

13.0 JACKSON CREEK

13.1 Watershed Description

Jackson Creek is an intermittent stream located in the northeastern portion of the Monument Creek watershed and flows southwesterly from the northwestern slope of the Black Forest. The Jackson Creek watershed has a contributing drainage area of approximately 4.4 square miles at its confluence with Monument Creek just north of the USAF Academy north boundary. The headwaters of Jackson Creek are dominated by dense ponderosa pine forest on 2- to 5-acre rural residential lots in unincorporated El Paso County. Just below the pines is grassland on undeveloped large-acreage tracts. The middle portion of the Jackson Creek watershed is a large development with single-family homes on small urban lots, a commercial center, and a school within the incorporated limits of the town of Monument. I-25 crosses the lower portion of the watershed surrounded by grassland on undeveloped large-acreage tracts.

13.2 Scope of Study

The portion of Jackson Creek investigated for this study is approximately 1.7 miles long starting at its confluence with Monument Creek and extending upstream to Jackson Creek Parkway. A location map of the studied reach of Jackson Creek is provided in Figure 13-1.

13.3 Channel Description

Jackson Creek is a shallow, grass-lined swale with a low-flow channel and a large connected floodplain. Downstream of Jackson Creek Parkway, the streambed and the overbank areas consist of extremely dense willow and high vegetation. The riparian vegetation consists mainly of grass and willows with some cottonwood trees in the lower reaches. Willows are very dense in some reaches. At its downstream end and closer to its confluence with Monument Creek, the streambed becomes a grassy swale with moderate-to-high vegetation along overbank areas.

13.4 Hydrology

The Jackson Creek HEC-HMS model was run for both existing and future conditions applying a 24-hour storm event with 2-, 5-, 10-, 25-, 50-, 100-, and 500-year recurrence intervals. The details related to hydrologic analysis of Jackson Creek are provided in a separate study report *Fountain Creek Watershed Preliminary Hydrology Report, URS, 2005*.

Table 13-1 summarizes URS-modeled peak discharges at points of interest throughout the Jackson Creek watershed.

Table 13-1. Peak Discharges at Points of Interest Along Jackson Creek

Location	HEC-HMS Element	Area (mi ²)	Existing Peak Discharge (cfs)							Future Peak Discharge (cfs)						
			2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	500-yr	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	500-yr
At Baptist Rd	JJA065	3.09	70	170	280	550	710	890	1,300	110	230	330	590	760	940	1,400
-	JJA095	-	130	290	420	740	920	1100	1700	170	350	490	830	1000	1200	1800
-	JJA105	-	140	300	440	770	960	1200	1700	200	390	550	910	1100	1300	1900
At I-25	JJA110	4.09	180	390	570	990	1,200	1,500	2,100	240	490	680	1,100	1,400	1,700	2,300
At confluence with Monument Creek	Jackson	4.35	210	450	660	1,100	1,400	1,700	2,400	320	610	850	1,400	1,700	2,000	2,700

Notes:
mi² = square miles
cfs = cubic feet per second
yr = year

13.5 Hydraulics

Hydraulic conditions and water surface profiles for Jackson Creek were determined by HEC-RAS modeling. The average channel slope for Jackson Creek was determined to be approximately 2.0%. Below is a brief description of different parameters involved in the modeling of Jackson Creek.

13.5.1 Manning's n-Values

Manning's n-values for the main channel and overbank portions of Jackson Creek were determined by field observation and aerial photographs. For the upper portion of the studied reach, the streambed and overbank areas of Jackson Creek consist of extremely dense willow and high vegetation. The riparian vegetation consists mainly of grass and willows with some cottonwood trees in the lower reaches. Willows are very dense in some reaches. Therefore, for the upper portion of studied reach, Manning's n-values of 0.05-0.08 and 0.12-0.15 were used for the main channel and overbank portions, respectively. At its downstream end and closer to its confluence with Monument Creek, the streambed becomes a grassy swale with moderate-to-high vegetation along overbank areas. Therefore, at all such cross sections, n-values of 0.07-0.13 and 0.03-0.045 were used for the main channel and overbank portions, respectively. Table 13-2 outlines the extent of n-values along Jackson Creek's main channel and overbank areas.

Table 13-2. Summary of Manning's Roughness n-Values Along Jackson Creek

	<i>Manning's n-Values (Overbank Portions)</i>	<i>Manning's n-Values (Main Channel)</i>
Minimum	0.07	0.03
Maximum	0.13	0.08

13.5.2 Boundary Conditions

The Jackson Creek modeling was performed under the mixed-flow regime that allows the HEC-RAS model to model both the supercritical and subcritical regimes. The downstream boundary condition for all the profiles for Jackson Creek was set at normal depth based on the downstream channel slope of 0.008 feet/feet. The upstream boundary condition for all the profiles for Jackson Creek was also set at the normal depth based on the upstream channel slope of 0.016 feet/feet.

13.5.3 Culvert Data

The information related to FHWA Chart and Scale numbers and entrance and exit loss coefficients for Jackson Creek is summarized in Table 13-3.

Table 13-3. Summary of Culvert Data for Jackson Creek

Culvert Location	FHWA Chart Number	FHWA Scale Number	Entrance Loss Coefficient	Exit Loss Coefficient
Baptist Rd	2	3	0.9	1
Struthers Rd	1	3	0.2	1
Santa Fe Trail	2	3	0.9	1

13.5.4 Study Results

Water surface profiles for Jackson Creek for the return intervals of 2-, 5-, 10-, 25-, 50-, 100-, and 500-years for the existing and future conditions are presented in Appendix J. Complete HEC-RAS output tables for Jackson Creek for the existing and future conditions are also provided in Appendix J. Tables 13-4 and 13-5 summarize hydraulic conditions from the Jackson Creek model results. This includes average channel velocity, average flow depth, average top width, and average Froude number for existing and future conditions, respectively. The average value for each of these parameters was computed by dividing the total sum of each parameter by the total number of cross sections at Jackson Creek.

**Table 13-4. Hydraulic Conditions in Jackson Creek from HEC-RAS Results
(Existing Conditions)**

Hydraulic Parameter	10-Year Event	100-Year Event	500-Year Event
Average channel velocity (ft/sec)	7.1	9.1	10.0
Average water surface depth in channel (ft)	4.9	7.2	8.4
Average top width (ft)	133.0	199.6	235.7
Average Froude number	0.7	0.7	0.7

Note:

ft/s = feet per second

**Table 13-5. Hydraulic Conditions in Jackson Creek from HEC-RAS Results
(Future Conditions)**

Hydraulic Parameter	10-Year Event	100-Year Event	500-Year Event
Average channel velocity (ft/sec)	7.4	9.3	10.3
Average water surface depth in channel (ft)	5.4	7.7	8.8
Average top width (ft)	145.8	213.7	250.4
Average Froude number	0.7	0.7	0.7

Note:

ft/s = feet per second

14.0 BLACK FOREST CREEK

14.1 Watershed Description

Black Forest Creek is an intermittent stream located in the northeastern portion of the Monument Creek watershed and flows southwesterly from the western slope of the Black Forest. The Black Forest Creek watershed has a contributing drainage area of approximately 2.2 square miles at its confluence with Monument Creek about 0.5 mile south of the USAF Academy north boundary. The headwaters of Black Forest Creek are dominated by dense ponderosa pine forest and 2- to 5-acre rural residential lots in unincorporated El Paso County. The middle of the Black Forest Creek watershed is a large development, Glen Eagle, consisting primarily of single-family homes on small lots along with some multi-family homes, a commercial center, and a school. I-25 crosses the lower reach of Black Forest Creek. The watershed in this area is characterized by grassland on the USAF Academy with new residential development occurring along the Academy's east boundary.

14.2 Scope of Study

The portion of Black Forest Creek investigated for this study is approximately 1.2 miles long starting at its confluence with Monument Creek and extending upstream to Gleneagle Detention Pond. A location map of the studied reach of Black Forest Creek is provided in Figure 14-1.

