Agua Fria River FEMA Levee Certification Package for Levee ID #16

Contract Number: FCD 2010C027 Assignment #5

Prepared for:
Flood Control District of Maricopa County
2801 West Durango Street
Phoenix, AZ 85009

Prepared by:
WEST Consultants, Inc.
8950 S 52nd Street
Suite 210
Tempe, AZ 85284

June 2011
Revised: August 2011

WEST CONSULTANTS, INC.

U.S. Department of Homeland Security
1111 Broadway, Suite 1200
Oakland, CA 94607-4052

FEMA

March 16, 2012

Frank Brown, P.E., CFM
Senior Civil Engineer
Flood Control District Maricopa County
2801 West Durango Street
Phoenix, Arizona 85009

RE: Floodplain Delineations in Support of Levee Certification Packages for Agua Fria River Levees with IDs #8, 11, 16 and 18

Dear Mr. Brown:

This letter is in reference to your submittal of a Technical Data Notebook prepared by Stanley Consultants, Inc. and WEST Consultants, Inc. to update the floodplain delineations along the Agua Fria River, generally from the Salt/Gila River to New River in August 2011. The study was submitted in support of the Provisionally Accredited Agua Fria River Levees (IDs 8, 11, 16 and 18) that were determined to meet the levee certification requirements outlined in the Code of Federal Regulation, Title 44, Section 65.10 (44 CFR 65.10).

We have completed our review and have approved the submitted data. The revised floodplain delineations for the Agua Fria River will be incorporated into a future Physical Map Revision (PMR) for Maricopa County.

If you have any questions regarding this matter, please contact me, either by telephone at (510) 627-7274, or by email at robert.bezek@fema.dhs.gov.

Sincerely,

Robert J. Bezek, CFM
Regional Engineer
Mitigation Division

cc: Brian Cosson, AZ DWR, NFIP State Coordinator
Scott Buchanan, Stanley Consultants, Inc.
Brian T. Wahlin, WEST Consultants, Inc.
Charlie McClendon, City Manager, City of Avondale
Sue McDermott, Floodplain Administrator, City of Avondale
Charles Andrews, Senior Project Manager, City of Avondale
David Cavazos, City Manager, City of Phoenix
Hasan Mushtaq, Floodplain Administrator, City of Phoenix

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FEMA

November 23, 2011

Frank Brown, P.E., CFM
Senior Civil Engineer
Flood Control District Maricopa County
2801 West Durango Street
Phoenix, Arizona 85009

Dear Mr. Brown:

This correspondence is in reference to the June 23, 2011, and August 25, 2011, letters and data submissions to the U.S. Department of Homeland Security's Federal Emergency Management Agency (FEMA) regarding certification of the city of Avondale, the city of Phoenix, and Maricopa County portions of the Agua Fria River Levee System in order to meet the criteria of the Code of Federal Regulations, Title 44, Section 65.10 (44 CFR 65.10). The submitted data has been approved, and the levees are considered accredited. The pertinent information regarding the specific levees is listed below.

Identifier:	Agua Fria Levee System (Levee ID Nos. 8, 11, 16, and 18)
Flooding Source:	Agua Fria River
September 30, 2005 Effective FIRM panels affected:	04013C1620H, 04013C2080J, 04013C2085G & 04013C2090H
December 3, 2010 Preliminary FIRM panels affected:	04013C1695L, 04013C2155L, 04013C2160L & 04013C2165L

In support of the Agua Fria Levee System segment certifications the following information was submitted:

1. A report prepared by West Consultants, Inc., "Agua Fria River FEMA Levee Certification Package for Levee ID #8."
2. A report prepared by JE Fuller Hydrology & Geomorphology, Inc., "Certification Report for Camelback Ranch Levee South (ID #11) – Camelback Road to 3600 feet south along the east bank of the Agua Fria River – Maricopa County, Arizona."
3. A report prepared by West Consultants, Inc., "Agua Fria River FEMA Levee Certification Package for Levee ID #16."
4. A report prepared by West Consultants, Inc., "Agua Fria River FEMA Levee Certification Package for Levee ID #18."

The Technical Data Notebooks prepared by JE Fuller Hydrology & Geomorphology, Inc. and West Consultants, Inc., were reviewed to verify 44 CFR 65.10 compliance. The following is a summary of the review:

1. Freeboard: Analysis and Supporting Documentation was reviewed and found to be in compliance with 44 CFR 65.10(b)(1).
2. Closures: Analysis and Supporting Documentation was reviewed and found to be in compliance with 44 CFR 65.10(b)(2).
3. Embankment Protection: Analysis and Supporting Documentation was reviewed and found to be in compliance with 44 CFR 65.10(b)(3).
4. Embankment and Foundation Stability: Analysis and Supporting Documentation was reviewed and found to be in compliance with 44 CFR 65.10(b)(4).
5. Settlement: Analysis and Supporting Documentation was reviewed and found to be in compliance with 44 CFR 65.10(b)(5).
6. Maintenance Plans and Criteria: Supporting Documentation was reviewed and found to be in compliance with 44 CFR 65.10(d).

All of the above documentation and data, along with the previously submitted documentation, have been reviewed and based on receipt of this information the Agua Fria River Levee System (Levee ID Nos. 8, 11, 16 and 18) as shown on the attached Agua Fria River Levee System Map, meets the minimum certification criteria outlined in 44 CFR 65.10. Therefore, we plan to continue to accredit this levee system on the new Digital Flood Insurance Rate Map (FIRM) as providing protection from the 1-percent-annual-chance (base) flood. The area protected from the base flood by this levee will continue to be mapped as a shaded Zone X and a note will be placed in that area warning of the flood risk that still exists.

Please be advised that levee systems and the estimated level of protection provided by these systems can and do change with time. Future map updates may require the levee system to be certified again at the time of update. Also, design, construction, operation, and/or maintenance documents may be requested at any time. Deviations from the documentation and data submitted to FEMA could result in the levee system no longer being mapped as providing protection from the base flood on future FIRMs. If at any point additional information is provided to FEMA that shows the levee system no longer meets certification criteria as outlined in 44 CFR 65.10, we will contact the levee owner and community about the possibility of de-accrediting the levee system.

Even though we have mapped the referenced levees as providing protection from the 1-percent-annual-chance flood, it is important to note that levees are only designed to provide a specific level of protection. They can be overtopped or fail in larger flood events. Levee systems require regular maintenance and periodic upgrades to retain their level of protection. When levees do fail, they fail catastrophically, and damage may be more significant than if the levee was not there. Therefore, we encourage you to annually discuss the status and condition of your levees with your governing body. Additionally, it is highly recommended that you consider this risk in your local emergency management plans, including creating evacuation plans for this area.

Everyone should understand the risk to life and property that resides behind levees—risk that even the best flood-control system can not completely eliminate. For this reason, FEMA encourages people to understand their risk. The National Flood Insurance Program (NFIP) was created to reduce flood damages by identifying flood risks, encouraging sound community floodplain management practices, and providing flood insurance to lessen the financial impact of flooding. Through the NFIP, property owners in participating communities are able to purchase flood insurance that will insure against flood losses. We hope that you will encourage property owners to purchase flood insurance.

If you have additional questions regarding this matter, please contact me, either by telephone at (510) 627-7274, or by email at robert.bezek@fema.dhs.gov.

Sincerely,

Robert J. Bezek, CFM
Regional Engineer
Mitigation Division

Enclosure:
Agua Fria River Levee System Map

Copies Furnished (w/out enclosures):
Brian Cosson, AZ DWR, NFIP Coordinator
Tony Freiman, AMEC Earth & Environmental, Inc.
Steve Nowaczyk, Ninyo and Moore
Jon T. Ahern, JE Fuller Hydrology & Geomorphology, Inc.
Scott Buchanan, Stanley Consultants, Inc.
Brian T. Wahlin, WEST Consultants, Inc.
Charlie McClendon, City Manager, City of Avondale
Sue McDermott, Floodplain Administrator, City of Avondale
David Cavazos, City Manager, City of Phoenix
Hasan Mushtaq, Floodplain Administrator, City of Phoenix

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December 22, 2011

Thomas W. Smith, P.E.
Engineering Technical Services Group
FEMA PTS Contractor
Michael Baker, Jr., Inc.
3601 Eisenhower Avenue
Alexandria, VA 22304

Subject: Floodplains Review for Agua Fria River Levees, Data Request

Dear Mr. Smith:

The Federal Emergency Management Agency, via Sarah Houghland, P.E., CFM, at BakerAECOM, has requested the digital floodplain information, recent aerial photographs and recent topographic mapping (contours and DTM) for the lower Agua Fria River. Enclosed is a DVD disk with the requested data in the appropriate format files. The District does not require a signed Public Records request for this data, because this data is in support of documents previously submitted to FEMA for levee accreditation. The data disk contains the data described in the attached File Inventory Report.

It is important to note that the topographic information has not been edge-matched for this project, therefore a map, from the interior Drainage Report (ID#8&16), listing the data sources for the contours is sent to assist you in loading/viewing the correct shape file, depending on which floodplain area you are reviewing.

If you have questions concerning this information, please call me at 602-506-4617.

Sincerely,

Frank Edward Brown

Frank Edward Brown, P.E., CFM
Senior Civil Engineer, Mitigation Planning & Technical Programs Branch,
Floodplain Management and Services Division

C: Bob Bezek, FEMA Region IX
Sarah Houghland, BakerAECOM

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August 25, 2011

Robert J. Bezek, CFM
Regional Engineer
U.S. Department of Homeland Security
Mitigation Division, FEMA Region IX
1111 Broadway, Suite 1200
Oakland, CA 94607-4052

Subject: Floodplain Delineations in support of Levee Certification Packages for Agua Fria River Levees, PAL ID#8-11-16-18

Dear Mr. Bezek:

This letter is in response to the Provisionally Accredited Levee (PAL) agreements which the District, the City of Avondale and the City of Phoenix entered into with the Federal Emergency Management Agency in June 2009 for the Agua Fria River Levees, generally between the New River and the Salt / Gila River. The Levee Certification Reports for each of PAL ID#8, ID#11, ID#16, and ID #18 were submitted in June 2011.

Provided in this submittal is an update to the Agua Fria River Floodplain work maps from the Salt / Gila River to New River. As discussed with you, the District directed Stanley Consultants to correct some graphic presentation items on the new work maps, and added the Zone AH delineations prepared by WEST Consultants for the interior drainage analysis. The work maps also depict the floodplain delineation adjacent to PAL ID#11 prepared by JE Fuller. On August 4 we met with the City of Avondale to coordinate some floodplain issues for proper depiction of certain areas on the work maps.

Submitted are 1 hard copy Agua Fria River Floodplain Re-Delineation Technical Data Notebook, 2 hard copy Interior Drainage Reports (one for each river side), work maps and annotated FIRM Panels. As stated in past conversations and stated in a one page TDN addendum, the HEC-RAS models are unchanged and are the same as the June 2011 submittal. The enclosed disks contain PDF format files of the submitted data along with the HEC-RAS models previously submitted.

Shipped are one box with the reports and disks and one tube with the floodplain / floodway work maps. Please replace the previously submitted information with this update information. A minor update is made to the levee certification reports to document the revised reference report dates.

FEMA now has all applicable information to begin review of the Agua Fria River levees. We ask that FEMA agree with the District that these Agua Fria River Levees are in full compliance with 44CFR §65.10 to provide protection from flooding during from the 1 percent annual chance flood, and request that all four of these levees be moved from Provisionally Accredited to Accredited status on the FIRM Panels.

If you have questions concerning this submittal, please call me at 602-506-4617.

Sincerely,

Frank Edward Brown

Frank Edward Brown, P.E., CFM
Senior Civil Engineer, Mitigation Planning & Technical Programs Branch,
Floodplain Management and Services Division

Cc: Sarah Houghland, Michael Baker Corporation (1 CD/DVD disk for each report, and 1 roll of floodplain work maps)
Brian Cosson, ADWR, NFIP Coordinator
Jon T. Ahern, JE Fuller Hydrology & Geomorphology, Inc.
Scott Buchanan, Stanley Consultants, Inc.
Brian T. Wahlin, WEST Consultants, Inc.
Charlie McClendon, City Manager, City of Avondale
Wayne Janis, Floodplain Administrator, City of Avondale
Sue McDermott, City Engineer, City of Avondale
Charles Andrews, Senior Project Manager, Engineering Dept., City of Avondale
David Cavazos, City Manager, City of Phoenix
Hasan Mushtaq, Floodplain Administrator, City of Phoenix

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June 23, 2011

Ed Curtis, P.E., CFM
Senior Civil Engineer
Risk Analysis Branch, FEMA Region IX
U.S. Department of Homeland Security
1111 Broadway, Suite 1200
Oakland, CA 94607-4052

Subject: Levee Certification Packages for Agua Fria River Levees, PAL ID#8-11-16-18

Dear Mr. Curtis:

This letter is in response to the Provisionally Accredited Levee (PAL) agreements (attached) which Maricopa County, the City of Avondale and the City of Phoenix entered into with the Federal Emergency Management Agency in June 2009 for the Agua Fria River Levees, generally between the New River and the Salt / Gila River. The submittal package is separate Levee Certification Reports for each of PAL ID#8, ID#11, ID#16, and ID #18, dated June 2011.

In addition, we are providing an update to the Agua Fria River floodplain and floodway with new BFE's from the Salt / Gila River to New River, based on recent topographic mapping. The Agua Fria River Floodplain Re-Delineation Technical Data Notebook is being sent to you on disk (only), along with the HEC-RAS models. As recently agreed, Maricopa County will correct some graphic presentation items on the new work maps, add Zone AH delineations prepared by others for the new interior drainage analysis and submit a paper TDN with updated disks and updated work maps by July 18, 2011. The HEC-RAS models will be unchanged with this update.

You are receiving two boxes with the reports and disks and one tube with the floodplain / floodway work maps. As previously agreed, you are receiving the survey disks with sealed report scan without a paper copy of each survey report.

We ask that FEMA agree with Maricopa County that these Agua Fria River Levees are in full compliance with 44CFR §65.10 to provide protection from flooding during from the 1 percent annual chance flood, and request that all four of these levees be moved from Provisionally Accredited to Accredited status on the FIRM Panels.

If you have questions concerning this submittal, please call me at 602-506-4617.

Sincerely,

Frank Edward Brown

Frank Edward Brown, P.E., CFM
Senior Civil Engineer, Mitigation Planning & Technical Programs Branch,
Floodplain Management and Services Division

Cc: Sarah Houghland, Michael Baker Corporation (1 CD/DVD disk for each levee report, and 1 roll of floodplain work maps)
Brian Cosson, AZ DWR, NFIP Coordinator
Tony Freiman, AMEC Earth & Environmental, Inc.
Steve Nowaczyk, Ninyo and Moore
Jon T. Ahern, JE Fuller Hydrology & Geomorphology, Inc.
Scott Buchanan, Stanley Consultants, Inc.
Brian T. Wahlin, WEST Consultants, Inc.
Charlie McClendon, City Manager, City of Avondale
Wayne Janis, Floodplain Administrator, City of Avondale
David Cavazos, City Manager, City of Phoenix
Hasan Mushtaq, Floodplain Administrator, City of Phoenix

Agua Fria River FEMA Levee Certification Package for Levee ID #16

Contract Number: FCD 2010C027 Assignment #5

Prepared for:
Flood Control District of Maricopa County
2801 West Durango Street
Phoenix, AZ 85009

Prepared by:
WEST Consultants, Inc.
8950 S 52nd Street
Suite 210
Tempe, AZ 85284

June 2011
Revised: August 2011

WEST CONSULTANTS, INC.

Registered Professional Engineer (Civil)
CERTIFICATE NO.
41980
BRIAN THOMAS
WAHLIN
Date Signed 08-22-2011
ARIZONA, U.S.A.

Expires 3/31/2014

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Registered Professional Engineer (Civil)
CERTIFICATE NO.
41980
BRIAN THOMAS
WAHLIN
Date Signed 08-22-2011
ARIZONA, U.S.A.
Expires 3/31/2014

1 Introduction

1.1 Purpose

The purpose of this study is to provide certification documentation in support of FEMA's accreditation of the Agua Fria River Levees located along the Agua Fria River south of the Indian School Road vicinity:

- Levee ID #8 – Along the east bank of the Agua Fria River from Indian School Road South to Buckeye Road (4.32 mile)
- Levee ID #16 – Along the east bank of the Agua Fria River at Lower Buckeye Road (0.4 miles)
- Levee ID #18 – Along the west bank of the Agua Fria River from just upstream of Indian School Road to a point downstream of Lower Buckeye Road (approximately 6 miles)

Currently Levee ID #8, #16, and #18 are Provisionally Accredited Levees (PAL) by FEMA and are shown as providing protection from the 1 percent annual chance flood on the most recent Flood Insurance Rate Map (FIRM Panel No 04013C2080J, 04012C2085G, and 04013C2090H). The PAL agreement between the Flood Control District of Maricopa County (FCDMC) and FEMA is due to expire on June 25th, 2011. In order for Levees ID #8, #16, and #18 to continue to be shown as providing flood protection the FIRM Panels beyond the PAL expiration date, levee certifications and FEMA accreditations are necessary.

This report addresses the certification of Levee ID #16 (see Figure 1-1 below).

This revised report reflects minor floodplain revisions based on input from the City of Avondale. There were no major changes between the orignial report (June 2011) and this report (August 2011).

1.2 Certification Team Members

Stanley Consultants (Stanley) updated the effective FEMA HEC-RAS model for the Agua Fria River based on recent topography. WEST Consultants, Inc. (WEST) prepared interior drainage, scour, freeboard analyses, and this certification summary report. The scour and freeboard analyses by WEST were based on the updated Agua Fria HEC-RAS model provided by Stanley.

Geotechnical analyses were performed by AMEC for the east levees (Levee ID #8 and #16).

Survey data for the channel, levee, and culverts under the levee was provided by Wilson & Company, Inc., Engineers and Architects (Wilson).

1.3 Certification Statement

After evaluating the current condition of Levee ID #16 with respect to Title 44 Code of Federal Regulations Section 65.10 (44 CFR 65.10), WEST concludes that Levee ID #16 meets 44 CFR 65.10 requirements based on analysis by the levee certification team (WEST, Stanley, AMEC, and Wilson).
The services provided by all certification team members are for the purpose of providing FCDMC with a certification, as defined in 44 CFR 65.2 (b), of the levee system(s) as required by 44 CFS 65.10 (e). No third party, including adjacent or nearby landowners, is intended to be a beneficiary of these services. The certification is expressly limited to the extent of the definition of "Certification" as provided in 44 CFR 65.2(b):

> *For the purpose of this part, a certification by a registered professional engineer or other party does not constitute a warranty or guarantee of performance, expressed or implied. Certification of data is a statement that the data is accurate to the best of the certifier's knowledge. Certification of analyses is a statement that the analyses have been performed correctly and in accordance with sound engineering practices. Certification of structural works is a statement that the works are designed in accordance with sound engineering practices to provide protection from the base flood. Certification of "as built" conditions is a statement that the structure(s) has been built according to the plans being certified, is in place, and is fully functioning.*

This certification should be reevaluated in ten years or subsequent to a major flood or other event having an impact on the protection provided by the levee system. Should significant unexpected changes occur for reasons such as inadequate operations and maintenance, excessive settlement/subsidence, unexpected streambed aggradation or degradation, or change in hydraulic conditions, such that the subject levee(s) no longer meet certification criteria, these changes must be corrected or the levees will be decertified. Upon decertification, it will be the responsibility of the FCDMC or other entity that desires to retain accreditation of this levee system to pursue recertification.

Figure 1-1. Levee locations

2 Study Documentation

This certification package includes levee hydraulic analysis, geotechnical investigation (including levee as-built drawings), survey data, operation and maintenance plans, and MT-2 forms. The certification package is prepared in compliance with FEMA regulatory requirements for levee certification per 44 CFR 65.10.

2.1 Submittal Package Reports

The analyses performed for the certification of Levee ID #16 by each contractor are summarized in Table 2-1. The documents referenced are provided with this submittal package as separate attachments due to their large size.

Table 2-1. Levee certification document summary

Consultant	Task	Document Name	Document Date
WEST CONSULTANTS, INC.	Scour and analysis for Levee ID #8, #16, and #18	Agua Fria Levee Scour Analysis Report: Levee ID #8, #16, and #18	June 2011
WEST CONSULTANTS, INC.	Freeboard analysis for Levee ID #8, #16, and #18	Agua Fria Levee Freeboard Analysis Report: Levee ID #8, #16, and #18	June 2011
WEST CONSULTANTS, INC.	Interior Drainage analysis for Levee ID #8 and #16 (including interior hydrology for Levee ID #16)	Agua Fria East Levee Interior Drainage Report: Levee ID #8 and #16	June 2011 (revised August 2011)
amec	Geotechnical analysis for Levee ID #8 and #16	Geotechnical Study for Federal Emergency Management Agency (FEMA) Partial Certification PAL ID Nos. 8 and 16 Agua Fria Levee, East Maricopa County, Arizona	June 2011

Stanley Consultants	River Hydraulic analysis for the Agua Fria River, including the subject levees	Agua Fria River Floodplain Re-Delineation, from Salt/Gila River to New River	June 2011 (revised August 2011)
WILSON & COMPANY ENGINEERS & ARCHITECTS	Survey for Agua Fria River, levee, and culverts	Agua Fria Mapping Survey Report	January 2011

2.2 MT-2 Forms

MT-2 Forms for Levee ID #16 are included as Appendix A. The appendix includes sections with the MT-2 forms completed by WEST and AMEC in their respective area of expertise as identified in Table 2-1.

2.3 Operation and Maintenance Plan and Inspection Reports

The operation and maintenance plan (Operation, Maintenance, Repair, Replacement, and Rehabilitation Manual for Phoenix, Arizona and Vicinity, U.S. Army Corps of Engineers) is included in Appendix B. The cooperation agreement between the U.S. Army Corps of Engineers and the FCDMC is also appended to the end of the document in Appendix B.

Sample annual levee inspection reports are provided in Appendix C. Sample maintenance inspection reports are provided in Appendix D.

2.4 Without Levee Floodplain

Per the requirement of FEMA's Procedure Memorandum (PM) 63, the FCDMC provided a without levee floodplain shape file called "Maricopa_approx_floodplains.shp". The without levee floodplain is shown in Figure 2-1 below. This floodplain comes from a study that HDR completed for FEMA in 2009 and that FCDMC has referenced as:

DFIRM 88 NAVD Dewberry and HDR\HDR Levee Embankment Info CD-DVD\April 2009 CD\Embankment_Delin_Shapefiles\Maricopa_apprx_floodplains.shp

Figure 2-1. Without levee floodplain provided by FEMA

APPENDIX A

MT-2 Forms for Levee ID #16

MT-2 Forms for Levee ID #16

Topics: Freeboard, Scour, and Interior Drainage

Prepared by:
WEST Consultants, Inc.

RIVERINE STRUCTURES FORM

O.M.B. NO. 1660-0016
Expires February 28, 2014

PAPERWORK BURDEN DISCLOSURE NOTICE

PRIVACY ACT STATEMENT

Flooding Source: Agua Fria River

Note: Fill out one form for each flooding source studied.

A. GENERAL

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

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

Description of Modeled Structure

1. Name of Structure: Agua Fria Levee ID #16

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

   Location of Structure: East bank of Agua Fria River near Lower Buckeye Road

   Downstream Limit/Cross Section: 3.24

   Upstream Limit/Cross Section: 3.34

2. Name of Structure: ______

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

   Location of Structure: ______

   Downstream Limit/Cross Section: ______

   Upstream Limit/Cross Section: ______

3. Name of Structure: ______

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

   Location of Structure: ______

   Downstream Limit/Cross Section: ______

   Upstream Limit/Cross Section: ______

NOTE: FOR MORE STRUCTURES, ATTACH ADDITIONAL PAGES AS NEEDED.

B. CHANNELIZATION

Flooding Source: ______________________________

Name of Structure: ______________________________

1. Hydraulic Considerations

The channel was designed to carry ________ (cfs) and/or the ______-year flood.

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

☐ Subcritical flow ☐ Critical flow ☐ Super critical flow ☐ Energy grade line

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

☐ Inlet to channel ☐ Outlet of channel ☐ At Drop Structures ☐ At Transitions

☐ Other locations (specify): ______________________________

2. Channel Design Plans

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

3. Accessory Structures

The Channelization includes (check one):

☐ Levees [Attach Section (E Levee/Floodwall)] ☐ Drop structures ☐ Super elevated sections

☐ Transitions in cross sectional geometry ☐ Debris basin/design basin [Attach Section D (Dam/Basin)] ☐ Energy dissipater

☐ Weir ☐ Other (describe): ______________________________

4. Sediment Transport Considerations

Are the hydraulics of the channel affected by sediment transport? ☐ Yes ☐ No

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

C. BRIDGE/CULVERT

Flooding Source: ______________________________

Name of Structure: ______________________________

1. This revision reflects (check one):

☐ Bridge/culvert not modeled in the FIS

☐ Modified bridge/culvert previously modeled in the FIS

☐ New analysis of bridge/culvert previously modeled in the FIS

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

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

☐ Dimensions (height, width, span, radius, length)

☐ Shape (culverts only)

☐ Material

☐ Beveling or Rounding

☐ Wing Wall Angle

☐ Skew Angle

☐ Distance Between Cross Sections

☐ Erosion Protection

☐ Low Chord Elevations - Upstream and Downstream

☐ Top of Road Elevations - Upstream and Downstream

☐ Structure Invert Elevations - Upstream and Downstream

☐ Stream Invert Elevation - Upstream and Downstream

☐ Cross-Section Locations

4. Sediment Transport Considerations

Are the hydraulics of the structure affected by sediment transport? ☐ Yes ☐ No

If Yes, then fill out Section F (Sediment Transport) of Form 3. If no, then attach an explanation.

D. DAM/BASIN

Flooding Source: ______________________

Name of Structure: ______________________

1. This request is for (check one): ☐ Existing dam/basin ☐ New dam ☐ Modification of existing dam/basin
2. The dam/basin was designed by (check one): ☐ Federal agency ☐ State agency ☐ Private organization ☐ Local government agency

   Name of the agency or organization: ______________________
3. The dam was permitted as (check one): ☐ Federal Dam ☐ State Dam

   Provide the permit or identification number (ID) for the dam and the appropriate permitting agency or organization

   Permit or ID number ____________ Permit Agency or Organization: ______________________

   ☐ Local Government Dam ☐ Private Dam

Provide related drawings, specifications and supporting design information.

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

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

Was the dam/basin designed using critical duration storm? (Must account for the maximum volume of runoff)

☐ Yes, provide supporting documents with your completed Form 2.

☐ No, provide written explanation and justification for not using the critical duration storm.

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

   If Yes, then fill out Section F (Sediment Transport). If No, then attach your explanation for why debris/sediment analysis was not considered?
6. Does the Base Flood Elevation behind the dam/basin or downstream of the dam/basin change? ☐ Yes ☐ No

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

FEQUENCY (% annual chance)	Stillwater Elevation Behind the Dam/Basin FIS	REVISED
10-year (10%)		
50-year (2%)		
100-year (1%)		
500-year (0.2%)		
Normal Pool Elevation		

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

E. LEVEE/FLOODWALL

1. System Elements

   a. This Levee/Floodwall analysis is based on (check one): ☐ upgrading of an existing levee/ floodwall system ☐ a newly constructed levee/ floodwall system ☒ reanalysis of an existing levee/ floodwall system

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

   ☒ earthen embankment, dike, berm, etc. Station 3.34 to 3.24

   ☐ structural floodwall Station ______ to ______

   ☐ other (describe): ______________ Station ______ to ______

   c. Structural Type (check one): ☐ monolithic cast-in place reinforced concrete ☐ reinforced concrete masonry block ☐ sheet piling

   ☒ other (describe): Earthen embankment/soil cement bank protection

   d. Has the levee/floodwall system been certified by a Federal agency to provide protection from the base flood? ☐ Yes ☒ No

   If Yes, by which agency? ______________________

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

   1. Plan of the levee embankment and floodwall structures — Sheet Numbers 12-13
   2. A profile of the levee/floodwall system showing the Base Flood Elevation (BFE), levee and/or wall crest and foundation, and closure locations for the total levee system. — Sheet Numbers 12-13
   3. A profile of the BFE, closure opening outlet and inlet invert elevations, type and size of opening, and kind of closure. — Sheet Numbers 17

4. A layout detail for the embankment protection measures. Sheet Numbers 15

5. Location, layout, and size and shape of the levee embankment features, foundation treatment, floodwall structure, closure structures, and pump stations. Sheet Numbers 15

2. Freeboard

a. The minimum freeboard provided above the BFE is:

8.0 feet

Riverine

3.0 feet or more at the downstream end and throughout ☒ Yes ☐ No

3.5 feet or more at the upstream end ☒ Yes ☐ No

4.0 feet within 100 feet upstream of all structures and/or constrictions ☒ Yes ☐ No

Coastal

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

2.0 feet above the 1%-annual-chance stillwater surge elevation ☐ Yes ☐ No

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

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

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

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

3. Closures

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

If opening exists, list all closures:

Channel Station	Left or Right Bank	Opening Type	Highest Elevation for Opening Invert	Type of Closure Device
3.27	Left	Culvert	947.6	Flap gate

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

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

4. Embankment Protection

a. The maximum levee slope land side is: 3H:1V

b. The maximum levee slope flood side is: 1H:1V

c. The range of velocities along the levee during the base flood is: 4.3 (min.) to 4.5 (max.)

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

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

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

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

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

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

N/A

Attach engineering analysis to support construction plans.

5. Embankment and Foundation Stability

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

____

☐ Overall height: Sta.: ______________ , height ________ ft.

☐ Limiting foundation soil strength

Strength ϕ = ________ degrees, c = ________ psf

Slope: SS = ________ (h) to ________ (v)

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

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

____

c. Summary of stability analysis results:

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

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

E. LEVEE/FLOODWALL (continued)

5. Embankment and Foundation Stability (continued)

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

If Yes, describe methodology used: ____________________

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

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

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

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

Attach engineering analysis to support construction plans.

6. Floodwall and Foundation Stability

a. Describe analysis submittal based on Code (check one): ☐ UBC (1988) ☐ Other (specify): ____________

b. Stability analysis submitted provides for: ☐ Overturning ☐ Sliding If not, explain: ____________

c. Loading included in the analysis were: ☐ lateral earth @ P_A= ______psf; Pp = psf

☐ Surcharge-Slope @ ________, ☐ surface ________psf

☐ Wind @ Pw = ________psf

☐ Seepage (Uplift): ____________ ☐ Earthquake @ Peq = ________%g

☐ 1%-annual-chance significant wave height ________ft.

☐ 1%-annual-chance significant wave period ________sec.

d. Summary of Stability Analysis Results: Factors of Safety.
Itemize for each range in site layout dimension and loading condition limitation for each respective reach.

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

(Ref: FEMA 114 Sept. 1986; USACE EM 1110-2-2502)
Note: (Extend table on an added sheet as needed and reference)

e. Foundation bearing strength for each soil type:

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

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

Attach engineering analysis to support construction plans.

7. Settlement

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

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

E. LEVEE/FLOODWALL (continued)

7. Settlement (continued)

c. Settlement of the levee crest is determined to be primarily from: ☐ Foundation consolidation ☐ Embankment compression

☐ Other (describe): ______________________________

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

Attach engineering analysis to support construction plans.

8. Interior Drainage

a. Specify size of each interior watershed:

Draining to pressure conduit: ________ acres

Draining to ponding area: ________ acres

b. Relationships Established

Ponding elevation vs. storage ☒ Yes ☐ No

Ponding elevation vs. gravity flow ☐ Yes ☒ No

Differential head vs. gravity flow ☐ Yes ☒ No

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

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

e. Which flooding conditions were analyzed?

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

If No for any of the above, attach explanation.

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

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

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

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

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

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

Will the operation be automatic? ☐ Yes ☐ No

8. Interior Drainage (continued)

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

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

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

9. Other Design Criteria

a. The following items have been addressed as stated:

Liquefaction ☐ is ☐ is not a problem

Hydrocompaction ☐ is ☐ is not a problem

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

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

Attach supporting documentation.

c. If the levee/floodwall is new or enlarged, will the structure adversely impact flood levels and/or flow velocities flood side of the structure?

☐ Yes ☐ No Attach supporting documentation.

d. Sediment Transport Considerations:

Was sediment transport considered? ☐ Yes ☒ No

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

10. Operational Plan and Criteria

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

b. Does the operation plan incorporate all the provisions for closure devices as required in Paragraph 65.10(c)(1) of the NFIP regulations?

☒ Yes ☐ No

c. Does the operation plan incorporate all the provisions for interior drainage as required in Paragraph 65.10(c)(2) of the NFIP regulations?

☒ Yes ☐ No If the answer is No to any to the above, please attach supporting documentation.

11. Maintenance Plan

a. Are the planned/installed works in full compliance with Part 65.10 of the NFIP regulations?

☒ Yes ☐ No If No please attach supporting documentation.

12. Operations and Maintenance Plan

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

CERTIFICATION OF THE LEVEE DOCUMENTATION

This certification is to be signed and sealed by a licensed registered professional engineer authorized by law to certify elevation information data, hydrologic and hydraulic, and any other supporting information as per NFIP regulations paragraph 65.10(e) and as described in the MT-2 Forms Instructions. All documents submitted in support of this request are correct to the best of my knowledge. I understand that any false statements may be punishable by fine or imprisonment under Title 18 of the United States Code, Section 1001.

Registered Professional Engineer (Civil)
CERTIFICATE NO.
41980
BRIAN THOMAS
WAHLIN
Date Signed
ARIZONA, U.S.A.

Certifier's Name	License No.	Expiration Date
Brian Wahlin	41980	Mar 31, 2014

Company Name	Telephone No.	Fax No.
WEST Consultants, Inc.	480-345-2155	480-345-2156

Signature	Date	E-Mail Address
[signature]	Jun 20, 2011	bwahlin@westconsultants.com

F. SEDIMENT TRANSPORT

Flooding Source: ____________________

Name of Structure: ____________________

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

Sediment load associated with the base flood discharge: Volume ________ acre-feet

Debris load associated with the base flood discharge: Volume ________ acre-feet

Sediment transport rate ________ (percent concentration by volume)

Method used to estimate sediment transport: ____________________

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

Method used to estimate scour and/or deposition: ____________________

Method used to revise hydraulic or hydrologic analysis (model) to account for sediment transport: ____________________

Please note that bulked flows are used to evaluate the performance of a structure during the base flood; however, FEMA does not map BFEs based on bulked flows.

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

Additional Information for Agua Fria Levee ID #16

Section E, Item 4e: Embankment Design Parameters

For the embankment design parameters for the soil cement embankment protection, see Appendix A of the scour report included in the submittal.

Section E, Item 8a: Interior Watershed Sizes

For information on watershed sizes, see interior drainage report and corresponding appendices included in the submittal.

Section E, Item 8e: Items Addressed

No information on historic ponding was available so historical ponding probability was not considered. Levee is not located near the coast, so coastal wave overtopping was not considered.

Section E, Item 9d: Sediment Transport Considerations

Sediment transport was considered in the original design of the levee.

MT-2 Forms for Levee ID #16

Topic: Geotechnical Considerations

Prepared by:
AMEC

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

RIVERINE STRUCTURES FORM

O.M.B No. 1660-0016
Expires: 12/31/2010

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

A. GENERAL

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

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

Description Of Structure

1. **Name of Structure:** **Agua Fria East Levee**

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

   Location of Structure: Maricopa County, Arizona

   Downstream Limit/Cross Section: Milepost 3.25 (200 feet south of Lower Buckeye Road), East side of river

   Upstream Limit/Cross Section: Milepost 8.51 (400 feet north of Indian School Road), East side of River

2. **Name of Structure:**

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

   Location of Structure:

   Downstream Limit/Cross Section:

   Upstream Limit/Cross Section:

3. **Name of Structure:**

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

   Location of Structure:

   Downstream Limit/Cross Section:

   Upstream Limit/Cross Section:

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

B. CHANNELIZATION

NOT APPLICABLE

Flooding Source:

Name of Structure:

1. Accessory Structures

The channelization includes (check one):

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

2. Drawing Checklist

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

3. Hydraulic Considerations

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

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

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

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

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

4. Sediment Transport Considerations

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

C. BRIDGE/CULVERT

NOT APPLICABLE

Flooding Source:

Name of Structure:

1. This revision reflects (check one):

- ☐ Bridge/culvert not modeled in the FIS
- ☐ Modified bridge/culvert previously modeled in the FIS
- ☐ Revised analysis of bridge/culvert previously modeled in the FIS

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

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

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

4. Sediment Transport Considerations

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

NOT APPLICABLE

Flooding Source:

Name of Structure:

1. This request is for (check one): ☐ Existing dam ☐ New dam ☐ Modification of existing dam
2. The dam was designed by (check one): ☐ Federal agency ☐ State agency ☐ Local government agency ☐ Private organization

   Name of the agency or organization:

3. The Dam was permitted as (check one):

   a. ☐ Federal Dam ☐ State Dam

   Provide the permit or identification number (ID) for the dam and the appropriate permitting agency or organization

   Permit or ID number Permitting Agency or Organization

   b. ☐ Local Government Dam ☐ Private Dam

   Provided related drawings, specification and supporting design information.

