Skunk Creek

Watercourse Master Plan

ATTACHMENT 5

EROSION & SEDIMENTATION REPORT

Volume I of II

Flood Control District of Maricopa County

AUGUST 2001

SKUNK CREEK WATERCOURSE MASTER PLAN

Attachment 5

Erosion and Sedimentation Report Volume I of II

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Project No. 82000141

Contract # FCD 99-23

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5-1.0 INTRODUCTION

5-1.1 PURPOSE AND SCOPE OF REPORT

The erosion and sedimentation analyses of the portion of Skunk Creek north of the Central Arizona Project (CAP) Canal and the Sonoran Wash of Skunk Creek are performed in support of the Skunk Creek Watercourse Master Plan. The study area is shown in Figure 5-1.1. Phase I of the project includes the section of Skunk Creek from the Carefree Highway bridge downstream to the CAP Canal and all of Sonoran Wash. Phase II of the project is the study area of Skunk Creek upstream of the Carefree Highway Bridge. Sedimentation analyses cannot be adequately performed for the Phase I portion of Skunk Creek without incorporating the Phase II portion at the same time. Therefore, this report is comprehensive for the entire study area.

The erosion and sedimentation analyses are performed for the purpose of:

- Developing an understanding of the fluvial process of erosion and sedimentation during floods.
- Qualitatively identifying tendencies for erosion and/or sedimentation that may occur in reaches of the study watercourses.
- Quantifying magnitudes of erosion and sedimentation that may occur under various existing and future conditions of watershed development and watercourse management.
- Establishing baseline sediment transport models for floods of selected frequency and a range of watershed and watercourse conditions.
- Providing sediment transport models that can be used to evaluate various structural and nonstructural flood management alternatives.

The erosion and sedimentation analysis is performed by use of the HEC-6 sediment transport model of the U.S. Army Corps of Engineers (1993). To achieve the purpose of the analysis, numerous HEC-6 models were developed. The results of the erosion and sedimentation analysis and an interpretation of the output of those models are presented. The models are made available for use and further interpretation as may be necessary to evaluate various alternatives.

5-1.2 AUTHORITY FOR STUDY

Pursuant to Arizona revised Statues 48-3609.01 the Flood Control District of Maricopa County is authorized to conduct watercourse master plans for river reaches within Maricopa County. Tetra Tech, Inc. (Tetra Tech) was awarded the Skunk Creek Watercourse Master Plan (FCD Contract 99-23) in October of 1999. Stantec Consulting Inc. conducted erosion and sedimentation analyses for the project under a contract to Tetra Tech.

5-2.0 DATA COLLECTION

5-2.1 HYDRAULIC AND GEOMETRIC INPUT

The base hydraulic and geometric data utilized in the erosion and sedimentation analyses for the study reaches of Skunk Creek are taken from three existing studies. Those studies are as follows:

- Skunk Creek Floodplain Delineation Study, June 1997, by Montgomery Watson prepared for the Flood Control District of Maricopa County.
- Skunk Creek Floodplain Redelineation and Hydraulic Analysis, 25 April 1996, revised 20 November 1996 by Erie and Associates, Inc. prepared for Del Webb Corporation, for submittal to the Flood Control District of Maricopa County.
- Case No. 99-09-0592R, Communities of City of Peoria and Maricopa County, Arizona Skunk Creek Floodplain and Floodway Conditional Letter of Map Revision Request, 19 August 1999 by Hoskin Engineering Consultants, Inc. for Communities Southwest.

The base hydraulic and geometric data utilized in the erosion and sedimentation analyses for Sonoran Wash are taken from the hydraulic study described in Attachment 4.

5-2.2 SEDIMENT INPUT

Pebble count and sieve-analyzed data provided by JE Fuller/Hydrology & Geomorphology, Inc. (JEF, Inc.) was used for the sediment input. The pebble count data were collected by the following procedure.

- Laying a cloth tape across the channel and measuring the channel width.
- A sampling interval was determined that would yield approximately 100 samples.
- At each sampling interval, the sediment particle directly beneath the tape interval was measured. In cases where that particle size was less than 3 mm, the sediment classification was recorded (that is; gravel, coarse sand, sand, fine sand, very fine sand, and silt).

The sieve-analyzed samples were collected from bulk samples generally taken at the locations where test pits were excavated and logged. The data collection is further described in Attachment 6.

5-2.3 HYDROLOGIC INPUT

The base hydrologic data utilized in the erosion and sedimentation analyses for the study reaches of Skunk Creek and Sonoran Wash were provided by Tetra Tech for the existing and future conditions. The development of the data is described in Attachment 3.

5-2.4 SEDIMENT YIELD

Sediment yield from small (less than 121 square miles) watersheds in Arizona and New Mexico is compiled and presented in Appendix A. The data consists of measured sediment yield from certain watersheds and also sediment yield estimates that were performed for the purpose of various regional studies. A summary of the sediment yields for the various watersheds (both measured and estimated sediment yields) is provided in Table A-1 (Appendix A). It is noted in that table that data point RR is a fully urbanized watershed in Albuquerque with correspondingly low sediment yield and that data is not plotted in either Figure A-1 or A-2. Figure A-1 is a plot of that data, and that figure indicates a range of sediment yield from about 0.01 to more than 1.0 acre-feet per square mile per year for small watersheds. The scatter of data generally covers more than two log cycles on the graph. Figure A-2 is a plot of only the measured sediment yield data. That figure indicates a range of sediment yield from about 0.3 to about 1.0 acre-feet per square mile per year. Envelope lines are shown in Figure A-2 indicating a wider variability for smaller watersheds. For a drainage area of about 100 square miles, which is slightly more than the drainage area of Skunk Creek at the upper study boundary, the sediment yield from Figure A-2 is in the range from about 0.2 to slightly more than 0.3 acre-feet per square mile per year.

The bed material component of sediment yield from the 100-year flood in Cave Creek, an adjoining watershed to the east, was estimated from HEC-6 output in the report Cave Creek and Apache Wash Watercourse Master Plan, Attachment 4, Erosion and Sedimentation Technical Data Notebook, November 2000. That bed material sediment yield estimate for Cave Creek can be compared to Skunk Creek. The figure, accumulative sediment deposited upstream of section, is used to estimate the bed material sediment yield from the flood. That figure is a running accumulation of sediment deposited (+ number) or eroded (- number) starting at the upstream end (right side of graph) and progressing downstream (to the left). Line segments (or trend of sections of the graph) sloping downward to the left indicate reaches of overall degradation. Line segments sloping upward to the left indicate reaches of overall aggradation. See Section 5-7.0 for further discussion of the figure, and Appendix 5-H.1 for the graph. For Skunk Creek, the approximate reach of degradation begins at cross section 23.55 and ends at cross section 17.48. Cline Creek enters Skunk Creek approximately at cross section 23.55 and is a major source of sediment to the system. Deposition from the ponding water from the CAP overchute starts approximately at cross section 17.48. The estimated sediment yield of bed material from the 100-year flood for the Cave Creek watershed (162 square miles) is 0.12 acre-feet per square mile, and for Skunk Creek (64 square miles) is 0.08 acre-feet per square mile. The higher bed material sediment yield for Cave Creek is expected because:

- Cave Creek has a greater area of steep sloped watershed resulting in greater total sediment yield,
- Peak discharges are greater for Cave Creek, and sediment transport capacity is greater, and
- Cave Creek has a higher elevation watershed resulting in greater storm magnitude – frequency relations, which also increase total sediment yield as compared to Skunk Creek.

5-3.0 HYDROLOGY

5-3.1 GENERAL

Hydrologic input to the HEC-6 model is in the form of discretized streamflow hydrographs at locations along the watercourse. Figure 5-1.1 identifies where streamflow changes along the watercourses. Only a finite number of inflows can be modeled with HEC-6 and locations of flow changes are selected based on the accumulative impact of lateral inflows to the watercourse. The modeled "flow change locations" shown in Figure 5-1.1 are the same as the locations of discharge changes in the base hydraulic models (HEC-2 and HEC-RAS) that are used to define the hydraulics for the HEC-6 models.

Streamflow hydrographs were provided based on HEC-1 modeling of the watershed. See Section 5.2 for a discussion of the source of the flood hydrographs. Four hydrologic conditions were analyzed; for Skunk Creek the 10-year and 100-year floods under both existing and future watershed conditions, respectively. For Sonoran Wash the 25-year and 100-year floods under both existing and future watershed conditions were analyzed, respectively. Figures 5-3.1 and 5-3.2 are plots of the 100-year, existing condition hydrographs at each flow change location for Skunk Creek and Sonoran Wash, respectively. Those hydrographs are shown to illustrate the discharge conditions in watercourses. Similar hydrographs were prepared for the other three hydrologic conditions and were used in defining input to the HEC-6 models.

The discharge in modeling reaches of the watercourses are assigned the discharge from the downstream flow change location.

For Skunk Creek, the majority of the streamflow is produced in the upper part of the watershed (above River Mile [RM] 23.55). Cline Creek, at RM 23.55, produces major inflow to Skunk Creek. The 100-year, existing condition peak flow at the upper boundary (S6C) is approximately 7,840 cfs, at Cline Creek (S14C) it is 24,427 cfs and at the downstream study limits (S23C) it is 26,513 cfs (Table 5-3.1). The time to peak at the downstream end of the study limits (S23C) occurs approximately 1 hour after the time to peak at Cline Creek (S6C). This indicates that the majority of Skunk Creek, from RM 23.55 to RM 13.00, functions primarily as a conveyance system for runoff produced in the upper part of the watershed. Therefore, only the tributary flows from the upper portion (S6C, S10C, S13C, and S14C) are considered to be significant. The greatest flow (S21C2) between RM 23.55 and RM 13.00 is used for the lower portion of the watershed.

For Sonoran Wash, the existing condition flows gradually increase as the discharge proceeds downstream. To simplify the model, the hydrographs at concentrations points C002L, C002, and C007 are used (Table 5-3.2).

Figure 5-3.1
Original Hydrographs
Skunk Creek, existing condition, 100-year event

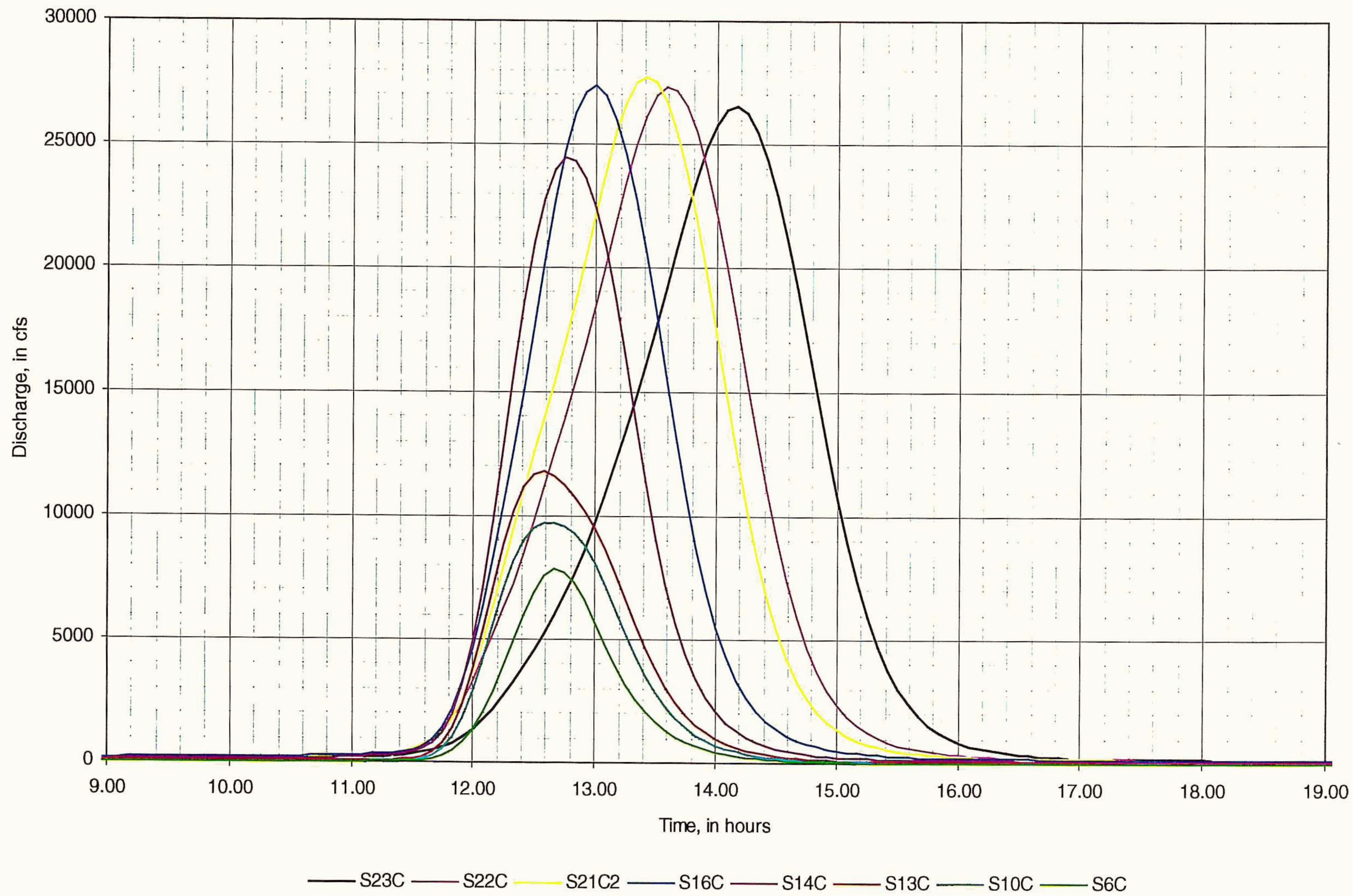


Figure 5-3.2
Original hydrographs
Sonoran Wash, existing condition, 100-year event

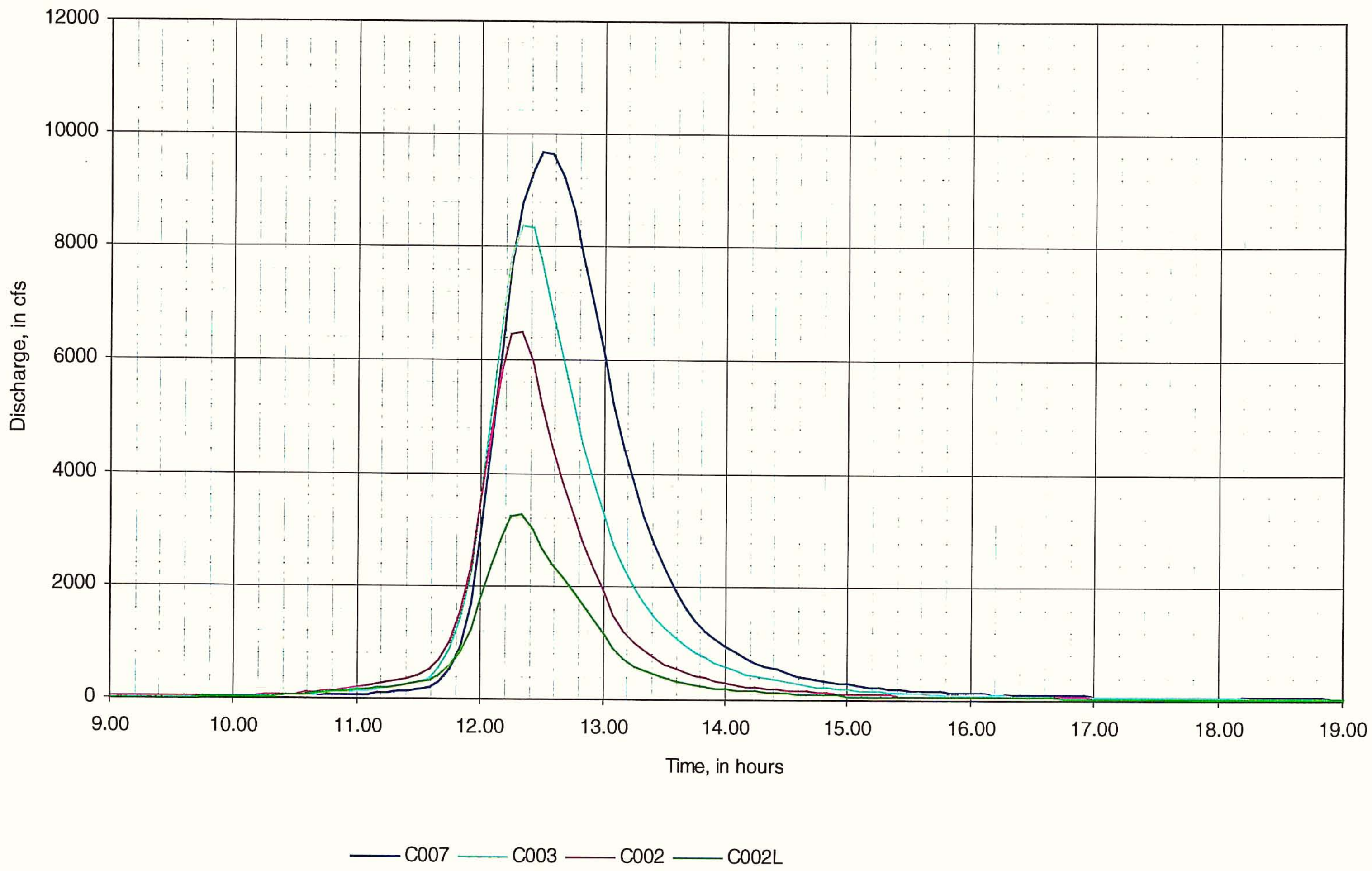


Table 5-3.1

Existing and future discharges

Skunk Creek

HEC-RAS Section	HEC-1 Concentration Point	10-year (cfs)		100-year (cfs)	
		Existing	Future	Existing	Future
25.72	S6C	3718	3718	7840	8811
24.74	S10C	4494	4494	9741	11837
24.12	S13C	5485	5485	11811	12587
23.55	S14C	11155	11155	24427	20910
22.79	S16C	12778	12778	27332	23669
18.57	S21C2	12807	12807	27733	24642
17.95	S22C	12583	12583	27283	24474
16.68	S23C	12229	12229	26513	24126

Table 5-3.2

Existing and future discharges

Sonoran Wash

HEC-RAS Section	HEC-1 Concentration Point	25-year (cfs)		100-year (cfs)	
		Existing	Future	Existing	Future
3.70	C002L	2498	1798	3267	3454
2.73	C002	4892	3295	6492	7246
-	C003L	4829	2227	6303	5695
2.08	C003	6235	2477	8359	6861
-	C007L	5754	3893	8039	5856
0.52	C007	6785	2539	9664	6671
-	C009 (U13A)	343	388	472	525
-	C010L	6369	2176	9203	5889
-	C010	6712	2241	9825	6098

5-3.2 HYDROGRAPH INPUT TO HEC-6 MODELS

Hydrographs are input into the various HEC-6 models as a series of discrete, steady flow values for a specified flow duration that represents the actual hydrographs. The first discretized hydrograph input to the HEC-6 models is at the downstream limit of each study reach. Hydrographs at each upstream flow change location along the mainstem that are coded into the model are the tributary or local inflow hydrographs. The mainstem hydrographs are then computed by subtracting the tributary or local inflow hydrograph from the downstream hydrograph. This process is accumulative in the sense that the calculated mainstem hydrograph becomes the downstream hydrograph for each subsequent inflow location. Discretization of these tributary and local inflow hydrographs is performed using the same time durations as the downstream hydrograph. This process is problematic for watercourses with significant hydrologic channel routing effects, particularly in regard to hydrograph timing. For watercourses where the downstream hydrograph is significantly lagged behind the upstream hydrograph and where tributary or local flow is negligible, subtraction of the tributary inflow from the downstream hydrograph may result in negative flow values along the rising limb of the computed mainstem hydrograph. This situation can be seen by inspection of runoff hydrographs at concentrations points S21C2 and S14C of Skunk Creek (Figure 5-3.1). Calculation of discrete steady flow values for each of these hydrographs at the same time duration and starting point in time will result in larger steady flow values for S14C along the rising limb of the hydrograph than for S21C2. This situation is resolved by aligning the peaks of the tributary and local hydrographs to the most downstream location. In other words, the hydrologic channel routing is eliminated from consideration.

The discrete steady flows are an average of the hydrograph for specified time intervals. The duration of the time intervals are adjusted until the discretized hydrograph is representative of the actual hydrograph. Five time steps are shown to represent the hydrograph, two time steps for the rising limb, one time step for the peak and two time steps for the falling limb. At low discharge rates, HEC-6 becomes unstable and therefore, only the main portion (2 hours) of the hydrograph is used. At low flow rates, the velocity of the water decreases and there is not enough time for the water to move from one cross section to another. Under that condition, HEC-6 will print out the following error message "Channel has filled with sediment at cross section X.XX Sediment movement computations are no longer valid."

The downstream hydrograph for each watercourse is discretized first. A ratio of the peak discharge of the tributary and local flows to the downstream hydrograph is used to calculate the discretized tributary and local flows. The process of hydrograph discretization is preformed for each of the hydrologic conditions, except for the Sonoran Wash 25-year event, future condition. Due to on-site retention, the streamflow for the 25-year, future condition flood is essentially eliminated, and therefore sediment transport modeling of that flood condition is irrelevant. The resulting discretized input hydrographs to HEC-6 for each watercourse for each hydrologic condition are shown in Tables 5-3.3 through 5-3.9. The discretized hydrographs are also shown in Figures 5-3.3 through 5-3.9.

Table 5-3.3

Discretized input hydrograph to HEC-6

Skunk Creek, 100-year, existing condition

Step	ΔTime (hours)	ΔTime (days)	HEC-6 Input, cfs				
			S21C2	S14C	S13C	S10C	S6C
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1	0.75	0.0313	12472	1487	5674	931	855
2	0.42	0.0174	23719	2827	10790	1770	1626
3	0.25	0.0104	27560	3285	12537	2057	1889
4	0.42	0.0174	23561	2809	10718	1759	1615
5	0.67	0.0278	9253	1103	4209	691	634

Table 5-3.4

Discretized input hydrograph to HEC-6

Skunk Creek, 100-year, future condition

Step	ΔTime (hours)	ΔTime (days)	HEC-6 Input, cfs				
			S21C2	S14C	S13C	S10C	S6C
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1	0.75	0.03125	10942	1657	3696	333	1344
2	0.42	0.01736	22347	3384	7548	680	2744
3	0.25	0.01042	24567	3721	8298	748	3017
4	0.42	0.01736	22861	3462	7722	696	2807
5	0.67	0.02778	11937	1808	4032	363	1466

Table 5-3.5

Discretized input hydrograph to HEC-6

Skunk Creek, 10-year, existing condition

Step	ΔTime (hours)	ΔTime (days)	HEC-6 Input, cfs				
			S21C2	S14C	S13C	S10C	S6C
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1	0.8	0.03125	6001	774	2657	464	364
2	0.4	0.01736	11169	1441	4945	864	677
3	0.3	0.01042	12729	1642	5635	985	771
4	0.4	0.01736	10700	1380	4737	828	648
5	0.7	0.02778	4100	529	1815	317	248

Table 5-3.6

Discretized input hydrograph to HEC-6

Skunk Creek, 10-year, future condition

Step (1)	ΔTime (hours) (2)	ΔTime (days) (3)	HEC-6 Input, cfs S21C2 (4)	S14C (5)	S13C (6)	S10C (7)	S6C (8)
1	0.75	0.03125	4314	711	1328	108	534
2	0.42	0.01736	10130	1669	3118	254	1255
3	0.25	0.01042	11756	1937	3619	295	1456
4	0.42	0.01736	10728	1768	3302	269	1329
5	0.67	0.02778	5460	900	1681	137	676

Table 5-3.7

Discretized input hydrograph to HEC-6

Sonoran Wash, 100-year, existing condition

Step (1)	ΔTime (hours) (2)	ΔTime (days) (3)	HEC-6 Input, cfs C010 (4)	C003 (5)	C002 (6)
1	0.75	0.03125	1576	565	487
2	0.42	0.01736	5238	1878	1619
3	0.25	0.01042	9055	3246	2798
4	0.42	0.01736	7973	2858	2464
5	0.67	0.02778	4307	1544	1331

Table 5-3.8

Discretized input hydrograph to HEC-6

Sonoran Wash, 100-year, future condition

Step (1)	ΔTime (hours) (2)	ΔTime (days) (3)	HEC-6 Input, cfs C010 (4)	C003 (5)	C002 (6)
1	0.75	0.03125	984	32	374
2	0.42	0.01750	3216	106	1224
3	0.25	0.01042	5768	190	2195
4	0.41	0.01708	4636	153	1764
5	0.67	0.02792	2311	76	879

Table 5-3.9

Discretized input hydrograph to HEC-6

Sonoran Wash, 25-year, existing condition

Step (1)	ΔTime (hours) (2)	ΔTime (days) (3)	HEC-6 Input, cfs C010 (4)	C003 (5)	C002 (6)
1	0.8	0.03125	232	65	82
2	0.4	0.01736	3964	1106	1399
3	0.3	0.01042	6689	1866	2360
4	0.4	0.01736	5554	1549	1960
5	0.7	0.02778	2166	604	764

Figure 5-3.3
Discretized input hydrographs to HEC-6
Skunk Creek, existing condition, 100-year event

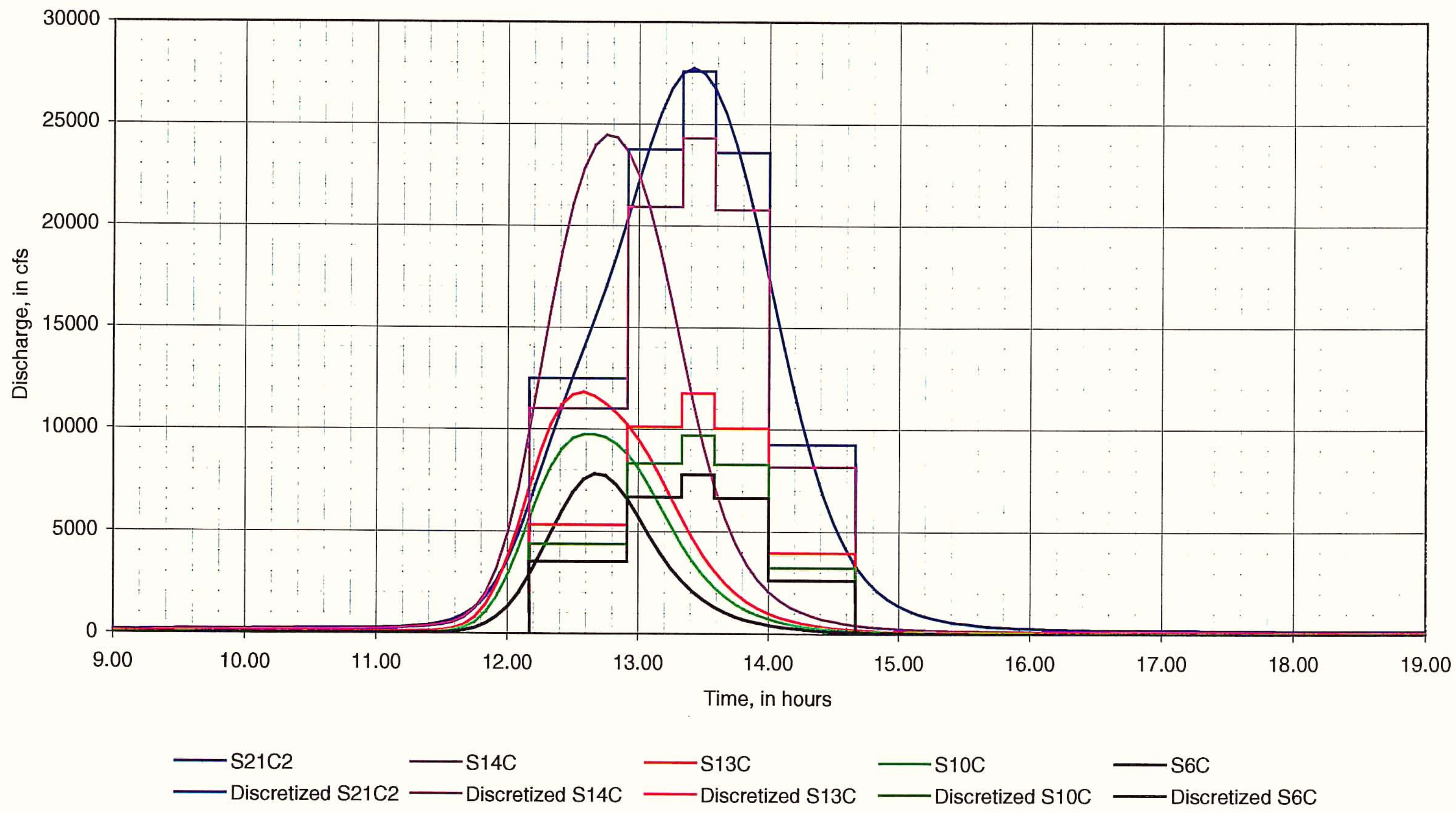


Figure 5-3.4
Discretized input hydrographs to HEC-6
Skunk Creek, future condition, 100-year event

