Gillespie Area Drainage Master Study

Sediment Yield and Conveyance Memo

Flood Control District of Maricopa County

August 2013

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Gillespie ADMS

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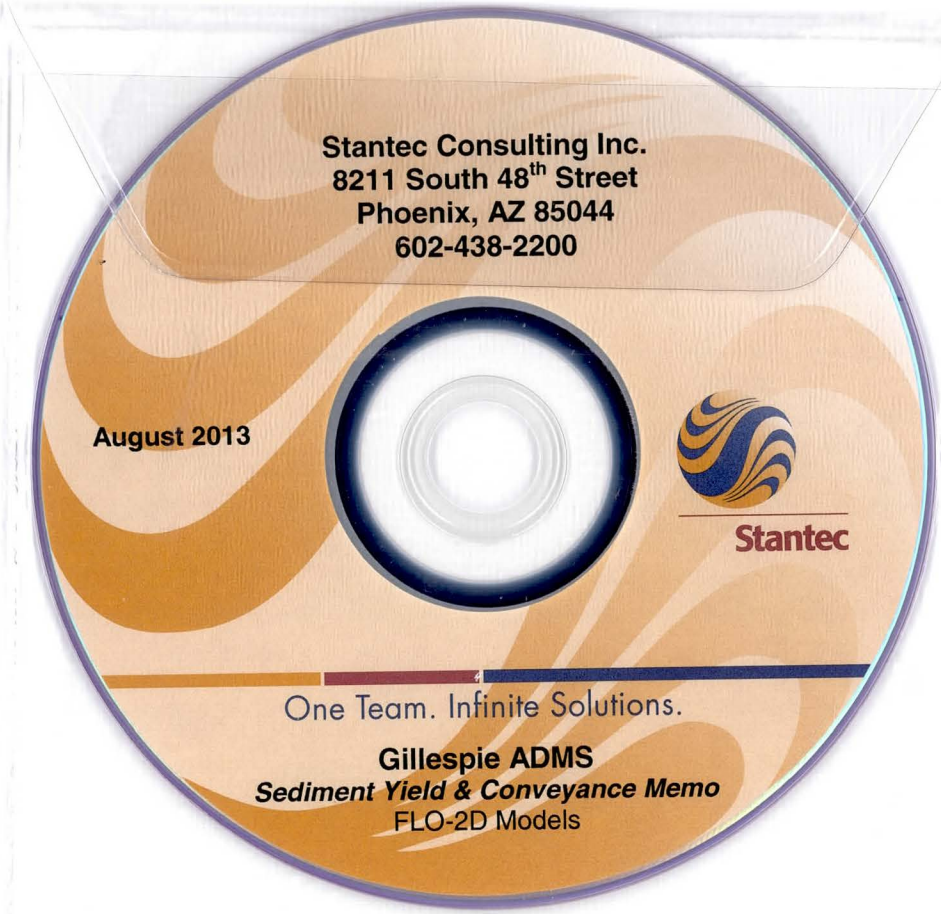

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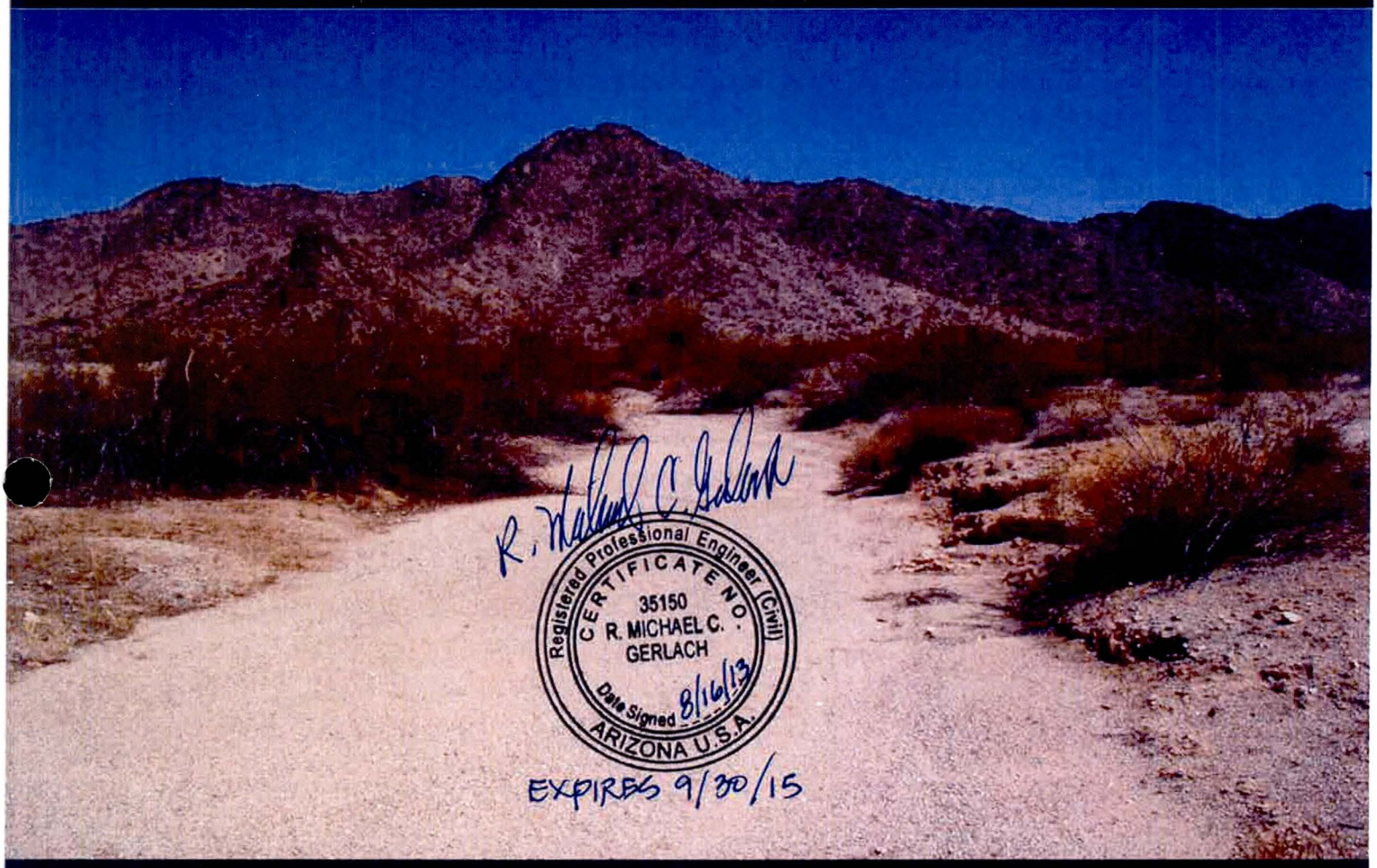

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Sediment Yield and Conveyance
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1.0 Introduction

The Gillespie Area Drainage Master Study (ADMS) project is a 150 square mile watershed located in the southwestern portion of Maricopa County and encompasses portions of the Towns of Buckeye and Gila Bend (see *Figure 1.1*). Currently, the watershed is mostly undeveloped desert rangeland, except the western portion along Gila River where agricultural fields dominate.

Most of the surface runoff within the watershed is generated in the mountainous areas in the northern and eastern boundary, where Buckeye Hills and Maricopa Mountains are located. The watershed is tributary to the Gila River which forms the western boundary of the study area. There are many drainage facilities within the project area such as channels, canals, embankments, bridges and culverts. The two major above grade features, State Route 85 and the Gila Bend Canal bisect the watershed from north to south perpendicular to the general direction of flow.

In general, the watershed is comprised of three major landforms, mountain, piedmont and alluvial plain. Much of the piedmont and alluvial plain portions of the watershed are characterized by unstable surface sediments such as Holocene deposits that have weak soil development and lack of varnish on the surface. In addition, the presence of distributary flow networks in these areas is an indication of active erosion and sediment processes.

Typically, these areas occur upstream of the agricultural lands. Over time, several drainage features, primarily non-engineered embankments and channels, were constructed to protect the agricultural lands from flooding and sediment deposition. Many of these features as well as SR-85 and the Gila Bend Canal are perpendicular to the natural watercourses or serve to divert runoff from its historic flow patterns. This in turn alters the sediment balance, both locally and regionally.

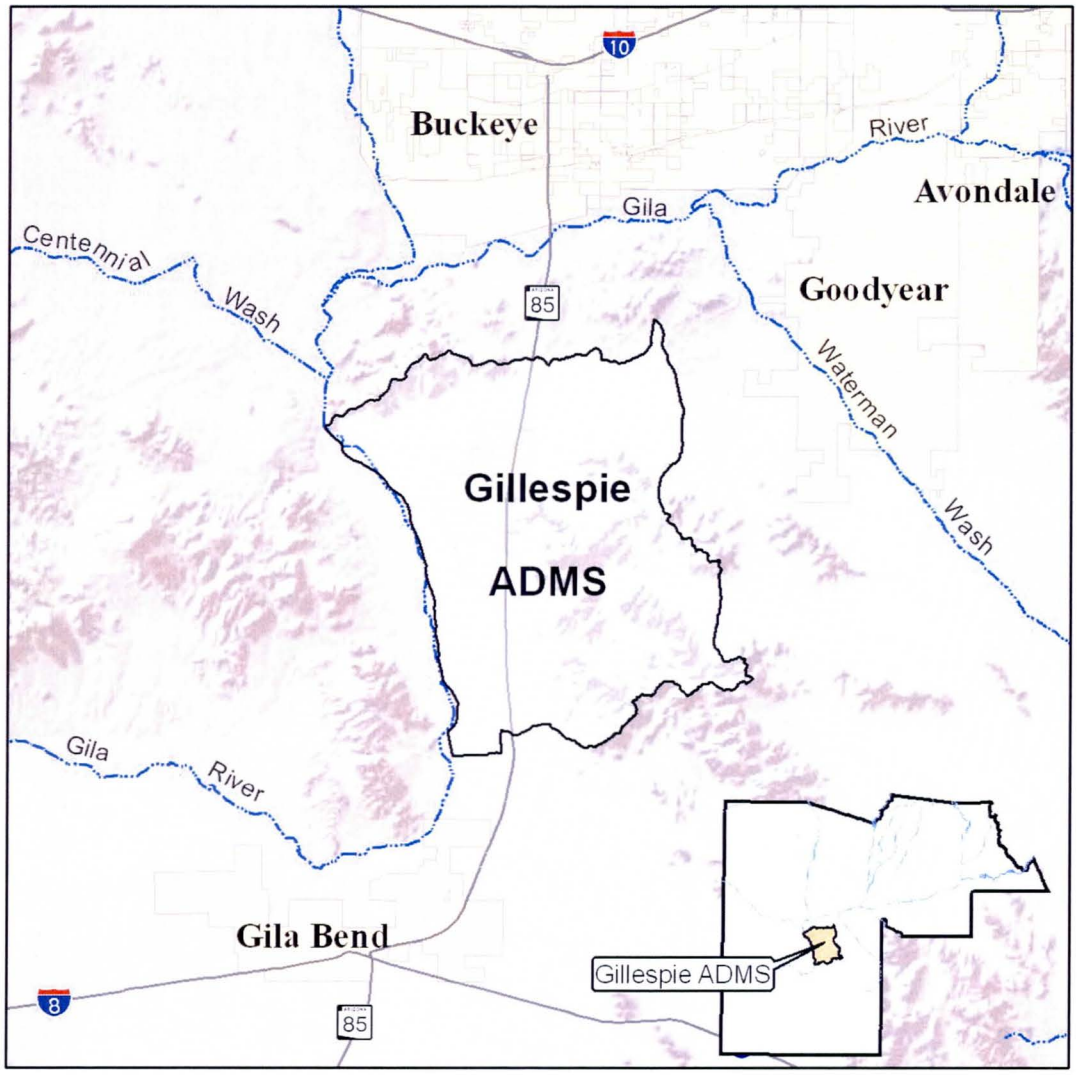
1.1 PURPOSE

The information and analysis presented in this Technical Memorandum are part of the scope of work performed by Stantec under contract with the Flood Control District of Maricopa County (District) as part of the Gillespie Area Drainage Master. The purpose of this memorandum is to present the findings of the Sediment Yield Analysis as described in the contract Scope of Work.

The Gillespie watershed has complex hydrologic and geomorphologic characteristics which, combined with unstable sediment deposits and several man-made drainage facilities that alter the natural flow paths, can lead to sediment issues. A primary consequence of sediment deposition is the reduction of conveyance capacities in culverts, siphons and channels. Sediment yield analysis is an important tool that can be used to understand the risks associated with sediment deposition. Moreover, sediment analyses can aid in identifying the necessary upgrades and/or required maintenance to mitigate sediment deposition.

Traditionally, the methodologies for estimating the total sediment yield provide results at a single location in a river reach or watershed. In the Gillespie ADMS study area, there are more than 161 culverts, 18 linear miles of drainage channels and 16 miles of earthen embankments. These features are significant drainage elements that influence the sediment dynamics of the watershed and are important locations for estimating sediment yield. Therefore, for the Gillespie ADMS watershed, an automated implementation of the traditional methodologies is developed that accounts for the distributive nature of the drainage network, takes advantage of the detailed hydrologic data prepared as part of the study and provides sediment yield estimates everywhere within the watershed.

Figure 1.1 – Vicinity Map



2.0 Methodology

Sediment yield analysis follows the methodology and procedures described in the River Mechanics Manual for DDMSW (***Reference* 1**). The prescribed methodology consists of two parts and is defined as the sum of the wash load and the total bed material load delivered to a point of interest.

The wash load component is estimated using the Modified Universal Soil Loss Equation (MUSLE). The MUSLE is an empirically derived methodology developed by United States Department of Agricultural (USDA), Soil Conservation Service. Parameters used to determine wash load consist of peak flow rate and runoff volume for a storm event of a particular return period along with factors representing erosion control practices, land cover and management, and topographic characteristics of the watershed. A brief description of the methodology and each parameter is provided in the following sections.

Total bed material load is estimated using the Zeller-Fullerton equation. The Zeller-Fullerton equation is a sediment transport equation derived through a regression analysis of data from a variety of channel bed and alluvial floodplain conditions. The equation is a computer generated solution of the Meyer-Peter, Muller bed load equation combined with Einstein's suspended load method that is found to give reasonable results especially when the bed load constitutes a significant portion of the total load. Parameters used to determine the total bed material load consist of hydraulic depth, flow velocity, roughness coefficient and soil gradation data. A brief description of the methodology and each parameter is provided in the following sections.

The implementation of the above-mentioned methods was accomplished through a GIS based process. This was achieved through the use of the ESRI Model Builder application (***Reference* 3**). A more detail description of how the GIS model is implemented, its capabilities, and limitations is provided in the following sections.

2.1 WASH LOAD

The wash load for the Gillespie watershed is estimated using the Modified Universal Soil Loss Equation method. The MUSLE equation is an empirically derived methodology for estimating watershed wash load (***Reference* 1**). A detail description of the MUSLE method can be found in the FCDMC River Mechanics Manual and is briefly described in this section. The equation has the form:

$$Y_s = \alpha\left(V q_p\right)^{\beta} KLSCP \qquad Eqn\ 1$$

Where:

Ys = watershed soil loss from the storm of a particular return period in tons,
α = 95,
V = runoff volume for a storm of a particular return period in acre-feet,
q_p = peak flow rate for a storm event of a particular return period in cfs,
β = 0.56,

K = the soil erodibility factor,
P = the erosion control practice factor (usually 1.0 for wildland areas),
C = the cover and management factor, and
LS = the topographic factor, defined as:

$$LS = \left(\frac{\lambda}{72.6}\right)^{n} (0.065 + 0.045S + 0.0065S^2) \qquad Eqn\ 2$$

Where:

S is the percent slope, n is an exponent depending upon slope and λ is the slope length defined as the distance from the point of origin of the overland flow to the point where either the slope gradient decreases enough such that deposition begin, or the runoff water enters a well-defined channel. The exponent n is given by

n = 0.3 for S<3 percent,
n = 0.4 for S = 4 percent, and
n = 0.5 for S > 5 percent

The wash load result as determined by the MUSLE method is in tons, but it is practical to have the sediment yield results in units of volume as it can be used to estimate required sediment storage in basin design. Bulk specific weight of sediment deposits is used to convert the wash load from weight to volume. The specific weight equation was developed by FCDMC by fitting a line to the data from Vavoni and has the form:

$$\gamma = 100.5 + 20.44\ log_{10}(D_{50}) \qquad Eqn\ 3$$

Where:

γ is the bulk specific weight for sediment deposits in pounds per cubic feet, and D_{50} is the median sediment size defined as the diameter where 50% is finer by weight in millimeter. The MUSLE method estimates only the sediment wash load; therefore the D_{50} is the median sediment size of the wash load and is usually taken as D_{10} of the entire sediment sample.

Last, the wash load result is multiplied by the Sediment Delivery Ratio (SDR). The SDR was first developed by USDA and later modified by FCDMC to reflect sediment yield data for arid and semiarid regions. The SDR is proportional to the contributing drainage area and has the form:

$$\boldsymbol{S}DR = -14.08(log_{10}A_D) + 2.44(log_{10}A_D)^2 - 0.45(log_{10}A_D)^3 + 60.85 \qquad Eqn\ 4$$

Where:

SDR is the sediment delivery ration in percent and A_D is the drainage area in square miles. A brief description of how each of the parameters in the above equations was determined is provided in the approach section of this report.

2.2 TOTAL BED MATERIAL LOAD

The total bed material load is estimated using the Zeller-Fullerton equation, which is based on the assumption that the reach is at an equilibrium condition (***Reference* 1**). A detail description of the Zeller-Fullerton equation can be found in the FCDMC River Mechanics Manual and is briefly described in this section. The equation has the form:

$$q_s = 0.0064\left(\frac{n^{1.77}V_a^{4.32}G^{0.45}}{Y_h^{0.3}D_{50}^{0.61}}\right) \qquad \textit{Eqn 5}$$

Where:

q_s = bed-material discharge in cfs per unit width,
n = Manning's roughness coefficient,
V_a = average velocity in ft/s,
Y_h = hydraulic depth in feet,
D_{50} = median sediment size, defined as the diameter where 50% is finer by weight in millimeter, and
G = gradation coefficient, where:

$$G = \frac{1}{2}\left(\frac{D_{84.1}}{D_{50}} + \frac{D_{50}}{D_{15.9}}\right) \qquad \textit{Eqn 6}$$

Where:

$D_{84.1}$, D_{50} and $D_{15.9}$ are the sediment diameters in millimeter on a percent finer by weight.

The result of Zeller-Fullerton equation is given as the peak bed load discharge of the storm, but similarly to the wash load, a more meaningful result for the sediment yield analysis would be to estimate the total bed load in units of volume. Assuming that the sediment discharge hydrograph follows the same shape as the water flow hydrograph, the total bed load volume of the storm can be determined from:

$$V_s = V_w\left(\frac{Q_s}{Q}\right) \qquad \textit{Eqn 7}$$

Where:

V_S = total volume of sediment under the sediment discharge hydrograph in ft^3,
Q = the water flow discharge hydrograph ordinates in cfs,
V_W = total volume of water under the water flow hydrograph in ft^3, and
Q_S = the sediment discharge hydrograph ordinates in cfs,

Sediment discharge, Q_S, is equal to q_s multiplied by the average channel bed width. A brief description on how each of the parameters in the above equations was determined is provided in the approach section of this report.

2.2.1 Allowable velocity

The Zeller-Fullerton equation is a sediment transport equation that is applied to riverine conditions. The sediment yield model developed for the Gillespie ADMS is a watershed based application. To limit the total bed material load calculations to just the portions of the watershed to the watercourses, the concept of allowable velocity is applied to determine if sediment transport in the form of bed load is taking place under specific flood conditions. The maximum allowable velocity as described in State Standard 5-96 (SSA-5-96), Watercourse System Sediment Balance is the velocity at and below which sediment transport is not expected to occur (***Reference* 2**). The equation has the form:

$$V_a = V_b \times C_a \times C_b \times C_d \qquad Eqn\ 8$$

Where:

V_a = maximum allowable flow velocity in ft/s,
V_b = basic maximum allowable flow velocity in ft/s,
C_a = correction factor for channel alignment,
C_b = correction factor for bank slope, and
C_d = correction factor for flow depth,

The basic maximum allowable velocity for unprotected earthen channels, V_b is determined from the relationship developed by USDA Soil Conservation Service and presented in ***Figure 2.1*** below (reproduced from SSA 5-96). The D_{75} sediment particle size obtained from sieve analysis is entered in either the sediment free or sediment laden curves to determine the basic maximum allowable flow velocity. Generally, natural washes in Arizona are classified as sediment laden, therefore only the sediment laden curve is implemented in the Sediment Yield Model. The correction factors, C_a, C_b, and C_d listed in Equation 8 are used to account for effects that variations in channel alignment, bank slope, and flow depth have on channel velocity. These correction factors are determined from ***Figure 2.2, Figure 2.3*** and ***Figure 2.4*** (reproduced from SSA 5-96). For implementation in the Sediment Yield Model, equations are fitted to the C_a, C_b, and C_d relations shown in Figures 2.1 through 2.4, respectively. The resulting equations are shown the corresponding figures.

