H3 Alluvial Fan

Wittmann Area FLO-2D Study

Prepared for:

Flood Control District of Maricopa County

Flood Control District of Maricopa County
2801 West Durango Street
Phoenix, Arizona 85009

(October 2009) Revised
April 2010
#9240E

Contact: David Jaffe, PhD, PE

PACE
Advanced Water Engineering

PACE
Advanced Water Engineering

April 9, 2010

J. Rafael Pacheco
Bing Zhao, PhD, PE
Engineering Application Development
And River Mechanics Branch, Engineering Division
Maricopa County Flood Control District
2801 West Durango
Phoenix, AZ 85009
Phone (602) 506-3293

Re: Report for the H3 Alluvial Fan Whittman Area Flo-2D Study, Dated October 2009, Revisions submitted on 2/18/10 and Revised Figures submitted on 2/22/10; Response to Comments # 9240E

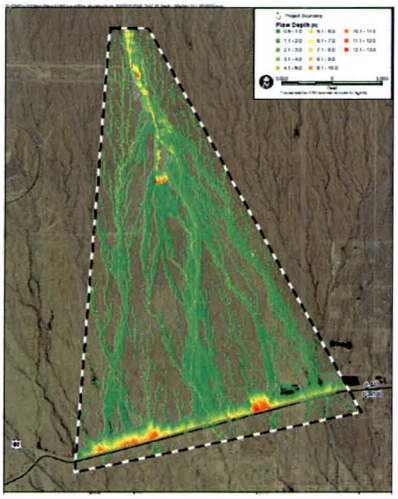
Dear Mr. Pacheco and Mr. Zhao:

Pacific Advanced Civil Engineering, Inc. (PACE) is pleased to provide the following responses to the comments provided by you on March 4, 2010, in reference to the subject project. The responses from PACE are as follows:

1. *Figures 6.2a and 6.2b are not mentioned in the report.*

   PACE RESPONSE:
   The text has been updated to reflect this comment.

2. *The two paragraphs in Section 7.2 on page 30 are based on the old Figure 7.1 and Figure 7.2. Since updated figures were received after the report was received, the discussion section needs to be revised taking into consideration the revised Figures 7.1 and 7.2. As can be seen from the revised figure shown below, the flooding area is much bigger than the old figure.*

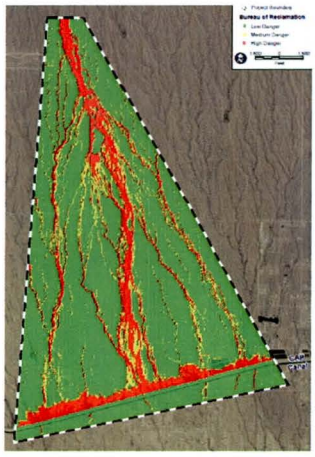


PACE RESPONSE:
The text has been updated to reflect this comment.

3. *Section 7.3 needs to be revised to reflect the revised figures for velocity.*

   PACE RESPONSE:
   The text has been updated to reflect this comment.

4. *Section 7.4 needs to be revised to reflect the revised figures for hazard zone. Please also indicate that the zone is for children. The following is your revised figure where the red indicates high hazard zone. As can be seen, the high hazard area is larger than that in the old figure.*



   PACE RESPONSE:
   The text has been updated to reflect this comment.

5. *The submitted FLO-2D models with sediment transport do not seem to be correct because they are missing ASED and BSED coefficients inside sediment input file. Please make sure the submitted models are the actual models that were used to generate the results.*

   PACE RESPONSE:
   The DVD-ROM has been updated to reflect this comment.

6. *Section 7.5 needs to be revised to reflect the revised figures for the sediment runs.*

   PACE RESPONSE:
   The text has been updated to reflect this comment.

7. *There are some minor typos throughout the text. Please correct them.*

   PACE RESPONSE:
   The text has been updated to reflect this comment.

If you have any questions regarding the above responses, please feel free to give us a call at PACE.

Sincerely,

David A. Jaffe, PhD, PE
Project Manager

DJ /kc
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PACE

PACE
Advanced Water Engineering

November 25, 2009

Tom Loomis, PE, RLS, CFM
Special Projects Branch Manager, Engineering Division
Flood Control District of Maricopa County
2801 West Durango Street
Phoenix, AZ 85009
Phone (602) 506-1501

Re: Wittmann H3 Fan – Two-Dimensional Numerical Modeling Study
Dated October 2009 - Response to Comments **# 9240E**

Dear Mr. Loomis,

Pacific Advanced Civil Engineering, Inc. (PACE) is pleased to provide the following responses to the subject comments letter dated November 2, 2009. The responses from PACE are as follows:

1. *Section 4.2. When discussing where inflow hydrographs are read onto the surface, include whether hydrographs were read into a single grid or multiple grids.*

   PACE RESPONSE:
   All inflow locations occur at a single node except the inflow location for the main feeder channel where inflow is divided into three cells to avoid model shocks. The text has been updated to reflect this comment.

2. *Section 6.2. Were checks made to verify that the large grid size will accurately model significant breakouts? In other words, will the average elevation for a 50-foot grid result in flow splits in the model that may not actually occur, or conversely prevent flow splits that will occur?*

   PACE RESPONSE:
   Preliminary studies, not included here, showed good comparison between 35-foot and 50-foot model grids. The 35-foot model grid was found to be too fine and produced run times that were too long for the present study. Other tests were made to check different grid development methods. It is believed that 50-foot cells are a good representation of the model topography for the overall scale of the current study.

3. *Section 6.3. A shallow flow n-value of 0.20 may be result in unrealistically high infiltration losses. FLO-2D is very sensitive to this parameter for large areas of shallow flow. Discuss the reasonableness of the total volume lost to infiltration.*

   PACE RESPONSE:
   The shallow flow Manning's number was chosen based on site conditions as observed during the project site visit. It is believed that for the current site conditions and the resolution of the model $n_{shallow}$=0.200 is appropriate. A sensitivity analysis, included in the Appendix, was conducted by running the model with $n_{shallow}$=0.150. The model results are generally within 10%, suggesting that $n_{shallow}$=0.200 is reasonable for the present study.

4. *Section 6.3. The TOL setting of 0.05 should be coordinated with initial abstraction, IA, so that double counting does not occur. Discuss how IA was assigned. Generally, the selection for TOL should be subtracted from the standard value of IA to assign IA for FLO-2D.*

PACE RESPONSE:
Initial abstraction values were assigned in the model using the GIS shape file provided by FCDMC. Abstraction was assigned on a cell-by-cell basis. Initial testing suggests that the value of infiltration is reasonable for the study area considering the model resolution, the site conditions, and uncertainties within the model data.

5. *Section 6.3. Discuss the selection of DEPTOL.*

PACE RESPONSE:
The equation for DEPTOL is provided on page 51 of the FLO-2D manual. A value of 0.25, 1, and 5 feet gives DEPTOL values of 0.19, 0.19, and 0.15, respectively. Since most model values are less than or equal to 1 foot, a DEPTOL value of 0.20 is believed to be reasonable.

6. *Section 6.3. Discuss in more detail why a uniform n-value was used rather than a spatially varied n-value. Was the FPLAIN.RGH file used for subsequent runs? If so, comment on the reasonableness of the revised n-values.*

PACE RESPONSE:
There is not good information on fan Manning's value variability presented in the provided GIS files. Land use data, however, generally depicts the study area as open space. The 50-foot grid resolution also serves to average out small variations in model topography. A Manning's value of 0.040, based on Cowan's method (see Appendix), compares well with published values for desert wash (Chow, 1959).

7. *Section 7.2. Where large depths occur in the non-ponded areas, discuss the reasonableness of those depths. These locations should be checked against the topography to be sure that flow breakouts may or may not be occurring due to grid elevation averaging. Are depths of 8-9 feet expected?*

PACE RESPONSE:
Ponding in the model is a function of model topography and of the presence of the CAP. Please see figures 2.1, 6.2, 7.1 and 7.2. Generally the deepest depths are on the upstream side of CAP and are expected. Depth is also a function of model topography, and where braiding and anabranching occur, as is typical in alluvial fan environments, depths are expected to be higher.

8. *FLO-2D cross sections should be aligned perpendicular to flow direction, or double counting of flow will occur. Many of the cross sections do not appear to be aligned properly. Please provide better description of how cross sections were aligned and coded.*

PACE RESPONSE:
Cross-sections were chosen by MCFCD and are based on existing property boundaries. The property boundary shape file is included in the Appendix.

9. *Section 7.5. Discuss the reasonableness of the large variation in erosion and deposition. Are the large values reasonable given the location and hydraulic properties? Do you agree with these results? How is flow distribution on the surface affected by erosion and deposition? The differences in discharge or depth between the base runs and the sediment runs should be shown graphically.*

PACE RESPONSE:
On alluvial surfaces high erosional and depositional rates can be expected, and these rates are strongly a function of surface velocity experienced at the site. Large changes in

bed elevation are frequently observed in arid environments, particularly on alluvial surfaces. Some of the bed change observed in the present study may be strongly a function of the transport equation used in the model. The purpose of the present study was to identify areas or erosion and deposition. While it is unlikely that erosion or deposition of the magnitude predicted in the present study will occur, it is expected that the areas experiencing high erosion or deposition in the model will do so in the field although magnitudes may be smaller. PACE recommends a more detailed sediment transport study examining model sensitivity to transport equation selection where more accurate estimates of bed change is needed.

If you have any questions regarding the above responses, please feel free to give us a call at PACE.

Sincerely,

David A. Jaffe, PHD, PE
Project Manager

DJ /kc

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PACE
Advanced Water Engineering

November 19, 2009

Jorge Garré, P.E.
Argus Consulting
15475 N Greenway Hayden Loop B
Scottsdale, AZ 85260
Phone (480) 596-1131

Re: Wittmann H3 Fan – Two-Dimensional Numerical Modeling Study
Dated October 2009 - Response to Comments **# 9240E**

Dear Mr. Garré,

Pacific Advanced Civil Engineering, Inc. (PACE) is pleased to provide the following responses to the subject comments Memorandum dated November 2, 2009. The responses from PACE are as follows:

1. *General - Report should include more exhibits and data tables to reveal and cross-reference the model results. As a minimum, the following should be considered:*

    - *Add table showing Q, Flow Depth and Flow Velocity for every identified cross section.*
    - *Add plots for every identified cross section (similar to HEC-RAS) showing at a minimum water surface and ground elevations.*

    PACE RESPONSE:
    The sectional data is included in full in the Appendix. Including plots of depth, velocity and other hydraulic parameters in the report text would be too cumbersome to be useful, and include in excess of 300 pages. The reader is free to plot the data as needed on a case-by-case basis. A table has been added to the text presenting the peak discharges at each model section. The text has been updated to reflect this comment.

2. *Section 2.1 – It must be noted that within the study area there is Arizona State Land property. It would be of significant value to have a table showing the percentages of land ownership within the study area classified (as a minimum) as follows:*

    - *U.S. Bureau of Reclamation (Federal Land)*
    - *Arizona State Land Department*
    - *Chrysler Proving Grounds*
    - *Private Owners*

    A graphical depiction of the different ownerships would also be very helpful. This exhibit could be later combined with Figure 6.6 to give the reader a better understanding on the location for the selected cross sections.

    PACE RESPONSE:
    Presently property designations are not available in the GIS files provided to PACE based on ownership. The available data is plotted. The text has been updated to reflect this comment.

3. *Section 7.2 – Explain why the maximum depth value for the 6- and 24-hour events is the same.*

   PACE RESPONSE:
   The locations of maximum depth, discharge and sediment transport vary by model. Please refer to model output in the Appendix.

4. *Section 7.3 – Explain why the maximum velocity value for the 6- and 24-hour events is the same.*

   PACE RESPONSE:
   The locations of maximum depth, discharge and sediment transport vary by model. Please refer to model output in the Appendix.

5. *Section 7.5 – Explain why the maximum bed change value for the 6- and 24-hour events does not change.*

   PACE RESPONSE:
   The locations of maximum depth, discharge and sediment transport vary by model. Please refer to model output in the Appendix.

6. *Of concern are the lack of data tables and exhibits to present the results. The reader must be able to understand the result of the study by cross referencing data tables and exhibits. A narrative with conclusions regarding the hydraulic capacity and floodplain limits for the main wash carrying the largest offsite peak flow must be included in the report. Any presence, or lack thereof, split flows along this main wash should be stated in the narrative of the report.*

   PACE RESPONSE:
   The model resolution of the present study prevents a definitive conclusion as to hydraulic capacity of the main feeder channel in the sub-fan area. While the present model indicates that the channel may contain the design runoff, additional studies at higher model grid resolutions are recommended for the area in question to confirm or refute this finding. The text has been updated to reflect this comment.

If you have any questions regarding the above responses, please feel free to give us a call at PACE.

Sincerely,

David A. Jaffe, PhD, PE
Project Manager

DJ /kc

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PACE
Advanced Water Engineering

November 19, 2009

Kathryn Gross, CFM, Senior Hydrologist, PPM Division
Flood Control District of Maricopa County
2801 West Durango Street
Phoenix, AZ 85009
Phone (602) 506-1501

Re: Wittmann H3 Fan – Two-Dimensional Numerical Modeling Study dated October 2009 - Response to Comments **# 9240E**

Dear Ms. Gross,

Pacific Advanced Civil Engineering, Inc. (PACE) is pleased to provide the following responses to the subject comments letter dated November 2, 2009. The responses from PACE are as follows:

1. ***Section 1*** *– no comments*

   PACE RESPONSE: N/A

2. ***Section 2*** *– no comments*

   PACE RESPONSE: N/A

3. **Section 3 –**

   1. *For the Site Photos Location Map, the photo identification numbers are hard to read. Can their size be increased for this exhibit?*

   PACE RESPONSE:
   The figure has been updated to reflect this comment.

4. **Section 4 –**

   1. *Section 4.1 – This section should also discuss how the distribution of the rainfall was determined and how it was entered into the FLO-2D model.*

   PACE RESPONSE:
   The following has been added to the text:

   The rainfall depths for the 100-year storms (24-hour and 6-hour) are based on NOAA Atlas 2 (Sabol et al., 1995). NOAA Atlas 2 instead of NOAA Atlas 14 was used to be consistent with Wittmann ADMS study recently completed by Entellus for FCDMC. The GIS shape files for the rainfall isopluvials were obtained from FCDMC. The rainfall distribution for the 24-hour event is based on SCS 24-hour Type II (Sabol et al., 1995). The rainfall distribution for the 6-hour event is based on Sabol et al. (1995). Pattern 1 is used for FLO-2D rainfall alluvial fan modeling to give a slightly more conservative peak discharge.

Sabol, G. V., Rumann, J.M., Khalili, D., Waters, S.D., and Lehman, T. (1995). "Drainage Design Manual for Maricopa County, Arizona Volme I, Hydrology," Engineering Division, Flood Control District of Maricopa County, Phoenix, Arizona.

2. *Section 4.2*

- *It appears that some information provided in this section should actually be located in section 4.1. This section makes reference to inflow hydrograph information being shown on Figures 4.4 and 4.5; however, those two figures actually depict the Cumulative Rainfall over Time for both the 6- and 24-hour storm events discussed in Section 4.1.*

PACE RESPONSE:
The text has been updated to reflect this comment.

- *The report should state that inflows onto the fan were identified using the Wittmann ADMSU hydrology. Placement of the inflow hydrographs on the FLO-2D grid should be discussed in the report stating that recommendations of placement in the grid were determined by FCD or by the "team".*

PACE RESPONSE:
The text has been updated to reflect this comment.

- *Additional figures should be provided that show the hydrographs used in the model. It is also recommended that both the original study hydrographs as well as the modified hydrographs used in the FLO-2D model be discussed and presented in the report.*

PACE RESPONSE:
The original and linearized hydrographs for both inflow and rainfall are provided in the Appendix. The rainfall hydrographs are SCS Type 2 and are based on GIS isohyet data provided by FCDMC. The 24-hour hydrograph is linearized while the 6-hour hydrograph is not. The inflowing hydrographs are linearized versions of the Whittmann ADMSU hydrology provided by FCDMC.

- *Additional information should be provided discussing the rainfall timing in comparison to the inflow hydrograph timing.*

PACE RESPONSE:
The text has been updated to reflect this comment.

- *An additional discussion should be provided regarding how the eastern hydrograph was modified from the original WADMSU.*

PACE RESPONSE:
The text has been updated to reflect this comment.

5. ***Section 5*** *– no comments*

PACE RESPONSE: N/A

6. ***Section 6*** *–*

1. *Section 6.2, please include more discussion regarding how the DTM used was developed. Documentation needs to be provided for future report users.*

PACE RESPONSE:
Attachment A has been added to the Appendix to reflect this comment.

2. *Section 6.2 last paragraph, please verify the use of "proposed conditions" in the first sentence. It is recommended that "proposed" be removed.*

PACE RESPONSE:
The text has been updated to reflect this comment.

7. ***Section 7*** *–*

1. *The distribution of depths across the fans shown in Figures 7.1 and 7.2 seems less than what has been shown in other model runs. Please verify and update the figures if necessary.*

PACE RESPONSE:
The figures have been updated to reflect this comment.

2. *If possible, it is recommended that the legend for the depths in Figures 7.1 and 7.2 go down to .3 ft of depth.*

PACE RESPONSE:
The figures are too difficult to read with the additional information included, therefore, no changes have been made.

3. *If possible, it is recommended that the legend for the sediment aggradation/degradation for Figures 7.7 and 7.8 go down to .2 or .3 ft.*

PACE RESPONSE:
The figures are too difficult to read with the additional information included, therefore, no changes have been made.

4. *It is recommended that an additional sub-section be added to discuss the results of the cross-section analysis. Please include a table with the cross-section ID and resulting discharges.*

PACE RESPONSE:
A table has been added to reflect this comment.

8. ***Supporting Documentation*** *– Overall, there is a lack of supporting documentation provided with the report. It is recommended that input products that were provided by FCD and by Argus be included in the appendices.*

1. *Regarding the rainfall data, please provide documentation regarding the rainfall distribution used in the model.*

PACE RESPONSE:
All of the rainfall data is currently included in the Appendix.

2. *Regarding the inflow hydrographs, please include supporting documentation.*
   - *Original WADMSU hydrology models*
   - *Original WADMSU inflow hydrographs used*
   - *Modified hydrographs.*

PACE RESPONSE:
The original WADMSU modeling was not conducted by PACE and, therefore, the models are not included here. All of the hydrograph data is currently included in the Appendix.

3. *Please include the DTM used in the analysis.*

PACE RESPONSE:
All of the DTM data is currently included in the Appendix.

4. *Please provide n value documentation.*

PACE RESPONSE:
All of the Manning's value data is currently included in the Appendix.

5. *Please include the culvert supporting documentation.*

PACE RESPONSE:
All of the culvert data is currently included in the Appendix.

9. ***Model Files*** *- I have not reviewed the model files. I defer to EADRM branch comments.*

PACE RESPONSE: N/A

10. ***GIS Files*** *- Please provide the shape files that FLO-2D can produce regarding depths, velocities, and elevations.*

PACE RESPONSE:
The entire model input and output data is currently included in the Appendix.

If you have any questions regarding the above responses, please feel free to give us a call at PACE.

Sincerely,

David A. Jaffe, PhD, PE
Project Manager

DJ /kc

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PACE
Advanced Water Engineering

November 19, 2009

Richard Waskowsky
Hydrologist
Flood Control District of Maricopa County
2801 West Durango Street
Phoenix, AZ 85009
Phone (602) 506-1501

Re: Wittmann H3 Fan – Two-Dimensional Numerical Modeling Study
Dated October 2009 - Response to Comments **# 9240E**

Dear Mr. Waskowsky,

Pacific Advanced Civil Engineering, Inc. (PACE) is pleased to provide the following responses to the subject comments letter dated October 27, 2009. The responses from PACE are as follows:

1. *The inflow hydrographs are not correct. The entire hydrographs were not used. For example, please see the 100-year 24-hour hydrographs for Flo-2D node number 21. The hydrographs are shown in Figures 1 and 2 below. Please use the entire hydrographs in the model as suggested previously by FCDMC and run the model for 24 hours for the 24-hour storm and 12 hours for the 6-hour storm.*

   PACE RESPONSE:
   An error was found in the previous version of the Appendix. The Appendix has been updated to reflect this comment.

2. *The spacing (how the columns line up) in the inflow.dat files do not appear correct. This text file formatting problem may have caused FLO-2D to incorrectly read the inflow.dat. For example, summary.out file gives 28 acre-feet for the total inflow hydrograph volume for the four hydrographs. But the inflow hydrograph volume for one of the three nodes at the fan apex is around 210 acre-ft shown in Figure 1. Please correct the text file formatting problem in the inflow.dat files.*

   PACE RESPONSE:
   Based on conversations with J. O'Brien (personal communication November 20, 2009) the formatting of the file is not in error. A variable was updated in the inflow.dat model file to resolve the comment. The models have been updated to reflect this comment.

3. *It appears the both the 6-hour and the 24-hour models use the same inflow hydrographs and the same rainfall. Please make sure the correct hydrographs are used.*

   PACE RESPONSE:
   An error was found in the previous version of the Appendix. The Appendix has been updated to reflect this comment.

4. *Grid element number 95754 should be at elevation 1556 feet, rather than 1553.82 feet.*

   PACE RESPONSE:
   The models have been updated to reflect this comment.

5. *One culvert (CN11970) does not match the rigid element (# 89232) associated with the culvert. The culvert location appears correct. Please change the rigid element to match the culvert.*

   PACE RESPONSE:
   The models have been updated to reflect this comment.

6. *Another culvert (CN5280) and rigid element (# 95544) has been changed from the previous location (grid element #95651). Why was this done? It appears that grid element number 95561 is the correct location.*

   PACE RESPONSE:
   The models have been updated to reflect this comment.

7. *Figure 6.2 shows topographic contour lines. However, only the Grand Vista area contour lines are used. The rest is based on the Wittman ADMS topographic DTM data. Please show the grids with ground elevation in color in Figure 6.2.*

   PACE RESPONSE:
   The figure has been updated to reflect this comment.

8. *More description, which clarifies how the grid (fplaint.dat) was developed, should be added to the report. A Word file, which documents this development, was provided to PACE previously. This Word file is provided again as Attachment A at the end of this document.*

   PACE RESPONSE:
   Attachment A has been added to the appendix of the report.

9. *More description, which clarifies how the infil.dat was developed, should be added to the report. A Word file, which documents this development, was provided to PACE previously. This Word file is provided again as Attachment A at the end of this document.*

   PACE RESPONSE:
   Attachment A has been added to the appendix of the report.

