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November 18, 2008

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Pueblo County Attorney's Office
215 W 10th St
Pueblo CO 81003

Re: Fountain Creek, El Paso and Pueblo Counties, Colorado

Dear Lawyers:

This firm represents the Speight Family Partnership, LLLP, and Ralph Williams, Trustee of the Greenview Trust, who recently lost a civil case against the City of Colorado Springs and others. I enclose a copy of the Order entered August 28, 2008, by Judge Samelson in Case No. 01CV1290, District Court, El Paso County, Colorado.

Evidence in that case included:

1) "Expert Report of Dr. Michael D. Harvey for the District Court of El Paso County, Colorado, Regarding Erosion at Two Sites along Fountain Creek During the Floods of April and May 1999," dated March 18, 2008;

2) "Supplemental Expert Report of Dr. Michael D. Harvey for the District Court of El Paso County, Colorado, Regarding Erosion at Two Sites along Fountain Creek During the Floods of April and May 1999," dated May 12, 2008; and

3) Expert Report to the City Attorney for Colorado Springs, Colorado in reference to El Paso County District Court Case No. 01CV1290, by Matthew Garcia, MS, under the direction of Prof. Larry Roesner, PhD, PE, PH, in four parts dated July 31, 2002, May 21, 2003, and June 3, 2003.

copies of which are enclosed on disk in PDF format.

I also enclose a copy of Hazard Mitigation Grant Program, related to the Stafford Act.

Please observe that the Judge in the Colorado District Court ruled that Colorado Springs and El Paso County have no legal duty to protect downstream riparian properties from greatly increased urban drainage, despite the established fact that the flooding danger created by this increased drainage and lack of detention were known and outlined in their own drainage basin planning studies. The expert reports show that the peak flow rate shown in Figure 29a increased from about 13,800 to about 17,400 cubic feet per second of time, and peak velocities shown in Figure 29b

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increased from about 12.6 to about 13.8 feet per second, in the floods of April 30, 1999 at Greenview Ditch Headworks, due to uncontrolled urban runoff from the Colorado Springs area.

The 1999 flooding was declared a Federal "disaster" and both Colorado Springs and El Paso County received grants in millions of dollars. The next big rainstorm is sure to cause more damage, but no mitigation of the problems which caused the 1999 disaster has been undertaken.

I have written letters to the local floodplain administrator, the Bureau of Reclamation, the Environmental Protection Agency, and the Federal Emergency Management Agency and other Federal officials.

Since Colorado state law does not protect riparian properties along Fountain Creek from similar disasters in the future, I respectfully ask that you consider this problem and encourage Federal legislation to protect those properties.

Thank you.

Very truly yours,

M. E. MacDougall
for the firm

MEM/em

Enclosures
cc: Greenview Trust (w/out encl)
Speight Family Partnership (w/out encl)
Shane White (w/out encl)
Lori Seago (w/out encl)

GRANTED Within 10 days from the date of this order, the moving party is directed to furnish a copy of this order to any pro se party who has entered an appearance in this action.	Kirk S. Samelson Kirk S. Samelson District Court Judge Date of order indicated on attachment

DISTRICT COURT, EL PASO COUNTY, COLORADO 270 South Tejon, Colorado Springs, CO 80903 P.O. Box 2980, Colorado Springs, CO 80901-2980	EFILED Document CO El Paso County District Court 4th JD Filing Date: Aug 28 2008 8:53AM MDT Filing ID: 21268352 Review Clerk: Kathy Livornese
Plaintiffs: THE SPEIGHT FAMILY PARTNERSHIP, LLLP, a Colorado Limited Liability Limited Partnership, and THE GREENVIEW TRUST, Ralph R. Williams, Trustee. v. **Defendants:** THE CITY OF COLORADO SPRINGS, a home rule City of the State of Colorado, and THE BOARD OF COUNTY COMMISSIONERS OF THE COUNTY OF EL PASO.	**Δ Court Use Only Δ** Case No.: 2001 CV 1290 Div. 14 Ctrm.: S502

FINDINGS, JUDGMENT AND ORDER

THE COURT, having heard the above-captioned matter at bench trial on July 22-24 and 29-31, 2008, makes the following findings of fact and law based upon the evidence presented, testimony elicited and exhibits submitted during trial:

1. This case is about an alleged failure on the part of the Defendants to construct certain storm water detention ponds and reduce storm water flows in excess of historical flows into Fountain Creek contributed by the Defendants and by the importation of trans-basin water by the Defendant City.

2. The Colorado Governmental Immunity Act provides that public entities waive sovereign immunity for injuries caused by the dangerous condition of a public water or sanitation facility. §24-10-106(e), C.R.S. To establish a waiver of sovereign immunity, Plaintiffs must establish that their injuries were the result of (1) a physical condition of a public facility or the use thereof, (2) which constitutes an unreasonable risk to the health or safety of the public, (3) which is known or should have been known to exist in the exercise of reasonable care, and (4) which condition is proximately caused by the negligent act or omission of a public entity in constructing or maintaining such facility. *Padilla ex rel. Padilla v. School Dist. No. 1 in City and County of Denver*, 1 P.3d 256, 259 (Colo.App. 1999) (emphasis added).

3. The Colorado Governmental Immunity Act also provides that public entities waive governmental immunity for injuries caused by the negligent operation and maintenance of public water and sanitation facilities if such operation and maintenance is negligent. §§24-10-106(1)(f) and (4).

4. In their Complaint, Plaintiffs also alleged that their injuries result from a private nuisance caused by Defendants. Negligence is also an element of this tort relating to an interference with the use and enjoyment of property. *Lowder v. Tina Marie Homes, Inc.*, 601 P.2d 657 (Colo.App. 1979).

5. In order to establish negligence, Plaintiffs must establish a duty owed them by Defendants, a breach of that duty, and that the breach proximately caused their damages.

6. Plaintiffs have failed to establish a duty owed them by Defendants, as Defendants had no duty to construct storm water detention ponds. In support of this finding, the Court notes the following:

   a. Plaintiffs have argued that the Defendants have a duty not to increase storm water flows in such a manner to do more harm than formerly. They rely on the cases of *Bittersweet Farms, Inc. v. Zimbelman*, 976 P.2d 326 (Colo.App. 1998); *Hankins v. Borland*, 431 P.2d 1007 (Colo. 1967); and *Docheff v. City of Broomfield*, 623 P.2d 69 (Colo. App. 1980). These cases are not applicable to the present case as they involve upstream property owners and trespass.

   b. The case of *Larry H. Miller Corporation-Denver v. Board of County Com'rs, Adams County*, 77 P.3d 870 (Colo.App. 2003) is more on point, however. In that case, the Court found that while Adams County had no duty to construct a particular detention facility, if it assumed responsibility for maintaining a drainage facility, it had to do so in a non-negligent manner. The Court defined a drainage facility as a specific element of a drainage system related to a particular piece of property, not the system as a whole.

   c. Applying the reasoning of the *Larry H. Miller* case and looking at individual facilities and devices referred to in the present action, the evidence indicates that Defendants have constructed several drainage channels but that some recommended detention ponds have not been constructed. If they have not been constructed, there can be no obligation to maintain them. Therefore, no duty existed and thus no negligence.

   d. The Court also relies on *Board of County Com'rs of County of La Plata v. Moreland*, 764 P.2d 812 (Colo. 1988), which held that there was no private remedy for a failure to enforce a county building code without a clear expression of intent to create such a remedy. Plaintiffs claim that Defendants had a duty to enforce recommendations identified in drainage basin planning studies. Such a clear expression of intent to create a private remedy cannot be found in the studies. Therefore, there is no private remedy in this case.

7. Plaintiffs have also failed to establish that the Defendants breached a duty owed to them. Because the Court has found that the Defendants had no duty to build the detention ponds recommended in various drainage basin planning studies, there can be no breach of duty.

8. Finally, Plaintiffs have further failed to establish that any excess storm water or trans-basin water released into Fountain Creek proximately caused their damages. The Court notes the following:

   a. The storms in this case were unusual. The magnitude and severity of the storms was so great that even if the recommended detention ponds had existed and trans-basin water was not released into Fountain Creek, the amount of rainfall produced was of such a degree as to exceed a 100-year event and was beyond the planning criteria and would have resulted in excessive flows into the creek.

   b. Even if the Defendants had a duty to construct the recommended detention ponds, they could not be found to have proximately caused Plaintiffs' injuries because of the extraordinary nature of the storms. Plaintiffs have not proved by a preponderance of the evidence that excess water proximately caused their injuries.

9. Plaintiffs have failed to establish that a duty was owed to them, that a breach of duty occurred and that their damages were proximately caused by a breach of duty. Therefore, Plaintiffs have not established a waiver of immunity under the Colorado Governmental Immunity Act, nor proved that Defendants acted negligently.

IT IS THEREFORE ORDERED, ADJUDGED AND DECREED that judgment shall enter against the Plaintiffs, the Speight Family Partnership, LLP and the Greenview Trust, and in favor of the Defendants, the City of Colorado Springs and the Board of County Commissioners of the County of El Paso.

DONE THIS ________ day of ____________________, 2008.

BY THE COURT:

____

JUDGE

This document constitutes a ruling of the court and should be treated as such.

Court:	CO El Paso County District Court 4th JD
Judge:	Kirk Stewart Samelson
File & Serve Transaction ID:	21076347
Current Date:	Aug 28, 2008
Case Number:	2001CV1290
Case Name:	SPEIGHT FAMILY PARTNERSHIP LLLP et al vs. CITY OF COLORADO SPRINGS et al
Court Authorizer:	Kirk Stewart Samelson

/s/ Judge Kirk Stewart Samelson

ROBERT T. STAFFORD DISASTER RELIEF
AND EMERGENCY ASSISTANCE ACT
(PUBLIC LAW 93-288, AS AMENDED BY PUBLIC LAW 100-707)
NOVEMBER 23, 1988

HAZARD MITIGATION GRANT PROGRAM
REGULATIONS AT 44 CFR PART 206 SUBPART N

HAZARD MITIGATION

Sec. 404. The President may contribute up to 75 percent of the cost of hazard mitigation measures which the President has determined are cost-effective and which substantially reduce the risk of future damage, hardship, loss, or suffering in any area affected by a major disaster. Such measures shall be identified following the evaluation of natural hazards under Section 409 and shall be subject to approval by the President. The total of contributions under this Section for a major disaster shall not exceed 15 percent of the estimated aggregate amounts of grants to be made under Section 406, 407, and 408 with respect to such major disaster...

HAZARD MITIGATION PLANNING
REGULATIONS AT 44 CFDR PART 206 SUBPART M

MINIMUM STANDARDS FOR PUBLIC AND PRIVATE STRUCTURES

Sec. 409. As a condition of any disaster loan or grant made under the provisions of this Act, the recipient shall agree that any repair or construction to be financed therewith shall be in accordance with applicable standards of safety, decency, and sanitation and in conformity with applicable codes, specifications, and standards, and shall furnish such evidence of compliance with this section as may be required by regulation. As a further condition of any loan or grant made under the provisions of this Act, the State or local government shall agree that the natural hazards in the areas in which the proceeds of the grants or loans are to be used shall be evaluated and appropriate action shall be taken to mitigate such hazards, including safe land-use and construction practices, in accordance with standards prescribed or approved by the President after adequate consultation with the appropriate elected officials of general purpose local governments, and the State shall furnish such evidence of compliance with this Section as may be required by regulation.

(6/1/94)

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FEMA

Robert T. Stafford Disaster Relief and Emergency Assistance Act (Public Law 93-288) as amended

Robert T. Stafford Disaster Relief and Emergency Assistance Act, PL 100-707, signed into law November 23, 1988; amended the Disaster Relief Act of 1974, PL 93-288. This Act constitutes the statutory authority for most Federal disaster response activities especially as they pertain to FEMA and FEMA programs.

- Robert T. Stafford Disaster Relief and Emergency Assistance Act, as amended, and Related Authorities as of June 2007 (PDF 521KB)

Figure 29a: Simulated hydrographs for the major storm event during April 28-May 2, 1999, at the location of the Greenview Ditch Headworks near Pueblo, Colorado, for the cases of current development and pre-development conditions in the area of the City of Colorado Springs in the upstream region. This result is compared with that shown above in **Figure 22a**. Statistics for these results are compiled in **Appendix B, Table 12.**

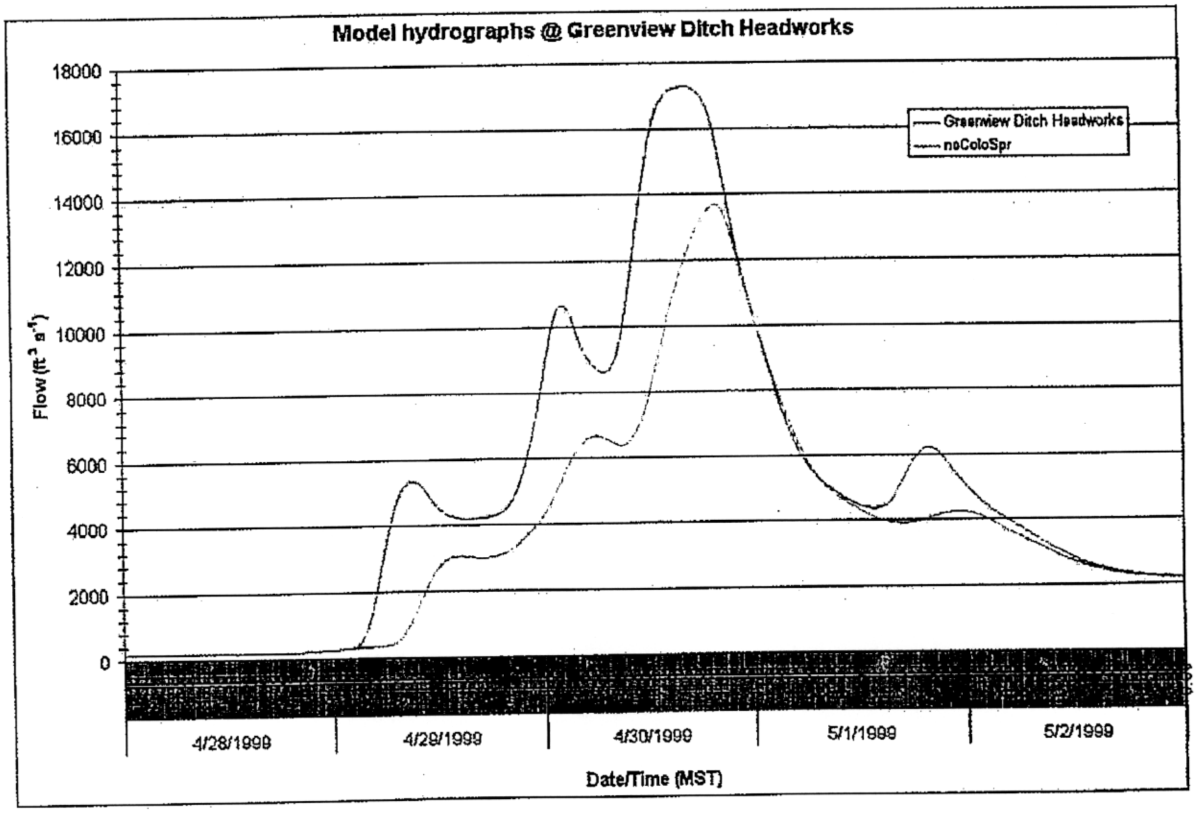
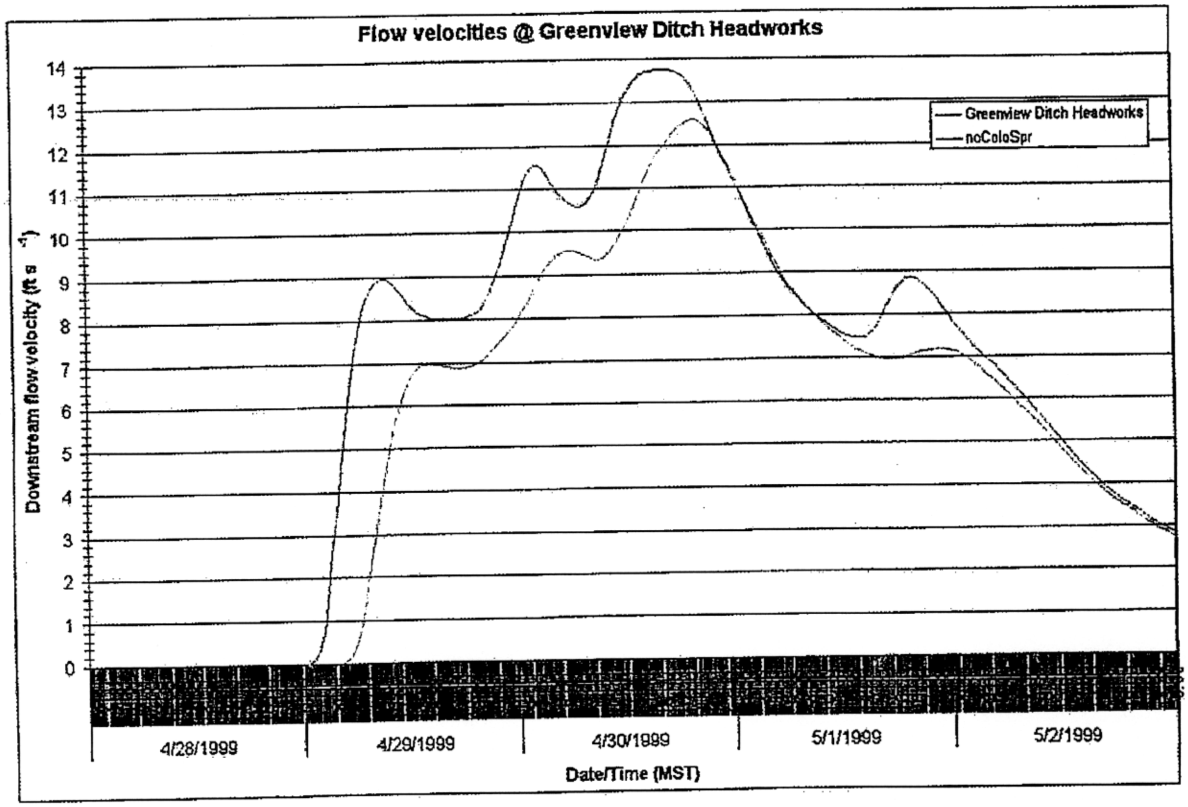


Figure 29b: Simulated flow velocities for the major storm event during April 28-May 2, 1999, at the location of the Greenview Ditch Headworks near Pueblo, Colorado, for the cases of current development and pre-development conditions in the area of the City of Colorado Springs in the upstream region. This result is compared with that shown above in **Figure 22b**. Statistics for these results are compiled in **Appendix B, Table 12**.



Expert Report of Dr. Michael D. Harvey for the District Court of El Paso County, Colorado, regarding Erosion at Two Sites along Fountain Creek during the Floods of April and May 1999

The Speight Family Partnership, LLLP (a Colorado Limited Liability Limited Partnership) and the Greenview Trust, Ralph R. Williams, Trustee

Plaintiffs

v. the City of Colorado Springs (a Home-rule City of the State of Colorado) and the Board of County Commissioners of the County of El Paso

Defendant(s)

Case No. 01 CV 1290

Mussetter Engineering, Inc.
1730 South College Avenue, Suite 100
Fort Collins, Colorado 80525

March 18, 2008

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1. Opinions to be Expressed

On the basis of my evaluation of the available data and accompanying reports, my observations during a number of field inspections of the two sites along Fountain Creek, as well as a reconnaissance of other reaches of Fountain, Monument and Sand Creeks, hydrologic and sediment-transport analyses, my general knowledge of fluvial geomorphology, bank erosion, and sediment-transport processes, and my research into the pertinent scientific literature, I have formed the following conclusions with regard to the technical basis for the case filed by the Speight Family Partnership and the Greenview Trust:

1. Urbanization of the Fountain Creek, Monument Creek and Sand Creek Basins without concurrent on-site stormwater detention has increased the magnitude and frequency of peak discharges in Fountain Creek downstream of the confluences of the three drainages. Under 1992 conditions, approximately 13 percent of the surface area of the Fountain Creek watershed upstream of the Monument Creek confluence was classified as impervious. In the Monument Creek watershed, the impervious area was about 9 percent of the watershed area, and in the Sand Creek basin, the impervious area was about 48 percent.

2. Hydrologic and hydraulic analyses of Fountain Creek, Monument Creek and Sand Creek Basins conducted for planning purposes for the City of Colorado Springs in the mid 1990s indicated that projected future development (2010) and urbanization of the basins in the absence of stormwater detention would further increase the magnitude of the 10- and 100-year floods, and would also cause further channel erosion. The estimates included a 2-percent increase in impervious area for Fountain Creek, a 10-percent increase for Monument Creek, and a 10-percent increase for Sand Creek.

3. U.S. Geological Survey (USGS) studies of Fountain Creek in the 1980s demonstrated that urbanization increased the daily suspended-sediment yields from the watersheds by a factor of about 17. Measured bank-erosion rates increased by about 65 percent, and part of this increase was attributed to the increase in frequency and magnitude of flood peaks due to urbanization (von Guerard, 1989a,b).

4. Urbanization of the Fountain Creek, Monument Creek and Sand Creek Basins and uncontrolled in-channel and channel margin sand-and-gravel mining have resulted in degradation of the channel bed of Fountain Creek that has led to increased rates of bank erosion. Channel deepening and widening have, in combination, resulted in increased channel capacity and retention of higher magnitude floods within bank that has increased the erosive capacity of the flows in Fountain Creek.

5. Importation of transbasin and transmountain flows into the Fountain Creek Basin and the discharge of about 24,000 ac-ft of water from the Colorado Springs Wastewater Treatment Plant to Fountain Creek have increased the baseflows in Fountain Creek by about 30 cfs daily. The USGS concluded that the combined effects of the imported flows and the cessation of most of the irrigation abstractions from Fountain Creek since about 1969 have permitted increased growth of riparian vegetation as well as increased sediment-transport rates for sand-sized particles that make up the bed of Fountain Creek (Stogner, 2000).

6. The increased density of in-channel riparian vegetation has resulted in increased channel energy that has been reflected in increased bank-erosion rates at the

Greenview Trust property. Because of the channel adjustments due to the encroachment of the vegetation into the channel, erosion rates resulting from moderate-sized floods are very similar to those that were experienced as a result of the flood of record in 1965 (about 10 ft/year). Stogner (2000) estimated that the east bank of the creek at the location of the Overton Road bridge, which is about 800 feet upstream of the Greenview Ditch headgate, retreated by about 15 feet during the 1999 flood that had a recurrence interval of about 63 years at the Pinon gage.

7. During the four flood events on Fountain Creek between April 29 and May 3, 1999, mean daily Colorado Springs Wastewater Treatment Plant discharges to Fountain Creek ranged from 29 to 44 cfs when the peak discharges in Fountain Creek exceeded the ordinary high-water mark as defined by the mean annual flood at the USGS Janitell Road gage.

8. A flood-frequency analysis based on the 1977—2001 flood-frequency curves for the peak discharges for the April—May 1999 events at seven USGS stream gages on Fountain Creek and its tributaries, indicated that the recurrence interval for the events ranged from 16 to 85 years, and were not, therefore, extreme hydrological events. At the Security gage, located about 1.3 miles upstream of the KOA property, the recurrence interval for the 1999 flood peak was 82 years.

9. Erosion of the KOA property during the 1999 floods was the result of a complex set of factors that included: (1) baselevel raising and consequent upstream slope reduction as a result of construction of the Chilcott Diversion structure at the head of the west branch channel, (2) increased sediment supply from upstream as a result of urbanization of the watershed (von Guerard, 1989a, b), (3) increased delivery of sediment to the reach as a result of increased flows, upstream channel degradation and levee construction, and (4) flanking of in-place pre-1999 bank protection along the west bank of the creek at the head of the diversion structure due to bed aggradation, armoring of the east bank and lateral migration of the channel to the west.

10. Absent man-made interventions in the upstream watershed, it is inevitable that similar adverse downstream impacts to those that occurred in the 1999 floods will eventuate in response to future flood flows in Fountain Creek.

2. Basis and Reasons for the Opinions, including Data and Information Relied upon and Considered in Forming the Opinions

2.1. Introduction

The Fountain Creek watershed lies within the Arkansas River Basin and encompasses all or portions of eight municipalities (Colorado Springs, Pueblo, Green Mountain Falls, Fountain, Manitou Springs, Monument, Palmer Lake and Woodland Park) and three counties (El Paso, Pueblo and Teller, **Figure 1**). It also includes other special districts or entities as follows: Southeastern Colorado Water District, Widefield, Security, Chipita Park, Cascade, Crystola, U.S. Army, U.S. Air Force, and U.S. Forest Service. The absence of a coordinated watershed plan among the various entities has resulted in erosion and flooding problems that have caused loss of river related infrastructure elements (roads, bridges, utility crossings) and loss of riparian lands as a result of flooding, erosion or sedimentation. During the four floods in Fountain Creek that occurred between April 29 and May 3, 1999, significant bank erosion occurred along Fountain Creek at the properties owned by the Speight Family Partnership (KOA Campground) and the Greenview Trust (Figure 1).

2.2. Background

The fact that a change from natural or agricultural land use to urban land use has dramatic effects on water and sediment yields from a drainage basin has been widely known and quantified since the 1960s (Wohl, 2001). Numerous studies in the United States (Wolman, 1967; Miller et al., 1971; Graf, 1975; Morisawa and LaFlure 1979; Harvey et al., 1983; Miller, 1987; von Guerard, 1989a.b; Urbonas and Benik, 1995; Mussetter et al., 1994; Stogner, 2000; Harvey and Morris, 2004) and around the world (Nanson and Young, 1981; Park, 1977; Lvovich and Chernogaeva, 1977; Balamururugan, 1991; Ruslan, 1995) have documented the adverse effects of urbanization on receiving channel characteristics and flood regimes. Following urbanization, reduced infiltration and depression storage results in greatly increased runoff volumes which reaches the channel system more rapidly (Cohen et al., 1960). The runoff regime is much flashier with shorter lag times, and the peak discharge increases with the percentage of the basin urbanized, especially in arid and semi-arid climatic zones (Hollis, 1974; Gregory, 1974; Mussetter et al., 1994). Urbanization can cause annual direct runoff to increase by a factor of 2.54 and flood peaks can increase by a factor of 10, depending on the return period of the event (Hollis, 1975). The size of the mean annual flood can increase by a factor of 4 following urbanization (Wilson, 1967), and the number of floods equal to, or greater than, bankfull can also increase by a similar factor (Leopold, 1968). Sediment yields can increase by a factor of 200 during the construction phase of urbanization, but tend to decline to pre-urbanization levels after construction is completed (Wolman, 1967; Wolman and Schick, 1967; von Guerard, 1989a). Natural channels tend to erode and enlarge as a result of the increased runoff following urbanization (Richards, 1982; Wolman and Schick, 1967; Hammer, 1972; Park, 1977b; von Guerard, 1989b). Channel degradation, aggradation and channel widening have been reported to have occurred following urbanization (Richards and Wood, 1977; Nixon, 1959; Shaw, 1974). Channel degradation frequently predisposes subsequent channel-bank failure and channel widening (Harvey et al., 1983; Schumm et al., 1984; Harvey and Watson, 1986). When stability thresholds are exceeded systematic disequilibrium occurs, and the recovery of a new state of equilibrium may be complex and take a considerable period of time (Schumm, 1977). Exceedence of thresholds of channel stability and the resulting morphological changes

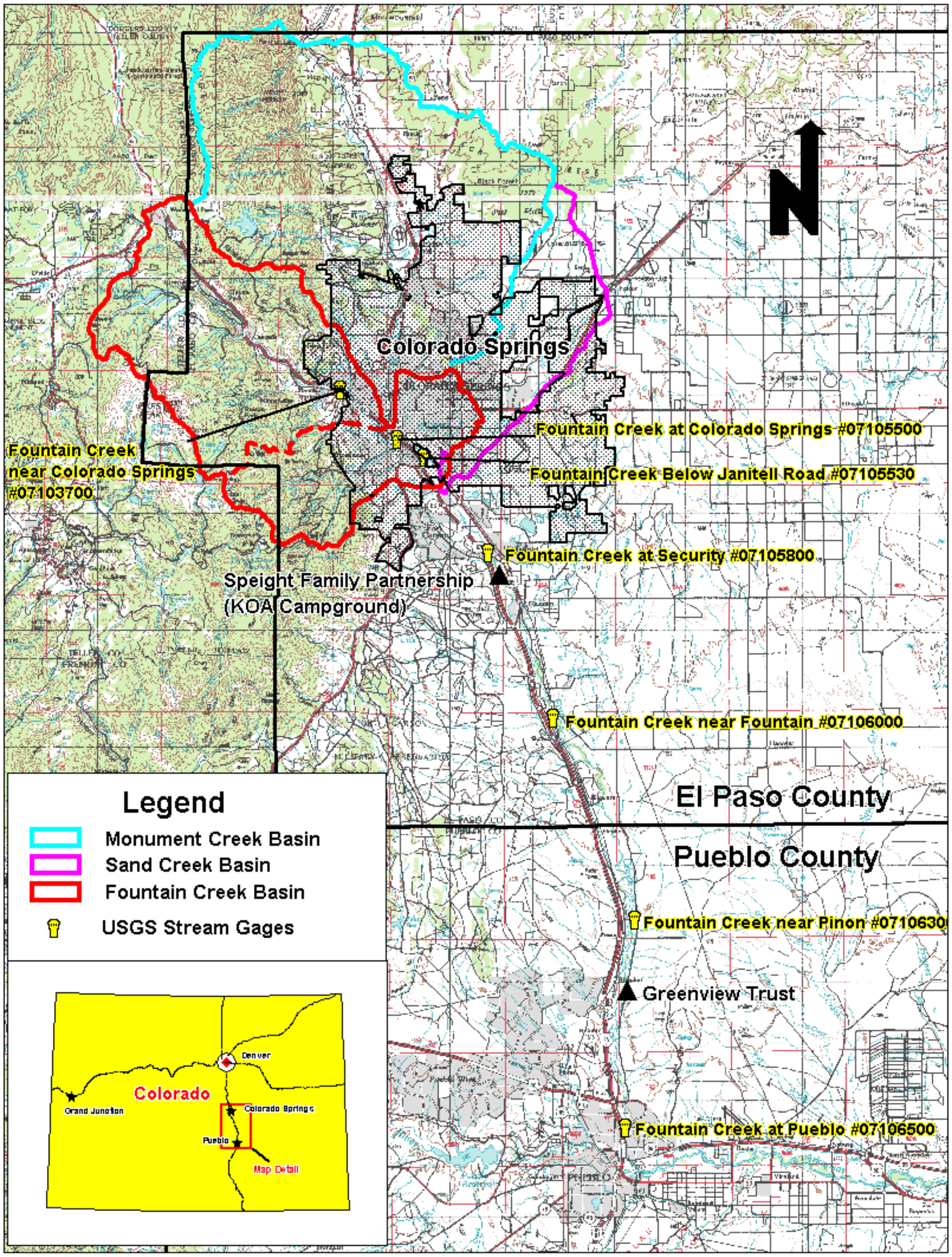

Figure 1. Map of Fountain Creek near Colorado Springs and Pueblo, El Paso and Pueblo Counties, Colorado, showing locations of major drainage basins near Colorado Springs, USGS stream gages, and Speight Family Partnership and Greenview Trust properties.

of the channel frequently can be described in terms of an incised channel-evolution model (Schumm et al., 1984; Harvey and Watson, 1986; Mussetter et al., 1994).

The Drainage Criteria Manual (DCM) that was developed in 1987, and subsequently modified in 1991 and 2002 (Volume 2), and is jointly used by the City of Colorado Springs and El Paso County for the provision of adequate drainage that preserves and promotes the general health, safety, welfare and economic well-being of the community (DCM, p.1-2), explicitly recognizes the adverse effects of stormwater discharge from urban development on receiving stream systems. Section 2.1 of Volume 2 of the DCM summarizes the impacts as follows:

- *Stream Hydrology: Urban development affects the environment through changes in the size and frequency of storm runoff events, changes in baseflows of the stream and changes in stream flow velocities during storms results in decrease in travel time for runoff. Peak discharges in a stream can increase from urbanization due to decrease in infiltration of rainfall into the ground, loss of buffering vegetation and resultant reduced evapotranspiration. This results in more surface runoff and larger loads of various constituents found in stormwater.*

- *Stream Morphology: When the hydrology of the stream changes, it results in changes to the physical characteristics of the stream. Such changes include streambed degradation, stream widening, and streambank erosion. As the stream profile degrades and the stream tries to widen to accommodate higher flows, instream bank erosion increases along with increases in sediment loads. These changes in the stream bed also result in changes to the habitat of aquatic life.*

- *Water Quality: Water quality is impacted through urbanization as a result of erosion during construction, changes in stream morphology, and washing off of accumulated deposits on the urban landscape. Water quality problems include turbid water, nutrient enrichment, bacterial contamination, organic matter loads, metals, salts, temperature increases and increased trash and debris.*

Review of the population statistics for the City of Colorado Springs and El Paso County indicates that significant increases in the population occurred in the mid-1970s. Since population growth is associated with urbanization, the hydrological and sedimentologic impacts of urbanization on Fountain Creek can be assessed by comparing the pre- and post-1976 records (Miller, 1987; von Guerard, 1989a, b; Stogner, 2000).

2.3. Hydrology

Urbanization of the Fountain Creek, Monument Creek and Sand Creek Basins and importation of transbasin and transmountain flows have resulted in changes to both the peak flow and flow-duration characteristics of Fountain Creek (Miller, 1987; Stogner, 2000). Seven USGS gaging stations with varying periods of record are available to evaluate the changed hydrology within the basins (**Figure 2**). Based on an analysis of the precipitation data for the April 28-May 2, 1999 period, Garcia and Roesner (2002) concluded that the maximum 24-hour rainfall totals exceeded the regional 100-year 24-hour storm as identified in the DCM adopted by the City of Colorado Springs and El Paso County. However, **Table 1** which is based on the gage records during the same April—May 1999 period and summarizes the peak discharges and their recurrence intervals for the individual gages on Fountain Creek, clearly shows that the resulting floods were large, but not extraordinary.

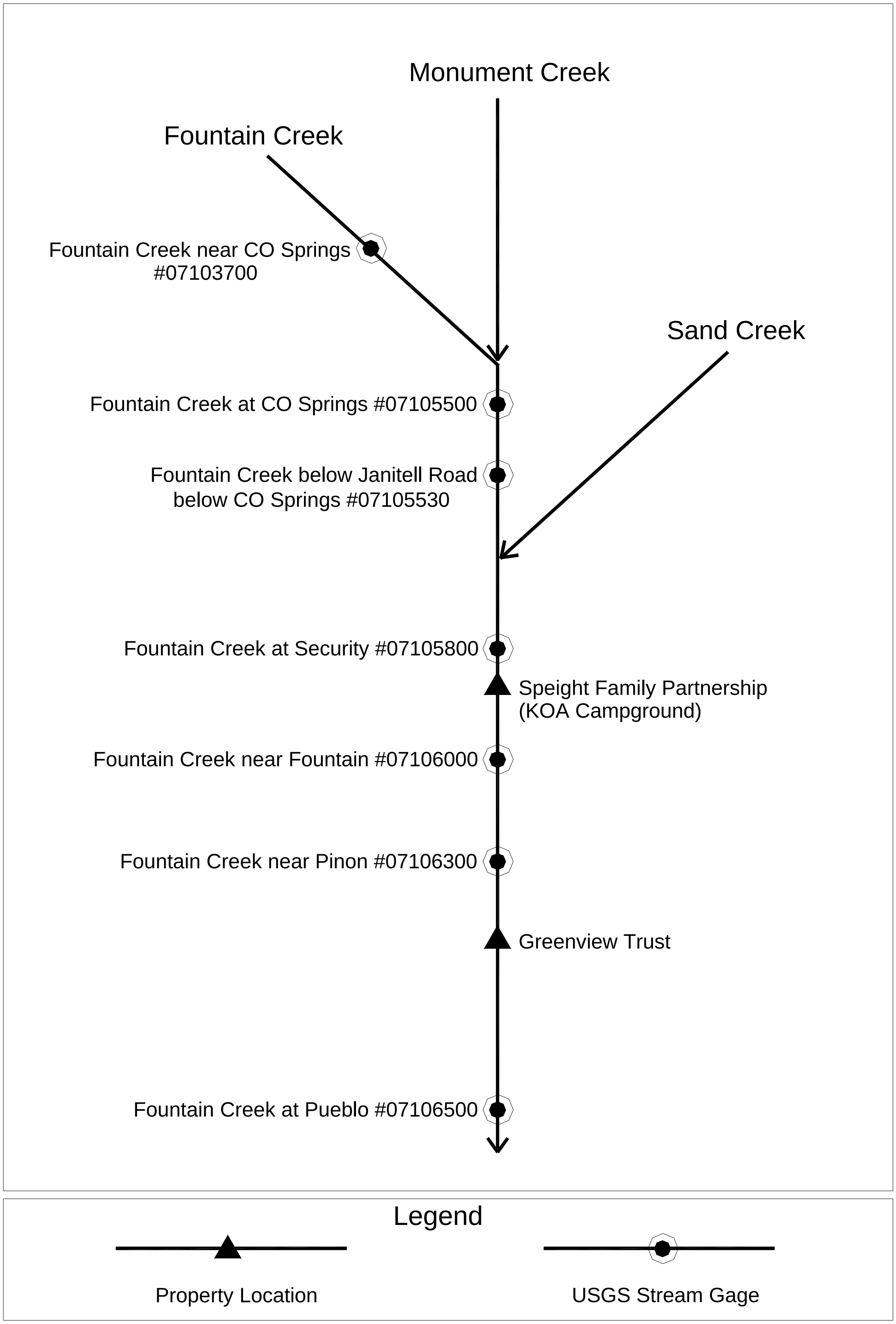

Figure 2. Schematic diagram of Fountain Creek from the headwaters to the city of Pueblo showing major tributaries, USGS stream gages, and Speight Family Partnership and Greenview Trust properties.

Table 1. Summary of 1999 peak flow discharges and associated recurrence intervals for USGS gages on Fountain Creek.			
USGS Stream Gage Number	Period of Record	1999 Peak Discharge (cfs)	Recurrence Interval (years)
#07103700 (near CO Springs)	1959-2001	1750	16
#07105500 (at CO Springs)	1977-2001	9490	37
#07105800 (at Security)	1965-2001	17600	82
#07106000 (near Fountain)	1939-1954, 1985-2001	20100	85
#07106300 (near Pinon)	1973-2001	19100	63
#07106500 (at Pueblo)	1923-1925, 1941-1965, 1971-2001	18900	29

*Based on 1977—2001 flood-frequency curves.

The peak discharges at the KOA and Greenview Trust properties during the 1999 floods are best approximated by the Security (# 07105800) and Pinon (# 07106300) gages, which were 17,600 and 19,100 cfs, respectively. The corresponding recurrence interval for these peak discharges was approximately 82 and 63 years, respectively which indicate that the April—May floods were significant, but not extreme, events at these locations. **Figures 3 and 4** show the annual flood peaks for the periods of record for the two gages. At the Security gage (Figure 3) the 1999 flood peak was the second largest in the period of record (1965—2001). At the Pinon gage, the 1999 flood peak was the largest in the period of record (1973—2001). However, neither gage record includes the very large events of 1921, 1924, 1935, 1942, 1944, 1946, 1951, and 1955 (Stogner, 2000).

Analyses of the flood flows in the April-May 1999 period by Garcia and Roesner (2003) showed that upstream development had increased the peak discharge at the KOA property by about 24 percent, the mean discharge during the event by 33 percent and the total volume of flow by about 33 percent. Mean flow velocity during the flood period, and hence the potential erosivity of the flows, was estimated to increase by about 15 percent. At the Greenview Ditch site, upstream development increased the peak discharge by about 26 percent, the mean discharge during the event by about 33 percent, and the total volume of flow by about 33 percent. The mean velocity during the event, and hence the potential erosivity of the flows, increased by about 17 percent as a result of the upstream development (Garcia and Roesner, 2003).

Figures 5, 6, 7 and 8 present the flood-frequency curves (developed using the WRC Bulletin 17B procedures, USGS, 1982) for the pre- and post-1977 data for the following gages: Fountain Creek near Colorado Springs (#07103700), Fountain Creek at Security (#07105800), Fountain Creek near Fountain (#07106000), and Fountain Creek at Pueblo (#07106500). The range of responses to the development in the basin can be seen by comparing the curves for the individual gages.

The flood-frequency curves for the Fountain Creek near Colorado Springs gage (Figure 5) for the pre- and post-1977 periods indicate that the magnitude of the less frequent events has increased, and the magnitude of the more frequent events has decreased somewhat. At the

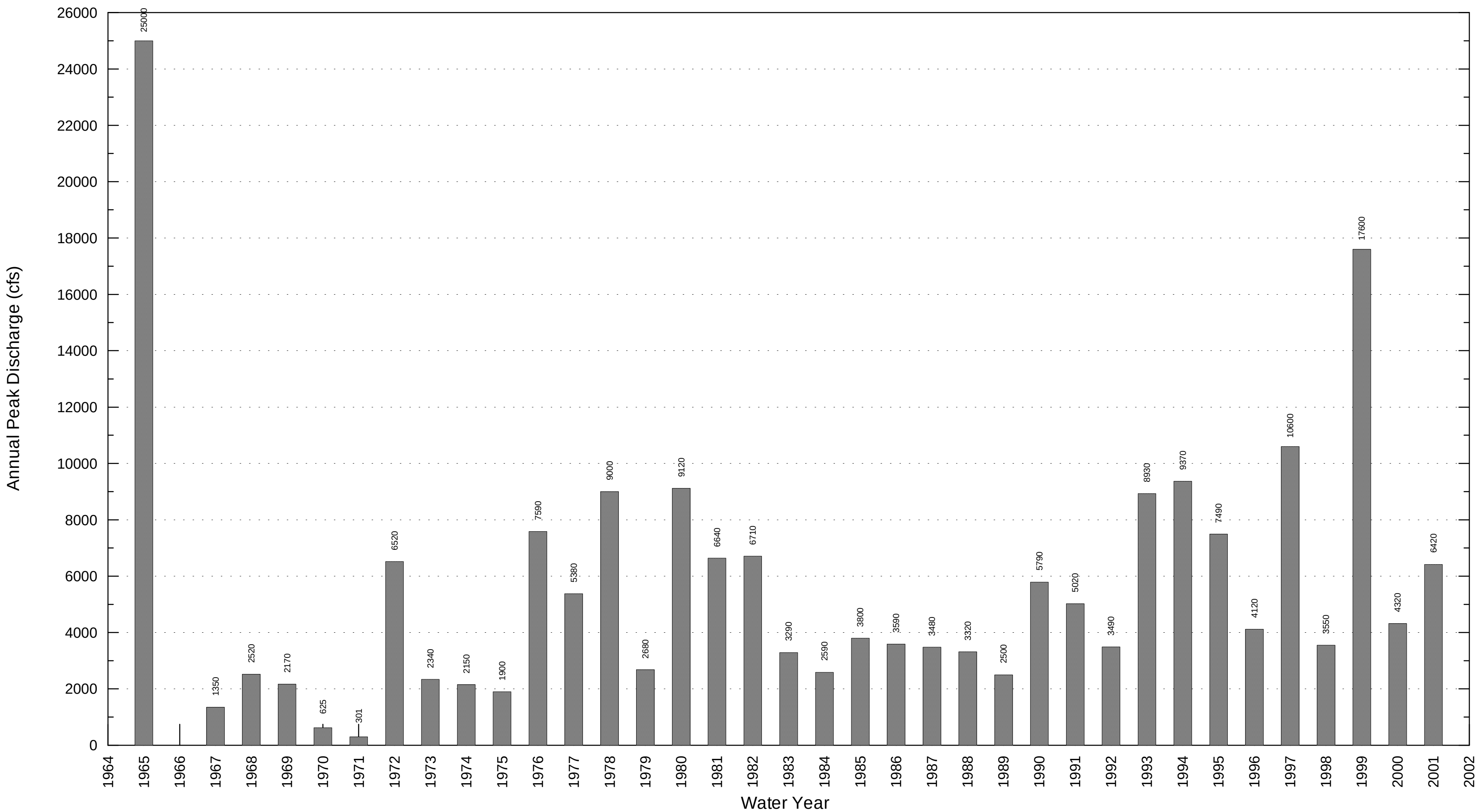

Figure 3. Peak flow record from 1965 to 2001 for the Fountain Creek at Security gage (No. 07105800).

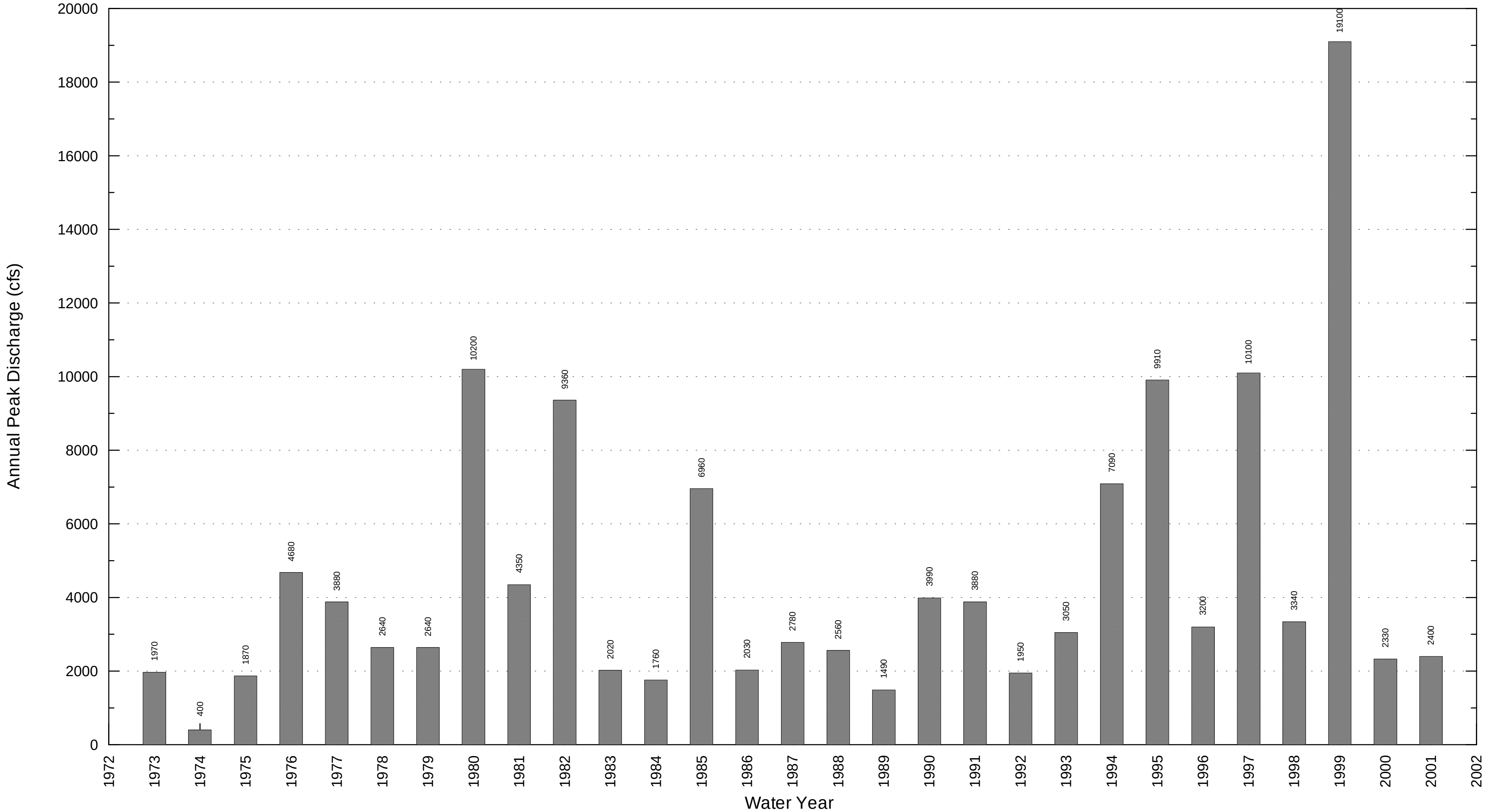

Figure 4. Peak flow record from 1973 to 2001 for the Fountain Creek near Pinon gage (No. 07106300).

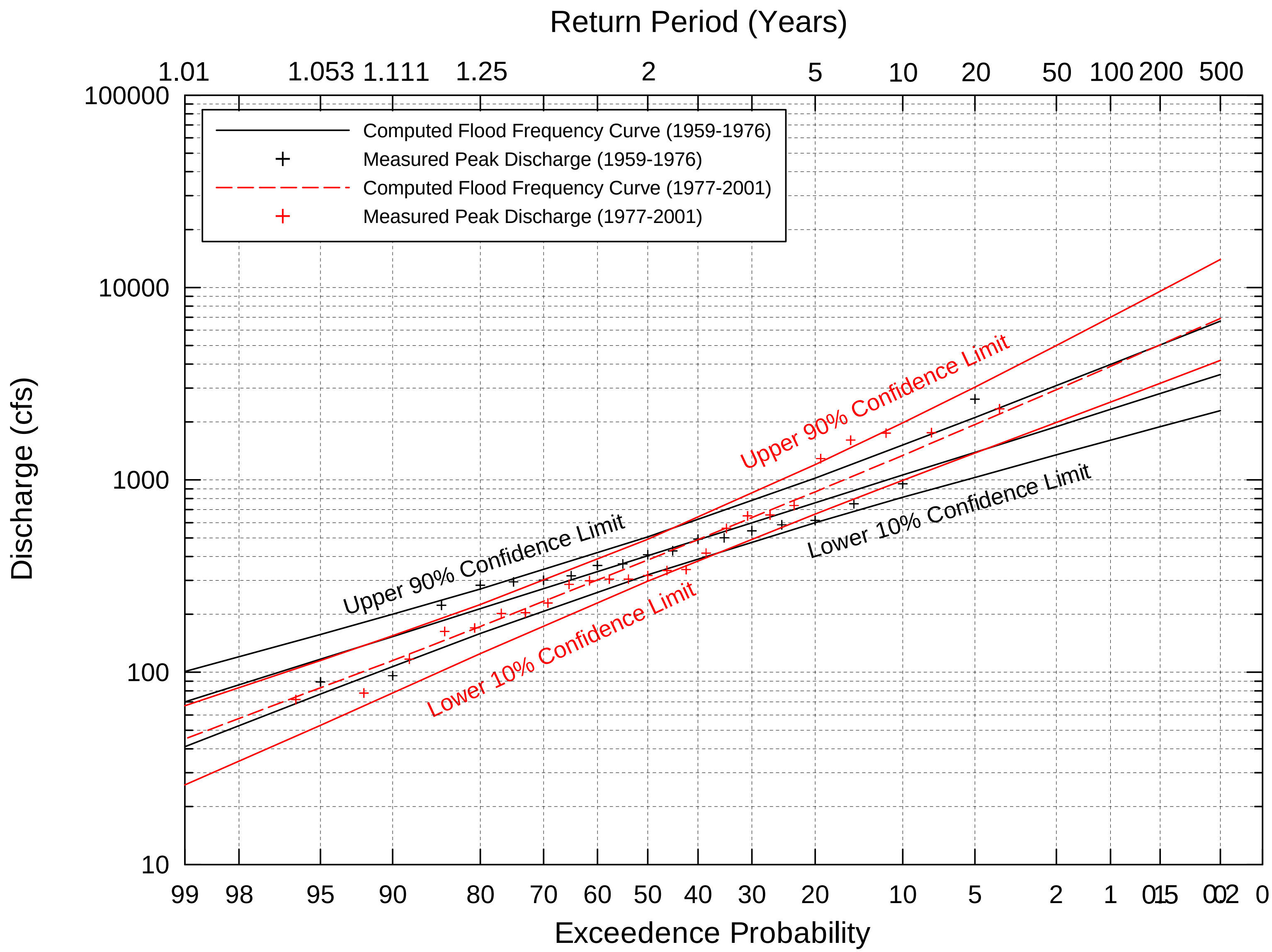

Figure 5. Flood-frequency curves for the Fountain Creek near Colorado Springs gage (No. 07103700) for the periods of 1959 to 1976 and 1977 to 2001.

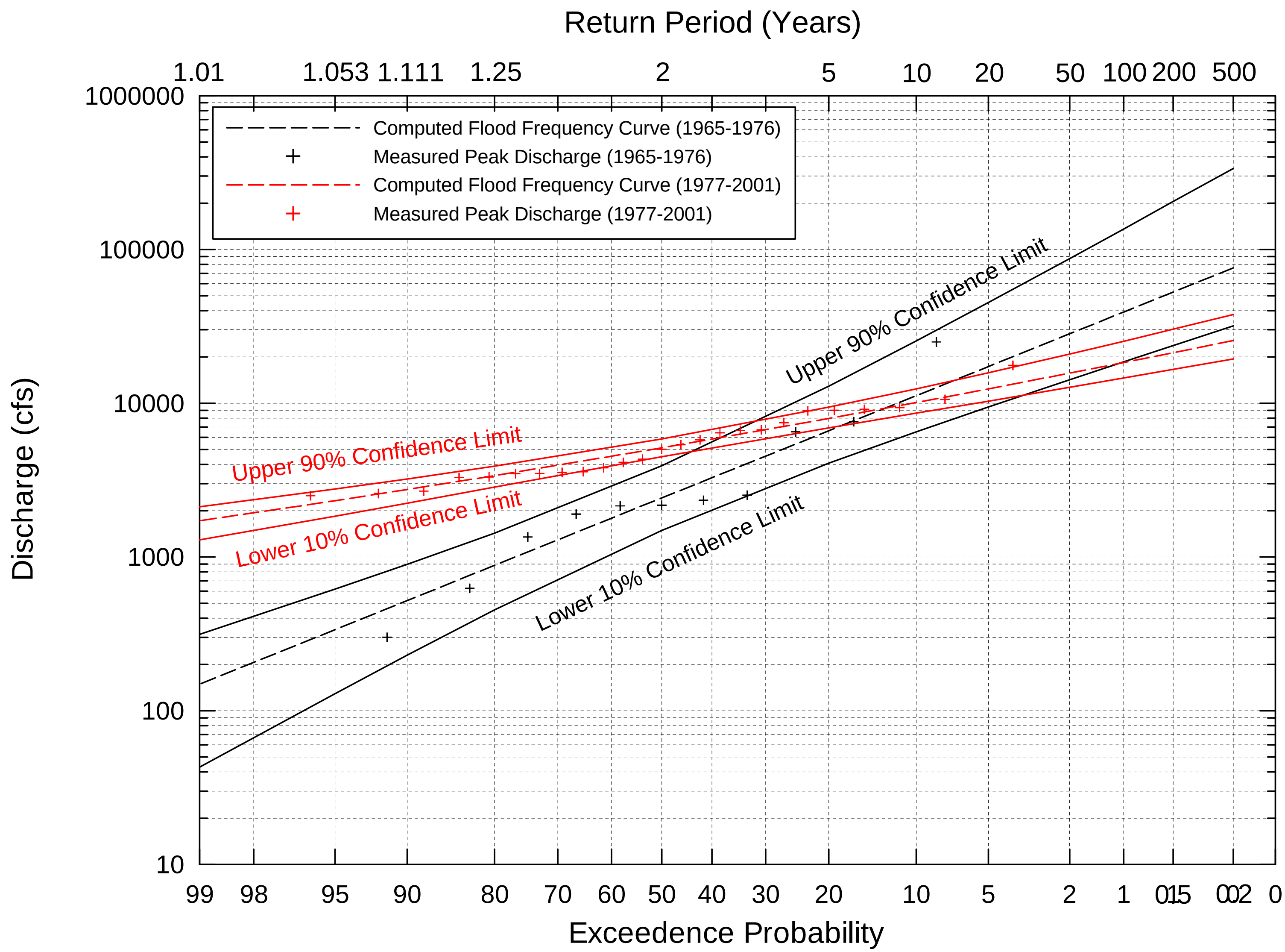

Figure 6. Flood-frequency curves for the Fountain Creek at Security gage (No. 07105800) for the periods of 1965 to 1976 and 1977 to 2001.

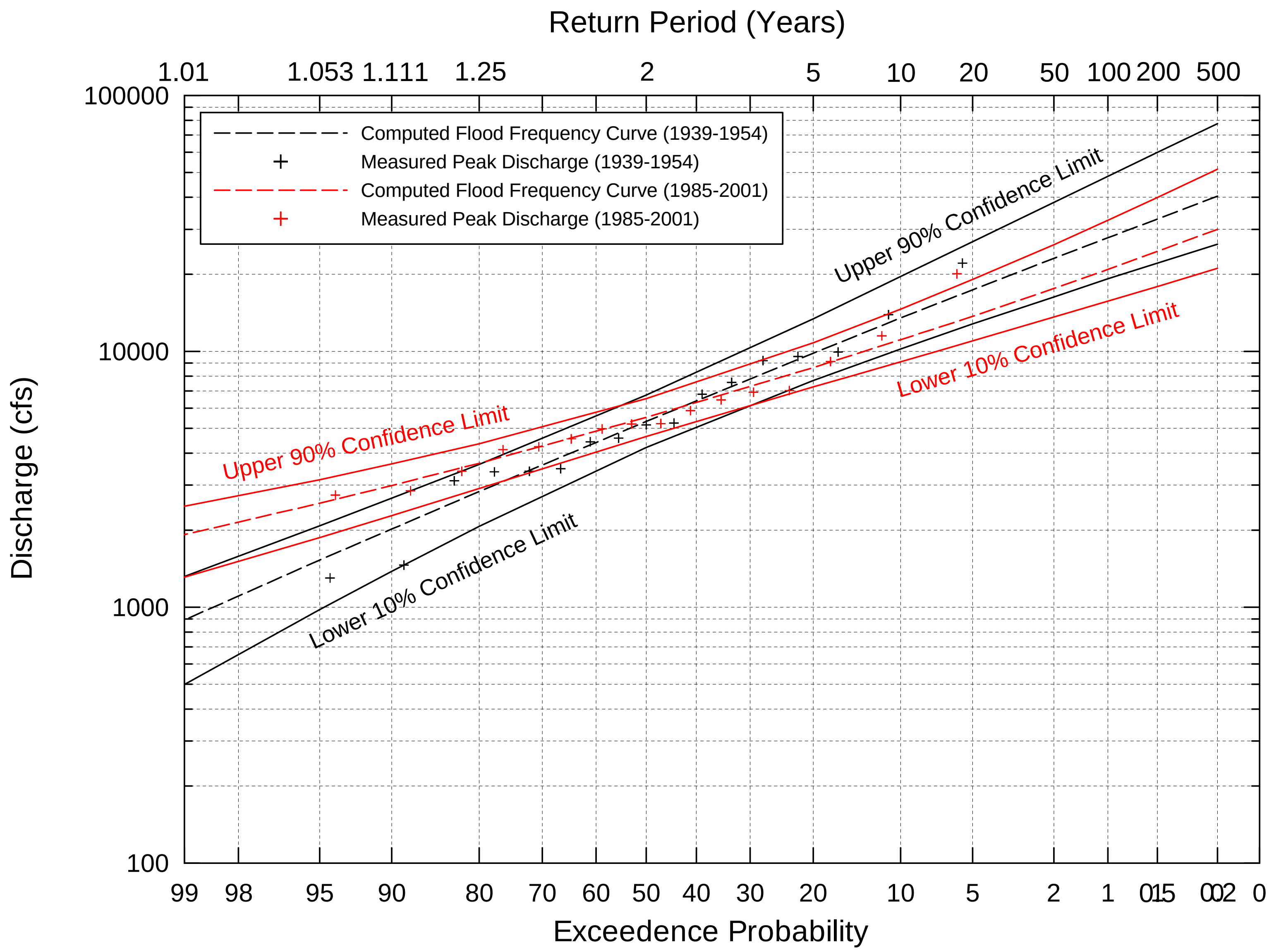

Figure 7. Flood-frequency curves for the Fountain Creek at Fountain gage (No. 07106000) for the periods of 1939 to 1954 and 1985 to 2001.

