Palo Verde Watershed
Detailed Floodplain Delineation Study

Hydrology TDN - Book 1

Contract FCD 2008C046

June 2011

Entellus™

In Association With

Stantec

Flood Control District of Maricopa County

Palo Verde Watershed Detailed Floodplain Delineation Study

HYDROLOGY TECHNICAL DATA NOTEBOOK

Contract FCD 2008C046

June 2011

Registered Professional Engineer (Civil)
CERTIFICATE NO.
35150
R. MICHAEL C. GERLACH
Date Signed 7/19/11
ARIZONA U.S.A.

R. Michael C. Gerlach

Expires 09/30/2012

Prepared by:

Intelligent Engineering
Environmental *Solutions*

Entellus™
2255 N. 44th Street
Suite 125
Phoenix, AZ 85008
Phone (602) 244 2566
Fax (602) 244 8947
Web: www.entellus.com

In association with:

Stantec
8211 S. 48th St
Phoenix, AZ 85044
Ph: (602) 438-2200
Fx: (602) 431-9562
Web: www.stantec.com

PALO VERDE WATERSHED DETAILED FLOODPLAIN DELINEATION STUDY

HYDROLOGY TECHNICAL DATA NOTEBOOK

FCD 2008C046

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HYDROLOGY TECHNICAL DATA NOTEBOOK

SECTION 1: INTRODUCTION

The information and analyses presented in this Technical Data Notebook (TDN) are part of the scope of work performed by Entellus, Inc. for the Flood Control District of Maricopa County (District) as part of the Palo Verde Watershed Detailed Floodplain Delineation Study authorized under Contract FCD No. 2008C046. Entellus, Inc. is the prime consultant for this study with Stantec Consulting Inc. as the subconsultant for the hydrologic modeling and LTM Engineering, Inc., performing technical review.

The purpose of this floodplain delineation study is to establish or refine 100-year flooding limits and associated flood zone designations. The development of the baseline data involves the estimation of peak discharges resulting from a 100-year (1% chance) storm at key locations in the watershed and the delineation of floodplain limits along designated study reaches. This report presents the hydrologic modeling for the watershed and is structured in TDN format in accordance with Arizona State Standard SS1-97. A second report will cover the hydraulic modeling and mapping portions of the study. The hydraulics TDN will be submitted to FEMA separately and will refer to this TDN.

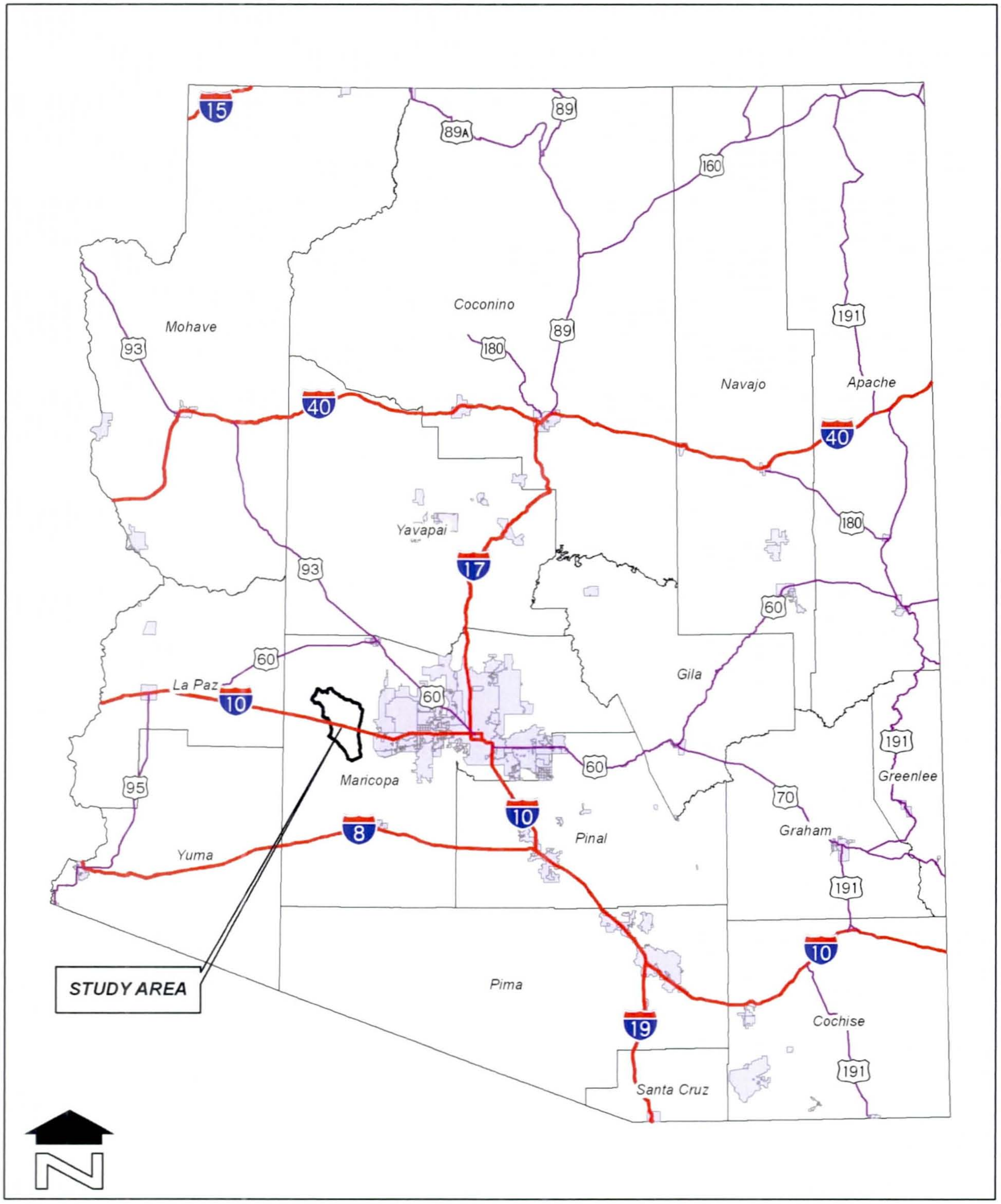
1.1 Project Location

The approximately 277-square-mile study area is located in northwest Maricopa County, shown in the Location Map (Figure 1-1), and is generally bounded by Sugarloaf and the Belmont Mountains to the north, Centennial Wash to the south, on the west by Burnt Mountain and Saddle Mountain, and approximately 365th Avenue to the east, shown in the Vicinity Map (Figure 1-2). The watershed is shown with the Townships and Ranges in Figure 1-3. There are two small unincorporated communities within the watershed area, Tonopah and Wintersburg.

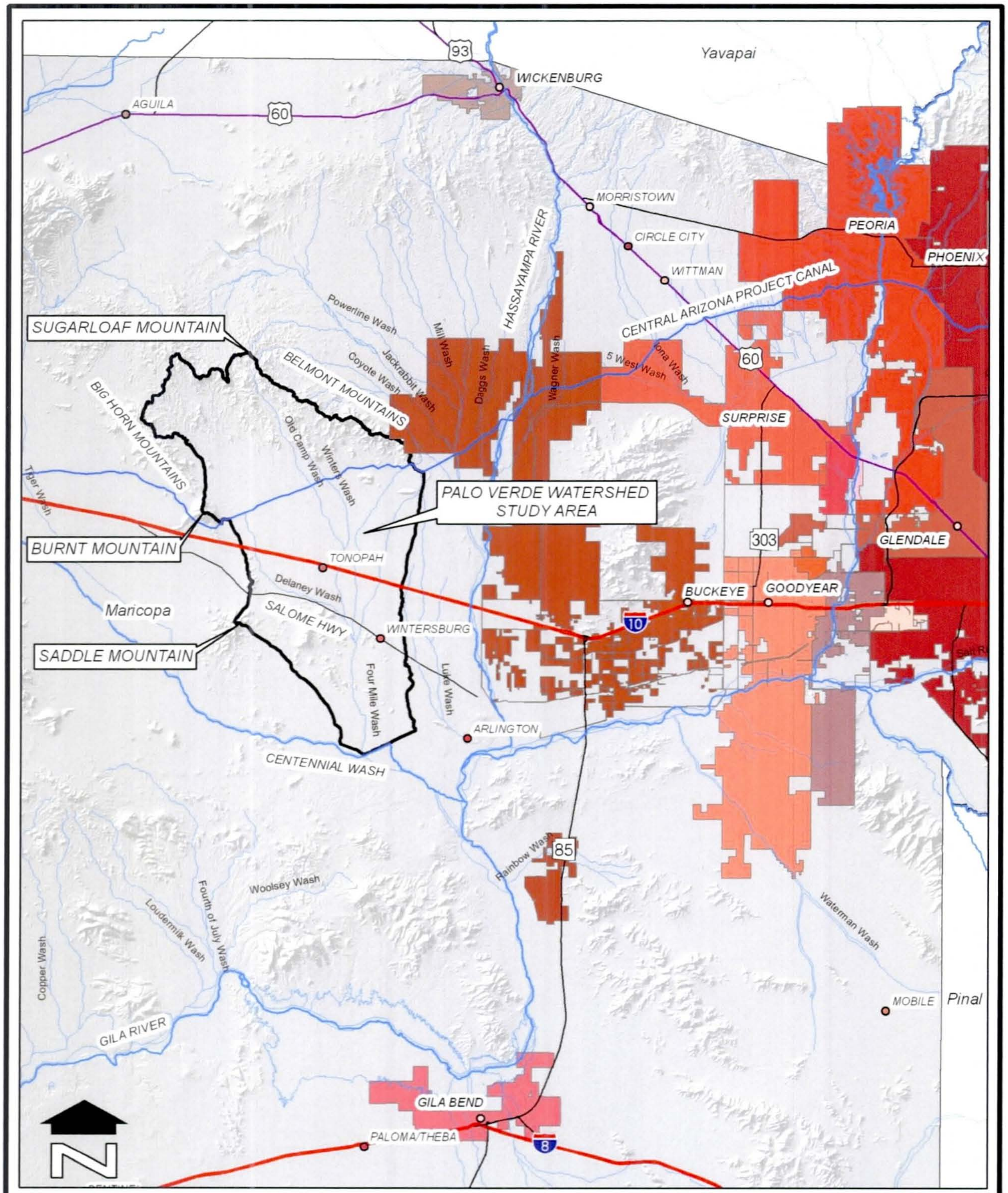
The majority of the watershed consists of undeveloped desert land; however, the study area includes active and retired agricultural fields, and the southeast portion contains the Palo Verde Nuclear Power Plant. The watershed is traversed east-west by three major features that impact the flow characteristic: the Central Arizona Project (CAP) Canal, Interstate 10, and Salome Highway. The CAP Canal has the greatest impact on the watershed in both the hydrologic results and the drainage characteristics of the watershed.

In general, all watercourses in the study area flow north to south with four primary washes within the watershed which, from west to east, are as follows: Delaney Wash, Old Camp Wash, Winter's Wash, and Fourmile Wash. The washes converge south of Salome Highway into Winters Wash before flowing into Centennial Wash at the southern end of the watershed. Centennial Wash is a tributary to the Gila River.

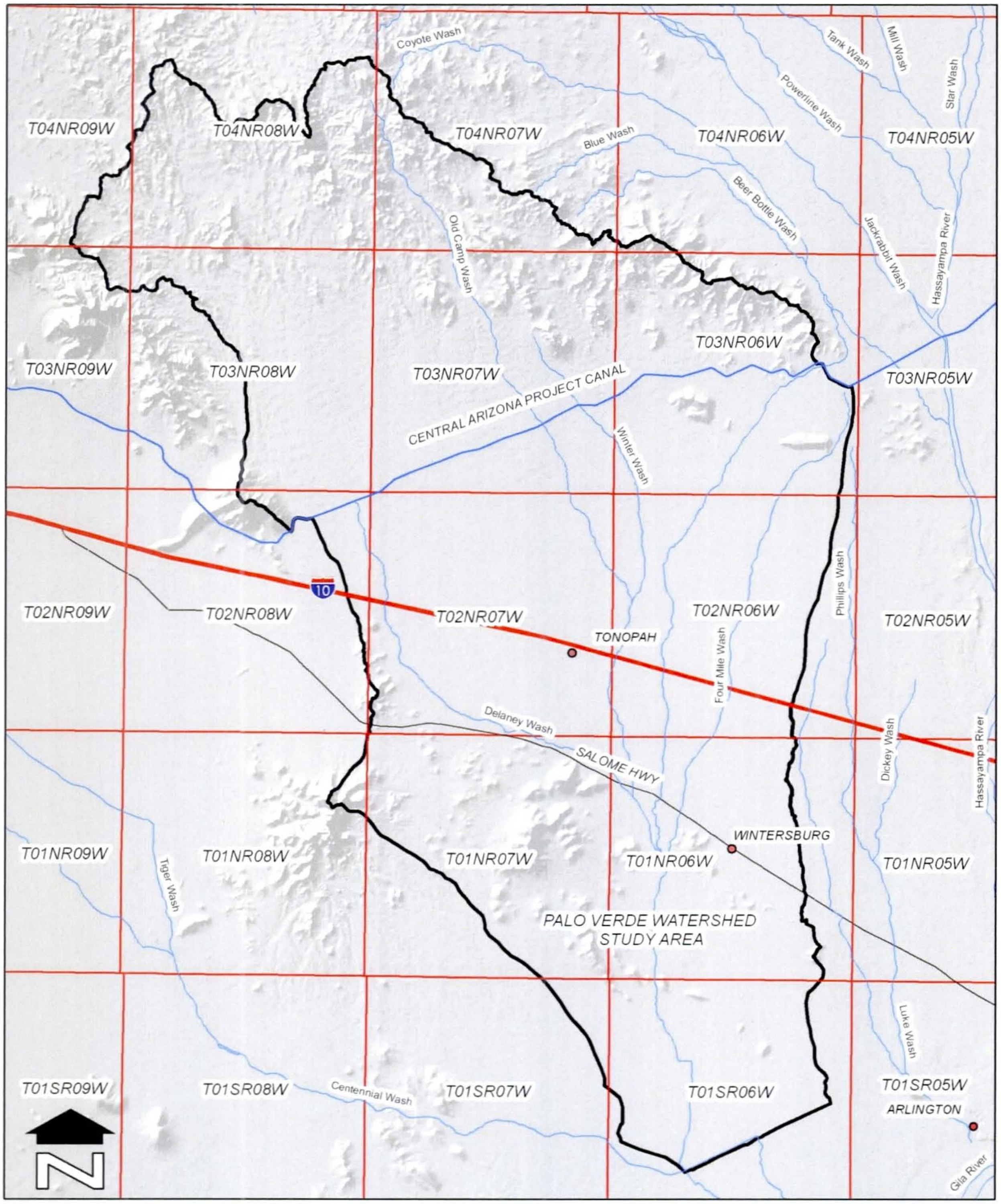
The watershed has been previously studied for the District under Contract FCD No. 2000C021 as the *Palo Verde Watershed Floodplain Delineation Study* **(Reference 1)** dated 2003 and consisting of nearly 400 miles of delineated Zone A floodplains. The Zone A floodplain delineation was based on peak discharge estimated using a regression equation and 10-foot contour interval mapping. For this new study, detailed watershed hydrology is prepared in support of detailed floodplain delineation using detailed, 2-foot contour interval mapping. The floodplains delineated under the previous contract have been issued a Best Available Data Letter (BADL) by FEMA on July 19, 2006. Since they reviewed the study as a Best Available Data, there is no LOMR case number or revised FIRM panels associated with this study. FEMA will incorporate the results of this study onto the next revisions of the FIRM panels. Figure 1-4, illustrates the FEMA flood zones in relation to the Palo Verde watershed.



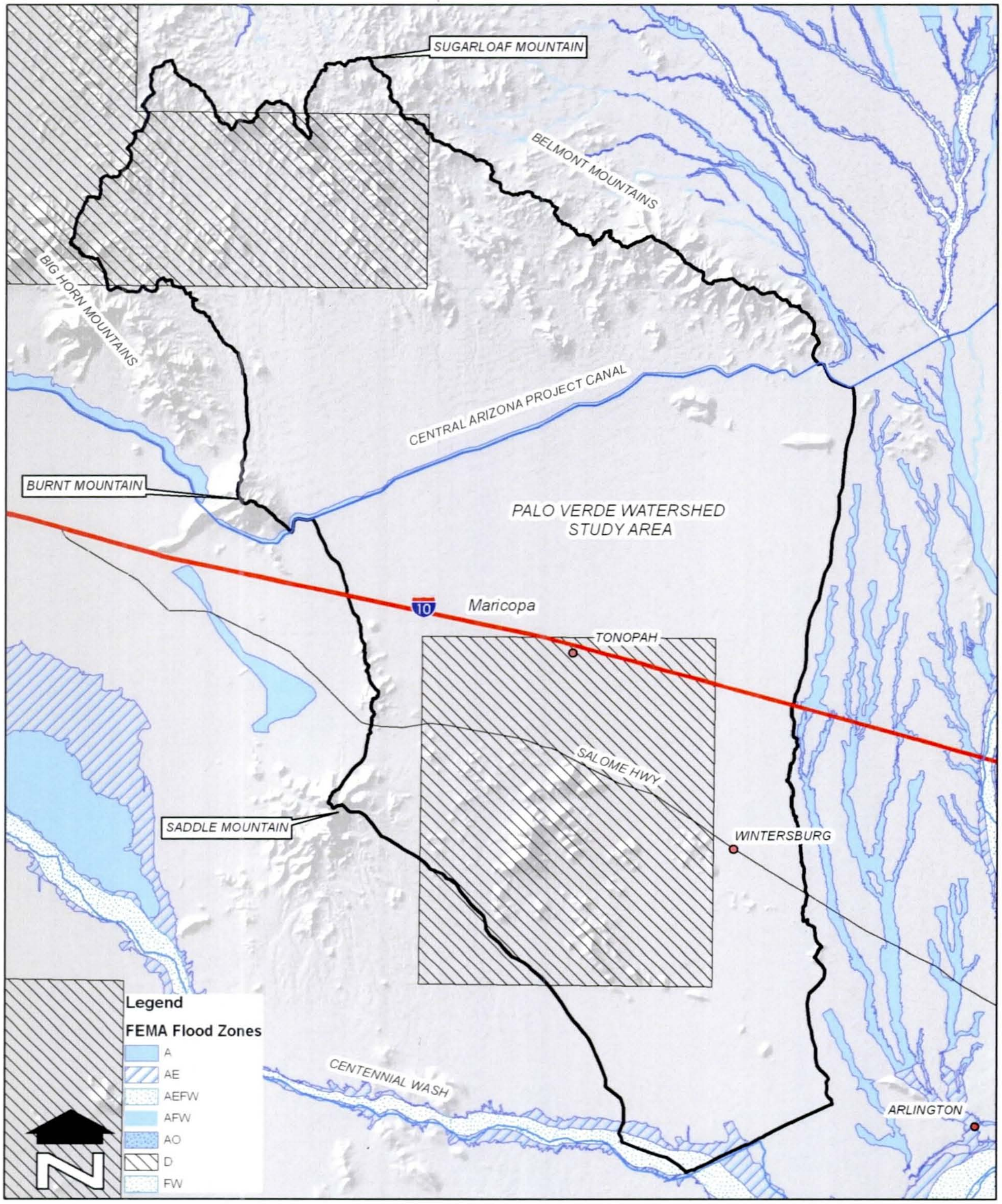
FLOOD CONTROL DISTRICT OF MARICOPA COUNTY		FIGURE 1-1 LOCATION MAP	PALO VERDE WATERSHED DETAILED FDS F.C.D. CONTRACT NO. 2008C046
DATE:	07-30-2010		Entellus IN ASSOCIATION WITH Stantec
SCALE:	NTS		
DRAWN BY:	NBL		



FLOOD CONTROL DISTRICT OF MARICOPA COUNTY		FIGURE 1-2 VICINITY MAP	PALO VERDE WATERSHED DETAILED FDS F.C.D. CONTRACT NO. 2008C046
DATE:	07-30-2010		Entellus IN ASSOCIATION WITH Stantec
SCALE:	NTS		
DRAWN BY:	NBL		



FLOOD CONTROL DISTRICT OF MARICOPA COUNTY		FIGURE 1-3 TOWNSHIP AND RANGE MAP	PALO VERDE WATERSHED DETAILED FDS F.C.D. CONTRACT NO. 2008C046
DATE:	07-30-2010		Entellus IN ASSOCIATION WITH Stantec
SCALE:	NTS		
DRAWN BY:	NBL		



FLOOD CONTROL DISTRICT OF MARICOPA COUNTY		FIGURE 1-4 EXISTING FEMA FLOOD ZONE MAP	PALO VERDE WATERSHED DETAILED FDS F.C.D. CONTRACT NO. 2008C046
DATE:	07-30-2010		Entellus IN ASSOCIATION WITH Stantec
SCALE:	NTS		
DRAWN BY:	NBL		

1.2 Hydrologic Methodology and Results

The hydrologic parameter analysis was performed using Drainage Design Management System for Windows (DDMSW) Version 4.1.9 (**Reference 2)** from the District. The DDMSW program utilizes the U.S. Army Corps of Engineers (COE) HEC-1 computer program Version 4.1, dated June 1998 (**Reference 3**) for the estimation of runoff magnitudes. The details of the hydrologic modeling methodology and the results are discussed in Section 4.

1.3 Hydraulic Methodology and Results

The hydraulic analysis of the study washes, including the floodplain delineation work maps, is included in a separate submittal.

1.4 Study Documentation Abstract

1. General Documentation Abstract		
1.1	Community	Unincorporated Maricopa County
1.2	Community Number	04013
1.3	County	Maricopa
1.4	State	Arizona
1.5	Date Study Accepted	
1.6	Study Contractor	Entellus, Inc.
1.6A	Contact	Hernan Aristizabal, P.E.
1.6B	Address	2255 North 44th Street Phoenix, AZ 85008
1.6C	Phone	602-244-2566 (ph) 602-244-8947 (fax)
1.6D	Subconsultants	Stantec Consulting Inc. (Hydrology) LTM Engineering, Inc. (Technical Review)
1.7	State Technical Reviewer	N/A
1.8	Local Technical Reviewer	Flood Control District of Maricopa County Jeff Shelton, P.E. 602-506-1501 (ph)
1.9	River/Stream Name	Tributaries of Centennial Wash
1.10	Reach Description	N/A
1.11	Study Type	Hydrology in support of Hydraulic analysis (Under Separate Cover) of the Palo Verde Watershed Floodplain Delineation Study

2. Mapping Information Abstract		
2.1	USGS Quad Sheets	Little Horn Peak
		Hummingbird Spring
		Belmont Mountain
		Star Well
		Burnt Mountain
		Hot Rock Mountain
		Flatiron Mountain
		Saddle Mountain
		Tonopah
		Wintersburg
		Gillespie
		Arlington
2.2	Mapping Source for Hydrologic Study	Countywide 10-foot contour intervals
		Palo Verde Mapping 2-foot contour intervals
		Luke Wash & Arlington Mapping 2-foot contour intervals
2.3	Scale	N/A
2.4	Date (respectively)	2000, 2007, 2005
2.5	Mapping Source for Hydraulic Study	N/A-See Hydraulic TDN to follow
2.6	Scale	N/A
2.7	Date	N/A

3. Hydrology Abstract		
3.1	Method and Model	Rainfall-Runoff DDMSW V4.1.9/HEC-1 V4.1 1998
3.2	Storm Duration	6- and 24-hour
3.3	Hydrograph Type	S-Graph
3.4	Frequencies Determined	100-year with two Levee Conditions
3.5	List of Gages used in Frequency Analysis or Calibration	None Used
3.6	Rainfall Amounts and Reference	100-Year 6-Hour: 3.168 100-Year 24-Hour: 3.967 NOAA Atlas 14
3.7	Unique Conditions and Problems	See Section 4 for details
3.8	Coordination of Q's	

See Hydraulic TDN to be submitted at a later date for the Hydraulics Abstract.

SECTION 2: ADWR/FEMA FORMS

The required ADWR/FEMA forms for the hydraulics and mapping portions of this study will be included in the Hydraulics TDN to be submitted at a later date. Forms for the hydrology portion of the submittal area provided on the following pages.

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

RIVERINE HYDROLOGY & HYDRAULICS FORM

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

PAPERWORK REDUCTION ACT

Flooding Source: Tributaries of the Palo Verde Watershed
Note: Fill out one form for each flooding source studied

A. HYDROLOGY

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

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

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

Location	Drainage Area (Sq. Mi.)	Effective/FIS (cfs)	Revised (cfs)
See TDN Section 4.5.2			

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

☐ Statistical Analysis of Gage Records   ☒ Precipitation/Runoff Model HEC-1 v4.1
☐ Regional Regression Equations   ☐ Other (please attach description)

Please enclose all relevant models in digital format, maps, computations (including computation of parameters) and documentation to support the new analysis.

4. Review/Approval of Analysis

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

5. Impacts of Sediment Transport on Hydrology

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

B. HYDRAULICS

1. Reach to be Revised

	Description	Cross Section	Water-Surface Elevations (ft.) Effective	Proposed/Revised
Downstream Limit				
Upstream Limit				

2. Hydraulic Method/Model Used

B. HYDRAULICS (CONTINUED)

3. Pre-Submittal Review of Hydraulic Models

DHS-FEMA has developed two review programs, CHECK-2 and CHECK-RAS, to aid in the review of HEC-2 and HEC-RAS hydraulic models, respectively. These review programs may help verify that the hydraulic estimates and assumptions in the model data are in accordance with NFIP requirements, and that the data are comparable with the assumptions and limitations of HEC-2/HEC-RAS. CHECK-2 and CHECK-RAS identify areas of potential error or concern. **These tools do not replace engineering judgment.** CHECK-2 and CHECK-RAS can be downloaded from http://www.fema.gov/plan/prevent/fhm/frm_soft.shtm. We recommend that you review your HEC-2 and HEC-RAS models with CHECK-2 and CHECK-RAS. Review of your submittal and resolution of valid modeling discrepancies may result in reduced review time.

4. Models Submitted

Models Submitted	Natural Run		Floodway Run		Datum
Duplicate Effective Model*	File Name:	Plan Name:	File Name:	Plan Name:	____
Corrected Effective Model*	File Name:	Plan Name:	File Name:	Plan Name:	____
Existing or Pre-Project Conditions Model	File Name:	Plan Name:	File Name:	Plan Name:	____
Revised or Post-Project Conditions Model	File Name:	Plan Name:	File Name:	Plan Name:	____
Other - (attach description)	File Name:	Plan Name:	File Name:	Plan Name:	____

* For details, refer to the corresponding section of the instructions.

☐ Digital Models Submitted? (Required)

C. MAPPING REQUIREMENTS

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

☐ Digital Mapping (GIS/CADD) Data Submitted

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

☐ Annotated FIRM and/or FBFM (Required)

D. COMMON REGULATORY REQUIREMENTS*

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

   a. For CLOMR requests, if either of the following is true, please submit **evidence of compliance with Section 65.12 of the NFIP regulations**:
      - The proposed project encroaches upon a regulatory floodway and would result in increases above 0.00 foot.
      - The proposed project encroaches upon a SFHA with or without BFEs established and would result in increases above 1.00 foot.

   b. For LOMR requests, does this request require property owner notification and acceptance of BFE increases? ☐ Yes ☐ No
      If Yes, please attach **proof of property owner notification and acceptance (if available)**. Elements of and examples of property owner notification can be found in the MT-2 Form 2 Instructions.

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

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

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

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

4. For LOMR/CLOMR requests, does this request have the potential to impact an endangered species? ☐ Yes ☐ No

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

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

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

SECTION 3: MAPPING AND SURVEY INFORMATION

The mapping data for this project was provided by the District. No additional survey or mapping work was performed for the hydrologic analysis. The information, including DTM data, provided by the District, was from the following sources; see Figure 3-1 for the coverage areas of each source:

1. **Palo Verde Mapping**

   Contract: FCD 06-28

   Contour Interval: 2-foot

   Date: 06/2007

   Vertical Datum: NAVD 88

   Horizontal Projection: State plane, Zone 3176 Units International Feet, GRS, 1980, NAD 83.

2. **Luke Wash & Arlington Mapping**

   Contract: FCD 04-48

   Contour Interval: 2-foot

   Date: 09/2005

   Vertical Datum: NAVD 88

   Horizontal Projection: State plane, Zone 3176 Units International Feet, GRS, 1980, NAD 83.