Figure 2.1 – Basic Maximum Allowable Velocity for Earthen Channels

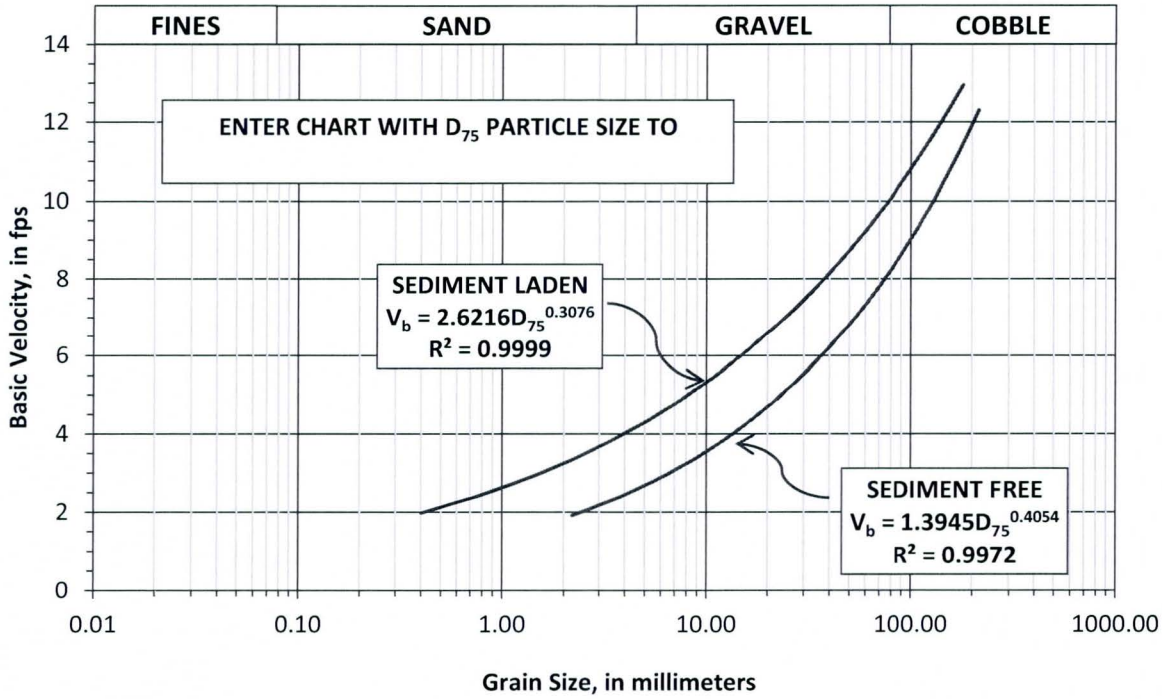


Figure 2.2 – Correction Factor C_a for Channel Alignment

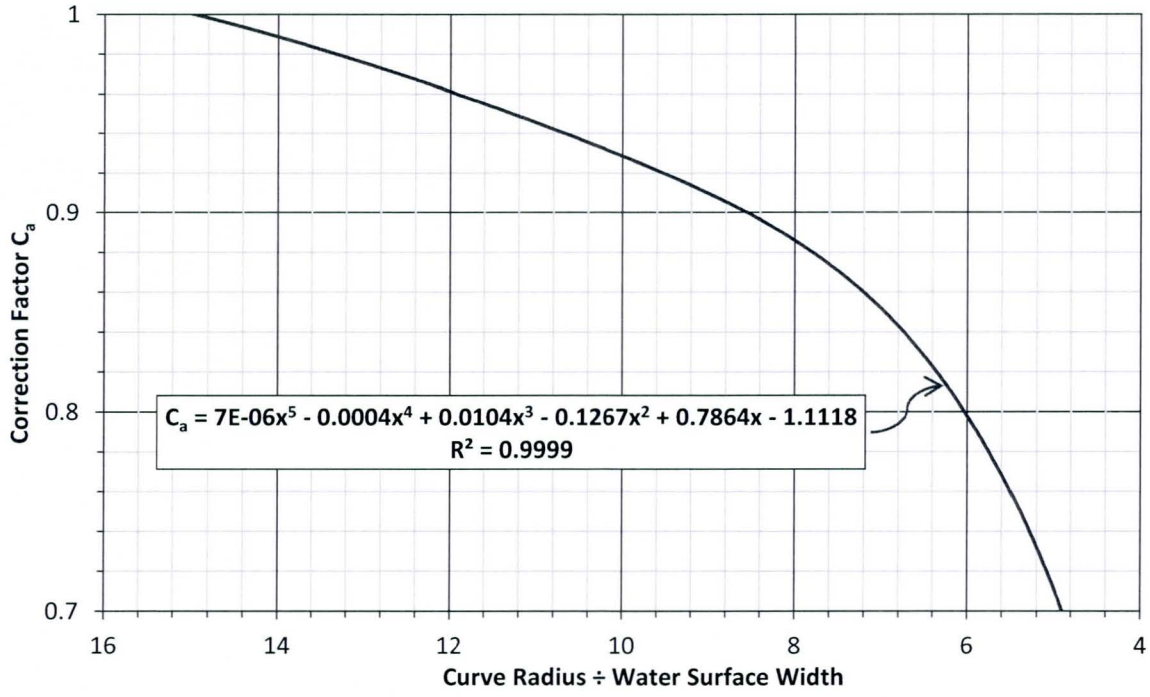


Figure 2.3 – Correction Factor C_b for Bank Slope

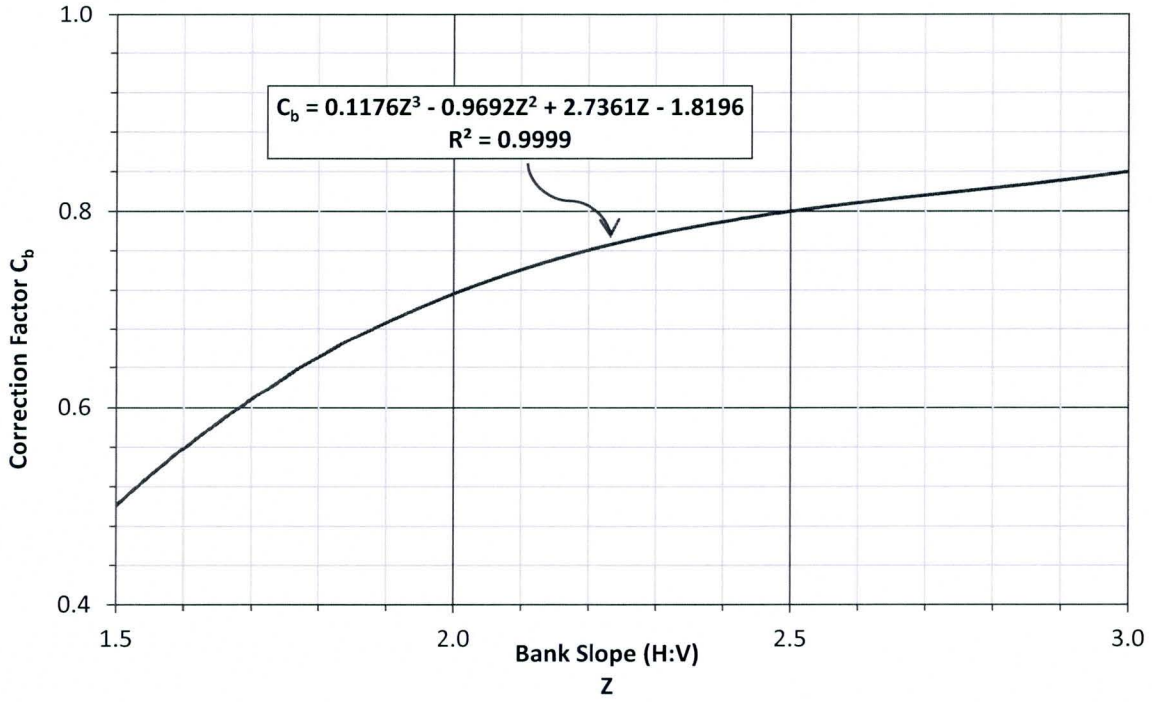
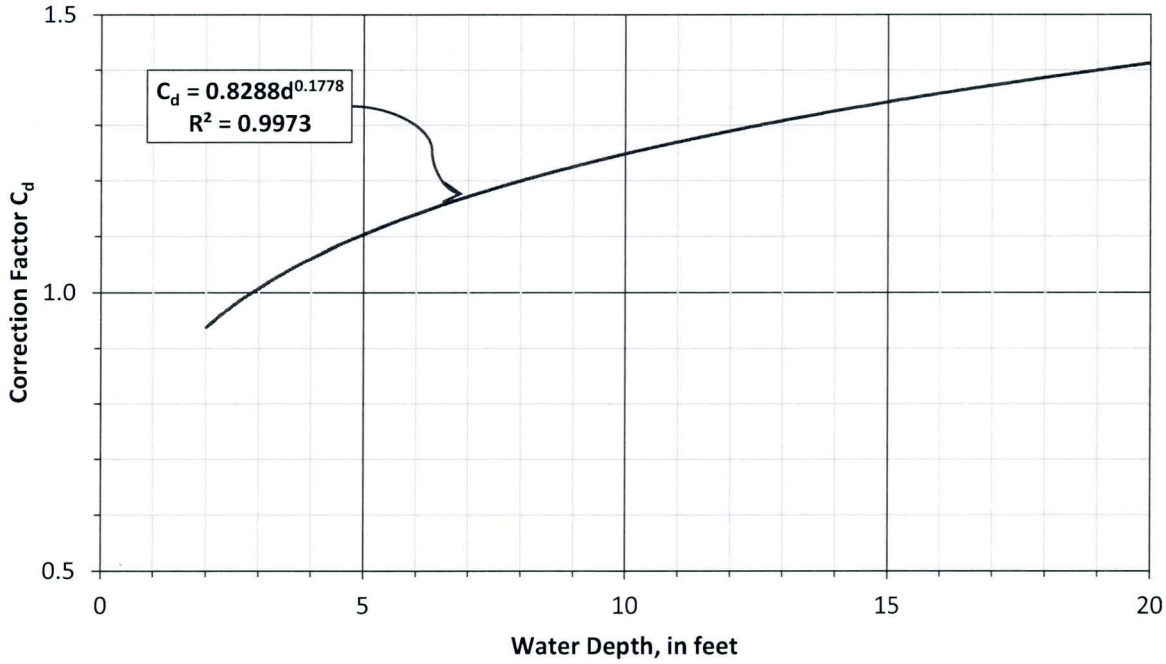


Figure 2.4 – Correction Factor C_d for Depth of Flow



2.3 ANNUAL SEDIMENT YIELD

An important end result of this investigation that is often used to determine the required maintenance of drainage facilities due to sediment deposition is the annual sediment yield. The annual sediment yield for the project area was determined based on the procedure developed by FCDMC and described in the River Mechanics Manual for DDMSW (***Reference* 1**). Probability-weighted values for sediment wash load and bed load for 100-, 50-, 25-, 10-, 5-, and 2-year return periods can be used to compute the annual sediment yield. The equation has the form:

$$Annual\ Sediment\ Yield\ = SDR * Wash_P + BedL_P \qquad Eqn\ 9$$

Where:

Wash_P = 0.015Wash_P_{100} + 0.015Wash_P_{50} + 0.04Wash_P_{25} + 0.08Wash_P_{10} + 0.2Wash_P_5 + 0.4Wash_P_2
BedL_P = 0.015 BedL_P_{100} + 0.015 BedL_P_{50} + 0.04 BedL_P_{25} + 0.08 BedL_P_{10} + 0.2 BedL_P_5 + 0.4 BedL_P_2
Wash_P = annual eroded sediment which is considered wash load,
Wash_P_i = wash load for i = 100-, 50-, 25-, 10-, 5-, and 2-year return periods,
BedL_P = annual total bed material load, and
BedL_P_i = total bed material for i = 100-, 50-, 25-, 10-, 5-, and 2-year return periods.

A detailed description of annual sediment yield procedure can be found in the River Mechanics Manual.

3.0 Approach

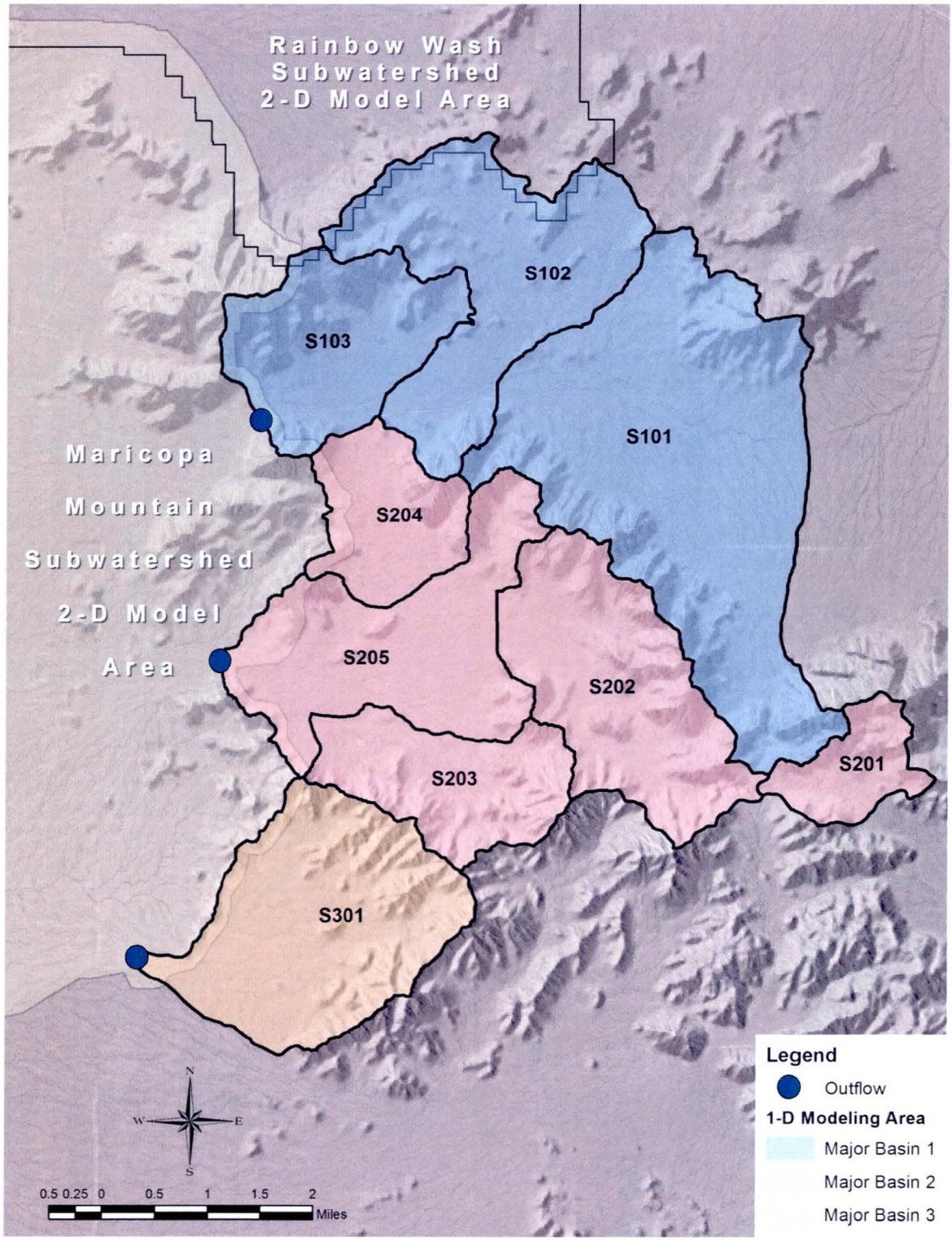
Total sediment yield calculations for the Gillespie ADMS watershed are implemented in a GIS environment developed using ESRI's Model Builder application. Key input for estimating both the wash load and total bed material load components includes sediment gradation data, FLO-2D modeling results, topographic data, and HEC-1 modeling results.

Topographic data for the entire Gillespie ADMS project area in the form of ground elevation was provided by the District. A summary of that data is provided in ***Section 3*** of the Hydrology TDN.

Sediment gradation data used in this investigation was determined from sieve analyses. Soil samples were collected as part of the Gillespie ADMS project and the results are documented in the Sediment Sample Memorandum. Sediment gradation data utilized to determine the sediment yield for both, Rainbow Wash and Maricopa Mountain subwatersheds are included in ***Appendix A***.

Peak discharge, runoff volume, flow depth and velocity data for the watershed are taken from a combination of HEC-1 and FLO-2D modeling results. A complete description of the data, methodology, modeling assumptions and results are provided in the Hydrology TDN. The intent of the Sediment Yield Model is that it is used in combination with gridded watershed runoff data. Therefore, the model results are specifically applicable to the limits of the FLO-2D study area for the watershed. HEC-1 model results are included only for the Maricopa Mountain portion of the study area. For this portion of the study area, the upland area is simulated using HEC-1 (see ***Figure 3.1***). HEC-1 model results are only included in the tool to provide the runoff data at the boundary of HEC-1 and FLO-D areas.

Figure 3.1 – 1 – D Modeling Area



3.1 WASH LOAD

This section describes the input data and their format required to estimate the sediment wash load as implemented into the Sediment Yield Model.

3.1.1 Soil Erodibility Factor, K

The soil erodibility factor is a measure of the susceptibility of soil particles to detachment and transport. Soil texture is the principle factor affecting K and therefore easily related to soil map units determined by the Natural Resource Conservation Service (NRCS). Specific values assigned to NRCS soil map units are determined by the District and those values for the soil map units that occur with the project area are listed in ***Table 3.1***. Soil erodibility factors are input to the model by associating Table 3.1 to the NRCS soil map unit shape file.

Table 3.1 – Soil Erodibility Factor, K

MUSYM	Description	Soil Erodibility Factor K
1	Agualt and Ripley soils	0.55
10	Cipriano-Momoli complex, 1 to 7 percent slopes	0.05
13	Dateland very fine sandy loam	0.55
14	Dateland-Cuerda complex, 0 to 3 percent slopes	0.24
15	Dateland-Denure fine sandy loams, saline-Sodic, 0 to 3 percent slopes	0.24
16	Denure sandy loam	0.20
17	Denure gravelly fine sandy loam, 1 to 3 percent slopes	0.20
2	Agualt and Ripley soils, saline-sodic	0.55
20	Denure-Coolidge complex, 1 to 3 percent slopes	0.17
21	Denure-Rillito-Why complex, 1 to 5 percent slopes	0.17
29	Glenbar silty clay loam	0.37
3	Ajo-Gunsight-Pompeii complex, 3 to 25 percent slopes	0.05
30	Glenbar silty clay loam, saline-sodic	0.37
33	Gunsight-Ajolito extremely gravelly sandy loams, 1 to 15 percent slopes	0.05
34	Gunsight-Chuckawalla complex, 1 to 15 percent slopes	0.05
35	Gunsight-Cipriano complex, 1 to 15 percent slopes	0.02
36	Gunsight-Pinamt complex, 1 to 15 percent slopes	0.05
37	Gunsight-Rillito-Carrizo complex, 1 to 15 percent slopes	0.05
38	Harqua fine sandy loam, 0 to 3 percent slopes	0.24
41	Indio silt loam	0.55
42	Indio silt loam, saline-sodic	0.55
43	Lagunita-Vint complex	0.10
49	Momoli-Carrizo extremely gravelly sandy loams, 1 to 10 percent slopes	0.10
51	Momoli-Comobabi association, 5 to 15 percent slopes	0.05
53	Quilotosa-Momoli-Carrizo complex, 1 to 15 percent slopes	0.02
54	Quilotosa-Rock outcrop complex, 15 to 55 percent slopes	0.02
55	Riverwash	0.00
6	Carrizo-Momoli complex, 0 to 3 percent slopes	0.17
63	Vint very fine sandy loam	0.49
67	Why-Carrizo complex, 0 to 3 percent slopes	0.24

Table 3.1 – Soil Erodibility Factor, K (continued)

MUSYM	Description	Soil Erodibility Factor K
9	Cipriano-Hyder-Rock outcrop complex, 15 to 65 percent slopes	0.20
AdB	Antho gravelly sandy loam, 1 to 3 percent slopes	0.15
Ae	Antho-Brios sandy loams	0.24
AfB	Antho-Carrizo complex, 1 to 3 percent slopes	0.24
CF	Carrizo and Brios soils	0.15
CO	Cheriono-Rock outcrop complex	0.10
GxB	Gunsight-Rillito complex, 1 to 3 percent slopes	0.17
HAB	Harqua complex, 0 to 3 percent slopes	0.17
HAC	Harqua complex, 3 to 8 percent slopes	0.17
RS	Rock outcrop-Cherioni complex	0.10

3.1.2 Peak Flow Rate, q_p

Peak flow rates are taken from a combination of the FLO-2D and HEC-1 model output. FLO-2D output files MAXQHYD.OUT and CHANMAX.OUT provide a listing of peak discharge results at each model grid element for all floodplain and 1-D channel elements respectively. From the model output a ESRI raster is created at the FLO-2D model grid cell size of 50 feet. For the HEC-1 area, peak discharge results and the basin outfalls are assigned as the uniform value to a ESRI raster file created from the HEC-1 subbasin polygons. The combined FLO-2D and HEC-1 model raster serves as the peak flow rate input to the Sediment Yield Model.

3.1.3 Cover and Management Factor, C

The cover and management factor represents the effects from three types of conditions; canopy cover, ground cover and land use (e.g. agriculture). Similar to the soil erodibility factor, the District has developed a table of recommended C factors that is related to the MAG land use for the entire county. Cover and management factors assigned to each MAG land use type were related to the land use classifications defined for this study and coded into a watershed specific land use shape file. The resulting values are listed in ***Appendix B***. The land use shape file is used as an input to the Sediment Yield Model.

3.1.4 Runoff Volume, V

Although FLO-2D tracks runoff volume, it does not report cumulative or incremental volume for each grid cell in the model domain. Therefore, grid based runoff estimates are developed using the total infiltration at each grid cell from the FLO-2D model, rainfall depth for the watershed and contributing area at each grid cell. Specifically, runoff volume at each grid cell is estimated by subtracting the total infiltration at each grid cell from the rainfall depth for the watershed and then multiplying that result by the contributing area at each grid cell. A discussion of the data used for this estimation of runoff volume is discussed in the following sections.

3.1.4.1 Infiltration Depth

A coverage of infiltration depths for the entire project area in raster format is required to approximate the runoff volume using the GIS Model. Unlike traditional rainfall-runoff models such as HEC-1 that infiltrate only rainfall, FLO-2D infiltrates the runoff also. This results in a portion of the grid elements, particularly those located in washes, to have infiltration depths greater than the rainfall depth. Consequently, there can be some grid cells that yield a negative result when the total infiltration is subtracted from the rainfall depth. To overcome this issue and minimize the number of grid elements with negative rainfall excess, the FLO-2D models were run for a shorter period of time equal to the duration of rainfall. The Rainbow Wash and Maricopa Mountain FLO-2D models for 100-, 50-, 25-, 10-, 5-, and 2-year return periods were run for 6 hours only and the resulting *FPINFILTRATION.OUT* files were used to create infiltration rasters for each storm event. While this approach limits the infiltration at any once grid cell, re-infiltration of runoff still occurs. In the Sediment Yield Model, if the calculated rainfall excess is negative, the model resets the value to zero.

For the Maricopa Mountain subwatershed, the infiltration raster was supplemented with HEC-1 results for runoff volume.

To approximate the runoff volume, the storm rainfall depth, infiltration depth and ground elevation at every grid element is required. It is important to recognize that the runoff volume estimated by the GIS Model using the abovementioned equation is only an approximation and the results can be different when compared to the volume determined by using a runoff hydrograph. To test the adequacy of the results presented in this investigation, the wash load and the volume at several locations where runoff hydrographs were available, was calculated using both methods and the comparison between the two is presented in ***Appendix C***.

3.1.4.2 Rainfall Depth

An input value equal to storm event rainfall depth in inches is required to determine the runoff volume at each grid element using the GIS Model. The rainfall depths for 100-, 50-, 25-, 10-, 5-, and 2-year return periods used in this investigation for Rainbow Wash and Maricopa Mountain subwatersheds are presented in ***Table 3.2*** below.

Table 3.2 – Rainfall Depths

Return Period (6-Hour Duration)	Rainfall Depth (inches)	
	Rainbow Wash	Maricopa Mountain
2-Year	1.104	1.072
5-Year	1.448	1.413
10-Year	1.724	1.687
25-Year	2.106	2.068
50-Year	2.412	2.373
100-Year	2.736	2.698

3.1.5 Ground Elevation

An input file in raster format depicting the ground elevation of the entire project area is required to estimate the contributing drainage area using the GIS Model. This is accomplished by performing a raster analysis to generate the flow accumulation raster that contains the number of grid elements upstream of each grid element in the ground elevation raster. The contributing drainage area at each element is determined by multiplying the flow accumulation raster with the grid element area.

To determine the contributing drainage area correctly, it is important that the ground elevation raster be reviewed prior to using it in the GIS Model. This is done to verify that all the major drainage features are properly captured in the ground elevation raster. Typically, an interpolation process is used to create the ground elevation raster from raw elevation data such as points and break-lines. During the interpolation process important drainage features such as levees, channels and canals can become less pronounced. As a result, flow accumulation can produce a drainage network that does not represent the real topology of the area. In addition, flow accumulation ignores any structures such as culvert and siphons that are usually not depicted in the ground elevation data. A two-step process utilizing Arc Hydro Tools (***Reference 6***) can be used to adjust the ground elevation raster and correct any potential problems. First, the DEM Reconditioning function is used to modify the ground elevation raster by dropping (burning) the elevation to represent below grade features such as drainage channels. Also, the elevation at the locations of cross drainage structures such as culverts and siphons is dropped to create breaks in above grade features and create a continuous drainage network, so it can be properly captured in the flow accumulation raster. In the Rainbow Wash and Maricopa Mountain subwatersheds the DEM Reconditioning function was used to adjust the elevation of culverts along SR-85, siphons along Gila Bend Canal and all the drainage channels. Next, the Build Walls function is used to raise the elevation of levees and other major above grade features. Gila Bend Canal and the four levees located within the Rainbow Wash and Maricopa Mountain subwatersheds were modified using the Build Walls function. A detail description of DEM Reconditioning and Build Walls functions can be found in Arc Hydro Tools User Manual.

3.1.6 Topographic Factor, LS

To determine the topographic factor, LS the GIS Model utilizes two separate inputs. An input file in raster format depicting the ground elevation of the entire project area as described in the above paragraph is required to estimate the slope, S. An input polygon shapefile depicting areas of different slope length, λ is also required. Areas of different slope lengths were identified using aerial photography, soil, land use and topographic data. After examining the above mentioned data it was concluded that generally areas with similar slope length coincide with unique hydrologic map unit areas that were identified in an earlier phase of this project. Therefore, slope length values for different hydrologic map unit areas were utilized and are presented in ***Appendix B***. Furthermore, recognizing the limitation of calculating the slope at every grid element, the maximum topographic factor value was set at 18. This was done to avoid unreasonable values of topographic factor especially in the steep mountainous areas were the calculated slope values can be extremely high.

3.1.7 Erosion Control Practice Factor, P

An input value equal to the erosion control practice factor, P is required to determine the sediment wash load using the GIS Model. The dominant land use in Gillespie watershed is undeveloped desert rangeland therefore an erosion control practice factor of one was used.

3.2 TOTAL BED MATERIAL LOAD

This section describes the necessary input data and their format required to estimate the sediment total bed load and allowable velocity as implemented into the Sediment Yield Model.

3.2.1 Sediment Size Gradation

As previously stated, sediment gradation analysis and the location of soil samples collected throughout Gillespie watershed were documented under a previous task of this project. Soil gradation data required to determine the total bed material load as described in the methodology section is presented in ***Table 3.3*** below. Specifically, values of D_{84}, D_{75}, D_{50} and D_{16} are utilized to determine the total bed material load, whereas D_{10} is utilized to determine the bulk specific weight of sediment necessary to convert the wash load from weight to volume.

Table 3.3 – Soil Gradation Data

Particle Diameter (Percent Finer)	Sediment Size (mm)	
	Rainbow Wash	Maricopa Mountain
D_{10}	0.30	0.30
D_{16}	0.44	0.45
D_{50}	1.68	1.78
D_{75}	4.17	3.66
D_{84}	6.02	4.53

3.2.2 Depth, Y_h

Coverage of flow depths for the entire project area in raster format is required to approximate the total sediment bed load using the GIS Model. Peak flow depths at every grid element for 100-, 50-, 25-, 10-, 5-, and 2-year return periods for Rainbow Wash and Maricopa Mountain subwatersheds were obtained from the FLO-2D modeling results. The output FLO-2D file, *DEPTH.OUT* was used to create the depth raster.

The depth raster was supplemented with HEC-1 results for the eastern portion of the Maricopa Mountain subwatershed.

3.2.3 Flow discharge, Q

Coverage of peak discharges for the entire project area in raster format is required to determine the total bed material load using the GIS Model. The same peak discharge files as described in ***Section 3.3*** above were used to estimate the total bed material load.

3.2.4 Volume, V_w

Runoff volume is required to determine the total bed material load as described in the methodology section. A method, described in ***Section 3.1*** above, was developed to approximate the runoff volume at each grid element.

3.2.5 Average Velocity, V_a

Coverage of velocities for the entire project area in raster format is required to determine the total bed material load using the GIS Model. Velocity values at every grid element for 100-, 50-, 25-, 10-, 5-, and 2-year return periods for the Rainbow Wash and Maricopa Mountain subwatersheds were obtained from the FLO-2D modeling results. However, FLO-2D does not create a single output file that includes the velocities for both, the floodplain and channel grid elements. Therefore, the FLO-2D output file *VELFP.OUT* was supplemented with *VELOC.OUT* to create a single file, *VTOTAL.OUT* that contains the velocities for both the floodplain and channel grid elements. This file was used to create the velocity raster.

The velocity raster was supplemented with HEC-1 results for the eastern portion of the Maricopa Mountain subwatershed.

3.2.6 Manning's N Value

An input polygon shapefile depicting areas of different Manning's N values is required to determine the wash load using the GIS Model. The N values for different land use types used in this analysis were first determined and utilized as an input to the FLO-2D model and are presented in the ***Appendix B***.

3.2.7 Bank Slope , Z and Curve Radius ÷ Water Surface Width

Input value equal to the bank slope, Z and curve radius ÷ water surface width are required to determine the allowable velocity using the GIS Model. Values of 2.5 and 14 were used for the bank slope and curve radius ÷ water surface width, respectively. The GIS Model uses the input values and the equations in ***Figure 2.2*** and ***Figure 2.3*** to adjust the basic velocity for bank slope and channel alignment. Note that if the input values for the above mentioned parameters are outside the domains of ***Figure 2.2*** and ***Figure 2.3***, the GIS model will default to the nearest bound.

3.3 GIS MODEL

The Sediment Yield Model was designed to estimate the total sediment yield of a watershed using soil gradation data and the FLO-2D modeling results. After careful consideration of the

soil and hydrologic characteristics of the area it was concluded that sediment transport processes can be represented by model parameters that generally reflect the average conditions within the project area. The Model was developed in the Model Builder application that operates within the ArcGIS environment. Model Builder is an application that is used to create, edit and manage models (***Reference* 3**). In addition, some of the individual tools within the model require Spatial Analyst (***Reference* 5**) and 3D Analyst (***Reference* 4**) extensions.