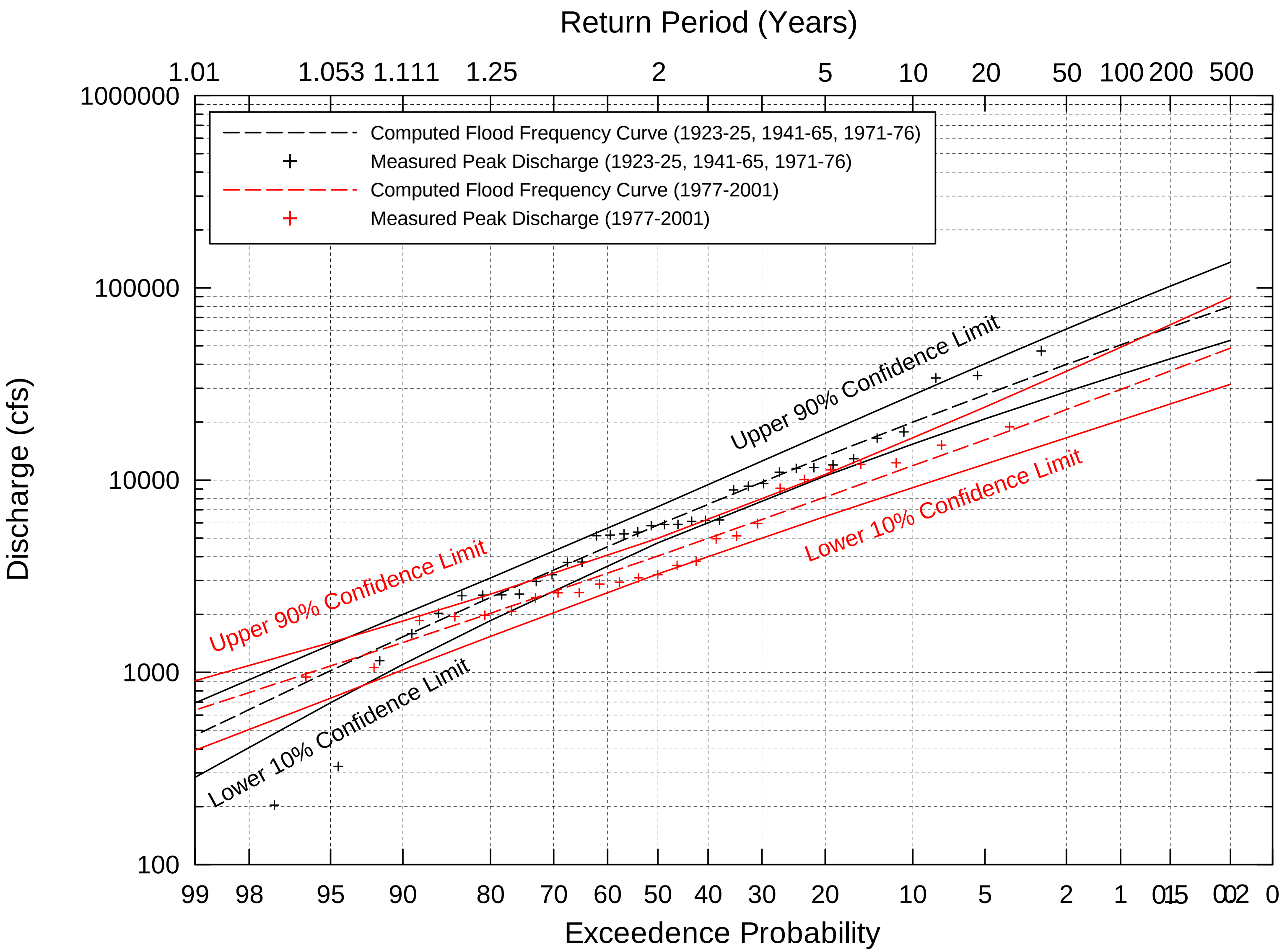

Figure 8. Flood-frequency curves for the Fountain Creek at Pueblo gage (No. 07106500) for the periods of 1923 to 1976, and 1977 to 2001.

Security gage (Figure 6), the magnitude of the more frequent events has increased dramatically, but the magnitude of the less frequent events has decreased somewhat. The relatively short period of record (1965—1976) for the pre-1977 period may be responsible for some of the disparity between the two curves.

A similar trend is observed at the Fountain Creek near Fountain gage (Figure 7). More frequent events have increased magnitude while less frequent events have somewhat lower magnitudes. At the Fountain Creek at Pueblo gage (Figure 8), the curves for the pre- and post-1977 period show the same trends.

Flow-duration curves based on the mean daily flows were developed for the seven USGS gages. **Table 2** summarizes the 1-, 50-, and 90-percent exceedence data for four of the gages.

Table 2. Summary of discharges equaled or exceeded 1, 50, and 90 percent of the time for the Fountain Creek near Colorado Springs, at Security, near Fountain, and Pueblo gages.

USGS Stream Gage Number	Period of Record	Discharge Equaled or Exceeded **1** Percent of the Time (cfs)	Discharge Equaled or Exceeded **50** Percent of the Time (cfs)	Discharge Equaled or Exceeded **90** Percent of the Time (cfs)
#07103700 (near Colorado Springs)	1959-1976	72	9	5
	1977-2001	145	12	6
#07105800 (at Security)	1965-1976	380	36	17
	1977-2001	845	98	44
#07106000 (near Fountain)	1939-1954	725	19	4
	1985-2001	1175	119	53
#07106500 (at Pueblo)	1923-1976	743	10	0.9
	1977-2001	1130	104	18

At the Fountain Creek near Colorado Springs gage (#07103700) the 1-percent exceedence flows increased from approximately 70 to 150 cfs in the post-1977 period. The 50- and 90-percent exceedence flows did not change significantly in the post-1977 period. At the Security gage (#07105800) the impacts of upstream development and water importation into the basin are very clear. In the post-1977 period, the 1-percent exceedence flows increased from 380 to 845 cfs, the 50-percent exceedence flows increased from 36 to 98 cfs, and the 90-percent exceedence flows increased from 17 to 44 cfs. Similar increases occurred in the post-1977 period at the Fountain Creek near Fountain (#07106000) and Fountain Creek at Pueblo (#07106500) gages.

Stogner (2000) showed very similar changes in the hydrology of the basin in the post-1977 period, and he correlated the increased baseflows and greater in-channel flows to increases in riparian vegetation, sediment-transport capacity of the flows and bank erosion and lateral migration of the channel of Fountain Creek. Miller (1987) attributed the degradation of Fountain Creek to the combined effects of urbanization, sand-and-gravel mining, abandonment of irrigation abstractions from Fountain Creek and importation of transbasin and transmountain flows. Von Guerard (1989a) also attributed the changed hydrology and greatly increased sediment yields to urbanization, primarily in the lower portion of the Monument Creek basin.

2.4. Colorado Springs Wastewater Treatment Plant Discharges

The annual water diversion report of the Office of the State Engineer for the Colorado Springs WWTP for Irrigation Year 1999 (November 1, 1998, to October 31, 1999) was used to evaluate the discharges to Fountain Creek during the floods of April—May 1999. The mean daily discharges for the Fountain Creek at Colorado Springs (#07105500) gage (upstream of WWTP), Fountain Creek below Janitell Road (#07105530) gage (downstream of WWTP), and the WWTP discharges from April 29 to May 5, 1999, are shown on **Figure 9**. Additional flows are delivered to Fountain Creek between the two gages by two tributaries (Shooks Run and Spring Creek). Figure 9 shows that WWTP discharges to Fountain Creek in the April 29 to May 5, 1999, period ranged from 29 to 44 cfs. The Colorado Springs Utilities 1999 Exchange Report indicates that about 32,000 (31,515) acre feet of water were returned to Fountain Creek.

2.5. 1999 Hydrographs

The 15-minute data were recovered from the USGS to evaluate the flood hydrographs at four gages on Fountain Creek for the period between April 29 and May 5, 1999 (**Figure 10**). The hydrographs demonstrate the increase in the flows from the increased contributing area between the Fountain Creek at Colorado Springs gage and the Fountain Creek near Fountain gage, as well as the downstream attenuation of the peaks and the increased travel time of the flood waves between the Fountain Creek near the Fountain and Pueblo gages. Figure 10 also shows that there were four separate flood peaks during the period between April 29 and May 3, 1999.

2.6. Ordinary High-Water and Colorado Springs WWTP Discharges

Under Colorado Revised Statutes, Title 37 Water and Irrigation Water Rights and Irrigation Reservoirs and Waterways Article 87 (37-87-102) the definition of the "Ordinary High-water Mark" of any stream means the visible channel of a natural watercourse within which water flows with sufficient frequency so as to preclude the erection or maintenance of man-made improvements without special provision for protection against flows of water in such channel or the channel defined by the mean annual flood, whichever is greater. The mean annual flood for the below Janitell Road gage (#07105530) was determined using a two-station comparison method to extend the peak-flow record at the below Janitell Road gage because of the short period of record for that gage. The mean annual flood was also computed for the Fountain Creek at Colorado Springs gage (#07105500). **Figure 11** shows the hydrographs for the two gages for the period between April 28 and May 7, 1999, as well as the mean annual flood values for the two gages. At both gages, the four flood peaks exceeded the respective mean annual floods, and therefore, the peak discharges also exceeded the ordinary high-water mark. During the period of exceedence of the ordinary high-water mark, flows were being discharged to Fountain Creek from the Colorado Springs WWTP (Figure 9).

2.7. Drainage Basin Studies

Drainage Basin Planning studies were conducted by the City of Colorado Springs for Fountain (Müller Engineering, Inc., 1994) Monument (CH2M Hill, 1992) and Sand (Kiowa Engineering Corporation, 1996) Creeks in the early 1990s. Existing condition (1992) and future condition

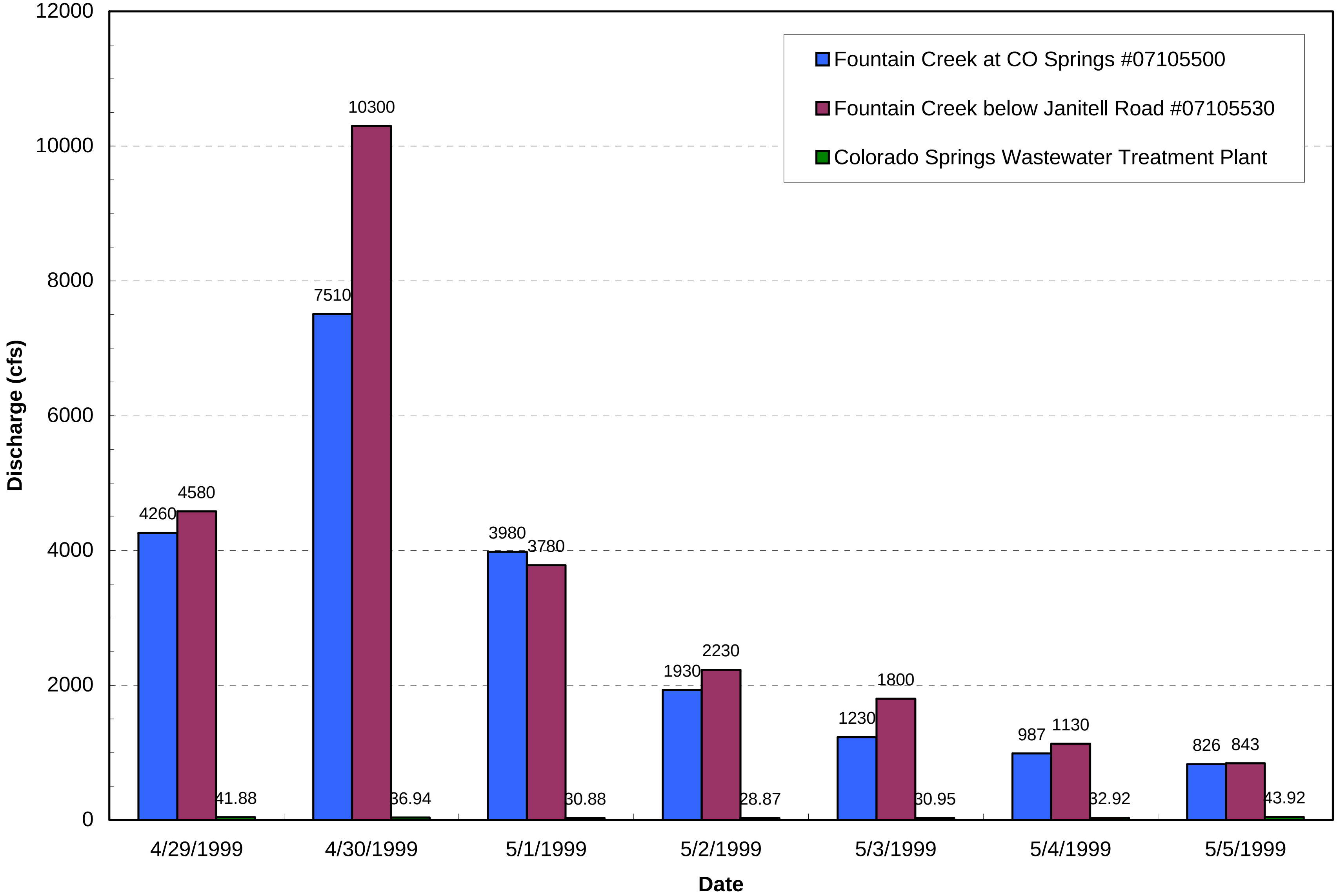

Figure 9. Mean daily flow records from April 29 to May 5, 1999 (duration of the 1999 flood), for the Fountain Creek at Colorado Springs and below Janitell Road gages, and the discharges from the Colorado Springs Wastewater Treatment Plant.

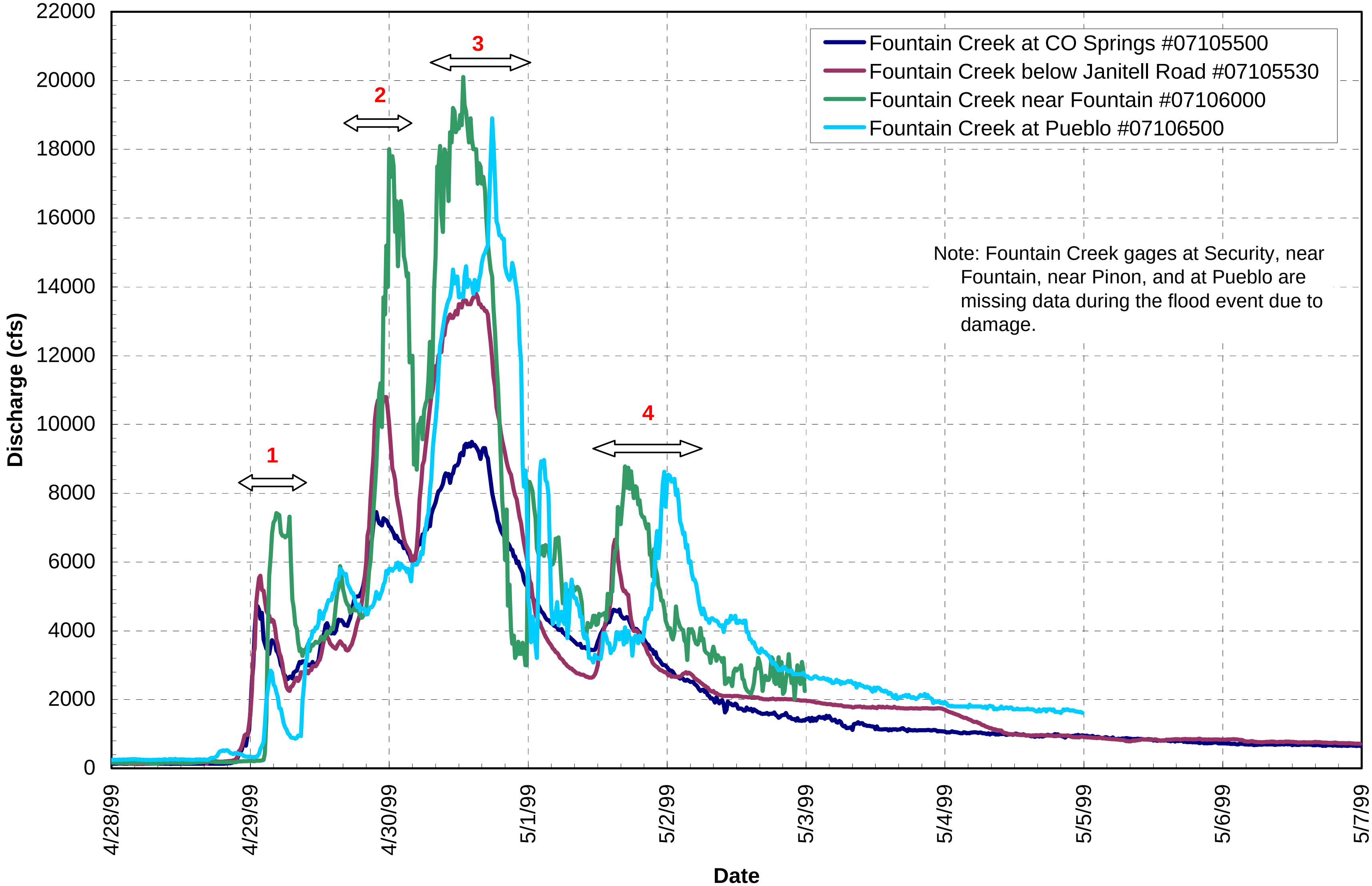

Figure 10. The 15-minute interval discharge records from April 28 to May 7, 1999, for the Fountain Creek gages at Colorado Springs, below Janitell Road near Fountain, and at Pueblo.

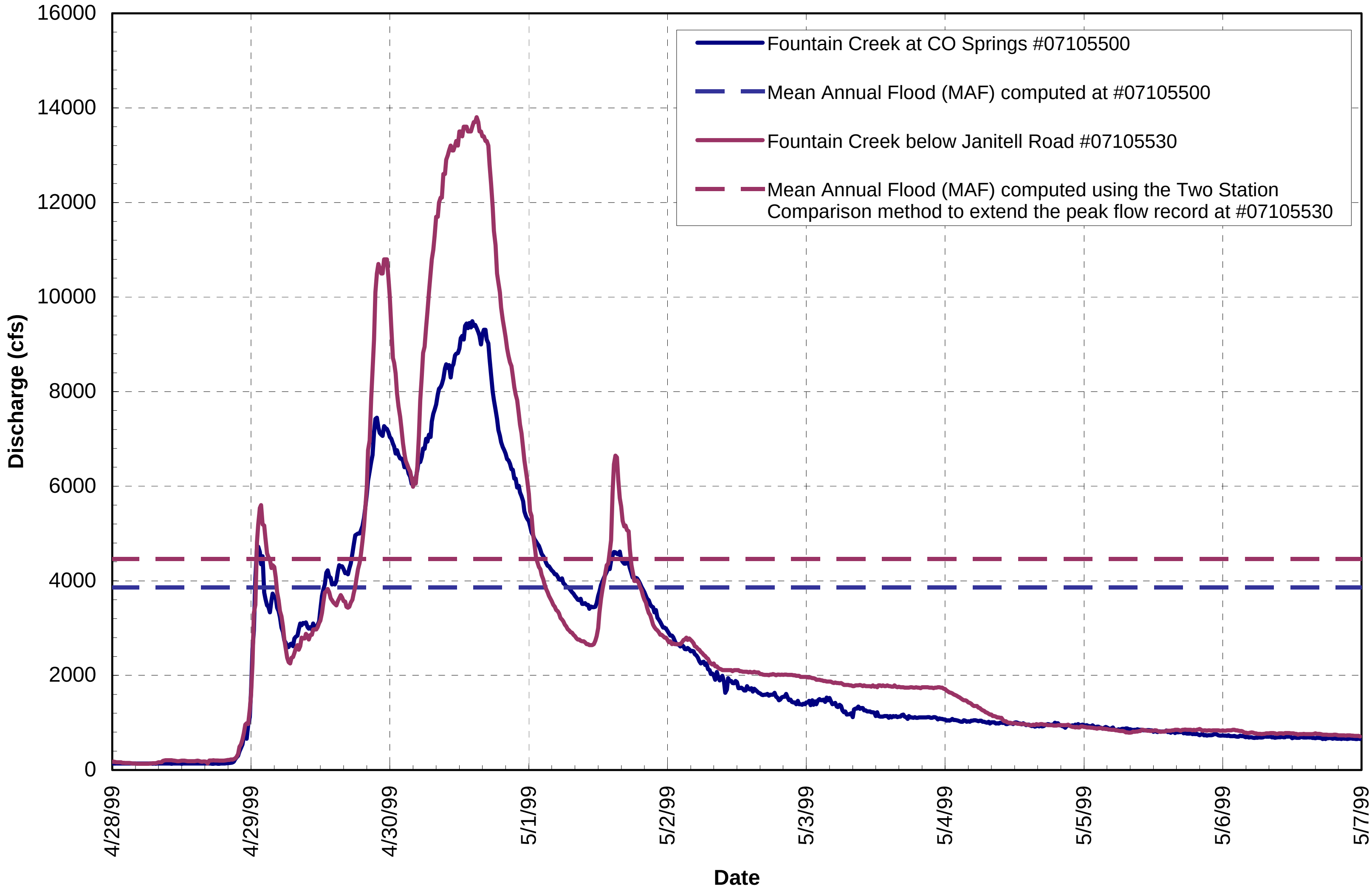

Figure 11. The 15-minute interval discharge records from April 28 to May 7, 1999, for the Fountain Creek at Colorado Springs and below Janitell Road gages comparing the actual flood discharges with the computed mean annual floods (MAF).

(beyond 2010) peak discharges for the 10- and 100-year events were computed to evaluate the effects of further development within the basins. **Table 3** summarizes the estimated discharges for the two recurrence intervals for existing and future conditions for the Fountain Creek basin above the confluence with Monument Creek, the Monument Creek, and Sand Creek basins.

Table 3. Summary of the 10- and 100-year peak discharges for both existing and future conditions in the Fountain Creek basin as reported in the drainage basin planning studies for Fountain, Monument, and Sand Creeks.

Basin	Existing Conditions*		Future Conditions	
	10-year Discharge (cfs)	100-year Discharge (cfs)	10-year Discharge (cfs)	100-year Discharge (cfs)
Fountain Creek above Monument Creek confluence	3,820	11,524	4,264	12,934
Monument Creek	7,650	27,900	9,270	32,800
Sand Creek	7,470	16,900	11,800	25,800

*Represents existing conditions at time of drainage basin planning studies (1992—1996).

The data in Table 3 clearly indicate that further development in the Fountain Creek basin will further increase the magnitudes of both the 10- and 100-year flood peaks in all three basins. For the 10-year event, the magnitudes are estimated to increase between 11 percent (Fountain Creek) and 58 percent (Sand Creek), and for the 100-year event, the magnitudes are estimated to increase by 12 percent (Fountain Creek), and 53 percent (Sand Creek) reflecting the degree of additional development that is projected to occur in the basins. Since the development that has already occurred to date in the Fountain Creek basin is causing downstream hydrologic and erosion impacts, it is reasonable to conclude that further development will further exacerbate the existing problems.

Successive planning studies for the Cottonwood Creek Drainage Basin (a tributary to Monument Creek), Lincoln DeVore, (1979), URS (1994) and Ayres Associates (2000) have quantified the effects of basin development on the magnitude of the 100-year flood. The most recent estimate of the future conditions 100-year peak discharge (Ayres Associates, 2002) (10, 738 cfs) is double the existing conditions 100-year peak discharge of 5,179 cfs. Mitigation alternatives that have been proposed for the increased runoff volume in the Cottonwood Creek basin have included 3 detention basins (Lincoln DeVore, 1979), 6 detention basins (URS, 1994) and a prudent line concept (Ayres Associates, 2002). The Prudent Line alternative was adopted by the City of Colorado Springs in lieu of detention (Resolution No. 104-00). However, adoption of the prudent line concept provides no downstream mitigation for the increased runoff to Monument and Fountain Creeks from historical and on-going development within the Cottonwood Creek basin. As pointed out in the Ayres Associates report, implementation of the prudent line concept provides flooding and erosion protection for properties along Cottonwood Creek, but in doing so it ensures increased delivery of runoff and sediment to Monument Creek.

2.8. Apportionment of Causes of Hydrologic Impacts

Estimation and apportionment of the causes of the hydrologic impacts of the development are based on the amount of impervious surface area among individual drainage basins and individual cities and counties within each of the drainage basins. The values are based on the 1992 conditions as identified in the various planning studies for each of the basins that were conducted for the City of Colorado Springs (Müller Engineering, Inc., 1994; CH2M Hill, 1992; Kiowa Engineering, 1996). Entities not party to this litigation such as Green Mountain Falls, Fountain, Manitou Springs, Monument, Palmer Lake, Woodland Park, Teller County, Southeastern Colorado Water District, Widefield, Security, Chipita Park, Cascade, Crystola, U.S. Army, U.S. Air Force, and U.S. Forest Service were included within El Paso County.

Figure 12 summarizes the data for Monument, Fountain and Sand Creeks. As of 1992, in the Monument Creek basin (upstream of the confluence with Fountain Creek), 9 percent of the surface area was classified as impervious. Five percent is located within the City of Colorado Springs, and the remainder (4 percent) is located within El Paso County and other minor entities. In the Fountain Creek basin (upstream of the confluence with Monument Creek), 13 percent of the surface area was classified as impervious. Ten percent is located within the City of Colorado Springs, 2 percent is located in El Paso County and other minor entities, and 1 percent is located outside of both Colorado Springs and El Paso County. Within the Sand Creek basin (upstream of the confluence with Fountain Creek), 48 percent of the surface area was classified as impervious. Twenty-nine percent is located within the City of Colorado Springs and 19 percent is located within El Paso County and other minor entities. When the basins are combined above the confluence of Sand and Fountain Creeks, about 15 percent of the surface area was classified as impervious, of which about 10 percent is located within the City of Colorado Springs and 5 percent is located in El Paso County and the other minor entities. Based on these values, it appears that the City of Colorado Springs has about twice as much impervious area as El Paso County and the other minor entities combined.

Based on the 2010 population trend projections, it was estimated that the impervious area in the Monument Creek basin would increase about 10 to 19 percent (CH2M Hill, 1992), and in the Fountain Creek basin it would increase about 2 to 15 percent (Müller Engineering, Inc., 1994) (**Figure 13**). The proportions of the impervious areas in the City of Colorado Springs and El Paso County and other minor entities remained the same as for the 1992 estimates. Estimates were not readily available for the Sand Creek basin, but the projected increases in the 10- and 100-year peak discharges were on the order of 55 percent, which suggests that the impervious area would have to increase substantially. A regression relationship was developed from the Monument and Fountain Creeks data, and this was used to estimate the future (2010) impervious area in the Sand Creek basin on the basis of the estimated increases in the 10- and 100-year peak discharges. The regression-based estimate for the impervious area was 58 percent, which is a 10-percent increase above the 1992 condition.

Based on the available information, it appears that there is approximately twice as much impervious area within the boundaries of the City of Colorado Springs than in El Paso County and the other minor entities. Consequently, it is reasonable to apportion twice as much of the hydrologic impact of urbanization to the City of Colorado Springs.

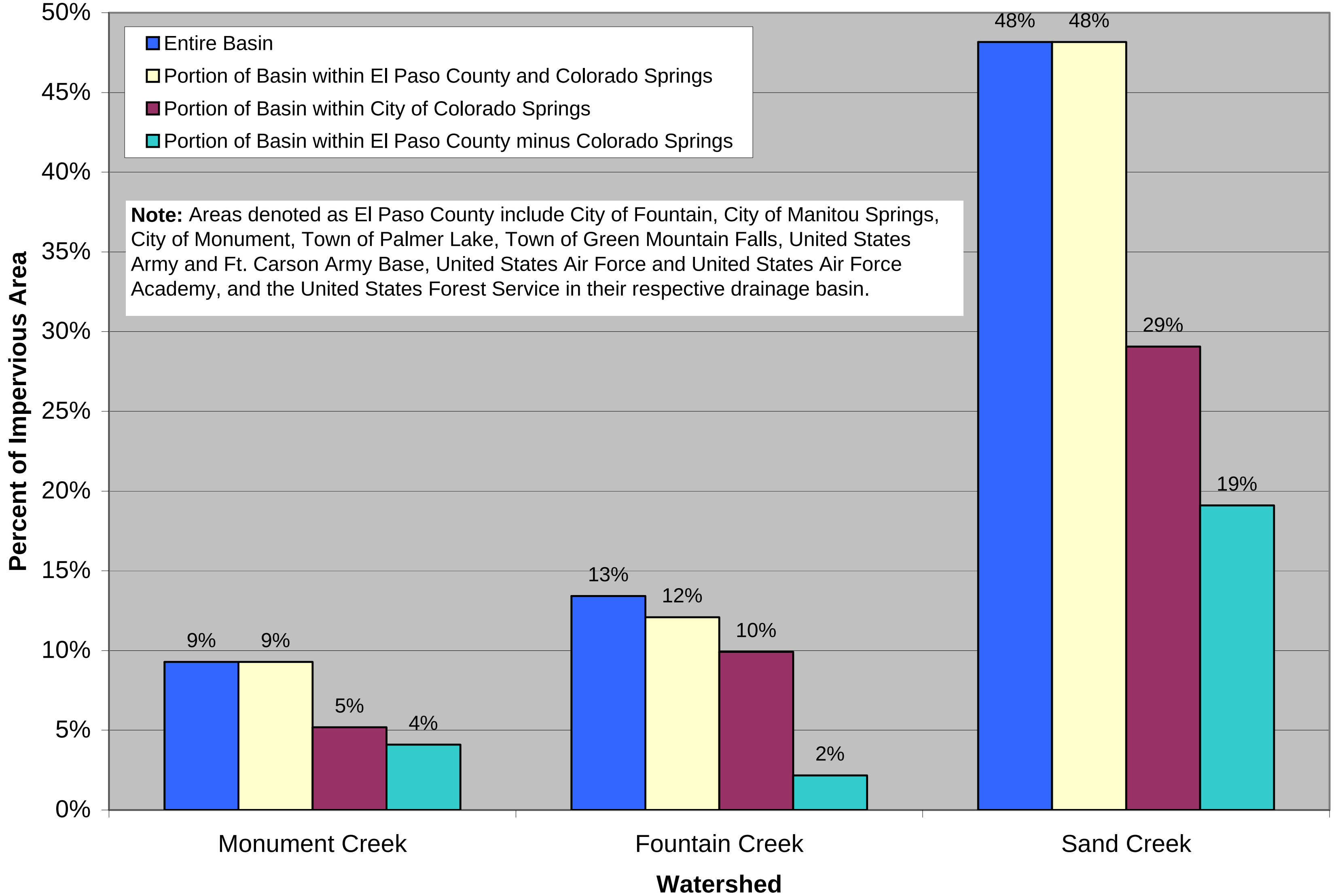

Figure 12. Estimates of the impervious areas in the Monument, Fountain and Sand Creek basins that are based on the c.1992 Drainage Basin Planning Studies that were conducted for the City of Colorado Springs.

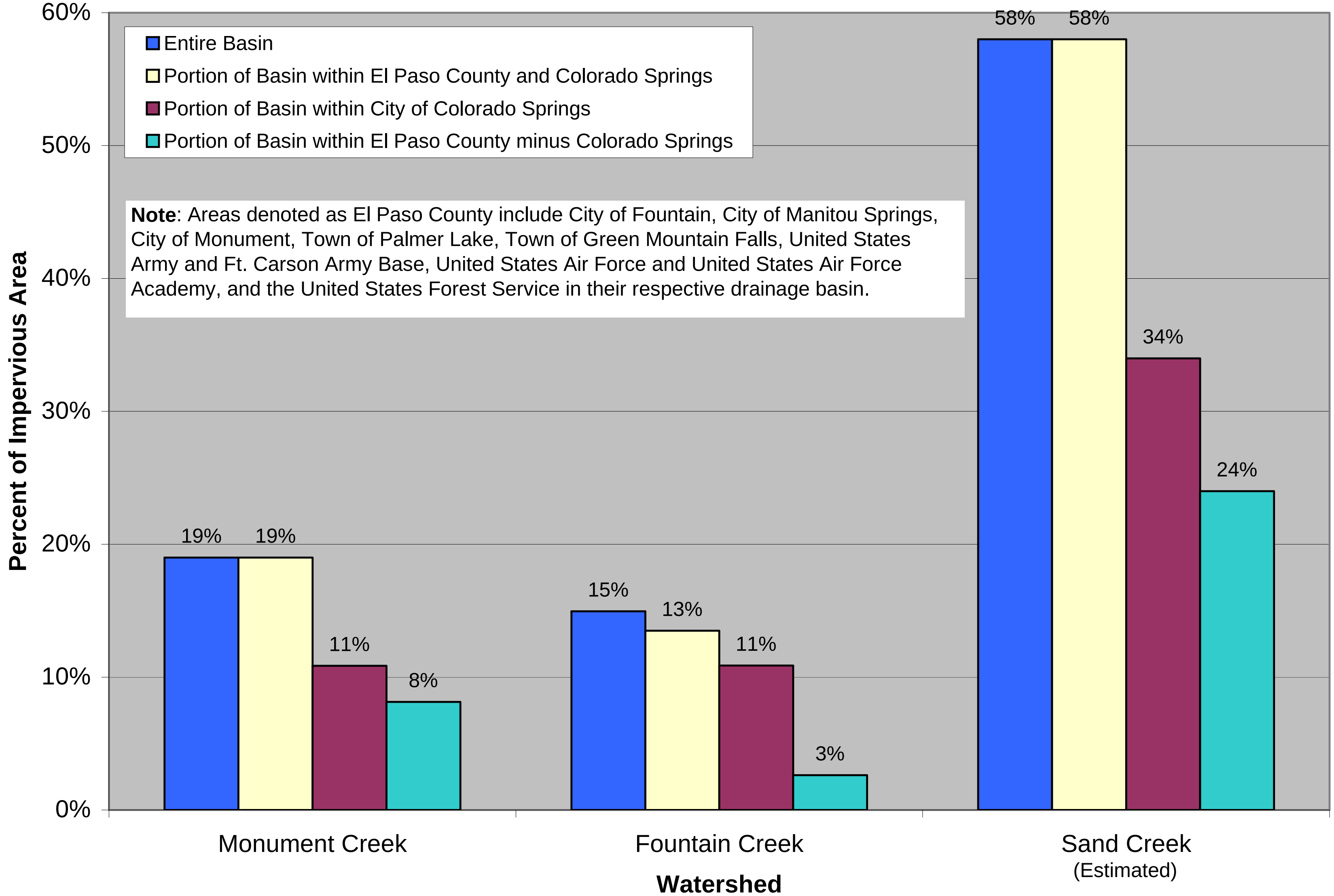

Figure 13. Estimates of the impervious areas in the Monument, Fountain and Sand Creek basins that are based on the 2010 projections in the Drainage Basin Planning Studies that were conducted for the City of Colorado Springs.

2.9. Quantification of Erosional Impacts of Upstream Development

Miller (1987), von Guerard (1989a, b), and Stogner (2000) have attributed increased rates of erosion and sediment transport along Fountain Creek to the hydrologic and sedimentologic impacts of urbanization and transbasin and transmountain water importation. Specifically, at the Greenview Trust property, Stogner (2000) has documented an increased rate of erosion of the high terrace located just upstream of the point of diversion. Stogner (2000) has also suggested that the increased baseflows have promoted the growth of riparian vegetation. Studies of the effects of increased riparian vegetation (Williams and Wolman, 1984; Harvey and Schumm, 1987; Harvey and Watson, 1988) have indicated that bank-erosion rates may be higher with the added vegetation because discharges must be passed through the unvegetated portions of the channel that have lower hydraulic roughness and higher more erosive velocities. Von Guerard (1989a) showed that urbanized areas in the Fountain Creek basin produced an order of magnitude more sediment than non-urbanized areas (7.7 tons/sq. mile/day compared to 0.5 tons/sq. mile/day). He also showed that measured bank-erosion rates at a site located about 1.05 miles upstream of the Security gage had increased by 65 percent over time, which he partially attributed to the increased frequency and magnitude of flood peaks due to upstream urbanization. Garcia and Roesner (2003) concluded that upstream development increased the mean flow velocities during the 1999 flood events, and hence the erosivity of the flows, by between 15 and 17 percent.

2.9.1. Vegetation and Channel Changes at Greenview Site

Aerial photography of the Greenview Trust reach of Fountain Creek was available for the following years: 1955, 1962, 1970, 1980, 1993 and 1999 (after the April—May floods). The photography was used to quantitatively evaluate changes in riparian vegetation within a defined polygon centered on the point of diversion for the Greenview Ditch (**Figure 14**), and to quantify the lateral erosion of the channel at a transect located just upstream of the point of diversion (**Figure 15**).

For the analyses of the changes in vegetation through time, the ground conditions were classified into seven mapping units for each time period: (1) bare sand and gravel (active channel), (2) bare ground with sparse vegetation, (3) bare ground with medium density vegetation, (4) complete ground cover (shrubs), (5) medium density trees and shrubs, (6) dense trees and shrubs, and (7) agricultural land. The various classes were not ground truthed, so no assignment of species was attempted even though the shrubs are dominated by willows and the trees by cottonwoods. The boundaries of the mapping units within the defined polygon were identified on each of the aerial photographs, and the areas within each mapping unit were digitized. **Figure 16** shows the distribution of the mapping units on the 1993 photography, and comparison of Figures 14 and 16 demonstrates that the amount of vegetation and the types of vegetation changed significantly between 1955 and 1993, which is most likely the condition that existed at the time of the 1999 floods since there were no large floods between 1993 and 1999 at the Pinon gage. **Figure 17** summarizes the distribution of the mapping units for each of the time periods between 1955 and 1993. **Table 4** presents the areas (ac) and corresponding percentages for each of the vegetation mapping units for 1955 and 1993.

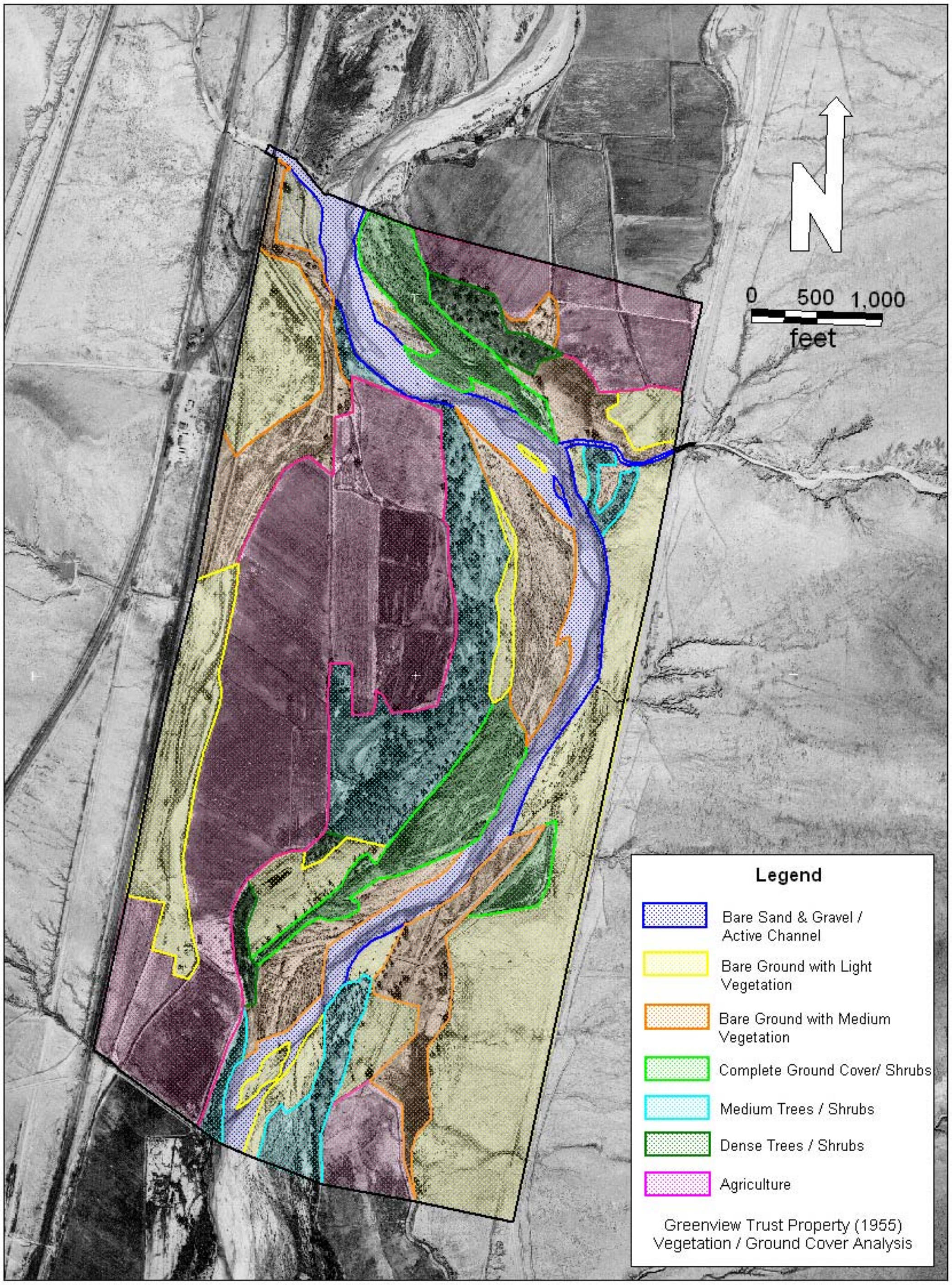

Figure 14. 1955 aerial photograph of Fountain Creek in the vicinity of the Greenview Ditch point of diversion showing the boundaries of the polygon that was used to quantify changes in vegetation between 1955 and 1999.

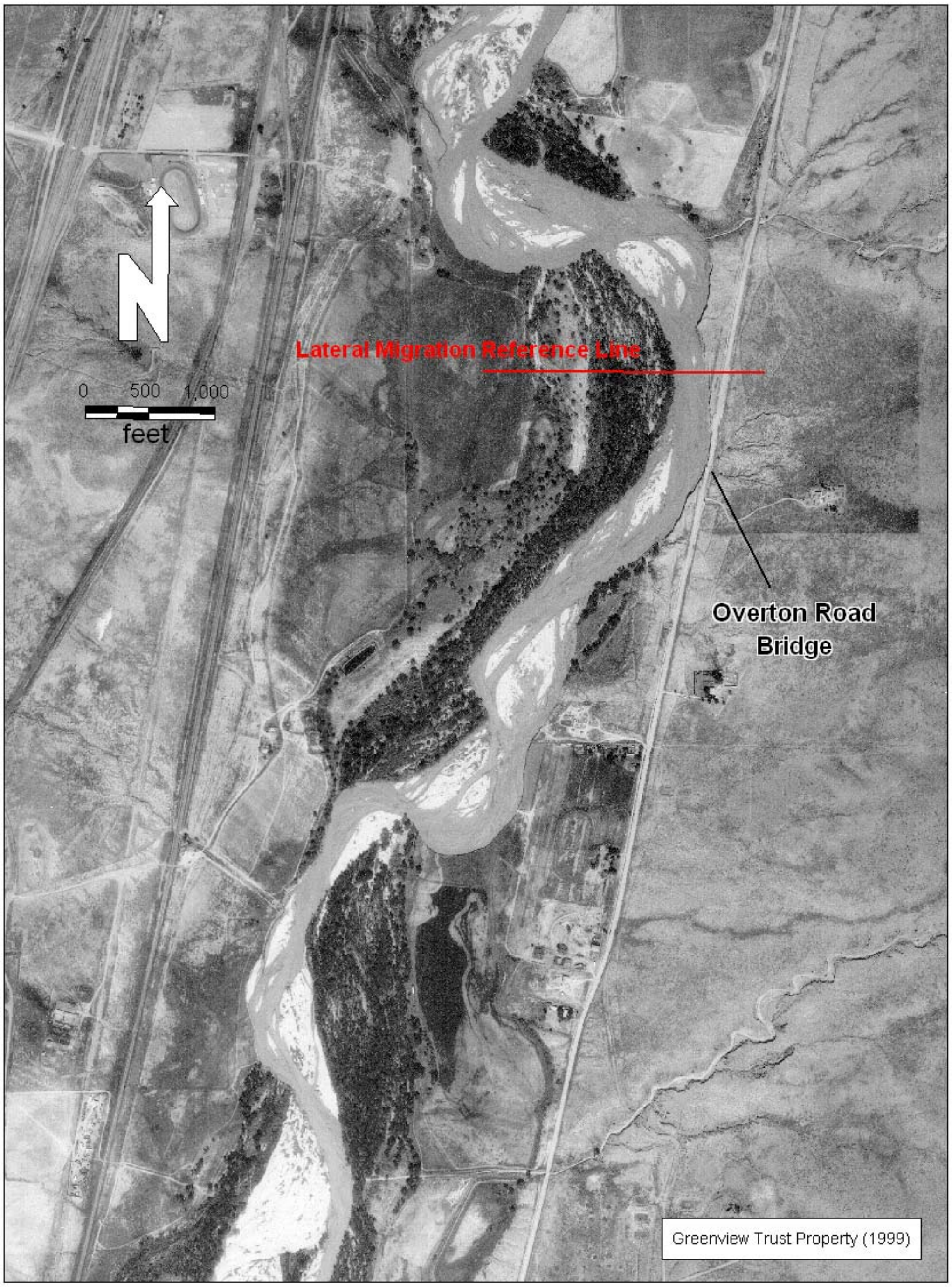

Figure 15. 1999 aerial photograph of Fountain Creek in the vicinity of the Greenview Ditch point of diversion showing the location of the transect that was used to quantify lateral migration of Fountain Creek between 1955 and 1999.

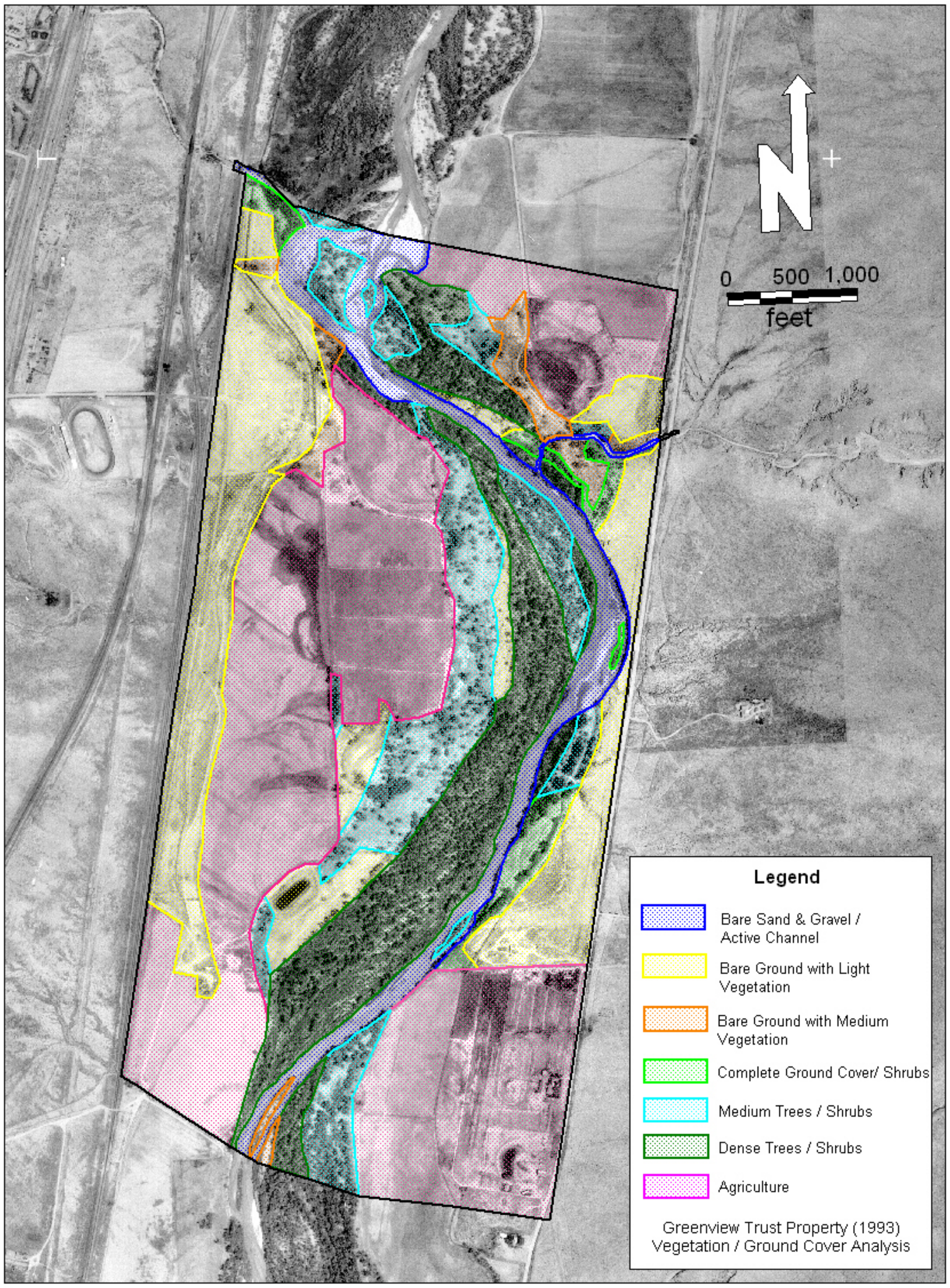

Figure 16. 1993 aerial photograph of Fountain Creek in the vicinity of the Greenview Ditch point of diversion showing the boundaries of the mapping units that were used to quantify the distribution of the vegetation mapping units within the defined polygon.

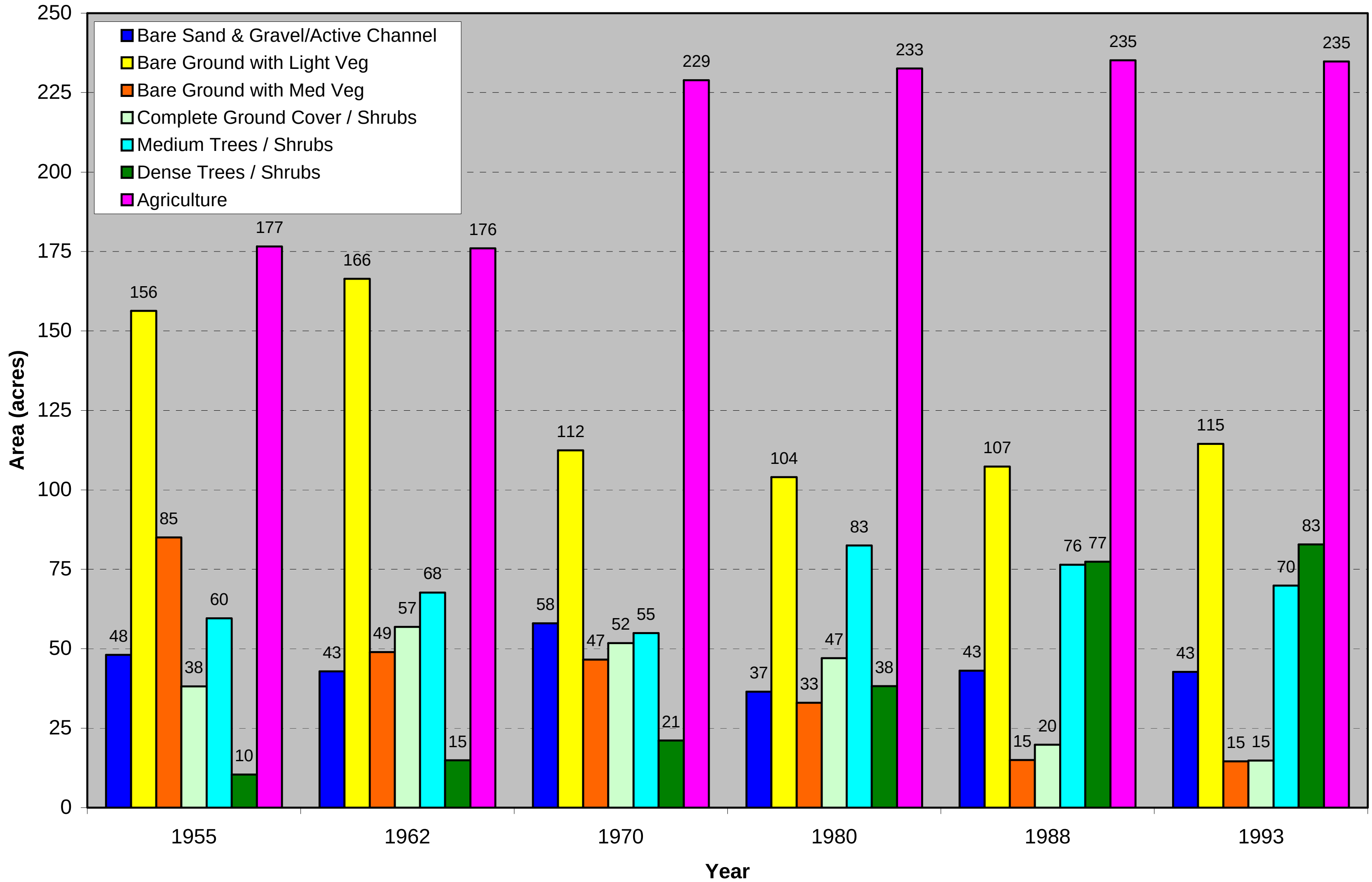

Figure 17. Summary of the distribution of the vegetation mapping units at the Greenview site between 1955 and 1993.

Table 4. Summary of acreages and percentages for 1955 and 1993 at Greenview Trust site.				
Vegetation Class	1955		1993	
	Area (ac)	Percent (%)	Area (ac)	Percent (%)
Bare Ground; sand and gravel	48	8	43	7
Bare ground with sparse vegetation	156	27	115	20
Bare ground with medium vegetation	85	15	15	3
Complete ground cover (shrubs)	38	7	15	3
Medium density trees and shrubs	60	10	70	12
Dense trees and shrubs	10	2	83	14
Agricultural land	177	31	235	41
Total	**574**		**576**	

The data in Table 4 clearly show that the areas of higher density vegetation (complete ground cover (shrubs), medium density trees and shrubs, and dense trees and shrubs) increased substantially between 1955 and 1993. If the agricultural land within the polygon in 1955 and 1993 are subtracted from the total areas, and the percentages are recomputed, it is apparent that the percentage of the three higher-density vegetation units increased from about 28 to 49 percent between 1955 and 1993. The increases in the amount and density of the riparian vegetation can be attributed to the increased base flows in Fountain Creek as a result of flow importation to the basin (Table 2), and the absence of large floods since 1965 (Stogner, 2000).

Riparian vegetation establishment increases the hydraulic roughness of the channel and increases the stability of the vegetated surface because of the binding effects of the roots (Smith, 1976). The presence of the vegetation encourages both lateral and vertical growth of the point bar on the inside of the bends by trapping sand and gravel. This tends to lead to the concentration of flow on the outside of the bend, and results in a narrower, deeper, more asymmetric and sinuous channel. All these processes increase shear stress (erosive force) on the outside of the bend (Ligon et al., 1995). As channel roughness increases due to the presence of vegetation, water velocity is reduced due to drag. Since the volume of water passing through the channel cross section is determined by how much water is entering from upstream, and the channel width is fixed, any reduction in water speed due to the vegetation must be compensated for by an increase in depth, which causes an increase in erosive force since shear stress is directly proportional to depth (Harvey and Watson, 1988). In addition, during higher flows, water that would have previously have spread out over the bottom of the channel to form a wide, relatively shallow flow is now confined to a narrower and deeper channel by the presence of the aggraded point bar. Additionally, whereas the pre-vegetated low-flow channel could migrate within the wider channel area, the establishment of a vegetated point bar tends to keep the channel in one place, thereby exposing the outside of the bend to more continuous erosive forces. This leads to the reasonable conclusion that smaller floods become more effective in causing bank erosion, and that increased baseflows accelerate the removal of failed bank materials, thereby effectively increasing the rates of erosion.

Stogner (2000) evaluated the erosion rates of the terrace margin on the east side of Fountain Creek at the Overton Road Bridge. He concluded that, between 1955 and 1970, there was little erosion at the site, even though the flood of record at the downstream Pueblo gage occurred in 1965 (47,400 cfs). Between 1970 and 1991, the terrace margin retreated about 100 feet at an average rate of 5 ft/year. Between 1991 and 1999, the terrace margin retreated a further 160 feet at an average rate of about 20 ft/year, which lead him to conclude that the rate of bank retreat had increased through time primarily because of the occurrence of five moderate-sized floods (>10,000 cfs at the Pueblo gage) between 1991 and 1999. Although he did not correlate the increased erosion rates with the increased riparian vegetation in the reach, he did note the presence of the higher vegetation density. He further noted that the increased baseflows in Fountain Creek had the capacity to transport sand-sized and finer material, which is the size range introduced to the channel by bank failure at the Overton Road Bridge site. Continued removal of failed bank materials during low-flow periods is the process by which bank failure is permitted to continue (Thorne, 1982).