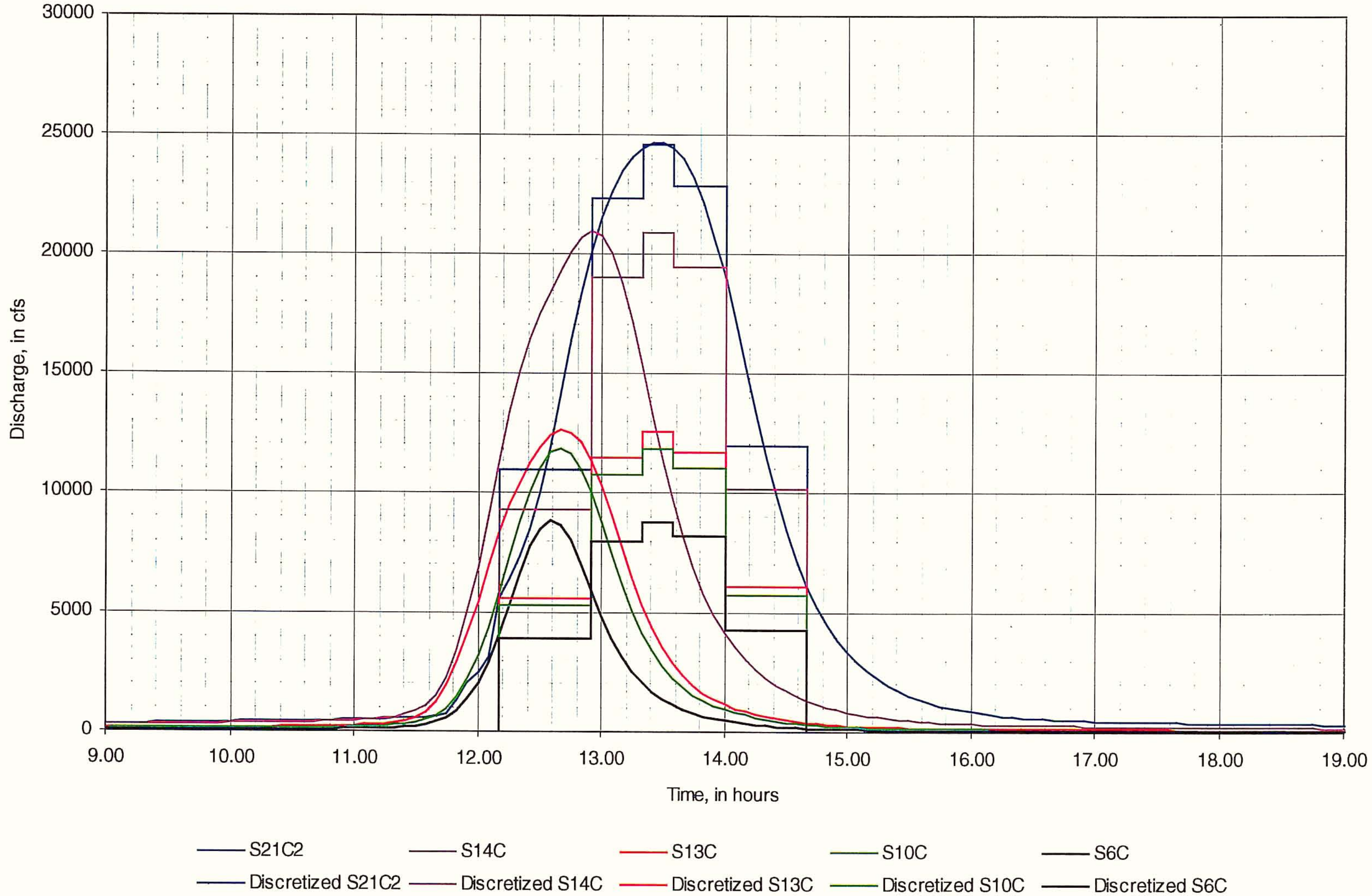


Figure 5-3.5
Discretized input hydrographs to HEC-6
Skunk Creek, existing condition, 10-year event

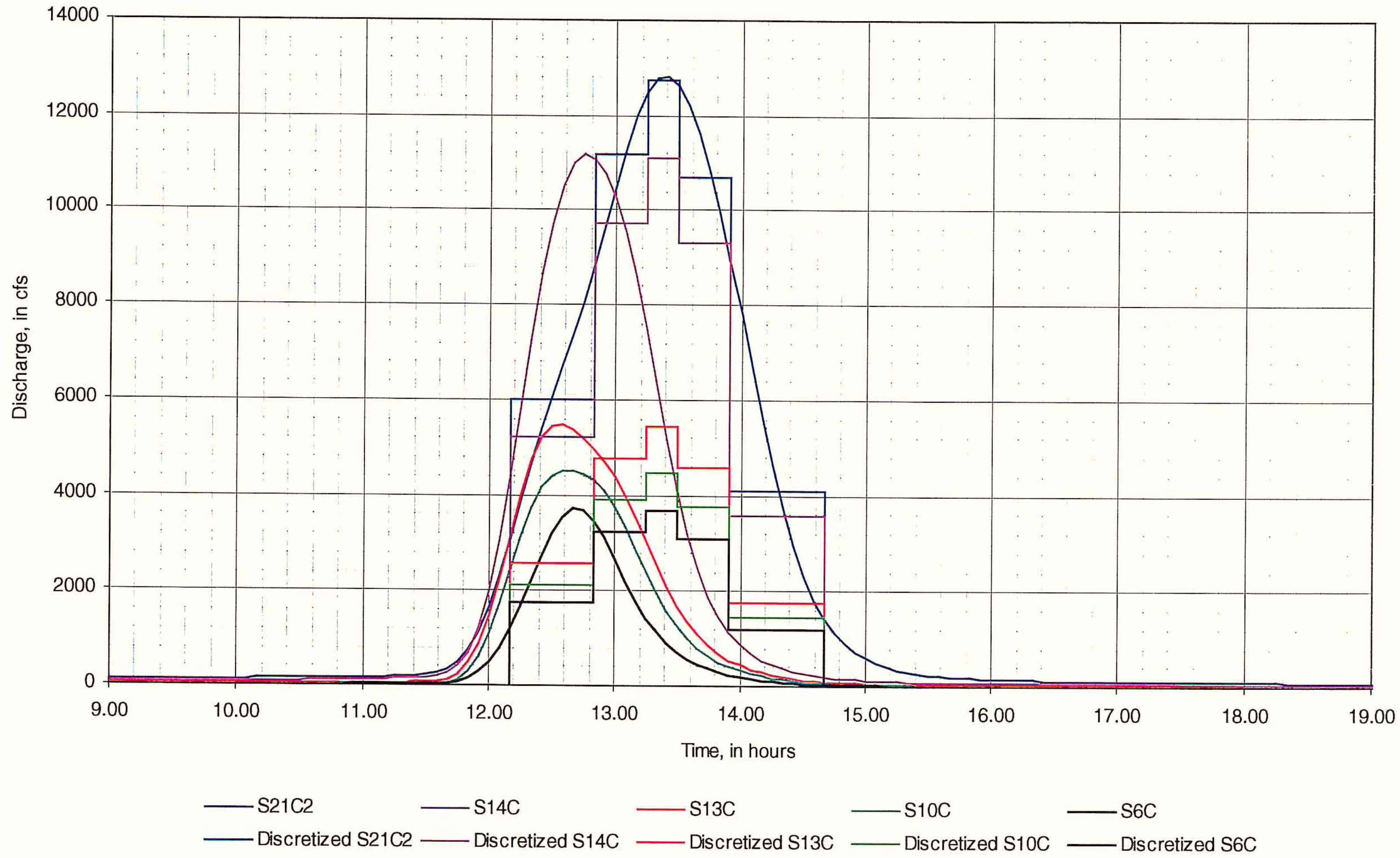


Figure 5-3.6
Discretized input hydrographs to HEC-6
Skunk Creek, future condition, 10-year event

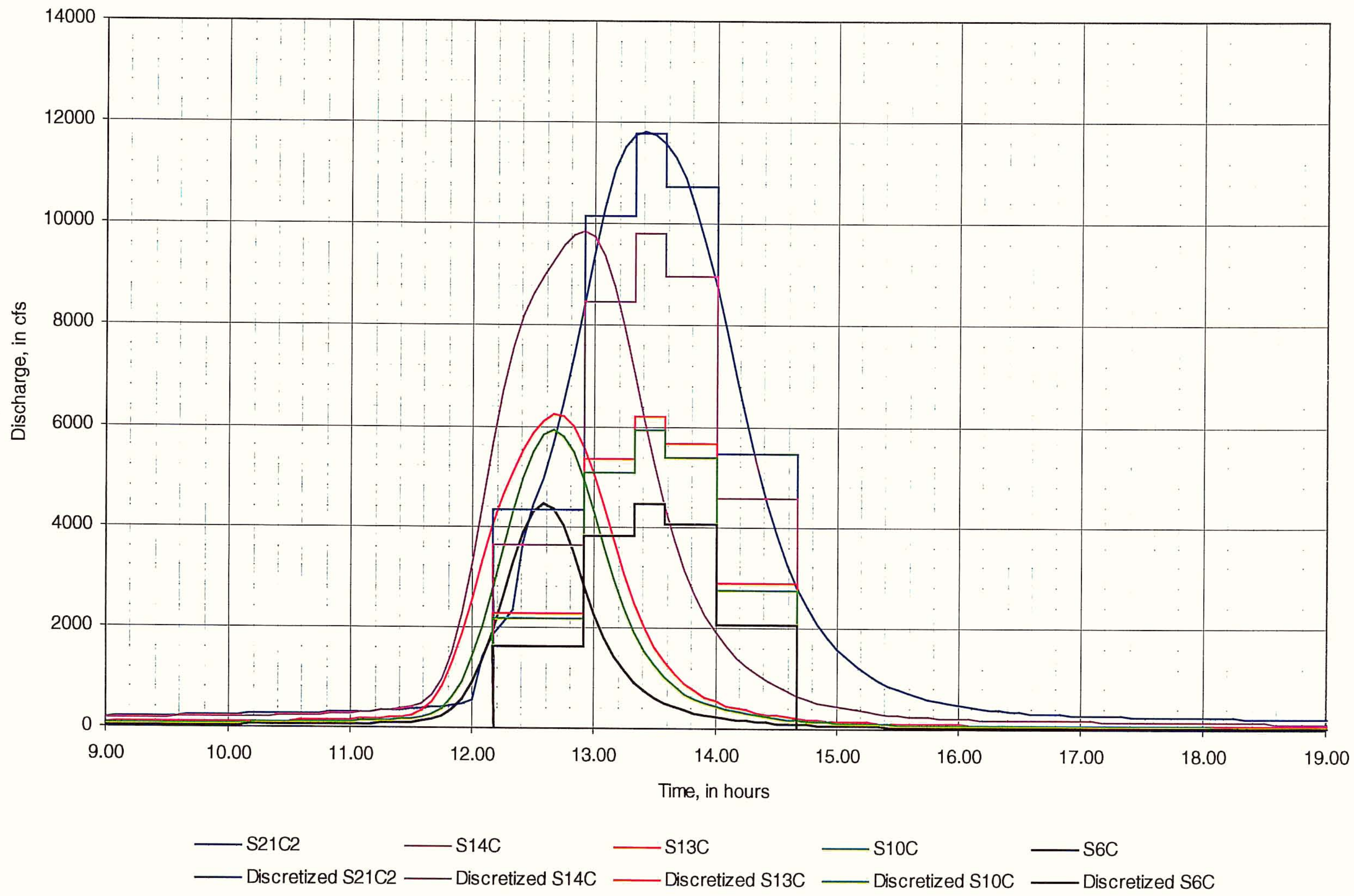


Figure 5-3.7
Discretized input hydrographs for HEC-6
Sonoran Wash, existing condition, 100-year event

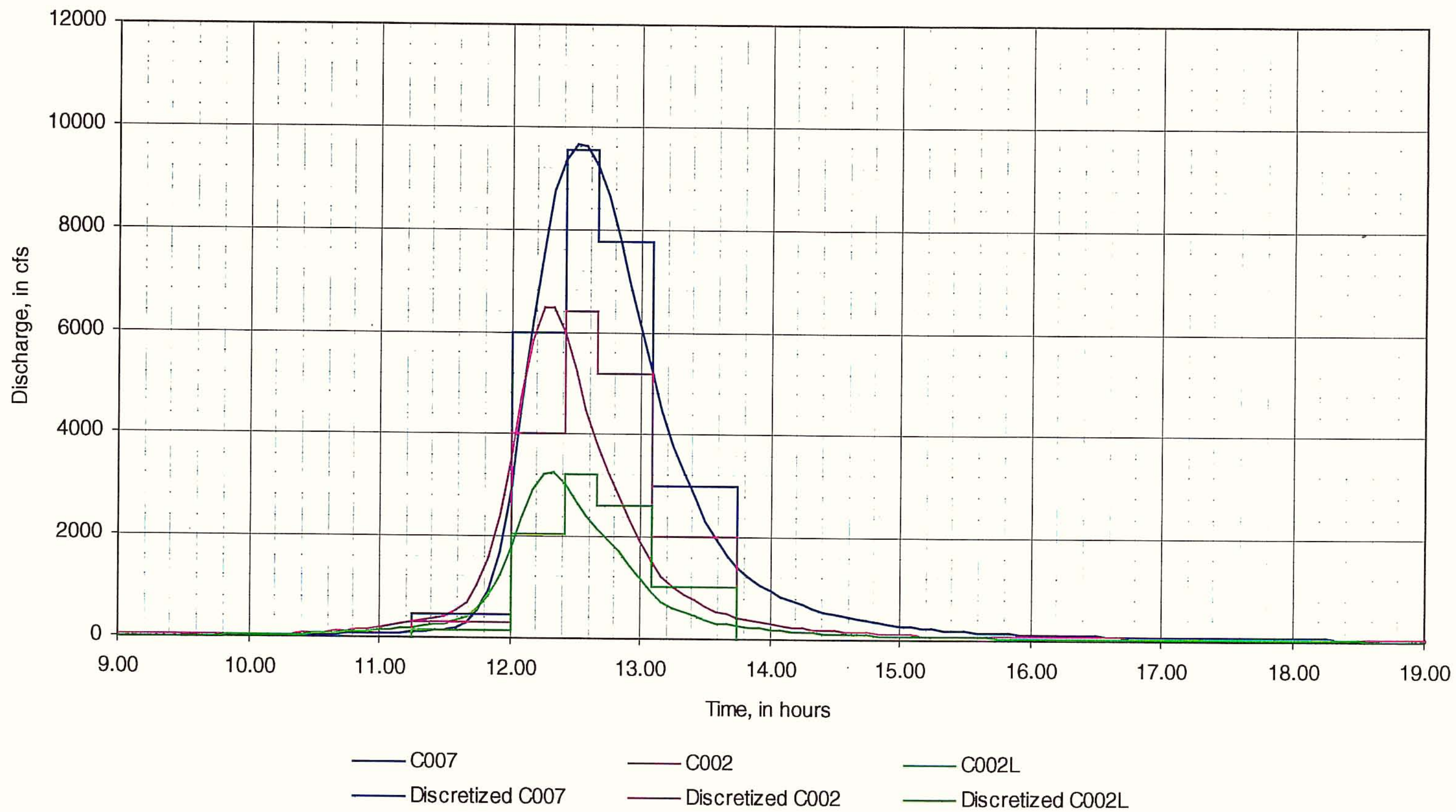


Figure 5-3.8
Discretized input hydrographs for HEC-6
Sonoran Wash, future condition, 100-year event

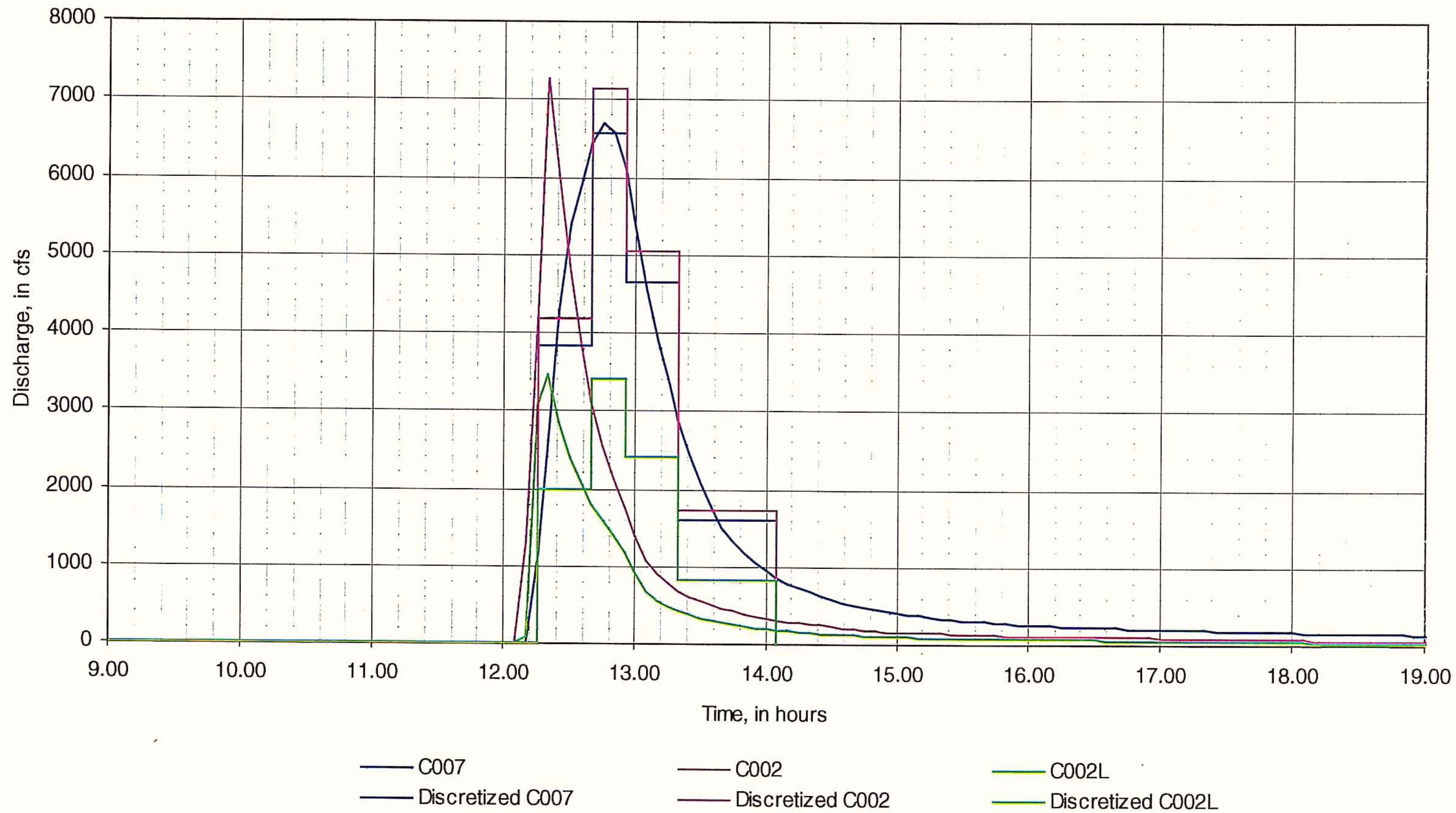
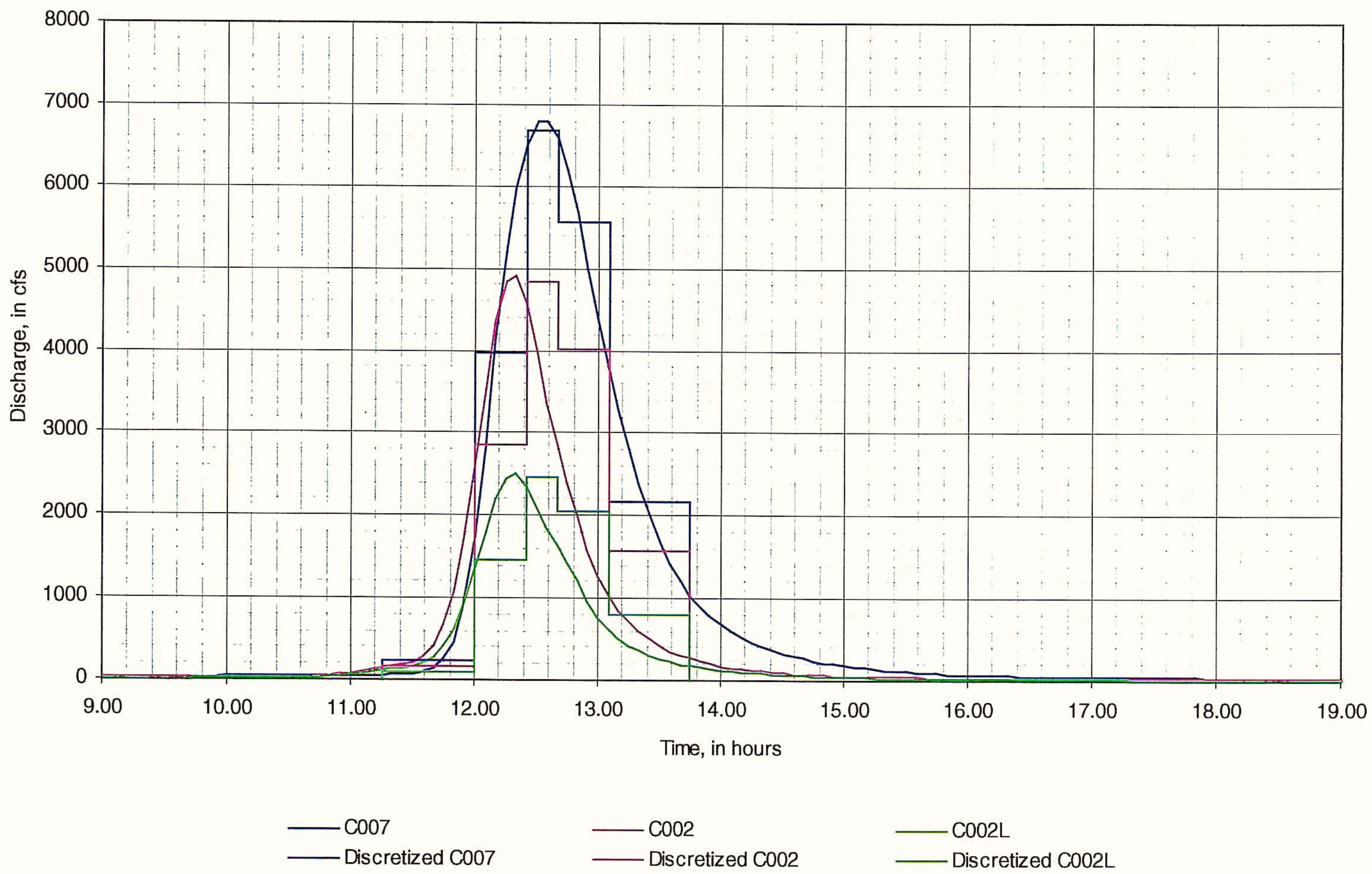


Figure 5-3.9
Discretized input hydrographs for HEC-6
Sonoran Wash, existing condition, 25-year event



5-3.3 LIMITATIONS AND ASSUMPTIONS

Various models were established to evaluate how the watershed would respond to various hydrologic conditions. The following are major assumptions and limitations.

- Runoff input to HEC-6 at all tributary and local inflow locations are at the same time increment, eliminating channel routing from consideration.
- All discrete, steady state discharges can be conveyed from one cross section to the next in the specified time interval.
- The runoff input was developed for a design storm. An actual storm will vary in magnitude, intensity, spatial distribution, temperature, distance, etc. The actual rate of sediment transport in any storm will vary from the values presented herein.
- Analysis assumes an independent storm without any antecedent storm.

5-4.0 EROSION & SEDIMENTATION ANALYSIS

5-4.1 ANALYSIS TECHNIQUE

The erosion and sedimentation of Skunk Creek and Sonoran Wash within the study area was investigated by modeling the sediment transport through each watercourse under a variety of hydrologic and development conditions. The modeling was performed using the U.S. Army Corps of Engineers, HEC-6 model (1993). Input to the HEC-6 models was obtained from hydraulic models (HEC-2 and HEC-RAS) of the watercourses, field data collection regarding sediment characteristics, assumptions regarding hydrologic and hydraulic conditions, and the selection of the appropriate sediment transport functions.

The models were verified by comparison of hydraulic results of the HEC-6 models as compared to corresponding HEC-2 or HEC-RAS models. Sensitivity of model input was investigated to assess how critical various model input and assumptions are to model results. Calibration of the models cannot be performed since there is not an adequate database for such calibration. Erosion and sedimentation results are analyzed by evaluation of quantitative results and by the qualitative interpretation of graphical results from the various HEC-6 models.

5-4.2 SEDIMENT DATA AND ANALYSES

5-4.2.1 General

Base models of each watercourse are established for analyzing sediment processes in the main channels and separate models for the overbanks. Those models are referred to as Main Channel Models, and Overbank Models, respectively. Those separate models are necessary because of the wide disparity in the bed material grain size between the main channels and the adjacent overbank floodplains. The main channels are composed of coarser sediments ranging in size up to boulders. The overbanks are composed of finer material in the silt and sand size with some gravel. The overbanks are also occupied by denser and more diverse vegetation. The Main Channel Models and Overbank Models are different in two ways; first, by grain size of the bed material, and second, by use of the sediment transport function. The Main Channel Models use the Meyer-Peter, Muller function and the Overbank Models use the Yang Stream Power function. The description of the selection of the sediment transport function is provided in Section 5-4.2.2.

Sediment data consists of rating curves of sediment load at upper boundaries and tributaries of each watercourse and size distributions of the bed material. The sediment load rating curves are a function of discharge and the size distribution of incoming sediment is specified. The sediment load rating curves are developed by modeling a "dummy" reach for each watercourse and using HEC-6 to estimate a bed material transport relation. Notice that the incoming sediment load is modeled as bed material and not total load. This is not a limitation to the model as it is reasonably assumed that the wash load component of total load will either be deposited upstream of the Central Arizona Project (CAP) Canal or will pass over the CAP Canal. The description of inflowing sediment data and its analyses are provided in Section 5-4.2.4.

Size distributions of the bed material for each watercourse are estimated based on field data. The bed material size distribution is different for the Main Channel and Overbank Models as represented by field data. The description of bed material and the analyses of that data are provided in Section 5-4.2.3.

5-4.2.2 Selection of Sediment Transport Function

Two sediment transport functions are used for the erosion and sedimentation modeling of the watercourses. The Meyer-Peter, Muller sediment transport function is used for the Main Channel Models, while the Yang Stream Power transport function is used for the Overbank Model.

The Meyer-Peter, Muller function, which was originally developed using coarse sands and gravels, is recommended for rivers with bed materials greater than 5.0 mm (Stevens and Yang, 1989; FCDMC, 1994 a and b). From the reach-wide characterization analysis of the sediment data for the watercourse systems, a large percentage of channel bed materials are larger than 5.0 mm.

The development and establishment of the Meyer-Peter, Muller function is based on flume data and extensive experiments (Stevens and Yang, 1989). The sediment transport function was derived from sediment data with mean sizes and effective diameters ranging from 0.40 to 30 mm (Vanoni, 1975). The selection of the Meyer-Peter, Muller function for the Main Channel Models is also supported by sediment modeling for the Agua Fria River in Arizona from 1983 to 1994 (SLA, 1983; WRA, 1986; FCDMC, 1994 a and b). Both the Agua Fria River and Skunk Creek, like most watercourses in Arizona, are ephemeral streams and some physical similarities between the watercourses justify the use of this sediment transport function.

The Yang Stream Power function was originally established using a sediment size range from 0.015 to 1.72 mm (Vanoni, 1975). Since a large percentage of the stream cross-section is covered by the overbank floodplain, a model to evaluate the erosion and sedimentation process in that part of the watercourse is needed.

The use of the Yang Stream Power function for the Overbank Models is due to the well-documented applications and capability of the Yang function to estimate sediment load for sand streams (Stevens and Yang, 1989; Yang, 1973, Yang 1984; Yang, 1988, Yang and Molinas, 1982; and Yang and Stall, 1976). Since the bed material in the overbanks of the watercourses are predominantly silt, sand and fine gravel and much finer than the bed material in the main channels, Yang's Stream Power function for sand is reasonable.

