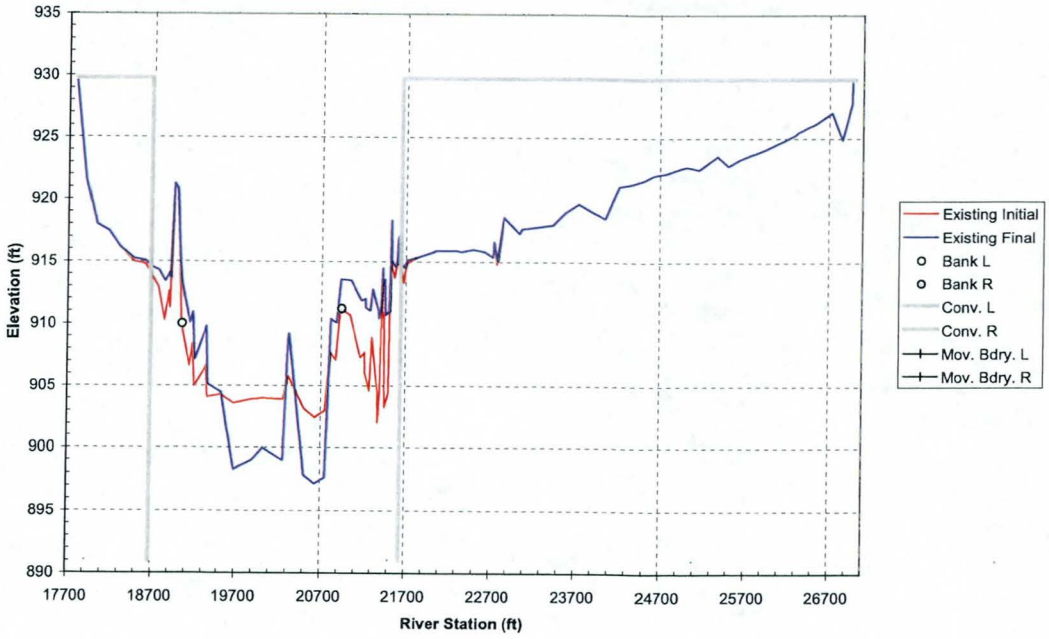

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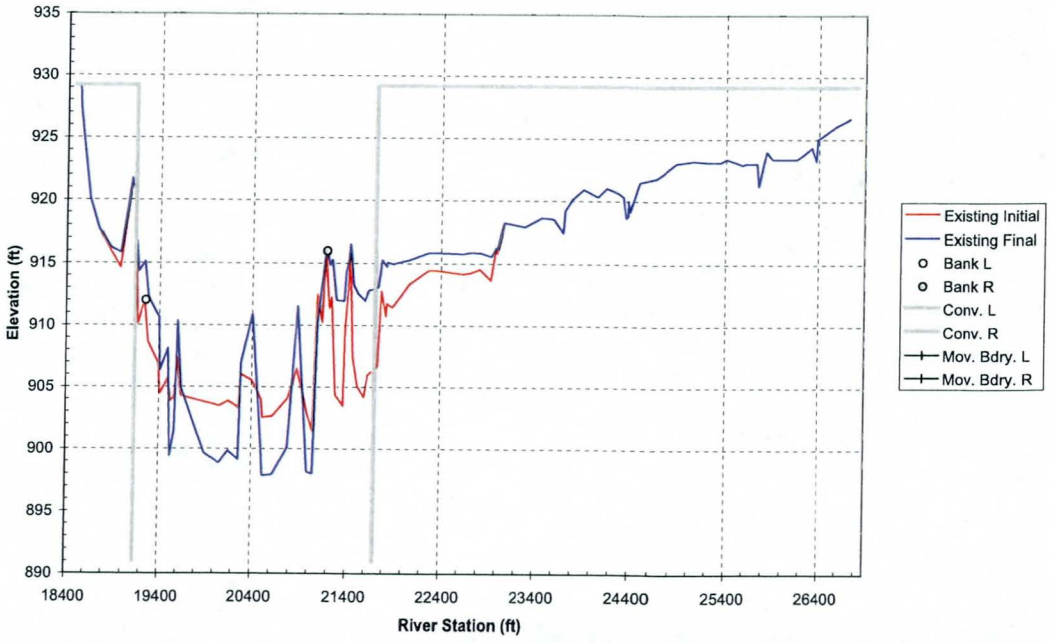

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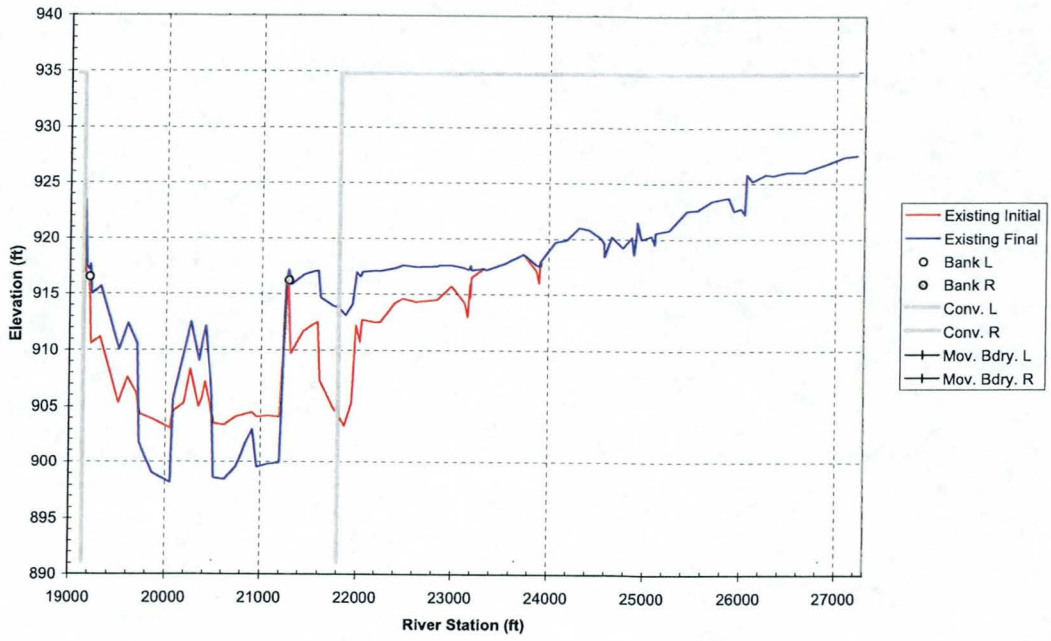

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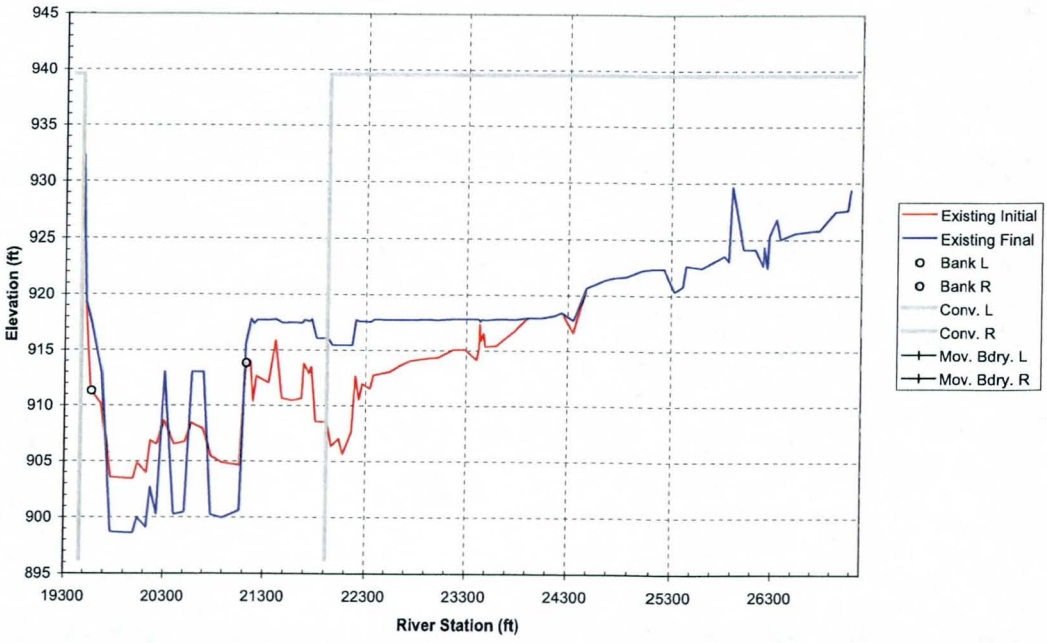