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

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

   Was the dam/basin designed using critical duration storm?

   ☐ Yes, provide supporting documentation with your completed Form 2.

   ☐ No, provide a written explanation and justification for not using the critical duration storm.

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

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

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

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

   Stillwater Elevation Behind the Dam

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

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

E. LEVEE/FLOODWALL

1. System Elements

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

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

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

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

   East Side of Agua Fria River
   Milepost 3.25 (200 feet south of Lower Buckeye Road) to
   Milepost 8.51 (400 feet north of Indian School Road)

   c. Structural Type (check one):

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

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

   ☐ Yes ☐ No

   If Yes, by which agency?

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

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

2. Freeboard

   a. The minimum freeboard provided above the BFE is:

   Riverine

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

   Coastal

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

2. Freeboard (continued)

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

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

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

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

3. Closures

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

If opening exists, list all closures:

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

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

Note: Geotechnical and geologic data

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

4. Embankment Protection

a. The maximum levee slope landside is: 3H:1V

b. The maximum levee slope floodside is: 1H:1V

c. The range of velocities along the levee during the base flood is: 3.13 ft/sec (min.) to 11.5 ft/sec (max.)

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

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

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

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

4. Embankment Protection (continued)

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

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

Attach engineering analysis to support construction plans.

5. Embankment And Foundation Stability

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

Milepost	Overall Height	Basis for Selection
MP 8.42	14	Height of soil cement slope above ground
MP 8.37	14	Height of soil cement slope above ground
MP 7.72	15	Height of soil cement slope above ground
MP 7.38	13	Depth of soil cement slope below ground
MP 7.03	15	Height of embankment
MP 6.49	10	Depth of soil cement slope below ground
MP 6.10	13	Height of embankment
MP 5.67	10	Embankment make completely of soil cement
MP 5.36	8	Height of soil cement slope above ground
MP 4.98	10	Height of soil cement slope above ground
MP 4.57	14	Height of soil cement slope above ground
MP 4.24	17	Height of soil cement slope above ground
MP 3.33	8	Depth of soil cement slope below ground

☒ Overall height: See table above

☒ Limiting foundation soil strength:

Description	Moist Unit Weight, □(pcf)	Effective Friction Angle, Φ' °	Effective Cohesion, c' psf	Saturated Hydraulic Conductivity, K_{sat} cm/s	Young's Modules E' psf
Embankment	120	28.5	200	6×10^{-5}	1×10^{6}
So□l cement	125	20	500	1×10^{-7}	1×10^{7}
Foundation backfill	100	33.5	100	5×10^{-5}	1×10^{6}
Native soil	120	30	200	5×10^{-5}	1×10^{5}

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

The slopes were analyzed using the general limit equilibrium method that produces a circular failure surface.

c. Summary of stability analysis results:

Case	Loading Conditions	Critical Safety Factor	Criteria (Min.)
I	End of construction	1.70 at MP 5.36 (Case 1B)	1.3
II	Sudden drawdown	1.26 at MP 8.42 (Case 2B)	1.0
III	Steady seepage at flood stage	2.58 at MP 7.03 (Case 3A)	1.4
IV	Earthquake (Case I)	1.47 at MP 5.36 (Case 4B)	1.0

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

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

If Yes, describe methodology used: SEEP/W was used to evaluate seepage under and through the levee for each critical section.

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

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

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

h. The duration of the base flood hydrograph against the embankment is approximately __ hours (based on the 100-year storm as a percent of the SPF).

Attach engineering analysis to support construction plans.

NOT APPLICABLE

6. Floodwall And Foundation Stability

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

☐ UBC (1988) or ☐ Other (specify):

b. Stability analysis submitted provides for:

☐ Overturning ☐ Sliding If not, explain:

c. Loading included in the analyses were:

☐ Lateral earth @ P_A = psf; P_p = psf

☐ Surcharge-Slope @ , ☐ surface psf

☐ Wind @ P_w = psf

☐ Seepage (Uplift); ☐ Earthquake @ P_e = %g

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

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

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

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

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

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

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

e. Foundation bearing strength for each soil type:

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

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

Attach engineering analysis to support construction plans.

7. Settlement

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

b. The computed range of settlement is 0.037 ft. to 0.14 ft.

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

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

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

Attach engineering analysis to support construction plans.

8. Interior Drainage

a. Specify size of each interior watershed:

Draining to pressure conduit:
Draining to ponding area:

b. Relationships Established

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

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

d. Specify the discharge capacity of the head pressure conduit: __ cfs See discussion in **Section 2**

e. Which flooding conditions were analyzed?

• Gravity flow (Interior Watershed)	☐ Yes	☐ No
• Common storm (River Watershed)	☐ Yes	☐ No
• Historical ponding probability	☐ Yes	☐ No (Not applicable)
• Coastal wave overtopping	☐ Yes	☐ No (Not applicable)

If No for any of the above, attach explanation.

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

If No, attach explanation.

g. The rate of seepage through the levee system for the base flood is cfs (Seepage due to interior drainage was not analyzed)

h. The length of levee system used to drive this seepage rate in item g: ft. (Seepage due to interior drainage was not analyzed)

8. Interior Drainage (continued)

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

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

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

NOT APPLICABLE

Will the operation be automatic? ☐ Yes ☐ No

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

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

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

9. Other Design Criteria

a. The following items have been addressed as stated:

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

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

Attach supporting documentation

c. If the levee/floodwall is new or enlarged, will the structure adversely impact flood levels and/or flow velocities floodside of the structure?
☐ Yes ☐ No Not Applicable

Attach supporting documentation

d. Sediment Transport Considerations:

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

Sediment Studies considered in the USACE design of the levee. .

E. LEVEE/FLOODWALL (CONTINUED)

10. Operational Plan And Criteria

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

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

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

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

11. Maintenance Plan

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

12. Operations and Maintenance Plan

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

See portions or the Operation, Maintenance, Repair, Replacement, and Rehabilitation Manual, November 2009 in **Appendix G**, with the full document on CD in **Appendix L**

F. SEDIMENT TRANSPORT

Flooding Source:

Name of Structure:

Sediment Studies considered in the USACE design of the levee. See GDM Appendix 3, Sediment Study located in Appendix C.

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

Sediment load associated with the base flood discharge: Volume acre-feet

Debris load associated with the base flood discharge: Volume acre-feet

Sediment transport rate (percent concentration by volume)

Method used to estimate sediment transport:

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

Method used to estimate scour and/or deposition:

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

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

APPENDIX B

Operation and Maintenance Plan

Operation and Maintenance Plan included on DVD

APPENDIX C

Sample Annual Levee Inspection Reports

Sample Annual Levee Inspection Reports included on DVD

APPENDIX D

Sample Maintenance Inspection Reports

Sample Maintenance Inspection Plans included on DVD

APPENDIX E

Levee As-Built Plans

Levee As-Built Plans included on DVD

Agua Fria East Levee Interior Drainage Report: Levee IDs #8 and #16

Contract Number: FCD 2010C027 Assignment #5

Prepared for:
Flood Control District of Maricopa County
2801 West Durango Street
Phoenix, AZ 85009

Prepared by:
WEST Consultants, Inc.
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June 2011
Revised: August 2011

WEST
CONSULTANTS, INC.

Registered Professional Engineer (Civil)
CERTIFICATE NO.
41980
BRIAN THOMAS
WAHLIN
Date Signed 08-22-2011
ARIZONA, U.S.A.

Expires 3/31/2014

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Registered Professional Engineer (Civil) CERTIFICATE NO. 41980 BRIAN THOMAS WAHLIN Date Signed 08-22-2011 ARIZONA, U.S.A. Expires 3/31/2014

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Appendix A. Lower Buckeye Hydrology

Appendix B. Durango Area Drainage Master Plan Report

Appendix C. Glendale Area Stormwater Management Plan Report

List of Abbreviations

ADMS .... Area Drainage Master Study

ADMP .... Area Drainage Master Plan

ADMPU .... Area Drainage Master Plan Update

DDMSW .... Drainage Design Management System for Windows

FEMA .... Federal Emergency Management Agency

FCDMC .... Flood Control District of Maricopa County

FIS .... Flood Insurance Study

GIS .... Geographic Information System

NAD 83 .... North American Datum of 1983

NAVD 88 .... North American Vertical Datum of 1988

NGVD 29 .... National Geodetic Vertical Datum of 1929

NOAA....................................National Oceanic and Atmospheric Administration

PAL..Provisionally Accredited Levee

WEST.....................................WEST Consultants, Inc.

WSE.......................................Water Surface Elevation

1 Introduction

1.1 Purpose

The purpose of this interior flooding analysis is to provide certification documentation in support of FEMA's accreditation of the Agua Fria River Levees located along the Agua Fria River south of the Indian School Road vicinity:

- Levee ID #8 – Along the east bank of the Agua Fria River from Indian School Road South to Buckeye Road (4.32 mile)
- Levee ID #16 – Along the east bank of the Agua Fria River at Lower Buckeye Road (0.4 miles)
- Levee ID #18 – Along the west bank of the Agua Fria River from just upstream of Indian School Road to a point downstream of Lower Buckeye Road (approximately 6 miles)

Currently Levee ID #8, #16, and #18 are Provisionally Accredited by FEMA and are shown as providing protection from the 1 percent annual chance flood on the most recent Flood Insurance Rate Maps (FIRM Panel No 04013C2080J, 04012C2085G, and 04013C2090H). The Provisionally Accredited Levee (PAL) agreement between the Flood Control District of Maricopa County (FCDMC) and FEMA is due to expire on June 25th, 2011. In order for Levee ID #8, #16, and #18 to continue to be shown as providing flood protection the FIRM Panels beyond the PAL expiration date, levee certifications and FEMA accreditations are necessary. The levee locations are shown in Figure 1-1 below.

This report addresses the interior flooding analysis for Levee ID #8 and #16 along the east bank of the Agua Fria River. The dominant drainage direction of the interior drainage on the east side of the river is from northeast to southwest.

This revised report reflects minor floodplain revisions based on input from the City of Avondale. There were no major changes between the orignial report (June 2011) and this report (August 2011).

Figure 1-1. Levee Locations

1.2 Previous Reports

There are multiple previous reports available for the study areas that were provided by the FCDMC. The *Glendale Area Stormwater Management Plan* (FCDMC, 2011) is an update to the Maryvale Area Drainage Master Study (ADMS) and the Glendale/Peoria Area Drainage Master Plan Update (ADMPU) and is the basis of the interior drainage hydrology for Levee ID #8. The *Durango Area Drainage Master Plan* (FCDMC, 2003) was also referenced to evaluate hydrology in the vicinity of Levee ID #8 and #16 (refer to Section 2.1 for further discussion of the basis of hydrology for Levee ID #16). Both the Glendale/Peoria ADMPU and the Durango ADMP make use of the topography described in the Maryvale ADMS.

Background information on the Union Pacific Railroad Ditch (formerly the Southern Pacific Railroad Ditch), which is located just north of Buckeye Road/State Highway 85, was obtained from a Letter of Map Revision (LOMR) for the Coldwater Springs development (CMX, 2002) as well as the *Floodplain Delineation of the Tolleson Area* report (JE Fuller, 1999.

1.3 Datum

All geographic and spatial data used in this study were adjusted to a horizontal datum of North American Datum of 1983 (NAD 83) HARN State Plane Arizona Central (FIPS 0202 International Feet) and the North American Vertical Datum of 1988 (NAVD 88).

2 Hydrology

2.1 Introduction

The hydrology for Levee ID #16 was calculated by WEST for this study because previous studies did not accurately reflect recent development. The subbasin tributary to Levee ID #16 was estimated from the 2-foot contour interval topography (see Section 2.2) and finalized based on field observations from a site visit on May 3, 2011. Other hydrologic parameters input to the Design Management System for Windows (DDMSW) Version 4.6 program such as land use data and longest flow path were estimated from the site visit, topography, and aerial photography. The DDMSW model generates an HEC-1 model, which was used to evaluate the interior flooding for Levee ID #16. Hydrologic backup data including the subbasin boundary, landuse data, longest flow path, and HEC-1 input/output data is provided in Appendix A.

The hydrologic data for Levee ID #8 was available from previous reports (see Section 1.2 and Table 2-1). This hydrologic data includes input/output for HEC-1 and Design DDMSW Version 4.6 models. Hydrologic reports for the studies identified in Table 2-1 are provided in Appendix B and C. Modifications to the precipitation data were necessary to the Durango ADMP model (see Section 2.3); otherwise no other changes were made to the models provided by FCDMC.

Table 2-1. Hydrologic Model Data for Levee ID #8

Report	Consultant	Year	HEC-1 Model
Maryvale ADMS	Kimley-Horn and Associates	2010	glendale smp-mv24ec.dat
Durango ADMP	Dibble and Associates	2003	1084.dat

2.2 Topography

Topographic data was provided by the FCDMC in six topographic datasets. These six datasets, including filename identifiers used by WEST, are as follows:

- 2-ft contour data for the Agua Fria River – ID = Agua Fria DTM
- 2-ft contour data from Loop 303/White Tanks ADMPU – ID = elvln 1003
- 2-ft contour data from Maryvale ADMS (aka Glendale ASMP) – ID = elvln 1005
- 2-ft contour data from Gillespie ADMS – ID = elvln 1290
- 2-ft contour data from Agua Fria Mapping – ID = elvln 1293
- 1-ft contour data for small area north of McDowell Road – ID = Avondale Topography

Figure 2-1 shows the location of each topographic dataset. Four of the datasets were in the NAVD 88 vertical datum and two were provided in the NGVD 29 datum. The NGVD 29 data were converted to NAVD 88 using the conversion raster provided by the FCDMC. The data were then combined into one 10-ft raster.

These topographic data were used to evaluate the depth of ponding for interior areas adjacent to the levees. Many of the interior areas include nearby gravel pits that are subject to frequent changes in topography. When necessary, the 10-ft raster topography was modified by filling in the gravel pits to the surrounding ground elevation to avoid overestimating the available flood storage volume.

Certification for the various topographic sources appears in the corresponding study.

2.3 Precipitation

The precipitation data used for the interior drainage analysis was based on NOAA Atlas 14 data. Table 2-2 shows the 100-year, 24-hour NOAA Atlas 14 average precipitation used for the interior drainage evaluations.

Table 2-2. 100-year, 24-hour NOAA Atlas 14 Precipitation Depths

Model	Point Precipitation (in)
Maryvale ADMS	3.45
Durango ADMP	3.43

2.4 Exterior Stage and Reservoir Routing

The approach for evaluating the maximum ponding elevation for each interior flooding area is summarized in the following steps:

1. Identify the inflow hydrograph to each interior area adjacent to the levee after running the HEC-1 model generated by the DDMSW program.
2. Identify the culvert(s) draining each interior area, and interpolate the maximum exterior water surface elevation at each culvert.
3. Develop the area-elevation-storage relationship for each interior area.
4. Create an HEC-HMS Version 3.5 model for each interior area with a reservoir element to account for the interior storage, an inflow hydrograph to the reservoir element (from HEC-1), an orifice or culvert element to account for the submerged discharge of the culvert(s) under the levee to the river, and a fixed exterior stage representing the maximum exterior water surface elevation.
5. Run HEC-HMS to compute the maximum interior ponding elevation, accounting for the reservoir routing.

From the steps described above, flow from the interior area to the river will only occur when the interior area water surface elevation exceeds the maximum 100-year water surface elevation in the Agua Fria River (plus the head loss of the flap gate).

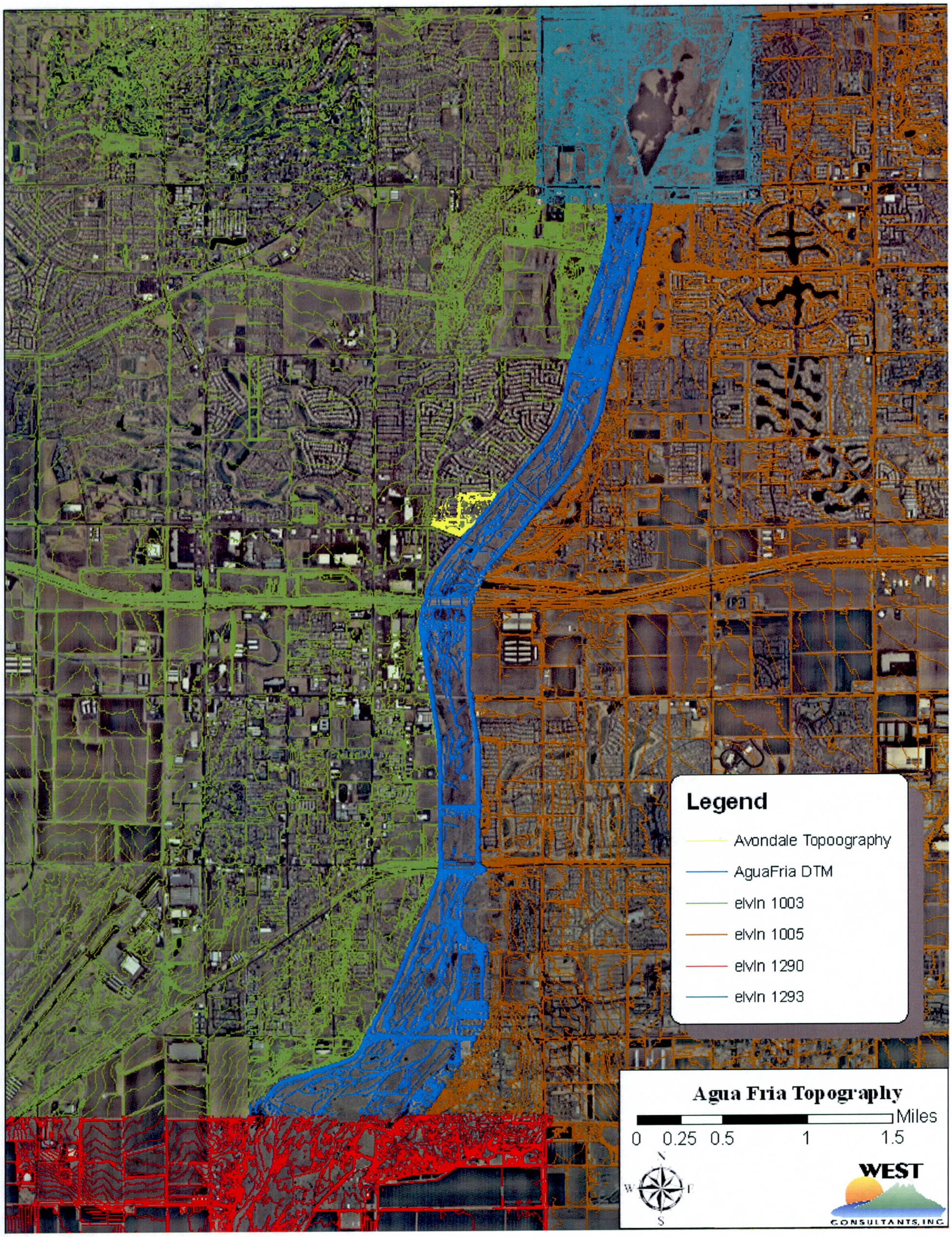

Figure 2-1. Topographic Data Sources

3 Results

3.1 Head Loss

Levee ID #16 is the only location along the east levee in which the interior ponding elevations reach the culvert invert and exceed the maximum water surface elevation of the Agua Fria River. However, the interior elevation is only slightly higher than the exterior elevation and not high enough to overcome the head loss due to the flap gate, which was calculated based on recommendations in the U.S. Army Corps of Engineers Hydraulic Design Criteria (USACE, 1987). A relationship developed by Nagler (provided in Hydraulic Design Chart 340-1) estimates the flap gate head loss coefficient as a function of the culvert diameter and velocity head. The head loss in feet of water is obtained by multiplying Nagler's head loss coefficient by the velocity head. WEST calculated the flap gate head loss for a range of velocities which revealed that the head loss is lower at both high and low velocities than for mid-range velocities. WEST selected the maximum head loss for all velocities as the adopted head loss for the Levee ID #16 culvert.

The adopted head loss of 0.31 feet for Levee ID #16 is greater than the difference between the interior and exterior stages, so no flow was assumed in the culvert. Therefore, the HEC-HMS modeling described in Section 2.4 was not necessary for the east levee. The entire hydrograph volume calculated for the interior area was mapped as the floodplain.

3.2 Maximum Ponding Elevations

HEC-1 model output was reviewed to identify the hydrograph volume flowing to each interior area that is blocked by Levee ID #8 and ID #16. There are three locations along Levee ID #8 and ID# 16 that WEST identified as an interior area blocked by the levee (see Figure 3-1). For each area, WEST calculated the water surface elevation resulting from the entire hydrograph volume ponding in the interior area adjacent to the levee. Table 3-1 summarizes hydrologic results for the Levee ID #8 and #16 interior areas.

Table 3-1. East Levee Interior Area Hydrologic Results

Location	Subbasin Name	Ponding Area ID	HEC-1 Node	Storage Volume (ac-ft)	Peak Flow (cfs)	Time to Peak (hr)	Maximum Interior WSEL (ft)
RID Canal to Thomas Rd.	TMAF	tmaf_pond	DWAF02	107.4	390	13.5	946.18
Thomas Rd. to McDowell Rd.	MDAF	mdaf_pond	DWAF03	99.3	286	14.5	983.15
Rio Vista Lane to End of Levee (near Lower Buckeye Rd.)	Lower Buckeye	kb_pond	1C1B	3.35	35	12.17	950.06

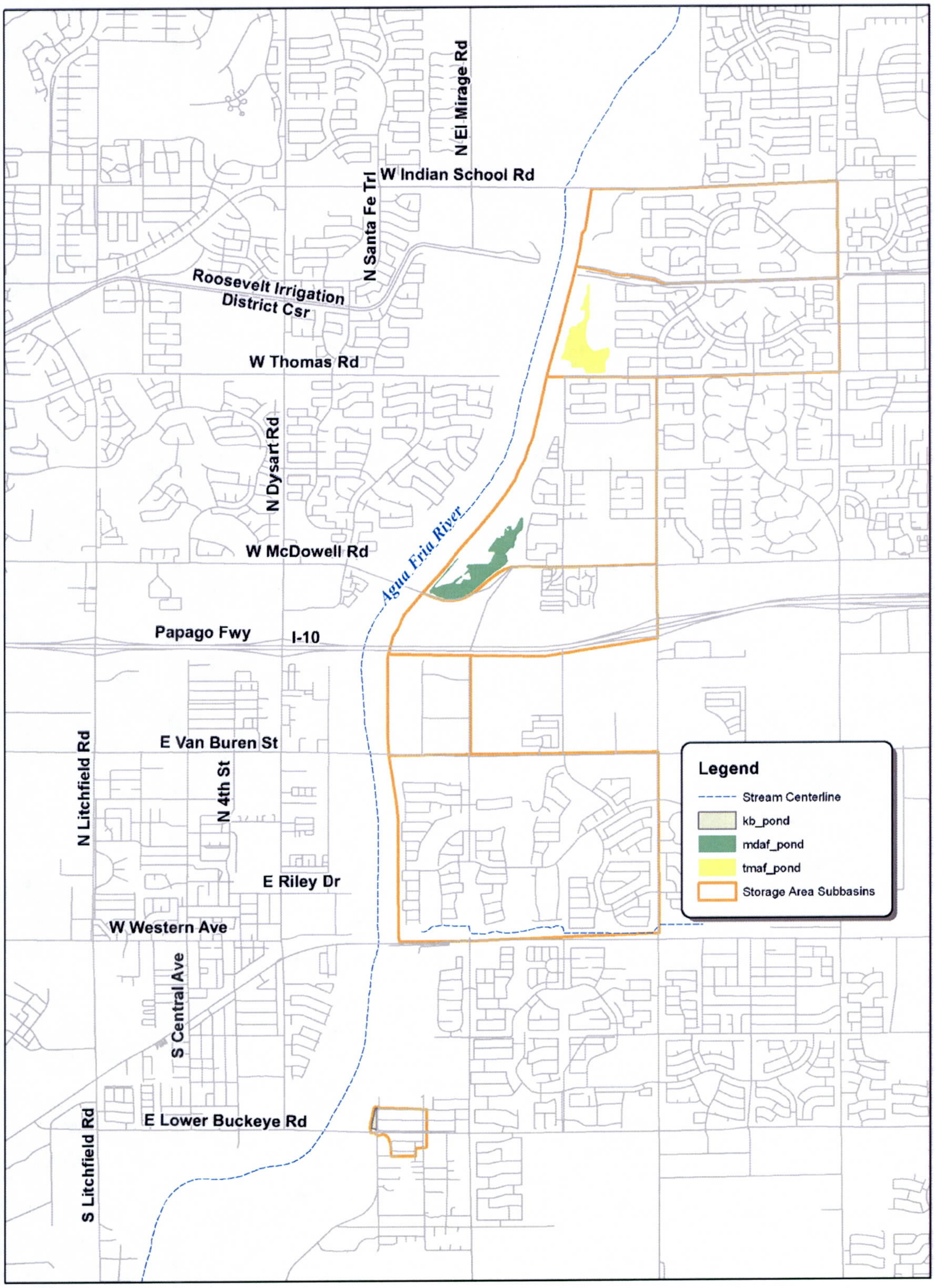

Figure 3-1. Location Map of the Various Ponding Areas

3.3 Interior Area Floodplain Revisions

The floodplain and maximum water surface elevations for interior areas adjacent to Levee ID #8 and #16 are shown in Figure 3-2 through Figure 3-11. For each interior area, two floodplain figures are presented—one with a current aerial photo and topography in the background and another with the effective DFIRM in the background. Both figures include a polygon labeled "subbasin adjacent to the levee." This subbasin is the most downstream subbasin adjacent to the levee. The entire basin tributary to each interior area could not be easily shown in a figure due to lateral flow between basins upstream (see Appendix B and C for additional discussion of lateral flow assumptions). Interior areas are identified in this report based on the bounding streets and/or landmarks along the levee.

3.3.1 Levee ID #8: Indian School Road to Roosevelt Irrigation District (RID) Canal

The interior area from the Indian School Road to Roosevelt Irrigation District (RID) Canal is shown in Figure 3-2 The Maryvale ADMS indicates that all the flow for the subbasin behind this section of the levee is diverted to the north before flowing to the Agua Fria River. Therefore, no ponding is anticipated between Indian School Road and the RID.

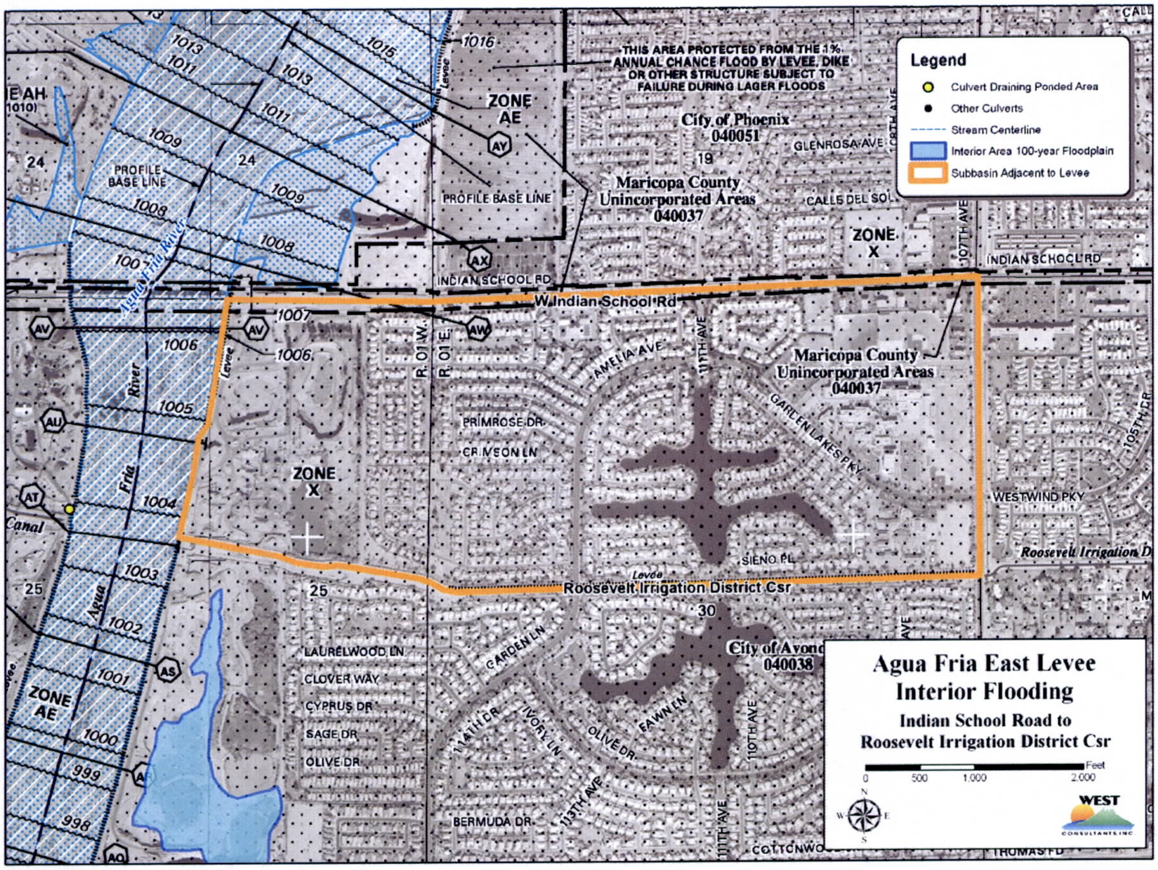

Figure 3-2. Interior Area Between Indian School Road and Roosevelt Irrigation District Canal (Effective Floodplain)

3.3.2 Levee ID #8: RID Canal to Thomas Road

The interior area from the RID Canal to Thomas Road is shown in Figure 3-3 and Figure 3-4. The area consists of mostly residential landuse and a large gravel pit next to the levee. The gravel pit in this area is highly regulated by the FCDMC. The revised floodplain shows interior ponding in the gravel pit that is not high enough to reach the culvert under the levee. It is proposed that this floodplain be added to the FIRM (even though it is a gravel pit) to communicate the possible flooding hazard if the gravel pit is ever backfilled and developed.

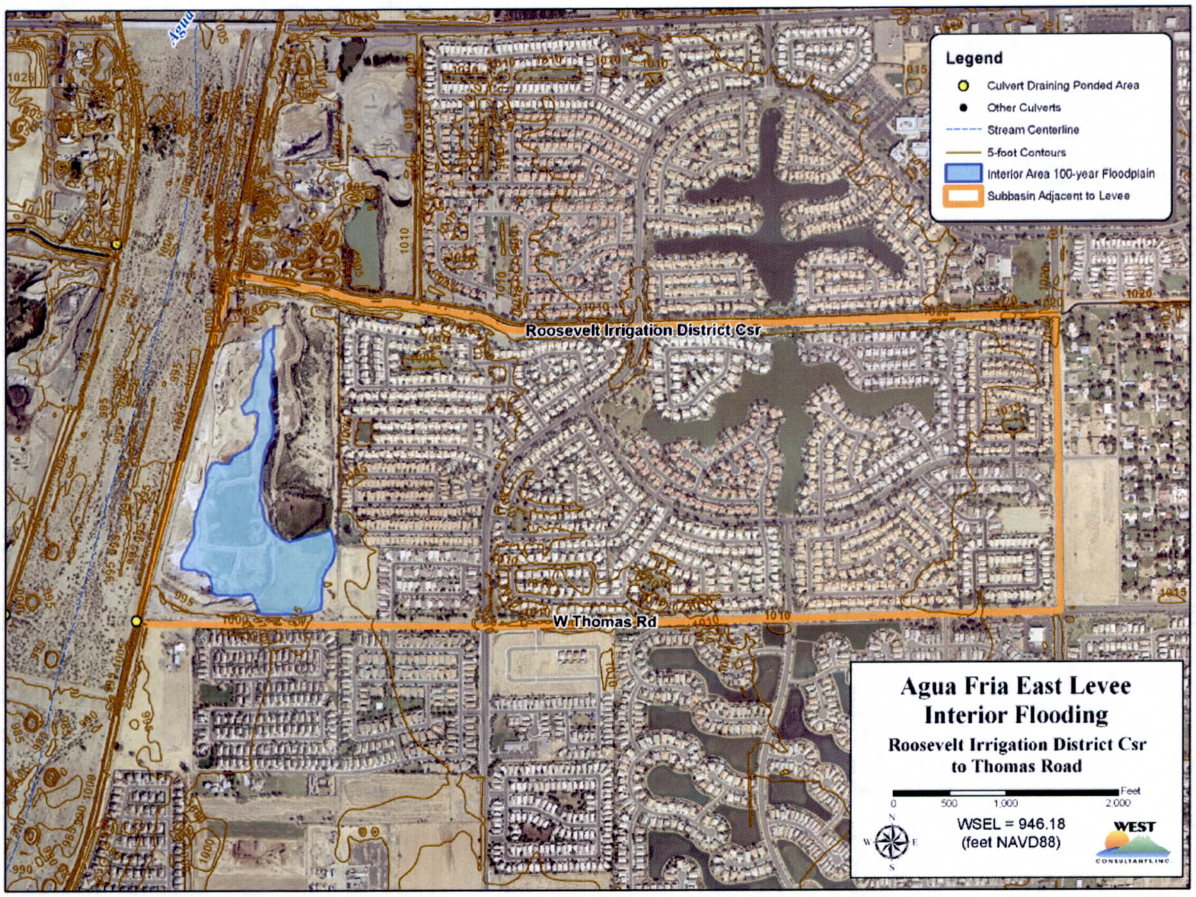

Figure 3-3. Interior Flooding Between Roosevelt Irrigation District Canal and Thomas Road (Revised Floodplain)

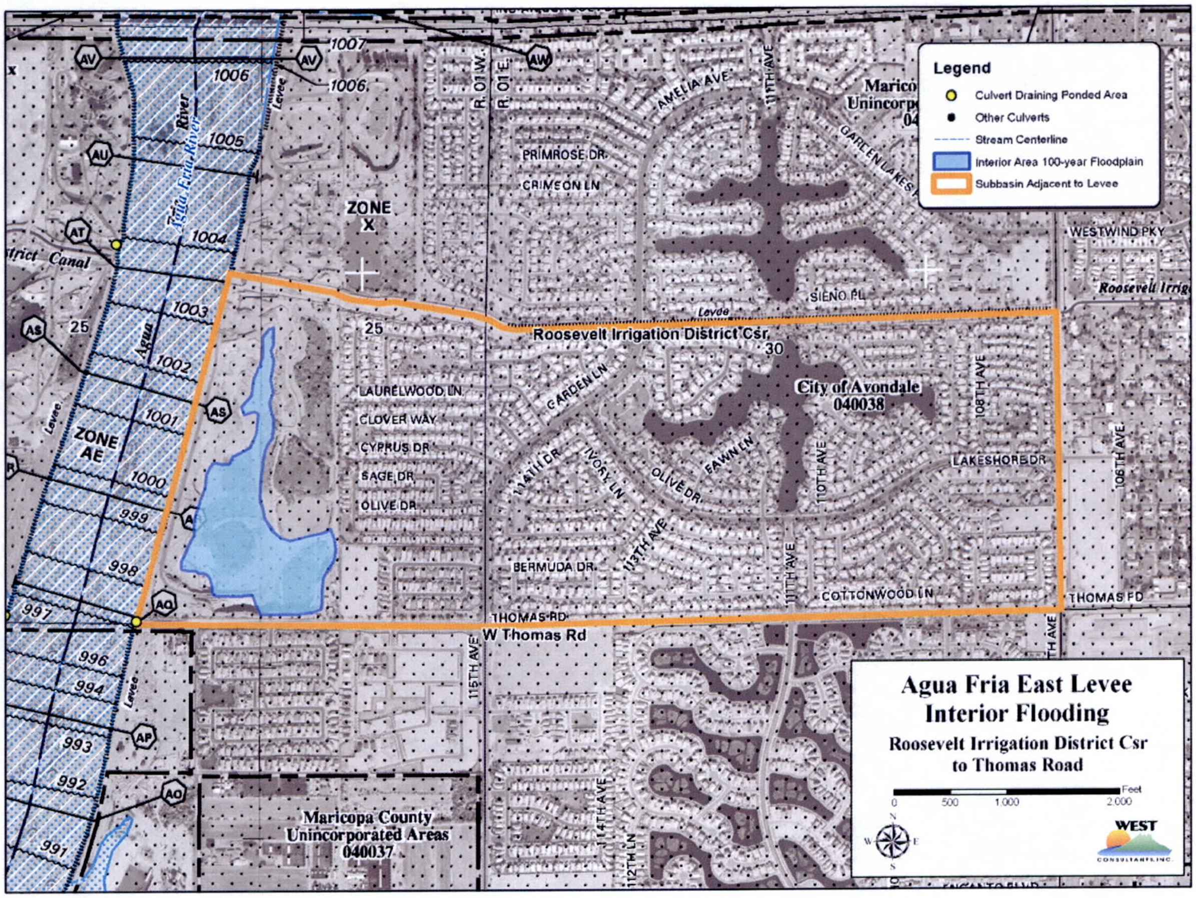

Figure 3-4. Interior Flooding Between Roosevelt Irrigation District Canal and Thomas Road (Revised and Effective Floodplains)

3.3.3 Levee ID #8: Thomas Road to McDowell Road

The interior area from Thomas Road to McDowell Road is shown in Figure 3-5 and Figure 3-6. The area consists of mostly residential landuse except the southwest corner, which is vacant open space. The revised floodplain is similar to the DFIRM but with less flooding.