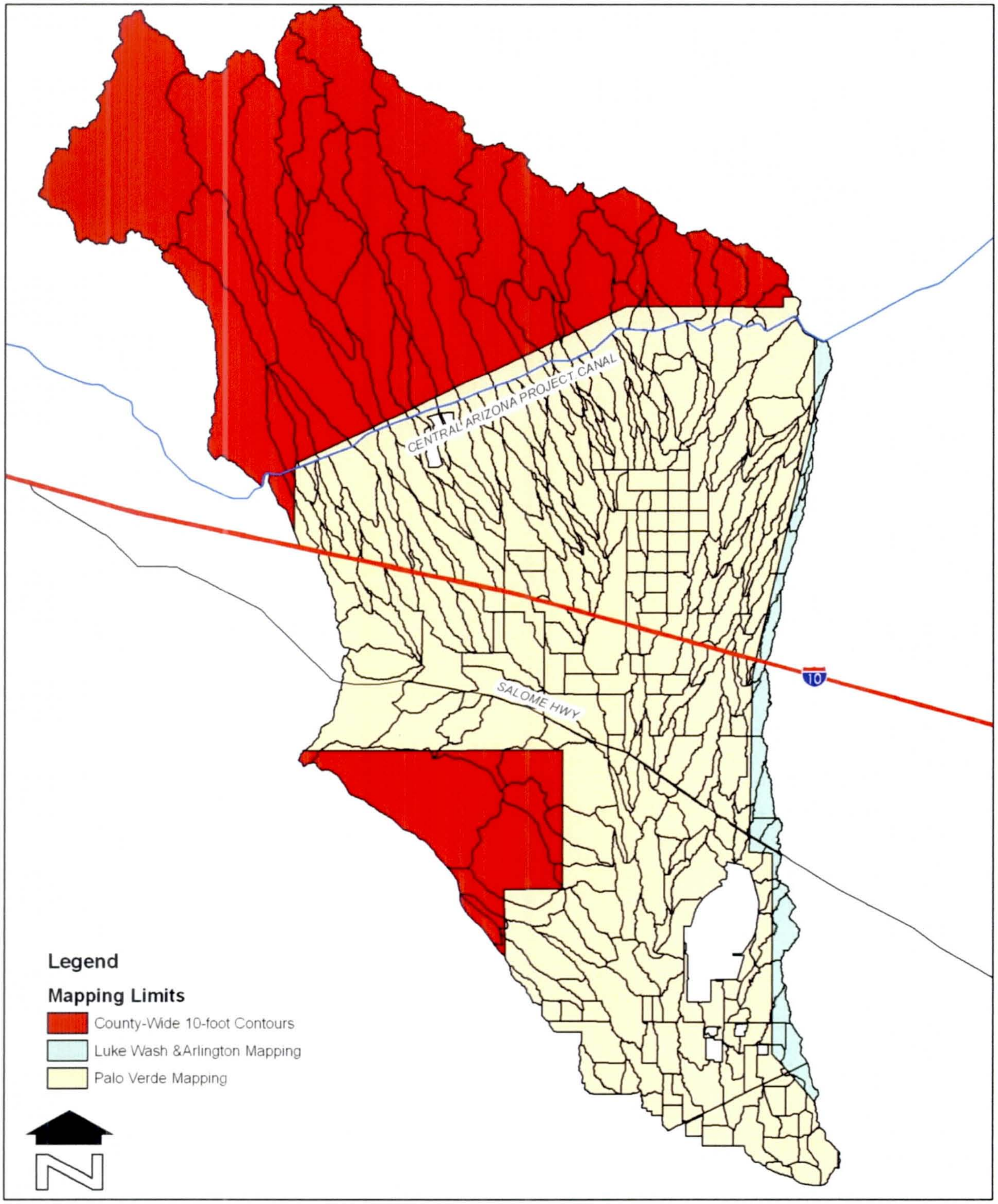
3. **Countywide 10-Foot Contours**

   Contour Interval: 10-foot

   Date: 12/2000

   Vertical Datum: NAVD 88

   Horizontal Projection: NAD 83, Arizona Coordinate System, Central Zone, 1992, Epoch



FLOOD CONTROL DISTRICT OF MARICOPA COUNTY		**FIGURE 3-1 MAPPING AREA LIMITS**	PALO VERDE WATERSHED DETAILED FDS F.C.D. CONTRACT NO. 2008C046
DATE:	07-30-2010		Entellus IN ASSOCIATION WITH Stantec
SCALE:	NTS		
DRAWN BY:	NBL		

SECTION 4: HYDROLOGY

The purpose of the hydrologic analysis is to determine the peak discharges for the 100-year recurrence interval storm at key locations throughout the watershed for floodplain delineations. In general those key locations are:

1. Major wash confluences and major culvert crossings of existing facilities such as I-10.
2. Beginning, ending, and intermediate points of washes designated for floodplain delineations.

Once obtained, the computed peak discharges are then used in the hydraulic analysis conducted for this study. The results of this analysis will then be used in the establishment of FEMA floodplain boundaries and zone designations.

4.1 Method Description

Watershed modeling is performed using the methodologies set forth in the *Drainage Design Manual for Maricopa County, Volume 1, Hydrology* (Flood Control District of Maricopa County, 2009), (Reference 4) which is herein referred to as the Design Manual. The analytical method employed for this study is the rainfall-runoff method of modeling, which was accomplished using the Drainage Design Management System for Windows (DDMSW) Version 4.1.9 from the District. The DDMSW program utilizes the COE's HEC-1 computer program Version 4.1, dated June 1998. Both the 100-year, 6- and 24-hour duration storm events are modeled for this watershed under two separate conditions, the "With Levee" and the "Without Levee" scenarios. The "With Levee" condition accounts for the effects of structures such as the CAP Canal, I-10, Palo Verde Power Plant, and Salome Highway. The "Without Levee" condition does not account for the effects of those structures. Two storm durations and levee conditions were used to determine which storm and levee condition results in the higher magnitude of discharge at the various locations throughout the watershed. Since there are two conditions for the study, there are two separate logic diagrams, one for each condition. The logic diagrams, With Levee and Without Levee, are located in Appendix D, and each condition is broken into separate portions for the north area and the south area.

The rainfall-depth-duration-frequency statistics for both the 6- and 24-hour storm durations are obtained from NOAA Atlas 14, Arizona. The rainfall distributions used are the SCS Type II for the 24-hour storm and the set of patterns for the 6-hour storm as suggested in the Design Manual. The unit hydrographs are derived from S-graphs using the methodology as explained in the Design Manual. The rainfall losses were estimated using the Green and Ampt infiltration equation. Runoff hydrographs are routed through the watershed using Normal Depth channel storage routing. Flow splits within the watershed are modeled as diversions and retrievals, and the rating curves for the diversions are based upon normal depth hydraulic calculations. Storage routings use stage-storage-discharge relationships using the Modified Puls method within HEC-1. Due to the size and complexity of the watershed, the input parameters and the model output are provided in Appendix D. There are 401 subbasins and 358 concentration points for the "With Levee" condition model and 402 subbasins and 338 concentration points for the "Without Levee" condition.

It should be noted that several key assumptions were made prior to the beginning of this study. The assumptions are discussed in more detail in the appropriate subsequent sections, but are as follows:

1. The subbasins north of the CAP Canal (see Figure 1-2 Vicinity Map for the canal location) are not delineated and sized to same level of detail as the subbasins south of the CAP Canal.
2. Flow split diversions are, in general, modeled so that the right branch is the main stem and the left branch is diverted for later retrieval.
3. The contributing area summation for the hydrograph combines at each concentration point includes the full area upstream of each split, regardless of the discharge ratio at the split.

4.2 Parameter Estimation

Arcview GIS Version 9.3 in conjunction with ArcHydro was used to determine many of the raw, physical data for the watershed such as basin boundaries and flow path lengths. The DDMSW modeling software imports shapefiles of the physical data and associated data created in GIS for use in constructing the hydrologic model. The following sections describe the estimation of each parameter in more detail.

4.2.1 Drainage area boundaries

The watershed study area encompasses approximately 277 square miles and consists of mostly undeveloped open desert land; it is complex with many flows splits throughout the watershed. There are areas of active and retired agricultural fields, and the southeast portion contains the Palo Verde Nuclear Power Plant. The watershed is traversed east-west by three major features that impact the subbasin delineation, the Central Arizona Project (CAP) Canal, Interstate 10, and Salome Highway. The watershed can be described as consisting of two distinct regions, the portions north and south of the CAP Canal.

The subbasins located within the portion of the watershed north of the CAP Canal, herein referred to as the north study area, were delineated using Arcview GIS and are based primarily on the 10-foot contour interval mapping. The subbasins in this region are primarily larger than those delineated in the portion south of the CAP Canal and range in size from 0.02 to 13.05 square miles, with the smaller subbasins being the result of the CAP Canal traversing the watershed. The terrain in the north portion is mostly rugged and mountainous with elevations ranging from 2,910 feet to 1,360 feet. The north basins are larger primarily due to the fact that there are no study reaches for floodplain delineation within the area. In addition, the land is owned by the Bureau of Land Management (BLM) and is not likely to be developed in the near future. As a result, the area was not subdivided in as much detail as that south of the CAP Canal.

The subbasins located south of the CAP Canal, herein referred to as the south study area, were delineated within Arcview GIS, with most of the area delineated using 2-foot contour interval mapping. A portion of the mountainous area on the western edge is covered under the 10-foot contours of the same source as the subbasins north of the CAP. See the Mapping Area Limits Map, Figure 3-1, in Section 3.0 for the coverage areas and mapping information.

The subbasins south of the CAP Canal are generally smaller than the basins north of the canal due to the complex, distributive nature and the need for appropriate definition of the watershed for floodplain delineation purposes. In order to obtain the peak discharges necessary for detailed floodplain mapping, the subbasins were delineated such that the peak flows can be computed at the major flow splits that would affect the hydraulics. The basin sizes in the south portion range from 0.07 to 7.58 square miles. The larger basins are located in the western portion where the terrain is more mountainous and steep. The remaining terrain is primarily flat open desert/rangeland with active and retired agricultural and industrial areas scattered throughout the watershed.

Several areas were identified as non-contributing areas within the south portion of the watershed, including portions of the Palo Verde Nuclear Power Plant and nearby cooling ponds. The Palo Verde Power Plant is a unique area that affects both the "With" and "Without" Levee conditions. See Section 4.2.6 Levee Conditions for more detail. A group of recharge basins just south of the CAP Canal and east of subbasin 180D are also designated as non-contributing. The non-contributing areas are labeled on the watershed maps located in Appendix D.

There is a drainage area northeast of the Palo Verde Watershed that contributes flow through a CAP Canal overchute at the extreme northeast corner of the south study area. The drainage area is for Coyote Wash and is part of the Jackrabbit Wash Floodplain Delineation Study (FCDMC project FCD 90-05) dated 1991(Reference 5); the area is 35.99 square miles in size. A portion of the runoff generated from this area is stored upstream against the CAP Canal before flowing into the Palo Verde watershed through the overchute. The inflow hydrograph to the storage route is C47I, and the outflow hydrograph from the storage route is C47O. The flow was captured in the hydrologic model by using an inflow hydrograph produced from the Jackrabbit Wash Floodplain Delineation Study data using the 6- and 24-hour storm duration models for each respective model. It is noted that the Jackrabbit Wash study was based on NOAA Atlas 2 precipitation data.

The naming convention adopted for the entire watershed is based upon the impacts of the Cap Canal and I-10. A series of storage areas and canal overchutes on the CAP Canal allow flows to cross the canal when runoff exceeds the storage capacity upstream. The westernmost storage area is identified by 100-series labels for all basins that generate and route flow to and from the storage area. Moving east, the next major storage area is identified by 200-series labels and so on up to the 700-series labels at the easternmost edge of the watershed. As runoff crosses I-10, the flow that is not conveyed through the I-10 culverts splits to the east, supporting the west-to-east basin naming convention. See the watershed maps and/or the HEC-1 logic diagram for the associated subbasin names and watershed routing logic. The subbasins are labeled beginning with "S" followed by a numeric label.

4.2.2 Watershed Work Maps and Parameter Estimation

4.2.2.1 Subbasin boundaries and concentration points

The subbasin boundaries, as described above, were delineated using ArcHydro within Arcview GIS using DTM data from the mapping sources identified in Section 3. The north study area was completed 10-foot contour interval mapping. Because the 10-foot contour DTM data had low resolution, 2008 aerials provided by the District were used as a guide to make final adjustments to the subbasin delineations. The use of the aerials also accounted for any changes that might have occurred in the north study area between the date of the topographic data, circa 2000, and the date of the aerials. The subbasin areas were determined from the shapefile created within GIS.

The south study area was completed using DTM data mostly from 2-foot contour interval mapping. The subbasin boundary shapefile was reviewed for accuracy, and the subbasins were adjusted for modeling purposes.

Subbasin concentration points were placed when two or more drainage areas combine; the points are labeled with an identifier beginning with a "C" to designate the combine, followed by a 4-character basin name. Subbasins that do not have a routing path through them were not assigned a concentration point since no hydrograph combine will take place at that specific point. In areas where multiple basins combine at the same point, more than one concentration point is necessary to obtain accurate peak discharges for floodplain delineation. These locations typically have a concentration point with an "L" or "R" after a typical label name. The "L" or "R" indicates that the contributing area is from the left or right, looking downstream, prior to combining with the remaining concentration point(s) and being routed.

Concentration points that combine drainage areas from an upstream flow split required hard coding the contributing areas into the model logic. This was done to prevent the model from losing track of area from the diversion and retrieval process. As HEC-1 retrieves a hydrograph into the model, the area associated with that hydrograph is lost and needs to be added back into the model at the combine. The method applied to the model logic to add the area back in to the model was to assume that the full area upstream of a split stays with each hydrograph routed down each branch of the wash from the split. Although this temporarily creates some large areas, ultimately the area is rectified toward the downstream end of the watershed where flow splits ultimately join together again.

4.2.2.2 Time of Concentration

The paths of the time of concentration (TC) lines were established by ArcHydro within GIS. The TC paths were reviewed for accuracy and in some areas adjusted for hydrologic modeling purposes. The LCA paths were created by using the TC lines and truncated at the point nearest to perpendicular with the subbasin centroids. The upstream and downstream elevations for the TC and LCA lines were taken from the contour data provided by the FCDMC, the lengths of each line was calculated by GIS. The TC and LCA shapefiles containing the elevations and length of each line was imported in DDMSW and the LAG time was computed by the program following the procedures outlined in the Design Manual equation 5.11. The Kn parameter used in the LAG equation is discussed as part of the land use discussion in Section 4.2.2.6.

4.2.2.3 Hydrograph routing paths

The routing of subbasin hydrographs is performed using the normal depth option of the Modified Puls channel storage method of HEC-1. The reach routing paths, shown on the Watershed Maps, were established by ArcHydro and the lengths of each reach calculated by GIS. The route paths were reviewed for accuracy and in some areas adjusted for hydrologic modeling purposes. The upstream and downstream elevations used to obtain the channel slope were taken from the supplied contour data.

The reach route labels have and identifier beginning with "R" to designate a route followed by the identifier of the concentration point the route is from. For example, R100C is the reach routing from concentration point C100C. In the instance there is no upstream concentration point then the route is labeled based upon the upstream subbasin identifier. For example, R105 is the reach route from subbasin S105. In the instance of a flow split, the reach label changes to add on an "L" or "R" identifier to indicate the direction of the reach whether it is going left or right. There are several cases within the watershed where there is a 3-way flow split. In addition to the "L" and "R" a reach with an "M" is added to indicate that it is the middle reach route.

Cross-Section Geometry

With the exception of the agricultural fields, the representative cross-section geometry for each reach was obtained by sampling a cross-section of the DTM data in a location that is typical of the reach. The supplied mapping data and aerial photography was used to verify the locations of the cross section placement and the provided DTM data was utilized to sample the cross-sections for the reach routes. An 8-point cross-section was derived and overlaid on the sampled cross-section for each reach.

The 8-point cross-sections in the agricultural areas were based upon typical farm field geometry. Cross-sections were not sampled within the farm fields due to the little topographic relief over the area. Instead, an idealized cross-section is used to simulate the wide, slow-moving, shallow sheet flow that is typical of agricultural areas. The typical geometry for the agricultural reaches has a 500-foot bottom width and is 2.0-feet deep with steep side slopes (2H:1V) for the first foot of depth and a flatter slope (25H:1V) for the second foot of depth.

Manning's n Estimates

The normal depth option of the Modified Puls channel storage option requires a Manning's 'n'-value estimate of each reach routing for left and right overbanks as well as the channel. The estimates for the reaches were based upon field reconnaissance and aerial photography. The field reconnaissance estimates of several washes were compared against their appearance on the aerial photography for topographic changes and vegetation density. The comparison was applied to the remaining washes based upon the aerial photography for vegetation density and topographic data. Manning's n-value estimates range from 0.068 to 0.03 for the overbanks and 0.03 to 0.10 for the channel. Channels that have lower roughness coefficients such as 0.03 are typically channelized routes that are cleared of vegetation. These routes include the agricultural drain located along the western edge of the active agricultural fields. The typical section used for the routes through fields as described previously have a higher n-value, 0.10, to account for the irregularity of the tilled ground as well as the dense vegetation. Finally, the natural washes were assigned values ranging from 0.04 to 0.05 for the overbanks and 0.035 to 0.045 for the channel. If the aerial photography showed that certain reaches had thicker vegetation or a higher degree of irregularity, then the n-value was adjusted accordingly.

Number of Steps (NSTPS)

NSTPS is a numerical parameter of the Modified Puls methodology. This parameter represents the travel time of the floodwave through the reach. In general, the NSTPS for each reach was calculated and optimized by DDMSW. The program will run the HEC-1 model three times to obtain the NSTPS convergence. The model was reviewed for reaches that could not converge on a specific NSTPS value, as well as any instability. When necessary, the NSTPS were adjusted manually to remove modeling warnings and instabilities that led to routed discharges being higher than the peak inflow. A discussion on the procedure to choose the manual NSTPS value as well as the reaches with manually entered NSTPS is provided in Section 4.3.1, Special Problems and Solutions.

Reach Routing Results

The reach routing data is included in Appendix D. There are more than 400 reaches within the watershed model. The routing data include the 8-point and sampled cross-sections, the stage-storage-discharge rating curve computed by HEC-1, and the physical parameters. The data is compiled for both the 100-year 6-hour and 24-hour duration models for both levee conditions.

4.2.2.4 Diversions/Flow Splits

In this complex watershed, there are many flow splits, whether natural or at structures, which were modeled in HEC-1 as diversions and retrievals. The flow splits at structures such as I-10 and Salome Highway occur as some runoff continues its path through cross-drainage structures and the remainder flows along the upstream side of the embankments to the next downstream structure. The rating curves of the flow splits are based upon a normal depth flow hydraulic analysis to determine the percentage of the total flow that splits in each direction.

The hydraulic analysis, performed by Entellus, is based upon cross-sections located at the split and their hydraulic capacity at various flow rates. The splits were analyzed using Manning's equation. The cross-sections and channel slopes were determined from the mapping information provided by the District. Due to the distributive nature of the watercourses and general nature of the terrain in the watershed, some of the cross sections describing the split flow area could not contain the anticipated flow used in the calculations. In those instances, the end points of the cross sections were extended at the existing slope to contain the flow. In locations where there are structures, such as I-10 and Salome Highway, culvert nomographs developed by the Federal Highway Administration (FHWA) were utilized to determine the cross-drainage structure rating curves.

The agricultural area has multiple splits resulting from farming activities. The splits are created by small irrigation canals, berms, and roadways built by farmers to control the watering of their fields. These structures can change with time depending on the types of crops planted and the watering needs. Also, the effectiveness of some of the structures is uncertain as they typically are not built to engineering standards. Entellus used engineering judgment to evaluate the flow splits in these areas.

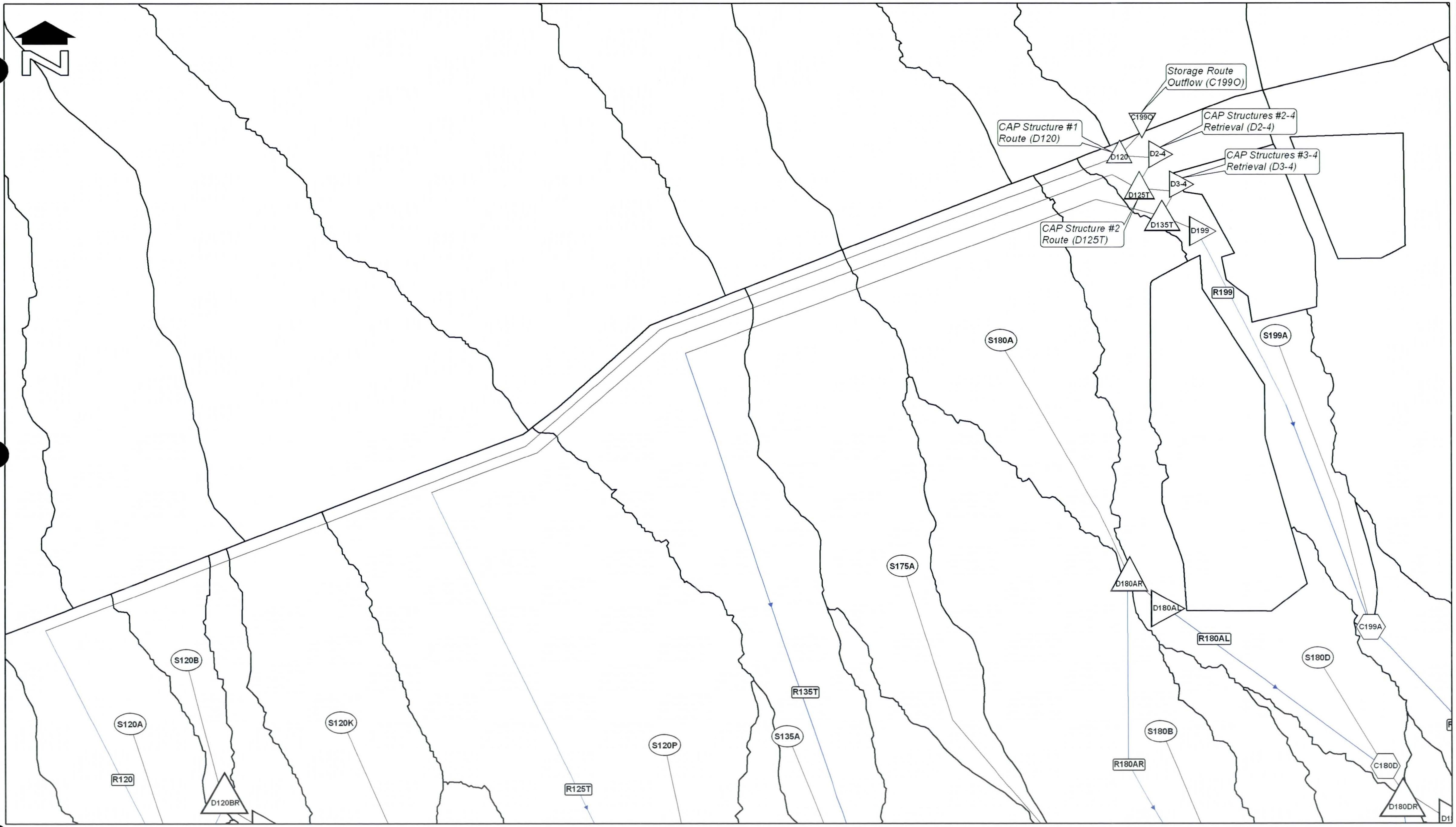
Once the rating curves were developed for the splits, a series of 10 data points were selected from the total rating table for input to DDMSW. The 10 data points were picked to best represent the rating curve shape. The diversion data rating curves, including printouts of the hydraulic analysis, are provided in Appendix D.

The diversions/retrievals are labeled in the same manner as the reach routes with the exception of a "D" in place of the "R" in order to designate a diversion. In general, diversions are modeled so that the right split is the main flow path that is routed and the left split is diverted for later retrieval. Exceptions are as follows: D100A, D100B, D120E, D820G, D920V, and D920W.

Diversions D100B and D120E were reversed so that the left split is routed and the right split is diverted for later retrieval. This was done so that the number of hydrographs in the queue did not exceed HEC-1's limitations. Diversions D100A, D820G, D920V, and D920W are reversed since the right flow split leaves the watershed and does not return.

In the case of a 3-way split, the right flow split "R" is routed and the first diversion for later retrieval is the combination of the middle and left split flows "M-L". Once the middle and left flows are retrieved and brought back into the model, another diversion immediately follows the retrieval to route the middle flow "M" and divert the left flow "L" for later retrieval.

There are a series of diversions and retrievals at the CAP canal overchutes that operate in the same manner as the 3-way splits. The retrieval labels are named after the CAP structures they will retrieve. For example, at C199O a single hydrograph from the storage outflow is split. D120 will route the flow through R120 based upon the CAP Structure #1 stage discharge relationship, and D2-4 is the remaining flow for structures 2, 3, and 4 to be diverted and later retrieved. Once D2-4 is retrieved, another diversion immediately follows to route flow through R125T based upon the CAP Structure #2 stage-discharge relationship, and D3-4 is now the remaining flow for structures 3 and 4. The process is repeated until it achieves a single split. Figure 4-1 illustrates the portion of the logic diagram for the C1990 pond diversion/retrieval process described in this example.



FLOOD CONTROL DISTRICT OF MARICOPA COUNTY	
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FIGURE 4-1
CAP CANAL OVERCHUTE DIVERSION/RETRIEVAL EXHIBIT

PALO VERDE WATERSHED DETAILED FDS
F.C.D. CONTRACT NO. 2008C046

Entellus IN ASSOCIATION WITH Stantec

4.2.2.5 Reservoir Route Parameters

The CAP Canal traverses the watershed and allows ponding against the northern side of the canal. There are nine separate storage pools upstream of the CAP Canal within the study area. Each storage pool is drained by a single overchute or series of overchutes. Simulation of the hydrologic routing at the storage areas was accomplished using the Modified Puls method of HEC-1. Input for this method is a stage-storage-discharge relationship. The stage-storage relationship for each storage pool was estimated using elevation data of the 2-foot contour data and the volume was calculated using the conic method. The discharge was estimated using an inlet control nomograph to develop the stage-discharge relationship. The storage ponds relative to their respective outlet overchute structures are summarized in Table 4-1.

For storage ponds that outlet through multiple overchutes, the modeling was accomplished by combining the drainage areas that contribute to the specific storage area and routing the combined inflow hydrograph with a combined stage-storage-discharge relationship of all of the individual overchutes. The routed outflow hydrograph was then diverted through each individual overchute which has its own stage-discharge relationship. This is accomplished by a series of diversions and retrievals as described in the Diversions and Flow Splits discussion in Section 4.2.2.3. Figure 4-1 illustrates the logic of the diversion and retrieval process used to route the runoff across the CAP canal. Table 4-1 summarizes the relation of the overchutes associated with the storage ponds.