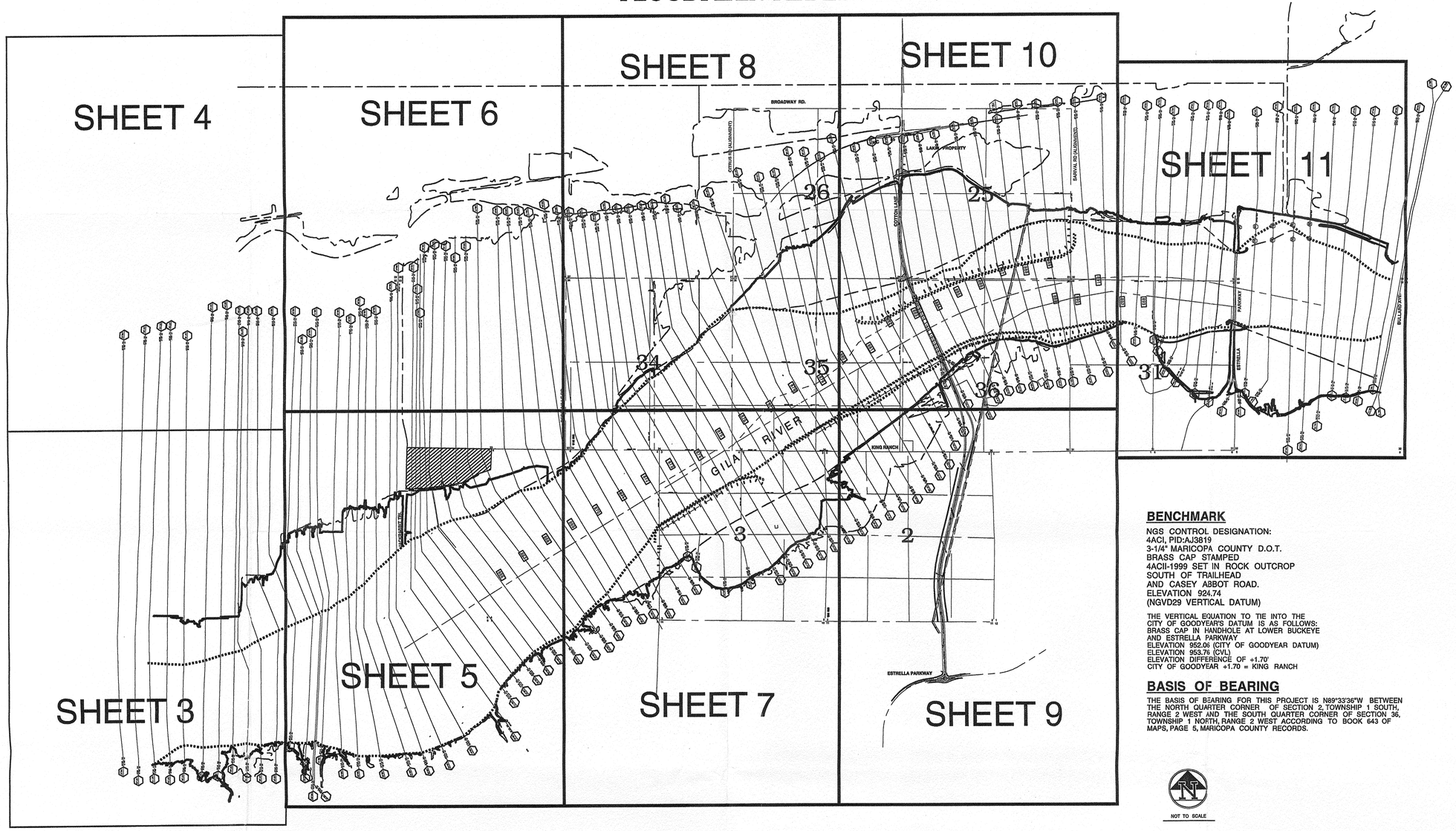
APPENDIX G

CHECK-RAS OUTPUT

The CHECK-RAS report was reviewed and no critical errors were found. The report files can be generated from the data on the enclosed CD if desired. This was done to conserve both paper and storage space.

EXHIBIT MAPS

COTTON LANE BRIDGE/KING RANCH
FLOODPLAIN REDELINEATION



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.

NOT TO SCALE

R2D

River Research & Design, Inc.
1345 E Spur Avenue
Gilbert, AZ 85296
Telephone 480-275-5077

NO.	REVISION	DATE
	90% SUBMITTAL	02-17-06
	95% SUBMITTAL	06-23-06
	99% SUBMITTAL	09-25-06
	FINAL SUBMITTAL	07-12-07

River Research & Design, Inc.

GILA RIVER FLOODPLAIN
SHEET INDEX AND VICINITY MAP

COTTON LANE BRIDGE/KING RANCH
FLOODPLAIN REDELINEATION

Registered Professional Engineer Corp
CERTIFICATE NO.
36225
GARY E.
FREEMAN
Date Signed 7/12/07
ARIZONA U.S.A.

SHEET
1 OF 11

R2D Contact: GARY FREEMAN
CVL Project #: 800001
DESIGN DATE: JULY 12, 2007

Two working days before you dig
CALL FOR THE BLUE STAKES
602-263-1100
1-800-STAKE-IT
(OUTSIDE MARICOPA COUNTY)

Kevink
8/1/2007
2:59:12 PM
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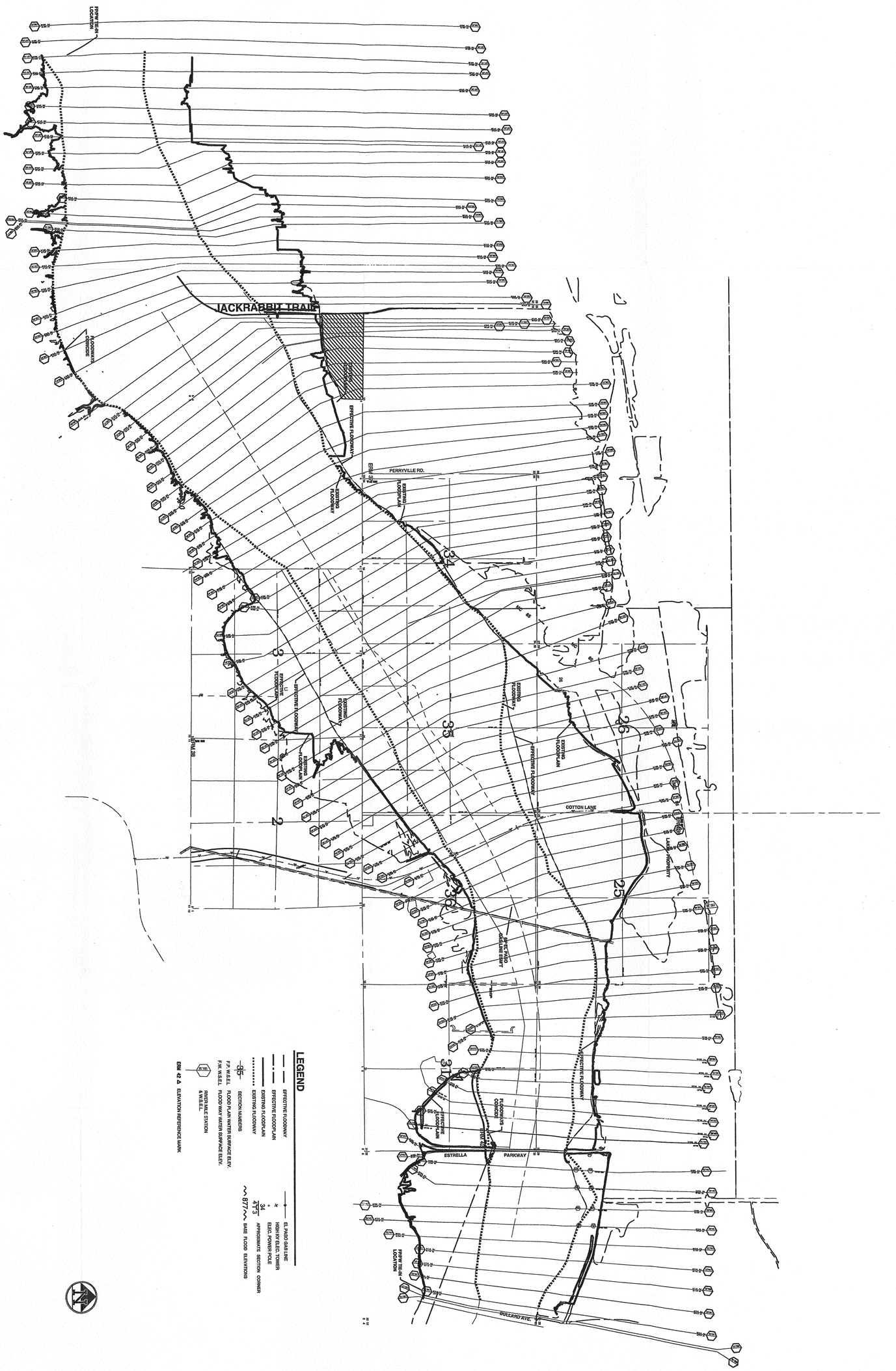
KevinK
7/12/2007
2:58:20 PM
n:\800001\LAND\GilaRiver\V8\sdn02400.dgn



CALL FOR THE MARICOPA COUNTY BLUE STAKE, INC.
602-263-1100
1-800-STAKE-IT
OUTSIDE MARICOPA COUNTY

R2D Contact: GARY FREEMAN
CIVIL Project #: 800001
DESIGN DATE: JULY 12, 2007

SHEET 2 OF 11

Registered Professional Engineer
35225
GARY E. FREEMAN
Date 7-12-07
ARIZONA

OVERVIEW MAP & LEGEND

COTTON LANE BRIDGE/KING RANCH FLOODPLAIN REDELINEATION

NO.	REVISION	DATE
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	95% SUBMITTAL	06-23-06
	99% SUBMITTAL	09-25-06
	FINAL SUBMITTAL	07-12-07