Figure 3-5. Interior Flooding Between Thomas Road and McDowell Road (Revised Floodplain)

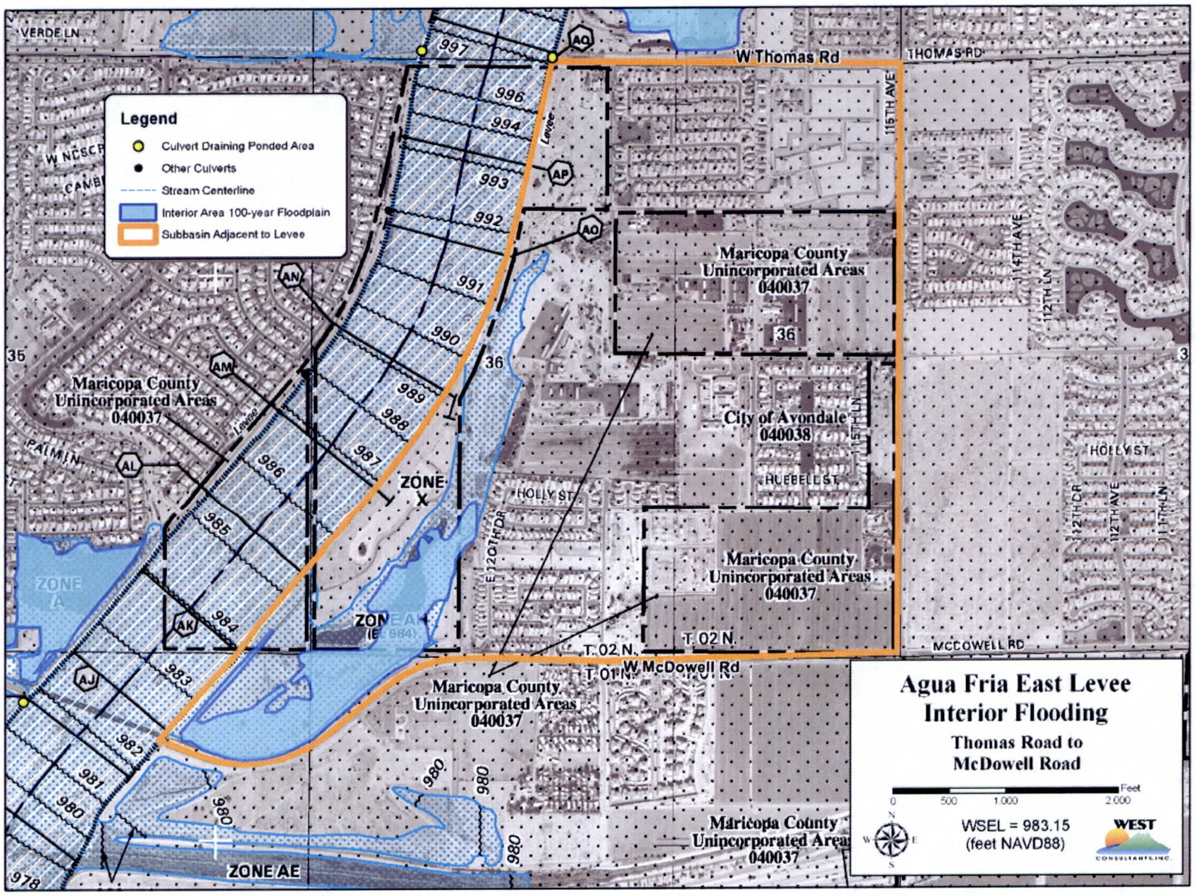

Figure 3-6. Interior Flooding Between Thomas Road and McDowell Road (Revised and Effective Floodplains)

3.3.4 Levee ID #8: McDowell Road to Interstate 10

The area from McDowell Road to Interstate 10 is shown in Figure 3-7. This subbasin drains to the I-10 Channel (Zone AE) which flows directly into the Agua Fria River and therefore is not an interior flooding area.

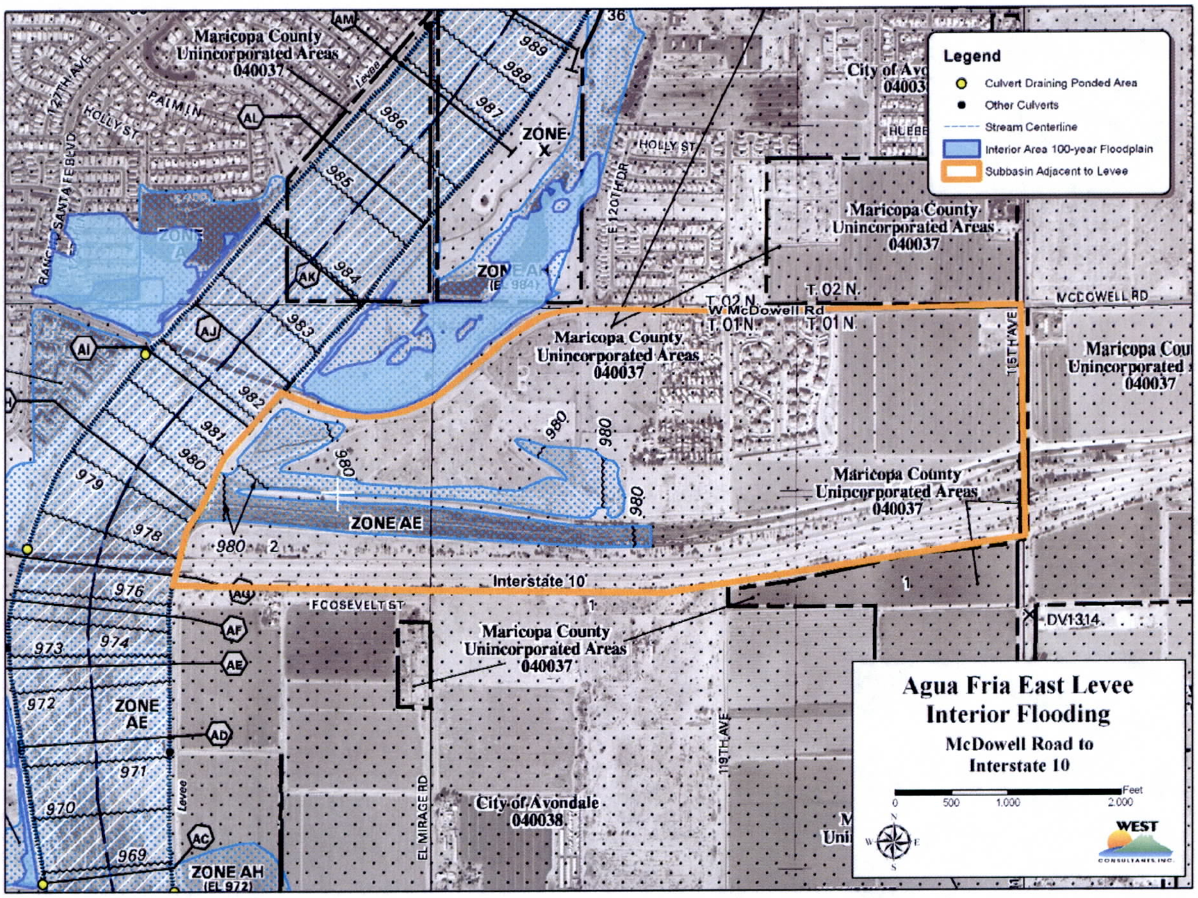

Figure 3-7. Interior Area Between McDowell Road and Interstate 10 (Effective Floodplain)

3.3.5 Levee ID #8: Interstate 10 to Van Buren Street

The interior area from Interstate 10 to Van Buren Street is shown in Figure 3-8. Flow accumulates in the southwest corner of this subbasin and then flows south through a newly constructed bike path tunnel under Van Buren Street. The bike path tunnel was confirmed during the site visit to be lower than the culvert at Van Buren Street to the Agua Fria River. Therefore, no floodplain is mapped in this reach and the effective Zone AH should be removed.

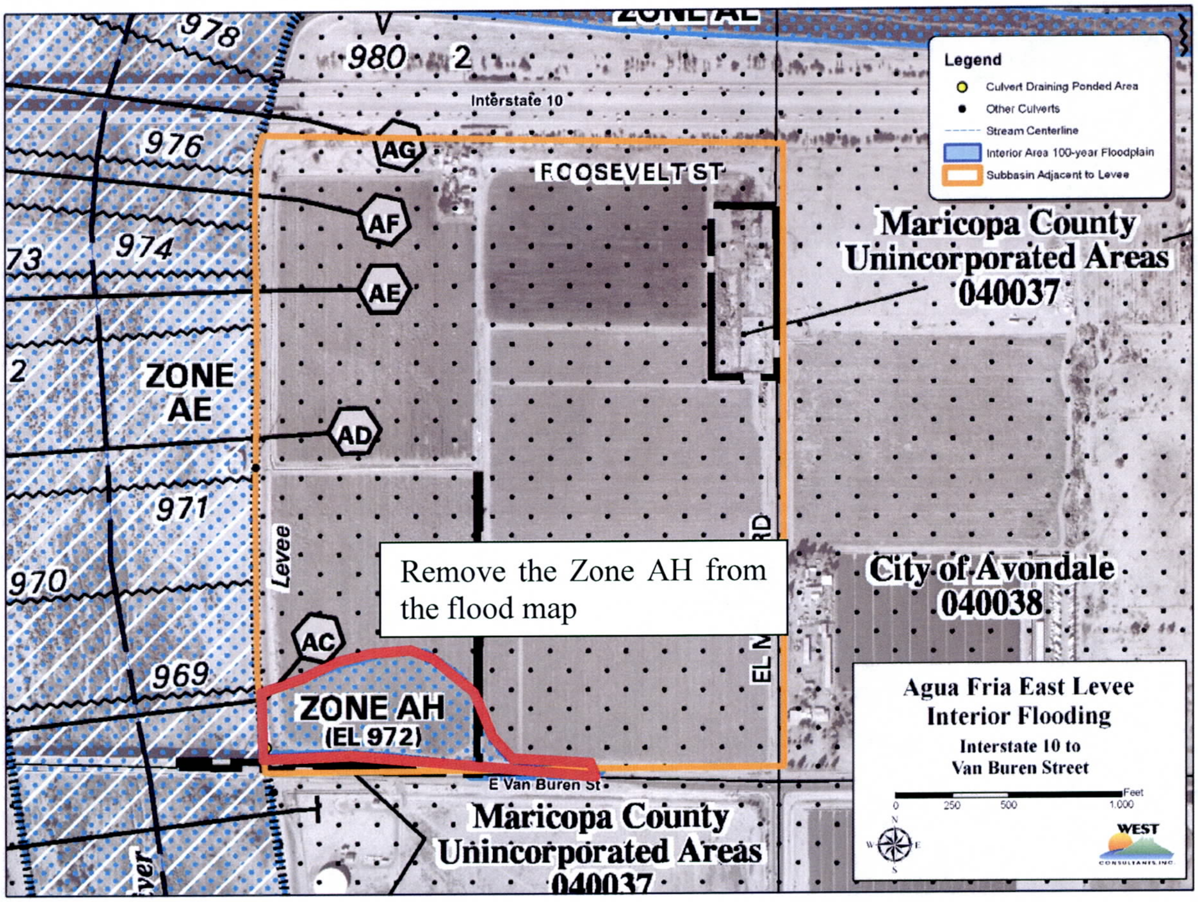

Figure 3-8. Interior Area Between Interstate 10 and Van Buren Street (Revised and Effective Floodplains)

3.3.6 Levee ID #8: Van Buren Street to State Highway 85

The interior area from Van Buren Street to State Highway 85 is shown in Figure 3-9. This interior area is tributary to the Union Pacific Railroad Ditch (formerly SPRR Ditch), which is mapped on the DFIRM as Zone AE. WEST requested the background information for this study from the FEMA project library. After reviewing the study and model for the Union Pacific Railroad Ditch provided by FEMA (see Section 1.2), WEST confirmed that interior flooding behind Levee ID #8 was modeled as part of the effective FEMA study. The methodology included a routing calculation to compute the maximum ponding elevation behind the levee. Therefore, additional interior flooding calculations are not necessary.

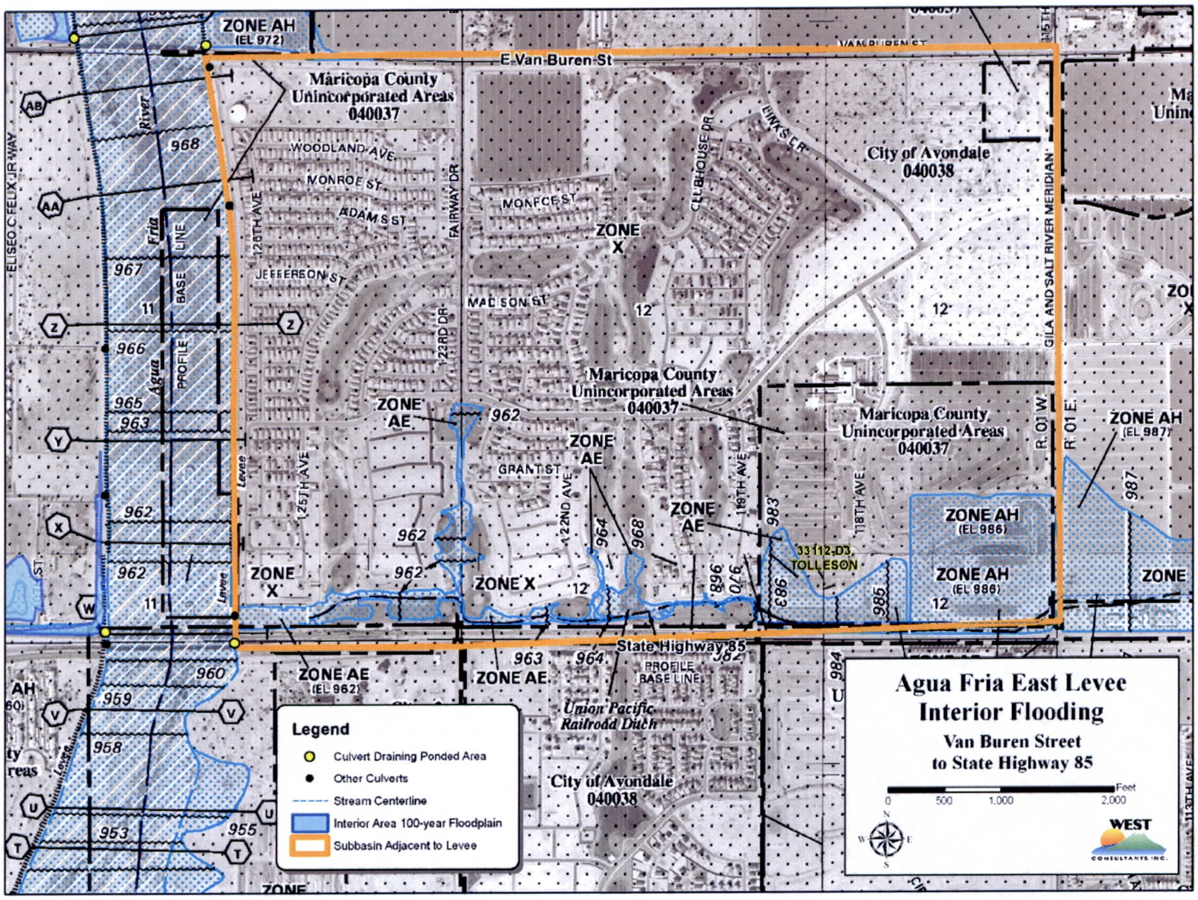

Figure 3-9. Interior Area Between Van Buren Street and State Highway 85 (Effective Floodplain)

3.3.7 Levee ID #16: Rio Vista Lane to Downstream End of Levee

The interior area behind Levee ID #16 is shown in Figure 3-10 and Figure 3-11. The area consists of residential landuse with some parks and open space. The revised floodplain shows flooding next to the levee but it does not extend east of 127th Avenue.

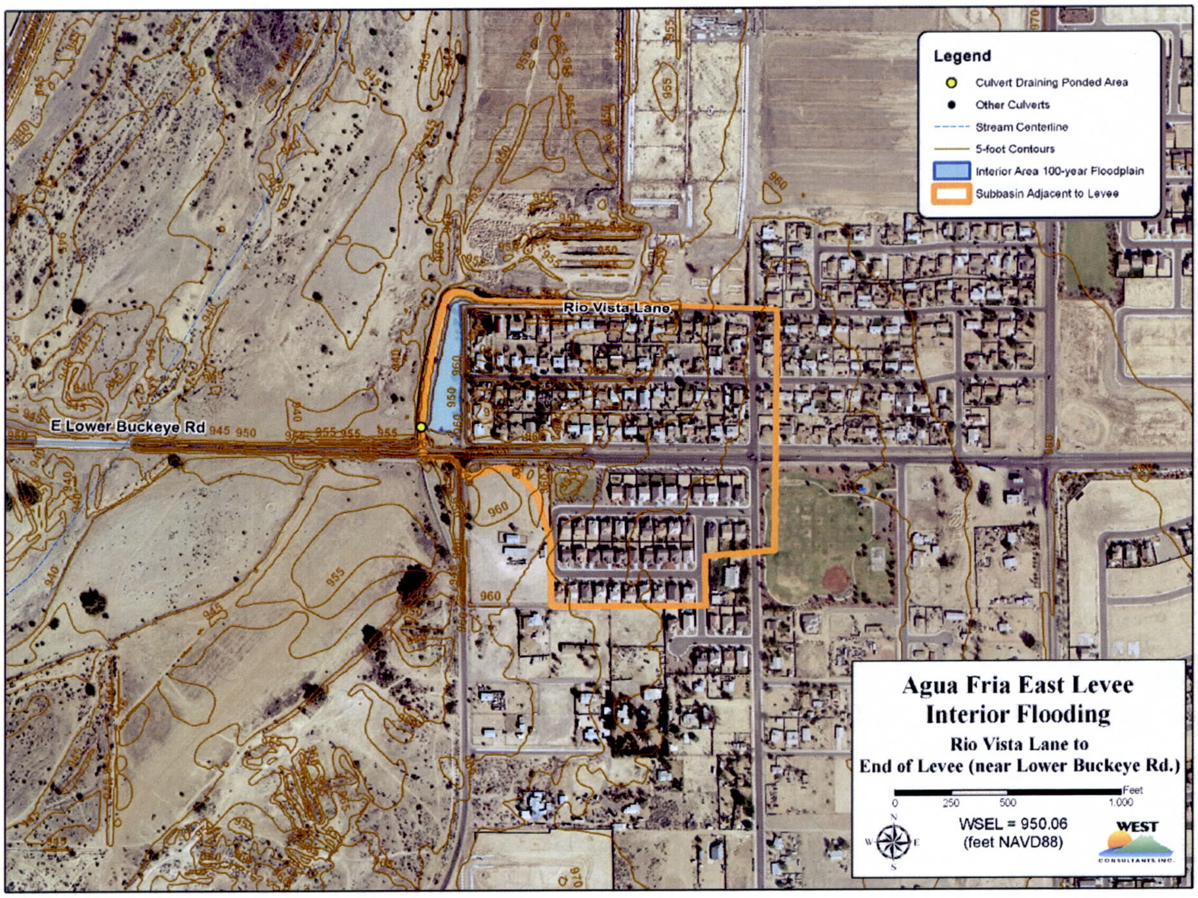

Figure 3-10. Interior Flooding Behind Levee ID #16 from Rio Vista Lane to the End of Levee (Revised Floodplain)

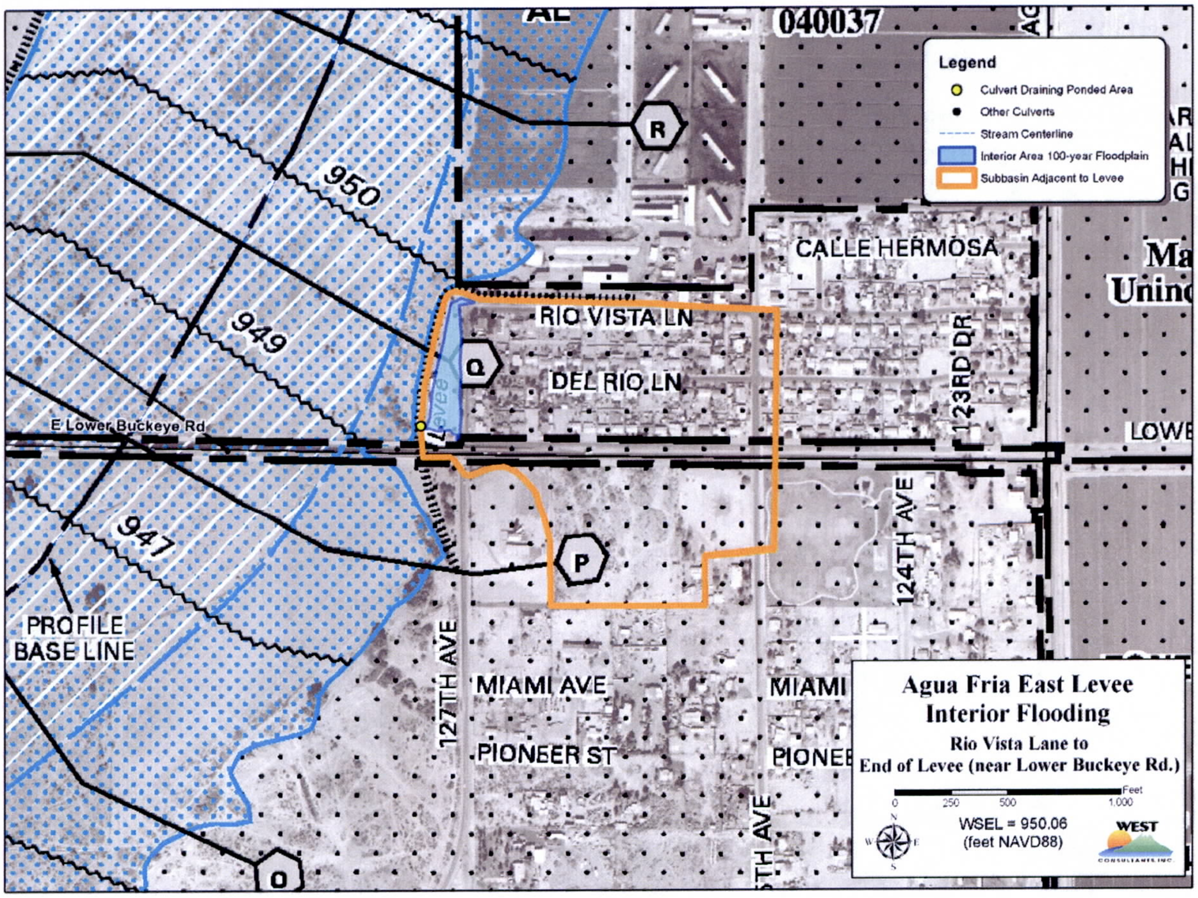

Figure 3-11. Interior Flooding Behind Levee ID #16 from Rio Vista Lane to the End of Levee (Revised and Effective Floodplain)

4 References

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APPENDIX A

Lower Buckeye Hydrology

Lower Buckeye Hydrology Notes

The soil data for the project area was provided by the FCDMC and was used in the DDMSW program. Current land use data was not available for the project area and was created based on aerial photography (see Figure 1). The land use code is based on the values in the DDMSW land use table.

The precipitation data used for the interior drainage analysis was based on NOAA Atlas 14 data. The 100-year, 24-hour NOAA Atlas 14 average precipitation used in the model is 3.43 inches.

Based on the design guidelines of Maricopa County, any new development must retain 80% of the flow on site. This was taken into account in Subbasin 1C by adding a diversion to the HEC-1 model causing all the flow to be diverted up to 80% of the total flow. The HEC-1 results are shown in Table 1 below.

Table 1. HEC-1 Output

Subbasin	Area (sq miles)	Volume (ac-ft)	Peak Flow (cfs)	Time to Peak (hr)
1B	0.04	3.08	35	12.17
1C	0.02	0.28	26	12.08