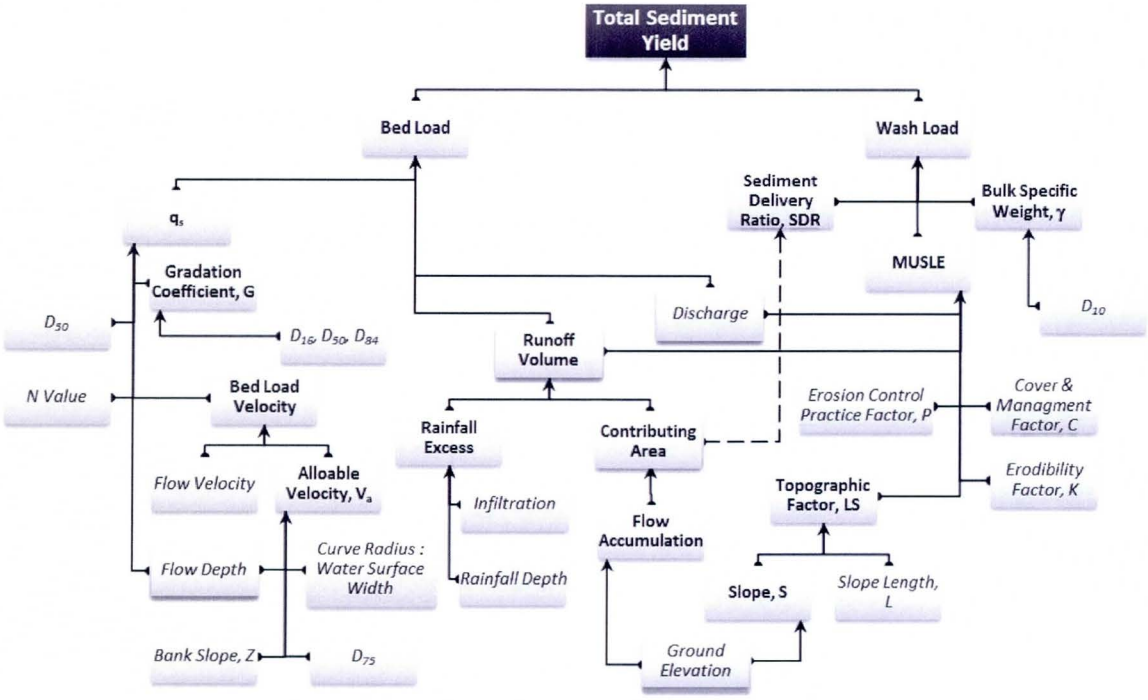
The GIS Model was created as a workflow that strings sequences of geoprocessing tools (steps), feeding the output of one tool into another tool as input. The model is a combination of 76 different tools that manipulate and modify 17 unique inputs to estimate the total sediment yield. Brief descriptions of all model processes and calculation steps, as well as the model schematic are included in ***Appendix D***. The model inputs and some of the data editing required prior to running the GIS model were discussed in the previous section. A condensed version of the model diagram showing all the inputs and the major intermediated calculations (outputs) is shown in ***Figure 3.2*** below. To distinguish between different model components in the figure below the model inputs are shown in italic text whereas the calculated intermediate steps are shown in bold text. As it can be seen from the diagram, the model has two main calculation branches; the bed load and wash load. The main intermediate steps under bed load branch are; allowable velocity, bed load velocity, gradation coefficient and bed material discharge per unit width, whereas the main calculation steps under wash load branch are; slope, topographic factor, MUSLE, sediment delivery ratio and bulk specific weight. As described in the methodology section the runoff volume is required to determine both the wash load and bed load, therefore the flow accumulation, contributing area, rainfall excess and runoff volume are shared between the two main calculation branches.

Even though it is not captured in the figure below, it is important to note that the flow accumulation process is also used to determine average values of several model parameters that correspond to upstream contributing drainage area of each grid element. This is accomplished by using the particular model parameter to determining the weighted flow accumulation and then dividing the result by flow accumulation. Average values at each grid element were determined for the coverage and management factor, soil erodibility factor, slope length, slope, and infiltration. A more detail description of flow accumulation process can be found in Arc Hydro Tools User Manual (***Reference* 6**).

The output of this analysis is a raster that covers the entire modeled area where each grid element has a value equal to the total sediment yield. To test the adequacy of the results presented in this investigation a verification analysis was conducted at several locations by comparing the GIS model results with hand calculations of the sediment wash load. The verification analysis shows that there is acceptable agreement between the GIS model results and the hand calculation. Nevertheless, it is important to understand that there is some variability between the two calculation methods due to the differences in runoff volume calculation. The technique that is used in the GIS Model to approximate the runoff volume and its limitations were described in the previous section. In addition, some discrepancy between the two calculation method results is also due to the flow accumulation process utilized in the GIS Model to average the parameters described above. However, the discrepancy in the total sediment yield results due to the parameter averaging process was found to be less significant

than the discrepancy introduced by the runoff volume approximation. The verification process is presented in ***Appendix C***.

Figure 3.2 – GIS Model Diagram



4.0 Results

The base 100-year, 6-hour sediment yield model results for Rainbow Wash subwatershed are shown in ***Figure 4.1***, whereas the base model results for Maricopa Mountain subwatershed are shown in ***Figure 4.3***. In addition, the annual sediment yield results for Rainbow Wash and Maricopa Mountain subwatersheds are displayed in ***Figure 4.2*** and ***Figure 4.4***, respectively. A summary of sediment yield results at key locations within the project area for the annual and 100-year return periods are presented in ***Table 4.1*** and ***Table 4.2*** below. Also, input and output files for all models and for each subwatershed are provided digitally in separate file geodatabases.

4.1 RAINBOW WASH SUBWATERSHED

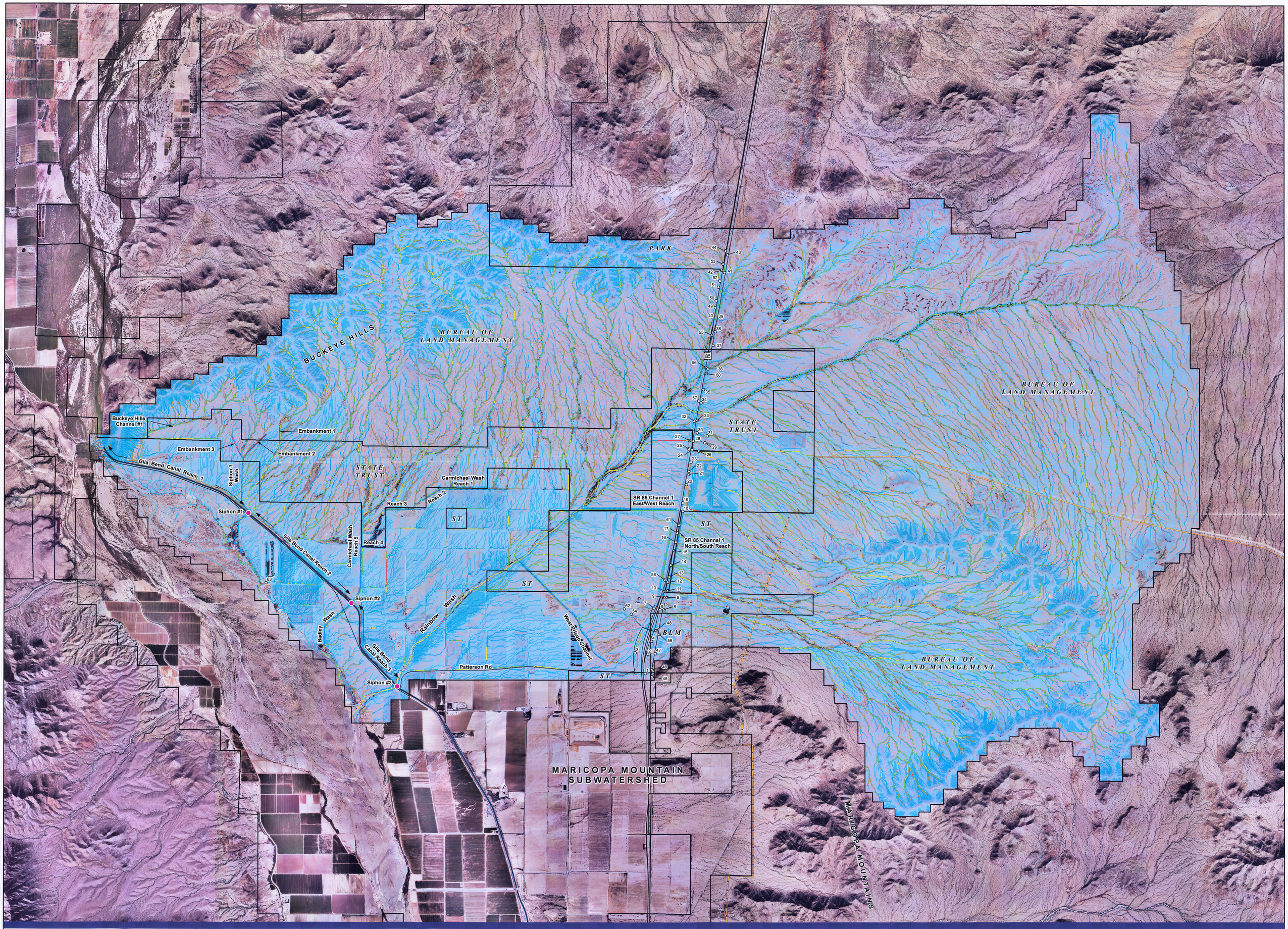
This section describes the total sediment yield results for Rainbow Wash subwatershed. As expected, the model results show that sediment yield increases as the contributing drainage area increases with higher values being found in the main washes and drainage facilities in the area. From ***Table 4.1*** the maximum sediment yield for the base 100-year, 6-hour storm event within Rainbow Wash subwatershed is found at Siphon #3, where Rainbow Wash crosses Gila Bend Canal and is approximately 1,622,727 cubic-feet (approximately 37 acre-feet) of sediment. Besides Rainbow Wash, total sediment yield was found to be significant in Badley Wash (approximately 7.6 acre-feet), Siphon #1 Wash (approximately 41.6 acre-feet), Carmichael Wash Reach 5 (approximately 2.0 acre-feet) and West Prison Channel (approximately 0.3 acre-feet). In addition, total sediment yield is significant at culverts #5, #6, and #18. Sediment yield results for all the culverts located within Rainbow Wash subwatershed are included in ***Appendix E***. It is important to note that due to the grid nature of the model output the total sediment yield values within a single wash or drainage feature can vary significantly and the maximum sediment yield values are presented in ***Table 4.1*** below.

Table 4.1 – Rainbow Wash Subwatershed Sediment Yield Summary

Location	Drainage Area sq. mi.	Sediment Yield (cu-ft)	
		100-Yr, 6-Hr	Annual
Rainbow Wash at SR 85 Bridge	18.1	832,345	122,419
Rainbow Wash at SR 85 Channel 1	40.0	199,389	18,495
Rainbow Wash at West Prison Channel	40.7	588,684	79,361
Rainbow Wash at Gila Bend Canal (Siphon #3)	45.3	1,622,727	653,423
Rainbow Wash Tributary at SR 85	3.7	80,647	48,055
SR 85 Channel 1 North-South Reach	4.4	17,978	3,195
SR 85 Channel 1 East West Reach	38.5	43,734	6,182
West Prison Channel	2.9	14,694	3,531
Carmichael Wash Reach 1	3.5	20,987	4,948

Table 4.1 – Rainbow Wash Subwatershed Sediment Yield Summary (Cont.)

Location	Drainage Area sq. mi.	Sediment Yield (cu-ft)	
		100-Yr, 6-Hr	Annual
Carmichael Wash Reach 2	3.6	17,425	4,544
Carmichael Wash Reach 3	5.0	68,262	9,462
Carmichael Wash Reach 4	7.3	37,583	7,870
Carmichael Wash Reach 5	10.1	85,672	15,932
Siphon #2	9.4	106,377	32,909
Buckeye Hill Channel	1.0	31,371	5,706
Siphon 1 Wash (Siphon #1)	5.8	1,813,253	490,950
Badley Wash	9.7	331,792	145,035
Culvert #5	1.5	22,518	5,159
Culvert #6	1.5	10,994	2,642
Culvert #18	4.4	17,978	3,195



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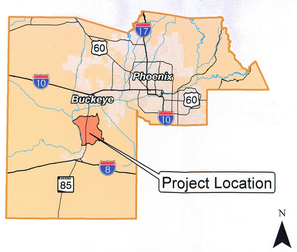

VICINITY MAP

NOTES:

Aerial imagery flight dates Oct 2009 and Nov 2006
V:\52813\active\181300167\GIS\Worktemp\BobB\SedYield\Rainbow Wash Watershed - Sediment Yield Map_Figure_4.1.mxd

LEGEND:

- Culvert Inlet Location
- Siphon
- Road
- Gila Bend Canal
- Channel
- Embankment
- National Monument Boundary

Total Yield (cu-ft)

No Color	< 0.1
	0.1 - 1.0
	1. - 10
	10 - 100
	100 - 1,000
	1,000 - 10,000
	10,000 - 100,000
	100,000 - 1,000,000
	> 1,000,000

FIGURE 4.1
RAINBOW WASH SUBWATERSHED
100-YEAR, 6-HOUR SEDIMENT YIELD

N

0 2,000 4,000
Feet

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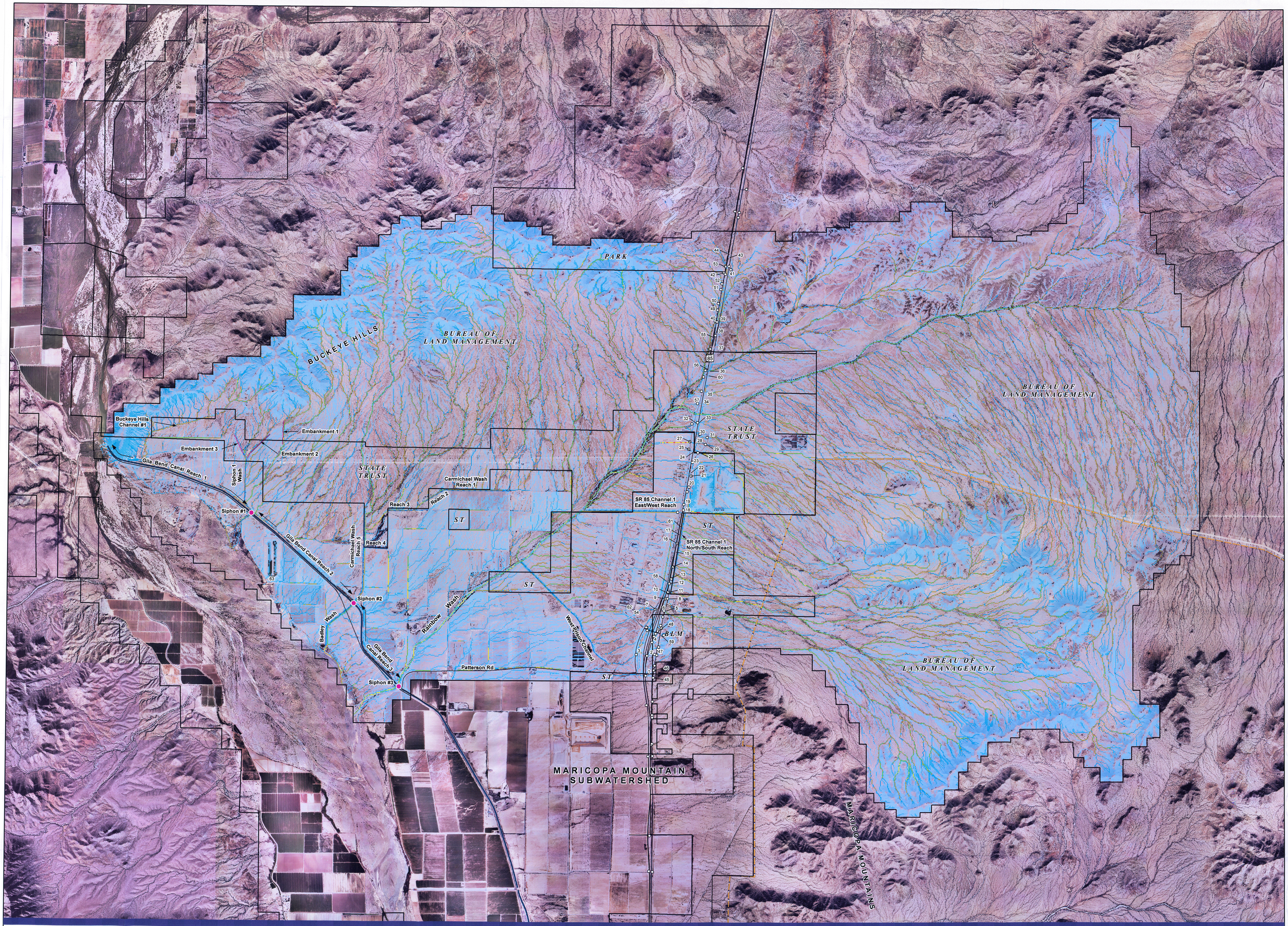

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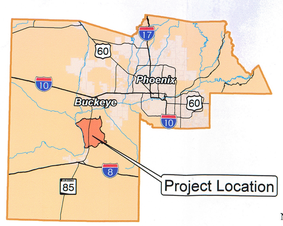

NOTES:

Aerial imagery flight dates Oct 2009 and Nov 2006
V:\52813\active\181300167\GIS\Worktemp\BobB\SedYield\Rainbow Wash Watershed - Sediment Yield Map_Figure_4.2.mxd

LEGEND:

- Culvert Inlet Location
- Siphon
- Road
- Gila Bend Canal
- Channel
- Embankment
- National Monument Boundary

Total Yield (cu-ft)

- No Color: < 0.1
- 0.1 - 1.0
- 1. - 10
- 10 - 100
- 100 - 1,000
- 1,000 - 10,000
- 10,000 - 100,000
- 100,000 - 1,000,000
- > 1,000,000

FIGURE 4.2
RAINBOW WASH SUBWATERSHED
ANNUAL SEDIMENT YIELD

N

0 2,000 4,000
Feet

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4.2 MARICOPA MOUNTAIN SUBWATERSHED

This section describes the total sediment yield results for Maricopa Mountain subwatershed. Similarly to Rainbow Wash subwatershed, the model results for Maricopa Mountain subwatershed show that total sediment yield is proportional to contributing drainage area. As a result, the higher values of sediment yield are found in the main washes and drainage facilities within the subwatershed. The maximum sediment yield for the base 100-year, 6-hour storm event within Maricopa Mountain subwatershed is found 1.8 miles upstream of Culvert #44 and is approximately 12,249,482 cubic-feet (approximately 281 acre-feet) of sediment. Sediment yield at the outlets of Major Basin 1, 2 and 3 was found to be 3.6, 4.2, 0.5 acre-feet, respectively. Furthermore, total sediment yield was found to be significant at Siphon #5 (approximately 16.7 acre-feet), Siphon #4 (approximately 59.4 acre-feet), Upper Woods Wash (approximately 4.0 acre-feet), Siphon #6 (approximately 3.1 acre-feet), Landfill Channel (approximately 0.8 acre-feet), Johns Wash (approximately 0.3 acre-feet), ADOT Channel Reach 1 (approximately 3.8 acre-feet) and Reach 2 (approximately 4.5 acre-feet). In addition, total sediment yield is significant at culverts #31, #34, #44, #47, #60, #62, #63, #68, #69, #70, #76, #96 and #100. Sediment yield results for all the culverts located within Maricopa Mountain subwatershed are included in ***Appendix E***.

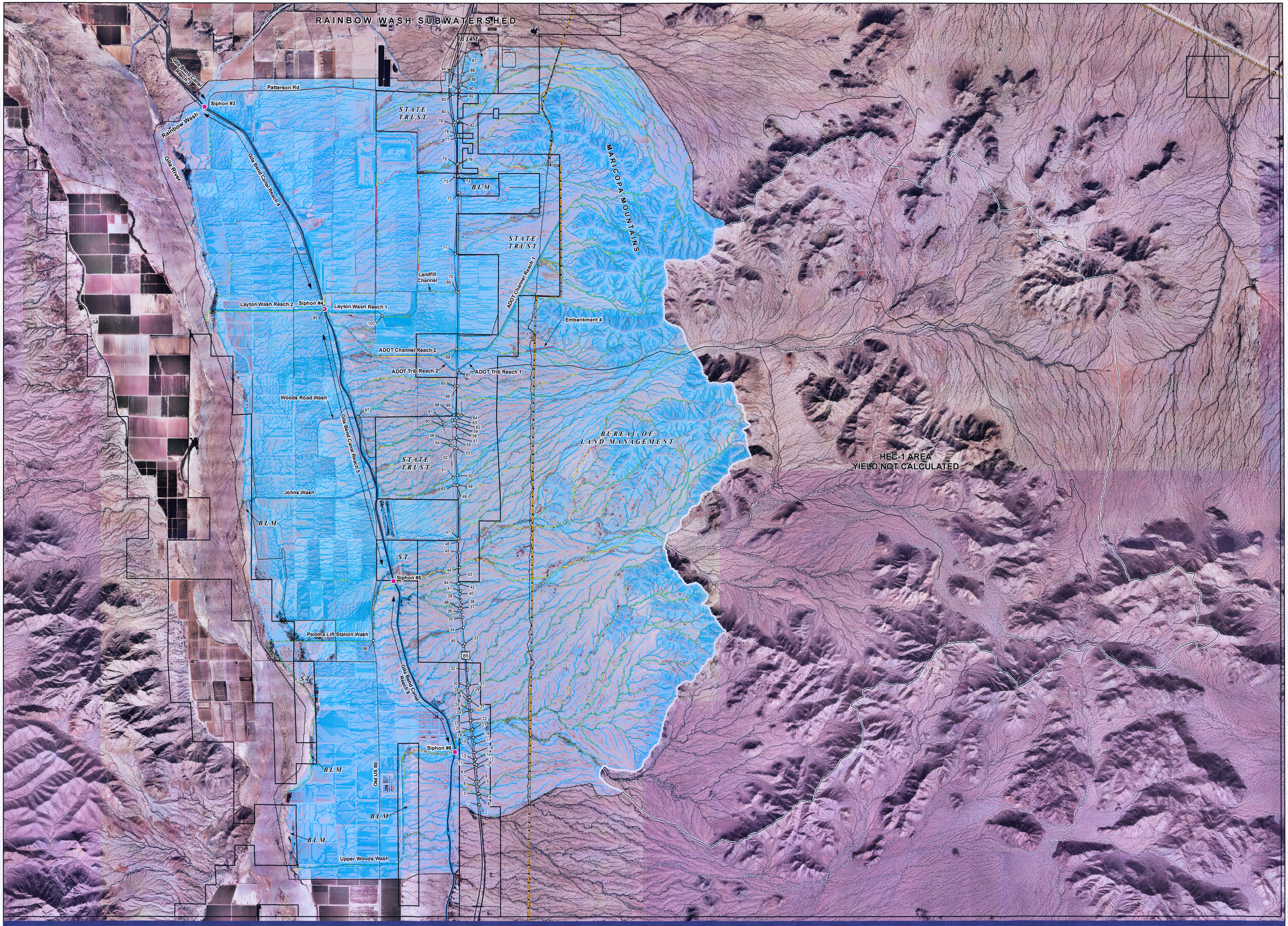
While analyzing the results of this investigation, it is important to understand some of the limitations of the sediment yield results as calculated using the GIS Model. Due to the grid nature of the model output, the total sediment yield values within a single wash or drainage facility can vary and the values shown in ***Table 4.2*** below represent the maximum total sediment yield. Furthermore, results at specific locations where total sediment yield could be overestimated should be carefully analyzed and engineering judgment should be used to evaluate the model results. These locations include in particular culverts along SR 85 and siphons along Gila Bend Canal. For instance, the sediment yield results for 100-year, 6-hour flood event show that there is 136,230 cubic-feet of sediment that is conveyed by all the tributary washes that drain at Siphon #6. To account for all the tributary washes that drain at the above mentioned location the combined upstream drainage area is used to calculate the total sediment yield. This is accomplished by utilizing the flow accumulation method which uses a cumulative process to determine the upstream contributing area at each grid element based on the ground elevation. However, as it was evident during field visits, it is possible that some of the sediment conveyed by tributary washes is deposited upstream of Gila Bend Canal prior to reaching Siphon #6. At first, several of the tributary washes that are taken into consideration flow westerly towards Gila Bend Canal and then flow along the Canal towards Siphon #6. When these tributary washes reach the ponding area upstream of Gila Bend Canal the flow velocities are reduced significantly, which in turn can lead to sediment being deposited prior to reaching Siphon #6. As a result, the sediment yield at this and other similar locations could be overestimated.

As previously stated, the location of the maximum sediment yield was identified based on the 100-year, 6-hour model results. Note that the maximum sediment yield for the other storm events can occur in a different grid element within the respective wash or drainage facility. Moreover, there are instances when the total sediment yield calculations for smaller storm event result in sediment yield values that are greater than those for larger storms. For example, the total sediment yield at grid element No. 194257 located in Layton Wash Reach 1 for the 100-

year, 6-hour storm event is 717,418 cubic –feet of sediment, whereas for the 2-year, 6-hour storm event is 318,648 cubic-feet of sediment. As described in the approach section, very high sediment yield values for smaller storms occur at locations where steep slopes and shallow flow conditions are present. The result of sediment yield analysis for the few grid elements where the above mentioned conditions are present do not represent the real sediment transport characteristic of the particular wash or drainage facility. Therefore, the sediment yield values at these grid elements should not be considered to arrive at any conclusions about the sediment yield and conveyance capacity of the drainage facilities.