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R2D
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Gilbert, AZ 85296
Telephone 480-275-5077

KevinK
8/1/2007
3:32:42 PM
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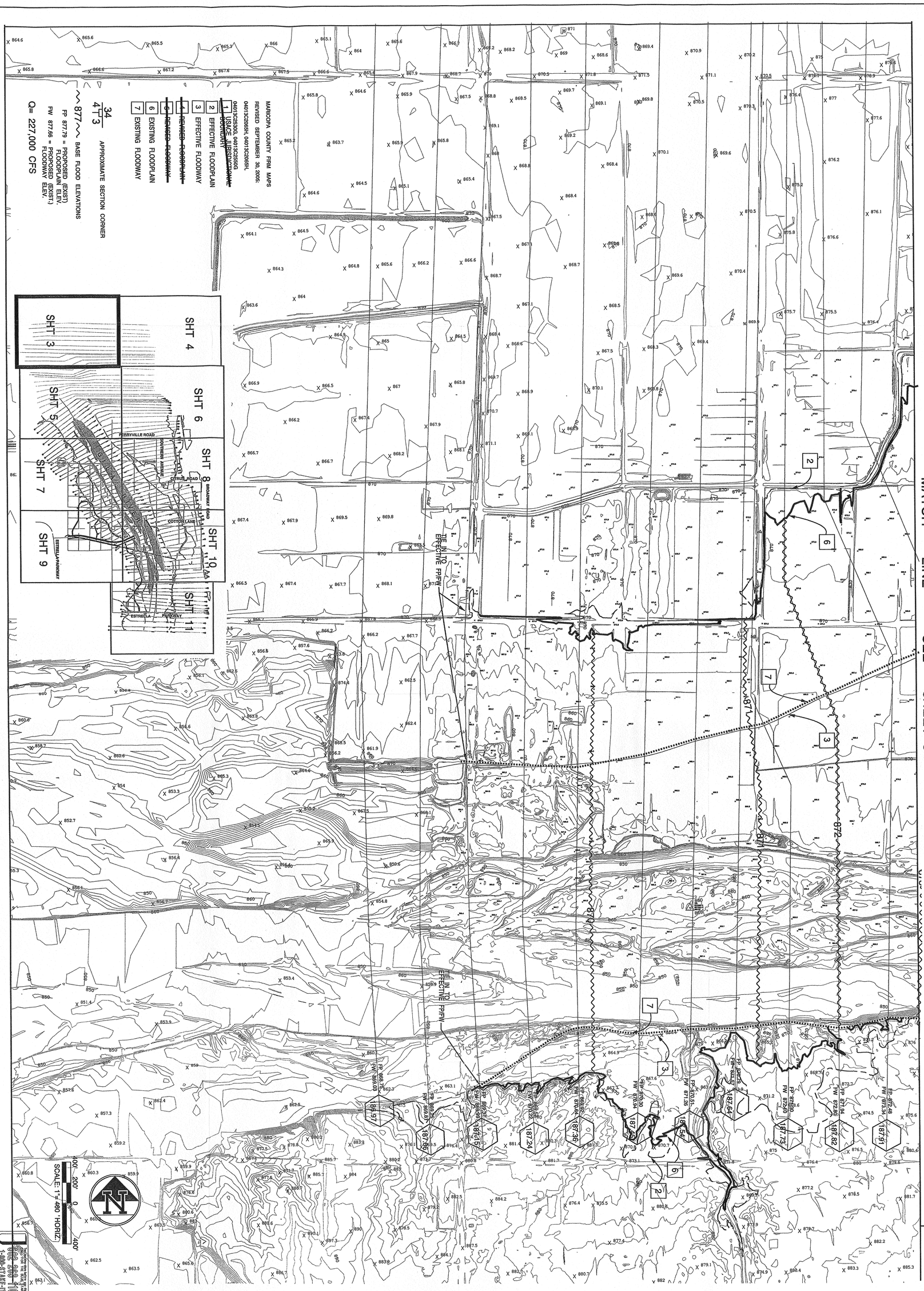

NO.	REVISION	DATE
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	95% SUBMITTAL	06-23-06
	99% SUBMITTAL	09-25-06
	FINAL SUBMITTAL	07-12-07

GILA RIVER FLOODPLAIN

COTTON LANE BRIDGE/KING RANCH FLOODPLAIN REDELINEATION

SHEET 3 OF 11

R2D CONTACT: GARY FREEMAN
CVR. Project # 800001
DESIGN DATE: JULY 16, 2007

Registered Professional Engineer
GARY E. FREEMAN
36228
PROVISIONAL
Civil

River Research & Design, Inc.

River Research & Design, Inc.
1345 E Spur Avenue
Gilbert, AZ 85296
Telephone 480-275-5077

KevinK
7/12/2007
3:42:23 PM
n:\800001\LAND\GilaRiver\V8\sd400s04new.dgn

1 USACE HURRICHROME BOUNDARY
2 EFFECTIVE FLOODPLAIN
3 EFFECTIVE FLOODWAY
4 REVISED FLOODPLAIN
5 REVISED FLOODWAY
6 EXISTING FLOODPLAIN
7 EXISTING FLOODWAY

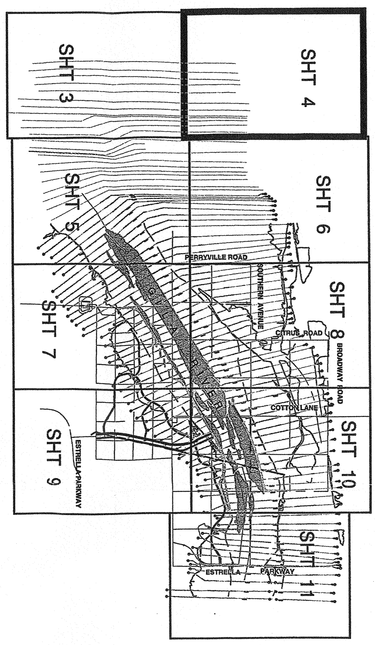
~ 877 ~ BASE FLOOD ELEVATIONS

34 / 4T3 APPROXIMATE SECTION CORNER

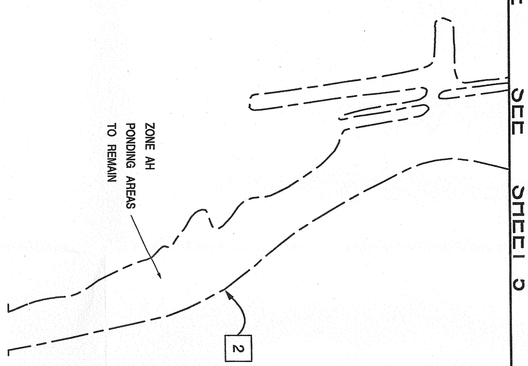
FP 877.79 = PROPOSED (EXIST) FLOODPLAIN ELEV.
FW 877.66 = PROPOSED (EXIST.) FLOODWAY ELEV.