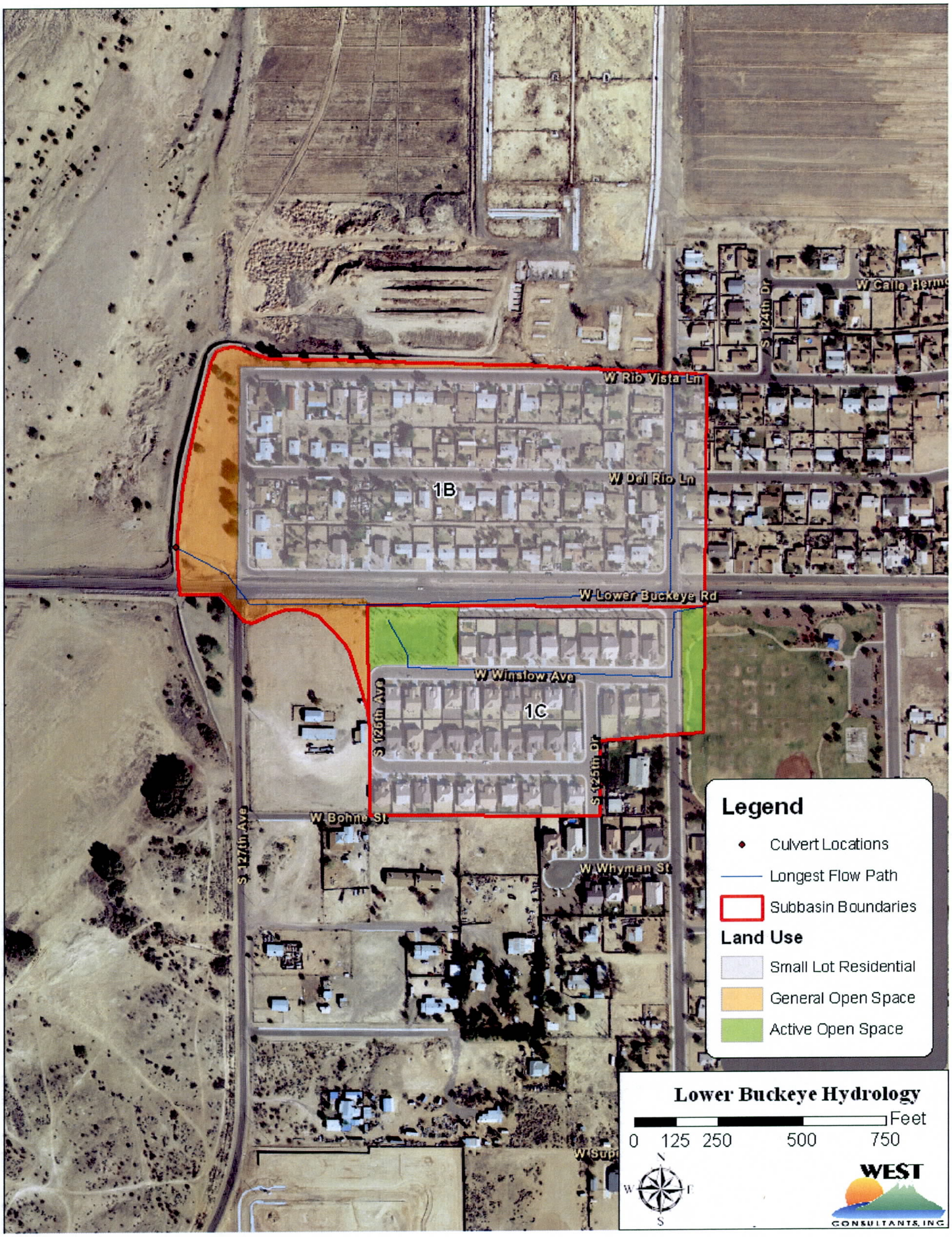

Figure 1. Lower Buckeye Hydrology

```
1*****************************************                                          ****************************************
 *                                       *                                          *                                      *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                                          *   U.S. ARMY CORPS OF ENGINEERS       *
 *              JUN   1998               *                                          *   HYDROLOGIC ENGINEERING CENTER      *
 *            VERSION 4.1                *                                          *         609 SECOND STREET            *
 *                                       *                                          *      DAVIS, CALIFORNIA 95616         *
 *  RUN DATE   13MAY11  TIME  13:04:18   *                                          *         (916) 756-1104               *
 *                                       *                                          *                                      *
 *****************************************                                          ****************************************


                                  X       X  XXXXXXX   XXXXX           X
                                  X       X  X        X     X         XX
                                  X       X  X        X                X
                                  XXXXXXX  XXXX       X         XXXXX  X
                                  X       X  X        X                X
                                  X       X  X        X     X          X
                                  X       X  XXXXXXX   XXXXX          XXX


          THIS PROGRAM REPLACES ALL PREVIOUS VERSIONS OF HEC-1 KNOWN AS HEC1 (JAN 73), HEC1GS, HEC1DB, AND HEC1KW.

          THE DEFINITIONS OF VARIABLES -RTIMP- AND -RTIOR- HAVE CHANGED FROM THOSE USED WITH THE 1973-STYLE INPUT STRUCTURE.
          THE DEFINITION OF -AMSKK- ON RM-CARD WAS CHANGED WITH REVISIONS DATED 28 SEP 81. THIS IS THE FORTRAN77 VERSION
          NEW OPTIONS: DAMBREAK OUTFLOW SUBMERGENCE , SINGLE EVENT DAMAGE CALCULATION, DSS:WRITE STAGE FREQUENCY,
          DSS:READ TIME SERIES AT DESIRED CALCULATION INTERVAL    LOSS RATE:GREEN AND AMPT INFILTRATION
          KINEMATIC WAVE: NEW FINITE DIFFERENCE ALGORITHM

1                                               HEC-1 INPUT                                          PAGE  1

          LINE           ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

             1           ID        Flood Control District of Maricopa County
             2           ID        LOWER BUCKEYE - Lower Buckeye Road Levee #16
             3           ID        100 YEAR
             4           ID        24 Hour Storm
             5           ID        Unit Hydrograph: Clark
             6           ID        05/13/2011
             7           IT       5       0       0    2000
             8           IN      15
             9           IO       4
                         *DIAGRAM
                         *
            10           JD   3.431  0.0001
            11           PC   0.000   0.002   0.005   0.008   0.011   0.014   0.017   0.020   0.023   0.026
            12           PC   0.029   0.032   0.035   0.038   0.041   0.044   0.048   0.052   0.056   0.060
            13           PC   0.064   0.068   0.072   0.076   0.080   0.085   0.090   0.095   0.100   0.105
            14           PC   0.110   0.115   0.120   0.126   0.133   0.140   0.147   0.155   0.163   0.172
            15           PC   0.181   0.191   0.203   0.218   0.236   0.257   0.283   0.387   0.663   0.707
            16           PC   0.735   0.758   0.776   0.791   0.804   0.815   0.825   0.834   0.842   0.849
            17           PC   0.856   0.863   0.869   0.875   0.881   0.887   0.893   0.898   0.903   0.908
            18           PC   0.913   0.918   0.922   0.926   0.930   0.934   0.938   0.942   0.946   0.950
            19           PC   0.953   0.956   0.959   0.962   0.965   0.968   0.971   0.974   0.977   0.980
            20           PC   0.983   0.986   0.989   0.992   0.995   0.998   1.000
            21           JD   3.259    10.0
                         *

            22           KK      1B   BASIN
            23           BA   0.040
            24           LG    0.23    0.25    4.55    0.44      26
            25           UC   0.374   0.396
            26           UA       0     5.0    16.0    30.0    65.0    77.0    84.0    90.0    94.0    97.0
            27           UA     100
                         *

            28           KK      1C   BASIN
            29           BA   0.020
            30           LG    0.23    0.25    4.55    0.44      27
            31           UC   0.217   0.194
            32           UA       0     5.0    16.0    30.0    65.0    77.0    84.0    90.0    94.0    97.0
            33           UA     100
                         *

            34           KK    1CDI  DIVERT
            35           DT      DT     1.3     0.0
            36           DI     0.0  1000.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
            37           DQ     0.0  1000.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
                         *

            38           KK    1C1B COMBINE
            39           KO       0
            40           HC       2
                         *
            41           ZZ
1
                SCHEMATIC DIAGRAM OF STREAM NETWORK
 INPUT
  LINE      (V) ROUTING          (--->) DIVERSION OR PUMP FLOW
```

```
NO.       (.) CONNECTOR         (<---) RETURN OF DIVERTED OR PUMPED FLOW

 22          1B
             .
             .
 28          .           1C
             .           .
             .           .
 35          .           .------->      DT
 34          .         1CDI
             .           .
             .           .
 38        1C1B............
(***) RUNOFF ALSO COMPUTED AT THIS LOCATION
1*****************************************
*                                         *
*   FLOOD HYDROGRAPH PACKAGE  (HEC-1)     *
*              JUN   1998                 *
*            VERSION 4.1                  *
*                                         *
* RUN DATE   13MAY11  TIME  13:04:18      *
*                                         *
*******************************************

*****************************************
*                                       *
*   U.S. ARMY CORPS OF ENGINEERS        *
*   HYDROLOGIC ENGINEERING CENTER       *
*        609 SECOND STREET              *
*     DAVIS, CALIFORNIA 95616           *
*        (916) 756-1104                 *
*                                       *
*****************************************


                    Flood Control District of Maricopa County
                    LOWER BUCKEYE - Lower Buckeye Road Levee #16
                    100 YEAR
                    24 Hour Storm
                    Unit Hydrograph: Clark
                    05/13/2011

 9 IO        OUTPUT CONTROL VARIABLES
                   IPRNT          4  PRINT CONTROL
                   IPLOT          0  PLOT CONTROL
                   QSCAL         0.  HYDROGRAPH PLOT SCALE

 8 IN        TIME DATA FOR INPUT TIME SERIES
                   JXMIN         15  TIME INTERVAL IN MINUTES
                  JXDATE      1   0  STARTING DATE
                  JXTIME          0  STARTING TIME

   IT        HYDROGRAPH TIME DATA
                    NMIN          5  MINUTES IN COMPUTATION INTERVAL
                   IDATE      1   0  STARTING DATE
                   ITIME       0000  STARTING TIME
                      NQ       2000  NUMBER OF HYDROGRAPH ORDINATES
                  NDDATE      7   0  ENDING DATE
                  NDTIME       2235  ENDING TIME
                   ICENT         19  CENTURY MARK

               COMPUTATION INTERVAL     0.08 HOURS
                    TOTAL TIME BASE   166.58 HOURS

        ENGLISH UNITS
             DRAINAGE AREA          SQUARE MILES
             PRECIPITATION DEPTH    INCHES
             LENGTH, ELEVATION      FEET
             FLOW                   CUBIC FEET PER SECOND
             STORAGE VOLUME         ACRE-FEET
             SURFACE AREA           ACRES
             TEMPERATURE            DEGREES FAHRENHEIT

 10 JD       INDEX STORM NO. 1
                   STRM        3.43  PRECIPITATION DEPTH
                   TRDA        0.00  TRANSPOSITION DRAINAGE AREA

 11 PI         PRECIPITATION PATTERN
                  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
                  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
                  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
                  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
                  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
                  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
                  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
                  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
                  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
                  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
                  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
                  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
                  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.01     0.00     0.01
                  0.01     0.01     0.01     0.01     0.01     0.01     0.01     0.01     0.03     0.03
                  0.03     0.09     0.09     0.09     0.01     0.01     0.01     0.01     0.01     0.01
                  0.01     0.01     0.01     0.01     0.01     0.01     0.00     0.00     0.00     0.00
                  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
                  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
                  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
                  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
                  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
                  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
                  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
```

```
                  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
                  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
                  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
                  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
                  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
                  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00

  21 JD         INDEX STORM NO. 2
                       STRM        3.26  PRECIPITATION DEPTH
                       TRDA       10.00  TRANSPOSITION DRAINAGE AREA

   0 PI           PRECIPITATION PATTERN
                  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
                  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
                  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
                  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
                  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
                  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
                  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
                  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
                  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
                  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
                  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
                  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
                  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.01      0.00      0.01
                  0.01      0.01      0.01      0.01      0.01      0.01      0.01      0.01      0.03      0.03
                  0.03      0.09      0.09      0.09      0.01      0.01      0.01      0.01      0.01      0.01
                  0.01      0.01      0.01      0.01      0.01      0.01      0.00      0.00      0.00      0.00
                  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
                  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
                  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
                  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
                  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
                  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
                  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
                  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
                  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
                  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
                  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
                  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
                  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00

*** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** ***

           **************
           *            *
  22 KK    *     1B     *        BASIN
           *            *
           **************

             SUBBASIN RUNOFF DATA

  23 BA         SUBBASIN CHARACTERISTICS
                      TAREA        0.04  SUBBASIN AREA

  24 LG         GREEN AND AMPT LOSS RATE
                      STRTL        0.23  STARTING LOSS
                        DTH        0.25  MOISTURE DEFICIT
                       PSIF        4.55  WETTING FRONT SUCTION
                      XKSAT        0.44  HYDRAULIC CONDUCTIVITY
                      RTIMP       26.00  PERCENT IMPERVIOUS AREA

  25 UC         CLARK UNITGRAPH
                         TC        0.37  TIME OF CONCENTRATION
                          R        0.40  STORAGE COEFFICIENT

  26 UA         ACCUMULATED-AREA VS. TIME,  11 ORDINATES
                   0.0       5.0      16.0      30.0      65.0      77.0      84.0      90.0      94.0      97.0
                 100.0

                                                           ***

                                                UNIT HYDROGRAPH PARAMETERS
                                           CLARK   TC=  0.37 HR,         R=  0.40 HR
                                          SNYDER   TP=  0.24 HR,        CP=  0.40

                                                       UNIT HYDROGRAPH
                                                 27 END-OF-PERIOD ORDINATES
              6.        25.       41.       41.       37.       31.       25.       20.       16.       13.
             11.         9.        7.        6.        5.        4.        3.        2.        2.        2.
              1.         1.        1.        1.        1.        0.        0.

*** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** ***

           **************
           *            *
  28 KK    *     1C     *        BASIN
           *            *
           **************
```

```
            SUBBASIN RUNOFF DATA

29 BA         SUBBASIN CHARACTERISTICS
                    TAREA         0.02  SUBBASIN AREA

30 LG         GREEN AND AMPT LOSS RATE
                    STRTL         0.23  STARTING LOSS
                      DTH         0.25  MOISTURE DEFICIT
                     PSIF         4.55  WETTING FRONT SUCTION
                    XKSAT         0.44  HYDRAULIC CONDUCTIVITY
                    RTIMP        27.00  PERCENT IMPERVIOUS AREA

31 UC         CLARK UNITGRAPH
                       TC         0.22  TIME OF CONCENTRATION
                        R         0.19  STORAGE COEFFICIENT

32 UA         ACCUMULATED-AREA VS. TIME,  11 ORDINATES
                    0.0       5.0      16.0      30.0      65.0      77.0      84.0      90.0      94.0      97.0
                  100.0

                                                ***

                                        UNIT HYDROGRAPH PARAMETERS
                                    CLARK   TC=  0.22 HR,        R=  0.19 HR
                                   SNYDER   TP=  0.15 HR,       CP=  0.45

                                             UNIT HYDROGRAPH
                                        14 END-OF-PERIOD ORDINATES
            16.       36.       34.       24.       16.       10.        7.        4.        3.        2.
             1.        1.        0.        0.

*** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** ***

          **************
          *            *
34 KK     *     1CDI   *       DIVERT
          *            *
          **************

  DT          DIVERSION
                    ISTAD           DT  DIVERSION HYDROGRAPH IDENTIFICATION
                   DSTRMX         1.30  MAXIMUM VOLUME TO BE DIVERTED

  DI               INFLOW        0.00   1000.00

  DQ        DIVERTED FLOW        0.00   1000.00

                                                ***

*** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** ***

          **************
          *            *
38 KK     *     1C1B   *      COMBINE
          *            *
          **************

39 KO         OUTPUT CONTROL VARIABLES
                    IPRNT            4  PRINT CONTROL
                    IPLOT            0  PLOT CONTROL
                    QSCAL           0.  HYDROGRAPH PLOT SCALE

40 HC         HYDROGRAPH COMBINATION
                    ICOMP            2  NUMBER OF HYDROGRAPHS TO COMBINE

                                                ***
1
                                             RUNOFF SUMMARY
                                        FLOW IN CUBIC FEET PER SECOND
                                      TIME IN HOURS,  AREA IN SQUARE MILES
```

OPERATION	STATION	PEAK FLOW	TIME OF PEAK	AVERAGE FLOW FOR MAXIMUM PERIOD 6-HOUR	24-HOUR	72-HOUR	BASIN AREA	MAXIMUM STAGE	TIME OF MAX STAGE
+ HYDROGRAPH AT	1B	35.	12.17	5.	2.	1.	0.04		
+ HYDROGRAPH AT	1C	26.	12.08	3.	1.	0.	0.02		
+ DIVERSION TO	DT	26.	12.08	2.	1.	0.	0.02		
+ HYDROGRAPH AT	1CDI	2.	12.58	0.	0.	0.	0.02		
2 COMBINED AT									

+	1C1B	35.	12.17	5.	2.	1.	0.06

*** NORMAL END OF HEC-1 ***

APPENDIX B

Durango Area Drainage Master Plan Report

Durango Area Drainage Master Plan Report included on DVD

APPENDIX C

Glendale Area Stormwater Management Plan

Glendale Area Stormwater Management Plan included on DVD

Agua Fria Levee Scour Analysis Report: Levee ID #8, Levee ID #16, and Levee ID #18

Prepared for:
Flood Control District of Maricopa County
2801 West Durango Street
Phoenix, AZ 85009

Prepared by:
WEST Consultants, Inc.
8950 S 52nd Street
Suite 210
Tempe, AZ 85284

June 2011

WEST CONSULTANTS, INC.

Registered Professional Engineer (Civil)
CERTIFICATE NO.
41980
BRIAN THOMAS
WAHLIN
Date Signed 06-16-2011
ARIZONA, U.S.A.

Expires 3/31/2014

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List of Abbreviations

FEMA ....Federal Emergency Management Agency

FCDMC.................................Flood Control District of Maricopa County

FIS...Flood Insurance Study

GIS ....Geographic Information System

NAD.......................................North American Datum

NAVD ....North American Vertical Datum of 1988

NGVD ....National Geodetic Vertical Datum of 1929

PAL.......................................Provisionally Accredited Levee

WEST....................................WEST Consultants, Inc.

WSE ....Water Surface Elevation

1 Introduction

1.1 Purpose

The purpose of this scour analysis is to provide certification documentation in support of FEMA's accreditation of the Agua Fria River Levees located along the east and west banks of the Agua Fria River from approximately Indian School Road to the south. The locations of the Agua Fria River Levees to be certified are shown in Figure 1-1, and these levees can be divided into the following segments:

- Levee ID #08 – Along the east bank of the Agua Fria River from Indian School Road South to immediately north of Buckeye Road (4.3 miles long);
- Levee ID #16 – Along the east bank of the Agua Fria River at Lower Buckeye Road (0.4 miles long); and,
- Levee ID #18 – Along the west bank of the Agua Fria River from just upstream of Indian School Road to a point downstream of Lower Buckeye Road (approximately 6 miles long).

Currently these three levees are Provisionally Accredited by Federal Emergency Management Agency (FEMA) and are shown as providing protection from the 1 percent annual chance flood on the most recent Flood Insurance Rate Map (FIRM Panel No 04013C2080J, 04012C2085G, and 04013C2090H). The Provisionally Accredited Levee (PAL) agreement between the Flood Control District of Maricopa County (District) and FEMA is due to expire on June 25, 2011. In order for the Levee ID's #08, #16, and #18 to continue to be shown as providing flood protection on the FIRM Panels beyond the PAL expiration date, levee certifications and FEMA accreditations are necessary.

1.2 Study Area Description

The study reach of the Agua Fria River in which scour could affect Levee ID's #08, #16, and #18 is approximately 6.5 miles in length, and the channel thalweg elevations within the study reach range from approximately 1000 feet to 931 feet, based on the North American Vertical Datum of 1988 (NAVD 88).

1.3 Previous Reports

There are several previous reports available for the scour analyses that were performed during the design of the levees by the District and the U.S. Army Corps of Engineers, Los Angeles District (USACE). The report titled *Agua Fria River SLA, Quantities, Scour, Etc.* (SLA, 1984) provides scour estimates for the east and west levees from north of Indian School Road to Buckeye Road. The report titled *Memo for the Record: Skunk Creek, New and Agua Fria Rivers, Phase II, General Design Memorandum – Depth of Toe Protection for Bank Stabilization and Levee Design* (USACE, 1986) provides scour estimates for the east and west levees from Buckeye Road to south of Lower Buckeye Road.

1.4 Datum

All geographic and spatial data used in this study were adjusted to a horizontal datum of North American Datum (NAD) 1983 HARN State Plane Arizona Central (FIPS 0202 International Feet) and a vertical datum of NAVD88.

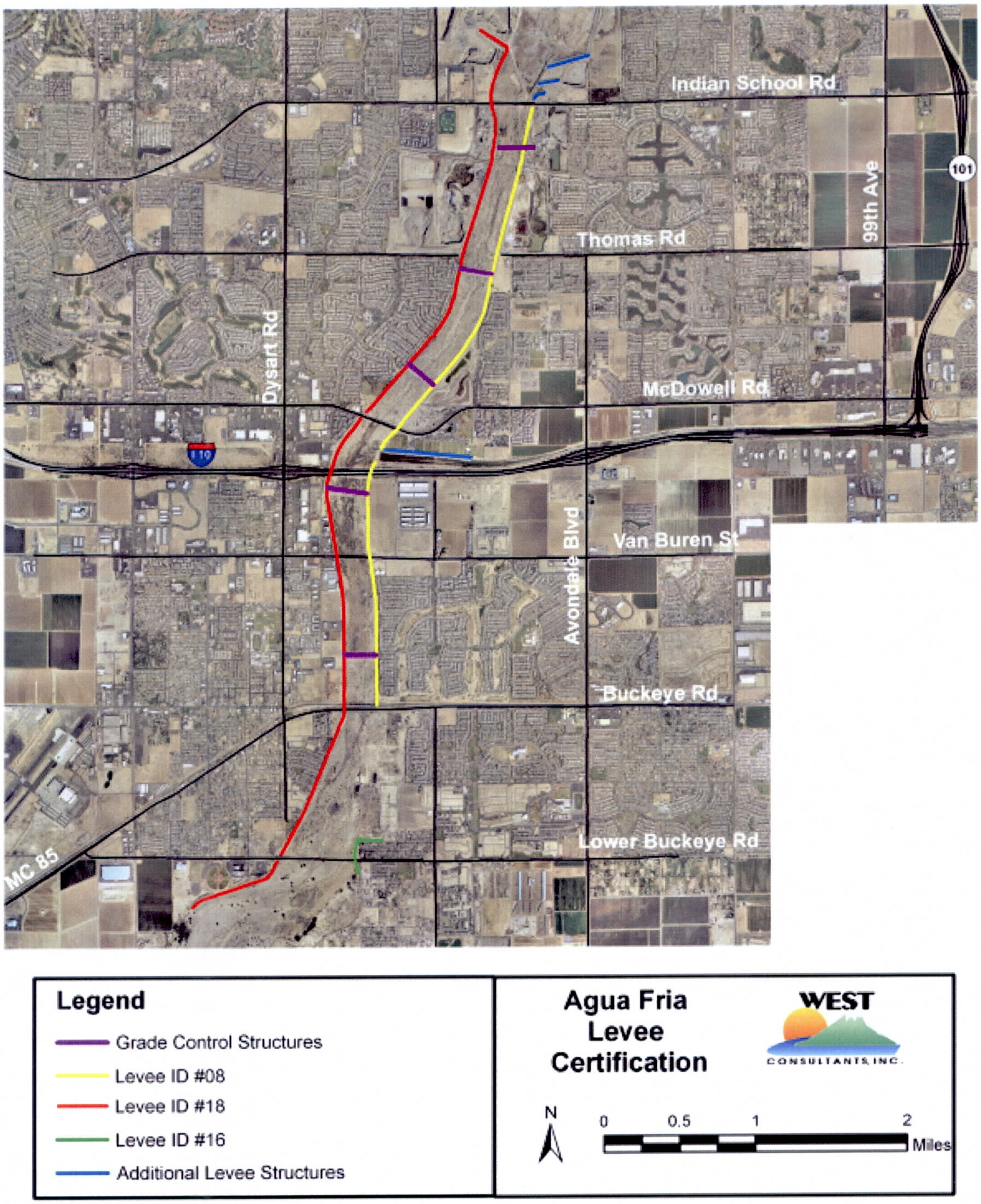

Figure 1-1. Levee locations

2 Hydraulics and Scour Calculations

2.1 Introduction

Hydraulic data provided by the FCDMC included a HEC-RAS model that was developed by Stanley Consultants (Stanley, 2011). This model updated the effective HEC-2 model used for floodplain re-delineation study along the Agua Fria River to reflect current conditions. This hydraulic model was utilized as-is; no additional changes were made to the model. It should be noted that all scour calculations were based on the assumption that the hydraulic modeling product provided by Stanley was accurate as per the direction of the District. WEST was not involved in the development of the hydraulic model and did not perform a technical review of the model per the request of the District. Note that the river mile stationing used in this report corresponds to the stationing in the newly developed Stanley hydraulic model, which may not agree with the stationing used in the effective model.

2.2 Topography and Survey

Survey data used in the scour analysis were provided by the District in two deliverables:

- Levee elevation and levee penetration structure survey completed by Wilson & Company, Inc., Engineers & Architects (Wilson) in late 2010 and early 2011 for the west levee south of Indian School Road to the downstream end of that levee, the east levees, and a majority of the structures penetrating the levees; and
- Levee elevation and levee penetration structure survey completed by Stanley in early 2011 for the west levee north of Indian School Road, the grade control structures in the reach, and a few remaining structures penetrating the levees.

2.3 Scour Calculations

The total scour depth was estimated along the Agua Fria River levees for the 1 percent annual chance flood event (formerly known as the 100-year flood event) in the Agua Fria River. The method to estimate scour in this reach was based on the District's Draft Hydraulics Manual (2010a).

Based on the District's standards from the Draft Hydraulics Manual (2010a), the total depth of scour at a given location is the sum of each scour components that apply to the site of interest. The primary scour components (in feet) and their corresponding designations are

- Local scour (y_{local})
- General scour or contraction scour ($y_{general}$)
- Bedform scour ($y_{bedform}$)
- Long-term degradation (y_{long})
- Low-flow incisement scour (y_{low})

Once the scour depths had been estimated along the three levees throughout the study reach, a factor of safety was calculated based on the final scour elevation compared to the as-built toe-down elevation. This factor was then compared to the District's recommended value of 1.3 for most of the scour components (FCDMC, 2010a).

Based on field measurements, the median grain diameter (D_{50}) of the bed was determined to be approximately 0.75 mm for the study reach. This value of D_{50} is the median grain diameter for the averages of the sediment samples taken in the study reach as part of the Agua Fria Water Course Master Plan (KHA, 2001). The median grain diameter was used to calculate most of the scour parameters which were estimated as reach-averaged scour parameters, but more site-specific gradation parameters obtained from the Agua Fria Water Course Master Plan documentation were used for the long-term degradation analysis as the local median grain diameter can significantly influence the results of equilibrium slope calculations (KHA, 2001).

2.3.1 Local Scour

Local scour is caused from the acceleration of flow and resulting vortices induced by an obstruction. It occurs at bridge piers, abutments, embankments, and other structures within a river. Five types of local scour were considered for this scour analysis: (1) local scour due to bridge piers and the effect of that scour on levee stability due to the migration of the scour hole in the transverse direction towards the levees, (2) local scour due to grade control structures located throughout the reach, (3) local scour due to abutment-type scour at the upstream end of the levees, (4) local scour due to wide pier-type scour at the ring dikes surrounding the Salt River Project (SRP) and Tucson Electric Power (TEP) transmission line tower foundations and the effect of that scour on levee stability due to the migration of the scour hole in the transverse direction towards the levees, and (5) tailcut scour due to the sand and gravel mining pit in the main channel of the Agua Fria River immediately upstream from the study reach. Each of these types of scour is discussed individually in the following sections.

2.3.1.1 Local Scour due to Bridge Piers

Bridge pier scour was estimated in accordance with HEC-18 (FHWA, 2001), assuming: (1) the correct pier nose shape (round or square throughout the study reach), (2) a zero degree angle of attack of flow (although some bridges are skewed to flow in the study reach, all bridge piers are aligned with the flow direction), (3) small dune bed conditions, and (4) the appropriate pier width with debris added as per the Maricopa County Drainage Policies and Standards (FCDMC, 2010b) which states the following: "To account for drift/debris build-up, increase pier column width/diameter, within the top 12 feet of water depth (per Arizona Department of Transportation {ADOT} Bridge Design Guidelines), to twice the design value, but no less than two feet on each side."

For each pier group in the study reach that was not designed and constructed as a single pier, the pile spacing is greater than 5 diameter widths indicating that the scour from each pile will not interact with each other for any of the bridges in the study reach.

After calculating the depth of scour for the bridge piers adjacent to the levee embankments, the angle of repose for the native sediment was used to determine if the horizontal extent of scour would affect the levee embankment. To calculate the angle of repose for the native material in the Agua Fria River, the following equation from the District's standard (FCDMC, 2010a) was utilized:

$$\phi = 32.5 + 1.27D_{50}$$

where ϕ is the angle of repose in degrees and D_{50} is the median sediment grain size in mm. For a D_{50} of 0.75 mm, the angle of repose is 33.5°. The calculations to determine which bridge piers could affect the levee embankments due to migration of pier scour in the transverse direction towards the levees are shown in Table 2-1 below.

Table 2-1 Local scour due to bridge piers near the levees

Bridge	**West Levee (ID # 18)**			**East Levees (ID # 08 and 16)**		
	Width of pier closest to levee (ft) / distance to levee (ft)	*Calculated pier scour (ft) / horizontal extent of scour hole (ft)**	*Scour depth added to the levee toe (ft)*	*Width of pier closest to levee (ft) / distance to levee (ft)*	*Calculated pier scour (ft) / horizontal extent of scour hole (ft)**	*Scour depth added to the levee toe (ft)*
Indian School Road	1.67 / 20	9.3 / 14.1	N/A	4.0 / 3	10.6 / 16.1	8.6
McDowell Road	5.0 / 80	13.6 / 20.5	N/A	5.0 / 100	13.6 / 20.5	N/A
I-10	3.0 / 40	10.6 / 16.0	N/A	3.0 / 60	10.6 / 16.0	N/A
Van Buren Street	5.5 / 100	14.4 / 21.8	N/A	5.5 / 85	14.4 / 21.8	N/A
Southern Pacific Railroad	1.83 / 8	9.7 / 14.7	4.4	1.83 / 13	9.7 / 14.7	1.1
Buckeye Road	3.5 / 55	11.7 / 17.7	N/A	3.5 / 55	11.7 / 17.7	N/A

** Horizontal extent of scour based on an estimated angle of repose of 33.5°*

The results of the HEC-RAS model reported at the nearest cross-section upstream of the corresponding bridge were used to estimate the hydraulic parameters, and the correction factors for the HEC-18 method were estimated by the method equations based on the field conditions in the study reach. The impact extents of the local scour were based on the estimated angle of repose of the material. Based on this analysis, the anticipated pier scour would impact the levees at three locations: the east abutment of the Indian School Road Bridge (Levee ID #08) and the east and west abutments of the Southern Pacific Railroad Bridge (Levee ID's #08 and #18, respectively). The scour added to the estimation of scour along the levees at these locations range from approximately 1.1 feet to 8.6 feet.

2.3.1.2 Local Scour due to Grade Control Structures

The District guidelines specify that local scour for a grade control structure with a free overfall of water on an unprotected river bed, as is the case for the grade control structures in the study reach, should be calculated using the Schoklitsch equation. This equation has the following form:

$$Z_{local} = \frac{3.15H^{0.2}q^{0.57}}{D_{90}^{0.32}} - y_m$$

where Z_{local} is the depth of scour below the grade control structure (ft), H is the vertical distance between the water level upstream and downstream of the structure (ft), q is the design discharge per unit width (cfs/ft), D_{90} is the particle size for which 90% of the bed sediment is finer (mm), and y_m is the downstream hydraulic depth in the channel (ft). D_{90} was approximated as 2.5 mm based on the sampling routine completed as part of the Agua Fria Water Course Master Plan Study (KHA, 2001). Results of this calculation for each grade control structure are shown in Table 2-2 below. As per the original design for the grade control structures, it was assumed that this scour affected the reach approximately 120 feet downstream from each grade control structure.

Table 2-2 Local scour downstream of the grade control structures

Grade control structure (approximate River Mile)	H (ft)	q (cfs/ft)	y_m (ft)	Z_{local} (ft)
Downstream of Indian School Road (8.47)	0.32	41	6.2	9.4
Downstream of Thomas Road (7.36)	0.35	49	7.4	10.1
Upstream of McDowell Road (6.58)	0.97	49	6.5	14.9
Downstream of I-10 (5.64)	0.39	38	7.1	8.3
Upstream of Buckeye Road (4.55)	1.87	47	9.5	14.3
Grouted Apron at the Buckeye Road Bridge (4.20)*	0.88	46	5.5	14.7

* *Note: Also functioning as bridge pier scour countermeasure*

It should also be noted that in the final results of this scour analysis, provided in Appendix A, that only local scour due to grade control structures is considered just downstream of the grade control structures. The other scour processes discussed herein (general scour, bedform scour, long-term degradation, and low-flow incisement scour) are not included in the scour estimate downstream of the grade control structure because these scour components are already accounted for in the local scour calculations. In the available design documentation for grade control structures (e.g., USACE, 1994a), the scour downstream of the grade control structure is determined by empirical equations such as the Schoklitsch equation. No other scour components are computed in the design of a grade control structure other than the local scour component. This implies that the other scour components are already included in the empirical local scour calculations and that they do not need to be separately calculated and added to the total scour.

2.3.1.3 Local Scour due to Abutment-Type Scour

There are two locations for which abutment scour was considered for the levees: the upstream end of the west levee (Levee ID #18) and the upstream end of the small east levee around Lower Buckeye Road (Levee ID #16). The upstream ends of these two levees were designed with flared wingwalls that are perpendicular to the flow direction, thereby creating the possibility for additional local scour due to abutment-type scour processes. The longer east levee (Levee ID #08) has a smooth transition with no section perpendicular to the flow direction. The upstream face is also protected by transverse dikes which will reduce the potential for abutment-type local scour to occur at the upstream end of this levee (see Figure 2-2).

For the shorter east levee (Levee ID #16), the water surface elevation at cross-section 3.43 is 950.84 feet. This water surface elevation is lower than all the ground points (minimum of 951.48 feet) surveyed in late 2010 for this study along the portion of the levee perpendicular to the flow (see Figure 2-1). Therefore, flow during the 1 percent annual chance flood event will not intersect the portion of the levee perpendicular to flow, and abutment-type scour processes are not likely to occur during the 1 percent annual chance flood event.

For the west levee (Levee ID #18), the water surface elevation at cross-section 8.85 is 1,012.88 feet. This water surface elevation wets approximately 450 feet of the flared wingwall at the northern end of this levee (see Figure 2-2). Therefore, flow will intersect the portion of the levee perpendicular to flow for a distance of 450 feet with an average flow depth of approximately 1.41 feet and an average flow velocity adjacent to the levee of 1.4 ft/s. These flow depths and velocities lead to an estimate of abutment scour of 5.5 feet for the west levee. This abutment-type scour was applied to the west levee at cross-section 8.85 and decreasing linearly to zero for approximately the first 500 feet downstream of the flared wingwall at the north end of the levee.

2.3.1.4 Local Scour due to Transmission Line Tower Foundation Ring Dikes

There are fifteen ring dike structures throughout the study reach protecting electric transmission line tower foundations from scour. Of these fifteen structures, four are protecting transmission line tower foundations owned by SRP (Tower Nos. 58, 59, 60, and 61), and eleven are protecting transmission line tower foundations owned by TEP (Tower Nos. 87, 88, 89, 94, 96, 97, 98, 100, 101, 102, and 103). These structures vary in location across the channel relative to the levees; some are located near the middle of the river while others are located as close as 33 feet away from the levees (see Figure 2-3 below). The structures closest to the levees are TEP Towers 97 and 98 which are both immediately downstream of the I-10 Bridge. Tower 97 is just upstream of the grade control structure downstream of I-10 while Tower 98 is just downstream of this grade control structure. These structures are approximately 33 feet (Tower #98) and 36 feet (Tower #97) away from the longer east levee (Levee ID #08) as measured from the point of the ring dike closest to the levee along the current ground elevation. Other structures close to the levees include SRP Tower 61 (approximately 75 feet away from Levee ID #08 between Thomas Road and McDowell Road) and TEP Tower 87 (approximately 105 feet away from Levee ID #18 on the west side of the river immediately upstream of the Thomas Road alignment).

Similarly to bridge piers, scour for these ring dike structures was considered in accordance with HEC-18 (FHWA, 2001), assuming: (1) the correct pier nose shape (round or square throughout the study reach), (2) a zero degree angle of attack of flow (although some bridges are skewed to flow in the study reach, all bridge piers are aligned with the flow direction), (3) small dune bed conditions, and (4) the appropriate pier width with no debris (debris is typically not considered for wide-pier scour). Additionally, a wide-pier correction was applied to the scour depth calculation for the ring dike scour based on the conditions outlined in HEC-18 for wide pier scour corrections including: (1) the ratio of flow depth to pier width is less than 0.8 for all of the ring dike structures, (2) the ratio of pier width to the median diameters of the bed material size is greater than 50 for all ring dike structures, and (3) the flow is subcritical in the study reach.

Since these conditions are met for all of the ring dike structures in the study reach, the wide-pier correction was applicable for these calculations.

After calculating the depth of scour for the ring dikes adjacent to the levee embankments, the angle of repose for the native sediment was used to determine if the horizontal extent of scour would affect the levee embankment. The angle of repose for the native material of 33.5° used in the estimation of horizontal extent of scour for the ring dikes was the same as the angle of repose used in the bridge pier scour analysis in Section 2.3.1.1 above. Based on this analysis, the horizontal extent of scour due to the ring dikes does not affect any of the levees at any location.

Figure 2-1. Levee ID #16 showing the upstream side of the levee perpendicular to flow

Figure 2-2. Levee IDs #18 and #08 showing the upstream side of Levee ID #18 perpendicular to flow (flared wingwall)

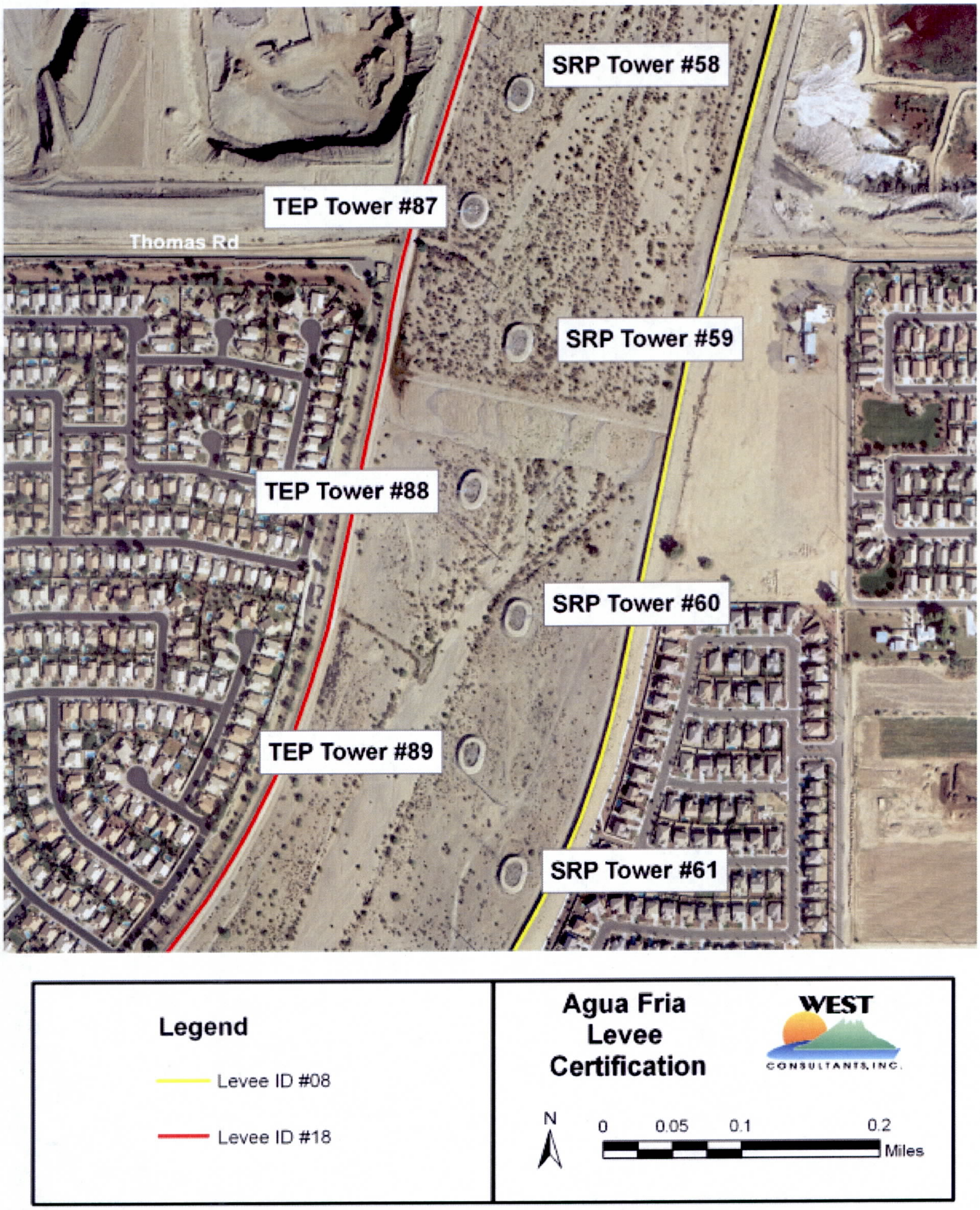

Figure 2-3. Location of electric transmission tower ring dikes throughout the study reach

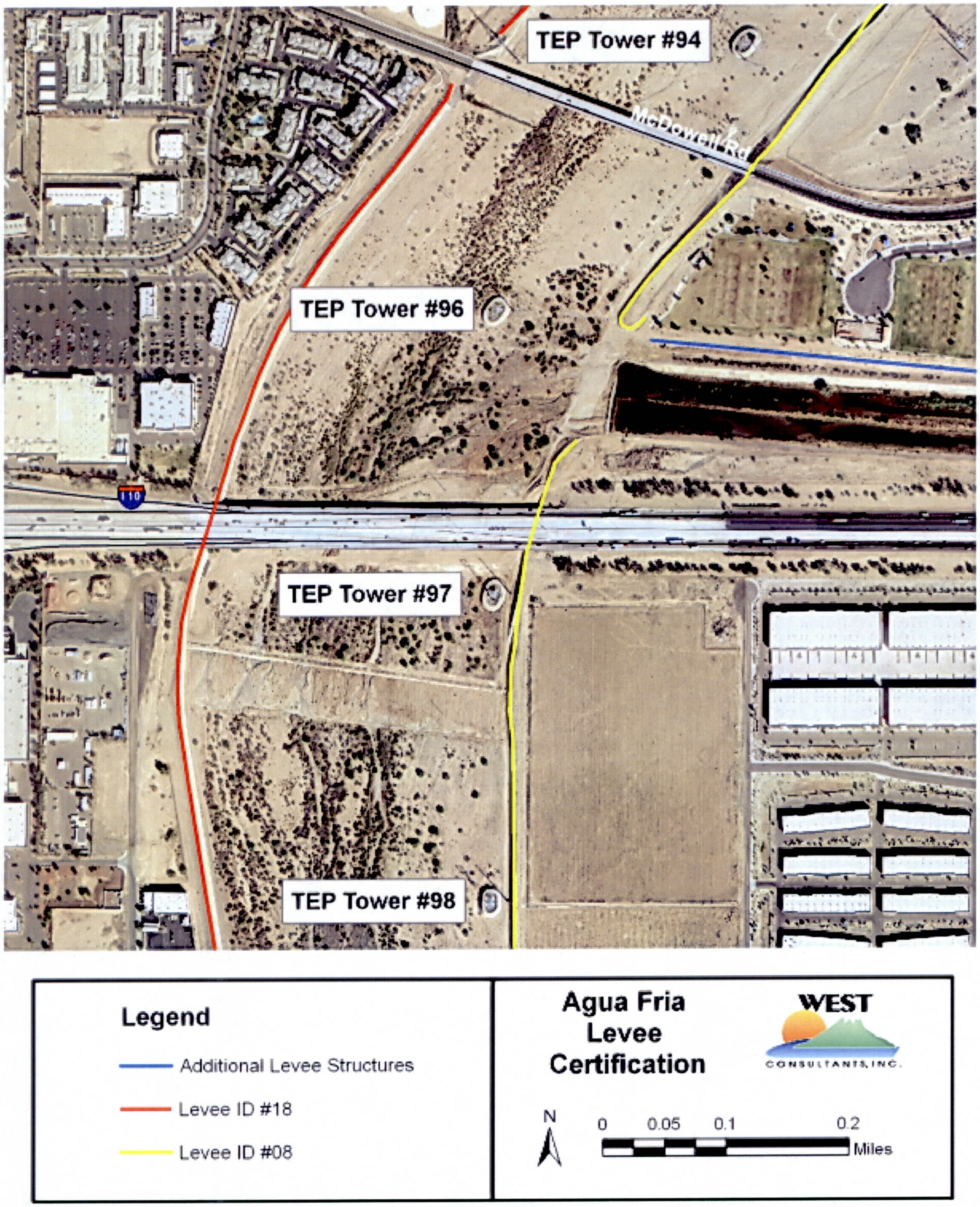

Figure 2-3 (cont'd). Location of electric transmission tower ring dikes throughout the study reach

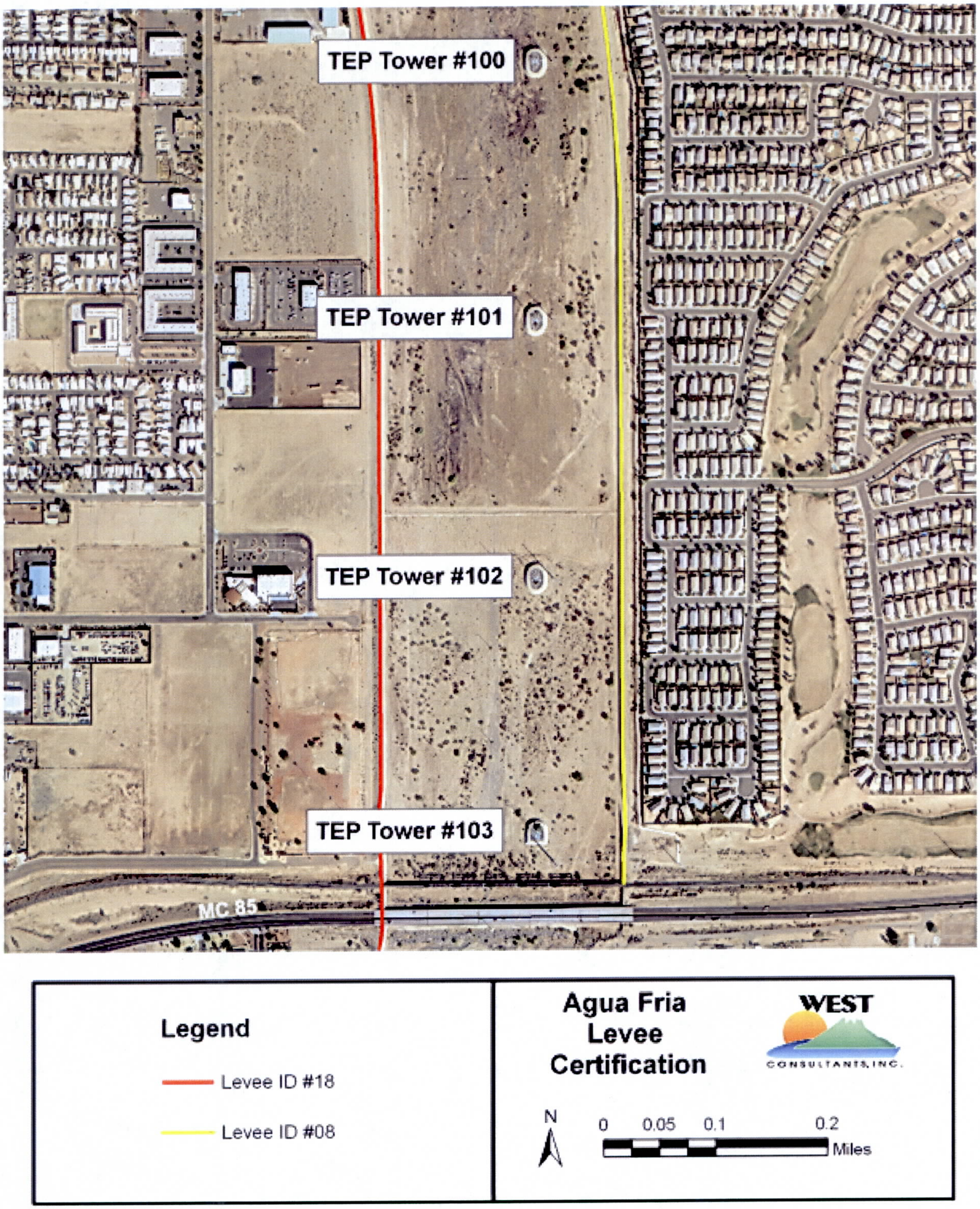

Figure 2-3 (cont'd). Location of electric transmission tower ring dikes throughout the study reach

2.3.1.5 Local Scour due to Tailcut from the Sand and Gravel Mining Pit

A sand and gravel mining pit is located immediately upstream of Indian School Road in the main channel of the Agua Fria River. The west levee (Levee ID #18) is adjacent to this pit in the right overbank of the river, and the upper east levee (Levee ID #08) is immediately downstream of the pit. The pit is approximately 4,700 feet long (i.e., in the direction of flow), spanning from just south of Camelback Road downstream to just north of Indian School Road in the main channel. The disruption of sediment transport caused by the pit could result in lowering of the bed (tailcut scour) near the downstream end of the pit. Therefore, the effect of this tailcut scour on the levees was considered as part of this scour analysis.