14.3 Existing HEC-RAS Data

As noted in Section 3.2 and Table 3-5, approximately 0.7 mile of Black Forest Creek was already modeled using HEC-RAS by URS in 2003 for a separate study, *Academy Floodplain Revisions–Phase II*, funded by the USAF Academy. The study reach length of Black Forest Creek for the 2003 USAF Academy Study was from the USAF Academy boundary at its upstream end to its confluence with Monument Creek. The remaining 0.5 mile of Black Forest Creek was modeled for the current study using WISE and HEC-RAS and merged with the existing HEC-RAS model of Black Forest Creek at the USAF Academy boundary. It should be noted that the boundary was very close to the furthest upstream cross section of the existing HEC-RAS model. A technical evaluation of the points where the two models were combined was conducted to ensure the stream elevations were similar, and the results are summarized in Table 3-5.

It should also be noted that the existing HEC-RAS model for Black Forest Creek was prepared to model the 10- and 100-year storm events only. Therefore, when these cross sections were evaluated

against the flows for the current study, these cross sections were not able to contain the flows for the 500-year storm event, especially for the future conditions at a few locations. The cross sections within the existing HEC-RAS model of Black Forest Creek were compared with the currently best available terrain and for the most part, they matched well. Therefore, all cross sections within the existing HEC-RAS model of Black Forest Creek that did not extend to the 500-year boundary were manually extended to the high ground by using the most current terrain. At one cross section where there was no available topography and a levee was placed to contain the higher flows; however, there was minimal overbank flow near the placed levee. In addition, the ineffective flow areas, n-values, and flows for the existing HEC-RAS model of Black Forest Creek were updated based on the latest hydrologic investigations, field visits, and aerial photographs.

14.4 Channel Description

For the major portion of the studied reach of Black Forest Creek, the streambed mostly consists of sand and weeds with a connected floodplain dominated by grass and willows at the I-25 crossing. Within the USAF Academy boundary, the main channel has some very dense willows and cattails in some reaches.

14.5 Hydrology

The Black Forest Creek HEC-HMS model was run for both existing and future conditions applying a 24-hour storm event with 2-, 5-, 10-, 25-, 50-, 100-, and 500-year recurrence intervals. The hydrologic flows for both existing and future conditions are same for Black Forest Creek. The details related to hydrologic analysis of Black Forest Creek are provided in a separate study report *Fountain Creek Watershed Preliminary Hydrology Report, URS, 2005*.

Table 14-1 summarizes URS-modeled peak discharges at points of interest throughout the Black Forest Creek watershed.

14.6 Hydraulics

Hydraulic conditions and water surface profiles for Black Forest Creek were determined by HEC-RAS modeling. The average channel slope for Black Forest Creek was determined to be approximately 2.6%. Below is a brief description of different parameters involved in the modeling of Black Forest Creek.

Table 14-1. Peak Discharges at Points of Interest Along Black Forest Creek

Location	HEC-HMS Element	Area (mi ²)	Existing Peak Discharge (cfs)							Future Peak Discharge (cfs)						
			2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	500-yr	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	500-yr
At Baptist Rd	BF010	0.74	23	75	120	240	320	390	580	23	75	120	240	320	390	580
Northeast of Pristine Dr	JBF040	1.52	170	300	400	690	850	1,000	1,400	170	300	400	690	850	1,000	1,400
At I-25	JBF050	1.98	220	450	630	1,100	1,300	1,500	2,100	220	450	630	1,100	1,300	1,500	2,100
At confluence with Monument Creek	BlkFrst	2.23	230	470	670	1,100	1,400	1,700	2,300	230	470	670	1,100	1,400	1,700	2,300

Notes:
mi² = square miles
cfs = cubic feet per second
yr = year

(The hydrologic flows for both existing and future conditions are same for Black Forest Creek)

14.6.1 Manning's n-Values

Manning's n-values for the main channel and overbank portions of Black Forest Creek were determined by field observation and aerial photographs. For the upper portion of the studied reach, the streambed of Black Forest Creek consists of sand, grass, and weeds with minor-to-moderate vegetation along overbank areas. Therefore, for the upper portion of studied reach, Manning's n-values of 0.04-0.05 and 0.07-0.10 were used for the main channel and overbank portions, respectively. At its downstream end (within the USAF Academy boundary), the main channel has some very dense willows and cattails in some reaches with moderate-to-high vegetation along overbank areas. Therefore, for the lower portion of the studied reach, Manning's n-values of 0.05-0.09 and 0.08-0.14 were used for the main channel and overbank portions, respectively. Table 14-2 outlines the extent of n-values along Black Forest Creek's main channel and overbank areas.

Table 14-2. Summary of Manning's Roughness n-Values Along Black Forest Creek

	Manning's n-Values (Overbank Portions)	Manning's n-Values (Main Channel)
Minimum	0.07	0.04
Maximum	0.14	0.09

14.6.2 Boundary Conditions

The Black Forest Creek modeling was performed under the mixed-flow regime that allows the HEC-RAS model to model both the supercritical and subcritical regimes. The downstream boundary condition for all the profiles for Black Forest Creek was set at normal depth based on the downstream channel slope of 0.05 feet/feet. The upstream boundary condition for all the profiles for Black Forest Creek was also set at the normal depth based on the upstream channel slope of 0.035 feet/feet.

14.6.3 Culvert Data

The information related to FHWA Chart and Scale numbers and entrance and exit loss coefficients for Black Forest Creek is summarized in Table 14-3.

Table 14-3. Summary of Culvert Data for Black Forest Creek

Culvert Location	FHWA Chart Number	FHWA Scale Number	Entrance Loss Coefficient	Exit Loss Coefficient
Struthers Rd	8	1	0.4	1
Bike path	2	3	0.9	1
I-25	8	1	0.4	1
Santa Fe Trail	2	3	0.9	1
Abandoned highway	8	1	0.4	1

14.6.4 Study Results

Water surface profiles for Black Forest Creek for the return intervals of 2-, 5-, 10-, 25-, 50-, 100-, and 500-years for the existing and future conditions are presented in Appendix K. Complete HEC-RAS output tables for Black Forest Creek for the existing and future conditions are also provided in Appendix K. Table 14-4 summarizes hydraulic conditions from the Black Forest Creek model results. This includes average channel velocity, average flow depth, average top width, and average Froude number for existing and future conditions, respectively. The average value for each of these parameters was computed by dividing the total sum of each parameter by the total number of cross sections at Black Forest Creek.

Table 14-4. Hydraulic Conditions in Black Forest Creek from HEC-RAS Results (Existing & Future Conditions)

Hydraulic Parameter	10-Year Event	100-Year Event	500-Year Event
Average channel velocity (ft/sec)	6.6	9.1	9.7
Average water surface depth in channel (ft)	3.5	5.2	6.2
Average top width (ft)	87.3	136.7	168.9
Average Froude number	0.7	0.8	0.8

Note:
ft/s = feet per second

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15.0 SMITH CREEK

15.1 Watershed Description

Smith Creek is a perennial stream located in the northeastern portion of the Monument Creek watershed and flows southwesterly from the western slope of Black Forest. The Smith Creek watershed has a contributing drainage area of approximately 5.7 square miles at its confluence with Monument Creek just southwest of North Gate Boulevard on the USAF Academy. The headwaters of Smith Creek are dominated by dense ponderosa pine forest on 2- to 5-acre rural residential lots and undeveloped large-acreage tracts, including Fox Run Regional Park, in unincorporated El Paso County. Just below the pines is grassland on undeveloped large-acreage tracts. The middle portion of the Smith Creek watershed has been developed with some single- and multi-family homes on small urban lots in unincorporated El Paso County and the city of Colorado Springs. The lower portion of the watershed contains the I-25 and North Gate Boulevard interchange, grassland on undeveloped large-acreage tracts, a private museum, and USAF Academy properties.

15.2 Scope of Study

The portion of Smith Creek investigated for this study is approximately 1.1 miles long starting at its confluence with Monument Creek and extending upstream to Northgate Road. A location map of the studied reach of Smith Creek is provided in Figure 15-1.

15.3 Existing HEC-RAS Data

As noted in Section 3.2 and Table 3-5, approximately 0.9 mile of Smith Creek was already modeled using HEC-RAS by URS in 2003 for a separate study, *Academy Floodplain Revisions–Phase II*, funded by the USAF Academy. The study reach length of Smith Creek for the 2003 USAF Academy Study was from the USAF Academy boundary at its upstream end to its confluence with Monument Creek. The remaining 0.2 mile of Smith Creek was modeled for the current study using WISE and HEC-RAS models and merged with the existing HEC-RAS model of Smith Creek at the USAF Academy boundary. It should be noted that the boundary was very close to the furthest upstream cross section of the existing HEC-RAS model. A technical evaluation of the points where the two models were combined was conducted to ensure the stream elevations were similar, and the results are summarized in Table 3-5.