A similar analysis was undertaken about 1,000 feet upstream of the Overton Road Bridge (Figure 15). The results of the analysis are shown on **Figure 18**. Between 1955 and 1962, the terrace retreated 15 feet, at an average rate of 2.1 ft/year. The 1965 flood of record (47,400 cfs) occurred between 1962 and 1970, where the bank retreated 85 feet at an average rate of 10.6 ft/year. Between 1970 and 1980, there was a further 31 feet of bank retreat at an average rate of 3.1 ft/year, primarily because of the occurrence of the 1980 flood (15,200 cfs). Five feet of retreat occurred between 1980 and 1988 (average rate of 0.6 ft/year) and the largest discharge in this period was 9,080 cfs in 1982. Between 1988 and 1993, there was no measurable bank retreat, and the largest flood event was less than 4,000 cfs. A further 60 feet of bank retreat occurred between 1993 and 1999 at an average rate of 10 ft/year. The retreat was driven by five events that exceeded 10,000 cfs, and included the 1999 event (18,900 cfs). The average rates of bank retreat suggest that smaller events in the 1993 to 1999 period were capable of producing similar rates of erosion (about 10 ft/year) to that of the flood of record in the 1962 to 1970 period. Review of the time-sequential aerial photography indicated that the channel in the reach changed from a braided to a narrower single-thread meandering planform between 1955 and 1993 as a result of vegetation encroachment. Following the 1999 flood, the channel width increased as a result of lateral migration to the east as well as removal of riparian vegetation on the west.

2.9.2. Channel Changes at the KOA Property Site

Aerial photography of the Speight Family Partnership (KOA) reach of Fountain Creek was available for the following years: 1955, 1962, 1967, 1983, 1988, 1993 and 1999 (after the April—May floods). Review of the time-sequential aerial photography revealed that a number of man-made changes have occurred within the reach, and these changes have affected the sediment- transport characteristics of the reach. On the 1955 and 1962 photographs, in the general location of the KOA property, a split-flow condition existed with the dominant channel being located on the east side of the valley floor. A small diversion structure for the Chilcott Ditch was present in the east branch. The east and west branches of the creek were separated by a tree-covered mid-channel bar or island (**Figure 19**). Following the 1965 flood (25,000 cfs at the Security gage), both branches of the creek widened as a result of erosion of the vegetated island and the floodplain on the west side of the west channel. To maintain flows at the Chilcott Ditch, a berm was constructed across the head of the west branch channel (**Figure 20**). By the time of the 1983 photography, the west branch was the dominant channel, and a diversion structure (about 8 feet high) had been constructed at the head of the channel to ensure that low flows could be diverted from Fountain Creek at the headgate for the Chilcott Ditch that was still located on the east branch channel (**Figure 21**). Flood flows in 1978 (9,000 cfs) and 1980 (9,120 cfs) were probably responsible for the widening of the west branch channel. Installation of the diversion structure effectively raised baselevel for the upstream portion of the channel of Fountain Creek and flattened the channel slope. Sand-and-gravel mining on the floodplain on the east side of the creek upstream of the KOA property appears to have required construction of a levee along the east bank that confined the flows between the levee and the terraces on the west side of the creek. Although there were no floods higher than 3,800 cfs between 1983 and 1988, the 1988 photography shows that there was upstream

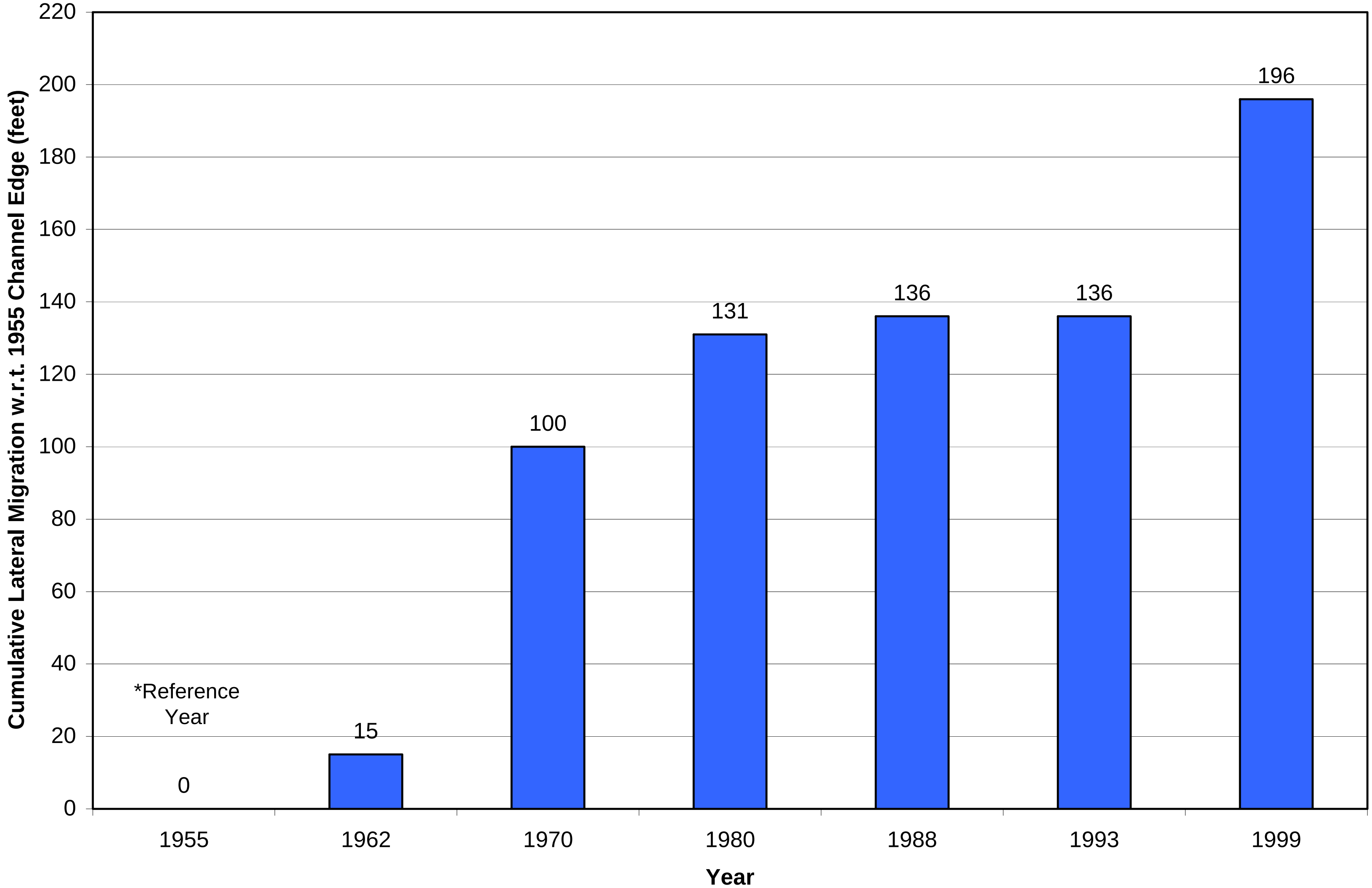

Figure 18. Cumulative bank erosion rates at the Greenview site from 1955 to 1999.

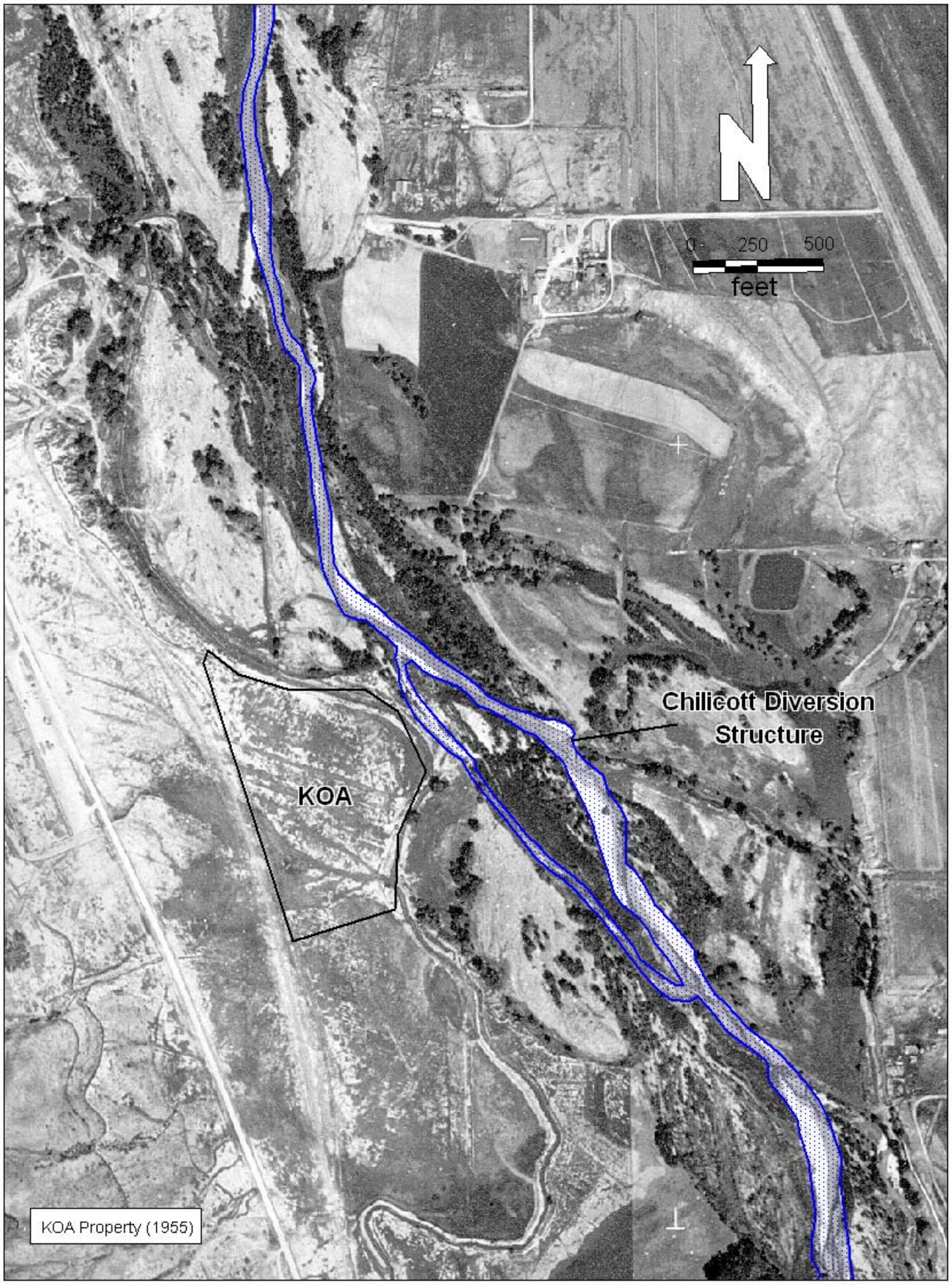

Figure 19. 1955 aerial photograph of the KOA reach of Fountain Creek.

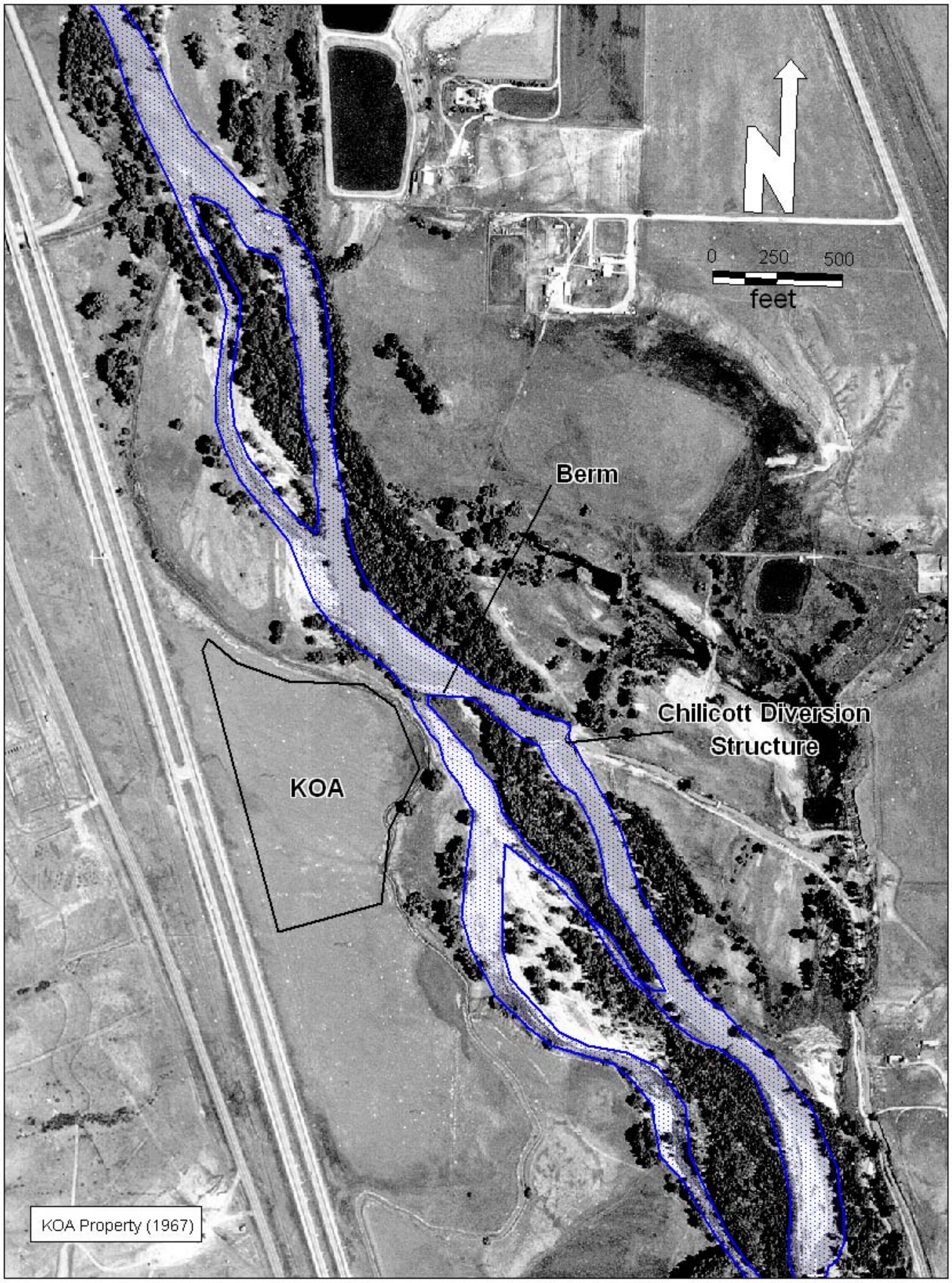

Figure 20. 1967 aerial photograph of the KOA reach of Fountain Creek.

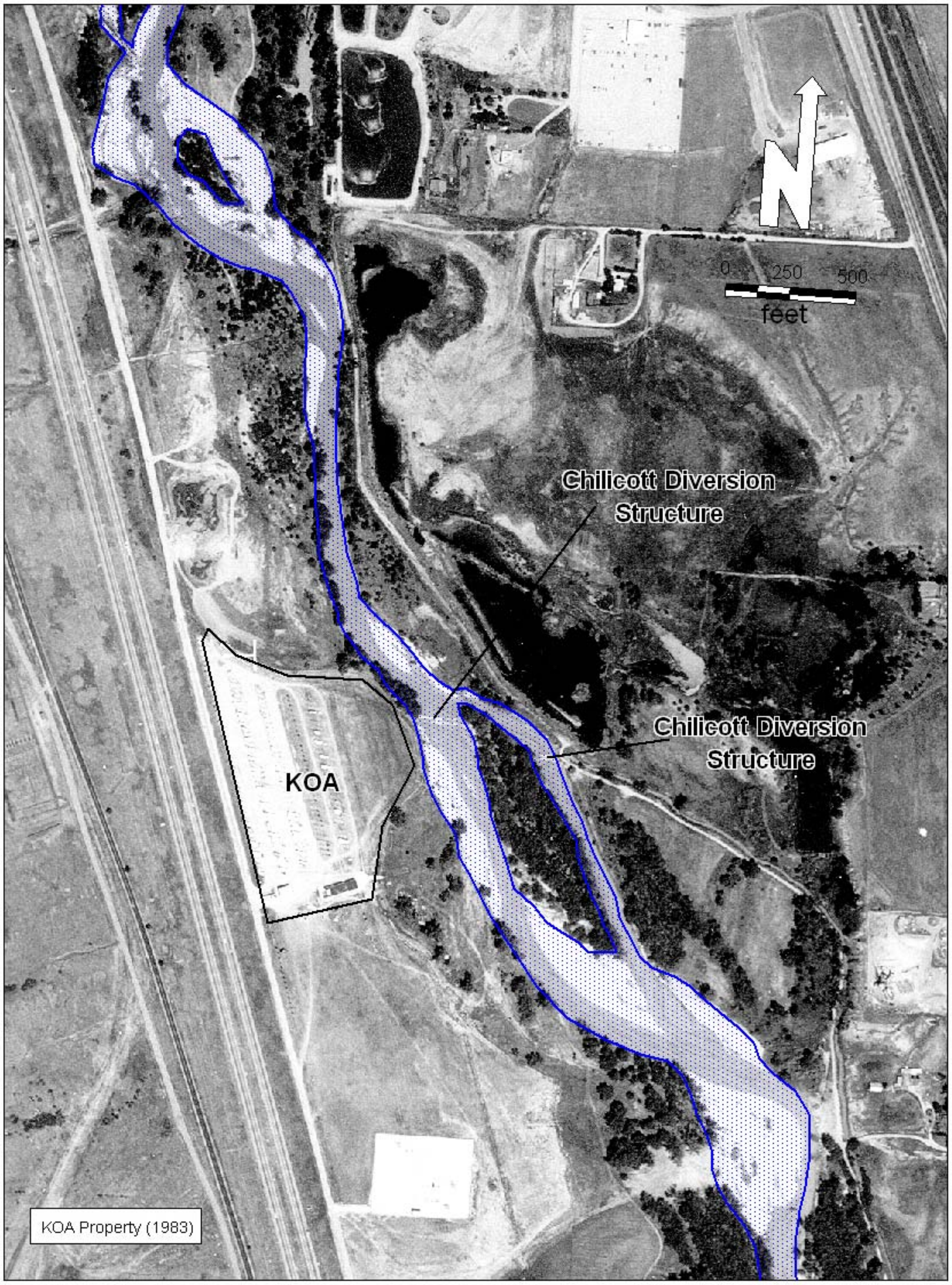

Figure 21. 1983 aerial photograph of the KOA reach of Fountain Creek.

channel widening, most probably caused by sediment deposition due to baselevel raising due to construction of the diversion structure at the head of the west branch channel. Very little change occurred in the reach between 1988 and 1993 (**Figure 22**). The 1999 post-event photography clearly shows the erosion of the KOA property, the failure of the diversion structure at the head of the west branch channel and removal of most of the vegetated island between the east and west branches. The photography also shows that there was extensive erosion of the west bank of the creek upstream of the KOA property (**Figure 23**). Based on the evidence of sediment deposition in the bed of the channel upstream of the diversion structure in the 1988 and 1993 photographs, it is highly likely that the upstream west bank erosion was driven by the aggradation of the bed in a similar manner that was reported by Stogner (2000) at other locations between Widefield and Pinon during the 1999 floods. The presence of riprap bank protection almost continuously along the east bank of the creek that had been emplaced to protect the east bank levee and wastewater treatment and other ponds, also made it more likely that the unprotected west bank of the creek upstream of the KOA property would erode. It is also highly likely that failure of the diversion structure during the 1999 floods also caused erosion along the KOA property. Failure of the structure would have lowered baselevel during the event, and also concentrated the flows in the vicinity of the KOA property.

2.9.3. Sediment-transport Evaluation at KOA Property Site

Erosion of the KOA property during the 1999 floods was the result of a complex set of factors that included: (1) baselevel raising and consequent upstream slope reduction as a result of construction of the Chilcott Diversion structure at the head of the west branch channel, (2) increased sediment supply from upstream as a result of urbanization of the watershed (von Guerard, 1989a, b), (3) increased delivery of sediment to the reach as a result of increased flows derived from upstream development, upstream channel degradation and levee construction, and (4) flanking of in-place pre-1999 bank protection along the west bank of the creek at the head of the diversion structure due to bed aggradation, armoring of the east bank and lateral migration of the channel to the west. To evaluate the impacts of the various man-made changes a sediment-transport analysis was conducted of the reach of Fountain Creek between the reconstructed diversion structure at the KOA property and the USGS Security gaging station, a channel distance of about 6,700 feet.

To conduct a sediment-transport analysis of the existing conditions (post-1999) since pre-1999 data were not available, a topographic survey of the reach was conducted by Mussetter Engineering, Inc. staff on June 5 and 6, 2003. During the course of the survey that was based on arbitrary coordinates, the thalweg of the creek was surveyed as were 11 cross sections that were tied together horizontally and vertically (**Figure 24**). Cross-section locations were selected by Dr. Harvey to reflect the morphological conditions within the reach. The survey data were reduced and were then used to develop a one-dimensional (1-D) HEC-RAS hydraulic model of the reach (USACOE, 2002). Hydraulic output from the HEC-RAS model and an average bed-load sediment gradation developed from 15 samples collected by the USGS at the Security gage (von Guerard, 1989b) (**Figure 25**) were then used to develop sediment-rating curves for each of the cross sections using the MPM-Einstein sediment-transport formulation (Simons, Li & Associates, 1982).

The modeled reach was subdivided into four subreaches based on the field-observed geomorphic characteristics of the reach (Figure 24). Subreach 1 includes Cross Sections 10 and 11. The bed of the creek in this subreach has degraded between about 4 and 6 feet and is composed of Pierre Shale outcrop, and the channel is confined between high terraces formed in Pierre Shale (von Guerard, 1989a, b; Stogner, 2000). The bed slope is about 0.006, and the width of the bankfull channel (i.e., the former floodplain surface) is about 160 feet. Subreach 2

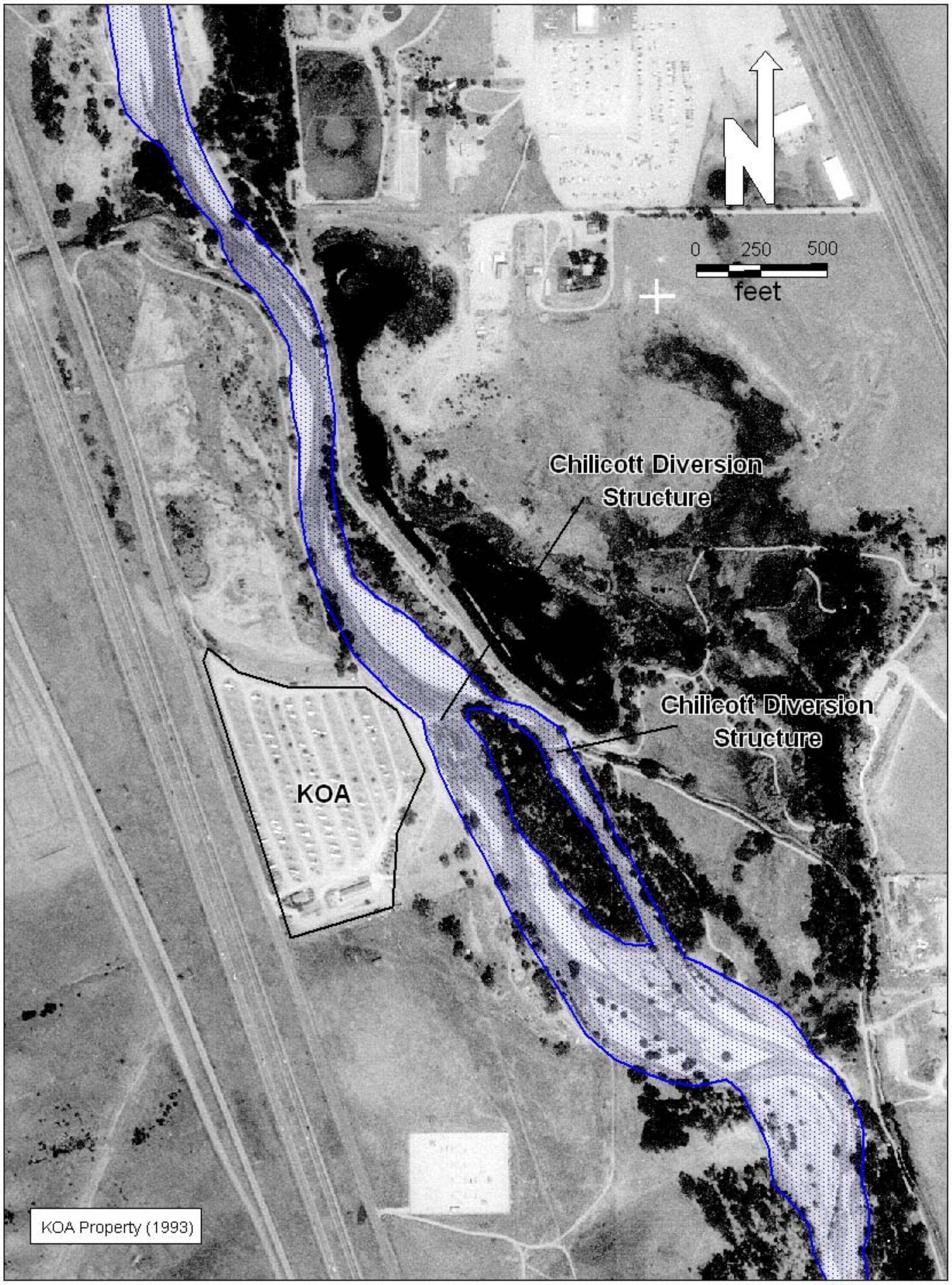

Figure 22. 1993 aerial photograph of the KOA reach of Fountain Creek.

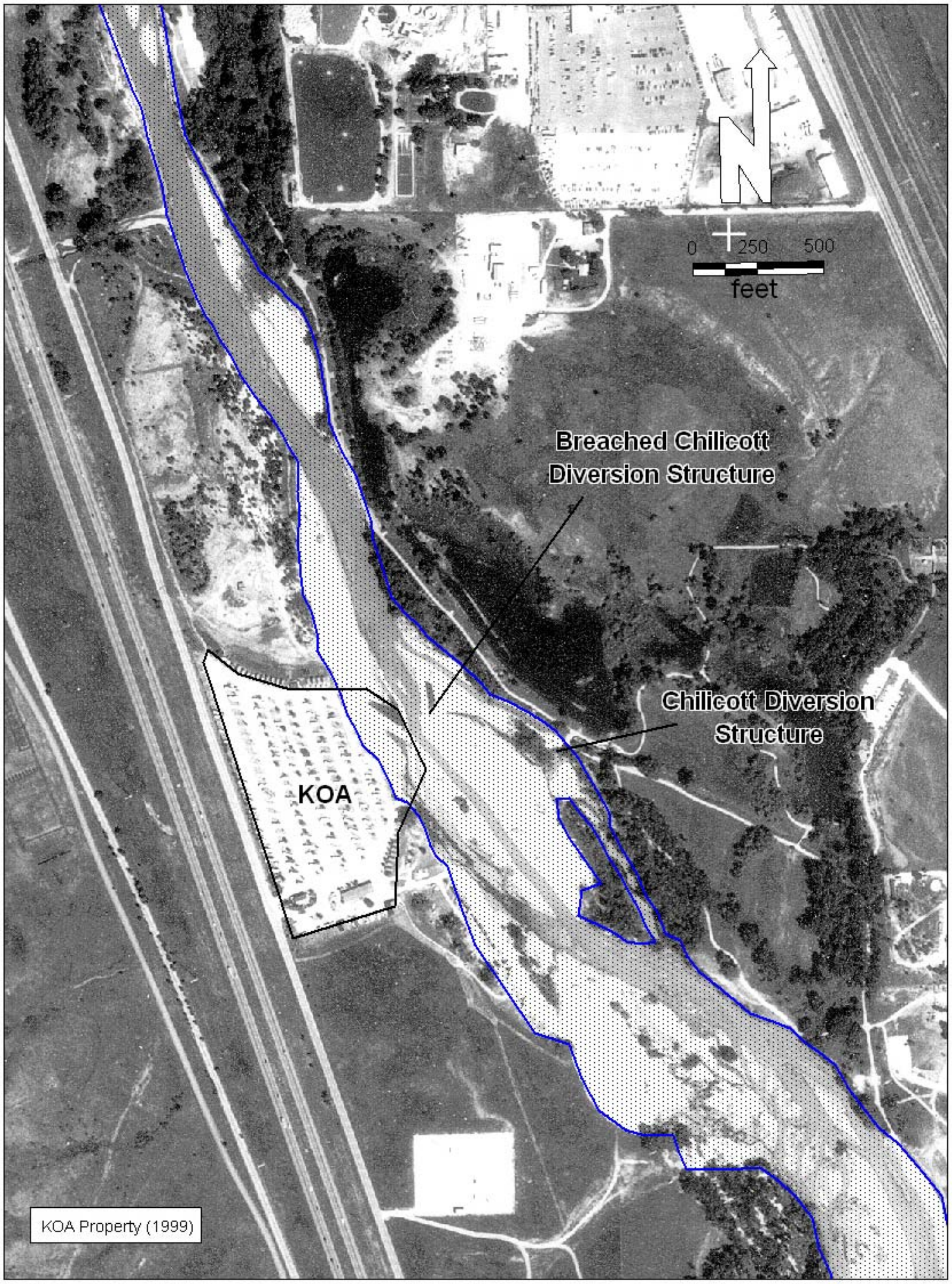

Figure 23. 1999 aerial photograph of the KOA reach of Fountain Creek.

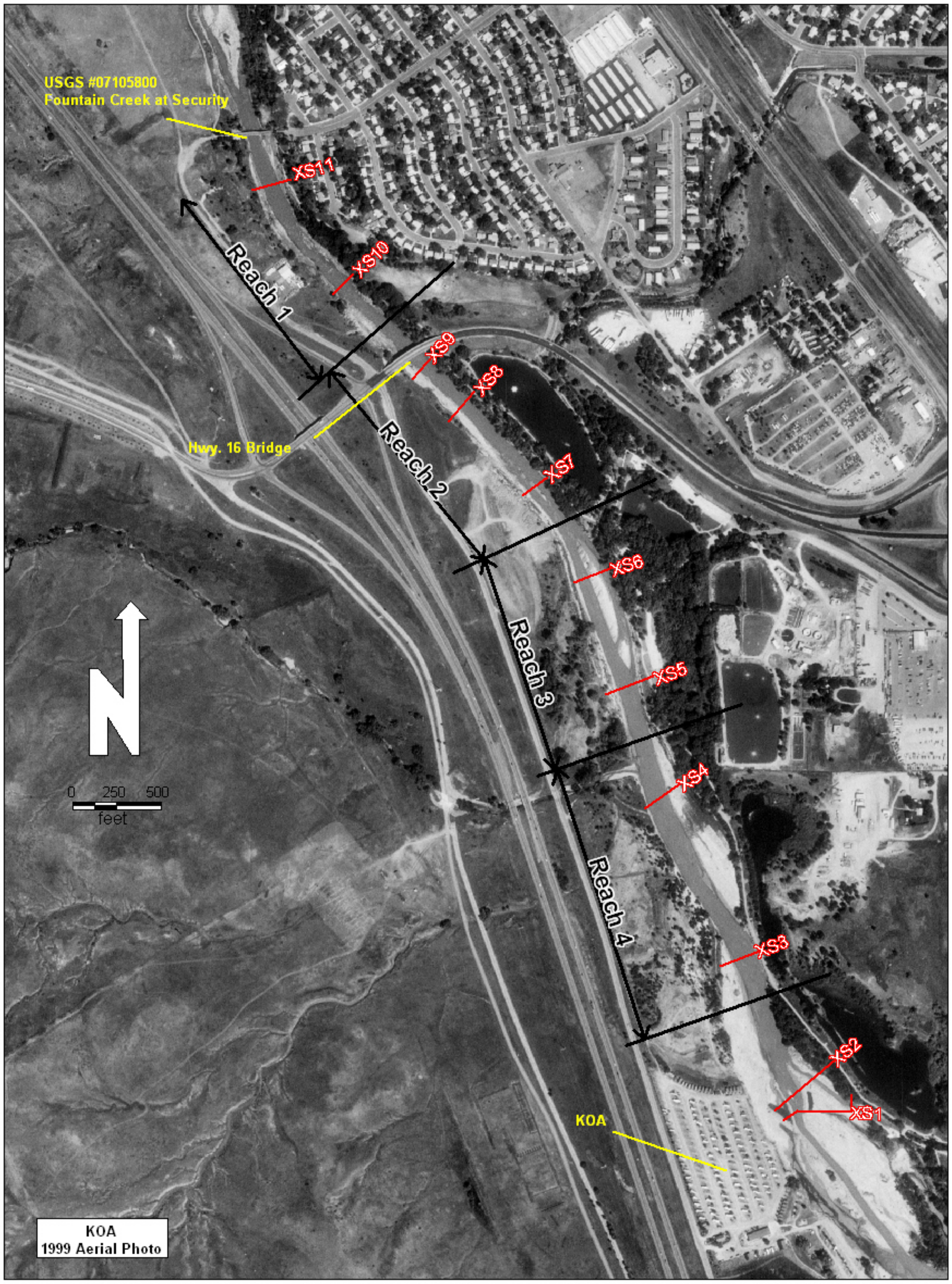

Figure 24. 1999 aerial photograph of the KOA reach of Fountain Creek showing the locations of the cross sections surveyed in June 2003.

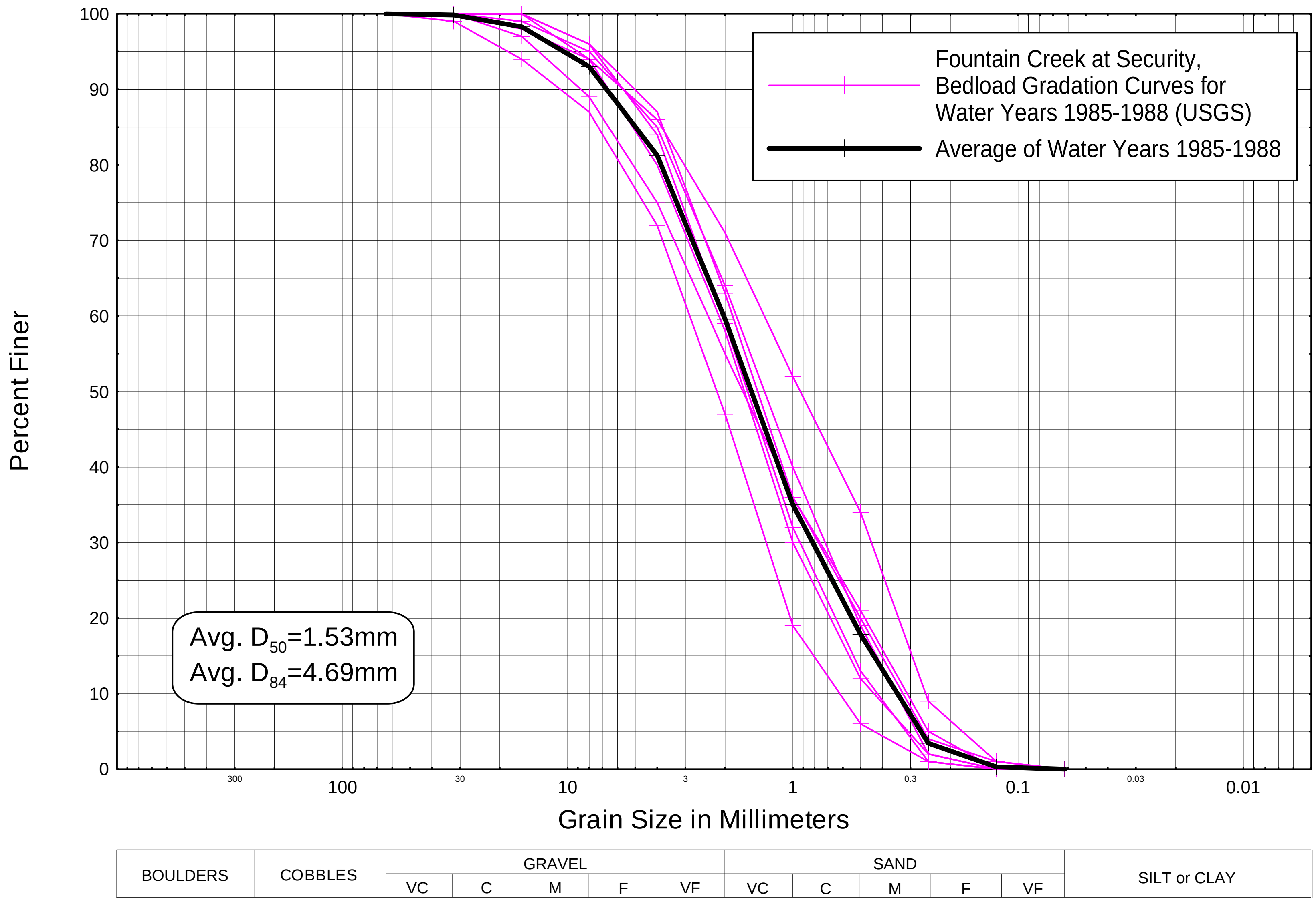

Figure 25. Bed-load gradation curves for samples collected at the Security gage by the USGS (von Guerard, 1989b). Also shown is an average gradation that was used to develop sediment-rating curves for the KOA reach.

includes Cross Sections 7, 8 and 9, and the bed of the channel is composed of very coarse rubble that overlies shale outcrop, that indicates that bed degradation has also occurred in this subreach. The channel is confined by a floodplain remnant and high terrace along the west (right) bank and by a riprapped levee along the east (left bank). The bed slope is about 0.006, and the width of the bankfull channel is about 166 feet. Subreach 3 includes Cross Sections 5 and 6, which encompass a large mid-channel bar that has formed in the bed of the channel. The channel is confined by a riprapped levee along the east bank, and by an alluvial terrace along the west bank. The bed of the channel is composed of sand and gravels, and the bed slope is about 0.003. The presence of the mid-channel bar has caused erosion of the west bank, and as a result the average width of the bankfull channel is about 197 feet. Subreach 4 includes Cross Sections 3 and 4. The channel is confined by a riprapped levee along the east bank and by the floodplain of Fountain Creek along the west bank. Field evidence and photographs taken during the 1999 floods indicate that the floodplain along the west bank was overtopped and water extended west to the terrace that supports Bandley Drive. The average bed slope in the reach is 0.003, and the bed is composed of sand and gravels. The average width of the channel at bankfull stage is about 252 feet. **Figure 26** presents the thalweg, left and right bank, and water-surface profiles for a range of flows between 10 and 15,000 cfs. Additionally, the east bank levee profile is shown on Figure 25 as well as the elevations of the terraces that flank the channel on the west side of the valley. The water-surface profiles show that the floodplain on the west side of the river between Cross Section 4 and the Chilcott Diversion structure was inundated in 1999. Cross Section 2 was not included in Subreach 4 because of uncertainty with respect to the downstream boundary conditions for the model. However, the bed slope at this cross section is very flat (0.00014), and the channel width at bankfull stage is about 380 feet. Cross Section 1 in the model represents the crest of the Chilcott Diversion structure.

Sediment-rating curves were developed for the individual subreaches (**Figure 27**). Based on the actual flow record at the Security gage, an average annual sediment-transport volume was computed for each of the subreaches for the 1965 to 1976 and 1977 to 2001 periods (**Figure 28**). These volumes were then compared with von Guerard's (1989b) estimates that were based on suspended-sediment measurements at the Security gage between 1985 and 1988. As a check of the MPM-Einstein-based estimates, the gradations from the MPM-Einstein relationship were compared with the measured gradations at the USGS gage (von Guerard, 1989b) (**Figure 29**). The MPM-Einstein gradations are a little finer than the measured gradations, which suggest that the sediment-rating curves may be a little steep, and the estimated sediment volumes may be a high.

Von Guerard (1989a) demonstrated that urbanization of the Fountain Creek basin increased the suspended-sediment yield by a factor of nearly 17. Based on suspended-sediment measurements at the Security gage, von Guerard (1989b) determined that the mean annual suspended-sediment load at the Security gage was 196,000 tons (Figure 28), of which 77,900 tons were sand. Because of the somewhat finer gradation computed by the MPM-Einstein formulation (Figure 29), and possibly because of increased slope due to degradation and exposure of the shale outcrop in the bed of the channel since the 1985—1988 period (William Payne, USGS personal communication, June 2003), the average annual estimate computed for Subreach 1 which is located just downstream of the Security gage (334,000 tons total; 132,800 tons sand assuming the same ratio as the USGS measurements), is much higher than the USGS estimate (Figure 28) for the Security gage (196,000 tons). The MPM-Einstein computation estimates the capacity to transport sediment based on the assumption of sediment availability. Von Guerard (1989b) noted that there was in-channel and floodplain sediment storage between the Fountain Creek at Colorado Springs gage (#0710500) and the Security gage, which may also explain why the computed and measured values at the Security gage are

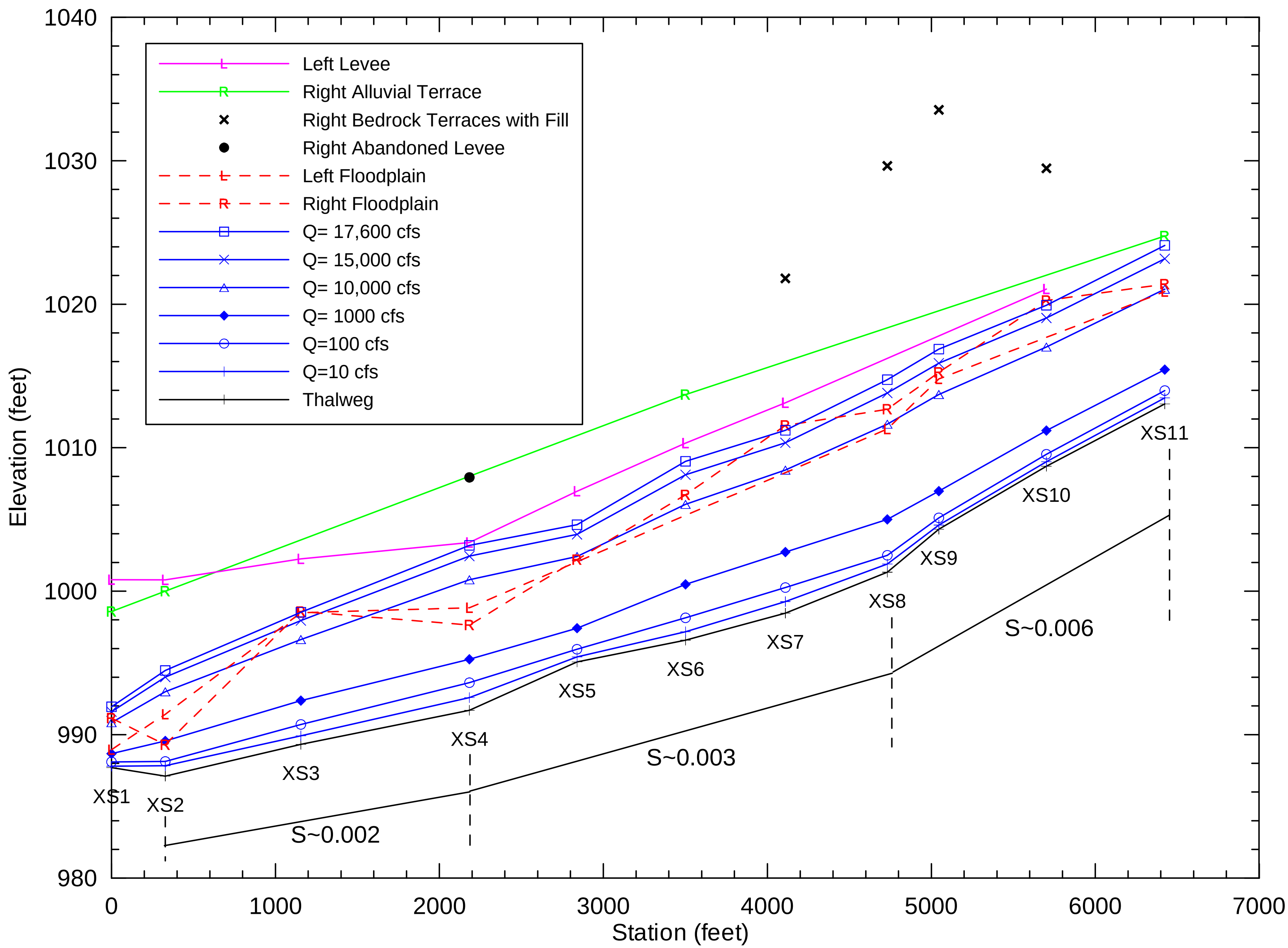

Figure 26. Thalweg, top of bank, levee, terrace and water-surface profiles for the KOA reach. Also shown are the locations of the cross sections that were used to develop the HEC-RAS hydraulic model of the reach.

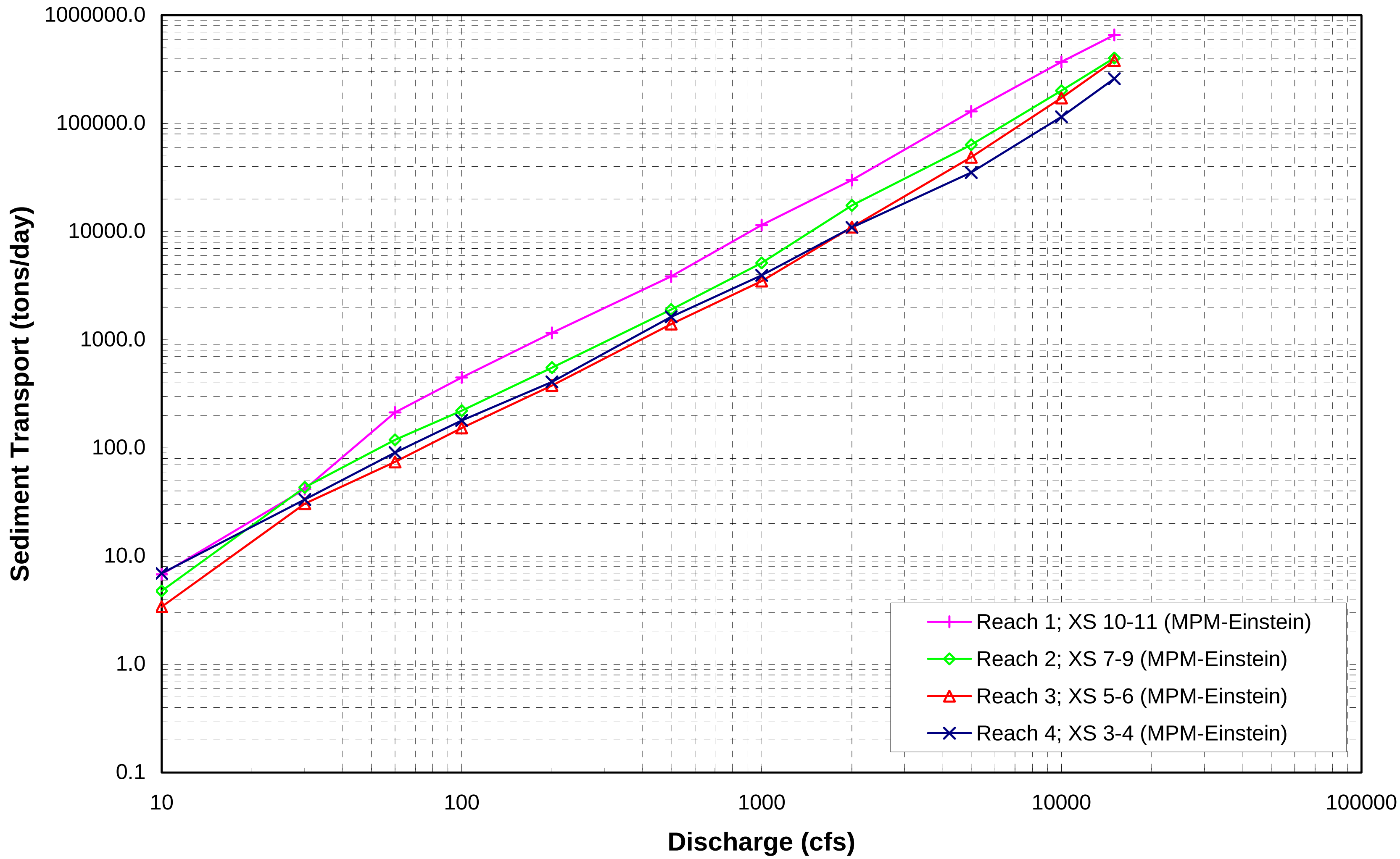

Figure 27. Sediment-rating curves for the four subreaches of Fountain Creek. The rating curves were developed from the MPM-Einstein formulation.

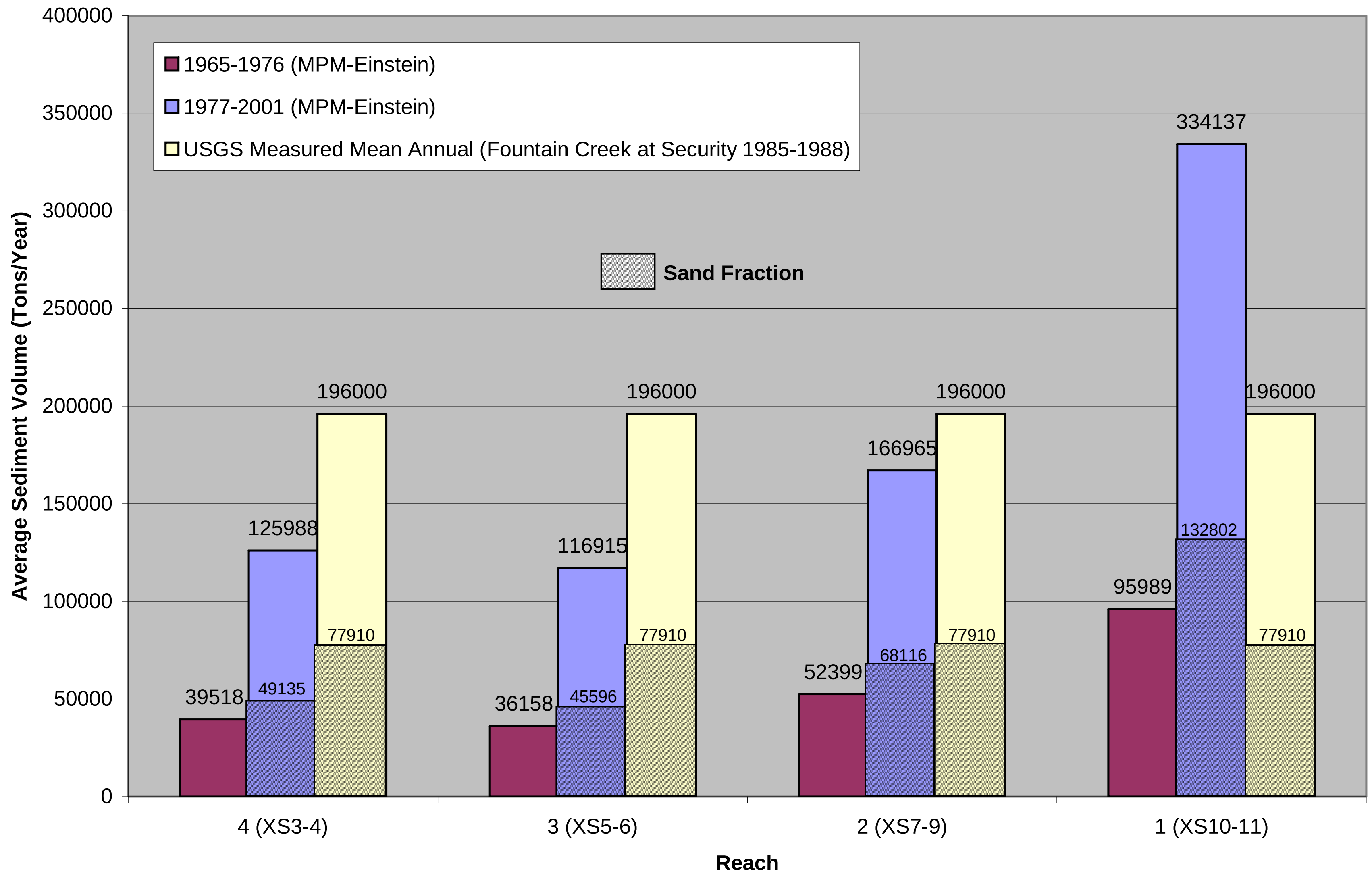

Figure 28. Subreach averaged annual sediment volumes for the 1965—1976 and 1977—2001 periods. Also shown is the mean annual sediment volume from 1985-1988 determined from measurements at the Security gage by the USGS (von Guerard, 1989b).

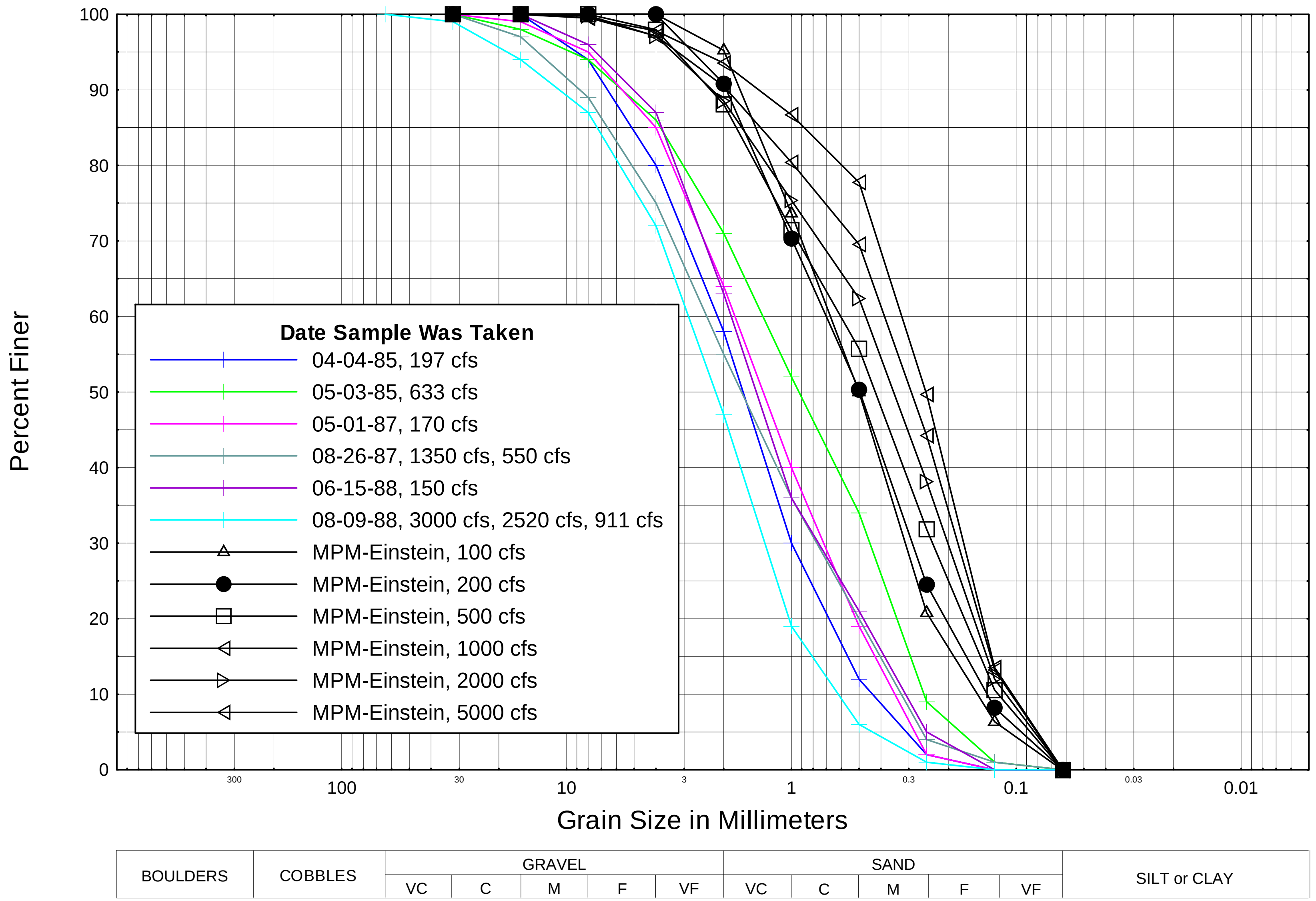

Figure 29. Comparison of sediment gradations determined from the MPM-Einstein formulation and the gradations of the sediment samples collected at the Security gage by the USGS (von Guerard, 1989b).

different. Sediment sizes less than sand (0.062 mm) do not have much effect on channel morphology, and therefore, the sand load is a better indicator of potential downstream impacts of increased sediment loads.

Regardless of the absolute values, Figure 28 shows a progressive reduction in the volume of sediment transported downstream in each subreach on an average annual basis based on the 1977—2001 flow record. The reduction in transport capacity in the downstream direction is due to the combined effects of slope reduction as a result of the presence of the diversion structure, and channel widening. In Subreach 2, the estimated volume (65,100 tons of sand) is similar to the volume computed by the USGS (77,900 tons of sand), and there is no evidence of sediment deposition in the channel (Figure 24) which suggests that the sediment supply and transport capacity are balanced. A large mid-channel bar is present in Subreach 3 (Figure 24) and the computed transport capacity (45,600 tons of sand) is significantly less (30 percent) than the upstream supply from Subreach 2 (65,100 tons of sand). The relatively low transport capacity in this subreach is also due to the increased channel width and reduced slope. Riprapping of the east bank has required that the channel adjustment to the aggradation occur by erosion of the west bank. In Subreach 4, the estimated sediment volume (49,100 tons of sand) is similar to that of Subreach 3, indicating that both reaches are equally aggradational. Since the east bank of the channel is riprapped, the aggradation-induced channel widening has occurred on the west side of the channel.