5-4.2.3 Bed Material Size Distribution

A series of pebble count data and sieve-analyzed samples from the main channel and overbanks were collected, as part of this study, by JEF, Inc. The pebble count data were collected as described in Section 5-2.2, and Attachment 6.

The sieve-analyzed samples were collected from bulk samples generally taken at the locations where test pits were excavated and logged (see Attachment 6).

Two different HEC-6 models are developed to model the channel and the overbanks. The watercourses in Skunk Creek and Sonoran Wash typically have coarse bed material, with grain sizes ranging from coarse sand to large cobbles and boulders. The watercourse banks and floodplains typically have finer material, with grain sizes predominantly being silt, sand and some fine gravel. Overbank floods, such as the 100-year flood and as small as the 10-year flood, occupy both the channel and portions of the floodplain. Thus, to correctly model the sediment transport of the watercourses would require delineation and quantification of the size gradation of the bed material of both the main channel and the floodplain. However, a limitation of the HEC-6 program is that only one bed material size character can be provided for any reach of the watercourse. Therefore, two HEC-6 models are developed for each watercourse; one for the main channel which uses bed material sized gradation for the channel, and the other for the floodplain which uses size gradation that is representative of the surface of the floodplain.

The Main Channel Model, with coarser bed material size gradation, uses the Meyer-Peter, Muller transport function. The bed material for that model is developed using a composite of the bed material count data and sieve-analyzed data provided by JEF, Inc. Various percentiles of the pebble count data are computed and plotted. Using the percentile plots, the data for Skunk Creek is divided into four reaches and Sonoran Wash is divided into two reaches. Selected percentile plots for Skunk Creek and Sonoran Wash are shown in appendix 5-B, Figures 5-B.1 through 5-B.6.

The pebble count composite for each reach of each watercourse is calculated by using the following method.

- For data where the sediment size classification was recorded, a geometric mean of the classification range is assigned. Classification ranges (Vanoni, 1975) are listed in Appendix 5-B, Tables 5-B.1 and 5-B.2.
- For each reach, the pebble count data are sorted based on grain size.
- An average is found for each grain size classification.
- The number of data points in each classification is totaled.
- The percentage of the number of points is calculated by dividing the number in the classification by the total number of data points.
- The percent finer is calculated by cumulatively adding the percentages.

The Overbank Model, with the finer bed material size gradation, uses Yang's Stream Power function for sand. A sieve-analyzed sample collected or an average of the sieve-analyzed samples from the overbanks is selected from the data provided by JEF, Inc. The following sections describe the data used to estimate bed material size distributions for the Main Channel and Overbank Models, and provides results of data analyses.

5-4.2.3.1 Skunk Creek

For the watercourse channel, the size distribution of the bed material is spatially varied and a composite bed material size distribution is computed for each of four reaches. Reach 1 is located between RM 21.58 and 26.17, Reach 2 is between RM 20.16 and 21.49, Reach 3 is between RM 18.84 and 20.05, and Reach 4 is between RM 13.00 and 18.74. The data for the rating curves are included in Appendix 5-B, Table 5-B.1. For the

Overbank Models, an average of the sieve-analyze data collected from the overbanks is calculated. That resulting rating curve is applied to the entire study reach of the Skunk Creek Overbank Models. The rating curves for the Main Channel and Overbank Models are shown on Figure 5-4.1.

5-4.2.3.2 Sonoran Wash

For the watercourse channel, the size distribution of the bed material is spatially varied and a composite bed material size distribution is computed for each of two reaches. Reach 1 is located between RM 1.90 to 3.84 and Reach 2 is between RM 1.84 and 0.52. The data for the rating curves is included in Appendix 5-B, Table 5-B.2. For the Overbank Models, a sieve-analyzed sample for the overbank is selected. The rating curve is applied to the entire study reach of Sonoran Wash Overbank Models. The rating curves for the Main Channel and Overbank Models are shown on Figure 5-4.2.

Figure 5-4.1
Comparison of Bed Material for Skunk Creek Models

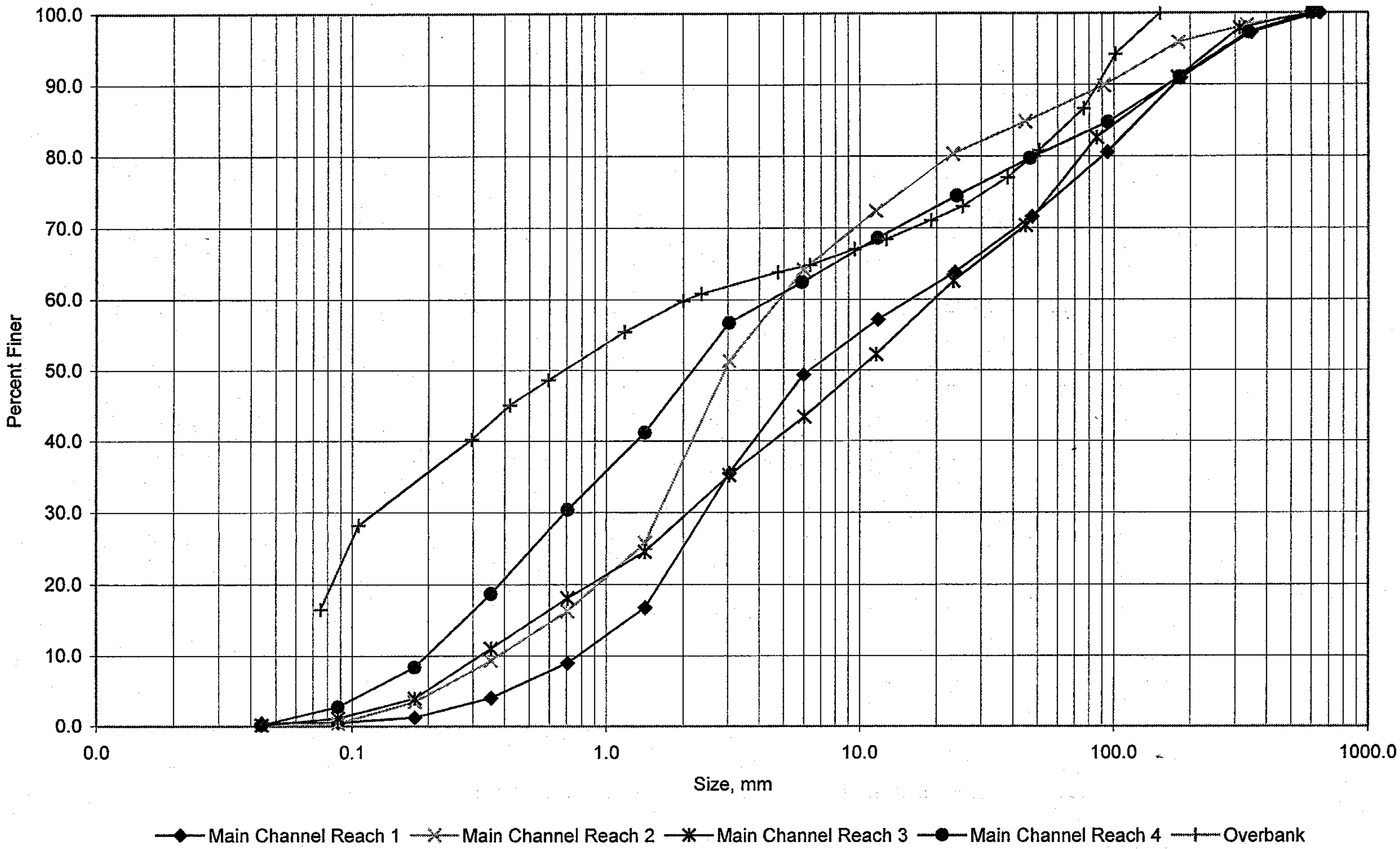
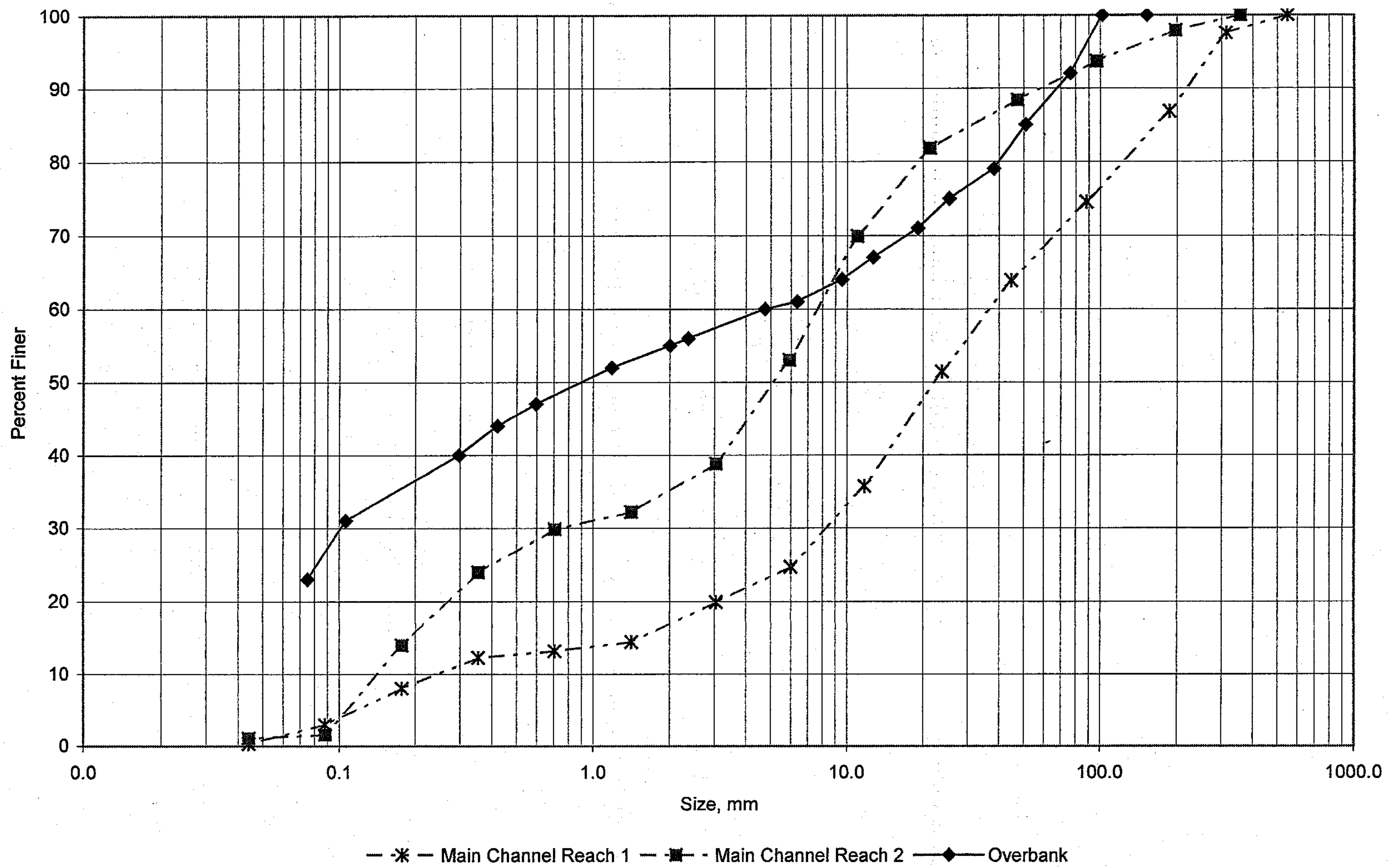


Figure 5-4.2
Comparison of Bed Material for Sonoran Wash



5-4.2.4 Inflowing Sediment Data

Inflowing sediment data is defined for each of the two watercourses, Skunk Creek and Sonoran Wash. For Skunk Creek, inflowing sediment data is defined for the upper boundary and a tributary (Cline Creek) at RM 23.55. For Sonoran Wash, inflowing sediment data is only defined for the upper boundary. The inflowing sediment for the minor tributaries of both watercourses are assumed to be zero because the discharges from those tributaries are relatively small.

5-4.2.4.1 Inflowing Sediment Rating Curves

Neither an established sediment load rating curve nor recorded sediment load data are available for the watercourses. Therefore, inflowing sediment rating curves for the watercourses are estimated as input to the HEC-6 models. Different rating curves are applied to the Main Channel and Overbank Models.

The synthesized rating curves are for bed material load not total load. Bed material is defined as the material moving on or near the bed. Total load is comprised of bed load and suspended load (Vanoni, 1975). The Meyer-Peter, Muller method was developed for estimating bed load for watercourses with coarse bed material. Suspended loads are typically comprised of finer material, such as clays, silts, and fine sand. Most of these materials will stay in suspension, even during low flow events, and pass through the system. For instance, the Table 5-4.1, lists the fall velocities of clay, very fine sand (VFS) and fine sand (FS) in still water.

Table 5-4.1

Fall Velocities of Very Fine Sand and Fine Sand

Sediment Class	Size Range mm	Fall Velocities cm/s (ft/s)
Clay [1]	2 µm	0.00035 (0.00001)
Very Fine Sand [2]	0.0675 – 1.250 mm	0.40 (0.013) – 1.5 (0.049)
Fine Sand [2]	0.1250 – 0.250 mm	1.25 (0.041) – 4.0 (0.131)

[1] From Fundamentals of Soil Behavior by Mitchell (1993).

[2] From Table 2.1 and Figure 2.2 of Sedimentation Engineering by Vanoni (1977).

Based on the tabulated values, the suspended materials in the VFS range will require from 20 to 77 seconds to settle to the channel bed bottom in a one-foot deep non-flowing stream. Settlement of the same material will take more time in a flowing stream because of turbulent mixing. Silts and clays will take considerably longer. Much of the critical transport processes in the study area are controlled by the coarser bed materials in the watercourses. From Table 5-4.2, a significant percentage (97 to 98 percent) of sediment from the inflowing sediment load consists of fine sand to coarse sand. Also, bed material is comprised of a significant percentage of coarse sediment (95 to 99 percent from fine sand to cobbles) (Figure 5-4.1). Since a significant percentage of the inflowing sediment and bed materials are coarse materials, it follows that the sediment transport processes are controlled by these materials.

An iterative approach using HEC-6 is used to generate synthetic inflowing sediment load rating curves. The HEC-6 models use the sediment load rating curve as the inflowing sediment loads at boundary conditions to the model. In general, the procedure involves adjusting the inflowing sediment until it balances with the outflowing sediment for a "dummy" reach. The HEC-6 models for developing the sediment rating curves are comprised of the following:

- Geometric data for five cross-sections are used as a "dummy" reach. These sections are assumed to be stable, and can neither degrade nor agrade. Therefore, the sediment transport for the reach is in equilibrium, that is, the inflowing sediment load equals outflowing sediment load.
- One sieve-analyzed sample is selected as representative of bed material in the "dummy" reach. Size gradation of the bed material is determined from the sieve-analysis.
- The initial inflowing sediment loads are set to zero. This is set as an initial condition in the iteration process.
- Sediment loads are estimated for a range of discharges using the Meyer-Peter, Muller sediment transport function for the Main Channel Models or the Yang Stream Power function for the Overbank Models.

The Main Channel and Overbank Models are identical except for bed material size gradation, inflowing sediment, and sediment transport function. Each model is run with the above conditions. The sediment outflow from the downstream cross-section is used to set the inflowing sediment load for the next iteration. The sediment outflow for each grain size classification is found in the output of HEC-6 in Table SB-1, Sediment Load Passing the Boundaries of Stream Segment (see Table 5-4.2 for an example). The outflowing loads according to grain size classifications are in tons per day. The values that are placed in the HEC-6 input are in terms of percent finer, which is found by dividing the load of each grain size classification by the total load. The models are iterated for each discharge until:

- The inflowing sediment by size fraction approximately equals the outflowing sediment by size fraction. This is found in Table SB-1 in the HEC-6 output (Table 5-4.2).
- The transport rate is approximately equal at each cross-section in the "dummy" reach. This is also found in Table SB-1 in the HEC-6 output. (Table 5-4.2).
- The change in bed elevation is relatively equal at each cross-section. This is found in the HEC-6 output Table SB-2 Status of the Bed Profile at Time in HEC-6 output (Table 5-4.2).

Table 5-4.2

Sample HEC-6 output for developing the inflowing sediment load rating curve

TABLE SB-1: SEDIMENT LOAD PASSING THE BOUNDARIES OF STREAM SEGMENT # 1

SEDIMENT INFLOW at the Upstream Boundary:

GRAIN SIZE	LOAD (tons/day)	GRAIN SIZE	LOAD (tons/day)
VERY FINE SAND....	32.43	FINE GRAVEL.......	1184.08
FINE SAND.........	43.07	MEDIUM GRAVEL.....	1412.17
MEDIUM SAND.......	202.04	COARSE GRAVEL.....	212.14
COARSE SAND.......	462.04	VERY COARSE GRAVEL	0.00
VERY COARSE SAND..	839.54	SMALL COBBLES.....	0.00
VERY FINE GRAVEL..	929.40	LARGE COBBLES.....	0.00
		TOTAL =	5316.91

SEDIMENT OUTFLOW from the Downstream Boundary

GRAIN SIZE	LOAD (tons/day)	GRAIN SIZE	LOAD (tons/day)
VERY FINE SAND....	32.32	FINE GRAVEL.......	1159.71
FINE SAND.........	42.96	MEDIUM GRAVEL.....	1375.68
MEDIUM SAND.......	199.19	COARSE GRAVEL.....	201.04
COARSE SAND.......	454.14	VERY COARSE GRAVEL	0.00
VERY COARSE SAND..	824.80	SMALL COBBLES.....	0.00
VERY FINE GRAVEL..	912.21	LARGE COBBLES.....	0.00
		TOTAL =	5202.05

TABLE SB-2: STATUS OF THE BED PROFILE AT TIME = 120.000 DAYS

SECTION NUMBER	BED CHANGE (ft)	WS ELEV (ft)	THALWEG (ft)	Q (cfs)	TRANSPORT RATE (tons/day) SAND
5.000	-1.50	1670.53	1666.94	3800.	5484.
4.000	-1.86	1670.28	1665.97	3800.	5497.
3.000	-0.95	1669.29	1666.27	3800.	5324.
2.000	-2.13	1669.29	1664.48	3800.	5241.
1.000	-1.12	1668.60	1663.47	3800.	5202.

5-4.2.4.2 Skunk Creek

The generation of the rating curves for Skunk Creek and Cline Creek are based on channel flow hydraulic and site-specific bed material characteristics. The "dummy" reach for the upper boundary of Skunk Creek uses cross-sections 25.7, 25.72, 25.83, 25.95, and 26.17. The "dummy" reach for Cline Creek uses cross-sections obtained from Flood Delineation study of Cline Creek and Tributary Washes, (Michael Baker, Jr., Inc., 1990). The cross-sections that are used are 0.172, 0.247, 0.327, 0.403, and 0.536.

The bed material for the upper boundary of Skunk Creek Main Channel Models use a composite of pebble count data collected by JEF, Inc. between cross-sections 21.58 and 26.17. For the Overbank Models, an average of the sieve-analyzed data collected from the overbanks is used. The bed material for Cline Creek for the Main Channel and Overbank Models is a composite of pebble count data located near RM 23.55. A separate bed material is not used for the floodplain because sieve-analyzed data is not located near the tributary. For a more detail description of the composite pebble count material and sieve-analyzed data see Section 5-4.2.3. The sediment load by size fraction for various discharges is provided in Tables 5-4.3 through 5-4.6 for the Skunk Creek Main Channel and Overbank Models. The inflowing sediment load rating curves for Skunk Creek are shown in Figure 5-4.3, and the equivalent sediment concentration graphs are shown in Figure 5-4.4. The inflowing sediment load rating curves for Cline Creek are shown in Figure 5-4.5, and the equivalent sediment concentration graphs are shown in Figure 5-4.6.

5-4.2.4.3 Sonoran Wash

An inflowing sediment rating curve is generated for only the upper boundary of Sonoran Wash. This is because the discharge from tributaries to Sonoran Wash are relatively small. The "dummy" reach uses cross-sections 3.7, 3.73, 3.76, 3.79, and 3.84. The bed material for the Main Channel Models is a composite of pebble count data for cross-sections 1.90 to 3.84. The bed material for the Overbank Models is a sieve-analyzed sample collected from the overbank. For a detailed description of the bed material, see Section 5-4.2.3. The sediment load by size fraction for various discharges is included in Tables 5-4.7 and 5-4.8. The total inflowing sediment load curves are shown in Figure 5-4.7, and the equivalent sediment concentration graphs are shown in Figure 5-4.8.

Table 5-4.3

Inflowing sediment load for the upper boundary of the Skunk Creek Main Channel Models

Discharge cfs (1)	Sediment Load Tons/day (2)	Sediment Load by Size Fraction, percent: Very Fine Sand (3)	Fine Sand (4)	Medium Sand (5)	Coarse Sand (6)	Very Coarse Sand (7)	Very Fine Gravel (8)	Fine Gravel (9)	Medium Gravel (10)	Coarse Gravel (11)
2600	12744	2.1	4.9	7.5	12.2	22.9	26.6	16.5	6.9	0.5
5200	24276	2.5	4.6	7.8	11.1	21.1	25.0	16.4	8.2	3.3
7850	35956	2.7	4.4	7.0	10.6	20.2	24.4	16.5	9.0	5.2

Table 5-4.4

Inflowing sediment load for the upper boundary of the Skunk Creek Overbank Models

Discharge cfs (1)	Sediment Load Tons/day (2)	Sediment Load by Size Fraction, percent *: Very Fine Sand (3)	Fine Sand (4)	Medium Sand (5)	Coarse Sand (6)	Very Coarse Sand (7)
2600	135308	48.5	16.8	16.1	9.4	5.2
5200	332,383	55.7	19.1	12.3	7.4	4.1
9000	555,588	48.5	13.1	19.9	8.8	4.7

* Values greater than very coarse sand are not significant.

Table 5-4.5

Inflowing sediment load from Cline Creek for the Skunk Creek Main Channel Models

Discharge cfs (1)	Sediment Load Tons/day (2)	Sediment Load by Size Fraction, percent: Very Fine Sand (3)	Fine Sand (4)	Medium Sand (5)	Coarse Sand (6)	Very Coarse Sand (7)	Very Fine Gravel (8)	Fine Gravel (9)	Medium Gravel (10)	Coarse Gravel (11)	Very Coarse Gravel (12)	Small Cobbles (13)
4000	15997	2.2	10.0	15.1	10.9	15.8	23.1	17.2	4.3	1.1	0.4	0
8200	29857	2.1	9.8	14.4	10.4	15.2	22.6	17.4	4.7	1.5	1.9	0
16400	39597	2.6	10.7	14.0	10.1	14.8	22.2	17.1	4.7	1.8	2.2	0

Table 5-4.6

Inflowing sediment load from Cline Creek for the Skunk Creek Overbank Models

Discharge cfs (1)	Sediment Load Tons/day (2)	Sediment Load by Size Fraction, percent: Very Fine Sand (3)	Fine Sand (4)	Medium Sand (5)	Coarse Sand (6)	Very Coarse Sand (7)	Very Fine Gravel (8)
4000	126882	54.7	13.4	6.2	14.0	10.4	0.1
8200	1,908,730	35.7	11.2	12.9	22.1	16.2	0.2
16400	2881340	23.6	7.4	8.5	32.9	23.5	0.2

* Values greater than very coarse sand are not significant.