The existing HEC-RAS model for Smith Creek was prepared to model the 10- and 100-year storm events only. Therefore, when these cross sections were evaluated against the flows for the current study, they were not able to contain the flows for the 500-year storm event, especially for the future conditions at a few locations. The cross sections within the existing HEC-RAS model of Smith Creek were compared with the currently best available terrain, and for the most part, they matched well with the most current terrain. Therefore, all cross sections within the existing HEC-RAS model of Smith Creek that did not extend to the 500-year boundary were manually extended to the high ground using the most current terrain. At two cross sections, there was no available topography and levees were placed to contain the higher flows within the right overbank; however there was minimal flow near the placed levees. In addition, the ineffective flow areas, n-values, and hydrologic flows for the existing HEC-RAS model of Smith Creek were updated based on the latest hydrologic investigations, field visits, and aerial photographs.

15.4 Channel Description

For the major portion of the studied reach of Smith Creek, the valley opens up with a low-flow channel. Downstream of I-25, the channel is deeply incised with numerous beaver dams and associated large pools. The streambed is mostly sand with the floodplain abutting the low-flow channel. The riparian vegetation consists mainly of grass and willows with some cottonwood trees in the lower reaches. Cottonwoods and willows are very dense in some reaches, especially within the main channel.

15.5 Hydrology

The Smith Creek HEC-HMS model was run for both existing and future conditions applying a 24-hour storm event with 2-, 5-, 10-, 25-, 50-, 100-, and 500-year recurrence intervals. The details related to hydrologic analysis of Smith Creek are provided in a separate study report *Fountain Creek Watershed Preliminary Hydrology Report, URS, 2005*.

Table 15-1 summarizes URS-modeled peak discharges at points of interest throughout the Smith Creek watershed.

Table 15-1. Peak Discharges at Points of Interest Along Smith Creek

Location	HEC-HMS Element	Area (mi ²)	Existing Peak Discharge (cfs)							Future Peak Discharge (cfs)						
			2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	500-yr	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	500-yr
Upstream of Pleier Dr	JSM060	3.70	42	190	340	750	1,000	1,300	2,000	42	190	340	750	1,000	1,300	2,000
At I-25	JSM090	5.37	77	280	490	1,100	1,400	1,800	2,700	95	310	540	1,100	1,500	1,900	2,900
At confluence with Monument Creek	Smith	5.66	82	290	510	1,100	1,400	1,800	2,800	110	320	560	1,200	1,500	1,900	2,900

Notes:
mi² = square miles
cfs = cubic feet per second
yr = year

15.6 Hydraulics

Hydraulic conditions and water surface profiles for Smith Creek were determined by HEC-RAS modeling. The average channel slope for Smith Creek was determined to be approximately 2.3%. Below is a brief description of different parameters involved in the modeling of Smith Creek.

15.6.1 Manning's n-Values

Manning's n-values for the main channel and overbank portions of Smith Creek were determined by field observation and aerial photographs. The streambed is mostly sand with the floodplain abutting the low-flow channel. The riparian vegetation consists mainly of grass and willows with some cottonwood trees in the lower reaches. Cottonwoods and willows are very dense in some reaches, especially within the main channel. Therefore, for most of the studied reach, Manning's n-values of 0.06-0.07 and 0.08-0.10 were used for the main channel and overbank portions, respectively. Table 15-2 outlines the extent of n-values along Smith Creek's main channel and overbank areas.

Table 15-2. Summary of Manning's Roughness n-Values Along Smith Creek

	Manning's n-Values (Overbank Portions)	Manning's n-Values (Main Channel)
Minimum	0.08	0.06
Maximum	0.10	0.07

15.6.2 Boundary Conditions

The Smith Creek modeling was performed under the mixed-flow regime that allows the HEC-RAS model to model both the supercritical and subcritical regimes. The downstream boundary condition for all the profiles for Smith Creek was set at normal depth based on the downstream channel slope of 0.046 feet/feet. The upstream boundary condition for all the profiles for Smith Creek was also set at the normal depth based on the upstream channel slope of 0.017 feet/feet.

15.6.3 Culvert Data

The information related to FHWA Chart and Scale numbers and entrance and exit loss coefficients for Smith Creek is summarized in Table 15-3.

Table 15-3. Summary of Culvert Data for Smith Creek

Culvert Location	FHWA Chart Number	FHWA Scale Number	Entrance Loss Coefficient	Exit Loss Coefficient
I-25 Northbound	8	1	0.4	1
I-25 Southbound	8	1	0.4	1
Santa Fe Trail	41	1	0.5	1

15.6.4 Study Results

Water surface profiles for Smith Creek for the return intervals of 2-, 5-, 10-, 25-, 50- 100-, and 500-years for the existing and future conditions are presented in Appendix L. Complete HEC-RAS output tables for Smith Creek for the existing and future conditions are also provided in Appendix L. Tables 15-4 and 15-5 summarize hydraulic conditions from the Smith Creek model results. This includes average channel velocity, average flow depth, average top width, and average Froude number for existing and future conditions, respectively. The average value for each of these parameters was computed by dividing the total sum of each parameter by the total number of cross sections at Smith Creek.

**Table 15-4. Hydraulic Conditions in Smith Creek from HEC-RAS Results
(Existing Conditions)**

Hydraulic Parameter	10-Year Event	100-Year Event	500-Year Event
Average channel velocity (ft/sec)	5.8	8.4	9.1
Average water surface depth in channel (ft)	2.9	5.5	7.1
Average top width (ft)	87.9	148.1	196.8
Average Froude number	0.6	0.6	0.7

Note:

ft/s = feet per second

**Table 15-5. Hydraulic Conditions in Smith Creek from HEC-RAS Results
(Future Conditions)**

Hydraulic Parameter	10-Year Event	100-Year Event	500-Year Event
Average channel velocity (ft/sec)	6.0	8.5	9.2
Average water surface depth in channel (ft)	3.0	5.7	7.3
Average top width (ft)	90.0	153.3	200.5
Average Froude number	0.6	0.6	0.7

Note:

ft/s = feet per second

16.0 MONUMENT BRANCH

16.1 Watershed Description

Monument Branch is an ephemeral stream located in the northeastern portion of the Monument Creek watershed and flows southwesterly from the southwestern edge of the Black Forest. The Monument Branch watershed has a contributing drainage area of approximately 3.3 square miles at its confluence with Monument Creek about 0.75 mile north of Reservoir No. 1 on the USAF Academy. The headwaters of Monument Branch are dominated by grassland on undeveloped large-acreage tracts in unincorporated El Paso County and the city of Colorado Springs, but single-family homes on small urban lots are planned in this area with the Flying Horse Ranch development. The middle portion of the Monument Branch watershed is a large development with single-family homes on small urban lots, multi-family apartments, and a school. I-25 crosses the lower portion of the watershed surrounded by grassland on undeveloped large-acreage tracts on the USAF Academy.

16.2 Scope of Study

The portion of Monument Branch investigated for this study is approximately 3.4 miles long starting at its confluence with Monument Creek and extending upstream to South Tributary/North Branch. A location map of the studied reach of Monument Branch is provided in Figure 16-1.

16.3 Existing HEC-RAS Data

As noted in Section 3.2 and Table 3-5, approximately 0.7 mile of Monument Branch was already modeled using HEC-RAS by URS in 2003 for a separate study, *Academy Floodplain Revisions–Phase II*, funded by the USAF Academy. The study reach length of Monument Branch for the 2003 USAF Academy Study was from the USAF Academy boundary at its upstream end to its confluence with Monument Creek. The remaining 2.7 miles of Monument Branch was modeled for the current study using WISE and HEC-RAS models and merged with the existing HEC-RAS model of Monument Branch at the USAFA boundary. It should be noted that the boundary was very close to the furthest upstream cross section of the existing HEC-RAS model. A technical evaluation of the points where the two models were combined was conducted to ensure the stream elevations were similar, and the results are summarized in Table 3-5.