10. *More description, which clarifies how the sediment rating curve was developed, should be added to the report. Attachment B is a brief discussion, which describes how the sediment yield rating curve was developed by FCD and sent to Argus previously. The digital files, which were used in the sediment yield analysis, are also provided in a zip file. Please include it into the DVD or CD.*

    PACE RESPONSE:
    Attachment B has been added to the appendix of the report.

11. *Please add a table in the report to show the peak flow rates for each floodplain cross-sections. There are 90 cross-sections.*

    PACE RESPONSE:
    A table has been added to the report including peak section flow rates.

12. *Many PDF files are already included in the DVD. But if the original files are Excel or other files, please include them into the DVD.*

    PACE RESPONSE:
    All of the original Excel and other files are already included in the Appendix DVD.

13. *The Hydrology section should show a map of concentration points that were used to inject the inflow hydrographs.*

    PACE RESPONSE:
    The inflow location figure has been updated to reflect this comment.

If you have any questions regarding the above responses, please feel free to give us a call at PACE.

Sincerely,

David A. Jaffe, PHD, PE
Project Manager

DJ /kc

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PACE

Wittmann H3 Fan

Two-Dimensional Numerical Modeling Study

April 2010
October 2009 (Revised)

Prepared For:

Flood Control District of Maricopa County
2801 West Durango Street
Phoenix, AZ 85009
(602) 506-4601

Prepared By:

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Registered Professional Engineer (Civil)
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Date Signed 4.12.10
ARIZONA, U.S.A.
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Contacts:

David A. Jaffe, PhD, PE

PACE JN 9240E

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1 Introduction

1.1 General Description

The following technical investigation provides a hydraulic evaluation of the characteristics and overland flow of Wittmann H3 alluvial fan along the eastern edge of the former Chrysler Proving Ground, and north of the Central Arizona Project (CAP) Canal in Maricopa County, Arizona (Figure 1.1).

Development is proposed within the H3 fan area and the Flood Control District of Maricopa County (FCDMC) plans to develop a regional outfall to be incorporated into the Wittmann Area Drainage Master Plan (ADMP) and implemented by the local jurisdictions and adjacent developers (Figure 1.1). The existing floodplain analysis criteria and the basis and results of the hydraulic modeling performed along Wittmann H3 fan are detailed below.

1.2 Study Objectives

The primary objective of this report is to develop a technical engineering analysis to assess the extent of alluvial fan flooding associated with the Wittmann H3 fan within the study area by utilizing a variety of engineering analysis and tasks associated with the different aspects of the floodplain hydraulics. A technical framework was developed to guide the analysis of the system. These major task areas reflect the various objectives of the study and include the following:

1. Existing data review – Review and collect existing hydrology, hydraulics, soil type and gradation data, land use and parcel maps, and culvert rating curves. Use GIS-based techniques, when possible.
2. Floodplain field investigations – Perform field reconnaissance of the existing watershed conditions as well as ground photo survey of fan conditions within the study boundary.
3. GIS-based topography development – Merge and/or convert existing digital topographic data for the study area to be utilized in numerical modeling efforts.
4. Grid resolution determination – Determine an appropriate grid resolution for numerical modeling based on topographic extent of the study area, on-site hydraulics and modeling run-time.
5. Baseline FLO-2D hydraulic model – Prepare floodplain model in FLO-2D based on the digital geometry and existing condition flow hydrograph. (Downstream boundary conditions are based on existing culvert conditions at CAP. Run a FLO-2D sediment modeling analysis.)
6. Sectional discharge analysis – Estimate runoff hydrographs for model sections based on on-site property boundaries.
7. BOR hazard zone development – Determine the BOR hazard zones for the 100-year, 24hour and 100-year, 6-hour storm events.

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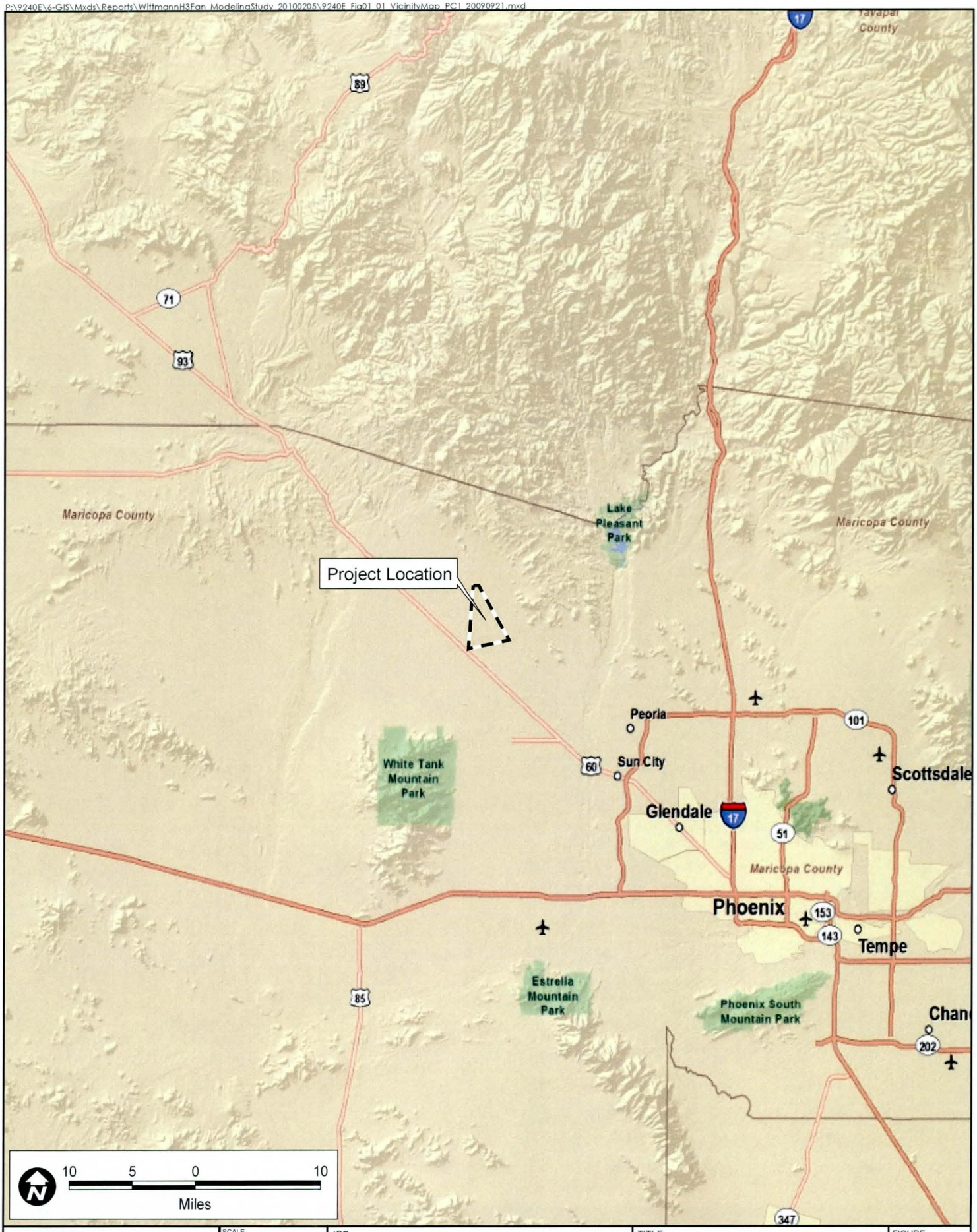

PACE Advanced Water Engineering	SCALE 1" = 10 miles DESIGNED PC DRAWING PC CHECKED DJ DATE 02/16/10 JOB NO. 9240-E	JOB Wittmann H3 Fan Modeling Study Maricopa County AZ	TITLE Vicinity Map	FIGURE 1.1

2 Project Description

2.1 Existing Condition

The Wittmann H3 Fan study area is approximately 5,555 acres on the east side of the former Chrysler Proving Ground, and north of the Central Arizona Project Canal (CAP) in Maricopa County, Arizona (Figure 2.1). The study area is triangular in shape, with the base extending along the CAP, and covers a sub-area of several coalescing alluvial fans. The study area and vicinity consists of residential, commercial, utilities, and agricultural development. A fan description is provided below.

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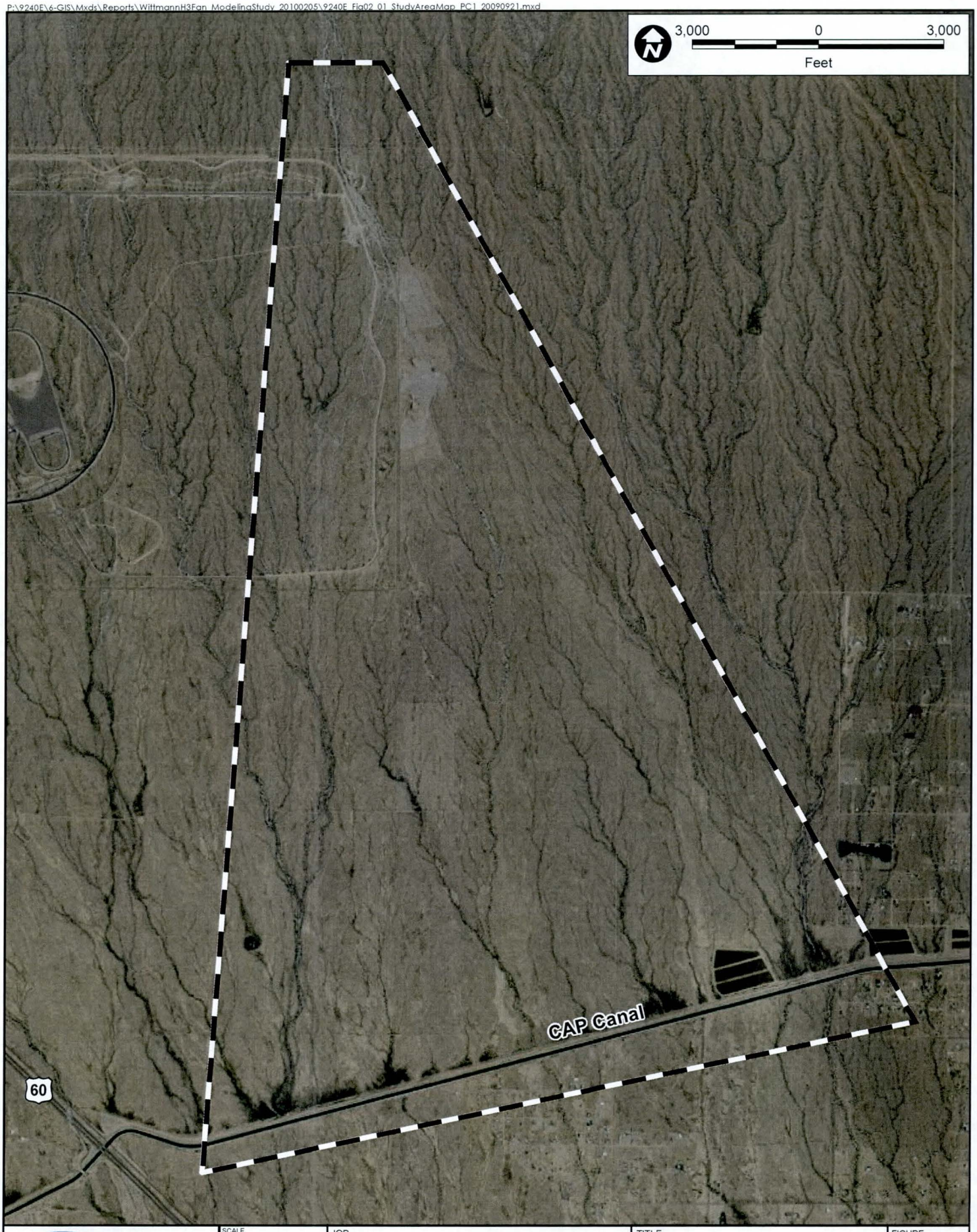

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SCALE 1" = 3000'	JOB	TITLE	FIGURE
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JOB NO. 9240-E	Maricopa County AZ		

3 Wittmann H3 Fan

3.1 Site Setting

The Wittmann H3 alluvial fan is located in western Maricopa County, Arizona. The watershed drains a part of the Hieroglyphic Mountains in a southerly direction. The H3 study area is an alluvial fan sub-area of several coalescing fans (Figure 3.1). The fan is composed of alluvial deposits radiating down from larger fan apexes. The fan toe is located below the CAP, however, the presence of the canal limits alluvial mechanics of H3 and ponding occurs on the upstream (northern) canal bank during some flow events. The study area resides in a semi-arid climate zone, which generally receives an annual rainfall of less than ten inches. Precipitation is seasonal and sporadic with intense short-duration rainfall events typical of the desert in the Southwestern United States.

3.2 Previous Studies

Several previous studies are available for the present study area. A partial review of these documents relevant to the present work is included below.

In 2005, the *Wittmann ADMP Update Technical Data Notebook ADMSU Hydrology Addendum* was prepared by Entellus Inc. The first volume used ACOE HEC-1 numerical modeling to compute runoff hydrographs and peak discharges that covered the present study area. The study also created unit hydrographs and channel routing approximations.

WEST Consultants (2005) prepared the *Wittmann ADMS Update Geomorphic and Sedimentation Analysis.* This report included alluvial fan delineation and a sediment yield analysis. The alluvial fan delineation in the WEST study does not include the present study area.

The Technical Data Notebook: *Approximate Zone A Floodplain Delineation Study of Hieroglyphic Mountain Alluvial Fan #3 (2007)* was prepared by J. E. Fuller Hydrology and Geomorphology. This report included hydrology and hydraulic analysis, but is composed of primarily geomorphic analysis to determine active and inactive sections of the H3 fan. The results of the Fuller study are used as a starting point for the present study.

3.3 Site Visit

A site visit was performed by PACE on March 10, 2009. The purpose of the visit was to become familiar with existing conditions and understand the nature of existing drainage conditions within the study area. A photographic survey of the visit was conducted using a GIS-enabled camera; all photographs are included in the Appendix. Figure 3.2 illustrates the locations of the site photographs.

During the visit, it was noted that roads, fences, former gravel mining operations, and other anthropogenic modifications were present on the site. The presence of these modifications appears to lead to incising of the alluvial channel features within the study area. This is particularly evident downstream of a former on-site gravel mining operation, and can be observed downstream of other features as well (Figure 3.2). A review of available aerial photography indicates that upstream gravel mining operations appear to cause channel incision, as well. This observed incision is likely caused by a break in sediment gradation and quantity.

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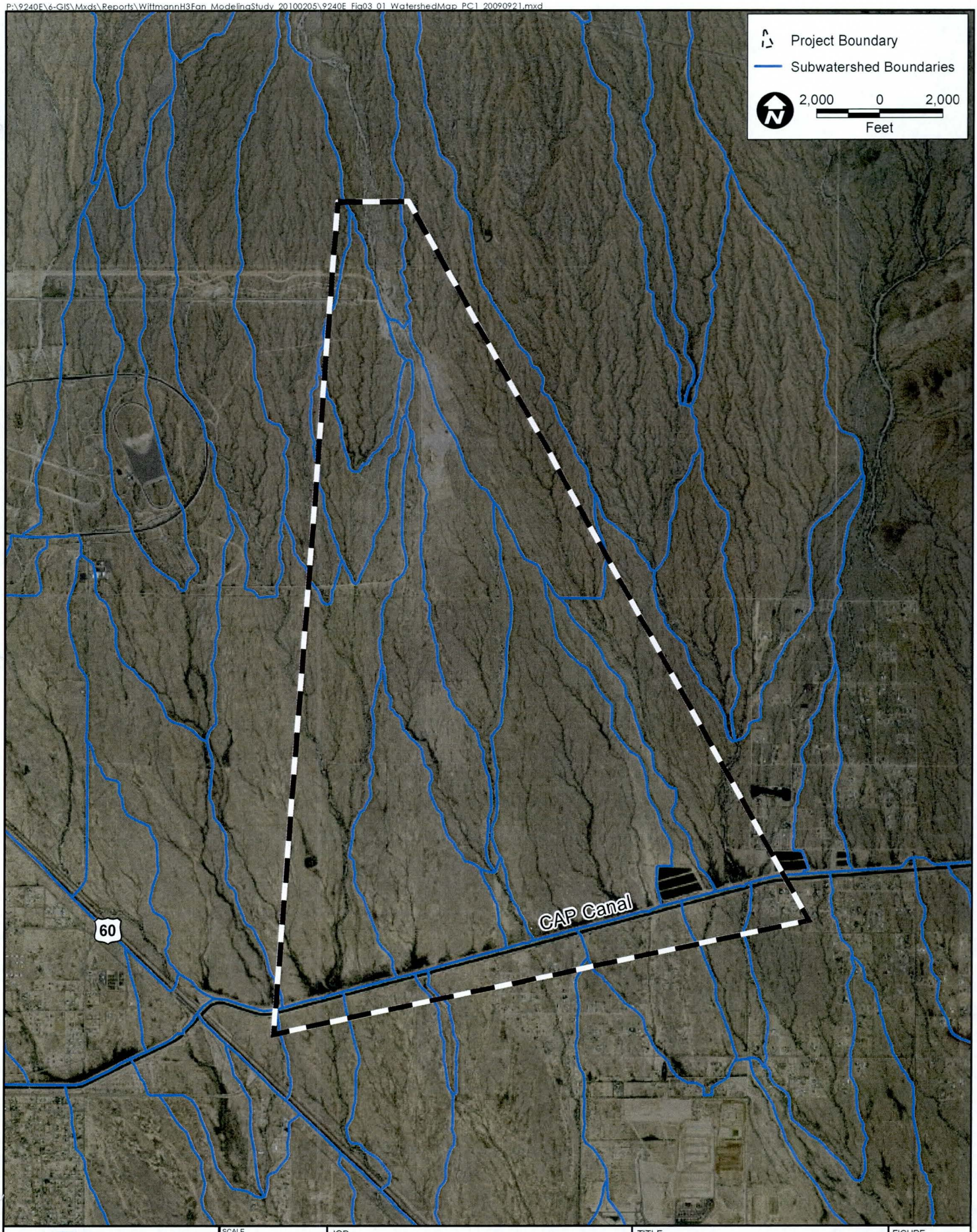

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JOB NO.	9240-E

JOB: Wittmann H3 Fan Modeling Study
Maricopa County AZ

TITLE: Watershed Map

FIGURE: 3.1

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FIGURE 3.2	PACE Advanced Water Engineering	SCALE 1" = 200'	JOB Wittmann H3 Fan Modeling Study
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		DRAWING PC	
		CHECKED DJ	
		DATE 02/16/10	
		JOB NO. 9240-E	Maricopa AZ

TITLE

Site Visit Photos Location Map

4 Hydrology

4.1 Rainfall

Two rainfall events are modeled in the present study: the 100-year 24-hour event, and the 100-year 6-hour event. Rainfall values for the study area were taken from GIS shape files provided by FCDMC. The rainfall depths for the 24- and 6-hour events are 3.3 and 4.2 inches, respectively. The isohyetal maps for the two events are shown in Figures 4.1-4.2. Additionally, the following information was provided by FCDMC:

> *The rainfall depths for the 100-year storms (24-hour and 6-hour) are based on NOAA Atlas 2 (Sabol et al., 1995). NOAA Atlas 2 instead of NOAA Atlas 14 was used to be consistent with Wittmann ADMS study recently completed by Entellus for FCDMC. The GIS shape files for the rainfall isopluvials were obtained from FCDMC. The rainfall distribution for the 24-hour is based on SCS 24-hour Type II (Sabol et al., 1995). The rainfall distribution for the 6-hour is based on Sabol et al. (1995). Pattern 1 is used for FLO-2D rainfall alluvial fan modeling to give a slightly more conservative peak discharge.*

4.2 Concentrated Discharges

Concentration points from four alluvial fan feeder channels were previously found to enter into the study area (B. Zhao, FCDMC, personal communication, April 2009). One inflow is located at the upstream end of the study area, while two inflows are located along the western project boundary and the final inflow is located along the eastern project boundary. Inflow locations and hydrographs were provided by FCDMC. Inflows onto the fan were identified using the Wittmann ADMSU hydrology, and fine placement of the inflow hydrographs on the FLO-2D grid was partially based on recommendations by FCDMC. The inflow locations and peak values are shown in Figure 4.3, and the rainfall hydrographs for the 100-year 24-hour event and the 100-year 6-hour events are shown in Figure 4.4-4.5. The inflow hydrographs, provided by Argus Consulting, are included in the model data files in the Appendix.

Additional modifications were made to the inflowing hydrograph along the eastern project boundary. These modifications were required because the sub-watershed area in the Wittmann ADMSU is not coincident with the model boundary. The following additional information was provided by Argus Consulting to describe the modification made the eastern inflow hydrograph to account for the sub-watershed area difference between the ADMSU and the model:

> *The FLO-2D study boundary does not match the drainage area boundaries of PI645A as identified in the Wittmann ADMSU hydrology. Therefore, the PI645A hydrograph was scaled to represent only the drainage area located outside the FLO-2D study boundaries. To estimate the inflow hydrograph, we first calculated the surface area of PI645A outside the FLO-2D [model boundary (sic)] (41%) and then reduced 59% each PI645A hydrograph ordinate values so the new hydrograph ordinate will represent 41% of the total PI645A value. This method is based on the assumption that excess runoff would be directly proportional to the surface area of the drainage basin.*

It is important to note that the initiation of the rainfall hydrograph and inflowing discharge hydrographs are coincident in time. This is generally expected to produce the most conservative estimate of peak depth and velocity for the model.