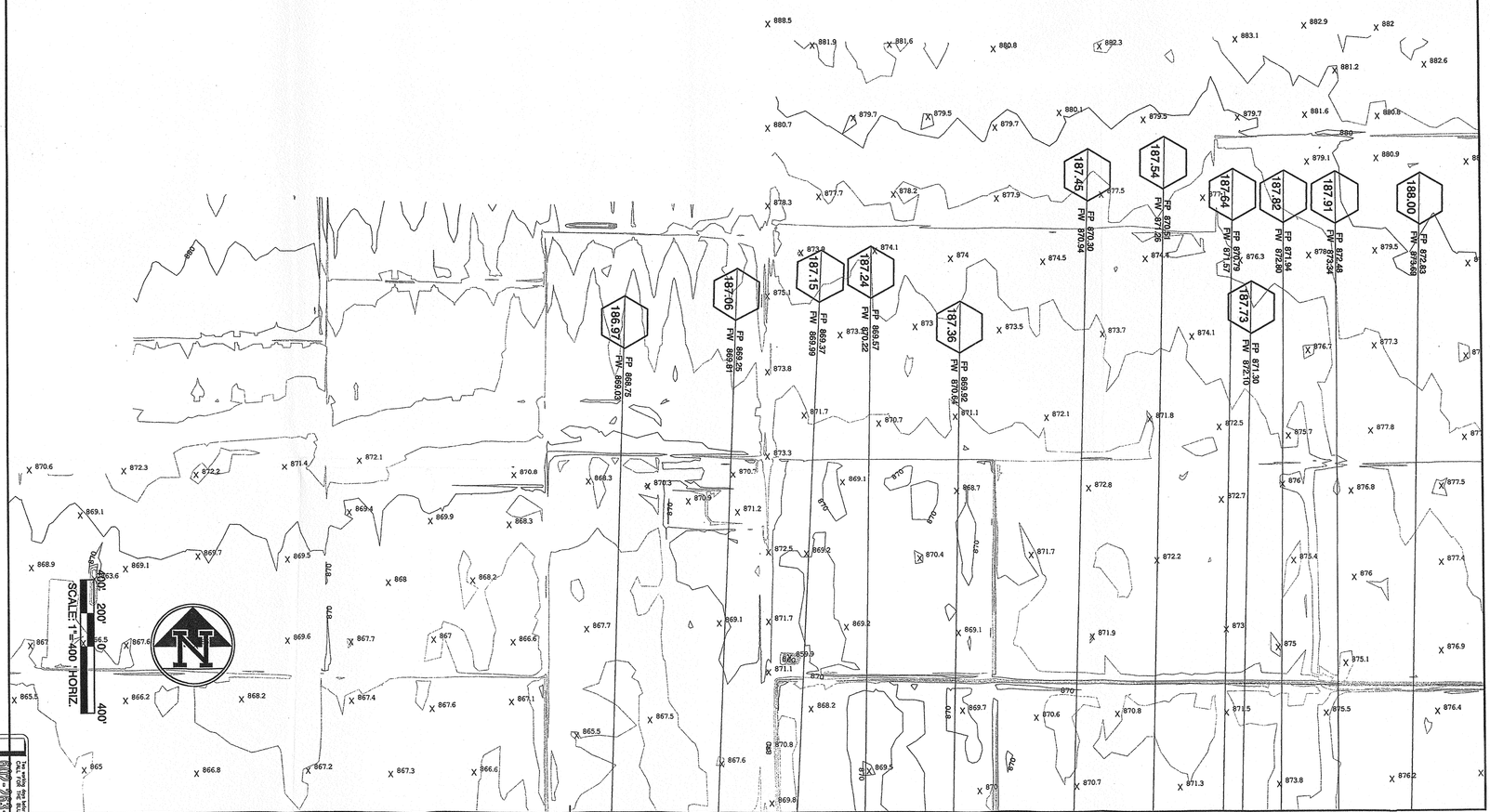
Q= 227,000 CFS

MARICOPA COUNTY FIRM MAPS REVISED SEPTEMBER 30, 2005: 0401C0265H, 0401C0266H, 0401C0265G



MATCH LINE SEE SHEET 3





MATCH LINE SEE SHEET 3

Call before you dig
1-800-STAKE-IT
(602) 263-1100
OUTSIDE MARICOPA COUNTY

NO.	REVISION	DATE
	90% SUBMITTAL	02-17-06
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	99% SUBMITTAL	09-25-06
	FINAL SUBMITTAL	07-12-07

SHEET 4 OF 11
RRD Contract: GARY FREEMAN
CVL Project #: 800001
DESIGN DATE: JULY 12, 2007

Registered Professional Engineer
35225
GARY E. FREEMAN
Date Signed
(602)

GILA RIVER FLOODPLAIN

COTTON LANE BRIDGE/KING RANCH FLOODPLAIN REDELINEATION

River Research & Design, Inc.
R2D
River Research & Design
1345 E Spur Avenue
Gilbert, AZ 85296
Telephone 480-275-507

8/1/2007
3:50:35 PM
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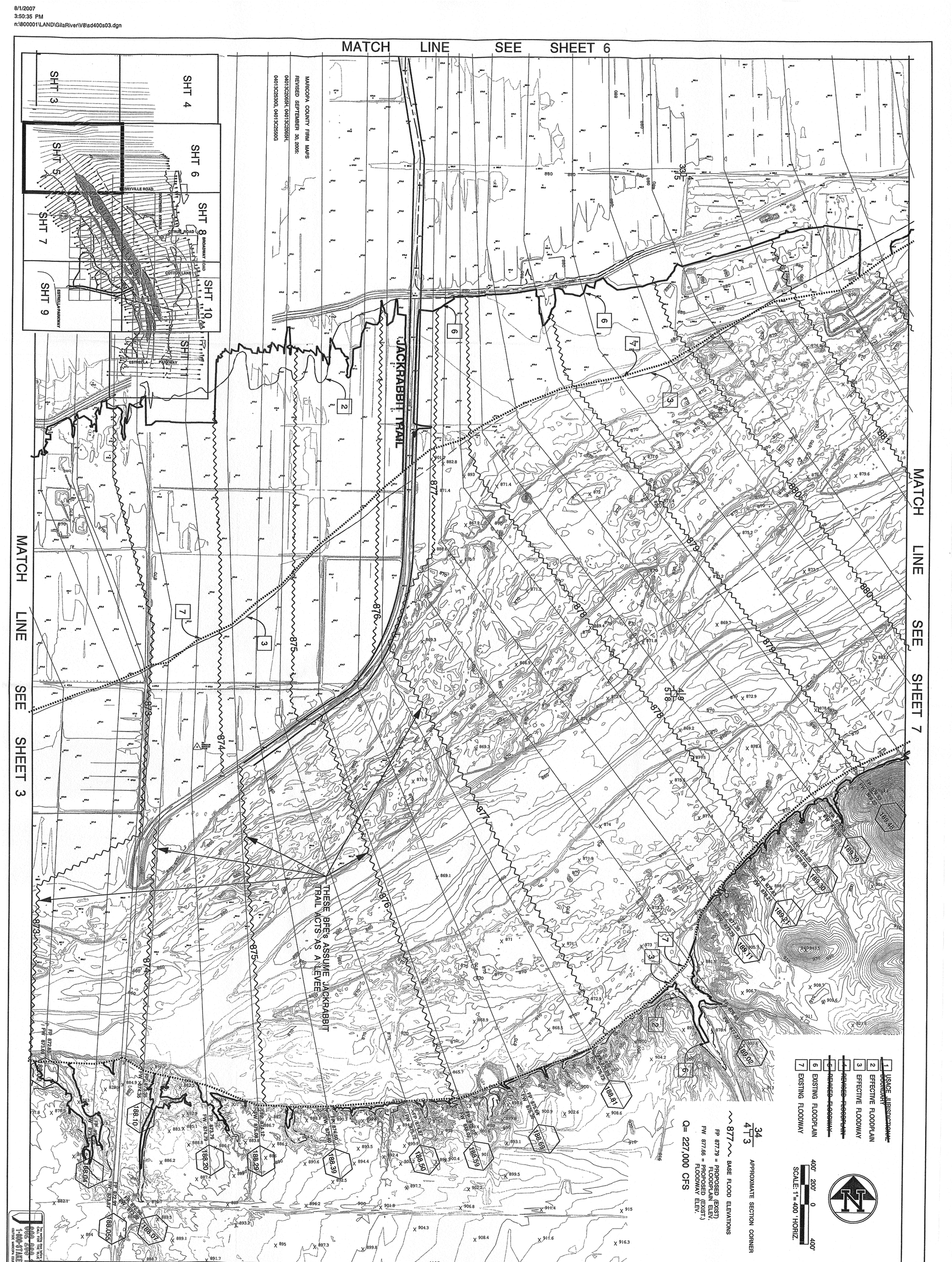


CALL FOR THE BLUE STAKE, INC. 1-800-STAKE-IT (1-800-782-5348)
OUTSIDE MARICOPA COUNTY

GILA RIVER FLOODPLAIN

COTTON LANE BRIDGE/KING RANCH FLOODPLAIN REDELINEATION

NO.	REVISION	DATE
	90% SUBMITTAL	02-17-06
	95% SUBMITTAL	06-23-06
	99% SUBMITTAL	09-25-06
	FINAL SUBMITTAL	07-12-07

River Research & Design, Inc.

R2D
River Research & Design, Inc.
1345 E Spur Avenue
Gilbert, AZ 85296
Telephone 480-275-5077

Registered Professional Engineer
GARY E. FREEMAN
16225
Date Signed 7-12-07
ARIZONA U.S.A.

SHEET 5 OF 11
R2D: Contact: GARY FREEMAN
R2D: Project #: 800001
DESIGN: DATE: JULY 12, 2007

MATCH LINE SEE SHEET 8

MATCH LINE SEE SHEET 5

MATCH LINE SEE SHEET 4

1 USACE JURISDICTIONAL BOUNDARY
2 EFFECTIVE FLOODPLAIN
3 EFFECTIVE FLOODWAY
4 REVISED FLOODPLAIN
5 REVISED FLOODWAY
6 EXISTING FLOODPLAIN
7 EXISTING FLOODWAY

ZONE AH
PONDING AREAS
TO REMAIN

ZONE AH
PONDING AREAS
TO REMAIN

ZONE AH
PONDING AREAS
TO REMIN

190.33 FP 884.11 FW 884.25
190.24 FP 883.58 FW 883.70
190.15 FP 882.72 FW 882.86
190.05 FP 882.10 FW 882.24
189.96 FP 881.46 FW 881.63
189.87 FP 880.80 FW 881.00
189.77 FP 880.30 FW 880.50
189.67 FP 879.81 FW 880.05
189.58 FP 879.34 FW 879.61
189.48 FP 878.93 FW 879.22
189.39 FP 878.58 FW 878.90
189.30 FP 878.25 FW 878.59
189.21 FP 877.83 FW 878.21
189.11 FP 877.35 FW 877.79
189.02 FP 876.85 FW 877.37
188.81 FP 876.09 FW 876.78
188.69 FP 875.64 FW 876.36
188.59 FP 875.22 FW 876.02
188.50 FP 874.87 FW 875.72
188.39 FP 874.50 FW 875.40
188.29 FP 874.12 FW 875.08
188.20 FP 873.79 FW 874.79
188.10 FP 873.35 FW 874.35
188.07 FP 872.98 FW 873.92
188.055 FP 872.97 FW 873.87
188.04 FP 872.95 FW 873.81