Table 4.2 – Maricopa Mountain Subwatershed Sediment Yield Summary

Location	Drainage Area sq. mi.	Sediment Yield (cu-ft) 100-Yr, 6-Hr	Sediment Yield (cu-ft) Annual
ADOT Channel Reach 1	3.3	164,814	28,895
ADOT Channel Reach 2	3.6	199,181	33,991
ADOT Tributary Channel Reach 1	0.2	4,263	985
ADOT Tributary Channel Reach 2	0.3	8,285	3,610
Landfill Channel	5.2	34,858	8,305
Layton Wash Reach 1 (Siphon #4)	17.7	2,588,454	296,637
Layton Wash Reach 2	18.0	57,913	11,629
Johns Wash	0.5	14,921	5,904
Paloma Lift Station Wash	40.1	42,618	6,084
Siphon #5	37.3	728,347	326,230
Siphon #6	1.3	135,807	20,307
Upper Woods Wash	15.3	172,855	15,953
Culvert #31	0.6	177,901	19,636
Culvert #34	0.3	7,589	1,896
Culvert #44	34.9	177,245	26,403
Culvert #47	1.4	30,602	8,869
Culvert #60	0.04	8,757	2,897
Culvert #62	1.0	10,492	1,346
Culvert #63	1.0	11,819	1,836
Culvert #68	3.3	15,246	4,617
Culvert #69	2.0	9,624	1,164
Culvert #70	1.6	2,639	409
Culvert #76	1.7	47,693	18,650
Culvert #96	37.5	194,051	18,325
Culvert #100	5.3	21,837	4,238



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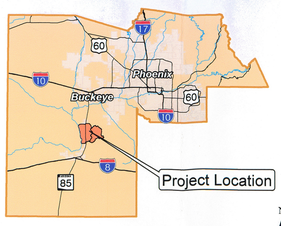

VICINITY MAP

NOTES:

Aerial imagery flight dates Oct 2009 and Nov 2006
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LEGEND:

- Culvert Inlet Location
- Siphon
- Road
- Gila Bend Canal
- Channel
- Embankment
- HEC-1 Area
- National Monument Boundary

Total Yield (cu-ft)

- No Color: < 0.1
- 0.1 - 1.0
- 1. - 10
- 10 - 100
- 100 - 1,000
- 1,000 - 10,000
- 10,000 - 100,000
- 100,000 - 1,000,000
- > 1,000,000

FIGURE 4.3
MARICOPA MOUNTAIN SUBWATERSHED
100-YEAR, 6-HOUR SEDIMENT YIELD

N

0 2,000 4,000 Feet

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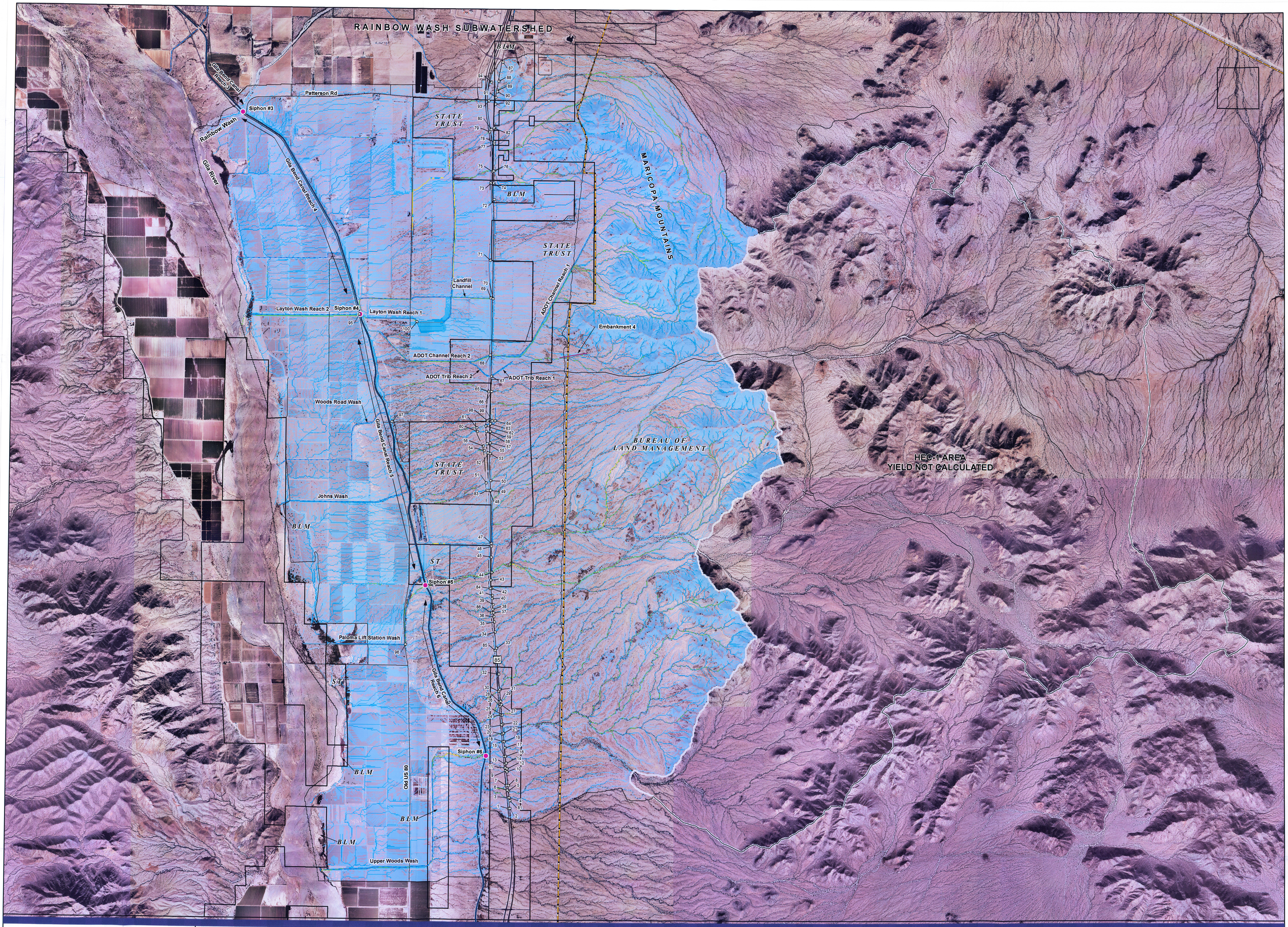

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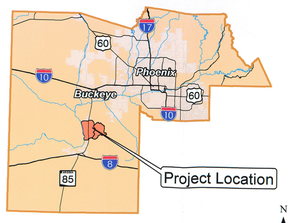

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Aerial imagery flight dates Oct 2009 and Nov 2006
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LEGEND:

- Culvert Inlet Location
- Siphon
- Road
- Gila Bend Canal
- Channel
- Embankment
- HEC-1 Area
- National Monument Boundary

Total Yield (cu-ft)

- No Color: < 0.1
- 0.1 - 1.0
- 1. - 10
- 10 - 100
- 100 - 1,000
- 1,000 - 10,000
- 10,000 - 100,000
- 100,000 - 1,000,000
- > 1,000,000

FIGURE 4.4
MARICOPA MOUNTAIN SUBWATERSHED
ANNUAL SEDIMENT YIELD

N

0 2,000 4,000 Feet

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5.0 Conclusions

The watershed is composed of complex landforms and a distributive drainage network. Man-made drainage features compound the complexity of the watershed by altering the natural flow patterns. To account for the complexity, a two-dimensional model was used to simulate the watershed hydrology. The sediment yield analysis was performed using a combination of the MUSLE and Zeller-Fullerton equations and implemented in a grid-based GIS environment on a watershed scale. The implementation of the sediment yield methodologies for a highly complex watershed is a very prescriptive approach that has some significant, inherent limitations that must be understood when interpreting the model results.

First, the MUSLE is an empirical method for estimating the soil loss from sheet and rill erosion. In the Sediment Yield Model, the wash load component of the total sediment yield estimated using the MUSLE is applied to every grid cell regardless of the landform and physical processes resulting in erosion and soil loss. Therefore, in portions of the watershed, the total sediment yield may be overestimated.

Second, the Zeller-Fullerton equation is a sediment transport equation that is applied to riverine conditions. Similar to the MUSLE, the Sediment Yield Model applies this equation everywhere in the watershed. Although the model does attempt to limit bed material load calculations using the concept of maximum allowable velocity, this does not ensure that the total bed material load calculations are being applied in truly riverine conditions within the watershed. Furthermore, the Zeller-Fullerton equation is based on the assumption that the study reach is in equilibrium. Field observations and review of historic aerial photography indicates that this is not the case everywhere in the watershed. Consequently, in portions of the watershed, the total sediment yield may be overestimated due to the potential application in non-riverine areas and simultaneously underestimated in alluvial fan areas due to the assumption of an equilibrium condition.

Third, the Zeller-Fullerton equation is a function of bed material size. Typically, there is tremendous variation in the size gradation of bed material at a watershed scale. Although, the size gradation of the wash bed material in the study watershed is reasonably uniform, there is obviously some variability. Therefore, use of a single size gradation in the analysis may result in an underestimation of total sediment yield in some portions of the watershed and an overestimation of the total sediment yield in other portions of the watershed.

Fourth, FLO-2D does not directly report runoff volume at each grid cell. Therefore, a simplified approach was developed to estimate runoff volume using the total infiltration at each grid cell, the rainfall depth and the contributing area. Because FLO-2D infiltrates any flow on a grid cell regardless if it is derived from rainfall or upstream runoff, use of the simplified approach can severely underestimate runoff volume. Although this effect was minimized by calculating runoff using a shortened duration, the resulting runoff volume in the main washes will still be underestimated. This is further complicated by the difficulty in determining the physical area contributing to any one location in the watershed due to the distributive nature of the drainage network. In the model, contributing area is determined using a very simple accounting based on the steepest slope in one dimension. Downstream of a flow split, the model chooses a path with

the steepest slope and that path carries all the upstream area. On the other branches of the wash, downstream of the split, the area accumulation is restarted at zero. This one-dimensional accounting approach is not commensurate with the percentage of flow that will be split at each branch of the wash. This results in an overestimation of the runoff volume on the steepest path downstream of the split and an underestimation on the other branches.

Finally, the model calculates total sediment yield at each and every grid cell in the watershed in a very rigorous and prescriptive manner. As a result, factors that tend to over and/or underestimate total sediment yield are combined together indiscriminately. At the same time, there is a great deal of subjectivity in many of the input parameters as well as in the applicability of the specific methods for wash load and total bed material load to any one particular area. Therefore, it is extremely important to keep the model limitations in mind when interpreting the results. Pinpointing results for individual any grid cell and comparing the results to other locations in the watershed and drawing conclusions regarding the adequacy of the results is not appropriate given the aforementioned limitations and the subjectivity of the methodologies themselves. Rather, the intent of the Sediment Yield Model is to facilitate on a watershed scale, provide a spatial representation of the locations where sediment erosion and/or deposition may occur and finally provide a reasonable target of the magnitude of sediment yield that could be expected on an event basis as well as an average annual target.

The results show that most of the sediment eroded from the areas prone to the sediment issues is conveyed by the major washes and drainage channels within the Gillespie Watershed. The sediment in Rainbow Wash subwatershed is concentrated and conveyed mostly by Rainbow Wash and Badley Wash, whereas in Maricopa Mountain subwatershed most of the sediment is conveyed by Layton Wash, Upper Woods Wash, Johns Wash, ADOT Channel Reaches 1 and 2 and the Landfill Channel.

Based on the model results and with a full understanding of the model limitations, the following recommendation are made concerning the inspection and maintenance of drainage facilities within Gillespie watershed. Based on the results of this investigation, it is recommended that the drainage facilities listed in ***Table 4.1*** and ***Table 4.2*** be inspected annually and cleaned as necessary in order to promote the future functioning of these facilities. It is important that these facilities be inspected and cleaned after significant storm events. Also, note that the list of locations presented in ***Table 4.1*** and ***Table 4.2*** is not all inclusive and the same recommendation is valid for other drainage facilities within the project area. In addition, the results of sediment yield analysis can be used by the responsible agencies to prioritize their inspection and maintenance of other drainage facilities located within Gillespie watershed, but not listed in the above-mentioned tables.

6.0 References

1. *River Mechanics Manual for DDMSW,* by Flood Control District of Maricopa County, Engineering Division, April 2010.

2. *Watercourse System Sediment Balance,* State Standard 5-96 (SSA 5-96), by Arizona Department of Water Resources (ADWR), Flood Warning and Dam Safety Section, September 1996.

3. *Model Builder, Version 10.0 (Software)*, by Environmental Systems Research Institute (ESRI), 2010.

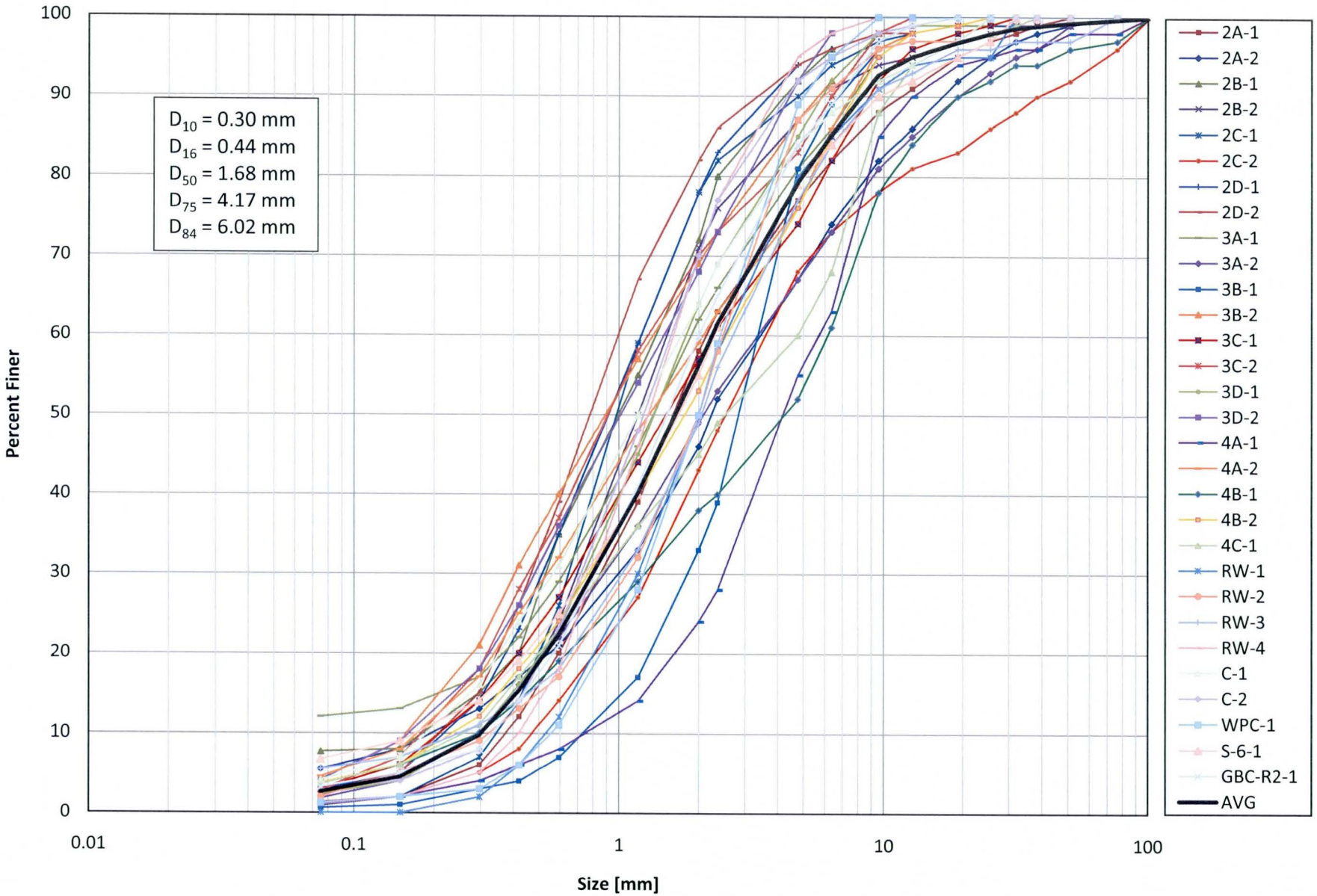
4. *3-D Analyst Extension of ArcGIS*, by ESRI, Version 10.0 Service pack 3, 2010.

5. *Spatial Analyst Extension of ArcGIS*, by ESRI, Version 10.0 Service pack 3, 2010.

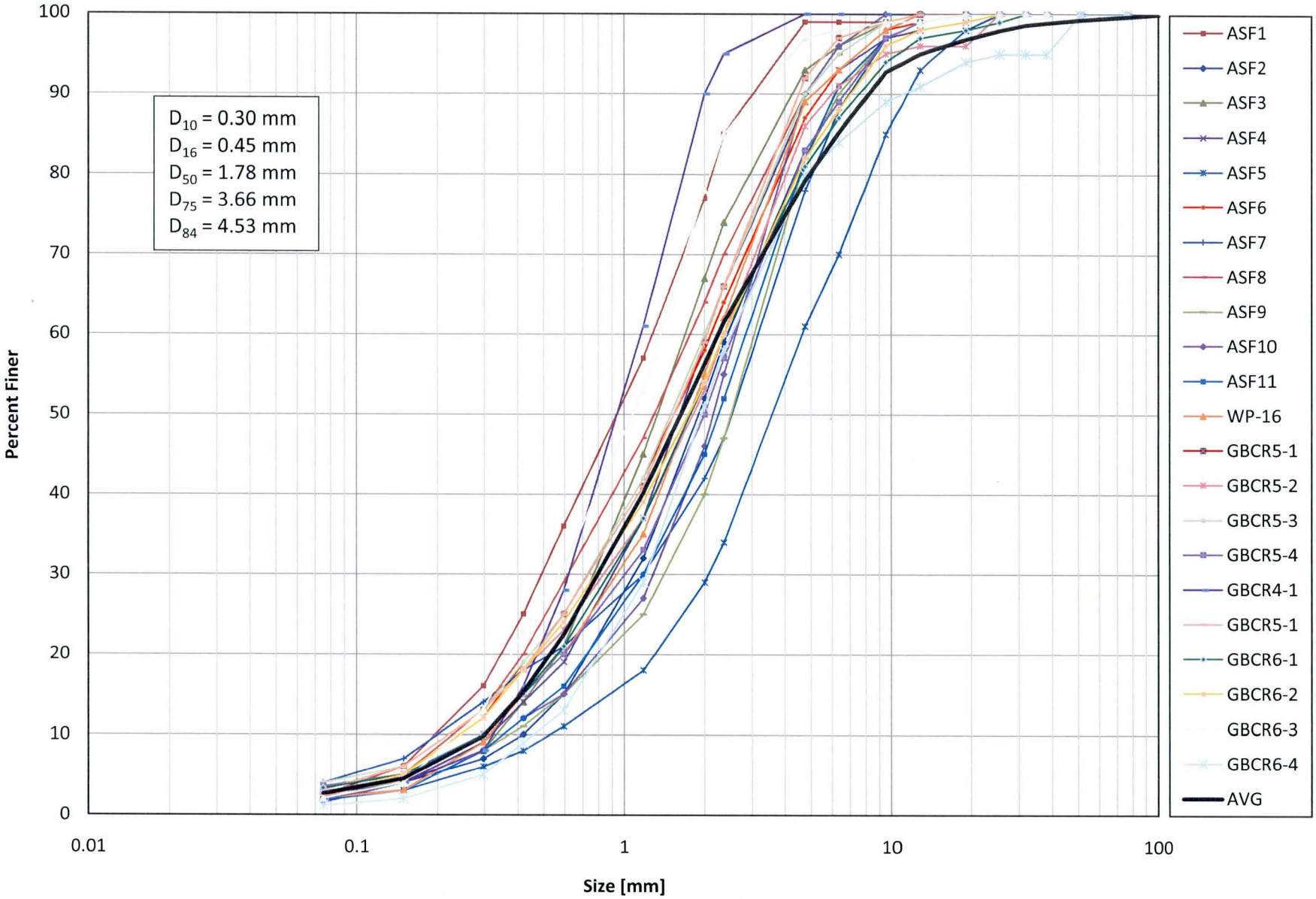
6. *Arc Hydro Tools for ArcGIS 10*, by ESRI, Version 2.1, 30 April 2012.

Appendix A – Soil Gradation

Rainbow Wash Subwatershed Soil Gradation



Maricopa Mountain Subwatershed Soil Gradation



Appendix B – Cover and Management Factor, Slope Length, and N-values

MUSLE Parameters for Each Hydrologic Map Unit

Hydrologic Map Unit		Description	N-value	Cover and Mangment Factor	Slope Length (feet)
Label	Key			C	λ
AG1-1	1101	Active Agriculture - NRCS Soil Map Unit 1	0.100	0.100	200
AG1-2	1102	Active Agriculture - NRCS Soil Map Unit 2	0.100	0.100	200
AG1-6	1106	Active Agriculture - NRCS Soil Map Unit 6	0.100	0.100	50
AG1-13	1113	Active Agriculture - NRCS Soil Map Unit 13	0.100	0.100	200
AG1-15	1115	Active Agriculture - NRCS Soil Map Unit 15	0.100	0.100	100
AG1-16	1116	Active Agriculture - NRCS Soil Map Unit 16	0.100	0.100	200
AG1-17	1117	Active Agriculture - NRCS Soil Map Unit 17	0.100	0.100	400
AG1-21	1121	Active Agriculture - NRCS Soil Map Unit 21	0.100	0.100	400
AG1-29	1129	Active Agriculture - NRCS Soil Map Unit 29	0.100	0.100	400
AG1-30	1130	Active Agriculture - NRCS Soil Map Unit 30	0.100	0.100	250
AG1-33	1133	Active Agriculture - NRCS Soil Map Unit 33	0.100	0.100	50
AG1-37	1137	Active Agriculture - NRCS Soil Map Unit 37	0.100	0.100	250
AG1-41	1141	Active Agriculture - NRCS Soil Map Unit 41	0.100	0.100	400
AG1-42	1142	Active Agriculture - NRCS Soil Map Unit 42	0.100	0.100	250
AG1-43	1143	Active Agriculture - NRCS Soil Map Unit 43	0.100	0.100	250
AG1-53	1153	Active Agriculture - NRCS Soil Map Unit 53	0.100	0.100	50
AG1-55	1155	Active Agriculture - NRCS Soil Map Unit 55	0.100	0.100	50
AG1-63	1163	Active Agriculture - NRCS Soil Map Unit 63	0.100	0.100	200
AG1-67	1167	Active Agriculture - NRCS Soil Map Unit 67	0.100	0.100	1000
AG2-6	1206	Fallow Agriculture - NRCS Soil Map Unit 6	0.080	0.100	400
AG2-10	1210	Fallow Agriculture - NRCS Soil Map Unit 10	0.080	0.100	50
AG2-13	1213	Fallow Agriculture - NRCS Soil Map Unit 13	0.080	0.100	200
AG2-15	1215	Fallow Agriculture - NRCS Soil Map Unit 15	0.080	0.100	200
AG2-17	1217	Fallow Agriculture - NRCS Soil Map Unit 17	0.080	0.100	200
AG2-20	1220	Fallow Agriculture - NRCS Soil Map Unit 20	0.080	0.100	400
AG2-21	1221	Fallow Agriculture - NRCS Soil Map Unit 21	0.080	0.100	400
AG2-30	1230	Fallow Agriculture - NRCS Soil Map Unit 30	0.080	0.100	50
AG2-33	1233	Fallow Agriculture - NRCS Soil Map Unit 33	0.080	0.100	50
AG2-35	1235	Fallow Agriculture - NRCS Soil Map Unit 35	0.080	0.100	50
AG2-37	1237	Fallow Agriculture - NRCS Soil Map Unit 37	0.080	0.100	1000
AG2-38	1238	Fallow Agriculture - NRCS Soil Map Unit 38	0.080	0.100	400

MUSLE Parameters for Each Hydrologic Map Unit

Hydrologic Map Unit		Description	N-value	Cover and Mangment Factor	Slope Length (feet)
Label	Key			C	λ
AG2-42	1242	Fallow Agriculture - NRCS Soil Map Unit 42	0.080	0.100	400
AG2-43	1243	Fallow Agriculture - NRCS Soil Map Unit 43	0.080	0.100	50
AG2-55	1255	Fallow Agriculture - NRCS Soil Map Unit 55	0.080	0.100	50
AG2-67	1267	Fallow Agriculture - NRCS Soil Map Unit 67	0.080	0.100	400
IND1-15	2115	Sand and Gravel - NRCS Soil Map Unit 15	0.050	0.170	100
IND1-43	2143	Sand and Gravel - NRCS Soil Map Unit 43	0.050	0.170	100
IND2-20	2220	Prison - NRCS Soil Map Unit 20	0.060	0.170	100
IND2-21	2221	Prison - NRCS Soil Map Unit 21	0.060	0.170	100
IND2-37	2237	Prison - NRCS Soil Map Unit 37	0.060	0.170	100
IND2-53	2253	Prison - NRCS Soil Map Unit 53	0.060	0.170	100
IND3-6	2306	Agricultural Related - NRCS Soil Map Unit 6	0.060	0.170	100
IND3-13	2313	Agricultural Related - NRCS Soil Map Unit 13	0.060	0.170	100
IND3-17	2317	Agricultural Related - NRCS Soil Map Unit 17	0.060	0.170	100
IND3-20	2320	Agricultural Related - NRCS Soil Map Unit 20	0.060	0.170	100
IND3-33	2333	Agricultural Related - NRCS Soil Map Unit 33	0.060	0.170	100
IND3-67	2367	Agricultural Related - NRCS Soil Map Unit 67	0.060	0.170	100
IND4-21	2421	Power Generation - NRCS Soil Map Unit 21	0.020	0.170	100
IND5-17	2517	Land Fill - NRCS Soil Map Unit 17	0.080	0.170	100
IND5-20	2520	Land Fill - NRCS Soil Map Unit 20	0.080	0.170	100
IND5-21	2521	Land Fill - NRCS Soil Map Unit 21	0.080	0.170	100
IND5-33	2533	Land Fill - NRCS Soil Map Unit 33	0.080	0.170	100
IND5-37	2537	Land Fill - NRCS Soil Map Unit 37	0.080	0.170	100
IND5-67	2567	Land Fill - NRCS Soil Map Unit 67	0.080	0.170	100
IND6-17	2617	Storage Yard - NRCS Soil Map Unit 17	0.060	0.170	100
IND6-21	2621	Storage Yard - NRCS Soil Map Unit 21	0.060	0.170	100
IND6-37	2637	Storage Yard - NRCS Soil Map Unit 37	0.060	0.170	100
IND6-67	2667	Storage Yard - NRCS Soil Map Unit 67	0.060	0.170	100
IND7-21	2721	Dairy - NRCS Soil Map Unit 21	0.100	0.170	100
IND7-33	2733	Dairy - NRCS Soil Map Unit 33	0.100	0.170	100
IND7-37	2737	Dairy - NRCS Soil Map Unit 37	0.100	0.170	100
IND7-54	2754	Dairy - NRCS Soil Map Unit 54	0.100	0.170	100