In summary, the data and the sediment-transport analyses confirm that erosion of the KOA property in the floods of 1999 was the result of the interaction of a complex set of processes. Upstream urbanization and the importation of transbasin and transmountain flows has resulted in increased flows at the Security gage which is located about 6,700 feet upstream of the KOA property. Computation of an average annual suspended-sediment volume for Subreach 4 based on the 1965 to 1976 actual flow record at the gage indicated that about 96,000 tons was transported annually. In comparison, for the 1977—2001 period, the estimated average annual volume is on the order of 334,100 tons, an increase by a factor of about 3.5. In other words, the increased flows due to upstream development have the potential to supply significantly more sediment to the KOA reach than occurred historically (Figure 28). Von Guerard (1989a, b) has demonstrated that upstream urbanization has significantly increased the sediment supply from the watershed as a result of both increased erosion rates of disturbed lands and due to channel adjustments (widening and deepening) to increased flows. Levee construction along the east bank of Fountain Creek prevented overbank flows, thereby increasing the sediment-transport capacity of the flows confined between the west bank terraces and the east bank levee. The confined flows delivered more sediment to the reach and in combination with the riprap protection of the east bank forced erosion of the unprotected west bank. Reduction in slope as a result of the construction of the Chilcott Diversion structure reduced the sediment-transport capacity of the flows, caused aggradation of the reach, and in turn led to erosion of the west bank of the creek and flanking of the riprap that had been constructed on the west bank immediately upstream of the diversion structure in the 1999 floods.

2.10. Conclusions

Based on the information and analyses that have been conducted, the following can be concluded regarding the erosion and damages that occurred at the Speight Family Partnership and Greenview Trust properties along Fountain Creek in the floods that occurred between April 29 and May 3, 1999:

1. Urbanization of the Fountain Creek, Monument Creek and Sand Creek basins without concurrent on-site stormwater detention has increased the magnitude and frequency of

peak discharges in Fountain Creek downstream of the confluences of the three drainages. Under 1992 conditions, approximately 13 percent of the surface area of the Fountain Creek watershed upstream of the Monument Creek confluence was classified as impervious. In the Monument Creek watershed, the impervious area was about 9 percent of the watershed area, and in the Sand Creek basin, the impervious area was about 48 percent.

2. Hydrologic and hydraulic analyses of the Fountain Creek, Monument Creek, and Sand Creek basins conducted for planning purposes for the City of Colorado Springs in the mid 1990s indicated that projected future development (2010) and urbanization of the basins in the absence of stormwater detention would further increase the magnitude of the 10- and 100-year floods, and would also cause further channel erosion. The estimates included a 2-percent increase in impervious area for Fountain Creek, a 10-percent increase for Monument Creek, and a 10-percent increase for Sand Creek.

3. USGS studies of Fountain Creek in the 1980s demonstrated that urbanization increased the daily suspended-sediment yields from the watersheds by a factor of about 17. Measured bank erosion rates increased by about 65 percent, and part of this increase was attributed to the increase in frequency and magnitude of flood peaks due to urbanization (von Guerard, 1989a, b).

4. Urbanization of the Fountain Creek, Monument Creek and Sand Creek basins and uncontrolled in-channel and channel margin sand-and-gravel mining have resulted in degradation of the channel bed of Fountain Creek that has led to increased rates of bank erosion. Channel deepening and widening have, in combination, resulted in increased channel capacity and retention of higher magnitude floods within bank that has increased the erosive capacity of the flows in Fountain Creek.

5. Importation of transbasin and transmountain flows into the Fountain Creek basin and the discharge of about 24,000 ac-ft of water from the Colorado Springs Wastewater Treatment Plant to Fountain Creek have increased the baseflows in Fountain Creek by about 30 cfs daily. The combined effects of the imported flows and the cessation of most of the irrigation abstractions from Fountain Creek since about 1969 have permitted increased growth of riparian vegetation as well as increased sediment-transport rates for sand-sized particles that make up the bed of Fountain Creek (Stogner, 2000).

6. The increased density of in-channel riparian vegetation has resulted in increased channel energy that has been reflected in increased bank-erosion rates at the Greenview Trust property. Because of the channel adjustments due to the encroachment of the vegetation into the channel, erosion rates resulting from moderate-sized floods are very similar to those that were experienced as a result of the flood of record in 1965 (about 10 ft/year). Stogner (2000) estimated that the east bank of the creek at the location of the Overton Road bridge, which is about 800 feet upstream of the Greenview Ditch headgate retreated by about 15 feet during the 1999 flood that had a recurrence interval of about 63 years at the Pinon gage.

7. During the four flood events on Fountain Creek between April 29 and May 3, 1999, mean daily Colorado Springs Wastewater Treatment Plant discharges to Fountain Creek ranged from 29 to 44 cfs when the peak discharges in Fountain Creek exceeded the ordinary high-water mark as defined by the mean annual flood at the USGS Janitell Road gage.

8. A flood-frequency analysis based on the 1977—2001 flood-frequency curves for the peak discharges for the April—May 1999 events at seven USGS stream gages on Fountain Creek and its tributaries, indicated that the recurrence interval for the events ranged from 16 to 85 years, and were not, therefore, extreme hydrological events. At the Security gage, located about 1.3 miles upstream of the KOA property, the recurrence interval for the 1999 flood peak was 82 years.

9. Erosion of the KOA property during the 1999 floods was the result of a complex set of factors that included: (1) baselevel raising and consequent upstream slope reduction as a result of construction of the Chilcott Diversion structure at the head of the west branch channel, (2) increased sediment supply from upstream as a result of urbanization of the watershed (von Guerard, 1989a, b), (3) increased delivery of sediment to the reach as a result of increased flows, upstream channel degradation and levee construction, and (4) flanking of in-place pre-1999 bank protection along the west bank of the creek at the head of the diversion structure due to bed aggradation, armoring of the east bank and lateral migration of the channel to the west.

10. Absent man-made interventions in the upstream watershed, it is inevitable that similar adverse downstream impacts to those that occurred in the 1999 floods will eventuate in response to future flood flows in Fountain Creek.

2.11. References Cited and Documents Reviewed

Ayres Associates, 2000. Cottonwood Creek Drainage Basin Planning Study. Prepared for Nor'Wood Ltd., Inc. and La Plata Investments, Inc., and City of Colorado Springs, June.

Balamururugan, G., 1991. Some characteristics of sediment transport in the Sungai Kelang Basin, Malaysia. Journal of the Institution of Engineers, Malaysia, v. 48, pp. 31-52.

CH2M Hill, 1992. Monument Creek Drainage Basin Planning Study, Volume 1. Prepared for the City of Colorado Springs Planning, Development and Finance Department.

Cohen, P. et al., 1960. An Atlas of Long Island's Water Resources. New York Water Res. Committee Bull., v. 62.

Graf, W.L., 1975. The impact of suburbanization on fluvial geomorphology. Water Resource Research 11, pp. 690-692.

Garcia, M., and Roesner, L., 2002. Report No.1 to the City Attorney for Colorado Springs, Colorado, in reference to El Paso County District Court, Case No. 01CV1290, July 31.

Garcia, M., and Roesner, L., 2003. Report No.2 to the City Attorney for Colorado Springs, Colorado, in reference to El Paso County District Court, Case No. 01CV1290, May 21.

Gregory, K.J., 1974. Streamflow and Building Activity. In Gregory, K.J. and Walling, D.E. (eds), Fluvial Processes in Instrumental Catchments, Inst. Brit. Geog. Spec. Publ. 6, pp. 107-122.

Hammer, T.R., 1972. Stream channel enlargement due to urbanization. Water Resources Research 8, pp. 1530-1540.

Harvey, M.D. and Schumm, S.A., 1987. Response of Dry Creek, California, to land use change, gravel mining and dam closure. Erosion and Sedimentation in the Pacific Rim. IAHS Publ. No. 165, pp. 451-460.

Harvey, M.D., and Watson, C.C., 1988. Channel response to grade-control structures on Muddy Creek, Mississippi. Regulated Rivers: Research and Management, v. 2, pp. 79-92.

Harvey, M.D. and Watson, C.C., 1986. Fluvial processes and morphological thresholds in incised channel restoration. Water Resources Bulletin, v. 22, no. 3, p. 359-368. Reprinted in W.L. Jackson (ed.), *Engineering Considerations in Small Stream Management*, AWRA Monograph Series, No. 5.

Harvey, M.D., Watson, C.C., and Schumm, S.A., 1983. Channelized Streams: An analog for the Effects of Urbanization. Proc. Tenth Int. Symp. on Urban Hydrology, Hydraulics and Sediment Control: Sterling, H.J. and DeVore, R.W. (eds), Univ. of Kentucky. Pub. No. UKYBU131, pp. 401-410.

Hollis, G.E., 1975. The effects of urbanization of floods of different recurrence intervals. Water Resour. Res. 11, pp. 431-435.

Hollis, G.E., 1974. The effect of urbanization on floods in Canon's Brook, Harlow. Essex. In Gregory, K.J. and Walling, D.E. (eds), Fluvial Processes in Instrumental Catchments, Inst. Brit. Geog. Spec. Publ. 6, pp. 107-122.

Kiowa Engineering Corporation, 1996. Sand Creek Drainage Basin Planning Study, Preliminary Design Report, City of Colorado Springs and El Paso County, Colorado. Prepared for the City of Colorado Springs Department of Comprehensive Planning, Development and Finance.

Leopold, L.B., 1968. Hydrology for urban land planning—a guidebook on the hydrologic effects of urban land use. U.S. Geological Survey Circular No. 554, 18 p.

Ligon, F.K., Dietrich, W.E., and Trush, W.J., 1995. Downstream ecological effects of dams: A geomorphic perspective. BioScience, v. 45, no. 3, March, pp. 183-192.

Lincoln DeVore, 1979. Engineering Study of Cottonwood creek Drainage Basin, Colorado Springs, Colorado. Prepared for Drainage Board of the City of Colorado Springs, August.

Lvovich, M.I. and Chernogaeva, G.M., 1977. The water balance of Moscow. In Effects of Urbanization and Industrialization on the Hydrological Regime and on Water Quality, IAHS Publ. 123, Wallingford, UK, pp 48-51.

Miller, D.R., 1987. The effect of diversion water on the channel morphology of Fountain Creek, Colorado. Masters Thesis, University of Colorado, Boulder, Colorado.

Miller, R.A., Troxell, J., and Leopold, L.B.,1971. Hydrology of two small river basins in Pennsylvania before urbanization. U.S. Geological Survey Professional Paper 701-A, 57 p.

Morisawa. M.E. and LaFlure, E., 1979. Hydraulic geometry, stream equilibrium and urbanization. In Rhodes, D.D. and Williams, G.P. (eds), *Adjustments of the Fluvial System*, pp. 333-350.

Muller Engineering, Company, Inc., 1994. Fountain Creek Drainage Basin Planning Study, Volume I. Prepared for the City of Colorado Springs Engineering Department.

Mussetter, R. A., Lagasse, P.F., and Harvey, M.D., 1994. Erosion and Sediment Design Guide, prepared for Albuquerque Metropolitan Arroyo and Flood Control Authority.

Nanson, G.C. and Young, R.W., 1981. Downstream reduction of rural channel size with contrasting urban effects in small coastal streams of southeastern Australia. Journal of Hydrology 52, pp. 239-255.

Nixon, M., 1959. A study of the bankfull discharge of rivers in England and Wales. Proceedings of the Institution of Civil Engineers, 12, pp. 157-175.

Park, C.C., 1977a. World wide variations in hydraulic geometry exponents of stream channels. An analysis and some observations, Journal of Hydrology, 33, pp. 133-146.

Park, C.C., 1977b. Man-induced changes in stream channel capacity. In Gregory, K.J. (ed), *River Channel Changes*, Chichester, Wiley, pp. 121-144.

Richards, K.S., 1982. *Rivers: form and process in alluvial channels*. Methuen, London, 358 p.

Richards, K.S. and Wood, R., 1977. Urbanization, water redistribution, and their effect on channel processes. In Gregory, K.J. (ed), *River Channel Changes*, Chichester, John Wiley & Sons, pp. 369-388.

Ruslan, I.W., 1995. Impact of urbanization and uphill land clearances on the sediment yield of an urbanizing catchment of Pulau Pinang, Malaysia. In McLelland, S.J., Skellern, A.R., and Porter, P.R. (eds), *Postgraduate Research in Geomorphology: Selected Papers from the 17th BGRG Postgraduate Symposium*, University of Leeds, School of Geography, pp. 28-33.

Schumm, S. A. 1977. *The Fluvial System.* New York, NY, Wiley.

Schumm, S.A., Harvey, M.D., and Watson, C.C., 1984. Incised Channels: Morphology, Dynamics and Control. Water Resources Publications, Littleton, Colorado, 200 p.

Shaw, T.L., 1974. Requirements of drainage design for large urban areas. In Rainfall, Runoff and Surface Water Drainage of Urban Catchments, Proc. Res. Colloquium, Cristol Univ, CIRIA, Paper 13, April.

Simons, Li & Associates, Inc., 1982. *Engineering Analysis of Fluvial Systems*. Fort Collins, Colorado.

Smith, D.G., 1976, Effect of vegetation on lateral migration of anastomosed channels of a glacial meltwater river. Geological Society of America Bulletin, v. 87., pp.857-860.

Stogner, R.W., 2000. Trends in Precipitation and Streamflow and Changes in Stream Morphology in the Fountain Creek Watershed, Colorado, 1939-1999. U.S. Geological Survey Water-Resources Investigations Report 00-4130, 43 p.

Thorne, C.R., 1982. Processes and mechanisms of riverbank erosion. In Hey, R.D., Bathurst J.C., and Thorne C.R. (eds), *Proceedings of the International Workshop on Engineering*

Problems in the Management of Gravel-Bed Rivers, Greynog, Wales, June 23-28, 1980, John Wiley & Sons, London, United Kingdom, pp. 227-271.

Urbonas, B. and Benik, B., 1995. Stream stability under a changing environment. In Herricks, E.E. (ed), Stormwater Runoff and Receiving Systems: Impact, Monitoring, and Assessment, Boca Raton, Florida, Lewis Publishers, pp. 77-101.

URS Consultants, 1994. Cottonwood Creek Drainage Basin Planning Study, City of Colorado Springs and El Paso County. Prepared for the City of Colorado Springs, June 9.

U.S. Army Corps of Engineers, Hydrologic Engineering Center, 2002. HEC-RAS, River Analysis System, User's Manual. Davis California, Version 3.1, CPD-68.

U.S. Geological Survey, 1982. Guidelines for Determining Flood Flow Frequency, Bulletin #17B of the Hydrology Subcommittee, 431 p.

Von Guerard, P., 1989a. Suspended sediment and sediment-source areas in the Fountain Creek Drainage Basin Upstream from Widefield, Southeastern Colorado. U.S. Geological Survey Water Resources Investigation Report 88-4136, 36 p.

Von Guerard, P., 1989b. Sediment-transport characteristics and effects of sediment transport on benthic invertebrates in the Fountain Creek Drainage Basin Upstream from Widefield, Southeastern Colorado. U.S. Geological Survey Water Resources Investigation Report 89-4161, 133 p.

Williams, G.P. and Wolman, M.G., 1984. Effects of dams and reservoirs on surface water hydrology: changes in rivers downstream from dams. U.S. Geological Survey Professional Paper 1286, 83 p.

Wilson, K.V., 1967. A preliminary study of the effect of urbanization on floods in Jackson, Mississippi. U.S. Geological Survey Professional Paper 575D, pp. 259-261.

Wohl, E.E. (ed), 2001. Inland Flood Hazards: Human, Riparian, and Aquatic Communities. Cambridge University Press, 498 p.

Wolman, M.G., 1967. A cycle of sedimentation and erosion in urban river channels. Geogr. Annaler 49A, pp. 385-395.

Wolman, M.G. and Schick, A.P., 1967. Effects of construction on fluvial sediment: Urban and suburban areas of Maryland. Water Resour. Res. 3, 2, pp. 451-462.

Overton Road Alternate Alignment Analysis

KOA Kamper Kitchen Building Plans, letter about soil testing at site

Aerial photographs with drawings of damage

SBA loss estimate

Legal description of KOA property from McCook

Notice of Claim, letter from PPACG with info on Fountain Creek Watershed Plan

Gregory Johnson's report of KOA property

KOA photograph log

USGS webpage with daily mean streamflow for April 1, 1999 through August 1, 1999 (provisional data), Water Discharge Records

Gazette article: City, county discuss joint measure on drainage

Geografiska: Sierra Club warns of flood risk

Newspaper article: Have Precipitation and Streamflow in Fountain Creek Watershed Changed over time?

Taming the Creek: Flood-control planning begins for Fountain Creek, State will get $6 million to help fight flooding

Copy of Gazette article: Landowners tired to treading water

Environmental Audit: Fountain and Monument Creeks

Hazard Mitigation Grant Program

PPACG: Environmental Program

Newspaper article: Waterways damaged by floods are required USGS Fact Sheet 136-00, Trends in Precip and Streamflow in the Fountain Creek Watershed, SE Colorado, 1977-99

Newspaper: City, County discuss joint measure on drainage

Newspaper: Sierra Club warns of flood risk

Legal encyclopedia with general law on "Act of God" defense, Ryan Gulch Reservoir Co. V Swartz, Barr v. Game Fish and Parks Commission

2000 Colorado Springs Utilities Water Resources Department's Arkansas River Exchange Report

USGS Trends in Precip and Streamflow and Changes in Stream Morphology in the Fountain Creek Watershed, Colorado, 1939-99

Annual Water Diversion Report, 1999 Exchange Report, Gage records

Gazette article: Two sue over flood

Fountain Creek Report by MacDonald and Sampson

USGS maps, drainage basin boundaries

Fountain Creek Watershed Plan website with photographs of KOA and Greenview Ditch

Field trip photographs of drainage structures

Curriculum Vitae for Lee MacDonald

An Overview of Issues in Fountain Creek Watershed, MacDonald and Sampson 1996

Effect of Urbanization of Floods of Different Recurrence Interval, Urbanization and the Natural Drainage System and Fountain Creek Chronicles 1996-1998 (not inclusive)

Changing Hydrology in Fountain Creek Watershed (Sampson Term Project)

Dr. Lee MacDonald's deposition

Gazette article: Tree removal will limit flooding

Gazette article: Floodplain mismanaged, group says

Appendix Survey Report Fountain River Watershed Colorado

Fountain Creek Watershed Plan Newsletter, October 2002

Monument Creek Drainage Basin Planning Study, Volume I, Report

Monument Creek Drainage Basin Planning Study, Volume IV, Appendixes C

Monument Creek Drainage Basin Planning Study, Volume III, Appendixes A-B, D-H

Fountain Creek Drainage Basin Planning Study, Volume I

Fountain Creek Drainage Basin Planning Study, Volume III, Supporting Info/Technical Addendum, Book 1 of 2

Fountain Creek Drainage Basin Planning Study, Volume III, Supporting Info/Technical Addendum, Book 2 of 2

Sand Creek Drainage Basin Planning Study, Preliminary Design Report

Sand Creek Drainage Basin Planning Study, Preliminary Design Report, Technical Addendum

Engineering Study and Revision of the North Shook's Run - Templeton Gap Drainage Basin, C. Springs CO

KOA map with line showing 1st, 2nd and 3rd events

Scanned photos of KOA campground

Scanned photos taken by MacDougall, examples of drainage structures

Fountain Creek Chronicles, 1996-1997 (not inclusive)

Plots of Bowl Assembly Performance' and 'Submersible Turbine Pump

Drainage Criteria Manual Volumes 1 and 2, Oct 1987, revised 1991

Monument Creek Drainage Basin Planning Study

Monument Creek Drainage Basin Planning Study, Volume II Drawings

Fountain Creek Drainage Basin Study

City of Colorado Springs Fee Basin Map

GIS sample of Fountain Creek Watershed

Fountain Creek Watershed Plan

USGS Surface Water Data for Fountain Creed Watershed

Sand Creek Drainage Basin Planning Study - Hydrology Report, technical addendum

West Fork Jimmy Camp Creek Drainage Basin Planning Study

Johnson/Security Creek Drainage Basin Planning Study

Arkansas River Report, Trans-Mountain water diversion records WY 1987-2001

TR20 and HEC2 models, data files but only two are readable

Sand Creek Drainage Structure Inventory, Quattro Pro Spreadsheet

ArcView image files for Pueblo County

Aerial photographs of Greenview Trust with property boundary and approximate damages

FEMA HEC models and GIS overlay

Aerial photograph of KOA campground showing post-flood conditions

Post-flood Assessment Report, Arkansas River Southern Colorado, USACOE, 1999

Gazette article: Landowners tired of treading water, *in* Growth, storms feed flooding' Pueblo Chieftain

The Effect of Diversion Water on the Channel Morphology of Fountain Creek, CO

3. Exhibits which Summarize or Provide Support for Opinions

The listings, tables, and figures set forth above, the documents and publications referenced above summarize or provide support for the opinions expressed.

4. Qualifications (including a list of all publications authored within the preceding ten years)

A copy of Dr. Michael Harvey's curriculum vitae is attached hereto which identifies his expert qualifications, including all publications authored by him within the preceding ten years.

5. Compensation

Dr. Michael D. Harvey's hourly billing rate for his work is $143 per hour. This rate increases to $215 per hour for deposition and trial testimony.

6. Expert Testimony within Preceding Four Years

Dr. Michael D. Harvey has testified as an expert at trial or by deposition in four judicial proceedings within the preceding four years as follows:

2003: Superior Court of California, Mono County, Louis A. deBottari v. California Department of Transportation—Case No. 12449 (deposition and expert testimony)

2006: R.C. Ingram, Jr. et al. vs. U.S. - Case No. 03-2430L, United States Court of Claims (deposition and expert testimony)

Date March 18, 2008,

Dr. Michael D. Harvey ______________________

Curriculum Vitae of Michael D. Harvey

MICHAEL D. HARVEY

TITLE: Vice President, Mussetter Engineering, Inc.
Principal Engineering Geomorphologist

BIRTH DATE: May 19, 1947

CITIZEN: New Zealand

VISA STATUS: U.S. Permanent Resident

EDUCATION:

B.S. 1968 University of Canterbury, New Zealand
Soil and Water Engineering

M.S. 1973 University of Canterbury, New Zealand
(Hons) Soils, Hydrology

Ph.D. 1980 Colorado State University
Fluvial Geomorphology

PROFESSIONAL EXPERIENCE:

1994-	Vice President, Mussetter Engineering, Inc.
1991-1994	Vice President, Resource Consultants & Engineers, Inc.
1990-1991	President, Water Engineering & Technology, Inc.
1983-1990	Vice President, Water Engineering & Technology, Inc.
1983-1988	Senior Research Scientist and Associate Professor of Geology, Colorado State University
1981-1983	Senior Research Associate, Colorado State University
1977-1980	Research Associate, Colorado State University
1975-1977	Project Leader, Water and Soil Division Ministry of Works and Development, New Zealand
1973-1974	Scientist, Water and Soil Division Ministry of Works and Development, New Zealand
1970-1971	Soil Conservator, Water and Soil Division Ministry of Works and Development, New Zealand

PROFESSIONAL SOCIETIES:

Geological Society of America (Fellow)
American Geophysical Union
Linnaen Society of London (Fellow)

TEACHING:

Courses Individually and Team Taught at Colorado State University:

1983-1984	ER 454	Geomorphology
1983-1984	ER 376	Field Methods
1984	ER 592	Seminar in Glacial Geology
1984-1987	ER 480	Continental Depositional Processes
1984	ER 696	Group Study in Engineering Geology
1985	ER 544	Engineering Geology
1986-1987	ER 692	Geomorphology Seminar
1983-1984	ER 440	Watershed Problem Analysis
1983-1984	CE 413	Environmental River Mechanics
1983	CE 717	River Mechanics

Short Courses and Seminars:

2002 Working at a Watershed Level, A workshop on water resource issues in California's Central Valley, California State University, Fresno, CA
2001 Advanced Streambank Protection Training Course, U.S. Army Corps of Engineers, Vicksburg, MS
1994 Sediment and Erosion Design Guide Short Course, Albuquerque Metropolitan Arroyo Flood Control Authority
1993 Sediment and Erosion Design Guide Short Course, Albuquerque Metropolitan Arroyo Flood Control Authority
1991 Soil Conservation Service, Design of Stable Earth Channels, Fort Worth, Texas
1990 USACE Hydrologic Engineering Center (HEC) - Application of engineering geomorphology to HEC-6 modeling, Davis, California
1988 USACE Hydrologic Engineering Center (HEC) - Applied geomorphology, Davis, California
1988 Soil Conservation Service - Geomorphology and channel design, Fort Worth, Texas
1987 Soil Conservation Service - Use of Geomorphology in Erosion Control and Channel Design, Portland, Oregon
1986 Office of Surface Mining - Design of Reclaimed Channels - Salt Lake City, Utah
1984 Erosion and River Behavior Analysis - Colorado State University
1984 Soil Conservation Service - Stream Mechanics - Colorado State University
1983 Soil Conservation Service - Geomorphology in channel design, Fort Worth, Texas, Greenville, S.C., Washington, D.C.

COMMITTEES:

American Society of Civil Engineers Hydraulics Division, River Bank Erosion Task Committee
National Academy of Sciences, Earth Surface Processes Panel

HONORS:

Fellow, Geological Society America, 1995
Fellow, Linnaen Society of London, 1994

LITIGATION SUPPORT AND TESTIMONY

Qualified as an expert in geomorphology and provided expert testimony as follows:

U.S. Court of Claims
J.R. Cooper vs. U.S. (Case No. 681-84L)—1986
M.A. Powers et al. vs. U.S. (Case No. 434-75)—1989
B. Bagwell et al. vs. U.S. (Case No. 439-87L)—1996
C.S. Green et al. vs. US (Case No. 00-167L)—2002
R.C. Ingram, Jr. et al. vs. US (Case No. 03-2430L)—2006

U.S. Federal Court Cheyenne, Wyoming
C.R. Hanson vs. U.S.—1981

District Court, Water Division No. 1, State of Colorado
State of Colorado vs. U.S. (Case No. W-8439-76)—1990

Superior Court of California, Yuba County
Multiple plaintiffs vs. Reclamation District 784 and the State of California (Case No. 2104)—1994

Superior Court of California, San Benito County
Sandman, Inc. vs. County of San Benito and Board of Supervisors (Case No. 22107)—2000

Superior Court of California, San Joaquin County
Reclaimed Island Lands Company vs. State of California and RD 2107, the Dept of Water Resources of the State of California (Case No. 004313)—1999

U.S. District Court for the District of Idaho
Napias Creek (Case No. 94-0159-S-HLR)—1996

Fifth Judicial District, State of Idaho, County of Twin Falls
Snake River Basin Adjudication (Case No. 39576) (Consolidated Case No. 63-25243)—1998

Fifth Judicial District, State of Idaho, County of Twin Falls
Snake River Basin Adjudication (Case No. 39576) (Consolidated Case No. 02-10063)—2001

Superior Court of California
San Benito County, Sandman, Inc. vs. County of San Benito and Board of Supervisors (Case No. 22107)—2001

U.S. District Court of Kansas
Jacquline Seyler v. Burlington Northern Santa Fe Corporation and AMTRAK (Case No. 99-2342-KHV)—2002

Superior Court of California, San Benito County
Sandman, Inc. vs. County of San Benito and Board of Supervisors (Case No. 22107)—2002

Superior Court of Arizona, County of Mariposa
The Burlington Northern and Santa Fe Railway Company v. The State of Arizona et al. (Case No. CV98-14172)—2002

U.S. District Court for the Eastern District of California
California Sportfishing Protection Alliance v. Diablo Grande, Inc.
(Case No. F-00-597- OWWDLB)—2001

Superior Court of California, Mono County
Louis A. deBottari v. California Department of Transportation (Case No. 12449)—2004

Superior Court of California, County of San Joaquin
Reclaimed Island Land Co. v. RD 2107 and the State of California
(Case No. 0043113)—2000

District Court of El Paso County, Colorado
Speight Partnership and Greenview Trust v. City of Colorado Springs and El Paso County (Case No. 01CV1290)—2004

PUBLICATIONS:

Harvey, M.D., Trabant, S.C., and Levitt, J.E., 2007. Predicted Sedimentation Rates at Proposed Lake Ralph Hall, North Sulphur River, Texas. Presented at the Texas Water 2007 Conference by the Texas Section of the American Water Works Association (TAWWA) and the Water Environment Association of Texas (WEAT), Fort Worth, Texas, April 10-13.

Mussetter, R.A., Harvey, M.D., and Parkinson, S., 2007. Boat Wake Erosion of Sand Bars in Hells Canyon of the Snake River, Idaho and Oregon. World Environmental and Water Resources Congress 2007, ASCE, Tampa, Florida, May.

Harvey, M.D. and Trabant, S.C., 2006. Evaluation of Bar Morphology, Distribution, and Dynamics as Indices of Fluvial Processes in the Middle Rio Grande. Abstract for Middle Rio Grande Endangered Species Collaborative Program, First Annual Symposium, Albuquerque, New Mexico, April.

Schumm, S.A. and Harvey, M.D., 2006. Engineering Geomorphology. American Society of Civil Engineers, *Sediment Engineering Manual*, Chapter 18.

Mussetter, R.A., Harvey, M.D., and Harner, R.F., 2005. Physical characteristics, flow regime and riparian vegetation in coarse-grained streams, Idaho Batholith, USA. Poster presented at the Sixth Gravel-bed Rivers Conference, Austria, September 5-9.

Mussetter, R.A. and Harvey, M.D., 2005. Design Discharges for Arroyos in an Urban Setting. Proceedings of the EWRI 2005 World Water and Environmental Resources Congress, Anchorage, ASCE, Alaska, May 15-19.

Harvey, M.D. and Mussetter, R.A., 2005. Difficulties of Identifying Design Discharges in Steep, Coarse-Grained Channels in the Arid Southwestern US. Proceedings of the EWRI 2005 World Water and Environmental Resources Congress, Anchorage, Alaska, May 15-19.

Armstrong, S., Miller, W., Mussetter, R.A., Harvey, M.D., and Thomas, D.B., 2004. Aquatic Habitat and Hydraulic Modeling Study, Rio Grande at Bosque del Apache National

Wildlife Refuge. Poster session for the 2004 Festival of Cranes, San Antonio, New Mexico, November.

Harvey, M.D., Trabant, S.C., Lunger, J.R., and Llewellyn, D., 2004. Bar Dynamics in the Bosque del Apache National Wildlife Refuge. Poster session for the 2004 Festival of Cranes, San Antonio, New Mexico, November.

Mussetter, R.A. and Harvey, M.D., 2004. Geomorphic, Hydrologic, Hydraulic and Sediment Transport Analyses: Tools for Evaluating In-channel and Channel-margin Habitat Dynamics. Proceedings of the 3rd Missouri River and North American Piping Plover and Least Tern Workshop, Sioux City, Iowa, April 12-14.

Harvey, M.D. and Mussetter, R.A., 2004. Fine Sediment Dynamics in Coarse-Grained Streams; Implications for Biological Productivity in Urbanized Western Streams. Proceedings of the EWRI Environmental Resources Congress 2004, Salt Lake City, Utah, June.

Harvey, M.D. and Morris, C.E., 2004. Downstream Effects of Urbanization in Fountain Creek, Colorado. Proceedings of the EWRI Environmental Resources Congress 2004, Salt Lake City, Utah, June.

Mussetter, R.A. and Harvey, M.D., 2004. Maintaining Natural Conditions in Urban Arroyos: Is It Possible? Proceedings of the EWRI Environmental Resources Congress 2004, Salt Lake City, Utah, June.

Lunger, J.R., Harvey, M.D., and Mussetter, R.A., 2004. Investigation of Habitat Formation and Fish Use during a Range of Flows in a Sand-bed Stream, the Pecos River, New Mexico. Abstract for the proceedings of the American Geophysical Union, Hydrology Days 2004, Colorado State University, Fort Collins, Colorado, March.

Thomas, D.B., Harvey, M.D., and Mussetter, R.A., 2004. Sediment Yield Estimates from Ungaged Tributaries to the Middle Rio Grande, New Mexico. Abstract for the proceedings of the American Geophysical Union, Hydrology Days 2004, Colorado State University, Fort Collins, Colorado, March.

Trabant, S.C. and Harvey, M.D., 2004. Landscape Evolution in High-Elevation Andean River Basins, Northern Peru: Mass Failure and Fluvial Transport. Abstract for the proceedings of the American Geophysical Union, Hydrology Days 2004, Colorado State University, Fort Collins, Colorado, March.

Wolff, C.G., Mussetter, R.A., and Harvey, M.D., 2004. Evaluation of the Effects of Dam Re-operation on Establishment of Riparian Vegetation, Verde River, Arizona. Abstract for the proceedings of the American Geophysical Union, Hydrology Days 2004, Colorado State University, Fort Collins, Colorado, March.

Mussetter, R.A., Harvey, M.D., Anthony, D.J., 2003. Identification of the Ordinary High-water Mark of the Snake River, Western Idaho, USA. Abstract: Proceedings of Hydrology Days 2003, American Geophysical Union, Fort Collins, Colorado.

Harvey, M.D., Mussetter, R.A., Anthony, D.J., 2003. Island Aging and Dynamics in the Snake River, Western Idaho, USA. Abstract: Proceedings of Hydrology Days 2003, American Geophysical Union, Fort Collins, Colorado.

Harvey, M.D., Mussetter, R.A., Morris, C.E., 2003. Fine Sediment in the Upper Colorado River During Spring Runoff and Summer Baseflows: Implications for Flow Recommendations and Biological Productivity. Abstract: Proceedings of Hydrology Days 2003, American Geophysical Union, Fort Collins, Colorado.

Harvey, M.D., Mussetter, R.A., Morris, C.E., 2003. Fine Sediment Dynamics in the Upper Colorado River During Spring and Summer Baseflows. Presented to the Upper Colorado River Basin Researcher's Annual Meeting, Grand Junction, Colorado, January 16.

Mussetter, R.A., Harvey, M.D., and Trabant, S.C., 2002. Historical and Present Day Sediment Loads in the Middle Rio Grande, New Mexico. Proceedings of Hydrology Days, 2002 American Geophysical Union, Colorado State University, Fort Collins, Colorado, April 1-2.

Harvey, M.D. ,2001. Napias Creek Falls, Idaho: A natural or man-made barrier for endangered chinook salmon. In *Applying Geomorphology to Environmental Management*, Anthony, D.J., Harvey, M.D., Laronne, J.B., and Mosley, M.P. (eds), Water Resource Publications, Englewood, Colorado, pp 291-307.

Mussetter, R.A., Harvey, M.D., Zevenbergen, L.W., and Tenney, R.D., 2001. A Comparison of One- and Two-Dimensional Hydrodynamic Models for Evaluating Colorado Squawfish Spawning Habitat, Yampa River, Colorado. In *Applying Geomorphology to Environmental Management*, Anthony, D.J., Harvey, M.D., Laronne, J.B., and Mosley, M.P. (eds), Water Resource Publications, Englewood, Colorado, pp 361-379.

Mussetter, R.A. and Harvey, M.D., 2001. The Effects of Flow Augmentation on Channel Geometry of the Uncompahgre River. In *Applying Geomorphology to Environmental Management*, Anthony, D.J., Harvey, M.D., Laronne, J.B., and Mosley, M.P. (eds), Water Resource Publications, Englewood, Colorado, pp 177-198.

Wolff, C.G., Harvey, M.D., and Mussetter, R.A., 2000. San Miguel River Restoration: Geomorphology and Hydraulic Engineering as a Basis of Design. 2000 Joint Conference on Water Resources Engineering and Water Resources Planning and Management, Minneapolis, Minnesota, July 30-August 2.

Mussetter, R.A., Harvey, M.D., Wolff, C.G., and McDowall, D.G., 2000. Whitewood Creek Reclamation Plan: A Sound Basis for Design. 2000 Joint Conference on Water Resources Engineering and Water Resources Planning and Management, Minneapolis, Minnesota, July 30-August 2.

Thomas, D.B., Abt, S.R., Mussetter, R.A., and Harvey, M.D., 2000. A Design Procedure for Sizing Step-Pool Structures. 2000 Joint Conference on Water Resources Engineering and Water Resources Planning and Management, Minneapolis, Minnesota, July 30-August 2.

Harvey, M.D., Trabant, S.C., Biedenharn, D.S. and Thomas, K.J., 2000. Formation and Maintenance of San Bernardino Kangaroo Rat Habitat, Santa Ana River Alluvial Fan, California. 2000 Joint Conference on Water Resources Engineering and Water Resources Planning and Management, Minneapolis, Minnesota, July 30-August 2.

Harvey, M.D. and Schumm, S.A., 1999. Indus River dynamics and the abandonment of Mohenjo Daro. In *The Indus River: Biodiversity, Resources and Humankind*, The Linnean Society of London, Symposium Report, A. and P.S. Meadows (eds).

Harvey, M.D., Mussetter, R.A., Chainey, S.J. and Landis, P.J., 1999. Geomorphic and Ecological Responses of the Upper San Joaquin River, California, to Multiple Anthropogenic Disturbances. GSA Abstracts with Programs, v. 31, no. 7, A-201.

Mussetter, R.A., Harvey, M.D. and Tenney, R.D., 1999. Geologic and Geomorphic Associations with Colorado Pikeminnow Spawning, Lower Yampa River, Colorado. GSA Abstracts with Programs, v. 31, no. 7, A-483.

Harvey, M,D. and Smith, T.W., 1998. Gravel Mining Impacts on San Benito River, California. Proceedings of the 1998 International Water Resources Engineering Conference, Hydraulics Division, ASCE, Memphis, Tennessee, August, pp. 3-5.

Mussetter, R.A., Harvey, M.D., Wolff, C.G., Peters, M.R., and Trabant, S.C., 1998. Channel Migration Effects on Bridge Failure in South Fork Snake River, Idaho. Proceedings of the 1998 International Water Resources Engineering Conference, Hydraulics Division, ASCE, Memphis, Tennessee, August, pp. 3-5.

Mussetter, R.A. and Harvey, M.D., 1996. Geomorphic and hydraulic characteristics of the Colorado River, Moab, Utah: Potential impacts on a uranium tailings disposal site. Proc. Conference on Tailings and Mine Waste, '96, Colorado State University, January 16-19, 1996, Balkema, Rotterdam, pp. 405-414.

Harvey, M.D., Mussetter, R.A. and Sing, E.F., 1995. Assessment of dam impacts on sediment transport in a steep mountain stream. In *Lecture Series, U.S. Committee on Large Dams*, San Francisco, California, May 13-19, pp. 299-310.

Mussetter, R.A., Harvey, M.D. and Sing, E.F., 1995. Assessment of dam impacts on downstream channel morphology. In *Lecture Series, U.S. Committee on Large Dams*, San Francisco, California, May 13-18, pp. 283-298.

Mussetter, R.A., Lagasse, P.F., Harvey, M.D. and Anderson, C.A., 1994. Procedures for evaluating the effects of sedimentation on flood hazards in urbanized areas in the southwestern U.S. Proceedings of Water Resources Planning and Management Div. ASCE, Phoenix, Arizona.

Harvey, M.D. and Mussetter, R.A., 1994. Geologic, geomorphic and hydraulic controls at spawning locations for endangered Colorado squawfish. EOS Trans. Amer. Geophys. Union, v. 75, 269 p.

Jorgensen Harbor, D., Schumm, S.A. and Harvey, M.D., 1994. Tectonic control of the Indus River in Sindh, Pakistan. In Schumm, S.A. and Winkley, B.R. (eds), *The Variability of Large Alluvial Rivers*, American Society of Civil Engineers Press, New York, pp. 161-176.

Harvey, M.D. and Schumm, S.A., 1994. Alabama River: Variability of overbank flooding and deposition. In Schumm, S.A. and Winkley, B.R. (eds), *The Variability of Large Alluvial Rivers*, American Society of Civil Engineers Press, New York, pp. 313-337.

Harvey, M.D. and Flam, L., 1993. Prehistoric soil and water detention structures (Gabarbands) at Phang, Sindh Kohistan, Pakistan. Geoarchaeology, v. 8(2), pp.109-126.

Germanoski, D. and Harvey, M.D., 1993. Asynchonous terrace development in degrading braided channels. Physical Geography, v. 14(4), pp. 16-38.

Jorgensen, D.W., Harvey, M.D., Schumm, S.A. and Flam, L.B., 1993. Morphology and dynamics of the Indus River: Implications for the Mohen Jo Daro Site. In Shroder, J.R. (ed), *Himalaya to the Sea: Geology, Geomorphology and the Quaternary*, Routledge, pp. 288-326.

Harvey, M.D., Mussetter, R.A., and Wick, E.J., 1993. A physical process-biological response model for spawning habitat formation for the endangered Colorado Squawfish. *Rivers*, v. 4 (2), pp. 114-131.

Mussetter, R.A., Harvey, M.D., and Lagasse, P.F., 1993. Fine sediment deposition and erosion at a Squawfish spawning bar, Yampa River, Colorado. Proceedings of the Int. Conference on Hydroscience and Engineering, Washington, D.C., Wang, S. (ed), v. 1 (B), June, pp. 265-272.

Schumm, S.A. and Harvey, M.D., 1993. Engineering Geomorphology. Proceedings of the ASCE National Conference on Hydraulic Engineering, San Francisco, California, July, Shen, H.W., Su, S.T., and Wen, F. (eds), v. 1, pp. 394-399.

MacArthur, R.C., Hamilton, D.L., Harvey, M.D. and Kekaula, H.W., 1992. Analyses of special hazards and flooding problems in tropical island environments. Proceedings of the ASCE, Hydr. Div. Annual Meeting, Baltimore, pp. 1061-1066.

Mussetter, R.A., Harvey, M.D., and Anderson, C.E., 1992. Delineation of erosion and flooding limits along arroyos in urbanizing areas. Proceedings of the ASFM, Los Vegas, Nevada, November.

Biedenharn, D.S., Combs, P.G., Harvey, M.D., Little, C.D. and Watson, C.C., 1991. Systems design approach in Northern Mississippi. Proceedings of the 5th Federal Interagency Sedimentation Conference, Las Vegas, Nevada, Fan, S.S. and Kuo, Y.H. (eds), pp. 3.8-3.15.

Fischer, K.J., Harvey, M.D. and Sing, E.F., 1991. Site prioritization for bank protection, Sacramento River, California. Proceedings of the 5th Federal Interagency Sedimentation Conference, Las Vegas, Nevada, Fan, S.S. and Kuo, Y.H. (eds), pp. 3.47-3.54.

Fischer, K.J., Harvey, M.D. and Pridal, D.B., 1991. Deposition on revetments along the Sacramento River, California. Proceedings of the 5th Federal Interagency Sedimentation Conference, Las Vegas, Nevada, Fan, S.S. and Kuo, Y.H. (eds), pp. 4.102-4.108.

Fischer, K.J. and Harvey, M.D., 1991. Geomorphic response of Lower Feather River, California, to 19th Century Hydraulic Mining Operations. Proceedings of the ASFPM Meeting, Denver, Colorado, June 10-14, pp. 128-132.

Zevenbergen, L.W., Peterson, M.R. and Harvey, M.D., 1991. 2-D hydrodynamic model of the Colusa flood overflow weir on the Sacramento River, California. Proceedings of the ASFPM Meeting, Denver, Colorado, June 10-14, pp. 148-154.

Fischer, K.J., Harvey, M.D. and Zevenbergen, L.W., 1991. Combined geomorphic, hydraulic and sediment transport analyses: Application to a sedimentation problem, Proceedings of the ASFPM Meeting, Denver, Colorado, June 14-17, pp. 123-127.

Harvey, M.D. and MacArthur, R.C., 1991. Estimating sediment delivery and yield on alluvial fans. In Proc. ASFPM Meeting, Denver, Colorado, June 14-17, pp. 238-242.

Harvey, M.D., Mussetter, R.A. and Wick, E., 1991. Recessional-flow bar dissection on the Yampa River: An alternative to high discharge flushing flows. (Abs), *EOS*, Trans. AGU, v. 72, no. 44, 208 p.

Anthony, D.J. and Harvey, M.D., 1991. Stage-dependent cross section adjustments in a meandering reach of Fall River, Colorado. *Geomorphology*, v. 4, pp. 187-203.

Harvey, M.D., Sing, E.F., and MacArthur, R.C., 1990. Sediment sources, transport and delivery to an alluvial fan, Caliente Creek, California. Proceedings of the Symp. Hydrology and Hydraulics of Arid Lands, ASCE, San Diego, French, R.H. (ed), August, pp. 706-711.

MacArthur, R.C., Harvey, M.D., and Sing, E.F., 1990. Estimating sediment delivery and yield on alluvial fans. Proceedings of the Symp. Hydrology and Hydraulics of Arid Lands, ASCE, San Diego, French, R.H. (ed), August, pp. 700-705.

Fischer, K.J. and Harvey, M.D., 1990. Geomorphic and stratigraphic evidence for sediment transport processes on a valley fan, Southern Utah. Proceedings of the Symp. Hydrology and Hydraulics of Arid Lands, ASCE, San Diego, French, R.H. (ed), August, pp. 602-607.

Fischer, K.J., Harvey, M.D. and Sing, E.F., 1990. Geomorphic and sedimentologic evaluation of a proposed flood control project, Truckee River, Reno, Nevada. Proc. National Conference on Hydraulic Engineering, ASCE, San Diego, California, Chang, H.H. and Hill, J.C. (eds), August, pp. 820-825.

Harvey, M.D., 1989. Meanderbelt dynamics of Sacramento River, California. Proceedings of the California Riparian Systems Conference, Davis, California, USDA Forest Service, General Technical Report, PSW-110, pp. 54-59.

Harvey, M.D. and Watson, C.C., 1989. Effects of bank revetment on Sacramento River, California. Proceedings of the California Riparian Systems Conference, Davis, California, USDA Forest Service Technical Report, PSW-110, pp. 47-50.

Combs, P., Biedenharn, D.S. and Harvey, M.D., 1989. A design approach for providing channel stability in Loess Hills streams. Proc. US-China Sedimentation Conference.

Harvey, M.D. and Sing, E.F., 1989. The effects of bank protection on river morphology. Proceedings of the 1989 National Conference on Hydraulic Engineering, Ports, M.A. (ed), ASCE, pp. 212-217.

Sing, E.F. and Harvey, M.D., 1989. An alternative approach to erosion control and mitigation. Proceedings of the Int. Symp. on Sediment Transport Modeling, Wang, S.Y. (ed), ASCE, pp. 215-220.

Fischer, K.J. and Harvey, M.D., 1989. Morphology and sedimentology of a confined prograding valley fan, Sink Valley, Utah. Geol. Soc. Amer. *Abstracts with Programs*, v. 21(6), p. A.40.

Williams, C.L. and Harvey, M.D., 1989. Post-fire sediment yield in the chaparral vegetation zone, Ash Creek drainage basin, Arizona. Geol. Soc. Amer. *Abstracts with Programs*, v. 21 (6), p. A.152.

Heede, B.H., Harvey, M.D. and Laird, J.F., 1988. Sediment delivery linkages in a chaparral watershed following fire. *Environmental Management*, v. 12, no. 3, pp. 349-358.

Harvey, M.D., and Watson, C.C., 1988. Channel response to grade-control structures on Muddy Creek, Mississippi. *Regulated* Rivers: Research and Management, v. 2, pp. 79-92.

Harvey, M.D., Biedenharn, D.S., and Combs, P., 1988. Adjustments of Red River following removal of the Great Raft in 1873. (Abs) *EOS*, Trans, AGU, v. 69, no. 18, pp. 567.

Anthony, D.J., and Harvey, M.D., 1988. Bed load transport and sorting in a meandering river. (Abs) *EOS,* Trans. AGU, v. 69, no. 18, p. 566.

Watson, C.C., and Harvey, M.D., 1988. Channel response to SCS Type-C grade-control structures on Burney Branch, Mississippi. ASCE Hyd. Div., 1988 National Conference, Abt, S.R. and Gessler, J. (eds), pp. 776-781.

Harvey, M.D., Pranger, H.H. II, Biedenharn, D.S., and Combs, P., 1988. Morphologic and hydraulic adjustments of Red River from Shreveport, LA to Fulton, AK, between 1886 and 1980. ASCE, Hyd. Div., 1988 National Conference, Abt, S.R. and Gessler, J. (eds), pp. 764-769.

Watson, C.C., Harvey, M.D., Biedenharn, D.S., and Combs, P., 1988. Geotechnical and hydraulic stability numbers for channel rehabilitation: Part I, The Approach. ASCE, Hyd. Div., 1988 National Conference, Abt, S.R. and Gessler, J. (eds), pp. 120-125.

Watson, C.C., Peterson, M.R., Harvey, M.D., Biedenharn, D.S., and Combs, P., 1988. Geotechnical and hydraulic stability numbers for channel rehabilitation: Part II, Application. ASCE Hyd. Div., 1988 National Conference, Abt, S.R. and Gessler, J. (eds), pp. 126-131.

Germanoski, D., Harvey, M.D., and Schumm, S.A., 1988. Experimental and field studies of terrace development in degrading braided rivers. N.E. Section, Geol. Soc. Amer. *Abstracts with Programs*, v. 20, no. 1, p. 21.

Erslev, E.A., Rogers, J.L., and Harvey, M.D., 1988. The Northeastern Front Range revisited: Horizontal compression and crustal wedging in a classic locality for vertical tectonics. *Field Trip Guidebook*. G.S.A. Annual Meeting, Denver, Colorado.

Flam, L., Harvey, M.D. and Schumm, S.A., 1988. Prehistoric Soil and Water Conservation structures in Sind Kohistan, Pakistan. Geol. Soc. Amer. *Abstracts with Programs*, v. 20, p. A37.

Harvey, M.D., Germanoski, D., and Pitlick, J., 1988. Terrace-forming processes in modern fluvial systems: Implications for Quaternary Studies. Geol. Soc. Amer., *Abstracts with Programs*, v. 20, p. A374

Harvey, M.D. and Schumm, S.A., 1987. Response of Dry Creek, California, to land use change, gravel mining and dam closure. *Erosion and Sedimentation in the Pacific Rim*, IAHS Publ. No. 165, pp. 451-460.

Harvey, M.D., Pitlick, J. and Laird, J.R., 1987. Temporal and spatial variability of sediment storage and erosion in Ash Creek, Arizona. *Erosion and Sedimentation in the Pacific Rim*, IAHS Publ. No. 165, pp. 281-282.

Anthony, D.J. and Harvey, M.D., 1987. Response of bed topography to increased bed load, Fall River, Colorado. *Erosion and Sedimentation in the Pacific Rim*, IAHS Publ. No. 165, pp. 387-388.

Pitlick, J. Blair, T.C., Anthony, D.J. and Harvey, M.D., 1987. Sedimentology of Lawn Lake flood deposits and geomorphic processes in Fall River, Rocky Mountain National Park, Colorado. *Field Trip Guidebook*, Geological Society of America Rocky Mountain Section Spring Meeting, University of Colorado, Boulder, Colorado. 37 p.

Anthony, D.J. and Harvey, M.D., 1987. Stage dependent point bar adjustments, Fall River, Colorado. (Abs) *EOS*, Trans. AGU, v. 68, no. 44, p. 1297.

Harvey, M.D., Pitlick, J., and Hagans, D.K., 1987. Adjustments of point bar morphology during a snowmelt runoff period. (Abs) *EOS*, Trans. AGU, v. 68, no. 44, p. 1297.

Clarkin, K.L., and Harvey, M.D., 1986. Sediment storage and delivery in four small watersheds-eastern Colorado. Proceedings of the Fourth Federal Interagency Sedimentation Conference, v. 1, pp. 3.54-3.63.

Watson, C.C., Harvey, M.D., and Garbrecht, J., 1986. Geomorphic-hydraulic simulation of channel evolution. Proceedings of the Fourth Federal Interagency Sedimentation Conference, v. 2, pp. 5.21-5.30.

Harvey, M.D., Watson, C.C., and Bernard, J., 1986. Predicting Channel Adjustment to Channelization. Proceedings of the Fourth Federal Interagency Sedimentation Conference, v. 2, pp. 5.21-5.30.

Harvey, M.D., and Watson, 1986. Fluvial processes and morphologic thresholds in stream channel restoration. Water Resources Bulletin, v. 22, no. 3, pp. 359-368.

Laird, J.R. and Harvey, M.D., 1986. Complex-response of chaparral drainage basin to fire. Proceedings of the Int. Symp. on Drainage Basin Sediment Delivery, IAHS Spec. Publ. No. 159, pp. 165-184.

Harvey, M.D., and Forsythe, P., 1986. Geologic origin of some dispersive soils in Mississippi. Bull. Eng. Geol.

Harvey, M.D., 1986. Review. Fluvial Forms and Processes. By David Knighton, Edward Arnold, Baltimore. Journal of Geology, 94(6), p. 907.

Harvey, M.D. and Watson, C.C., 1986. Fluvial processes and morphological thresholds in incised channel restoration. Water Resources Bulletin, v. 22, no. 3, pp. 359-368. Reprinted in *Engineering Considerations in Small Stream Management*, Jackson, W.L. (ed), AWRA Monograph Series, No. 5.

Harvey, M.D., Watson, C.C., and Schumm, S.A., 1985. Stream channel restoration criteria. Proceedings of the 2nd Hydrology Symp. on Surface Coal Mining in the Northern Great Plains, Feb. 26-27, Gillette, Wyoming, pp. 61-73.

Finley, J.B., Harvey, M.D., and Watson, C.C., 1985. Experimental Study: Erosion of overburden cap material protected by rock mulch. Proceedings of the 7th Symp. on Management of Uranium Mill Tailings, Low-Level Waste and Hazardous Waste, Geotechnical Eng. Program, Colorado State University, Fort Collins, Colorado, Feb. 6-8, pp. 273-282.

Flores, R.M. and Harvey, M.D., (Eds), 1985. Field guidebook to modern and ancient fluvial systems in the United States. Third Int. Fluvial Sedimentology Conf., Ft. Collins, Colorado, August 7-9, 113 p.

Harvey, M.D., Crews, S., Pitlick, J., and Blair T., 1985. Holocene braided streams of eastern Colorado and the sedimentologic effects of Lawn Lake Dam failure, Rocky Mountain National Park. In *Field Guidebook to Modern and Ancient Fluvial Systems in the United States*, Flores, R.M. and Harvey, M.D. (eds), Third International Fluvial Sedimentology Conference, Ft. Collins, Colorado, August 7-9, pp. 87-106.

Harvey, M.D. and Pitlick, J., 1985. Low-flow erosion of a sediment storage zone. (Abs.). *EOS* Trans. AGU, v. 66, no. 46, pp. 912-913.

Pitlick, J. and Harvey, M.D., 1985. Variability associated with portable bed load samplers. (Abs.). *EOS*, Trans. AGU, v. 66, no. 46, p. 910.

Harvey, M.D., and Watson, C.C., 1984. Erosion control in channelized streams. Proceedings of the International Erosion Control Association, Denver, Colorado, February, pp. 31-40.

Watson, C.C., and Harvey, M.D., 1984. Equilibrium criteria for some incised channels of Western United States. Proceedings of the Specialty Conference, Irrigation and Drainage Division, ASCE, Replogle, J.A. and Renard, K.G. (eds), Flagstaff, Arizona, July, pp. 537-543.

Harvey, M.D., Watson, C.C., and Schumm, S.A., 1983. Channelized Streams: An analog for the Effects of Urbanization. Proceedings of the 10th Int. Symp. on Urban Hydrology, Hydraulics and Sediment Control: Sterling, H.J. and DeVore, R.W. (eds), Univ. of Kentucky. Pub. No. UKYBU131, pp. 401-410.

Watson, C.C. and Harvey, M.D., 1983. Equilibrium Criteria for Channelized Streams. Proceedings of the Conference on Frontiers in Hydraulic Engineering, Hyd. Div. Am. Soc. of Civil Engr., Shen, H.T. (ed), Cambridge, Massachusetts, 602 p.

Harvey, M.D., 1983. A geomorphic evaluation of a grade-control structure in a meandering channel. Proceedings of the conference on River Meandering, Waterways, Ports, Coastal and Ocean Division, ASCE, Elliott, C.M. (ed), New Orleans, Louisiana, October, pp. 284-294.

Watson, C.C., Schumm, S.A., and Harvey, M.D., 1983. Neotectonic Effects on River Pattern. Proceedings of the Conference on River Meandering, Waterways, Ports, Coastal and Ocean Division, ASCE, Elliott, C.M. (ed), New Orleans, Louisiana, October, pp. 55-66.

Harvey, M.D., 1982. Use of a physical model to determine the effects of periodic erosion in steep terrain on sediment characteristics and loads. Proceedings of the Symp. on Sediment Routing and Budgeting in Forest Watershed, Corvallis, Oregon, USFS, PNW, FRES., General Technical Report, PNW-141, pp 50-58.

Schumm, S.A., Bean, D.W., and Harvey, M.D., 1982. Bed-form-dependent pulsating flow in Medano Creek, Southern Colorado. *Earth Surface Processes and Landforms*, v. 7, pp. 17-28.

Harvey, M.D., Watson, C.C., and Schumm, S.A., 1982. A Geomorphic Approach to Channel Rehabilitation. Geol. Soc. Am. (Abs.), v. 15, no. 7.

Harvey, M.D., 1982. Late Pleistocene-Holocene stratigraphy of Northern Mississippi Valleys. Jour., Colorado-Wyoming Academy of Sciences, v. XIV, no. 1, April, pp. 26-27.

Schumm, S.A., and Harvey, M.D., 1982. Natural erosion rates in the U.S.A. American Society of Agronomy Special Paper, ASA Publication No. 45, pp. 15-22.

Harvey, M.D., Rentschler, R.E., and Schumm, S.A., 1981. Environments of deposition: Controls on channel erosion in Northern Mississippi. Geological Soc. Am. (Abs.), v. 14, no. 7.

Harvey, M.D., 1980. The Cache la Poudre River: A coarse grained meandering river in the Colorado Piedmont. *Field Trip Guidebook for Third Biennial Course on the Fluvial System with Applications to Economic Geology*. Colorado State University, March 17-21, pp. 27-40.

Harvey, M.D., 1980. Steepland channel response to episodic erosion. Unpublished Ph.D. Dissertation, Colorado State University, Fort Collins, Colorado 253 p.

Harvey, M.D., 1977. An analysis of soil slip erosion and sedimentation that occurred on the Port Hills, Canterbury as a result of the August 19-25, 1975, storm. Water and Soil Division Technical Report, New Zealand Ministry of Works.

Harvey, M.D., 1976. Site tolerance in urban subdivision. Proc. Annual NZIAS Conference, Lincoln College, May.

Harvey, M.D., 1975. Characterization of the physical, chemical and hydraulic properties of a Puketeraki silt loam. Proc. Annual NZIAS Conference, Massey University, May.

Harvey, M.D., 1974. Periodic instability in a high country catchment. Proc. Annual NZIAS Conference, Lincoln College, May.