2
28 33
29 32

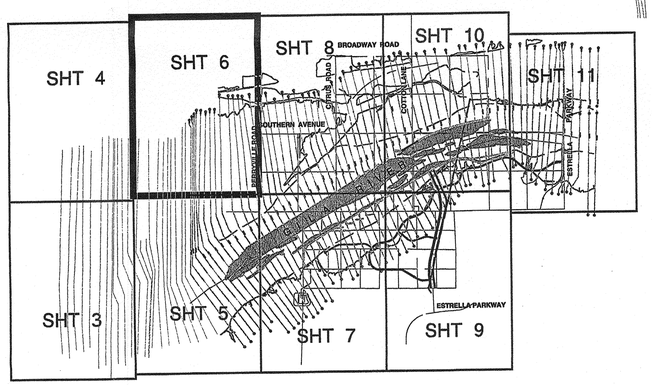
877 BASE FLOOD ELEVATIONS

34 / 4 T 3 APPROXIMATE SECTION CORNER

FP 877.79 = PROPOSED (EXIST) FLOODPLAIN ELEV.
FW 877.66 = PROPOSED (EXIST.) FLOODWAY ELEV.

Q= 227,000 CFS

MARICOPA COUNTY FIRM MAPS
REVISED SEPTEMBER 30, 2005:
04013C2065H, 04013C2065H,
04013C2530G, 04013C2550G



400' 200' 0 400'
SCALE: 1"= 400 ' HORIZ.

Two working days before you dig
CALL FOR THE BLUE STAKE
602.263.1100
1-800-STAKE-IT
(OUTSIDE MARICOPA COUNTY)

R2D

River Research & Design, Inc.
1345 E Spur Avenue
Gilbert, AZ 85296
Telephone 480-275-5077

NO.	REVISION	DATE
	90% SUBMITTAL	02-17-06
	95% SUBMITTAL	06-23-06
	99% SUBMITTAL	09-25-06
	FINAL SUBMITTAL	07-12-07

River Research & Design, Inc.

GILA RIVER FLOODPLAIN

COTTON LANE BRIDGE/KING RANCH
FLOODPLAIN REDELINEATION

Registered Professional Engineer (Civil)
CERTIFICATE NO.
36225
GARY E.
FREEMAN
Date Signed
ARIZONA, U.S.A.

SHEET
6 OF 11

R2D Contact: GARY FREEMAN
CVL Project #: 800001
DESIGN DATE: JULY 12, 2007

KevinK
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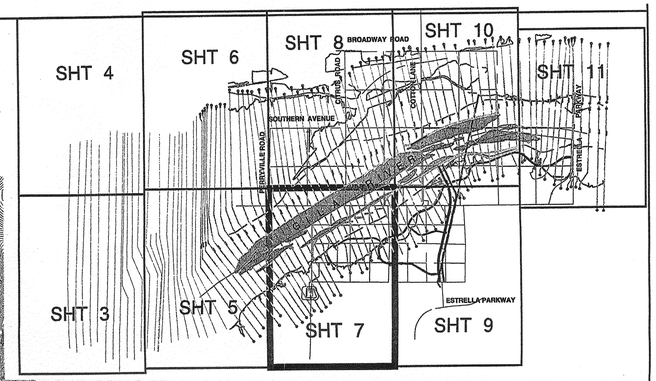
MATCH LINE SEE SHEET 9

SHEET 8

MATCH LINE SEE SHEET 5



1 USACE JURISDICTIONAL BOUNDARY
2 EFFECTIVE FLOODPLAIN
3 EFFECTIVE FLOODWAY
4 REVISED FLOODPLAIN
5 REVISED FLOODWAY
6 EXISTING FLOODPLAIN
7 EXISTING FLOODWAY

MARICOPA COUNTY FIRM MAPS
REVISED SEPTEMBER 30, 2005:
04013C2065H, 04013C2065H,
04013C2530G, 04013C2550G

34 / 4 T 3 APPROXIMATE SECTION CORNER

~877~ BASE FLOOD ELEVATIONS

ERM 42 △ ELEVATION REFERENCE MARK

FP 877.79 = PROPOSED (EXIST) FLOODPLAIN ELEV.

FW 877.66 = PROPOSED (EXIST.) FLOODWAY ELEV.

Q= 227,000 CFS

ELEVATION REFERENCE MARK

I.D.	ELEV. (FT)	DESCRIPTION/LOCATION
37	887.63	A ADOT BC in the center of an irrigation structure headwall,- approximately 36 feet southerly of the centerline of SR85, and 25 feet easterly of the centerline of Perryville Rd. This point is located in the proximity of the SE corner of Sec 33, T1N, R2W of the G&SRB&M, Maricopa Cnty, Arizona
38	945.73	A BC on a 2" pipe. This point is the SE corner of Section 3, T1S, R2W of the G&SRB&M, Maricopa Cnty, Arizona

400' 200' 0 400'
SCALE: 1" = 400'

Two working days before you dig, call for the exact locations
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
	FINAL SUBMITTAL	07-12-07

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Telephone 480-275-5077

River Research & Design, Inc.

GILA RIVER FLOODPLAIN

COTTON LANE BRIDGE/KING RANCH FLOODPLAIN REDELINEATION

Registered Professional Engineer (Civil)
CERTIFICATE NO.
36225
GARY E.
FREEMAN
Date Signed
ARIZONA, U.S.A.

SHEET 7 OF 11

R2D Contact: GARY FREEMAN

CVL Project #: 800001

DESIGN DATE: JULY 12, 2007

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MATCH LINE SEE SHEET 10

1 USACE JURISDICTIONAL BOUNDARY
2 EFFECTIVE FLOODPLAIN
3 EFFECTIVE FLOODWAY
4 REVISED FLOODPLAIN
5 REVISED FLOODWAY
6 EXISTING FLOODPLAIN
7 EXISTING FLOODWAY

34 / 4T 3 APPROXIMATE SECTION CORNER

~877~ BASE FLOOD ELEVATIONS

FP 877.79 = PROPOSED (EXIST) FLOODPLAIN ELEV.

FW 877.66 = PROPOSED (EXIST.) FLOODWAY ELEV.

Q= 227,000 CFS

ZONE AH PONDING AREAS TO REMAIN

BUCKEYE CANAL

191.95 FP 891.66 FW 892.15
191.86 FW 891.09 FW 891.68
191.76 FP 890.60 FW 891.10
191.67 FP 890.03 FW 890.42
191.57 FP 889.55 FW 889.84
191.48 FP 889.10 FW 889.39
191.38 FP 888.62 FW 888.98
191.29 FP 886.20 FW 886.41
191.19 FP 887.79 FW 887.98
191.10 FP 887.44 FW 887.63
191.00 FP 887.05 FW 887.27
190.91 FP 886.63 FW 886.87
190.81 FP 886.27 FW 886.59
190.72 FP 885.93 FW 886.14
190.62 FP 885.56 FW 885.75
190.52 FP 885.10 FW 885.26
190.43 FP 884.58 FW 884.74
192.14 FP 892.65 FW 893.05
192.04 FP 892.06 FW 892.08

MC 85

26 35
27 34

ZONE AH PONDING AREAS TO REMAIN

ZONE AH PONDING AREAS TO REMAIN

ZONE AH PONDING AREAS TO REMAIN

SEE SHEET 7

MATCH LINE

27 34
28 33

PERRYVILLE RD ALIGNMENT

MATCH LINE SEE SHEET 6

400' 200' 0 400'

SCALE: 1" = 400'

MARICOPA COUNTY FIRM MAPS
REVISED SEPTEMBER 30, 2005:
04013C2065H, 04013C2065H,
04013C2530G, 04013C2550G

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NO.	REVISION	DATE
	90% SUBMITTAL	02-17-06
	95% SUBMITTAL	06-23-06
	99% SUBMITTAL	09-25-06
	FINAL SUBMITTAL	07-12-07

R2D

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Gilbert, AZ 85296
Telephone 480-275-5077

River Research & Design, Inc.

GILA RIVER FLOODPLAIN
COTTON LANE BRIDGE/KING RANCH FLOODPLAIN REDELINEATION

Registered Professional Engineer (Civil) CERTIFICATE NO. 36225 GARY E. FREEMAN Date Signed 7/12/07 ARIZONA, U.S.A.