MUSLE Parameters for Each Hydrologic Map Unit

Hydrologic Map Unit		Description	N-value	Cover and Mangment Factor	Slope Length (feet)
Label	Key			C	λ
IND7-67	2767	Dairy - NRCS Soil Map Unit 67	0.100	0.170	100
LDR-67	3067	Low Density Residential - NRCS Soil Map Unit 67	0.030	0.120	100
LDR1-13	3113	Partially Developed Low Density Res. - NRCS Soil Map Unit 13	0.030	0.120	100
LDR1-42	3142	Partially Developed Low Density Res. - NRCS Soil Map Unit 42	0.030	0.120	100
LDR1-43	3143	Partially Developed Low Density Res. - NRCS Soil Map Unit 43	0.030	0.120	100
LDR1-67	3167	Partially Developed Low Density Res. - NRCS Soil Map Unit 67	0.030	0.120	100
NC-1	4100	Active Alluvial Wash	0.025	0.090	80
NC-2	4200	Wash Terrace	0.040	0.090	60
NC-3	4300	Wash Terrace / Channel	0.035	0.090	100
NC-4	4400	Wash with heavy vegetation	0.070	0.090	50
NDR-1	5100	Undeveloped Desert Rangeland (Sheet Flow)	0.045	0.090	150
NDR-2	5200	Undeveloped Desert Rangeland (course grained alluvial deposits)	0.040	0.090	150
NDR-3	5300	Undeveloped Desert Rangeland (dissected alluvial & terrace deposits)	0.040	0.090	150
NHS-1	6100	Steep Hillslope, Sonoran Desert	0.055	0.090	80
NHS-2	6200	Moderate Slope, Sonoran Desert (gravelly surface layer)	0.060	0.090	60
NHS-3	6300	Moderate Slope, Sonoran Desert	0.055	0.090	60
NHS-4	6400	Moderate to steeply sloping debris deposit	0.050	0.090	50
NMT-1	7100	Mountain Terrain	0.060	0.090	60
NMT-2	7200	Mountain Terrain 15% Rock Outcrop	0.060	0.090	80
NMT-3	7300	Mountain Terrain 20% Rock Outcrop	0.060	0.090	80
NMT-4	7400	Mountain Terrain 25% Rock Outcrop	0.060	0.090	60
NMT-5	7500	Mountain Terrain 65% Rock Outcrop	0.060	0.090	60
P	8000	Pavement	0.025	0.120	1000
W	9000	Water	0.020	0.000	1000
760*	N/A	Alluvial Open Space	0.040	0.090	150
770*	N/A	Foothills Open Space	0.055	0.090	80
780*	N/A	Mountain	0.060	0.090	60

* Located within 1-D Modeling Area

Appendix C – Sediment Wash Load Comparison

Gillespie ADMS
FDC No. 2009C024
Stantec Sediment Wash Load Comparison

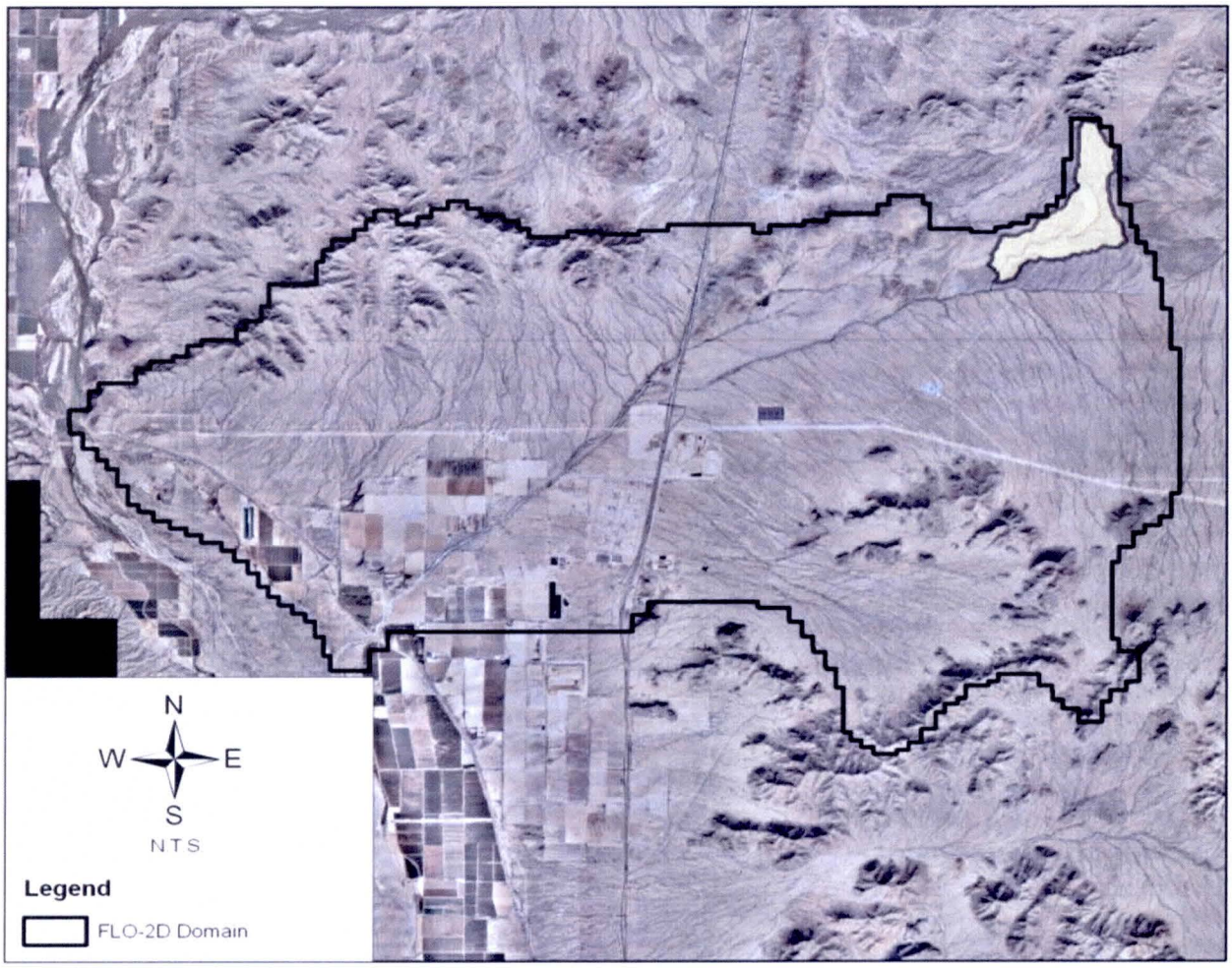
Area ID	Floodplain XSEC	Sediment Wash Load, in tons											
		GIS Model						Hand Calculations					
		K	LS	C	V [af]	q_p [cfs]	Ys	K	LS	C	V [af]	q_p [cfs]	Ys
1	65	0.07	0.24	0.09	127	448	63	0.07	0.18	0.09	113	944	60
2	69	0.12	1.55	0.09	45	133	200	0.16	0.18	0.09	31	208	30
3	61	0.04	3.77	0.09	35	301	238	0.04	1.68	0.09	57	733	218
4	56	0.02	7.55	0.09	101	1,692	1,371	0.03	6.04	0.09	98	1,785	1,135
5	52	0.03	6.91	0.09	4	371	97	0.03	5.21	0.09	86	1,321	906

Gillespie ADMS
FDC No. 2009C024
Sediment Wash Load Hand Calculations

Date: 7/18/2012 By: al
Checked: 9/12/2012 By: mcg

Test Area: 1 **Wash Load: 59.67 tons**

LOCATION

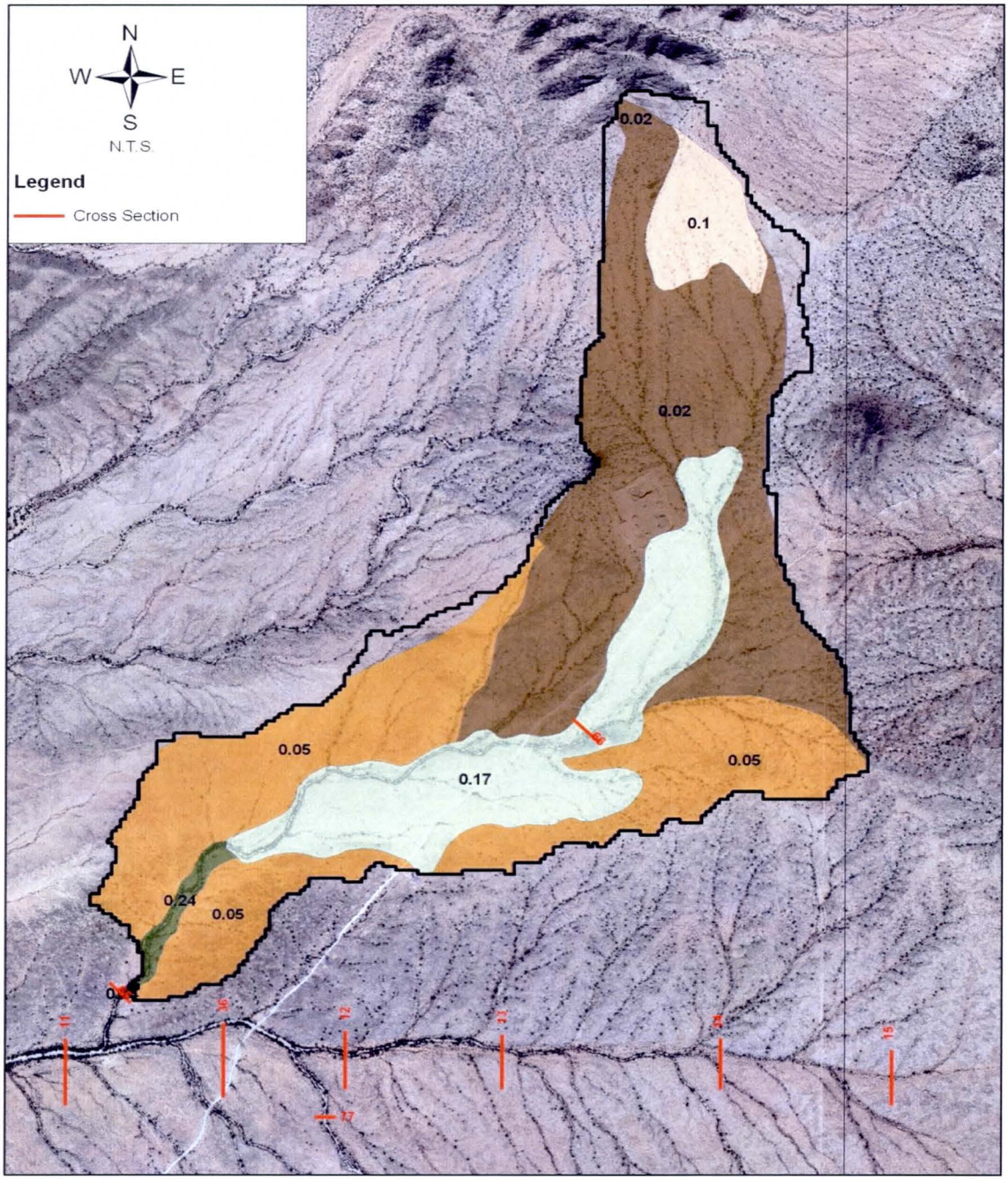


YIELD CALCULATION

Constants		Watershed Parameters	
P:	1	Erodibility Factor:	0.07
α:	95	Slope Factor:	0.18
C:	0.09	Runoff Factor:	82,720
β:	0.56	**Wash Load:**	**60**

Test Area: 1 **Erodibility Factor: 0.07**

ERODIBILITY



ERODIBILITY AREAS

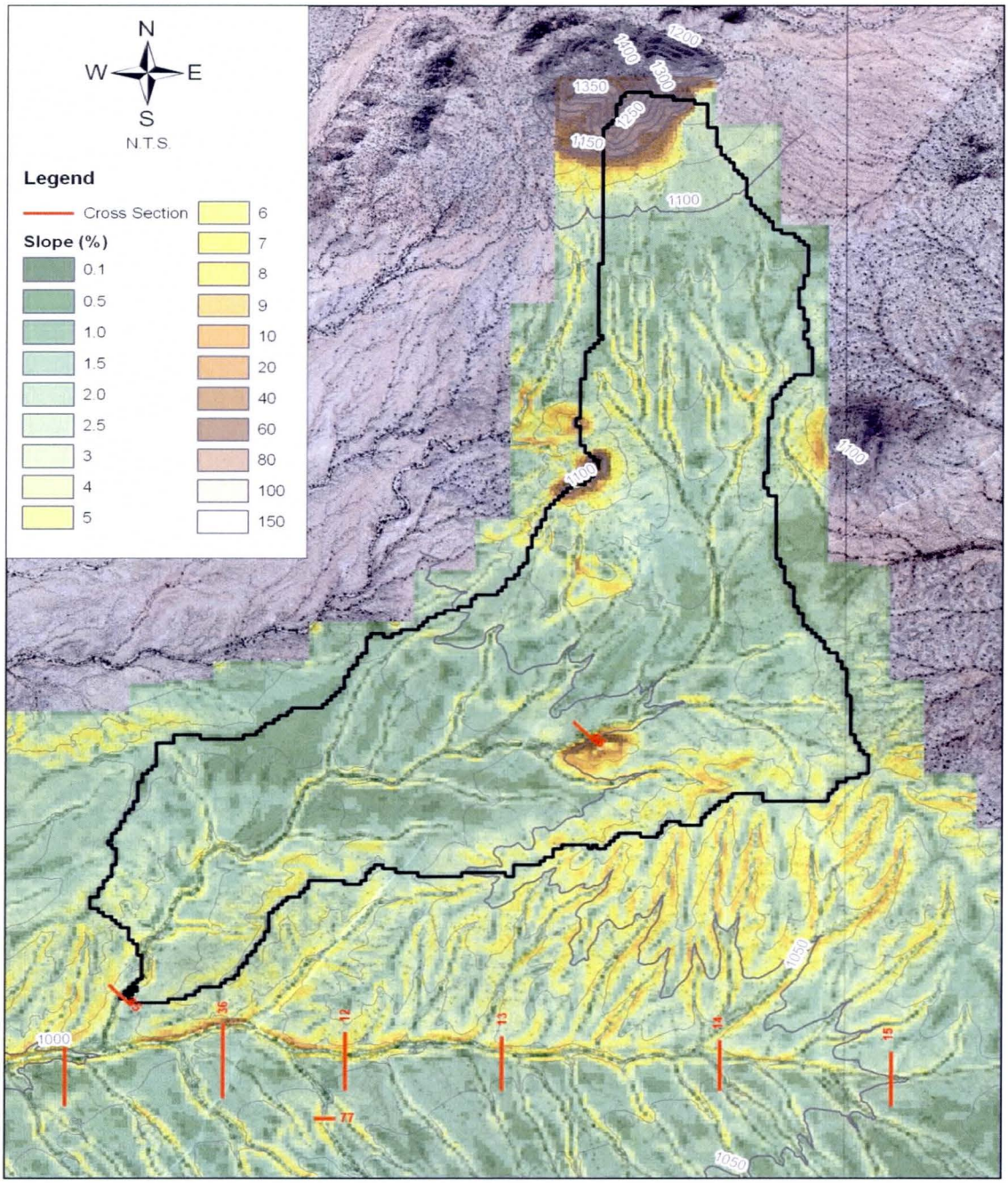
Area (ac)	3.6	41.4	314.8	142.8	174.6	147.0	9.9	**834.1**
K	0.02	0.10	0.02	0.05	0.17	0.05	0.24	**0.07**

Gillespie ADMS
FDC No. 2009C024
Sediment Wash Load Hand Calculations

Date: 7/18/2012 By: al
Checked: 9/12/2012 By: mcg

Test Area: 1 **Slope Factor: 0.18**

SLOPE FACTOR

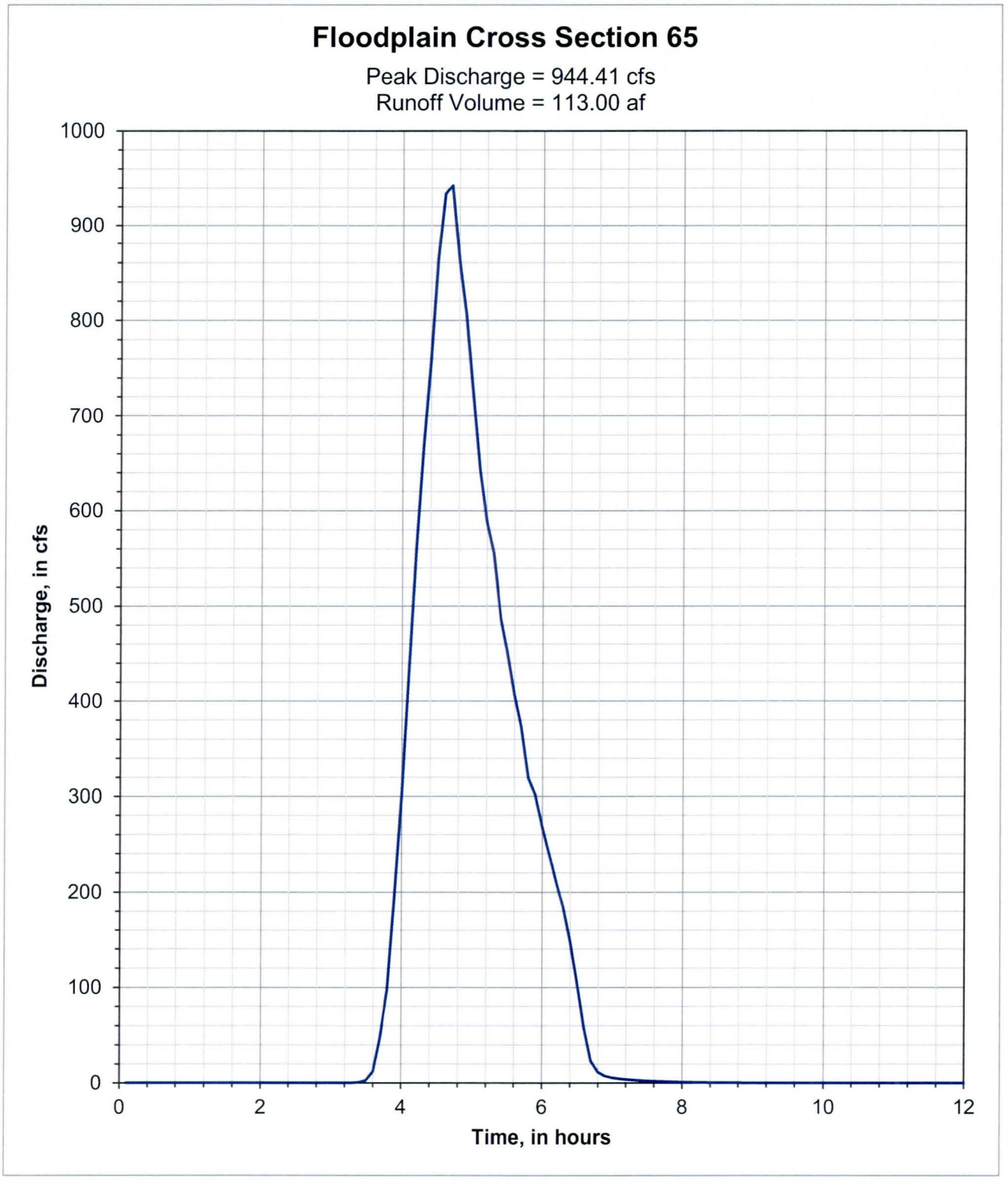


PARAMETERS

Length	Slope	n	LS
70	2.00	0.30	0.18

Test Area: 1 **Runoff Factor: 82,720**

RUNOFF FACTOR

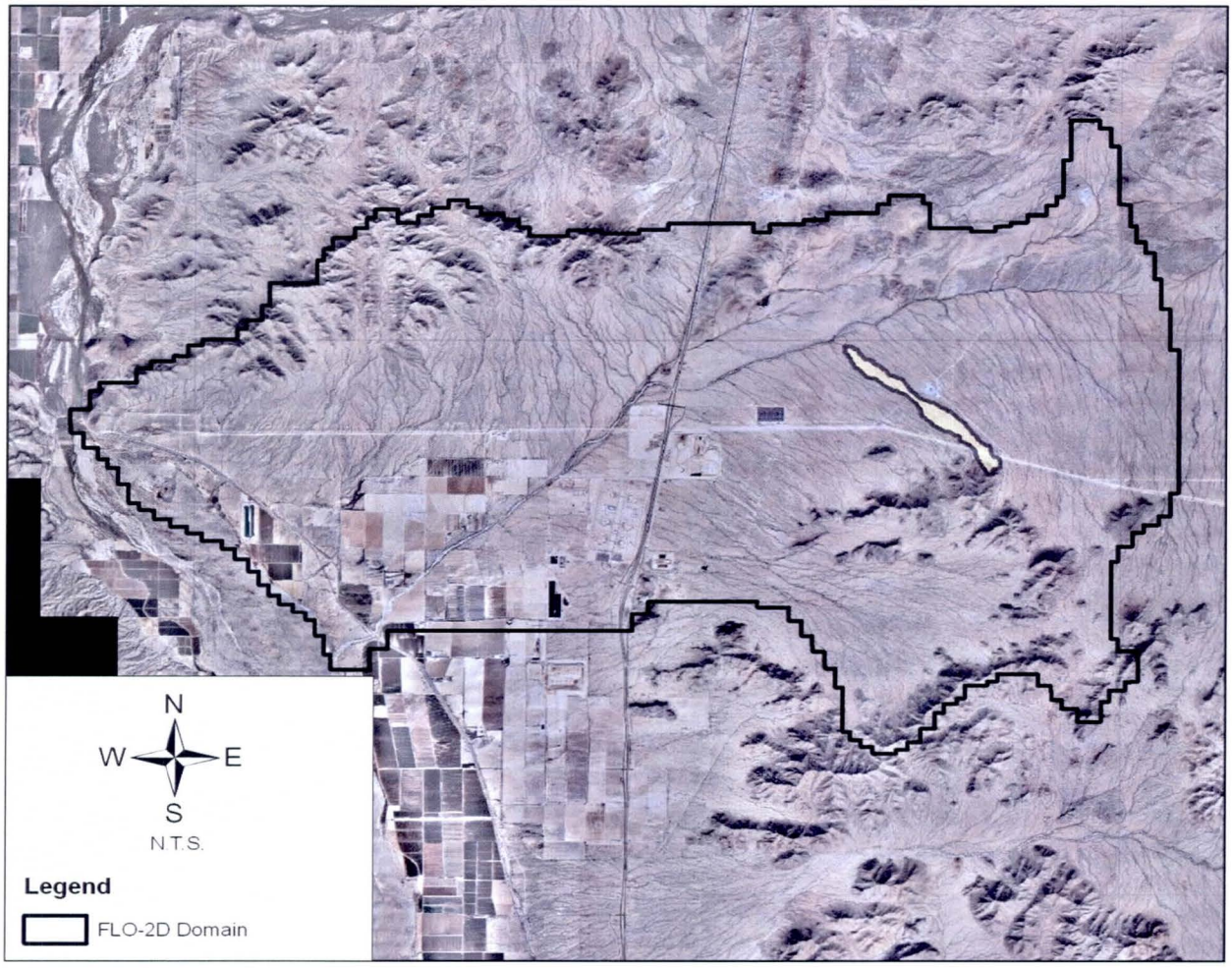


Gillespie ADMS
FDC No. 2009C024
Sediment Wash Load Hand Calculations

Date: 7/18/2012 By: al
Checked: 9/12/2012 By: mcg

Test Area: 2 **Wash Load: 29.84 tons**

LOCATION

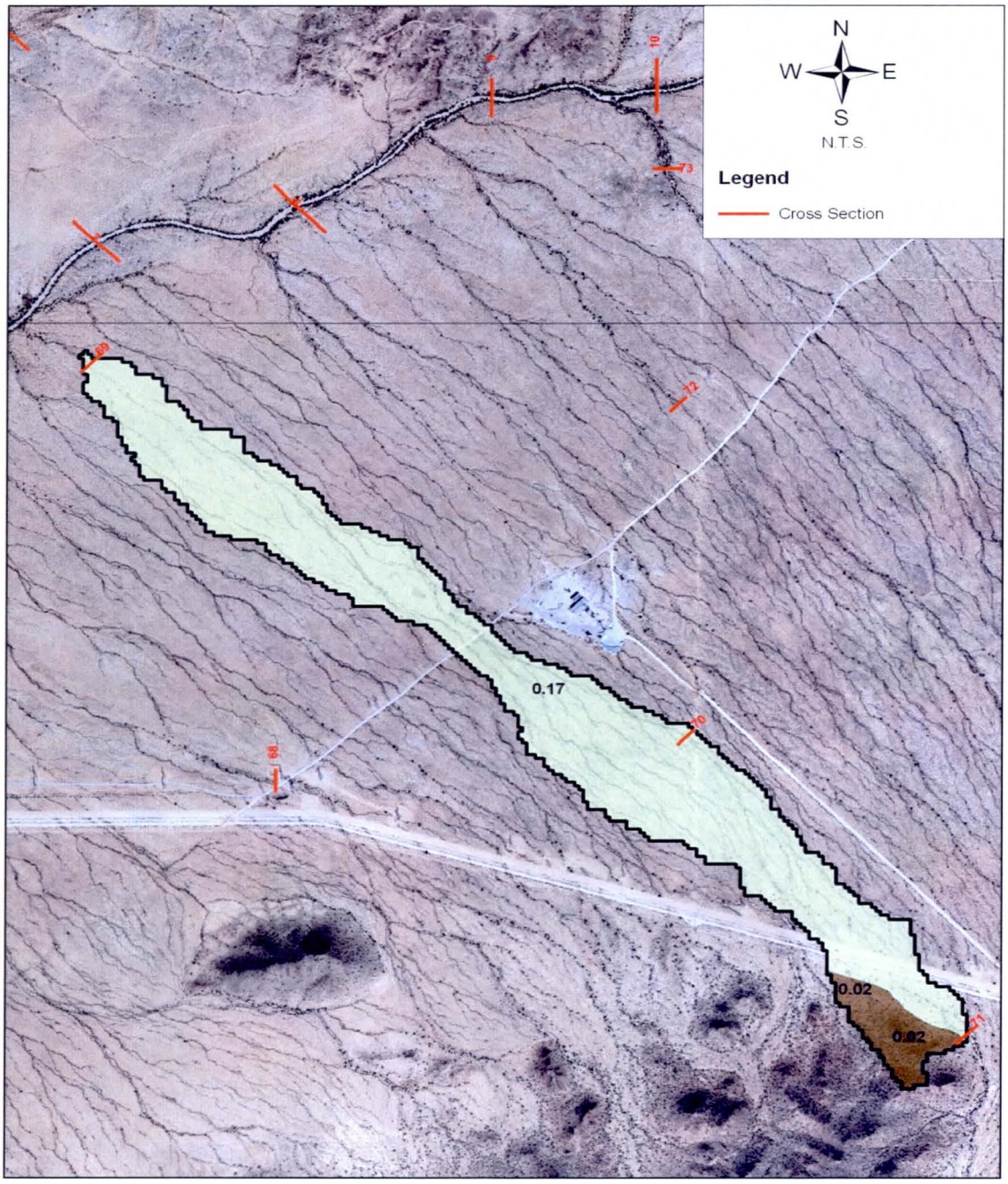


YIELD CALCULATION

Constants		Watershed Parameters	
P:	1	Erodibility Factor:	0.16
α:	95	Slope Factor:	0.18
C:	0.09	Runoff Factor:	5,148
β:	0.56	**Wash Load:**	**30**