Table 4-1

Storage Route Summary

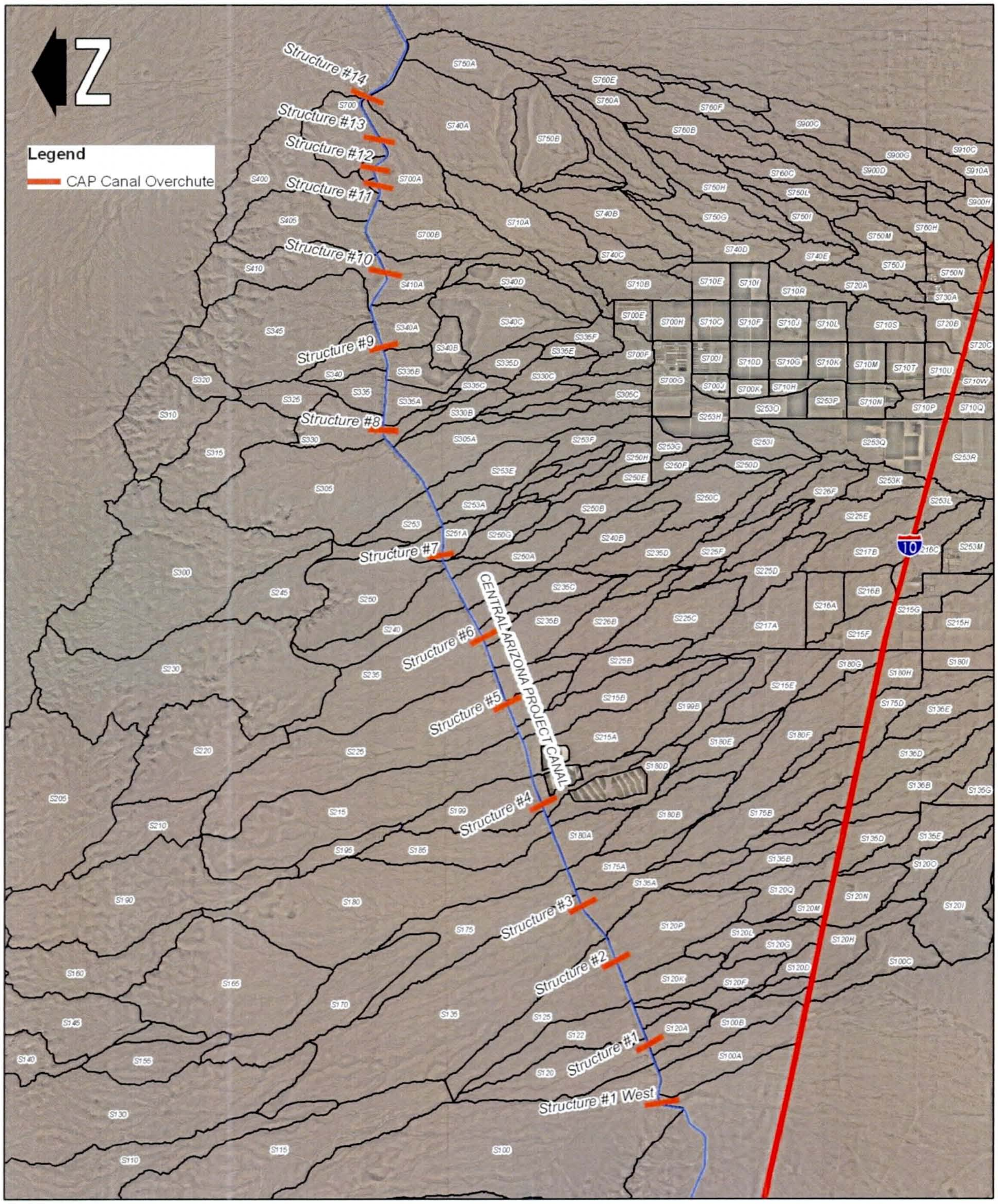
Storage Name	CAP Canal Ovechutes	Downstream Reach Route Respective to CAP Structure
C100O	1-West	N/A
C199O	1, 2, 3, & 4	R120, R125T, R135T, & R199
C253OS	5, 6, & 7	R225T, R235T, & R251T
C345O	8 & 9	R330T & R340
C410O	10	R410O
C500O	11	R500O
C600O	12	R600O
C700O	13	R700O
C47O	14	R47O

The runoff from storage route C100O through structure 1-West leaves the watershed and does not return. The flow from storage route C47O was obtained directly from the 1991 Jackrabbit Wash Floodplain Delineation Study prepared by others under FCDMC Contract number FCD 90-05. The flow was inserted into the model by the use of an inflow hydrograph. The C47O hydrograph accounts for storage on the upstream side of the canal before entering the Palo Verde Watershed via CAP Structure #14. Table 4-2 provides the dimensions and elevations for the overchutes, and Figure 4-2 shows the locations of each.

Table 4-2

CAP Canal Overchute Summary

CAP Structure	Type	Dimension	Invert Elevation feet	Berm Elevation Feet
1 West	Pipe	1 - 72-inch	1383.78	1400.00
1	Pipe	1 - 72-inch	1383.30	1398.00
2	Pipe	1 - 72-inch	1382.96	1398.00
3	Pipe	1 - 72-inch	1383.03	1398.00
4	Pipe	1 - 72-inch	1381.79	1398.00
5	Pipe	1 - 72-inch	1381.37	1396.00
6	Pipe	1 - 72-inch	1380.91	1396.00
7	Pipe	1 - 72-inch	1380.40	1396.00
8	Pipe	1 - 72-inch	1383.03	1396.00
9	Pipe	1 - 72-inch	1383.11	1396.00
10	Box	2 - 8-ft x 8-ft	1345.89	1378.00
11	Pipe	1 - 30-inch	1358.47	1378.00
12	Pipe	1 - 30-inch	1359.24	1378.00
13	Pipe	2 - 48-inch	1355.58	1378.00
14	Open Channel	68-ft(w) x 7-ft(h)	1379.30	1388.00



FLOOD CONTROL DISTRICT OF MARICOPA COUNTY		FIGURE 4-2 CAP CANAL OVERCHUTE LOCATION MAP	PALO VERDE WATERSHED DETAILED FDS F.C.D. CONTRACT NO. 2008C046
DATE:	07-30-2010		Entellus IN ASSOCIATION WITH Stantec
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4.2.2.6 Soils boundaries

Soil properties and texture classifications were used to estimate the bare ground XKSAT variable of the Green and Ampt method. Typically, soils information and studies also identify the presence of rock outcrop and often provide percentage estimates as part of the study. Due to the numerous soil types in the study area, the data is not tabulated in the text of the report but is summarized for each subbasin in Appendix D. There are 113 different soil classifications in the watershed, ranging from various loams to clay and rock outcrop. The XKSAT value for these soil classes ranges from 1.20 to 0.0 inches per hour respectively.

The soils data for this study was provided by the District adapted from information published by the Natural Resources Conservation Service (NRCS). Two soil surveys cover the watershed:

1. Aguila-Carefree Area, Arizona, Parts of Maricopa and Pinal Counties (AZ645)

2. Maricopa County, Arizona, Central Part (AZ651)

The northern roughly one-third of the watershed falls within the Aguila-Carefree Area survey, whereas the remaining area falls within the Maricopa County survey. The NRCS soil survey information for both studies is in shapefile format and provides digital mapped soils boundary with the soil type and map unit identification.

The soils shapefile was imported into DDMSW where the soils defaults database contains the XKSAT and rock outcrop percentages for individual soil map units. The total XKSAT and rock outcrop percentages were then weighted for each subbasin, depending on the composite soil makeup. The Soils Overview Exhibit located in Appendix D displays the soils data with the subbasin boundaries. The data disc located in Appendix E contains exhibits that have the same data; however, the sheets are more detailed instead of a single large overview exhibit The CD also includes the DDMSW files for each model.

The rock outcrop percentages listed in the default soils data table in DDMSW were taken directly from the NRCS soil surveys. Depending on the subbasin delineation relative to soil map units with rock outcrop, the rock outcrop values may not be appropriate for rainfall-runoff modeling. A key assumption in rainfall-runoff modeling is that impervious area is hydraulically connected to the point of interest. Soil map units with rock outcrop were therefore reviewed with regard to the subbasin delineation to estimate an effective contribution from a hydrologic perspective. The method used to determine the effective, hydraulically connected impervious area associated with the naturally occurring rock outcrop is based upon two factors.

1. The percent area of soil map units (within a subbasin) that have rock outcrop as an identified component.
2. The location of the soil map units containing rock outcrop with respect to the subbasin outlet.

The process for assigning effective contribution is as follows:

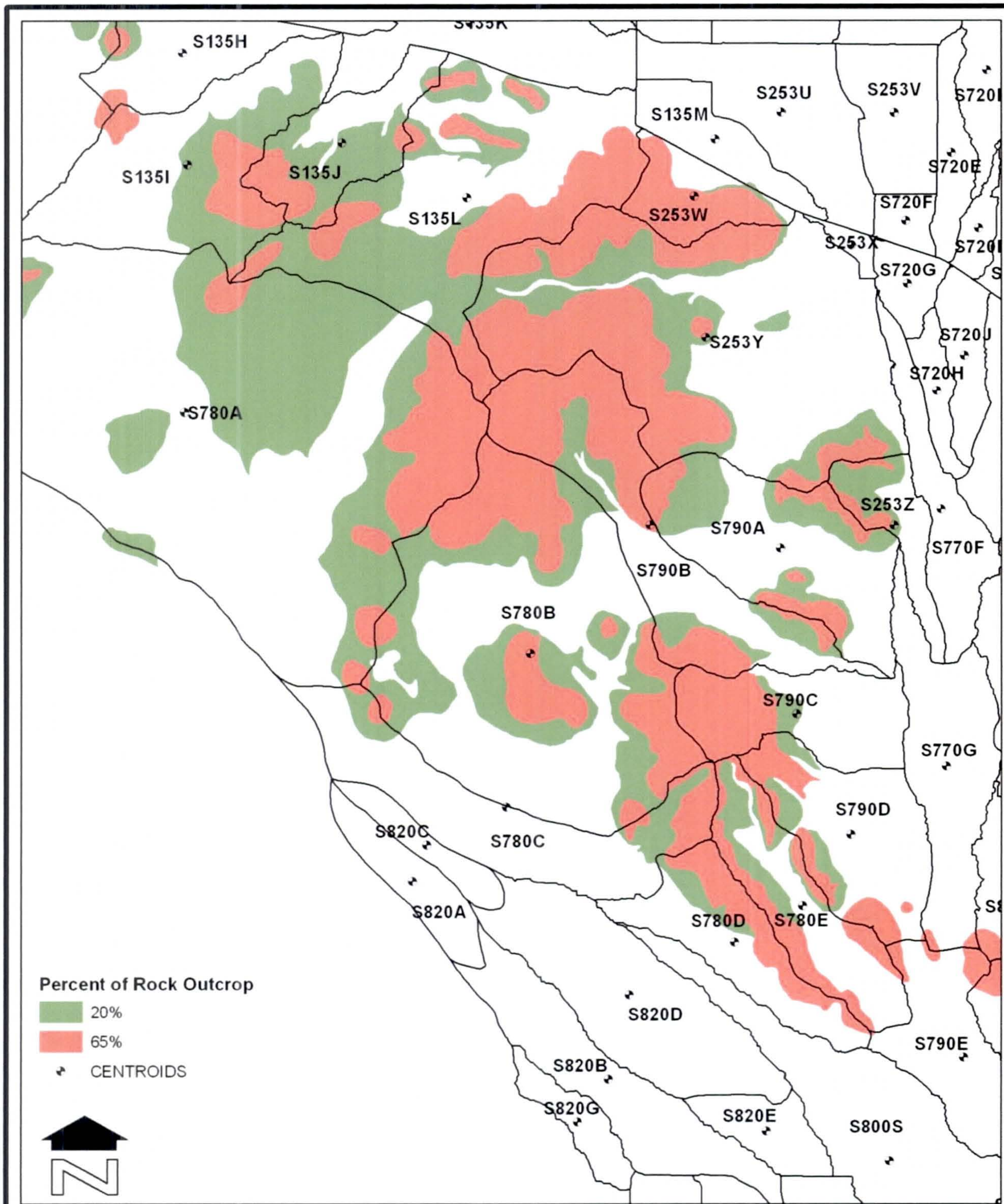
- On a map of the watershed, identify which soil map units include rock outcrop as a component.
- Compare the location of those soil map units to the drainage network and subbasin centroid.
- If the soil map units with rock outcrop are located upstream of the subbasin centroid, then the rock outcrop was assumed to not be hydraulically connected, and those soil map units (within the subbasin) were assigned an effective contribution of 0%. This assignment was based on an assumption that direct runoff from the rock outcrop flows over a sufficient area of pervious ground infiltrating into the soil, thus never reaching the subbasin outlet.
- If any soil map unit within a subbasin that contains rock outcrop lies downstream of the subbasin centroid, then all those map units are

assumed to be hydraulically connected to the subbasin outlet. However, within the Palo Verde Watershed, the maximum area percentage of rock outcrop with any unit is 65%. Therefore, it can be concluded that the direct runoff from the rock land flows over pervious ground at some point. To simulate this "partial loss", the effective contribution is reduced from the full amount based on the areal extent of occurrence within the subbasin. Reduction of the effective contribution was accomplished by creating five ranges of areas. Each range represents the area of a subbasin with soil map units that contain rock outcrop. The effective contribution assigned to each range is set at the minimum value of the range. The selected ranges are:

Percent Area of Soil Map Units with Rock Outcrop	Effective Contribution
0% - 10%	0%
10% - 25%	10%
25% - 50%	25%
50% - 75%	50%
75% - 100%	75%

- Implementation in DDMSW – for each subbasin containing soil map units with rock outcrop, the effective values were set based on the conditions above. DDMSW uses the effective value in the area-weighting process of RTIMP for each subbasin.

Figure 4-3 illustrates a typical example of how the percent area of rock outcrop was identified for a subbasin, as well as the outcrop location relative to the location of the subbasin centroid. Subbasin S780E has rock outcropping located within the subbasin, including a portion below the centroid of the basin; the rock outcrop is therefore considered hydraulically connected to the outlet. The total percentage of rock outcrop within the basin as calculated within GIS based upon the soils data is 56%. The effective percent impervious is therefore set to 50% for the subbasin.



FLOOD CONTROL DISTRICT OF MARICOPA COUNTY		FIGURE 4-3 TYPICAL PERCENTAGE OF ROCK OUTCROP WITH BASIN CENTROIDS	PALO VERDE WATERSHED DETAILED FDS F.C.D. CONTRACT NO. 2008C046
DATE:	07-30-2010		Entellus IN ASSOCIATION WITH Stantec
SCALE:	NTS		
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4.2.2.7 Land-use boundaries

Land use within the watershed consists of residential, commercial, industrial, institutional, open space, agriculture, and foothills/mountain. For each unique land use, data describing the rainfall loss and unit hydrograph parameters were assigned. The existing land use was assembled in a shapefile that was compiled based upon inspection of 2008 aerial photography and field reconnaissance. The shapefile breaks the watershed up into a variety of polygons consisting of different land uses. As a starting point, the shapefile was developed with the default land use types discussed in the Design Manual; the shapefile was then modified to reflect the existing land uses specific to the watershed. The changes consisted of updating the rural residential areas, retired agricultural fields, the industrial areas around the Palo Verde Nuclear Power Plant, and adding areas of natural mountainous terrain (NMT) and areas of natural desert rangeland (NDR). The changes required an update to the DDMSW Land Use Defaults database by adding new land use codes.

Within the land use database of DDMSW, the default values of IA, RTIMP (for land use, not for natural impervious areas such as rock outcroppings), vegetative cover, DTHETA condition, and the Kn values are set based upon the Design Manual criteria. When new land use codes were added to the defaults, adjustments were made based upon actual watershed conditions that affect variables such as the vegetative cover or Kn values. For all subbasins that use the Desert/Rangeland S-Graph, see Figure 4-4 and the S-graph discussion in Section 4.2.2.7. The Kn value was custom set to a value of 0.042. The purpose of this was to reduce the velocities of the subbasin to be closer to that of the routing reaches, which is typically in the range of 3 to 6 fps. A summary of the different land uses and their associated parameters is provided in Table 4-3.

Table 4-3

Land Use Parameters

Land Use Code	Description	DTHETA Condition	Veg. Cover %	RTIMP %	IA inches	Kn
111	Rural Residential	Dry	30	5	0.35	0.025
130	Residential (1-2 du/ac)	Normal	50	15	0.3	0.020
160	Residential (>6 du/ac)	Normal	50	40	0.25	0.020
210	Commercial (<=50,000 sq. ft.)	Normal	65	80	0.1	0.020
320	Industrial	Normal	60	55	0.15	0.020
520	Educational	Normal	80	45	0.29	0.020
740	Open Space - Water	Wet	0	0	0	0.030
750	Agriculture	Normal	85	0	0.5	0.100
900	Open Space - Vacant	Dry	25	0	0.35	0.025
910	Retired Agricultural Fields	Dry	10	0	0.4	0.030
920	Mountain Terrain (NMT-1)	Dry	25	0	0.25	0.050
930	Foothills, Moderate Slope (NDR-2)	Dry	19	0	0.35	0.030
940	Foothills, Moderate Slope (NDR-3)	Dry	18	0	0.35	0.027
950	Foothills, Steep Slope (NMT-2)	Dry	23	0	0.15	0.033

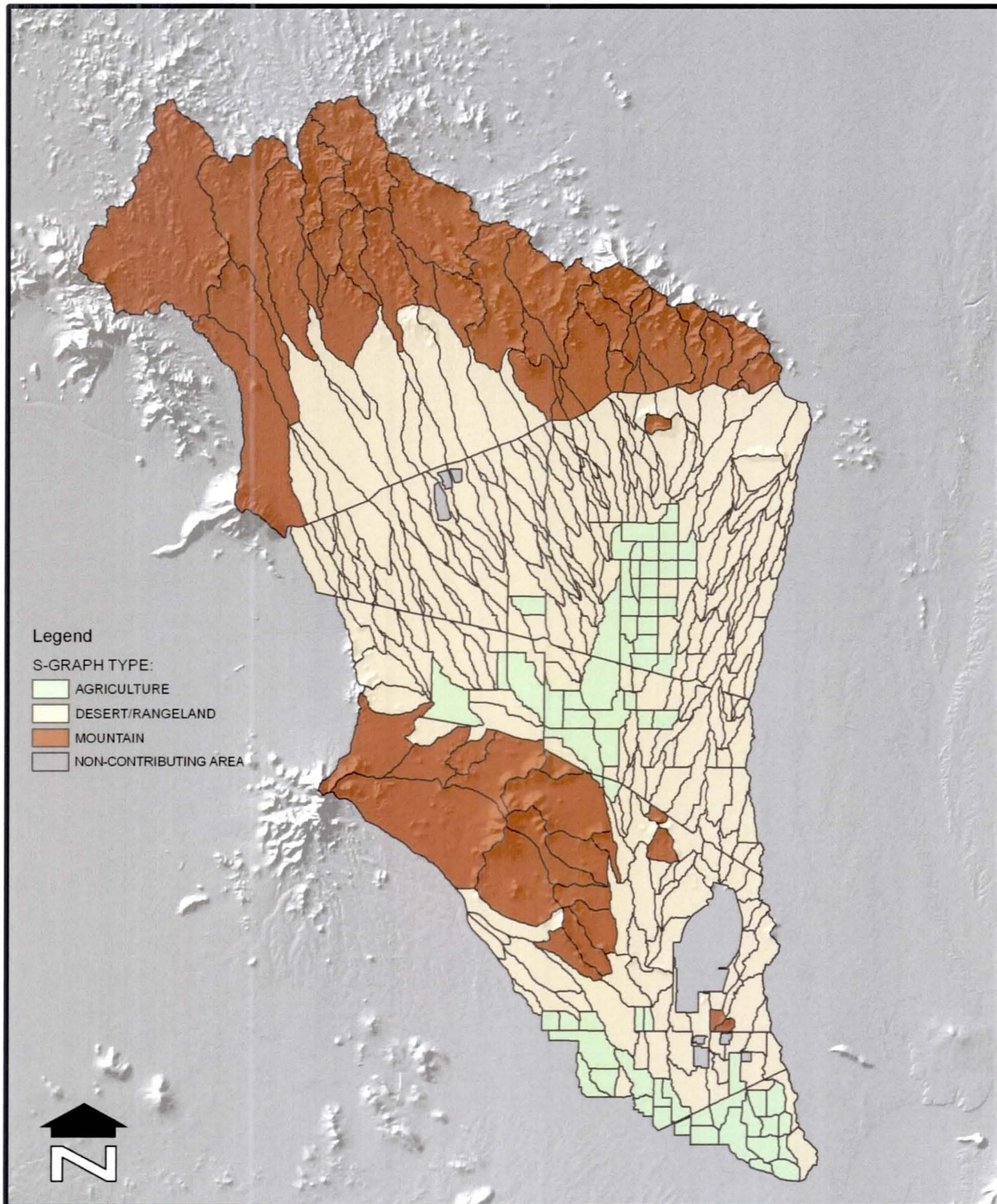
The custom land use codes and associated group type are as follows: 111-Residential, 910-Open Space (Retired Agricultural Fields), 920-NMT-1 (Mountain Terrain), 930-NDR-2 (Foothills, Moderate Slope), 940-NDR-3 (Foothills, Moderate Slope), and 950-NMT-2 (Foothills, Steep Slope). The remaining land uses kept the default values for the parameters. For a summary of the land use parameters for each subbasin and the Land Use Overview Exhibit, see Appendix D. The data disc located in Appendix E contains exhibits that have the same data, but the sheets are more detailed instead of a single large overview exhibit. The disc also includes the DDMSW files for each model.

4.2.2.8 Unit Hydrograph Parameters

The S-graph method as prescribed in the Design Manual was used to transform rainfall excess to a runoff hydrograph. There are four types of S-graphs for use within Maricopa County per the manual: Valley, Agricultural, Desert/Rangeland,

and Mountain. The valley S-graph was not used in the modeling since there are no subbasins with a major urban component. The areas of very little topographic relief are primarily at the farm fields, in which the Agricultural S-graph was used.

The S-graph lag time for each subbasin was calculated within DDMSW through the method discussed in the Design Manual using equation 5.11. The parameters required to calculate the lag time are discussed in Section 4.2.2.2 Time of Concentration. See Appendix D for the subbasin summary, which includes the type of S-graph used for each subbasin. Figure 4-4 shows the subbasin boundaries with the classification of S-graph used for each subbasin.



FLOOD CONTROL DISTRICT OF MARICOPA COUNTY		FIGURE 4-4 GRAPHICAL REPRESENTATION OF SUB BASINS AND S-GRAPH CLASSIFICATION	PALO VERDE WATERSHED DETAILED FDS F.C.D. CONTRACT NO. 2008C046
DATE:	07-30-2010		Entellus IN ASSOCIATION WITH Stantec
SCALE:	NTS		
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4.2.3 Gage Data

Per the FCDMC ALERT station locater map, nine gages are located in or near the study watershed. Four of the nine gages report precipitation data only, four report both precipitation and stream flow, and one reports stream flow only. All nine gages are owned and operated by the District and are located as follows:

1. **Sugarloaf Mountain**: Precipitation ID-5055 located 16 miles NW of Tonopah. The gage was installed 05/27/2004 at elevation 2,760 ft.

2. **Belmont Mountains**: Precipitation ID-5240 located 5 miles SW of Wickenburg Road at Aguila Road. The gage was installed 12/16/2002 at elevation 1,860 ft.

3. **Fourmile Wash**: Precipitation ID-5135 located at the intersection of roadway alignments 371st Avenue and Glendale Avenue. The gage was installed 07/05/2001 at elevation of 1,125 ft.

4. **Harquahala FRS**: Precipitation ID-5125, Water-Level ID-5128 located 10 miles NW of Tonopah. The gage was installed 09/15/1993 at elevation 1,420 ft.

5. **Winters Wash**: Precipitation ID-5115, Water-Level ID-5118 located 1 mile N of the intersection of Indian School Road and 403rd Avenue. The gage was installed 07/11/2000 at elevation of 2,760 ft.

6. **Winters Wash @ Indian School Road**: Water-Level ID-5098 located 2 miles E of 411th Avenue on Indian School Road. The gage was installed 07/14/2005 at elevation 1,105 ft.

7. **I-10@355th Avenue**: Precipitation ID-5070 located 3 miles NW of the Hassayampa River Crossing at I-10. The gage was installed 09/07/2001 at elevation 1,095 ft.

8. **Delaney Wash**: Precipitation ID-5105, Water-Level ID-5108 located 3 miles SSW of Tonopah. The gage was installed 12/20/1999 at elevation 1,130 ft.

9. **Centennial Railroad**: Precipitation ID-5100, Water-Level ID-5103 located 8 miles NW of Gillespie Dam. The gage was installed 02/09/1990 at elevation 850 ft.

None of the gages have a sufficient period of record for statistical analysis of a 100-year recurrence interval precipitation depth or for stream flow comparison. Therefore, data from these gages was not used in this study. A significant storm event occurred over the watershed in early January 2010, and the data from the gages was reviewed for the watershed but ultimately not used.

4.2.4 Statistical Parameters

There is no precipitation or stream flow statistical data of significant record available to be used for this watershed other than the regional precipitation data published by NOAA.

4.2.5 Precipitation

The storm events specified for analysis in this study are the 100-year 6- and 24-hour duration storms. The rainfall distributions for the 6-hour duration storm are based upon the watershed area; those distributions, listed in the Design Manual as Patterns 1-5, were calculated by DDMSW. The 24-hour duration storm used for this study is the SCS type II. The precipitation data is from NOAA Atlas 14 data for Arizona. The average point rainfall data for the 100-year 6- and 24-hour durations are 3.168 and 3.967 inches, respectively.

Areal reduction factors for the 6- and 24-hour duration storms were computed automatically within DDMSW based off of the values listed in the Design Manual. The appropriate depth-area reduction for all storms and accumulated drainage areas was simulated in HEC-1 through the use of JD records. Table 4-4 summarizes the areal reduction factors and the JD records for both the 6- and 24-hour duration storms events.

Table 4-4

Areal Reduction / JD Record Summary

6-hour Duration			24-hour-Duration		
Area sq. mi	**Reduction Factor**	**Rainfall Depth inches**	**Area sq. mi**	**Reduction Factor**	**Rainfall Depth inches**
0.0001	1.0000	3.168	0.0001	1.0000	3.967
0.50	0.9940	3.149	10.0	0.9500	3.769
2.80	0.9750	3.089	30.0	0.9000	3.570
16.0	0.9220	2.921	60.0	0.8700	3.451
90.0	0.8100	2.566	90.0	0.8520	3.380
400.0	0.7900	2.503	120.0	0.8410	3.336
			150.0	0.8320	3.301
			300.0	0.8060	3.197

4.2.6 Levee Conditions

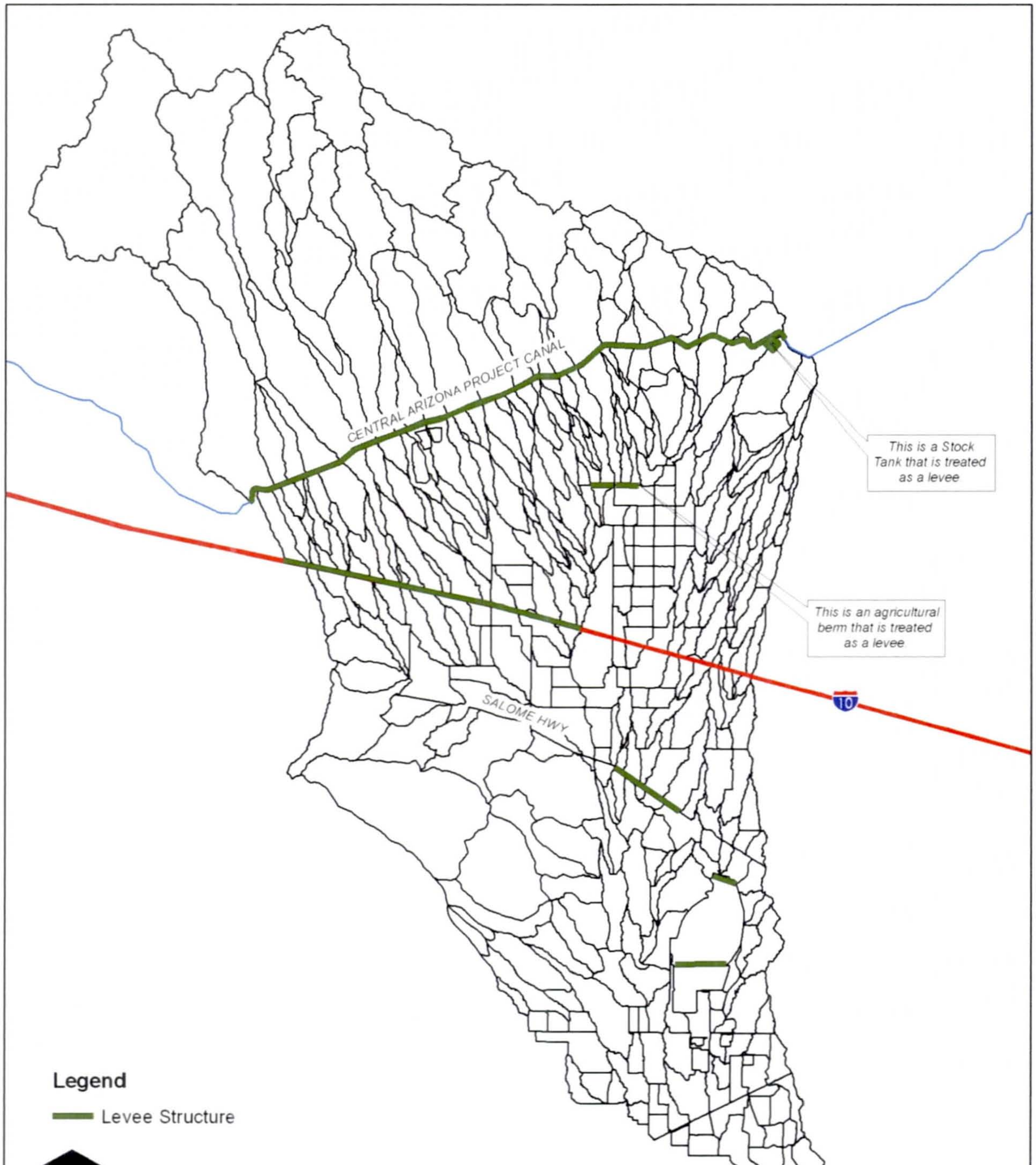
The watershed was modeled under two distinct scenarios, "With Levee" and "Without Levee". Separate watershed maps, logic diagrams, and HEC-1 models were assembled for each condition. The Levee Structures Map, Figure 4-5, shows the location of the structures that act as levees throughout the watershed. The structures considered as levees are only structures that have an impact on the watershed by changing flow rates, watercourse routings, or flow paths. Areas that do not have a large impact are not considered as levees. For example, if a flow split occurs because of a small road and the split joins together shortly downstream, that is not considered as a levee. Structures such as the CAP Canal and I-10 have large impacts on the watershed due to storage, flow splits, and re-routing of washes.