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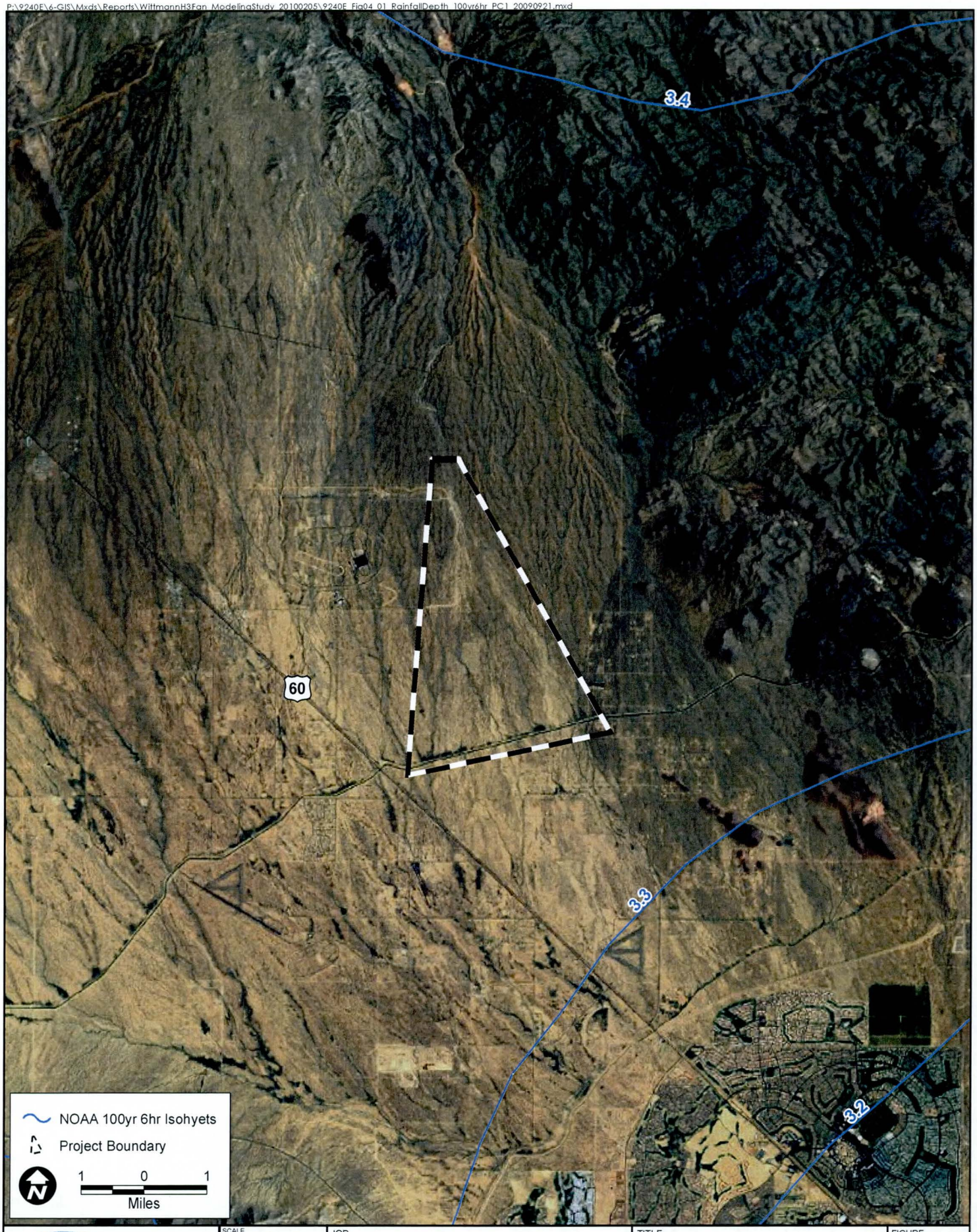

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JOB NO.	9240-E

JOB: Wittmann H3 Fan Modeling Study

Maricopa County AZ

TITLE: Rainfall Depth 100 Year 6 Hour

FIGURE: 4.1

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DATE	02/16/10
JOB NO.	9240-E

JOB: Wittmann H3 Fan Modeling Study

Maricopa County AZ

TITLE: Rainfall Depth 100 Year 24 Hour

FIGURE: 4.2

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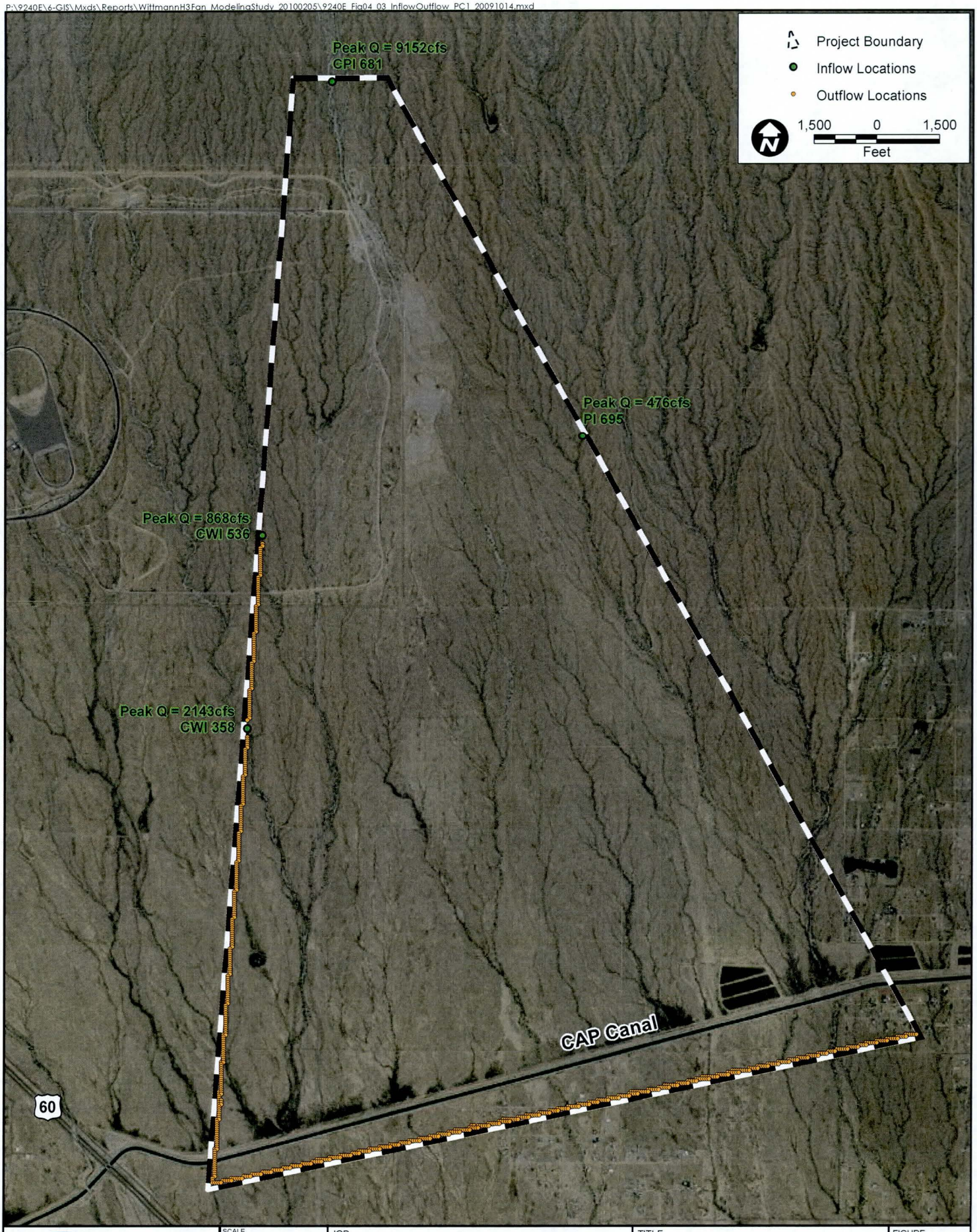

PACE Advanced Water Engineering	SCALE 1" = 3000'	JOB	TITLE	FIGURE
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	DRAWING PC			
	CHECKED DJ			
	DATE 02/16/10			
	JOB NO. 9240-E	Maricopa County AZ		

Figure 4-4 - 100-year, 6-hour Rainfall Depth

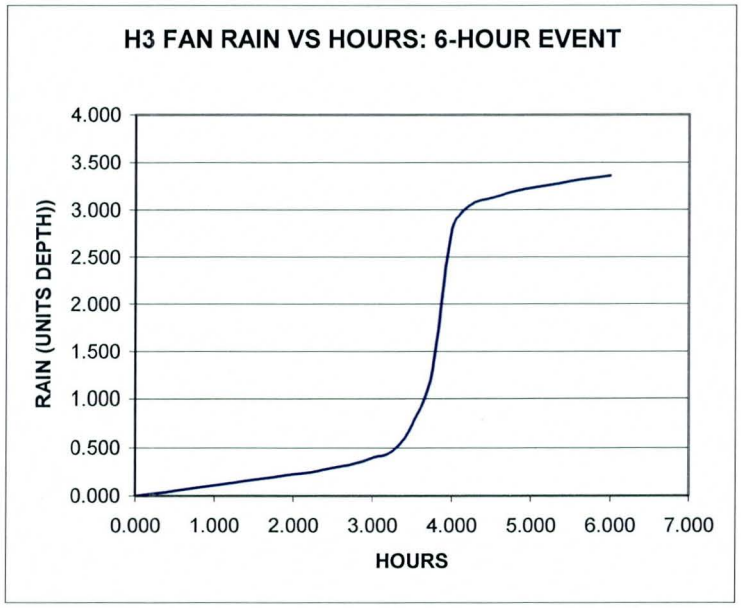
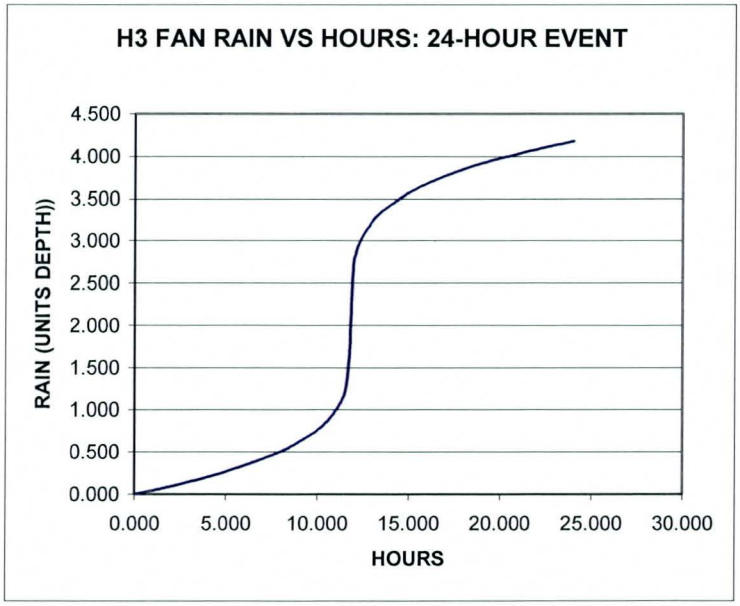


Figure 4-5 – 100-year, 24-hour Rainfall Depth



5 Flood Models

Several types of models can be used to simulate flood flows in both channel and overland settings. These include steady and unsteady models in one or two spatial dimensions. In one-dimensional models, which are generally limited to channel discharges, spatial dimension is given as distance along the channel centerline and the variables being solved for, stage and velocity are cross-sectionally averaged quantities. Two-dimensional models may be used for very complex channels (i.e. channels with hydraulic jumps, abrupt bends, etc.) or overland flow problems. In two-dimensional models, the spatial dimensions are along- and cross-channel distances and solves for stage and depth-averaged discharge. Both of these models make an important assumption that vertical pressure is hydrostatic, so that the flows are said to be gradually varied. While HEC-RAS was not used in this study, a discussion of the model foundations is included below in an effort to help explain the model foundations of FLO-2D. The one-dimensional formulation of HEC-RAS may be thought of as a springboard of understanding for the more complex two-dimensional formulation of FLO-2D.

5.1 Equations of Motion

The equations of motion in one dimension consider two dependent variables, depth *(h)* and volumetric discharge *(Q)*. For the purposes of this study the equations of motion are essentially simplified versions of the St. Venant equations comprising a mass balance and a momentum balance equation. These equations take the form (Cunge *et al.* 1980):

$$\frac{\partial \eta}{\partial t} + \frac{1}{w}\frac{\partial Q}{\partial x} = 0 \tag{1}$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right) + gA\frac{\partial \eta}{\partial x} = -gAS_f \tag{2}$$

where η is the free surface elevation, Q is the discharge, w is the channel top width, A is the cross-sectional area, g is the gravitational constant, x is the distance along the channel center line, and t is time. The friction slope, the energy loss in units of length over the length of a channel segment, is represented by the variable S_f.

5.2 HEC-RAS

The U.S. Army Corps of Engineers' HEC-RAS numerical model was designed to calculate water surface profiles in channels assuming a steady flow and uniform discharge based on site hydrology. The HEC-RAS model is a one-dimensional model widely used throughout the United States for analysis of open channels.

5.3 One Dimensional HEC-RAS Model Equations in Steady State

In steady state time dependent terms of equations (1) and (2) drop out leaving, after rearranging,

$$\frac{\partial}{\partial x}\left(\frac{v^2}{2g}\right) + \frac{\partial}{\partial x}\eta = -S_f \tag{3}$$

where v is the cross-sectionally averaged velocity in the x, or along-stream, direction. Upon integration over a single channel reach located from x_1 to x_2, becomes,

$$\left[\frac{v^2}{2g} + \eta\right]_{x_1}^{x_2} = -\int_{x_1}^{x_2} S_f\,dx \tag{4}$$

Examination of this equation shows that the HEC-RAS model essentially balances momentum and loss terms in steady state between two specific river stations.

5.4 HEC-RAS Numerical Scheme

To employ Equation (4) for use in the HEC-RAS model, the study channel must be broken into reaches and then the equation may be applied to individual reaches. To use Equation (4) for water surface calculations, rearranging gives,

$$(\eta_2 - \eta_1) + \frac{1}{2g}\left(\alpha_{v_2} v_2^2 - \alpha_{v_1} v_1^2\right) = L_e \tag{5}$$

$$L_e = x_w S_f + \frac{C_c}{2g}\left(\alpha_{v_2} v_2^2 - \alpha_{v_1} v_1^2\right) \tag{6}$$

where C_c is the contraction coefficient, L_e is the energy head loss within each reach, and subscripts 1 and 2 represent the downstream and upstream ends of a channel reach, respectively.

Friction slope cross-sectional variability occurs when floodwaters inundate the flood plain and the coefficient α_v accounts for this as,

$$\alpha_v = \left(\frac{A_{ttl}^2}{K_{ttl}^3}\right)\left(\frac{K_{lob}^3}{A_{lob}^2} + \frac{K_{ch}^3}{A_{ch}^2} + \frac{K_{rob}^3}{A_{rob}^2}\right) \tag{7}$$

where the conveyance, K, is derived from the Manning/Strickler equation,

$$K = \frac{1.49}{n} A R_h^{2/3} \tag{8}$$

where n is Manning's number, R_h is the hydraulic radius of the reach, and the subscripts *ttl*, *lob*, *ch*, and *rob* represent the total, left overbank, main channel, and right overbank portions of the reach, respectively. The discharge-weighted reach length, x_w, can then be defined as:

$$x_w = \frac{x_{lob}\overline{Q}_{lob} + x_{ch}\overline{Q}_{ch} + x_{rob}\overline{Q}_{rob}}{\overline{Q}_{lob} + \overline{Q}_{ch} + \overline{Q}_{rob}} \tag{9}$$

where $\overline{Q}$ is the arithmetic mean of the discharge at the end of each reach. Finally, the friction slope, S_f, is given by,

$$S_f = \left(\frac{\overline{Q}_1 + \overline{Q}_2}{K_1 + K_2}\right) \tag{10}$$

No special numerical methods are required to employ the proceeding equations (5)-(10), and the simplicity of the HEC-RAS model is ideal for calculating water surface elevations in mild-slope channels in the presence of culverts and bridges. Because of the steady state assumption and the one-dimensional nature of the model, however, HEC-RAS is not appropriate for overland flow calculations, and a new series of equations must be developed.

5.5 FLO-2D

The FLO-2D numerical model is designed to be utilized for delineating flood hazards or designing flood mitigation. The model is made up of a series of modules that separate analysis into component parts including rainfall, channel discharge, overland flow, street flow, infiltration, culverts and other physical features. Channel discharge, as well as street flow, is modeled in one-dimension. Overbank flow is computed when channel capacity is exceeded.

5.6 Two-Dimensional Model Diffusive Wave Equations for Overland Flow

The equations of motion in two dimensions contain a mass and momentum balance, similar to that in (1) above, and take the form,

$$\frac{\partial h}{\partial t} + \frac{\partial h v_x}{\partial x} + \frac{\partial h v_y}{\partial y} = i \tag{11}$$

$$S_{fx} = S_{ox} - \frac{\partial h}{\partial x} - \frac{v_x \partial v_x}{g \partial x} - \frac{v_y \partial v_x}{g \partial y} - \frac{\partial v_x}{g \partial t} \tag{12}$$

$$S_{fy} = S_{oy} - \frac{\partial h}{\partial y} - \frac{v_{vy} \partial v_y}{g \partial y} - \frac{v_x \partial v_y}{g \partial x} - \frac{\partial v_y}{g \partial t} \tag{13}$$

where subscripts x and y represent the two component directions, i is inputs (e.g. precipitation), S_f is friction slope, and S_o is the bedslope. It is important to note here that unlike Equation (2), above, two equations are used to represent the momentum balance; one for each component direction.

A diffusive wave approximation neglects the last three terms on the right hand side of Equations (12) and (13). In the case of the diffusive wave approximation, the accelerations are ignored but pressure gradients participate in the balance of momentum and balance bed slope and bed friction leaving.

$$\frac{\partial h}{\partial x} = S_{ox} - S_{fx} \tag{14}$$

$$\frac{\partial h}{\partial y} = S_{oy} - S_{fy} \tag{15}$$

This is an important difference compared with the one-dimensional model presented above. The diffusion model is not restricted to channels, and the time dependent components of Equation (11) allow for discharge to vary during a simulation.

5.7 FLO-2D Numerical Scheme

Unlike HEC-RAS, FLO-2D uses a complex set of equations, which require detailed numerical methods to solve them. In the case of FLO-2D, the differential form of Equations (14)-(15) is solved with a central, explicit, finite difference scheme such that the discharge across one grid element boundary into another is accomplished one element at a time. The uniform grid elements that comprise the model are used to calculate discharge in eight flow directions: four compass directions and four compass diagonals.

The explicit numerical schemes are simple to formulate but usually are limited to small time steps by strict numerical stability criteria. Finite difference explicit numerical schemes require significant computational time when simulating complex flow hydraulics.

Numerical computations begin in each grid element by estimating the depth of flow at the boundary between two adjacent elements. The equations of motion are applied to determine the velocity one direction at a time for all eight of the flow directions of a given element. Discharge across the element boundary is calculated by multiplying velocity with the cross-sectional flow area. Once all four boundary

element discharges have been calculated, the change in volume for the individual element can be calculated by multiplying the sum of discharges by the time step. The change in water depth can then be determined by dividing the change in volume by the element surface area. Volume conservation is checked at every time step in every computational element to provide a check of accuracy and as a tool to determine if user selected parameters are properly exercised.

One of the most important computational components of a finite difference numerical scheme is the numerical stability criteria, essentially a limit of the size of the time step. In the case of FLO-2D, the stability is based on the Courant-Friedrichs-Lewy (CFL) condition, and is variable.

While a complete overview of the full numerical scheme of FLO-2D is beyond the scope of this report, the purpose of this section has been to provide a brief background of the assumptions and formulation of the model. For an in-depth overview, the reader is encouraged to refer to the model's user manual.

Table 6.1 - Model Input Files

TABLE 6.1: SUMMARY OF INFILE CONTENTS	
DATA INFILE	FILE CONTENTS
CADPTS	CELL NUMBER, NORTHING, EASTING
CONT	SIMULATION TIME, SUBROUTINE SWITCHES, FROUDE NUMBER
FPLAIN	CELL NUMBER, CONTIGUOUS CELLS, MANNING'S NUMBER, CELL ELEVATION
HYSTRUC	STRUCTURE TYPE, INFLOW CELL, OUTFLOW CELL, RATING TABLE
INFIL	ABSTRACTION, SATURATION, POROSITY, CONDUCTIVITY, SUCTION
INFLOW	INFLOW LOCATION, INFLOW HYDROGRAPH
OUTFLOW	OUTFLOW LOCATION
RAIN	RAINFALL HYDROGRAPH
SED	TRANSPORT EQUATION, D50, SPECIFIC GRAVITY, BED THICKNESS, SIZE DISTRIBUTION, HARD CELLS
TOLER	SURFACE DETENTION, NUMERICAL STABILITY COEFFICIENT

Each model run time was set in CONT.DAT for 12- and 24-hours, respectively for the 6- and 24-hour events. Also set in CONT.DAT were the maximum overland Froude number and the shallow, overland flow Manning's number, set at 0.99 and 0.200, respectively. These values were chosen based on suggestions from the software developer and previous modeling experience. Additional simulations were also run to confirm that these values are appropriate.

The tolerance value for flood routing, which effectively represents depression storage abstraction, was set to 0.05 feet based on the expected average abstraction for flow in the study area was prescribed in TOLER.DAT. The stability coefficient for maximum wave speed was set at 0.35.

Inflow nodes and inflow hydrographs for overland flow were prescribed in INFLOW.DAT. Inflow occurs only at four specific locations (Figure 4.3), and rainfall. Inflow hydrographs are unique for each inflow location such that the total discharge entering the upstream boundary is divided among inflow locations. The hydrographs take the form of a discretized inflow values provided by Argus Consulting. All inflowing discharges enter the model in single grid cells except for at the apex of the subfan where the inflow is divided into three cell to increase model stability. Outflow nodes for overland flow and were prescribed in OUTFLOW.DAT. Downstream (southern, western) grid cells only were set as outflow nodes (Figure 4.3).

Model Manning's values in FPLAIN.DAT were set to n=0.040 because the project site visit suggested that this value was appropriate for the land use and cover. This value is corroborated by Chow (1959). Additionally, some Manning's values were increased on a cell-by-cell basis to increase model stability. As noted above, grid cell elevations in FPLAIN.DAT were provided by FCDMC. FCDMC provided the additional comments concerning the development of the FPLAIN.DAT file:

> *The ground elevation values in fplain.dat (FLO-2D input file) are based on a combination of several topographic data sources. Most of them are from the topographic data for 2004 Wittmann ADMS (2-ft contour interval with flight date 4/18/2002 and 4-ft contour interval with flight date 4/23/2002). Some portion is from the topographic data for Surprise Grand Vista area (1-ft contour interval, ESE Aerial Mapping 2006). Both the Wittmann and Grand Vista data are combined to generate the ground elevation values in fplain.dat. It should be mentioned that the original DTM data for the Wittmann area is used to create TINs for most of the modeling area and the 1-ft contour lines are used to create TINs for Surprise Grand Vista area. Both data are combined to generate the ground elevation values in fplain.dat. The final grid size is 50-ft. The ground elevation values at the CAP dike were manually set at 1556 ft which is the crest elevation for the CAP banks. It should be mentioned that the Manning's n values are reviewed and adjusted accordingly by PACE.*

There are several culverts within the study area (Figure 6.3) that convey water from up- to downstream of the CAP Canal. The locations and design rating curves for these culverts, provided by Argus Consulting, is entered into HYSTRUC.DAT. In cases where rating curves were not available (5280, 18050) rating tables were approximated by extrapolation (5280) or interpolation (18050).