Test Area: 2 **Erodibility Factor: 0.16**

ERODIBILITY

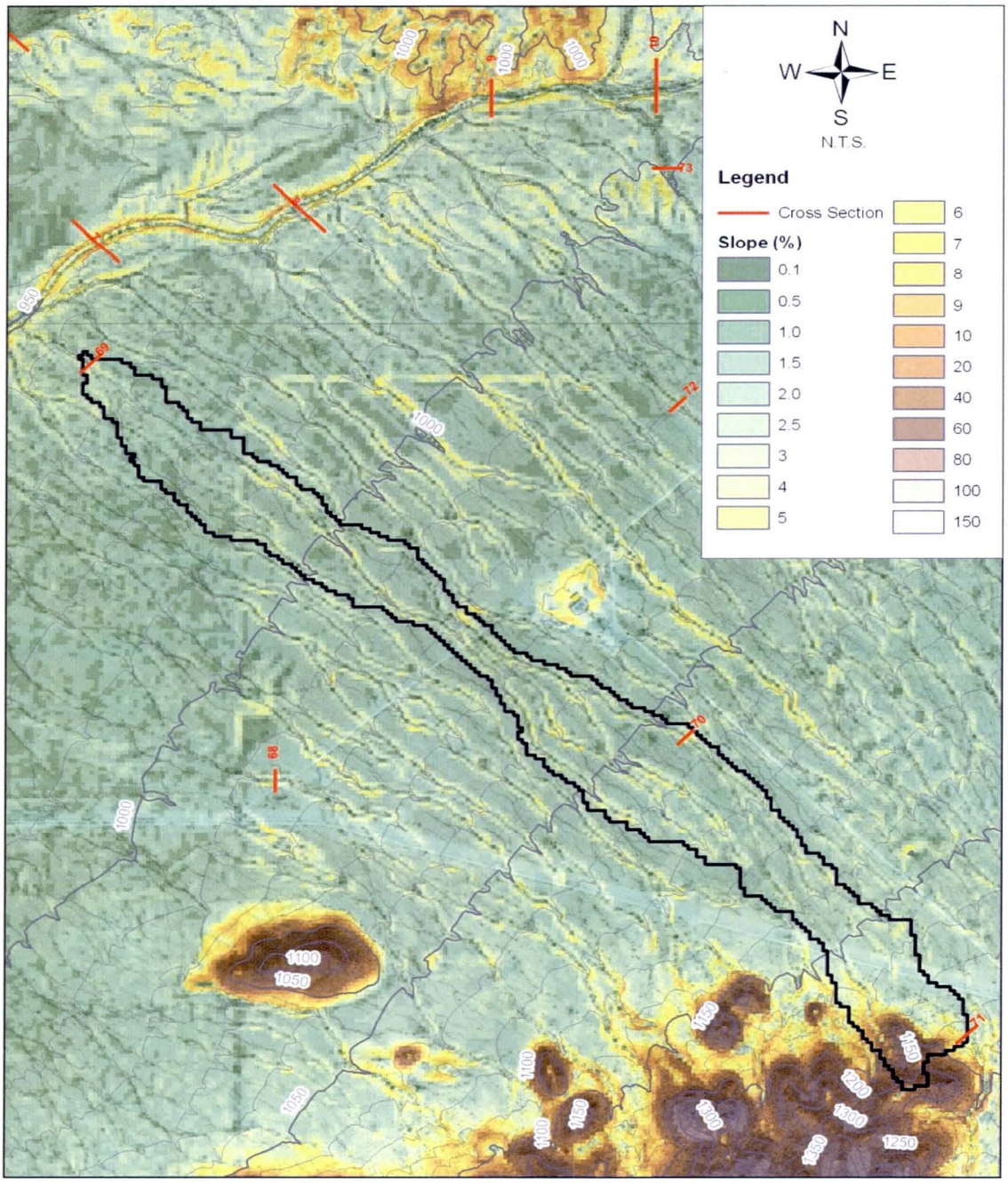


ERODIBILITY AREAS

Area (ac)	260.6	3.6	17.8					**282.0**
K	0.17	0.02	0.02					**0.16**

Test Area: 2 **Slope Factor: 0.18**

SLOPE FACTOR

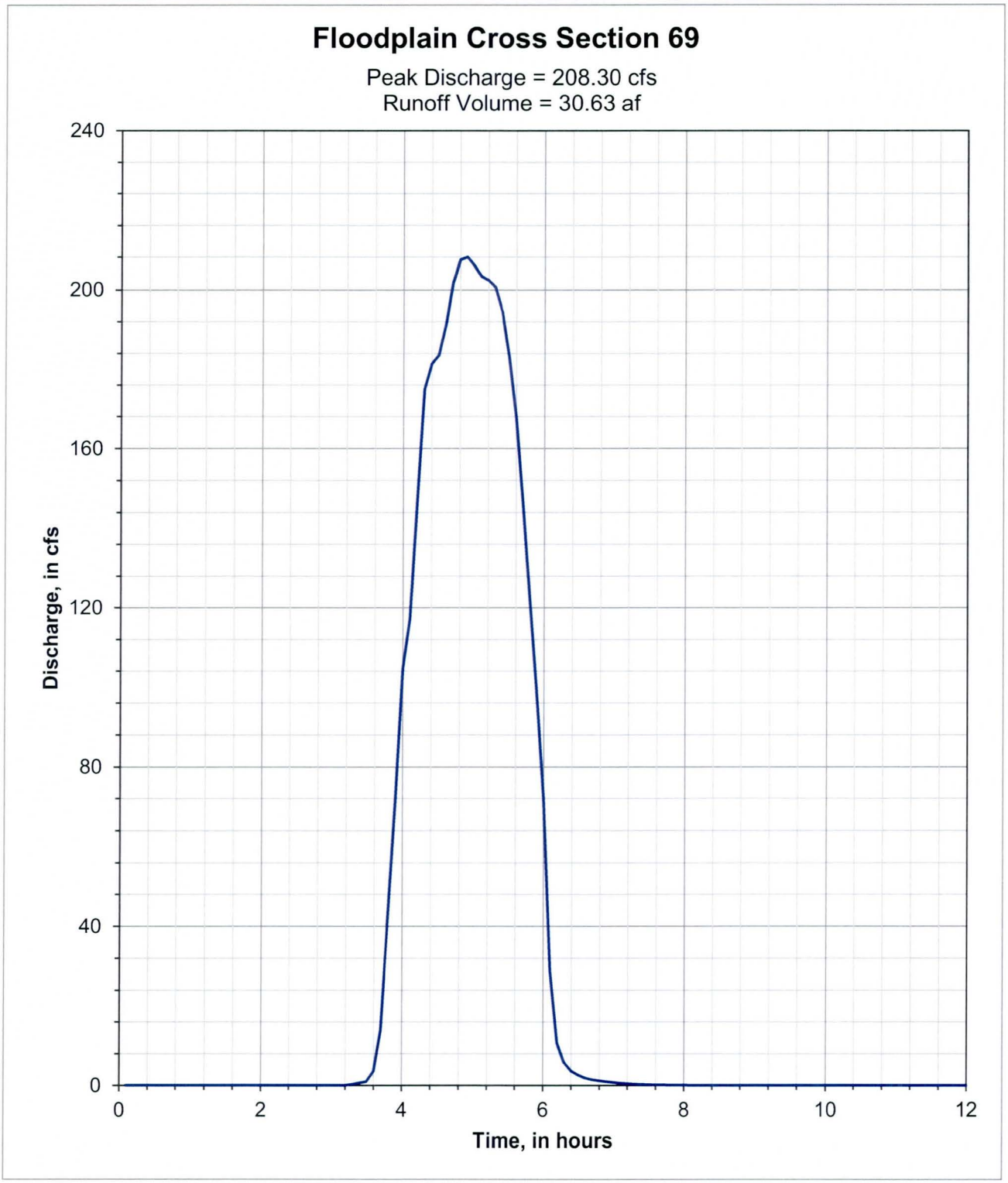


PARAMETERS

Length	Slope	n	LS
150	1.50	0.30	0.18

Test Area: 2 **Runoff Factor: 5,148**

RUNOFF FACTOR

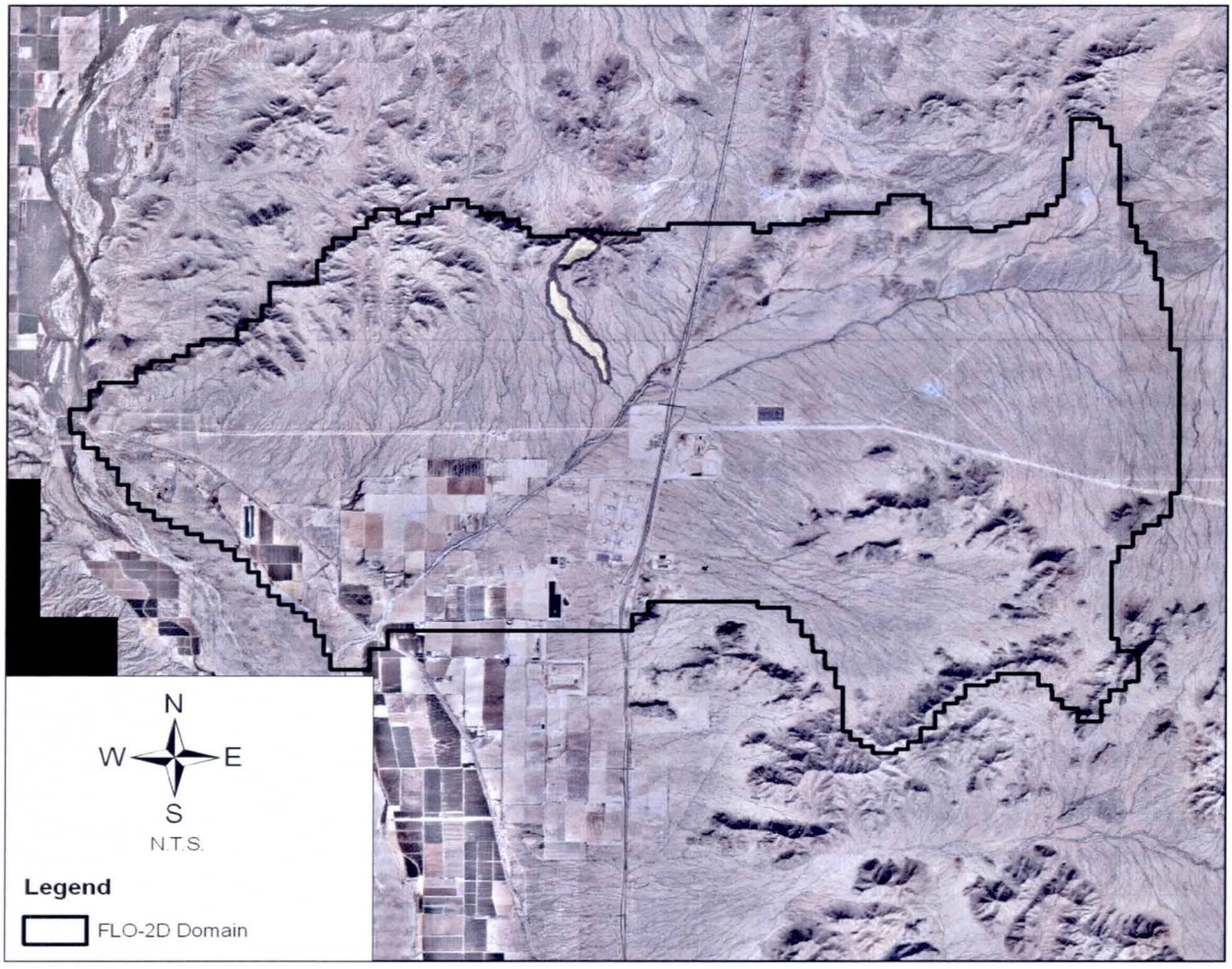


Gillespie ADMS
FDC No. 2009C024
Sediment Wash Load Hand Calculations

Date: 7/18/2012 By: al
Checked: 9/12/2012 By: mcg

Test Area: 3 **Wash Load: 218 tons**

LOCATION



YIELD CALCULATION

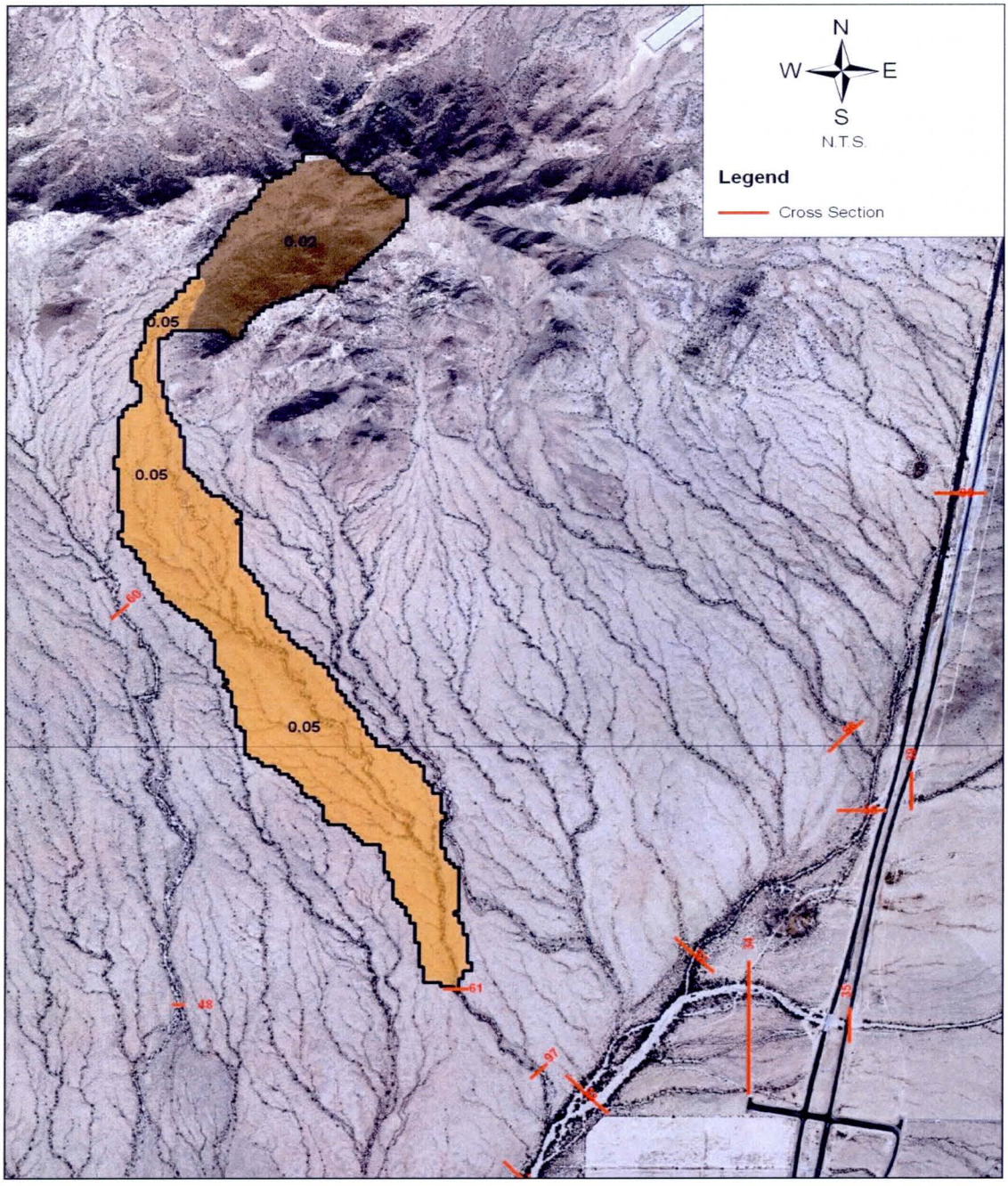
Constants		Watershed Parameters	
P:	1	Erodibility Factor:	0.04
α:	95	Slope Factor:	1.68
C:	0.09	Runoff Factor:	37,454
β:	0.56	**Wash Load:**	**218**