Harvey, M.D., 1974. Erosional and deposition aspects of the Puketeraki soil series. Proc. Annual NZIAS Conference, Lincoln College, May.

Harvey, M.D., 1973. Soil studies in a high country catchment, Paddle Creek, South Canterbury. Unpublished M.S. Thesis, University of Canterbury, 240 p.

Harvey, M.D. and Williams, N.W., 1972. Land use capability survey of the Awatere River Catchment, Marlborough. New Zealand, Ministry of Works and Development Publication. 85 p.

BOOKS:

Anthony, D.J., Harvey, M.D., Laronne, J.B., and Mosley, M.P., 2001 (eds). *Applying Geomorphology to Environmental Management*. Water Resources Publications, LLC, 483 p.

Ethridge, F.G., Flores, R.M., and Harvey, M.D., 1987 (eds). Recent *Developments in Fluvial Sedimentology*. Society of Economic Paleontologists and Mineralogists, Spec. Publ. No. 39.

Harvey, M.D., Watson, C.C., and Schumm, S.A., 1985. *Gully Erosion*. Technical Note No. 366, U.S. Dept. of Interior, Bureau of Land Management, U.S. Govt. Printing Office, 1985-578-193/25153, March, 181 p.

Schumm, S.A., Harvey, M.D., and Watson, C.C., 1984. *Incised Channels: Morphology, Dynamics and Control*. Water Resources Publications, Littleton, Colorado, 200 p.

PROJECT REPORTS:

Harvey, M.D. and Trabant, S.C., 2006. Geomorphic and Sedimentation Evaluation of North Sulphur River and Tributaries for the Lake Ralph Hall Project. Prepared for Chiang Patel & Yerby, Inc., Dallas, Texas, October.

Mussetter, R.A., Harvey, M.D., and Thomas, D.B., 2006. Two-dimensional Modeling to Evaluate Potential River Training Works at M&T Pumping Plant Sacramento River, RM 192.5 (2005 Topography and Bed Material). Prepared for Ducks Unlimited, Rancho Cordova, California, April.

Harvey, M.D., 2006. Yuba County Water Agency South Diversion Fish Screen Project. Technical Memorandum prepared for Montgomery Watson Harza for the Geomorphology and 2-D Hydraulic Analysis of Yuba-Brophy (South) Diversion Project, California, July.

Mussetter, R.A. and Harvey, M.D., 2006. Evaluation of Factors Affecting the Persistence, Number, and Size of Sandbars in Hells Canyon, Idaho. Prepared for Davis Wright Tremaine, LLP, Washington, DC, May.

Mussetter, R.A. and Harvey, M.D., 2006. Hells Canyon Wave Impact Study. Prepared for Davis Wright Tremaine, LLP, Washington, DC, January.

Mussetter, R.A., Harvey, M.D., and Thomas, D.B., 2005. Two-dimensional Modeling to Evaluate Potential River Training Works at M&T Pumping Plant Sacramento River, RM192.5. Prepared for Ducks Unlimited, Rancho Cordova, California, January.

Harvey, M.D., Trabant, S.C., and Thomas, D.B., 2005. Evaluation of Bar Morphology, Distribution and Dynamics as Indices of Fluvial Processes in the Middle Rio Grande, New Mexico. Prepared for the New Mexico Interstate Stream Commission and Middle Rio Grande Endangered Species Act Collaborative Project (Project 04-081 Science), November.

Harvey, M.D., Morris, C.E., Thomas, D.B., Muldoon, K.A., and Sanborn, S.C., 2005. WTB Bar Habitat Restoration Evaluation Project. Prepared for SWCA Consultants, Albuquerque, New Mexico, October.

Harvey, M.D. and Hathaway, D.L., 2005. Joint Expert Report of Michael D. Harvey, PhD, PG, and Deborah Hathaway, PE for Ralph C. Ingram, Jr. et al. v. U.S. and related Red River cases. Case No. 03-2430L, October.

Harvey, M.D., 2005. Expert Report of Dr. Michael D. Harvey Regarding Geomorphic Requirements for Restoration of an Anadromous Fishery in the Upper San Joaquin River, California. Prepared for Case No. S-88-1658-LKK/GGH, U.S. District Court, Eastern District, Sacramento Division v. Kirk Rogers as Regional Director of the U.S., Bureau of Reclamation et al., Orange Cove Irrigation et al., and Friant Water Users Authority et al., August.

Miller, W.J., Rees, D.E., Ptacek, J.A., Harvey, M.D., Mussetter, R.A., and Morris, C.E., 2004. Ecological and Physical Processes during Spring Peak Flow and Summer Base Flows in the Colorado River above the Gunnison River, Volume I, Draft Final Report. Prepared for the Colorado River Water Conservation District, Glenwood Springs, Colorado, MEI Project 98-15, March.

Harvey, M.D., 2003. Sediment Yields from Ungaged Tributaries to the Middle Rio Grande Between San Acacia and Elephant Butte Reservoir. Prepared for the New Mexico Interstate Stream Commission, Albuquerque, New Mexico, Project 00-10 T756, December.

Harvey, M.D., 2003. Evaluation of Trinity River Channel Restoration Flow Alternatives. Prepared for the Northern California Power Agency, Roseville, California, Project Number 03-07, October.

Harvey, M.D. and Trabant, S.C., 2003. Design of Channel Restoration and Stabilization Measures on Quebrada Pampa Larga, Quebrada Honda Drainage Basin, Peru. Prepared for the Minera Yanacocha SRL, Lima, Peru, Project Number 03-04, September.

Harvey, M.D. and Mussetter, R.A., 2003. Pilot Hydraulic and Habitat Modeling, Middle Rio Grande. Prepared with Miller Ecological Consultants for Bohannan-Huston and the U.S. Army Corps of Engineers, Albuquerque District, Project Number 01-08, March.

Mussetter, R.A. and Harvey, M.D., 2002. Carmel River Sediment-Transport Study, Monterey County, California. Prepared for the California Dept. of Water Resources, Fresno, California, MEI Project 01-05, January.

Anthony, D.J., Harvey, M.D., and Mussetter, R.A., 2002. Analysis of Proposed Conservation Measures, Western Sarpy and Clear Creek Levee Project, Platte River, Nebraska. Prepared for the Nebraska Game and Parks Commission, Lincoln, Nebraska, MEI Project 01-09, January.

Mussetter, R.A. and Harvey, M.D., 2002. Geomorphic and Sedimentologic Investigations of the Middle Rio Grande between Cochiti Dam and Elephant Butte Reservoir. Prepared for the New Mexico Interstate Stream Commission, MEI Project 00-10, June.

Mussetter, R.A. and Harvey, M.D., 2002. San Joaquin River 2002 Experimental Flow Project Design Report. Prepared for Friant Water Users Authority and Natural Resources Defense Council, MEI Project 02-02, June.

Mussetter, R.A., and Harvey, M.D., 2002. Initial Evaluation of U.S. Flow Claims for the Black Canyon of the Gunnison National Monument, Colorado Water Division No. 4. Prepared for the Colorado River Water Conservation District, Glenwood Springs, Colorado, MEI Project 02-03, September.

Mussetter, R.A., and Harvey, M.D., 2002. Scour Analysis for the Lower Northwest Interceptor Pipeline Crossings at RM62 and RM 47, Sacramento River, California. Prepared for Hatch Mott MacDonald, Pleasanton, California, MEI Project 02-10, October.

Harvey, M.D. and Mussetter, R.A., 2001. Indian Bar Sediment Disposal Site Study, Ralston Afterbay, California. Prepared for Placer County Water Agency, Foresthill, California, MEI Project 00-16, May.

Gessler, D, Mussetter, R.A., and Harvey, M.D., 2001. Investigation of Various Entry Angles for Westbay Diversion, Mississippi River, RM 4.7. Prepared for the U.S. Army Corps of Engineers, New Orleans District, Louisiana, MEI Project 01-15, November.

Harvey, M.D. and Mussetter, R.A., 2001. Expert Report of Dr. Michael D. Harvey and Dr. Robert A. Mussetter Regarding the Age of Islands in the Snake River Sector of the Deer Flat National Wildlife Refuge, State of Idaho, Case No. CIV97-0426-S-BLW. Prepared for the Idaho Attorney General's Office, Boise, Idaho, MEI Project 96-16, May.

Mussetter, R.A. and Harvey, M.D., 2001. Expert Report of Dr. Robert A. Mussetter and Dr. Michael D. Harvey Regarding Identification of the Ordinary High-water Mark along the Snake River from the Upper End of Brownlee Reservoir to Sign Island, State of Idaho, Case No. CIV97-0426-S-BLW. Prepared for the Idaho Attorney General's Office, Boise, Idaho, MEI Project 96-16, February.

Mussetter, R.A. and Harvey, M.D., 2000. Hydraulic and Sediment Continuity Modeling of the San Joaquin River from Mendota Dam to Merced River, California. Prepared for the US. Bureau of Reclamation, MEI Project 99-12, September.

Harvey, M.D. and Mussetter, R.A., 2000. Expert Report of Dr. Michael D. Harvey and Dr. Robert A. Mussetter Regarding Seyler v. Burlington Northern Santa Fe Corporation et al., Case No. 99-2342 KHL. Prepared for Preston, Gates & Ellis, LLP, Seattle, Washington, MEI Project 99-14, February.

Harvey, M.D., 2000. Daguerre Point Dam Fish Passage Study. Prepared for U.S. Army Corps of Engineers, Sacramento District, California, August.

Miller, W.J. and Harvey, M.D., 2000. Year 2 Summary of Biological and Physical Process Studies to Determine the Effect of Peak Flows on the 15-mile Reach, Colorado. Prepared for the Colorado River Water Conservation District, Glenwood Springs, Colorado, October.

Harvey, M.D., 2000. Geomorphic Assessment of Upper Truckee River Watershed and Section 206 Aquatic Ecosystem Restoration Project Reach, City of South Tahoe, El Dorado County, California. Prepared for U.S. Army Corps of Engineers, Sacramento District, California, November.

Harvey, M.D., 1999. Final River Stabilization Report, Batu Hijau Project, Sumbawa, Indonesia. Prepared for Shepherd Miller, Inc, and P.T. Newmont Nusa Tengarra, Lombok, Indonesia, November.

Harvey, M.D. and Mussetter, R.A., 1999. Geomorphic and Sediment Baseline Evaluation of the San Joaquin River from the Delta to the Confluence with the Merced River, Including Bypasses and Major Tributaries. Prepared for Jones & Stokes Associates and U.S. Corps of Engineers, Sacramento District, California, May.

Harvey, M.D., 1999. Geomorphic Evaluation of Santa Ana River Alluvial Fan and San Bernadino Kangaroo Habitat, California. Prepared for U.S. Corps of Engineers, Los Angeles District, California, May.

Harvey, M.D., 1999. Expert Witness Report Regarding the U.S. Forest Service Organic Act Claims in the Snake River Basin Adjudication, Consolidated Subcase #63-25243. Prepared for the Office of Attorney General, State of Idaho, March.

Mussetter, R.A. and Harvey, M.D., 1999. Hydraulic and Sediment Continuity Modeling of the San Joaquin River from Friant Dam to Mendota Dam, California. Prepared for the US. Bureau of Reclamation, September.

Mussetter, R.A. and Harvey, M.D., 1999. Hydraulic Analysis of Levee Realignment Shanghai Bend, Feather River, California. Prepared for U.S. Corps of Engineers, Sacramento District, California, March.

Harvey, M.D., 1998. Preliminary Evaluation of River Aggregate Mining Batu Hijau Project, Sumbawa, Indonesia. Prepared for P.T. Newmont Nusa Tengarra, Indonesia, April.

Harvey, M.D., 1998. Channel Stability Assessment of Pacheco Creek at Hollister Conduit Crossing in San Benito County, California. Prepared for San Benito County Water District, Hollister, California, March.

Harvey, M.D., 1998. Reconnaissance-Level Evaluation of Flooding, Erosion and Sedimentation Problems along Ritchey Creek, in the Vicinity of Sterling Vineyards Property, near Calistoga, Napa Valley, California. Prepared for Sterling Vineyards, Calistoga California, January.

Harvey, M.D., 1998. Analysis of Physical Processes and Riparian Habitat Potential of the San Joaquin River, Friant Dam to the Merced River. Prepared for the US. Bureau of Reclamation with Jones & Stokes Associates, Inc., October.

Mussetter, R.A. and Harvey, M.D., 1998. Hydraulic and Channel Stability Analysis for the Replacement of the Twin Bridges over the Snake River, Ririe-Archer Highway, Idaho. Prepared for Idaho Department of Transportation, November.

Mussetter, R.A. and Harvey, M.D., 1998. Little Puerco Wash Feasibility Study, Sediment Transport Appendix. Prepared for Bohannan Huston, Inc. and the Albuquerque District, U S. Army Corps of Engineers, May.

Mussetter, R.A. and Harvey, M.D., 1998. Reconnaissance Level Evaluation of the Snake River Bridges, Bingham County, Idaho. Prepared for HDR Engineering, Inc. and Idaho Department of Transportation, December.

Mussetter, R.A. and Harvey, M.D., 1997. Geomorphic and Sediment Transport Study, Spearfish Creek Between Hydro No. 2 and Maurice Intake Dam. Prepared for South Dakota Department of Game, Fish and Parks, Rapid City, SD, December.

Mussetter, R.A. and Harvey, M.D., 1997. Channel Stability Analysis, Silver Bow Creek SSTOU, Subarea 1. Prepared for Montana Department of Environmental Quality, November.

Harvey, M.D., 1997. Evaluation of the Significance of the 15-Mile Reach of the Colorado River to Basinwide Recovery of the Federally-Listed and Candidate for Listing Native Fish Species. Prepared for Colorado River Water Conservation District, October.

Harvey, M.D., 1997. Investigation of Physical Conditions at Napias Creek Falls, Napias Creek, Idaho. Prepared for Meridian Gold Company, Salmon, Idaho, September.

Mussetter, R.A. and Harvey, M.D., 1997. Skyrocket Creek Debris Flow Analysis. Prepared for Jones & Stokes Associates and U.S. Corps of Engineers, Sacramento District, California, November.

Harvey, M.D., 1997. Review of the Natural and Man-Made Changes to the Garcia River in the Vicinity of the Kendall Property Following the January 1997 Flood. Prepared for Rawles, Hinkle, Carter, Behnke, and Oglesby, March.

Harvey, M.D., 1997. Reconnaissance-Level Geomorphic Evaluation of the Twin Bridges Reach, Snake River, Idaho. Prepared for the Idaho Department of Transportation, September.

Mussetter, R.A. and Harvey, M.D., 1996. Evaluation of the potential effects of subsidence on the Genesee River and tributaries. Report to Akzo Nobel Salt, Inc., January, 127 p.

Harvey, M.D. and Mussetter, R.A., 1996. Assessment of bank erosion along lower Whitewood Creek, South Dakota. Report to Homestake Mining Company, November.

Harvey, M.D., 1996. Evaluation of channel stability impacts to the Genesee River between Big Tree Lane and York Landing. Report to Azko Nobel Salt, Inc., November.

Mussetter, R.A. and Harvey, M.D., 1996. West Interstate-40 Drainage Management Plan: Analysis of existing conditions, sediment yields, and detention dam trap efficiencies. Report to Bohannan-Huston, Albuquerque, New Mexico, March.

Harvey, M.D. and Mussetter, R.A., 1996. Calabacillas Arroyo Prudent Line Study: Hydraulic capacity and stability analysis for levees between Coors Road and the Rio Grande. Report the Albuquerque Metropolitan Arroyo Flood Control Authority, April.

Harvey, M.D., 1996. Direct shear testing of root-reinforced soils within the Lower American River Parkway, California. Report to U.S. Army Corps of Engineers, Sacramento District, October.

Mussetter, R.A. and Harvey, M.D., 1996. Evaluation of Beards Creek degradation and development of a conceptual mitigation plan. Report to Akzo Nobel Salt, Inc., August.

Mussetter, R.A. and Harvey, M.D., 1995. Uncompahgre River channel stability study, Report to Montrose Partners, Ltd, 62 p.

Harvey, M.D. and Smith, T., 1995. Geologic hazard assessment and mitigation planning for Crested Butte Mountain Resort, Gunnison County, Colorado, Report to Pioneer Environmental Services, Inc., U.S. Forest Service and Crested Butte Mountain Resort, 40 p. and Appendices.

Harvey, M.D., 1995. Evaluation of the Genesis of Napias Creek Falls, Napias Creek Drainage Basin, Idaho. Report to Holland and Hart and FMC Gold Corporation, August, 43 p.

Mussetter, R.A. and Harvey, M.D., 1995. Preliminary Design for Reclamation Plan for the Redex Mine reach of Whitewood Creek, South Dakota. Report to Homestake Mining Co., December, 132 p. plus Appendices.

Harvey, M.D., 1995. Review of "Relationships between flow and rare fish habitat in the 15-Mile reach of the Upper Colorado River", Final Report, May, 1995, U.S. Fish and Wildlife Service. Report to Colorado River Water Conservation District, September.

Harvey, M.D. and Mussetter, R.A., 1995. A methodology for establishing flow recommendations. Report to Colorado River Water Conservation District, December, 23 p.

Harvey, M.D. and Mussetter, R.A., 1994. Green River Endangered Fish Species Habitat Investigations, Report to Colorado River Water Conservation District and Denver Water, February, 62 p. and Appendices.

Harvey, M.D. and Schneck, T., 1994. Straight Creek sedimentation investigation, Summit County, Colorado, Report to Summit County Water Quality Committee, February, 58 p. and Appendices.

Harvey, M.D. and Spitz, W.J., 1994. Geomorphological assessment of North Fork Feather River from Rock Creek Reservoir to Lake Oroville, California, Report to Pacific Gas and Electric Company, San Francisco, 89 p.

Mussetter, R.A. and Harvey, M.D., 1994. Bar dynamics assessment, RM 17.7 to RM 18.2, North Fork Feather River, California, Report to Pacific Gas and Electric Co., San Francisco, 30 p.

Mussetter, R.A. and Harvey, M.D., 1994. Geomorphic, hydraulic and lateral migration characteristics of the Colorado River Moab, Utah, Report to Canonie Environmental and Atlas Corporation, 45 p.

Harvey, M.D., 1993. Review of Natural Resource Agency comments on Echo Bay's Section 10 and 404 Permit Applications (Gastinequ Channel 420), Report to Echo Bay Alaska, Inc., 27 p.

Harvey, M.D. and Mussetter, R.A., 1993. Yuba River Basin, California Project, Geomorphic, Sediment Engineering, and Channel Stability Analysis, Report to U.S. Army Corps of Engineers, Sacramento District, Contract No. DACW05-92-C-0077, March, 133 p.

Harvey, M.D. and Mussetter, R.A., 1993. American and Sacramento Rivers, California Project, Geomorphic, Sediment Engineering, and Channel Stability Analysis, Report to U.S. Army Corps of Engineers, Sacramento District, Contract No. DACW05-93-C-0045, November, 175 p.

Mussetter, R.A. and Harvey, M.D., 1993. Evaluation of Channel Maintenance Flows on North Boulder Creek, Report to Engineering-Science, Inc., November, 35 p.

Peterson, M.R. and Harvey, M.D., 1993. Configuration Data Report, Riverbed Gradient Restoration, Glenn Colusa Irrigation District, Report to U.S. Army Corps of Engineers, Sacramento District, Contract No. DACW05-90-C-0168, September, 15 p. Appendices.

Harvey, M.D. and Spitz, W.J., 1993. Panhandle Creek Sediment Yield Study, report to Crystal Lakes Water and Sewer Association, Red Feather Lakes, CO, 10 p.

Mussetter, R.A. and Harvey, M.D., 1993. Yampa River Endangered Fish Species Habitat Investigations, Report to Colorado River Water Conservation District, December, 38 p.

Harvey, M.D., 1992. Kensington Gold Venture, Review and Redesign of Tailings Impoundment Reclamation, Report to Echo Bay, Alaska, Inc., 8 p.

MacArthur, R.C. and Harvey, M.D., 1992. Nonpoint source sediment pollution investigation of the Pearl Harbor Drainage Basin, Hawaii, Report to the Pearl Harbor Estuary Program, Interagency Committee, Dept. of Health, Honolulu, HI, 32 p.

MacArthur, R.C. and Harvey, M.D., 1991. Urban Flooding and Debris Flow Analysis for Niu, Aina Haina and Kuliouou Valleys, Report to U.S. Army Corps of Engineers, Pacific Ocean Division, Honolulu, Hawaii, Contract No. DACW83-91-P0055, May, 50 p.

Harvey, M.D., 1991. Caliente Creek, California project: Field Circumstantiation of Sediment Engineering Investigation. Report to U.S. Army Corps of Engineers, Sacramento District, Contract No. DACW05-88-D-0044, March, 18 p.

Harvey, M.D. and Mussetter, R.A., 1991. Geomorphic, Hydraulic and Channel Stability Analyses of Whitewood Creek, South Dakota, Report prepared for Homestake Mining Company, Lead, South Dakota, June, 96 p.

Fischer, K.J., Harvey, M.D. and Spitz, W.J., 1991. Geomorphic Analysis and Bank Protection Analysis for Sacramento River (RM 0-78), Feather River (RM 28-61), Yuba River (RM 0-11), Bear River (RM 0-17), American River (RM 0-23) and portions of Three Mile, Steamboat, Sutter, Miner, Georgiana, Elk and Cache Sloughs. Report to U.S. Army Corps of Engineers, Sacramento District, Contract No. DACW05-88-D-0044, June, 334 p.

Fischer, K.J. and Harvey, M.D., 1991. Reconnaissance geomorphic investigation of Truckee River from Vista to Pyramid Lake, Nevada, Report to U.S. Army Corps of Engineers, Sacramento District, Contract No. DACW05-91-P-1543, 106 p.

Fischer, K.J. and Harvey, M.D., 1990. Geomorphic analysis of Truckee River from RM 56 to RM 43, Report to U.S. Army Corps of Engineers, Sacramento District, Contract No. DACW05-88-D-0044, October, 99 p.

Harvey, M.D., 1990. Geomorphic Analysis of the Caliente Creek Basin, California. Report to U.S. Army Corps of Engineers, Sacramento District, Contract No. DACW05-88-D-0044, October, 58 p.

Fischer, K.J. and Harvey, M.D., 1989, Field investigation and geomorphic analysis of Abiaca Creek Watershed. Report to U.S. Army Corps of Engineers, Vicksburg District, Contract No. DACW38-88-D-0099, 128 p.

Harvey, M.D., Fischer, K.J. and Thaemert, R.L., 1989, Cache Creek Basin (Outlet Channel) project: Cache Creek Erosion Mitigation Alternatives, Report to U.S. Army Corps of Engineers, Sacramento District Contract No. DACW05-88-D-0044, 142 p.

Fischer, K.J. and Harvey, M.D., 1989, Geomorphic analysis and bank protection alternatives for Sacramento and Feather Rivers. Report to U.S. Army Corps of Engineers, Sacramento District, Contract No. DACW05-88-D-0044, 256 p.

Harvey, M.D. and Watson, C.C., 1989. Systems Approach to Watershed Analysis. Report to U.S. Army Corps of Engineers, Vicksburg District, Contract No. DACW38-88-D-0099, 151 p.

Harvey, M.D., 1989. Assessment of effects of sand and gravel mining on Wagwater River, Jamaica. Report to Jamaica Banana Producers Association, August, 75 p.

Fischer, K.J., Gregory, D.I. and Harvey, M.D., 1989. Geologic analysis of site contamination at American Wyott Corporation, Cheyenne, Wyoming. Report to Stewart Environmental Consultants, Fort Collins, Colorado, 42.

Harvey, M.D., 1989. Analysis of geomorphic behavior of Arkansas River from Fort Smith to Lock and Dam, No. 13, Sebastian and Crawford Counties, Arkansas. Report to U.S. Department of Justice, Land and Resources Division, Washington, D.C., February, 27 p.

Schug, J.D. and Harvey, M.D., 1989. Sedimentation surveys of Big Caney, Middle Caney, Lost Creek and Spring Creek reservoirs, Kansas. Reports (4) to U.S.D.A. Soil Conservation Service, Salina, KS, Contract No. 53-6215-9-1, April.

Harvey, M.D. and Fischer, K.J., 1989. Sediment Impact Analysis: Phase I Napa River Sediment Engineering Analysis. Report to U.S. Army Corps of Engineers, Sacramento District, Contract No. DACW05-88-D-0044, 67 p.

Harvey, M.D., Watson, C.C., and Schumm, S.A., 1988. Geomorphic analysis of Sacramento River, Phase II Report. Geomorphology of Sacramento River from Colusa to Red Bluff. Report to U.S. Army Corps of Engineers, Sacramento District, Contract No. DACW05-87-C-0094, 343 p.

Peterson, M.R., Watson, C.C., and Harvey, M.D., 1988. Performance evaluation of channels stabilized with ARS-Type low-drop structures. Report to Waterways Expt. Station, U.S. Army Corps of Engineers, Vicksburg, MS. Contract No. DACW39-87-CO9921, 114 p.

Harvey, M.D., Peterson, M.R. and Watson, C.C., 1988. Geomorphic and hydraulic engineering study of Sacramento River from Hamilton City to Woodson Bridge. Report to California Dept. Fish and Game and Glenn-Colusa Irrigation District, 174 p.

Anthony, D.J. and Harvey, M.D., 1988. Report for the 1987 field season, Fall River Research, Rocky Mountain National Park. Report to USDI, National Park Service, June, 50 p.

Harvey, M.D. and Fisher, K.J., 1988. Geomorphological and sedimentological characteristics of Sink Valley, Kane County, Utah. Report to Nevada Electric Investment Company, August, 86 p.

Harvey, M.D., Peterson, M.R. and Watson, C.C., 1988. Geomorphic and hydraulic engineering study of Sacramento River from Hamilton City to Woodson Bridge. Report to California Dept. Fish and Game and Glenn-Colusa Irrigation District, 174.

Harvey, M.D., Watson, C.C., Schumm, S.A. and Pranger, H.H., 1987. Geomorphic and hydraulic analysis of Red River from Shreveport, Louisiana to Dennison Dam, Texas. Report to U.S. Army Corps of Engineers, Vicksburg District, Contract No. DACW38-86-D-0062/7, August, 226 p.

Pitlick, J.C. and Harvey, M.D., 1987. Geomorphic response of Fall River following the lawn Lake flood, Rocky Mountain National Park, Colorado. Report to U.S. Army Laboratory Command, Army Research Office, Contract No. DAAG29-85-K-0108, June, 33 p.

Harvey, M.D., Watson, C.C. and Schumm, S.A., 1987. Geomorphic analysis of Sacramento River, Phase I Report. Geomorphic Analysis of Butte Basin reach, RM 174 to RM 194. Report to U.S. Army Corps of Engineers, Sacramento District, Contract No. DACW05-87-C-0094, 303 p.

Harvey, M.D., 1987. Observations on the status of the tributaries to Dry Creek, Sonoma County, California, from Warm Springs Dam to Russian River Confluence. Report to USACE, Sacramento District, Contract No. DACW05-86-P-2744, February, 34 p.

Harvey, M.D. and Schumm, S.A., 1987. Geomorphology and sedimentology of Sink Valley, Alton, Utah. Report to BHP-Utah International Inc., Alton Coal Project, June, 33 p.

Harvey, M.D., Watson, C.C. and Peterson, M.R., 1987. Recommended Improvements for Stabilization of Hotopha Creek Watershed, Mississippi: Report to U.S. Army Corps of Engineers, Vicksburg District, Contract No. DACW38-86-D-0062/3, April, 97 p.

Watson, C.C., Harvey, M.D., and Peterson, M.R., 1987. Investigation of erosion and flood control alternatives for Batupan Bogue Watershed. Report to U.S. Army Corps of Engineers, Vicksburg District, Contract No. DACW38-86-D-0062/5, July, 95 p.

Pitlick, J.C. and Harvey, M.D., 1986. A summary of 1985 channel changes and sediment transport on Fall River, Rocky Mountain National Park. Report to National Park Service, March, 38 p.

Schumm, S.A. and Harvey, M.D., 1986. Preliminary geomorphic evaluation of the Sacramento River, Red Bluff to Butte Basin. Report to U.S. Army Corps of Engineers, Sacramento District, Contract NO. DACW05-86-P-0293. 45 p.

Watson, C.C., Harvey, M.D., Gregory, D.I., 1986. Investigation of hydrologic, geomorphic and sedimentologic characteristics of the Lower Alabama River. Report to U.S. Army Corps of Engineers Mobile District, Contract NO. DACW01-85-D-0018. 196 p.

Laird, J.R. and Harvey, M.D., 1986. Complex response of a small chaparral vegetated basin to geomorphically-effective fire, El Oso Creek, Tonto Basin, Arizona. Report to U.S.D.A. Forest Service, Rocky Mountain Forest and Range Experiment Station, Tempe, Arizona. 192 p.

Harvey, M.D., and Spitz, W.J., 1986. Investigation of the causes of timber mortality, Cooper property, Itawamba county, Mississippi. Report to U.S. Army Corps of Engineers, Mobile District, Contract No. DACW01-86-M-5018, September, 69 p.

Watson, C.C., Harvey, M.D., Schumm, S.A., and Gregory, D.I., 1986. Geomorphic study of Oaklimiter Creek, Burney Branch, and Muddy Creek, in Benton, Lafayette and Tippah Counties, Mississippi. Section 1. Simulation of Oaklimiter Creek Evolution and Alternative Designs for Flood Mitigation. Report to USDA, Soil Conservation Service, MS, Project No. SCS-54-MS-83, June, 197 p.

Watson, C.C., Harvey, M.D., Schumm, S.A. and Gregory, D.I., 1986. Geomorphic study of Oaklimiter Creek, Burney Branch and Muddy Creek in Benton, Lafayette and Tippah Counties, MS. Performance of Burney Branch and Muddy Creek Channel Stabilization Measures. Report to USDA, Soil Conservation Service, MS, Project No. SCS-54-MS-83, 117 p.

Anthony, D.J. and Harvey, M.D., 1986. Internal channel adjustments, velocity patterns, and bed load movement, 1986 field season, Fall River, Rocky Mountain National Park, Colorado. Report to U.S.D.I., National Park Service, Rocky Mountain National Park, November, 37 p.

Harvey, M.D. and Schumm, S.A., 1985. Geomorphic analysis of Dry Creek, Sonoma County, California from Warm Springs Dam to Russian River Confluence. Report, U.S. Army Corps of Engineers, Sacramento District, Contract No. DACW-0585-P001, August, 91 p.

Harvey, M.D., Watson, C.C., and Schumm, S.A., 1984. Geomorphic study of Muddy Fork, Silver Creek Watershed, Clarke, Floyd and Washington Counties, Indiana. Final Report, Project SCS-AS-80, 8/79, USDA Soil Conservation Service, June, 77 p.

Schumm, S.A., Watson, C.C., Gregory, D.I., and Harvey, M.D., 1984. Episodic behavior of sand-bed rivers. U.S. Army Research Office, Contract NO. DAA929-81-C-0037, Final Report. 61 p.

Finley, J., Harvey, M.D., and Watson, C.C., 1984. Experimental studies of erosion from slopes protected by rock mulch. Final Report, U.S. Environmental Protection Agency, Contract No. 68-02-4040. 39 p.

Schumm, S.A. and Harvey, M.D., 1983. Geomorphic evaluation of the Grand Junction and Rifle Uranium Mill Tailings Piles. Report to NUS Corp., Denver, CO, Water Engineering & Technology, Inc., February, 17 p.

Harvey, M.D. and Schumm, S.A., 1983. Report on the alluvial valley floor mapping Coal Creek Mine, Wyoming. Report prepared for Thunder Basin Coal Company, Wright, Wyoming, February, 6 p.

Harvey, M.D., and Schumm, S.A., 1983. Geomorphology of Toposhaw, Abiaca and Pelucia Creeks, Mississippi Final Report, Project 53-44423-1-221, USDA, Soil Conservation Service, 14 p.

Harvey, M.D., and Schumm, S.A., 1983. Geomorphology of Middle Fork Tillatoba Creek, Mississippi. Final Report, Project 53-44423-1-221, USDA, Soil Conservation Service, July, 60 p.

Harvey, M.D., and Schumm, S.A., 1981. Geomorphic evaluation of the long-term stability of Atlas Minerals Uranium Mill Site, Moab, Utah. Report prepared for Woodward Clyde, Consultants, Denver, CO 28 p.

Schumm, S.A. and Harvey, M.D., 1981. Report on alluvial valley floor mapping, landform identification and erosion hazards, Coal Creek Mine, Wyoming. Report prepared for ARCO Coal Company, December, 12 p.

Harvey, M.D., Schumm, S.A., Buchanan, J.B., and Mizuyama, T., 1981. Geomorphic evaluation of Lower Truckee River, between Wadsworth and Marble Bluff Dam, Nevada. Report prepared for Bureau of Indian Affairs, December, 21 p.

Harvey, M.D. and Schumm, S.A., 1981. The geomorphology of Oaklimiter Creek, Northern Mississippi. Report, Soil Conservation Service, Project SCS-23-MS-80. 76 p.

Schumm, S.A., Harvey, M.D., and Watson, C.C., 1981. Yazoo Basin Geomorphology. Soil Conservation Service, Project SCS-23-MS-80. 483 p.

Harvey, M.D., Schumm, S.A., and Watson, C.C., 1980. The geology and geomorphology of Cypress Creek Watershed, Yalobusha County, Mississippi. Report prepared for Smith and Sanders, Inc., Jackson, MS. Water Engineering and Technology, Inc., Shreveport, LA. 37 p.

Supplemental Expert Report of Dr. Michael D. Harvey for the District Court of El Paso County, Colorado, regarding Erosion at Two Sites along Fountain Creek during the Floods of April and May 1999

The Speight Family Partnership, LLLP (a Colorado Limited Liability Limited Partnership) and the Greenview Trust, Ralph R. Williams, Trustee

Plaintiffs

v. the City of Colorado Springs (a Home-rule City of the State of Colorado) and the Board of County Commissioners of the County of El Paso

Defendant(s)

Case No. 01 CV 1290

Mussetter Engineering, Inc.
1730 South College Avenue, Suite 100
Fort Collins, Colorado 80525

May 12, 2008

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1. Apportionment of Causes of Downstream Hydrologic Impacts

Failure to implement upstream runoff detention in the Fountain Creek Basin resulted in an estimated 33 percent increase in the total volume of flow in Fountain Creek at the KOA and Greenview properties during the April-May 1999 storm events (Garcia and Roesner, 2003). Estimation and apportionment of the causes of the hydrologic impacts of upstream development on the downstream channel and landowners during the April 28 to May 2, 1999 period is based on the amount of impervious surface area within the individual drainage basins that make up the Fountain Creek watershed, and their spatial distribution within the City of Colorado Springs and El Paso County. The total drainage area of Fountain Creek within El Paso County is 760 square miles, of which about 197 square miles are located within the City of Colorado Springs. Entities not party to this litigation such as Green Mountain Falls, Fountain, Manitou Springs, Monument, Palmer Lake, Woodland Park, Teller County, Southeastern Colorado Water District, Widefiled, Security, Chipita park, Cascade, Crystola, U.S. Army, U.S. Air Force, and U.S. Forest Service are included within El Paso County for the purposes of this analysis.

The amount of impervious area within the basins used in this analysis is based on the assumed 2010 conditions (refer to Figure 13 in my Expert Report of March 18, 2008) that were derived from various planning studies that were conducted for the City of Colorado Springs and El Paso County (CH2M Hill, 1992; Muller Engineering, Inc., 1994; Kiowa Engineering Corporation, 1996) and from a regression equation developed to predict the 2010 impervious area for the Sand Creek Basin. For the Monument Creek Basin, it is estimated that the total percentage of impervious area is about 19 percent, and in the Fountain Creek and Sand Creek Basins the estimated percentages of impervious area are 13 and 58 percent, respectively. Further breakdown of the impervious data, indicates that within the Monument Creek Basin about 11 percent of the impervious area is located within the City of Colorado Springs, and about 8 percent is located in El Paso County. In the Fountain Creek Basin, the apportionment between the City and County is about 11 and 3 percent, respectively, and in the Sand Creek Basin, the apportionment is 34 and 24 percent, respectively.

2. Runoff Estimation

Garcia and Roesner (2003) developed isohyetal maps of the Fountain Creek Basin for the rainfall events of April 28, 1999, April 29, 1999, April 30, 1999, May 1, 1999, and May, 2, 1999, as well as a combined total for the period between April 28 and May 2, 1999. For the purposes of this analysis, the individual storm event and period total maps were digitized and registered on the map of Fountain Creek and the boundaries of the City of Colorado Springs and El Paso County were identified on the maps (**Figures 1 through 6**). The mid-point value between adjacent isohyets (inches) was multiplied by the area (acres) between the isohyets to compute the volume of rainfall (acre-feet) that fell on both the City and the County within the Fountain Creek Basin for each of the events and for the period between April 28 and May 2. In the April 28th event, rainfall totals over the City and County ranged from about 0.25 in. to >1 in. (Figure 1). In the April 29th event rainfall totals over the City and County ranged from >1 in. to >4 in. (Figure 2). In the April 30th event, rainfall totals over the City and County ranged from >1 in. to >3 in. (Figure 3). In the May1st event, rainfall totals over the City and County ranged from >0.25 in. to > 1 in. (Figure 4) and in the May 2nd event rainfall totals over the City and County ranged from >0.25 in. to >0.75 in. (Figure 5). For the entire period from April 28 to May 2, the rainfall totals ranged from >1 in. to >9 in. (Figure 6).

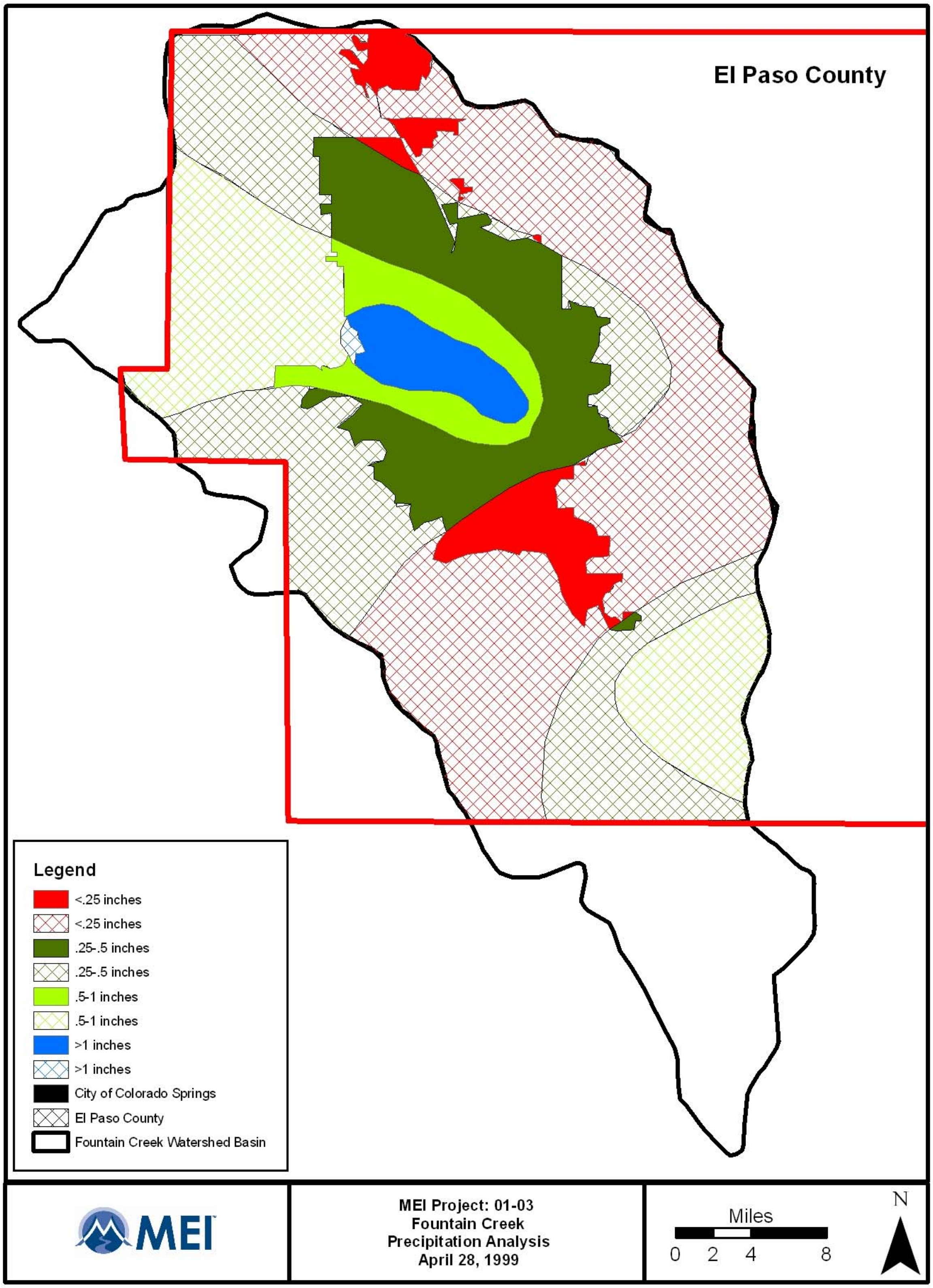

Figure 1. Isohyetal map of the Fountain Creek basin showing the distribution of rainfall on the City of Colorado Springs and on El Paso County on April 28, 1999.

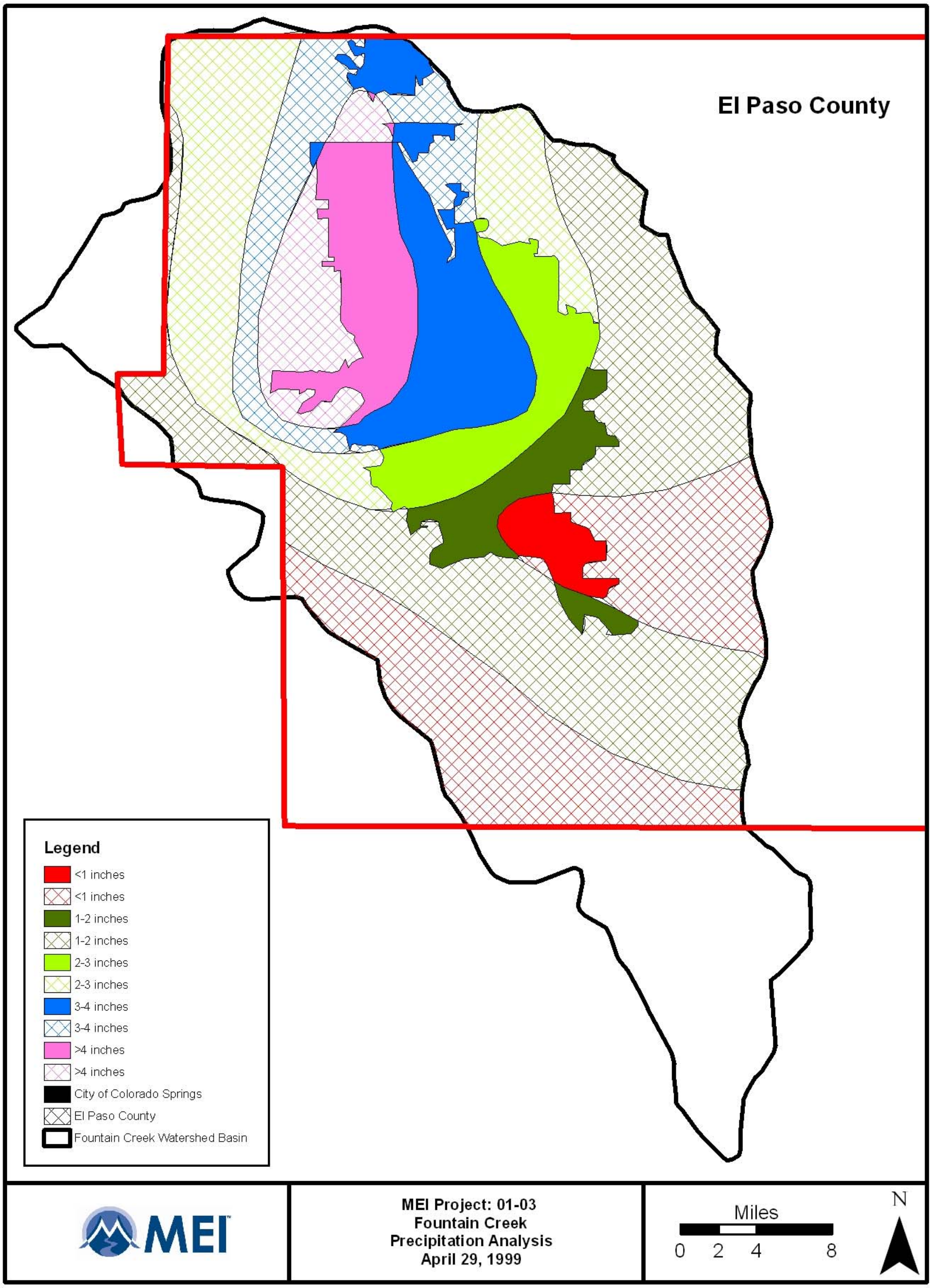

Figure 2. Isohyetal map of the Fountain Creek basin showing the distribution of rainfall on the City of Colorado Springs and on El Paso County on April 29, 1999.

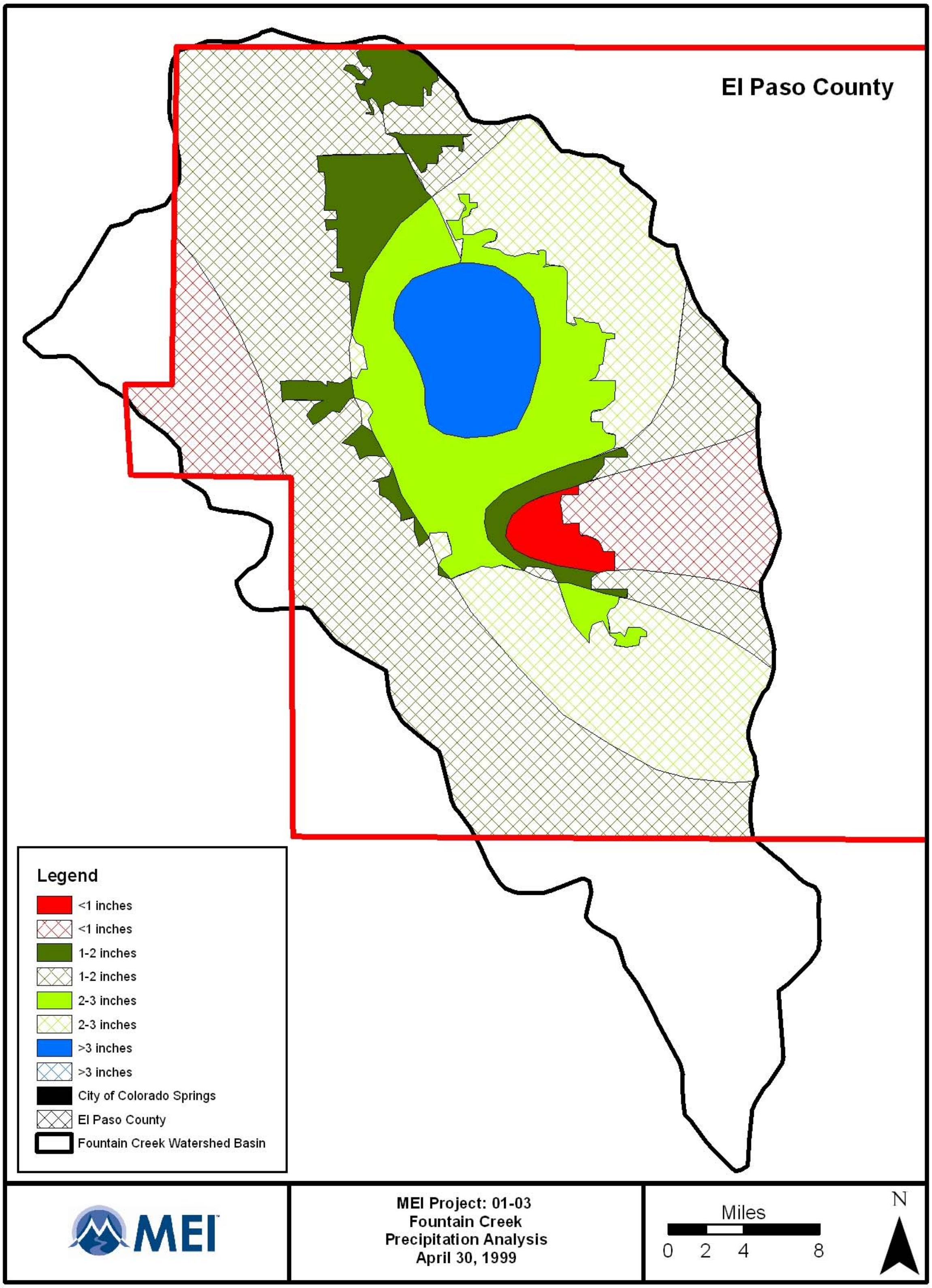

Figure 3. Isohyetal map of the Fountain Creek basin showing the distribution of rainfall on the City of Colorado Springs and on El Paso County on April 30, 1999.

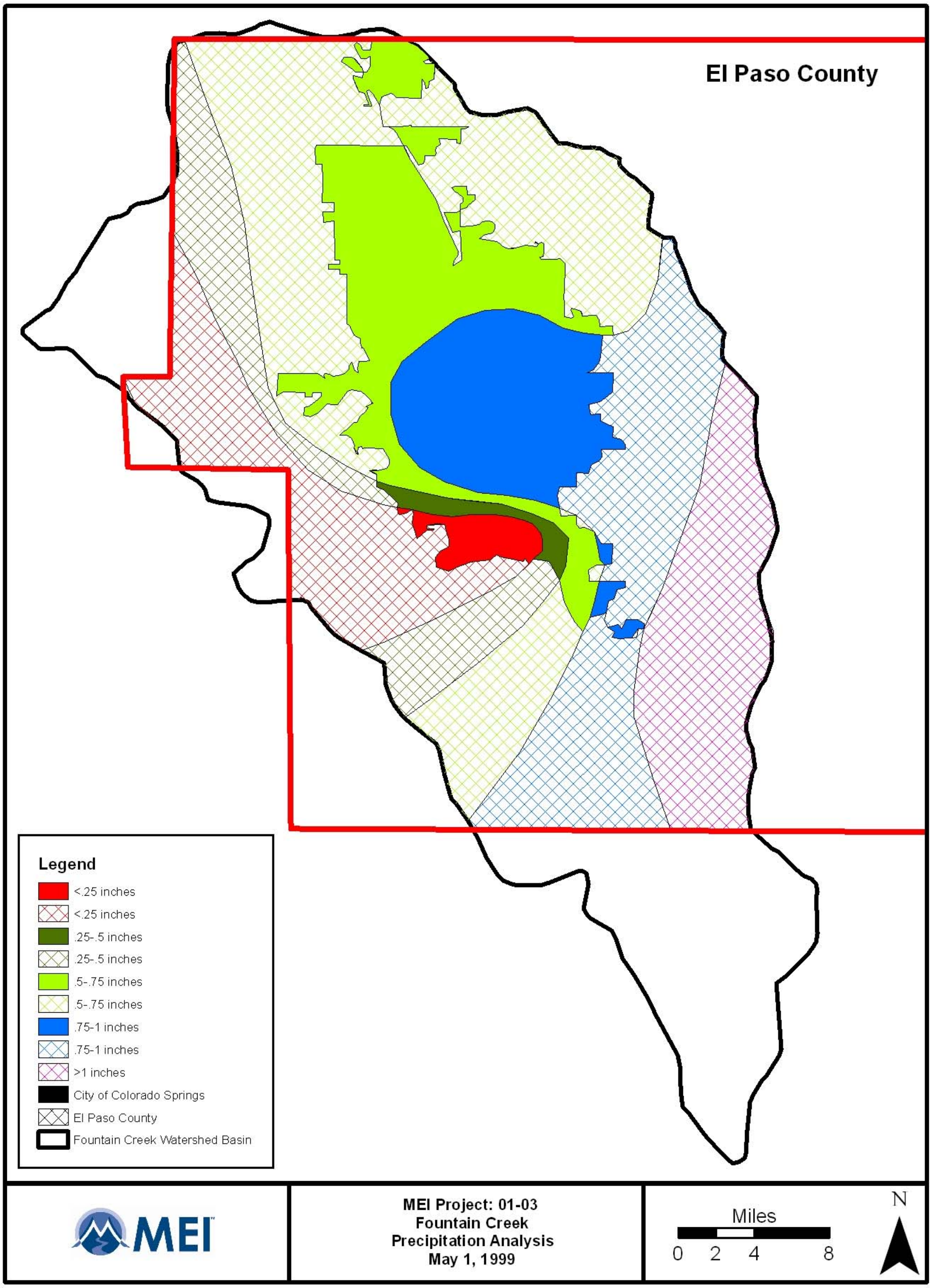

Figure 4. Isohyetal map of the Fountain Creek basin showing the distribution of rainfall on the City of Colorado Springs and on El Paso County on May 1, 1999.

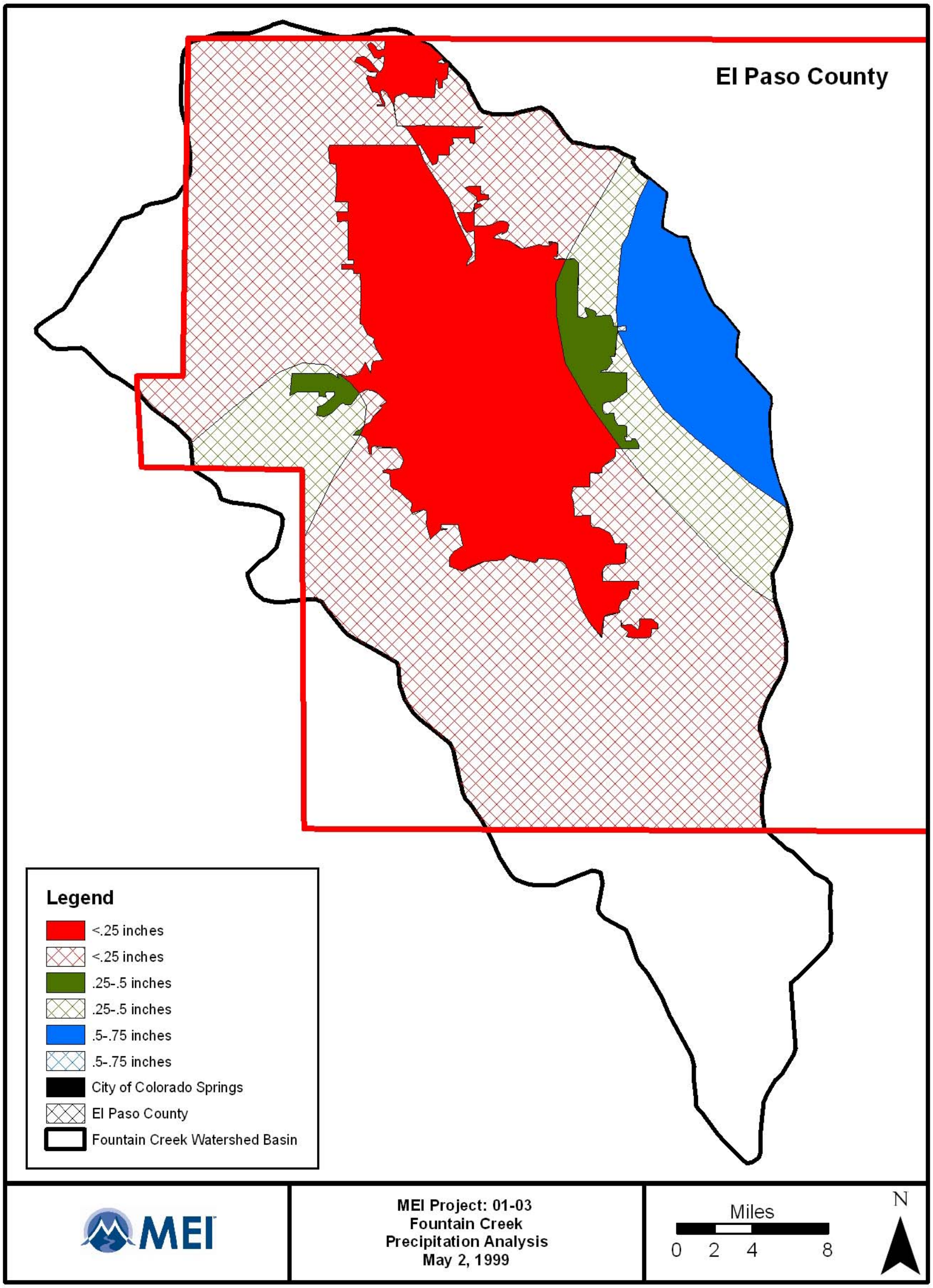

Figure 5. Isohyetal map of the Fountain Creek basin showing the distribution of rainfall on the City of Colorado Springs and on El Paso County on May 2, 1999.