Arizona Blue Stake, Inc. Call Toll Free Before You Dig 602-263-1100 1-800-STAKE-IT (OUTSIDE MARICOPA COUNTY)

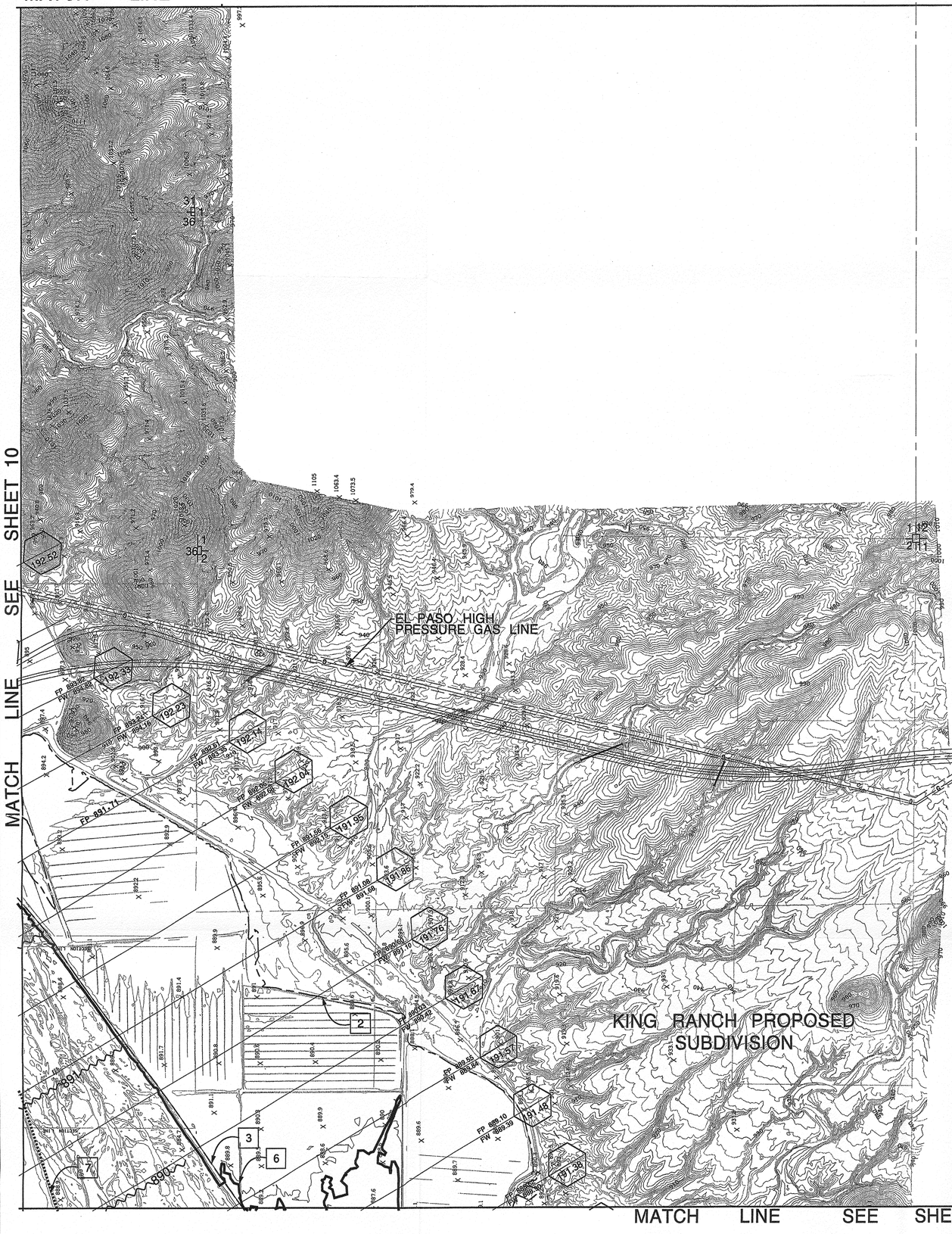
SHEET 8 OF 11

R2D Contact: GARY FREEMAN
CVL Project #: 800001
DESIGN DATE: JULY 12, 2007

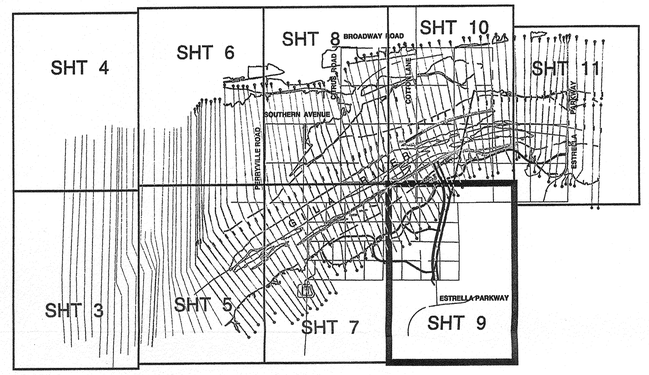
MATCH LINE SEE SHEET 11

SEE SHEET 10

MATCH LINE



MATCH LINE SEE SHEET 7



MARICOPA COUNTY FIRM MAPS
REVISED SEPTEMBER 30, 2005:
04013C2065H, 04013C2065H,
04013C2530G, 04013C2550G

1 USACE JURISDICTIONAL ~~BOUNDARY~~
2 EFFECTIVE FLOODPLAIN
3 EFFECTIVE FLOODWAY
~~4 REVISED FLOODPLAIN~~
~~5 REVISED FLOODWAY~~
6 EXISTING FLOODPLAIN
7 EXISTING FLOODWAY

877 BASE FLOOD ELEVATIONS
34 / 4 T 3 APPROXIMATE SECTION CORNER
FP 877.79 = PROPOSED (EXIST) FLOODPLAIN ELEV.
FW 877.66 = PROPOSED (EXIST.) FLOODWAY ELEV.
Q= 227,000 CFS

N

400' 200' 0 400'
SCALE: 1" = 400'

Two working days before you dig CALL FOR THE BLUE STAKES
602 263 1100
1-800-STAKE-IT (OUTSIDE MARICOPA COUNTY)

R2D

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Gilbert, AZ 85296
Telephone 480-275-5077

NO.	REVISION	DATE
	90% SUBMITTAL	02-17-06
	95% SUBMITTAL	06-23-06
	99% SUBMITTAL	09-25-06
	FINAL SUBMITTAL	07-12-07

River Research & Design, Inc.

GILA RIVER FLOODPLAIN

COTTON LANE BRIDGE/KING RANCH FLOODPLAIN REDELINEATION

Registered Professional Engineer (Civil)
CERTIFICATE NO.
36225
GARY E. FREEMAN
Date Signed 7-12-07
ARIZONA U.S.A.

SHEET 9 OF 11

R2D Contact: GARY FREEMAN
CVL Project #: 800001
DESIGN DATE: JULY 12, 2007

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MATCH LINE SEE SHEET 11

400' 200' 0 400'

SCALE: 1" = 400'

34 / 4T3 APPROXIMATE SECTION CORNER

~877~ BASE FLOOD ELEVATIONS

ERM 42 Δ ELEVATION REFERENCE MARK

FP 877.79 = PROPOSED (EXIST) FLOODPLAIN ELEV.

FW 877.66 = PROPOSED (EXIST.) FLOODWAY ELEV.

Q= 227,000 CFS

ELEVATION REFERENCE MARK

I.D.	ELEV. (FT)	DESCRIPTION/LOCATION
39	909.14	An ADOT BC in the center of an irrigation structure headwall,- approximately 25 feet southerly of the centerline of Cotton Lane. This point is approximately 700 feet S and 100 feet E of the NW corner of Sec 25, T1N, R2W of the G&SRB&M, Maricopa Cnty, Arizona

1 ~~USACE JURISDICTIONAL BOUNDARY~~

2 EFFECTIVE FLOODPLAIN

3 EFFECTIVE FLOODWAY

4 ~~REVISED FLOODPLAIN~~

5 ~~REVISED FLOODWAY~~

6 EXISTING FLOODPLAIN

7 EXISTING FLOODWAY

MARICOPA COUNTY FIRM MAPS

REVISED SEPTEMBER 30, 2005:

04013C2065H, 04013C2065H,

04013C2530G, 04013C2550G

AH ZONE PONDING AREAS TO REMAIN

AH ZONE PONDING AREAS TO REMAIN

193.43 FP 901.10 FW 901.60

193.34 FP 900.75 FW 901.32

193.25 FP 900.33 FW 900.95

193.16 FP 899.82 FW 900.33

193.07 FP 899.45 FW 900.23

192.98 FP 899.02 FW 899.83

192.89 FP 898.37 FW 899.27

192.79 FP 897.69 FW 898.46

192.70 FP 896.65 FW 897.65

192.61 FP 896.06 FW 897.06

192.52 FP 895.44 FW 896.45

192.42 FP 894.76 FW 895.76

192.33 FP 893.82 FW 894.89

192.23 FP 893.24 FW 894.16

193.16 FP 899.89 FW 900.39

193.07 FP 899.45 FW 900.23

192.98 FP 899.02 FW 899.83

192.89 FP 898.37 FW 899.27

192.79 FP 897.69 FW 898.46

192.70 FP 896.65 FW 897.65

192.61 FP 896.06 FW 897.06

192.52 FP 895.44 FW 896.45

192.42 FP 894.76 FW 895.76

901 900 899 898 897 896 895 894 893 892

30/31 25/36 25/36 25/35

COTTON LANE

BUCKEYE CANAL

ERM 39

MATCH LINE SEE SHEET 9

MATCH LINE SEE SHEET 8

SHT 4 SHT 6 SHT 8 SHT 10 SHT 11

SHT 3 SHT 5 SHT 7 SHT 9

BROADWAY ROAD SOUTHERN AVENUE PERRYVILLE ROAD COTTON LANE ESTRELLA PARKWAY

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R2D

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1345 E Spur Avenue
Gilbert, AZ 85296
Telephone 480-275-5077

NO.	REVISION	DATE
	90% SUBMITTAL	02-17-06
	95% SUBMITTAL	06-23-06
	99% SUBMITTAL	09-25-06
	FINAL SUBMITTAL	07-12-07

GILA RIVER FLOODPLAIN

COTTON LANE BRIDGE/KING RANCH FLOODPLAIN REDELINEATION

Registered Professional Engineer (Civil) CERTIFICATE NO. 36225 GARY E. FREEMAN Date Signed 7/12/07 ARIZONA U.S.A.