Values for infiltration parameters are stored in INFIL.DAT. The data in this file was created using the FLO-2D GDS. Data used to create the INFIL.DAT file was taken from GIS shape file of soils and land use information provided by FCDMC (Figures 6.4 and 6.5, respectively). Likewise, rainfall data in the RAIN.DAT file was received in the form of GIS shape file from FCDMC. FCDMC provided the additional comments concerning the development of the INFIL.DAT file:

> *The landuse and soils Arcview shapefiles were taken from the Wittmann ADMSU 2004 report to keep consistent with the Wittmann ADMSU because the inflow discharges used for FLO-2D modeling are based on the 2004 Wittmann ADMSU study. The landuse table attached (see Appendix) was slightly modified on LU_CODE 570 which corresponds to proving grounds and landfills. Based on 2004 aerial photos, the area for the proving ground within the FLO-2D modeling area does not have 80% impervious area (RTIMP). In this study, RTIMP is reduced to 0 percent. The initial abstraction (IA) and vegetation cover percent are taken from "vacant" land use type from the Wittmann ADMSU 2004 report. The vegetation cover percent is slightly reduced based on the 2004 aerial photo. The DTHETA value is changed from "dry" to "normal." It may be mentioned that the proving ground area is no longer to be used for vehicle testing. The differences are highlighted in yellow as shown in tables below (see Appendix). The soil table used for H3-fan FLO-2D modeling can be seen in the table below (see Appendix). Both the land use table and the soil table are used with the 2000 MAG land use Arcview shape files to generate infil.dat (sic) by using GDS.*

Multiple sections are analyzed within the model. Generally these sections correspond to property boundaries. The locations of the analyzed sections were provided by FCDMC and the locations of the analyzed sections are shown in Figure 6.6.

Sediment data used in the sediment transport calculation was taken from sieve analysis of soil samples taken by Construction Inspection & Testing Company (Figure 6.4). The sieve analysis, presented in the appendix along with a map of soil sample locations, was prepared and two samples, S5 and S8, were removed from consideration since it is believed that they do not represent soils with in the study area because of their location (a gravel mine tailings pile and a road, respectively). The soil sample data was

averaged and entered into the SED.DAT file. The parameters of the averaged soil data are the transport equation, the D_{50}, the gradient coefficient, and the grain size distribution. The transport equation chosen was Woo since that equation was based on alluvial fan transport. The D_{50} for the averaged soil sample is 4.05 mm, with a gradient coefficient of G=11.4. The individual and average grain size distributions are shown in Figures 6.7 and 6.8, respectively. The inflowing sediment load is given the same sediment distribution as that found in the soil samples, and the inflowing sediment rating curve, provided by Argus Consulting, is estimated as $Q_s=2.5491Q^{1.2726}$. FCDMC provided the following additional information, previously provided to Argus Consulting:

The total sediment yield was developed with the DDMSW 4.5.2 software. The 100-year flow rates for the 6-hour and 24-hour storms were taken from the Wittmann ADMSU existing conditions HEC-1 model.

Wash Load:
The Soil and Land Use shapefiles were taken from the Wittmann ADMSU. For the soils in Maricopa County, the default K factors (from the DDMSW – River Mechanics document) were used. For the soils in Yavapai County, the K factor was taken from the NRCS Web Soil Survey. A screen capture of the Web Soil Survey is shown in the "YavapaiSoils.xls" file.

The default Land Use C factors (from the DDMSW – River Mechanics document) were used. However, the DDMSW gave an error when the software tried to automatically calculate the total (area-weighted) C factor. Therefore, the total C factor was calculated in the "LANDUSEDATA.xls" file.

The specific weight was calculated using the formula from the DDMSW – River Mechanics document. The D10 of the bed material sample was estimated from Samples 1 and 2 of the Construction Inspection & Testing Company (CIT) geotechnical report, which was performed for Argus Consulting.

The slope percentage was calculated using the basin average. First, three USGS 100-foot gridascii files (for the basin area) were converted to three ESRI grid files. Then, the three grid files were merged and clipped into one grid file that matched the basin area. This grid file was then converted to a TIN file. The TIN file was subsequently used to calculate a slope grid file (with 200-foot grid size). The average slope was found to be 11.4 percent.

The slope length was estimated using a stream arc shapefile, which was generated by WMS. The slope length was estimated to be half the distance between stream arcs. The length was found to be ~500 feet.

Bed Load:
The cross-section data was taken from a HEC-RAS model for the H3 channel, which is upstream of the Fuller-delineated apex. The sediment data was taken from the CIT geotechnical report.

Rating Curve:
The total sediment yield results (in acre-feet) from DDMSW are the total amount of sediment delivered to a point during the whole storm event. Therefore, the ratio between the total sediment yield and the total flow volume was calculated. Then, the peak flow rates for the 2-year, the 10-year and the 100-year storm events were multiplied by the calculated ratio to find the peak sediment flow rate.

The peak sediment flow rate was converted from cfs to tons/day with the specific weight equation (from the DDMSW – River Mechanics document) and other relevant conversion factors.

With the sediment flow rates (in tons/day) and the water flow rates (in cfs), the ASED and BSED factor were calculated using an Excel spreadsheet (Regression under Tool's Data Analysis). ASED was found to be 2.766, while BSED was found to be 1.265 for the 6-hour storm event. ASED and BSED for the 24-hour is 2.55 and 1.265 respectively. As a note, the 6-hour and the 24-hour storm events results in very similar sediment results. The calculations are shown in the "sedimentratingcurve6hr.xls" and "sedimentratingcurve24hr.xls" files.

The raw rating curve data is shown in the appendix.

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PACE Advanced Water Engineering	SCALE 1" = 3000'	JOB	TITLE	FIGURE
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	DRAWING PC			
	CHECKED DJ			
	DATE 02/16/10			
	JOB NO. 9240-E	Maricopa County AZ		

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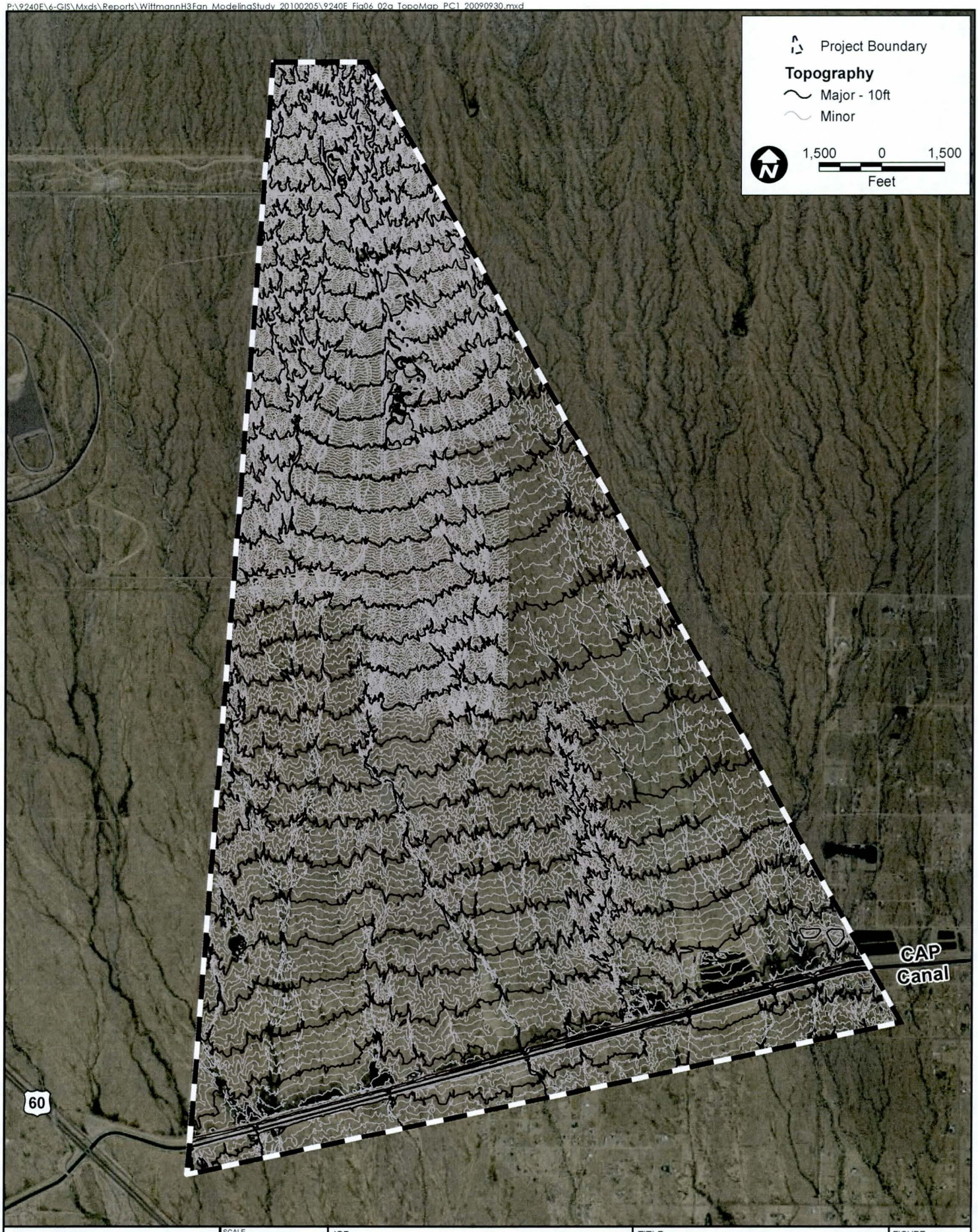

PACE Advanced Water Engineering	SCALE 1" = 3000'	JOB	TITLE	FIGURE
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	DRAWING PC			
	CHECKED DJ			
	DATE 02/16/10			
	JOB NO. 9240-E	Maricopa County AZ		

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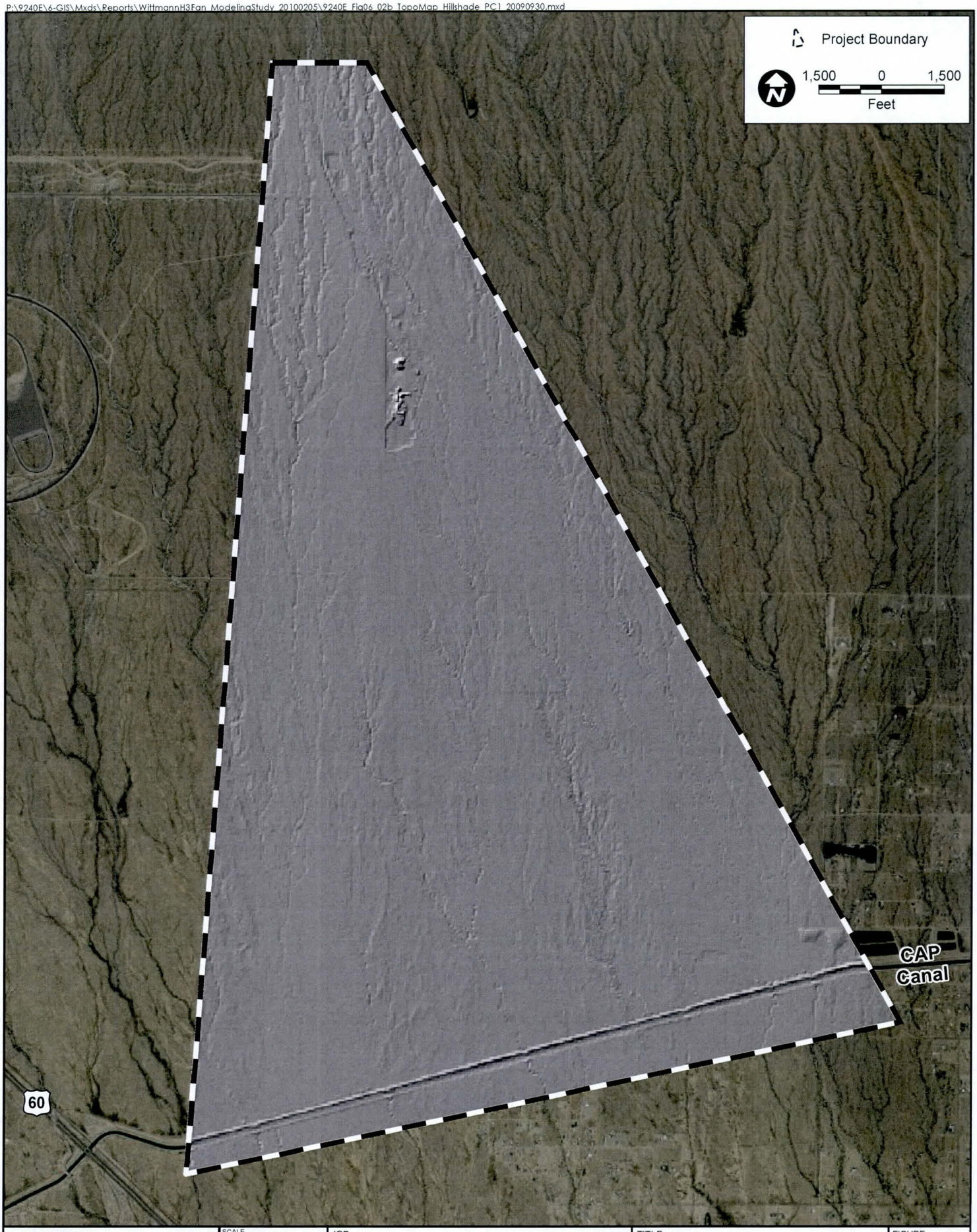

PACE
Advanced Water Engineering

SCALE 1" = 3000'	JOB	TITLE	FIGURE
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DRAWING PC			
CHECKED DJ			
DATE 02/16/10			
JOB NO. 9240-E	Maricopa County AZ		

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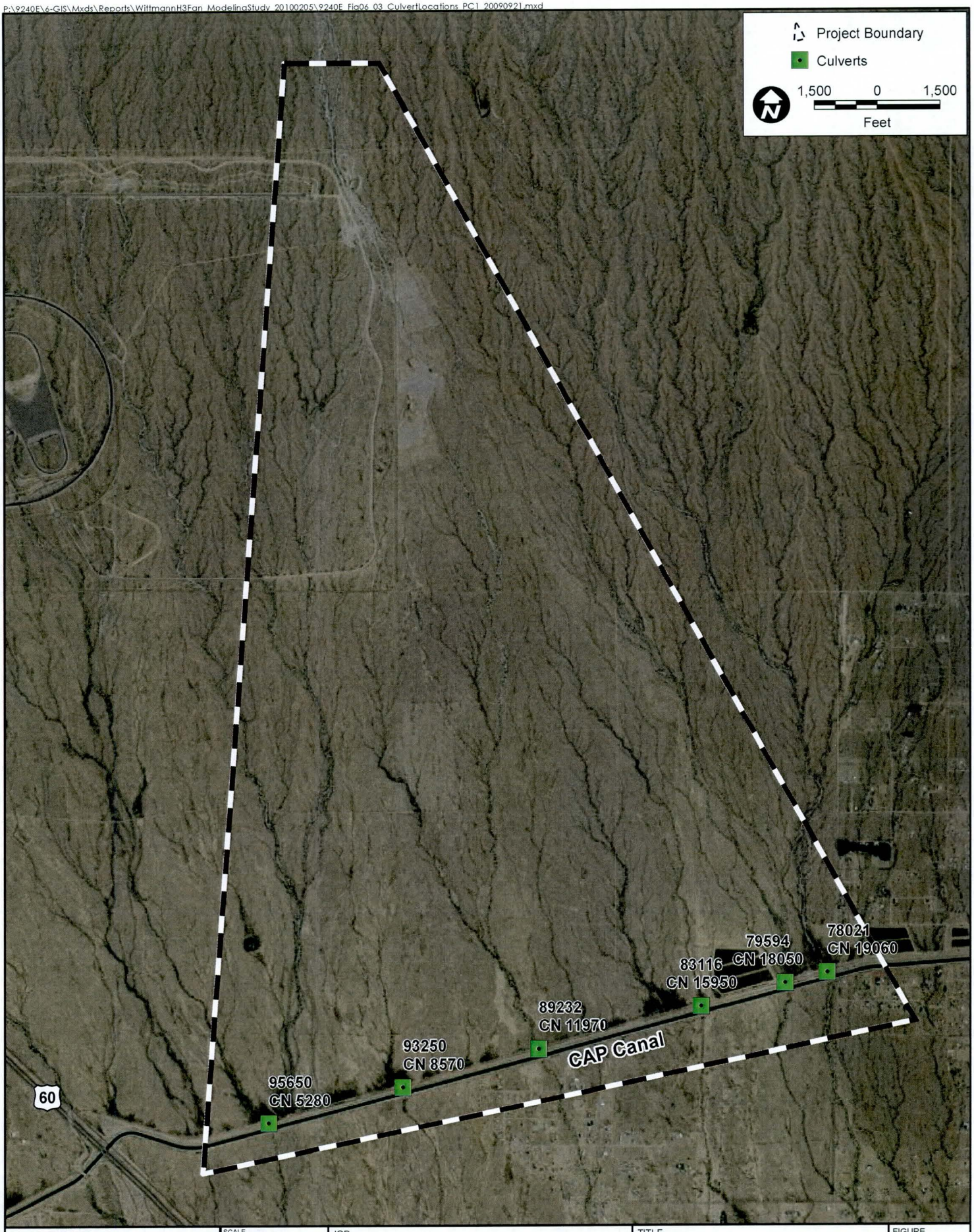

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	DRAWING PC			
	CHECKED DJ			
	DATE 02/16/10			
	JOB NO. 9240-E	Maricopa County AZ		

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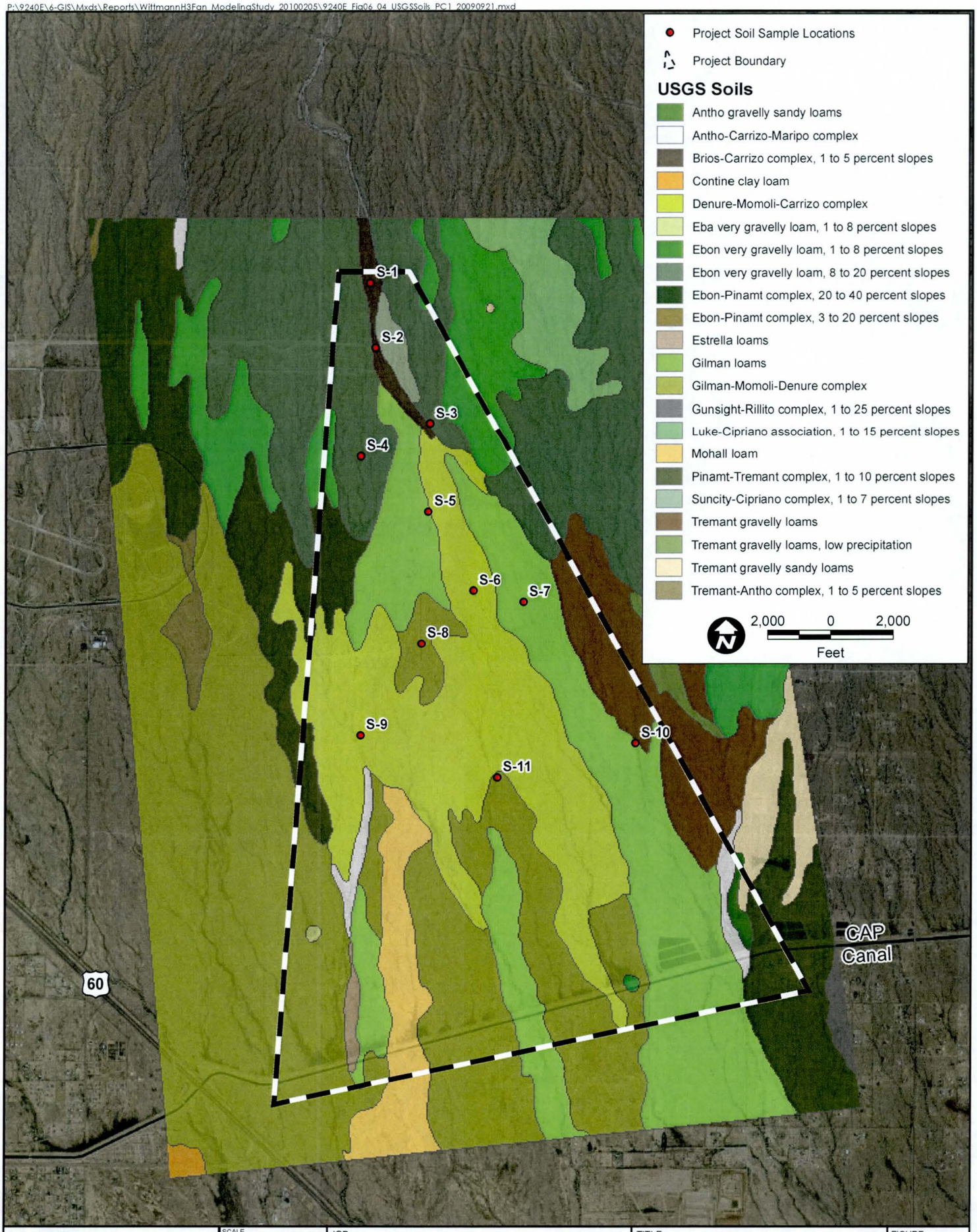

PACE Advanced Water Engineering	SCALE 1" = 4000'	JOB	TITLE	FIGURE
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	DRAWING PC			
	CHECKED DJ			
	DATE 02/16/10			
	JOB NO. 9240-E	Maricopa County AZ		