Figure 5-4.3
Inflowing sediment load rating curves
Skunk Creek

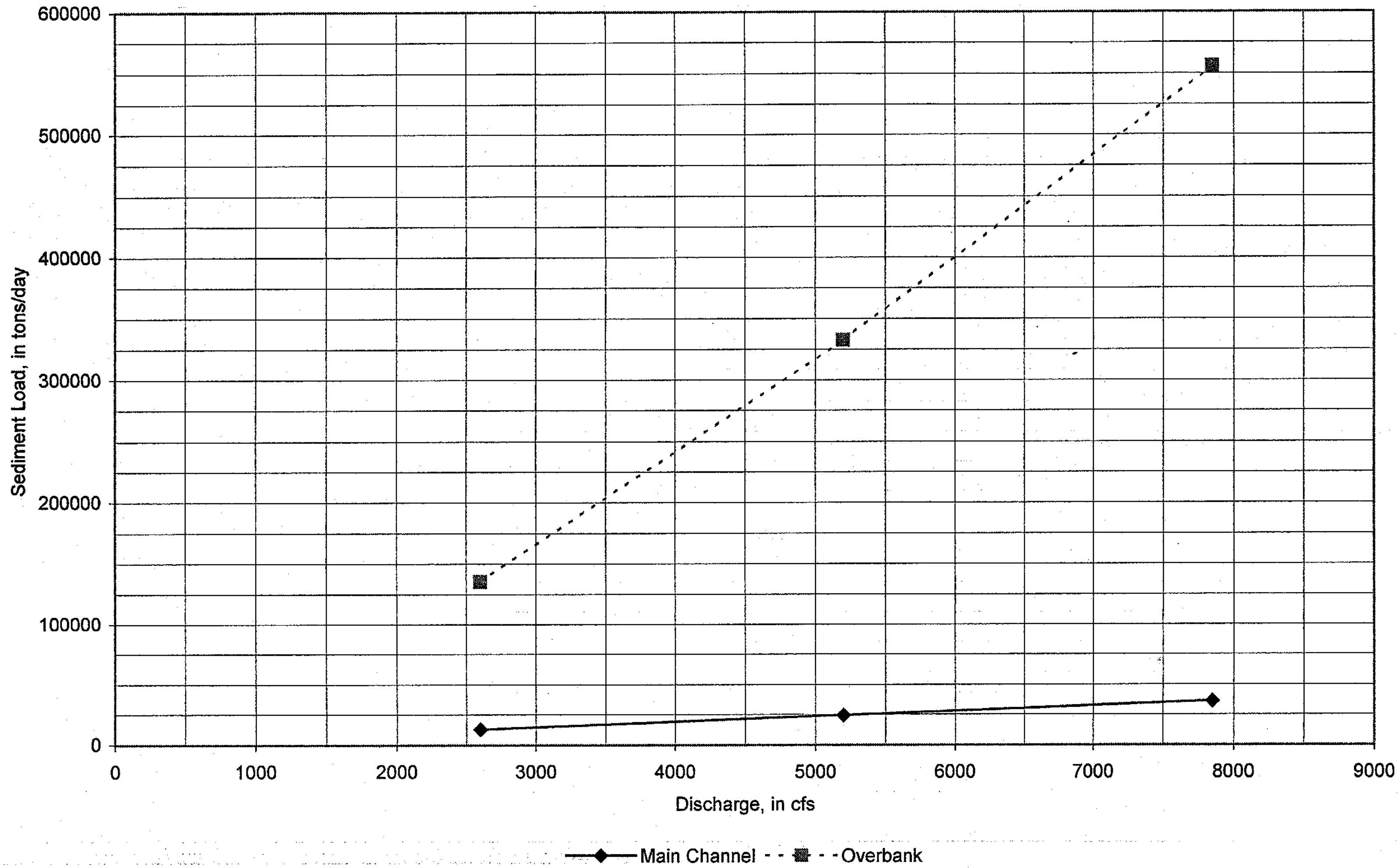


Figure 5-4.4
Inflowing sediment load concentration rating curves
Skunk Creek

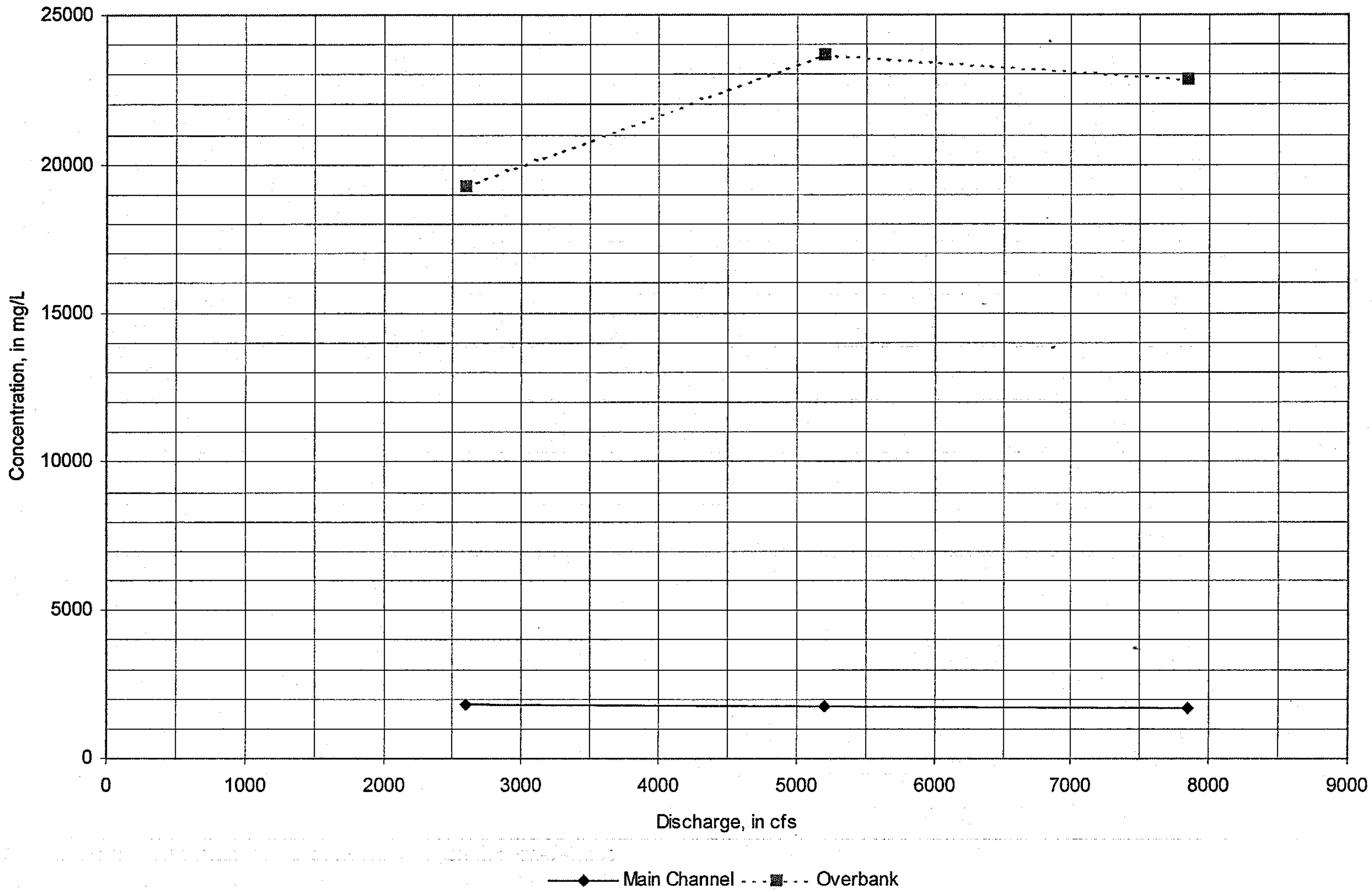


Figure 5-4.5
Inflowing sediment load rating curves
Cline Creek

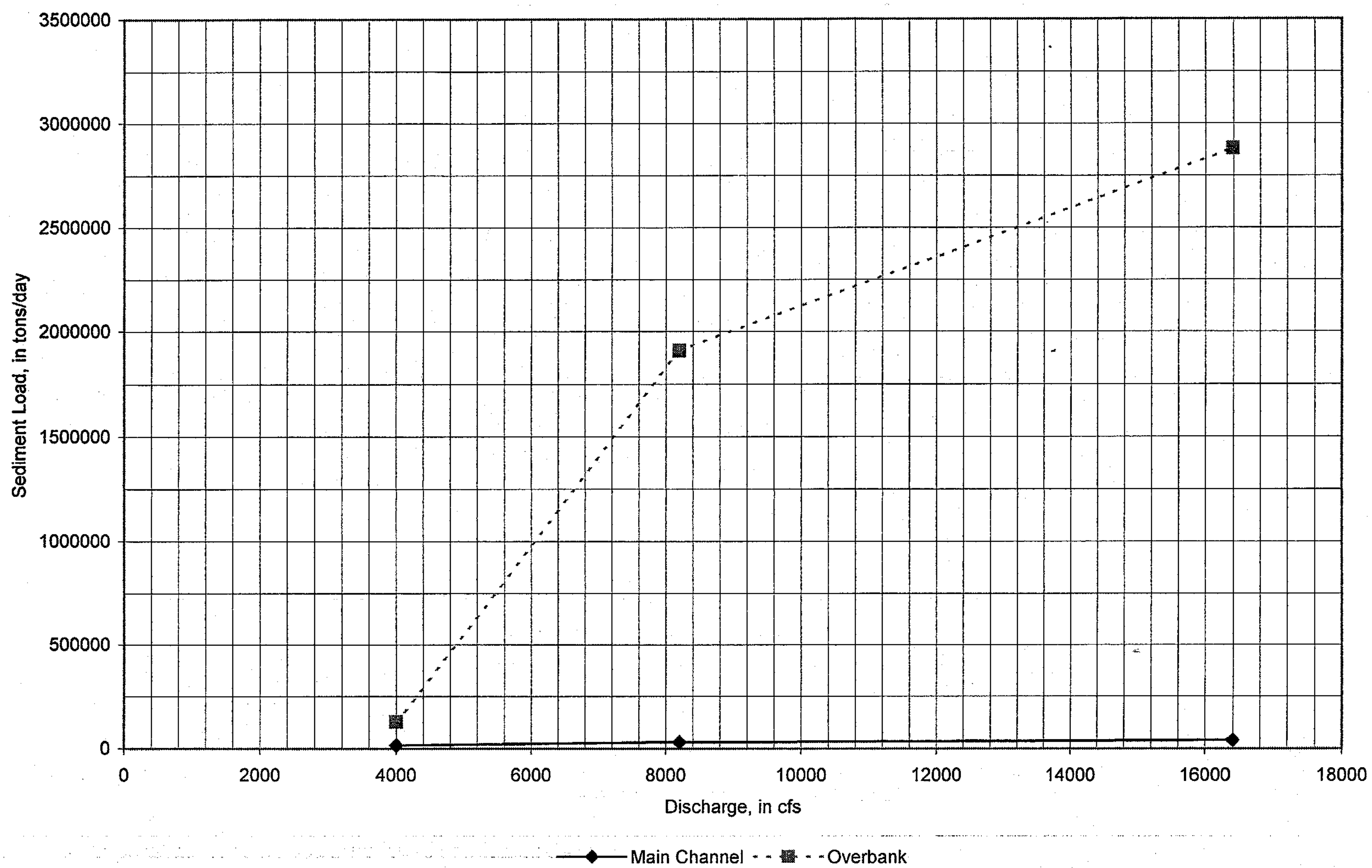


Figure 5-4.6
Inflowing sediment load concentration rating curves
Cline Creek

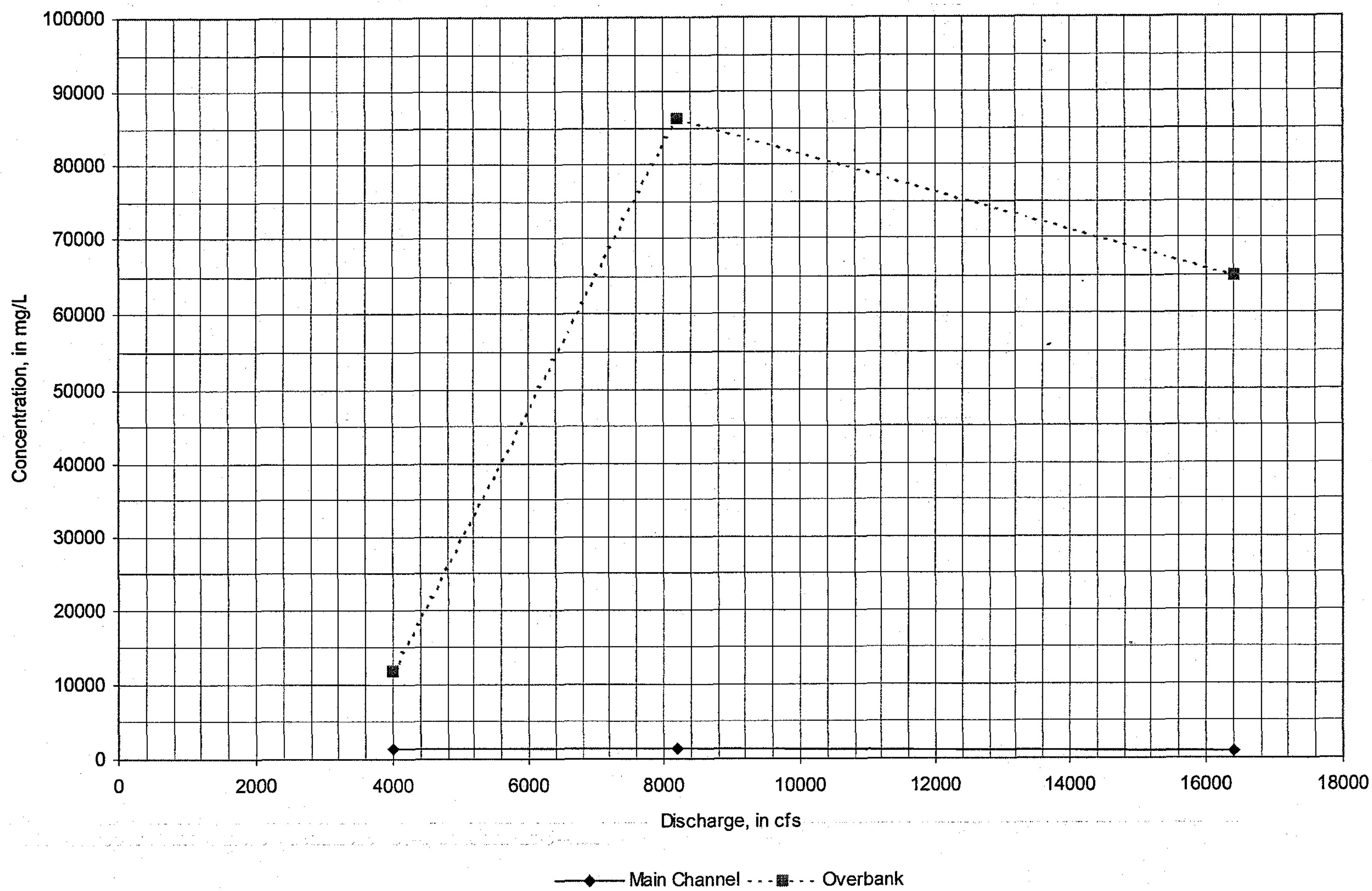


Table 5-4.7

Inflowing sediment load for the upper boundary of the Sonoran Wash Main Channel Models

Discharge cfs (1)	Sediment Load Tons/day (2)	Sediment Load by Size Fraction, percent									
		Very Fine Sand (3)	Fine Sand (4)	Medium Sand (5)	Coarse Sand (6)	Very Coarse Sand (7)	Very Fine Gravel (8)	Fine Gravel (9)	Medium Gravel (10)	Coarse Gravel (11)	Very Coarse Gravel (12)
2700	8384	9.7	9.2	5.5	2.2	6.0	9.1	13.2	20.4	17.3	7.4
5400	13507	11.0	10.1	4.9	2.0	5.4	8.2	12.0	18.9	16.9	8.8
7500	16878	10.0	9.2	4.7	1.9	5.2	7.9	11.6	18.7	17.4	9.7

Table 5-4.8

Inflowing sediment load for the upper boundary of the Sonoran Wash Overbank Models

Discharge cfs (1)	Sediment Load Tons/day (2)	Sediment Load by Size Fraction, percent				
		Very Fine Sand (3)	Fine Sand (4)	Medium Sand (5)	Coarse Sand (6)	Very Coarse Sand (7)
2600	55006	59.4	14.5	07.4	11.4	6.5
5400	69035	47.3	11.5	5.9	21.5	11.7
7500	79238	41.2	10.1	5.1	26.2	14.4

* Values greater than very coarse sand are not significant.

Figure 5-4.7
Inflowing sediment load rating curves
Sonoran Wash

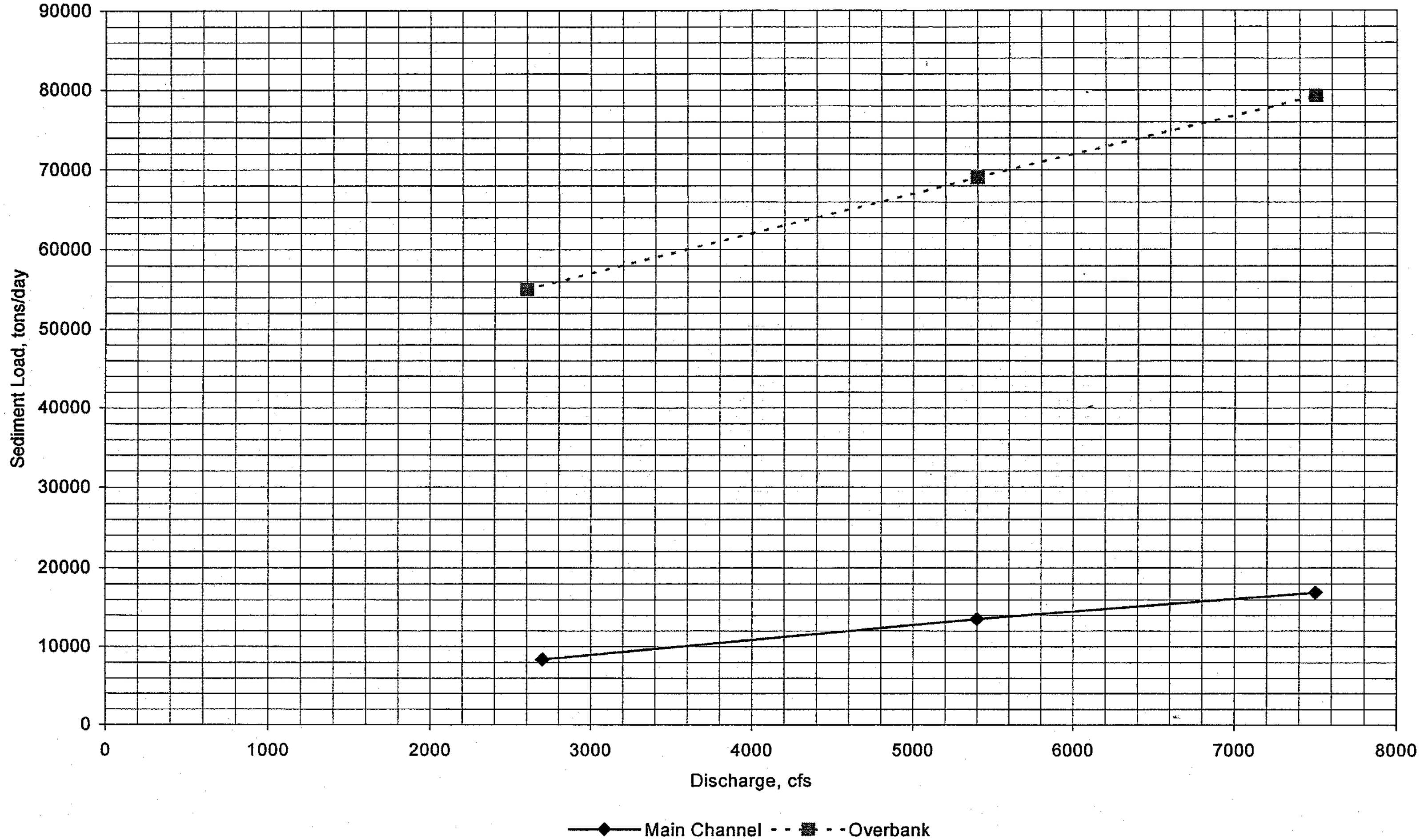
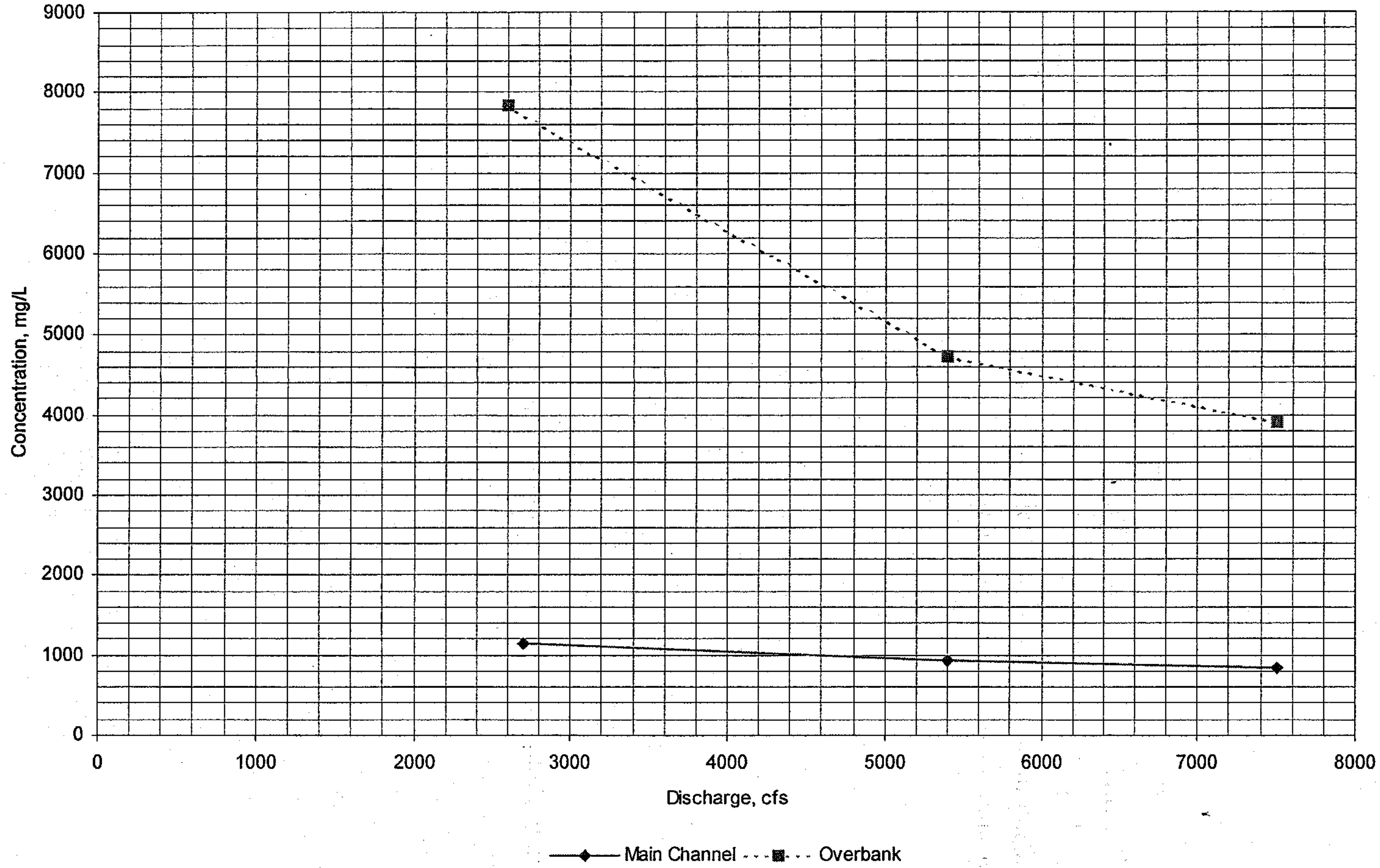


Figure 5-4.8
Inflowing sediment load concentration rating curves
Sonoran Wash



5-4.3 HYDRAULIC DATA AND OTHER MODEL INPUT

5-4.3.1 General

The hydraulic and geometric data describes the physical geometry of the watercourse and flow resistance factors. That data is essentially the same information that is required for a water surface profile analysis such as is performed using HEC-2 or HEC-RAS. The existing HEC-2 models of the Skunk Creek watercourses that were previously developed by others for the purpose of floodplain delineation studies are used as the source of the hydraulic and geometric data. A HEC-RAS model was developed for Sonoran Wash as part of the watercourse master plan for the purpose of floodplain delineation and sediment studies. Certain modifications to those models are made to achieve the purpose of the HEC-6 models. This section includes a verification of the hydraulic performance of the HEC-6 as compared to the corresponding HEC-2 or HEC-RAS models for each watercourse.

5-4.3.2 Skunk Creek

5-4.3.2.1 Base HEC-2 Models

The base hydraulic and geometric data utilized in the sediment transport analysis for the study reaches of Skunk Creek are taken from three existing studies. Those studies are described in Section 5-2.1.

Water surface profile models were developed for each of the floodplain delineation studies (FDS) using the U.S. Army Corps of Engineers HEC-2 computer program, Version 4.6.0, May 1991. The study limits of the Skunk Creek Floodplain Delineation Study HEC-2 model, herein referred to as the Montgomery model, were from the CAP overchute (RM 13.00) to north of Jenny Lin Road (RM 26.17) (Figure 5-1.1). That study was performed for submittal to FEMA.

The study limits of the Skunk Creek Floodplain Redelineation and Hydraulic Analysis, herein referred to as the Erie model, were from just south of Desert Hills Drive (RM 20.64) to Honda Bow Road (RM 22.95). The model was completed prior to the Montgomery model for the Anthem (Villages) development. The model was later incorporated into the Montgomery model by the FCDMC. The FCDMC modified the Erie model by first increasing the cross-section identifiers by a factor ranging from 0.25 to 0.14 miles. For example, Erie model RM 20.39 becomes RM 20.64 in the revised

Montgomery model. The second modification included adding one cross-section, RM 21.58, to the Erie model. Third modification is the addition of two traffic lanes to Carefree Highway.

The study limits of the Communities of City of Peoria and Maricopa County, Arizona Skunk Creek Floodplain and Floodway Conditional Letter of Map Revision Request, herein referred to as the Hoskin model, were from CAP overchute (RM 13.00) to Joy Ranch Road (RM 18.96). That model included modifications from the Tramonto development. Those changes included removing the split flow at the Carefree Highway bridge and encroachment to Skunk Creek by the development. The Hoskin model was added to the Montgomery model by Stantec.

The final HEC-2 model was converted to a HEC-RAS format. Although the HEC-2 models used for the conversion included the most current bridge data, the data required for analysis using HEC-RAS is more extensive. The bridge data included in the HEC-2 model is therefore supplemented using as-built plans from Maricopa County Department of Transportation (MCDOT).

5-4.3.2.2 Verification of the Converted HEC-2 Model

In order to verify that the updated HEC-RAS models are performing similarly to the original FDS models, the water surface elevations at each cross-section are compared. The water surface elevation comparison for Skunk Creek is included in Table 5-4.9 and shown on Figure 5-4.9. In general, the water surface elevation differential (difference between the original model and the HEC-RAS model) for Skunk Creek is less than 0.05 feet with a maximum difference of 3.81 feet at RM 25.83, which is just upstream of the downstream study limits. The HEC-RAS model did not include the two most downstream flowsplits, flow spliting to the I-17 Highway and flow spliting to Sonoran Wash. These flow splits were modeled using a two-dimension model of ponding at the CAP overchute. The difference occurring near RM 13.04 (New River bridge) and RM 16.86 (Carefree Highway bridge) are caused by the different techniques HEC-2 and HEC-RAS use to model bridges. See Attachment 4 Hydraulics for a detailed discussion of these differences. Therefore, the hydraulic performance of the Skunk Creek HEC-RAS model is considered verified.

Table 5-4.9
Comparison of HEC-RAS and HEC-2 model results for Skunk Creek
(100-year, existing conditions)

River Mile	Water Surface Elevation, feet			River Mile	Water Surface Elevation, feet		
	HEC-2	HEC-RAS	Difference		HEC-2	HEC-RAS	Difference
(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
13.00	1523.44	1525.68	-2.24	20.62	1848.79	1849.01	-0.22
13.02	1524.91	1526.19	-1.28	20.64	1850.90	1850.99	-0.09
13.04	1526.65	1530.46	-3.81	20.71	1852.87	1853.02	-0.15
13.08	1527.60	1531.00	-3.40	20.79	1857.17	1857.25	-0.08
13.16	1528.55	1531.36	-2.81	20.90	1862.43	1862.63	-0.20
13.28	1532.61	1533.11	-0.50	20.98	1866.18	1866.22	-0.04
13.40	1538.03	1538.42	-0.39	21.05	1869.77	1869.82	-0.05
13.55	1543.21	1543.00	0.21	21.11	1872.00	1872.14	-0.14
13.66	1547.91	1548.22	-0.31	21.18	1876.07	1876.20	-0.13
13.86	1555.92	1555.93	-0.01	21.25	1880.86	1881.09	-0.23
14.07	1564.65	1564.88	-0.23	21.31	1882.64	1882.67	-0.03
14.30	1574.16	1574.37	-0.21	21.35	1883.36	1883.33	0.03
14.54	1583.69	1583.52	0.17	21.41	1886.75	1887.32	-0.57
14.74	1591.88	1591.75	0.13	21.49	1890.86	1891.12	-0.26
14.89	1596.90	1597.42	-0.52	21.58	1895.50	1895.72	-0.22
15.06	1602.99	1602.84	0.15	21.63	1897.88	1898.05	-0.17
15.12	1605.22	1605.22	0.00	21.69	1902.22	1902.59	-0.37
15.22	1610.20	1610.24	-0.04	21.77	1905.63	1905.71	-0.08
15.41	1617.54	1617.54	0.00	21.82	1908.88	1909.38	-0.50
15.55	1623.07	1622.93	0.14	21.91	1914.04	1914.49	-0.45
15.75	1630.40	1630.67	-0.27	21.99	1917.76	1918.15	-0.39
15.89	1635.37	1635.50	-0.13	22.08	1922.61	1922.92	-0.31
16.07	1644.24	1644.22	0.02	22.15	1925.39	1925.80	-0.41
16.19	1648.89	1649.04	-0.15	22.22	1928.96	1929.69	-0.73
16.27	1652.31	1652.43	-0.12	22.29	1933.00	1933.80	-0.80
16.49	1661.97	1662.08	-0.11	22.36	1936.94	1937.44	-0.50
16.68	1668.62	1668.70	-0.08	22.43	1941.79	1941.80	-0.01
16.86	1679.49	1680.63	-1.14	22.48	1944.10	1944.20	-0.10
16.87	1680.56	1682.13	-1.57	22.56	1948.18	1948.68	-0.50
16.96	1684.87	1682.50	2.37	22.67	1954.37	1954.48	-0.11
17.06	1689.88	1689.62	0.26	22.73	1957.89	1958.10	-0.21
17.18	1695.25	1694.96	0.29	22.79	1960.94	1961.00	-0.06
17.30	1701.37	1700.97	0.40	22.86	1964.52	1964.75	-0.23
17.39	1705.16	1705.06	0.10	22.95	1972.66	1972.62	0.04
17.48	1709.75	1708.95	0.80	22.96	1974.46	1974.78	-0.32
17.57	1713.84	1713.89	-0.05	23.13	1981.33	1981.62	-0.29
17.65	1717.52	1717.51	0.01	23.25	1987.17	1987.22	-0.05
17.78	1722.50	1722.03	0.47	23.33	1991.35	1991.71	-0.36
17.84	1724.75	1724.99	-0.24	23.45	1998.50	1998.55	-0.05
17.95	1730.47	1729.89	0.58	23.55	2003.92	2004.23	-0.31
18.09	1734.96	1735.14	-0.18	23.64	2008.98	2008.77	0.21
18.16	1736.55	1736.85	-0.30	23.87	2018.87	2019.03	-0.16
18.23	1741.75	1741.76	-0.01	23.94	2020.86	2020.91	-0.05
18.29	1743.06	1742.82	0.24	24.03	2025.13	2025.44	-0.31
18.49	1750.88	1751.73	-0.85	24.12	2028.90	2028.97	-0.07
18.57	1754.08	1754.40	-0.32	24.25	2033.67	2034.12	-0.45
18.74	1760.57	1760.65	-0.08	24.38	2038.55	2038.59	-0.04
18.84	1764.69	1765.05	-0.36	24.48	2043.74	2043.92	-0.18
18.96	1771.34	1771.75	-0.41	24.61	2050.04	2050.39	-0.35
19.07	1775.13	1775.25	-0.12	24.74	2055.85	2055.59	0.26
19.18	1780.34	1780.40	-0.06	24.87	2061.94	2062.03	-0.09
19.26	1784.76	1785.06	-0.30	24.95	2064.96	2065.02	-0.06
19.41	1790.80	1790.84	-0.04	25.12	2072.77	2072.78	-0.01