Arizona Blue Stake, Inc. Know what's below before you dig. CALL FOR THE BLUE STAKES 602 263-1100 1-800-STAKE-IT (OUTSIDE MARICOPA COUNTY)

SHEET 10 OF 11

R2D Contact: GARY FREEMAN

CVL Project #: 800001

DESIGN DATE: JULY 12, 2007

KevinK
7/12/2007
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SHEET 11 OF 11	GILA RIVER FLOODPLAIN	
ROD Contract: 8000001	COTTON LANE BRIDGE/KING RANCH FLOODPLAIN REDELINEATION	
DESIGN DATE: JULY 12, 2007		

NO.	REVISION	DATE
	90% SUBMITTAL	02-17-06
	95% SUBMITTAL	06-23-06
	99% SUBMITTAL	09-25-06
	FINAL SUBMITTAL	07-12-07

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1345 E Spur Avenue
Gilbert, AZ 85296
Telephone 480-275-5077

NFIP

NATIONAL FLOOD INSURANCE PROGRAM

PANEL 2065H

FIRM
FLOOD INSURANCE RATE MAP
MARICOPA COUNTY, ARIZONA
AND INCORPORATED AREAS

PANEL 2065 OF 4350

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

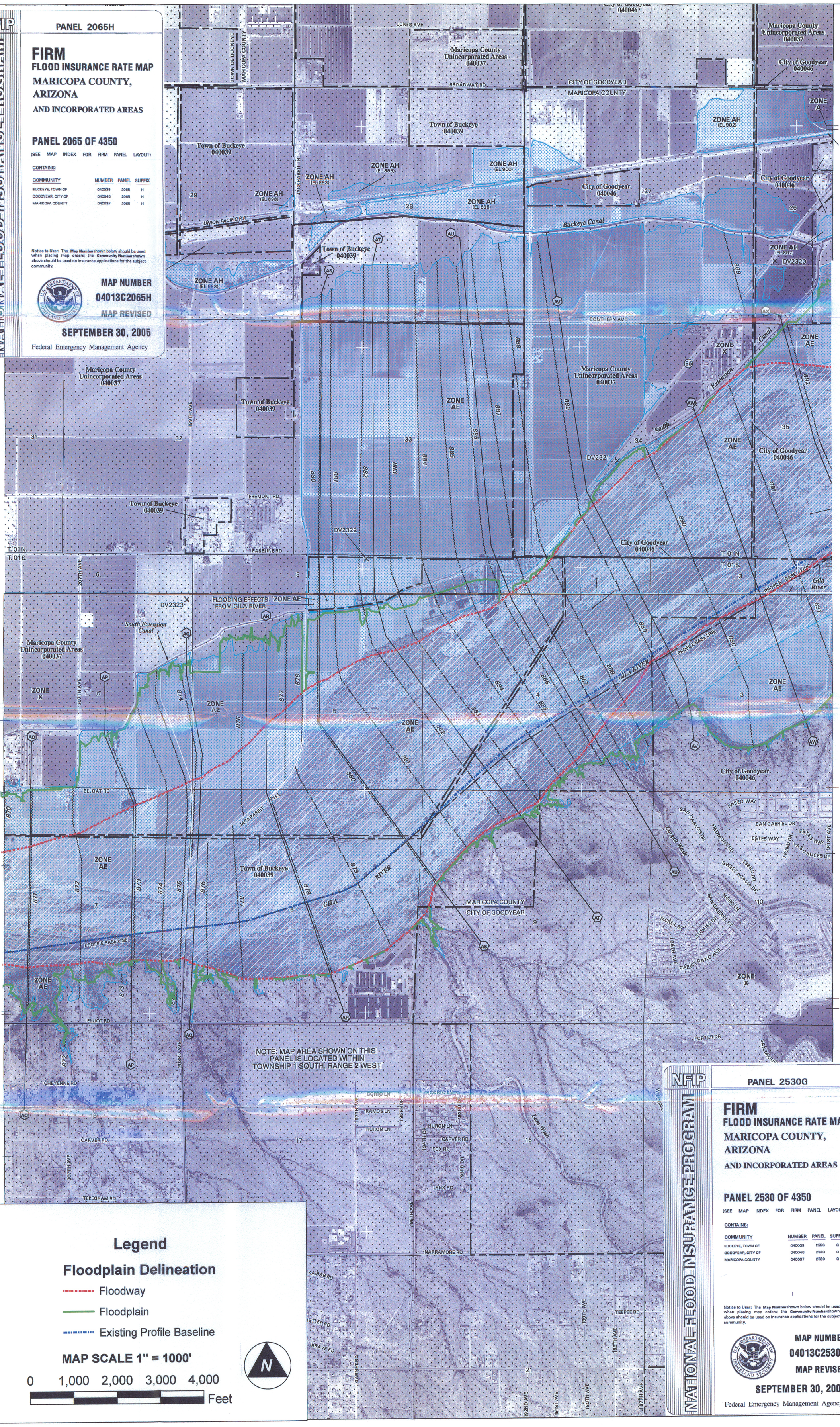
CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
BUCKEYE, TOWN OF	040039	2065	H
GOODYEAR, CITY OF	040046	2065	H
MARICOPA COUNTY	040037	2065	H

Notice to User: The **Map Numbers** shown below should be used when placing map orders; the **Community Numbers** shown above should be used on insurance applications for the subject community.

MAP NUMBER
04013C2065H
MAP REVISED
SEPTEMBER 30, 2005

Federal Emergency Management Agency



NOTE: MAP AREA SHOWN ON THIS PANEL IS LOCATED WITHIN TOWNSHIP 1 SOUTH, RANGE 2 WEST

Legend

Floodplain Delineation

- Floodway
- Floodplain
- Existing Profile Baseline

MAP SCALE 1" = 1000'

0 1,000 2,000 3,000 4,000 Feet

N

NFIP

NATIONAL FLOOD INSURANCE PROGRAM

PANEL 2530G

FIRM
FLOOD INSURANCE RATE MAP
MARICOPA COUNTY, ARIZONA
AND INCORPORATED AREAS

PANEL 2530 OF 4350

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
BUCKEYE, TOWN OF	040039	2530	G
GOODYEAR, CITY OF	040046	2530	G
MARICOPA COUNTY	040037	2530	G

Notice to User: The **Map Numbers** shown below should be used when placing map orders; the **Community Numbers** shown above should be used on insurance applications for the subject community.

MAP NUMBER
04013C2530G
MAP REVISED
SEPTEMBER 30, 2005

Federal Emergency Management Agency

NFIP

NATIONAL FLOOD INSURANCE PROGRAM

PANEL 2070H

FIRM
FLOOD INSURANCE RATE MAP
MARICOPA COUNTY, ARIZONA
AND INCORPORATED AREAS

PANEL 2070 OF 4350

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
GOODYEAR, CITY OF	040046	2070	H
MARICOPA COUNTY	040037	2070	H

Notice to User: The **Map Number** shown below should be used when placing map orders; the **Community Number** shown above should be used on insurance applications for the subject community.

MAP NUMBER
04013C2070H
MAP REVISED
SEPTEMBER 30, 2005

Federal Emergency Management Agency

JOINS PANEL 2060

JOINS PANEL 2550

Maricopa County Unincorporated Areas 040037
City of Goodyear 040046
ZONE AE
ZONE X
ZONE A
ZONE AH
ZONE AE (EL 915)
ZONE AH (EL 908)
ZONE AH (EL 910)
ZONE AH (EL 909)
ZONE AH (EL 903)
ZONE AH (EL 887)
ZONE AH (EL 913)
PAPAGO ST
PIMA ST
MOHAVE ST
DURANGO ST
HILTON AVE
MAGNOLIA ST
LOWER BUCKEYE RD
DUNLAP RD
BROADWAY RD
YUMA RD
ELWOOD ST
VICTORY ST
PIONEER ST
SIERRA ST
LUPINE AVE
WATKINS ST
LOWER BUCKEYE PKY
APACHE ST
SONOPA ST
GOODYEAR BLVD
SUPAI DR
VILLAGE BLVD
ESTRELLA PKY
TROCAR AVE
VINEYARD AVE
CASEY ABBOTT RD
GOLF COURSE DR
TIP AT THE HEAD DR
PARK BOUNDARY
Estrella Mountain Regional Park
LIMIT OF DETAILED STUDY
1% ANNUAL CHANCE FLOOD DISCHARGE CONTAINED IN CHANNEL
Gila River
Buckeye Canal
East Tributary Channel
Bullard Wash
Reservoir
LOWER BUCKEYE PKY.
PROFILE BASE LINE
UNION PACIFIC R.R.
MARICOPA COUNTY
CITY OF GOODYEAR
DV0515
DV0488
DV2318
DV2319
FLOODING EFFECTS FROM GILA RIVER
SAN GABRIEL
T.01N.
T.01S.
R.02W.
R.01W.