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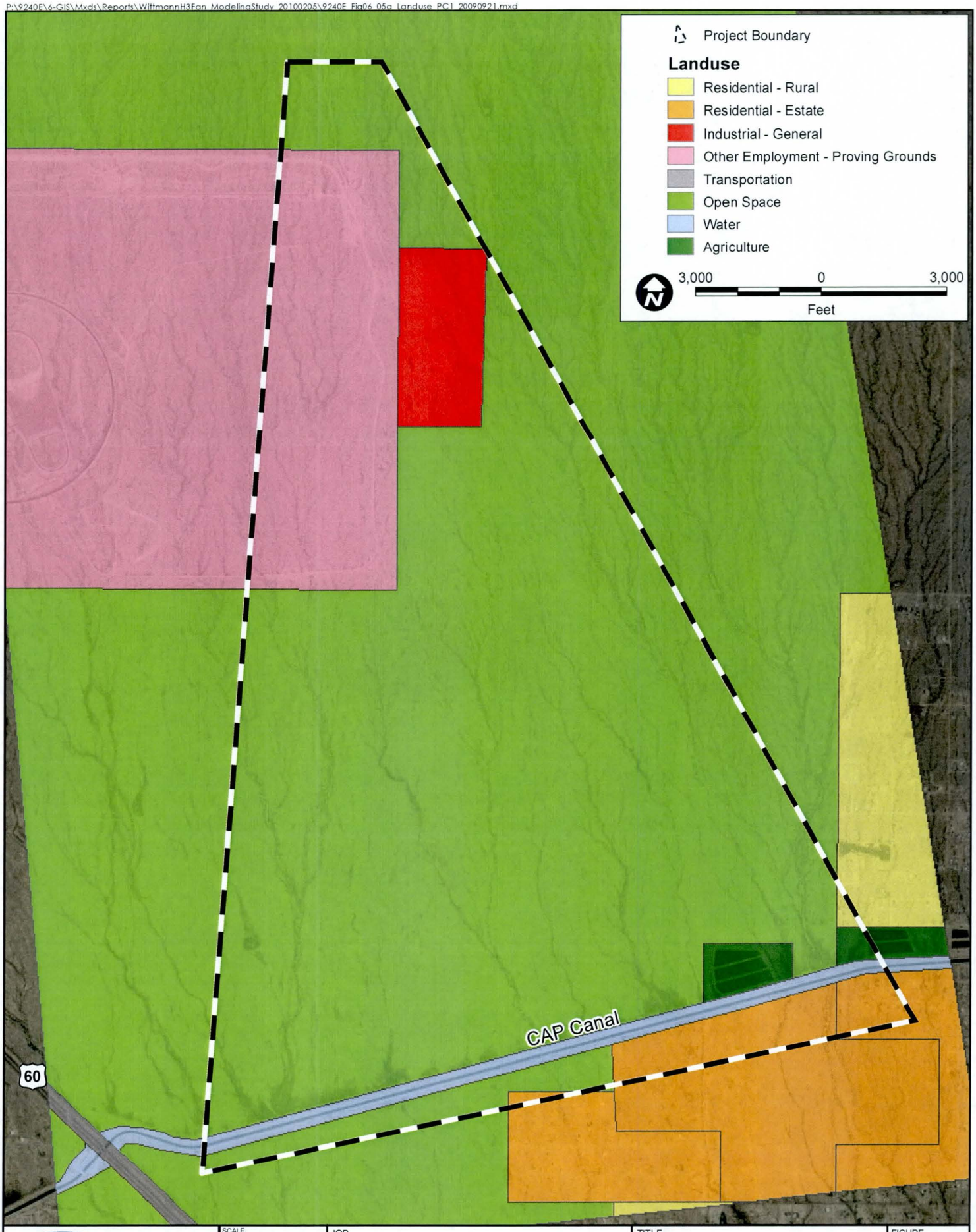

PACE
Advanced Water Engineering

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DRAWING	PC
CHECKED	DJ
DATE	02/16/10
JOB NO.	9240-E

JOB: Wittmann H3 Fan Modeling Study
Maricopa County AZ

TITLE: Maricopa County Landuse

FIGURE: 6.5a

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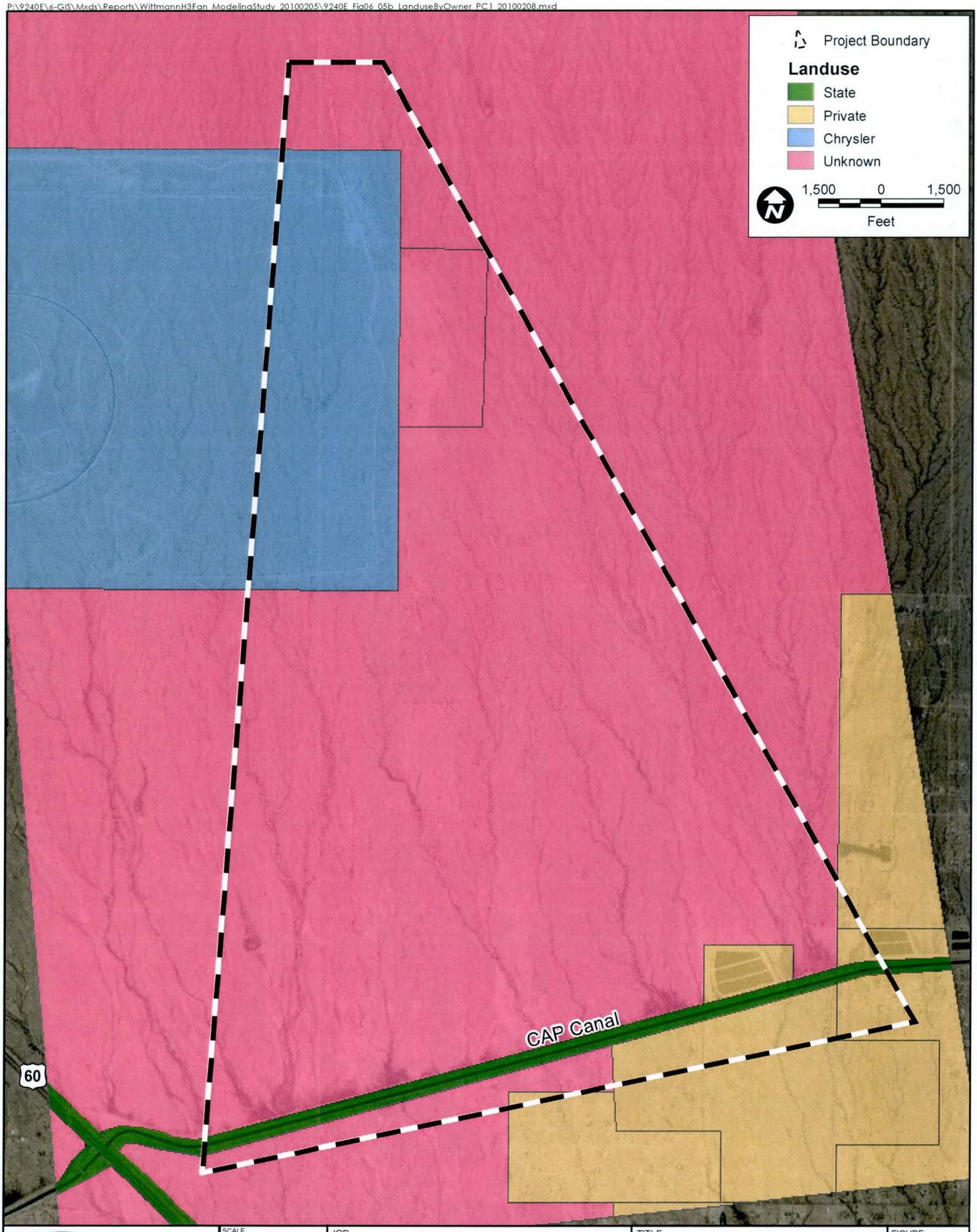

PACE
Advanced Water Engineering

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DRAWING	PC
CHECKED	DJ
DATE	02/16/10
JOB NO.	9240-E

JOB: Wittmann H3 Fan Modeling Study
Maricopa County AZ

TITLE: Maricopa County Land Ownership

FIGURE: 6.5b

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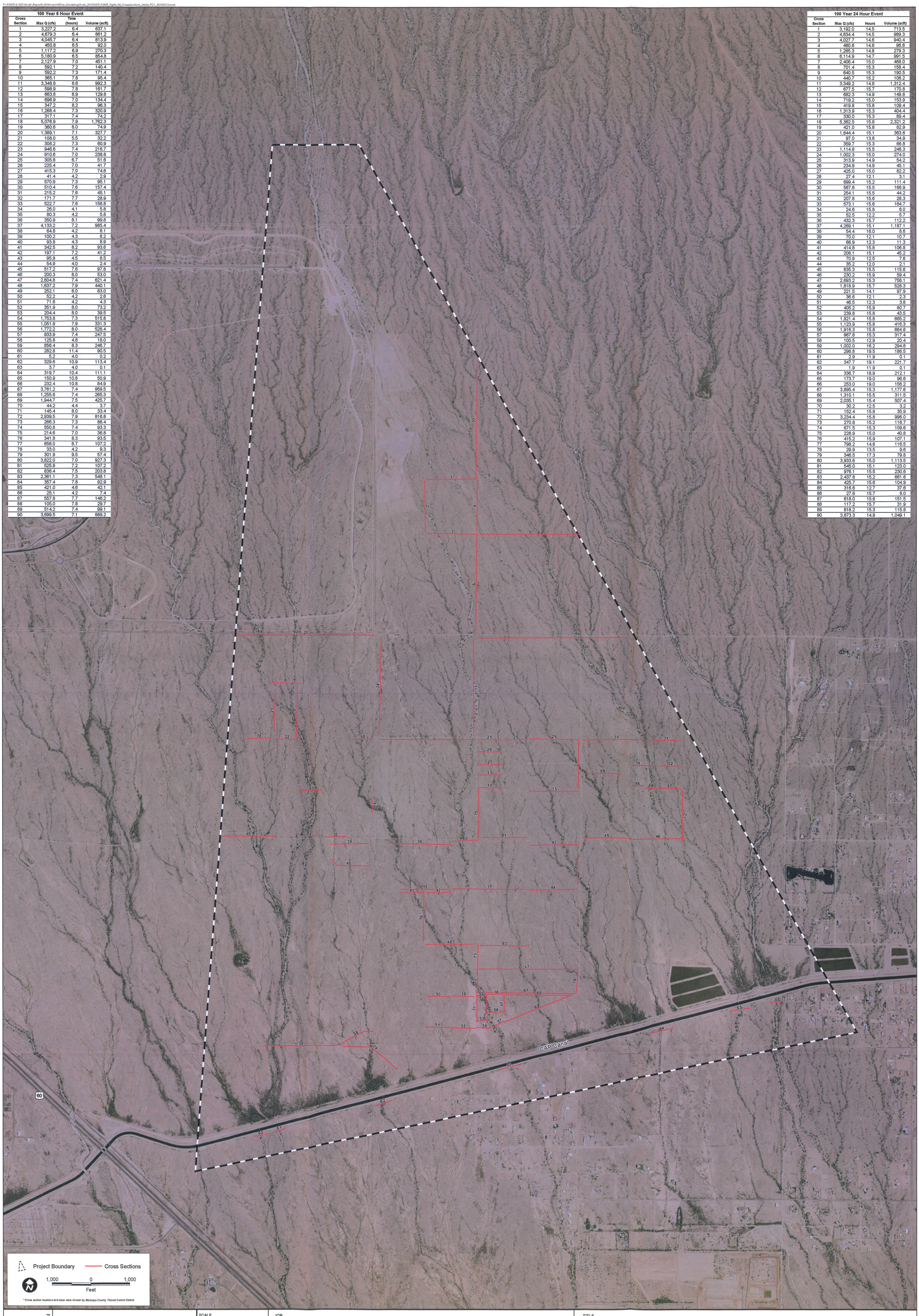


100 Year 6 Hour Event

Cross Section	Max Q (cfs)	Time (hours)	Volume (acft)
1	3,227.2	6.4	637.1
2	4,679.3	6.4	861.2
3	4,045.7	6.4	813.9
4	450.8	6.5	92.0
5	1,117.2	6.9	270.3
6	5,180.9	6.5	854.8
7	2,127.9	7.0	451.1
8	592.1	7.2	140.4
9	592.2	7.3	171.4
10	365.1	7.8	95.4
11	3,348.8	6.6	992.3
12	598.9	7.8	161.7
13	663.8	6.9	129.6
14	696.9	7.0	134.4
15	347.2	8.2	96.3
16	1,268.4	7.3	320.9
17	317.1	7.4	74.2
18	5,076.9	7.9	1,762.3
19	360.6	8.0	74.9
20	1,389.1	7.1	327.7
21	108.0	5.5	32.2
22	308.2	7.3	60.9
23	946.6	7.4	216.7
24	910.6	7.0	238.8
25	305.6	6.7	51.6
26	225.4	7.0	41.7
27	415.3	7.0	74.6
28	41.4	4.2	2.9
29	570.9	7.3	95.1
30	510.4	7.6	157.4
31	215.2	7.6	45.1
32	171.7	7.7	28.9
33	522.7	7.6	156.8
34	26.0	4.1	5.8
35	80.3	4.2	5.8
36	350.9	8.1	99.8
37	4,133.2	7.2	985.4
38	64.8	4.2	6.1
39	100.2	4.3	8.2
40	93.8	4.3	8.9
41	342.5	8.2	93.6
42	197.1	7.2	41.2
43	95.9	4.5	8.5
44	54.9	4.0	2.4
45	517.2	7.6	97.8
46	200.3	8.0	53.0
47	2,604.8	7.4	621.4
48	1,637.2	7.9	440.1
49	252.1	6.0	83.0
50	52.2	4.2	2.6
51	71.6	4.2	4.3
52	351.9	8.0	73.2
53	204.4	8.0	39.5
54	1,753.8	7.3	515.8
55	1,051.9	7.9	331.3
56	1,772.2	8.0	528.4
57	933.9	7.4	247.5
58	125.8	4.8	18.0
59	856.4	8.3	246.7
60	282.8	11.4	90.5
61	5.2	4.0	0.2
62	329.6	10.9	113.4
63	3.7	4.0	0.1
64	319.7	10.4	111.1
65	150.9	10.8	50.9
66	232.4	10.8	84.9
67	3,761.2	7.4	959.5
68	1,255.6	7.4	265.3
69	1,944.7	7.5	425.7
70	44.2	4.4	3.7
71	145.4	8.0	33.4
72	2,939.5	7.9	816.8
73	266.3	7.3	86.4
74	550.8	7.4	93.3
75	214.6	7.0	36.8
76	341.8	8.3	93.5
77	656.0	6.7	107.2
78	33.0	4.2	9.3
79	301.9	9.5	57.4
80	3,822.0	7.0	927.3
81	525.9	7.2	107.2
82	836.4	7.5	203.8
83	2,361.1	7.3	548.1
84	357.4	7.8	92.9
85	421.0	4.6	42.1
86	25.1	4.2	7.4
87	557.8	7.7	146.2
88	105.0	7.8	29.7
89	514.2	7.4	99.1
90	3,699.5	7.1	889.2

100 Year 24 Hour Event

Cross Section	Max Q (cfs)	Hours	Volume (acft)
1	3,192.0	14.5	713.5
2	4,634.4	14.5	989.3
3	4,027.7	14.6	940.4
4	460.6	14.6	96.6
5	1,265.3	14.8	279.3
6	6,114.9	14.7	991.5
7	2,406.4	15.0	488.0
8	701.4	15.3	158.4
9	640.5	15.3	190.5
10	440.7	15.2	106.2
11	3,349.2	14.8	1,312.4
12	677.5	15.7	170.8
13	682.3	14.9	149.8
14	719.2	15.0	153.9
15	419.8	15.8	109.4
16	1,313.9	15.3	404.4
17	330.0	15.3	89.4
18	5,362.5	15.8	2,321.2
19	421.0	15.8	82.9
20	1,644.4	15.1	363.6
21	97.0	13.6	34.9
22	359.7	15.3	66.8
23	1,114.8	15.5	246.3
24	1,002.3	15.0	274.0
25	313.9	14.9	54.2
26	234.9	14.9	45.1
27	425.0	15.0	82.2
28	27.4	12.1	3.1
29	699.4	15.2	111.4
30	567.6	15.5	166.9
31	254.1	15.5	44.2
32	207.8	15.6	28.3
33	573.1	15.6	164.7
34	24.6	15.8	6.0
35	52.5	12.2	5.7
36	432.3	15.7	112.2
37	4,269.1	15.1	1,187.1
38	54.4	16.0	8.6
39	70.0	12.1	10.7
40	66.9	12.3	11.3
41	414.8	15.8	106.8
42	208.1	15.1	45.2
43	70.9	12.5	7.6
44	35.2	12.0	2.1
45	635.3	15.5	115.6
46	230.2	15.9	59.4
47	2,693.2	15.3	758.1
48	1,818.9	15.7	528.3
49	221.5	14.1	97.9
50	36.6	12.1	2.3
51	46.5	12.3	3.8
52	405.2	15.9	80.7
53	239.8	15.8	43.5
54	1,821.4	15.8	665.2
55	1,123.9	15.8	416.3
56	1,916.3	15.8	664.8
57	967.8	15.3	317.4
58	100.5	12.9	20.4
59	1,002.0	16.2	294.8
60	298.8	19.5	186.5
61	2.9	11.9	0.1
62	347.7	19.1	221.7
63	1.9	11.9	0.1
64	336.7	18.9	212.1
65	173.7	19.0	96.6
66	253.0	19.0	156.2
67	3,895.4	15.3	1,177.6
68	1,310.1	15.5	311.5
69	2,035.1	15.4	507.4
70	30.2	12.5	3.2
71	152.4	15.8	35.9
72	3,234.4	15.8	996.0
73	270.8	15.2	116.7
74	671.5	15.3	109.6
75	228.9	15.0	40.8
76	415.2	15.9	107.1
77	798.2	14.6	116.5
78	29.9	13.5	9.6
79	346.5	17.3	79.8
80	3,933.6	15.0	1,113.5
81	545.0	15.1	123.0
82	976.1	15.5	230.6
83	2,437.8	15.2	661.6
84	425.7	15.6	104.9
85	316.6	12.7	37.6
86	27.8	15.7	8.0
87	618.0	15.6	151.5
88	117.2	15.7	31.9
89	618.2	15.3	115.8
90	3,873.3	14.9	1,049.1

FIGURE 6.6

PACE Advanced Water Engineering

SCALE	1" = 1000'
DESIGNED	PC
DRAWING	PC
CHECKED	DJ
DATE	02/16/10
JOB NO.	9240-E

JOB

Wittmann H3 Fan Modeling Study

Maricopa County CA

TITLE

Flo-2D Analysis Cross Sections

Figure 6-7 – H3 Fan Grain Size Gradation Curves

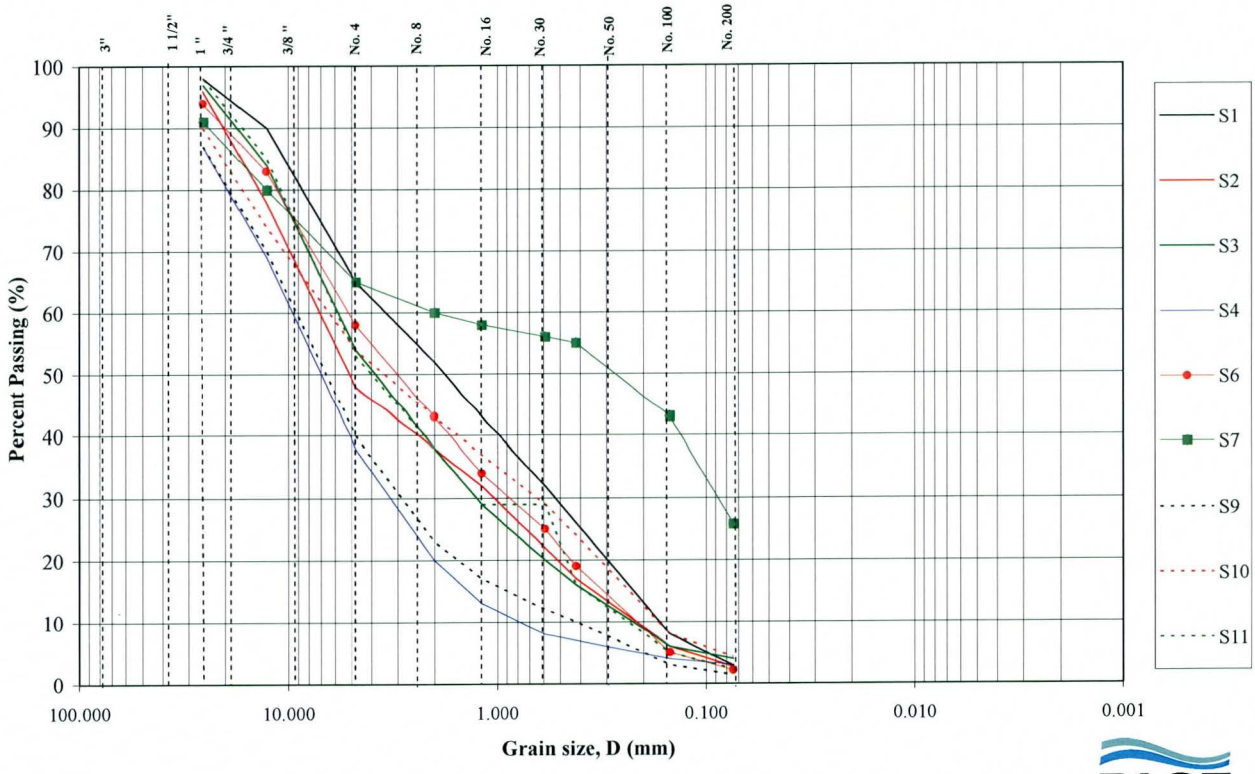
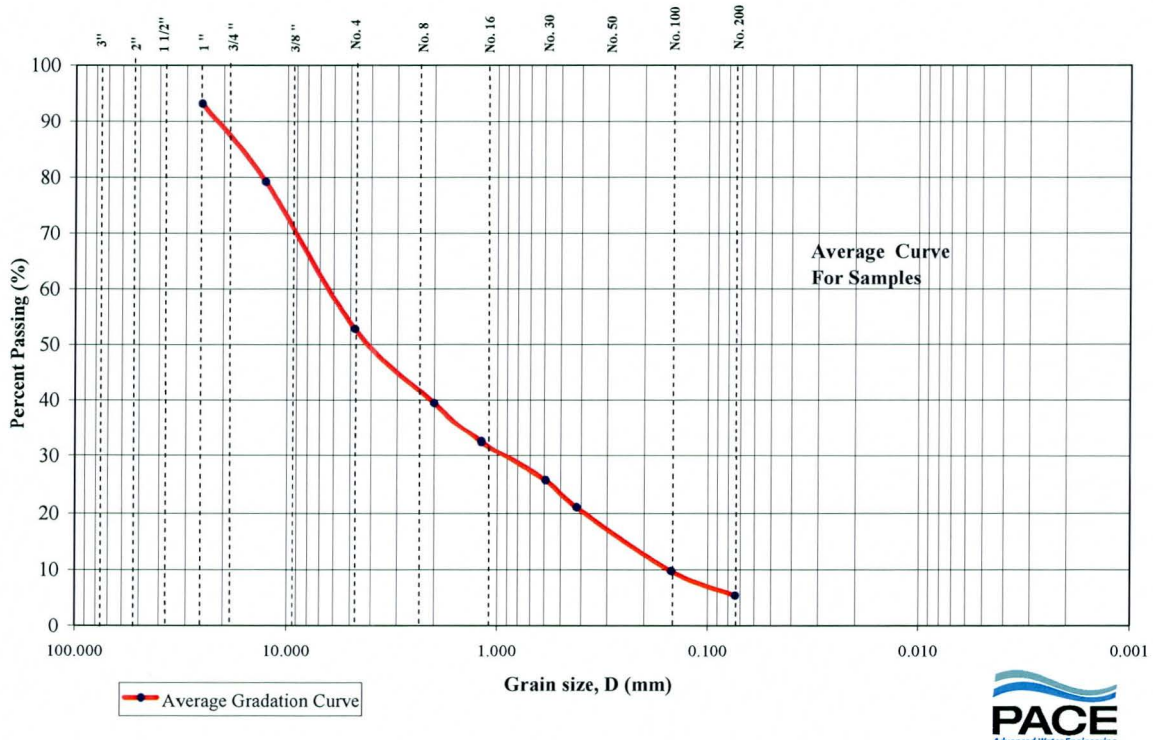


Figure 6-8 – H3 Fan Average Gradation Curve



7 Numerical Simulation Results

7.1 Introduction (Version 2007.06; FLO.EXE compiled on 4/24/2010) JRP 6.1.2010 for FCD

The FLO-2D model was run for 12 and 24 model hours for the 6- and 24-hour rainfall events, respectively. The initial system is dry (no water on the model grid). The only discharge into the grid results from upstream discharge. All simulations demonstrated volume conservation to $O(10^{-8})$. The results of the numerical simulations are presented below; with the complete FLO-2D model input and output found in the Appendix.