Gillespie ADMS
FDC No. 2009C024
Sediment Wash Load Hand Calculations

Date: 7/18/2012 By: al
Checked: 9/12/2012 By: mcg

Test Area: 3 **Erodibility Factor: 0.04**

ERODIBILITY



ERODIBILITY AREAS

Area (ac)	72.1	10.5	31.6	145.6				**259.8**
K	0.02	0.05	0.05	0.05				**0.04**

Gillespie ADMS

FDC No. 2009C024

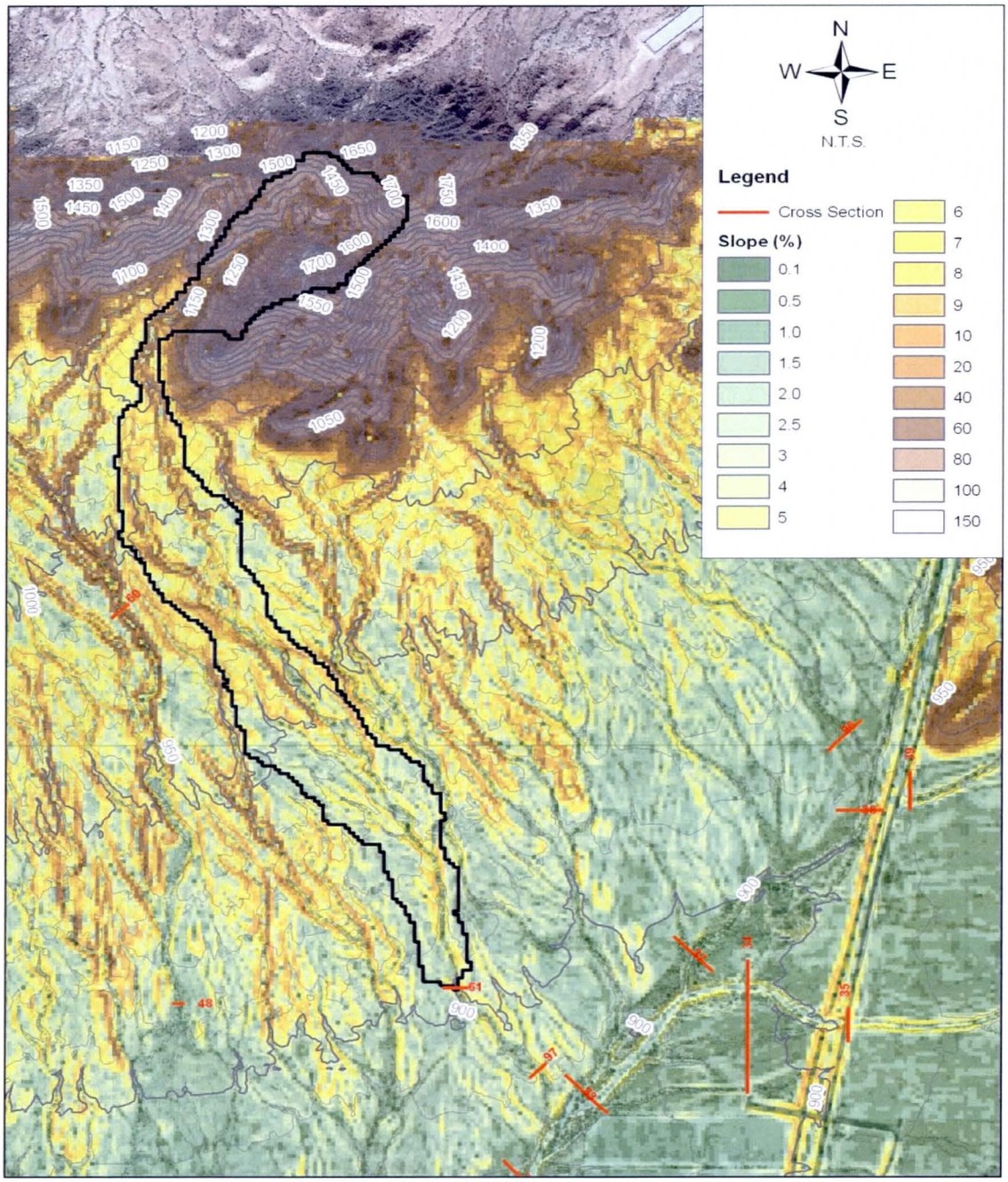
Sediment Wash Load Hand Calculations

Date: 7/18/2012 By: al

Checked: 9/12/2012 By: mcg

Test Area: 3 **Slope Factor: 1.68**

SLOPE FACTOR

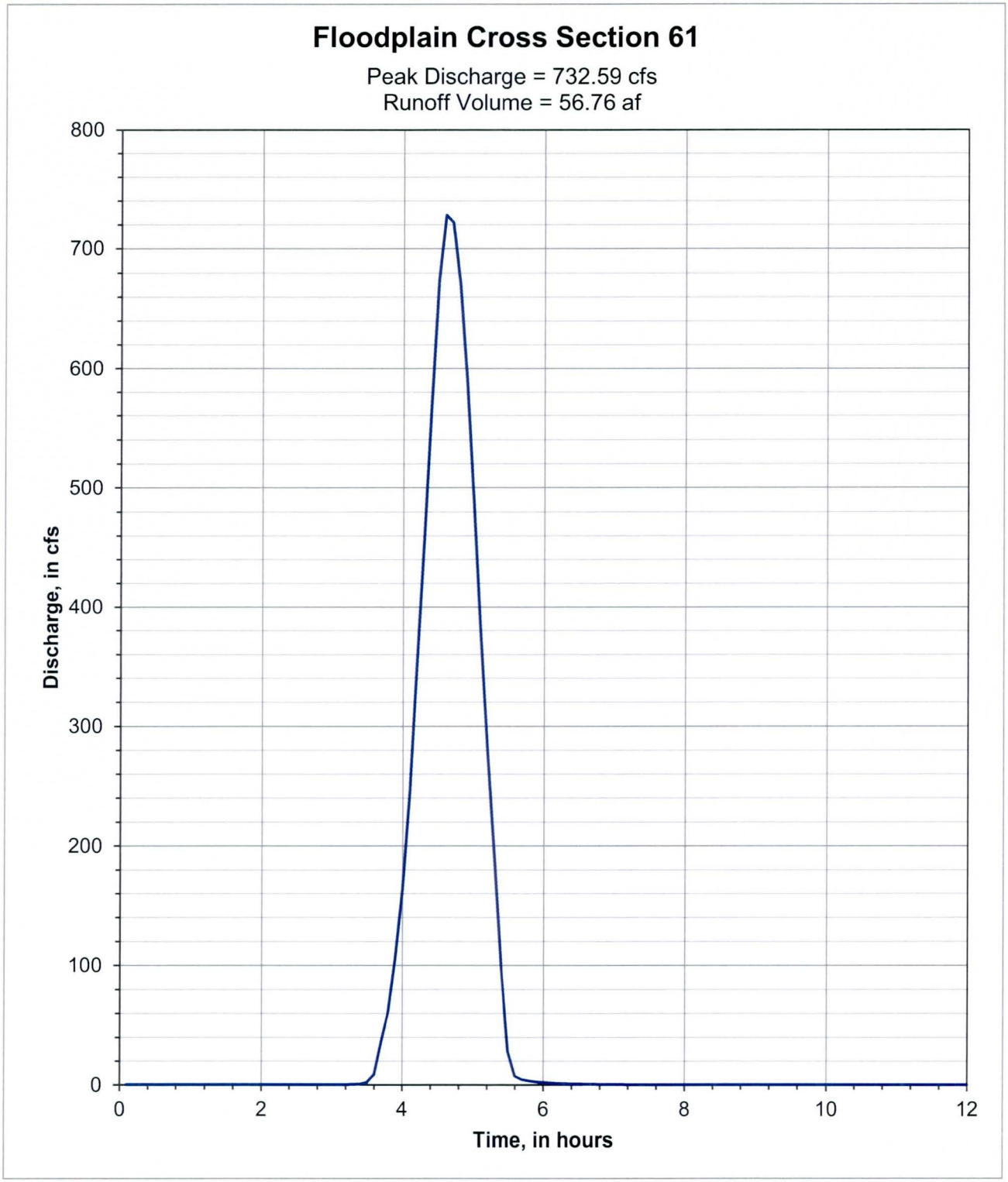


PARAMETERS

Length	Slope	n	LS
150	10.00	0.50	1.68

Test Area: 3 **Runoff Factor: 37,454**

RUNOFF FACTOR

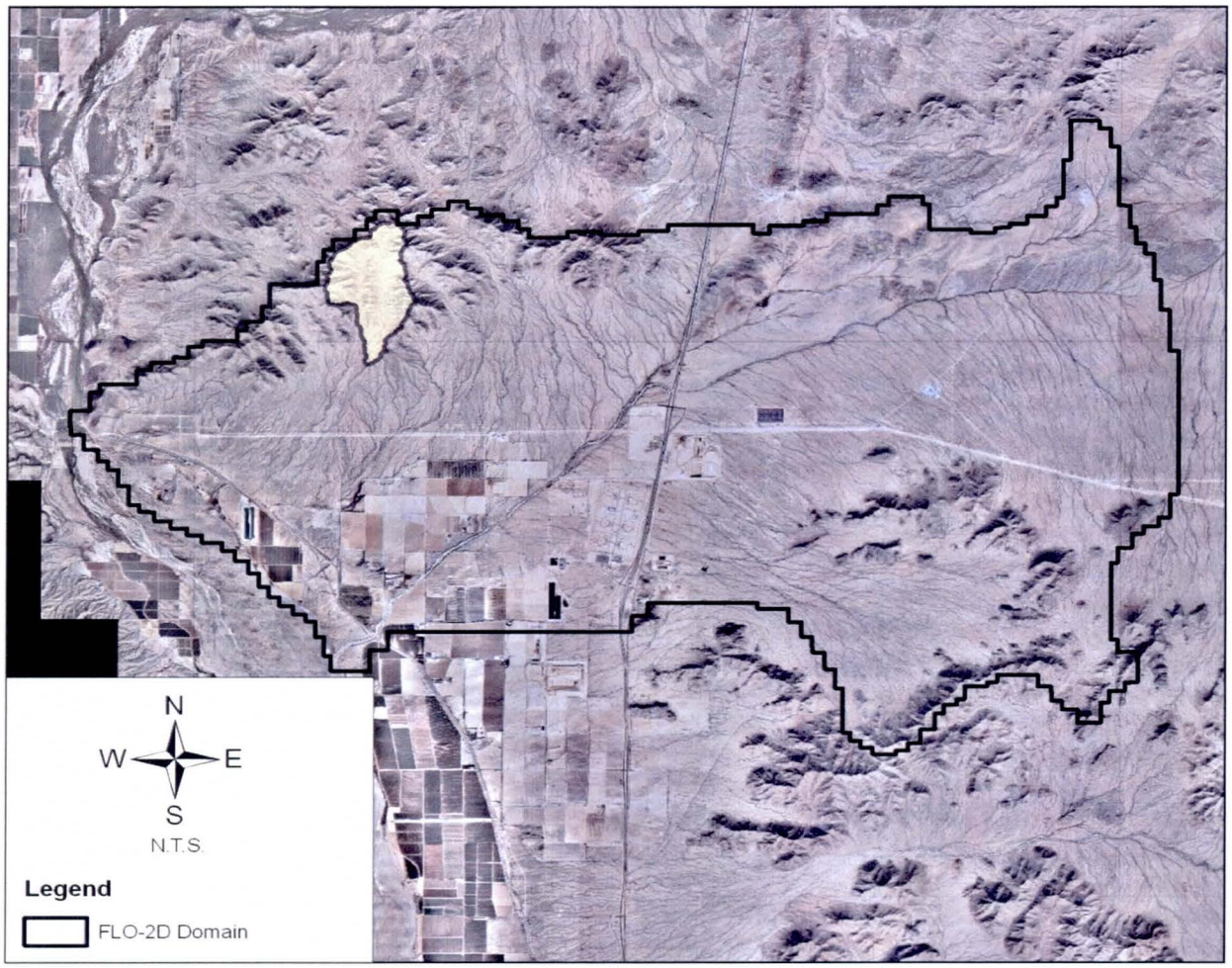


Gillespie ADMS
FDC No. 2009C024
Sediment Wash Load Hand Calculations

Date: 7/18/2012 By: al
Checked: 9/12/2012 By: mcg

Test Area: 4 **Wash Load: 1,135 tons**

LOCATION

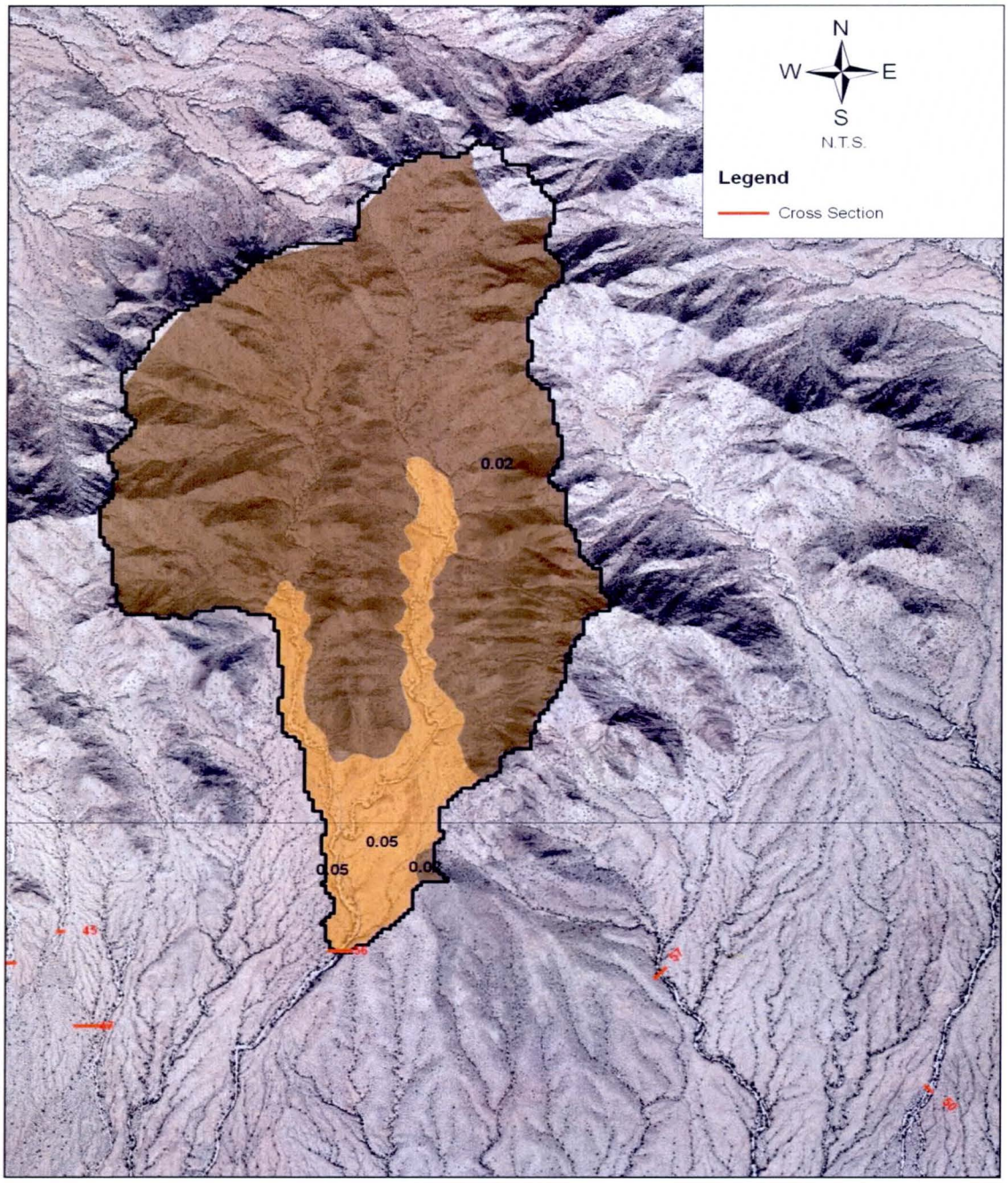


YIELD CALCULATION

Constants		Watershed Parameters	
P:	1	Erodibility Factor:	0.03
α:	95	Slope Factor:	6.04
C:	0.09	Runoff Factor:	180,734
β:	0.56	**Wash Load:**	**1135**

Test Area: 4 **Erodibility Factor: 0.03**

ERODIBILITY

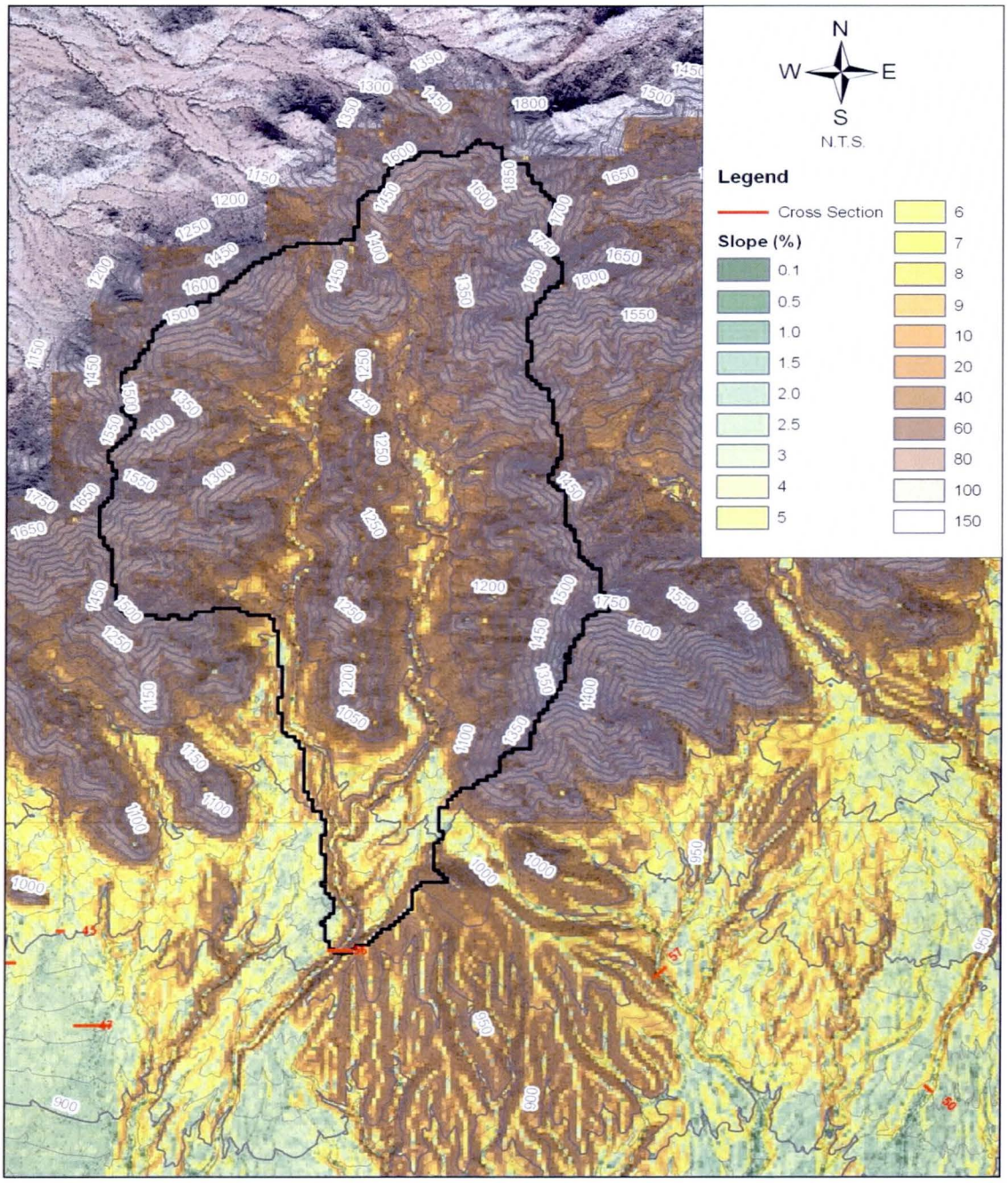


ERODIBILITY AREAS

Area (ac)	628.7	113.8	12.5	2.3				**757.3**
K	0.02	0.05	0.05	0.02				**0.025**

Test Area: 4 **Slope Factor: 6.04**

SLOPE FACTOR

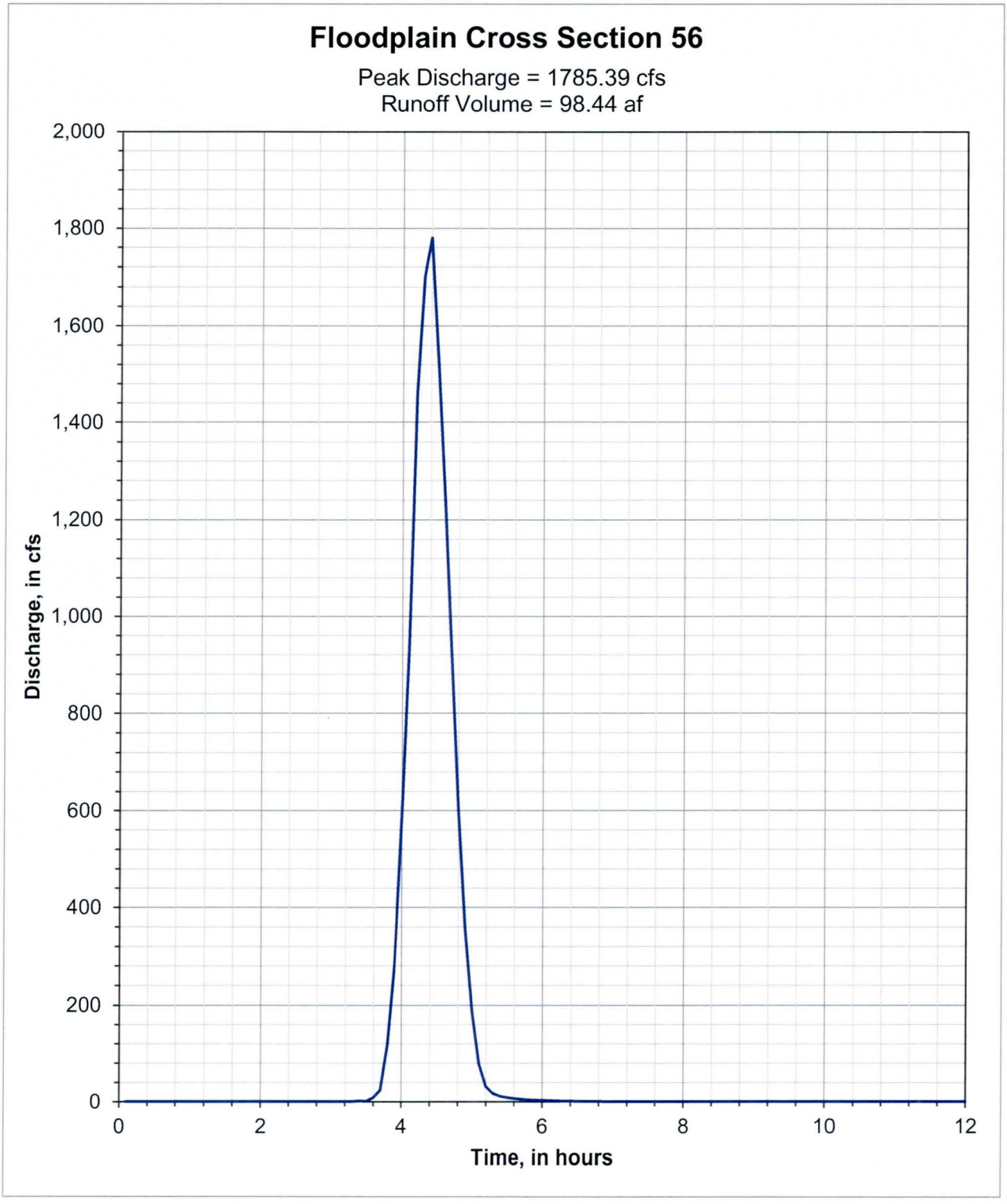


PARAMETERS

Length	Slope	n	LS
50	30.00	0.50	6.04

Test Area: 4 **Runoff Factor: 180,734**

RUNOFF FACTOR

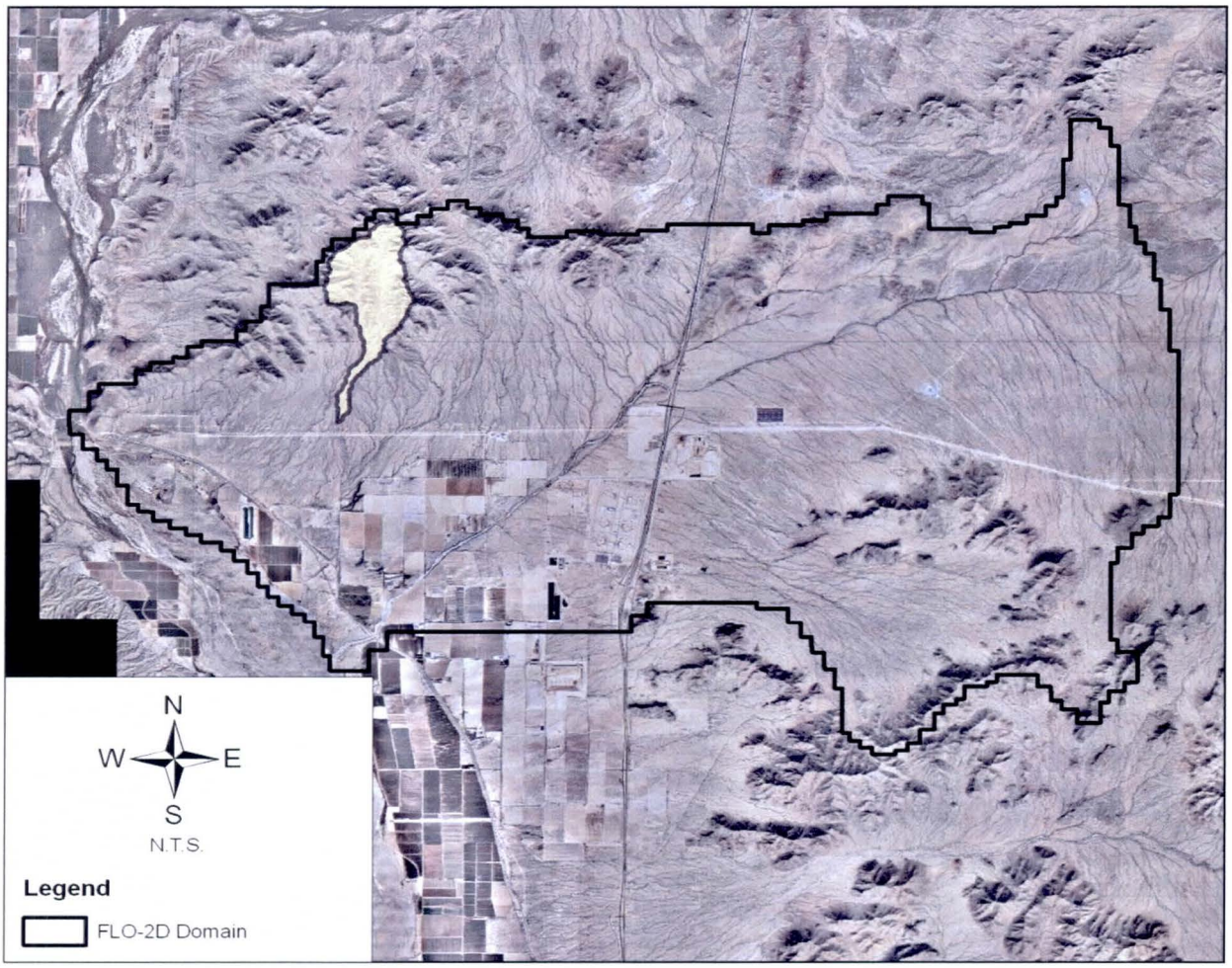


Gillespie ADMS
FDC No. 2009C024
Sediment Wash Load Hand Calculations

Date: 7/18/2012 By: al
Checked: 9/12/2012 By: mcg

Test Area: 5 **Wash Load: 906 tons**

LOCATION



YIELD CALCULATION

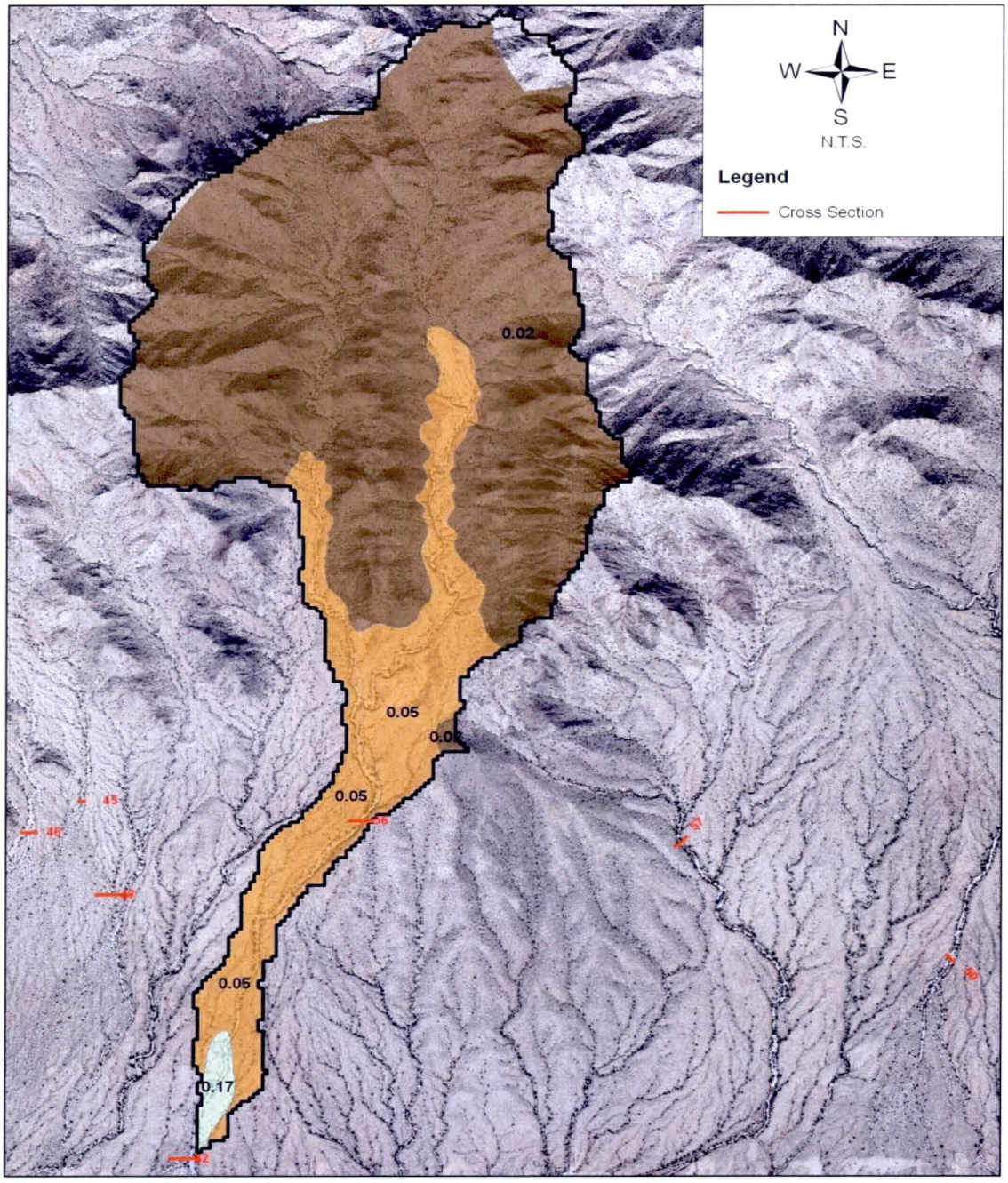
Constants		Watershed Parameters	
P:	1	Erodibility Factor:	0.03
α:	95	Slope Factor:	5.21
C:	0.09	Runoff Factor:	124,608
β:	0.56	**Wash Load:**	**906**

Gillespie ADMS
FDC No. 2009C024
Sediment Wash Load Hand Calculations

Date: 7/18/2012 By: al
Checked: 9/12/2012 By: mcg

Test Area: 5 **Erodibility Factor: 0.03**

ERODIBILITY



ERODIBILITY AREAS

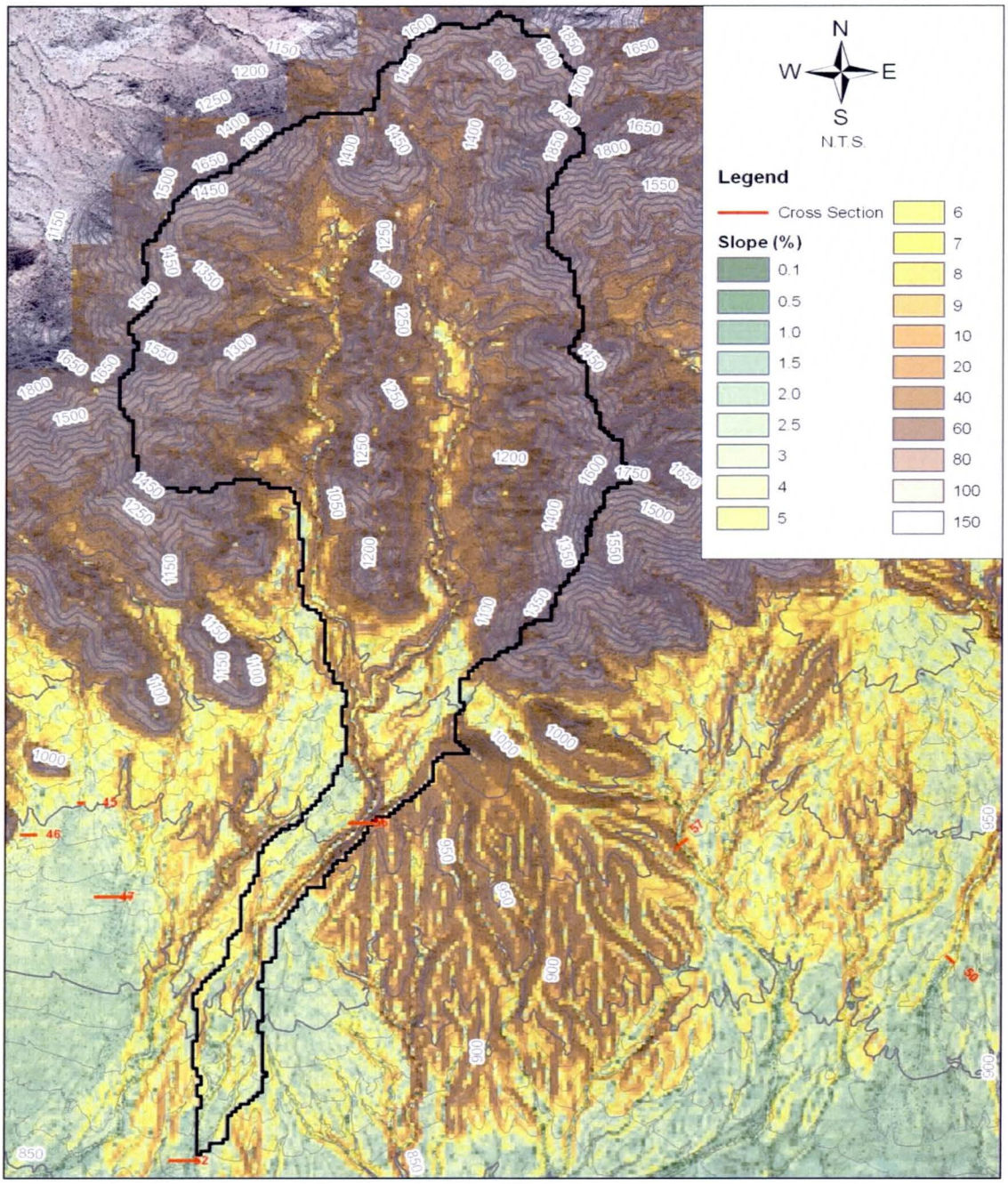
Area (ac)	628.7	115.9	39.6	30.8	2.3	9.5		**826.8**
K	0.02	0.05	0.05	0.05	0.02	0.17		**0.03**