The existing HEC-RAS model for Monument Branch was prepared to model the 10- and 100-year storm events only. Therefore, when these cross sections were evaluated against the flows

for the current study, they were not able to contain the flows for the 500-year storm event especially for the future conditions at a few locations. The cross sections within the existing HEC-RAS model of Monument Branch were compared with the currently best available terrain, and for the most part, they matched well with the latest terrain. Therefore, all cross sections within the existing HEC-RAS model of Monument Branch that did not extend to the 500-year boundary were manually extended to the high ground by using the most current terrain. In addition, the ineffective flow areas, n-values, and hydrologic flows for the existing HEC-RAS model of Monument Branch were updated based on the latest hydrologic investigations, field visits, and aerial photographs.

16.4 Channel Description

A grass-lined channel exists in the upper portion of the studied reach with a large connected floodplain. The middle and lower portions of the stream are a sand-bed channel with a connected floodplain and riparian vegetation on the banks at the I-25 crossing. The riparian vegetation consists mainly of grass and willows. Willows are very dense in the lower reaches.

16.5 Site-Specific Issues

Reviews of the orthophotos and the available topography determined that two small dams exist at Monument Branch. Both of these dams are located on private property, and therefore no surveying information is available for them. The first dam is located approximately 0.7 mile upstream of Voyager Parkway, and the second dam is located approximately 0.2 mile upstream of Newrd-In-Northgate 2. Both of these dams are not of significant height and impound small ponds at the upstream end.

These dams were included within the HEC-RAS model using the available topography as in-line structures (uncontrolled overflow weirs). Also, three additional cross sections were manually added at each of these dam structures. These three cross sections included a cross section at the downstream face of the structure, a cross section at the upstream face of the structure, and a cross section at the top of embankment. The available topography indicates the presence of emergency spillways adjacent to the embankments of these dams. Therefore, the cross sections drawn at the top of these embankments were extended to include the emergency spillways. Consequently, the streamline for Monument Branch was adjusted to indicate the flow passing through the emergency spillway at each dam. The available topography indicates that the normal pool level within these ponds is approximately at the corresponding emergency spillway level and remains consistent

throughout the ponds. Therefore, no natural cross section was placed within these ponds except the one placed at the upstream face of each dam. It should also be noted that no hydrologic analysis was performed for these ponds and, therefore, the flows for different storm events remain the same upstream and downstream of these ponds.

It should be noted that the hydraulic analysis at these dams was performed conservatively; however, due to the absence of the actual surveying information, the WSEs determined at and near these ponds should not be used for FEMA analysis or for any other study.

16.6 Hydrology

The Monument Branch HEC-HMS model was run for both existing and future conditions applying a 24-hour storm event with 2-, 5-, 10-, 25-, 50-, 100-, and 500-year recurrence intervals. The details related to hydrologic analysis of Monument Branch are provided in a separate study report *Fountain Creek Watershed Preliminary Hydrology Report, URS, 2005*.

Table 16-1 summarizes URS-modeled peak discharges at points of interest throughout the Monument Branch watershed.

Table 16-1. Peak Discharges at Points of Interest Along Monument Branch

Location	HEC-HMS Element	Area (mi ²)	Existing Peak Discharge (cfs)							Future Peak Discharge (cfs)						
			2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	500-yr	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	500-yr
Southeast of 90 degree bend in North Gate Rd	MB020	0.70	22	65	100	200	250	310	460	140	240	310	470	560	650	850
Downstream of Voyager Pkwy	JMB030	1.66	66	190	290	550	700	860	1,300	260	480	650	1,000	1,200	1,400	1,900
At I-25	JMB060	2.64	120	330	510	940	1,200	1,500	2,100	490	880	1,200	1,800	2,200	2,500	3,300
At confluence with Monument Creek	MonBr	3.31	160	410	630	1,200	1,500	1,800	2,600	580	1,100	1,400	2,200	2,600	3,100	4,100

Notes:
mi² = square miles
cfs = cubic feet per second
yr = year

16.7 Hydraulics

Hydraulic conditions and water surface profiles for Monument Branch were determined by HEC-RAS modeling. The average channel slope for Monument Branch was determined to be approximately 2.4%. Below is a brief description of different parameters involved in the modeling of Monument Branch.

16.7.1 Manning's n-Values

Manning's n-values for the main channel and overbank portions of Monument Branch were determined by field observation and aerial photographs. For the upper portion of the studied reach, the streambed of Monument Branch consists of sand, grass, and weeds with minor-to-moderate vegetation along overbank areas. Therefore, for the upper portion of studied reach, Manning's n-values of 0.03-0.05 and 0.07-0.10 were used for the main channel and overbank portions, respectively. At its downstream end (within the USAF Academy boundary), the main channel has some very dense willows in some reaches with moderate-to-high vegetation along overbank areas. Therefore, for the lower portion of the studied reach, Manning's n-values of 0.06-0.08 and 0.09-0.12 were used for the main channel and overbank portions, respectively. Table 16-2 outlines the extent of n-values along Monument Branch's main channel and overbank areas.

Table 16-2. Summary of Manning's Roughness n-Values Along Monument Branch

	Manning's n-Values (Overbank Portions)	Manning's n-Values (Main Channel)
Minimum	0.07	0.03
Maximum	0.12	0.08

16.7.2 Boundary Conditions

The Monument Branch modeling was performed under the mixed-flow regime that allows the HEC-RAS model to model both the supercritical and subcritical regimes. The downstream boundary condition for all the profiles for Monument Branch was set at normal depth based on the downstream channel slope of 0.023 feet/feet. The upstream boundary condition for all the profiles for Monument Branch was also set at the normal depth based on the upstream channel slope of 0.023 feet/feet.

16.7.3 Culvert Data

The information related to FHWA Chart and Scale numbers and entrance and exit loss coefficients for Monument Branch is summarized in Table 16-3.

Table 16-3. Summary of Culvert Data for Monument Branch

Culvert Location	FHWA Chart Number	FHWA Scale Number	Entrance Loss Coefficient	Exit Loss Coefficient
Newrd-in-northgate 2	29	3	0.7	1
Newrd-in-northgate	1	3	0.2	1
Voyager Pkwy	8	1	0.4	1
Northbound I-25	8	1	0.4	1
Southbound I-25	8	1	0.4	1
Santa Fe Trail	41	1	0.5	1

16.7.4 Study Results

Water surface profiles for Monument Branch for the return intervals of 2-, 5-, 10-, 25-, 50-, 100-, and 500-years for the existing and future conditions are presented in Appendix M. Complete HEC-RAS output tables for Monument Branch for the existing and future conditions are also provided in Appendix M. Tables 16-4 and 16-5 summarize hydraulic conditions from the Monument Branch model results. This includes average channel velocity, average flow depth, average top width, and average Froude number for existing and future conditions, respectively. The average value for each of these parameters was computed by dividing the total sum of each parameter by the total number of cross sections at Monument Branch.

Table 16-4. Hydraulic Conditions in Monument Branch from HEC-RAS Results (Existing Conditions)

Hydraulic Parameter	10-Year Event	100-Year Event	500-Year Event
Average channel velocity (ft/sec)	5.2	7.4	8.2
Average water surface depth in channel (ft)	2.5	4.2	5.0
Average top width (ft)	69.4	89.6	99.6
Average Froude number	0.7	0.7	0.7

Note:

ft/s = feet per second

Table 16-5. Hydraulic Conditions in Monument Branch from HEC-RAS Results (Future Conditions)

Hydraulic Parameter	10-Year Event	100-Year Event	500-Year Event
Average channel velocity (ft/sec)	6.9	8.6	9.1
Average water surface depth in channel (ft)	3.7	5.5	6.6
Average top width (ft)	85.2	105.6	127.8
Average Froude number	0.7	0.7	0.7

Note:

ft/s = feet per second

17.0 MIDDLE TRIBUTARY

17.1 Watershed Description

Middle Tributary is an intermittent stream located in the northeastern portion of the Monument Creek watershed and flows southwesterly from the southwestern edge of the Black Forest. The Middle Tributary watershed has a contributing drainage area of approximately 1.3 square miles at its confluence with Monument Creek about 0.25 mile west of Reservoir No. 1 on the USAF Academy. The headwaters of Middle Tributary are dominated by grassland on undeveloped large-acreage tracts in unincorporated El Paso County. The middle portion of the Middle Tributary watershed is a large development with single-family homes on small urban lots in the city of Colorado Springs. I-25 crosses the lower portion of the watershed surrounded by grassland and ponderosa pines on undeveloped large-acreage tracts on the USAF Academy.