The scour associated with the tailcut from this pit was estimated using the methodology and empirical equations developed by Simons, Li and Associates (SLA, 1989) for ADOT. This method calculates a regime width (empirical regime width equations were developed for both gravel- and sand-bed rivers) and then estimates the scour depth and tailcut length based on this regime width. This method is used to estimate short-term longitudinal channel response due to in-stream mining. SLA assumed that long-term longitudinal channel response to in-stream mining in sand-bed rivers, including the Agua Fria, would be inconsequential since sand-bed channels would recover from in-stream mining over a short time period. The following parameters are needed to estimate the tailcut due to an in-stream pit:

- Shape of the gravel pit (i.e., width, length, depth)
- Discretized design flow hydrograph
- Channel bed gradient
- Excavation pit fill time

The physical dimensions of the pit were obtained by examining the recent aerial photographs and 2009 in-channel topography. It was estimated from the aerial photographs (see Figure 2-4) and topography that the pit was 2,600 feet wide (W_p), 4,700 feet long (L_p), and 7 feet deep (y_p). This implies that the total volume of the pit (V_f) is 85,540,000 ft^3. Using the newly developed HEC-RAS model provided by the District (Stanley, 2011), the channel slope (S_0) between Camelback Road and Indian School Road was estimated to be 0.001. The Agua Fria Watercourse Master Plan (KHA, 2001) includes a 1% annual chance flood hydrograph for the Agua Fria River. This hydrograph was discretized and is shown in Figure 2-5. Using the pit volume (V_f) and the discretized hydrograph, the time it would take to fill the pit (T_f) would be approximately 3.15 hours (T_f = 11,350 seconds).

For each discretized block of the hydrograph, the following calculations were performed. First, the inflow channel width (W_c) was calculated based on a regime width equation developed using the concept of minimum stream power at the excavation boundaries (SLA, 1989):

$$W_c = 2.60\ Q^{0.43}$$

where Q is the design flow rate for the 1%-annual chance flood event (cfs).

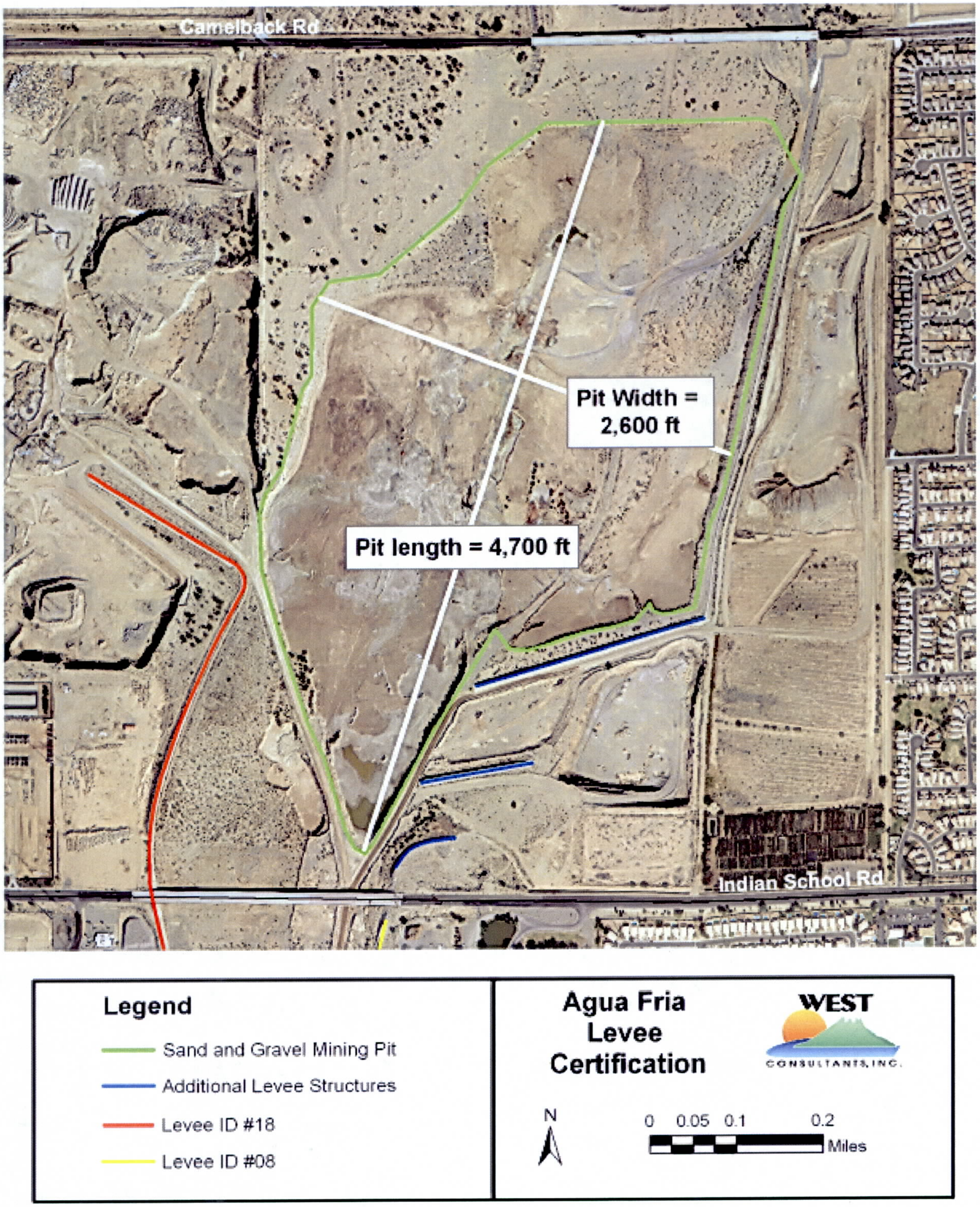

Figure 2-4. Sand and gravel mining pit location and dimensions upstream of Indian School Road

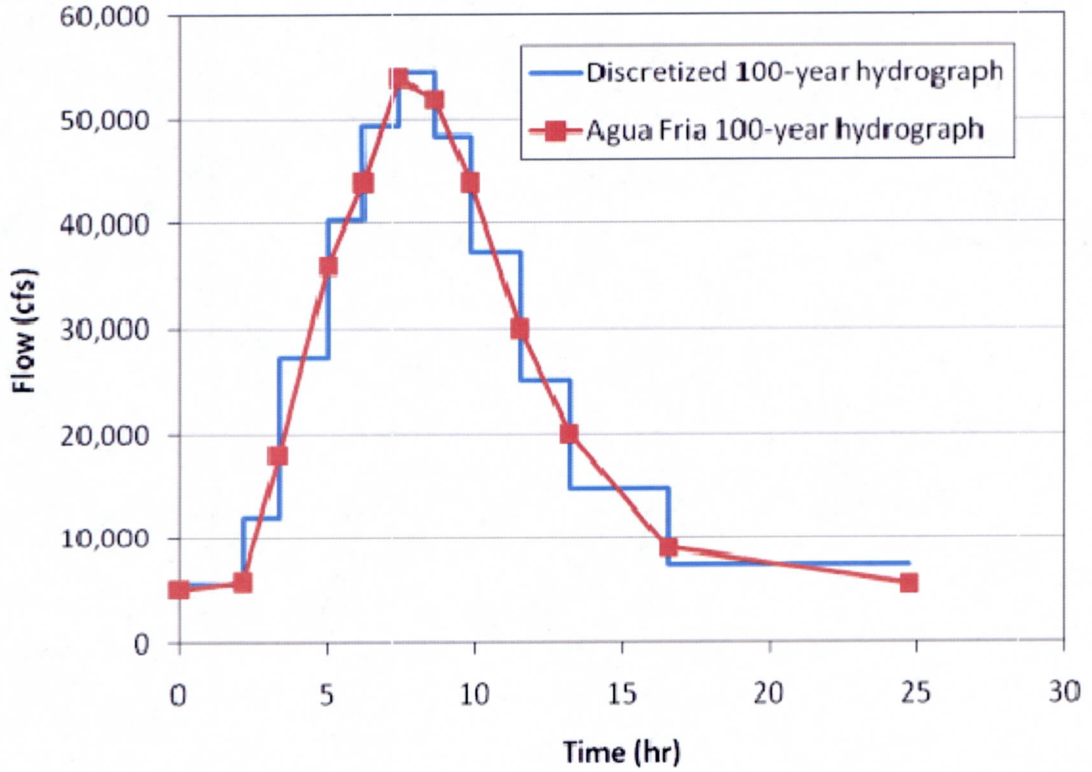

Figure 2-5. Discretized 100-year hydrograph along the Agua Fria River used in the analysis of tailcut scour for the sand and gravel pit upstream of Indian School Road

Next the unit flow rate of the reach (q_c) based on W_c was calculated:

—

and the unit flow rate through the pit (q_p) rate based on W_p was calculated:

—

Then the sediment wave celerity (C_s) in the excavation was calculated using the following equation:

Sediment wave celerity is critical to the process of calculating tailcut scour because the travel time of the sediment wave through the pit (the product of the pit length and the inverse of the sediment wave celerity) and the depth of the excavation are the primary drivers for tailcut scour. The following explanation is taken from the SLA report (1989):

As sediment is transported into the excavation, it is trapped and deposits near the upstream brink of the excavation. Sediment is subsequently transported further downstream over time creating a sediment wave. As this sediment wave propagates through the excavation, a deficit in sediment supply results which creates a downstream scour. This scour is largest at the downstream brink, and gradually decreases as sediment is re-supplied to the flow. The length and depth of downstream scour increases with increasing excavation length and depth. Increased excavation length increases the time required for the sediment wave to move through the excavation, thus increasing the duration of the downstream sediment deficit. Increased excavation depth permits the downstream scour depths to increase.

The next step of the process was to calculate the accumulated dimensionless time (T^*) as follows:

$$T^* = min\left(\frac{t}{L_p/C_s}, 1.0\right)$$

where t is the current time of the discretized hydrograph (sec). As shown in the equation above, the dimensionless time (T^*) must be less than or equal to 1.0.

The tailcut scour depth at the brink of the pit (y_s) can be calculated using the following equation:

$$y_s = 0.960\, q_c^{0.25}\, y_p^{0.50}\, T^{*0.435}$$

for $y_s < y_p$ and $T^* < 0.84$. Finally, the tailcut scour length at 5 percent of the tailcut scour depth (L_{s5}) can be calculated using the following equation:

$$L_{s5} = 41.8\, q_c^{-0.0625}\, \left(L_p\, y_p\right)^{0.50}\, T^{*0.631}$$

These calculations provide the maximum scour depth and maximum length for the tailcut scour geometry downstream of the excavated pit; however, the evolution of the tailcut scour profile must also be estimated for the scour analysis. Table 2-3 below shows the dimensionless scour profiles as presented in SLA (1989) to estimate evolution of the tailcut geometry downstream of the excavated pit and the final dimensions of the pit for the study herein. As summarized in that table, the ADOT methodology estimated a maximum scour depth at the downstream end of the pit of 1.54 feet, with a maximum downstream tailcut length of 429 feet.

Table 2-3 Tailcut scour profile downstream of the sand and gravel mining pit in the study reach based on the ADOT Methodology (SLA, 1989)

Dimensionless scour profiles		**Dimensions of the geometry for the estimated tailcut scour due to the pit upstream of Indian School Rd**		
$y_s / y_{s,\,max}$ at the downstream face of the excavated pit	L_s / L_{s5}	y_s (ft)	L_s (ft)	River mile associated with the corresponding L_s value
0.05	1.00	0.08	429	8.68
0.25	0.50	0.38	215	8.72
0.50	0.25	0.77	107	8.74
0.75	0.10	1.15	43	8.75
1.00	0.00	1.54	0	8.76

2.3.2 General Scour and Bend Scour

General scour is the lowering of the streambed across the channel or stream over relatively short time periods (e.g., the general scour in a given reach after the passage of a single flood event). The lowering may be uniform across the bed or non-uniform (i.e., the depth of scour may be deeper in some parts of the cross-section).

The District's standards require one of three empirical equations to be used to estimate the general scour in a reach: Neill's equation (1973), Blench's equation (1969), or Lacey's equation (1930). However, this study varied from the District's standards for the calculation of general scour using empirical methods due to the availability of a sediment transport analysis completed recently for the Agua Fria River Water Course Master Plan (KHA, 2001). This sediment transport analysis estimated the sediment routing in the study reach using a HEC-6T model for a single 1% annual chance flood hydrograph using Yang's streampower sediment transport function. For this case, the HEC-6T sediment transport modeling will give a more accurate indication of the general scour since the modeling takes into account the upstream sediment load which empirical equations such as Neill, Blench, and Lacey do not. Since the Agua Fria River is a sand bed river, sediment transport of the bed material will occur under all flows. In addition, the numerous grade control structures throughout the reach will have a tendency to limit the amount of general scour that occurs. Thus, the results of the previously developed HEC-6T sediment transport model will give a more accurate estimation of the general scour in the Agua Fria River than the empirical general scour equations.

Table 5.2 of the document titled *Agua Fria River Watercourse Master Plan: Sediment Trend Analysis Final Report* (KHA, 2001) provides values of maximum scour or deposition at each cross-section in the HEC-6T model for the entire simulation period. For cross-sections showing overall scour for the simulation period, the maximum scour for any time step in the model simulation was set equal to the general scour in the scour analysis herein. For cross-sections showing overall deposition instead of scour, the general scour was set to zero. The maximum general scour in the reach from the sediment transport model output was 2.6 feet. The general scour estimates utilized for this study at each cross-section are shown in Appendix A at the end of this report.

In addition to estimates of general scour using the HEC-6T model, bend scour was calculated separately to ensure any additional scour due to the two bends in the study reach was considered. Bend scour was calculated using the Zeller equation per the District's guidelines (FCDMC, 2010a). The results of these calculations are shown in

Table 2-4 below. The bend scour for the curve south of Thomas Road was applied to the east levee from river mile 7.16 to river mile 6.66 (corresponding to cross-section locations in the updated HEC-RAS model provided by the District), and the bend scour for the curve between McDowell Road and I-10 was applied to the west levee from river mile 5.84 to river mile 5.43 (corresponding to cross-section locations in the updated HEC-RAS model provided by the District).

Table 2-4 Bend scour throughout the reach

Location	Flow (cfs)	Top width (ft)	Zeller's bend scour estimate (ft)
Curve south of Thomas Road	54,400	1,130	2.6
Curve between McDowell Road and I-10	54,400	1,130	4.2

2.3.3 Bedform Scour

For sand bed channels, natural or manmade, it is necessary to estimate the height of the bedforms (e.g., dunes or antidunes) moving through the channel. Dunes form in lower regime flow with antidunes forming in transitional or upper regime flow. For the Agua Fria River, the flow is within the dune-forming range of lower regime flow (Froude numbers less than 0.7). As per the District's standards, dune heights, d_h (ft), were estimated using the following equation presented in Gyr and Hoyer (2006) and Zanke (1976):

$$0.15 < \frac{d_h}{Y_h} < 0.3$$

where Y_h is the hydraulic depth of flow (ft), a hydraulic parameter which may be obtained from the HEC-RAS analysis. For the study reach, the coefficient 0.15 was chosen for estimation of dune height.

The bedform scour depth is equal to approximately one-half of the dune height. The bedform scour calculated for each cross-section varied from approximately 0.2 feet to 0.7 feet, and the final estimated bedform scour values throughout the study reach can be found in Appendix A of this document.

2.3.4 Long-Term Degradation

Long-term degradation in the reach was considered using the equilibrium slope analysis per the District's standards (FCDMC, 2010a). These standards specify the use of a lower return-interval flow—in this case, the 10% annual chance flood event or 10-year flow—compared to the design flow for the levees (i.e., the 1% annual chance flood event). The 10% annual chance flows were obtained from the 1995 study characterizing the hydrology of the Agua Fria River after the completion of the New Waddell Dam (USACE, 1995); these flows are summarized in Table 2-5 below. Also, it should be noted that this report is the source of the 1% annual chance flood event design flows utilized for the Flood Insurance Study (FIS) and the scour analysis herein.

Table 2-5 Summary of 1% and 10% annual chance flood event flows in the study reach

Location at the upstream end of the reach for which the flows apply	1% annual chance flow (cfs)	10% annual chance flow (cfs)
Downstream of New River Confluence (HEC-RAS RS 10.22)	54,400	16,100
At the I-10 Bridge (HEC-RAS RS 5.78)	52,000	15,300
At Buckeye Road (HEC-RAS RS 4.25)	50,900	15,000

Although there is a sand and gravel mining pit immediately upstream of the study reach, the depth of this pit will not significantly influence the amounts of sediment transported to the study reach. Based on this assumption, the iterative method from Section 5.3.7 in the *Design Manual for Engineering Analysis of Fluvial Systems* (SLA, 1985) was used to estimate equilibrium slopes in the various reaches. Based on the District's standards (FCMDC, 2010a), the Zeller-Fullerton total bed material load equation was the sediment transport function utilized to define the equilibrium slope:

$$Q_s = q_s\,W = 0.0064\left(\frac{n^{1.77}\cdot V_a^{4.32}\cdot G^{0.45}}{Y_h^{0.3}\cdot D_{50}^{0.61}}\right)$$

where:

Q_s = total bed material discharge in cfs;
$q_s = Q_s / W$ = total bed material discharge in cfs per unit width;
W = flow average width, which can be defined as the flow wetted area divided by flow depth (the flow depth can be the Manning's equation-based normal depth or maximum flow depth from HEC-RAS);
n = Manning's roughness coefficient;
V_a = average velocity (ft/s);
Y_h = hydraulic depth (ft);
D_{50} = median diameter, also defined as the diameter where 50% is finer by weight, (mm);
G = gradation coefficient, where:

$$G = \frac{1}{2}\left(\frac{D_{84.1}}{D_{50}} + \frac{D_{50}}{D_{15.9}}\right)$$

and $D_{84.1}$, D_{50} and $D_{15.9}$ are sediment diameters based on a percent finer (by dry weight), (mm).

To implement this method, the total bed material sediment discharge was computed using the Zeller-Fullerton equation for the supply reach which was assumed to be in equilibrium (HEC-RAS cross-sections 9.7 to 8.96 with slight modifications made to the updated hydraulic model to better estimate sediment supply scenarios). Then the study reach was broken into 8 separate sub-reaches, and the total bed material sediment discharge was computed for each sub-reach using the Zeller-Fullerton equation as well. The calculation was performed iteratively by varying the channel slope for the sub-reach until the sediment transport capacity of the sub-reach in question matched the sediment transport capacity of the supply reach. During this process, Manning's equation was used to compute the hydraulic variables for the sub-reaches assuming normal depth was achieved in each reach.

Finally, the equilibrium slope was converted to a calculation of long-term degradation using the following equation:

$$Z_{long-term} = L\,\Delta S$$

where $Z_{long\text{-}term}$ is the long-term scour, in feet, at a distance, L, in feet, upstream of the pivot point and $\Delta S = S_0 - S_{eq}$ where S_0 is the channel bed existing slope and S_{eq} is the channel bed equilibrium slope. If the equilibrium slope is less than the existing bed slope upstream from the pivot point, the calculation of long-term scour is positive and indicates degradation in the reach. Alternatively, if the equilibrium slope is larger than the existing bed slope upstream from the pivot point, the calculation of long-term scour is negative and indicates aggradation in the reach. As per the District's standards, sub-reaches for which the long-term scour analysis indicated aggradation would occur were assumed to have zero long-term trend for the scour analysis herein (i.e., $Z_{long\text{-}term}$ was set to zero).

The study reach herein contains five grade control structures (Figure 1-1) and one structure that acts as grade control (a grouted apron beneath the Van Buren Street Bridge). The study reach was divided into 8 separate reaches for the long-term degradation analysis based on the locations of these structures and the Lower Buckeye Road low-flow crossing.

In the calculation of long-term degradation for the reach, the median grain size was varied based on the sediment sampling routine completed by KHA for the Agua Fria River Watercourse Master Plan completed for the Flood Control District of Maricopa County (KHA, 2001). The values of median grain size (i.e., D_{50}) varied between 0.32 and 0.7 mm throughout the study reach. The KHA report provides sampled D_{50} values for bed sediment approximately every half mile throughout the study reach as well as upstream and downstream of the study reach along the Agua Fria River (KHA, 2001). This range of values agrees with other sources as well, including the document titled "Final Report: System Analysis and Conceptual Design of Channelization in the Agua Fria River" completed by SLA for the District (SLA, 1983) which was the basis for the design of the levees in the study reach from the north end of the levees to Buckeye Road. The SLA report lists a single value of 0.76 mm as the D_{50} value for the study reach (SLA, 1983). Other reports, including the bridge scour assessment for the Camelback Road Bridge (Cannon & Associates, 1996) and the *General Design Memorandum for the New and Agua Fria Rivers* (USACE, 1986), report an estimated D_{50} for the study reach as 1.0 mm. However, due to the collection of data for the Agua Fria River Water Course Master Plan completed by KHA (2001) verifying a smaller median bed sediment size based on a more recent sampling routine, the large value of 1.0 mm was ignored in the analysis of scour herein.

The results of the long-term degradation analysis are summarized in Table 2-6 below. As shown in this table, long-term degradation does not exist for any of the sub-reaches considered herein. Therefore, the long-term degradation was set equal to zero.

Table 2-6 also provides the equilibrium slopes calculated by SLA for the original design of the levee based on the 10% annual chance flood hydrograph (i.e., the 10-year event). As can be seen from these values, the current bed slopes of the study reach are near the equilibrium slopes calculated by SLA for the original design of the levees. It should be noted that these values were calculated based on (1) sub-reaches before the final design and installation of the current grade control structures and (2) a different sediment transport function (Pima County unit width regressions for sediment transport capacity).

Table 2-6 Summary of the long-term degradation analysis in the study reach

Long-term degradation sub-reach	HEC-RAS RS	S_0 (ft/ft)	10% annual chance flow, Q (cfs)	S_{eq} (ft/ft)	Reach Length, L (ft)	Long-term Scour* (ft)	S_{eq} from original SLA Design Calculations (ft/ft)
1	8.85 to 8.53	0.0017	16,100	0.0027	1,636	0.0	0.0016
2	8.49 to 7.38	0.0018	16,100	0.0021	5,844	0.0	0.0014
3	7.31 to 6.66	0.0010	16,100	0.0026	3,440	0.0	0.0012
4	6.57 to 5.65	0.0018	16,100	0.0029	4,779	0.0	0.0012
5	5.60 to 4.55	0.0011	15,300	0.0025	5,504	0.0	0.0017
6	4.51 to 4.21	0.0008	15,300	0.0024	1,618	0.0	0.0017
7	4.18 to 3.15	0.0012	15,000	0.0029	5,453	0.0	N/A
8	3.05 to 2.20	0.0012	15,000	0.0025	4,461	0.0	N/A

**Note: Sub-reaches showing aggradation for the long-term calculation (i.e., the equilibrium slope is greater than the existing slope) are listed with 0 feet for estimated long-term scour*

2.3.5 Low-Flow Incisement Scour

The low-flow incisement refers to the depth of a low-flow channel due to a predominance of low-flow conditions or low-flows that persist after a flood. The magnitude of low-flow incisement scour can be estimated as no less than 1 foot and possibly in excess of 2 feet (FCDMC, 2010a). In addition, the District's standards indicate that if the low-flow channel is very stable and the toe-down or total scour is measured from the channel thalweg, then the low-flow incisement can be ignored (FCDMC, 2010a). The Agua Fria River has established a low-flow channel over the life of the channelization and levee project that is the focus of this study. Additionally, the scour depths were applied to the channel thalweg elevation at all cross-sections. Thus, no low-flow incisement scour was assumed for this analysis.

2.3.6 Embankment Protection

The majority of the Levee ID's #08, #16, and #18 are soil cement levees with a typical lift thickness of 8.0 feet. Based on the specifications of the soil cement outlined in the design plans and as-built drawings for these levees, the soil cement displayed at least a 7-day compressive strength of 750 psi. As per the Portland Cement Association's *Soil-Cement Guide for Water Resources Applications* publication (PCA, 2006) and the U.S. Federal Highway Administrations' *Hydraulic Engineering Circular 23* (FHWA, 2009), this application of soil cement is estimated to be able to withstand the abrasive force of Agua Fria River flows with velocities up to 20 ft/sec. Based on the hydraulic model provided by the District (Stanley, 2011), the maximum channel velocity in the study reach is 11.5 ft/sec. Therefore, the soil cement portions of the levees are adequately protected for embankment scour.

There is a reach of the west levee (Levee ID #18) that is protected by riprap instead of soil cement. The section of this levee protected by riprap stretches from 1,100 feet south of Indian School Road to approximately 2,000 feet north of the Thomas Road alignment, for a total distance of approximately 2,300 feet. The reason for this portion of the levee being protected by riprap is that the Roosevelt Irrigation District (RID) canal that passes through a siphon below the Agua Fria River at this location and the large offline sand and gravel mining pit in the right overbank of the river at this location had already utilized a similar levee-like structure at this location, and a riprap structure allowed for settlement and repair during continued mining activities in the right overbank. The riprap section of the levee extends approximately 900 feet north of the canal and 1,400 feet south of the canal. Based on the as-built plans of the levees, the D_{50} of the riprap gradation used along this portion of the levee is 18 inches, and the slope of the levee face is 3H:1V for this section.

The District's modification to the Isbash formula (FCDMC, 2010a) was used to determine the required riprap sizing based on the hydraulic model provided by the District (Stanley, 2011). The following text is taken directly from the District's standards (FCDMC, 2010a):

> *In Simons and Senturk (1992) and Vanoni (2006), the Isbash equation for low turbulent flow has a term which accounts for bank slope effects. However, in USACE (1994b), the Isbash equation does not account for bank slope effects, but has coefficients to account for both low and high turbulent flows. By combining these equations, the Flood Control District of Maricopa County (FCDMC) has developed and [sic] Isbash equation which accounts for both the bank slope effects and the flow regime (whether low of [sic] high turbulent flows).*
>
> *In USACE (1994b), the Isbash equation is based on an average channel velocity. However, the channel velocity for a cross-section is not uniform. The maximum velocity is higher than the average velocity. The maximum velocity usually occurs in the middle of a cross-section. In alluvial channels, the main channel may laterally migrate within the floodplain. Therefore, using maximum velocity is more reasonable. To account for the maximum velocity for a particular cross-section that which [sic] may occur anywhere, the FCDMC uses the maximum velocity, V. The maximum velocity can be approximated by 1.33V_a (Subramanya, 1997). The FCDMC-recommended Isbash equation has the form*

$$d_{50} = \frac{V^2}{2gC^2 cos\varphi}\left(\frac{\gamma_w}{\gamma_s - \gamma_w}\right)$$

> *where:*
>
> *V = maximum velocity = 1.33 V_a (Subramanya, 1997) (ft/s),*
> *V_a = average channel velocity for the approach section (ft/s),*
> *C = coefficient (use 1.2 for low turbulence areas or 0.86 for high turbulence areas),*
> *g = gravitational acceleration (ft/s^2),*
> *γ_s = specific weight of stone (lb/ft^3),*
> *γ_w = specific weight of water (lb/ft^3),*
> *φ = bank angle (degrees), and*
> *d_{50} = median rock size (ft).*

For the portion of the west levee protected by riprap, the HEC-RAS hydraulic model was used to estimate the average channel velocity at the cross-sections crossing that portion of the levee, which was 7.7 feet/sec. In this application of the methodology, the *C* factor was chose to be 0.86

for high turbulence areas. Based on these inputs, the calculated riprap size for this portion of the levee was estimated to be 17.0 inches. This value is less than the constructed levee riprap sizing of 18 inches for the d_{50} of the embankment riprap material.

Another important consideration for embankment protection using riprap is the gradation of the riprap and the thickness of the riprap layer. The riprap layer thickness for this portion of the levee is 30 inches. To assess the adequacy of this thickness, the recommended gradations and thicknesses recommended by the USACE in Engineering Technical Letter (ETL) 1110-2-120 (1971) corresponding to the methodology proposed to size riprap in Engineer Manual 1110-2-1601 (1994b) were utilized. The tables of gradations in ETL 1110-2-120 are based on the d_{30} of the riprap instead of the d_{50} as calculated using the FCDMC-Isbash method. ETL 1110-2-120 recommends estimating d_{30} as 82% of the d_{50} size for their methodology; for the case of the portion of Levee #18 protected by riprap, that calculation would estimate a d_{30} value of approximately 14.8 inches (1.2 feet). The recommended riprap thickness corresponding to this specific gradation would be 30 inches, the as-built condition of the riprap embankment protection.

Based on the as-built d_{50} and riprap thickness of the riprap embankment protection along Levee #18, the embankment protection for this portion of the levee is adequate.

3 Results

Based on the analyses discussed above, the estimated total scour values are provided in Appendix A at the end of this report for all three levees (Levee ID #18 on the west bank of the river and Levee ID's #08 and #16 on the east bank).

3.1 Scour Analysis Compared to Existing Toe-Down Elevations

The method described in the preceding sections provides estimates of scour depths throughout the study reach based on the method outlined above per the District's standards or recommendations from District personnel when deviations from the standards have occurred. Also, to compare these scour depths to the toe-down elevations of the levees, the scour depths were converted to scour elevations by subtracting the scour depth from the thalweg of each cross-section in the hydraulic model (as well as several additional locations throughout the study reach to properly display local scour depths downstream of grade control structures and the sand and gravel mining pit upstream of Indian School Road). The plots of top of levee, channel thalweg elevation, toe-down elevation from the as-built plans, and the estimated scour elevations are shown in Figure 3-1, Figure 3-2, and Figure 3-3. Additionally, this information has been provided in tabular format in Table A-1, Table A-2, and Table A-3 in Appendix A. As mentioned previously, the factors of safety for levee toe-down were estimated along the length of the levees (i.e., calculated scour depth divided by the vertical distance from the current thalweg elevation to the toe-down elevation). These results are reported in the tables of Appendix A as well. Since the scour elevations are above the toe-down elevations along the entire lengths of all three levees, the factors of safety were estimated to be 1.0 or greater at all locations. However, estimates of factor of safety at several locations along the levees were less than 1.3 which is the current District standard for factors of safety in scour and toe-down calculations (FCDMC, 2010a). This can be attributed to the more stringent and conservative standards currently enforced by the District compared to the District's standards at the time of the construction of the levees. Although this would not meet current design criteria for the design of a new levee along the Agua Fria River, the toe-down depths of a previously constructed levee are shown to provide adequate toe protection of the levee from embankment scour with a factor of safety greater than or equal to 1.0.

To assist in interpreting the results of the analysis, the various structures and their approximate location along the Agua Fria River is shown in Table 3-1. As shown in these figures and tables, all three levees provide adequate toe protection from being undermined from scour. Additionally, the embankment protection is adequate to sufficiently protect the levees from embankment scour. Based on this analysis and the computations of scour depths along the levee, it was determined that the levee embankment is sufficiently protected from scour.