7.2 Floodplain Flow Depths

The maximum floodplain flow depths for the 6- and 24-hour events are shown in Figures 7.1 and 7.2. The maximum depths for the 6- and 24-hour events are approximately 13.0 ft for both simulations. The figures illustrate that the greatest depths are largely confined to either the fan feeder channels or result from ponding in the upstream side of the CAP. Relatively high depths in the feeder channels are indicative of flow concentrations in the channels. Generally, the surface depths on the fan are less than 0.5 ft outside of the feeder channels, although some overbank flooding occurs adjacent to feeder channels where more recent anabranching and avulsion of braids has occurred. These values are reasonable considering the incised nature of the major feeder channels, the lesser extent of the anabranched fan areas, and to the presence of the CAP levee.

Comparisons of the 50-grid elevation against topography near three breakout areas of the main channel show that elevations (cell center) in the model grid compare well with topographic data. However, a model with a finer grid is strongly recommended for design purposes. The results for the 50 ft grid model are accurate for planning purposes.

7.3 Floodplain Flow Velocities

The maximum floodplain velocities for the 6- and 24-hour events are shown in Figures 7.3 and 7.4. The maximum velocities for the 6- and 24-hour events are approximately 10.0 fps except at the location of some of the inflow boundaries. These inflow boundary values should not be considered part of the floodplain, but rather an artifact of the model. The figures illustrate that the greatest velocities are located within fan feeder channels. Generally, the surface velocities on the fan outside of the feeder channels are less than 0.5 fps.

7.4 BOR Hazard Zone Analysis for Children

Velocity and depth data is combined for each cell from each run and plotted against the Bureau of Reclamation's Hazard Zone criteria for children. These combined data sets are plotted in the appendix for the 6- and 24-hour events, respectively. The figures show that the combined velocity and depth data distributes into the three BOR hazard zones, and that there are few cells with high velocity and low depth. Once each model cell is assigned a BOR hazard zone, the hazard zone for that cell is plotted on the model grid in Figures 7.5 and 7.6 for the 6- and 24-hour events, respectively. The plots illustrate that high velocity and high depth occur in locations in the middle and high hazard zones. As noted above, these two flow characteristics occur within the feeder channels, recently anabranched areas, and on the upstream side of the CAP. It is important to note, however, that maximum depth and maximum velocity for each cell are considered irrespective of the time they occur during the simulation. Therefore, the present BOR analysis is conservative in that the maximum depth for a given cell and the maximum velocity for a given cell may not occur simultaneously.

7.5 FLO-2D Sediment Transport Analysis

The maximum floodplain bed change for the 6- and 24-hour events are shown in Figures 7.7 and 7.8. The maximum bed change for the 6- and 24-hour events range from approximately -13.0. to 12.0 ft, for both simulations. The figures illustrate that the greatest aggradation is largely confined to either the fan feeder

channels or recently anabranched areas during the falling limb of the hydrograph, or results from ponding along the upstream side of the CAP. Likewise, the greatest degradation is largely confined to either the fan feeder channels and recently anabranched areas, or result from flows along the upstream side of the CAP, on the rising limb of the hydrograph. Generally, the degradation and aggradation on the fan is less than 0.5 ft. The difference in general change results from alluvial fans being aggradational systems. Some extremely high values of erosion (approximately $\Delta z>15$ ft) are observed at a few cells within the model. Values of this magnitude on an aggrading alluvial surface are not expected, in general. This result within the specific model cells appears to be a function of the model and may be related to model transport equation selection, and is not expected in the field.

On alluvial surfaces, high erosional and depositional rates can be expected and are a function of surface velocity experienced at the site. Large changes in bed elevation are frequently observed in arid environments, particularly on alluvial surfaces. Some of the bed change observed in the present study may be strongly a function of the transport equation used in the model. The purpose of the present study was to identify areas or erosion and deposition. While it is unlikely that erosion or deposition of the magnitude predicted in the present study will occur, it is expected that the areas experiencing high erosion or deposition in the model will do so in the field although magnitudes may be smaller. PACE recommends a more detailed sediment transport study examining model sensitivity to transport equation selection where more accurate estimates of bed change is needed.

7.6 Shallow Manning's n Sensitivity Analysis

During the initial review provided by FCDMC, concern was raised that the model might be sensitive to shallow Manning's n=0.200. While PACE believes that this value was field verified, an additional simulation was carried out with shallow n=0.150 to assess the sensitivity of the model to changes in the shallow Manning's value. Generally, the results indicate that the change in shallow n value does not greatly alter the results of the modeling. The full sensitivity analysis model is included in the Appendix.

7.7 Comment on the Accuracy of Model Topography

Comparisons with the model grid against topography show that elevations in the model grid compare well with topographic data in areas of abrupt change. These areas include channel banks and alluvial fan features. The model grid resolution is appropriate for the scale of the study presented here. If detailed information about discharge and flow direction is required on a particular section of the fan, a higher level of study is recommended in the specific area of interest. While elevations within the model grid may match topography well, volumes that may be contained in a cell may not be accurate enough to present detailed information about discharge in a small sub-area of the study.

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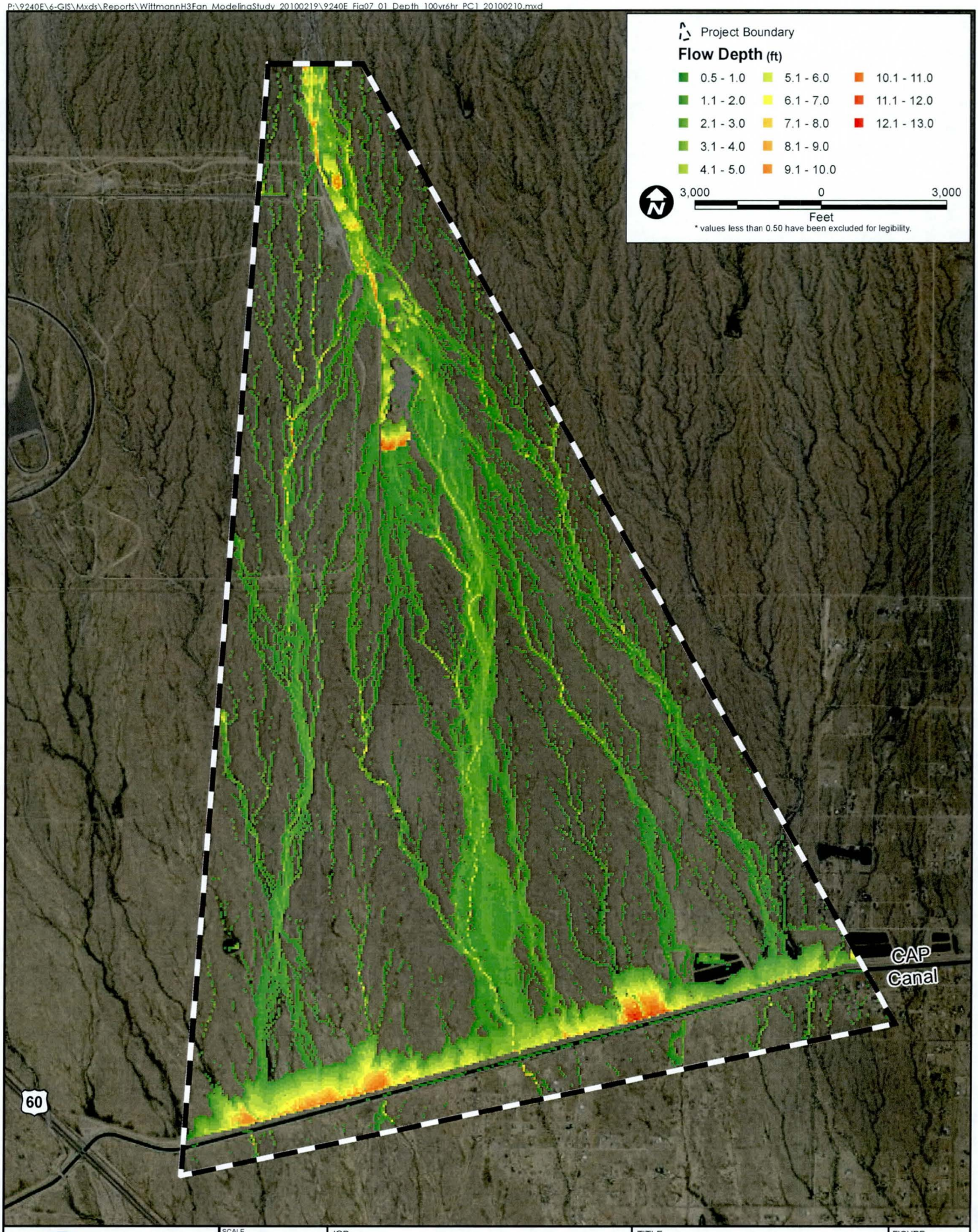

PACE
Advanced Water Engineering

SCALE 1" = 3000'	JOB	TITLE	FIGURE
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DRAWING PC			
CHECKED DJ			
DATE 02/22/10			
JOB NO. 9240-E	Maricopa County AZ		

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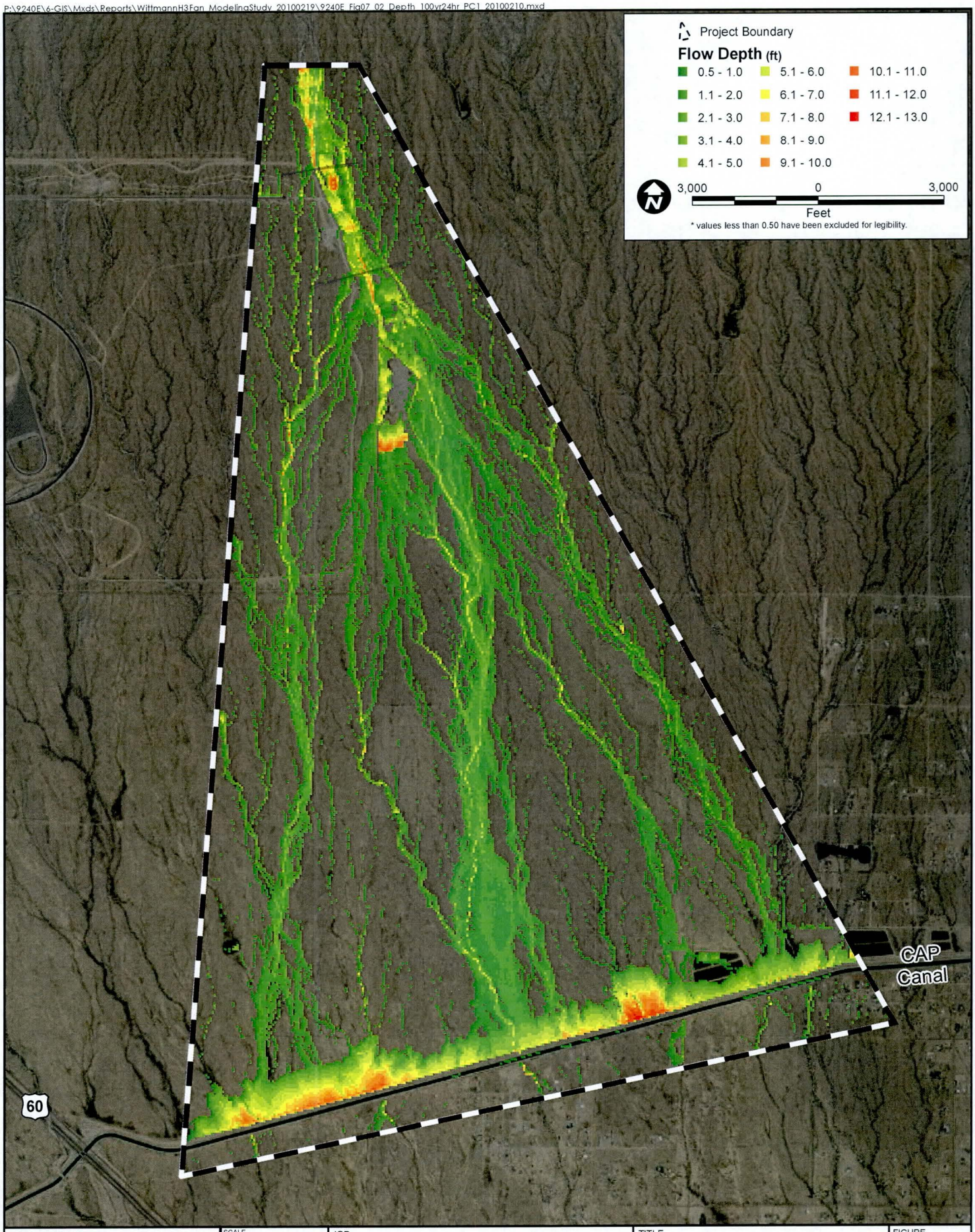

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	JOB NO. 9240-E	Maricopa County AZ		

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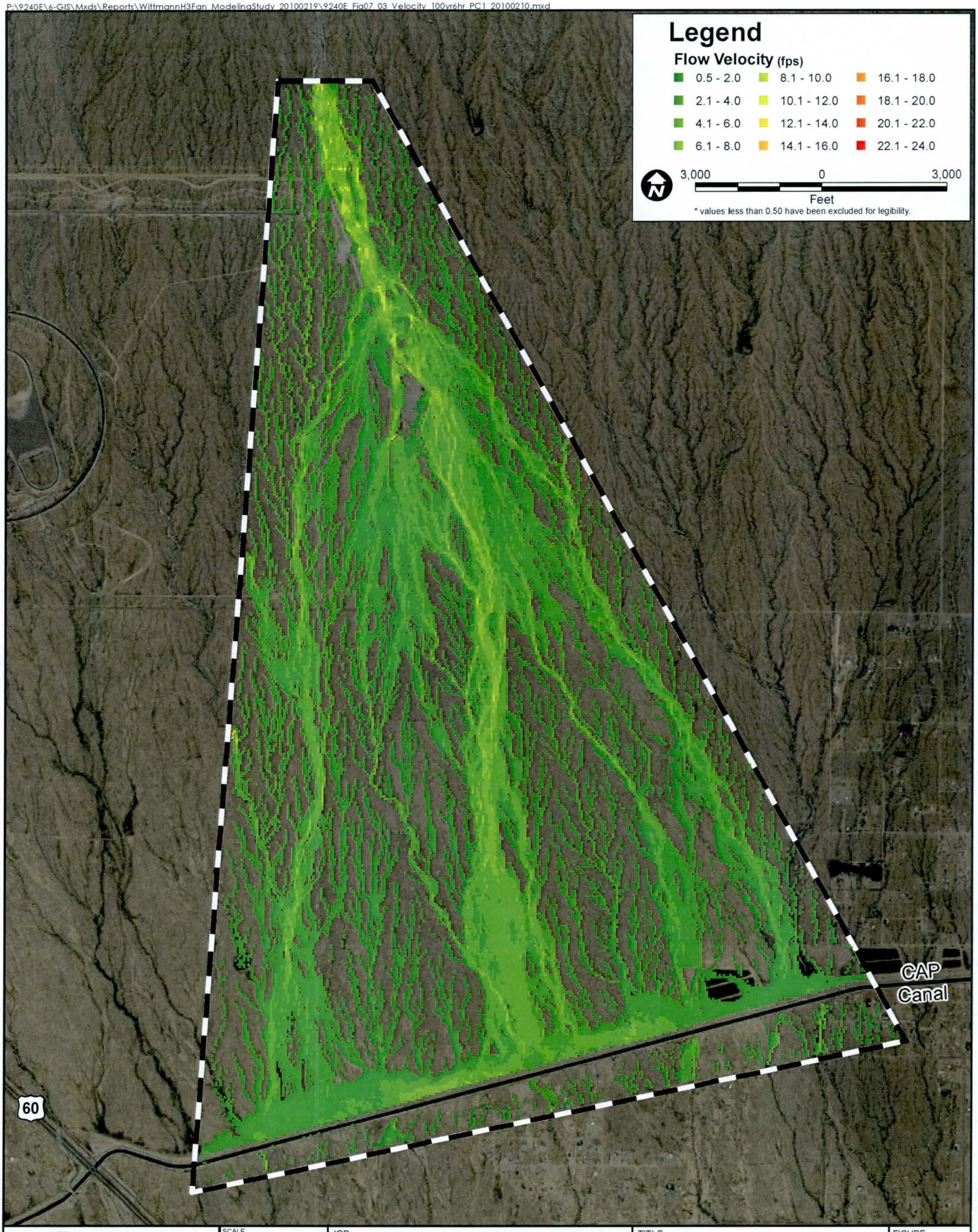

PACE Advanced Water Engineering	SCALE 1" = 3000' DESIGNED PC DRAWING PC CHECKED DJ DATE 02/22/10 JOB NO. 9240-E	JOB Wittmann H3 Fan Modeling Study Maricopa County AZ	TITLE Flow Velocity 100 Year 6 Hour	FIGURE 7.3

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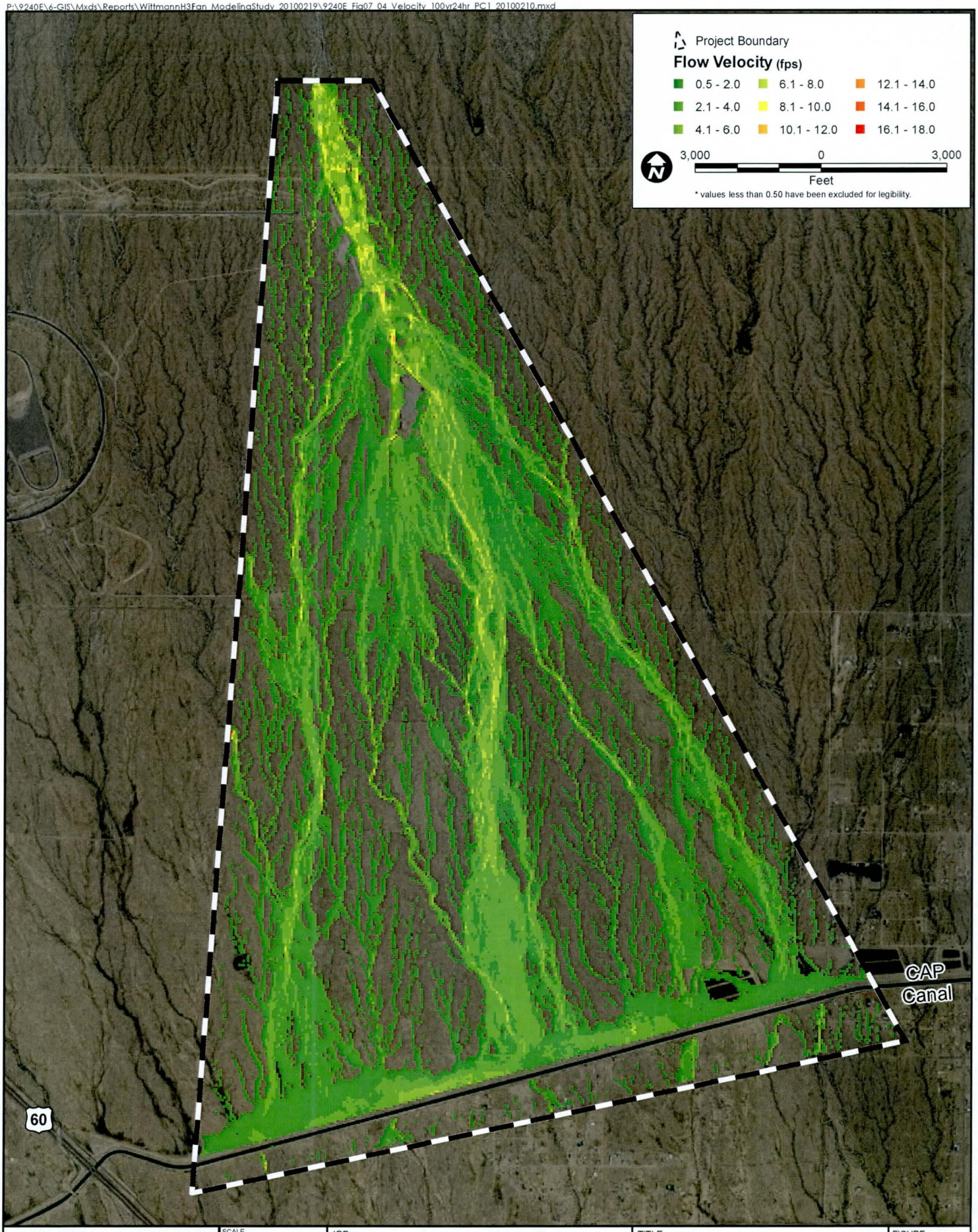

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DATE	02/22/10
JOB NO.	9240-E