Legend

Floodplain Delineation

- Floodway
- Floodplain
- Existing Profile Baseline

MAP SCALE 1" = 1000'

0 1,000 2,000 3,000 4,000 Feet

N

NFIP

NATIONAL FLOOD INSURANCE PROGRAM

PANEL 2550G

FIRM
FLOOD INSURANCE RATE MAP
MARICOPA COUNTY, ARIZONA
AND INCORPORATED AREAS

PANEL 2550 OF 4350

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

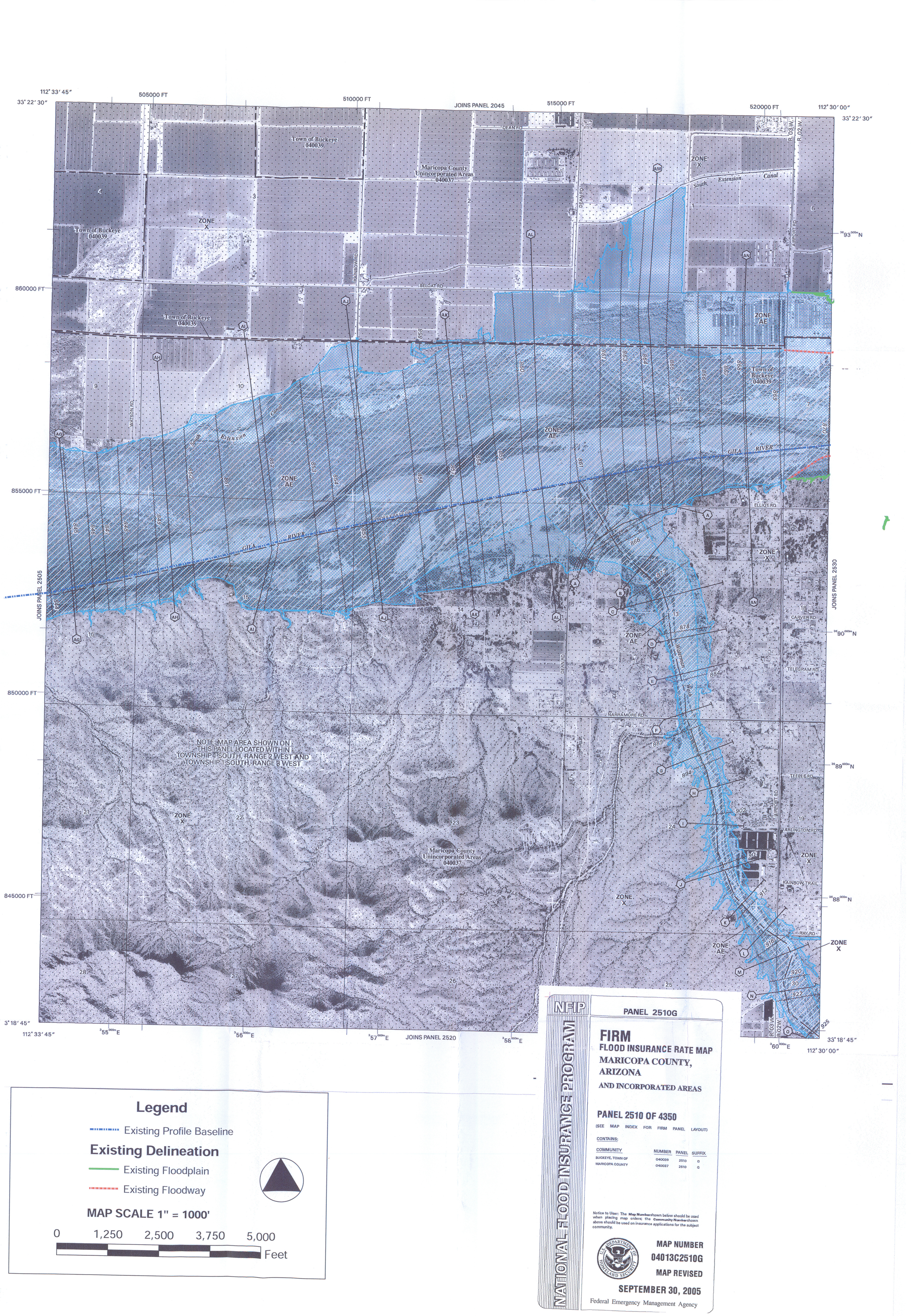
CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
GOODYEAR, CITY OF	040046	2550	G
MARICOPA COUNTY	040037	2550	G

Notice to User: The **Map Number** shown below should be used when placing map orders; the **Community Number** shown above should be used on insurance applications for the subject community.

MAP NUMBER
04013C2550G
MAP REVISED
SEPTEMBER 30, 2005

Federal Emergency Management Agency



Legend

Existing Profile Baseline

Existing Delineation

Existing Floodplain

Existing Floodway

MAP SCALE 1" = 1000'

0 1,250 2,500 3,750 5,000 Feet

NFIP

NATIONAL FLOOD INSURANCE PROGRAM

PANEL 2510G

FIRM

FLOOD INSURANCE RATE MAP

MARICOPA COUNTY, ARIZONA

AND INCORPORATED AREAS

PANEL 2510 OF 4350

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
BUCKEYE, TOWN OF	040039	2510	G
MARICOPA COUNTY	040037	2510	G

Notice to User: The **Map Number** shown below should be used when placing map orders; the **Community Number** shown above should be used on insurance applications for the subject community.

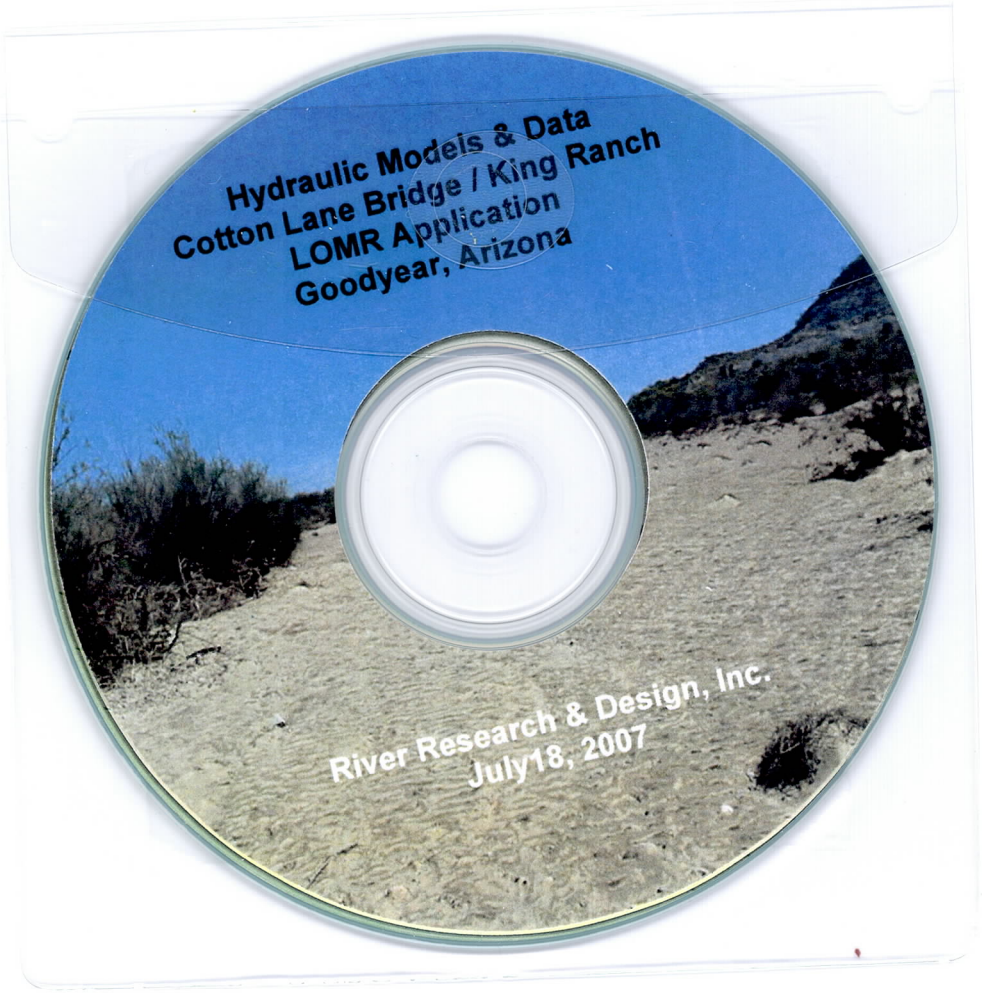
MAP NUMBER

04013C2510G

MAP REVISED

SEPTEMBER 30, 2005

Federal Emergency Management Agency


Hydraulic Models & Data
Cotton Lane Bridge / King Ranch
LOMR Application
Goodyear, Arizona
River Research & Design, Inc.
July18, 2007