The two levee condition models are necessary due to requirements by FEMA since the structures within the watershed are not certified levees under the FEMA guideline criteria in Section 65.10 of the National Flood Insurance Program (NFIP) regulations. As a result, it must be assumed that the structures were not designed to withstand the runoff from the 100-year storm event or could be removed or altered in the future, which would change runoff patterns. However, since the structures are present in the existing conditions and can alter the natural flow patterns, it must also be assumed that the features might withstand a 100-year storm and be present for the duration of the event. Therefore, the two levee conditions must be modeled for both storm durations.

Figure 4-5 shows the structures that are considered to be levees within the watershed. Only the man-made features or portions of features that store runoff and/or alter the natural flow patterns and are not certified levees are treated as non-levee embankments in the with and without levee condition models. A discussion of how each of the features is modeled is provided in the following sections.

1. CAP Canal
2. Stock tank berm at the boundary of subbasins S700A and S740A, approximately 3,500 feet downstream of CAP Canal overchute #14
3. Agricultural berm located north of subbasins S253G and S700G
4. Interstate 10
5. Portions of Salome Highway
6. Palo Verde Nuclear Generating Station Berms

The floodplain delineations as a result of this data will incorporate the "worst-case scenario" of each levee condition. For example, floodplains must be delineated for the ponding area upstream of the CAP Canal and likewise downstream of the canal in the event that it does not store runoff on the upstream side and instead all flow is routed across the canal without any storage or re-routing.



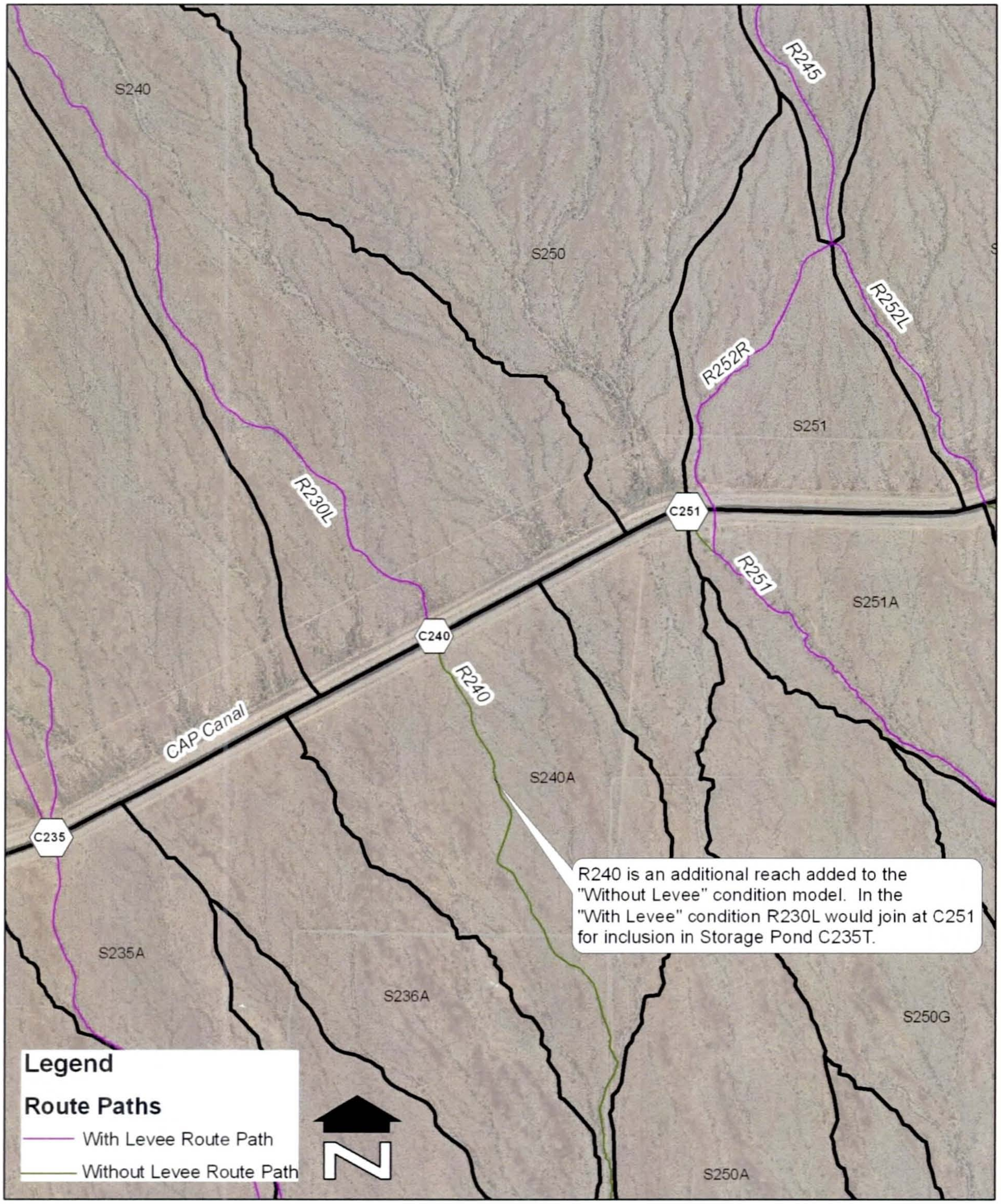
FLOOD CONTROL DISTRICT OF MARICOPA COUNTY		FIGURE 4-5 LEVEE STRUCTURES MAP	PALO VERDE WATERSHED DETAILED FDS F.C.D. CONTRACT NO. 2008C046
DATE:	07-30-2010		Entellus IN ASSOCIATION WITH Stantec
SCALE:	NTS		
DRAWN BY:	NBL		

4.2.6.1 CAP Canal

The CAP canal is an important feature due to the storage that is provided on the upstream side and the redirecting of flow routes. The "With Levee" condition allows for ponding and the storage of runoff against the canal embankment on the upstream side. As the canal intersects natural washes, it re-routes the runoff to cross the canal at specific overchute locations, thus altering the natural flow characteristics of the watershed downstream. Figure 4-2 shows the locations for each overchute, and Tables 4-1 and 4-2 in Section 4.2.2.5 summarize the overchute dimensions and storage volume for each pond.

The "Without Levee" condition effectively removes the canal by changing the logic of the hydrologic model. The storage behind the canal is no longer accounted for, which increases the magnitude of runoff that enters the south portion of the watershed. Without the canal in place to intersect the natural washes and re-direct flow, the routings are also updated to route the inflow hydrographs from the north to enter the south portion at their historic location rather than combining at the storage ponds. The historic reaches were determined by inspection of topographic data and aerial photography. The routing updates involved adding in new reaches that are not present in the "With Levee" condition model, creating more flow crossing locations at the canal than in the "With Levee" condition.

Figure 4-6 illustrates how additional reaches were added. Reach R240 does not exist in the "With Levee" condition but was added to the "Without Levee" model to route the flow from subbasin S240 through subbasin S240A. In the "With Levee" condition the runoff from S240 would combine with concentration point C253T before being routed through storage route C253OS. The reach was added at the apparent historical flow path, based upon topographic data and aerial photography prior to the construction of the canal.



FLOOD CONTROL DISTRICT OF MARICOPA COUNTY		FIGURE 4-6 CAP CANAL REACH ADDITION EXHIBIT	PALO VERDE WATERSHED DETAILED FDS F.C.D. CONTRACT NO. 2008C046
DATE:	07-30-2010		Entellus IN ASSOCIATION WITH Stantec
SCALE:	NTS		
DRAWN BY:	NBL		

4.2.6.2 Stock Tank

Along the basin boundary between S700A and S740A approximately 3,500 feet downstream of CAP Canal overchute #14 there is a stock tank with a berm that has the ability to redirect flow from the overchute (Figure 4-7). As the stock tank fills up, the excess flow is redirected to the west by the berm. CAP Canal overchute #14 is where the inflow hydrograph from Coyote Wash enters the watershed. The Coyote Wash inflow hydrograph is taken from the Jackrabbit Wash Floodplain Delineation Study. The hydrograph was calculated in the Jackrabbit Wash study using NOAA Atlas 2 rainfall data and has a contributing area of 35.99 square miles. Under the "With Levee" condition, the hydrograph, which accounts for storage along the upstream embankment of the CAP Canal, is routed into subbasin S700A as a result of the stock tank berm redirecting the flow.

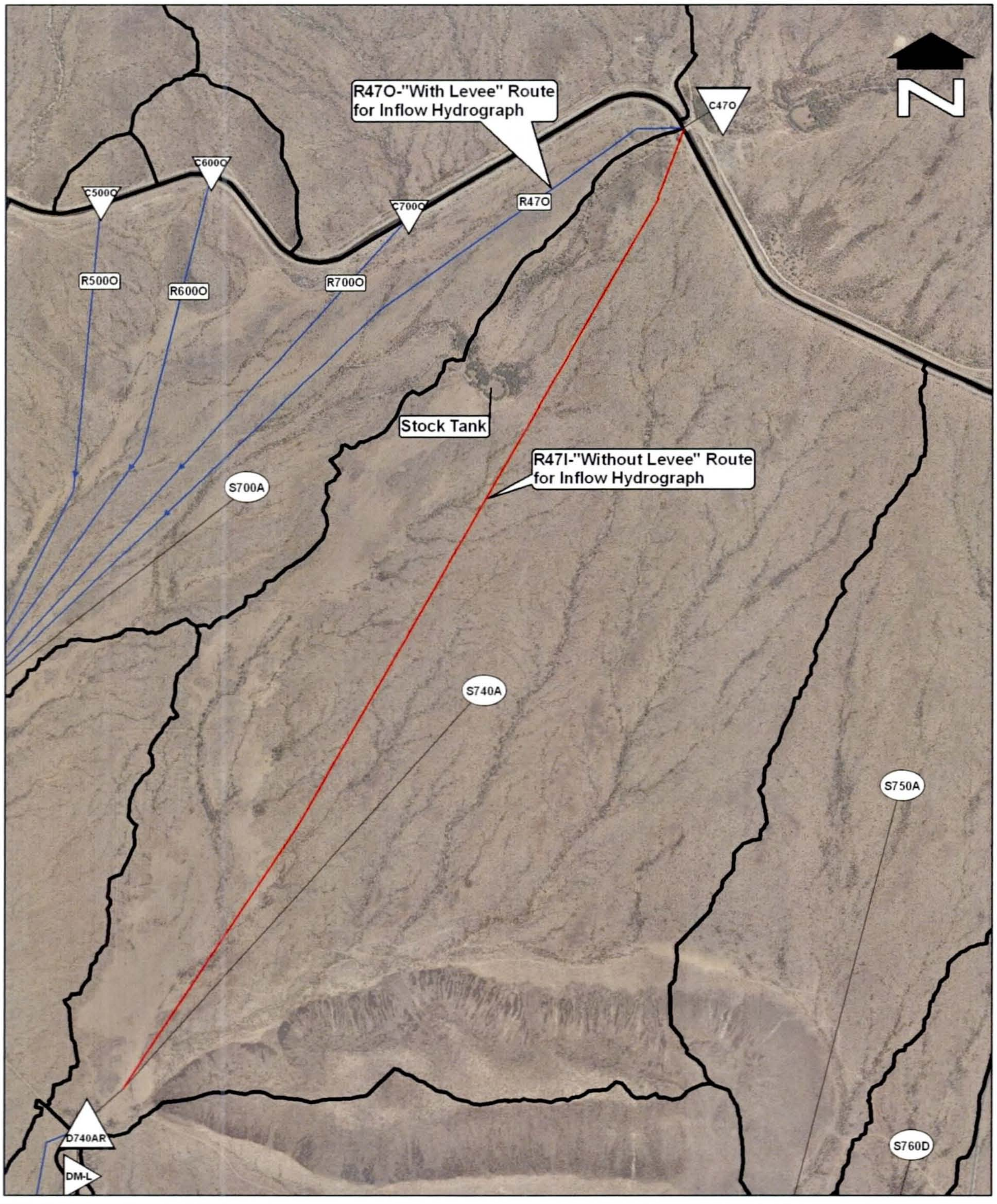
In the "Without Levee" condition, the berm is assumed to no longer redirect flow and the full Coyote Wash hydrograph is routed into subbasin S740A. This area is unique also in the fact that when the "With Levee" hydrograph, C47O, from Coyote Wash is routed in to S700A, it is accounting for the storage from the CAP Canal. However, in the "Without Levee" condition, the inflow hydrograph, C47I, is higher since the canal storage is no longer accounted for. Table 4-5 summarizes the data for the Jackrabbit Wash inflow.

Table 4-5

Jackrabbit Wash Floodplain Delineation Study Inflow Hydrograph

Storm Event	With Levee C47O*		Without Levee C47I*	
	Peak Flow cfs	Time to Peak hours	Peak Flow cfs	Time to Peak Hours
6-hour	934	8.17	2,433	6.33
24-hour	1,526	15.92	3,416	14.17

*C47O and C47I are from the Jackrabbit Wash Floodplain Delineation study FCD90-05.



FLOOD CONTROL DISTRICT OF MARICOPA COUNTY	
DATE:	07-30-2010
SCALE:	NTS
DRAWN BY:	NBL

FIGURE 4-7
STOCK TANK LEVEE EXHIBIT

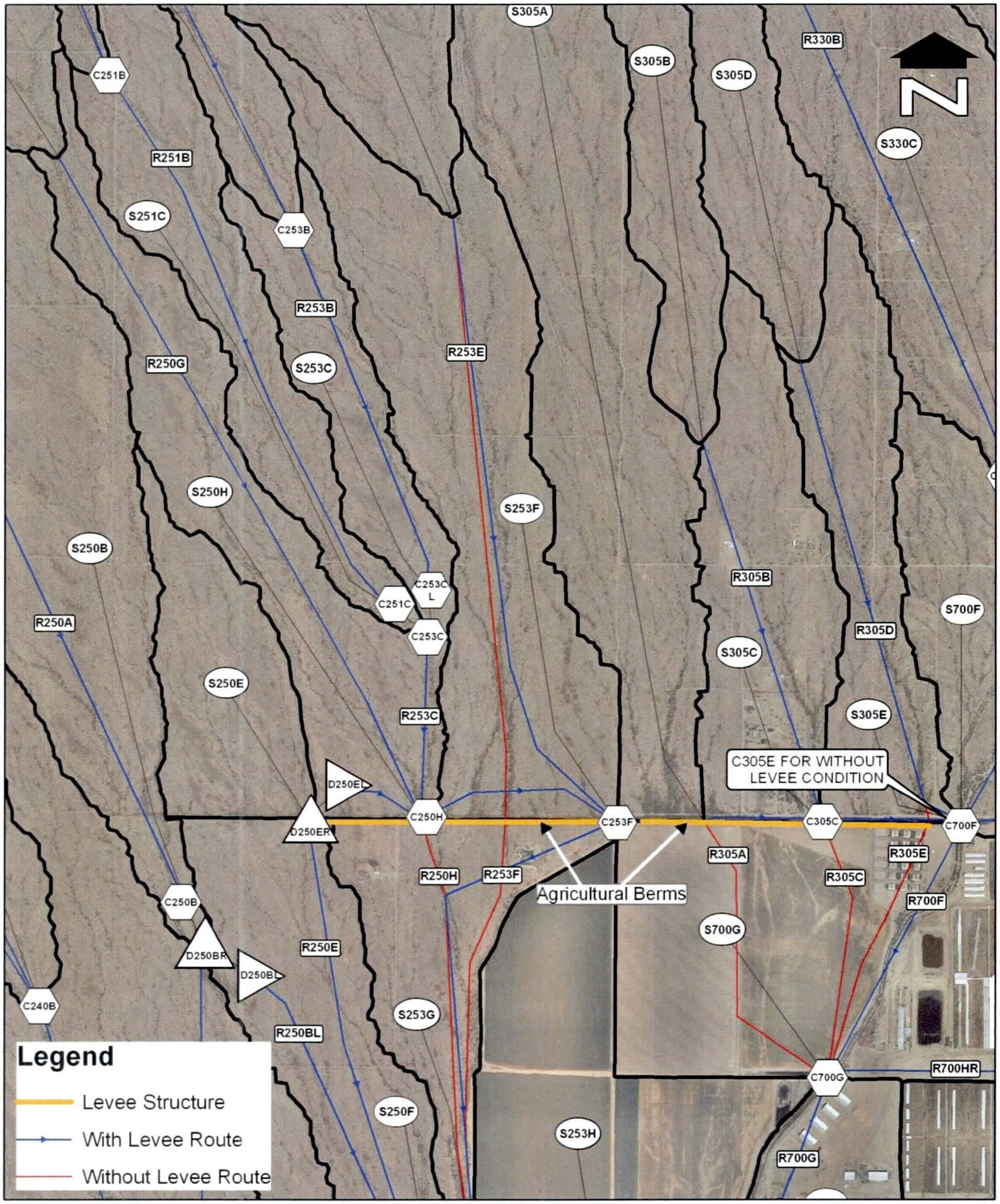
PALO VERDE WATERSHED DETAILED FDS
F.C.D. CONTRACT NO. 2008C046

Entellus IN ASSOCIATION WITH Stantec

4.2.6.3 Agricultural Berm

The agricultural berm north of subbasins S253G and S700G impacts the watershed by redirecting natural watercourses to the east. In the "With Levee" condition the flow from C250H combines with C253F at the far eastern edge of S253F before crossing at an opening in the berm to flow into S253G. Likewise, the flow from S305A and C305C are redirected east to combine at C700F before being routed into S700G. The berm only redirects flow, no storage is accounted for on the upstream side.

In the "Without Levee" condition the berm is effectively removed from the model by allowing the flow to follow its natural watercourse path. As in the case with the CAP Canal, this required additional reach routes to be added to the "Without Levee" condition model that do not exist in the "With Levee" condition. The historical flowpaths were selected based upon the topographic data and aerial photography. As a result, the runoff from C250H is not combined with C253F but rather flows south into S253G via routing reach R250H. Additionally, C253F is no longer located at the berm opening but is shifted to the point at which the runoff naturally crossed the basin boundary. The runoff from subbasins S305A, C305C, and C305E are directed south into S700G instead of being combined at C700F. This created additional reach routes for the "Without Levee" condition that are not in the "With Levee" modeling. Figure 4-8 illustrates the change to the logic of the model from the berm levee condition.

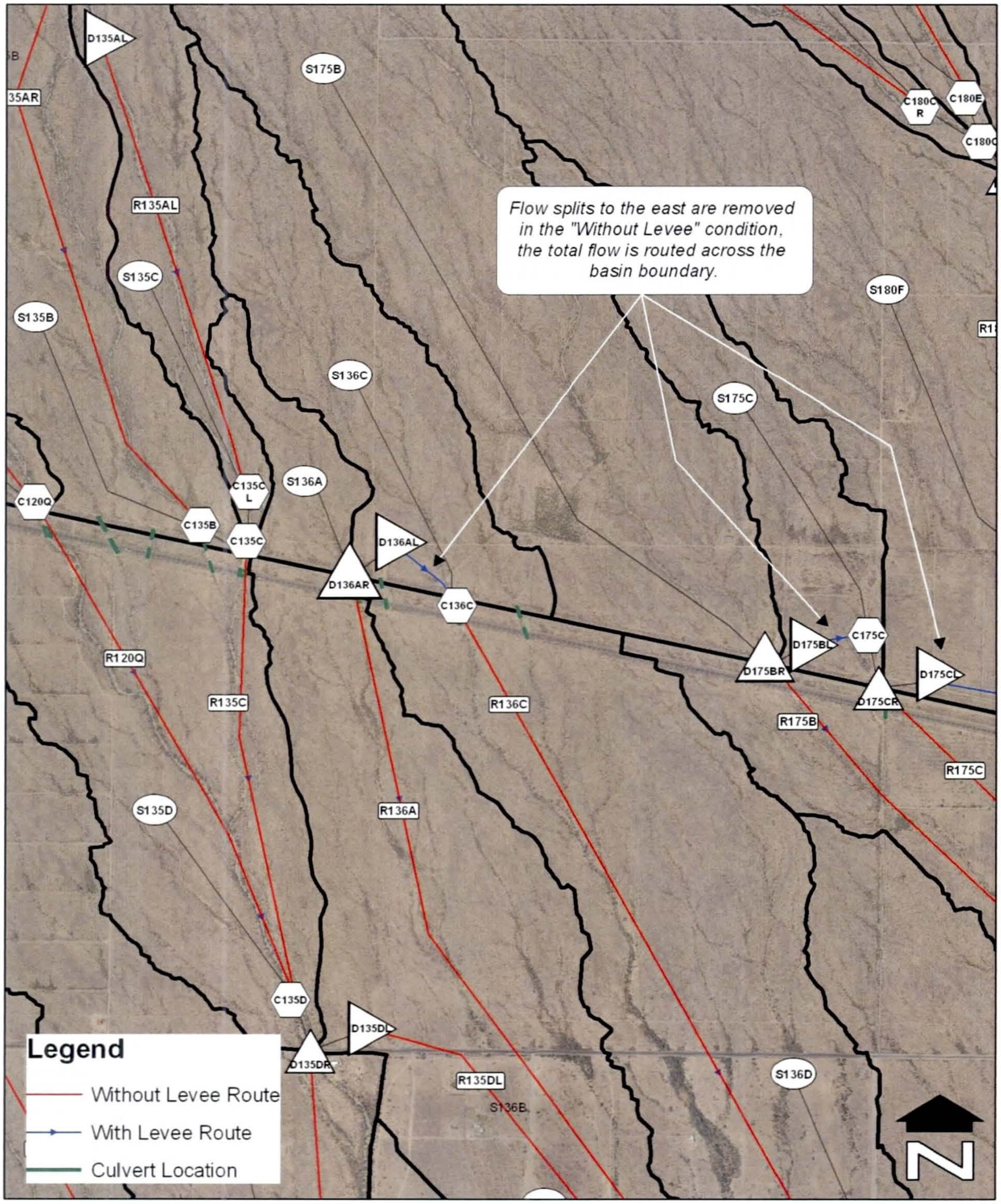


FLOOD CONTROL DISTRICT OF MARICOPA COUNTY		FIGURE 4-8 AGRICULTURAL BERM EXHIBIT	PALO VERDE WATERSHED DETAILED FDS F.C.D. CONTRACT NO. 2008C046
DATE:	07-30-2010		Entellus IN ASSOCIATION WITH Stantec
SCALE:	NTS		
DRAWN BY:	NBL		

4.2.6.4 Interstate 10/Salome Highway

Interstate-10 is a levee feature that creates flow splits and re-directs runoff to the east at many of the culvert crossings as it crosses the western portion of the watershed. It should be noted that culverts with diameters less than 36 inches were not modeled. Although there is no storage upstream of the interstate, the splits alter the historic flow paths and reduce the peak discharges that would naturally have continued downstream by diverting a portion of the total flow, while adding flow in washes to the east of the split location. The flow splits occur at eight crossings, D100AR/L, C100B, C120E, D136AR/L, D175BR/L, C175C, C180F, and C180G. Some subbasins have more than one culvert crossing. However, the runoff flowing through these series of culverts join together shortly downstream so the total culvert flow is combined into one rating curve treating the multiple culverts as a single crossing; this is also done to reduce the number of culvert rating curves in an effort to simplify the modeling. The runoff that crosses the eastern portion of I-10 is a "flow-through" condition and no splits occur since all flow crosses through the culverts. In the "Without Levee" condition, the flow splits to the east will not occur since the interstate is not accounted for in the model, i.e., the total inflow hydrograph is routed across I-10. Figure 4-9 provides an example of which reaches were removed at several split locations along I-10.

Salome Highway acts like I-10 as it redirects flow to the east at four locations, C720E, C720I, C760M, and C770C. Most wash crossings along Salome Highway are low water crossings (dip sections), including the flow splits at C720E and C720I. These splits occur due to elevated roadway embankments near the low water crossings that enable a flow diversion to occur, whereas C760M and C770C are the result of culverts. The flow splits along Salome highway are treated in the same manner as I-10, and the flow that is redirected to the east is removed for the "Without Levee" condition while the full flow is routed across the highway.



FLOOD CONTROL DISTRICT OF MARICOPA COUNTY		FIGURE 4-9 I-10 LEVEE EXHIBIT	PALO VERDE WATERSHED DETAILED FDS F.C.D. CONTRACT NO. 2008C046
DATE:	07-30-2010		Entellus IN ASSOCIATION WITH Stantec
SCALE:	NTS		
DRAWN BY:	NBL		

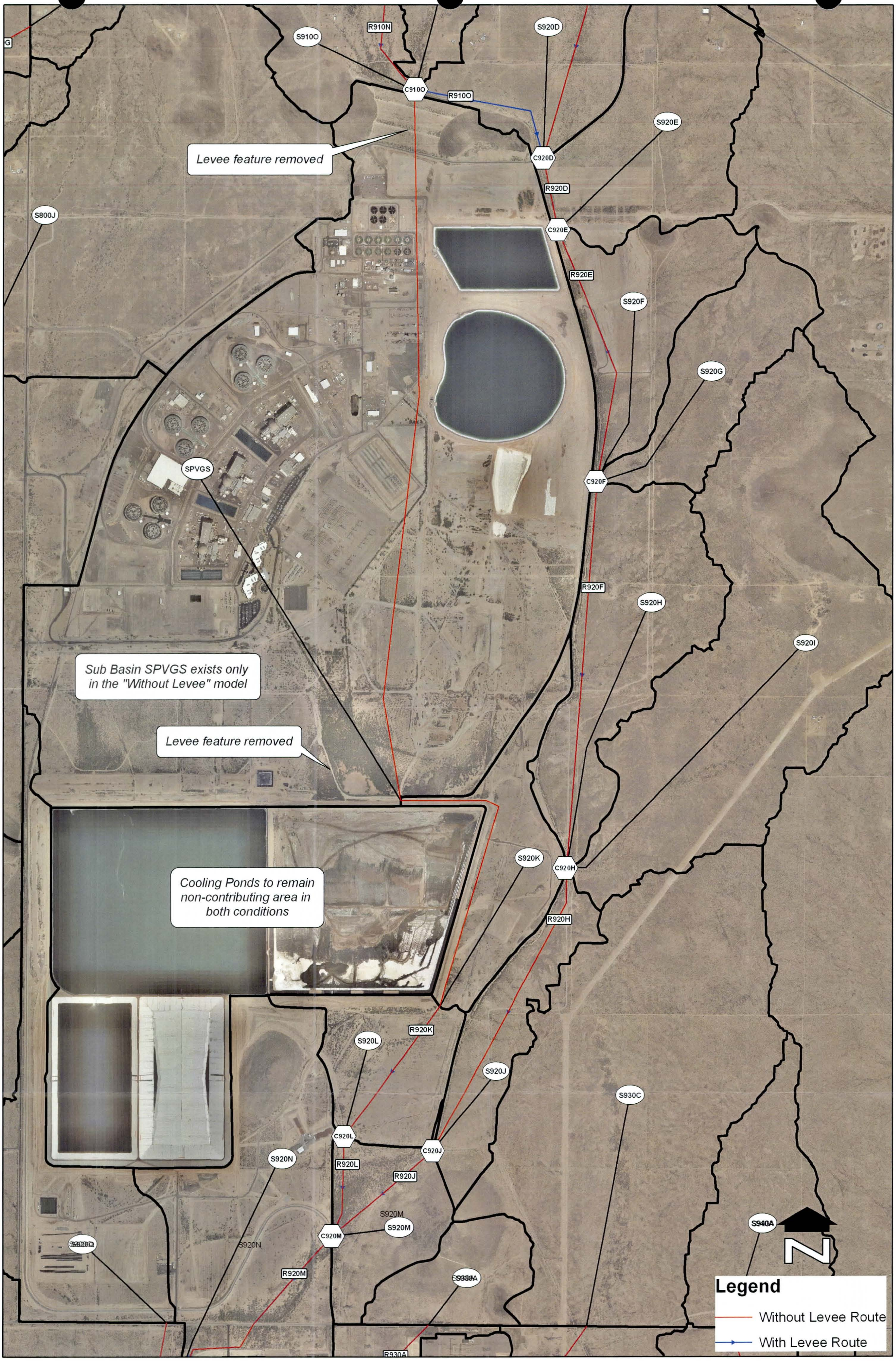
4.2.6.5 Palo Verde Power Plant

In the "With Levee" condition the entire power plant is considered to be non-contributing, due to berms located on the power plant site. The Palo Verde Power Plant contains two sets of berms that serve two distinct purposes. One berm located north of the power plant keeps the off-site runoff from entering the site. This berm is located just south of C910O and redirects flow from C910O to the east via reach route R910O. The flow from R910O combines with C920D and flows south along the east side of the power plant. The berms located at the south end of the power plant just north of the cooling ponds create retention storage for on-site runoff. Since the site is not affected by off-site flows and the on-site runoff is retained on-site behind berms, the power plant is designated as non-contributing for the "With Levee" condition.