17.2 Scope of Study

The portion of Middle Tributary investigated for this study is approximately 2.6 miles long starting at its confluence with Monument Creek and extending upstream to South Trib./North Branch. A location map of the studied reach of Middle Tributary is provided in Figure 17-1.

17.3 Existing HEC-RAS Model

As noted in Section 3.2 and Table 3-5, approximately 1.0 mile of Middle Tributary was already modeled using HEC-RAS by URS in 2003 for a separate study, *Academy Floodplain Revisions–Phase II*, funded by the USAF Academy. The study reach length of Middle Tributary for the 2003 USAF Academy Study was from the USAF Academy boundary at its upstream end to its confluence with Monument Creek. The remaining 1.6 miles of Middle Tributary was modeled for the current study using WISE and HEC-RAS models and merged with the existing HEC-RAS model of Middle Tributary at the USAF Academy boundary. It should be noted that the boundary was very close to the furthest upstream cross section of the existing HEC-RAS model. A technical evaluation of the points where the two models were combined was conducted to ensure the stream elevations were similar, and the results are summarized in Table 3-5.

The existing HEC-RAS model for Middle Tributary was prepared to model the 10- and 100-year storm events only. Therefore, when these cross sections were evaluated against the flows for the current study, they were not able to contain the flows for the 500-year storm event, especially for the

future conditions at a few locations. The cross sections within the existing HEC-RAS model of Middle Tributary were compared with the currently best available terrain as discussed in Section 2.1, and for the most part, they matched well with the most current terrain. Therefore, all cross sections within the existing HEC-RAS model of Middle Tributary that did not extend to the 500-year boundary were manually extended to the high ground by using the latest terrain. However, there was no available topography for approximately 0.25 mile between Stations 3006 and 4234. Therefore, levees were placed to contain the higher flows within that portion. In addition, the ineffective flow areas, n-values, and hydrologic flows for the existing HEC-RAS model of Middle Tributary were updated based on the latest hydrologic investigations, field visits, and aerial photographs.

17.4 Channel Description

A grass-lined channel exists in the upper portion of the watershed with a large connected floodplain. The middle portion of Middle Tributary has been channelized through residential development with a narrow floodplain. The lower portion of the watershed has a confined narrow valley with steep side slopes and a sand-bed channel with vegetation on the banks at the I-25 crossing. The streambed is sandy with very dense riparian vegetation encroaching on the low-flow channel.

17.5 Hydrology

The Middle Tributary HEC-HMS model was run for both existing and future conditions applying a 24-hour storm event with 2-, 5-, 10-, 25-, 50-, 100-, and 500-year recurrence intervals. The details related to hydrologic analysis of Middle Tributary are provided in a separate study report *Fountain Creek Watershed Preliminary Hydrology Report, URS, 2005*.

Table 17-1 summarizes URS-modeled peak discharges at points of interest throughout the Middle Tributary watershed.

Table 17-1. Peak Discharges at Points of Interest Along Middle Tributary

Location	HEC-HMS Element	Area (mi ²)	Existing Peak Discharge (cfs)							Future Peak Discharge (cfs)						
			2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	500-yr	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	500-yr
At Voyager Pkwy	JMT010	0.51	74	140	200	320	390	460	630	170	270	350	500	590	670	860
At I-25	RMT035	0.90	160	300	400	630	760	890	1,200	220	380	500	770	900	1,000	1,400
At confluence with Monument Creek	MidTrib	1.25	250	470	640	1,000	1,200	1,400	1,900	320	570	760	1,200	1,400	1,600	2,100

Notes:
mi² = square miles
cfs = cubic feet per second
yr = year

17.6 Hydraulics

Hydraulic conditions and water surface profiles for Middle Tributary were determined by HEC-RAS modeling. The average channel slope for Middle Tributary was determined to be approximately 2.6%. Below is a brief description of different parameters involved in the modeling of Middle Tributary.

17.6.1 Manning's n-Values

Manning's n-values for the main channel and overbank portions of Middle Tributary were determined by field observation and aerial photographs. A grass-lined channel exists in the upper portion of the watershed with a large connected floodplain. The middle portion of Middle Tributary has been channelized through residential development with a narrow floodplain. The lower portion of the watershed has a confined narrow valley with steep side slopes and a sand-bed channel with vegetation on the banks at the I-25 crossing. The streambed is sandy with very dense riparian vegetation encroaching on the low-flow channel with moderate-to-high vegetation along overbank areas. Therefore, for most of the studied reach, Manning's n-values of 0.06-0.08 and 0.08-0.12 were used for the main channel and overbank portions, respectively. Table 17-2 outlines the extent of n-values along Middle Tributary's main channel and overbank areas.

Table 17-2. Summary of Manning's Roughness n-Values Along Middle Tributary

	Manning's n-Values (Overbank Portions)	Manning's n-Values (Main Channel)
Minimum	0.08	0.06
Maximum	0.12	0.08

17.6.2 Boundary Conditions

The Middle Tributary modeling was performed under the mixed-flow regime that allows the HEC-RAS model to model both the supercritical and subcritical regimes. The downstream boundary condition for all the profiles for Middle Tributary was set at normal depth based on the downstream channel slope of 0.014 feet/feet. The upstream boundary condition for all the profiles for the Middle Tributary was also set at the normal depth based on the upstream channel slope of 0.05 feet/feet.

17.6.3 Culvert Data

The information related to FHWA Chart and Scale numbers and entrance and exit loss coefficients for Middle Tributary is summarized in Table 17-3.

Table 17-3. Summary of Culvert Data for Middle Tributary

Culvert Location	FHWA Chart Number	FHWA Scale Number	Entrance Loss Coefficient	Exit Loss Coefficient
Behind Devinci Academy	1	3	0.2	1
Voyager Pkwy	8	1	0.4	1
I-25	8	1	0.4	1
Santa Fe Trail	41	1	0.5	1

17.6.4 Study Results

Water surface profiles for Middle Tributary for the return intervals of 2-, 5-, 10-, 25-, 50-, 100-, and 500-years for the existing and future conditions are presented in Appendix N. Complete HEC-RAS output tables for Middle Tributary for the existing and future conditions are also provided in Appendix N. Tables 17-4 and 17-5 summarize hydraulic conditions from the Middle Tributary model results. This includes average channel velocity, average flow depth, average top width, and average Froude number for existing and future conditions, respectively. The average value for each of these parameters was computed by dividing the total sum of each parameter by the total number of cross sections at Middle Tributary.

**Table 17-4. Hydraulic Conditions in Middle Tributary from HEC-RAS Results
(Existing Conditions)**

Hydraulic Parameter	10-Year Event	100-Year Event	500-Year Event
Average channel velocity (ft/sec)	5.3	6.8	7.2
Average water surface depth in channel (ft)	3.5	5.3	6.3
Average top width (ft)	59.5	82.4	95.7
Average Froude number	0.6	0.6	0.6

Note:

ft/s = feet per second

**Table 17-5. Hydraulic Conditions in Middle Tributary from HEC-RAS Results
(Future Conditions)**

Hydraulic Parameter	10-Year Event	100-Year Event	500-Year Event
Average channel velocity (ft/sec)	5.8	7.2	7.5
Average water surface depth in channel (ft)	4.0	5.7	6.8
Average top width (ft)	65.4	89.3	103.7
Average Froude number	0.6	0.6	0.6

Note:

ft/s = feet per second

18.0 BLACK SQUIRREL CREEK

18.1 Watershed Description

Black Squirrel Creek is a perennial stream located in the northeastern portion of the Monument Creek watershed and flows southwesterly from the southwestern slope of the Black Forest. The Black Squirrel Creek watershed has a contributing drainage area of approximately 11 square miles at its confluence with Monument Creek near Reservoir No. 1 on the USAF Academy about 0.5 mile east of Stadium Boulevard and Road 402 interchange. The headwaters of Black Squirrel Creek are dominated by dense ponderosa pine forest and 2- to 5-acre rural residential lots in unincorporated El Paso County. Just below the pines is grassland on undeveloped large-acreage tracts. The lower portion of the Black Squirrel Creek watershed is single-family homes on small urban lots with interspersed commercial centers within the limits of the city of Colorado Springs. I-25 crosses the lower reach of Black Squirrel Creek on the USAF Academy, which is characterized by grassland.