JOB: Wittmann H3 Fan Modeling Study
Maricopa County AZ

TITLE: Flow Velocity 100 Year 24 Hour

FIGURE: 7.4

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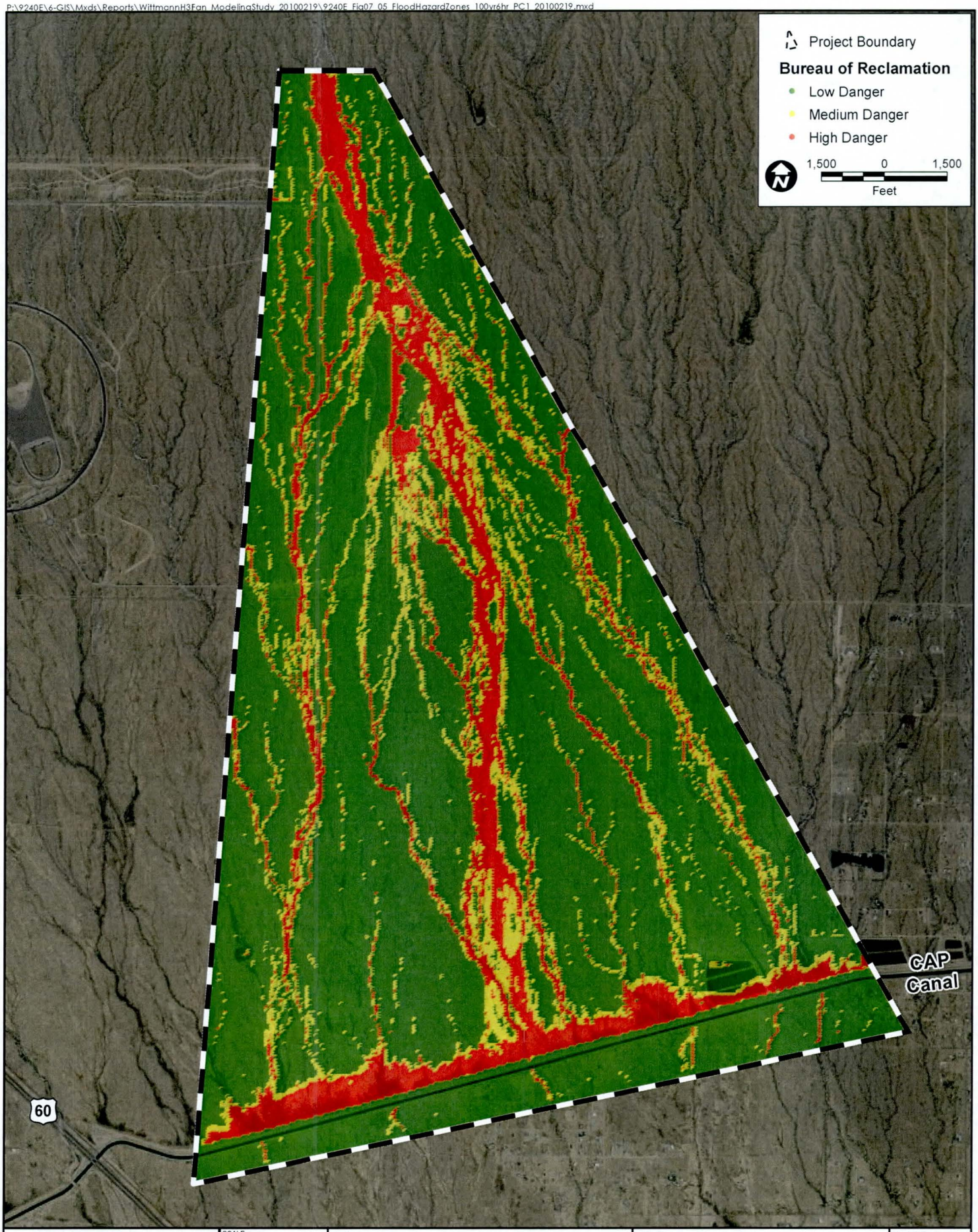

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DATE	02/19/10
JOB NO.	9240-E

JOB: Wittmann H3 Fan Modeling Study
Maricopa County AZ

TITLE: BOR Flood Hazard Zones (Children) 100 Year 6 Hour

FIGURE: 7.5

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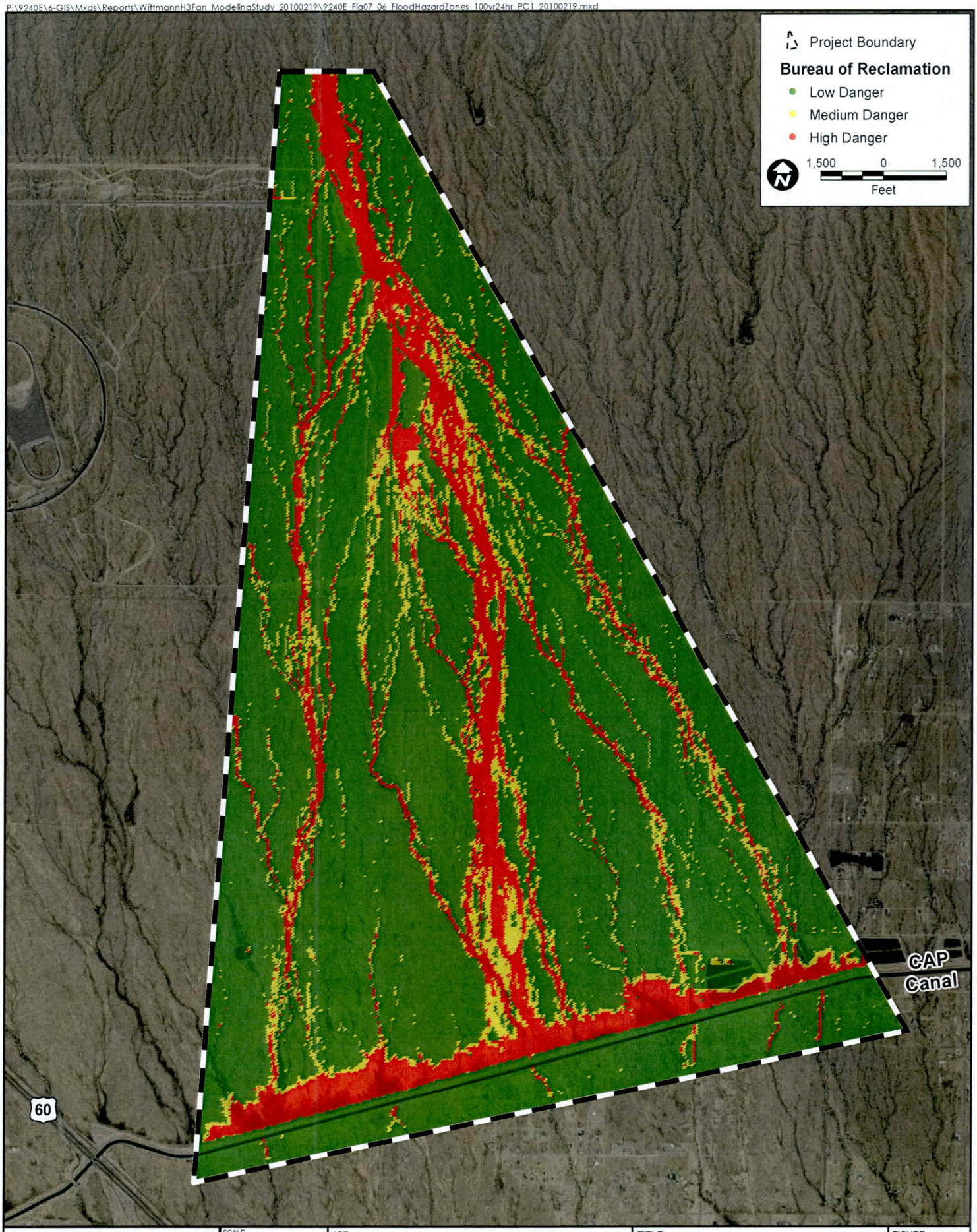

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DATE	02/19/10
JOB NO.	9240-E

JOB: Wittmann H3 Fan Modeling Study
Maricopa County AZ

TITLE: BOR Flood Hazard Zones (Children) 100 Year 24 Hour

FIGURE: 7.6

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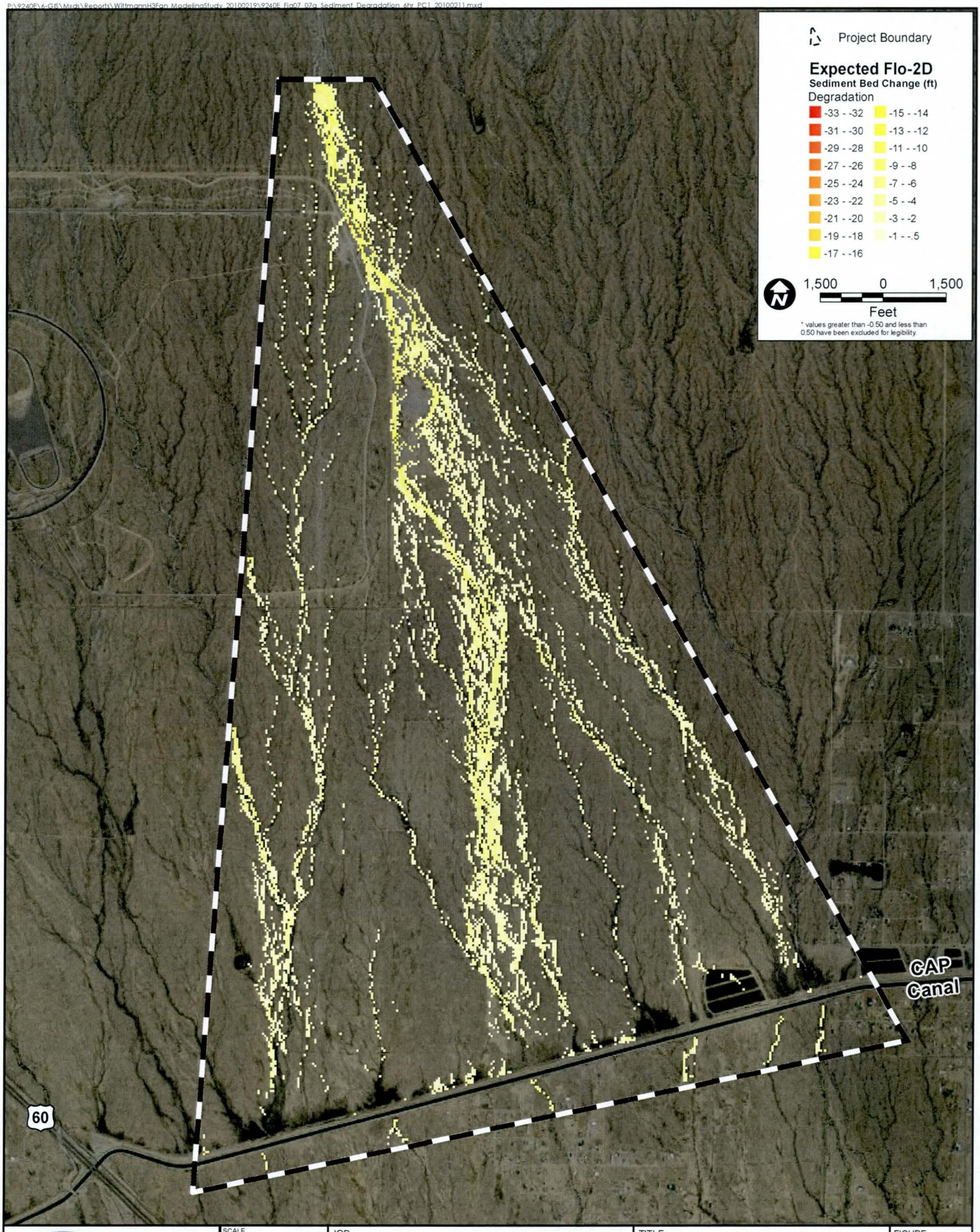

PACE Advanced Water Engineering	SCALE 1" = 3000'	JOB	TITLE	FIGURE
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	DRAWING PC			
	CHECKED DJ			
	DATE 02/22/10			
	JOB NO. 9240-E	Maricopa County AZ		

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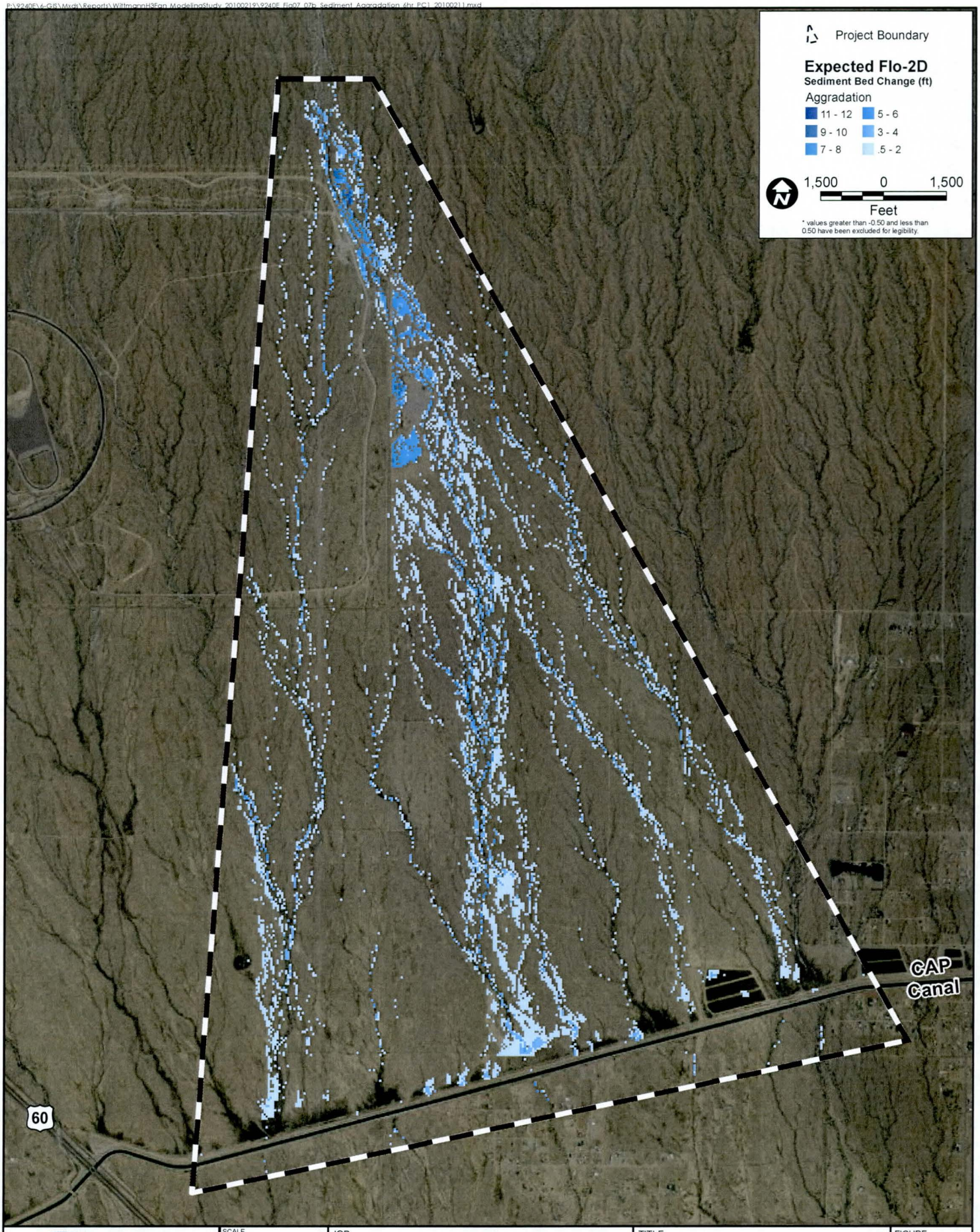

PACE
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DATE	02/22/10
JOB NO.	9240-E

JOB: Wittmann H3 Fan Modeling Study
Maricopa County AZ

TITLE: Sediment Bed Change Aggradation 100 Year 6 Hour

FIGURE: 7.7b

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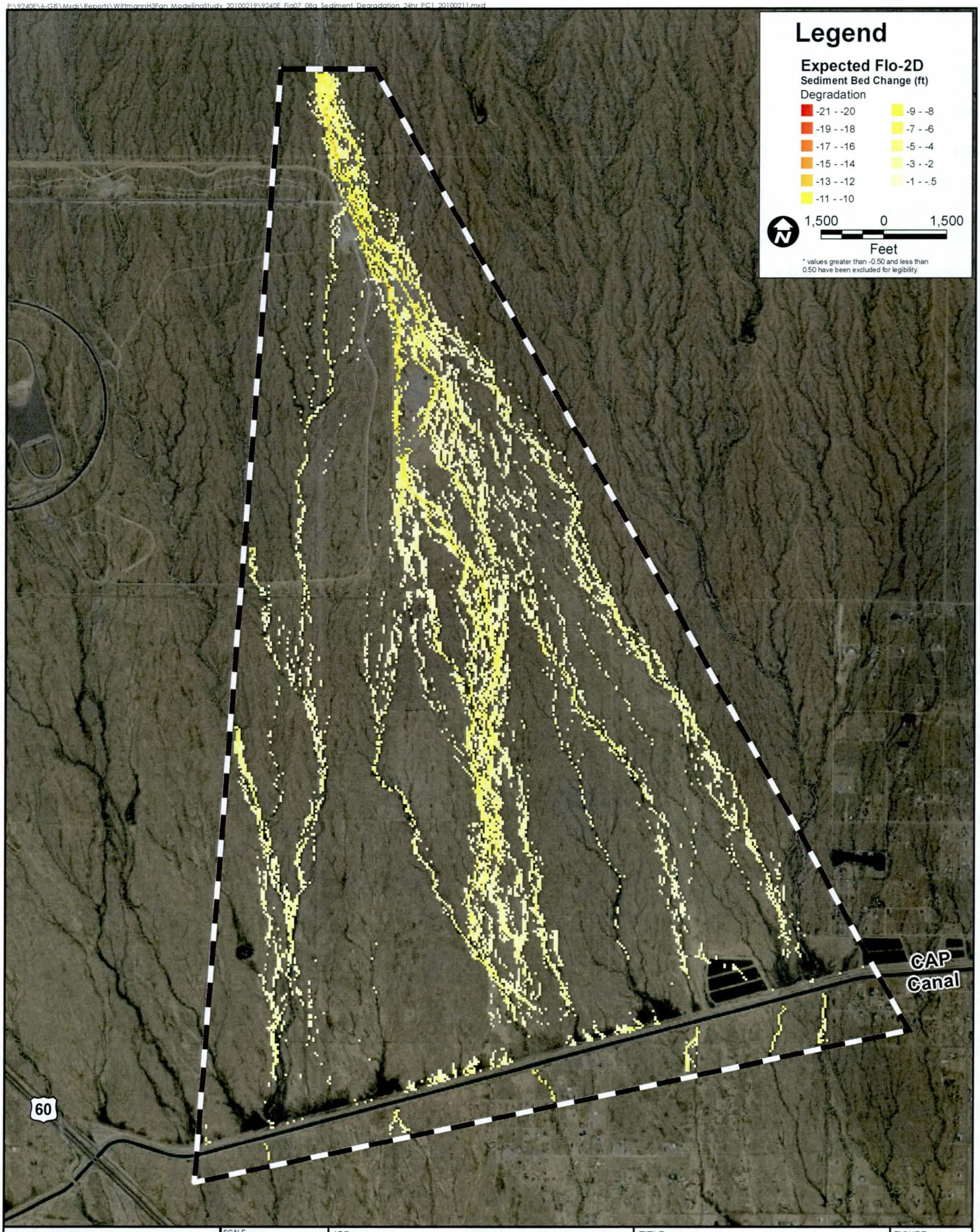

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Advanced Water Engineering

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DRAWING	PC
CHECKED	DJ
DATE	02/22/10
JOB NO.	9240-E

JOB: Wittmann H3 Fan Modeling Study
Maricopa County AZ

TITLE: Sediment Bed Change Degradation 100 Year 24 Hour

FIGURE: 7.8a

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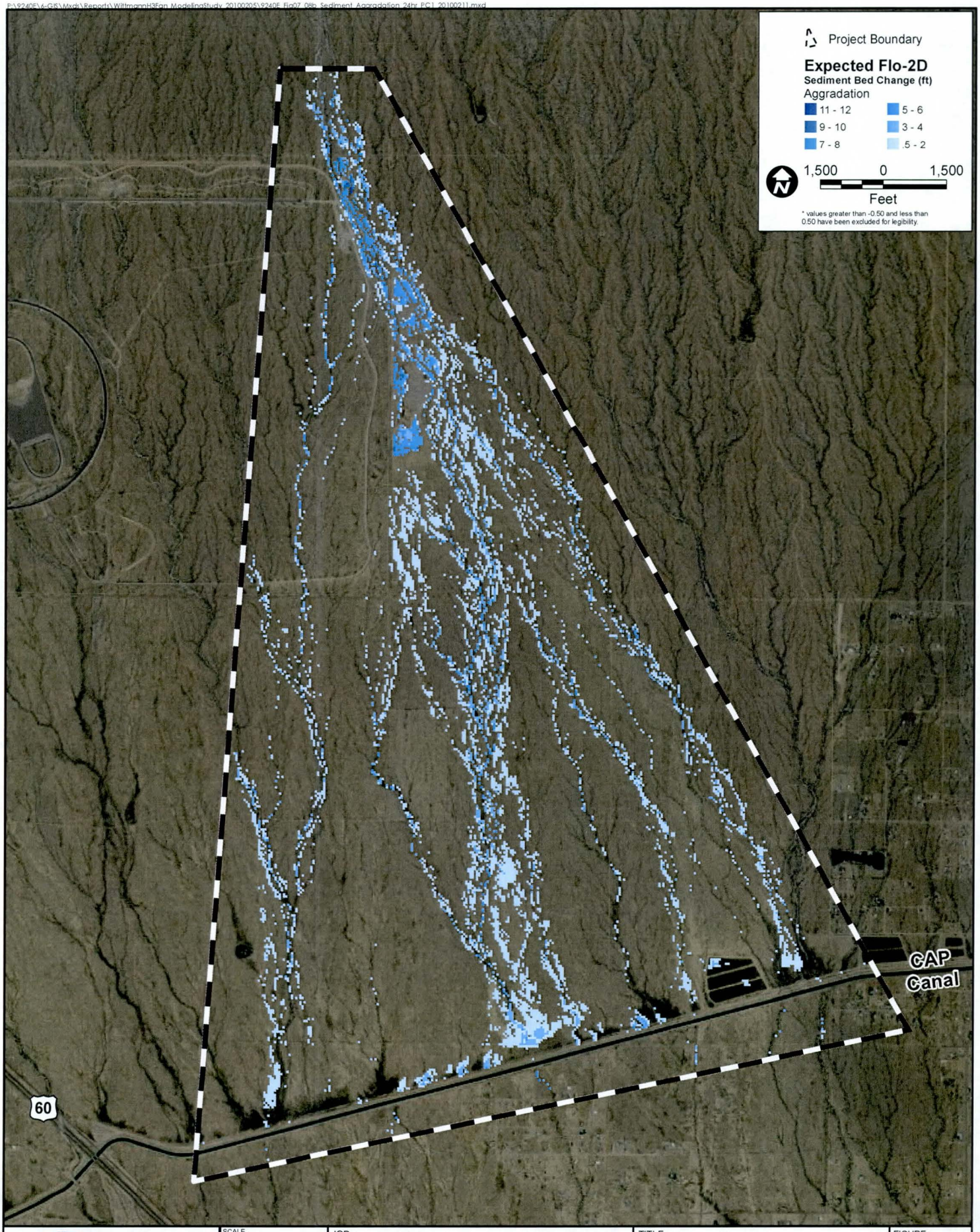

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	DRAWING PC			
	CHECKED DJ			
	DATE 02/16/10			
	JOB NO. 9240-E	Maricopa County AZ		

8 References

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9 Appendix

Please see attached DVD:

Models:
- 6-Hour
- 24-Hour
- 6-Hour with Sediment
- 24-Hour with Sediment

GIS Data:
- Soils
- Cross-sections
- Land Use
- Parcels
- BOR Flood Hazard Zones
- Culverts
- Depth
- Elevation Raster
- Inflow
- Outflow
- Sediment
- Velocity

Input Data:
- Sediment
- Culverts
- Hydrographs

Site Photographs

BOR Plots

Flood Control District
of Maricopa County

INTEROFFICE MEMORANDUM

Date: September 1, 2010

To: Bing Zhao, Engineering Application Development and River Mechanics Branch Manager, Engineering Division

From: J. Rafael Pacheco, Engineering Application Development and River Mechanics Branch, Engineering Division

CC: Richard Waskowsky, Engineering Application Development and River Mechanics Branch, Engineering Division

Subject: Revised FLO-2D Sediment Transport Models for H3 Alluvial Fan area in Wittmann ADMS area by Dr. Jim O'Brien of FLO2D/Riada

Dr. Jim O'Brien reviewed the 6-hour and 24-hour H3 Alluvial Fan FLO-2D sediment transport input files and results prepared by PACE, provided some comments, and revised the input files (O'Brien, 7/28/2010). Dr. O'Brien is the author of FLO-2D software. These revised input data files for the 6-hour and 24-hour events with the sediment transport features enabled were re-run at the Flood Control District with version 2007.06 (executable flo.exe compiled on date 3/6/2008). The input file, the results, and Dr. O'Brien's memorandum can be found in the attached CD.