Once the berms are no longer accounted for in the "Without Levee" condition model, the power plant site is impacted by off-site flows and the runoff generated on-site enters the downstream watershed. The addition of the on-site runoff from the power plant requires that the area be considered as a contributing drainage area. The power plant is therefore designated as subbasin SPVGS for the "Without Levee" condition. The cooling ponds located south of the power plant are still designated as non-contributing since they are jurisdictional dams regulated by the Arizona Department of Water Resources and are excluded from this study. Without the berm at the north end of the power plant, the runoff from concentration point C910O is directed into and routed through SPVGS. Since the area of the power plant is very flat with many roads, small embankments, culverts, and channels a generic routing reach for R910O was used to route the flow through subbasin SPVGS. A small low-flow channel was included to represent the small drainage channels located on-site.

Without the berms at the south end of SPVGS to hold the runoff generated on-site, the entire SPVGS site is considered to be a contributing area. The retention provided by small local below-grade retention basins is not accounted for in the modeling since the effects of the small basins is considered negligible compared to the generated runoff. The runoff flows to CPVGS and is routed into subbasin S920K via routing reach RPVGS.

Since subbasin SPVGS is only in the "Without Levee" condition models, the land use and soils exhibits located in Appendix D do not show SPVGS. Individual exhibits are included in Appendix D that show the land use and soils data just for subbasin SPVGS, as well as the tabulated subbasin data parameter. Figure 4-10 provides an overview of the logic for the two levee conditions for the power plant. This figure is provided for illustrative purposes only. For more detail, refer to the full size exhibits included with this report.



FLOOD CONTROL DISTRICT OF MARICOPA COUNTY		**FIGURE 4-10** **PALO VERDE POWER PLANT** **LEVEE EXHIBIT**	PALO VERDE WATERSHED DETAILED FDS F.C.D. CONTRACT NO. 2008C046
DATE:	07-30-2010		Entellus IN ASSOCIATION WITH Stantec
SCALE:	NTS		
DRAWN BY:	NBL		

4.3 Problems encountered during the study

4.3.1 Special problems and solutions

The complex nature of the Palo Verde Watershed presented numerous modeling challenges. Most of these challenges are due to physical characteristics of the watershed (such as the CAP Canal, I-10, and natural flow splits), and model conditions imposed for with and without levee. Directly related to those characteristics and conditions are numerical processes used by HEC-1 for estimating runoff magnitudes. There are two sets of problems in particular that were encountered with the modeling. These problems and corresponding solutions are presented in the following sections.

4.3.1.1 Hydrograph Combines

The first special problem encountered in the duration of the study is the limitation of HEC-1 in the maximum number of hydrographs allowed in the queue. Due to the size and complexity of the watershed with all of the flow splits, the maximum number of hydrographs, nine, was reached several times within the model. To avoid the error of having too many hydrographs, two solutions were utilized. The first was to use an intermediate combine.

The intermediate combines temporarily combined "hanging" hydrographs to free up space in the queue. The intermediate combines are labeled in the model with KK comment records and are noted that they are not labeled on the Logic Diagram since they do not serve a hydrologic function other than being a temporary combine. They are labeled with an "I" at the end to designate that it is an intermediate combine; this should not be confused with the subbasins that end with an "I". Table 4-6 lists the intermediate combine identifiers for both the "With" and "Without" conditions.

Table 4-6

Summary of Intermediate Combines

With Levee Condition	Without Levee Condition
C250HI	C165I
C253II	C251I
C335FI	C253AI
C700AI	C253II
	C335FI
	C700AI
	C700BI

There are, however, some instances where an intermediate combine was not a practical solution. In areas where a hydrograph had to be left "hanging" in the southern portion of the watershed while the model logic returned to the northern part to follow a new reach or a split, a different approach was necessary. The solution for this was to divert the hanging hydrograph in the southern portion until it was needed. The routed portion of the HEC-1 diversion function was combined with the "CLEAR" hydrograph, which is the first hydrograph in the queue. Instead of the typical "R" and "L" label at the end of each diversion and retrieval, the temporary diversions are labeled with a "C" and "I" at the end of the diversion and retrieval labels, respectively. The "C" designates that portion of the diversion that is combined with the "CLEAR" hydrograph, and the "I" designates the diversion for later retrieval into the model. Table 4-7 lists hydrograph clear combines for both the "With" and "Without" conditions.

Table 4-7

Summary of Intermediate Diversion "Clear" Combines

With Levee Condition	Without Levee Condition
D135MC/D135MI	D135MC/D135MI
D215IC/D215II	D215IC/D215II
D216CC/D216CI	D216CC/D216CI

4.3.1.2 NSTPS Optimization

A second problem encountered during the study is the NSTPS optimization. Variations in the NSTPS are the result of the multiple peaked hydrographs that occur from the flow splits and the attenuation in the reaches of the agricultural region. To address this, the NSTPS for the models were first optimized within DDMSW for a minimum of four model runs. This process showed which routing reaches were not capable of converging on a specific NSTPS value as they consistently bounced back and forth between two distinct values. The reason for the oscillation in the NSTPS is the multiple peaked hydrographs. An example of this is shown with reach R135AR. The "With Levee" 24-hour model computes the peak flow at C135A at 383 cfs at a time to peak (TP) of 12.67 hours. The first optimization run of the model calculated the NSTPS for R135AR at 79 NSTPS, yielding a peak of 145 cfs at a TP of 13.58 hours. However, calculating the correct travel time of the inflow routed peak, 12.67 hours to 13.58 hours, gives a calculated NSTPS of 11 based upon the results from the HEC-1 model. NSTPS can be calculated by dividing the difference in time from the pre and post routed hydrographs of an identical peak by the NMIN of the HEC-1 calculated in seconds. In optimizing, DDMSW sometimes subtracts non-identical peaks.

The model was optimized again, and DDMSW converged on 11 NSTPS for the reach, which matched the correct routed peak travel time. However, changing NSTPS to 11 would produce a peak flow of 117 cfs at a TP of 19.17 hours, which corresponds to an NSTPS value of 79 steps (12.67 hours to 19.17 hours) based upon the HEC-1 output. A third optimization converged back to 79 NSTPS.

To determine which NSTPS to use when DDMSW could not converge on a consistent number, the inflow hydrographs were plotted with the routed hydrographs to identify the correct NSTPS value of the correct routed peak. In the case of the R135AR example, the chosen value was 11 NSTPS to match the correct TP. Figure 4-11 includes the overlaid hydrographs from each NSTPS value for this example.

In most cases where there are large differences between the 6- and 24-hour model NSTPS, it is the result of the NSTPS optimization process described above and the use of custom NSTPS values. As previously noted, this occurs primarily in the agricultural field areas where DDMSW had the most trouble with convergence. To some extent, different NSTPS are expected between the two storm duration models as the result of different runoff peak flows and times to peak. The optimization process was completed for each storm duration model for each levee condition. The reaches that are set with custom NSTPS values are tabulated in Tables 4-8 and 4-9 for the "With Levee" and "Without Levee" conditions respectively.

Figure 4-11
R135AR With Levee-24 Hour Hydrograph

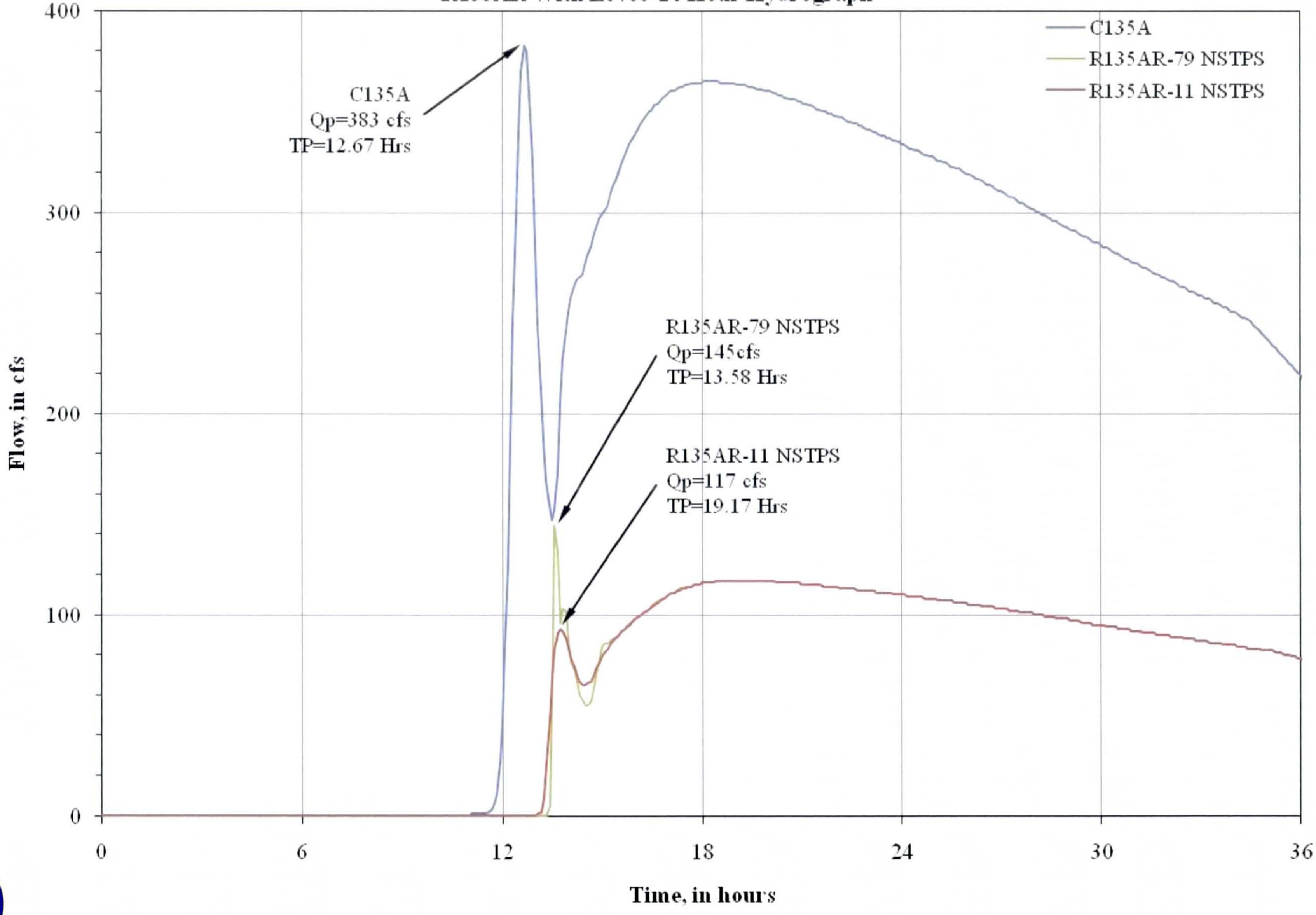


Table 4-8

With Levee Custom NSTPS Summary

6-hour model		24-hour model	
Reach	**NSTPS**	**Reach**	**NSTPS**
R226BL	18	R120C	6
R253N	1	R120A	5
R700DR	1	R135AL	7
R750B	7	R135AR	11
R760L	3	R180GL	41
R700IL	45	R253Z	17
R710EL	17	R330AL	3
R710JL	21	R330AR	11
R710LL	178	R700DR	2
R770F	11	R710CR	23
R710IR	37	R710DL	15
R710CL	55	R710DR	23
R710IL	11	R710ER	32
R710LR	97	R710JL	15
R820IL	9	R710LL	44
R820HL	8	R710LR	67
		R760FR	20
		R820HL	8
		R820IL	5
		R820J	5

Table 4-9

Without Levee Custom NSTPS Summary

6-hour model		24-hour model	
Reach	**NSTPS**	**Reach**	**NSTPS**
R305E	4	R136D	5
R700DR	2	R253Y	6
R710CR	24	R253Z	12
R710JL	16	R700DR	1
R710LL	46	R710IL	6
R710FL	7	R710JL	14
R710LR	107	R710LL	39
R820IL	9	R710LR	60
R820HL	8	R760FR	20
R940HL	8	R820HL	8
		R820IL	5
		R820J	5

4.3.2 Modeling Warnings and Error Messages

Three warning messages occur within all of the models and are reported as follows:

1. *** WARNING *** MODIFIED PULS ROUTING MAY BE NUMERICALLY UNSTABLE FOR OUTFLOWS BETWEEN XXXX. TO XXXX THE ROUTED HYDROGRAPH SHOULD BE EXAMINED FOR OSCILLATIONS OR OUTFLOWS GREATER THAN PEAK INFLOWS. THIS CAN BE CORRECTED BY DECREASING THE TIME INTERVAL OR INCREASING STORAGE (USE A LONGER REACH.)

2. WARNING --- ROUTED OUTFLOW (XXXX.) IS GREATER THAN MAXIMUM OUTFLOW (XXXX.) IN STORAGE-OUTFLOW TABLE

3. WARNING EXCESS AT PONDING LESS THAN ZERO FOR PERIOD. EXCESS SET TO ZERO

The first warning listed above specifies a range of peak flows for which the routing numerics may be unstable. Each routing reach for which this warning message was issued was checked for the following:

1. The routed peak discharge was checked to determine if it fell within the range of numerically unstable outflows listed in the warning message.

2. The routed peak discharge was compared with the inflow peak discharge to determine if an increase resulted due to the routing computations.

3. If either of the two conditions were met, then the routed hydrograph was plotted and checked for oscillations or other signs of numerical instability. The routed peak discharges within the range did not show extreme oscillations. Reaches with routed peaks higher than the inflow were adjusted by incrementally decreasing the NSTPS until the routed peak was equal to or less than the inflow.

The second warning message is the result of the multiple storm approach simulated with the JD records. These warning messages are only reported for the index hydrographs representing drainage areas smaller than the area associated with the hydrograph being routed. For a given area, regardless of the contributing drainage size, peak discharge for each index hydrograph will decrease with increasing area. Therefore, the hydrologic routing cross-section capacity can be exceeded at lower index areas but be adequate for larger index areas. A warning message will be generated just for those index areas where the peak inflow is larger than the maximum capacity of the section. This message is only of concern if the index area for which the message is generated is used in interpolation of the runoff hydrograph for the specific location. For example, if the index areas generating the message are 0.0001, 0.5, and 2.8 square miles (referring to Table 4-4) and the drainage area for the routing reach is 20 square miles, then the hydrographs for index areas of 0.0001, 0.5, and 2.8 square miles are not used. Only the bounding area index hydrographs, in this example 16 and 90 square miles, are used for the interpolated hydrograph and subsequent downstream operations. This is the case for all routing reaches for which this warning message occurs. Therefore, no action was required.

The third warning message listed is in regard to the rainfall loss calculations performed by HEC-1 using the Green and Ampt methodology. After satisfying the surface retention loss requirement, HEC-1 then performs check calculations for each modeling time period to determine when a combination of accumulated rainfall and sufficient rainfall intensity occur to begin ponding (rainfall excess generation). All rainfall is infiltrated to that point and accounted for in the calculations. Once the program determines that ponding has occurred, an infiltration rate is then calculated for each time period and subtracted from the rainfall intensity for that same period to obtain the rate of rainfall excess. Due to HEC-1 computing limitations, it is possible to have rainfall intensity for the modeling time period that results in the calculation of a ponding condition, yet that ponded depth is less than the calculated infiltration capacity of the soil for that time period. This results in a negative value for the rainfall excess calculation. HEC-1 issues its message and sets the loss to zero. This message is not an indication of model instability and may be disregarded.

4.4 Calibration

Calibration of the HEC-1 model is not possible because of the lack of available data. In lieu of calibration, indirect methods of model verification were performed and compared to the modeling results. The indirect methods follow the methodology as described in Chapter 8 of the Design Manual. However, the indirect methods analysis is more of a verification of results rather than a model calibration effort. The indirect methods analysis will be discussed further in Section 4.5, Final Results.

4.5 Final Results

The final results will be presented in the next three subsections, followed by a discussion of verification of results. The first discussion will address the "With Levee" condition results, next the "Without Levee" condition, and finally a comparison of the effects on the watershed of the controlling scenario between the two conditions. The electronic HEC-1 input and output files and the DDMSW files are included on the data disc in Appendix E.

4.5.1 Hydrologic Analysis Results

4.5.1.1 With Levee Condition

The "With Levee" model accounts for the effects of the non-levee embankment structures within the watershed. These structures, highlighted in the Levee Structures Map (Figure 4-5) are the CAP Canal, I-10, Salome Highway, an agricultural berm, a stock tank, and berms at the Palo Verde Nuclear Generating Station . The structures affect the drainage characteristics by rerouting flow from its historical flow paths or, as in the case with the CAP Canal, creating a ponding condition in which runoff is stored on the upstream side. Due to the large quantity of output generated from the models, the summary tables for the results are located in Appendix D rather than in the body of the report. However, an overview of the model results, organized by the major physical features, is provided in the following sections.

CAP Canal

The peak discharges north of the CAP Canal range from 5,306 cfs at subbasin S105 to 57 cfs at subbasin S500. The subbasins are typically controlled by the 6-hour storm event; however, basins that are primarily larger than 2.5 square miles are controlled by the 24-hour event. The smaller basins, such as S500, S600, S150, S251, and S252, are less than 0.25 square mile and consist of small areas that drain directly to the CAP Canal embankment. Concentration point discharges along the canal embankment range from 9,156 cfs at C199T to 3,124 cfs at C410I. The high discharges reflect the steep mountainous terrain and high percentages of rock outcropping. The steep slopes typical of the routing reaches, ranging from 0.93% to 2.70%, minimize the attenuation in the channels, keeping the flow rates high at the concentration points. The runoff ponds against the CAP Canal, attenuating a large amount of runoff volume before discharging across the canal at multiple overchutes. Table 4-10 summarizes the effects of the CAP Canal storage on the model.

Table 4-10

Storage Effect Summary

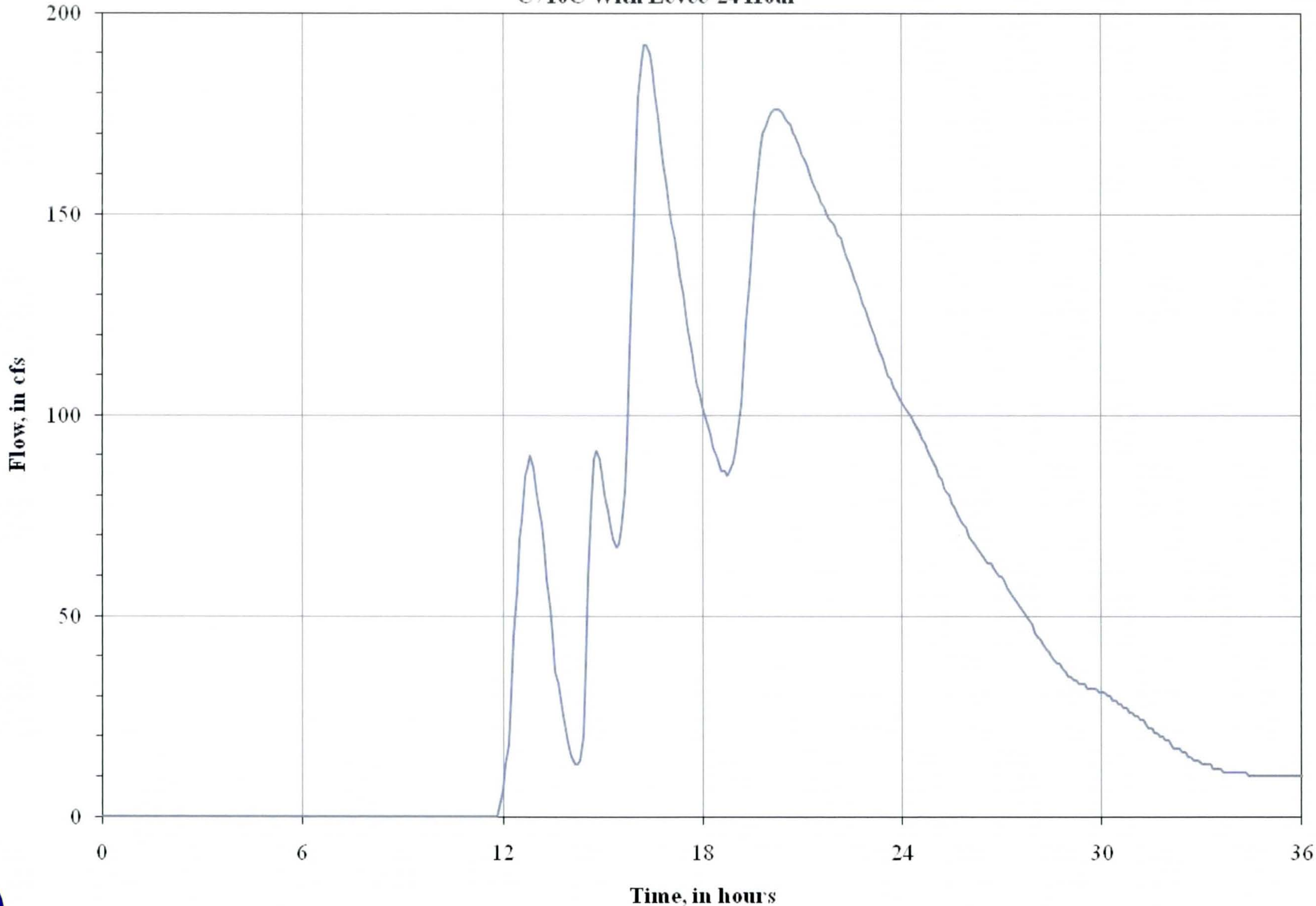
HEC-1 ID	Drainage Area sq. mi.	Controlling Storm	Peak Inflow cfs	Time to Peak hours	Peak Outflow cfs	Time to Peak hours
C100O	6.22	24-hour	2,479	13.17	404	15.08
C199O	52.994	24-hour	9,156	14.50	1,485	17.67
C253OS	29.521	24-hour	6,664	13.67	1,042	16.33
C345O	13.003	24-hour	6,640	12.42	282	15.50
C410O	3.525	24-hour	3,124	12.42	1,951	12.67
C500O	0.019	6-hour	57	4.08	32	4.17
C600O	0.058	6-hour	176	4.08	58	4.17
C700O	0.748	6-hour	1,148	4.25	332	4.75
C47O*	35.99	24-hour	3,416	14.17	1,526	15.92

*C47O is the inflow hydrograph from the Jackrabbit Wash study.

The watershed south of the CAP Canal is characterized by flatter desert rangeland with defined desert washes or agricultural land. The south portion is modeled in more detail to provide locations for peak discharges for the floodplain delineations of the study washes. The subbasins have lower peak discharges and unit discharges due to the smaller sizes and less impervious area from naturally occurring rock outcrop. The discharges range from 4,251 cfs from S780A to 78 cfs from S710H. The concentration point discharges range from 9,712 cfs in Fourmile Wash at C790E to 85 cfs at C700I in the agricultural areas. The ranges of subbasin discharge for the three S-graph classifications are 5,306 cfs to 57 cfs for Mountain, 1,750 cfs to 131 cfs for Desert/Rangeland, and 1,248 cfs to 78 cfs for Agricultural. The individual subbasins are generally controlled by the 6-hour duration storm with the exception of some of the larger basins that are greater than 2.50 square miles. However, the concentration points are controlled primarily by the 24-hour duration because of the large area at the combine locations. The flatter reach routings, which mainly have slopes less than 1%, have more attenuation than the reaches north of the CAP Canal.

In many cases, the hydrographs of the reach routes have multiple peaks due to agricultural activities and the numerous flow splits with varying times to peak occurring in the watershed. Given the complexity of the watershed, the multiple-peak hydrographs were expected. An example of this is shown in Figure 4-12 which presents the plotted hydrograph for C710C for the "With Levee" 24-hour storm event. C710C is downstream of three flow splits: two are natural splits and one is in the agricultural fields. The concentration points at each split and the contributing subbasin S710C all have varying times to peak. The most upstream concentration point, C700B, splits and the portion of flow that is directed to the east, D700BL, peaks with 922 cfs at 13.17 hours. D710AL peaks with 612 cfs at 13.42 hours, D710BL peaks with 144 cfs at 14.58 hours, S710C peaks at 12.83 hours, and C710C peaks with 192 cfs at 16.33 hours. Figure 4-13 shows the model logic for the area contributing to C710C.

Figure 4-12
C710C With Levee-24 Hour



Agricultural Fields

The agricultural fields have a large impact on the results of the hydrology and have many splits throughout the area. The splits are the result of the many small man-made agricultural berms, ditches, culverts, and roads scattered throughout the fields. The cross-sectional geometry of reach routes through the fields are not based on a sampled cross-section but rather a section that is typical of the farm field geometry, which is shallow and very wide. The intent of the modeling of a typical section is to mimic the typical behavior of runoff in agricultural areas by reducing the velocity and attenuating the flow. A high channel roughness coefficient, n=0.10, was chosen to represent the effects of tilled irregular ground with heavy vegetation. The reach routing velocities are low, less than 1 ft/sec, in the sheet flow areas of the fields.

The resulting hydrographs produced the expected results of the anticipated attenuation in the agricultural fields. The peak discharges were lowered and the times to peak lengthened as the runoff was routed through a series of flow splits across the fields. An example of the effects of the farm field is C710B with the controlling 24-hour duration storm. Concentration point C710B has a natural desert rangeland upstream contributing area typical of the watershed. The runoff then splits at C710B when the runoff reaches the farm fields and flow is routed through the typical farm field cross-section. The results are illustrated in Table 4-11 C710B, Farm Field Example Summary. The times to peak for the routing reaches from C710B are much longer than the time to peak of the concentration point and flow split. The routed peak discharges are reduced, which is expected due to the attenuation in the reaches. Figure 4-13 shows the model logic for the area of C710B. This figure is provided for illustrative purposes only. For more detailed refer to the full size exhibits included with this report.

Table 4-11

C710B Farm Field Example Summary

HEC-1 ID	Peak Flow cfs	Time to Peak hours	Downstream HEC-1 ID
C710B	360	14.58	D710BR/D710BL
D710BR	216	14.58	R710BR
D710BL	144	14.58	R710BL
R710BR	191	16.33	C710C
R710BL	135	15.42	C710E

FLOOD CONTROL DISTRICT OF MARICOPA COUNTY	
DATE:	07-30-2010
SCALE:	NTS
DRAWN BY:	NBL

FIGURE 4-13
C710C/C710B EXHIBIT

PALO VERDE WATERSHED DETAILED FDS
F.C.D. CONTRACT NO. 2008C046

Entellus IN ASSOCIATION WITH Stantec

Interstate-10 and Salome Highway

Interstate 10 and Salome Highway affect the hydrologic modeling due to the flow splits that the features create. The inflow hydrograph is split and a portion of the runoff is directed across the roadway, and the remainder is redirected to the east. Table 4-12 summarizes the flow splits occurring along I-10 and Salome Highway.

Table 4-12

I-10 / Salome Highway Flow Split Summary

HEC-1 ID	Inflow cfs	Flow Across I-10 cfs	Diverted Peak Flow cfs
Interstate 10			
S100A	691	535	156
C100B	528	30	498
C120E	512	379	133
S136A	162	77	86
S175B	723	638	84
C175C	236	228	8
C180F*	760	500	261
Salome Highway			
C720E*	269	260	9
C720I*	2,162	2,127	35
C760M*	2,096	408	1,687
C770C*	1,674	1,355	319

*Controlled by the 24-hour event; all others are controlled by the 6-hour event.

Stock Tank

Another important feature in the "With Levee" condition model is the stock tank located just downstream of the CAP Canal on the eastern side of the watershed. The stock tank was constructed with an earthen berm and is considered to act as a levee since it redirects the flow from C47O to the west into subbasin S700A as runoff exceeds the tank capacity. The inflow hydrograph to the stock tank is from the Jackrabbit Wash overchute and is controlled by the 24-hour condition with a peak flow of 1,526 cfs peaking at 15.92 hours. The time to peak for C47O is much longer than the adjacent basins and routings, which results in multiple peaks in the hydrographs downstream.

4.5.1.2 Without Levee Condition

The "Without Levee" model removes the effects of the structures identified as levees in the "With Levee" model. These structures, highlighted in the Levee Structures Map (Figure 4-5) are the CAP Canal, I-10, Salome Highway, an agricultural berm, a stock tank, and berms north and south of the Palo Verde Nuclear Generating Station. The "Without Levee" model assumes that these structures are not present during the storm events. Once the levee structures were removed, model had to be revised to remove the storage routings and certain reach routingsin some areas while adding routes in others. For example, along I-10 where flow would split in the "With Levee" model but not in the "Without Levee" condition since I-10 is not modeled, the "split" reaches were removed from the model and the routings were treated as "flow through" conditions. However, some areas also required the addition of new reaches, specifically along the CAP Canal and the agricultural and Palo Verde Nuclear Generating Station berms. Without the canal and berm re-directing the runoff, the flow will pass through unimpeded, requiring new reaches downstream of the canal/berms.