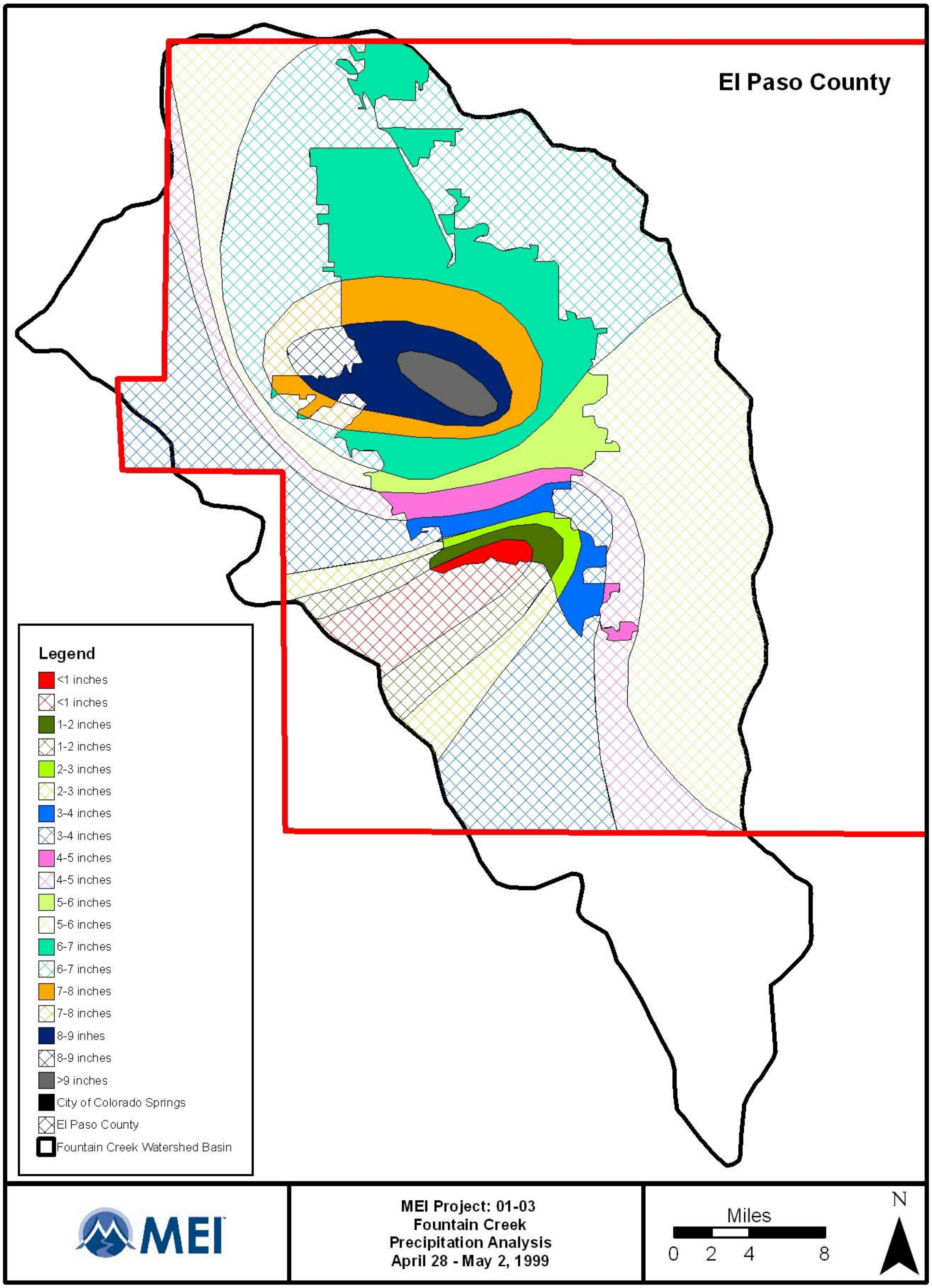

Figure 6. Isohyetal map of the Fountain Creek basin showing the distribution of rainfall on the City of Colorado Springs and on El Paso County between April 28 and May 2, 1999.

For each of the rainfall events and for the entire period between April 28 and May 2, 1999, the runoff volumes for the City and County were estimated by applying runoff coefficients to the estimated rainfall volumes. For undeveloped and pervious conditions a runoff coefficient of 0.2 was applied, and for impervious and developed conditions a value of 0.7 was applied for each storm event and for the entire period (American Society of Civil Engineers cited in Pilgrim and Cordery, 1993). No corrections to the runoff coefficients were made to account for reduced detention storage between successive events, and the events were treated singularly. Runoff volume estimates were developed for the City and County for the projected 2010 conditions and for a pre-development condition where it was assumed that there was no development and thus no impervious areas in the basin. The difference in the runoff volumes for the two conditions represents the contribution of the two entities to the increased runoff, and therefore, provides a means of apportioning the downstream hydrologic impact.

Table 1 summarizes the estimated runoff volumes for the City and County for the five rainfall events and for the period between April 28 and May 2, 1999.

Table 1. Summary of the estimated runoff volumes for 2010 and pre-development conditions in the Fountain Creek Basin.

Rainfall Event Date	Runoff Volumes for 2010 Conditions (acre-feet)		Runoff Volumes for Undeveloped Conditions (acre-feet)		Runoff Volume Due to Development (acre-feet)	
	City	County	City	County	City	County
4-28-99	9,595	19,753	3,163	6,157	6,432	13,596
4-29-99	56,763	104,981	18,713	32,721	38,050	72,260
4-30-99	44,135	94,102	14,550	29,331	29,585	64,771
5-1-99	13069	39041	4309	12169	8760	26872
5-2-99	2,805	11,865	925	3,698	1,880	8,167
4-28-99 to 5-2-99	126,444	278,905	41,685	86,932	84,759	191,973

For the individual rainfall events and for the period from April 28 to May 2, 1999, the percentage increase in estimated runoff volume as a result of development for the City of Colorado Springs was about 67 percent, and for El Paso County it was about 68 percent. Therefore, it can be concluded that development in the two entities contributed equally to the downstream increase in runoff in Fountain Creek.

3. References

CH2M Hill, 1992. Monument Creek Drainage Basin Planning Study, Volume 1. Prepared for the City of Colorado Springs Planning, Development and Finance Department.

Garcia, M. and Roesner, L., 2003. Report No. 2 to the City Attorney for Colorado Springs, Colorado, in reference to El Paso County District Court, Case No. 01CV1290, May, 21.

Kiowa Engineering Corporation, 1996. Sand Creek Drainage Basin Planning Study, Preliminary Design Report, City of Colorado Springs and El Paso County, Colorado. Prepared for the City of Colorado Springs Department of Comprehensive Planning, Development and Finance.

Muller Engineering Company, Inc., 1994. Fountain Creek Drainage Basin Planning Study, Volume 1. Prepared for the City of Colorado Springs Engineering Department.

Pilgrim, D.H. and Cordery, I., 1993. Flood Runoff. Chapter 9, in *Handbook of Hydrology*, D.R. Maidment (ed), McGraw-Hill, Inc.

DISTRICT COURT, EL PASO COUNTY, COLORADO 20 E. Vermijo, Colorado Springs, CO 80903 PO Box 2980, Colorado Springs, CO 80901-2980	
Plaintiffs: THE SPEIGHT FAMILY PARTNERSHIP, LLLP, a Colorado Limited Liability Limited Partnership, and THE GREENVIEW TRUST, Ralph R. Williams, Trustee.	
Defendant: THE CITY OF COLORADO SPRINGS, a home rule City of the State of Colorado, and THE BOARD OF COUNTY COMMISSIONERS OF THE COUNTY OF EL PASO,	
Attorney for Defendant City of Colorado Springs: PATRICIA K. KELLY, CITY ATTORNEY Shane White, Senior Attorney P.O. Box 1575, Mail Code 510 30 South Nevada Avenue, Suite 501 Colorado Springs, CO 80901 Telephone: (719) 385-5909 Fax number: (719) 578-6209 Atty. Reg. # 019034	▲ COURT USE ONLY ▲ Case Number: 01CV1290 Div: 14 Ctrm.:

DEFENDANT CITY OF COLORADO SPRINGS' C.R.C.P. 26(A)(2) EXPERT DISCLOSURES

COMES NOW Defendant, the City of Colorado Springs ("City"), by and through the Office of the City Attorney, and hereby provides the following disclosures with respect to expert witnesses:

1. Professor Larry A. Roesner, Ph.D., P.E., P.H., Department of Civil Engineering, Colorado State University, Fort Collins, CO 80523. Dr. Roesner is expected to testify in accordance with the report provided herewith. The report contains a statement of Dr. Roesner's opinions and the basis and reasons therefore, a listing of data sources and references, and figures and tables to support the opinions. The report is accompanied by Dr. Roesner's qualifications and experience, a listing of publications and presentations, and the compensation for the report.

RECEIVED

Dr. Roesner has not testified as an expert within the preceding four years.

2. Matthew Garcia, M.S., Department of Civil Engineering, Colorado State University, Fort Collins, CO 80523. Mr. Garcia is expected to testify as to his involvement with the report provided herewith. Mr. Garcia's curriculum vitae is attached hereto indicating Mr. Garcia's qualifications, and a list of publications. Mr. Garcia has not testified as an expert within the preceding four years.

3. The City reserves the right to supplement this disclosure in accordance with any new dates set following vacation of the trial.

Dated this 28 day of July, 2003.

Respectfully submitted,

Shane White, Senior Attorney
Attorney for Defendant City of
Colorado Springs

CERTIFICATE OF MAILING

I hereby certify that I have mailed a true copy of the foregoing **DEFENDANT CITY OF COLORADO SPRINGS' C.R.C.P. 26(A)(2) EXPERT DISCLOSURES** by United States mail, first class postage paid, this 28 day of July, 2003, to the following:

M.E. MacDougall
MACDOUGALL, WOLDRIDGE & WORLEY, P.C.
530 Communication Circle, Suite 204
Colorado Springs, CO 80905-9288

Jay Lauer
County Attorney's Office
27 E. Vermijo
Colorado Springs, CO 80903

By: ______________________

shane/speight/disc/003/tmh

LARRY A. ROESNER

Professor
Department of Civil Engineering
Colorado State University

QUALIFICATIONS SUMMARY

Dr. Roesner has more than 30 years of experience in water resources and water quality engineering and management. He is a nationally recognized expert in the development and application of hydrologic, hydraulic, and water quality simulation models. He presently holds the endowed Harold H. Short Chair of Civil Engineering Infrastructure Systems at Colorado State University.

EXPERIENCE

Dr. Roesner's area of specialization since 1970 has been urban hydrology and nonpoint source pollution control. He is a principal developer of the Corps of Engineers model STORM, a simplified urban stormwater management model, and EPA's SWMM EXTRAN model, a sophisticated flow-routing model for urban drainage systems. Applications experience includes nonpoint source pollution studies in California, Michigan, Georgia, and Florida, and storm drainage/combined sewer studies in Seattle, San Francisco, Boston, Cincinnati, Detroit, Cleveland, Omaha, and many Florida cities. He also has considerable experience with time series analysis of hydrologic records and has developed stochastic models of monthly precipitation and runoff.

Another of Dr. Roesner's areas of specialization is water quality simulation of surface water bodies. Dr. Roesner is the principal author of QUAL-II, a stream water quality model developed for USEPA which simulates 11 water quality parameters. He has conducted a number of USEPA-sponsored workshops on the application of QUAL-II and has experience with model applications throughout the United States and in Canada. QUAL-II has been used extensively for wasteload allocation studies throughout the United States. Other major responsibilities include the development of a reservoir temperature model and the application of Ecologic-Water Quality Models to Monterey Bay, California, Puget Sound, Washington, and Montevideo, Uruguay to study the effects of discharges from proposed ocean outfalls on the receiving waters in these areas.

EDUCATION	B.S. - Civil Engineering, Valparaiso University, Indiana, 1963 M.S. - Hydrology, Colorado State University, 1965 Ph.D. - Sanitary Engineering, University of Washington, 1969
REGISTRATION	Professional Engineer: California, Florida, Virginia, Michigan, Ohio Professional Hydrologist: American Institute of Hydrology
HONORS	Walter L. Huber Civil Engineering Research Prize, 1975 Diplomat, American Academy of Environmental Engineers, 1983 Elected Member, National Academy of Engineering, 1990

HONORS (cont.)	Tau Beta Pi, Eminent Engineer, 1994 Who's Who in America (since 1975) Who's Who in Engineering (since 1975) Outstanding Service and Commitment Award from Friends of Wekiva River 1986-87 Outstanding Service and Commitment Award from the Technical Services Committee of the Water Environment Federation, 1997 Services to the Profession Award from ASCE Water Resources Planning and Management Division, 1999
SOCIETIES	American Society of Civil Engineers, Fellow Urban Water Resource Research Council, ASCE American Water Resources Association Water Pollution Control Federation American Institute of Hydrology National Society of Professional Engineers
PROFESSIONAL	Member, Urban Water Resources Research Council (UWRRC), ASCE Member, Wet Weather Advisory Committee, WERF Member, Public Affairs Wet Weather Committee, WEF Task Force Chairman, WPCF/ASCE Manual of Practice on Urban Runoff Quality Management, 1998 Contributor to ASCE/WPCF Manual of Practice on Urban Storm Drainage System Design, 1993 Reviewer of WPCF Manual of Practice on Combined Sewer Overflow Pollution Abatement, 1989 Co-chair, Engineering Foundation Conference on Stormwater Management -- Creating sustainable Urban Water Resources for the 21st Century", Malmo, Sweden, 1997 Editor, Proceedings of an Engineering Foundation Conference on Effects of Watershed Development an Management on Aquatic Ecosytems, 1996 Chairman, Engineering Foundation Conference on "Current Practice and Design Criteria for Urban Runoff Quality Control," 1988 Member, Organizing Committee for Engineering Foundation Conference on "Urban Runoff Quality -- Impacts and Quality Assessment Technology," 1986 Executive Committee Member, National Research Council Committee on Wastewater Management in Coastal Urban Areas.

PROFESSIONAL HISTORY

1999 to present

Harold H. Short Professor of Civil Engineering Infrastructure Systems, Colorado State University

- Applied research on the development of sustainable urban water infrastructure systems

1998 to present

Senior Vice President -- Camp Dresser & McKee Inc.

- Technical Director, Water Resources Practice
- Dean, CDM Corporate University
- Technical Advisor/Director
  - Development of Web-based BMP manual for San Antonio, and the state of Texas
  - Expert witness regarding adequacy of stormwater BMPs on an industrial clients property

1992 to 1998

Senior Vice President and Chief Technical Officer -- Camp Dresser & McKee

- Chair, CDM Technical Council
  - Administer CDM's internal Research and Development Program.
  - Ensure that CDM is using state-of-the-art technology in its projects.
  - Support CDM's Technical Mentoring Program
- Dean, CDMU Corporate University
- Technical Director of CDM's National Storm Water Practice
- Project Technical Director:
  - Master plan for stormwater management (quantity and quality) for an area nine km^2 in Edinburgh, Scotland to be developed from agriculture to an urban community.
  - Rouge River (Metropolitan Detroit) Wet Weather Water Quality Management, National Demonstration Program. This program examines integrated and cost-effective management of non-point sources of pollution, and combined sewer overflows.

- Project Technical Director: (cont)
  - Charlotte, NC Inflow/infiltration study developing and integrating wet-weather system management program that includes I/I reduction, relief sewers, flow equalization and treatment plant operation.
  - Development of a river-wetlands phosphorus transport model for river tributary to Lake Okeechobee, Florida.
  - Development of an urban runoff quality management program for Monterey Bay, California.

Senior Technical Advisor:
- Development of an electronic Best Management Practices manual for San Antonio, Texas.
- Development of an electronic Best Management Practices manual for Texas APWA member cities.
- Development for Caltrans (California Department of Transportation) of planning design and construction handbooks for control of water quality in highway runoff and staff training in use of handbooks.
- Wet Weather analysis of wastewater system for Orange County California.
- Development of a Best Management Practices Handbook for urban runoff quality management for North Central Texas Council of Governments.
- Value Engineering; CSO management strategy and storage-treatment basin design, New York City Department of Environmental Protection.
- Analysis and optimization of Allegheny County Sanitation District Metropolitan Pittsburgh.
- Development of computer model of the Detroit Metropolitan area combined sewer system (200 square miles).
- CSO river and Lake Erie, water quality impact study for Cleveland Metropolitan Area (Northeast Ohio Regional Sewerage District).
- CSO system optimization plan and long term master plan, Indianapolis, IN.
- Water quality impact evaluation of City of Albuquerque wastewater treatment plant effluent discharges to the Rio Grande River.

1988 to 1992

Senior Vice President and Technical Director of Water Resource and Environmental Sciences for the South Region -- Camp Dresser & McKee Inc.

- Project Director, Integrated Wastewater, Stormwater and Combined Sewer Overflow Reduction Masterplan for Cincinnati and Hamilton County, Ohio.

- Technical Advisor:
  - Combined sewer overflow control studies in Indianapolis, IN, Detroit, MI and Pittsburgh, PA
  - Boston Harbor combined sewer overflow facilities plan
  - Chattanooga, TN combined sewer overflow control masterplan
  - Management and treatment of contaminated runoff from the Oakridge, Tennessee Y-12 plant.
  - Control of phosphorous loading to Cherry Creek Reservoir, Denver, CO.
  - Platte river water quality impacts on Denver Metro Wastewater effluent discharges.
  - Water quality modeling of the impact of discharges from Chicago Metropolitan Water Reclamation District of Greater Chicago treatment plants on the Illinois River.
  - Non-point source wasteload allocation for East Lake Tohopekalaga, FL.
  - Stormwater management master plans, Daytona Beach, FL, Jacksonville FL, Virginia Beach, VA, Kent County, MI.

1983 to 1988

Vice President and Technical Director of Water Resources and Environmental Sciences for the South Region - Camp Dresser & McKee Inc.

- Project director, technical support for EPA water-based programs. Technical review of current studies and literature to provide technical support for EPA's assessment of water quality standards criteria.

- Expert witness regarding non-point source pollution to outstanding Florida Waters of the Wekiva River, and for the drinking water supply -- Occaquan Reservoir in Fairfax County, Virginia.

- Technical advisor for the following projects:
  - Stormwater management studies in Sarasota, Leon, Hillsborough, and Manatee counties and the cities of Tampa, Miami, Tallahassee, and Kissimmee, Florida.
  - Study to determine location, sizing, and design of an ocean outfall for the City of Montevideo, Uruguay.
  - Development of a water quality ecologic model of coral reefs in the Key Largo Marine Sanctuary and the northern keys reef tract.

1975 to 1983 Associate - Camp Dresser & McKee Inc.

- Responsible for water resource investigations and analysis as principal-in-charge and project manager.
- Project director, sewer system planning and management computer program--Washington Suburban Sanitary Commission.
- Principal investigator, design drainage model for urban highway systems--Federal Highway Administration.
- Consultant, mitigation of coliform pollution due to storm sewer discharges into the Rideau River in Ottawa Canada--Gore & Storrie Engineers, Ltd.
- Project manager, improvement of the EPA EXTRAN model for simulation of dynamic hydraulics in storm and combined sewer systems--University of Florida.
- Consultant, use of mathematical models for drainage facilities planning--Tennessee Valley Authority.
- Project manager, preparation and delivery of stream water quality modeling (QUAL-II) workshops across the United States--EPA.
- Staff support, pre-impoundment water quality study for proposed drinking water supply reservoir -- Rivanna Water and Sewer Authority.
- Task leader, effectiveness of system operation and alternative wet weather treatment levels on the reduction of combined sewer overflow (CSO) loads to the Missouri River--City of Omaha, Nebraska.

- Task leader, effectiveness of alternative mitigation measures on reduction of CSO pollution loads to Dorchester Bay and evaluation of hydraulic response of Boston interceptor system to wet weather inflows--Metropolitan District Commission, Boston, Massachusetts.

- Project manager, determination of non-point source loads and examination of cost-effectiveness of control measures in Sonoma County, California, Southeast Michigan (Detroit), and Orlando, Florida.

1968 to 1975 — Principal Engineer - Water Resources Engineers, Inc.

- Study for EPA of the state-of-the-art and recommendations for future direction of water management models.

- Development of a strategy for real time automatic control of a combined sewer system--San Francisco, California.

- Effectiveness of inflow and infiltration controls on reduction of wet weather overflows from a sanitary sewer system, East Bay Municipal Utility District, Oakland, California.

- Development and application of screening models (SEMSTORM) anddetailed models (RUNQUAL) describing the quantity and quality of runoff in urban/ suburban areas and a screening model (STORM) to evaluate the effectiveness of alternative treatment rates and storage capacities for reducing the magnitude and frequency of uncontrolled stormwater overflows.

- Development and application of detailed stormwater runoff models describing the quantity and quality of surface runoff and the hydraulic and water quality response of the drainage system. Models have been developed and applied both for urban areas (RUNQUAL) and for agricultural/rural (AGRUN) areas.

- Development and presentation of a one-week seminar on Management of Urban Storm Runoff for the U.S. Army Corps of Engineers. Presentation of lectures on this topic at seminars sponsored by various public agencies and professional organizations.

- Analysis of the diurnal dynamic behavior of water distribution systems.

- Development and application of QUAL-II stream water quality model (12 parameters) for the U.S. EPA.

1968 to 1975 (Continued)

- Development and application of a circulation model and a water quality-ecologic model of Monterey Bay, California, and Puget Sound, Washington. Models were used to evaluate the impact of wastewater discharges on water quality and the ecologic balance of these waters.

- Study of nearshore circulation, dispersion, and water quality of Lake Michigan in its southwest corner (industrialized sector).

- Provision of consultation and assistance to Romanian study team in the development and application of water quality models for the Mures and Arges River Basins in Romania.

- Development of a mathematical model to simulate dissolved nitrogen gas (N2) concentrations in the Lower Columbia River.

- Formulation of a general mathematical model for the U.S. EPA to predict thermal energy regimes in impoundments.

1965 to 1967 Graduate Research Assistant - University of Washington

- Compilation and analysis of water quality data for assessing the present (1966) and predicted future quality of inland waters in the State of Washington.

- Modeling of water filtration systems on an analog computer.

1963 to 1965 Graduate Research Assistant - Colorado State University

- Research in theoretical hydrology and digital computer applications to the solution of hydrologic models for precipitation and runoff.

- Experimental investigation of the properties of three-dimensional slot jets.

PUBLICATIONS and PRESENTATIONS

1. "Mathematical Models for Time Series of Monthly Precipitation and Monthly Runoff," Colorado State University Hydrology Paper No. 15, October 1966 (with V. M. Yevjevich).

2. Water Resources Engineers, Inc., Mathematical Models for the Prediction of Thermal Energy Changes in Impoundments, Water Pollution Control Research Series 16130EXT12/69, Environmental Protection Agency, Decembe, 1969 (with W. R. Norton and G. T. Orlob).

3. "Decision Criteria for Using Stochastic Hydrology," J. Hydraulics Div., ASCE, Vol. 96, HY4, April 1970 (with G. K. Young and G. T. Orlob).

4. "A Mathematical Model of Urban Storm Drainage," Presented at National Science Foundation Seminar, Logan, Utah, August 2-14, 1970 (with R. P. Shubinski).

5. "A Mathematical Model for Simulating the Temperature Structure of Stratified Reservoirs and Its Use in Reservoir Outlet Design," Presented at the International Symposium on Mathematical Models in Hydrology, Sponsored by IASH, Warsaw, Poland, July 26-31, 1971.

6. "Use of Storm Drainage Models in Urban Planning," Presented at the American Water Resources Association Symposium on Watersheds in Transition, Colorado State University, Fort Collins, Colorado, June 1972 (with D. F. Kibler and J. R. Monser).

7. "A Nitrogen Gas (N2) Model of the Lower Columbia River," Presented at the Joint Automatic Controls Conference, Stanford University, August 16-18, 1972 (with G. T. Orlob and W. R. Norton).

8. "Linked Process Routing Models," Presented at the Symposium on Models for Urban Hydrology, Spring Meeting American Geophysical Union, Washington, D.C., April 16-20, 1973 (with R. P. Shubinski).

9. "Water Quality Simulation Studies in the Iowa-Cedar River Basin," Presented at the Ninth American Water Resources Conference, American Water Resources Association, Seattle, Washington, October 21-26, 1973 (with J. R. Monser and D. E. Evenson).

10. "Ecosystem Response of Monterey Bay to Alternative Wastewater Management Plans," Presented at the ASCE National Meeting on Water Resources Engineering, Los Angeles, California, January 21-25, 1974 (with H. M. Nichandros).

11. A Model for Evaluating Runoff-Quantity and Quality in Metropolitan Master Planning, Technical Memorandum No. 23, ASCE Urban Water Resources Research Program, ASCE, New York, April 1974.

12. "Quality of Aspects of Urban Runoff" and "Impact of Stormwater Runoff on Receiving Water Quality," Prepared for U.S. Environmental Protection Agency course-applications of stormwater management models, University of Massachusetts, July-August, 1974.

13. "Pollutional Characteristics of Stormwater," Presented at the Urban Drainage Workshop, American Public Works Association, Workshop 10D, San Francisco, California, January 23-24, 1975.

14. "A Storage Treatment, Overflow, and Runoff Model for Metropolitan Master Planning," Prepared for U.S. Environmental Protection Agency course-Applications of Stormwater Management Models, University of Massachusetts, July-August 1975.

15. "Urban Water Management Models," Urban Runoff: Quantity and Quality, William Whipple, Jr., editor, American Society of Civil Engineers, New York, 1975 (with M. B. Sonnen and R. P. Shubinski).

16. "Data Analysis for Nonpoint Pollution Control" Urban Runoff Quantity Measurement and Analysis, Preprint 3091, ASCE Fall Convention and Exhibit, San Francisco, California, October 17-21, 1977 (with P. G. Collins).

17. "Near and Far-Field Dispersion Analyses in Support of a Secondary Treatment Waiver," Presented at 52nd Annual Conference of Water Pollution Control Federation, Houston, Texas, October 7-12, 1979 (with M. Rosenberg).

18. "Water Quality Aspect of Urban Runoff and Impacts of Detention," Presented at Second Annual Stormwater Management Symposium, The Pennsylvania State University, University Park, Pennsylvania, March 4-6, 1981.

19. "An Improved Dynamic Flow Routing Model for Storm Drainage Systems," Presented at the Second International Conference on Urban Storm Drainage, University of Illinois, Urbana-Champaign, Illinois, June 15, 1981 (with R. P. Shubinski).

20. "Development and Application of a Dynamic Urban Highway Drainage Model," Presented at the Second International Conference on Urban Storm Drainage, University of Illinois, Urban-Champaign, Illinois, June 15-19, 1981 (with R. J. Dever and D. C. Woo).

21. "Analysis of the Effectiveness of Alternative Wet Weather Diversion and Treatment Strategies on the Reduction of Receiving Water Loads," Presented at the 1981 International Symposium in Urban Hydrology, Hydraulics, and Sediment Control, University of Kentucky, July 27-30, 1981 (with C. Clarkson).

22. Chapter 5, "Urban Runoff Processes," Chapter 6, "Quality of Urban Runoff," in Urban Stormwater Hydrology, D. F. Kibler, Ed., American Geophysical Union Monograph 7, 1982.

23. "An Improved Surcharge Computation in EXTRAN," Proceedings of the Water Quality Management User's Conference, Alexandria, Virginia, March 25-26, 1982, EPA (with J. A. Aldrich).

24. "Continuous Simulation of Instream Fecal Coliform Bacteria," Proceedings of the Water Quality Management User's Conference, Alexandria, Virginia, March 25-26, 1982, EPA (with A. C. Rowney).

25. "An Ecologic Model for the Key Largo National Marine Sanctuary," Presented at Coastal Society-8, Baltimore, Maryland, October 1982 (with R. Walton, R. R. Comegys, and J. B. Hamilton).

26. "Stormwater Models," Chapter 5 in Stormwater Management in Urbanizing Areas, by Whipple, et al., Prentice Hall, Englewood Cliffs, New Jersey, 1983 (with R. P. Shubinski).

27. "Sanitary Sewer Analysis/Design with a Microcomputer," Presented 3rd Conference in Computerizing in Civil Engineering, ASCE, April 2-6, 1984 (with J. A. Aldrich and C. R. Bristol).

28. "Washington Suburban Sanitary Commission Sewer System Computer Model," ASCE Urban Water '84, Baltimore, Maryland, May 28-31, 1984 (with C. R. Bristol, J. L. Higgins, and R. L. Humphries).

29. "Receiving Water Modeling in Support of the Design of an Ocean Outfall," Presented at the 20th Annual AWRA Conference, Washington, DC, August 12-17, 1984 (with M.S. Rosenberg and R. Walton).

30. "Transient Mixed-Flow Models for Storm Sewers," in ASCE's Journal of Hydraulic Engineering, March 1985 (with J.A. Aldrich).

31. "Hydrograph Decomposition: Using a Technical Database," Proceedings of the ASCE Computer Applications in Water Resources Conference, Buffalo, New York, June 10-12, 1985 (with C.R. Bristol and S.A. Hanson).

32. "Water Quality Modeling of Key Largo Coral Reef," Proceedings of the ASCE Computer Applications in Water Resources Conference, Buffalo, New York, June 10-12, 1985 (with R. Walton, M.P. Wang, and W.M. Williams).

33. "Coral Reef Modeling: Key Largo Case Study," Presented at the Coastal Zone '85--The Fourth Symposium on Coastal and Ocean Management, Baltimore, Maryland, July 30-August 2, 1985 (with R. Walton, W.M. Williams, and M.P. Wang).

34. "Realistic Water Quality Modeling," presented at NATO Conference in Montpelier, France, August 1985 (with R. Walton and J. P. Hartigan).

35. "Probability Model of Stream Quality Due to Runoff", in Journal of Environmental Engineering, ASCE, Vol. 111 No. 5, October 1985 (with S. A. Dendrou).

36. "Receiving Water Modeling in Support of the Design on a Ocean Outfall," Presented at Oceans '85, San Diego, California, November 1985 (with M. S. Rosenberg and R. Walton).

37. Urban Runoff Quality: Impact and Quality Enhancement Technology, American Society of Civil Engineers, New York, New York, 1986 (editor with B. Urbonas).

38. "Selecting a Stormwater Service Level for Urban Control," Proceedings of Water Forum '86: World Water Issues in Evolution, August 4-6, 1986, Long Beach, California (with R. D. Gibney).

39. "PC-RUNOFF and dBASE-III for Stormwater Data Management, Planning and Design," Proceedings of the Fourth Conference on Computing in Civil Engineering, Boston, Massachusetts, October 27-31, 1986 (with J. A. Aldrich).

40. "Role of Models in Today's Management Programs," Presented at the American Geophysical Union Fall Meeting, San Francisco, California, December 8-12, 1986 (with J. P. Hartigan and J. A. Aldrich).

41. "New Trends in Stormwater Management," Presented at the Virginia Water Resources Research Forum, Blacksburg, Virginia, April 6-7, 1987 (with J. A. Aldrich).

42. "Model Studies for Managing the Key Largo Coral Reef," Proceedings of Coastal Zone '87, Seattle, Washington, May 1987 (with W. M. Williams, R. Walton, and H. Kaufman).

43. "Numerical Model Study of an Ocean Outfall from Montevideo, Uruguay," Presented at "Triennial Conference of IFORS, Buenos Aires, Argentina, August 1987 (with R. Walton, R. Nitrosso, and M. S. Rosenberg).

44. "Comprehensive Sampling Program for the Y-12 Plant: Area Source Pollution Assessment and Control Plan," Proceedings of the Oakridge Model Conference, Oakridge, Tennessee, October 13-16, 1987 (with E. F. Amiella, R. H. Kingrea, and T. Quasebarth).

45. "Urban Water Resources Issues in the 21st Century," Journal of Professional Issues in Engineering, ASCE, Vol. 114, No. 3, July 1988 (with S. G. Walesh).

46. "National Perspectives on Urban Runoff Technologies," Presented at the Urban Runoff Quality Conference, Denver, Colorado, September 8-9, 1988.

47. "Aesthetic Implementation of Nonpoint Source Controls,", Proceedings of the Nonpoint Pollution Symposium of the Twenty-fourth Annual American Water Resources Association Conference and Symposia, Milwaukee, Wisconsin, November 6-11, 1988.

48. Design of Urban Runoff Water Quality Controls, American Society of Civil Engineers, New York, 1989 (editor with B. Urbonas and M. B. Sonnen).

49. "A GIS Interface for EPA-SWMM in Cincinnati", ASCE Sixth Conference on Computing in Civil Engineering, Atlanta, Georgia, September 11-13, 1989.

50. "Living Master Plan/Combined Sewer System" Proceedings of the Engineering Foundation Conferences Urban Stormwater Quality Enhancement, Source Control Retrofitting and Combined Sewer Technology, Davos, Switzerland, October 22-28, 1989.

51. "Stormwater Management for the 1990s", American City and County, Volume 105, No. 2, page 44, February 1990 (with Bob Matthews).

52. "A 100-Year Master Plan for Cincinnati's Combined Sewer System", WPCF Specialty Conference Series Control of Combined Sewer Overflows, Boston, Massachusetts, April 8-11, 1990.

53. "Use of Mathematical Models for Urban Stormwater Management Planning", International Symposium on Urban Planning and Stormwater Management, Kuala Lumpur, Malaysia, May 28 - June 1, 1990.

54. "Advances in SWMM Extran Flow Routing" Proceedings of the IAWPRC Fifth International Conference on Urban Storm Drainage, Osaka, Japan, July 23-27, 1990 (with R. Dickinson and W. Huber).

55. "Hydrology of Urban Runoff Quality Management" Proceedings of the 18th National Conference on Water Resources, Planning and Management/Symposium on Urban Water Resources, New Orleans, Louisiana, May 20-22, 1991.

56. "Hydrology of Urban Runoff Quality Management" Proceedings of the International Conference on Computer Applications in Water Resource, Taipei, Taiwan, July 3-6, 1991.

57. "Planning Subsurface Storage - Transport Facilities for Combined Sewer Overflow Control in Cincinnati, Ohio", Proceedings of the 1991 ASCE National Conference on Environmental Engineering, Reno, Nevada, July 8-10, 1991 (with Martin M. Umberg and Thomas A. Saygers.)

58. "Discharge Characterization for Urban Runoff Loads" Proceedings of the WPCF Pre-Conference Workshop Storm Water NPDES Permitting, Issues and Impacts for Municipalities and Industries, Toronto, Canada, October 5-6, 1991.

59. "The Role of Computer Modeling in Combined Sewer Overflow Abatement Planning", Water Science Technology, Volume 26, No. 7-8, pp. 1831-1840, 1992.

60. "Water Quality Issues in Stormwater Management in the U.S." Proceedings of the International Conference Urban Hydrology, Sydney, Australia, February 4-7, 1992.

61. "Application of the STORM Computer Program to Evaluate the Effects of Mining on Urban Runoff in Butte, Montana", Presented at the Geotechnology, Energy, Environment, Materials and Minerals Network 1992 Annual Meeting and Environmental Seminar, Denver, Colorado, March 2, 1992 (with T. Johnson and S. Morea).

62. "Development of a Multiple-Phase Tunnel and Cavern Plan for Combined Sewer Overflow Control" Proceedings of the WEF Conference on the Control of Wet Weather Quality Problems, Indianapolis, Indiana, May 31 - June 3, 1992 (with E. H. Burgess).

63. "A Systemwide Program to Reduce Wet-Weather Overflows in Charlotte, North Carolina",

Water Environment Federation Specialty Conference, Indianapolis, Indiana, June 1992.

64. "CSO Rehabilitation Strategies for Urban Areas" Proceedings of the ASCE Water Forum '92, Baltimore, Maryland, August 2-6, 1992 (with E. H. Burgess).

65. "Development of the Lake Okeechobee Watershed Phosphorus Transport Model" Proceedings of the WEF 65th Annual Conference and Exposition, New Orleans, Louisiana, September 20-24, 1992 (with R. Wagner).

66. "Stopping Stormwater Pollution at its Source" Public Works Journal, Volume 123, No. 13, page 55, December 1992 (with M. Hobel).

67. "Urban Runoff Considerations in the Design of Wastewater Management Programs for Coastal Areas" Presented at the 20th Anniversary Conference of the Water Resources Planning and Management Division, Seattle, Washington, May 3-5, 1993.

68. "Adapting BMPs to California Hydrology and Climatology" Presented at the 1993 National Conference On Hydraulic Engineering and International Symposium on Engineering Hydrology, Hydraulics Division, ASCE, San Francisco, California, July 25-30, 1993 (with G. Minton, J. Aldrich, M. Walker and G. Brosseau).

69. "Development of the Lake Okeechobee Watershed Phosphorus Transport Model", Presented at the 1993 National Conference On Hydraulic Engineering and International Symposium on Engineering Hydrology, Hydraulics Division, ASCE, San Francisco, California, July 25-30, 1993 (with R. Wagner).

70. "Hydraulic Modeling of Combined Sewer Interceptors", Presented at the 6th International Conference on Urban Storm Drainage, Niagara Falls, Ontario, Canada, September 12-17, 1993.

71. "Overview of Federal Law and USEPA Regulations for Urban Runoff", Presented at the 6th International Conference on Urban Storm Drainage, Niagra Falls, Ontario, Canada, September 12-17, 1993.

72. "Source Controls for Improving Urban Runoff Quality", Presented at the Water Environment Federation 1993 Preconference Seminar, Urban Planning and Stormwater, Annaheim, California, October 2-8, 1993.

73. "MTV -- Analysis Tool for Review of Computer Models", Published in the proceedings of the WEF Specialty Conference held in Santa Clara the week of August 9th, 1993. Ted Burgess gave a paper at the same conference (with M. TenBroek).

74. "Source Controls for Improving Urban Runoff Quality", Presented at the 66th WEF Annual Conference & Expo, Anaheim, California, October 2-8, 1993.

75. "Joint Management of Urban Runoff Quality and Combined Sewer Overflows", Presented at the ASCE Management of Resource Pollution Seminar, Paris, France, July 4-7, 1994.

76. "Facility Master Planning for CSO Management in an Uncertain Regulatory Environment", Presented at the WEF Specialty Conference on A Global Perspective for CSOs: Balancing Technologies, Costs, and Water Quality, Louisville, Kentucky, July 10-13, 1994.

77. "Overview of Stormwater Monitoring Needs" Presented at the Engineering Foundation conference on NPDES Related Monitoring Needs, Crested Butte, Colorado, August 8-12, 1994.

78. "Minimum Technologies to Achieve Water Quality Goals," Presented at the WEF 67th Annual Conference, Chicago, Illinois, October 15-19, 1994.

79. "Design and Operation of a Wet-Weather Storage Facility to Eliminate Sanitary Sewer Overflows in the Vicinity of a POTW Using an Extended Period Simulation Model," Presented at the EPA National Conference on Sanitary Sewer Overflows, Washington, DC, April 24-26, 1995 (with R. Carrier).

80. "Non Point Sources - Common Sense City, County Controls", Water Environment and Technology, Water Environment Federation, September, 1995 (with Ron Ott).

81. "Hydrology for Optimal Sizing of Urban Runoff Treatment Control Systems", Water Quality International, January/February 1996, (with Ben R. Urbonas and C. Y. Guo).

82. "National Storm Water Quality Regulations and Standards", Journal of Hydraulic Research, Volume 34, 1996 (with Charles Rowney).

83. Effects of Watershed Development and Management on Aquatic Ecosystems, Proceedings of an Engineering Foundation Conference, Snowbird, Utah, August 4-9, 1996 (Editor).

84. □Adaptive Management of the Impacts of In-Stream Flow on Water Temperature in the Central Platte River: Results of a Peer Panel Review□, Presented at Waterpower □97, Atlanta, Georgia, August 5-8, 1997 (with Steven C. McCutcheon and Frank L. Parker).

85. The Hydrology of Urban Runoff Quality Mangaement□, Proceedings Engineering Foundation Conference □Stormwater Management, Sustaining Urban Water Resources in the 21st Century□ Malmo, Sweden, September 7 - 12, 1997.

86. Integrating Stormwater Management into Urban Planning in Orlando, Florida□, Proceedings Engineering Foundation Conference □Stormwater Management, Sustaining Urban Water Resources in the 21st Century□ Malmo, Sweden, September 7 - 12, 1997.

87. Combined Sewer Overflows and Urban Runoff Regulations and Control Technologies□, Presented at the Workshop on Research needs for Coastal Pollution in Urban Areas, Milwaukee, Wisconsin, October 16, 1997.

88. Urban Runoff Quality Management, WEF Manual of Practice No. 23, ASCE Manual and Report on Engineering Practice No. 87, 1998 (Task Force co-chair).

89. Corporate University: A Consulting Firm Case Study, Journal of Management in Engineering, March/April, 1998, Volume 14, Number 2.

90. Utilizing the World Wide Web to Organize and Convey Urban Storm Water Management Principals to Diverse Audiences. Proceedings of the 8th International Conference on Urban Storm Drainage, Sydney Australia, 30 August – 3 September, 1999, Vol. 1, pp 210 – 217, (w/ R. W. Brashear, and John Promise) (Ed. Ian B. Joliffe and James E. Ball).

91. Are BMP Criteria Really Environmentally Friendly. Proceedings of the 8th International Conference on Urban Storm Drainage, Sydney Australia, 30 August – 3 September, 1999, Vol. 3, pp 1366 – 1373, (w/ R. W. Brashear) (Ed. Ian B. Joliffe and James E. Ball).

CDM REPORTS

1. A Nitrogen Gas (N2) Model for the Lower Columbia River, Final Report to the Portland District, U.S. Army Corps of Engineers, January 1971 (with W. R. Norton).

2. Computer Supplement and Users' Guides, A Nitrogen Gas (N2) Model for the Lower Columbia River, Final Report to the Portland District, U.S. Army Corps of Engineers, January 1971 (with W. R. Norton).

3. Final Report for the Iowa Cedar River Basins Model Project, Prepared for Systems Development Branch, Environmental Protection Agency, Washington, D.C., September 1973 (with J. R. Monser).

4. Computer Program Documentation for the Stream Quality Model QUAL-II, Prepared for the Systems Development Branch, Environmental Protection Agency, Washington, D.C., May 1973 (with D. E. Evenson and J. R. Monser).

5. An Analysis of Circulation and Dispersion in the Inshore Waters of Southwest Lake Michigan, Prepared for Mayor, Brown and Platt, Attorneys at Law, Chicago, Illinois, April 1974 (with G. T. Orlob).

6. The User of Stormwater Simulation Models in Developing a Coordinated Wastewater Management Plan for the City of San Francisco, Prepared for the Division of Sanitary Engineering City and County of San Francisco, California, September 1974 (with D. F. Kibler and R. P. Shubinski).

7. San Francisco Stormwater Model, Users' Manual and Program Documentation, Prepared for the Division of Sanitary Engineering, City and County of San Francisco, California, February 1975 (with D. F. Kibler and J. R. Monser).

8. The San Francisco Stormwater Model for Computer Simulation of Urban Runoff Quantity and Quality in a Combined Sewer System, Final Report to the Department of Public Works, City and County of San Francisco, California, June 1975 (with D. F. Kibler).

9. Consulting on Water Quality Management Modeling--Missions to Romania, Final Report prepared for the Regional Office for Europe, World Health Organization, Copenhagen, July 1975 (with M. B. Sonnen and I. P. King).

10. Agricultural Watershed Runoff Model for the Iowa-Cedar River Basins, Addendum to the Final Report, Prepared for the Systems Development Branch, Environmental Protection Agency, Washington, D.C., July 1975 (with S. W. Zison, J. R. Monser and T. C. Lyons).

11. Future Direction of Urban Water Models, Final report to the Municipal Environmental Research Laboratory, Office of Research and Development, Environmental Protection Agency, Cincinnati, Ohio, September 1975.

12. "Computer Program Documentation for the Storm Runoff Quality Model-RUNQUAL," Prepared for Southeast Michigan Council of Governments, Detroit, Michigan, July 1977 (with P. R. Giguere and L. C. Davis).

13. "Computer Program Documentation for the Stream Quality Model, QUAL-II," Prepared for Southeast Michigan Council of Governments, Detroit, Michigan, July 1977, (with P. R. Giguere and D. E. Evenson).

14. "Application of Nonpoint Source Control Techniques at Alternative Institutional Levels," Prepared for East Central Florida Regional Planning Council, December 1977 (with A. J. Knepp, C. R. Bristol and R. J. Trotter).

15. "Analysis Strategy for Estuaries, Dynamic Rivers and Lakes," Prepared for Georgia Department of Natural Resources, June 1978 (with T. S. George).

16. "Nonpoint Source Modeling Strategy," Prepared for Georgia Department of Natural Resources, August 1978 (with T. S. George).

17. "Modeling Procedures Manual," Prepared for Georgia Department of Natural Resources, August 1978 (with R. P. Shubinski).

18. Urban Highway Storm Drainage Model," prepared for the Federal Highway Administration, March 1981.
    "Vol. 3. Inlet Design Program," FHWA-RD-81-013 (with R. J. Dever and R. A. Schmalz).
    "Vol. 4. Surface Runoff Program," FHWA-RD-81-014 (with R. J. Dever and J. A. Aldrich).
    "Vol. 5. Drainage Design Program," FHWA-RD-81-015 (with R. J. Dever).
    "Vol. 6. Analysis Module," FHWA-RD-81-016 (with R. J. Dever and J. A. Aldrich).

19. "Stormwater Management Model User's Manual Version III - Addendum I EXTRAN," Prepared for Municipal Environmental Research Laboratory, Office of Research and

Development U.S. Environmental Protection Agency, Cincinnati, Ohio, May 1981 (with R. P. Shubinski and J. A. Aldrich).

20. "Documentation for the Three-Dimensional Current Processor Model SIM3D," Camp Dresser & McKee, Annandale, Virginia, August 1985 (with R. Walton and W. M. Williams).

21. "Documentation for the Three-Dimensional Coral Reef Simulation Model CORALSIM," Camp Dresser & McKee, Annandale, Virginia, August 1985 (with W. M. Williams, R. Walton, and M. P. Wang).

22. "An Assessment of Stormwater Management Programs," Prepared for the Florida Department of Environmental Regulation, Tallahassee, Florida, October 1985 (with J. P. Hartigan).

23. "Development of the Lake Okeechobee Watershed Phosphorus Transport Model," Prepared for Presentation at: Water Environment Federation, 65th Annual Conference and Exposition, New Orleans, Louisiana, September 20-24, 1992 (with Richard A. Wagner and Michael G. Cullum).

Matthew Garcia, M.S.
Curriculum Vitae

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Education

January, 2002 to Present	M.S., Department of Civil Engineering College of Engineering Colorado State University
January, 1999 to Present	Ph.D., Department of Atmospheric Science College of Engineering Colorado State University
August, 1996 to December, 1999	M.S., Department of Atmospheric Science College of Engineering Colorado State University Thesis Title: *Simulated Tropical Convection*
August, 1992 to May, 1996	B.S., Department of Mathematics and Physics, and Department of Earth and Environmental Studies College of Science and Mathematics Montclair State University

Employment Experience

January, 2002 to Present	Graduate Research Assistant, M.S. program Department of Civil Engineering Colorado State University
January, 2000 to December, 2001	Graduate Research Assistant, Ph.D. program Department of Atmospheric Science Colorado State University
August, 1996 to December, 1999	Graduate Research Assistant, M.S. program Department of Atmospheric Science Colorado State University
January, 1995 to July, 1996	Supervising Lab Assistant Academic Computing and Technology Montclair State University
October, 1992 to December, 1994	Computer Lab Student Assistant Academic Computing and Technology Montclair State University

Other Experience

January, 2001 to May, 2001	Graduate Teaching Assistant AT602: Atmospheric Dynamics II Prof. W.H. Schubert Department of Atmospheric Science Colorado State University
August, 2000 to December, 2000	Graduate Teaching Assistant AT601: Atmospheric Dynamics I Prof. W.H. Schubert Department of Atmospheric Science Colorado State University

Research Program Participation

May to June, 1998	South China Sea Monsoon Experiment (SCSMEX) Shipboard scientist and instrument technician
June to August, 1994	National Science Foundation (NSF) Research Experiences for Undergraduates in Particulate Systems Engineering Program Particulate Systems Research Center College of Engineering University of Missouri, Columbia

Refereed Scientific Publications

Schubert, W.H., S.A. Hausman, M. Garcia, K.V. Ooyama, and H.-C. Kuo, 2002: Potential vorticity in a moist atmosphere. *J. Atmos. Sci.*, **58**, 3148-3157.

Other Scientific Publications

Garcia, M., 1999: Simulated Tropical Convection. *Atmospheric Science Report No. 690*, Colorado State University, Fort Collins, Colorado. 273 pp.

Garcia, M., 2000: Characteristics of convective development in simulated squall lines. 24th Conference on Hurricanes and Tropical Meteorology (Extended Abstracts), Ft. Lauderdale, Florida, Amer. Meteor. Soc., pp. 135-136.

Schubert, W.H., S.A. Hausman, M. Garcia, K.V. Ooyama, and H.-C. Kuo, 2000: Potential vorticity in a moist atmosphere. 24th Conference on Hurricanes and Tropical Meteorology (Extended Abstracts), Ft. Lauderdale, Florida, Amer. Meteor. Soc., pp. 563-564.

Other Published Materials

Garcia, M., Tuesday, August 6, 2002: Flood preparedness—Steps are being taken to improve safety. *The (Fort Collins) Coloradoan*, Opinion, p. A6.

Awards and Honors

May, 1996	Outstanding Physics Student College of Science and Mathematics Montclair State University
May, 1996	Ben Minor Physics Award Montclair State University Foundation
May, 1995	Hodson Physics Award Montclair State University Foundation

Study Budget

1. Salaries

		Fringe Rate	Salary	Fringe	Total
a. Faculty (2000)	2 mo	19.1	25,333	4,839	30,172
b. Admin Prof (2100)		19.1	0	0	0
c. State Classified (2400)		19.1	0	0	0
d. Student Hourly (2600)		0.08	0	0	0
e. GRA	4 mo @ 20 hr/wk		5,800		
	3 mo @ 30 hr/wk		6,525		
GRA Total		4.00	12,325	493	12,818
Total Salaries and Fringe					42,990

2. Travel (3000) (6 round trips @ 265 miles/trip @ $0.34 per mile) — 541

3. Other Operating Expenses (3400) — 0

4. Other Direct Costs

a. Services	0	
b. Equipment Rental	0	
c. Graduate Tuition	1,485	
d. Unrelated Income Tax	0	
e. Costs of Services Provided by 2-1 Accounts	0	
f. Other (Please explain on Page 3.)	0	
Total Other Direct Costs (4000)		1,485

5. Utilities (7800) (FOR OFF-CAMPUS FACILITIES ONLY) — 0

6. Leased Equipment (8000) — 0

7. Subtotal Expenditures — 45,016

8. University G&A Overhead @ 21.5% (9000) — 9,678

9. TOTAL EXPENDITURES — $54,694

Fee Schedule for Dr. Larry Roesner:

Preparation time for deposition or court testimony: (includes travel time from and to Fort Collins)	**$150/hr**
Deposition or court testimony: (includes time in court)	**$200/hr**

Report No. 1 to the City Attorney for Colorado Springs, Colorado, in reference to El Paso County District Court case no. 01CV1290

Matthew Garcia, M.S., under the direction of
Prof. Larry Roesner, Ph.D., P.E., P.H.
Department of Civil Engineering
Colorado State University
Fort Collins, Colorado 80523

July 31, 2002

ABSTRACT

This report pertains to El Paso County District Court case no. 01CV1290, Speight *et al.* v. the City of Colorado Springs and El Paso County, Colorado. This is the first of four reports to the City Attorney for Colorado Springs, Colorado. The report will address the circumstances of several rainfall events during the period from April through August of 1999, from which flood-related damages may have resulted at locations along Fountain Creek downstream of Colorado Springs. Several of these storm events are described and analyzed, and the largest event is evaluated with regard to the drainage design criteria adopted by the City of Colorado Springs and El Paso County, Colorado.

1. Introduction

The complaint filed by the above-named plaintiffs lists three periods in the spring and summer of 1999 during which storm events may have caused flood-related property damages in locations along Fountain Creek downstream of Colorado Springs, Colorado. We have identified the five largest of these storm events and will analyze these here in the contexts of both meteorological development and urban drainage design criteria. Within the periods specified in the plaintiffs' complaint (April 29 to May 10, May 24 to June 4, and July 9 to August 10, 1999), the largest storm events occurred on April 28-May 2, May 24-27, July 16-18, July 30-August 1, and August 3-7. In four of these five cases, the event was actually composed of two or more smaller storms with distinct underlying meteorological causes. In addition, winter storms prior to the first of these events led to near-saturated soil conditions in the upstream portions of the Fountain Creek Basin, exacerbating surface runoff during the first event. This report addresses the circumstances and magnitudes of these storm events.

The City of Colorado Springs is located directly east of Pikes Peak at the southern end of the Rampart Range, a subgroup of the Rocky Mountain Front Range, at the confluence of Monument and Fountain Creeks. A map of the region surrounding Colorado Springs, including the total drainage area of these Creeks, is shown in **Appendix A, Figure 1**. The drainage basin of Fountain Creek occupies approximately 930 sq. mi. spanning the Rocky Mountain Front Range and the Colorado Piedmont. Elevations in the basin range from the summit of Pikes Peak at 14,110 feet to the confluence of Fountain Creek and the Arkansas River in Pueblo, Colorado, at approximately 4,650 feet. A brief description of the Fountain Creek basin can be found in the U.S. Geological Survey's Water Resources Investigation Report No. 88-4136 and is summarized briefly here.

Monument Creek, a major tributary to Fountain Creek, is a perennial stream that flows generally eastward from its headwaters in the Rampart Range to Monument Lake, west of the Town of Monument, and then southward to its confluence with Fountain Creek in Colorado

Springs. Monument Creek is actively eroding the underlying soils in most locations. Upstream of its confluence with Cottonwood Creek in the northern portion of Colorado Springs, the Creek is classified as a meandering pool-and-riffle stream with sand, gravel and cobble bed materials. Downstream of this confluence, within the City of Colorado Springs, the Creek is classified as a braided stream with primarily sand and gravel bed materials. The reader is referred to Knighton (1998) for detailed explanations of these and other stream classifications.

Fountain Creek originates on the northern slopes of Pikes Peak near Woodland Park, Colorado, and flows generally southeastward through an incised canyon to Manitou Springs, Colorado, and then through a terraced alluvial plain to its confluence with Monument Creek. Upstream of Manitou Springs, the Creek is classified as a meandering pool-and-riffle stream with sand, gravel, cobble and intermittent boulder bed materials. Through the alluvial terraces downstream of Manitou Springs, the Creek is classified as a meandering pool-and-riffle stream with sand, gravel and cobble bed materials.

Below its confluence with Monument Creek, Fountain Creek flows generally southeastward through Colorado Springs and then southward to Pueblo, Colorado. The stream along this reach varies between meandering and braided configurations, with similarly variable bed materials. Active bank erosion has been observed at most locations along this reach of Fountain Creek downstream of Colorado Springs.

Several reservoirs in the drainage basins of Monument and Fountain Creeks upstream of Colorado Springs are supplied with water imported from the Upper Arkansas River and Upper Colorado River basins for the purposes of domestic and agricultural use. This contribution to the total available water in the Fountain Creek basin results from "trans-basin" and "trans-mountain" diversions that have existed for considerable periods prior the events in 1999 that are addressed here. The contributions from these reservoirs to the flow in the basin, up- and downstream of Colorado Springs, may be addressed in the second report of this series.

Report Organization

Several sources of data employed in this report are listed in Section 2. These sources include drainage design criteria manuals provided by the City of Colorado Springs, planning studies of the Monument and Fountain Creek basins performed by private engineering firms for the City, and printed and on-line meteorological data and graphics to support the analyses presented here.

Urban storm drainage systems are designed to convey runoff from developed areas to locations appropriate for storage, such as detention and retention basins, and discharge to receiving waters, typically a pre-existing creek or river channel. In order to facilitate uniformity and responsibility in the construction of these systems by developers and contractors, municipal utilities and public works departments often issue drainage criteria to address the system sizes and capacities appropriate to the "minor" (but more frequent) and "major" (but significantly less frequent) storms that may be expected in the region. In all cases, the primary goals of these design criteria are the health, safety and convenience of the population served by the constructed systems. Typically, the minor storm is employed in the sizing of constructed subsurface conveyance systems ("storm sewers") for small runoff events without street or property flooding, whereas the major storm is expected to produce enough runoff that the minor drainage system capacity is exceeded and much of the conveyance to the receiving waters occurs on the land surface. In the Drainage Criteria Manual adopted by the City of Colorado Springs and El Paso

County, Colorado, the minor storm is that of 5-year recurrence and the major storm is that of 100-year recurrence. Determination of the respective rainfall totals for these "design storms" will be addressed in Section 3 of this report.

The rainfall climatology, large-scale meteorological influences and antecedent moisture conditions in the vicinity of Colorado Springs prior to the time of the identified storm events will be addressed in Section 4 of this report. A chronology and analysis of each storm event is provided in Section 5 of this report. Observations of rainfall at various locations in the Fountain Creek Basin for each storm event are discussed in Section 6 of this report. The April 28-May 2, 1999, storm event produced the greatest rainfall totals in the region during these periods and is compared with the drainage design criteria for the City of Colorado Springs in Section 7 of this report. A brief summary of this report and its conclusions relevant to the questions posed by the City Attorney for Colorado Springs are presented in Section 8. Figures are included in **Appendix A**, while tables referred to here are included in **Appendix B**, and references employed here are identified in **Appendix C**.

2. Data Sources

Sources of data employed for analyses presented in this report are listed here. Data and references provided by the City Attorney for Colorado Springs include:

- Drainage Criteria Manual adopted by the City of Colorado Springs and El Paso County, Colorado (dated 1990/1991, amended 1994).
- Fountain Creek Drainage Basin Planning Study (including maps), prepared for the City of Colorado Springs, Colorado, by Muller Engineering Company, Inc. (dated 1994).
- Monument Creek Drainage Basin Planning Study (including maps), prepared for the City of Colorado Springs, Colorado, by CH2M HILL (dated 1994).
- Hourly and daily precipitation data at sites operated or maintained by the Colorado Springs Utilities Department.

Additional data, particularly meteorological observations, were obtained at various website locations, including:

- Climate data, specifically related to El Niño and La Niña phenomena, by the NOAA Climate Prediction Center (*http://www.cpc.ncep.noaa.gov/data/indices*) and the NOAA-CIRES Climate Diagnostic Center (*http://www.cdc.noaa.gov/Climaterisks*).
- NOAA Atlas 2 (Volume III: Colorado) maps and Records of General Climate Summary (Precipitation) by the Western Regional Climate Center (*http://www.wrcc.dri.edu*).
- Local regular (hourly) and special weather observations by the United States Weather Pages (*http://www.uswx.com*).
- Infrared satellite images and maps of Eta weather model initialization output and surface observations at 12-hour intervals by Unisys Weather (*http://weather.unisys.com*).
- Storm Data publications, precipitation data and weather observations by the NOAA National Climatic Data Center (*http://lwf.ncdc.noaa.gov/oa/ncdc.html*). Certified copies of some of these data were also provided by the City Attorney for Colorado Springs.
- Regional reference map for the Fountain Creek Basin by the Pikes Peak Area Council of Governments (*http://www.ppacg.org*).

Additional textbook materials and journal articles relevant to the material presented here are referenced where appropriate and listed in **Appendix C** to this report.

3. Design Criteria

The Drainage Criteria Manual (DCM) adopted by the City of Colorado Springs and El Paso County, Colorado, lists a number of purposes for the initial and major drainage systems. The definitions of the specific storms or events for which these systems are designed are listed in several locations in the DCM. The methods for determination of runoff, and thus drainage system size, using these storm events is also described in the DCM. These aspects of drainage criteria for the region of Colorado Springs, Colorado, are summarized briefly here.