18.2 Scope of Study

The portion of Black Squirrel Creek investigated for this study is approximately 5.0 miles long starting at its confluence with Monument Creek and extending upstream to a point approximately 0.6 mile upstream of SH83. A location map of the studied reach of Black Squirrel Creek is provided in Figure 18-1.

18.3 Existing HEC-RAS Model

As noted in Section 3.2 and Table 3-5, approximately 1.0 mile of Black Squirrel Creek was already modeled using HEC-RAS by URS in 2003 for a separate study, *Academy Floodplain Revisions–Phase II*, funded by the USAF Academy. The study reach length of Black Squirrel Creek for the 2003 USAF Academy Study was from the USAF Academy boundary at its upstream end to its confluence with Monument Creek. The remaining 4.0 miles of Black Squirrel Creek was modeled for the current study using WISE and HEC-RAS models and merged with the existing HEC-RAS model of Black Squirrel Creek at the USAF Academy boundary. The USAF Academy boundary was very close to the furthest upstream cross section of the existing HEC-RAS model. A technical evaluation of the points where the two models were combined was conducted to ensure the stream elevations were similar, and the results are summarized in Table 3-5.

The existing HEC-RAS model for Black Squirrel Creek was prepared to model the 10- and 100-year storm events only. Therefore, when these cross sections were evaluated against the flows for the current

study, they were not able to contain the flows for the 500-year storm event, especially for the future conditions at a few locations. The cross sections within the existing HEC-RAS model of Black Squirrel Creek were compared with the currently best available terrain, and for the most part, they matched well with the most current terrain. Therefore, all cross sections within the existing HEC-RAS model of Black Squirrel Creek that did not extend to the 500-year boundary were manually extended to the high ground by using the most current terrain. In addition, the ineffective flow areas, n-values, and hydrologic flows for the existing HEC-RAS model of Black Squirrel Creek were updated based on the latest hydrologic investigations, field visits, and aerial photographs.

18.4 Channel Description

For the major portion of the studied reach, the main channel remains a grass swale with a sandy bed experiencing moderate-to-high vegetation along overbank areas. Just upstream of the USAF Academy are a series of ponds and a wide channel. Within the USAF Academy boundary, the streambed is sandy with grass and brush in the low-flow channel. Willows and cattails are very dense in some reaches.

18.5 Site-Specific Issues

Reviews of the orthophotos and the available topography determined that upstream of the USAF Academy is a series of ponds. These ponds are located on private property, and therefore no surveying information is available for them. The upstream-most dam is located approximately 0.3 mile upstream of the USAF Academy boundary. The downstream-most dam is located only 150 feet upstream of the USAF Academy boundary. These dams were included within the HEC-RAS model using the available topography as in-line structures (uncontrolled overflow weirs). Also, three additional cross sections were manually added at each of these dam structures. These three cross sections included a cross section at the downstream face of the structure, a cross section at the upstream face of the structure, and a cross section at the top of the embankment. The available topography indicates the presence of emergency spillways adjacent to the embankments of these dams. Therefore, the cross sections drawn at the top of these embankments were extended to include the emergency spillways. Consequently, the streamline for Black Squirrel Creek was adjusted to indicate the flow passing through the emergency spillway at each dam. The available topography indicates that the normal pool level within these ponds is approximately at the corresponding emergency spillway level and remains consistent throughout the ponds. Therefore, no natural cross section was placed within these ponds except the one placed at the upstream face of each dam. It should also be noted that no

hydrologic analysis was performed for these ponds and, therefore, the flows for different storm events remain the same upstream and downstream of these ponds.

In addition to the series of dams as discussed above, the review of the orthophotos and the available topography indicated the presence of two small dams at Black Squirrel Creek further upstream. No surveying information is available for these structures. They are located approximately 0.2 and 0.4 mile upstream of Voyager Parkway. The available topography indicates the presence of an emergency spillway adjacent to the embankment of only one dam, the one 0.4 mile upstream of Voyager Parkway. These structures were modeled using the same approach as discussed in the paragraph above.

It should be noted that the hydraulic analysis at these dams was performed conservatively; however, due to the absence of the actual surveying information, the WSELs determined at and near these ponds should not be used for FEMA analysis or for any other study.

18.6 Hydrology

The Black Squirrel Creek HEC-HMS model was run for both existing and future conditions applying a 24-hour storm event with 2-, 5-, 10-, 25-, 50-, 100-, and 500-year recurrence intervals. The details related to hydrologic analysis of Black Squirrel Creek are provided in a separate study report *Fountain Creek Watershed Preliminary Hydrology Report, URS, 2005*.

Table 18-1 summarizes URS-modeled peak discharges at points of interest throughout the Black Squirrel Creek watershed.

Table 18-1. Peak Discharges at Points of Interest Along Black Squirrel Creek

Location	HEC-HMS Element	Area (mi ²)	Existing Peak Discharge (cfs)							Future Peak Discharge (cfs)						
			2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	500-yr	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	500-yr
At Hwy 83	JBS180	9.0	43	270	550	1,400	1,900	2,500	4,100	46	280	570	1,400	2,000	2,600	4,200
At Voyage Pkwy	JBS200	9.9	60	300	600	1,500	2,000	2,700	4,400	190	350	680	1,600	2,200	2,900	4,600
At I-25	JBS220	10.6	73	320	630	1,500	2,100	2,800	4,500	210	390	720	1,700	2,300	3,000	4,800
At confluence with Monument Creek	BlkSqrl	11.0	72	320	640	1,600	2,100	2,800	4,500	210	390	730	1,700	2,300	3,000	4,800

Notes:
mi² = square miles
cfs = cubic feet per second
yr = year

18.7 Hydraulics

Hydraulic conditions and water surface profiles for Black Squirrel Creek were determined by HEC-RAS modeling. The average channel slope for Black Squirrel Creek was determined to be approximately 1.7%. Below is a brief description of different parameters involved in the modeling of Black Squirrel Creek.

18.7.1 Manning's n-Values

Manning's n-values for the main channel and overbank portions of Black Squirrel Creek were determined by field observation and aerial photographs. For most of the studied reach, the main channel remains a grass swale with a sandy bed experiencing moderate-to-high vegetation along overbank areas. Therefore, for the upper portion of the studied reach, Manning's n-values of 0.04-0.05 and 0.08-0.13 were used for the main channel and overbank portions, respectively. However, between Voyager Parkway and Santa Fe Trail, the main channel has some very dense willows in some reaches. Therefore, for that portion, n-values of 0.07-0.10 were used for the main channel. Table 18-2 outlines the extent of n-values along Black Squirrel Creek's main channel and overbank areas.

Table 18-2. Summary of Manning's Roughness n-Values Along Black Squirrel Creek

	Manning's n-Values (Overbank Portions)	Manning's n-Values (Main Channel)
Minimum	0.08	0.04
Maximum	0.13	0.10

18.7.2 Boundary Conditions

The Black Squirrel Creek modeling was performed under the mixed-flow regime that allows the HEC-RAS model to model both the supercritical and subcritical regimes. The downstream boundary condition for all the profiles for the Black Squirrel Creek was set at normal depth based on the downstream channel slope of 0.014 feet/feet. The upstream boundary condition for all the profiles for Black Squirrel Creek was also set at the normal depth based on the upstream channel slope of 0.02 feet/feet.

18.7.3 Culvert Data

The information related to FHWA Chart and Scale numbers and entrance and exit loss coefficients for Black Squirrel Creek is summarized in Table 18-3.

Table 18-3. Summary of Culvert Data for Black Squirrel Creek

Culvert Location	FHWA Chart Number	FHWA Scale Number	Entrance Loss Coefficient	Exit Loss Coefficient
Voyager Pkwy	8	1	0.4	1
Private road	34	3	0.9	1
Santa Fe Trail	41	1	0.5	1

18.7.4 Study Results

Water surface profiles for Black Squirrel Creek for the return intervals of 2-, 5-, 10-, 25-, 50-, 100-, and 500-years for the existing and future conditions are presented in Appendix O. Complete HEC-RAS output tables for Black Squirrel Creek for the existing and future conditions are also provided in Appendix O. Tables 18-4 and 18-5 summarize hydraulic conditions from the Black Squirrel Creek model results. This includes average channel velocity, average flow depth, average top width, and average Froude number for existing and future conditions, respectively. The average value for each of these parameters was computed by dividing the total sum of each parameter by the total number of cross sections at Black Squirrel Creek.