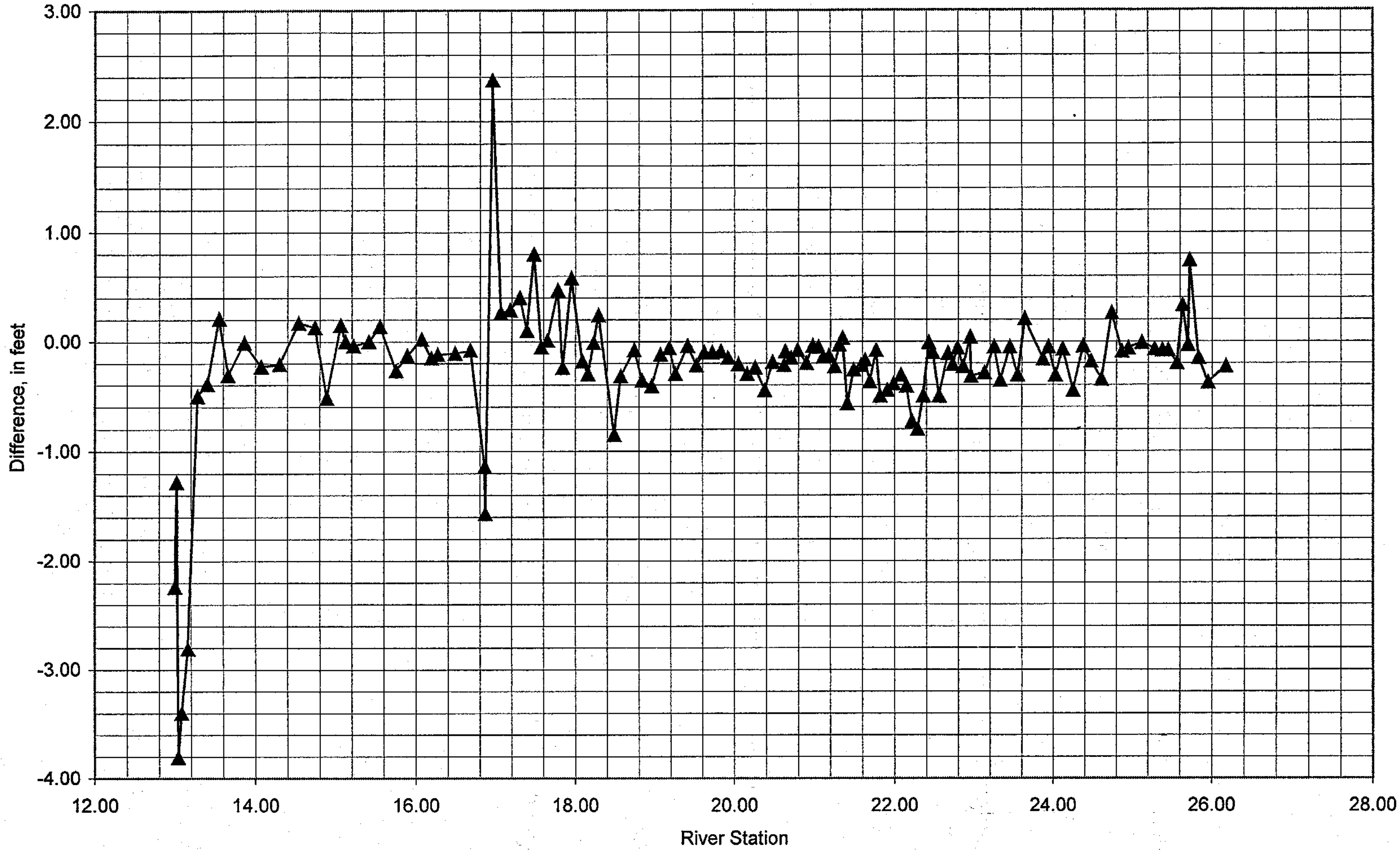
Table 5-4.9 continued

Comparison of HEC-RAS and HEC-2 model results for Skunk Creek

(100-year, existing conditions)

River Mile (1)	Water Surface Elevation, feet HEC-2 (2)	HEC-RAS (3)	Difference (4)	River Mile (1)	Water Surface Elevation, feet HEC-2 (2)	HEC-RAS (3)	Difference (4)
19.52	1794.85	1795.07	-0.22	25.28	2081.36	2081.43	-0.07
19.62	1800.83	1800.93	-0.10	25.38	2084.98	2085.06	-0.08
19.72	1805.02	1805.12	-0.10	25.45	2088.35	2088.43	-0.08
19.83	1810.83	1810.92	-0.09	25.56	2095.84	2096.04	-0.20
19.92	1814.80	1814.95	-0.15	25.63	2099.06	2098.73	0.33
20.05	1820.70	1820.91	-0.21	25.70	2102.31	2102.34	-0.03
20.16	1824.75	1825.05	-0.30	25.72	2104.11	2103.37	0.74
20.26	1831.31	1831.55	-0.24	25.83	2112.46	2112.61	-0.15
20.38	1835.69	1836.14	-0.45	25.95	2119.31	2119.69	-0.38
20.48	1841.48	1841.67	-0.19	26.17	2132.48	2132.71	-0.23
						minimum	-3.81
						maximum	2.37
						average	-0.23

Figure 5-4.9
Comparison of HEC-2 and HEC-RAS water surface elevations
Skunk Creek, existing conditions, 100-year flood event



5-4.3.2.3 Alternative Analysis HEC-RAS Model

The HEC-RAS model is further modified for alternative analysis modeling. For alternative analysis, the model is modified such that the hydraulic parameters are representative of 100- and 10-year hydrologic events and for both existing and future conditions, respectively. The following is a list of the hydraulic and geometric properties that are modified:

- Cross-sections near the New River bridge (RM 25.70 and RM 25.72) are realigned. Cross-sections are skewed.
- Channel bank stations are adjusted based on concepts of bank full discharge.
- Horizontal variations in Manning's n-value are added to include roughness differences between braided channels and overbank areas.
- Levees and ineffective flow areas are modified where it is necessary because of the cross-section changes.
- The geometry data were modified to include the Tramonto development fill. The original HEC-2 model included the encroachment by using the ET cards.
- The peak discharge in the Tramonto development was modified to include the split flow at the Carefree Highway bridge.
- The contraction and expansion coefficients in the Anthem development are changed from 0.3 and 0.5, respectively, to 0.1 and 0.3, respectively.

Appendix 5-C, Tables 5-C.1 through 5-C.3, compare Manning's n-values, bank stations and other hydraulic parameters to the original HEC-2 model.

5-4.3.2.4 Sediment Model

Prior to conversion to HEC-6, the alternative analysis model was modified because HEC-6 does not have the full range of hydraulic computational options as HEC-RAS. For instance HEC-6 is sensitive to braided channels or tributaries that have a lower invert elevation than the main channel. Those cross-sections are either realigned and/or ineffective flow areas are added. Also, HEC-6 does not model horizontal variation in

Manning's n-value or bridges. The following lists the changes to the alternative analysis HEC-RAS model:

- A cross-section (RM 25.73) was added to include the effects of the New River bridge.
- Several cross-sections were realigned. A complete list geometry changes to the cross-sections is included in Table 5-4.10. That table also includes changes that are made for the alternative analysis model. The realigned cross-sections are shown in Appendix 5-D.
- Bank stations are widened to include multiple braids. This allows HEC-6 to agrade and degrade sediment in multiple braids during a flow event.
- Levees and ineffective flow areas are added where it is necessary to restrict flows, particularly the low flows in the main channel.
- The bridges are removed. The HEC-6 model can not model bridges.

Table 5-4.10

Final list of modifications to cross-sections for Skunk Creek

Original Cross-section ID (1)	Modified Cross-section ID (2)	Comment (3)
13.86	13.86	Add vertical wall on LHS
15.06	15.06	Delete 544' on LHS in HEC-RAS to match x-sec in ACAD
15.12	15.12	Delete 422' on LHS in HEC-RAS to match x-sec in ACAD
15.22	15.22	Delete 402' on LHS in HEC-RAS to match x-sec in ACAD
15.41	15.41	Delete 398' on LHS in HEC-RAS to match x-sec in ACAD
15.55	15.55	Delete 310' on LHS in HEC-RAS to match x-sec in ACAD
16.86	16.86	Delete geometry beyond bank stations
16.87	16.87	Delete geometry beyond bank stations
17.18	17.18	Add changes from Tramonto development, added vertical wall
17.30	17.30	Add changes from Tramonto development
17.39	17.39	Add changes from Tramonto development
17.48	17.48	Add changes from Tramonto development
17.57	17.57	Add changes from Tramonto development
17.65	17.65	Add changes from Tramonto development
17.78	17.78	Add changes from Tramonto development
17.84	17.84	Add changes from Tramonto development, fix geometry in HEC-RAS to match topo
17.95	17.95	Fixed geometry in HEC-RAS to match topo
18.09	18.09	Realign
18.23		Delete
18.84	18.84	Extend line in ACAD to match HEC-RAS
20.64	20.64	Add to ACAD drawing
20.71	20.71	Add to ACAD drawing
20.79	20.79	Extend line in ACAD to match HEC-RAS
20.90	20.90	Delete 350' on LHS
20.98	20.98	Delete 465' on LHS
21.05	21.05	Delete 435' on LHS
21.11	21.11	Delete 615' on LHS
21.18	21.18	Delete 360' on LHS
21.25	21.25	Realign cross-section
21.31	21.31	Delete 190' on RHS
21.58	21.58	Add to ACAD drawing
21.69	21.69	Fixed geometry in HEC-RAS to match topo
22.36	22.36	Delete ACAD by 120' on LHS to match HEC-RAS, Delete HEC-RAS by 560' on RHS
22.43	22.43	Delete ACAD by 48' on LHS to match HEC-RAS, Delete HEC-RAS by 655' on RHS
22.48	22.48	Delete ACAD by 20' on LHS to match HEC-RAS, Delete HEC-RAS by 230' on RHS
22.95		Delete cross-section
23.13	23.13	Lengthen cross-section using topo
23.55	23.55	Delete 425' on LHS
23.64	23.60	Realign cross-section
	23.80	Add cross-section
24.38	24.35	Realign cross-section
25.12	25.08	Realign cross-section
25.38		Delete cross-section
25.70	25.69	Realign cross-section
	25.73	Add cross-section
25.72	25.78	Realign cross-section

The HEC-RAS sediment model that was developed for hydraulic analyses and evaluation of alternatives was converted to HEC-6. Since HEC-6 can not model horizontal variation in Manning's n-value, a composite n-value for the left overbank, right overbank and channel is calculated using the following equation (Chow, 1959):

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

where n_1, n_2, n_3 – Manning's n-values

P_1, P_2, P_3 – wetted perimeter

P – total wetted perimeter

Hydraulic results of the HEC-RAS model are compared to the HEC-6 model to verify that there are no significant deviations in the hydraulic results from the models. Table 5-4.11 is a comparison of the calculated water surface elevations. The comparison is shown on Figure 5-4.10. In general, the water surface elevation differential (difference between the HEC-RAS model and the HEC-6 model) is less than 0.5 feet. The maximum difference of 2.15 feet occurs upstream of New River bridge. This difference is due to New River bridge. HEC-6 does not have the capability to model bridges. These results are reasonable. Manning's n-values, bank stations and hydraulic parameters are provided in Appendix 5-C, Tables 5-C.4 through 5-C.6.

Table 5-4.11
Comparison of the water surface elevation from the HEC-RAS model and the HEC-6 model for Skunk Creek

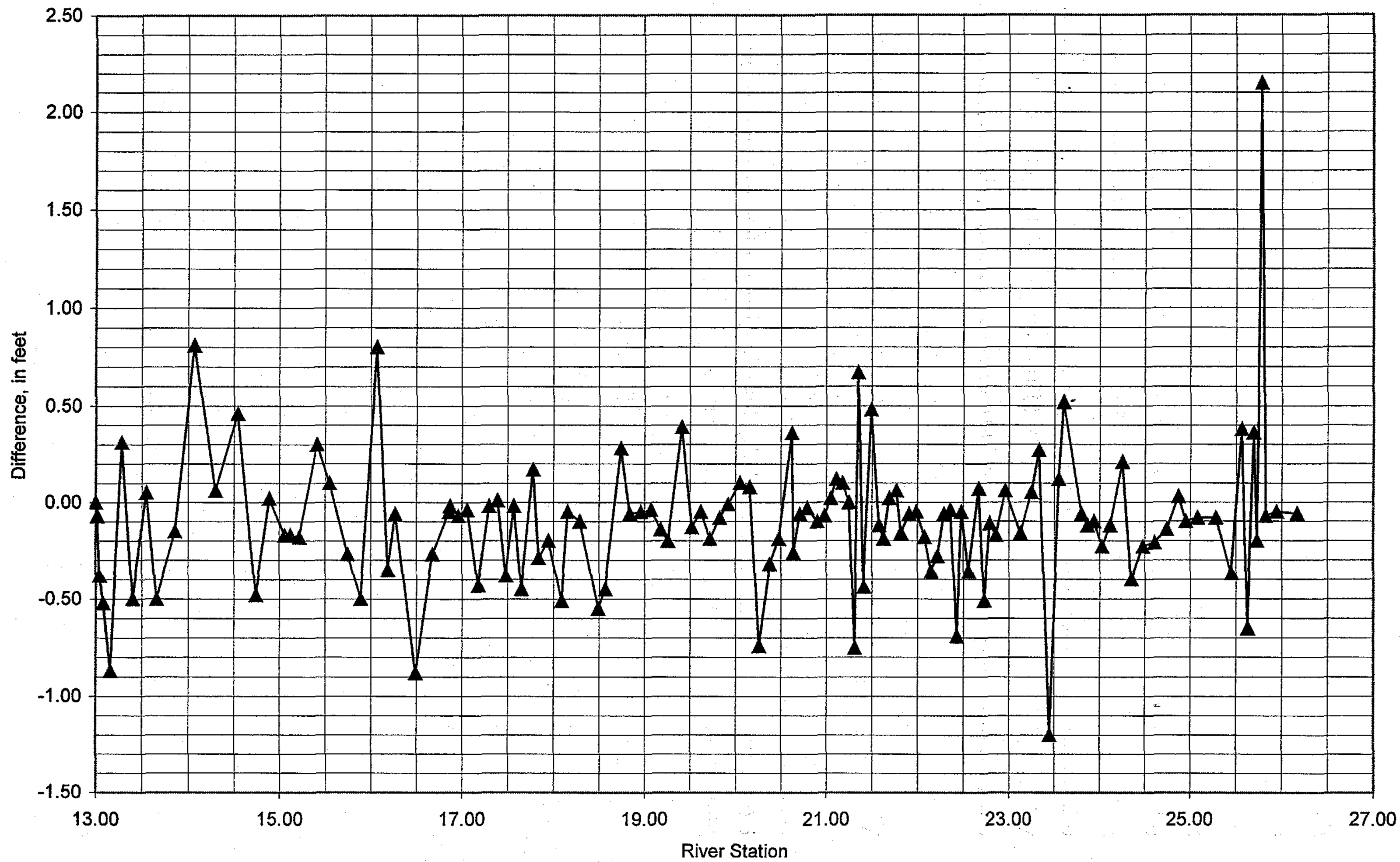
Cross-section (1)	Water Surface Elevation, feet HEC-RAS (2)	HEC-6 (3)	Difference (4)	Cross-section (1)	Water Surface Elevation, feet HEC-RAS (2)	HEC-6 (3)	Difference (4)
13.00	1523.74	1523.74	0.00	20.64	1849.51	1849.77	-0.26
13.02	1524.24	1524.31	-0.07	20.71	1852.90	1852.96	-0.06
13.04	1527.33	1527.71	-0.38	20.79	1856.91	1856.94	-0.03
13.08	1527.76	1528.28	-0.52	20.90	1862.33	1862.43	-0.10
13.16	1528.03	1528.90	-0.87	20.98	1866.34	1866.41	-0.07
13.28	1533.27	1532.96	0.31	21.05	1869.74	1869.72	0.02
13.40	1537.62	1538.12	-0.50	21.11	1872.13	1872.01	0.12
13.55	1543.51	1543.46	0.05	21.18	1876.07	1875.97	0.10
13.66	1547.84	1548.34	-0.50	21.25	1880.14	1880.14	0.00
13.86	1555.99	1556.14	-0.15	21.31	1881.73	1882.48	-0.75
14.07	1565.47	1564.66	0.81	21.35	1884.59	1883.92	0.67
14.30	1574.68	1574.62	0.06	21.41	1887.48	1887.92	-0.44
14.54	1582.88	1582.42	0.46	21.49	1891.28	1890.80	0.48
14.74	1591.63	1592.11	-0.48	21.58	1895.74	1895.86	-0.12
14.89	1596.39	1596.37	0.02	21.63	1898.28	1898.47	-0.19
15.06	1603.22	1603.39	-0.17	21.69	1902.44	1902.42	0.02
15.12	1605.31	1605.48	-0.17	21.77	1905.94	1905.88	0.06
15.22	1610.24	1610.42	-0.18	21.82	1908.96	1909.12	-0.16
15.41	1618.57	1618.27	0.30	21.91	1914.02	1914.08	-0.06
15.55	1623.14	1623.04	0.10	21.99	1918.01	1918.06	-0.05
15.75	1630.21	1630.48	-0.27	22.08	1922.30	1922.48	-0.18
15.89	1635.29	1635.79	-0.50	22.15	1925.29	1925.65	-0.36
16.07	1644.34	1643.54	0.80	22.22	1930.01	1930.29	-0.28
16.19	1648.91	1649.26	-0.35	22.29	1934.01	1934.07	-0.06
16.27	1652.90	1652.96	-0.06	22.36	1938.01	1938.05	-0.04
16.49	1661.93	1662.81	-0.88	22.43	1940.97	1941.66	-0.69
16.68	1669.28	1669.55	-0.27	22.48	1944.01	1944.06	-0.05
16.86	1679.78	1679.83	-0.05	22.56	1947.38	1947.74	-0.36
16.87	1682.79	1682.81	-0.02	22.67	1954.62	1954.55	0.07
16.96	1684.94	1685.01	-0.07	22.73	1958.12	1958.63	-0.51
17.06	1692.27	1692.31	-0.04	22.79	1961.25	1961.36	-0.11
17.18	1698.70	1699.13	-0.43	22.86	1964.49	1964.66	-0.17
17.30	1700.89	1700.91	-0.02	22.96	1973.80	1973.74	0.06
17.39	1705.40	1705.39	0.01	23.13	1981.19	1981.35	-0.16
17.48	1709.34	1709.72	-0.38	23.25	1987.42	1987.37	0.05
17.57	1714.02	1714.04	-0.02	23.33	1991.31	1991.04	0.27
17.65	1716.86	1717.31	-0.45	23.45	1998.57	1999.77	-1.20
17.78	1722.34	1722.17	0.17	23.55	2004.36	2004.24	0.12
17.84	1724.34	1724.63	-0.29	23.60	2006.91	2006.39	0.52

Table 5-4.11 continued

Comparison of the water surface elevation from the HEC-RAS model and the HEC-6 model for Skunk Creek

Cross-section (1)	Water Surface Elevation, feet HEC-RAS (2)	HEC-6 (3)	Difference (4)	Cross-section (1)	Water Surface Elevation, feet HEC-RAS (2)	HEC-6 (3)	Difference (4)
17.95	1730.05	1730.25	-0.20	23.80	2014.76	2014.82	-0.06
18.09	1734.95	1735.46	-0.51	23.87	2020.91	2021.03	-0.12
18.16	1739.01	1739.06	-0.05	23.94	2021.83	2021.93	-0.10
18.29	1742.15	1742.25	-0.10	24.03	2024.94	2025.17	-0.23
18.49	1751.70	1752.25	-0.55	24.12	2029.13	2029.25	-0.12
18.57	1754.26	1754.71	-0.45	24.25	2034.84	2034.63	0.21
18.74	1762.49	1762.21	0.28	24.35	2037.38	2037.78	-0.40
18.84	1765.95	1766.01	-0.06	24.48	2043.69	2043.92	-0.23
18.96	1771.30	1771.35	-0.05	24.61	2049.78	2049.99	-0.21
19.07	1776.49	1776.53	-0.04	24.74	2056.09	2056.23	-0.14
19.18	1780.71	1780.85	-0.14	24.87	2061.97	2061.94	0.03
19.26	1786.29	1786.49	-0.20	24.95	2065.19	2065.29	-0.10
19.41	1792.21	1791.82	0.39	25.08	2069.63	2069.71	-0.08
19.52	1796.72	1796.85	-0.13	25.28	2081.08	2081.16	-0.08
19.62	1801.52	1801.57	-0.05	25.45	2088.51	2088.88	-0.37
19.72	1807.37	1807.56	-0.19	25.56	2095.60	2095.22	0.38
19.83	1811.25	1811.33	-0.08	25.63	2098.61	2099.26	-0.65
19.92	1815.12	1815.13	-0.01	25.69	2101.43	2101.07	0.36
20.05	1819.96	1819.86	0.10	25.73	2103.86	2104.06	-0.20
20.16	1824.71	1824.63	0.08	25.78	2106.77	2104.62	2.15
20.26	1830.58	1831.32	-0.74	25.83	2111.81	2111.88	-0.07
20.38	1835.92	1836.24	-0.32	25.95	2117.71	2117.76	-0.05
20.48	1841.04	1841.23	-0.19	26.17	2132.43	2132.49	-0.06
20.62	1848.51	1848.15	0.36			Maximum	2.15
						Minimum	-1.20
						Average	-0.10

Figure 5-4.10
Comparison of HEC-RAS and HEC-6 Water Surface Elevations
Skunk Creek, 100-year Flood, Existing Condition



5-4.3.3 Sonoran Wash

The base hydraulic and geometric data utilized in the HEC-6 models for Sonoran Wash are taken from the hydraulic study described in Attachment 4. Water surface profiles are developed using the HEC-RAS computer program. For sediment modeling the Manning's n-values are changed from the HEC-RAS model because HEC-6 can not model horizontal variation in roughness. A composite of the Manning's n-value for the left overbank, right overbank and channel is calculated using the equation presented in Section 5-4.3.2.4. Also, many of the cross sections in the HEC-RAS model contain more than 100 geometry data points. HEC-6 (like HEC-2) only accepts up to 100 geometry points. The HEC-RAS geometry was reduced to 100 points by removing points in the overbank area.

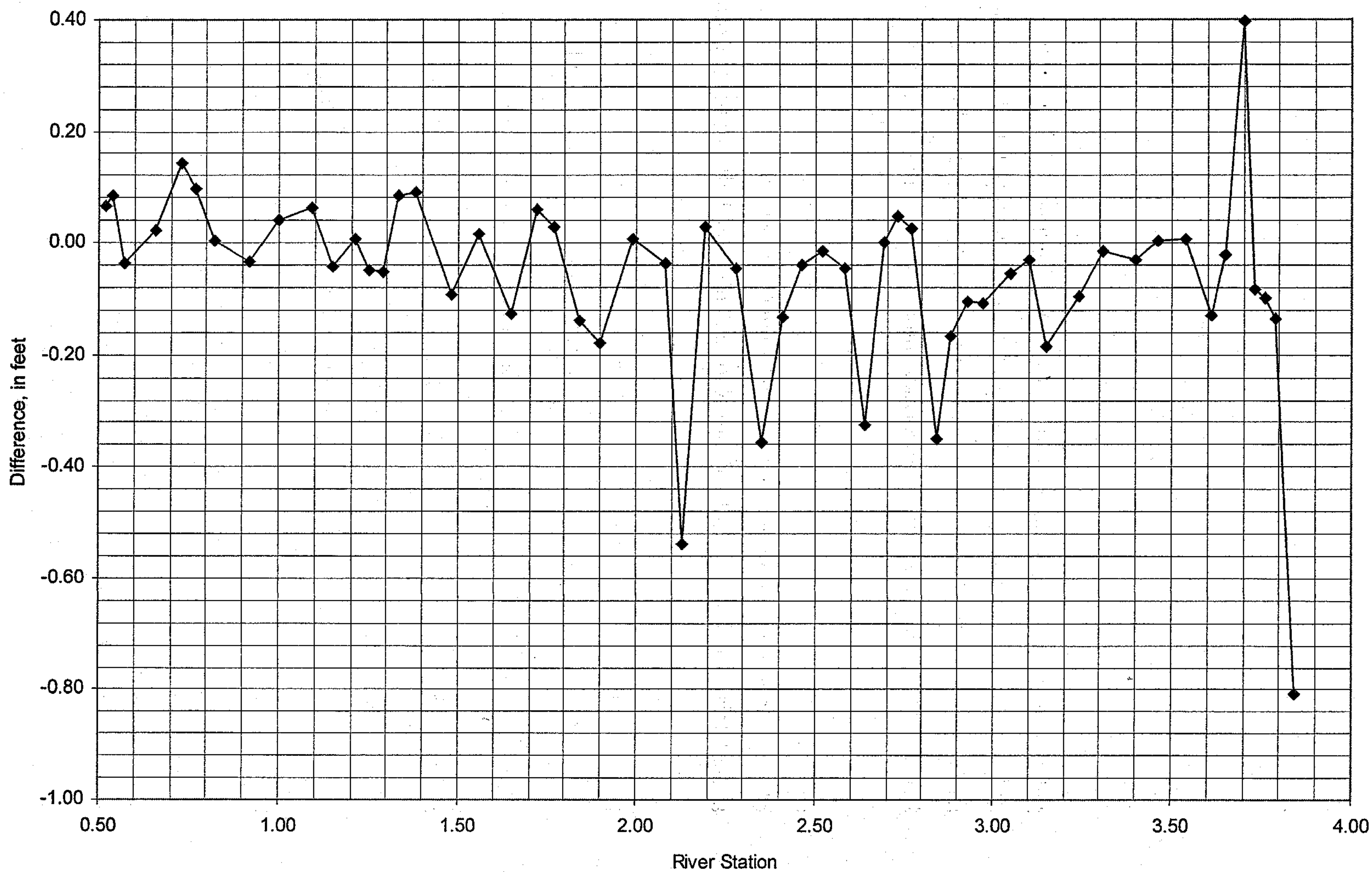
The results of the HEC-6 sediment model are compared to the HEC-RAS model to verify that there are no significant changes in the hydraulic conditions. Table 5-4.12 is a comparison of the water surface elevations. The comparison is shown in Figure 5-4.11. In general, the water surface elevation differential (difference between the HEC-RAS model and the HEC-6 model) is less than 0.5 feet. The maximum difference of –0.81 feet occurs at RM 3.84, the most upstream cross section. This difference is due to the modeling differences between HEC-RAS and HEC-2. These results are reasonable.

Table 5-4.12

Comparison of the water surface elevation from the HEC-RAS model and the HEC-6 model for Sonoran Wash

Cross-section	Water Surface Elevation, feet			Cross-section	Water Surface Elevation, feet		
	HEC-RAS	HEC-6	Difference		HEC-RAS	HEC-6	Difference
(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
0.52	1523.44	1523.38	0.06	2.41	1576.79	1576.92	-0.13
0.54	1525.77	1525.69	0.08	2.46	1577.86	1577.90	-0.04
0.57	1525.79	1525.83	-0.04	2.52	1580.60	1580.62	-0.02
0.66	1526.92	1526.90	0.02	2.58	1581.62	1581.67	-0.05
0.73	1527.66	1527.52	0.14	2.64	1583.96	1584.29	-0.33
0.77	1527.95	1527.85	0.10	2.69	1585.41	1585.41	0.00
0.82	1528.39	1528.39	0.01	2.73	1586.21	1586.16	0.05
0.92	1531.05	1531.08	-0.03	2.77	1587.84	1587.81	0.03
1.00	1532.98	1532.94	0.04	2.84	1590.71	1591.06	-0.35
1.09	1535.80	1535.74	0.06	2.88	1592.60	1592.77	-0.17
1.15	1537.85	1537.89	-0.04	2.93	1595.64	1595.75	-0.10
1.21	1539.63	1539.62	0.01	2.97	1597.31	1597.42	-0.11
1.25	1540.89	1540.94	-0.05	3.05	1600.89	1600.94	-0.05
1.29	1541.54	1541.59	-0.05	3.10	1602.13	1602.16	-0.03
1.33	1542.83	1542.75	0.08	3.15	1604.11	1604.30	-0.19
1.38	1543.95	1543.86	0.09	3.24	1607.24	1607.34	-0.10
1.48	1547.03	1547.12	-0.09	3.31	1610.21	1610.23	-0.02
1.56	1550.07	1550.05	0.02	3.40	1612.72	1612.75	-0.03
1.65	1552.86	1552.99	-0.13	3.46	1614.45	1614.45	0.00
1.72	1555.07	1555.01	0.06	3.54	1617.90	1617.89	0.01
1.77	1556.41	1556.38	0.03	3.61	1620.18	1620.31	-0.13
1.84	1558.38	1558.52	-0.14	3.65	1622.25	1622.27	-0.02
1.90	1560.18	1560.36	-0.18	3.70	1623.29	1622.89	0.40
1.99	1563.32	1563.31	0.01	3.73	1623.89	1623.97	-0.08
2.08	1565.55	1565.59	-0.04	3.76	1624.82	1624.92	-0.10
2.13	1567.37	1567.91	-0.54	3.79	1626.09	1626.23	-0.14
2.19	1570.01	1569.98	0.03	3.84	1628.24	1629.05	-0.81
2.28	1572.05	1572.10	-0.05			Minimum	-0.81
2.35	1574.86	1575.22	-0.36			Maximum	0.40
						Average	-0.06

Figure 5-4.11
Comparison of HEC-RAS and HEC-6 Water Surface Elevations
Sonoran Wash, 100-year Flood, Existing Condition



5-4.3.4 Boundary Conditions

In HEC-6, the water surface elevation is specified at the downstream limit at each hydrograph time step using a rating curve. The rating curve is developed for each watercourse assuming critical depth at the CAP Canal. The rating curves are used as a boundary condition for each hydrologic condition.