Gillespie ADMS
FDC No. 2009C024
Sediment Wash Load Hand Calculations

Date: 7/18/2012 By: al
Checked: 9/12/2012 By: mcg

Test Area: 5 **Slope Factor: 5.21**

SLOPE FACTOR

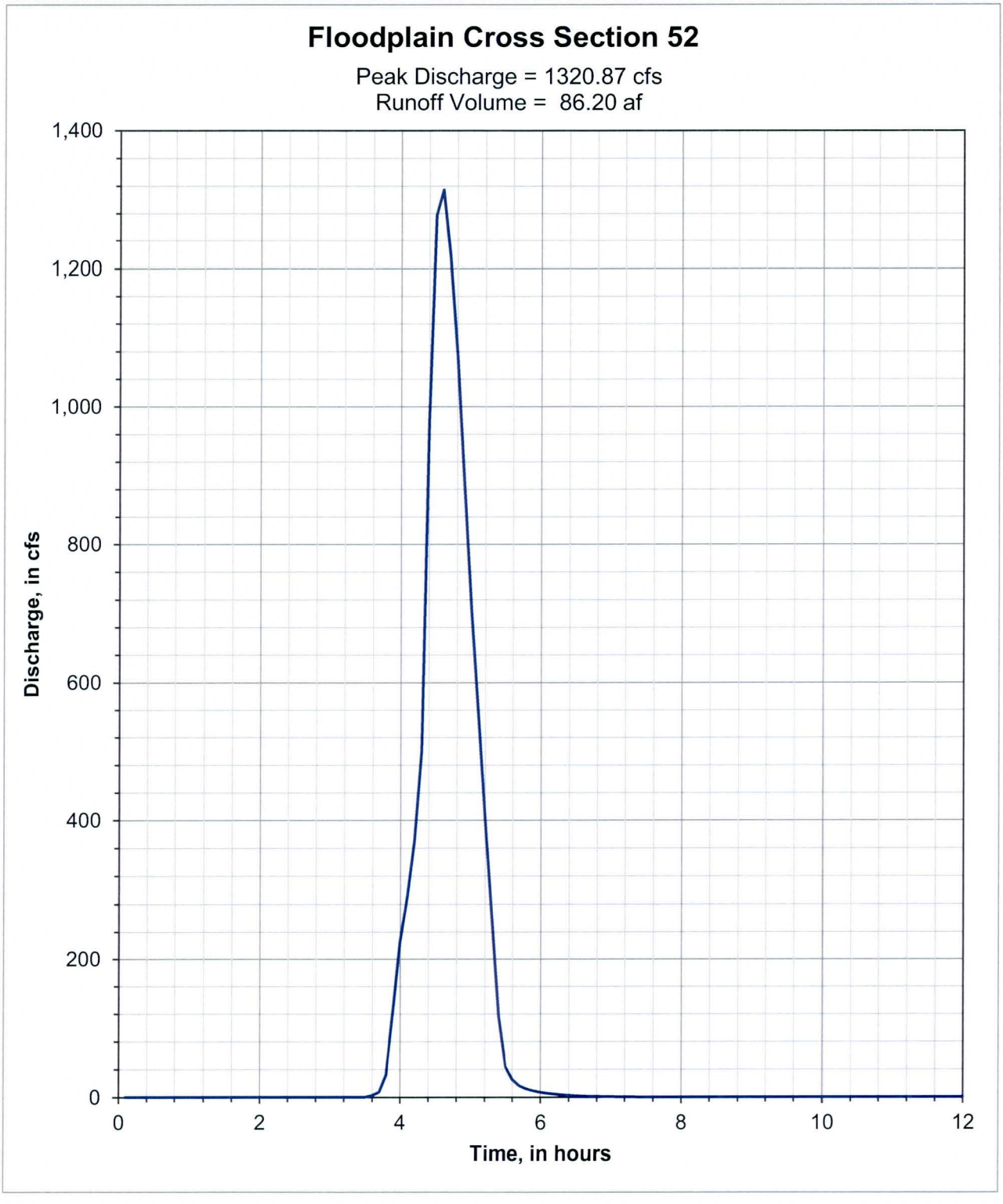


PARAMETERS

Length	Slope	n	LS
60	25.00	0.05	5.21

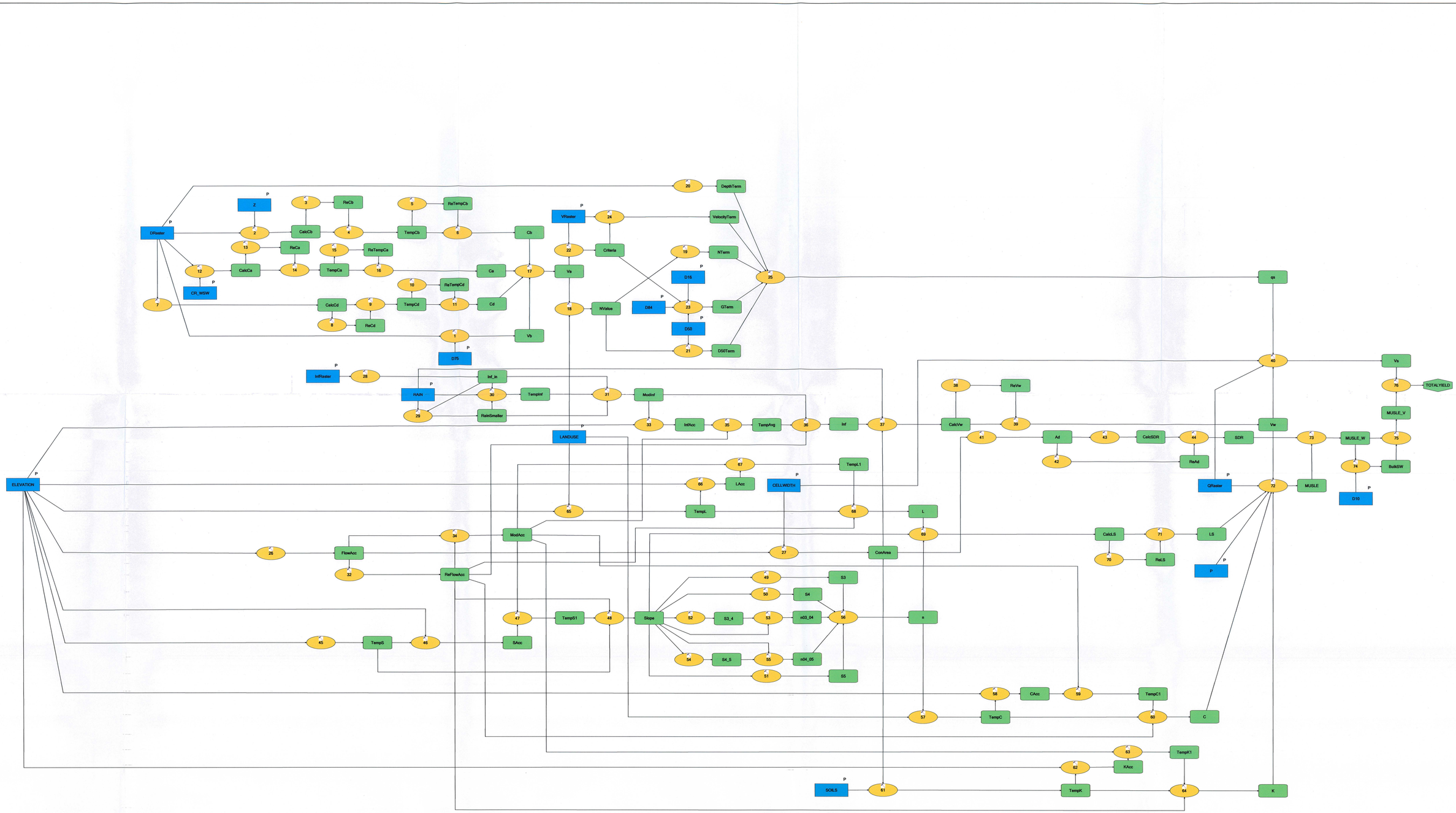
Test Area: 5 **Runoff Factor: 124,608**

RUNOFF FACTOR



Appendix D – Sediment Yield Model Schematic and Calculation Steps

SEDIMENT YIELD MODEL SCHEMATIC



Sediment Yield Model

INPUT PARAMETERS

1 Input shapefile depicting areas of different Manning's "n" value, cover and management factor, C and slope length, L.
2 Input raster depicting infiltration depths (feet).
3 Input value equal to the D_{10} sediment size (mm) defined as the diameter where 10% is finer by weight.
4 Input shapefile depicting areas with different soil erodibility factor K.
5 Input value equal to the wash curve radius / water surface width.
6 Input value equal to wash bank slope Z (H:V).
7 Input value equal to the storm event rainfall depth (inches).
8 Input value equal to the D75 sediment size (mm) defined as the diameter where 75% is finer by weight.
9 Input value equal to the D16 sediment size (mm) defined as the diameter where 16% is finer by weight.
10 Input value equal to the D84 sediment size (mm) defined as the diameter where 84% is finer by weight.
11 Input value equal to the erosion control practice factor P.
12 Input value equal to the input data cell width (feet).
13 Input value equal to the D50 sediment size (mm) defined as the diameter where 50% is finer by weight.
14 Input raster depicting flow depth (feet).
15 Input raster depicting flow velocity (fps).
16 Input raster representing a continuous surface.
17 Input raster depicting discharge (cfs).

MODEL PROCESSES AND CALCS

1 Basic velocity raster, $V_b = (2.6216*D_{75}^{0.3076})$ is determined using D_{75} particle size.
2 Correction factor, $C_b = 0.1176*Z^3 - 0.9692*Z^2 + 2.7361*Z - 1.8196)$ is calculated from bank slope value.
3 A 0 or 1 integer raster is created from the C_b raster based on the lower limit value of 0.5.
4 Correction factor C_b is modified, so in cases when the calculated value for C_b is smaller than the lower limit, C_b will default to a value of 0.5.
5 A 0 or 1 integer raster is created from the C_b raster based on the upper limit value of 0.85.
6 Correction factor C_b is modified, so in cases when the calculated value for C_b is greater than the upper limit, C_b will default to a value of 0.85.
7 Correction factor, $C_d = 0.8288*d^{0.1778}$ is calculated using the depth raster.
8 A 0 or 1 integer raster is created from the C_d raster based on the lower limit value of 0.9.

9 Correction factor C_d is modified, so in cases when the calculated value for C_d is smaller than the lower limit, C_d will default to a value of 0.9.

10 A 0 or 1 integer raster is created from the C_d raster based on the upper limit value of 1.42.

11 Correction factor C_d is modified, so in cases when the calculated value for C_d is greater than the upper limit, C_d will default to a value of 1.42.

12 The correction factor, $C_a = 0.0000696*(CR/WSW)^5-0.00042753*(CR/WSW)^4+0.01042155*(CR/WSW)^3-0.12666362*(CR/WSW)^2+0.78642304*(CR/WSW) - 1.11184546$ equation is calculated using the curve radius ÷ water surface width value.

13 A 0 or 1 integer raster is created from the C_a raster based on the lower limit value of 0.7.

14 Correction factor C_a is modified, so in cases when the calculated value for C_a is smaller than the lower limit, C_a will default to a value of 0.7.

15 A 0 or 1 integer raster is created from the C_a raster based on the upper limit value of 1.0.

16 Correction factor C_a is modified, so in cases when the calculated value for C_a is greater than the upper limit, C_a will default to a value of 1.0.

17 Maximum allowable flow velocity raster in fps is calculated, $V_a = V_b * C_a * C_b * C_d$.

18 Land use shapefile depicting areas with different Manning's "n" is converted into a raster format.

19 The "n" value term ($n^{1.77}$) is calculated using "n" value raster.

20 The depth term ($Y_h^{-0.3}$) is calculated from depth raster.

21 The D_{50} term ($D_{50}^{-0.61}$) is calculated from D_{50} particle size.

22 A 0 or 1 integer raster is created by comparing velocity and maximum allowable velocity on a cell by cell basis.

23 Gradation coefficient term ($[0.5*(D_{84}/D_{50} + D_{50}/D_{16}]^{0.45}$) is calculated from D_{84}, D_{50}, D_{16} sediment particle sizes.

24 Velocity term ($V_a^{4.32}$) is calculated from velocity raster.

25 Bed material discharge, q_s (cfs/ft) is calculated using steps #19, #20, #21, #23, #24 above ($q_s = 0.0064 * [step19] * [step20] * [step21] * [step23] * [step24]$).

26 Flow accumulation raster is calculated using elevation raster.

27 Contributing area at each cell is calculated from flow accumulation raster.

28 Infiltration depth raster is converted from feet to inches.

29 A 0 or 1 integer raster is created by comparing the infiltration depths with storm rainfall depth on a cell by cell basis.

30 Infiltration raster is modified by setting infiltration values greater than rainfall depth equal to zero.

31 Infiltration raster is modified by setting infiltration depth upper limit equal to the storm event rainfall depth.

32 A 0 or 1 integer raster is created using flow accumulation raster.

33 Flow accumulation is weighted with infiltration raster.

34 Flow accumulation raster is modified, such that grid cell with 0 flow accumulation are set equal to 1.

35 Average infiltration for contributing area at each cell is calculated by dividing weighted flow accumulation [step33] with flow accumulation [step34].

36 Average infiltration raster is modified by adding their initial infiltration to the cells with 0 flow accumulation.

37 Excess contributing volume (ft^3) at each cell is estimated from rainfall, infiltration and contributing area (V_w = (Rainfall - [step36]) * [step27]).

38 A 0 or 1 integer raster is created to identify any contributing volume raster cells with negative values due to number rounding.

39 Contributing volume raster is modified by setting any cell with negative value equal to 0.

40 The total volume of bed load sediment (ft^3) at each cell is calculated from discharge raster and steps # 25, and #39 (V_s = ([step39] * (([step25] * Cell Width) / [Q Raster])).

41 Contributing area raster units are converted from square feet to square miles.

42 A 0 or 1 integer raster is created based on contributing area lower limit value of 0.04.

43 Sediment delivery ratio (SDR = $-14.08*(\log_{10}[step41]) + 2.44 * (\log_{10}[step41])^2 - 0.45 * (\log_{10}[step41])^3 + 60.85$) is calculated from contributing area.

44 SDR is modified, so in cases when the calculated value for SDR is smaller than the lower limit, SDR will default to a value of 1.0.

45 Percent slope at each cell is calculated from elevation raster.

46 Flow accumulation is weighted with slope raster.

47 Average slope for contributing area at each cell is calculated by dividing weighted flow accumulation [step46] with flow accumulation [step34].

48 Average slope raster is modified by adding their initial slope value to the cells with 0 flow accumulation.

49 Areas with topographic factor exponent n equal to 0.3 (slope < 3%) are identified using the slope raster.

50 Areas with topographic factor exponent n equal to 0.4 (slope = 4%) are identified using the slope raster.

51 Areas with topographic factor exponent n equal to 0.5 (slope > 5%) are identified using the slope raster.

52 Areas with slope values from 3% to 4% (3% ≤ slope < 4%) are identified using the slope raster.

53 Topographic factor exponent, n for areas with slope from 3% to 4%, is calculated using linear interpolation.

54 Areas with slope values from 4% to 5% (4% < slope ≤ 5%) are identified using the slope raster.

55 Topographic factor exponent, n for areas with slope from 4% to 5%, is calculated using linear interpolation.

56 Topographic factor exponent, n for the entire project area is calculated from steps #49, #50, #51, #53 and #55 above.

57 Land use shapefile depicting areas with different cover and management factor C is converted into a raster format.

58 Flow accumulation is weighted with C factor raster.

59 Average C factor for contributing area at each cell is calculated by dividing weighted flow accumulation [step58] with flow accumulation [step34].

60 Average C raster is modified by adding their initial C value to the cells with 0 flow accumulation.

61 Soils shapefile depicting areas with different soil erodobility factor K is converted into a raster format.

62 Flow accumulation is weighted with K factor raster.

63 Average K factor for contributing area at each cell is calculated by dividing weighted flow accumulation [step62] with flow accumulation [step34].

64 Average K raster is modified by adding their initial K value to the cells with 0 flow accumulation.

65 Land use shapefile depicting areas with different slope length factor, L is converted into a raster format.

66 Flow accumulation is weighted with L factor raster.

67 Average L for contributing area at each cell is calculated by dividing weighted flow accumulation [step66] with flow accumulation [step34].

68 Average L raster is modified by adding their initial L value to the cells with 0 flow accumulation.

69 Topographic factor LS is calculated from steps #48, #56 and #68 above (LS = ([step68] / 72.6)$^{[step56]}$*(0.065 + 0.0454*[step48]+0.0065*[step48]^2).

70 A 0 or 1 integer raster is created based on LS upper limit value of 18.

71 Topographic factor raster is modified by setting values greater than upper limit equal to 18.

72 Wash load (Y_s [tons]= 95*(V*q_p)$^{0.56}$ K*LS*C*P) is calculated from discharge raster, erosion control practice factor (P), and steps #39, #60, #64, and #71 above.

73 Wash load raster is adjusted by applying the sediment delivery ratio.

74 Bulk specific weight for sediment is determined from D_{10} particle size (g=100.5 +20.44*$\log_{10}(D_{10})$).

75 Wash load is converted from tons to cubic feet.

76 Total sediment yield at each cell is determined by adding total bed load and wash load.

Rainbow Wash Subwatershed		
Culvert ID	Sediment Yield (cu-ft)	
	100-Year, 6-Hour	Annual
1*	5,087	1,959
2	90	18
3	13,427	2,738
4	51	10
5	22,518	5,159
6	1,795	72
7	170	38
8	1,156	86
9	77	14
10	197	48
11	2,647	758
12	188	13
13	19	1
14	16	1
15	1	0.3
16	6	1
17	4	1
18	17,978	3,195
19	51	10
20	1,977	498
21	36	8
22	16	1
23	1,575	162
24	29	6
25	54	10
26	43,580	11,312
27	5,145	736
28	5,575	1,080
29	3,764	367
30	522	165
31	291	69
32	104	17
33	174	30
34	116	11
35	4,873	7,473
36	80,647	48,055
37	34	10
38	16	2
39	4,443	1,050
40	32	7
41	18	3
42	8	2
43*	251	56

*Culvert located in the overlap region between Rainbow Wash and Maricopa Mountain models. Sediment Yield result taken from Maricopa Mountain model.

Rainbow Wash Subwatershed		
Culvert ID	Sediment Yield (cu-ft)	
	100-Year, 6-Hour	Annual
44*	2,066	332
45*	39	9
46	811	40
47	1,636	970
48	1,890	472
49	56	4
50	158	28
51	3,841	1,295
52	396	177
53	76	15
54	10	2
55	15	4
56	2	1
57	933	261
58	103	10
59	4	1
60	35	9
61	422	66

*Culvert located in the overlap region between Rainbow Wash and Maricopa Mountain models. Sediment Yield result taken from Maricopa Mountain model.

Maricopa Mountain Subwatershed		
Culvert ID	Sediment Yield (cu-ft)	
	100-Year, 6-Hour	Annual
1	4	1
2	6	2
3	9,057	3,587
4	1,560	529
5	23,312	6,980
6	30,247	13,075
7	13	2
8	391	22
9	17	3
10	15	2
11	3	0.5
12	13	2
13	4	1
14	2	0.5
15	15	3
16	2,415	1,430
17	164	21
18	212	37
19	485	104
20	273	50
21	11,829	4,767
22	10	3
23	3	1
24	35	15
25	1,075	204
26	88	21
27	564	98
28	176	40
29	51,859	23,726
30	1,820	319
31	177,901	19,636
32	704	46
33	92	18
34	7,589	1,896
35	10	1
36	39	1
37	635	140
38	84	20
39	7	2
40	38	10
41	19	3
42	17,364	5,969
43	77	18
44	177,245	26,403

*Culvert located in the overlap region between Rainbow Wash and Maricopa Mountain models. Sediment Yield result taken from Rainbow Wash model.

Maricopa Mountain Subwatershed		
Culvert ID	Sediment Yield (cu-ft)	
	100-Year, 6-Hour	Annual
45	33	3
46	5	1
47	30,602	8,869
48	80	9
49	2,655	827
50	92,296	13,760
51	578	84
52	20	4
53	58	9
54	53	7
55	133	26
56	178	37
57	91	23
58	85	17
59	32	5
60	8,757	2,897
61	8,387	1,139
62	10,492	1,346
63	11,819	1,836
64	306	41
65	182	36
66	1,224	241
67	751	132
68	15,246	4,617
69	9,624	1,164
70	2,639	409
71	255	25
72	907	229
73	37	7
74	22	3
75	82,544	15,258
76	47,693	18,650
77	25	2
78	52	9
79	3,130	951
80	4,084	461
81	45	9
82	99,453	20,985
83	400	61
84	282	22
85	78	19
86	20	2
87*	22	6
88	39	9

*Culvert located in the overlap region between Rainbow Wash and Maricopa Mountain models. Sediment Yield result taken from Rainbow Wash model.

Maricopa Mountain Subwatershed		
Culvert ID	Sediment Yield (cu-ft)	
	100-Year, 6-Hour	Annual
89	20,440	7,609
90	2	1
91	2,066	332
92	251	56
93	5,087	1,959
94*	11	3
95	2,588,454	296,637
96	194,051	18,325
97	1,832	413
98	9	1
99	6,799	1,247
100	21,837	4,238

*Culvert located in the overlap region between Rainbow Wash and Maricopa Mountain models. Sediment Yield result taken from Rainbow Wash model.

Appendix F – 1-D Modeling Area Input Parameters

1-D Modeling Area Input Parameters						
Major	**100-Year**	**50-Year**	**25-Year**	**10-Year**	**5-Year**	**2-Year**
Basin	**6-Hour Duration**					
	Infiltration, in inches					
1	1.91	1.78	1.64	1.45	1.30	1.05
2	1.51	1.46	1.41	1.33	1.25	1.01
3	1.78	1.68	1.57	1.43	1.30	1.04
	Discharge, in cfs					
1	3,833	2,844	1,994	1,021	490	72
2	5,213	3,919	2,751	1,405	597	181
3	1,596	1,215	870	450	179	37
	Depth, in feet					
1	3.27	2.72	2.29	1.67	1.22	0.59
2	2.88	2.69	2.41	1.94	1.43	0.89
3	4.50	4.12	2.85	2.15	1.51	0.84
	Velocity, in fps					
1	7.98	9.94	8.01	6.28	4.83	2.58
2	9.90	9.58	9.41	9.52	8.02	5.93
3	4.27	4.04	6.01	4.83	3.50	2.24

NOTES:

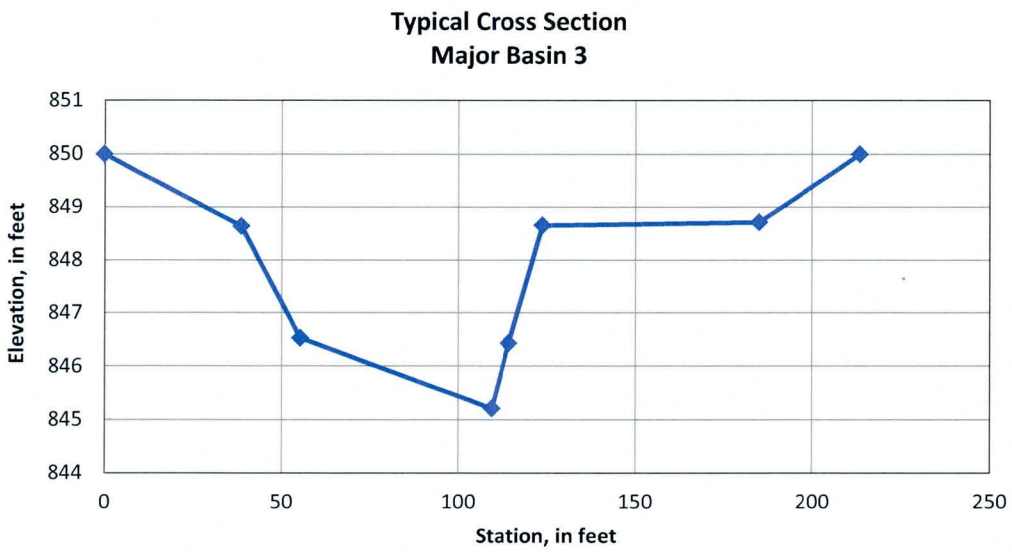
1) The 1-D modeling input parameters for each storm event were taken from the respective HEC-1 model results.

2) Flow discharges and infiltration depths for Major Basins 1, 2, and 3 were taken from C103, C205 and S301, respectively.

3) Hydrologic routes R10R and R203 typical cross sections and discharges from C103 and C205 were used to estimate flow depth and velocity for Major Basin 1 and 2.

4) A typical cross section at the outlet of Major Basin 3 was estimated from the topographic data.

5) The typical cross section at the outlet of Major Basin 3 was analyzed in Flow Master computer program to develop a rating table (see next page) for flow depths and velocity.



Flow Master Results					
WSE (ft)	Discharge (ft^3/s)	Velocity (ft/s)	Flow Area (ft^2)	Wetted Perimeter (ft)	Top Width (ft)
845.5	2.08	1.1	1.89	13.08	13.04
845.7	8.42	1.56	5.4	22.1	22.03
845.9	20.98	1.96	10.7	31.12	31.03
846.1	41.37	2.32	17.81	40.15	40.02
846.3	71.03	2.66	26.71	49.17	49.02
846.5	111.28	2.97	37.42	58.21	58.04
846.7	170.44	3.45	49.45	61.67	61.46
846.9	241.96	3.9	61.99	64.14	63.89
847.1	324.22	4.32	75.01	66.6	66.32
847.3	417.03	4.71	88.51	69.07	68.75
847.5	520.3	5.08	102.51	71.53	71.17
847.7	633.98	5.42	116.98	73.99	73.6
847.9	758.08	5.75	131.95	76.46	76.03
848.1	892.63	6.06	147.39	78.92	78.46
848.3	1037.71	6.35	163.33	81.39	80.89
848.5	1193.38	6.64	179.75	83.85	83.31
848.7	784.55	3.97	197.67	136.35	135.79
848.9	861.82	3.78	228.18	158.51	157.94
849.1	1017.04	3.9	260.78	168.65	168.07
849.3	1188.03	4.02	295.41	178.78	178.2
849.5	1375.39	4.14	332.06	188.92	188.33
849.7	1579.68	4.26	370.74	199.06	198.46
849.9	1801.46	4.38	411.45	209.2	208.59