The individual subbasin discharges remain unchanged with respect to the "With Levee" model, since the levee conditions do not affect the subbasin runoff. The basins remain controlled primarily by the 6-hour storm event except for basins larger than roughly 2.50 square miles. The concentration points range from 18,236 cfs at C790E along Fourmile Wash to 111 cfs at C710L in the agricultural areas. As a result of the higher flows, the cross-sections for some of the reaches had to be extended to keep the flow contained so the routed flow does not exceed the stage-discharge rating curve. Due to the large quantity of output generated from the models the summary tables for the results are located in Appendix D rather than in the body of the report. However, an overview of the model results, organized by each of the major features, is provided in the following sections.

<u>CAP Canal</u>

The portion north of the CAP Canal is unchanged from the "With Levee" model up to the canal. Since the canal is not modeled the storage is not accounted for and the full inflow hydrographs are routed into the south portion, this produces a significant change to the results due to the higher peaks and lack of attenuation time behind the canal. The removal of the canal also adds additional locations of where flow crosses the canal requiring additional routing reaches. Table 4-10 in the "With Levee" discussion illustrates the effects of the CAP Canal storage on the hydrology and lists the inflow hydrographs with the peak discharge and time to peaks. The additional flow added to the south portion of the model affects the entire watershed area downstream as can be seen by concentration point C790E near the downstream end of Fourmile Wash, which is the point of maximum flow magnitude in the watershed for both conditions. In the "With Levee", C790E has a peak flow of 9,712 cfs and in the "Without Levee" condition the peak flow at C790E is 18,236 cfs.

An example of the impacts of the CAP canal is illustrated in Table 4-13; the table summarizes the downstream effects of the removal of the canal storage for the 24-hour storm duration. Due to the changes in the model logic from the removal of the canal, some concentration points are not in both models but are unique to each condition. For this example, the 200 series subbasins are presented. The 200 series subbasins in the north area "With Levee" condition combine at C253T before the storage route at the CAP Canal, C253OS. The combined runoff is routed through the storage route which outlets to three overchutes. The routings resulting from the overchutes are from diversions D225T, D235T, and D251T. In the "Without Levee" condition, the logic is altered so that storage route outflow at C253OS does not exist and the subbasins that would drain from the north into C253T now flow directly into the south basins through concentration points C225, C235, C240, C251, and C253, refer to the different logic diagrams for each levee condition.

There are two flow splits, D215BL and D215DL, from the "100 series" subbasin area that flow from the west into the "200 series" basins in the example. Due to the effects of the removal of the canal has on the "100 series" model, the two flow splits have been altered. The "200 series" area in the example drain toward I-10 and cross at three locations, C216B, C217B, and C253K, before combining at concentration point C253L downstream of I-10. The three crossings at I-10 are in both levee condition models and are flow-through crossings where there are no splits in either condition.

Table 4-13

CAP Canal Impact Summary

With Levee Condition		Without Levee Condition	
HEC-1 ID	**Peak Flow cfs**	**HEC-1 ID**	**Peak Flow cfs**
C253T	6,664	N/A	-
C253OS	1,042	N/A	-
D225T	333	C225	2,936
D235T	347	C235	1,985
N/A	-	C240	1,353
D251T	362	C251	1,300
N/A	-	C253	739
D215BL	577	D215BL	756
D215DL	457	D215DL	2,040
C216B	418	C216B	418
C217B	872	C217B	2513
C253K	2,170	C253K	5,999
C253L	2,658	C253L	7,905

<u>Stock Tank</u>

The stock tank located just downstream of the CAP Canal on the eastern side of the watershed has a significant impact on the results of the model since it affects the inflow hydrograph from the Jackrabbit Wash Floodplain Delineation study. The inflow hydrograph (C47I) is controlled by the 24-hour condition with a flow of 3,416 cfs peaking at 14.17 hours and, since it is the inflow hydrograph, is not routed through the storage routing to account for the CAP Canal. Since the stock tank is not modeled in the "Without Levee" condition, the flow from C47I is not redirected into S700A as in the "With Levee" model; instead, the runoff is routed into subbasin S740A. Table 4-14 illustrates the impact of the stock tank on subbasins S700A and S740A.

Table 4-14

Stock Tank Impact Summary

HEC-1 ID	With Levee		Without Levee	
	Peak Flow cfs	Time to Peak hours	Peak Flow cfs	Time to Peak hours
C47O/I	1,526	15.92	3,416	14.17
C700A	1,533	16.58	724**	13.00
(S740A) C740A*	1,270**	12.58	3,366	14.67

*In the "With Levee" condition there is no C740A since only subbasin S740A is contributing. In the "Without Levee" condition the flow from C47I combines with S740A at C740A.

**S740A is controlled by the 6-hour event with 1,373 cfs at a TP at 4.67 hours. The 24-hour peak discharge (1,270 cfs) is listed in this table just for the comparison to the 24-hour data listed for the other elements. Likewise, C700A is controlled by the 6-hour event with a peak discharge of 886 cfs at a TP of 5.00 hours.

I-10 and Salome Highway

Several split flow locations along I-10 and Salome Highway were removed as part of the "Without Levee" condition. The watercourse alterations have an impact on downstream flow magnitudes as well as which areas receive flow from the split. To illustrate the effects of I-10 on the model results for each levee condition, Table 4-15 summarizes the conditions of subbasins S100A and S100B for the 6-hour storm duration. These two subbasins were selected because they are not impacted by the CAP Canal; the downstream location where they combine at concentration point C100C is affected only by the I-10 levee condition. For the "With Levee" condition, S100A splits at I-10, and the right split, D100AR, crosses through culverts under the interstate and leaves the watershed and does not return. The left split, D100AL, flows along the upstream side of the interstate to C100B via routing reach R100A. At C100B, another flow split occurs at the interstate culverts and the right split, D100BR, flows to C100C via routing reach R100BR. The left split, D100BL, flows along the upstream side of I-10 to concentration point C120E. In the "Without Levee" condition, I-10 is not modeled and therefore the splits don't occur. Subbasins S100A leaves the watershed and does not return, and S100B is routed directly to C100C via routing reach R100B.

Table 4-15

Interstate 10 Impact Summary

With Levee Condition		Without Levee Condition	
HEC-1 ID	**Peak Flow cfs**	**HEC-1 ID**	**Peak Flow cfs**
S100A	691	S100A	691
D100AR	535	-	-
D100AL	156	-	-
R100A	132	-	-
S100B	548	S100B	548
C100B	528	-	-
D100BR	30	-	-
D100BL	498	-	-
R100BR	24	R100B	416
S100C	789	S100C	789
C100C	600	C100C	690

As previously mentioned, the I-10 example for subbasins S100A and S100B is not impacted by the CAP Canal levee condition; it is only impacted by the I-10 levee condition. For other areas where the canal and I-10 levee conditions affect the model, the differences in the results are compounded and become more complex. Although the majority of the wash crossings along Salome Highway are at-grade dip sections, several locations have culverts that create flow splits. Since the splits occur as a result of the roadway, it is considered as a levee and therefore removed for the "Without Levee" condition.

Palo Verde Power Plant Berms

The Palo Verde Nuclear Generating Station, located in the southern portion of the watershed, is considered to be non-contributing in the "With Levee" condition. The reason for this is that the off-site runoff is prevented from entering the site by berms on the northern edge and the on-site runoff is retained on-site behind above grade berms. The "Without Levee" condition does not include the berms, so the off-site flow from C910O is routed through the power plant as R910O, and the on-site runoff leaves the site instead of being retained. This required an additional subbasin for the power plant area, SPVGS. Reach route R910O and the runoff from SPVGS is routed through S920K by the additional routing reach RPVGS, which increases the runoff through the series of reaches downstream. The cooling ponds located south of the power plant are still considered to be non-contributing since they are jurisdictional dams regulated by ADWR.

Subbasin SPVGS generates an additional 2,158 cfs at C920K via route RPVGS. The runoff along the eastern side of SPVGS is reduced since runoff from C910O is routed through SPVGS instead of around it. However, the impact of the additional flow from SPVGS can be seen at C920M where all the flow combines. Table 4-16 illustrates the impact resulting from the change around the power plant.

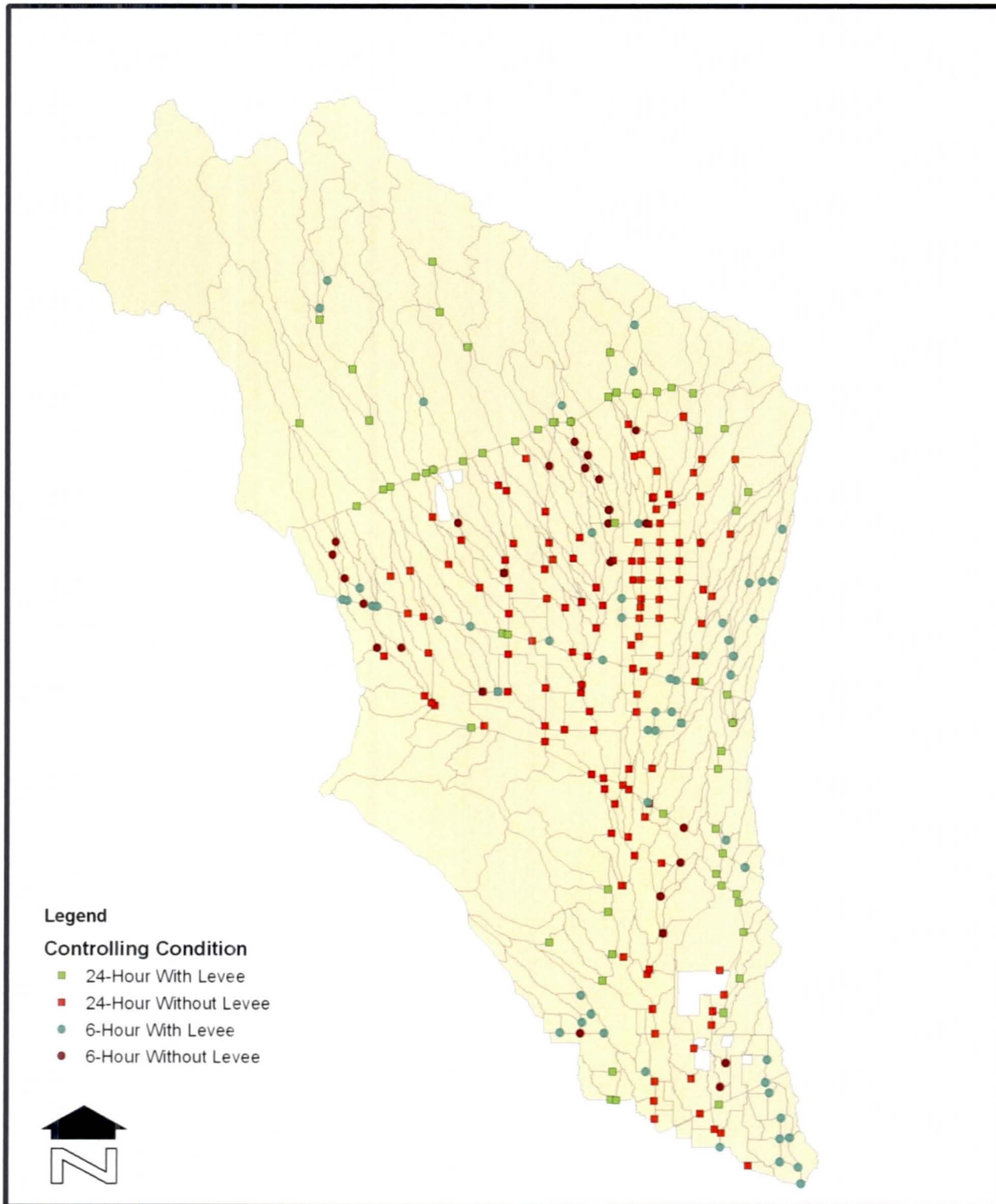
Table 4-16

Palo Verde Power Plant Impact Summary

HEC-1 ID	With Levee Peak Flow cfs	Without Levee Peak Flow Cfs
C910O	982	982
C920D	1,274	662
C920E	1,273	806
C920F	1,224	735
C920H	1,203	879
C920J	1,196	846
C920M	1,221	2,158

4.5.1.3 Controlling Condition

The models for both storm durations for each levee condition were compared to determine the controlling condition at each concentration point location throughout the watershed. However, it should be noted that the models are unique because the levee condition does change the logic of the model and some concentration points are unique to each model. Therefore, certain areas can be difficult to directly compare. The subbasin peak flows are the same for each levee condition since the levee scenarios have no impact on the outflows and, as mentioned in the previous sections, the subbasins are primarily controlled by the 6-hour storm. Figure 4-14 illustrates graphically the controlling scenarios throughout the watershed. The exhibit was created by compiling the concentration points for each scenario. First, the concentration points were compared to determine the storm event that produced the maximum peak flow for each levee condition, and then the two sets of concentration points were compared to determine the final controlling condition. The exhibit is meant to give an approximate idea of where each scenario controls. The portion north of the CAP canal is not impacted by the different levee scenarios. For illustrative purposes, these locations are shown as being controlled by without levee. However, at the CAP Canal, the "With Levee" condition controls due to the hydrograph combining at the storage routes. However, downstream of the canal, the "Without Levee" condition controls since the storage is no longer accounted for. In general, with the exception of areas directly around the levee structures, downstream of the CAP Canal the south portion of the watershed is controlled by the 24-hour event of the "Without Levee" condition. Some locations are very close in the peak flow, within a few cfs, and might be controlled by the "Without Levee" condition even though there are no levee structures present that affect the flow characteristics. This is only the result of minor differences in reach routing NSTPS that might vary by 1 NSTPS. It was not deemed necessary to set custom NSTPS for reaches that might differ by 1 step between the models. A summary table providing the complete comparison of each concentration point for the controlling storm event and the controlling levee condition is supplied in Appendix D.



FLOOD CONTROL DISTRICT OF MARICOPA COUNTY		Figure 4-14 Controlling Condition Exhibit	PALO VERDE WATERSHED DETAILED FDS F.C.D. CONTRACT NO. 2008C046
DATE:	07-30-2010		Entellus IN ASSOCIATION WITH Stantec
SCALE:	NTS		
DRAWN BY:	NBL		

4.5.2 Verification of Results

The results of the models were verified to check the reasonableness of the model results against regional data for Arizona. The results of the 6- and 24-hour storm durations for both levee conditions were verified against three indirect methods as described in Chapter 8 of the Design Manual. Method 1 contains envelope curves that are based upon flood, discharge, and streamflow data that is generally collected from the western part of the United States. Method 2 focuses on USGS streamflow and statistical data for the entire state of Arizona. Lastly, Method 3 focuses more closely on USGS Flood Region 13, in which the Palo Verde Watershed is located. In general, the HEC-1 results fall within the expected ranges for each of the three methods of verification.

4.5.2.1 Method 1

The first method is a check of the results of the analytical model against a series of seven unit peak discharge relations and envelope curves. A description of each of the seven curves is included in Chapter 8 of the Design Manual. Figures 4-15 and 4-16 show a comparison of subbasin and watershed combine unit peak discharges to the envelope curves for the with and without levee condition, respectively. The unit discharge data plotted is for the controlling storm at each HEC-1 operation. The vertical clustering of data points (at 30 square miles, for example) is the result of the area summation process for the hydrograph combines. With the total area added for each direction of a flow split regardless of the flow split ratio, some concentration points have large areas associated with them but with little flow. The data is expected to plot below the curves for this method since the curves are envelope curves that represent envelopes of maximum observed flood discharges for different hydrologic regions.

Figure 4-15
Indirect Verification Method 1-With Levee

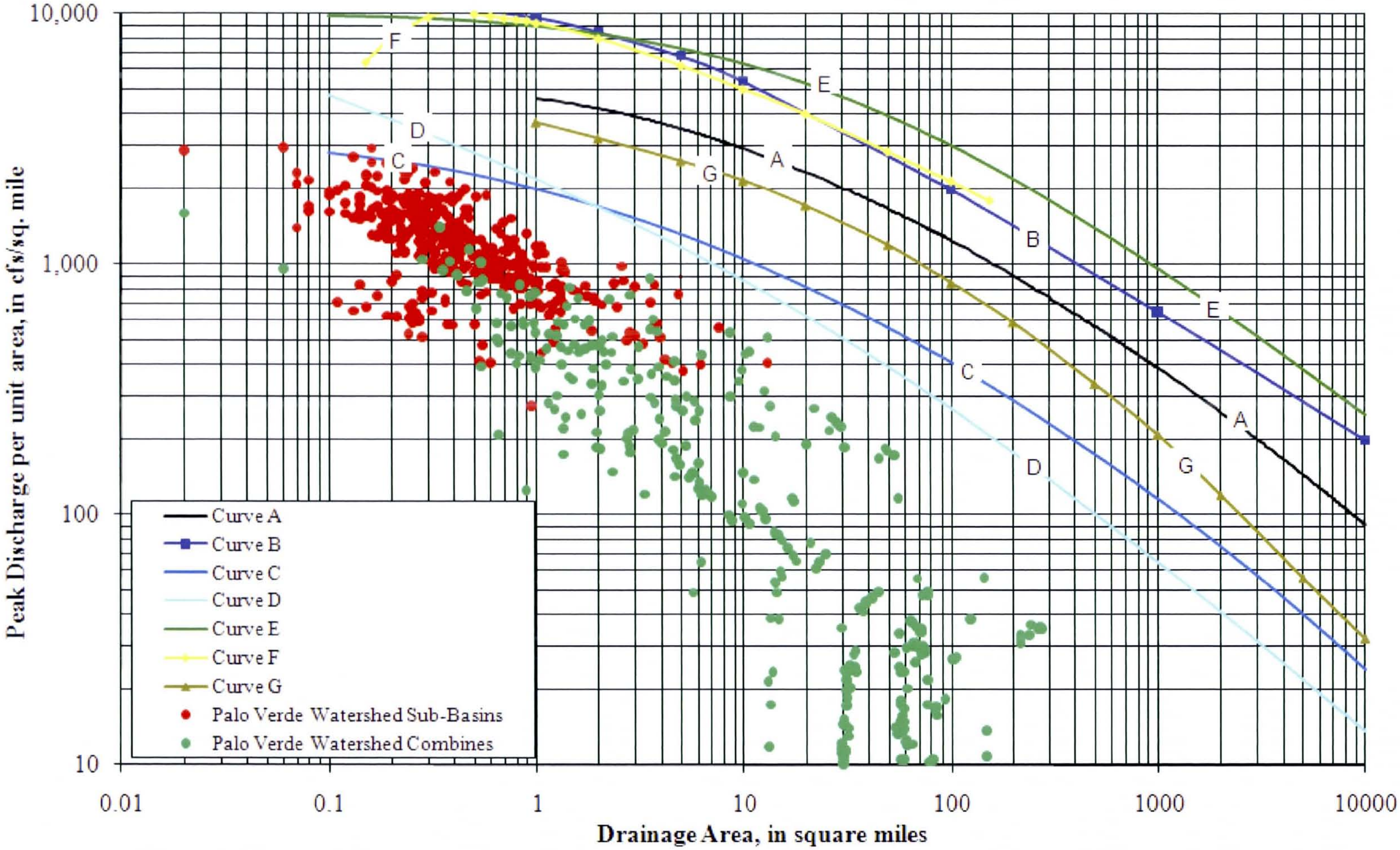
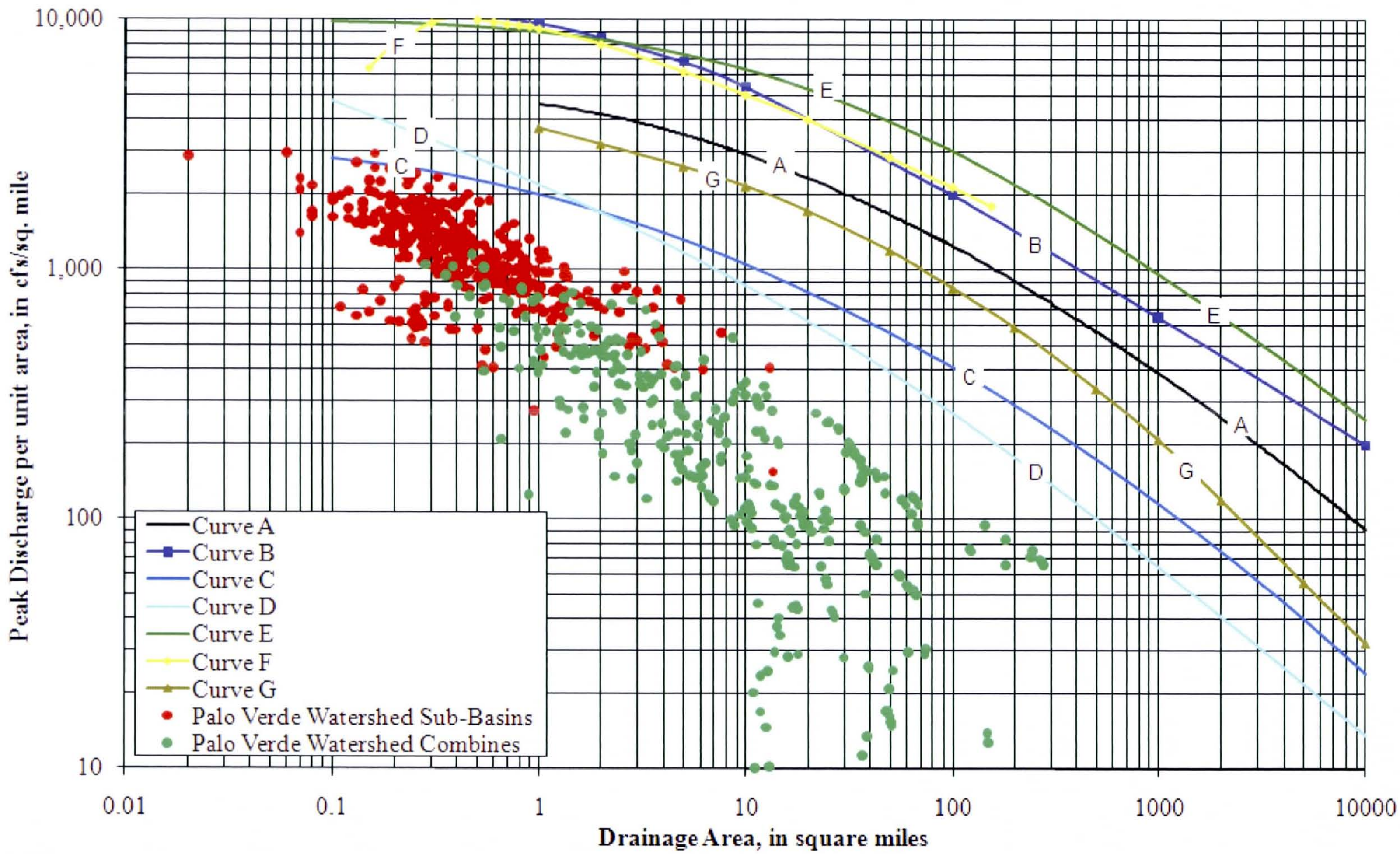


Figure 4-16
Indirect Verification Method 1-Without Levee



4.5.2.2 Method 2

The second indirect method is a check of the HEC-1 model results against streamflow and statistical data from the USGS for Arizona. The USGS data was analyzed using Log-Pearson Type 3 (LP3) analyses as described in Chapter 8 of the Design Manual. The plots for each condition illustrate that the data falls within the 75% tolerance limits with few outliers. The outlying combines are due to the same area summation process. The outlying subbasin data points are generally the agricultural areas. The model results are expected to plot within the tolerance limit lines of the graph and in general the subbasin data points are tightly clustered along the LP3 regression curve line. Although some data points fall outside of the 75% tolerance limits, the data is generally within the scatter of data for the LP3 Q100 data points. Figures 4-17 and 4-18 show the plotted unit discharges for the subbasins and combines against the USGS data for the with and without levee condition, respectively.

Figure 4-17
Indirect Verification Method 2-With Levee

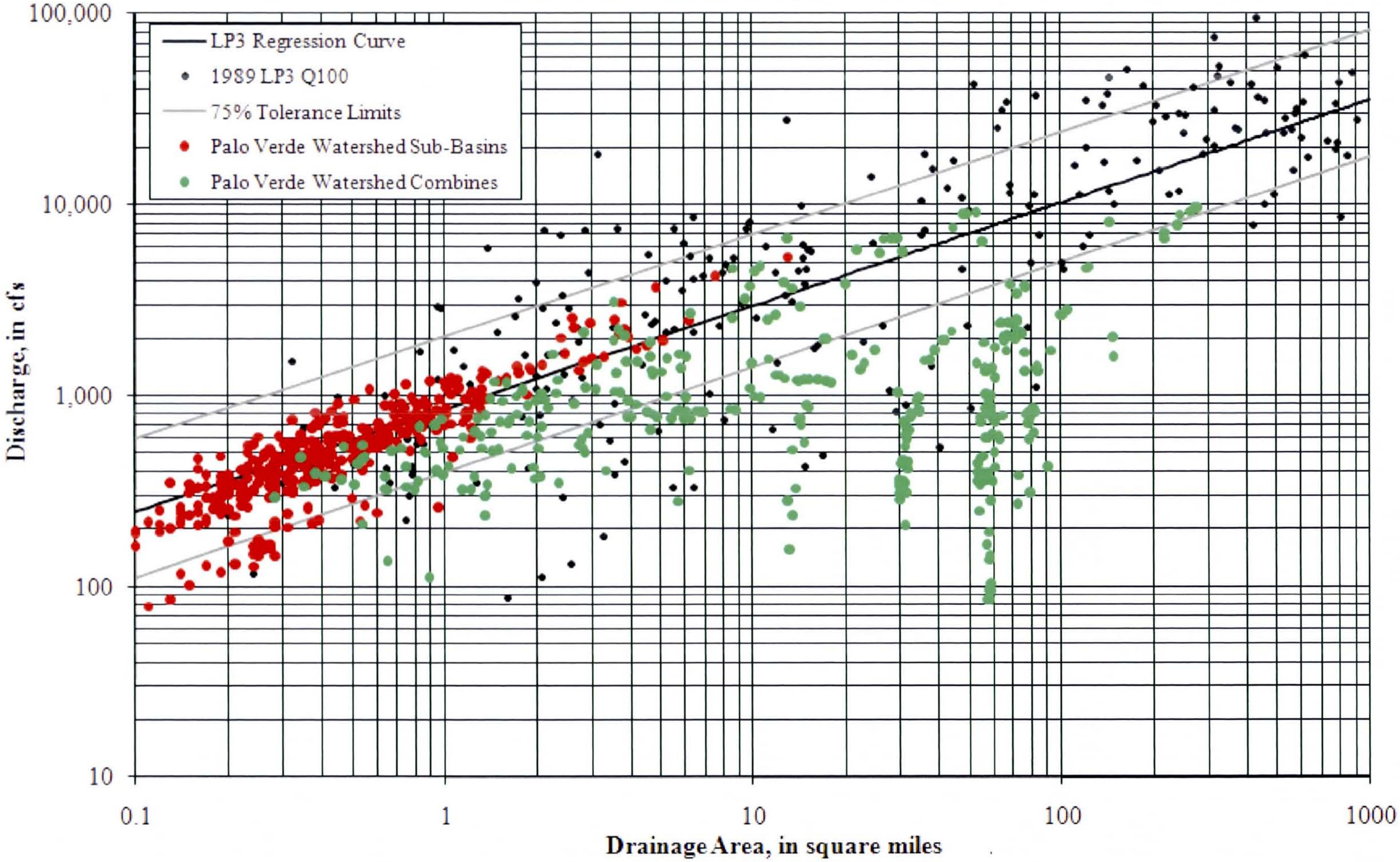
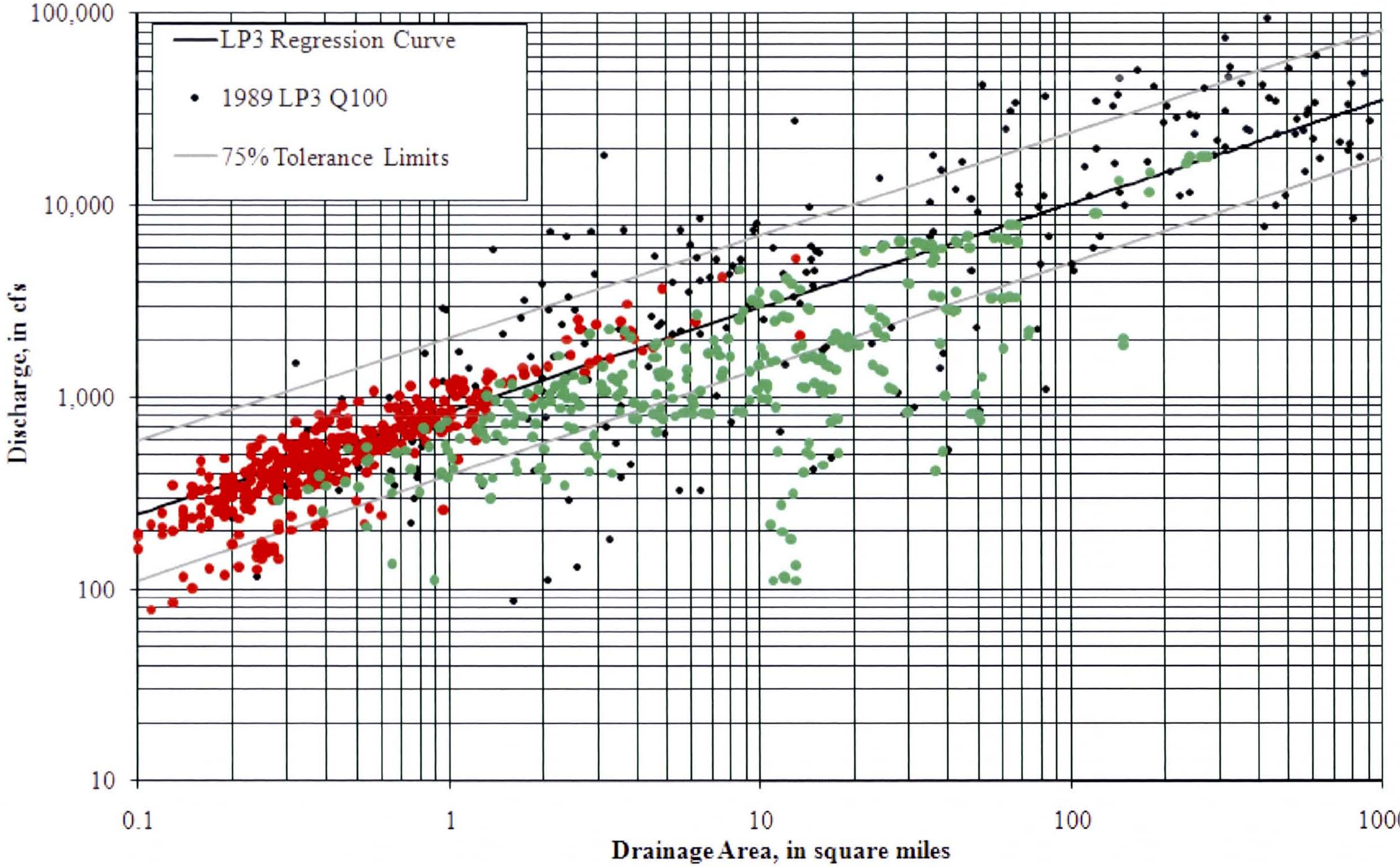


Figure 4-18
Indirect Verification Method 2-Without Levee



4.5.2.3 Method 3

The third method for verification of results is a check against regional regression equations. The watershed falls within Region 13 and the verification process follows that prescribed in Chapter 8 of the Design Manual using Table 8.3 and Figure 8.9. The plotted data for the subbasins follow just below the 100-year peak discharge relation curve and the outlying points, as previously described, are the result of the area summation process at the hydrograph combines and the agricultural S-Graph subbasins. The subbasin data points are clustered just below the 100-year peak discharge relationship curve and in general the HEC-1 results data points are within the scatter of data points for the Q100 LP3 discharge estimates. Figures 4-19 and 4-20 show the plotted unit discharges for the subbasins and combines against the Q100LP3 data for the with and without levee condition, respectively.