Table 3-1 Summary and approximate locations of structures on the Agua Fria River

Structure	Approximate River Mile		Structure	Approximate River Mile
Camelback Road	9.71		Grade Control	5.64
Indian School Road	8.51		Van Buren Street	5.2
Grade Control	8.47		Grade Control	4.55
Grade Control	7.36		SPRR Bridge	4.215
Grade Control	6.58		Buckeye Road Bridge	4.2
McDowell Road	6.155		Lower Buckeye Road	3.15
I-10	5.76			

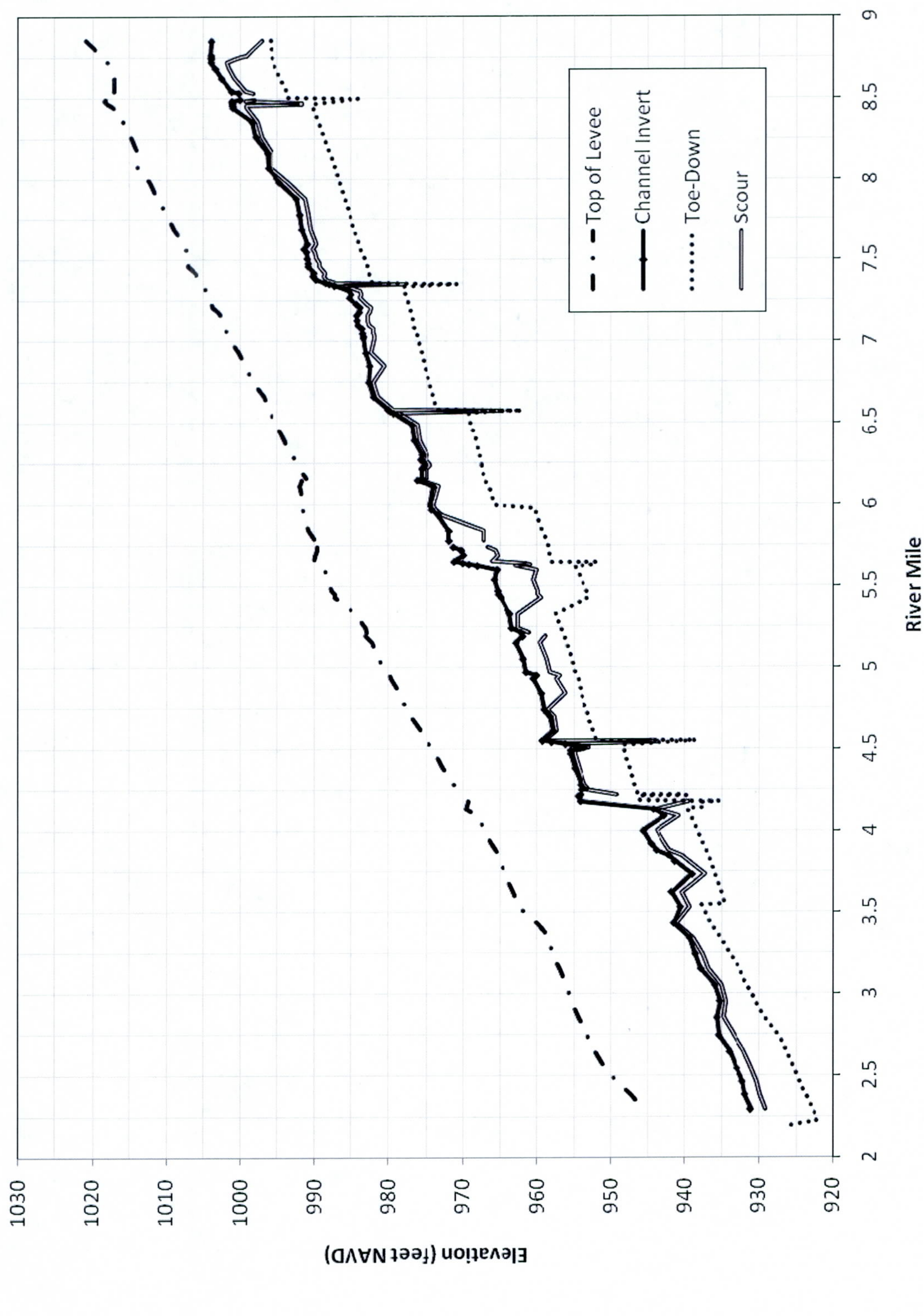

Figure 3-1. Scour elevations compared to toe-down elevations for the west levee (Levee ID #18)

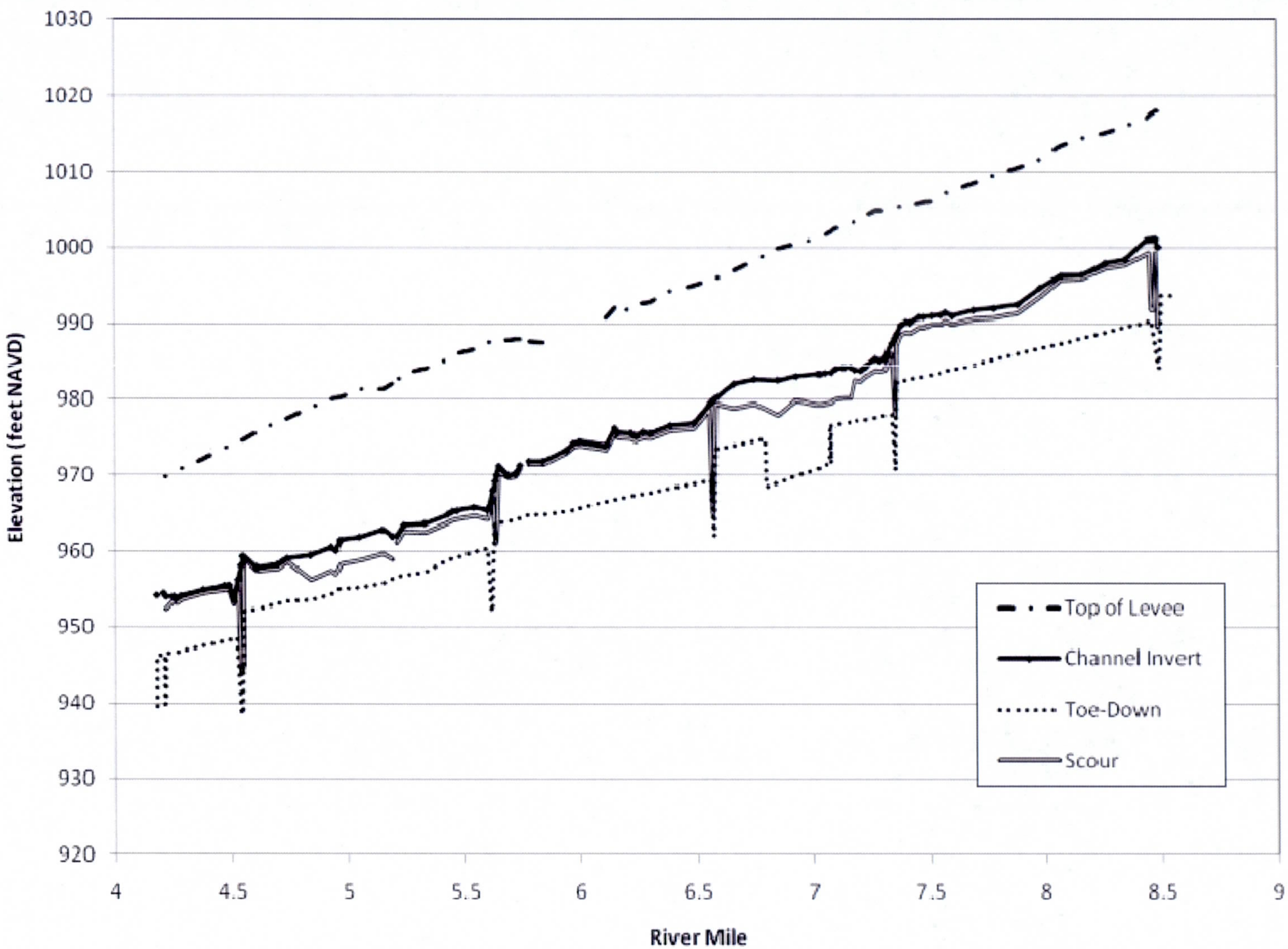

Figure 3-2. Scour elevations compared to toe-down elevations for the longer east levee (Levee ID #08)

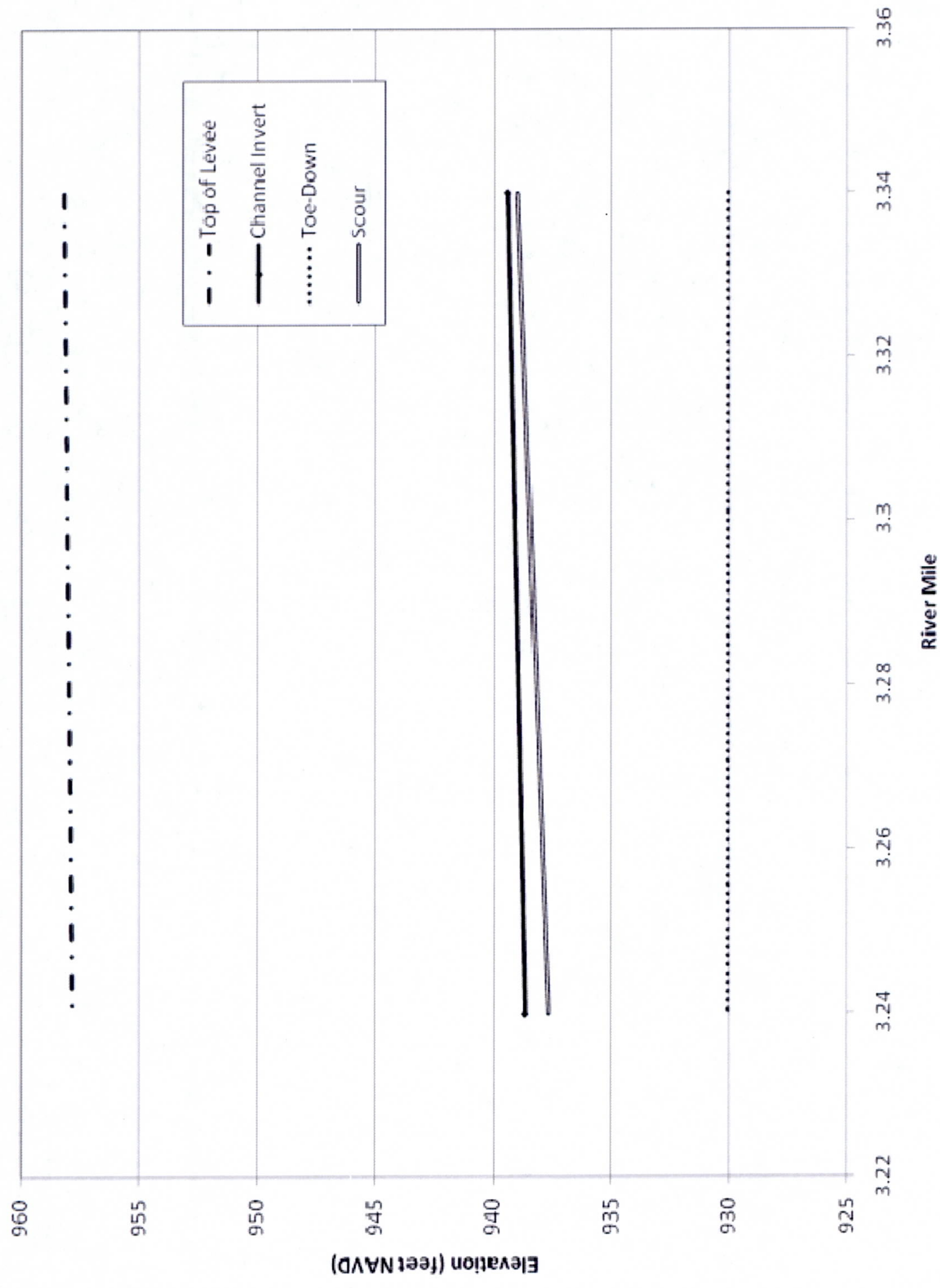

Figure 3-3. Scour elevations compared to toe-down elevations for the shorter east levee (Levee ID #16)

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Appendix A: Final Scour Estimates at Each Cross-section in the HEC-RAS Model

Table A-1 West Levee (Levee ID #18) Scour Estimates

Location (River Mile)	SCOUR ESTIMATES										Toe-down elevation (ft NAVD88)	Remaining Distance to Toe-Down (ft)	Calculated Factor of Safety
	General Scour from HEC-6T (ft)	Bedform Dune Scour (ft)	Bend Scour (ft)	Local Scour				Total West Levee Scour* (ft)	Channel Invert (ft)	Scour Elevation (ft NAVD88)			
				Abutment Scour (ft)	*Pier Scour (ft)*	*Tail-Cut Scour (ft)*	*Grade Control Scour (ft)*						
8.85	1.4	0.0	0	5.5	0	0	0	6.8	1003.94	997.1	996.0	1.1	1.2
8.76†	1.4	0.2	0	1.7	0	1.5	0	4.8	1003.96	999.1	995.8	3.4	1.7
8.75†	1.4	0.2	0	1.3	0	1.2	0	4.0	1003.96	1000.0	995.7	4.2	2.1
8.74†	1.4	0.2	0	0.8	0	0.8	0	3.2	1003.97	1000.8	995.7	5.1	2.6
8.72	1.4	0.5	0	0	0	0.4	0	2.2	1003.97	1001.8	995.7	6.1	3.8
8.68†	1.4	0.5	0	0	0	0.1	0	1.9	1003.42	1001.5	995.3	6.2	4.3
8.62	1.4	0.5	0	0	0	0	0	1.8	1002.59	1000.8	994.7	6.1	4.3
8.54	1.4	0.5	0	0	0	0	0	1.8	1001.19	999.3	993.8	5.6	4.0
8.53	1.4	0.6	0	0	0	0	0	1.9	1000.28	998.4	993.6	4.8	3.5
8.51	INDIAN SCHOOL ROAD BRIDGE												
8.49	1.4	0.5	0	0	0	0	0	1.9	1000.11	998.2	987.0	11.2	7.0
8.48	1.4	0.5	0	0	0	0	0	1.8	1001.17	999.4	986.6	12.8	8.1
8.47††	1.4	0.5	0	0	0	0	9.4	9.4	1001.14	991.7	987.5	4.2	1.5
8.46††	1.4	0.5	0	0	0	0	9.4	9.4	1001.11	991.7	988.2	3.5	1.4
8.45††	1.4	0.5	0	0	0	0	0	1.8	1001.07	999.3	989.1	10.2	6.6
8.44	1.4	0.5	0	0	0	0	0	1.8	1001.03	999.2	990.2	9.0	6.0

**Note: Total scour is equivalent to either the sum of all of the scour components not including grade control structure local scour or grade control structure local scour individually, whichever is greater.*

†Indicates this river mile is not in the final hydraulic model provided by Stanley, but was added to show the correct tailcut scour profile

††Indicates this river mile is not in the final hydraulic model provided by Stanley, but was added to show the correct grade control scour profile

Table A-1 West Levee (Levee ID #18) Scour Estimates (cont'd.)

Location (River Mile)	SCOUR ESTIMATES										Toe-down elevation (ft NAVD88)	Remaining Distance to Toe-Down (ft)	Calculated Factor of Safety
	General Scour from HEC-6T (ft)	Bedform Dune Scour (ft)	Bend Scour (ft)	Local Scour				Total West Levee Scour* (ft)	Channel Invert (ft)	Scour Elevation (ft NAVD88)			
				Abutment Scour (ft)	*Pier Scour (ft)*	*Tail-Cut Scour (ft)*	*Grade Control Scour (ft)*						
8.35	0.2	0.5	0	0	0	0	0	0.7	998.47	997.7	989.5	8.2	12.2
8.26	0.2	0.6	0	0	0	0	0	0.8	997.97	997.2	988.8	8.4	12.1
8.16	0.0	0.5	0	0	0	0	0	0.5	996.42	995.9	988.0	7.8	15.5
8.07	0.0	0.5	0	0	0	0	0	0.5	996.28	995.8	987.4	8.4	17.1
7.98	0.7	0.5	0	0	0	0	0	1.2	994.78	993.6	986.7	6.8	6.6
7.88	0.7	0.5	0	0	0	0	0	1.2	992.51	991.3	986.0	5.3	5.3
7.78	0.7	0.5	0	0	0	0	0	1.2	992.02	990.8	985.3	5.5	5.6
7.69	0.7	0.5	0	0	0	0	0	1.2	991.78	990.6	984.6	6.0	5.9
7.6	0.7	0.5	0	0	0	0	0	1.2	991.01	989.8	984.0	5.8	5.8
7.57	0.7	0.5	0	0	0	0	0	1.2	991.47	990.3	983.7	6.5	6.5
7.55	0.7	0.5	0	0	0	0	0	1.2	991.13	989.9	983.5	6.5	6.4
7.51	0.7	0.5	0	0	0	0	0	1.2	991.04	989.8	983.2	6.6	6.5
7.48	1.0	0.5	0	0	0	0	0	1.5	990.9	989.4	983.1	6.4	5.4
7.46	1.0	0.5	0	0	0	0	0	1.5	990.9	989.4	982.8	6.6	5.6
7.42	1.0	0.5	0	0	0	0	0	1.4	990.14	988.7	982.7	6.0	5.2
7.4	1.0	0.4	0	0	0	0	0	1.4	990.22	988.8	982.5	6.3	5.5
7.38	1.0	0.4	0	0	0	0	0	1.4	989.87	988.5	982.5	6.0	5.3

**Note: Total scour is equivalent to either the sum of all of the scour components <u>not including</u> grade control structure local scour or grade control structure local scour individually, whichever is greater.*

†Indicates this river mile is not in the final hydraulic model provided by Stanley, but was added to show the correct tailcut scour profile

††Indicates this river mile is not in the final hydraulic model provided by Stanley, but was added to show the correct grade control scour profile

Table A-1 West Levee (Levee ID #18) Scour Estimates (cont'd.)

Location (River Mile)	SCOUR ESTIMATES										Toe-down elevation (ft NAVD88)	Remaining Distance to Toe-Down (ft)	Calculated Factor of Safety
	General Scour from HEC-6T (ft)	Bedform Dune Scour (ft)	Bend Scour (ft)	Local Scour				Total West Levee Scour* (ft)	Channel Invert (ft)	Scour Elevation (ft NAVD88)			
				Abutment Scour (ft)	*Pier Scour (ft)*	*Tail-Cut Scour (ft)*	*Grade Control Scour (ft)*						
7.36††	1.0	0.5	0	0	0	0	0	1.5	988.60	987.1	982.2	4.9	4.3
7.35††	1.0	0.5	0	0	0	0	10.1	10.1	988.11	978.0	970.7	7.3	1.7
7.34††	1.0	0.5	0	0	0	0	0	1.5	987.44	986.0	978.1	7.9	6.4
7.31	1.0	0.6	0	0	0	0	0	1.5	985.41	983.9	977.9	6.0	4.9
7.29	1.0	0.5	0	0	0	0	0	1.5	985.13	983.6	977.8	5.9	4.9
7.27	1.0	0.5	0	0	0	0	0	1.5	985.37	983.9	977.7	6.2	5.1
7.23	1.0	0.5	0	0	0	0	0	1.5	984.36	982.9	977.4	5.5	4.6
7.21	1.0	0.5	0	0	0	0	0	1.5	983.84	982.3	977.3	5.1	4.4
7.18	1.0	0.5	0	0	0	0	0	1.5	983.94	982.4	977.1	5.3	4.5
7.16	1.0	0.5	0	0	0	0	0	1.5	984.29	982.8	977.0	5.8	4.9
7.13	1.0	0.5	0	0	0	0	0	1.5	984.24	982.7	976.8	5.9	4.9
7.1	1.0	0.5	0	0	0	0	0	1.5	984.11	982.6	976.7	6.0	5.0
7.08	1.0	0.5	0	0	0	0	0	1.5	983.59	982.1	976.5	5.6	4.8
7.05	1.0	0.5	0	0	0	0	0	1.5	983.5	982.0	976.4	5.6	4.8
7.03	1.0	0.5	0	0	0	0	0	1.5	983.37	981.9	976.2	5.6	4.8
7.02	1.0	0.5	0	0	0	0	0	1.5	983.39	981.9	976.1	5.8	4.9
6.93	0.2	0.5	0	0	0	0	0	0.7	983.06	982.4	975.6	6.7	10.7

**Note: Total scour is equivalent to either the sum of all of the scour components not including grade control structure local scour or grade control structure local scour individually, whichever is greater.*

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††Indicates this river mile is not in the final hydraulic model provided by Stanley, but was added to show the correct grade control scour profile

Table A-1 West Levee (Levee ID #18) Scour Estimates (cont'd.)

Location (River Mile)	SCOUR ESTIMATES										Toe-down elevation (ft NAVD88)	Remaining Distance to Toe-Down (ft)	Calculated Factor of Safety
	General Scour from HEC-6T (ft)	Bedform Dune Scour (ft)	Bend Scour (ft)	Local Scour				Total West Levee Scour* (ft)	Channel Invert (ft)	Scour Elevation (ft NAVD88)			
				Abutment Scour (ft)	*Pier Scour (ft)*	*Tail-Cut Scour (ft)*	*Grade Control Scour (ft)*						
6.85	1.5	0.5	0	0	0	0	0	2.0	982.55	980.6	975.1	5.4	3.7
6.75	0.2	0.5	0	0	0	0	0	0.7	982.68	982.0	974.5	7.5	12.3
6.66	0.2	0.4	0	0	0	0	0	0.6	982.04	981.4	974.0	7.5	13.3
6.58††	0.2	0.4	0	0	0	0	0	0.6	980.08	979.4	973.5	5.9	10.2
6.57	0.2	0.5	0	0	0	0	14.9	14.9	979.84	964.9	964.5	0.4	1.0
6.56††	0.2	0.5	0	0	0	0	0	0.7	979.39	978.7	969.4	9.3	14.2
6.49	0.2	0.5	0	0	0	0	0	0.7	976.93	976.2	968.9	7.3	11.0
6.39	0.2	0.5	0	0	0	0	0	0.7	976.59	975.9	968.3	7.6	11.8
6.3	0.2	0.5	0	0	0	0	0	0.7	975.54	974.8	967.8	7.0	10.8
6.27	0.2	0.5	0	0	0	0	0	0.7	975.73	975.0	967.7	7.3	11.3
6.24	0.2	0.5	0	0	0	0	0	0.7	975.19	974.5	967.5	6.9	10.6
6.22	0.2	0.5	0	0	0	0	0	0.7	975.6	974.9	967.4	7.5	11.5
6.16	0.2	0.5	0	0	0	0	0	0.7	975.63	974.9	967.2	7.8	12.0
6.155	MCDOWELL ROAD BRIDGE												
6.15	0.2	0.5	0	0	0	0	0	0.7	976.22	975.5	967.1	8.4	13.1
6.11	0.2	0.5	0	0	0	0	0	0.7	973.96	973.3	966.5	6.7	10.8
6	0	0.5	0	0	0	0	0	0.5	974.45	974.0	965.8	8.1	17.4

**Note:* *Total scour is equivalent to either the sum of all of the scour components <u>not including</u> grade control structure local scour or grade control structure local scour individually, whichever is greater.*

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††*Indicates this river mile is not in the final hydraulic model provided by Stanley, but was added to show the correct grade control scour profile*

Table A-1 West Levee (Levee ID #18) Scour Estimates (cont'd.)

Location (River Mile)	SCOUR ESTIMATES										Toe-down elevation (ft NAVD88)	Remaining Distance to Toe-Down (ft)	Calculated Factor of Safety
	General Scour from HEC-6T (ft)	Bedform Dune Scour (ft)	Bend Scour (ft)	Local Scour: *Abutment Scour (ft)*	Local Scour: *Pier Scour (ft)*	Local Scour: *Tail-Cut Scour (ft)*	Local Scour: *Grade Control Scour (ft)*	Total West Levee Scour* (ft)	Channel Invert (ft)	Scour Elevation (ft NAVD88)			
5.97	0	0.5	0	0	0	0	0	0.5	974.2	973.7	960.2	13.6	29.0
5.94	0	0.5	0	0	0	0	0	0.5	973.34	972.8	960.0	12.9	26.8
5.84	0	0.4	4.2	0	0	0	0	4.6	971.86	967.2	959.3	7.9	2.7
5.78	0	0.4	4.2	0	0	0	0	4.6	971.89	967.3	958.7	8.5	2.8
5.76	I-10 BRIDGE												
5.74	0	0.4	4.2	0	0	0	0	4.6	971.3	966.7	958.5	8.2	2.8
5.72	0	0.4	4.2	0	0	0	0	4.6	970.24	965.6	958.4	7.2	2.6
5.69	0	0.4	4.2	0	0	0	0	4.6	969.97	965.4	958.3	7.1	2.6
5.65	0.6	0.3	4.2	0	0	0	0	5.1	971.21	966.1	955.8	10.4	3.0
5.64††	0.6	0.4	4.2	0	0	0	8.3	8.3	970.05	961.7	955.5	6.2	1.7
5.63††	0.6	0.4	4.2	0	0	0	8.3	8.3	969.23	960.9	955.4	5.5	1.7
5.62††	0.6	0.4	4.2	0	0	0	0	5.2	968.13	962.9	955.1	7.8	2.5
5.6	0.6	0.5	4.2	0	0	0	0	5.3	965.42	960.1	954.6	5.5	2.0
5.54	0.6	0.5	4.2	0	0	0	0	5.3	965.79	960.4	954.0	6.4	2.2
5.47	0.6	0.5	4.2	0	0	0	0	5.4	965.32	960.0	953.3	6.6	2.2
5.45	0.6	0.6	4.2	0	0	0	0	5.4	965.25	959.9	953.2	6.7	2.3
5.43	0.6	0.6	4.2	0	0	0	0	5.4	964.86	959.5	953.0	6.5	2.2

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Table A-1 West Levee (Levee ID #18) Scour Estimates (cont'd.)

Location (River Mile)	SCOUR ESTIMATES										Toe-down elevation (ft NAVD88)	Remaining Distance to Toe-Down (ft)	Calculated Factor of Safety
	General Scour from HEC-6T (ft)	Bedform Dune Scour (ft)	Bend Scour (ft)	Local Scour				Total West Levee Scour* (ft)	Channel Invert (ft)	Scour Elevation (ft NAVD88)			
				Abutment Scour (ft)	*Pier Scour (ft)*	*Tail-Cut Scour (ft)*	*Grade Control Scour (ft)*						
5.33	0.6	0.5	0	0	0	0	0	1.2	963.66	962.5	957.6	4.9	5.2
5.24	0.4	0.5	0	0	0	0	0	0.8	963.41	962.6	956.8	5.8	7.9
5.21	0.4	0.5	0	0	0	0	0	0.9	962.04	961.2	956.6	4.6	6.1
5.2	VAN BUREN STREET BRIDGE												
5.19	2.6	0.5	0	0	0	0	0	3.1	961.93	958.8	956.5	2.4	1.8
5.15	2.6	0.5	0	0	0	0	0	3.1	962.81	959.7	956.0	3.6	2.2
5.05	2.6	0.5	0	0	0	0	0	3.1	961.88	958.7	955.4	3.3	2.1
4.97	2.6	0.5	0	0	0	0	0	3.1	961.47	958.4	954.9	3.5	2.1
4.95	2.6	0.5	0	0	0	0	0	3.1	960.07	957.0	954.7	2.2	1.7
4.93	2.6	0.5	0	0	0	0	0	3.1	960.51	957.4	954.6	2.8	1.9
4.84	2.6	0.5	0	0	0	0	0	3.1	959.43	956.3	954.0	2.3	1.7
4.74	0	0.5	0	0	0	0	0	0.5	959.05	958.5	953.4	5.1	10.7
4.72	0	0.5	0	0	0	0	0	0.5	958.65	958.1	953.2	4.9	10.7
4.7	0	0.5	0	0	0	0	0	0.5	958.28	957.8	953.1	4.6	10.0
4.61	0	0.5	0	0	0	0	0	0.5	957.84	957.4	952.5	4.9	11.0
4.55	0	0.3	0	0	0	0	0	0.3	959.31	959.0	952.1	6.9	23.7
4.55††	0	0.5	0	0	0	0	14.3	14.3	959.31	945.0	938.6	6.5	1.5

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Table A-1 West Levee (Levee ID #18) Scour Estimates (cont'd.)

Location (River Mile)	SCOUR ESTIMATES										Toe-down elevation (ft NAVD88)	Remaining Distance to Toe-Down (ft)	Calculated Factor of Safety
	General Scour from HEC-6T (ft)	Bedform Dune Scour (ft)	Bend Scour (ft)	Local Scour				Total West Levee Scour* (ft)	Channel Invert (ft)	Scour Elevation (ft NAVD88)			
				Abutment Scour (ft)	*Pier Scour (ft)*	*Tail-Cut Scour (ft)*	*Grade Control Scour (ft)*						
4.54††	0	0.5	0	0	0	0	14.3	14.3	958.07	943.8	938.6	5.2	1.4
4.53††	0	0.5	0	0	0	0	0	0.5	956.24	955.7	948.5	7.2	15.2
4.51	0	0.7	0	0	0	0	0	0.7	953.67	953.0	948.4	4.5	7.4
4.49	0	0.6	0	0	0	0	0	0.6	955.54	955.0	948.3	6.7	12.9
4.47	0	0.6	0	0	0	0	0	0.6	955.51	954.9	948.1	6.8	12.9
4.38	0	0.5	0	0	0	0	0	0.5	954.94	954.4	947.5	6.9	14.1
4.28	0	0.5	0	0	0	0	0	0.5	954.12	953.6	946.8	6.8	13.9
4.26	0	0.5	0	0	0	0	0	0.5	953.71	953.2	946.7	6.5	13.9
4.25	0	0.5	0	0	0	0	0	0.5	954.06	953.5	946.6	7.0	14.6
4.22	0	0.5	0	0	4.4	0	0	4.9	954.06	949.2	946.4	2.7	1.6
4.215	SPRR BRIDGE												
4.21	0	0.5	0	0	4.4	0	0	4.9	954.49	949.6	946.3	3.3	1.7
4.2	BUCKEYE ROAD BRIDGE												
4.18	0	0.4	0	0	0	0	14.7	14.7	954.2	939.5	935.4	4.0	1.3
4.13	0	0.5	0	0	0	0	0	0.5	944.3	943.8	939.6	4.1	8.7
4.09	1.4	0.5	0	0	0	0	0	2.0	942.8	940.8	939.2	1.6	1.8
4	1.4	0.5	0	0	0	0	0	1.9	945.68	943.8	938.3	5.5	3.9
3.92	1.4	0.4	0	0	0	0	0	1.8	944.62	942.8	937.6	5.2	3.9

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Table A-1 West Levee (Levee ID #18) Scour Estimates (cont'd.)

Location (River Mile)	SCOUR ESTIMATES										Toe-down elevation (ft NAVD88)	Remaining Distance to Toe-Down (ft)	Calculated Factor of Safety
	General Scour from HEC-6T (ft)	Bedform Dune Scour (ft)	Bend Scour (ft)	Local Scour				Total West Levee Scour* (ft)	Channel Invert (ft)	Scour Elevation (ft NAVD88)			
				Abutment Scour (ft)	*Pier Scour (ft)*	*Tail-Cut Scour (ft)*	*Grade Control Scour (ft)*						
3.88	1.4	0.4	0	0	0	0	0	1.8	943.93	942.1	937.2	5.0	3.8
3.85	1.4	0.4	0	0	0	0	0	1.8	942.17	940.4	936.9	3.5	3.0
3.81	1.4	0.5	0	0	0	0	0	1.9	941.36	939.5	936.5	2.9	2.6
3.73	1.1	0.5	0	0	0	0	0	1.6	939.04	937.4	936.0	1.4	1.8
3.62	0.9	0.4	0	0	0	0	0	1.4	941.81	940.5	935.1	5.3	4.9
3.53	0.9	0.3	0	0	0	0	0	1.3	940.63	939.4	937.6	1.8	2.4
3.43	0.0	0.4	0	0	0	0	0	0.4	941.49	941.1	936.6	4.5	13.0
3.34	0.0	0.4	0	0	0	0	0	0.4	939.4	939.0	935.4	3.6	9.4
3.24	0.5	0.4	0	0	0	0	0	0.9	938.61	937.7	934.0	3.7	4.9
3.15	0.5	0.4	0	0	0	0	0	0.9	937.88	937.0	932.7	4.3	5.7
3.05	0.5	0.4	0	0	0	0	0	0.9	936.05	935.2	931.7	3.5	4.9
2.95	0.5	0.3	0	0	0	0	0	0.9	935.35	934.5	930.4	4.1	5.7
2.85	0.5	0.3	0	0	0	0	0	0.9	935.73	934.9	929.2	5.6	7.6
2.74	1.7	0.3	0	0	0	0	0	2.0	935.48	933.4	927.4	6.0	4.0
2.64	1.7	0.3	0	0	0	0	0	2.0	934.03	932.0	926.3	5.7	3.8
2.54	1.7	0.2	0	0	0	0	0	2.0	933.03	931.0	925.4	5.7	3.9
2.46	1.7	0.2	0	0	0	0	0	2.0	932.25	930.3	924.6	5.7	3.9
2.38	1.7	0.2	0	0	0	0	0	2.0	931.87	929.9	923.7	6.2	4.1
2.29	1.7	0.2	0	0	0	0	0	2.0	931.11	929.2	922.8	6.4	4.3

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Table A-2 Upper East Levee (Levee ID #08) Scour Estimates

Location (River Mile)	SCOUR ESTIMATES										Toe-down elevation (ft NAVD88)	Remaining Distance to Toe-Down (ft)	Calculated Factor of Safety
	General Scour from HEC-6T (ft)	Bedform Dune Scour (ft)	Bend Scour (ft)	Local Scour				Total West Levee Scour* (ft)	Channel Invert (ft)	Scour Elevation (ft NAVD88)			
				Abutment Scour (ft)	*Pier Scour (ft)*	*Tail-Cut Scour (ft)*	*Grade Control Scour (ft)*						
8.51	INDIAN SCHOOL ROAD BRIDGE												
8.49	1.4	0.5	0	0	8.6	0	0	10.5	1000.11	989.6	987.0	2.6	1.3
8.48	1.4	0.5	0	0	0	0	0	1.8	1001.17	999.4	986.6	12.8	8.1
8.47[††]	1.4	0.5	0	0	0	0	9.4	9.4	1001.14	991.7	988.8	3.0	1.3
8.46[††]	1.4	0.5	0	0	0	0	9.4	9.4	1001.11	991.7	990.4	1.3	1.1
8.45[††]	1.4	0.5	0	0	0	0	0	1.8	1001.07	999.3	990.3	9.0	5.9
8.44	1.4	0.5	0	0	0	0	0	1.8	1001.03	999.2	990.2	9.0	6.0
8.35	0.2	0.5	0	0	0	0	0	0.7	998.47	997.7	989.5	8.2	12.2
8.26	0.2	0.6	0	0	0	0	0	0.8	997.97	997.2	988.8	8.4	12.1
8.16	0.0	0.5	0	0	0	0	0	0.5	996.42	995.9	988.0	7.8	15.5
8.07	0.0	0.5	0	0	0	0	0	0.5	996.28	995.8	987.4	8.4	17.1
7.98	0.7	0.5	0	0	0	0	0	1.2	994.78	993.6	986.7	6.8	6.6
7.88	0.7	0.5	0	0	0	0	0	1.2	992.51	991.3	986.0	5.3	5.3
7.78	0.7	0.5	0	0	0	0	0	1.2	992.02	990.8	985.3	5.5	5.6
7.69	0.7	0.5	0	0	0	0	0	1.2	991.78	990.6	984.6	6.0	5.9
7.6	0.7	0.5	0	0	0	0	0	1.2	991.01	989.8	984.0	5.8	5.8
7.57	0.7	0.5	0	0	0	0	0	1.2	991.47	990.3	983.7	6.5	6.5
7.55	0.7	0.5	0	0	0	0	0	1.2	991.13	989.9	983.5	6.5	6.4

**Note: Total scour is equivalent to either the sum of all of the scour components not including grade control structure local scour or grade control structure local scour individually, whichever is greater.*

[††]Indicates this river mile is not in the final hydraulic model provided by Stanley, but was added to show the correct grade control scour profile

Table A-2 Upper East Levee (Levee ID #08) Scour Estimates (cont'd.)