5-4.3.5 Other Input Data

The following input data are the same for all models.

- The depth of sediment reservoir for most cross-section stations is set to 10 feet. That limits scour or streambed degradation to 10 feet, or less. Model results are checked to verify that the 10-foot limit was not reached for any of the models. For cross-sections that contain bedrock, the depth of sediment reservoir is set to zero. Locations that contain bedrock were identified during site visits.

- The fraction of bed material that is exposed to erosion is set to 100 percent for those sections that do not contain bedrock. This indicates that the entire bed is allowed to erode. For cross-sections that contain bedrock the fraction of bed material that is exposed is set to 0.001.

- The limits of transported sediment are in the range of very fine sand (0.0625 to 0.125 mm) to large cobbles (128 to 256 mm), (U.S. Army Corps of Engineers, 1993).

- The specific gravity of bed material is set to the HEC-6 default of 2.65.

- The grain shape factor is set to the HEC-6 default of 0.667. A shape factor of a perfect sphere is 1.0 while a very irregular shape has a factor as low as 0.1.

- The coefficient in surface area exposed is set to the HEC-6 default of 0.5.

- The unit weight of deposited sediment is set to the HEC-6 default of 93 pounds per cubic feet.

- The water temperature is set to 68° Fahrenheit.

5-4.4 LIMITATIONS AND ASSUMPTIONS

The following is a summary of limitations and assumptions made in this section.

- Base hydraulic parameters are taken from previous studies for specific purposes (100-year floodplain/floodway mapping) using a one-dimensional, fix-bed model.
- HEC-6 does not model horizontal variations in Manning's *n* value. A composite n-value for the left and right overbanks and channel are calculated where necessary.
- HEC-6 can not model bridges or culverts. Those structures were replaced with equivalent hydraulic sections in the HEC-6 models.
- HEC-6 agrades and degrades sediment only located between bank stations. Bank stations are adjusted to account for multiple channels, where appropriate.
- HEC-6 allows only one set of bed material data for a cross section. There is a wide variability in the bed material between the main channels and overbank floodplains. Two types of models, Main Channel and Overbank Models, are used to model the two types of material.
- The coarser bed materials in the channel are modeled using the Meyer-Peter, Muller transport function. The finer bed materials in the overbank floodplain are modeled using the Yang Stream Power transport function.
- Neither an established sediment load rating curve nor recorded sediment load data are available for the watercourses. Inflowing sediment data are synthesized based on transport capacity of hydraulic section and bed material size distribution.
- Inflowing sediment for minor tributaries of Skunk Creek and Sonoran Wash are assumed to be zero because the discharges from the tributaries are relatively small. Inflowing sediment is defined for the upper boundaries of each wash and a tributary of Skunk Creek (Cline Creek).
- Bed material size gradation is based on field data collection.
- Starting water surface elevations that are based on normal depth hydraulics assume a stable reach with neither scour nor fill.

5-5.0 MODELING METHODOLOGY

5-5.1 MODELING APPROACH

5-5.1.1 Model Selection and Application

The HEC-6 program, Scour and Deposition in Rivers and Reservoirs, (U.S. Army Corps of Engineers, 1993), was selected during the scoping phase of the project for erosion and sedimentation modeling. This program is typically used for such applications and has been used for erosion and sedimentation studies in Arizona and Maricopa County. However, it is well recognized by the developer of that program (U.S. Army Corps of Engineers, Hydrologic Engineering Center) and the users of that program, that use of HEC-6 for single-event modeling is limited. Results of HEC-6 modeling must be used with care and HEC-6 output is subject to interpretation. Furthermore, use of HEC-6 for Skunk Creek and Sonoran Wash is complicated by the following:

a. Flow is unsteady with rapidly rising and falling discharge rates.

b. Flow is nonuniform and may be critical or supercritical under certain flow conditions in various reaches of the watercourse.

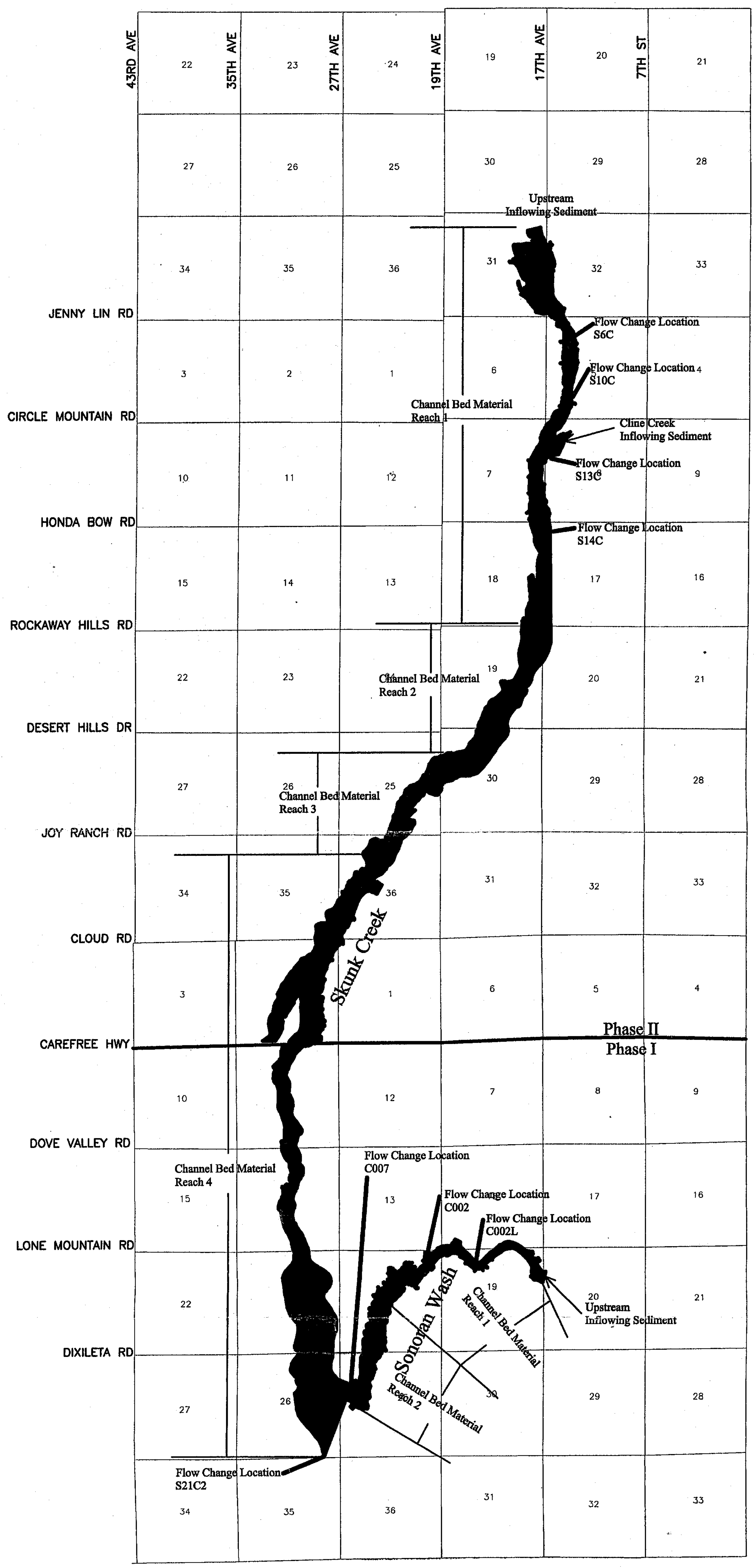
c. The geometry of the watercourse varies spatially leading to frequent changes in flow characteristics (velocity, depth, width, etc.).

d. The hydraulic resistance to flow is highly variable due to nonuniform bed and bank material and vegetation conditions throughout the watercourse.

e. The size gradations of the material comprising the bed, bank and overbank floodplains are highly variable.

f. The watercourses can be subject to large sediment inflows during floods.

Those factors, coupled with the lack of model calibration data for the study watercourses, requires that model input be carefully developed and evaluated by sensitivity analyses, and that several models be developed so that results can be interpreted within the realm of physical possibilities.



Stantec

Figure 5-1.1
Skunk Creek Study Area
Watercourse Master Plan

The use of multiple models and the interpretation of those model results provide reasonable confidence that the qualitative aspects of erosion and sedimentation can be correctly assessed, and that quantitative magnitudes of sedimentation (sediment loads, erosion, deposition, aggradation and degradation) can be estimated and compared under various development alternatives for the watersheds and watercourses.

5-5.1.2 Model Development

HEC-6 models of Skunk Creek and Sonoran Wash were developed for the following conditions and/or modeling assumptions:

Hydrology – The Skunk Creek models were developed for the 10-year and 100-year floods with both existing (1999) watershed conditions and future (full build-out) watershed conditions. The Sonoran Wash models were developed for the 25-year and 100-year floods with both existing (1999) watershed conditions and future (full build-out) watershed conditions.

Condition of Watercourse – Models were developed for two conditions of the watercourses. First, models are developed for the watercourses in their existing (1999) physical condition, and second, for conditions of full watercourse encroachment as per FEMA guidelines.

Bed Material Size Gradation – Models were developed under two assumptions of bed material size gradation. First, models were developed based on bed material size gradation as determined by field data collection from the main channels of the watercourses. Those models are identified as "Main Channel" models. Second, models were developed based on bed material size gradation as determined by field data collection from the overbanks of the watercourses. Those models are identified as "overbank" models. The bed material in the main channels is composed of a high percentage of gravel and the selected sediment transport function for those models is the Meyer-Peter, Muller. The bed material in the watercourse overbanks is predominantly sand and the selected sediment transport function is the Yang Stream Power.

Incoming Sediment Load – The incoming sediment load for the models was estimated, as previously described, and was entered into the models by a rating curve. Those rating curves are used for all models except for the sensitivity analyses, regarding the incoming sediment load.

<u>Sensitivity Analyses</u> – Numerous HEC-6 models were developed for the purpose of evaluating the sensitivity of model input. Discussion of HEC-6 models for sensitivity analyses is presented in Section 5-6.0.

5-5.2 MODEL IDENTIFICATION

A total of 52 HEC-6 models were developed and used for the purpose of evaluating erosion and sedimentation of Skunk Creek and Sonoran Wash and for sensitivity analysis of model input. Tables 5-5.1 through 5-5.4 identify each of the HEC-6 models. Table 5-5.1 is for the Skunk Creek Main Channel Models, Table 5-5.2 is for the Skunk Creek Overbank Models, Table 5-5.3 is for the Sonoran Wash Main Channel Models, and Table 5-5.4 is for the Sonoran Wash Overbank Models. The first six models that are listed in each of those tables are used for evaluating the erosion and sedimentation of either Skunk Creek or Sonoran Wash. The seven models at the bottom of each list are the HEC-6 models that were used for sensitivity analyses. A CD containing the input files for each of the 52 HEC-6 models is provided in Appendix 5-E. The following input and output files are provided in Appendix 5-F.

- Skunk Creek, Main Channel Model, 100-Year Flood, Existing Conditions
- Skunk Creek, Overbank Model, 100-Year Flood, Existing Conditions
- Skunk Creek, Main Channel Model, 100-Year Flood, Future Conditions
- Skunk Creek, Overbank Model, 100-Year Flood, Future Conditions
- Skunk Creek, Main Channel Model, 100-Year Flood, Existing Conditions, Encroached
- Skunk Creek, Overbank Model, 100-Year Flood, Existing Conditions, Encroached
- Skunk Creek, Main Channel Model, 100-Year Flood, Future Conditions, Encroached
- Skunk Creek, Overbank Model, 100-Year Flood, Future Conditions, Encroached
- Sonoran Wash, Main Channel Model, 100-Year Flood, Existing Conditions
- Sonoran Wash, Overbank Model, 100-Year Flood, Existing Conditions
- Sonoran Wash, Main Channel Model, 100-Year Flood, Future Conditions

- Sonoran Wash, Overbank Model, 100-Year Flood, Future Conditions
- Sonoran Wash, Main Channel Model, 100-Year Flood, Existing Conditions, Encroached
- Sonoran Wash, Overbank Model, 100-Year Flood, Existing Conditions, Encroached
- Sonoran Wash, Main Channel Model, 100-Year Flood, Future Conditions, Encroached
- Sonoran Wash, Overbank Model, 100-Year Flood, Future Conditions, Encroached

Table 5-5.1
Skunk Creek HEC-6 Main Channel Models

File Name	Condition	Flood Event	Tributary [1] Sediment Inflow	Transport Function	D_{50} Bed Material, in mm [2] Reach 1	Reach 2	Reach 3	Reach 4	Cline Creek
F-CH100E	Existing	100-year	Cline Creek	Meyer-Peter, Muller	6.0	2.9	10.2	2.3	2.5
F-CH100F	Future	100-year	Cline Creek	Meyer-Peter, Muller	6.0	2.9	10.2	2.3	2.5
F-CH10E	Existing	10-year	Cline Creek	Meyer-Peter, Muller	6.0	2.9	10.2	2.3	2.5
F-CH10F	Future	10-year	Cline Creek	Meyer-Peter, Muller	6.0	2.9	10.2	2.3	2.5
ENCCHEX	Existing	100-year	Cline Creek	Meyer-Peter, Muller	6.0	2.9	10.2	2.3	2.5
ENCCHFUT	Future	100-year	Cline Creek	Meyer-Peter, Muller	6.0	2.9	10.2	2.3	2.5
BM-GRTR	Existing	100-year	Cline Creek	Meyer-Peter, Muller	9.0	4.4	15.3	3.5	3.8
BM-LESS	Existing	100-year	Cline Creek	Meyer-Peter, Muller	3.0	1.5	5.1	1.2	1.3
INFL-0	Existing	100-year	Cline Creek	Meyer-Peter, Muller	6.0	2.9	10.2	2.3	2.5
INFL-10	Existing	100-year	Cline Creek	Meyer-Peter, Muller	6.0	2.9	10.2	2.3	2.5
N-AVG	Existing	100-year	Cline Creek	Meyer-Peter, Muller	6.0	2.9	10.2	2.3	2.5
N-HIGH	Existing	100-year	Cline Creek	Meyer-Peter, Muller	6.0	2.9	10.2	2.3	2.5
N-LOW	Existing	100-year	Cline Creek	Meyer-Peter, Muller	6.0	2.9	10.2	2.3	2.5

File Name	Inflowing Sediment [3]	n-Value [4] ROB	LOB	Channel	Encroached	Purpose
F-CH100E	Base	--	--	--	No	100-year, existing watershed condition base model
F-CH100F	Base	--	--	--	No	100-year, future watershed condition base model
F-CH10E	Base	--	--	--	No	10-year, existing watershed condition base model
F-CH10F	Base	--	--	--	No	10-year, future watershed condition base model
ENCCHEX	Base	--	--	--	Yes	100-year, existing watershed condition, encroached floodplain
ENCCHFUT	Base	--	--	--	Yes	100-year, future watershed condition, encroached floodplain
BM-GRTR	Base	--	--	--	No	Evaluate sensitivity to larger bed material
BM-LESS	Base	--	--	--	No	Evaluate sensitivity to smaller bed material
INFL-0	None	--	--	--	No	Evaluate sensitivity to low sediment inflow
INFL-10	10 times Base	--	--	--	No	Evaluate sensitivity to high sediment inflow
N-AVG	Base	0.048 [5]	0.045 [5]	0.042 [5]	No	Evaluate sensitivity to n-value
N-HIGH	Base	0.063 [6]	0.06 [6]	0.057 [6]	No	Evaluate sensitivity to high n-value
N-LOW	Base	0.033 [7]	0.03 [7]	0.027 [7]	No	Evaluate sensitivity to low n-value

Notes:

[1] Cline Creek enters Skunk Creek at 23.55.

[2] The Skunk Creek Channel Model is divided into four reaches. Reach 1 includes cross-sections 21.58 to 26.17, Reach 2 includes 20.16 to 21.49, Reach 3 includes 18.84 to 20.05 and Reach 4 includes 13.00 to 18.74.

[3] Inflowing sediment at the upper end of Skunk Creek and from Cline Creek is by the base condition sediment load rating curve unless otherwise specified.

[4] The n-values in the HEC-6 model are the same as the HEC-RAS model except where there is horizontal variation n-value; in those cases, a composite n-value is used. That is the base condition n-value used in the HEC-6 models, except for sensitivity analyses of n-valve.

[5] Reach averaged n-value from HEC-RAS model.

[6] High n-value = average plus 0.015

[7] Low n-value = average minus 0.015

Table 5-5.2
Skunk Creek HEC-6 Overbank Models

File Name	Condition	Flood Event	Tributary [1] Sediment Inflow	Transport Function	D_{50} Bed Material, in mm Reach 1	Cline Creek
F-FP100E	Existing	100-year	Cline Creek	Yang Stream Power	0.7	0.7
F-CH100F	Future	100-year	Cline Creek	Yang Stream Power	0.7	0.7
F-FP10E	Existing	10-year	Cline Creek	Yang Stream Power	0.7	0.7
F-FP10F	Future	10-year	Cline Creek	Yang Stream Power	0.7	0.7
ENCFPEX	Existing	100-year	Cline Creek	Yang Stream Power	0.7	0.7
ENCFPFUT	Future	100-year	Cline Creek	Yang Stream Power	0.7	0.7
BM-GRTR	Existing	100-year	Cline Creek	Yang Stream Power	1.1	1.1
BM-LESS	Existing	100-year	Cline Creek	Yang Stream Power	0.4	0.4
INFL-0	Existing	100-year	Cline Creek	Yang Stream Power	0.7	0.7
INFL-10	Existing	100-year	Cline Creek	Yang Stream Power	0.7	0.7
N-AVG	Existing	100-year	Cline Creek	Yang Stream Power	0.7	0.7
N-HIGH	Existing	100-year	Cline Creek	Yang Stream Power	0.7	0.7
N-LOW	Existing	100-year	Cline Creek	Yang Stream Power	0.7	0.7

File Name	Inflowing Sediment [2]	n-Value [3] ROB	LOB	Channel	Encroached	Purpose
F-FP100E	Base	--	--	--	No	100-year, existing watershed condition base model
F-FP100F	Base	--	--	--	No	100-year, future watershed condition base model
F-FP10E	Base	--	--	--	No	10-year, existing watershed condition base model
F-FP10F	Base	--	--	--	No	10-year, future watershed condition base model
ENCFPEX	Base	--	--	--	Yes	100-year, existing watershed condition, encroached floodplain
ENCFPFUT	Base	--	--	--	Yes	100-year, future watershed condition, encroached floodplain
BM-GRTR	Base	--	--	--	No	Evaluate sensitivity to larger bed material
BM-LESS	Base	--	--	--	No	Evaluate sensitivity to smaller bed material
INFL-0	None	--	--	--	No	Evaluate sensitivity to low sediment inflow
INFL-10	10 times Base	--	--	--	No	Evaluate sensitivity to high sediment inflow
N-AVG	Base	0.048 [4]	0.045 [4]	0.042 [4]	No	Evaluate sensitivity to n-value
N-HIGH	Base	0.063 [5]	0.06 [5]	0.057 [5]	No	Evaluate sensitivity to high n-value
N-LOW	Base	0.033 [6]	0.03 [6]	0.027 [6]	No	Evaluate sensitivity to low n-value

Notes:

1 Cline Creek enters Skunk Creek at 23.55.

2 Inflowing sediment at the upper end of Skunk Creek and from Cline Creek is by the base condition sediment load rating curve unless otherwise specified.

3 The n-values in the HEC-6 model are the same as the HEC-RAS model except where there is horizontal variation n-value; in those cases, a composite n-value is used. That is the base condition n-value used in the HEC-6 models, except for sensitivity analyses of n-valve.

4 Reach averaged n-value from HEC-RAS model.

5 High n-value = average plus 0.015

6 Low n-value = average minus 0.015

Table 5-5.3
Sonoran Wash HEC-6 Main Channel Models

File Name	Condition	Flood Event	Tributary Sediment Inflow	Transport Function	D_{50} Bed Material, in mm [1] Reach 1	D_{50} Bed Material, in mm [1] Reach 2
F-CH100E	Existing	100-year	None	Meyer-Peter, Muller	22.6	5.3
F-CH100F	Future	100-year	None	Meyer-Peter, Muller	22.6	5.3
F-CH10E	Existing	25-year	None	Meyer-Peter, Muller	22.6	5.3
F-CH10F	Future	25-year	None	Meyer-Peter, Muller	22.6	5.3
ENCCHEX	Existing	100-year	None	Meyer-Peter, Muller	22.6	5.3
ENCCHFUT	Future	100-year	None	Meyer-Peter, Muller	22.6	5.3
BM-GRTR	Existing	100-year	None	Meyer-Peter, Muller	33.9	8.0
BM-LESS	Existing	100-year	None	Meyer-Peter, Muller	11.3	2.7
INFL-0	Existing	100-year	None	Meyer-Peter, Muller	22.6	5.3
INFL-10	Existing	100-year	None	Meyer-Peter, Muller	22.6	5.3
N-AVG	Existing	100-year	None	Meyer-Peter, Muller	22.6	5.3
N-HIGH	Existing	100-year	None	Meyer-Peter, Muller	22.6	5.3
N-LOW	Existing	100-year	None	Meyer-Peter, Muller	22.6	5.3

File Name	Inflowing Sediment [2]	n-Value [3] ROB	n-Value [3] LOB	n-Value [3] Channel	Encroached	Purpose
F-CH100E	Base	--	--	--	No	100-year, existing watershed condition base model
F-CH100F	Base	--	--	--	No	100-year, future watershed condition base model
F-CH10E	Base	--	--	--	No	10-year, existing watershed condition base model
F-CH10F	Base	--	--	--	No	10-year, future watershed condition base model
ENCCHEX	Base	--	--	--	Yes	100-year, existing watershed condition, encroached floodplain
ENCCHFUT	Base	--	--	--	Yes	100-year, future watershed condition, encroached floodplain
BM-GRTR	Base	--	--	--	No	Evaluate sensitivity to larger bed material
BM-LESS	Base	--	--	--	No	Evaluate sensitivity to smaller bed material
INFL-0	None	--	--	--	No	Evaluate sensitivity to low sediment inflow
INFL-10	10 times Base	--	--	--	No	Evaluate sensitivity to high sediment inflow
N-AVG	Base	0.064 [4]	0.053 [4]	0.039 [4]	No	Evaluate sensitivity to n-value
N-HIGH	Base	0.079 [5]	0.068 [5]	0.054 [5]	No	Evaluate sensitivity to high n-value
N-LOW	Base	0.049 [6]	0.038 [6]	0.024 [6]	No	Evaluate sensitivity to low n-value

Notes

1 The Sonoran Wash Channel Model is divided into two reaches. Reach 1 includes cross-sections 1.90 to 3.84 and Reach 2 includes 0.52 to 1.84.

2 Inflowing sediment at the upper end of Sonoran Wash is by the base condition sediment load rating curve unless otherwise specified.

3 The n-values in the HEC-6 model are the same as the HEC-RAS model except where there is horizontal variation n-value; in those cases, a composite n-value is used. That is the base condition n-value used in the HEC-6 models, except for sensitivity analyses of n-valve.

4 Reach averaged n-value from HEC-RAS model.

5 High n-value = average plus 0.015

6 Low n-value = average minus 0.015

Table 5-5.4
Sonoran Wash HEC-6 Overbank Models

File Name	Condition	Flood Event	Tributary	Transport Function	D_{50} Bed Material in mm
F-FP100E	Existing	100-year	None	Yang Stream Power	0.95
F-FP100F	Future	100-year	None	Yang Stream Power	0.95
F-FP10E	Existing	25-year	None	Yang Stream Power	0.95
F-FP10F	Future	25-year	None	Yang Stream Power	0.95
ENCFPEX	Existing	100-year	None	Yang Stream Power	0.95
ENCFPFUT	Future	100-year	None	Yang Stream Power	0.95
BM-GRTR	Existing	100-year	None	Yang Stream Power	1.42
BM-LESS	Existing	100-year	None	Yang Stream Power	0.47
INFL-0	Existing	100-year	None	Yang Stream Power	0.95
INFL-10	Existing	100-year	None	Yang Stream Power	0.95
N-AVG	Existing	100-year	None	Yang Stream Power	0.95
N-HIGH	Existing	100-year	None	Yang Stream Power	0.95
N-LOW	Existing	100-year	None	Yang Stream Power	0.95

File Name	Inflowing Sediment [1]	n-Value [2] ROB	n-Value [2] LOB	n-Value [2] Channel	Encroached	Purpose
F-FP100E	Base	--	--	--	No	100-year, existing watershed condition base model
F-FP100F	Base	--	--	--	No	100-year, future watershed condition base model
F-FP10E	Base	--	--	--	No	10-year, existing watershed condition base model
F-FP10F	Base	--	--	--	No	10-year, future watershed condition base model
ENCFPEX	Base	--	--	--	Yes	100-year, existing watershed condition, encroached floodplain
ENCFPFUT	Base	--	--	--	Yes	100-year, future watershed condition, encroached floodplain
BM-GRTR	Base	--	--	--	No	Evaluate sensitivity to larger bed material
BM-LESS	Base	--	--	--	No	Evaluate sensitivity to smaller bed material
INFL-0	None	--	--	--	No	Evaluate sensitivity to low sediment inflow
INFL-10	10 times Base	--	--	--	No	Evaluate sensitivity to high sediment inflow
N-AVG	Base	0.064 [3]	0.053 [3]	0.039 [3]	No	Evaluate sensitivity to n-value
N-HIGH	Base	0.079 [4]	0.068 [4]	0.054 [4]	No	Evaluate sensitivity to high n-value
N-LOW	Base	0.049 [5]	0.038 [5]	0.024 [5]	No	Evaluate sensitivity to low n-value

Notes

[1] Inflowing sediment at the upper end of Sonoran Wash is by the base condition sediment load rating curve unless otherwise specified.

[2] The n-values in the HEC-6 model are the same as the HEC-RAS model except where there is horizontal variation n-value; in those cases, a composite n-value is used. That is the base condition n-value used in the HEC-6 models, except for sensitivity analyses of n-valve.

[3] Reach averaged n-value from HEC-RAS model.

[4] High n-value = average plus 0.015

[5] Low n-value = average minus 0.015

5-6.0 SENSITIVITY ANALYSES

5-6.1 PURPOSE OF SENSITIVITY ANALYSES

Sensitivity analyses of input to the HEC-6 models were performed to assess if variability in model input would substantively change the model results. Sensitivity analyses were performed on the major input parameters that are expected to have significant impact on model results. The sensitivity analyses were performed for bed material size distribution, incoming sediment load, and Manning's resistance coefficient, as discussed in the following.

The HEC-6 models that are used for sensitivity testing are identified in Tables 5-5.1 through 5-5.4. HEC-6 input files are provided in Appendix 5-E. The results of the sensitivity analyses are presented in graphical form in Appendix 5-G. A set of four graphs is used to illustrate the HEC-6 model results for each sensitivity run. Those four graphs are described as follows:

<u>Bed Elevation Change at Last Time Step</u> – This graph shows the change in bed elevation at each modeling cross section at the end of the flood hydrograph. A positive number indicates bed aggradation and a negative number indicates bed degradation.

<u>Sediment Passing Through Section</u> – This graph illustrates the sediment load, in tons, that passes through each modeling section for the duration of the flood hydrograph. Water flow and sediment transport is from larger River Mile to smaller River Mile (right to left on the graph). A rise in the line (from right to left) indicates an increasing sediment load passing the next downstream section, and that indicates "scour" from the intervening reach of watercourse. Conversely, a fall in the line indicates "fill" from the intervening reach of watercourse.

<u>Sediment Deposited Between Sections</u> – This graph illustrates the sediment load, in cubic yards, that is deposited (+ number) or eroded (- number) between modeling sections.

<u>Accumulative Sediment Deposited Upstream of Section</u> – This is a running accumulation of sediment deposited (+ number) or eroded (- number) starting at the upstream end (right side of graph) and progressing downstream (to the left). Line segments (or trend of sections of the graph) sloping downward to the left indicate reaches of overall

degradation. Line segments sloping upward to the left indicate reaches of overall aggradation.

5-6.2 BED MATERIAL SIZE DISTRIBUTION

Sensitivity to the input of sediment bed material size distribution was evaluated by running each HEC-6 model with finer bed material and coarser bed material, respectively. For the finer bed material, the base input size distribution was multiplied by 0.5. That is, each sediment size within a fraction of the grain size distribution was multiplied by 0.5. For certain Overbank Models, the smaller grain size fractions were not multiplied by 0.5 because that would reduce that fraction of the bed material to be smaller than very fine sand thus negating its transport by the Yang Stream Power function. That would have the effect of reducing the sediment supply and therefore result in unreasonably low sediment transport as compared to the runs with the base size gradation. In these cases the original sediment size was used.