Figure 4-19
Indirect Verification Method 3-With Levee

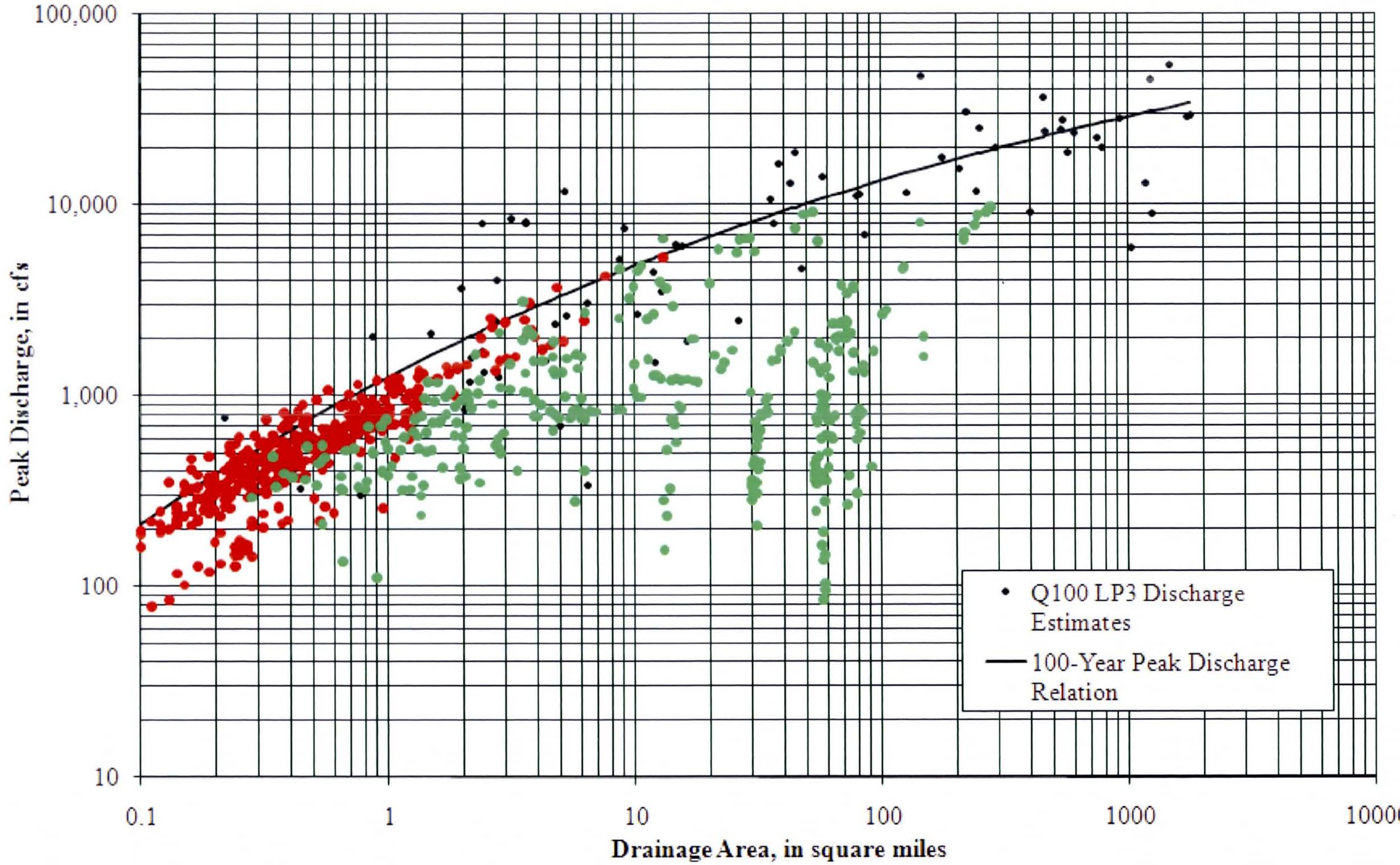
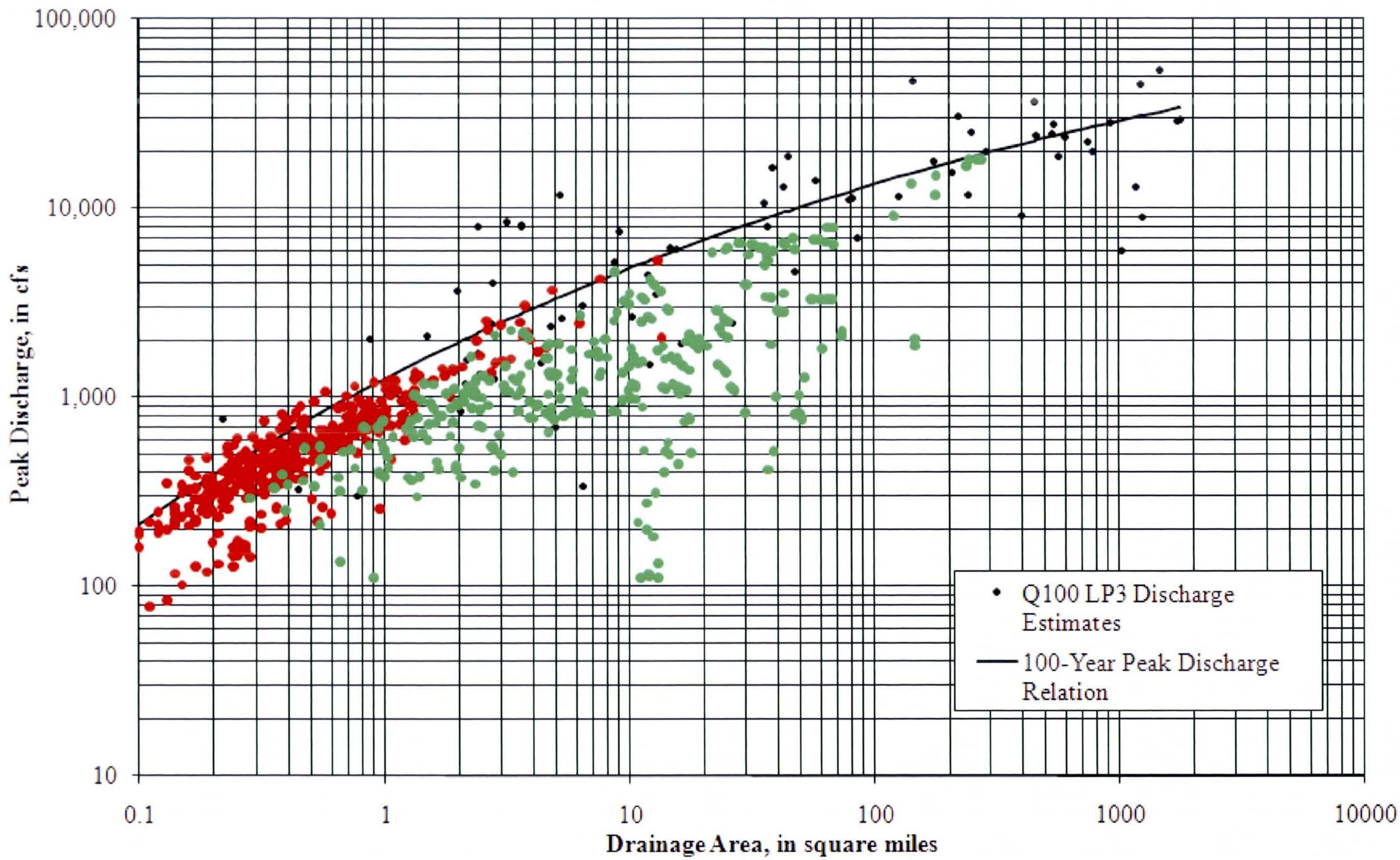


Figure 4-20
Indirect Verification Method 3-Without Levee



4.5.3 Conclusion

The purpose of this hydrology study is for the development of estimated peak discharges resulting from a 100-year (1% chance) storm at key locations in the watershed for use in delineating floodplains along designated study reaches. The focus of this particular report is to document the assumptions, methodology, analysis, and results of the hydrologic data.

The results of each scenario model compare favorably to the various indirect methods verification. The watershed characteristics and drainage patterns vary greatly depending on the levee conditions. The CAP Canal has the greatest impact on this complex watershed in terms of levee structures. The watershed along the upstream side of the CAP Canal is controlled by the "With Levee" condition, and the portion south of the canal is controlled primarily by the "Without Levee" condition with the exception of areas directly around the levee structures. It is concluded that these results are appropriate for the stated purpose of this study.

SECTION 5: HYDRAULICS

Documentation of the hydraulic modeling conducted for this study will be included in the Hydraulics TDN to be submitted at a later date.

SECTION 6: EROSION AND SEDIMENT TRANSPORT

Erosion and sediment transport analyses are not part of this study.

SECTION 7: DRAFT FIS DATA

Draft FIS data prepared as part of this study will be included in the Hydraulics TDN to be submitted at a later date.

APPENDIX A. REFERENCES

The following is a list of references used during the course of this study:

1. Palo Verde Watershed Zone A Floodplain Delineation Study Technical Data Notebook-Contract FCD 2000C021, by *Entellus*, May 2003.
2. Drainage Design Management System (DDMSW) V4.1.9, Flood Control District of Maricopa County.
3. HEC-1 4.1, Army Corps of Engineers, 1998.
4. Drainage Design Manual for Maricopa County, Arizona-Hydrology, Flood Control District of Maricopa County, November 2009.
5. Jackrabbit Wash Floodplain Delineation Study FCD90-05, Burgess & Niple, Inc., February 1991.
6. Hydraulic Design of Highway Culverts Hydraulic Design Series No. 5, U.S. Department of Transportation Federal Highway Administration, 1985

APPENDIX B. GENERAL DOCUMENTATION AND CORRESPONDENCE

Appendix B material will be provided as part of the Hydraulic TND submitted at a later date.

APPENDIX C. SURVEY AND FIELD NOTES

No additional survey was prepared for the hydrologic modeling of the watershed.

APPENDIX D. HYDROLOGIC ANALYSIS SUPPORTING DOCUMENTATION

D.1 Overview Watershed Maps

a) North

b) South – With Levee

c) South – Without Levee

Note – only overview maps are provided as hard copies. A full set of detailed maps for both the north and south portions of the watershed are provided digitally, on CD, as Appendix E.

D.2 Over View Land Use Maps

a) North

b) South – Without Levee

Note – only overview maps are provided as hard copies. A full set of detailed maps for both the north and south portions of the watershed are provided digitally, on CD, as Appendix E.

D.3 Overview Soils Maps

a) North

b) South – Without Levee

Note – only overview maps are provided as hard copies. A full set of detailed maps for both the north and south portions of the watershed are provided digitally, on CD, as Appendix E.

D.4 Logic Diagrams

a) With Levee

b) Without Levee

D.5 Jack Rabbit Wash C47I/C47O Inflow Hydrograph Data

a) 6-Hour

b) 24-Hour

D.6 Input Data-With Levee

a) Land Use Data

b) Soils Data

c) Subbasin Data

d) Diversion Data

e) Routing Data

f) Storage Routing Data

D.7 Input Data-Without Levee

a) Land Use Data
b) Soils Data
c) Subbasin Data
d) Diversion Data
e) Routing Data

D.8 Model Output

a) With Levee-6-Hour
    a. Flow Summary
    b. Routing Data / Results
b) With Levee-24-Hour Flow Summary
c) Without Levee-6-Hour Flow Summary
d) Without Levee-24-Hour Flow Summary

Note – routing data / results are provided in hard copy for the 100-year, 6-hour model only. Routing data / results for the other modeled conditions are provided digitally, on CD, as Appendix E.

D.9 HEC-1 Input and Output

a) With Levee-6-Hour
b) With Levee-24-Hour – this data is provided digitally and not in hard copy format
c) Without Levee-6-Hour Hour – this data is provided digitally and not in hard copy format
d) Without Levee-24-HourHour – this data is provided digitally and not in hard copy format

D.10 Controlling Conditions Flow Summaries

APPENDIX E. CD

APPENDIX A

References

APPENDIX A. REFERENCES

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1. Palo Verde Watershed Zone A Floodplain Delineation Study Technical Data Notebook-Contract FCD 2000C021, by *Entellus*, May 2003.

2. Drainage Design Management System (DDMSW) V4.1.9, Flood Control District of Maricopa County.

3. HEC-1 4.1, Army Corps of Engineers, 1998.

4. Drainage Design Manual for Maricopa County, Arizona-Hydrology, Flood Control District of Maricopa County, November 2009.

5. Jackrabbit Wash Floodplain Delineation Study FCD90-05, Burgess & Niple, Inc., February 1991.

APPENDIX B

General Documentation and Correspondence

APPENDIX B. GENERAL DOCUMENTATION AND CORRESPONDENCE

Appendix B material will be provided as part of the Hydraulic TND submitted at a later date.

APPENDIX C

Survey and Field Notes

APPENDIX C. SURVEY AND FIELD NOTES

No additional survey was prepared for the hydrologic modeling of the watershed.

APPENDIX D

Hydrologic Analysis Supporting Documentation

APPENDIX D. HYDROLOGIC ANALYSIS SUPPORTING DOCUMENTATION

D.1 Overview Watershed Maps

a) North

b) South – With Levee

c) South – Without Levee

Note – only overview maps are provided as hard copies. A full set of detailed maps for both the north and south portions of the watershed are provided digitally, on CD, as Appendix E.

D.2 Over View Land Use Maps

a) North

b) South – Without Levee

Note – only overview maps are provided as hard copies. A full set of detailed maps for both the north and south portions of the watershed are provided digitally, on CD, as Appendix E.

D.3 Overview Soils Maps

a) North

b) South – Without Levee

Note – only overview maps are provided as hard copies. A full set of detailed maps for both the north and south portions of the watershed are provided digitally, on CD, as Appendix E.

D.4 Logic Diagrams

a) With Levee

b) Without Levee

D.5 Jack Rabbit Wash C47I/C47O Inflow Hydrograph Data

a) 6-Hour

b) 24-Hour

D.6 Input Data-With Levee

a) Land Use Data

b) Soils Data

c) Subbasin Data

d) Diversion Data

e) Routing Data

f) Storage Routing Data

D.7 Input Data-Without Levee

a) Land Use Data

b) Soils Data

c) Subbasin Data

d) Diversion Data

e) Routing Data

D.8 Model Output

a) With Levee-6-Hour

  a. Flow Summary

  b. Routing Data / Results

b) With Levee-24-Hour Flow Summary

c) Without Levee-6-Hour Flow Summary

d) Without Levee-24-Hour Flow Summary

Note – routing data / results are provided in hard copy for the 100-year, 6-hour model only. Routing data / results for the other modeled conditions are provided digitally, on CD, as Appendix E.

D.9 HEC-1 Input and Output

a) With Levee-6-Hour

b) With Levee-24-Hour – this data is provided digitally and not in hard copy format

c) Without Levee-6-Hour Hour – this data is provided digitally and not in hard copy format

d) Without Levee-24-HourHour – this data is provided digitally and not in hard copy format

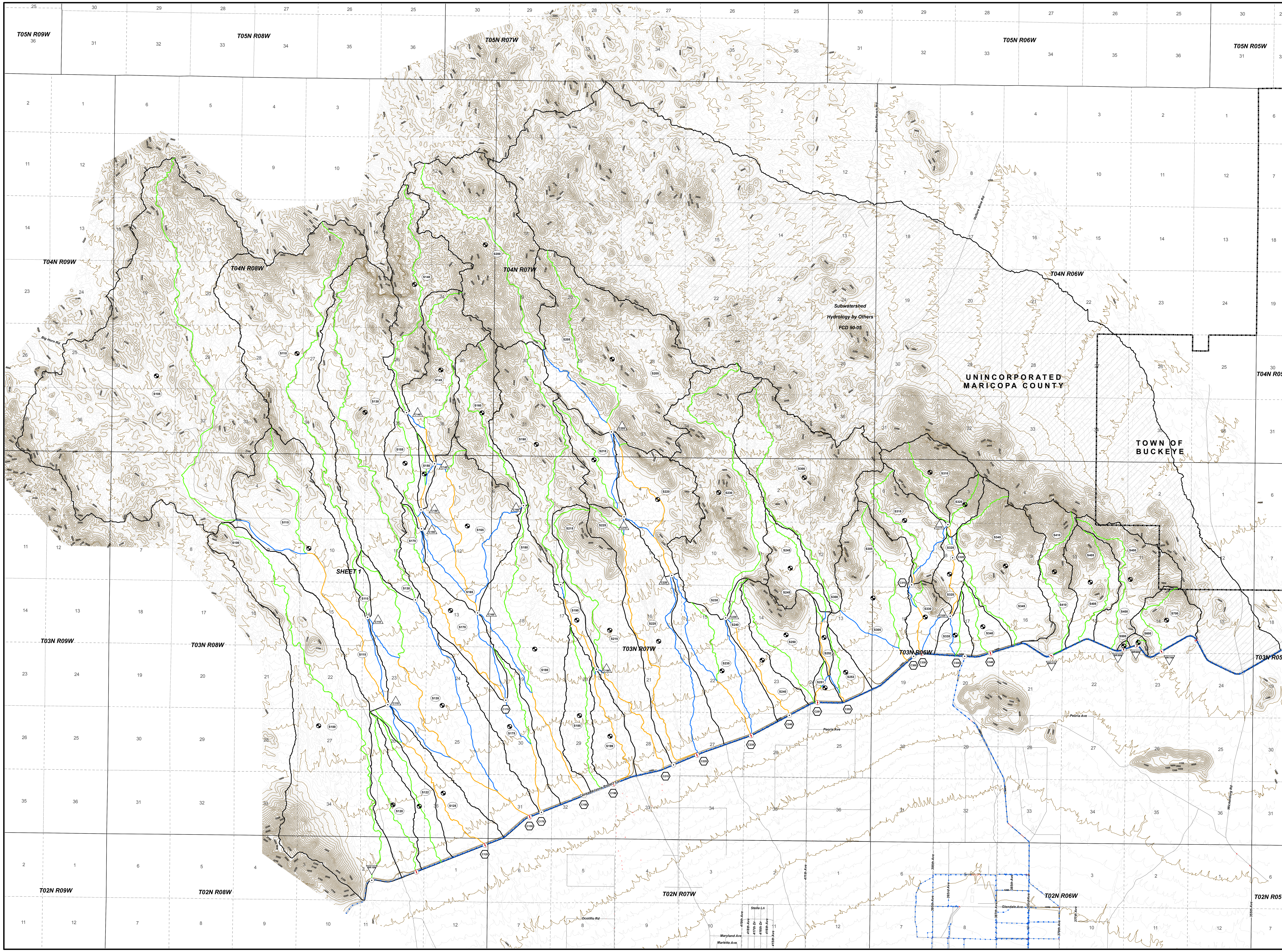
D.10 Controlling Conditions Flow Summaries

Note – only overview maps are provided in hard copy format. A full set of detailed maps for both the north and south portions of the watershed are provided digitally, on CD, as Appendix E.

APPENDIX D.1

Watershed Maps

PALO VERDE WATERSHED
DETAILED FDS
F.C.D. CONTRACT NO. 2008C046

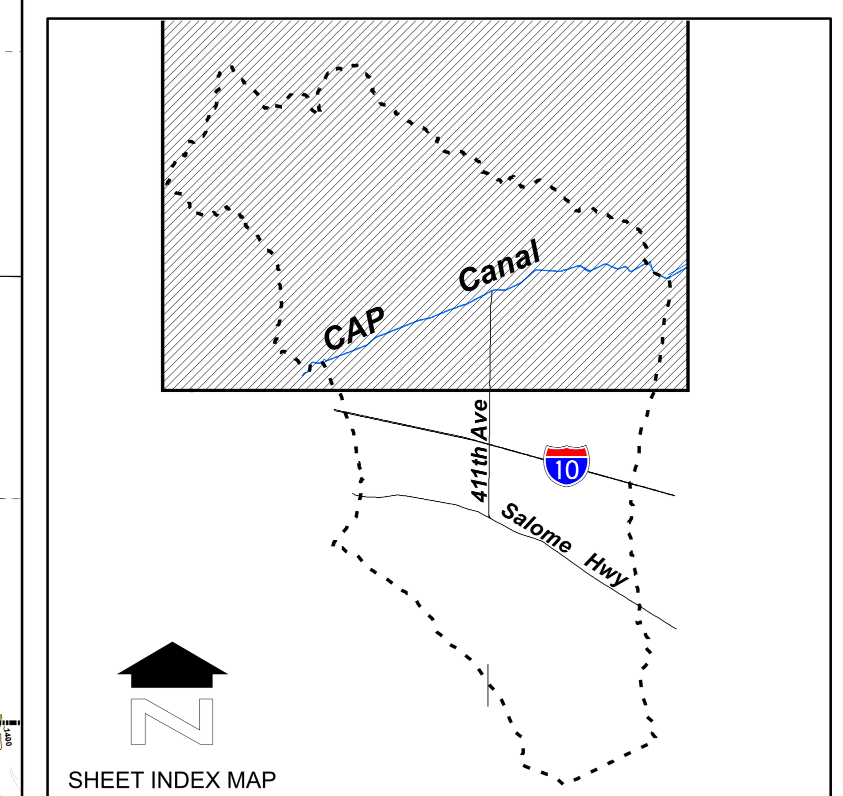


LEGEND

- Centroid
- Concentration Points
- Routing Reach
- Time of Concentration
- Routing Reach & T.O.C.
- Canal
- Culvert
- Street
- Subbasin Boundary
- City Boundary
- Section
- Township and Range
- Concentration Point ID
- Flow Split ID
- Storage Route ID

NOTES

1. Elevation Data: Circa 2000 10' C.I. mapping extracted from FCDMC countywide coverage



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North Watersheds

FLOOD CONTROL DISTRICT OF MARICOPA COUNTY

	BY	DATE
DESIGN	MG	10/22/09
DESIGN CHK.	PE	10/26/09
PLANS	MG	10/22/09
PLANS CHK.	PE	11/02/09

SHEET 1 OF 1

PALO VERDE
FLOODPLAIN DELINEATION STUDY
F.C.D. CONTRACT NO. 2008C046

LEGEND

- Centroid
- Concentration Point
- Routing Reach
- Time of Concentration
- Routing Reach & T.O.C.
- Intermediate Contour
- 50' Contour
- Canal
- Culvert
- Street
- Railroad
- City Boundary
- Section
- Township and Range

NOTES

1. Elevation Data: Circa 2000 10' C.I. mapping extracted from FCDMC countywide coverage

CAP Canal
411th Ave
10
Salome HWY
SHEET INDEX MAP

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Fax 602.244.8947
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South Watersheds without Levee

FLOOD CONTROL DISTRICT OF MARICOPA COUNTY

	BY	DATE
DESIGN	-	12 FEB 2010
DESIGN CHK.	-	12 FEB 2010
PLANS	-	12 FEB 2010
PLANS CHK.	-	12 FEB 2010

SHEET 1 OF 1

T03N R08W
T03N R07W
T03N R06W
T03N R05W
T02N R08W
T02N R07W
T02N R06W
T02N R05W
T01N R08W
T01N R07W
T01N R06W
T01N R05W
T01S R07W
T01S R06W
T01S R05W
T02S R07W
T02S R06W
T02S R05W
Non-Contributing Area
PALO VERDE
FLOODPLAIN DELINEATION STUDY
F.C.D. CONTRACT NO. 2008C046
LEGEND
Centroid
Concentration Point
Routing Reach
Time of Concentration
Routing Reach & T.O.C.
Intermediate Contour
50' Contour
Canal
Culvert
Street
Railroad
City Boundary
Section
Township and Range
NOTES
1. Elevation Data: Circa 2000 10' C.I. mapping extracted from FCDMC countywide coverage
CAP Canal
411th Ave
10
Salome HWY
SHEET INDEX MAP
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REVISION
BY
DATE
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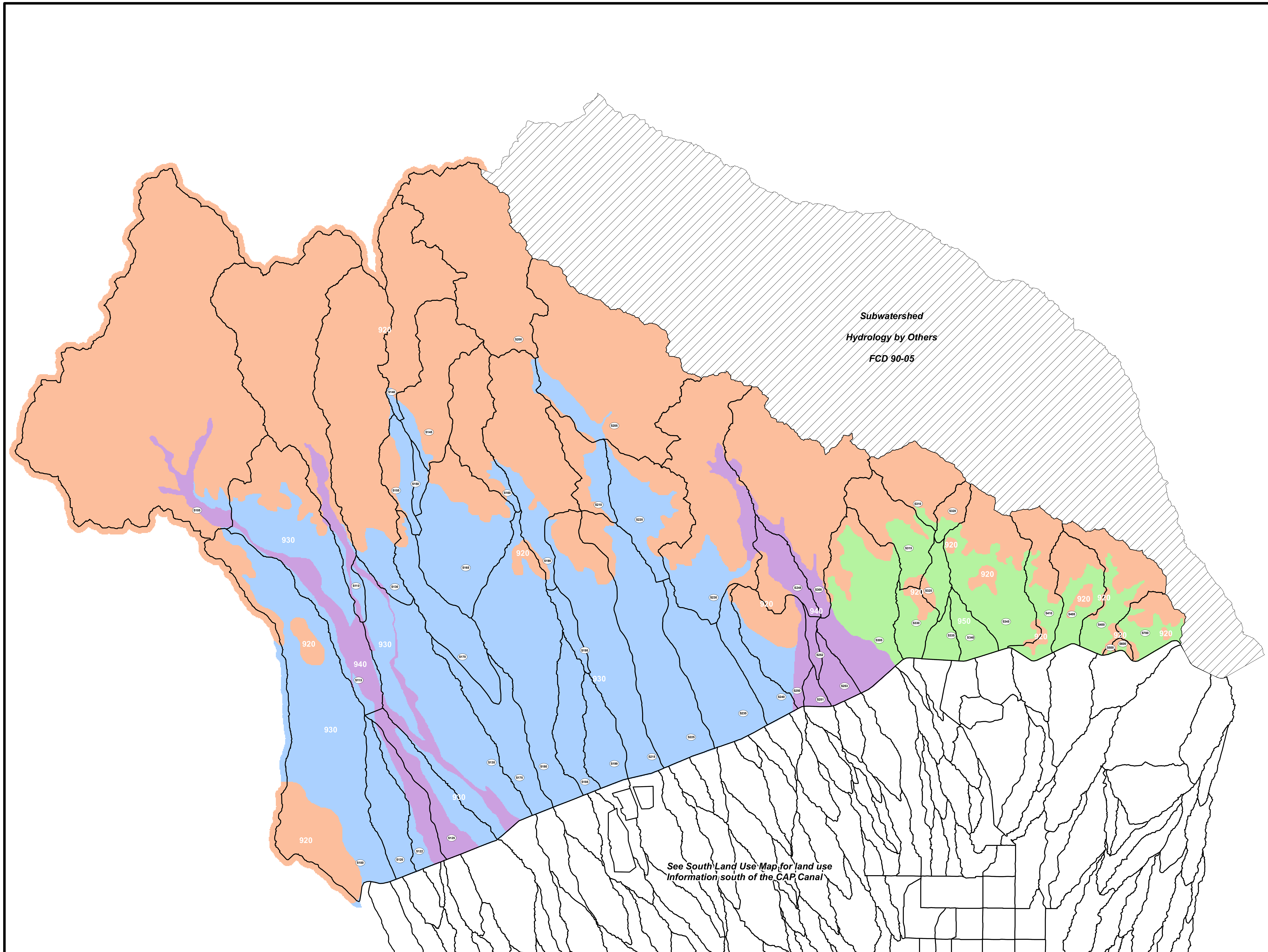
Phoenix, AZ U.S.A. 85044
South Watersheds with Levee
FLOOD CONTROL DISTRICT OF MARICOPA COUNTY
BY
DATE
DESIGN
-
12 FEB 2010
DESIGN CHK.
-
12 FEB 2010
PLANS
-
12 FEB 2010
PLANS CHK.
-
12 FEB 2010
SHEET 1 OF 1

Note – only overview maps are provided in hard copy format. A full set of detailed maps for both the north and south portions of the watershed are provided digitally, on CD, as Appendix E.