Location (River Mile)	SCOUR ESTIMATES										Toe-down elevation (ft NAVD88)	Remaining Distance to Toe-Down (ft)	Calculated Factor of Safety
	General Scour from HEC-6T (ft)	Bedform Dune Scour (ft)	Bend Scour (ft)	Local Scour				Total West Levee Scour* (ft)	Channel Invert (ft)	Scour Elevation (ft NAVD88)			
				Abutment Scour (ft)	*Pier Scour (ft)*	*Tail-Cut Scour (ft)*	*Grade Control Scour (ft)*						
7.51	0.7	0.5	0	0	0	0	0	1.2	991.04	989.8	983.2	6.6	6.5
7.48	1.0	0.5	0	0	0	0	0	1.5	990.9	989.4	983.1	6.4	5.4
7.46	1.0	0.5	0	0	0	0	0	1.5	990.9	989.4	982.8	6.6	5.6
7.42	1.0	0.5	0	0	0	0	0	1.4	990.14	988.7	982.7	6.0	5.2
7.4	1.0	0.4	0	0	0	0	0	1.4	990.22	988.8	982.5	6.3	5.5
7.38	1.0	0.4	0	0	0	0	0	1.4	989.87	988.5	982.5	6.0	5.3
7.36††	1.0	0.5	0	0	0	0	0	1.5	988.60	987.1	982.2	4.9	4.3
7.35††	1.0	0.5	0	0	0	0	10.1	10.1	988.11	978.0	970.7	7.3	1.7
7.34††	1.0	0.5	0	0	0	0	0	1.5	987.44	986.0	978.1	7.9	6.4
7.31	1.0	0.6	0	0	0	0	0	1.5	985.41	983.9	977.7	6.2	5.0
7.29	1.0	0.5	0	0	0	0	0	1.5	985.13	983.6	977.9	5.7	4.8
7.27	1.0	0.5	0	0	0	0	0	1.5	985.37	983.9	977.8	6.1	5.0
7.23	1.0	0.5	0	0	0	0	0	1.5	984.36	982.9	977.4	5.5	4.6
7.21	1.0	0.5	0	0	0	0	0	1.5	983.84	982.3	977.3	5.1	4.4
7.18	1.0	0.5	0	0	0	0	0	1.5	983.94	982.4	977.1	5.3	4.5
7.16	1.0	0.5	2.6	0	0	0	0	4.1	984.29	980.2	977.0	3.2	1.8
7.13	1.0	0.5	2.6	0	0	0	0	4.1	984.24	980.1	976.8	3.3	1.8
7.1	1.0	0.5	2.6	0	0	0	0	4.1	984.11	980.0	976.7	3.4	1.8

**Note: Total scour is equivalent to either the sum of all of the scour components not including grade control structure local scour or grade control structure local scour individually, whichever is greater.*

††Indicates this river mile is not in the final hydraulic model provided by Stanley, but was added to show the correct grade control scour profile

Table A-2 Upper East Levee (Levee ID #08) Scour Estimates (cont'd.)

Location (River Mile)	SCOUR ESTIMATES										Toe-down elevation (ft NAVD88)	Remaining Distance to Toe-Down (ft)	Calculated Factor of Safety
	General Scour from HEC-6T (ft)	Bedform Dune Scour (ft)	Bend Scour (ft)	Local Scour				Total West Levee Scour* (ft)	Channel Invert (ft)	Scour Elevation (ft NAVD88)			
				Abutment Scour (ft)	*Pier Scour (ft)*	*Tail-Cut Scour (ft)*	*Grade Control Scour (ft)*						
7.08	1.0	0.5	2.6	0	0	0	0	4.1	983.59	979.5	971.6	7.9	2.9
7.05	1.0	0.5	2.6	0	0	0	0	4.1	983.5	979.4	971.3	8.1	3.0
7.03	1.0	0.5	2.6	0	0	0	0	4.1	983.37	979.3	971.1	8.2	3.0
7.02	1.0	0.5	2.6	0	0	0	0	4.1	983.39	979.3	970.9	8.4	3.1
6.93	0.2	0.5	2.6	0	0	0	0	3.3	983.06	979.8	970.0	9.8	4.0
6.85	1.5	0.5	2.6	0	0	0	0	4.6	982.55	978.0	969.0	8.9	2.9
6.75	0.2	0.5	2.6	0	0	0	0	3.3	982.68	979.4	974.5	4.9	2.5
6.66	0.2	0.4	2.6	0	0	0	0	3.2	982.04	978.8	974.0	4.9	2.5
6.58††	0.2	0.4	0	0	0	0	0	0.6	980.08	979.4	973.5	5.9	10.2
6.57	0.2	0.5	0	0	0	0	14.9	14.9	979.84	964.9	964.5	0.4	1.0
6.56††	0.2	0.5	0	0	0	0	0	0.7	979.39	978.7	969.4	9.3	14.2
6.49	0.2	0.5	0	0	0	0	0	0.7	976.93	976.2	968.9	7.3	11.0
6.39	0.2	0.5	0	0	0	0	0	0.7	976.59	975.9	968.3	7.6	11.8
6.3	0.2	0.5	0	0	0	0	0	0.7	975.54	974.8	967.8	7.1	10.9
6.27	0.2	0.5	0	0	0	0	0	0.7	975.73	975.0	967.6	7.4	11.4
6.24	0.2	0.5	0	0	0	0	0	0.7	975.19	974.5	967.4	7.0	10.8
6.22	0.2	0.5	0	0	0	0	0	0.7	975.6	974.9	967.3	7.6	11.7
6.16	0.2	0.5	0	0	0	0	0	0.7	975.63	974.9	966.9	8.0	12.4

**Note: Total scour is equivalent to either the sum of all of the scour components <u>not including</u> grade control structure local scour or grade control structure local scour individually, whichever is greater.*

††Indicates this river mile is not in the final hydraulic model provided by Stanley, but was added to show the correct grade control scour profile

Table A-2 Upper East Levee (Levee ID #08) Scour Estimates (cont'd.)

Location (River Mile)	SCOUR ESTIMATES										Toe-down elevation (ft NAVD88)	Remaining Distance to Toe-Down (ft)	Calculated Factor of Safety
	General Scour from HEC-6T (ft)	Bedform Dune Scour (ft)	Bend Scour (ft)	Local Scour				Total West Levee Scour* (ft)	Channel Invert (ft)	Scour Elevation (ft NAVD88)			
				Abutment Scour (ft)	*Pier Scour (ft)*	*Tail-Cut Scour (ft)*	*Grade Control Scour (ft)*						
6.155	MCDOWELL ROAD BRIDGE												
6.15	0.2	0.5	0	0	0	0	0	0.7	976.22	975.5	966.9	8.7	13.5
6.11	0.2	0.5	0	0	0	0	0	0.7	973.96	973.3	966.6	6.7	10.8
6	0	0.5	0	0	0	0	0	0.5	974.45	974.0	965.7	8.3	17.7
5.97	0	0.5	0	0	0	0	0	0.5	974.2	973.7	965.4	8.3	18.1
5.94	0	0.5	0	0	0	0	0	0.5	973.34	972.8	965.2	7.6	16.3
5.84	0	0.4	0	0	0	0	0	0.4	971.86	971.4	964.7	6.7	16.2
5.78	0	0.4	0	0	0	0	0	0.4	971.89	971.5	964.7	6.7	16.7
5.76	I-10 BRIDGE												
5.74	0	0.4	0	0	0	0	0	0.4	971.3	970.9	964.4	6.5	16.0
5.72	0	0.4	0	0	0	0	0	0.4	970.24	969.8	964.2	5.7	15.5
5.69	0	0.4	0	0	0	0	0	0.4	969.97	969.6	964.0	5.6	15.9
5.65	0.6	0.3	0	0	0	0	0	0.9	971.21	970.3	960.1	10.2	12.6
5.64††	0.6	0.4	0	0	0	0	8.3	8.3	970.05	961.7	952.1	9.7	2.2
5.63††	0.6	0.4	0	0	0	0	8.3	8.3	969.23	960.9	952.1	8.8	2.1
5.62††	0.6	0.4	0	0	0	0	0	1.0	968.13	967.1	960.1	7.0	7.9
5.6	0.6	0.5	0	0	0	0	0	1.1	965.42	964.3	960.0	4.3	4.7

**Note: Total scour is equivalent to either the sum of all of the scour components <u>not including</u> grade control structure local scour or grade control structure local scour individually, whichever is greater.*

††Indicates this river mile is not in the final hydraulic model provided by Stanley, but was added to show the correct grade control scour profile

Table A-2 Upper East Levee (Levee ID #08) Scour Estimates (cont'd.)

Location (River Mile)	SCOUR ESTIMATES										Toe-down elevation (ft NAVD88)	Remaining Distance to Toe-Down (ft)	Calculated Factor of Safety
	General Scour from HEC-6T (ft)	Bedform Dune Scour (ft)	Bend Scour (ft)	Local Scour				Total West Levee Scour* (ft)	Channel Invert (ft)	Scour Elevation (ft NAVD88)			
				Abutment Scour (ft)	*Pier Scour (ft)*	*Tail-Cut Scour (ft)*	*Grade Control Scour (ft)*						
5.54	0.6	0.5	0	0	0	0	0	1.1	965.79	964.6	959.9	4.8	5.2
5.47	0.6	0.5	0	0	0	0	0	1.2	965.32	964.2	959.2	4.9	5.2
5.45	0.6	0.6	0	0	0	0	0	1.2	965.25	964.1	959.1	5.0	5.3
5.43	0.6	0.6	0	0	0	0	0	1.2	964.86	963.7	958.9	4.8	5.1
5.33	0.6	0.5	0	0	0	0	0	1.2	963.66	962.5	957.3	5.2	5.5
5.24	0.4	0.5	0	0	0	0	0	0.8	963.41	962.6	956.8	5.8	7.8
5.21	0.4	0.5	0	0	0	0	0	0.9	962.04	961.2	956.7	4.5	6.1
5.2	VAN BUREN STREET BRIDGE												
5.19	2.6	0.5	0	0	0	0	0	3.1	961.93	958.8	956.4	2.4	1.8
5.15	2.6	0.5	0	0	0	0	0	3.1	962.81	959.7	955.8	3.9	2.2
5.05	2.6	0.5	0	0	0	0	0	3.1	961.88	958.7	955.2	3.5	2.1
4.97	2.6	0.5	0	0	0	0	0	3.1	961.47	958.4	955.1	3.3	2.1
4.95	2.6	0.5	0	0	0	0	0	3.1	960.07	957.0	954.9	2.0	1.6
4.93	2.6	0.5	0	0	0	0	0	3.1	960.51	957.4	954.3	3.1	2.0
4.84	2.6	0.5	0	0	0	0	0	3.1	959.43	956.3	953.6	2.7	1.9
4.74	0	0.5	0	0	0	0	0	0.5	959.05	958.5	953.4	5.1	10.7
4.72	0	0.5	0	0	0	0	0	0.5	958.65	958.1	953.3	4.8	10.6
4.7	0	0.5	0	0	0	0	0	0.5	958.28	957.8	953.2	4.6	9.9

**Note: Total scour is equivalent to either the sum of all of the scour components not including grade control structure local scour or grade control structure local scour individually, whichever is greater.*

††Indicates this river mile is not in the final hydraulic model provided by Stanley, but was added to show the correct grade control scour profile

Table A-2 Upper East Levee (Levee ID #08) Scour Estimates (cont'd.)

Location (River Mile)	SCOUR ESTIMATES										Toe-down elevation (ft NAVD88)	Remaining Distance to Toe-Down (ft)	Calculated Factor of Safety
	General Scour from HEC-6T (ft)	Bedform Dune Scour (ft)	Bend Scour (ft)	Local Scour				Total West Levee Scour* (ft)	Channel Invert (ft)	Scour Elevation (ft NAVD88)			
				Abutment Scour (ft)	*Pier Scour (ft)*	*Tail-Cut Scour (ft)*	*Grade Control Scour (ft)*						
4.61	0	0.5	0	0	0	0	0	0.5	957.84	957.4	952.5	4.9	11.0
4.55	0	0.3	0	0	0	0	0	0.3	959.31	959.0	952.1	6.9	23.7
4.55††	0	0.5	0	0	0	0	14.3	14.3	959.31	945.0	938.6	6.5	1.5
4.54††	0	0.5	0	0	0	0	14.3	14.3	958.07	943.8	938.6	5.2	1.4
4.53††	0	0.5	0	0	0	0	0	0.5	956.24	955.7	948.5	7.2	15.2
4.51	0	0.7	0	0	0	0	0	0.7	953.67	953.0	948.4	4.6	7.4
4.49	0	0.6	0	0	0	0	0	0.6	955.54	955.0	948.3	6.7	12.9
4.47	0	0.6	0	0	0	0	0	0.6	955.51	954.9	948.1	6.8	12.9
4.38	0	0.5	0	0	0	0	0	0.5	954.94	954.4	947.5	6.9	14.1
4.28	0	0.5	0	0	0	0	0	0.5	954.12	953.6	946.8	6.8	13.9
4.26	0	0.5	0	0	0	0	0	0.5	953.71	953.2	946.7	6.5	13.9
4.25	0	0.5	0	0	0	0	0	0.5	954.06	953.5	946.6	6.9	14.6
4.22	0	0.5	0	0	1.1	0	0	1.6	954.06	952.5	946.4	6.0	4.8
4.215	SPRR BRIDGE												

**Note: Total scour is equivalent to either the sum of all of the scour components not including grade control structure local scour or grade control structure local scour individually, whichever is greater.*

††Indicates this river mile is not in the final hydraulic model provided by Stanley, but was added to show the correct grade control scour profile

Table A-3 Lower East Levee (Levee ID #16) Scour Estimates

Location (River Mile)	SCOUR ESTIMATES										Toe-down elevation (ft NAVD88)	Remaining Distance to Toe-Down (ft)	Calculated Factor of Safety
	General Scour from HEC-6T (ft)	Bedform Dune Scour (ft)	Bend Scour (ft)	Local Scour				Total West Levee Scour* (ft)	Channel Invert (ft)	Scour Elevation (ft NAVD88)			
				Abutment Scour (ft)	*Pier Scour (ft)*	*Tail-Cut Scour (ft)*	*Grade Control Scour (ft)*						
3.34	0	0.4	0	0	0	0	0	0.4	939.40	939.0	930.1	8.9	21.7
3.24	0.5	0.4	0	0	0	0	0	0.9	938.61	937.7	930.1	7.6	9.2

**Note: Total scour is equivalent to either the sum of all of the scour components <u>not including</u> grade control structure local scour or grade control structure local scour individually, whichever is greater.*

Agua Fria Levees Freeboard Analysis Report: Levee PAL IDs #08, 16, and 18

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Expires 3/31/2014

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List of Abbreviations

District ..... Flood Control District of Maricopa County
FEMA ..... Federal Emergency Management Agency
FIS ..... Flood Insurance Study
GIS ..... Geographic Information Systems
HARN ..... High Accuracy Reference Network
NAD ..... North American Datum
NAVD88 ..... North American Vertical Datum of 1988
NGVD29 ..... National Geodetic Vertical Datum of 1929
PAL ..... Provisionally Accredited Levee
WEST ..... WEST Consultants, Inc.
WSE ..... Water Surface Elevation

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1 Introduction

1.1 Purpose

The purpose of this freeboard analysis is to provide certification documentation in support of FEMA's accreditation of the Agua Fria River Levees located along the Agua Fria River south of the Indian School Road. The locations of the levees are shown in Figure 1-1, and they consist of the following:

- Levee ID #08 – Along the East Bank of the Agua Fria River from Indian School Road South to Buckeye Road (4.32 miles long)
- Levee ID #16 – Along the East Bank of the Agua Fria River at Lower Buckeye Road (0.4 miles long)
- Levee ID #18 – Along the West Bank of the Agua Fria River from just upstream of Indian School Road to a point downstream of Lower Buckeye Road (approximately 6 miles long)

Currently Levee ID #08, #16, and #18 are Provisionally Accredited Levees (PAL) by the Federal Emergency Management Agency (FEMA) and are shown as providing protection from the 1-percent annual chance flood on the most recent Flood Insurance Rate Map (FIRM Panel No 04013C2080J, 04012C2085G, and 04013C2090H). The Provisionally Accredited Levee agreement between the Flood Control District of Maricopa County (District) and FEMA is due to expire on June 25th, 2011. In order for Levees ID #08, #16, and #18 to continue to be shown as providing flood protection on the FIRM Panels beyond the PAL expiration date, levee certifications and FEMA accreditations are necessary.

1.2 Study Area Description

The study reach of the Agua Fria River for which freeboard will be estimated, which includes Levee IDs #08, #16, and #18, covers approximately 6.5 miles of the river. The channel thalweg elevations within the study reach ranges from approximately 1,000 feet to 931 feet in relation to the North American Vertical Datum of 1988 (NAVD88).

1.3 Datum

All geographic and spatial data used in this study were adjusted to a horizontal datum of North American Datum (NAD) 1983 HARN State Plane Arizona Central (FIPS 0202 International Feet) and a vertical datum of NAVD88.

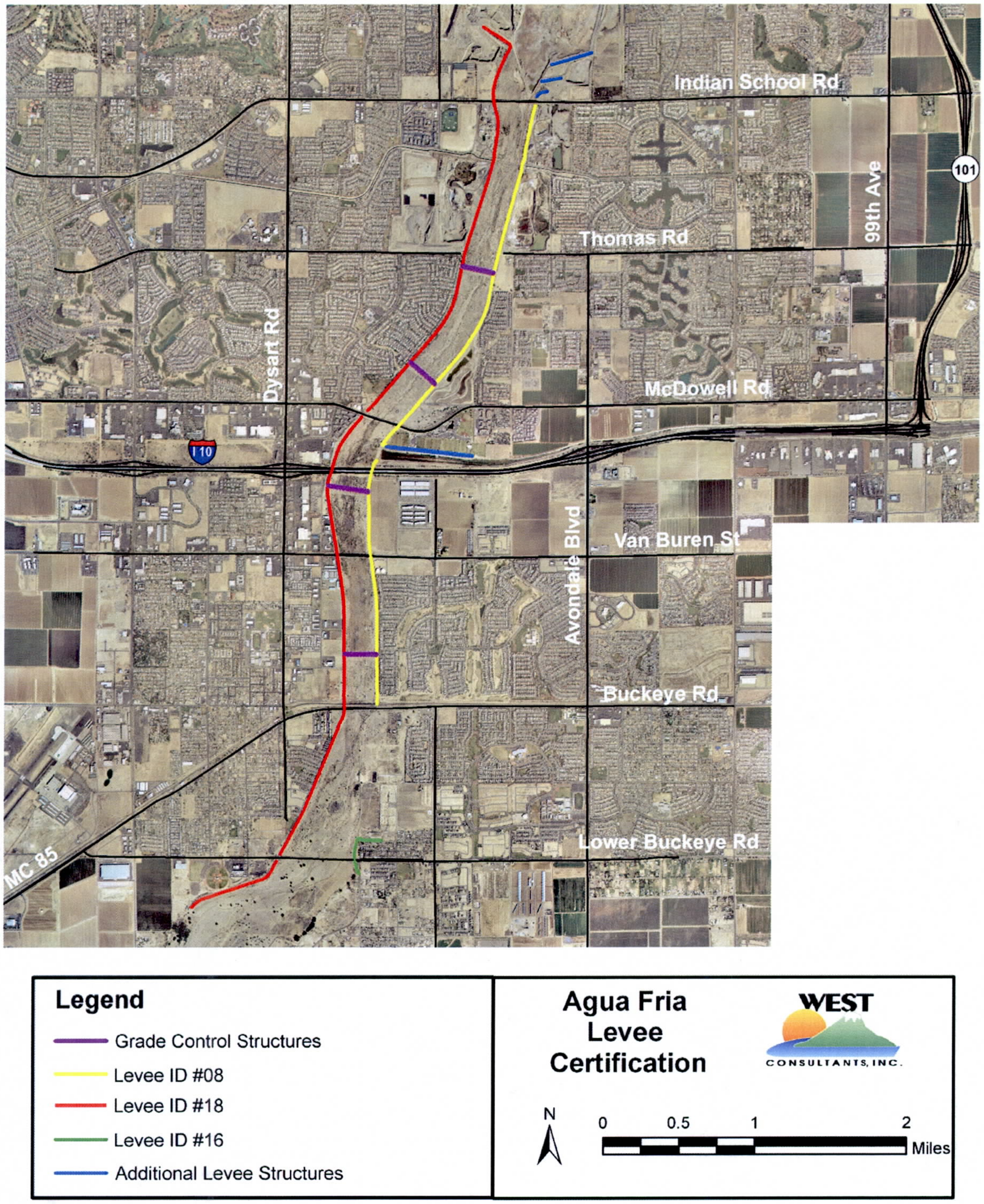

Figure 1-1. Levee Locations

2 Hydraulics and Freeboard Calculations

2.1 Introduction

Hydraulic data provided by the District included a HEC-RAS model that was developed by Stanley Consultants (2011). This model updated the effective HEC-2 model used for floodplain delineation along the Agua Fria River to reflect current conditions for the FEMA levee certification submittal. This hydraulic model was utilized as-is, and no additional changes were made to the model. It should be noted that all freeboard calculations were based on the assumption that the hydraulic modeling product provided by Stanley was accurate as per the direction of the District. WEST was not involved in the development of the hydraulic model and did not perform a technical review of the model per the request of the District. Note that the river mile stationing used in this report corresponds to the stationing in the newly developed Stanley hydraulic model, which may not agree with the stationing used in the effective model.

2.2 Topography and Survey

Survey data used in the freeboard analysis were provided by the District in two deliverables:

- Levee elevation and levee penetration structure survey completed by Wilson & Company, Inc., Engineers & Architects in late 2010 and early 2011 for the west levee (#18) south of Indian School Road to the downstream end of that levee, the east levees (#08 and #16), and a majority of the structures penetrating the levees; and
- Levee elevation and levee penetration structure survey completed by Stanley Consultants in early 2011 for the west levee (#18) north of Indian School Road, the grade control structures in the reach, and a few remaining structures penetrating the levees.

Levee cross section surveys (i.e., river natural ground adjacent grade, riverward confluence of the natural ground and the levee structure, top of levee, landward confluence of the natural ground and the levee structure, and the landward natural ground adjacent grade) were collected on approximately 200' spacing along the entire length of Levee ID #08, #16, and #18. The cross sections were utilized to develop top of levee profiles for the entire length of all three levees.

2.3 Freeboard Calculations

The total amount of freeboard was estimated along the Agua Fria River levees for the 1-percent annual chance flood event (formerly known as the 100-year flood event) in the Agua Fria River. The method to estimate freeboard in this reach was based on the Flood Control District of Maricopa County's Draft Hydraulics Manual (FCDMC, 2010).

Based on the District's standards from the Draft Hydraulics Manual (2010), freeboard along the levees for the Agua Fria River was estimated as the distance between the calculated water surface and the top of the levee. The minimum freeboard at any point along the levee should be greater than or equal to the FEMA regulations (FEMA, 2010a) which state the following regarding freeboard for riverine levees:

- A minimum freeboard of 3 feet above the water-surface level of the base flood must be provided.
- An additional 1 foot above the minimum is required within 100 feet on either side of structures (e.g., bridges) riverward of the levee or wherever the flow is constricted.
- An additional 0.5 foot above the minimum at the upstream end of the levee, tapering to not less than the minimum at the downstream end of the levee, is also required.

Additionally, the District's standards require that superelevation be considered when assessing freeboard along a levee. Superelevation can be defined as the rise in the water surface elevation along the outside of a curve in the channel due to the shift of the maximum flow velocity towards the outside of that bend. Based on the District standards (2010), superelevation can be calculated using the following equation:

$$y = \frac{0.5\, V^2\, T}{g\, r_c}$$

where y is the superelevation or rise in water surface (ft), V is the channel average cross sectional velocity (ft/s), T is the top width of flow in the curve (ft), g is the acceleration due to gravity (assumed to be 32.2 ft/s^2), and r_c is the radius of curvature for the bend (ft).

Two curves were considered for superelevation calculations in the estimation of freeboard for the study reach: the curve immediately downstream of Thomas Road (extending from River Station 7.16 to 6.66 in the HEC-RAS model) and the slightly more severe curve beginning downstream of McDowell Road and extending downstream of the I-10 bridge (extending from River Station 5.84 to 5.43 in the HEC-RAS model). It should be noted that while the eastbound and westbound lanes of I-10 have separate structural bridges, these bridges are spaced significantly close to one another as to act as a single hydraulic structure. The updated HEC-RAS model reflects this in that the two bridges are represented as a single hydraulic structure in the geometry data of the model. The radii of curvature for these curves were taken to be 4,450 feet and 3,500 feet, respectively, as shown in Figure 2-1 below.

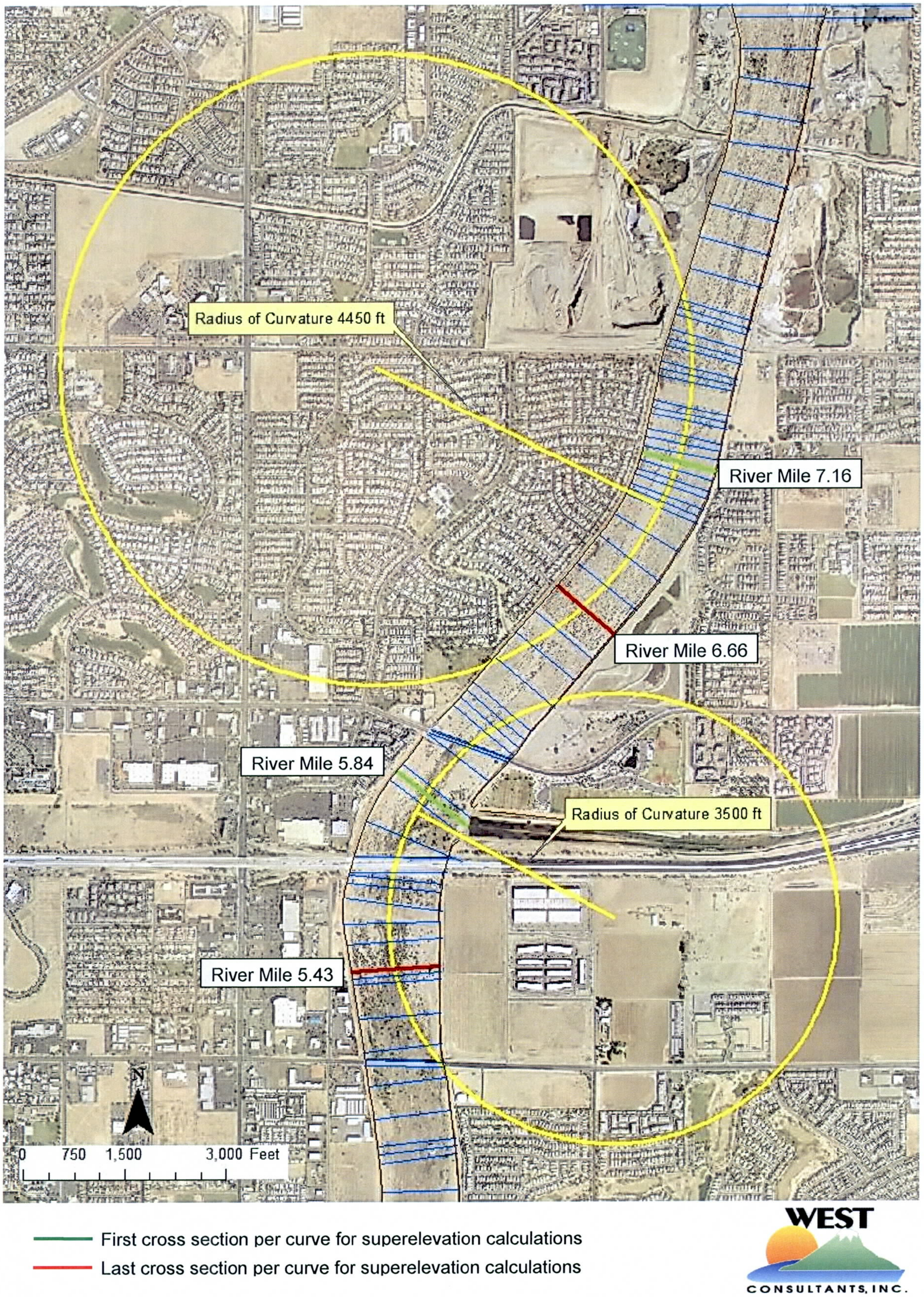

Figure 2-1. Radii of Curvature in the Study Reach for Superelevation Calculations

3 Results

Based on the analyses discussed above, the estimated freeboard values are provided in Appendix A at the end of this report for all three levees (PAL ID #18 on the west bank of the river and PAL ID #08 and #16 on the east bank).

3.1 Freeboard Analysis Compared to Existing Top of Levee Elevations

Table A-1, Table A-2, and Table A-3 in Appendix A below provide estimates of freeboard based on the method outlined in the District's standards. Additionally, these tables provide comparisons of the estimated freeboard values to the FEMA requirements for freeboard along all the levees throughout the study reach. The tables also provide a calculated factor of safety for the estimated freeboard compared to the FEMA requirements at each cross section in the HEC-RAS model. This factor of safety was calculated as the estimated available freeboard divided by the freeboard required as per FEMA's standards. The minimum factor of safety at any point along the levees was 1.6, well above typical values of factor of safety in the District's standards (FCDMC, 2010).

The plots of top of levee, maximum allowable water surface elevation based on FEMA requirements, and the water surface elevations from the HEC-RAS model are shown in Figure 3-1, Figure 3-2, and Figure 3-3 for PAL Levee ID #18, #08, and #16, respectively. As shown in these figures and the tables in Appendix A, all three levees provide sufficient freeboard for the 1-percent annual chance flood event throughout the reach. In fact, the estimated freeboard is 1.75 feet or greater than the FEMA requirements at all locations along the levees. This is due primarily to the fact that the levees were originally designed by the U.S. Army Corps of Engineers, Los Angeles District, and the Flood Control District of Maricopa County to provide 2.5 feet of freeboard for the Standard Project Flood hydrograph developed for the Old Waddell Dam with a peak flow of approximately 94,000 cfs in the study reach (USACE, 1987; SLA, 1983). FEMA requires that freeboard be assessed based on the 1-percent annual chance flood, not the larger Standard Project Flood. Additionally, in the case of the Agua Fria River, the construction of New Waddell Dam in 1992 by the U.S. Bureau of Reclamation provided a reduced 1-percent annual chance flow compared to the Old Waddell Dam hydrology (USACE, 1995). In total, the reduction in peak flows from the original levee design to the current analysis is approximately 40,000 cfs (from 94,000 cfs based on the Standard Project Flood to 54,000 cfs based on the current 1-percent annual chance flood in the study reach). This reduction in flows provided a lowered water surface elevation profile, and now no location along the levees has an estimated freeboard less than 4.75 feet.

Additionally, it should be noted that all freeboard calculations herein were based on the HEC-RAS model developed by Stanley Consultants (Stanley, 2011) to support this levee certification process. This model, although representing the best available data to date, has not yet been approved by FEMA as the effective hydraulic analysis to issue flood insurance rate maps (FIRMs). This model will be submitted to FEMA with the levee certification packages. Based on the recently released Procedure Memorandum Number 63 (FEMA, 2010b), the freeboard analysis should be based on the currently effective Base Flood Elevations (BFE's) of the 1-percent annual chance flood event as per the current FIS. In addition to using the recent hydraulic model delivered by the District (Stanley Consultants, 2011) to estimate freeboard, WEST compared the top of levee elevations as surveyed for this study to the currently effective BFE's, and the freeboard requirements were also met for this scenario. These results are shown below in Figure 3-4, Figure 3-5, and Figure 3-6. As per the direction of the District, the newly developed HEC-RAS model water surface elevations (Stanley Consultants, 2011) were used to estimate freeboard for the levee certification process.