For the coarser grain size, the base input size distribution was multiplied by 1.5. The same procedure was used as for the finer grain size.

The results of the sensitivity analyses of bed material size distribution are shown in Appendix 5-G.1 for Skunk Creek and Appendix 5-G.2 for Sonoran Wash. The runs with the finer bed material generally result in greater magnitudes of sediment transport, and the runs with coarser bed material generally result in lesser magnitudes of sediment transport, both as expected. However, in general, a change in bed material size distribution does not change the overall performance of the models; that is, although the magnitudes of scour (degradation) and fill (aggradation) change, the overall sedimentation process is not significantly affected by a change in bed material size.

5-6.3 INFLOWING SEDIMENT LOAD

Sensitivity to the input of inflowing sediment load was evaluated by running each HEC-6 model with increased sediment load and reduced sediment load, respectively. For increased sediment load, the inflowing sediment load rating curves were multiplied by 10. For reduced sediment load, the inflowing sediment load was completely eliminated; that is, zero inflowing sediment load as compared to the base models.

The results of the sensitivity analyses of inflowing sediment load are shown in Appendix 5-G.3 for Skunk Creek and Appendix 5-G.4 for Sonoran Wash.

For Skunk Creek, the major source of inflowing sediment is at Cline Creek (River Mile 23.55). Increased inflowing sediment at Cline Creek has a local affect, but that affect does not propagate downstream any appreciable distance. Clearly, a large sediment inflow from Cline Creek could result in a large deposit of sediment in Skunk Creek. However, other than the local impact at the confluence of Cline Creek, variation in inflowing sediment load has little impact on Skunk Creek. A decrease of sediment inflow causes Skunk Creek to be slightly more degradational and an increase of sediment inflow could cause Skunk Creek to become aggradational below Cline Creek.

For Sonoran Wash, there is little net impact due to variation in inflowing sediment load. One area of significant impact is at the lower end (between River Miles 0.5 and 0.85) where increased sediment inflow would result in larger magnitudes of sediment deposition upstream of the CAP Canal. Another area of significant impact is at the upper end (between River Miles 3.7 and 3.84) where increased sediment inflow would result in deposition of sediment at the upstream study limit.

Overall, this analysis indicates that both Skunk Creek and Sonoran Wash have the hydraulic capacity to transport large quantities of inflowing sediment through the systems. High concentrations of inflowing sediment can result in the build-up of local sediment bars that would likely result in breakout flooding. Any increase in inflowing sediment exacerbates the sediment deposition upstream of the CAP Canal. Reduced sediment inflow would result in some long-term degradation, however bed armoring would likely limit that degradation, and would favorably reduce deposition upstream of the CAP Canal.

5-6.4 MANNING'S *n*

Sensitivity to the selection of Manning's *n* was evaluated by running the HEC-6 models with increased and decreased Manning's *n* values, respectively. For increased Manning's *n*, the base values were increased by 0.015, and for the decreased Manning's *n* the values were decreased by 0.015.

For the purpose of simplification, reach averaged values of Manning's *n* were determined from the base HEC-6 models. Those reach averaged values were increased or decreased by 0.015 for the sensitivity analyses. The figures in Appendices 5-G.5 and 5-G.6 show the graphical results for the base models, the reach averaged n value models, the increased n value models and the decreased n value models. Those appendices include tables that show the various n values that were used.

The results for both Skunk Creek (Appendix 5-G.5) and for Sonoran Wash (Appendix 5-G.6) are similar. An increase in n value has little impact on the erosion and sedimentation process, however, reduced n values result in higher velocities and therefore higher transport capacities. For Skunk Creek and Sonoran Wash, the consequence of increasing the hydraulic efficiency is an increase in transport capacity and increased upstream erosion and watercourse degradation. The major impact of smaller n values than the assumed base condition is greater deposition volume at the downstream end of the watercourses.

Although a reduction in Manning's *n* results in greater upstream transport rates and simultaneous greater downstream deposition, the variation in n only produces greater or lesser rates of sedimentation, but does not alter the general response of the watercourses.

5-6.5 CONCLUSION OF SENSITIVITY ANALYSES

The sensitivity analyses indicate that modeling uncertainties that tend to increase erosion and sedimentation (finer bed material grain size, increased inflowing sediment load, and reduced Manning's *n*) and those that tend to decrease erosion and sedimentation (coarser bed material grain size, decreased inflowing sediment load, and increased Manning's *n*) do not dramatically alter the HEC-6 results over the base HEC-6 input conditions. Alteration of those model uncertainties results in changes in the magnitudes of the model responses but not in the general trends.

The HEC-6 models are not considered to be particularly sensitive to bed material grain size. That factor has been directly incorporated into the analyses by the modeling methodology of using coarser sediments with the Main Channel Models and finer sediments with the Overbank Models. The actual sedimentation response of the watercourses is assessed by interpretation of the results of both of those models.

The HEC-6 models are not considered to be particularly sensitive to inflowing sediment load. For both watercourses, an adequate quantity of transportable sediment exists in the bed of the watercourses (assuming no limiting armor layer). The watercourses are transport controlled. Large variation in inflowing sediment load can have significant local impacts, but those impacts will not immediately affect downstream sedimentation.

The HEC-6 models are sensitive to a decrease in Manning's n. This indicates that increasing the hydraulic efficiency could result in increased upstream transport (scour and degradation) and greater rates of aggradation and fill in the backwater regions of the CAP Canal.

5-7.0 EROSION & SEDIMENTATION ANALYSES RESULTS

5-7.1 GENERAL

The erosion and sedimentation of Skunk Creek within the study area (see Figure 5-1.1) and of Sonoran Wash were performed by modeling the watercourses by use of the HEC-6 program. Various models were established to investigate the erosion and sedimentation of Skunk Creek and Sonoran Wash under a variety of watershed hydrologic conditions, hydraulic conditions of the watercourses and sedimentation modeling assumptions.

The HEC-6 results are interpreted with the intent of understanding how the watercourses will respond under various development conditions in the watersheds and under selected management scenarios for the watercourses. The interpretation of those model results are presented herein. The project is being conducted in two phases; Phase I including the reach of Skunk Creek commencing at the CAP Canal and progressing upstream to the Carefree Highway bridge (RM 16.86) and all of Sonoran Wash, Phase II being Skunk Creek above the Carefree Highway bridge (RM 16.87) to the upper study limit. This report covers both Phase I and Phase II.

HEC-6 modeling was performed for existing and future watershed conditions, two hydrologic conditions, and for encroached and unencroached floodplains. Those are termed "base conditions," and they provide a range of conditions that can be expected under reasonable scenarios of land development and flood management. Interpretation of those results is adequate for the assessment of erosion and sedimentation impacts due to alternatives in watercourse management. However, for final design, it may be necessary to model a watercourse management alternative if the physical conditions for such an alternative are not representative or exceed the limitations of the modeling that was performed for these base conditions.

HEC-6 modeling was also performed for two different sediment size distributions, Main Channel Models and Overbank Models. HEC-6 can not model spatial variability of size gradation across the width of the channel. Both Skunk Creek and Sonoran Wash show a wide variation in bed material between channel and overbank. The Main Channel model represents the transport characteristics of the coarser material generally found in the main channel. While the Overbank Model represents the finer material generally found in the overbank. Neither model is an entirely adequate representation of transport of the sediment in the watercourse. The results presented herein are an interpretation of both models. For specific differences between the models see Section 5-4.0.

5-7.2 HEC-6 MODELS

Twenty-four HEC-6 models are developed for the analysis of the base conditions. Sixteen of those models are for the 100-year flood, and eight of those are for the 10-year flood for Skunk Creek or 25-year flood for Sonoran Wash. Analysis of the 10-year flood or 25-year flood under encroached conditions is irrelevant. The model results are not discussed in the report since the results of the HEC-6 modeling indicate that, on average, the predicted erosion or deposition from a single 10-year or 25-year design flood is less significant than the erosion from a series of smaller floods, a longer duration flood, or a single 100-year design flood. The 100-year floods present a more serious design condition in regard to channel aggradation or degradation, local scour and channel lining toe-down requirements, and erosion of channel banks. Inspection of the 10-year model results for Skunk Creek or 25-year model results for Sonoran Wash may be relevant in regard to maintenance costs for selected alternatives.

As discussed in Section 5-6, 28 HEC-6 models were developed for the purpose of investigating the sensitivity to various model input. Along with the 24 HEC-6 models for analyzing the sedimentation of Skunk Creek and Sonoran Wash, a total of 52 HEC-6 models were developed. Listings and fundamental descriptions of each of the 52 models are provided in Tables 5-5.1 through 5-5.4. The HEC-6 input and output files are provided on a CD in Appendix 5-E.

5-7.3 GRAPHICAL RESULTS FOR THE 100-YEAR FLOODS

5-7.3.1 Description of Graphs

Voluminous output of the HEC-6 models are developed and provided herein (see Appendix 5-F). However, a convenient means to present and interpret those results is necessary. The HEC-6 model output for the 100-year flood models are presented in Appendix 5-H in a set of five graphs for each of the 16 models. Each of those five graphs is described as follows:

Bed Elevation Change at Last Time Step – This graph shows the change in bed elevation at each modeling cross section at the end of the 100-year flood hydrograph. A positive number indicates bed aggradation and a negative number indicates bed degradation. A 5-point moving average line is also shown which better illustrates reach average conditions.

Maximum and Minimum Bed Elevation Change – This graph shows both the maximum fill (aggradation) and maximum scour (degradation) that occurs at any time during the 100-year flood. The maximum scour is represented by the "Minimum" bed elevation change line, and the maximum fill by the "Maximum" bed elevation change line. During the passage of a flood, a section may only experience scour, or it may only experience fill, or it may at times be scouring and at other times filling. A section that has a zero for maximum bed elevation change is always in a scour mode. A section that has a zero for minimum bed elevation change is always in a fill mode. A section that has both a positive number for maximum bed elevation change and a negative number for minimum bed elevation change experiences both scour and fill during passage of the 100-year flood. This information is useful in estimating potential toe-down requirements for watercourse bank lining and also the potential for excessive local fill that could cause breakout flows.

Sediment Passing through Section – This graph illustrates the sediment load, in tons, that passes through each modeling section for the duration of the 100-year flood. Water flow and sediment transport is from larger River Mile to smaller River Mile (right to left on the graph). A rise in the line (from right to left) indicates an increasing sediment load passing the next downstream section, and that indicates "scour" from the intervening reach of watercourse. Conversely, a fall in the line indicates "fill" from the intervening reach of watercourse. A 5-point moving average line is also shown which better illustrates reach average conditions.

Sediment Deposited Between Sections – This graph illustrates the sediment load, in cubic yards, that is deposited (+ number) or eroded (- number) between modeling sections. A 5- point moving average line is also provided.

Accumulative Sediment Deposited Upstream of Section – This is a running accumulation of sediment deposited (+ number) or eroded (- number) starting at the upstream end (right side of graph) and progressing downstream (to the left). Line segments (or trend of sections of the graph) sloping downward to the left indicate reaches of overall degradation. Line segments sloping upward to the left indicate reaches of overall aggradation. A 5-point moving average line is also provided.

An index of the 16 100-year flood HEC-6 models is provided in the Table 5-7.1. The graphical results are provided in Appendices 5-H.1 through 5-H.16.

5-7.3.2 General Scour and Fill

The maximum general scour and fill during the 100-year flood for both Skunk Creek and Sonoran Wash for existing and future watershed conditions are shown in Table 5-7.2. The general scour in Skunk Creek could reach as much as about 1.4 feet. However, the fill could exceed 4 feet locally at the confluence of Cline Creek due to large sediment inflow at that location. In general, encroachment of the floodplain can be expected to increase scour by as much as about 1 foot under existing watershed conditions. Under future conditions with diminished flood peaks and volumes, encroachment could increase deposition locally at Cline Creek.

Table 5-7.1
Index of graphical results of HEC-6 models for the Skunk Creek Watercourse Master Plan

Appendix Number (1)	Skunk Creek (2)	Sonoran Wash (3)	Main Channel Model (4)	Overbank Model (5)	100-year Peak Discharge (6)	Existing Conditions (7)	Future Conditions (8)	Encroached Floodplain (9)
5-H.1	•		•		•	•		
5-H.2	•			•	•	•		
5-H.3	•		•		•		•	
5-H.4	•			•	•		•	
5-H.5		•	•		•	•		
5-H.6		•		•	•	•		
5-H.7		•	•		•		•	
5-H.8		•		•	•		•	
5-H.9	•		•		•	•		•
5-H.10	•			•	•	•		•
5-H.11	•		•		•		•	•
5-H.12	•			•	•		•	•
5-H.13		•	•		•	•		•
5-H.14		•		•	•	•		•
5-H.15		•	•		•		•	•
5-H.16		•		•	•		•	•

For Sonoran Wash, general scour and fill is typically ± 0.5 feet. Encroachment exacerbates the magnitudes of general scour and fill but the magnitudes are a fraction of a foot.

Table 5-7.2

Maximum general scour and fill during the 100-year flood

	Without Encroachment Scour, ft (1)	Without Encroachment Fill, ft (2)	With Encroachment Scour, ft (3)	With Encroachment Fill, ft (4)
		Skunk Creek		
Existing Conditions, Main Channel Model	-0.69	0.49	-1.30	0.61
Existing Conditions, Overbank Model	-0.50	3.0*	-1.40	4.2*
Future Conditions, Main Channel Model	-0.64	0.43	-1.06	0.62
Future Conditions, Overbank Model	-1.4	1.3*	-0.65	1.7*
		Sonoran Wash		
Existing Conditions, Main Channel Model	-0.10	0.12	-0.26	0.29
Existing Conditions, Overbank Model	-0.42	0.46	-0.66	0.50
Future Conditions, Main Channel Model	-0.20	0.14	-0.18	0.14
Future Conditions, Overbank Model	-0.42	0.46	-0.78	0.38

* Occurs at the confluence of Cline Creek due to large sediment inflow.

5-7.3.3 Interpretation of Erosion and Sedimentation

The graphs of results (see Appendix 5-H) that are particularly useful in interpreting the erosion and sedimentation process are the Accumulative Sediment Deposited Upstream of Section graphs. Figures 5-7.1 through 5-7.8 are selected compilations of those graphs. Those graphs are used to interpret the erosion and sedimentation process in Skunk Creek and Sonoran Wash in the following discussions.

5-7.3.3.1 Skunk Creek

The overall erosion and sedimentation process for Skunk Creek is shown in Figures 5-7.1 through 5-7.4. Figure 5-7.1 are the results from the Main Channel Models using the coarser bed material size distribution and the Meyer-Peter, Muller transport function. Figure 5-7.2 is a 5-point moving average of Figure 5-7.1. Those two graphs indicate that the main channel of Skunk Creek will respond in about the same manner to the 100-year flood under existing and future watershed conditions and with or without floodplain encroachment. That is a reasonable result because of the coarse nature of the bed material in the well defined main channel that is well armored from previous floods.

Figure 5-7.2 indicates that the main channel of Skunk Creek from about RM 26.2 to about RM 21.3 is generally degradational. The next approximately 0.2 mile (RM 21.3 to 21.1) shows dramatic local scour tendency followed by a dramatic fill reach from RM

21.1 to 21.0. From RM 21.0 to about RM 19.8 is a generally aggrading reach. Starting at about RM 19.8, the main channel of Skunk Creek will experience increasing rates of scour to about RM 17.8. From RS 17.8 to the CAP Canal, Skunk Creek is in an overall deposition and aggradation mode.

Figure 5-7.3 is the results from the Overbank Models using the finer bed material size gradation and the Yang Stream Power transport function. Figure 5-7.4 is a 5-point moving average of Figure 5-7.3. Figures 5-7.3 and 5-7.4 illustrate that changing watershed conditions (that is, either existing or future conditions) and floodplain encroachment will have significant erosional and sedimentational impacts to the floodplains of Skunk Creek. Notice, that as noted above, those same conditions had little impact on the main channel of coarser bed material. Figure 5-7.4 indicates that under existing conditions and no encroachment that Skunk Creek upstream of the CAP Canal is in approximate sediment balance, that is, sediment inflow equals sediment outflow. However, future conditions and floodplain encroachment will tend to shift Skunk Creek to an overall degradational mode; although significant localized fill would occur at the confluence of Cline Creek.

Downstream of the Carefree Highway bridge (RM 16.86), the main channel of Skunk Creek can be expected to be in an aggradational mode (see Figure 5-7.2). That may cause avulsions of the main channel to occur during floods. The overbank floodplain of Skunk Creek is particularly susceptible to aggradation and filling for the approximately 2 miles upstream of the CAP Canal (see Figure 5-7.4). Avulsions of the main channel would likely exacerbate that problem due to high sediment loads and reduced downgradient conveyance capacity.

Upstream of the Carefree Highway bridge (RM 16.86), the main channel is subject to degradation immediately upstream of the bridge and in a few other relatively short reaches (see Figure 5-7.2). The overbank floodplain is susceptible to serious sedimentation (fill and aggradation) immediately downstream of Cline Creek (see Figure 5-7.4).

Figure 5-7.1
Accumulative sediment deposited upstream of section
Skunk Creek, Main Channel Models, 100-year flood

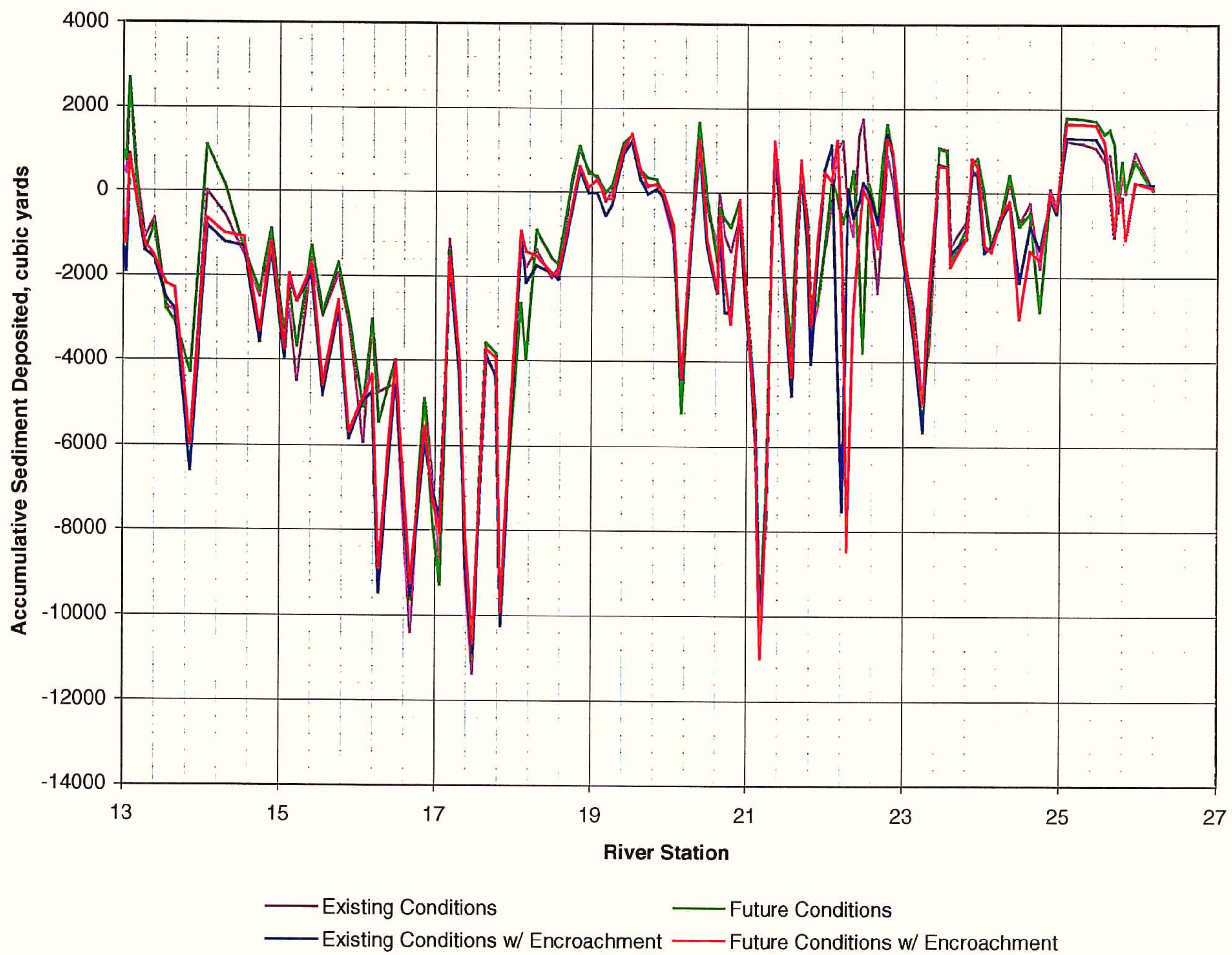


Figure 5-7.2
Accumulative sediment deposited upstream of section
Skunk Creek, Main Channel Models, 100-year flood
5-point Moving Averages

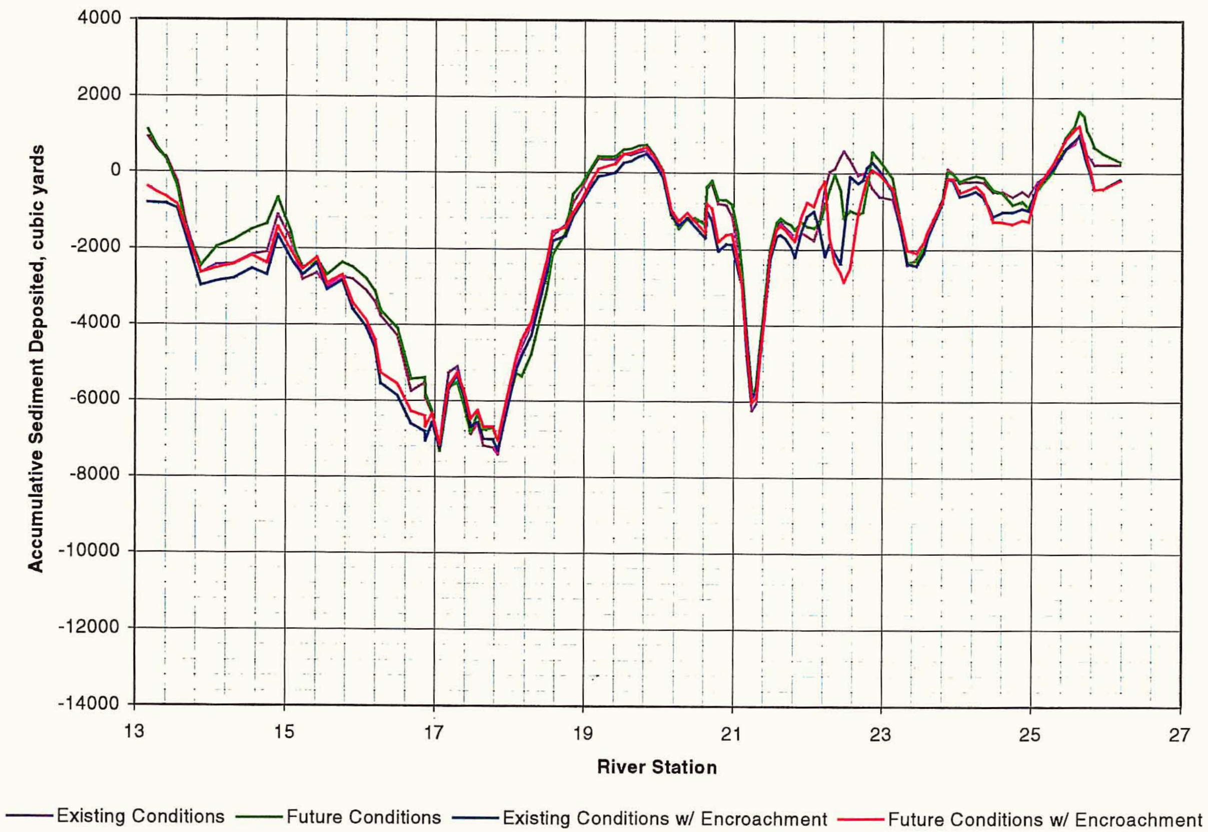


Figure 5-7.3
Accumulative sediment deposited upstream of section
Skunk Creek, Overbank Models, 100-year flood

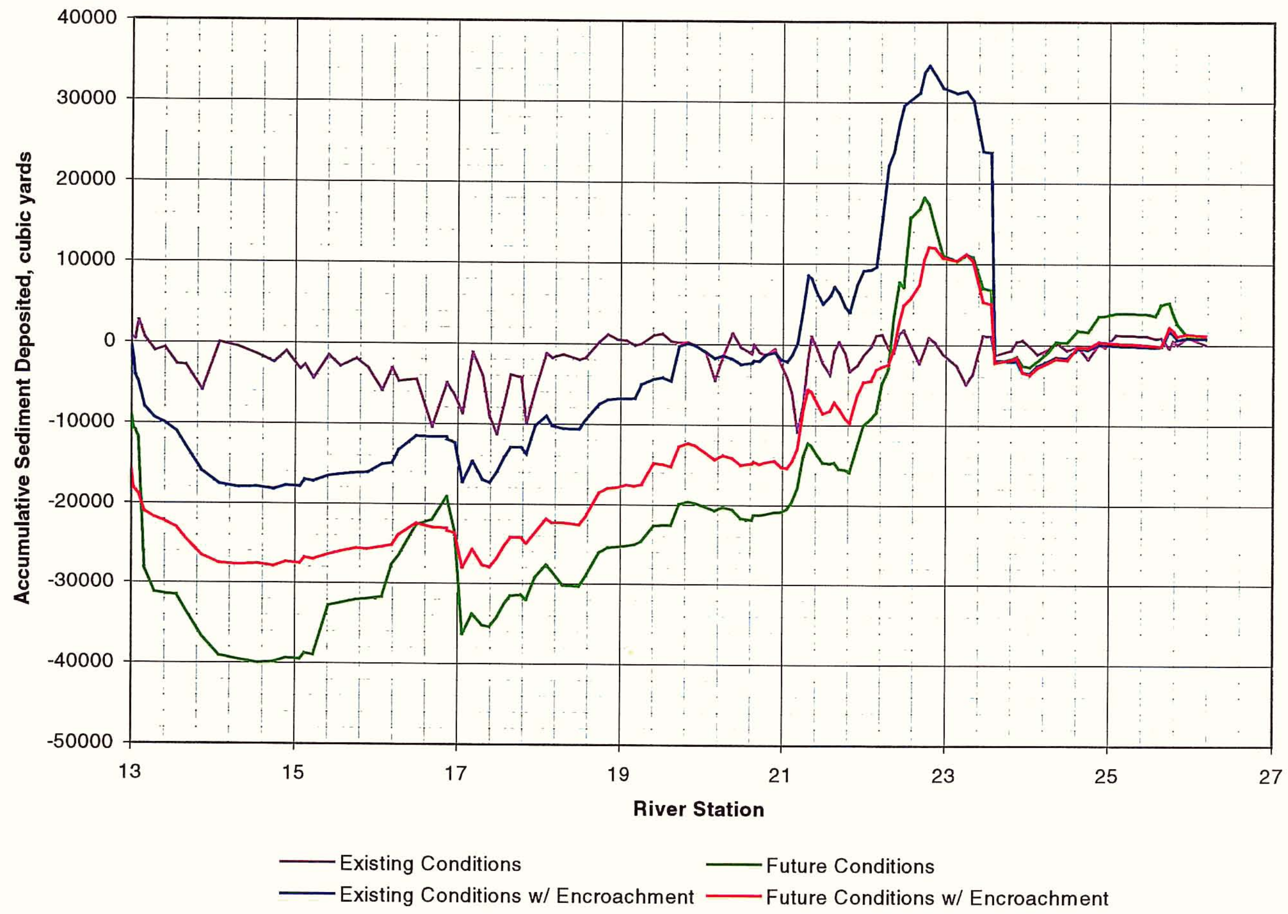
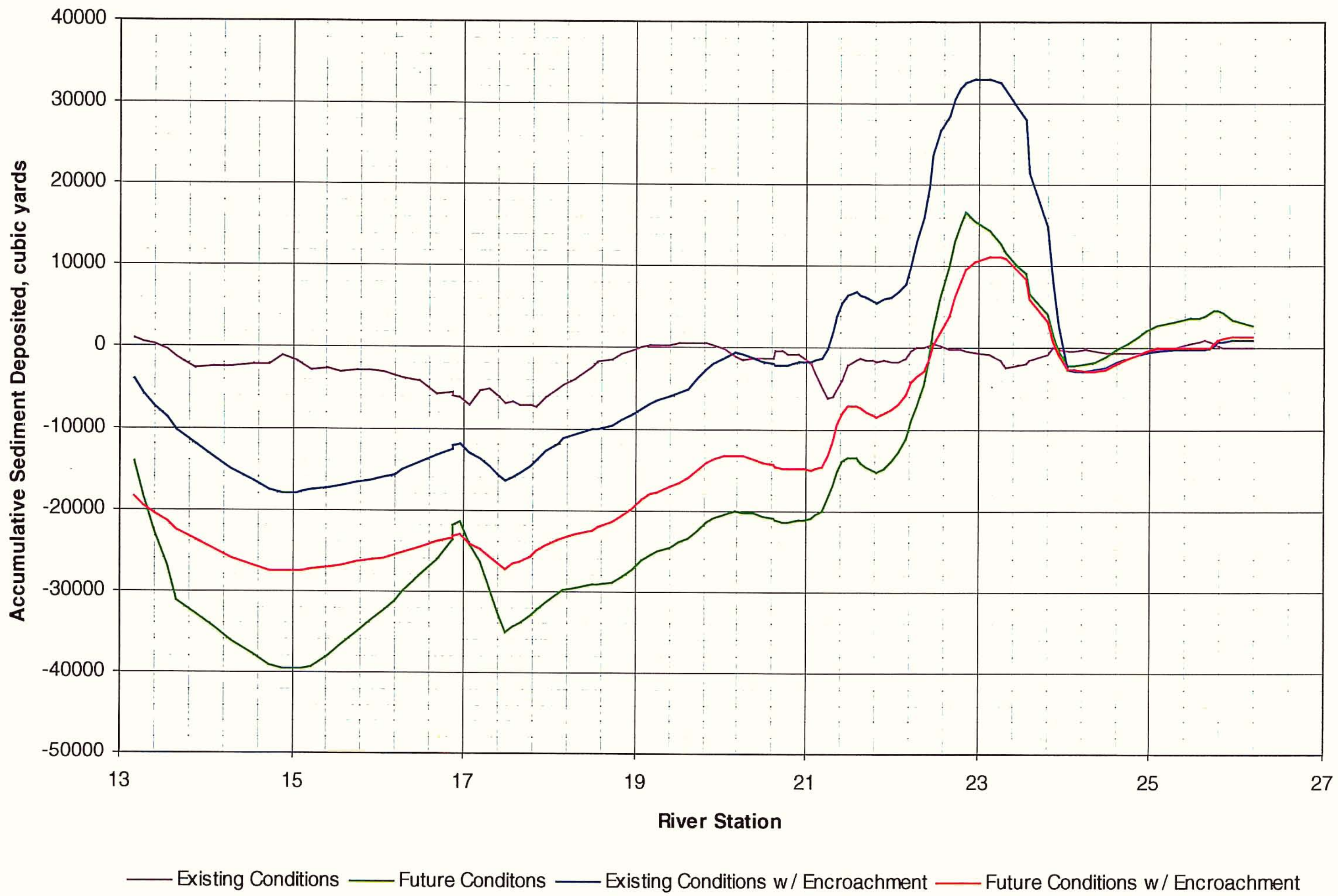


Figure 5-7.4
Accumulative sediment deposited upstream of section
Skunk Creek, Overbank Models, 100-year flood
5-point Moving Averages



5-7.3.3.2 Sonoran Wash

The overall erosion and sedimentation process for Sonoran Wash is shown in Figures 5-7.5 through 5-7.8. Figure 5-7.5 is the results from the Main Channel Models using the coarser bed material size distribution and the Meyer-Peter, Muller transport function. Figure 5-7.6 is a 5-point moving average of Figure 5-7.5. Those figures would seem to indicate rather significant changes in the main channel under existing and future conditions and with or without floodplain encroachment. However, notice that the magnitude on the vertical scales (+500 tons maximum to –1500 tons minimum) are very small in regard to sediment transport and the effects of watershed conditions and encroachment are minor to the main channel. Figure 5-7.6 indicates that the main channel will be a zone of deposition from the CAP Canal (about RM 0.75) upstream about 0.4 mile (about RM 1.20). Overall, the main channel of Sonoran Wash for this relatively small watershed would probably be only moderately impacted by development and/or floodplain encroachment.