According to section 1.2.3 (p. 1-6) of the DCM, the initial storm drainage system reduces maintenance costs, provides protection against flooding from frequent storms, and is a convenience to the resident population. The definition of the minor storm, for which the initial storm drainage system is designed, is given in sections 1.2.1 (p. 1-3), 1.2.3 (p. 1-6), and 2.1 (p. 2-2) of the DCM and is known as the 10-year storm. The prescribed flow capacity of the initial drainage system is not given explicitly in the DCM, but is rather to be calculated by developers and engineers using standard methods for the determination of runoff from specific storm events. One such method listed is the rational method, which is advocated for drainage basins with sizes of 100 acres (approx. 0.156 sq. mi.) or less and is described in section 5.2 (p. 5-5) of the DCM. Rainfall totals for the 10-year storm event are not listed explicitly in the DCM but are to be determined from NOAA Atlas 2 (Volume III: Colorado) maps provided in section 5.3.3 (p. 5-15) of the DCM. However, a memo included with the DCM and dated October 1994 altered the definition of the minor storm to a rainfall event of 5-year recurrence following interim adoption of the Cottonwood Creek Drainage Basin Planning Study and additional studies of cost effectiveness. A method for the determination of total point rainfall for the 5-year storm is also presented in section 5.3.3 of the DCM.

Of greater interest to the work presented here is the major storm, to which the storm events of 1999 will be compared in Section 7 below. According to section 1.2.3 (p. 1-6) of the DCM, the major storm drainage system is designed primarily to prevent major property damage and loss of life during the major storm. The definition of the major storm is given in sections 1.2.1 (p. 1-3), 1.2.3 (p. 1-6), and 2.1 (p. 2-2) of the DCM and is known as the 100-year storm. A significant portion of the major storm drainage system is natural drainageways, for many of which 100-year floodplains have been designated. The major drainageways in the vicinity of Colorado Springs are listed in section 1.2.4 (p. 1-6) of the DCM and include the stream reaches of Monument and Fountain Creeks. As for the 10-year minor storm discussed above, rainfall totals for the 100-year storm must be determined from NOAA Atlas 2 (Volume III: Colorado) maps provided in section 5.3.3 (p. 5-15) of the DCM, and for planning and design purposes the corresponding storm event runoff must be determined as described in section 5.2 (p. 5-5) of the DCM. For rainfall/runoff simulations, the SCS Type IIA temporal distribution of major storm rainfall over a 24-hour period is advocated in section 5.3.3 (p. 5-16) of the DCM.

It should be noted that the general public and many municipal officials often misunderstand terms such as "100-year storm" and "100-year flood." In reference to such floods, Pielke (1999) stated:

> "The 100-year standard refers to a flood that has a one percent chance of being exceeded in any given year. It does *not* refer to a flood that occurs 'once every 100 years.' In fact, for a home in a 100-year flood zone there is a greater than

26% chance that it will see at least one 100-year flood over a period of 30 years (and, similarly, more than a 74% chance over 100 years)."

The recurrence of a particular storm or flood is found by evaluation of historical records for frequencies of exceedance, of which the inverse is the recurrence interval. It should be noted that storms of infinite variety might produce rainfall totals of the same recurrence interval, the evaluation of which is inherently limited by the period of record. It should also be noted that exceedance frequencies and recurrence intervals are not forecasting tools, and imply nothing with regard to the time of occurrence of future events. In addition, the *N*-year rainstorm and *N*-year flood are not necessarily correlated, that is, a rainstorm of one particular recurrence interval may produce a flood of an entirely different recurrence interval, depending on the size and use of the watershed and the antecedent moisture conditions there. This work considers the rainstorm that has a 1% chance of being equaled or exceeded in total 24-hour rainfall during any given year, based on historical records, and is typically referred to as the "100-year storm."

The standard references for rainfall totals during storms of 100-year recurrence interval are NOAA Technical Paper No. 40 and NOAA Atlas 2, for storm durations less than 24 hours, and NOAA Technical Paper No. 49 for storm durations longer than 24 hours. Though the NOAA Technical Papers together provide rainfall totals for storm durations both shorter and longer than 24 hours, it is generally accepted that these references are not as accurate in mountainous regions (such as the Colorado Front Range, including the Fountain Creek watershed) as the more up-to-date NOAA Atlas 2. For the purposes of the work presented here, the 100-year 6- and 24-hour storm event rainfall totals were determined from the NOAA Atlas 2 maps and are taken as 3.5 and 4.4 inches, respectively, in the vicinity of Colorado Springs, Colorado. A portion of the NOAA Atlas 2 map for this region is reproduced here in **Appendix A, Figure 2**. It should be noted that greater rainfall totals would be expected in the immediate vicinity of Pikes Peak. Storm rainfall totals for events of other durations less than 24 hours can be calculated using formulas provided in the NOAA Atlas 2 reference. For storm events of duration greater than 24 hours, rainfall totals determined from maps provided in NOAA Technical Paper No. 49 will be employed here. Despite the greater accuracy of NOAA Atlas 2 maps for storm events less than 24 hours in duration, no better reference exists for storm events greater than 24 hours in duration. Specifically, this reference lists the 100-year 48- and 96-hour storm rainfall totals as 4.9 inches and 5.5 inches, respectively, in the vicinity of Colorado Springs, Colorado.

4. Large-scale Influences and Pre-season Conditions

The long-term (1948-2000) monthly mean and extreme rainfall totals observed at the Colorado Springs National Weather Service (NWS) station for the period from April through August have been compiled by the Western Regional Climate Center and are listed in **Appendix B, Table 1**. The monthly total observed rainfall during the same period in 1999 is also listed there. It should be noted that the rainfall observed on April 30, 1999, contributed 35% of that month's total, and that the total April 1999 rainfall was more than 4.5 standard deviations above the long-term mean for April. It should also be noted that August 1999 provided a similar case, when the rainfall during August 4, 1999, comprised nearly 57% of that month's total, which was nearly 2.5 standard deviations above the long-term mean for August.

There are two primary large-scale influences on weather patterns and the occurrence of rainfall along the Rocky Mountain Front Range during most seasons. One of these, the El

Niño/Southern Oscillation (ENSO) cycle in the eastern equatorial Pacific Ocean, is the large-scale climatic cycle that exerts the strongest influence on weather over the western United States during the warm seasons. A general reference for discussion of the effects of ENSO on regions of North America, especially with regard to rainfall patterns, is Ropelewski and Halpert (1986). Most studies of ENSO refer only to the warm (El Niño) period of the multi-year climate cycle and the extra-tropical effects of that warm eastern equatorial Pacific Ocean water. The cold (La Niña) period of the cycle is less well understood and is the subject of continuing study. During the period of interest here, La Niña conditions affected the major weather patterns over Colorado Springs.

According to the NOAA Climate Prediction Center, general La Niña (cold) conditions were observed from the July-August-September (JAS) quarter of 1998 through the April-May-June (AMJ) quarter of 2000. Details regarding the progression of this La Niña event across the equatorial Pacific Ocean have been described by Bell *et al.* (1999). A strong La Niña condition was observed within that period during the January-February-March (JFM) quarter of 1999, immediately prior to the events examined here. The NOAA-CIRES Climate Diagnostic Center (*http://www.cdc.noaa.gov*) reports that moderate-to-dry seasonal precipitation extremes are expected in the Arkansas River basin during La Niña episodes, and a dry March-April-May (MAM) period is as much as seven times more likely than a wet MAM period following a strong La Niña during the December-January-February (DJF) period. Their chart demonstrating these relations is shown here in **Appendix A, Figure 3**.

Another large-scale factor of significant influence on weather and rainfall in the vicinity of Colorado Springs and the Fountain Creek basin is the Rocky Mountains. The Rocky Mountain Front Range lies immediately to the west of this region, and the Palmer Divide extends eastward from the Front Range to provide the northern boundary of this basin. The interactions between passing weather systems, at all levels of the atmosphere, and this topographic configuration are complex. However, we may classify two primary effects of the Rocky Mountains on such weather events:

- *Solar heating of the land surface in a highly variable pattern*, which often leads to abrupt changes in wind speed and direction. Such patterns produce regions of convergent winds near the surface, forcing air upward to form clouds and, possibly, thunderstorms. Along the Front Range of the Rocky Mountains, a nightly reversal of winds along the eastern slopes in otherwise calm weather conditions, in response to cooling ground surfaces, is well studied and is known to lead to common summer thunderstorm events. A useful reference for this topic is Toth and Johnson (1985).
- *Upward forcing of near-surface winds*, which often leads to large-scale areas of clouds and sometimes to sustained rainfall on the eastern slopes of the Front Range. In the vicinity of Colorado Springs, this effect requires near-surface winds from the east and southeast that are forced upward by the Rampart Range and, to a lesser degree, by the Palmer Divide. When the winds at higher levels are from the northwest, west, or southwest, such a pattern may produce long-lived storms as moist easterly air forced upward from near the surface forms clouds that are then pushed back toward the east, producing rain over the most populated areas along the Front Range.

The National Climatic Data Center's (NCDC) Storm Data publication reported several snow and rain events during April 1999 prior to the first flood-related event described below. These events are listed here:

- April 1-2: a storm produced rain and then 8-16 inches of snow in western El Paso County and along the Rampart Range.
- April 4-5: 6 inches of snow was reported in Monument.
- April 14-15: 11-15 inches of snow was reported in Monument and Palmer Lake.
- April 21-23: 8-10 inches of snow was reported in Woodland Park and 6-8 inches of snow was reported along the Rampart Range and in Monument. During this event, as much as 6 inches of snow was reported in the northern and western areas of Colorado Springs.

NCDC data provided by the City Attorney show that a total of 1.86 inches of liquid-equivalent precipitation fell at the Colorado Springs NWS gauge in the two weeks prior to the first period listed in the plaintiffs' complaint and the first flood-related event described below. Observations at the Colorado Springs NWS station show that all of the accumulated snow had melted by April 28, 1999.

5. Event Descriptions

The plaintiffs' complaint, provided by the City Attorney for Colorado Springs, lists three periods during the 1999 warm season within which flood-related damages may have occurred at locations along Fountain Creek downstream of Colorado Springs. The daily total rainfall during these periods at three locations in the vicinity of Colorado Springs is listed in **Appendix B, Table 2**. Five major storm events have been identified within these periods and are shown shaded in Table 2. These events occurred on April 28-May 2, May 24-27, July 16-18, July 30-August 1, and August 3-7. During these major storm events, a weather pattern other than isolated thunderstorms or rain associated with frontal passages has been indicated by the available data. While such isolated thunderstorm events and brief frontal showers may produce locally heavy rainfall, such intensity is often of small duration and produces a similarly short-lived rise and fall in stream and creek flows.

In addition to these five major storm events, several isolated storm events with measured rainfall greater than 0.1 inches at any of the stations included there can also be identified: May 31, July 8, July 24, July 28, and August 9, 1999. Afternoon and evening thunderstorms have been indicated in NCDC data for the events in May and July, while convective conditions ahead of a cold front along the Front Range were observed to produce the longer-lived, but low-intensity, event in August. The events in July can also be associated with the extension of the North American monsoon over Colorado. Though most often thought of as a large-scale rainfall event, the monsoon is technically defined as a seasonal wind shift and is often observed over much of the southwestern United States by mid-June. In this case, the monsoon pattern reached Colorado on or about July 7, 1999. This wind shift typically brings moisture to an area from alternate sources, specifically for Colorado from the eastern equatorial Pacific Ocean and the Gulf of California, and is a factor that often leads to increased rainfall in affected regions. Helpful references regarding the North American monsoon include Adams and Comrie (1997) and Castro *et al.* (2001).

Weather patterns similar to those that produced the minor events described above, in combination with other large-scale weather features, were found to contribute to the more significant rainfall events during the 1999 warm season discussed here. The following sections address these events individually, providing a chronological account of the major weather patterns as well as an overall analysis of each event. The development of the initial weather patterns, prior to the first storm in each event, has been summarized as briefly as possible. In addition to the local contribution from upslope flows to storm initiation and sustained rainfall events, discussed above, some general principles of weather patterns should be taken into consideration when reading these accounts:

- The upper-level "jet stream" is characterized by a band of strong winds at an elevation of 40,000-45,000 feet (about 8 miles) in the middle latitudes and marks the boundary between cooler air to the north and warmer air to the south. This boundary also marks significant changes in weather, including the likely development of precipitation.
- There are actually two jet streams that affect weather over the U.S. during the warm season: the polar jet is typically found over southern Canada and the extreme northern U.S., whereas the subtropical jet is usually located over Mexico and the extreme southern U.S.
- A "trough" is analyzed where the polar jet stream dips toward the equator, whereas a "ridge" indicates that the polar jet stream is far from the equator. Different terminology applies to the subtropical jet but is not employed here.
- The strongest destabilization of the atmosphere, and thus the greatest potential for heavy rainfall events, typically occurs on the east side of an upper-level trough. The strongest development of surface weather features, such as cold fronts, often occurs directly beneath and immediately ahead of this area.
- A "short wave" trough is a "bump" in the jet stream where particularly strong destabilization can occur, leading to consequently strong weather changes near the surface.
- Air flows counter-clockwise around a low-pressure center ("low" or "cyclone") or the axis of a trough, and clockwise around a high-pressure center ("high" or "anticyclone") or the axis of a ridge. For this reason, troughs and ridges are often indicated in regions away from the polar jet stream where strong local curvature of the wind field is found.
- A "cut-off low" or "cut-off cyclone" is a nearly circular region of strong winds in the upper levels that has separated from the polar jet stream. These systems can last for long periods before they rejoin the polar jet stream and, in the meantime, can cause major weather changes near the surface as they pass overhead.
- Upper-level troughs, and their associated fronts near the surface, tend to initiate storm development, whereas ridges tend to suppress the development of convective storms.
- A monsoon is a seasonal shift of wind direction, a phenomenon that is not limited to India and Southeast Asia. The North American monsoon occurs during the summer and is typically indicated by southwesterly upper-level flow over the southwestern U.S. and a large upper-level anticyclone over the Gulf of Mexico and adjacent regions of the U.S. The monsoon is a cyclical pattern, with "active" periods of strong southwesterly flow and a strong anticyclone, and "break" periods when the flow and the upper-level anticyclone are much weaker.
- While weather patterns in the mid-latitude upper levels generally move from west to east, they may remain relatively stationary for long periods and may, if strong enough, move from east to west. Weather patterns at the surface do not necessarily move from west to east, especially in the vicinity of the Rocky Mountains.

The following analyses are based on infrared satellite images and maps of Eta weather model initialization output and surface observations provided by Unisys Weather (see Section 2 for website). Archives of these data include products at 12-hour intervals, issued at 00 UTC[1] (5 pm LST[2] on the previous date) and 12 UTC (5 am LST on the same date). It should be noted that these times to not account for Daylight Saving Time. Additional observations have been obtained from other sources (see Section 2) and are included where appropriate.

5.1. April 28-May 2, 1999

Event Chronology

The movement and development of large-scale weather patterns during the period prior to April 28 can be characterized as typical of middle latitude spring conditions. The formation of a strong surface cyclone on the east side of the Rocky Mountains near northern Colorado by the afternoon of April 26 was associated with the slow passage of an upper-level cyclone over the central Rocky Mountains during the previous two days. By April 27, high surface pressures had re-established over Colorado, associated with a weak upper-level ridge over the Four Corners region, and another upper-level trough was beginning to move into the Pacific Northwest region. The low-level high weakened considerably by the evening of April 27, and by the next morning a large trough was established over Utah and western Colorado. In the upper levels, the trough over the Pacific Northwest strengthened and moved slightly southward over the same period. By the morning of April 28, scattered convection had begun over much of the Rocky Mountains in association with the strengthening of the surface trough and the eastward movement of the upper-level trough.

This event was composed of three distinct storms over a period of about 3.5 days. The first storm of this event began at approximately 00 UTC on April 29 (5 pm LST on April 28), and can be associated with the development of a surface cyclone over western Colorado beneath a short wave in the upper-level trough over the western U.S. The combination of upslope flows, drawn into eastern Colorado by the surface cyclone, and high relative humidity over the Great Plains led to the development of strong thunderstorms with heavy rainfall around this time. By the next morning, around 12 UTC (5 am LST) on April 29, the region of heavy rainfall over central Colorado had moved to the east along with its associated major weather features.

By 00 UTC on April 30 (5 pm LST on April 29), a low-level trough had developed over the Four Corners region in association with a cut-off cyclone in the upper levels over northwestern Arizona, a pattern that induced strong upslope flows over southeastern Colorado. The second storm of this event began at about 5 pm LST on April 30, concurrent with the available data products. A slight eastward movement of the surface features, and a slight northward movement of the upper-level cyclone, contributed to the intensification of upslope flows in eastern Colorado by the next morning. By the afternoon of April 30, however, the upper-level cyclone and its associated low-level trough had moved significantly northeastward, out of the positions most favorable for upslope flows along the Colorado Front Range.

The third storm of this event developed slowly during the morning of May 1, and can be associated with a weakening upper-level cyclone and short wave trough over Arizona and a weak surface trough over New Mexico. By that evening, weak surface lows had formed over western Colorado and extreme northern Texas. Though this pattern favors weak upslope flows and sustained rainfall in southeastern Colorado, the major weather features moved out of this position

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[1] UTC: Universal Coordinated Time, an equivalent of Greenwich Mean Time (GMT).

[2] LST: Local Standard Time. Note that Local Daylight Time (LDT) = LST + 1 hour.

by the next morning. By 12 UTC (5 am LST) on May 2, a surface cyclone had formed over eastern Wyoming and was supported by an upper-level trough, into which the weakening upper-level cut-off cyclone had dissipated, that had moved over the northern Great Plains.

Event Analysis

The patterns described for 00 UTC on April 29 (5 pm LST on April 28) conform almost perfectly with those described by Doswell (1980) for severe thunderstorms over the western High Plains, with the positions of meteorological features shifted slightly south and west from that archetype so as to place the greatest threat of severe thunderstorms along the southern Front Range in Colorado. The archetype schematic for these storm events (Figure 2 from Doswell 1980) is shown here in **Appendix A, Figure 4**. Similar patterns have been associated with the periods prior to flash flood events in the Big Thompson Canyon, Colorado (July 31, 1976), and in Rapid City, South Dakota (June 9, 1972) by Maddox *et al.* (1978).

The patterns described for 00 UTC and 12 UTC on May 1 (5 pm LST on April 30 and 5 am LST on May 1, respectively) generally conform to those characterized by Maddox *et al.* (1980) for Type I western flash flood events, during which a surface low forms on the east side of an upper-level trough and produces conditions favorable for flash flooding on the east and north sides of the surface low pressure system. The archetype schematic for these storm events (Figure 1 from Maddox *et al.* 1980) is shown here in **Appendix A, Figure 5**. It should be noted that, in that study, the map of western North America underlying the meteorological schematic for Type I events is provided only for reference of scale. Maddox *et al.* (1980) associated similar Type I patterns with flash flood events along the Rocky Mountain Front Range in Cheyenne, Wyoming (July 19 and September 8, 1973), in the Big Thompson Canyon, Colorado (July 31, 1976), and across Larimer and Weld Counties, Colorado (July 24, 1977). Of the more publicized historical events, similar weather patterns resulted in flash floods in Rapid City, South Dakota (June 9, 1972) (Maddox *et al.* 1980) and Fort Collins, Colorado (July 28-29, 1997) (Petersen *et al.* 1999). According to NCDC data (see Section 7), the Colorado Springs NWS station recorded 3.90 inches of rainfall from July 27 through July 30, 1997, the period over which the same storm system affected the Fort Collins area even more significantly. It is interesting to note that flash flooding and river flooding were also observed in Fort Collins, Colorado, on April 30, 1999, following more than 3.5 inches of precipitation (liquid equivalent) in the previous week and nearly 4.0 inches of rainfall over that region during April 29-30, 1999 (Weaver et al. 2000).

The near-surface wind patterns during this event should be considered equal in significance to the surface frontal and upper-air trough patterns. Near-surface winds from the southeast and reports of high humidity were indicated over much of southeastern Colorado, western Kansas and northern Texas for the duration of this event. This flow pattern, which drew moisture from the area around the Gulf of Mexico, approached the Front Range and was forced upward, producing sustained convection with moderate rainfall rates over much of central and eastern Colorado between April 29 and May 1. The contribution of upslope flows to Front Range precipitation events, with low-level winds generally from the east and southeast, is widely recognized in weather forecasts and post-storm analyses for this region, and has been cited as a contributing factor in major flood events in the Big Thompson Canyon (July 31, 1976) (Maddox *et al.* 1978) and Fort Collins (July 28-29, 1997) (Petersen *et al.* 1999).

The succession of meteorological patterns favorable for western High Plains and Rocky Mountain Front Range flash floods events is not unique, as suggested by the specific events listed here. Conditions similar to the severe event archetypes for both regions have produced extensive flash flooding in Rapid City, South Dakota (June 9, 1972), the Big Thompson Canyon, Colorado (July 31, 1976), and in the event discussed here for Manitou Springs and Colorado Springs, Colorado (April 29 through May 1, 1999). Whereas some flood events may occur from localized heavy rainstorms, and others under conditions of widespread and sustained precipitation, these events seem to have resulted from combining both of these storm types in a single event. The precipitation amounts recorded at the Colorado Springs NWS station over the period described here support this conclusion of a long-lasting hybrid event archetype, during which a storm of one type was followed closely by another storm with a slightly different supporting pattern.

5.2. May 24-27, 1999

Event Chronology

This event was preceded during May 23-24 by the development of a strong upper-level cut-off cyclone over southern California and the establishment of an associated weak surface cyclone over southwestern Nevada to the west of a weak surface ridge that covered much of eastern Colorado. This event was composed of two distinct storms over a period of about 3.5 days, though no rainfall was reported at Colorado Springs during the two days between those storms. The first storm of this event began at about 2 pm on May 24. Around this time, a large surface trough was established over the Great Basin and Four Corners regions, and a low-pressure center was analyzed over southeastern Colorado with associated surface trough axes extending to the north, east, and south. By that time, the upper-level cut-off cyclone had moved over southwestern Utah and was embedded in a broad upper-level ridge that covered much of the western U.S. By 12 UTC (5 am LST) on May 25, the upper-level cut-off cyclone had moved eastward over southern Utah and was associated with a developing surface cyclone over northern Texas. Immediately after this time, the first storm of this event reached its peak and then began to decline in intensity. By the evening of May 25, a surface ridge began to form over northern New Mexico and southeastern Colorado associated with a significantly weaker upper-level cyclone over the Four Corners region.

Surface ridge conditions persisted over Colorado through the morning and afternoon of May 26, suppressing convective development along the Front Range. In the upper levels, the weakening cyclone had degenerated to a narrow trough and had passed to the east of the Rocky Mountains. By 12 UTC (5 am LST) on May 27, however, a cold front had entered northern Colorado from Wyoming and was associated with this weak upper-level trough over eastern Colorado and northern Texas. Scattered pre-frontal convection was observed over central and eastern Colorado during the day on May 27, associated with the southward passage and eventual dissipation of this cold front along the Front Range. By the time of peak intensity of the second storm of this event in Colorado Springs, around 00 UTC on May 28 (5 pm LST on May 27), a surface high-pressure center was established over central Colorado and the surface cold front had re-formed over southwestern Nebraska, associated with the northward movement of the weak upper-level trough over this period. Rainfall at Colorado Springs diminished soon after the passage of these systems to the east during the evening of May 27.

Event Analysis

The surface patterns described for the first storm during this period, specifically around 00 UTC and 12 UTC on May 25 (5 pm LST on May 24 and 5 am LST on May 25, respectively), generally resembled those described by Doswell (1980) for severe thunderstorms over the western High Plains, though the upper-level patterns differed significantly from that archetype. Specifically, the upper-level short-wave trough described by Doswell was replaced with a stronger cut-off cyclone, and the upper-level winds were significantly weaker and more southerly than expected. The observed pattern over this period was thus also similar to that suggested for Type I western flash floods by Maddox *et al.* (1980), with the same caveats.

The patterns described for the second storm during this period, specifically just prior to 00 UTC on May 28 (5 pm LST on May 27), indicate that this storm was likely frontal or pre-frontal in origin and, with some contribution from strong convection, produced locally heavy rainfall. The possibility of pre-frontal thunderstorms during this event was supported by reports of moderate-to-high humidity in Denver and Pueblo prior to frontal passage, and the brevity of the event resulted from the disintegration of the front at is moved southward along the Front Range, such that no front was shown in surface analyses over eastern Colorado by 00 UTC on May 28.

5.3. July 16-18, 1999

Event Chronology

This event was preceded by the extension of the North American monsoon to the Colorado region in conjunction with the establishment of a wide upper-level trough over the western U.S. and generally southwesterly flow over Colorado. The extension of the North American monsoon across the southwestern U.S. has been discussed in the introduction to this section. This event was composed of two distinct storms over a period of about 1.5 days. By 12 UTC (5 am LST) on July 16, a surface low-pressure center had formed over southeastern Colorado with an associated warm front along the Colorado Front Range and a stationary front extending eastward into southeastern Kansas. The peak intensity of the first storm of this event occurred around 00 UTC on July 17 (5 pm LST on July 16), when this front was still located along the Front Range and northeasterly winds were reported at Denver and Pueblo.

By the next morning this front had retreated to eastern Colorado, but the monsoon-related pattern in the upper levels had begun to strengthen. Prior to the beginning of the second storm of this event, around 00 UTC on July 18 (5 pm LST on July 17), an upper-level trough was established over the Pacific Northwest and a strong upper-level anticyclone was located over southwestern Kansas, producing south-southwesterly and later southerly flows over Colorado. Generally upslope surface winds were reported at Denver and Pueblo at this time and scattered storms were reported during the evening on July 18. By the morning of July 19, however, a surface ridge was established over southern Colorado as the upper-level trough had moved to the east of the Rocky Mountains.

Event Analysis

The patterns described for 00 UTC and 12 UTC on July 17 and 00 UTC on July 18 (5 pm LST on July 16 and 5 am and 5 pm LST on July 17, respectively) conform almost perfectly with those described by Doswell (1980) for severe thunderstorms over the western High Plains, with the positions of meteorological features shifted only slightly south from that archetype so as to place the greatest threat of severe thunderstorms along the southern Front Range in Colorado. The archetype schematic for these storm events (Figure 2 from Doswell 1980) is shown in **Appendix A, Figure 4.**

An additional influence on this event was a resurgence of the North American monsoon around July 16, leading to increased moisture over Colorado during this period. An attempt to draw analogies between the patterns described here and the archetypes for western flash flood events presented by Maddox *et al.* (1980) are difficult, due primarily to the orientation of the upper level trough axis and its tendency to remain relatively stationary over the Pacific Northwest. That the North American monsoon was not recognized in that work only adds to the difficulty of such an analogy. However, an examination of the upper-level flows for the minor events during July that were listed above, but not explored further here, indicates a similar configuration with a trough over the Pacific Northwest and the monsoon-related anticyclone over the southern United States. The establishment of this strong upper-level anticyclone over the southern Great Plains contributed to an enhanced transport of moisture over Colorado from the Gulf of California, leading to increased thunderstorm activity over the Rocky Mountains and eastern plains of Colorado. Of the archetypes presented by Maddox *et al.* (1980), the closest analogy in upper-level patterns may be drawn with the Type IV event, shown here in **Appendix A, Figure 6,** though the region of greatest flash flood threat indicated there is not located in the "proper" position with regard to this event. Another Maddox *et al.* (1980) Type IV event resulted in flash flooding in the vicinity of Aurora, Colorado, on July 21, 1976, and was included that study. Though it is possible that that event can also be attributed to weather patterns associated with the North American monsoon, evidence to support an accurate analogy with this storm event is not available at this time.

5.4. July 30-August 1, 1999

Event Chronology

As for the previous event, this event was concurrent with a resurgence of the North American monsoon over the Colorado region. This event was comprised of two storms over a period of about two days. The first storm of this event began with the southward passage and disintegration of a cold front along the Front Range during the afternoon and evening of July 30. In the surface analysis of 00 UTC on July 31 (5 pm LST on July 30), the cold front was found immediately to the north of Pueblo. Examining surface weather reports at the Colorado Springs NWS station around this time, it was found that this front passed through Colorado Springs at about 2230 UTC (1530 LST) on July 30, producing a marked shift to northerly winds followed by a peak wind gust of 34 knots (39 mph). At about the same time, the temperature decreased by 7°F and the relative humidity increased by 45%. Thunderstorms in the vicinity of Colorado Springs were reported consistently in regular (hourly) and special weather observations during this period of frontal passage, as well.

By the time of this frontal passage along the Front Range, an upper-level short wave trough was established over Arizona on the western limit of the monsoon ridge. This short wave trough remained relatively stationary while a broad surface trough was re-established over the Rocky Mountains by 00 UTC on August 1 (5 pm LST on July 31), with a weak cyclone centered over western New Mexico and trough axes stretching into western Colorado and northern Texas. By this time, the second storm of this event had peaked in intensity. By 00 UTC on August 2 (5 pm LST on August 1), the upper-level short wave trough had weakened considerably and a surface ridge had become established over eastern Colorado, suppressing further convective development during this period.

Event Analysis

As stated in the event chronology, the first storm of this event was concurrent with the southward passage of a cold front along the Front Range during the afternoon and evening of July 30. Though such frontal passage events occur less frequently during the summer months, this analysis is supported by a shift and strengthening of winds and an increase in surface pressure (based on surface observations) at Denver and relatively unchanged weather at Pueblo by the time of the cited surface analysis. By lifting the warm and potentially unstable air ahead, the passing cold front forced the development of deep convection and thunderstorms that produced locally heavy rainfall in the post-frontal region, especially in the vicinity of the Colorado College weather station.

The patterns described for the second storm of this event, specifically around 00 UTC on August 1 (5 pm LST on July 31), generally resembled those described by Doswell (1980) for severe thunderstorms over the western High Plains. Upslope flow along the Front Range was indicated in that archetype as a contributor to locally heavy rainfall during such thunderstorms. Special attention should be given to the presence of a short wave trough over western Arizona, as in the Doswell archetype, that mitigated some of the suppressive effects of the monsoon ridge that covered much of the southern U.S. The observed pattern at this time was thus also generally similar to that suggested for Type I western flash floods by Maddox *et al.* (1980).

5.5. August 3-7, 1999

Event Chronology

This event was preceded by the storm event described in section 5.4. Between these two events, relatively calm conditions persisted over much of eastern Colorado through the morning of August 3. This event was composed of three storms over a period of about 2.5 days. As discussed above, the southern United States was covered by an upper-level monsoon anticyclone during this period. By 00 UTC on August 4 (5 pm LST on August 3), the first storm of this event began following the strengthening of a surface trough over the Rocky Mountains and the establishment of a surface cyclone in northwestern Colorado. In the upper levels, a broad ridge extended from the monsoon anticyclone over the southeastern U.S. to the northern Rocky Mountains, leading to moderate southwesterly flows over Colorado. The first storm of this event ended by 12 UTC (5 am LST) on August 4, by which time the surface trough over the Rocky Mountain region had weakened considerably but a short wave was beginning to form over southwestern Arizona ahead of a strong upper-level trough over the Pacific Northwest.

A stronger surface trough was re-established over the Rocky Mountain region by 00 UTC on August 5 (5 pm LST on August 4), around which time the second storm of this event began to produce rainfall over the Colorado Springs area. A surface cyclone was centered over Nevada at this time, drawing winds over eastern Colorado into an upslope pattern, but the upper-level short wave had completely disappeared as the monsoon ridge strengthened over the eastern Rocky Mountains, producing more southerly upper-level flows over Colorado. A trough axis, associated with the expansion of the cyclone over the western U.S., was then established over eastern Colorado during the morning of August 5 and essentially blocked further upslope flows after that time, ending the second storm of this event.

The third storm of this event resulted from the movement of this trough axis over the eastern Rocky Mountains and the formation of a surface low over southeastern Colorado during the afternoon of August 5. A stationary front extended to the east from this surface low into southwestern Kansas, leading to renewed upslope conditions in the central and southern Colorado Front Range. In addition, by 00 UTC on August 6 (5 pm LST on August 5) another short wave trough had developed over southern Arizona on the edge of the upper-level monsoon anticyclone. By 12 UTC (5 am LST) on August 6, however, the surface cyclone and its associated fronts and troughs had moved northeastward ahead of an advancing upper-level cyclone, ending the third storm of this event.

Event Analysis

The patterns described for 00 UTC on August 4 (5 pm LST on August 3) indicate that the first storm of this event was most likely an isolated late-day thunderstorm, common in the Rocky Mountains and High Plains during the summer months and especially after the extension of the upper-level North American monsoon circulation into this region. The patterns described for 00 UTC and 12 UTC on August 5 (5 pm LST on August 4 and 5 am LST on August 5, respectively) indicate a similar occurrence of late-day thunderstorms, though the second storm of this event was supported by low-level flow from the southern Great Plains and therefore was of greater intensity and duration than the storm on the previous day. The patterns described for 00 UTC on August 6 (5 pm LST on August 5) are almost exactly those described by Doswell (1980) for severe thunderstorm events over the western High Plains, and thus are similar to those described here for the event on July 16-18, 1999.

6. Observed Rainfall

Histograms of hourly rainfall at locations where such data were available in and near the Fountain Creek basin during the period April 28-May 2, 1999, for the storm event described in Section 5.1 above, are shown in **Appendix A, Figure 7**. Specifically, hourly rainfall at the Colorado Springs, Manitou Springs, Greenland and Pueblo National Weather Service (NWS) stations are shown in **Figures 7a, c, d** and **g**, respectively. Hourly rainfall at gauges operated by the Colorado Springs Department of Utilities at Colorado College, Nixon Base and Piniello Ranch are shown in **Figures 7b, e** and **f**, respectively. The hourly rainfall observations at these stations demonstrate a clear distinction between the three storms that comprised this event, as discussed above. It should be noted that the 2.63 inches of rainfall recorded at the Colorado Springs NWS station on April 30, 1999, is the largest daily precipitation amount during April on record for that location.

The locations of these rainfall gauges, as well as others in and near the Fountain Creek Basin, are listed in **Appendix B, Table 3**. The location of each numbered rainfall gauge listed there is also shown on the schematic basin map in **Appendix A, Figure 8a**. The basin outline employed there corresponds to that on the map shown in **Appendix A, Figure 1**. Contour maps of daily total rainfall during the period April 28-May 2, 1999, for the storm event described in Section 5.1 above, are also shown in **Appendix A, Figure 8**. Specifically, the daily total rainfall for April 28, 29 and 30 and May 1 and 2, 1999, are shown in **Figures 8b, c, d, e** and **f**, respectively. A schematic map of Fountain Creek basin showing the total rainfall observed during the period April 28-May 2, 1999, is shown in **Appendix A, Figure 8g**. It should be noted that, based on the available data, the greatest total rainfall during this event was observed directly over the area of Colorado Springs and, especially, north of the confluence of Monument and Fountain Creeks.

A histogram of hourly rainfall at the Colorado Springs NWS station during the period May 24-28, 1999, for the storm event described in Section 5.2 above, is shown in **Appendix A, Figure 9**. Though based on this figure it may seem that this event was comprised of three storms, the consistency of weather patterns in the vicinity of Colorado during May 24-25, 1999, must also be considered. The distinction between this extended first storm and the later storm on May 27, 1999, is clear.

A histogram of hourly rainfall at the Colorado Springs NWS station during the period July 15-19, 1999, for the storm event described in Section 5.3 above, is shown in **Appendix A, Figure 10**. A clear correspondence may be drawn between the storms indicated by the figure and those described above.

A histogram of hourly rainfall at the Colorado Springs NWS station during the period from July 28 to August 1, 1999, for the storm event described in Section 5.4 above, is shown in **Appendix A, Figure 11**. As explained in the introduction to Section 5 above, the rainfall event on July 28 can be attributed to an evening thunderstorm associated with the extension of upper-level monsoon flows to the region of Colorado. The later storms during this period have been attributed to the passage of a disintegrating cold front along the Front Range, during the evening of July 30, 1999, and a thunderstorm supported by recognizable weather patterns and upper-level monsoon flows during the evening of July 31, 1999.

A histogram of hourly rainfall at the Colorado Springs NWS station during the period August 3-7, 1999, for the storm event described in Section 5.5 above, is shown in **Appendix A, Figure 12**. A succession of intense late-day thunderstorms, as discussed above, is clearly shown in that figure. It should be noted that the 3.98 inches of rainfall recorded at the Colorado Springs NWS station on August 4, 1999, is the largest single-day precipitation amount on record for that location.

7. Comparison of Observed Rainfall with Design Criteria

The rainfall totals for the major storm indicated in the drainage design criteria adopted by the City of Colorado Springs and El Paso County, Colorado (see Section 3), are listed in **Appendix B, Table 4**. As discussed previously, the NOAA Atlas 2 reference generally provides more acceptable design storm rainfall totals in the vicinity of the Rocky Mountains, but does not provide rainfall totals for events of duration longer than 24 hours. For such sustained events, NOAA Technical Paper No. 49 (TP-49) is employed for the rainfall totals listed in **Table 4**. Event rainfall totals provided in NOAA Technical Paper No. 40 (TP-40) are listed there only for comparison with those provided in NOAA Atlas 2, and are not employed in the evaluation of the storm events and design criteria discussed here.

In that table, it is indicated that some rainfall totals are obtained from provided maps. Specifically, these are the rainfall totals for the 100-year 6- and 24-hour storms listed in NOAA

Atlas 2, and the 100-year 48- and 96-hour storms listed in NOAA TP-49. Rainfall totals for events of other durations less than 24 hours are determined with a regression equation, provided in NOAA Atlas 2, that depends on the given 6- and 24-hour rainfall totals and the elevation of the desired location. For the rainfall totals listed there, the 100-year 6- and 24-hour rainfall and the elevation at the Colorado Springs NWS station were employed. The 100-year 96-hour design storm total rainfall provided in NOAA TP-49 was selected for comparison with the total 84-hour event rainfall during the period April 28-May 2, 1999.

Also listed in **Table 4** are the maximum rainfall totals for the given duration observed at the Colorado Springs Utilities' Colorado College station and at the Colorado Springs and Manitou Springs NWS stations. It is clear that the 100-year 24-hour design storm total rainfall was exceeded by a small amount at the Manitou Springs NWS station and by a much larger amount at the Colorado College station. It is also clear that the 100-year 96-hour design storm total rainfall was exceeded at all of these stations, by a small amount at the Colorado Springs NWS station and by far greater amounts at the Manitou Springs NWS and Colorado College stations. For the event discussed here this total rainfall was observed over a period of only 84 hours.

It is illustrative to examine the distribution of rainfall over time during this event and to compare the observed distribution with that suggested in the Drainage Criteria Manual (DCM) discussed in Section 3 of this report. For the purposes of modeling rainfall/runoff relationships, the DCM suggests using a modified version of the Soil Conservation Service's (SCS) Type II rainfall distribution, called Type IIA in the DCM. Specifically, the DCM suggests the SCS Type IIA distribution for use in eastern Colorado. This distribution describes a "front-loaded" storm or event, that is, a storm for which nearly 80% of the rainfall occurs in the first 30% of the total storm duration. The SCS Type IIA distribution may properly describe the type of High Plains thunderstorm that is common to eastern Colorado, for which an early period of heavy rainfall is followed by a longer period of light, diminishing rainfall. However, these thunderstorms typically last only 1-3 hours and may comprise only a small period in the total duration, but a large portion of the total rainfall, of the longer events discussed here.

The distribution of rainfall at the Colorado Springs NWS and Colorado College stations are compared with the SCS Type IIA distribution in **Appendix A, Figure 13**. Specifically, rainfall over the entire period April 28-May 2, 1999, at these two stations is compared with the corresponding SCS Type IIA distribution over the same period in **Figure 13a**. It is shown there that the total observed rainfall is much greater that the suggested distribution during the first 20% of the event, but that the SCS Type IIA distribution would then produce significantly heavier rainfall than was observed during the latter part of the first day. Examining the slopes of the lines on that figure (which are indicators of rainfall rate, rather than the total accumulated rainfall), it is also shown that much heavier rainfall was observed during the middle and later portions of the event (the second and third day) than would have been suggested by the SCS Type IIA distribution.

If we consider only the rainfall distribution during the period of maximum 24-hour rainfall at each of the stations discussed here, similar conclusions may be drawn in comparison with the SCS Type IIA distribution over the same period. These are shown in **Appendix A, Figure 13b**, where the period of maximum 24-hour rainfall at the Colorado Springs NWS station corresponds to the period from 5 pm LST on April 29 to 5 pm LST on April 30, 1999, and at the Colorado College station corresponds to the period from 4 pm LST on April 29 to 4 pm LST on April 30, 1999. In comparison with the SCS Type IIA distribution over the same 24-hour period, it is shown in the figure that more rainfall was observed during the first 20% (about 5 hours) of the period, but that the SCS Type IIA distribution would produce significantly heavier rainfall during the sixth hour of the period. This rainfall rate, shown by the slope of the line in **Figure 13b**, would be greater than any observed rate during the events discussed here. Similar to the total event distribution discussed above, observed rainfall rates were during the latter half of the period of maximum 24-hour rainfall were greater than would be found with the suggested distribution.

8. Summary and Conclusions

This report has addressed several rainfall events during the period from April through August of 1999, from which flood-related damages may have resulted at locations along Fountain Creek downstream of Colorado Springs, Colorado. The Fountain Creek basin was described briefly, and ten rainfall events during the periods specified in the plaintiffs' complaint have been addressed. The sources of data used to evaluate these events have also been listed here. Following an examination of large-scale influences on weather patterns in the vicinity of the Rocky Mountains, as well as an account of heavy snowstorms in the basin during the spring of 1999, the meteorological conditions supporting each of these events were identified. The five largest of these events were described and analyzed with regard to several specific weather patterns known to produce heavy rainfall and flash flood conditions along the Rocky Mountain Front Range. Hourly and daily total rainfall data have been examined at several locations for each of these events.

The largest of these events, which occurred during the period April 28-May 2, 1999, was examined in detail in this report. Hourly rainfall data have been shown here for several stations in and near the Fountain Creek basin and daily total rainfall data have been compiled and shown on schematic maps of the basin, demonstrating the concentration of rainfall within the City of Colorado Springs during that event. The total event rainfall at three stations in the vicinity of Colorado Springs has been compared with the 100-year storm rainfall totals available in several references applicable to this region, most notably in the Drainage Criteria Manual that has been adopted by the City of Colorado Springs and El Paso County, Colorado. The distributions of hourly rainfall throughout the event and during the peak 24-hour period of that event have been compared with the storm rainfall distribution suggested for eastern Colorado in the Drainage Criteria Manual.

Some conclusions regarding the largest rainfall events in the vicinity of Colorado Springs during the periods specified in the plaintiffs' complaint are listed here:

1. The period from April through August of 1999 can generally be characterized as a wet season with regard to rainfall in the vicinity of Colorado Springs, despite pre-season indications of a dry spring and summer due to La Niña conditions in the eastern equatorial Pacific Ocean. A portion of this large seasonal rainfall total can be attributed to an early extension of the North American monsoon to the Colorado region.
2. The weather patterns supporting each of the rainfall events discussed here were easily identified, even for the minor events not examined in detail, and the contribution of several of these patterns to heavy, sometimes flood-producing rainfall along the Colorado Front Range is well known.
3. Though the meteorological conditions supporting the April 28-May 2, 1999, event have been documented previously, a succession of these specific weather patterns is rare and,

in previous known cases, has produced excessive rainfall and devastating flood and flash flood conditions. Specifically, similar conditions and flood events have been observed for the Big Thompson Canyon flood on July 31, 1976, and for the Fort Collins flood on July 27-29, 1997.

4. The April 28-May 2, 1999, event was preceded by heavy snowstorms in upstream portions of the Fountain Creek basin that likely led to near-saturated soil conditions in that portion of the basin. A combination of near-saturated soil conditions and heavy initial rainfall during the April 28-May 2, 1999, event led to greater runoff than would have occurred for dry antecedent conditions. Given the complete saturation of soils during the first storm of this event, all of the rainfall during the sustained and intense second storm of the event was likely converted to runoff.
5. As shown in **Appendix B, Table 4**, maximum 24-hour rainfall totals at the Colorado College and Manitou Springs NWS stations during the April 28-May 2, 1999, event exceeded all available measures of the regional 100-year 24-hour storm, including that provided in the Drainage Criteria Manual adopted by the City of Colorado Springs and El Paso County, Colorado. In addition, the total event (84-hour) rainfall at each of these two stations and at the Colorado Springs NWS station exceeded the 100-year 96-hour storm total rainfall as indicated in the only available reference for such data. It has been noted that the 2.63 inches of rainfall recorded at the Colorado Springs NWS station on April 30, 1999, is the largest daily precipitation amount during April on record for that location.
6. For the event described here during August 3-7, 1999, a maximum 24-hour rainfall total of 4.22 inches was recorded at the Colorado Springs NWS station around August 4, 1999. The total rainfall for this event also approached, but did not exceed, the 100-year 24-hour storm indicated for the region of Colorado Springs in the available references. However, it has been noted that the 3.98 inches of rainfall recorded at the Colorado Springs NWS station on August 4, 1999, is the largest single-day precipitation amount on record for that location.
7. References such as the NOAA Atlas 2 maps employed for the estimation of total storm rainfall in the Drainage Criteria Manual adopted by the City of Colorado Springs and El Paso County, Colorado, do not account for the rare succession of meteorological patterns that led to the April 28-May 2, 1999, event.
8. The observed rainfall distributions during the April 28-May 2, 1999, event differed significantly from the SCS Type IIA rainfall distribution suggested in the Drainage Criteria Manual. While the distribution suggested for the design of drainage facilities may accurately represent a type of High Plains thunderstorm that is common to the region of Colorado Springs, intense rainfall during the observed event resulted from nearly stationary convective storms that were supported by upslope flows.

APPENDIX A

Figures

Figure 1: Colorado Springs and surrounding areas within the Fountain Creek basin. This map was created by the Pikes Peak Area Council of Governments (*http://www.ppacg.org*).

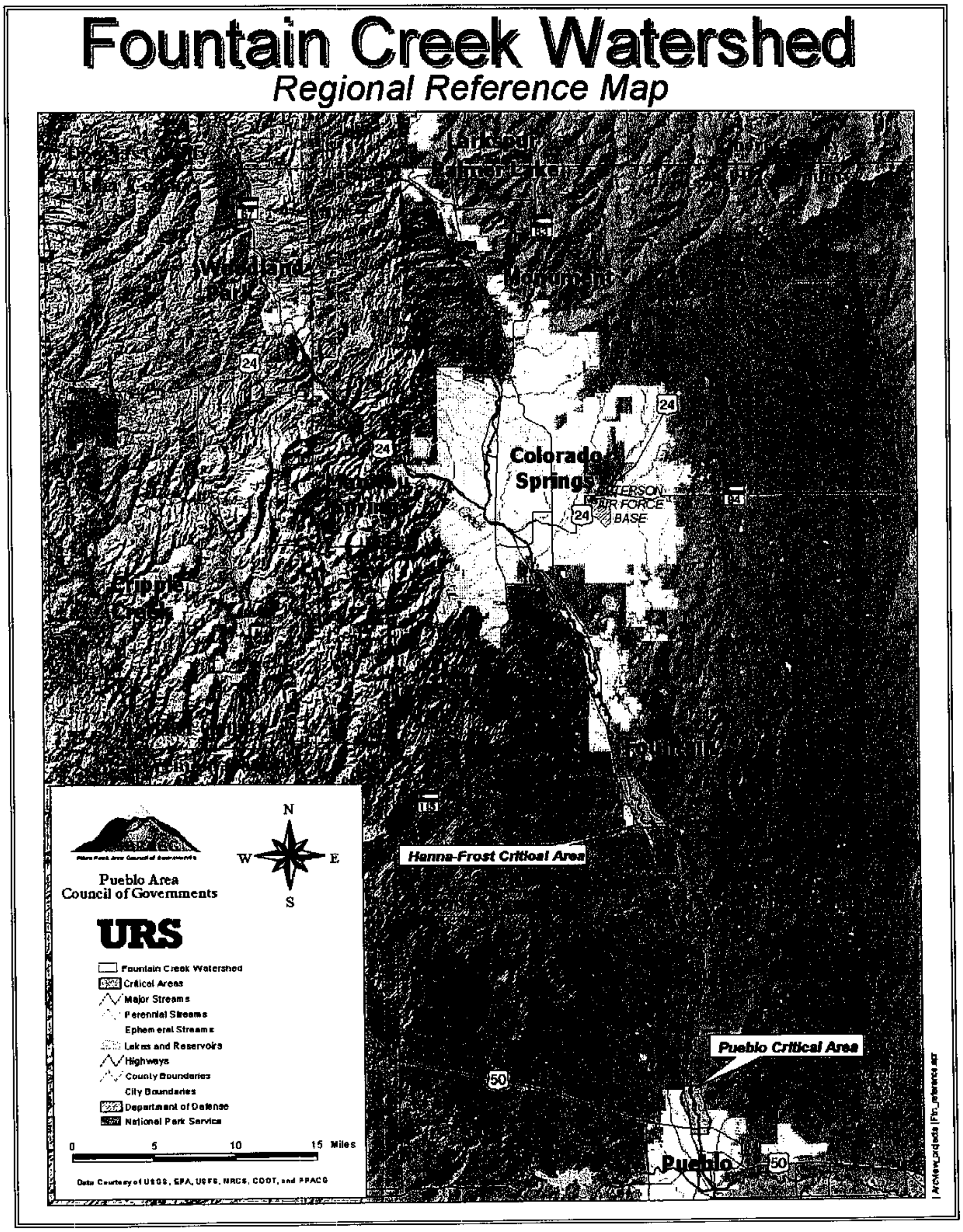


Figure 2: A portion of the NOAA Atlas 2 (Volume III: Colorado) map for Colorado Springs and the surrounding area showing rainfall totals for the 100-year 24-hour storm. Blue contour lines indicate surface elevation in thousands of feet. Black contour lines indicate 100-year 24-hour rainfall in tenths of an inch.

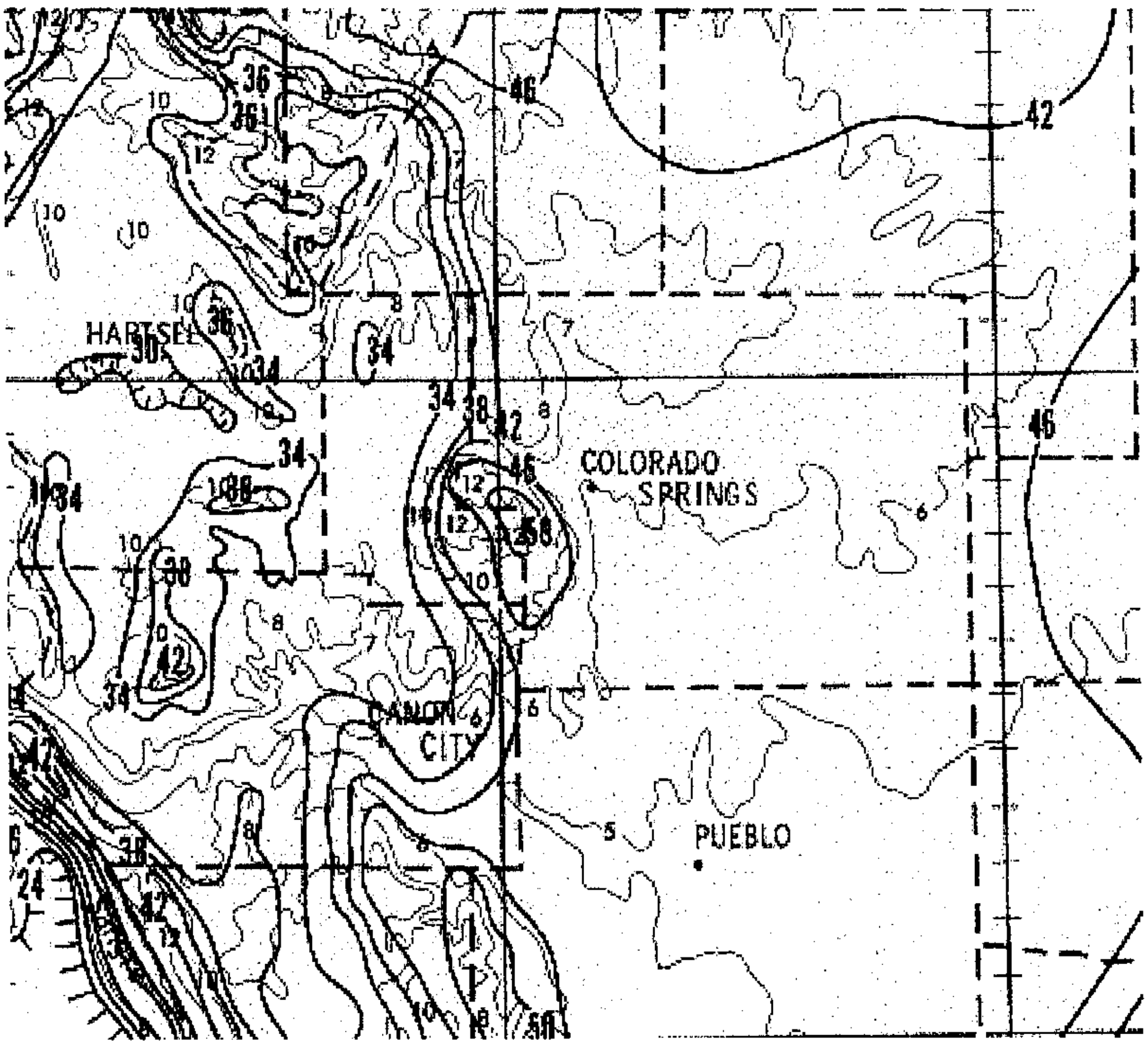


Figure 3: Charts showing the correlation of La Niña conditions in the eastern equatorial Pacific Ocean and seasonal precipitation along the Rocky Mountain Front Range, from the NOAA-CIRES Climate Diagnostic Center (*http://www.cdc.noaa.gov/Climaterisks*). Months are abbreviated: "DJF" indicates December-January-February, "MAM" indicates March-April-May, etc. The Southern Oscillation Index (SOI) is an indicator of El Niño/La Niña status that employs surface pressure observations in the tropical Pacific Ocean. These charts apply to the observation of precipitation extremes along the Rocky Mountain Front Range following La Niña events only; charts for precipitation extremes following El Niño events can also be found at the above website. To use these charts:

1. Select the chart corresponding to the season or period of the precipitation extreme (listed at the top of each chart).
2. On that chart, select the pair of histogram bars corresponding to the season or period of the most recent extreme La Niña event (listed on the horizontal axis of each chart).

The numbers of observed wet and dry seasonal precipitation extremes are then read from the selected pair of histogram bars.

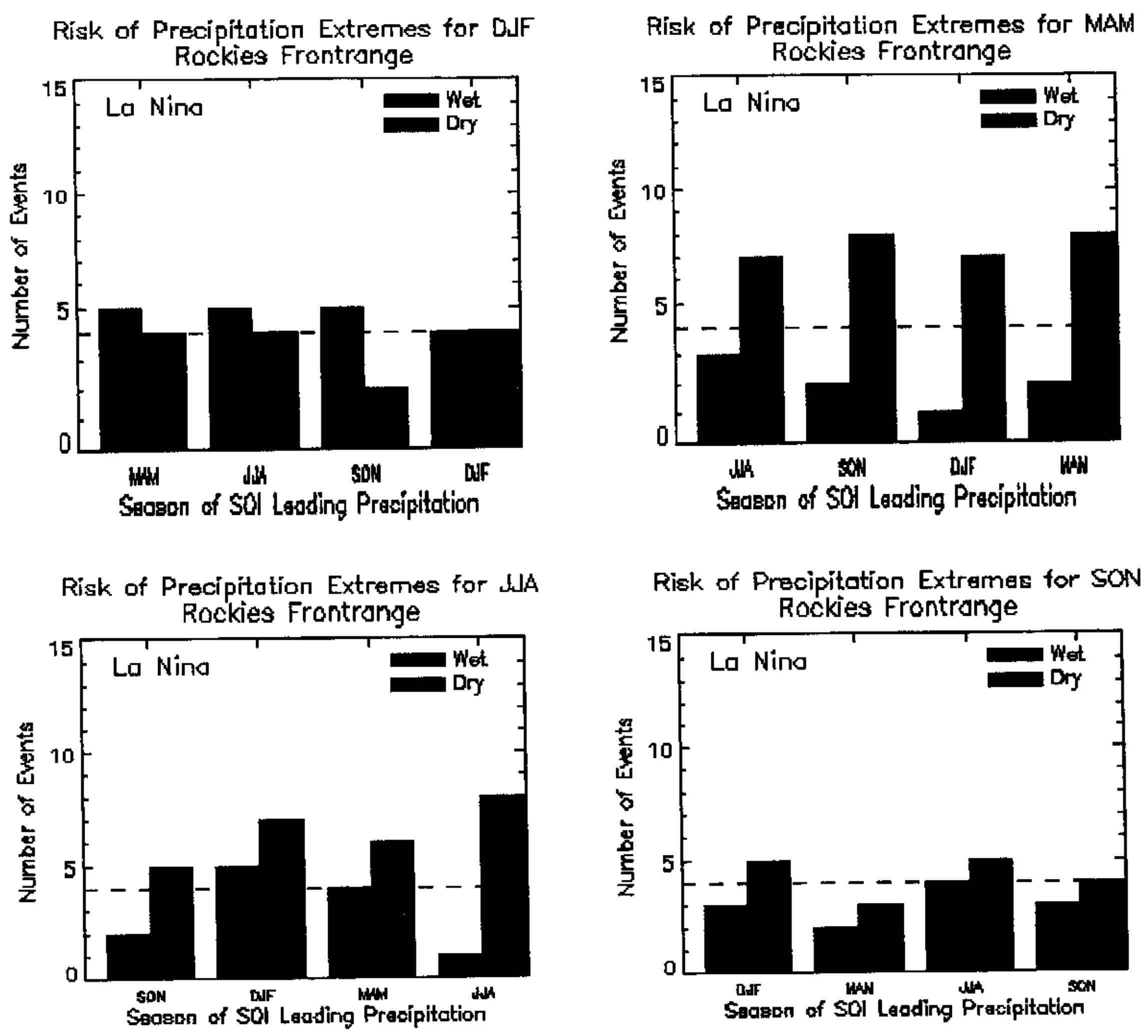


Figure 4: Figure 2 from Doswell (1980), showing the configuration of weather features most favorable for severe thunderstorm events along the Rocky Mountain Front Range and in eastern Colorado. Explanations of the schematic markings are given in the original caption, below.