It should be mentioned that the scour/deposition results are for planning level purposes. The results should not be used for actual design. The scour/deposition estimation for actual design should follow the FCDMC's hydraulics manual and DDMSW software.

A summary of the modifications done by Dr. O'Brien follow:

1. A new user-assigned variable Courant number was set to 0.8 with the WAVEMAX = 101.00, so that all the timestep decrements were the result of the Courant stability criteria.

2. Initially, scour depths were reduced by increasing the *n*-value and decreasing the velocity.

3. Scour depths for a few elements that were greater than 10-ft were eliminated by setting the scour depth limitation (SCOURDEP in the SED.DAT file) to 8.0-ft.

4. Turn off the sediment supply (by size fraction) to the three inflow nodes near the fan apex and instead raised the grid elements by approximately 10-ft. Three rows

of grid elements near the inflow elements were raised. This additional sediment availability from the bed of the grid elements then constituted the supply to the fan apex area. This was a reasonable approach because deposition then *ensued* (sic?) just a few grid elements downstream of the inflow nodes. The final bed elevation shown in Figure 3 indicates that deposition (red grid elements) had occurred in elements surrounding the inflow nodes (20, 21, and 22).

5. Turn off the size fraction analysis for the alluvial fan surface. This additional complexity was not critical to the scour depth calculations because there was insufficient coarse material in the sediment size distribution to limit the scour for the steep sloped alluvial fan.

6. The fine sediment concentration by volume was reduced from 5% to 2% in SED.DAT. It is unlikely that 5% of the sediment on the fan was clay. This fine sediment concentration is only used for the MPM Woo equation.

7. The size gradation was reduced from 9 to 5 to better reflect the sediment size distribution listed in the data file.

8. Finally the display element for the SEDTRANS.OUT file was changed from the arbitrary 12345 grid element to node 4406 in the middle of the alluvial fan flooding.

I performed another set of FLO2D runs using the input data from FLO2D/Riada (from Dr. O'Brien) with a slight modification to SCOURDEP in the SED.DAT file by setting the scour depth to no-limitation; the objective was to determine how many grid elements have scour depths greater than 10 ft. The results shown in the figures 1 and 2 below demonstrate that the number of grid elements with scour depths greater than 10 have been substantially reduced (left-hand side of figures 1 and 2) compared to the results from PACE's model (figures 1 and 2 right-hand side). Notwithstanding, the number of grid elements with scouring depths of 10-ft or greater has been reduced, the unrealistic scouring depths of 10-ft or more were not completely eliminated.

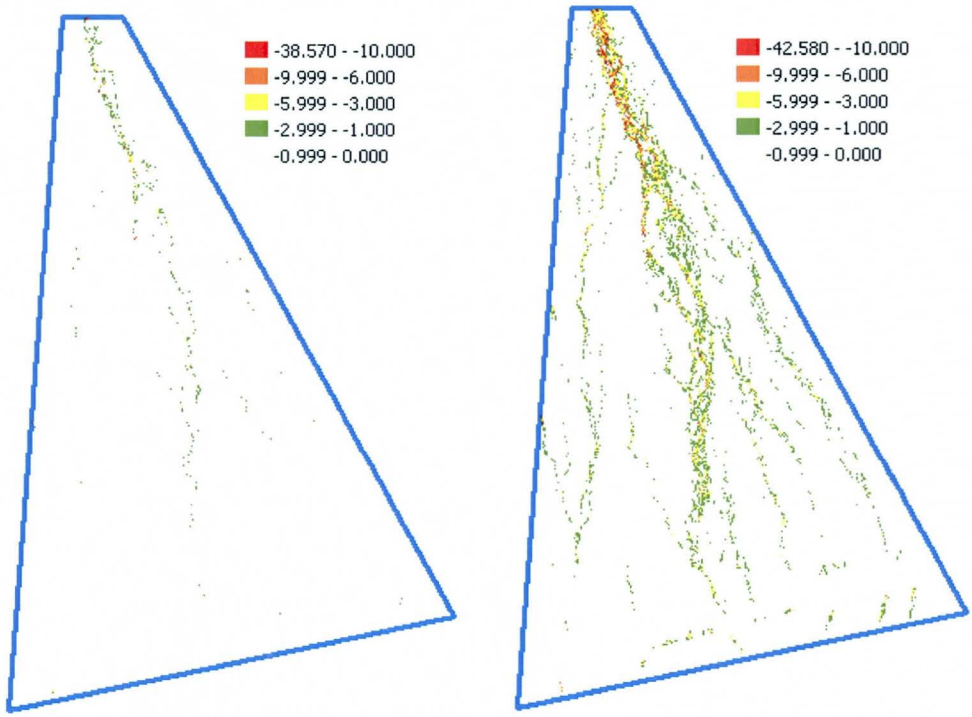

Figure 1: Scour depth in ft. On the left, the results using the input files from Dr. O'Brien (without restricting the scouring depth to no more than 10-ft). On the right, the results from PACE's model.

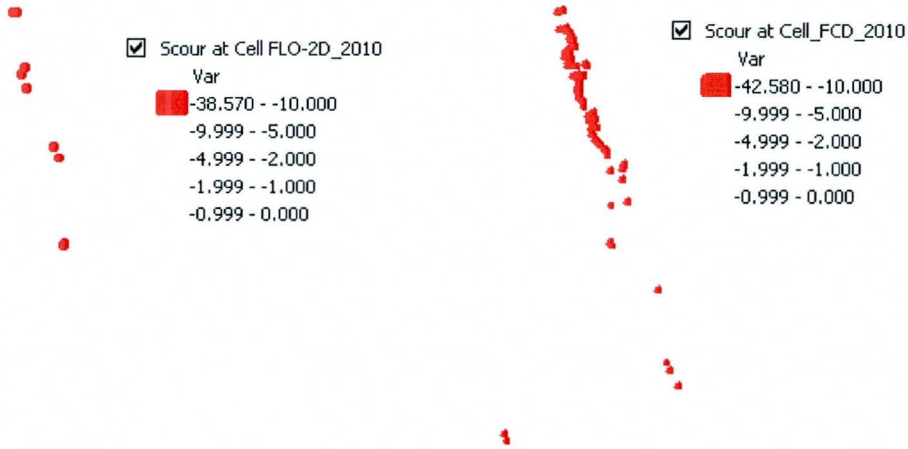

Figure 2: Elements whose scouring depth is more than 10-ft. On the left, the results using the input files from Dr. O'Brien (without restricting the scouring depth to no more than 10-ft). On the right, the results from PACE's model.

FLO-2D/Riada Memo

To: Bing Zhao

From: Jim O'Brien

Date: 7/28/2010

Re: Comments and Suggestions on the H3 Alluvial Fan Wittmann Area FLO-2D Model

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About a week or so was spent working on the 6-hour and 24-hour Wittmann FLO-2D models that were provided from PACE. The revised data files are attached. Changes to the data files are outlined below. All of the simulations were completed with the most recent update of Version 2009.06 of the FLO-2D model and the original simulation times of 54 hours for the 6-hour storm and 43 hours for the 24 hour storm listed in the SUMMARY.OUT file were reduced to 2.5 hours and 4.1 hours respectively. Some of this computer runtime difference is related to the computer processing speed. At the end of the Memo, several suggestions for improving the model are listed.

Overview

In general, the alluvial fan model is relatively simple. For water flooding, the primary modeling issues would be:

1. The verification of the inflow hydrographs and rainfall;
2. Range of assigned n-values;
3. Topographic adjustments;
4. Numerical stability;
5. Infiltration and percent runoff versus percent loss;
6. Hydraulic structures.

Applying the sediment transport component to this model expands the model complexity and the issue of scour/deposition is a focus. Each of these model issues will be briefly addressed except for the sediment transport which will be discussed in more detail.

Hydrology - Inflow Hydrographs and Rainfall

The model was initially prepared by PACE. The adequacy or accuracy of the inflow hydrology and rainfall is the responsibility of the District and its contractor. Reviewing the inflow hydrographs and rainfall is beyond the scope of this model review. The model has four inflow locations: one near the fan apex (assumed to be north), two on the west side and one on east side. The fan apex inflow was distributed into three grid elements. The remaining three inflow locations were confined to one grid element. The three fan apex elements were assigned a sediment supply rating curve by size fraction.

Correlating the inflow hydrology with the outflow locations of the model, it was noted that outflow nodes were assigned along the model south and west sides (assuming north being the top of the computer screen). It appears that the flow contacts the west boundary, so the outflow elements along this edge of the model are necessary. In couple of locations the outflow element assignment involved either doubled outflow nodes or several elements that were supposed to have outflow element assignment were missed. This is minor, however, and did not affect the overall fan flood simulation.

Spatially Variable Roughness

It appears that the initial global n-value assignment for the grid system was 0.090. This is satisfactory for most alluvial fan surfaces in the desert southwest. A typical range of n-values for desert fan conditions is 0.065 to 0.200. A generic n-value of 0.085 is suggested for most model starting conditions. For areas of the fan with channels, an n-value in the range of 0.040 to 0.050 appears to be applied. The final mix of high and low n-values does not appear to be appropriately distributed (see Figure 1). Aerial imagery was not available to verify the relative accuracy of the n-value assignment.

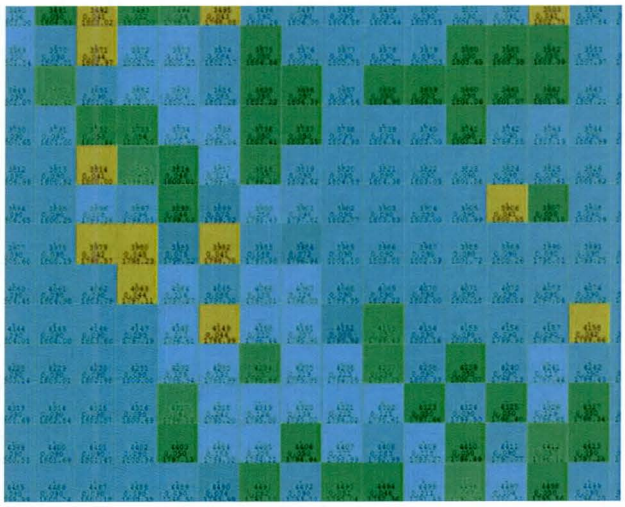

Figure 1. Spatial Distribution of n-values
(Brown and green elements have low n-values possibly indicating channel elements)

The n-values were spatially varied by applying either the limiting Froude number or the numerical stability criteria. It appears that the n-values were varied both for water and sediment simulations. From the data files, it is unknown if a limiting Froude number was applied and what value may have been used. The n-values were varied on the basis of the numerical stability parameter WAVEMAX = 0.35 (a negative value was used to vary the n-value). Whereas the limiting Froude number is used to adjust n-values to reduce unrealistic velocities, the dynamic wave stability criteria (WAVEMAX) is used to address the potential mismatch between flow area, slope and n-value. The resulting erratic distribution of n-values (discontinuous channels) shown in Figure 1 may have been contributing to both the numerical surging and the high scour depths.

Topographic Adjustments

There appears to be some locations where the grid element elevations are not appropriate. It is unknown if the grid element elevations were adjusted by the District or PACE. Nevertheless, it is unclear without an aerial image or the DTM points if the some of the topographic features are properly represented. In Figure 2 grid elements 15508,16209 and 16358 are higher than the upstream elements (16357,16208, and 16059), but there are gaps between the elements (see grid element 16359 and 16509). The upstream grid elements (16357,16208 and 16059) were elements that were experiencing significant scour. Some further grid element elevation adjustment would probably eliminate the predicted large scour in these elements.

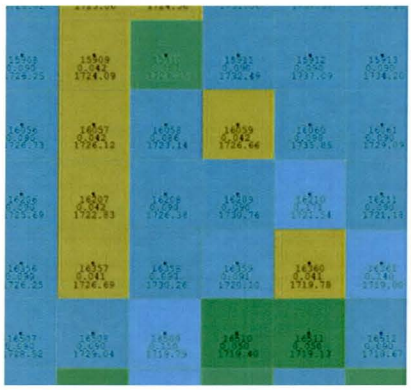

Figure 2. Grid Element Elevations (third variable).

Numerical Instability

The original predicted maximum velocities were reasonable. Only five grid elements in the 6-hour simulation had computed maximum velocities that were greater than 10 fps based on DEPTOL (percent change in flow depth) = 0.20 and a WAVEMAX stability criteria value of 0.35. It was likely that these high velocities were simply a matter of the timesteps being too large.

To eliminate any high velocities, a limiting Froude number of 0.99 was assigned and several runs were completed with corresponding adjustments to the n-values. These flood simulations were completed with the rainfall and sediment transported turned off. Subsequently, the ROUGH.OUT file was emptied and the n-value adjustments were complete. A new user-assigned variable Courant number was set to 0.8 with the WAVEMAX = 101.00, so that all the timestep decrements were the result of the Courant stability criteria. The reported maximum velocities were reasonable and it was construed that the numerical surging in the model was negligible.

Infiltration

The infiltration was not requested by the District to be reviewed, so only a few comments are provided. The infiltration was spatially variability in the original model. A global hydraulic conductivity of 0.1 in/hr was assigned, but the individual grid element hydraulic conductivity ranged from 0.3 to 0.5 in/hr for large portions of the alluvial fan. This range is considered to be high and this is reflected in the total infiltration loss that is almost as much as the total rainfall as listed in the SUMMARY.OUT file. For this reason, it is suggested that the inflow hydrographs be turned off and the rainfall runoff on the fan be simulated alone to determine whether the percent loss is appropriate.

Hydraulic Structures

The hydraulic structures were all located on the lower portion of the alluvial fan downstream of the locations where the predicted grid elements with high scour depths were identified. No review of the hydraulic structures was undertaken.

Scour and Deposition

The primary focus of this review was to reduce the high scour predicted for 10 to 20 grid elements. Most of the high scour was associated with high velocities and depths. The Zeller Fullerton sediment transport equation was originally applied in the model. This equation is a function of velocity raised to the power of 4.32 and is inversely proportional to the depth raised to 0.3 power. Thus as depth increases, the sediment transport slightly decreases, but as the velocity increases, the sediment transport significantly increases. Sediment transport also increases with n-value raised to the 1.77 power. Initially, scour depths were reduced by increasing the n-value and decreasing the velocity. Not all of the high scour could be decreased without further investigation related to topographic features

and possibly some adjustment to the grid element elevations as discussed above. Scour depths for a few elements that were greater than 10 ft were eliminated by setting the scour depth limitation (SCOURDEP in the SED.DAT file) to 8.0 ft. Eight feet of scour is possible on an alluvial fan unless the depth to bedrock is known.

A number of adjustments were made for the sediment transport to address the high maximum scour depths:

- Turned off the sediment supply (by size fraction) to the three inflow nodes near the fan apex and instead raised the grid elements by approximately 10 ft. Three rows of grid elements near the inflow elements were raised. This additional sediment availability from the bed of the grid elements then constituted the supply to the fan apex area. This was a reasonable approach because deposition then ensued just a few grid elements downstream of the inflow nodes. The final bed elevation shown in Figure 3 indicates that deposition (red grid elements) had occurred in elements surrounding the inflow nodes (20, 21, and 22).

- Turned off the size fraction analysis for the alluvial fan surface. This additional complexity was not critical to the scour depth calculations because there was insufficient coarse material in the sediment size distribution to limit the scour for the steep sloped alluvial fan.

- The fine sediment concentration by volume was reduced from 5% to 2% in SED.DAT. It is unlikely that 5% of the sediment on the fan was clay. This fine sediment concentration is only used for the MPM Woo equation.

- The size gradation was reduced from 9 to 5 to better reflect the sediment size distribution listed in the data file.

- Finally the display element for the SEDTRANS.OUT file was changed from the arbitrary 12345 grid element to node 4406 in the middle of the alluvial fan flooding.

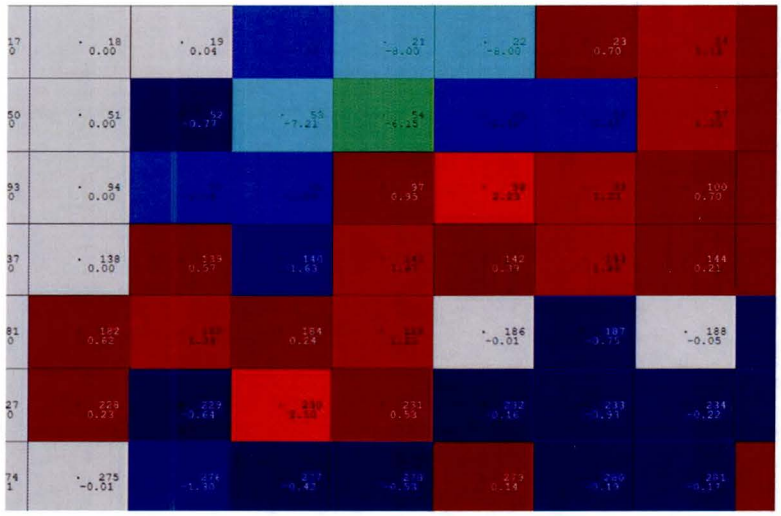

Figure 3. Final Scour and Deposition Near the Fan Apex
(Blue = Scour, Red = Deposition)

The net impact of these sediment parameter revisions was to temper the magnitude of the sediment scour. The primary control of the sediment scour is the sediment transport equation which computes the fourth highest sediment discharge of the nine equations after Englund-Hansen, MPM-Smart, and Yang's equation. Although it can be argued that none of the sediment transport equations apply to alluvial fans based on their formulation, Zeller Fullerton is regarded to be representative or slightly over-

predictive. It is important to remember, that the application of these equations should be viewed in a general perspective on the fan. The available equations are limited in their application to generally mild slopes and to specific sediment sizes, so the results should be regarded in terms of overall sediment scour and deposition trends on different portions of the alluvial fan and should not be viewed as definite estimates of scour and deposition at specific locations.

Recommendations

At this point, further adjustment of the sediment transport parameters is not advised until other revisions of the model are finalized. It is recommended that the Whittmann Fan FLO-2D model be revised as follows:

- With a background image and DTM points, adjust the grid element elevations to better define the water courses and distributary channels on the alluvial fan taking into account topographic features such as berms and mounds as indicated above. Some grid elements that are in the water course may have failed to represent the channel bed elevation when the DTM data was interpolated. The water course as represented by the grid element elevations should depict a continuous downslope channel without interruptions by high grid elements. This topographic adjustment effort may eliminate all the potential large scour holes.

- At this point, the n-value variation may not be very representative of the conditions on the fan. The n-values appear to have been significantly revised using the limiting Froude number and/or stability criteria. It is recommended that the n-values be re-assigned to represent the conditions on the fan including the water courses using a background image. This will also have a significant effect on the development of scour holes.

- Test other sediment transport equations such as Yangs, MPM-Woo, MPM-Smart and Englund-Hansen to determine the potential range of sediment scour and deposition conditions on different locations on the fan.

- After these results are reviewed and finalized, it may be appropriate to consider sediment routing by size fraction again.

- The floodplain cross sections were turned off. There were many cross sections in many directions and at this point, these cross sections have limited utility for the purpose of analyzing the sediment transport results.

Summary

To summarize the findings in this review, the Whittmann FLO-2D model is very basic with only hydraulic structures, spatially variable infiltration and sediment transport adding to the complexity of the predicting flooding. Before these results are used for flood hazard mapping or planning is recommended that the grid element topography representing the water courses on the alluvial fan be carefully reviewed and, if necessary, further adjusted. In addition, the n-values should be reviewed with a background aerial image and adjustments made to remove the erratic assignment of n-values. When these two tasks are completed, the sediment transport equations and parameters can be tested for sensitivity to identify the potential range of scour and deposition in response to the 6-hour and 24-hour storms.