Figure 5-7.7 is the results from the Overbank Models using the finer bed material size gradation and the Yang Stream Power transport function. Figure 5-7.8 is a 5-point moving average of Figure 5-7.7. Those two graphs are very similar and the 5-point moving average graph (Figure 5-7.8) is used. That figure indicates that future watershed conditions, with decreased flood peaks and runoff volumes, will decrease the rates of erosion from RM 2.6 to 1.7 and thereby reduce the amount of sediment deposition in the overbank floodplain upstream of the CAP Canal from RM 0.75 to 1.1.

Sonoran Wash is in the Phase I study area. Under existing watershed conditions, approximately 8,000 tons of bed material load will be produced upstream of RM 1.1 during a 100-year flood of which about 5,000 tons would be deposited in the backwater of the CAP Canal. Under future watershed conditions, only about 4,000 tons of bed material load will be produced of which about 3,000 tons would be deposited in the backwater of the CAP Canal. Overall, Sonoran Wash is rather stable regarding erosion and sedimentation rates with the major factor being sediment deposition upstream of the CAP Canal.

Figure 5-7.5
Accumulative sediment deposited upstream of section
Sonoran Wash, Main Channel Models, 100-year flood

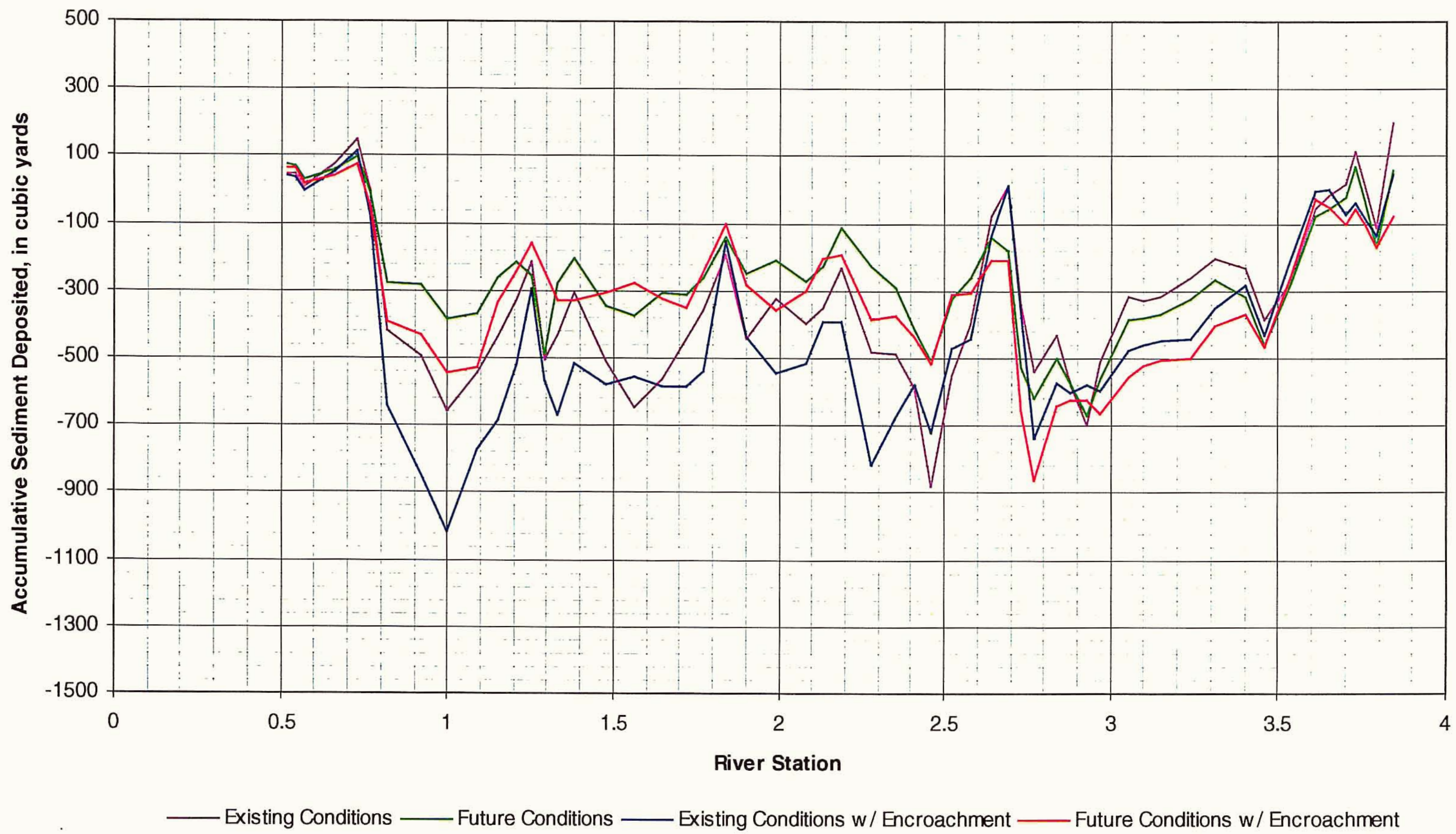


Figure 5-7.6
Accumulative sediment deposited upstream of section
Sonoran Wash, Main Channel Models, 100-year flood
5-point Moving Averages

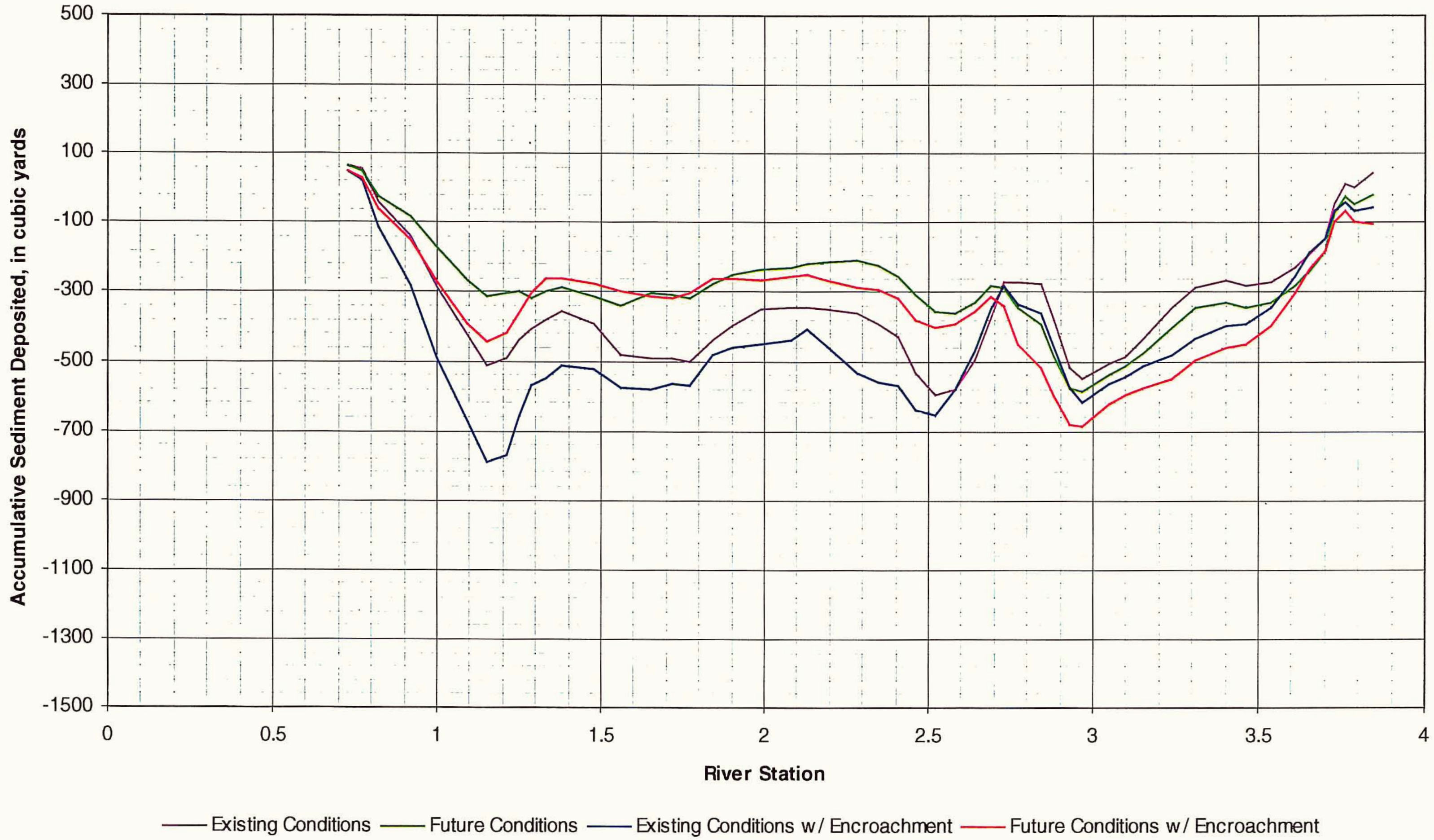


Figure 5-7.7
Accumulative sediment deposited upstream of section
Sonoran Wash, Overbank Models, 100-year flood

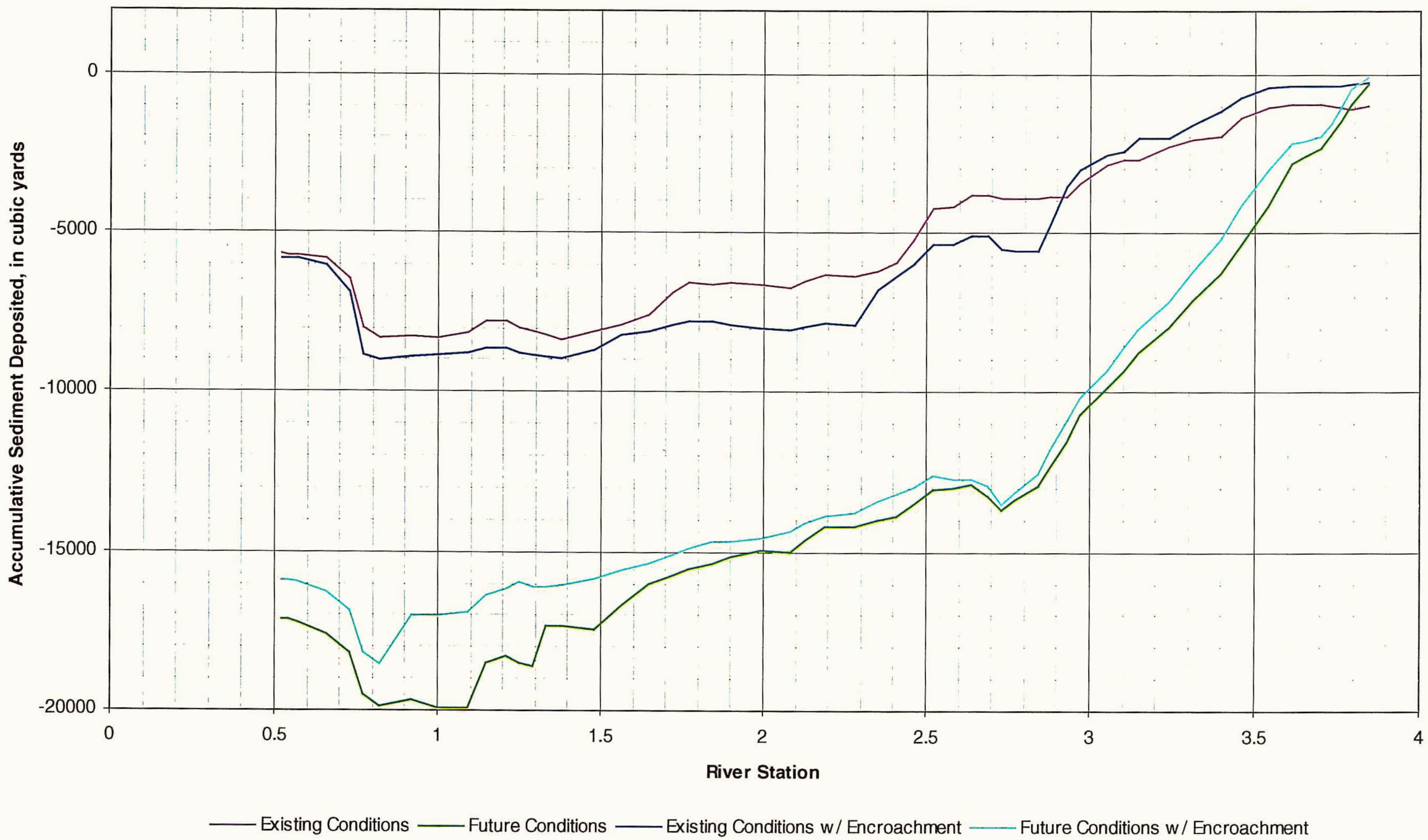
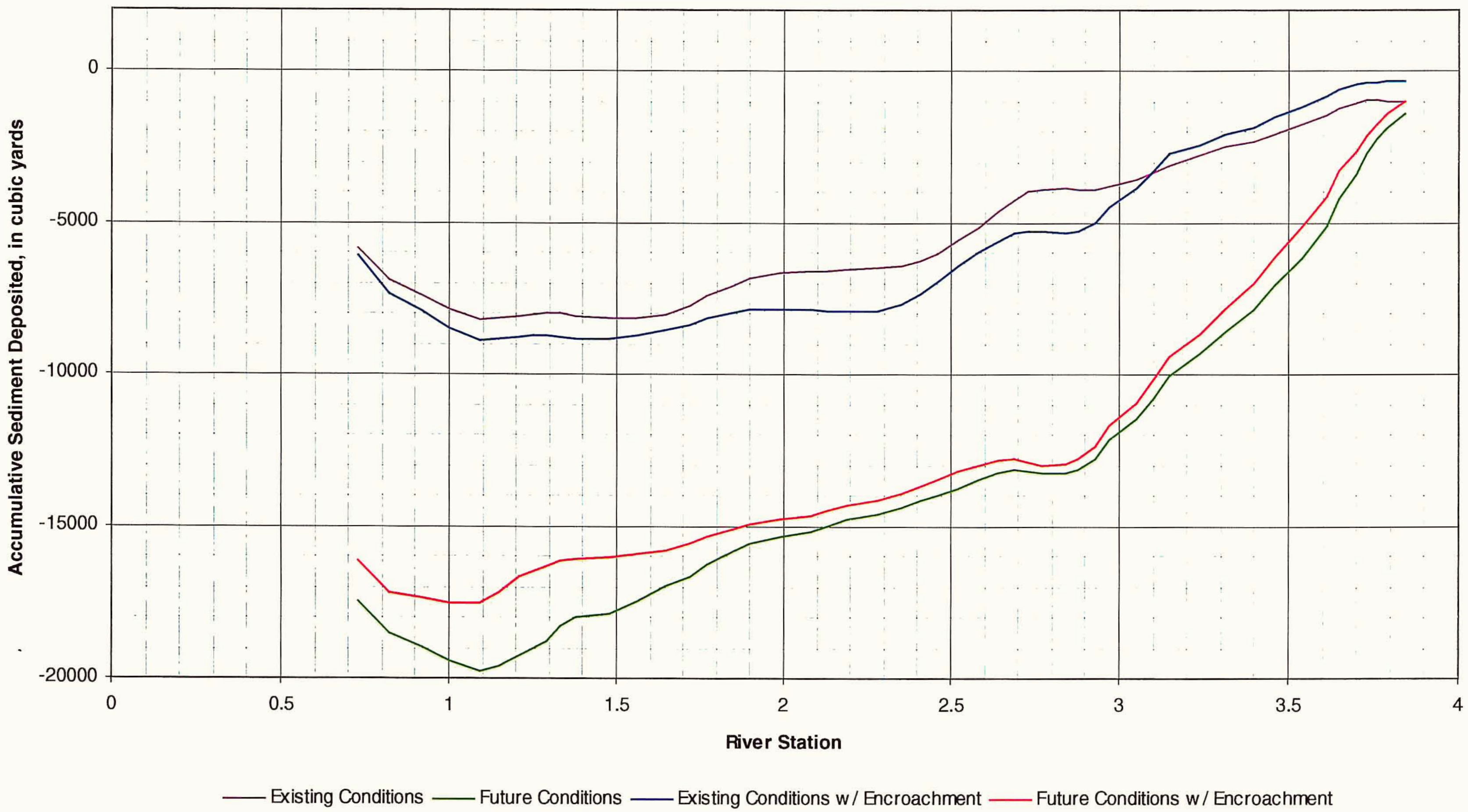


Figure 5-7.8
Accumulative sediment deposited upstream of section
Sonoran Wash, Overbank Models, 100-year flood
5-point Moving Average



5-8.0 CONCLUSIONS

5-8.1 GENERAL

An erosion and sedimentation analysis of Skunk Creek and Sonoran Wash was performed by HEC-6 modeling for the purpose of evaluating trends and spatial distributions of scour and fill in those watercourses. The information is used in the Skunk Creek Watercourse Master Plan for evaluating erosion lateral migration limits and in formulating alternatives for the study watercourses. HEC-6 modeling and analysis were conducted for the 100-year and the 10-year flood, and for existing and future conditions in the watershed for Skunk Creek. Modeling and analysis for Sonoran Wash were conducted for the 100-year and the 25-year flood, and for existing and future conditions in the watershed. Two different bed material size gradations and sediment transport functions are used in the analyses. The results of the HEC-6 models must be interpreted from the output from the two modeling methodologies. The actual rate of sediment transport in any storm could be greater or less than the values presented herein. But in general the magnitude of fill and erosion are estimates for watercourse master planning. The hydraulic components of the models are validated by comparing the hydraulics from a fixed-bed configuration of the HEC-6 models to the hydraulics from equivalent HEC-RAS models. The sensitivity of model input was evaluated and there are no unduly sensitive parameters that could adversely affect the outcome of these studies when using reasonable values for those parameters.

5-8.2 HEC-6 MODEL INPUT

5-8.2.1 Hydrology

Hydrographs for the 100-year and 10-year floods for Skunk Creek or 25-year floods for Sonoran Wash under existing and future hydrologic conditions, respectively, in the watershed were determined by watershed modeling using HEC-1. The flood hydrology was performed by others and those hydrographs are discretized, as shown in Section 5-3.2, for input into the HEC-6 models.

5-8.2.2 Watercourse Geometry

The hydraulic geometry of water courses was determined from previously developed HEC-2 models for Skunk Creek and studies performed by others for Sonoran Wash.

Those models were reviewed and adjustments made, as described in Section 5-4.3., to meet HEC-6 model requirements.

5-8.2.3 Bed Material Size Gradation

The size gradation of bed material in the watercourses was established by using field data as supplied by others. The spatial variability of the bed material size distribution was assessed. It was determined that modeling would need to be performed to meet the bed material size characteristics of the main channel and another set of models meeting the bed material size characteristics of the overbank floodplains. Bed material data and related HEC-6 modeling is described in Section 5-4.2.3.

5-8.2.4 Inflowing Sediment Load

For Sonoran Wash inflowing sediment load rating curves were developed for the upper end based on sediment transport capacity, as described in Section 5-4.2.4. For Skunk Creek, inflowing sediment data is defined for the upper boundary and a tributary (Cline Creek). Incoming sediment from minor tributaries to each watercourse are negligible compared to the sediment load in Skunk Creek, Cline Creek and Sonoran Wash.

5-8.2.5 Initial Water Surface Elevation

The initial water surface at the downstream end of Skunk Creek and Sonoran Wash was established by assuming critical depth at the CAP canal. Determination of the initial water surface elevation is described in Section 5-4.3.4.

5-8.3 HEC-6 MODEL OUTPUT

Input and output files of HEC-6 models used in these analyses are provided in digital and hard copy. The analyses of results are facilitated by numerous graphs prepared from model output. Model input and output, and graphical representation of the output is provided in the appendices.

5-8.4 EROSION AND SEDIMENTATION RESULTS

5-8.4.1 General

The HEC-6 models indicate that all the watercourses are subject to erosion and sedimentation to some extent both for large floods (100-year) and for small floods (10-

year for Skunk or 25-year for Sonoran Wash). Erosion will be exhibited largely as bank scour, but there will be some overall degradation throughout certain reaches of the watercourses. Bank scour of finer material will result in channel widening and lateral migration. Degradation, where occurring locally, will most likely be due to sorting of finer material with a tendency toward armoring of the channel bed. Fill will occur locally where there are reductions in sediment transport capacity. HEC-6 models indicate that the coarser bed material will be moved in gravel bars, resulting in pool and riffle formation. Certain reaches of the watercourses will be subject to general aggradation, mainly due to backwater from CAP overchute or diminished transport capacity. Model results are presented and interpreted in Section 4-7.0.

5-8.4.2 Skunk Creek

Large floods in Skunk Creek will result in the following erosion (scour) and sedimentation (fill) tendencies:

- Downstream of the Carefree Highway bridge, the main channel can be expected to be in an aggradation mode. That may cause avulsion of the main channel to occur during floods.
- The overbank floodplain of Skunk Creek is susceptible to aggradation and filling for the approximately 2 miles upstream of the CAP Canal.
- Upstream of the Carefree Highway bridge the main channel is subject to degradation immediately upstream of the bridge and in a few other relatively short reaches.
- The overbank floodplain is susceptible to serious sedimentation (fill and aggradation) immediately downstream of Cline Creek.
- Changing watershed conditions (that is, either existing or future conditions) for the 100-year flood will not have significant erosion and sedimentation impact to the watercourse. This is because for the study reach of Skunk Creek, there is little change in hydrology between existing and future watershed conditions. Therefore, the sediment transport capacity remains about the same resulting in little overall erosion and sedimentation impacts to the watercourse.
- Floodplain encroachment will not significantly alter the rate of sediment transport through the study reach of Skunk Creek. This is because encroachment results in

water surface elevation rise of 1 foot or less, and such a change in depth of flow does not significantly increase the sediment transport in the floodway and it eliminates any sediment transport in the floodplain fringe that is removed from the active watercourse. However, encroachment does usually result in local scour and bank attack tendencies that must be adequately accounted for and appropriate watercourse protection provided.

- Although changing watershed conditions (existing and future hydrology) and floodplain encroachment have little overall impact to sediment transport capacity in the study reach of Skunk Creek, the banks will continue to be subjected to lateral erosion and migration under both existing and future watershed conditions, and floodplain encroachment could adversely affect the rate of bank erosion and lateral migration.

5-8.4.3 Sonoran Wash

Large floods in Sonoran Wash will result in the following erosion (scour) and sedimentation (fill) tendencies:

- The main channel will be a zone of deposition from the CAP Canal upstream about 0.4 miles.
- The overbank will be a zone of deposition from the CAP Canal upstream about 1.1 miles.
- Overall, the Sonoran Wash is rather stable regarding erosion and sedimentation rates with the major factor being sediment deposition upstream of the CAP Canal.
- The wash would probably be only moderately impacted by development and/or floodplain encroachment.

5-8.5 MAJOR LIMITATIONS AND ASSUMPTIONS

The following are the major limitations and assumptions that are inherent in the analyses of erosion and sedimentation of the study watercourses:

- The HEC-6 program requires appropriate input data based on physical measurements, and data analyses.

- Interpretation of HEC-6 results is contingent upon model input and the limitations of certain modeling assumptions. Because of those input contingencies and modeling assumptions, two modeling conditions are used; one for coarse bed material, as occurs in the main channels and the other for finer material in the overbanks.

- The flood hydrology is adequately represented by HEC-1 watershed modeling methodology as defined in the District's Hydrology Manual.

- Hydraulic geometry of the watercourse is obtained from previous floodplain delineation studies.

- Size gradation of the bed material is represented by a finite sampling of that material. Although the sample size is quite large, it represents a small area of the watercourses. Sensitivity analyses indicates that uncertainty in this parameter has small effect on model results.

- Incoming sediment loads are transport capacity controlled and are estimated by sediment transport methodologies.

- Sediment transport in the watercourses can be modeled by the Meyer-Peter, Muller transport function that is representative of the coarse material in the main channel, or by the Yang Stream Power transport function for the finer material that generally occurs in the overbank floodplains.

- Future development in the watersheds does not deviate from present zoning restrictions.

- Data are not available to determine whether sediment yield from the watershed will be significantly altered by land development. However, a large part of the watershed is in National Forest or is rugged hillslope. Hydrologic analysis of existing and future watershed conditions indicates only slight impacts to flood discharges due to urbanization in this watershed. Therefore, based on those factors, the sediment yield is not expected to appreciably vary from existing conditions due to future land development.

- These results are based on future hydrologic conditions as have occurred in the recent past. It is assumed that there are no large scale impacts to the contributing watershed such as a major wildfire or extreme precipitation events producing dramatic changes to runoff or sediment yield to Skunk Creek.

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