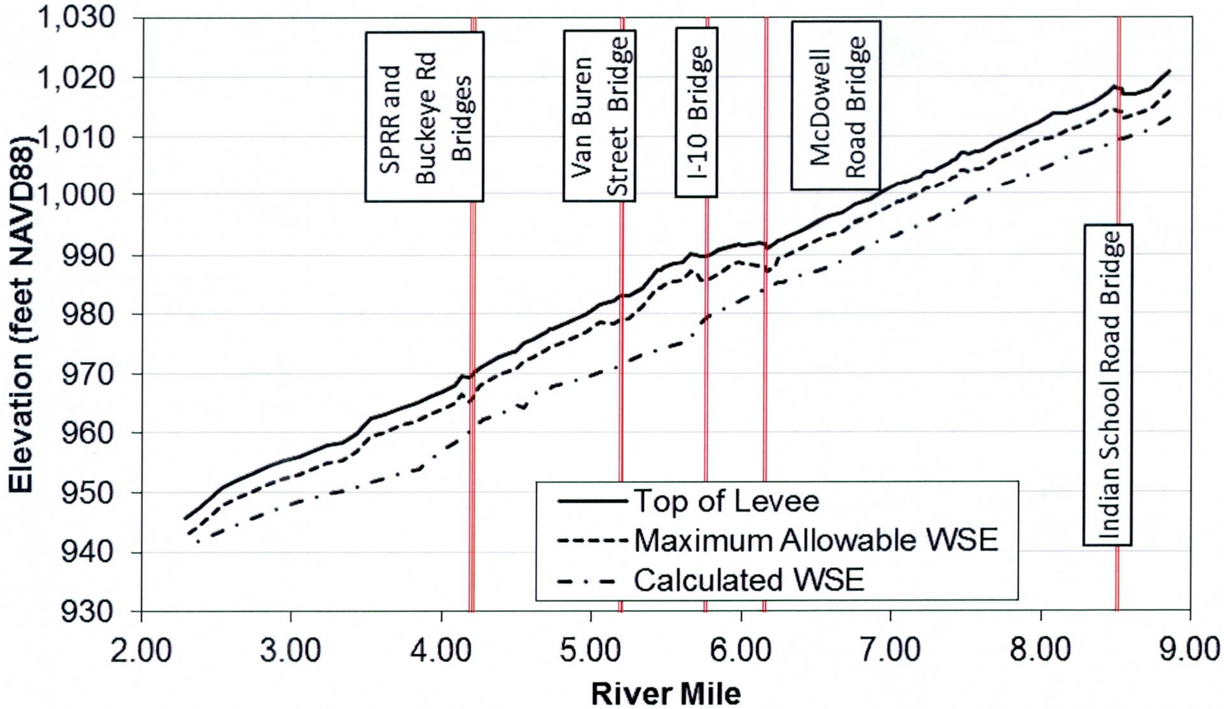

Figure 3-1. HEC-RAS Water Surface Elevations Compared to Top of Levee Elevations for the West Levee (PAL ID #18)

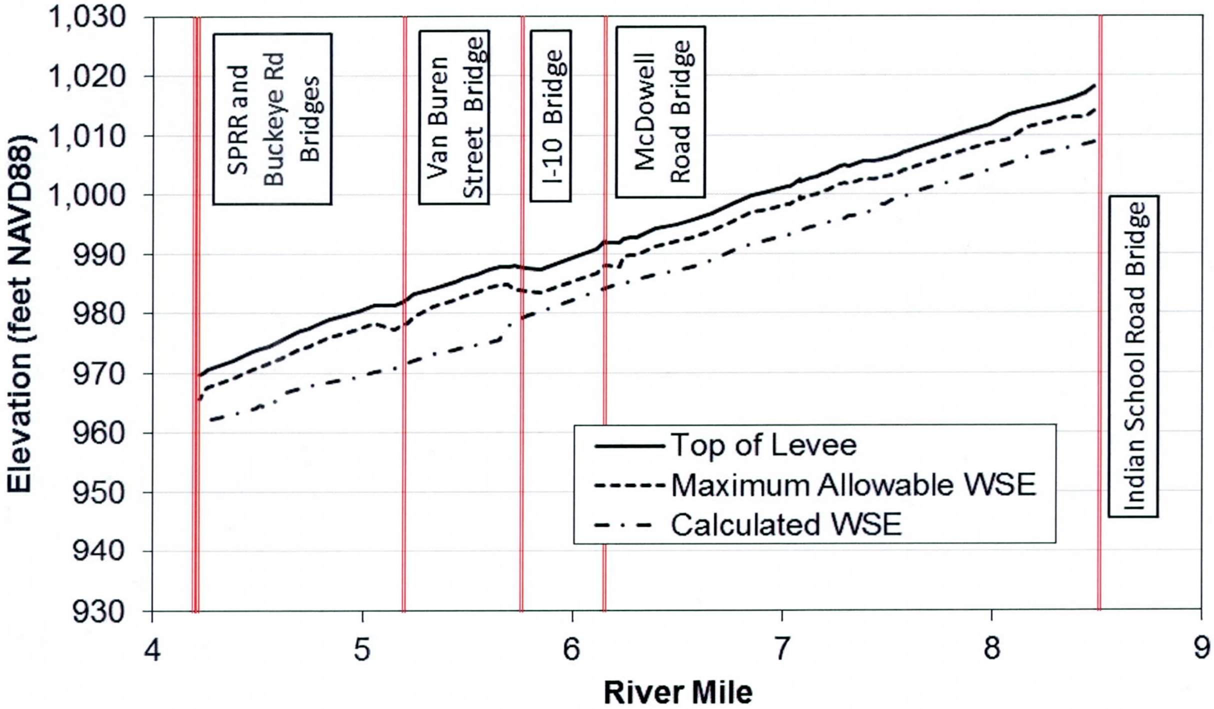

Figure 3-2. HEC-RAS Water Surface Elevations Compared to Top of Levee Elevations for the Longer East Levee (PAL ID #08)

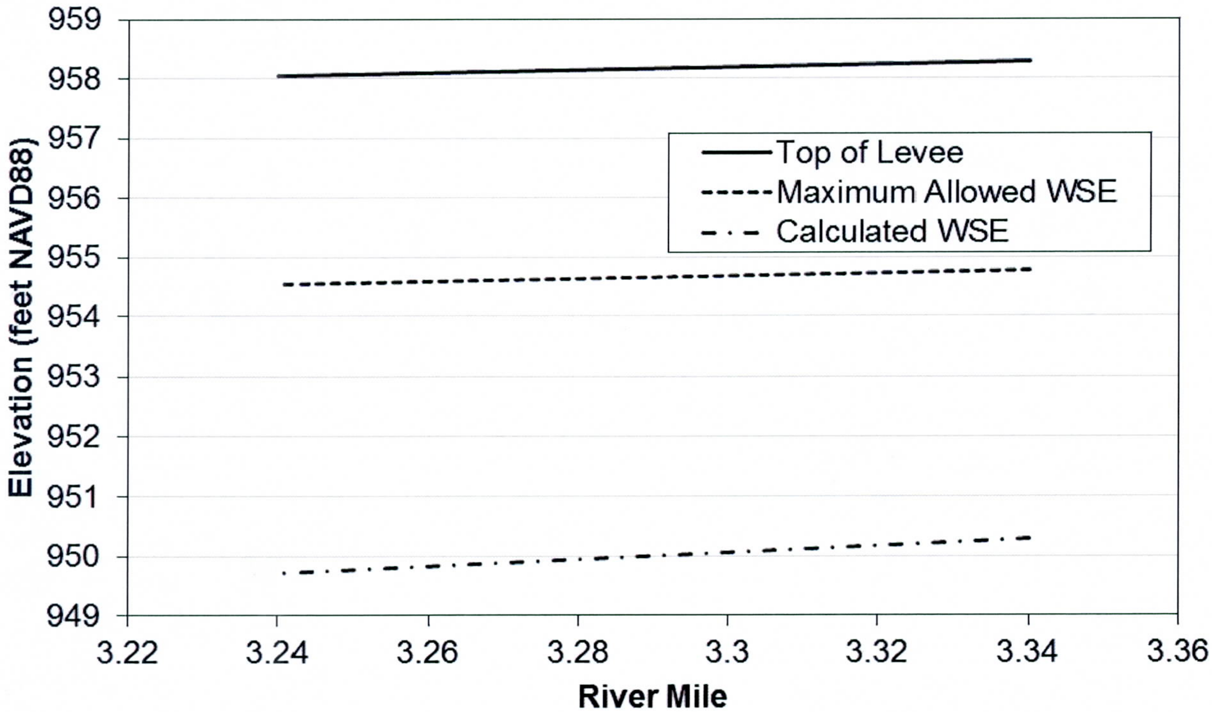

Figure 3-3. HEC-RAS Water Surface Elevations Compared to Top of Levee Elevations for the Shorter East Levee (PAL ID #16)

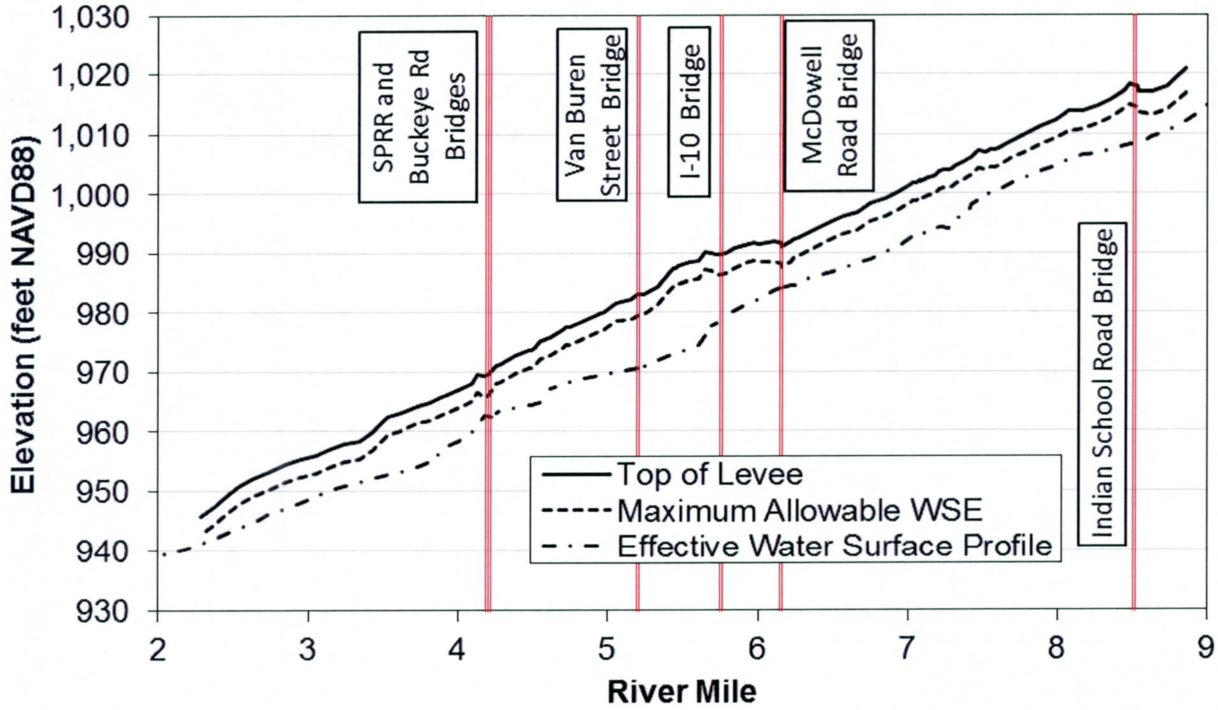

Figure 3-4. Effective Base Flood Elevation Profile Compared to Top of Levee Elevations for the West Levee (PAL ID #18)

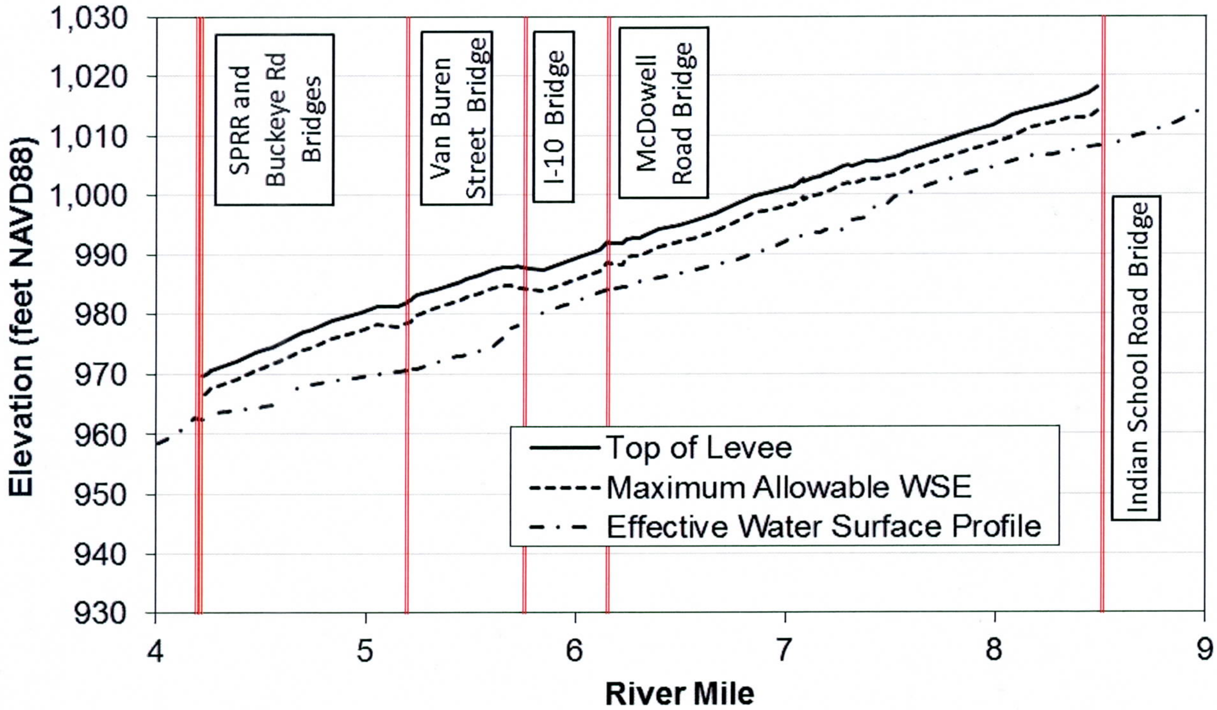

Figure 3-5. Effective Base Flood Elevation Profile Compared to Top of Levee Elevations for the Longer East Levee (PAL ID #08)

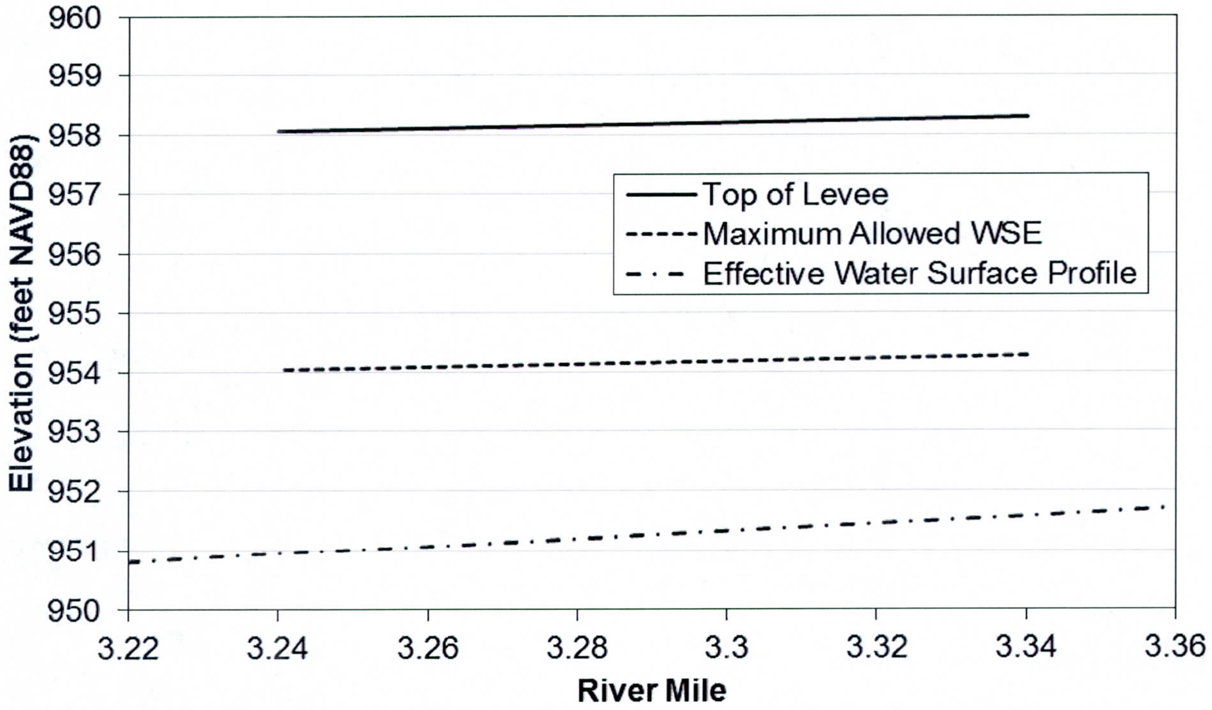

Figure 3-6. Effective Base Flood Elevation Profile Compared to Top of Levee Elevations for the Shorter East Levee (PAL ID #16)

4 References

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Appendix A: Final Freeboard Estimates at Each Cross Section in the HEC-RAS Model

Table A-1 West Levee (PAL ID #18) Freeboard Estimates (all elevations reference the NAVD88 datum)

River Station from HEC-RAS*	Top of Levee Elev (ft)	HEC-RAS Water Surface Elev (ft)	Superelevation (+ for outside of bend, - for inside of bend) (ft)	Final Water Surface Elev (ft)	Freeboard (ft)	FEMA Required Freeboard (ft)	Calculated Factor of Safety	Comments
8.85	1020.88	1012.88	0.00	1011.29	9.59	3.5	2.3	Near Upstream End of Levee
8.72	1017.96	1010.97	0.00	1010.99	6.97	3.5	2.0	Near Upstream End of Levee
8.62	1017.09	1010.16	0.00	1010.12	6.97	3.5	2.0	Near Upstream End of Levee
8.54	1017.03	1009.48	0.00	1009.42	7.61	4.0	1.9	Within 100' of Indian School Road Bridge
8.53	1017.97	1009.50	0.00	1009.44	8.53	4.0	2.1	Within 100' of Indian School Road Bridge
8.49	1018.21	1009.15	0.00	1009.11	9.10	4.0	2.3	Within 100' of Indian School Road Bridge
8.48	1018.41	1008.85	0.00	1008.85	9.56	4.0	2.4	Within 100' of Indian School Road Bridge
8.44	1017.23	1008.53	0.00	1008.53	8.70	3.0	2.9	
8.35	1015.83	1007.84	0.00	1007.84	7.99	3.0	2.7	
8.26	1014.68	1007.11	0.00	1007.11	7.57	3.0	2.5	
8.16	1013.80	1006.21	0.00	1006.21	7.59	3.0	2.5	
8.07	1013.79	1005.28	0.00	1005.28	8.51	4.0	2.1	Within 100' of Roosevelt Irrigation District Canal
7.98	1012.23	1004.15	0.00	1004.15	8.08	3.0	2.7	
7.88	1011.24	1003.07	0.00	1003.07	8.17	3.0	2.7	
7.78	1009.96	1002.00	0.00	1002.00	7.96	3.0	2.7	
7.69	1008.97	1001.06	0.00	1001.06	7.91	3.0	2.6	
7.60	1007.64	1000.11	0.00	1000.11	7.53	3.0	2.5	
7.57	1007.43	999.52	0.00	999.52	7.91	3.0	2.6	
7.55	1007.37	999.44	0.00	999.44	7.93	3.0	2.6	
7.51	1006.84	998.99	0.00	998.99	7.85	3.0	2.6	
7.48	1007.14	998.43	0.00	998.43	8.71	3.0	2.9	

**River stationing corresponds to the recent Stanley hydraulic model (2011) and differs from the stationing in the current effective model*

Table A-1 West Levee (PAL ID #18) Freeboard Estimates (all elevations reference the NAVD88 datum) (cont'd.)

River Station from HEC-RAS*	Top of Levee Elev (ft)	HEC-RAS Water Surface Elev (ft)	Superelevation (+ for outside of bend, - for inside of bend) (ft)	Final Water Surface Elev (ft)	Freeboard (ft)	FEMA Required Freeboard (ft)	Calculated Factor of Safety	Comments
7.46	1007.14	998.33	0.00	998.33	8.81	3.0	2.9	
7.42	1006.10	997.74	0.00	997.74	8.36	3.0	2.8	
7.40	1005.83	996.91	0.00	996.91	8.92	3.0	3.0	
7.38	1005.36	996.70	0.00	996.70	8.66	3.0	2.9	
7.31	1004.61	996.35	0.00	996.35	8.26	3.0	2.8	
7.29	1004.18	995.90	0.00	995.90	8.28	3.0	2.8	
7.27	1003.96	995.84	0.00	995.84	8.12	3.0	2.7	
7.23	1003.90	995.45	0.00	995.45	8.45	3.0	2.8	
7.21	1003.74	995.04	0.00	995.04	8.70	3.0	2.9	
7.18	1003.02	994.97	0.00	994.97	8.05	3.0	2.7	
7.16	1002.75	994.71	-0.20	994.51	8.24	3.0	2.7	
7.13	1002.60	994.56	-0.18	994.38	8.22	3.0	2.7	
7.08	1002.04	994.03	-0.22	993.81	8.24	3.0	2.8	
7.08	1002.28	993.92	-0.21	993.71	8.57	3.0	2.9	
7.05	1001.83	993.68	-0.20	993.48	8.35	3.0	2.8	
7.03	1001.70	993.19	-0.24	992.95	8.75	3.0	2.9	
7.02	1001.57	993.16	-0.21	992.95	8.62	3.0	2.9	
6.93	1000.26	992.43	-0.20	992.23	8.03	3.0	2.7	
6.85	999.27	991.66	-0.21	991.45	7.81	3.0	2.6	
6.75	998.35	990.46	-0.24	990.22	8.13	3.0	2.7	
6.66	996.88	988.81	-0.32	988.49	8.39	3.0	2.8	
6.57	996.17	987.84	0.00	987.84	8.33	3.0	2.8	

**River stationing corresponds to the recent Stanley hydraulic model (2011) and differs from the stationing in the current effective model*

Table A-1 West Levee (PAL ID #18) Freeboard Estimates (all elevations reference the NAVD88 datum) (cont'd.)

River Station from HEC-RAS*	Top of Levee Elev (ft)	HEC-RAS Water Surface Elev (ft)	Superelevation (+ for outside of bend, - for inside of bend) (ft)	Final Water Surface Elev (ft)	Freeboard (ft)	FEMA Required Freeboard (ft)	Calculated Factor of Safety	Comments
6.49	995.29	987.25	0.00	987.25	8.04	3.0	2.7	
6.39	994.07	986.43	0.00	986.43	7.64	3.0	2.5	
6.30	992.99	985.69	0.00	985.69	7.30	3.0	2.4	
6.27	992.57	985.26	0.00	985.26	7.31	3.0	2.4	
6.24	992.33	985.15	0.00	985.15	7.18	3.0	2.4	
6.22	991.97	984.92	0.00	984.92	7.05	4.0	1.8	Within 100' of McDowell Rd Bridge
6.16	991.12	984.47	0.00	984.47	6.65	4.0	1.7	Within 100' of McDowell Rd Bridge
6.15	991.75	984.26	0.00	984.26	7.49	4.0	1.9	Within 100' of McDowell Rd Bridge
6.11	991.97	983.67	0.00	983.67	8.30	4.0	2.1	Within 100' of McDowell Rd Bridge
6.00	991.49	982.40	0.00	982.40	9.09	3.0	3.0	
5.97	991.60	981.94	0.00	981.94	9.66	3.0	3.2	
5.94	991.39	981.73	0.00	981.73	9.66	3.0	3.2	
5.84	990.78	980.27	0.30	980.57	10.21	4.0	2.6	Close to I-10 Bridge
5.78	989.93	979.67	0.27	979.94	9.99	4.0	2.5	Within 100' of I-10 Bridge
5.74	989.72	979.01	0.26	979.27	10.45	4.0	2.6	Within 100' of I-10 Bridge
5.72	989.73	978.29	0.36	978.65	11.09	4.0	2.8	Within 100' of I-10 Bridge
5.69	989.91	977.87	0.35	978.22	11.70	3.0	3.9	
5.65	990.14	975.53	0.70	976.23	13.91	3.0	4.6	
5.60	988.66	975.14	0.17	975.31	13.34	3.0	4.4	
5.54	988.39	974.76	0.18	974.94	13.45	3.0	4.5	
5.47	987.83	974.24	0.18	974.42	13.41	3.0	4.5	
5.45	987.39	974.02	0.19	974.21	13.18	3.0	4.4	

**River stationing corresponds to the recent Stanley hydraulic model (2011) and differs from the stationing in the current effective model*

Table A-1 West Levee (PAL ID #18) Freeboard Estimates (all elevations reference the NAVD88 datum) (cont'd.)

River Station from HEC-RAS*	Top of Levee Elev (ft)	HEC-RAS Water Surface Elev (ft)	Superelevation (+ for outside of bend, - for inside of bend) (ft)	Final Water Surface Elev (ft)	Freeboard (ft)	FEMA Required Freeboard (ft)	Calculated Factor of Safety	Comments
5.43	987.33	973.95	0.18	974.13	13.21	3.0	4.4	
5.33	984.33	973.15	0.00	973.15	11.18	3.0	3.7	
5.24	983.13	972.07	0.00	972.07	11.06	4.0	2.8	Within 100' of Van Buren St Bridge
5.21	983.00	971.78	0.00	971.78	11.22	4.0	2.8	Within 100' of Van Buren St Bridge
5.19	983.01	971.31	0.00	971.31	11.70	4.0	2.9	Within 100' of Van Buren St Bridge
5.15	982.26	970.88	0.00	970.88	11.38	4.0	2.8	Close to Van Buren St Bridge
5.05	981.49	970.16	0.00	970.16	11.33	3.0	3.8	
4.97	980.01	969.44	0.00	969.44	10.57	3.0	3.5	
4.95	979.81	969.13	0.00	969.13	10.68	3.0	3.6	
4.93	979.73	969.10	0.00	969.10	10.63	3.0	3.5	
4.84	978.57	968.51	0.00	968.51	10.06	3.0	3.4	
4.74	977.59	967.83	0.00	967.83	9.76	3.0	3.3	
4.72	977.49	967.41	0.00	967.41	10.08	3.0	3.4	
4.70	977.13	967.39	0.00	967.39	9.74	3.0	3.2	
4.61	975.75	966.50	0.00	966.50	9.25	3.0	3.1	
4.55	975.10	964.16	0.00	964.16	10.94	3.0	3.6	
4.51	974.16	964.63	0.00	964.63	9.53	3.0	3.2	
4.49	973.67	964.14	0.00	964.14	9.53	3.0	3.2	
4.47	973.69	964.08	0.00	964.08	9.61	3.0	3.2	
4.38	972.67	963.18	0.00	963.18	9.49	3.0	3.2	
4.28	971.21	962.29	0.00	962.29	8.92	3.0	3.0	
4.26	971.05	961.83	0.00	961.83	9.22	3.0	3.1	

**River stationing corresponds to the recent Stanley hydraulic model (2011) and differs from the stationing in the current effective model*

Table A-1 West Levee (PAL ID #18) Freeboard Estimates (all elevations reference the NAVD88 datum) (cont'd.)

River Station from HEC-RAS*	Top of Levee Elev (ft)	HEC-RAS Water Surface Elev (ft)	Superelevation (+ for outside of bend, - for inside of bend) (ft)	Final Water Surface Elev (ft)	Freeboard (ft)	FEMA Required Freeboard (ft)	Calculated Factor of Safety	Comments
4.25	970.82	961.79	0.00	961.79	9.03	3.0	3.0	
4.22	970.28	961.49	0.00	961.49	8.79	4.0	2.2	Within 100' of the Southern Pacific Railroad and/or Buckeye Road Bridges
4.21	969.85	960.93	0.00	960.93	8.92	4.0	2.2	Within 100' of the Southern Pacific Railroad and/or Buckeye Road Bridges
4.18	969.28	960.05	0.00	960.05	9.23	4.0	2.3	Within 100' of the Southern Pacific Railroad and/or Buckeye Road Bridges
4.13	969.63	959.22	0.00	959.22	10.41	3.0	3.5	
4.09	968.10	958.42	0.00	958.42	9.68	3.0	3.2	
4.00	967.04	957.00	0.00	957.00	10.04	3.0	3.3	
3.92	966.18	955.45	0.00	955.45	10.73	3.0	3.6	
3.88	965.64	954.67	0.00	954.67	10.97	3.0	3.7	
3.85	965.23	953.83	0.00	953.83	11.40	3.0	3.8	
3.81	964.86	953.76	0.00	953.76	11.10	3.0	3.7	
3.73	964.29	953.24	0.00	953.24	11.05	3.0	3.7	
3.62	963.16	952.43	0.00	952.43	10.73	3.0	3.6	
3.53	962.37	951.68	0.00	951.68	10.69	3.0	3.6	
3.43	959.94	950.84	0.00	950.84	9.10	3.0	3.0	
3.34	958.29	950.30	0.00	950.30	7.99	3.0	2.7	
3.24	958.05	949.71	0.00	949.71	8.34	3.0	2.8	
3.15	957.03	949.24	0.00	949.24	7.79	3.0	2.6	
3.05	956.12	948.56	0.00	948.56	7.56	3.0	2.5	
2.95	955.31	947.68	0.00	947.68	7.63	3.0	2.5	

**River stationing corresponds to the recent Stanley hydraulic model (2011) and differs from the stationing in the current effective model*

Table A-1 West Levee (PAL ID #18) Freeboard Estimates (all elevations reference the NAVD88 datum) (cont'd.)

River Station from HEC-RAS*	Top of Levee Elev (ft)	HEC-RAS Water Surface Elev (ft)	Superelevation (+ for outside of bend, - for inside of bend) (ft)	Final Water Surface Elev (ft)	Freeboard (ft)	FEMA Required Freeboard (ft)	Calculated Factor of Safety	Comments
2.85	954.43	946.84	0.00	946.84	7.59	3.0	2.5	
2.74	953.21	945.80	0.00	945.80	7.41	3.0	2.5	
2.64	952.14	944.62	0.00	944.62	7.52	3.0	2.5	
2.54	950.79	943.54	0.00	943.54	7.25	3.0	2.4	
2.46	949.16	942.69	0.00	942.69	6.47	3.0	2.2	
2.38	947.34	941.88	0.00	941.88	5.46	3.0	1.8	Near Downstream End of Levee
2.29	945.68	940.93	0.00	940.93	4.75	3.0	1.6	Near Downstream End of Levee

**River stationing corresponds to the recent Stanley hydraulic model (2011) and differs from the stationing in the current effective model*

Table A-2 Upper East Levee (PAL ID #08) Freeboard Estimates (all elevations reference the NAVD88 datum)

River Station from HEC-RAS*	Top of Levee Elev (ft)	HEC-RAS Water Surface Elev (ft)	Superelevation (+ for outside of bend, - for inside of bend) (ft)	Final Water Surface Elev (ft)	Freeboard (ft)	FEMA Required Freeboard (ft)	Calculated Factor of Safety	Comments
8.48	1018.05	1008.85	0.00	1008.85	9.20	4.0	2.3	Near Upstream End of Levee and within 100' of Indian School Rd Bridge
8.44	1016.97	1008.53	0.00	1008.53	8.44	4.0	2.1	Near Upstream End of Levee and within 100' of Indian School Rd Bridge
8.35	1015.95	1007.84	0.00	1007.84	8.11	3.0	2.7	
8.26	1015.02	1007.11	0.00	1007.11	7.91	3.0	2.6	
8.16	1014.32	1006.21	0.00	1006.21	8.11	3.0	2.7	
8.07	1013.27	1005.28	0.00	1005.28	7.99	4.0	2.0	Within 100' of the Roosevelt Irrigation District Canal
7.98	1011.67	1004.15	0.00	1004.15	7.52	3.0	2.5	
7.88	1010.56	1003.07	0.00	1003.07	7.49	3.0	2.5	
7.78	1009.54	1002.00	0.00	1002.00	7.54	3.0	2.5	
7.69	1008.38	1001.06	0.00	1001.06	7.32	3.0	2.4	
7.60	1007.40	1000.11	0.00	1000.11	7.29	3.0	2.4	
7.57	1007.10	999.52	0.00	999.52	7.58	3.0	2.5	
7.55	1006.79	999.44	0.00	999.44	7.35	3.0	2.4	
7.51	1006.20	998.99	0.00	998.99	7.21	3.0	2.4	
7.48	1006.01	998.43	0.00	998.43	7.58	3.0	2.5	
7.46	1005.94	998.33	0.00	998.33	7.61	3.0	2.5	
7.42	1005.72	997.74	0.00	997.74	7.98	3.0	2.7	
7.40	1005.61	996.91	0.00	996.91	8.70	3.0	2.9	
7.38	1005.55	996.70	0.00	996.70	8.85	3.0	2.9	
7.31	1004.88	996.35	0.00	996.35	8.53	3.0	2.8	

**River stationing corresponds to the recent Stanley hydraulic model (2011) and differs from the stationing in the current effective model*

Table A-2 Upper East Levee (PAL ID #08) Freeboard Estimates (all elevations reference the NAVD88 datum) (cont'd.)

River Station from HEC-RAS*	Top of Levee Elev (ft)	HEC-RAS Water Surface Elev (ft)	Superelevation (+ for outside of bend, - for inside of bend) (ft)	Final Water Surface Elev (ft)	Freeboard (ft)	FEMA Required Freeboard (ft)	Calculated Factor of Safety	Comments
7.29	1004.93	995.90	0.00	995.90	9.03	3.0	3.0	
7.27	1004.88	995.84	0.00	995.84	9.04	3.0	3.0	
7.23	1004.11	995.45	0.00	995.45	8.66	3.0	2.9	
7.21	1003.79	995.04	0.00	995.04	8.75	3.0	2.9	
7.18	1003.47	994.97	0.00	994.97	8.50	3.0	2.8	
7.16	1003.03	994.71	0.20	994.91	8.12	3.0	2.7	
7.13	1002.82	994.56	0.18	994.74	8.08	3.0	2.7	
7.08	1002.12	994.03	0.22	994.25	7.86	3.0	2.7	
7.08	1002.57	993.92	0.21	994.13	8.44	3.0	2.8	
7.05	1001.68	993.68	0.20	993.88	7.79	3.0	2.6	
7.03	1001.42	993.19	0.24	993.43	7.99	3.0	2.7	
7.02	1001.29	993.16	0.21	993.37	7.92	3.0	2.6	
6.93	1000.53	992.43	0.20	992.63	7.90	3.0	2.6	
6.85	999.95	991.66	0.21	991.87	8.08	3.0	2.7	
6.75	998.24	990.46	0.24	990.70	7.54	3.0	2.5	
6.66	996.93	988.81	0.32	989.13	7.80	3.0	2.6	
6.57	995.82	987.84	0.00	987.84	7.98	3.0	2.7	
6.49	995.01	987.25	0.00	987.25	7.76	3.0	2.6	
6.39	994.27	986.43	0.00	986.43	7.84	3.0	2.6	
6.30	992.86	985.69	0.00	985.69	7.17	3.0	2.4	
6.27	992.71	985.26	0.00	985.26	7.45	3.0	2.5	
6.24	992.63	985.15	0.00	985.15	7.48	3.0	2.5	

**River stationing corresponds to the recent Stanley hydraulic model (2011) and differs from the stationing in the current effective model*

Table A-2 Upper East Levee (PAL ID #08) Freeboard Estimates (all elevations reference the NAVD88 datum) (cont'd.)

River Station from HEC-RAS*	Top of Levee Elev (ft)	HEC-RAS Water Surface Elev (ft)	Superelevation (+ for outside of bend, - for inside of bend) (ft)	Final Water Surface Elev (ft)	Freeboard (ft)	FEMA Required Freeboard (ft)	Calculated Factor of Safety	Comments
6.22	991.80	984.92	0.00	984.92	6.88	4.0	1.7	Within 100' of McDowell Rd Bridge
6.16	991.94	984.47	0.00	984.47	7.47	4.0	1.9	Within 100' of McDowell Rd Bridge
6.15	992.09	984.26	0.00	984.26	7.83	4.0	2.0	Within 100' of McDowell Rd Bridge
6.11	990.72	983.68	0.00	983.68	7.04	4.0	1.8	Within 100' of McDowell Rd Bridge
5.84	987.49	980.28	-0.30	979.98	7.51	4.0	1.9	Within 100' of I-10 Bridge
5.78	987.70	979.69	-0.27	979.42	8.28	4.0	2.1	Within 100' of I-10 Bridge
5.74	987.88	978.97	-0.27	978.70	9.18	4.0	2.3	Within 100' of I-10 Bridge
5.72	987.97	978.29	-0.34	977.95	10.02	4.0	2.5	Within 100' of I-10 Bridge
5.69	987.82	977.87	-0.35	977.52	10.30	3.0	3.4	
5.65	987.87	975.53	-0.70	974.83	13.04	3.0	4.3	
5.6	987.48	975.14	-0.17	974.97	12.51	3.0	4.2	
5.54	986.58	974.76	-0.18	974.58	12.00	3.0	4.0	
5.47	985.97	974.24	-0.18	974.06	11.90	3.0	4.0	
5.45	985.55	974.02	-0.19	973.83	11.72	3.0	3.9	
5.43	985.23	973.95	-0.18	973.77	11.45	3.0	3.8	
5.33	984.11	973.15	0.00	973.15	10.96	3.0	3.7	
5.24	983.36	972.07	0.00	972.07	11.29	4.0	2.8	Within 100' of Van Buren St Bridge
5.21	982.37	971.78	0.00	971.78	10.59	4.0	2.6	Within 100' of Van Buren St Bridge
5.19	982.12	971.31	0.00	971.31	10.81	4.0	2.7	Within 100' of Van Buren St Bridge
5.15	981.36	970.88	0.00	970.88	10.48	4.0	2.6	Close to Van Buren St Bridge
5.05	981.30	970.16	0.00	970.16	11.14	3.0	3.7	
4.97	980.24	969.44	0.00	969.44	10.80	3.0	3.6	

**River stationing corresponds to the recent Stanley hydraulic model (2011) and differs from the stationing in the current effective model*

Table A-2 Upper East Levee (PAL ID #08) Freeboard Estimates (all elevations reference the NAVD88 datum) (cont'd.)

River Station from HEC-RAS*	Top of Levee Elev (ft)	HEC-RAS Water Surface Elev (ft)	Superelevation (+ for outside of bend, - for inside of bend) (ft)	Final Water Surface Elev (ft)	Freeboard (ft)	FEMA Required Freeboard (ft)	Calculated Factor of Safety	Comments
4.95	980.13	969.13	0.00	969.13	11.00	3.0	3.7	
4.93	979.93	969.10	0.00	969.10	10.83	3.0	3.6	
4.84	978.95	968.51	0.00	968.51	10.44	3.0	3.5	
4.74	977.54	967.83	0.00	967.83	9.71	3.0	3.2	
4.72	977.28	967.41	0.00	967.41	9.87	3.0	3.3	
4.7	977.00	967.39	0.00	967.39	9.61	3.0	3.2	
4.61	975.67	966.50	0.00	966.50	9.17	3.0	3.1	
4.55	974.60	964.16	0.00	964.16	10.44	3.0	3.5	
4.51	974.02	964.63	0.00	964.63	9.39	3.0	3.1	
4.49	973.81	964.14	0.00	964.14	9.67	3.0	3.2	
4.47	973.57	964.08	0.00	964.08	9.49	3.0	3.2	
4.38	972.18	963.18	0.00	963.18	9.00	3.0	3.0	
4.28	970.84	962.29	0.00	962.29	8.55	3.0	2.9	
4.26	970.58	961.83	0.00	961.83	8.75	3.0	2.9	
4.25	970.21	961.79	0.00	961.79	8.42	3.0	2.8	Near Downstream End of Levee
4.22	969.73	961.49	0.00	961.49	8.24	4.0	2.1	Within 100' of Southern Pacific Railroad Bridge and Near Downstream End of Levee

**River stationing corresponds to the recent Stanley hydraulic model (2011) and differs from the stationing in the current effective model*

Table A-3 Lower East Levee (PAL ID #16) Freeboard Estimates (all elevations reference the NAVD88 datum)

River Station from HEC-RAS*	Top of Levee Elev (ft)	HEC-RAS Water Surface Elev (ft)	Superelevation (+ for outside of bend, - for inside of bend) (ft)	Final Water Surface Elev (ft)	Freeboard (ft)	FEMA Required Freeboard (ft)	Calculated Factor of Safety	Comments
3.34	958.29	950.30	0.00	950.30	7.99	3.5	2.3	Near Upstream End of Levee
3.24	958.05	949.72	0.00	949.72	8.33	3.5	2.4	Near Upstream End of Levee

**River stationing corresponds to the recent Stanley hydraulic model (2011) and differs from the stationing in the current effective model*