**Table 18-4. Hydraulic Conditions in Black Squirrel Creek from HEC-RAS Results
(Existing Conditions)**

Hydraulic Parameter	10-Year Event	100-Year Event	500-Year Event
Average channel velocity (ft/sec)	6.5	10.6	12.2
Average water surface depth in channel (ft)	4.0	7.7	9.6
Average top width (ft)	83.4	119.6	138.4
Average Froude number	0.7	0.7	0.7

Note:
ft/s = feet per second

**Table 18-5. Hydraulic Conditions in Black Squirrel Creek from HEC-RAS Results
(Future Conditions)**

Hydraulic Parameter	10-Year Event	100-Year Event	500-Year Event
Average channel velocity (ft/sec)	6.7	10.7	12.3
Average water surface depth in channel (ft)	4.2	8.0	9.9
Average top width (ft)	85.8	122.5	140.6
Average Froude number	0.7	0.7	0.7

Note:
ft/s = feet per second

19.0 ELKHORN TRIBUTARY

19.1 Watershed Description

Elkhorn Tributary is an ephemeral stream located in the northeastern portion of the Monument Creek watershed and flows southwesterly from the southwestern edge of the Black Forest. The Elkhorn watershed has a contributing drainage area of approximately 0.89 square mile for existing conditions and 1.1 square miles for future conditions at its confluence with Monument Creek northwest of the USAF Academy Airfield. The headwaters of Elkhorn watershed are dominated grassland on undeveloped large-acreage tracts in the city of Colorado Springs. The middle portion of the Elkhorn watershed is currently being developed into a commercial park also contained within the limits of the city of Colorado Springs. The lower portion of the Elkhorn watershed is grassland and crosses I-25 on the USAF Academy.

19.2 Scope of Study

The portion of Elkhorn Tributary investigated for this study is approximately 1.4 miles long starting at its confluence with Monument Creek and extending upstream to the USAF Academy boundary. A location map of the studied reach of Elkhorn Tributary is provided in Figure 19-1.

19.3 Existing HEC-RAS Model

As noted in Section 3.2 and Table 3-5, approximately 1.4 miles of Elkhorn Tributary was already modeled using HEC-RAS by URS in 2003 for a separate study, *Academy Floodplain Revisions–Phase II*, funded by the USAF Academy. That the existing HEC-RAS model for Elkhorn Tributary was prepared to model the 10- and 100-year storm events only. Therefore, when these cross sections were evaluated against the flows for the current study, they were not able to contain the flows for the 500-year storm event, especially for the future conditions at a few locations. The cross sections within the existing HEC-RAS model of Elkhorn Tributary were compared with the currently best available terrain, and for the most part, they matched well with the latest terrain. Therefore, all cross sections within the existing HEC-RAS model of Elkhorn Tributary that did not extend to the 500-year boundary were manually extended to the high ground by using the latest terrain. However, there was no available topography for approximately 0.60 mile between Stations 6059 and 2743. Therefore, levees were placed to contain the higher flows within that portion, wherever needed. In addition, the ineffective flow areas, n-values, and hydrologic flows for the

existing HEC-RAS model of Elkhorn Tributary were updated based on the latest hydrologic investigations, field visits, and aerial photographs.

19.4 Channel Description

In the upper portion of the studied reach, the main channel is an eroded sand-bed channel that crosses I-25 on the USAF Academy. The overbank areas experience minor-to-moderate vegetation. Downstream of I-25, the main channel becomes a low-flow channel with grass and weeds in the main channel experiencing moderate-to-high vegetation along the overbank areas.

19.5 Hydrology

The Elkhorn Tributary HEC-HMS model was run for both existing and future conditions applying a 24-hour storm event with 2-, 5-, 10-, 25-, 50-, 100-, and 500-year recurrence intervals. The details related to hydrologic analysis of Elkhorn Tributary are provided in a separate study report *Fountain Creek Watershed Preliminary Hydrology Report, URS, 2005*.

Table 19-1 summarizes URS-modeled peak discharges at points of interest throughout the Elkhorn Tributary watershed.

Table 19-1. Peak Discharges at Points of Interest Along Elkhorn Tributary

Location	HEC-HMS Element	Area (mi ²)	Existing Peak Discharge (cfs)							Area ¹ (mi ²)	Future Peak Discharge (cfs)						
			2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	500-yr		2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	500-yr
At Hwy 83	JEC020	0.31	0.2	1.5	7.7	44	72	100	190	0.54	200	340	440	650	760	880	1,100
At I-25	JEC040	0.71	3.6	11	15	38	52	68	110	0.94	21	78	150	280	320	390	740
At confluence with Monument Creek	Elkhorn	0.89	4.2	14	31	75	100	130	210	1.12	21	82	160	300	350	420	810

Note:
mi² = square miles
cfs = cubic feet per second
yr = year

19.6 Hydraulics

Hydraulic conditions and water surface profiles for Elkhorn Tributary were determined by HEC-RAS modeling. The average channel slope for Elkhorn Tributary was determined to be approximately 2.7%. Below is a brief description of different parameters involved in the modeling of Elkhorn Tributary.

19.6.1 Manning's n-Values

Manning's n-values for the main channel and overbank portions of Elkhorn Tributary were determined by field observation and aerial photographs. In the upper portion of the studied reach, the main channel is an eroded sand-bed channel that crosses I-25 on the USAF Academy. The overbank areas experience minor-to-moderate vegetation. Therefore, for most of the upper portion of the studied reach, Manning's n-values of 0.02 and 0.07 were used for the main channel and overbank portions, respectively. Downstream of I-25, the main channel becomes a low-flow channel with grass and weeds in it and moderate-to-high vegetation along overbank areas. Therefore, for most of the lower portion of the studied reach, Manning's n-values of 0.04-0.05 and 0.08-0.12 were used for the main channel and overbank portions, respectively. Table 19-2 outlines the extent of n-values along Elkhorn Tributary's main channel and overbank areas.

Table 19-2. Summary of Manning's Roughness n-Values Along Elkhorn Tributary

	Manning's n-Values (Overbank Portions)	Manning's n-Values (Main Channel)
Minimum	0.07	0.02
Maximum	0.12	0.05

19.6.2 Boundary Conditions

The Elkhorn Tributary modeling was performed under the mixed-flow regime that allows the HEC-RAS model to model both the supercritical and subcritical regimes. The downstream boundary condition for all the profiles for Elkhorn Tributary was set at normal depth based on the downstream channel slope of 0.075 feet/feet. The upstream boundary condition for all the profiles for Elkhorn Tributary was also set at the normal depth based on the upstream channel slope of 0.096 feet/feet.

19.6.3 Culvert Data

The information related to FHWA Chart and Scale numbers and entrance and exit loss coefficients for Elkhorn Tributary is summarized in Table 19-3.

Table 19-3. Summary of Culvert Data for Elkhorn Tributary

Culvert Location	FHWA Chart Number	FHWA Scale Number	Entrance Loss Coefficient	Exit Loss Coefficient
I-25	1	3	0.2	1
Abandoned highway	8	1	0.4	1
18-inch CMP	2	3	0.9	1
30-inch CMP	2	3	0.9	1

19.6.4 Study Results

Water surface profiles for Elkhorn Tributary for the return intervals of 2-, 5-, 10-, 25-, 50-, 100-, and 500-years for the existing and future conditions are presented in Appendix P. Complete HEC-RAS output tables for Elkhorn Tributary for the existing and future conditions are also provided in Appendix P. Tables 19-4 and 19-5 summarize hydraulic conditions from the Elkhorn Tributary model results. This includes average channel velocity, average flow depth, average top width, and average Froude number for existing and future conditions, respectively. The average value for each of these parameters was computed by dividing the total sum of each parameter by the total number of cross sections at Elkhorn Tributary.