APPENDIX D.2

Land Use Maps

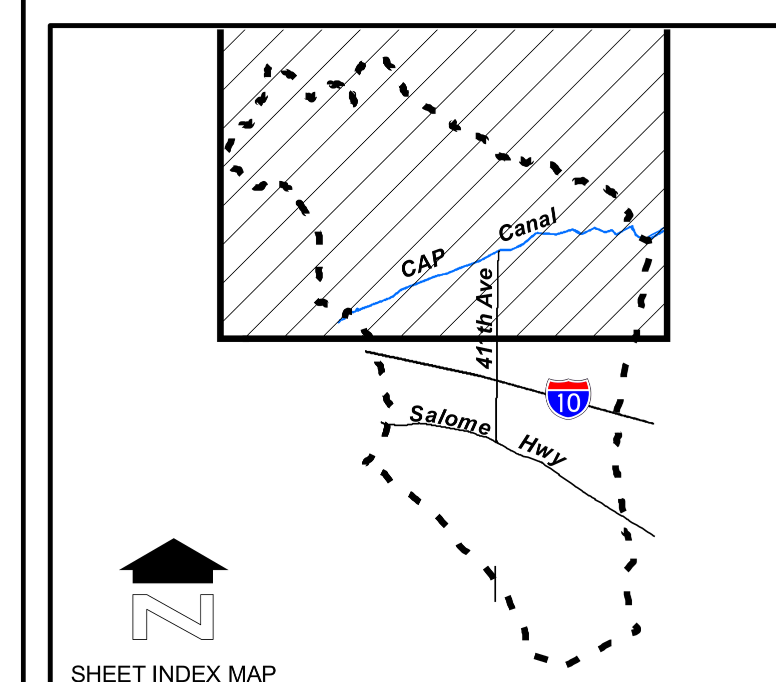
PALO VERDE
WATERSHED DETAILED FDS
F.C.D. CONTRACT NO. 2008C046



LEGEND

LANDUSE
LUCODE
- 920
- 930
- 940
- 950
- Study by Others

NOTES



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North Overview Land Use Map

FLOOD CONTROL DISTRICT
OF MARICOPA COUNTY

	BY	DATE
DESIGN	-	-
DESIGN CHK.	-	-
PLANS	-	-
PLANS CHK.	-	-

Sheet 1 of 1

PALO VERDE
FLOODPLAIN DELINEATION STUDY
F.C.D. CONTRACT NO. 2008C046

LEGEND

Legend

Landuse

LUCODE

111	520
130	740
160	750
210	900
320	910
	920

NOTES

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South Overview
Land Use Map

FLOOD CONTROL DISTRICT
OF MARICOPA COUNTY

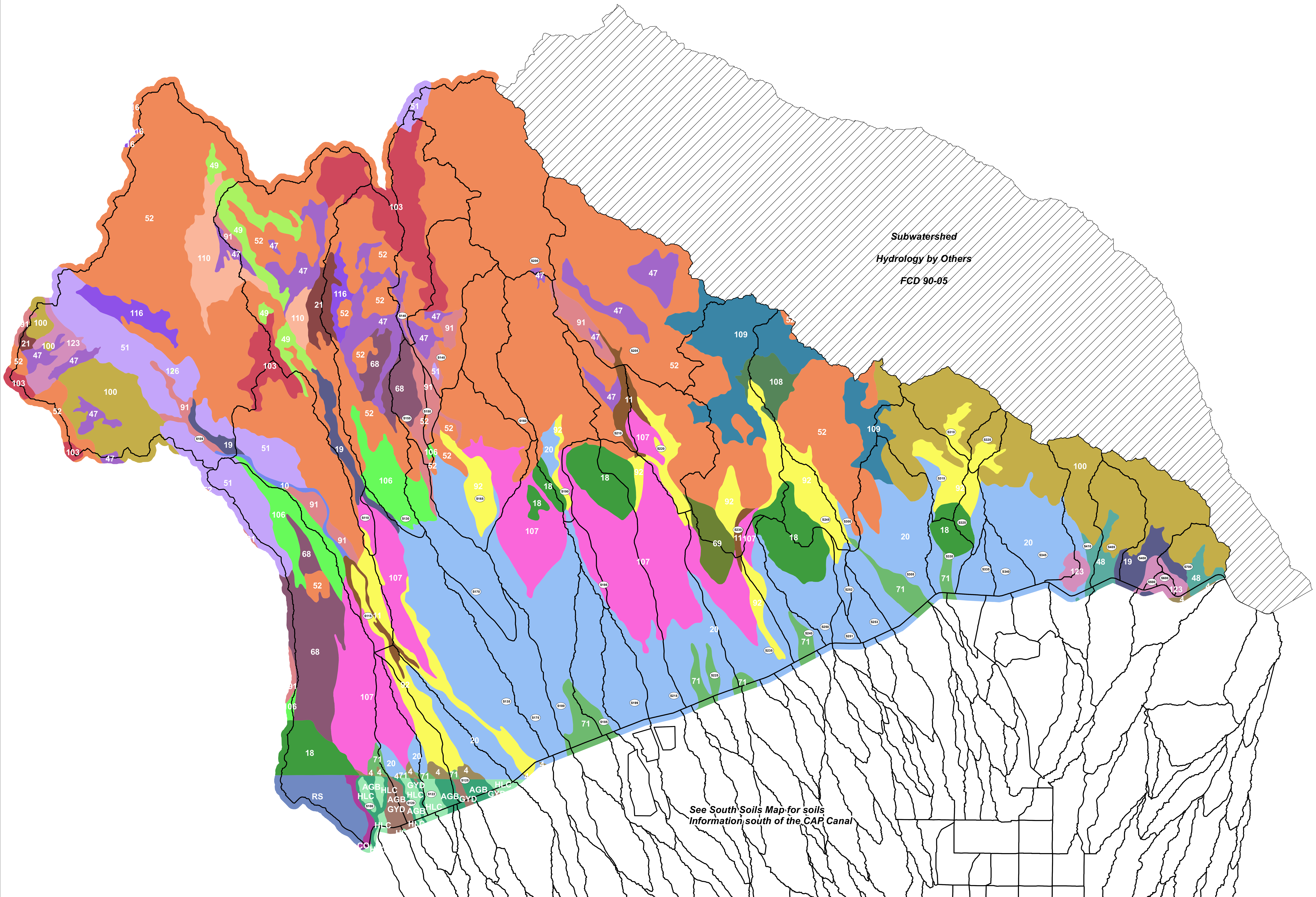
	BY	DATE
DESIGN	-	12 FEB 2010
DESIGN CHK.	-	12 FEB 2010
PLANS	-	12 FEB 2010
PLANS CHK.	-	12 FEB 2010

SHEET 1 OF 1

Note – only overview maps are provided in hard copy format. A full set of detailed maps for both the north and south portions of the watershed are provided digitally, on CD, as Appendix E.

APPENDIX D.3

Soil Maps



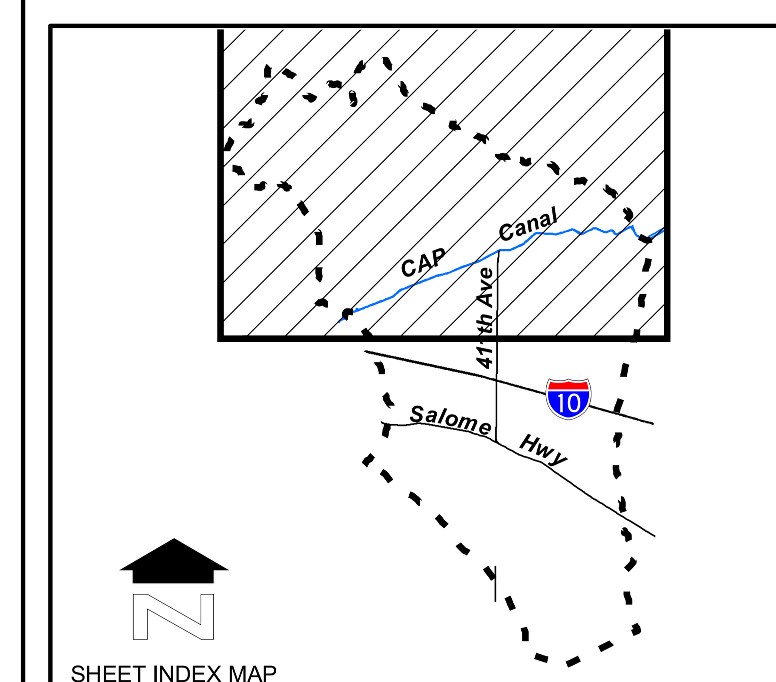
PALO VERDE
WATERSHED DETAILED FDS
F.C.D. CONTRACT NO. 2008C046

LEGEND

Study by Others

Soil Map Unit
MUSYM

10	123	68
100	126	69
102	14	71
103	18	76
106	19	81
107	20	91
108	21	92
109	30	99
11	4	AGB
110	47	CO
116	48	GWD
117	49	GYD
	51	HLC
	52	RS
	56	



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North Overview Soils Map

FLOOD CONTROL DISTRICT
OF MARICOPA COUNTY

	BY	DATE
DESIGN	-	-
DESIGN CHK	-	-
PLANS	-	-
PLANS CHK	-	-

Sheet 1 of 1

PALO VERDE
FLOODPLAIN DELINEATION STUDY
F.C.D. CONTRACT NO. 2008C046

LEGEND

SCS Soil

MUSYM

100, 102, 11, 117, 123, 18, 19, 20, 30, 4, 48, 50, 56, 60, 71, 92, AGB, AL, AM, Aa, AbA, AbB, Ac, AdA

AdB, Ae, AfA, AfB, Ao, Ap, BPI, Bs, CO, Cb, CeD, Cg, Ch, Ck, Cm, Cp, Dn, Es, Et, GL, GM, GPI, GWD, GYD, Ge

Gf, GgA, GgB, Gh, Go3, Gp, Gs, Gu, GxA, GxB, HAB, HAC, HLC, HM, HrB, La, Lb, LcA, LcB, Ld, Ma, Mo, Mp, PRB, PT

PYD, Pb, PeA, PeB, PsB, RS, RaA, RbA, RbB, RhB, TB, TD, Ta, Te, TfA, Th, TrA, TrB, Tu, Va, Vb, Vc, Ve, Vf

NOTES

CAP Canal
411th Ave
10
Salome HWY
SHEET INDEX MAP

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South Overview Soils Map

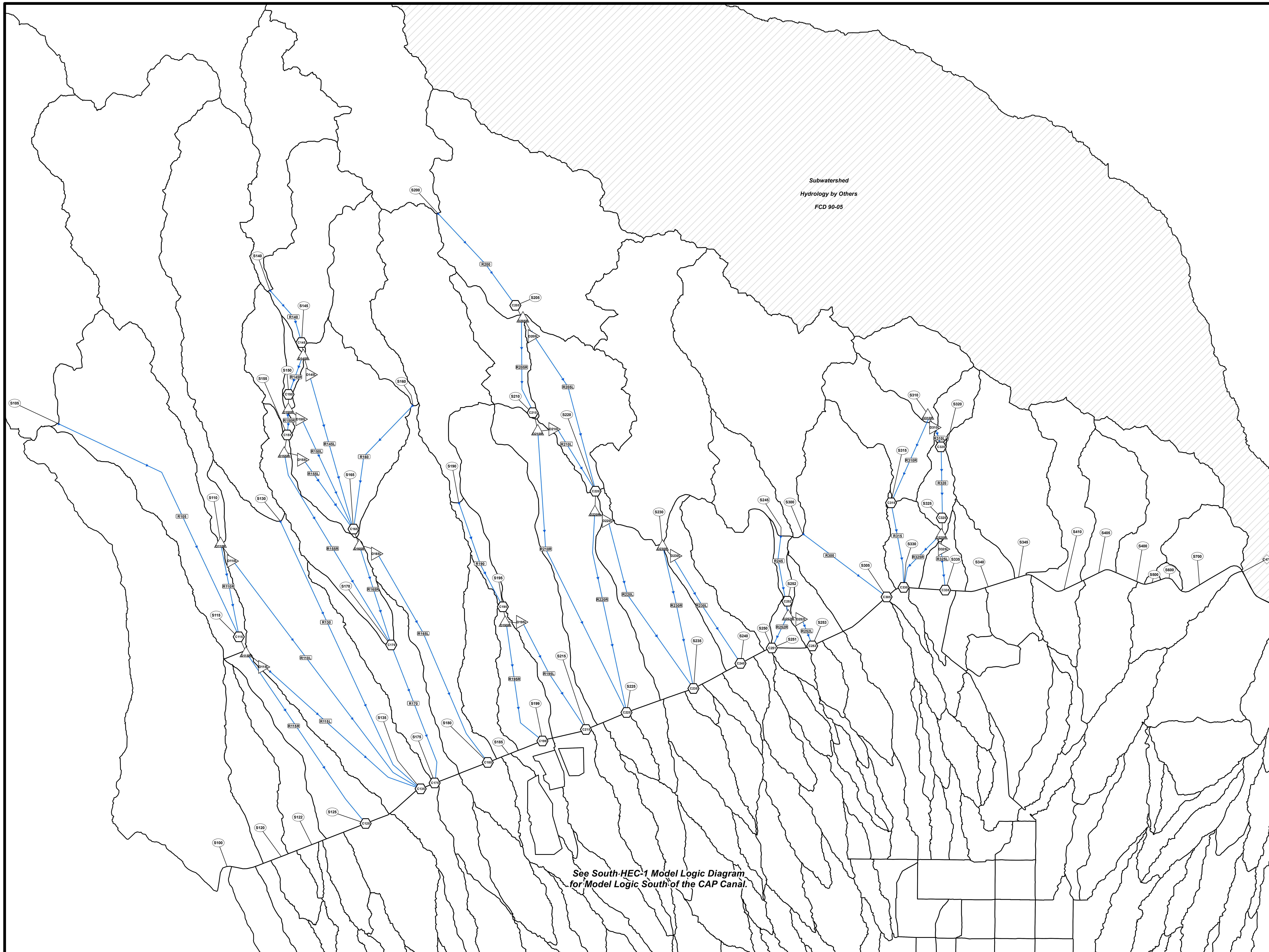
FLOOD CONTROL DISTRICT OF MARICOPA COUNTY

	BY	DATE
DESIGN	-	12 FEB 2010
DESIGN CHK.	-	12 FEB 2010
PLANS	-	12 FEB 2010
PLANS CHK.	-	12 FEB 2010

SHEET 1 OF 1

APPENDIX D.4

Logic Diagram

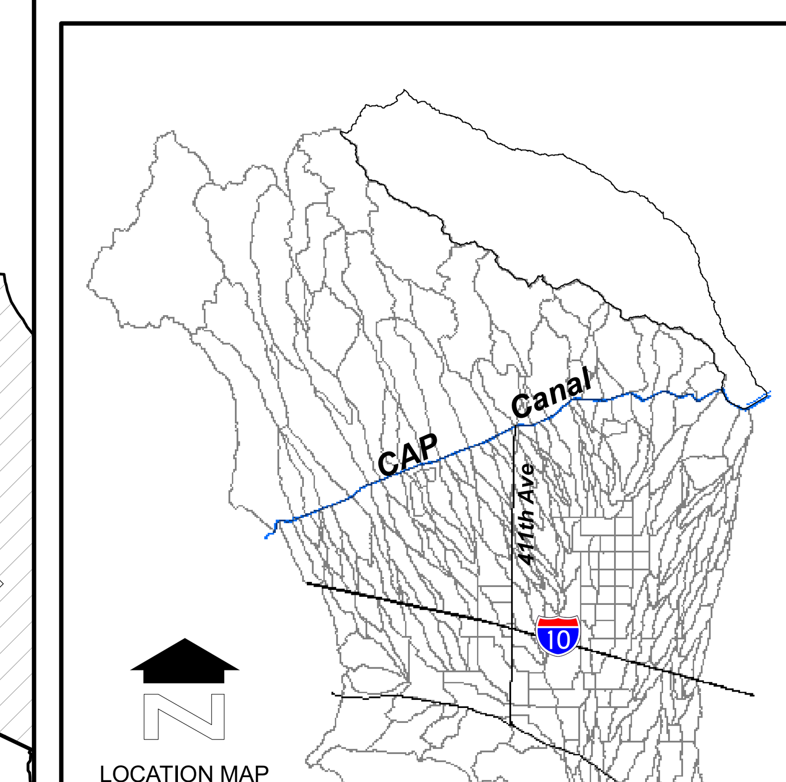


PALO VERDE WATERSHED
DETAILED FDS
F.C.D. CONTRACT NO. 2008C046

LEGEND

- Subbasin ID
- Diversion
- Hydrograph Retreive
- Inflow Hydrograph
- Hydrograph Combine
- Routing Reach
- Subbasin
- Basin by Others

NOTES



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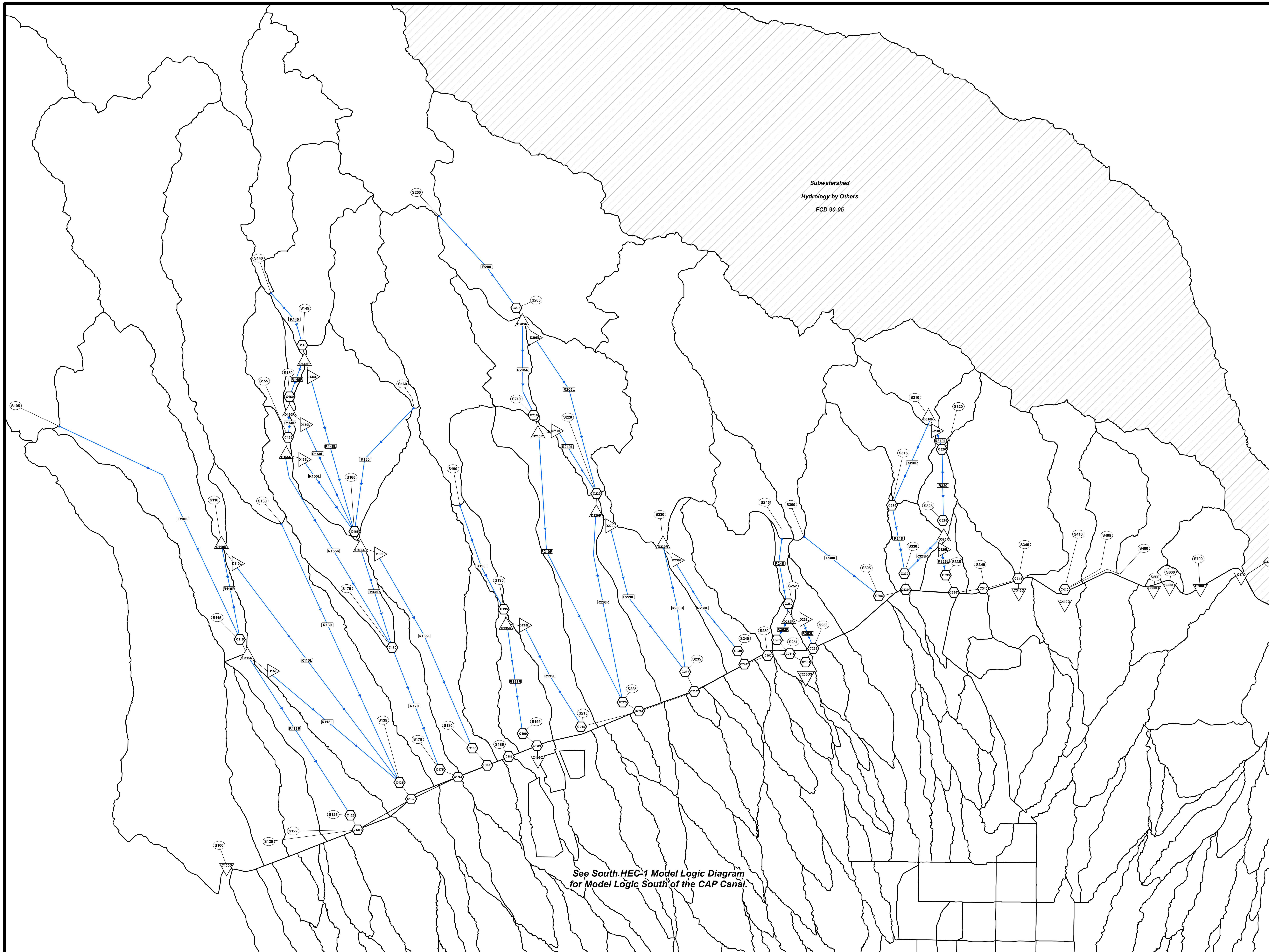
North HEC-1 Model Logic Diagram
Without Levee Condition

FLOOD CONTROL DISTRICT
OF MARICOPA COUNTY

	BY	DATE
DESIGN	MG	01/06/10
DESIGN CHK.	PE	01/06/10
PLANS	MG	01/06/10
PLANS CHK.	PE	01/06/10

SHEET 1 OF 1

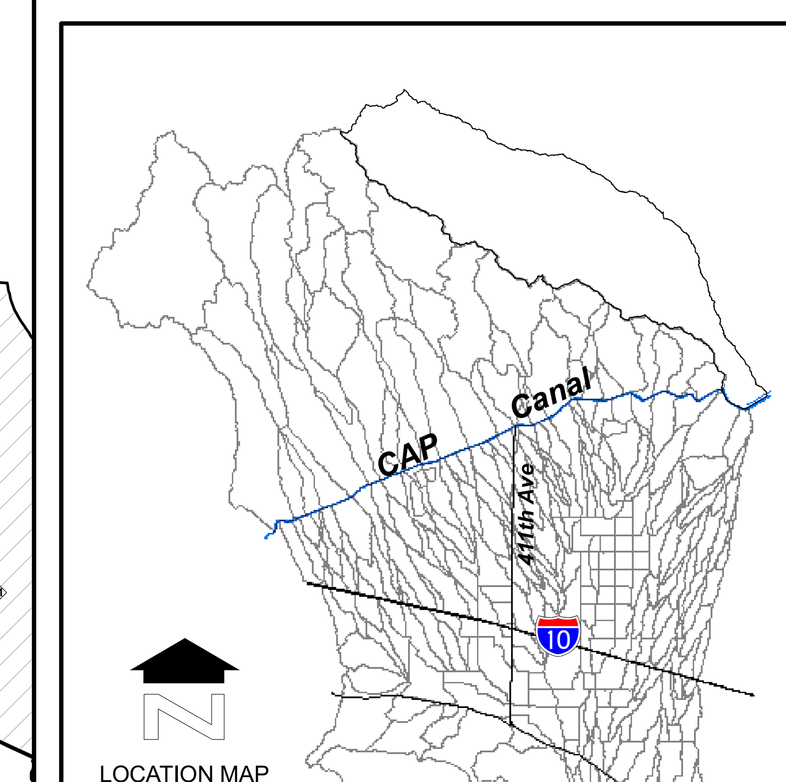


PALO VERDE WATERSHED
DETAILED FDS
F.C.D. CONTRACT NO. 2008C046

LEGEND

- Subbasin ID
- Storage Route
- Diversion
- Hydrograph Retreive
- Inflow Hydrograph
- Hydrograph Combine
- Routing Reach
- Subbasin
- Basin by Others

NOTES



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North HEC-1 Model Logic Diagram
With Levee Condition

FLOOD CONTROL DISTRICT
OF MARICOPA COUNTY

	BY	DATE
DESIGN	MG	01/06/10
DESIGN CHK.	PE	01/06/10
PLANS	MG	01/06/10
PLANS CHK.	PE	01/06/10

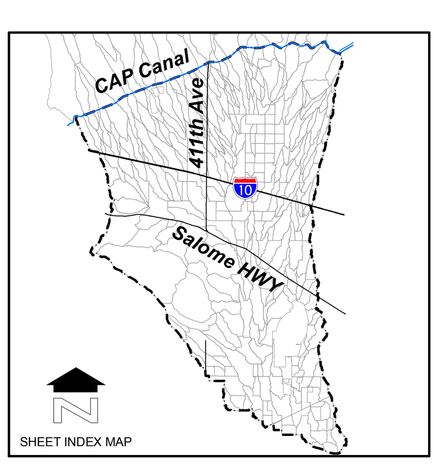
SHEET 1 OF 1

PALO VERDE
FLOODPLAIN DELINEATION STUDY
F.C.D. CONTRACT NO. 2008C046

LEGEND

- Subbasin ID
- Diversion
- Hydrograph Retreive
- Inflow Hydrograph
- Hydrograph Combine
- Routing Reach
- Subbasin
- Basin by Others

NOTES



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South HEC-1 Model Logic Diagram
Without Levee Condition

FLOOD CONTROL DISTRICT
OF MARICOPA COUNTY

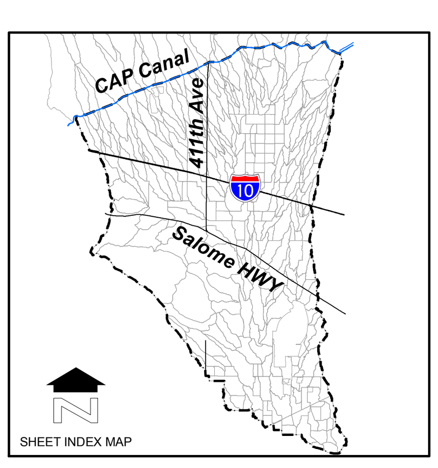
	BY	DATE
DESIGN	-	12 FEB 2010
DESIGN CHK.	-	12 FEB 2010
PLANS	-	12 FEB 2010
PLANS CHK.	-	12 FEB 2010

PALO VERDE
FLOODPLAIN DELINEATION STUDY
F.C.D. CONTRACT NO. 2008C046

LEGEND

- Subbasin ID
- Storage Route
- Diversion
- Hydrograph Retreive
- Inflow Hydrograph
- Hydrograph Combine
- Routing Reach
- Subbasin
- Basin by Others

NOTES



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**South HEC-1 Model Logic Diagram
With Levee Condition**

FLOOD CONTROL DISTRICT
OF MARICOPA COUNTY

	BY	DATE
DESIGN	-	12 FEB 2010
DESIGN CHK.	-	12 FEB 2010
PLANS	-	12 FEB 2010
PLANS CHK.	-	12 FEB 2010

APPENDIX E

Project Data on CD