**Table 19-4. Hydraulic Conditions in Elkhorn Tributary from HEC-RAS Results
(Existing Conditions)**

Hydraulic Parameter	10-Year Event	100-Year Event	500-Year Event
Average channel velocity (ft/sec)	3.7	5.7	6.6
Average water surface depth in channel (ft)	0.8	1.4	1.8
Average top width (ft)	44.1	69.8	82.3
Average Froude number	1.1	1.1	1.1

Note:

ft/s = feet per second

**Table 19-5. Hydraulic Conditions in Elkhorn Tributary from HEC-RAS Results
(Future Conditions)**

Hydraulic Parameter	10-Year Event	100-Year Event	500-Year Event
Average channel velocity (ft/sec)	6.3	7.9	9.8
Average water surface depth in channel (ft)	1.7	2.9	3.6
Average top width (ft)	78.2	125.9	142.1
Average Froude number	1.1	1.0	1.1

Note:

ft/s = feet per second

20.0 PINE CREEK

20.1 Watershed Description

Pine Creek is an intermittent stream located in the eastern portion of the Monument Creek watershed and flows southwesterly from the southwestern edge of the Black Forest. The Pine Creek watershed has a contributing drainage area of approximately 9.4 square miles at its confluence with Monument Creek about 0.5 mile northwest of the I-25 and Woodmen Road interchange in north-central Colorado Springs. The headwaters of Pine Creek are dominated grassland on undeveloped large-acreage tracts and 2- to 5-acre rural residential lots in unincorporated El Paso County and the city of Colorado Springs. The middle and lower portions of the Pine Creek watershed are contained within the limits of the city of Colorado Springs. These portions of the watershed have been densely developed into residential areas consisting primarily of single-family homes on small urban lots and commercial centers including the Chapel Hills Mall. The I-25 and Academy Boulevard interchange is located in the lower portion of the watershed near the mouth of Pine Creek.

20.2 Scope of Study

The portion of Pine Creek investigated for this study is approximately 1.4 miles long starting at its confluence with Monument Creek and extending upstream to the USAF Academy boundary. A location map of the studied reach of Pine Creek is provided in Figure 20-1.

20.3 Existing HEC-RAS Model

As noted in Section 3.2 and Table 3-5, approximately 0.8 mile of Pine Creek was already modeled using HEC-RAS by URS in 2003 for a separate study, *Academy Floodplain Revisions–Phase II*, funded by the USAF Academy. The study reach length of Pine Creek for the 2003 USAF Academy Study was from the USAF Academy boundary at its upstream end to the Academy Boulevard. The remaining 0.6 mile of Pine Creek, from Academy Boulevard to its confluence with Monument Creek, was modeled for the current study using WISE and HEC-RAS models and merged with the existing HEC-RAS model of Pine Creek at the boundary. A technical evaluation of the points where the two models were combined was conducted to ensure the stream elevations were similar, and the results are summarized in Table 3-5. The Pine Creek streamline within the USAF Academy boundary was adjusted and matched with the streamline used in 2003 study to ensure that the stream elevations at the merging point of the two models do not differ significantly.

The existing HEC-RAS model for Pine Creek was prepared to model the 10- and 100-year storm events only. Therefore, when these cross sections were evaluated against the flows for the current study, they were not able to contain the flows for the 500-year storm event especially for the future conditions at a few locations. The cross sections within the existing HEC-RAS model of Pine Creek were compared with the currently best available terrain, and for the most part, they matched well with the most current terrain. Therefore, all cross sections within the existing HEC-RAS model of Pine Creek that did not extend to the 500-year boundary were manually extended to the high ground by using the most current terrain. In addition, the ineffective flow areas, n-values, and hydrologic flows for the existing HEC-RAS model of Pine Creek were updated based on the latest hydrologic investigations, field visits, and aerial photographs.

20.4 Channel Description

For the upper portion of the studied reach, the channel is well developed with heavy vegetation on both the channel bottom and the floodplains. The lower Pine Creek becomes deeply incised with boulder, gravel on the bottom, and bushes/trees on the floodplains.

20.5 Hydrology

The Pine Creek HEC-HMS model was run for both existing and future conditions applying a 24-hour storm event with 2-, 5-, 10-, 25-, 50-, 100-, and 500-year recurrence intervals. The details related to hydrologic analysis of Pine Creek are provided in a separate study report *Fountain Creek Watershed Preliminary Hydrology Report, URS, 2005*.

Table 20-1 summarizes URS-modeled peak discharges at points of interest throughout the Pine Creek watershed.

Table 20-1. Peak Discharges at Points of Interest Along Pine Creek

Location	HEC-HMS Element	Area (mi ²)	Existing Peak Discharge (cfs)							Future Peak Discharge (cfs)						
			2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	500-yr	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	500-yr
At Briargate Blvd	Detention Pine	3.53	180	390	570	1,000	1,300	1,500	2,000	380	680	930	1,400	1,700	1,900	2,900
Downstream of Hwy 83	JPC040	4.25	210	430	620	1,100	1,400	1,600	2,100	400	720	980	1,500	1,800	2,000	3,100
At North Academy Blvd	JPC050	4.50	210	440	630	1,100	1,400	1,600	2,100	400	730	990	1,500	1,800	2,000	3,100
At confluence with Monument Creek	PineCrk	9.43	2,600	4,300	5,500	8,100	9,500	11,000	14,000	2,600	4,300	5,500	8,100	9,500	11,000	14,000

Notes:
mi² = square miles
cfs = cubic feet per second
yr = year

20.6 Hydraulics

Hydraulic conditions and water surface profiles for Pine Creek were determined by HEC-RAS modeling. The average channel slope for Pine Creek was determined to be approximately 2.3%. Below is a brief description of different parameters involved in the modeling of Pine Creek.

20.6.1 Manning's n-Values

Manning's n-values for the main channel and overbank portions of Pine Creek were determined by field observation and aerial photographs. In the upper portion of the studied reach, the channel is well developed with heavy vegetation on both the channel bottom and the floodplains. Therefore, for most of the upper part of the studied reach, Manning's n-values of 0.04-0.05 and 0.07-0.11 were used for the main channel and overbank portions, respectively. The lower Pine Creek becomes deeply incised with boulder, gravel on the bottom, and bushes/trees on the floodplains. Therefore, for the lower Pine Creek, Manning's n-value of 0.03 was used for the main channel. It should be noted that at some structures, extensive riprap has been used within the main channel and the overbank areas. Accordingly, n-value for the riprap has been used at those cross sections. Table 20-2 outlines the extent of n-values along Pine Creek's main channel and overbank areas.

Table 20-2. Summary of Manning's Roughness n-Values Along Pine Creek

	Manning's n-Values (Overbank Portions)	Manning's n-Values (Main Channel)
Minimum	0.07	0.03
Maximum	0.11	0.05

20.6.2 Boundary Conditions

The Pine Creek modeling was performed under the mixed-flow regime that allows the HEC-RAS model to model both the supercritical and subcritical regimes. The downstream boundary condition for all the profiles for Pine Creek was set at normal depth based on the downstream channel slope of 0.007 feet/feet. The upstream boundary condition for all the profiles for Pine Creek was also set at the normal depth based on the upstream channel slope of 0.0001 feet/feet.

20.6.3 Culvert Data

There is no culvert at Pine Creek in our studied reach; therefore, no information related to FHWA Chart and Scale numbers and entrance and exit loss coefficients is required.

20.6.4 Study Results

Water surface profiles for Pine Creek for the return intervals of 2-, 5-, 10-, 25-, 50-, 100-, and 500-years for the existing and future conditions are presented in Appendix Q. Complete HEC-RAS output tables for Pine Creek for the existing and future conditions are also provided in Appendix Q. Tables 20-3 and 20-4 summarize hydraulic conditions from the Pine Creek model results. This includes average channel velocity, average flow depth, average top width, and average Froude number for existing and future conditions, respectively. The average value for each of these parameters was computed by dividing the total sum of each parameter by the total number of cross sections at Pine Creek.

**Table 20-3. Hydraulic Conditions in Pine Creek from HEC-RAS Results
(Existing Conditions)**

Hydraulic Parameter	10-Year Event	100-Year Event	500-Year Event
Average channel velocity (ft/sec)	10.3	12.9	14.1
Average water surface depth in channel (ft)	6.9	10.4	11.9
Average top width (ft)	64.5	88.6	99.7
Average Froude number	0.9	0.9	0.9

Note:

ft/s = feet per second

**Table 20-4. Hydraulic Conditions in Pine Creek from HEC-RAS Results
(Future Conditions)**

Hydraulic Parameter	10-Year Event	100-Year Event	500-Year Event
Average channel velocity (ft/sec)	11.3	13.7	15.2
Average water surface depth in channel (ft)	7.4	10.7	12.4
Average top width (ft)	71.5	93.9	108.6
Average Froude number	0.9	0.9	0.9

Note:

ft/s = feet per second