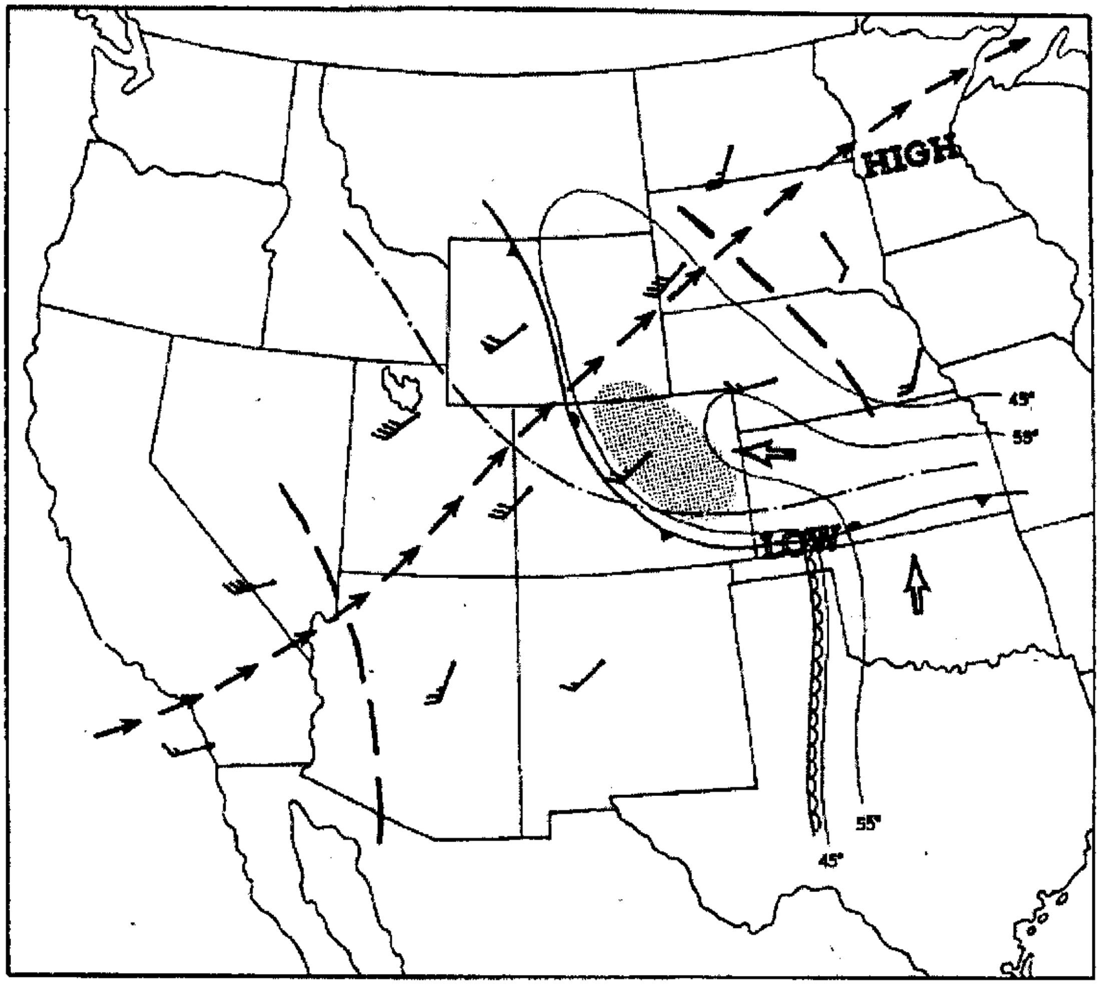


FIG. 2. Composite High Plains severe thunderstorm parameter chart. Frontal symbols are conventional, surface isodrosotherms (°F) denoted by fine lines, scalloped line indicates surface dryline, large arrows depict surface flow, and "High" and "Low" refer to surface pressure centers. Dash-dot line locates the 700 mb thermal ridge. Wind barbs show 500 mb winds (full barb signifies 5 m s⁻¹, flag signifies 25 m s⁻¹), and heavy dashed lines locate short-wave trough axes. Chain of arrows is aligned along core of strong high-level winds, above 500 mb. Stippling denotes region of expected severe thunderstorms.

Figure 5: Figure 1 from Maddox *et al.* (1980), showing the configuration of weather features most favorable for Type I flash flood events over the western U.S. Explanations of the schematic markings are given in the original caption, below. Note that the underlying map is provided only for scale, and does not indicate that the only region of flash flood threat lies in and near Idaho at all times.

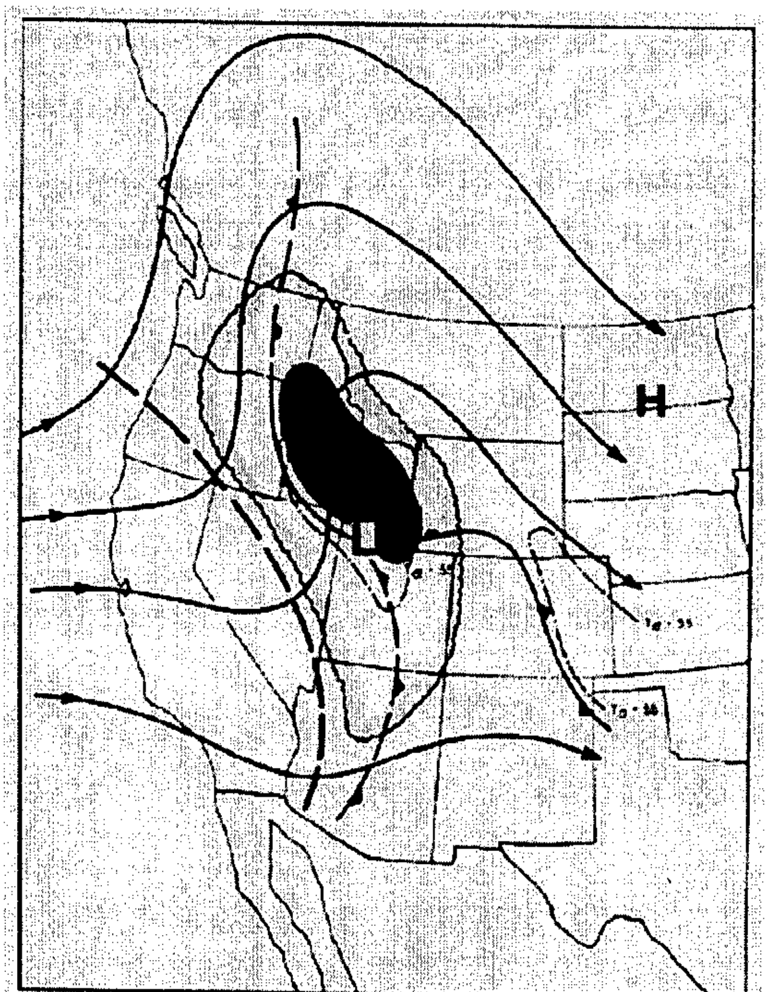


FIG. 1. Generalized 500 mb and surface patterns for Type I western flash floods. Streamlines for 500 mb flow are shown and 500 mb trough position is depicted as a heavy dashed line. Region at 500 mb with $T - T_d \le 6°C$ is outlined. Surface fronts and pressure centers are indicated, as well as isopleths for regions with high surface dewpoint temperatures. Time of analysis is just prior (0–3 h) to onset of storm activity. Region with potential for heavy precipitation is shaded.

Figure 6: Figure 4 from Maddox *et al.* (1980), showing the configuration of weather features most favorable for Type IV flash flood events over the western U.S. Explanations of the schematic markings are given in the original caption in **Figure 5**, above. Note that the underlying map is provided only for scale, and does not indicate that the only region of flash flood threat lies in and near Arizona at all times.

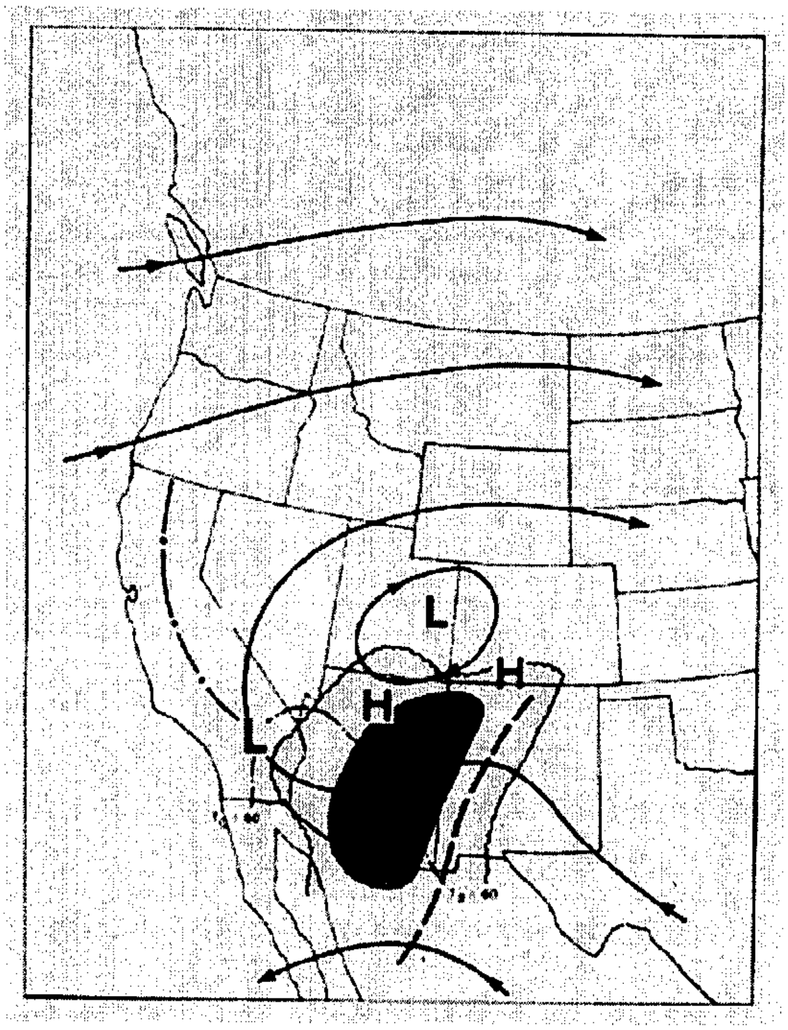


FIG. 4. Generalized 500 mb and surface patterns for Type IV western flash floods; details are similar to those of Fig. 1.

Figure 7a: Histogram of hourly rainfall, in inches, at the Colorado Springs NWS station during the period April 28-May 2, 1999, for the storm event described in Section 5.1 of this report. This station corresponds to the location marked **2** in **Figure 8a**.

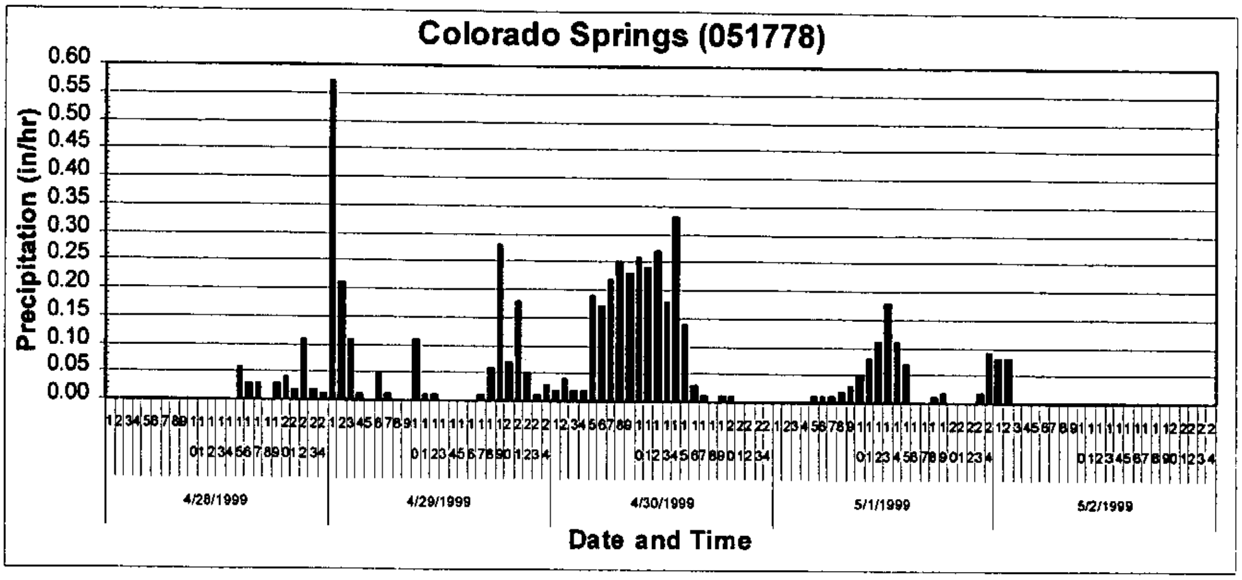


Figure 7b: Histogram of hourly rainfall, in inches, at the Colorado College (Colorado Springs Utilities) weather station during the period April 28-May 2, 1999, for the storm event described in Section 5.1 of this report. This station corresponds to the location marked **1** in **Figure 8a**.

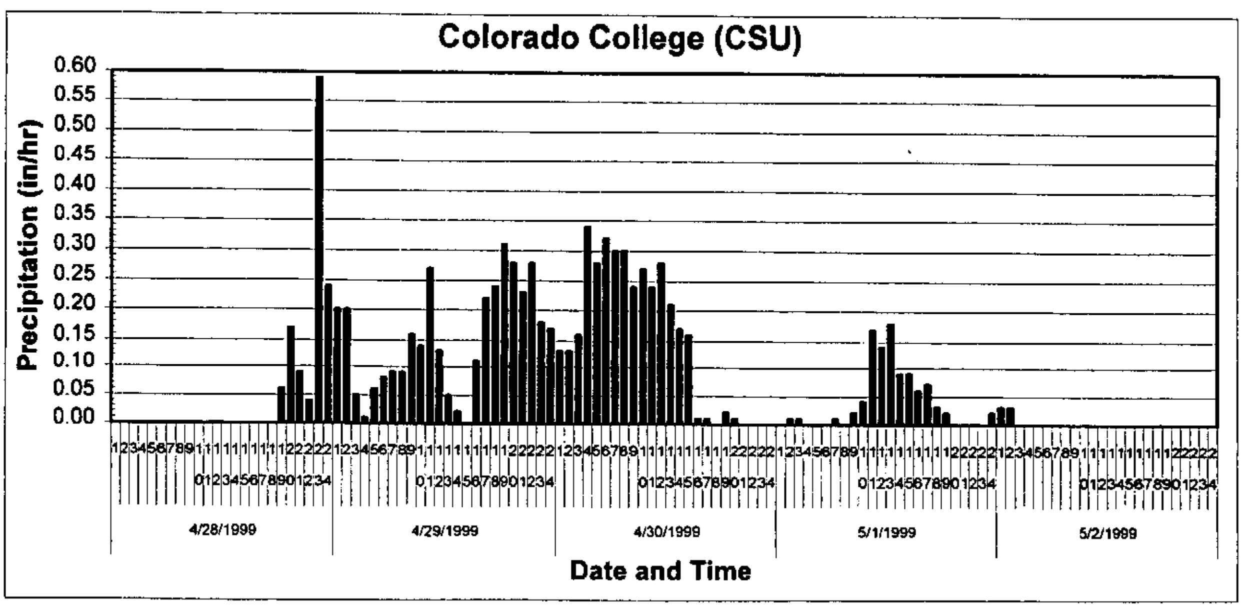


Figure 7c: Histogram of hourly rainfall, in inches, at the Manitou Springs NWS station during the period April 28-May 2, 1999, for the storm event described in Section 5.1 of this report. This station corresponds to the location marked **7** in **Figure 8a**.

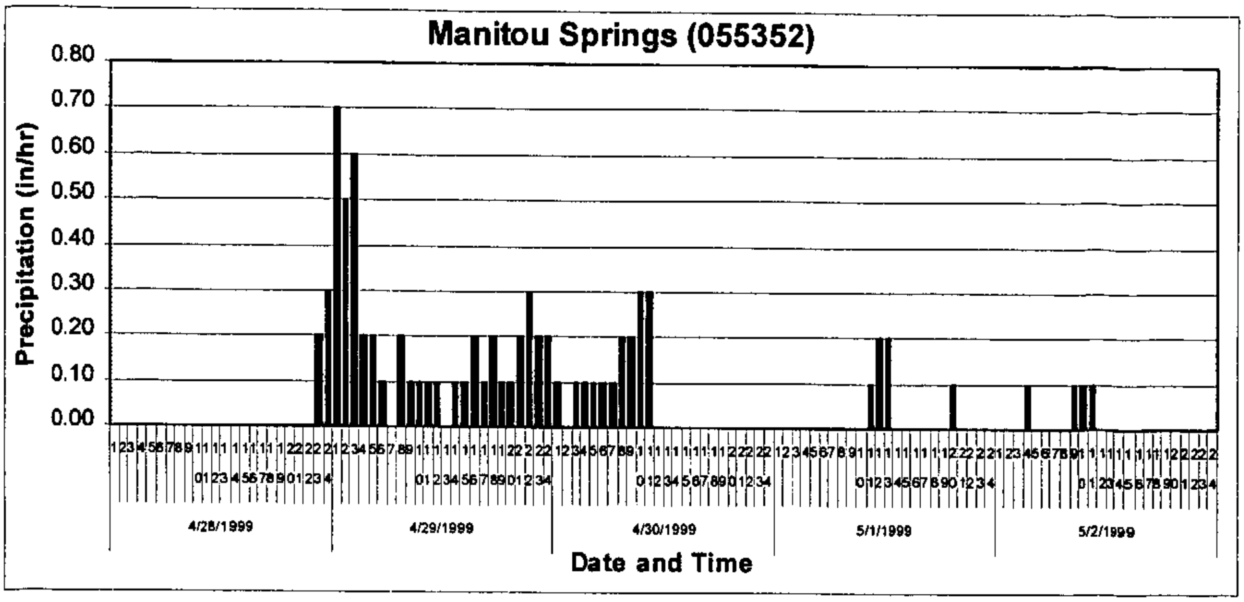


Figure 7d: Histogram of hourly rainfall, in inches, at the Greenland 9 SE NWS station during the period April 28-May 2, 1999, for the storm event described in Section 5.1 of this report. This station corresponds to the location marked **6** in **Figure 8a**.

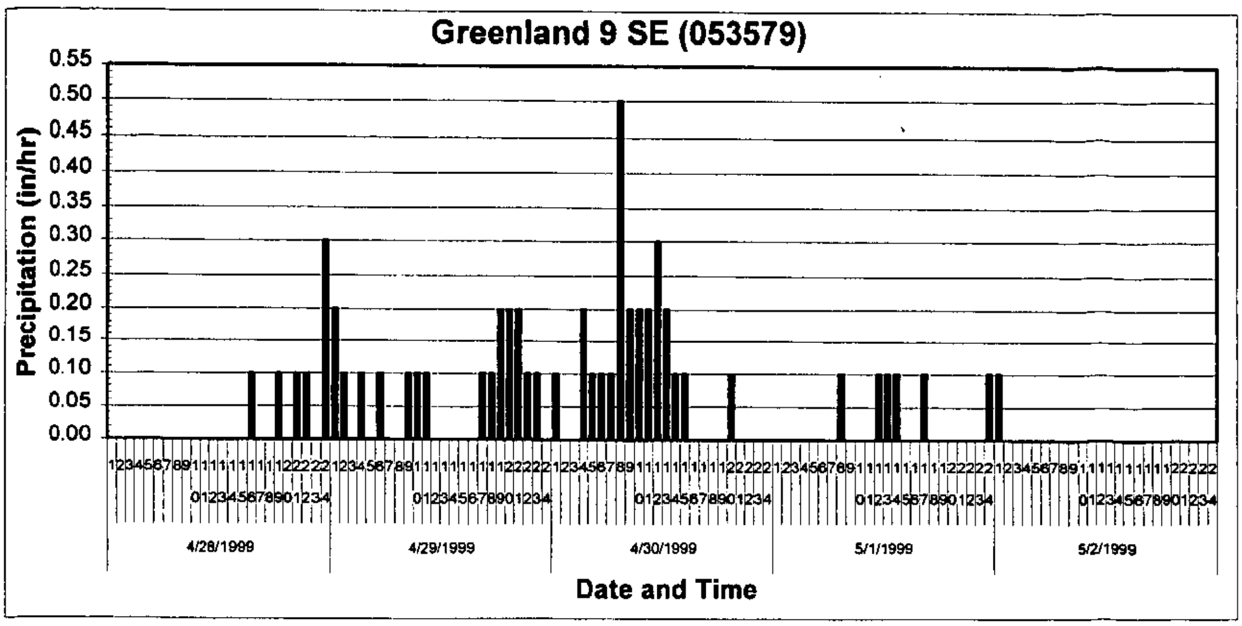


Figure 7e: Histogram of hourly rainfall, in inches, at the Nixon Base (Colorado Springs Utilities) weather station during the period April 28-May 2, 1999, for the storm event described in Section 5.1 of this report. This station corresponds to the location marked **11** in **Figure 8a.**

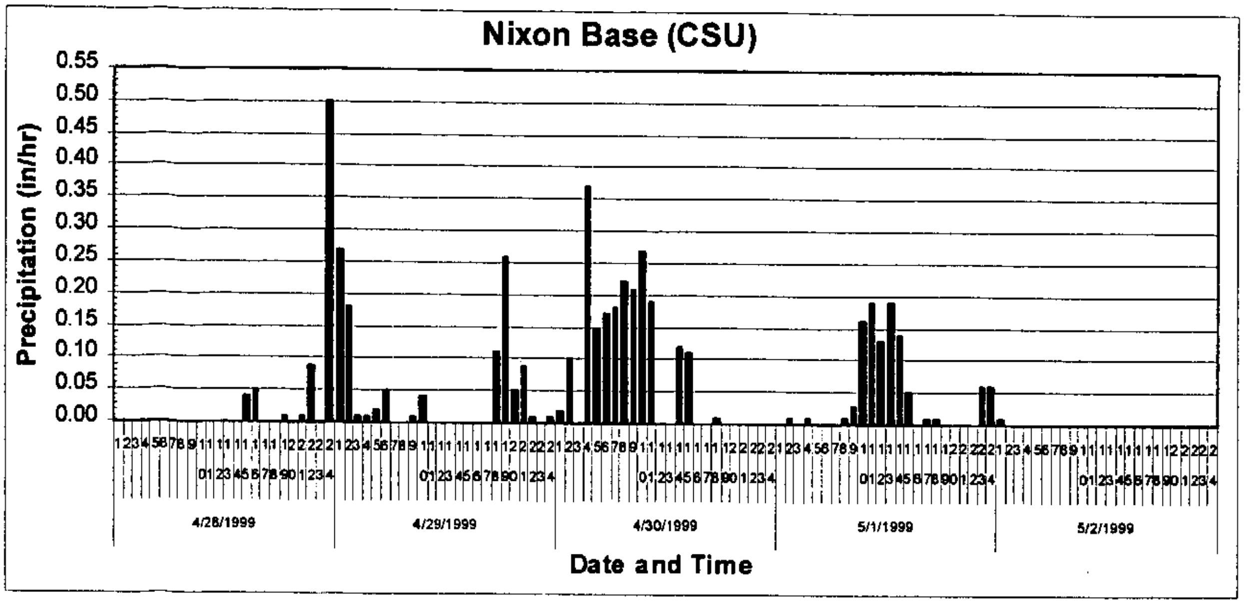


Figure 7f: Histogram of hourly rainfall, in inches, at the Piniello Ranch (Colorado Springs Utilities) weather station during the period April 28-May 2, 1999, for the storm event described in Section 5.1 of this report. This station corresponds to the location marked **13** in **Figure 8a.**

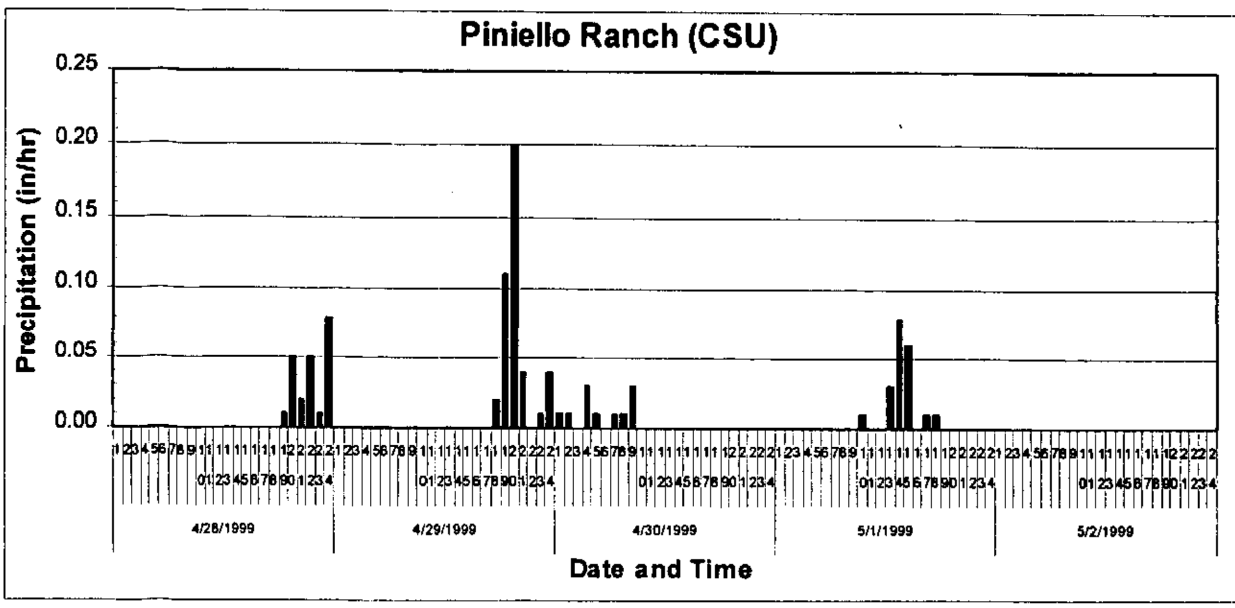


Figure 7g: Histogram of hourly rainfall, in inches, at the Pueblo NWS station during the period April 28-May 2, 1999, for the storm event described in Section 5.1 of this report. This station corresponds to the location marked **14** in **Figure 8a**.

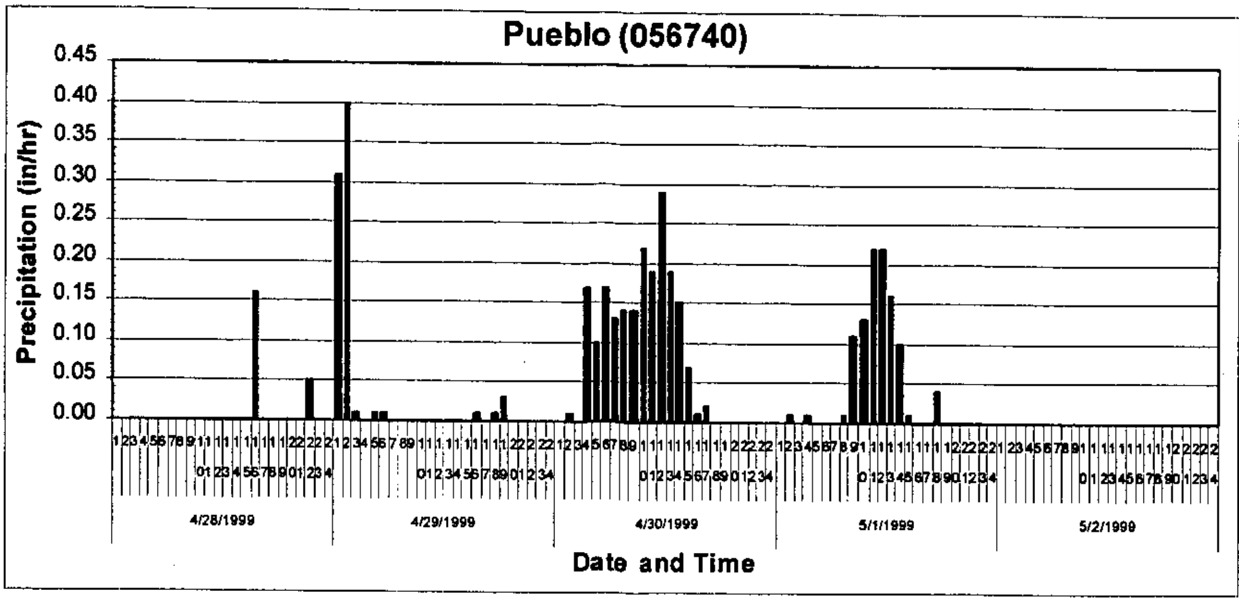


Figure 8a: Schematic map of Fountain Creek basin showing the locations of rainfall gauges employed in this work. The location numbers correspond to gauges listed in **Appendix B, Table 3**. The dotted lines represent the approximate courses of Monument and Fountain Creeks.

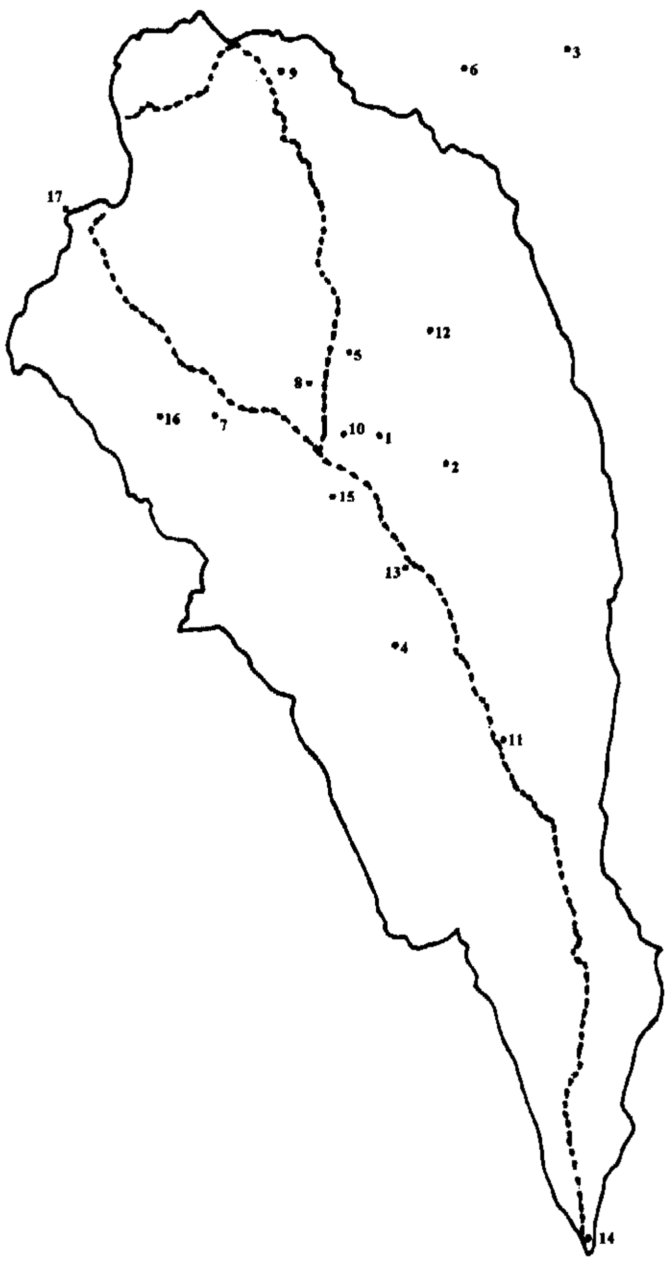


Figure 8b: Schematic map of Fountain Creek basin showing the daily total rainfall observed for April 28, 1999, during the storm event described in Section 5.1 of this report. Contour lines indicate rainfall in inches.

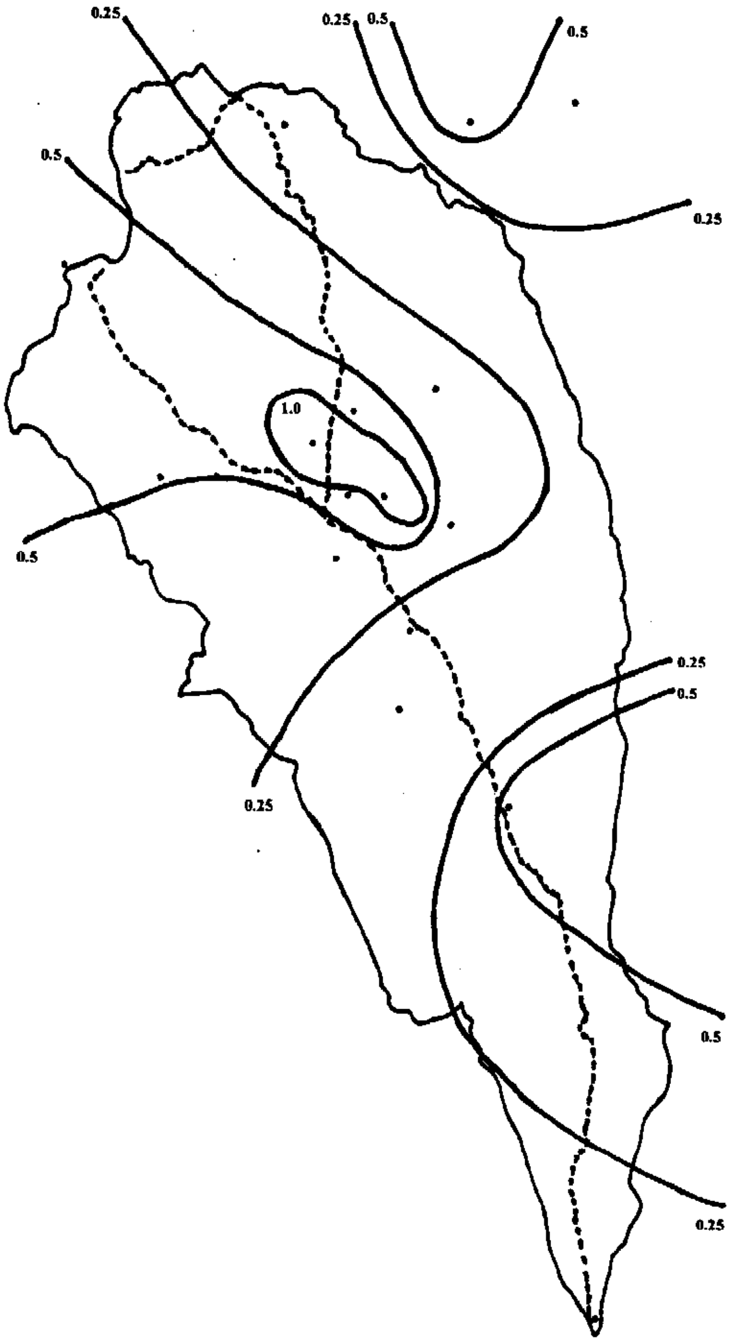


Figure 8c: Schematic map of Fountain Creek basin showing the daily total rainfall observed for April 29, 1999, during the storm event described in Section 5.1 of this report. Contour lines indicate rainfall in inches.

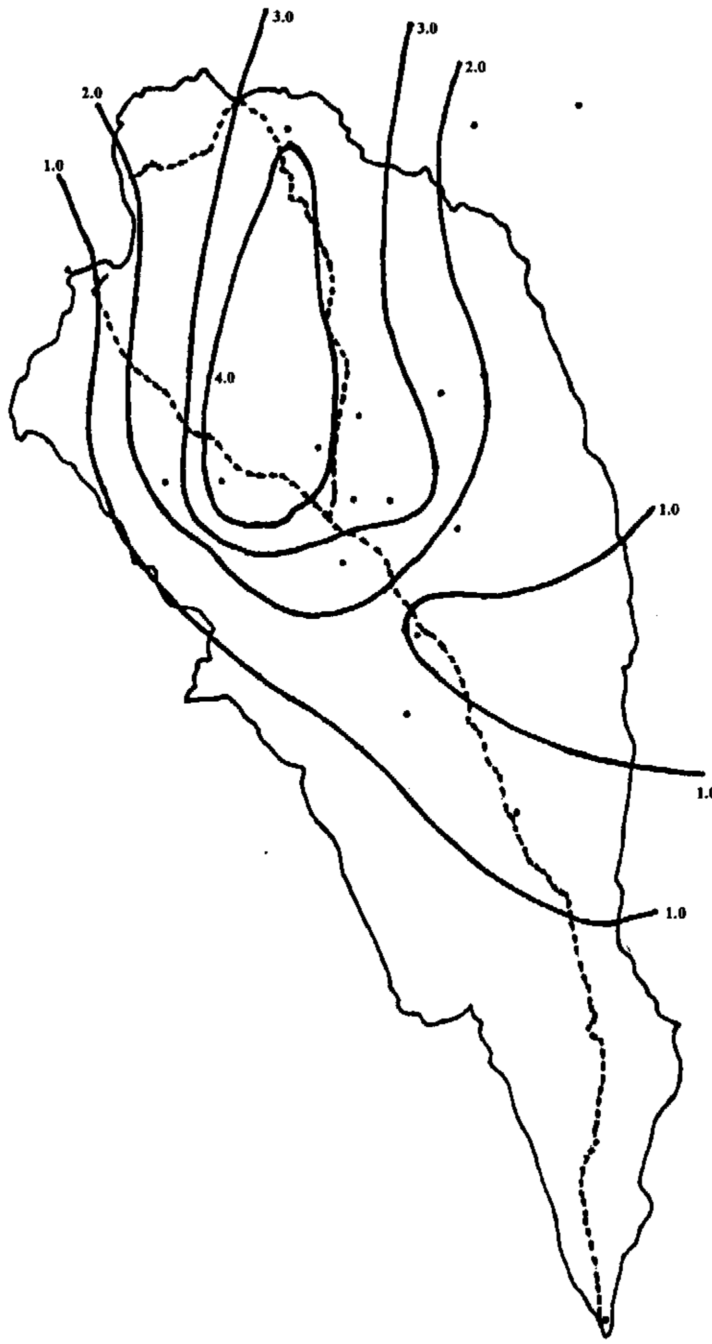


Figure 8d: Schematic map of Fountain Creek basin showing the daily total rainfall observed for April 30, 1999, during the storm event described in Section 5.1 of this report. Contour lines indicate rainfall in inches.

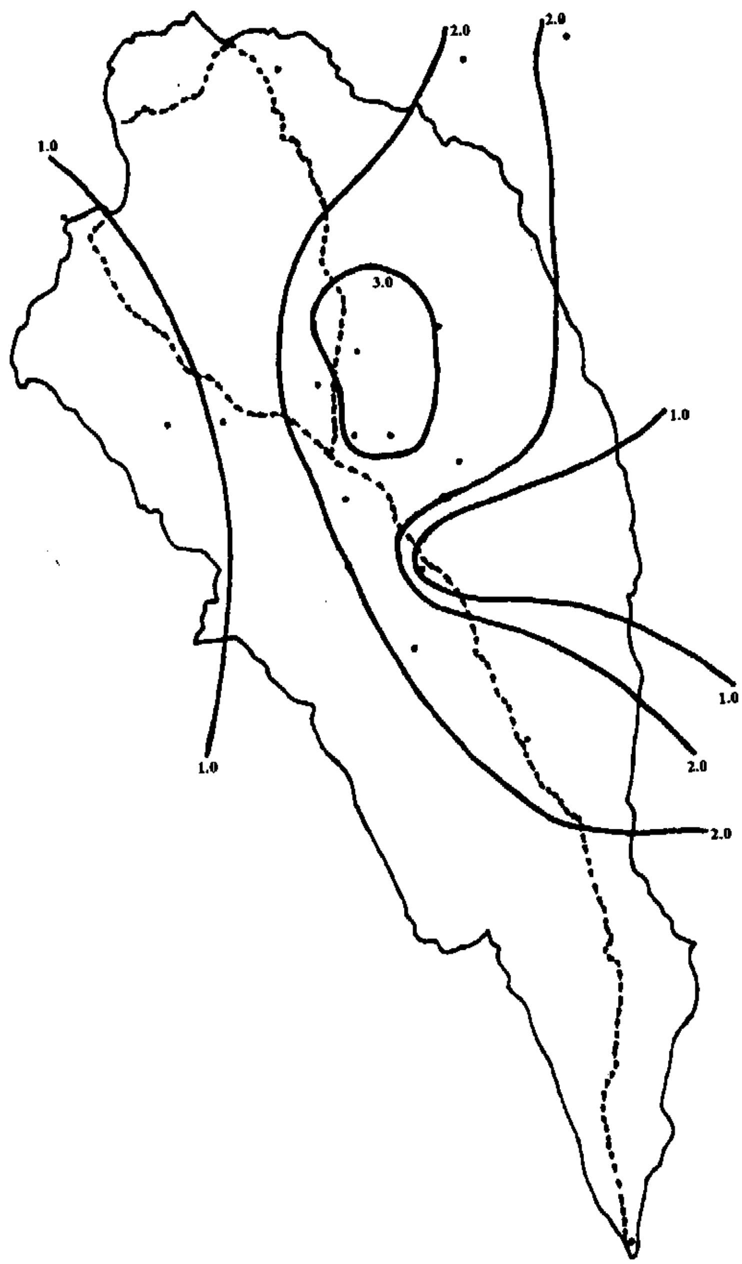


Figure 8e: Schematic map of Fountain Creek basin showing the daily total rainfall observed for May 1, 1999, during the storm event described in Section 5.1 of this report. Contour lines indicate rainfall in inches.

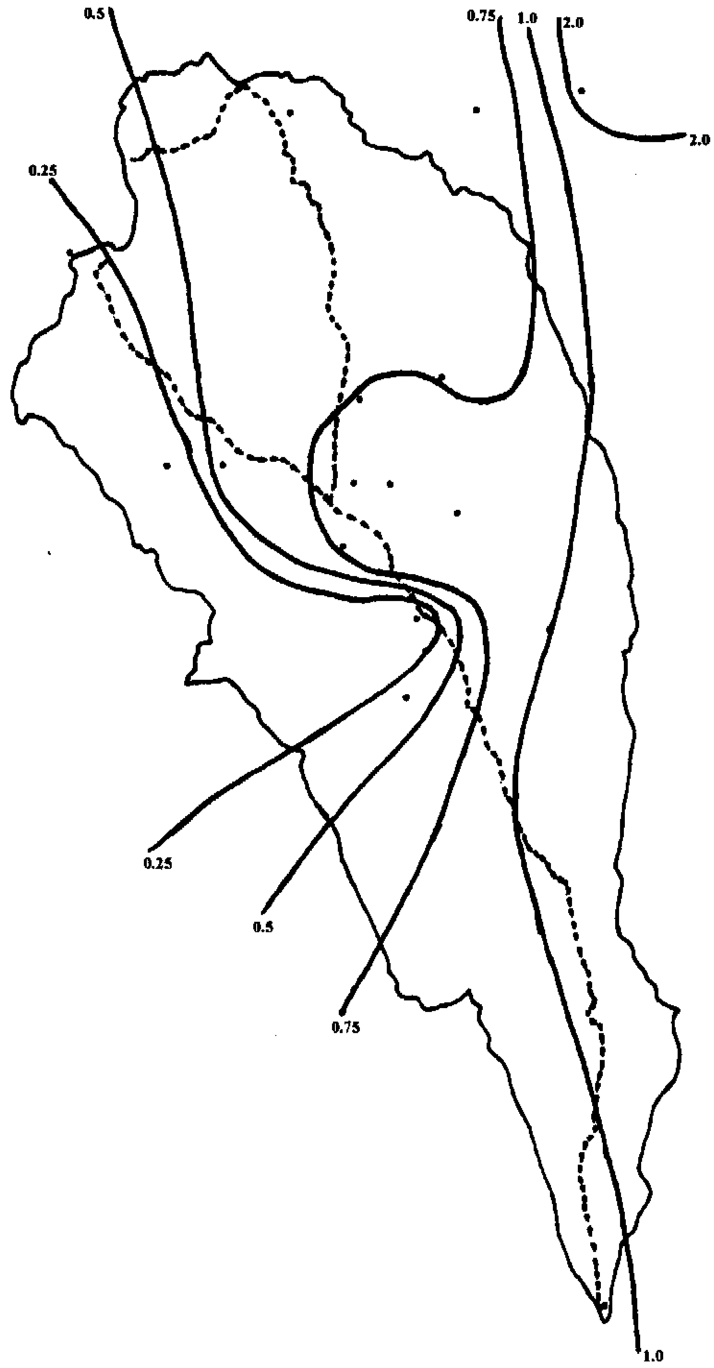


Figure 8f: Schematic map of Fountain Creek basin showing the daily total rainfall observed for May 2, 1999, during the storm event described in Section 5.1 of this report. Contour lines indicate rainfall in inches.

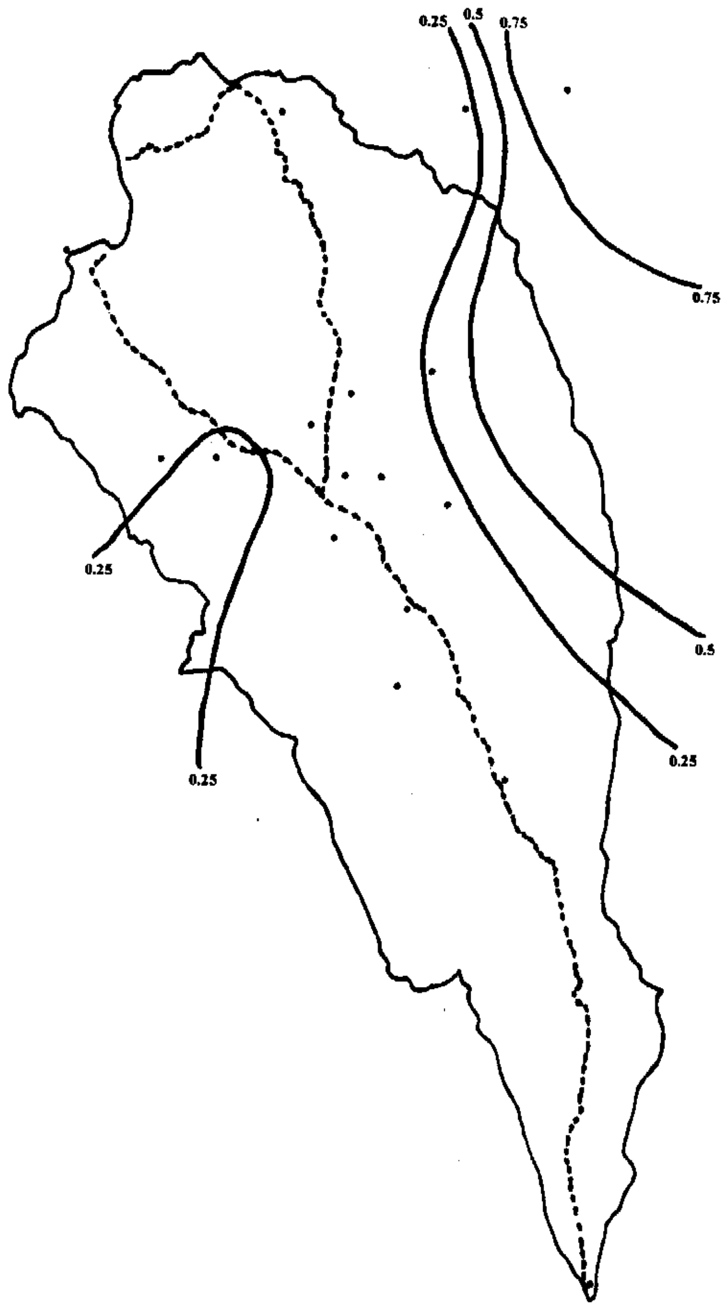


Figure 8g: Schematic map of Fountain Creek basin showing the total rainfall observed during the period April 28-May 2, 1999, for the storm event described in Section 5.1 of this report. Contour lines indicate rainfall in inches.

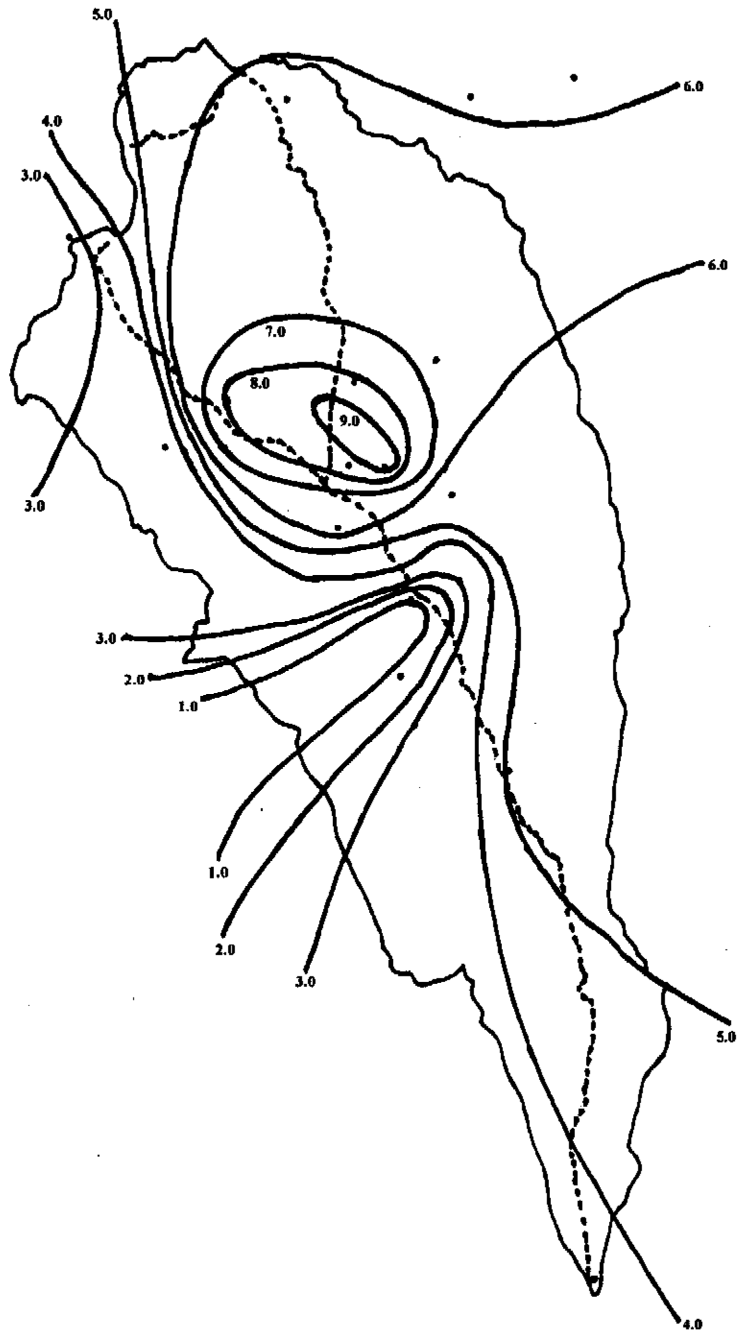


Figure 9: Histogram of hourly rainfall, in inches, at the Colorado Springs NWS station during the period May 24-28, 1999, for the storm event described in Section 5.2 of this report. This station corresponds to the location marked **2** in **Figure 8a**

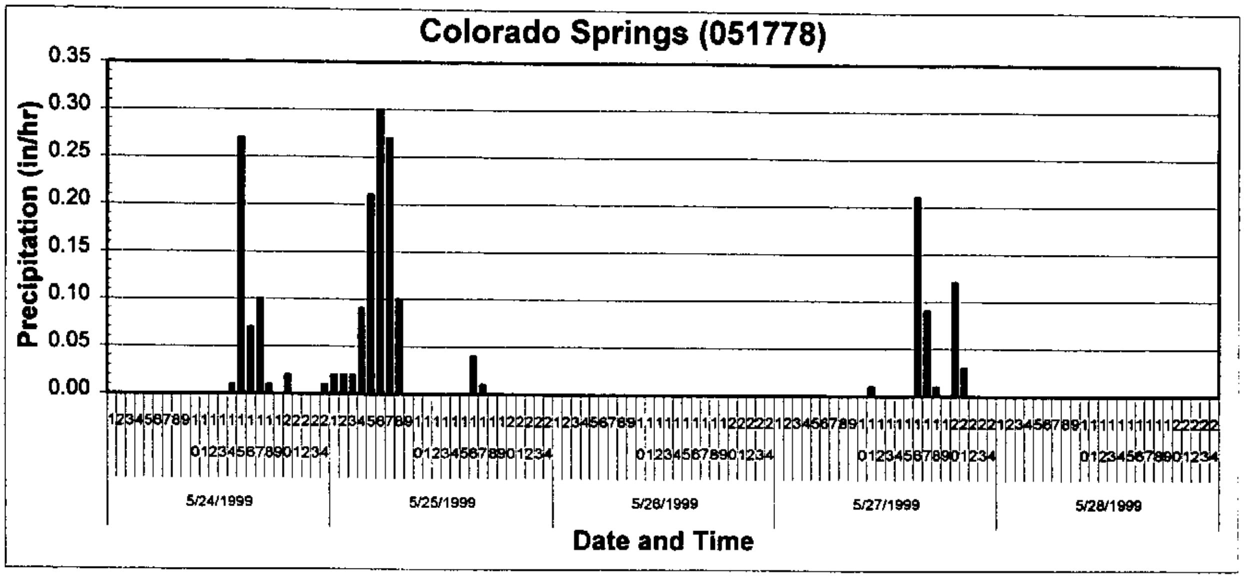


Figure 10: Histogram of hourly rainfall, in inches, at the Colorado Springs NWS station during the period July 15-19, 1999, for the storm event described in Section 5.3 of this report. This station corresponds to the location marked **2** in **Figure 8a**

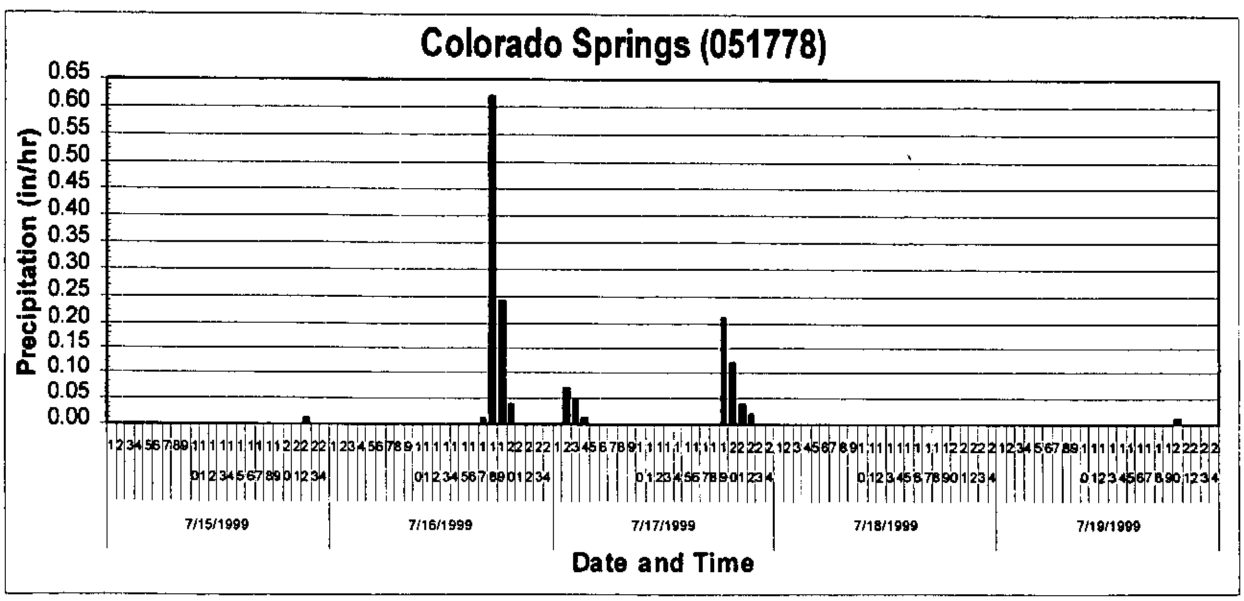


Figure 11: Histogram of hourly rainfall, in inches, at the Colorado Springs NWS station during the period from July 28 to August 1, 1999, for the storm event described in Section 5.4 of this report. This station corresponds to the location marked **2** in **Figure 8a**

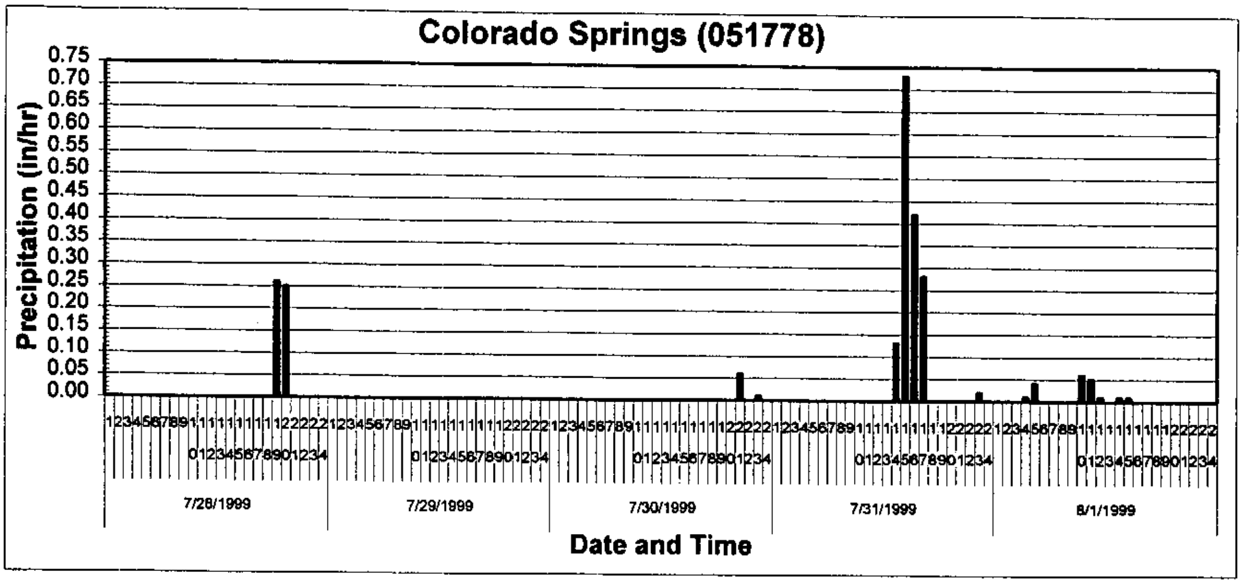


Figure 12: Histogram of hourly rainfall, in inches, at the Colorado Springs NWS station during the period August 3-7, 1999, for the storm event described in Section 5.5 of this report. This station corresponds to the location marked **2** in **Figure 8a**

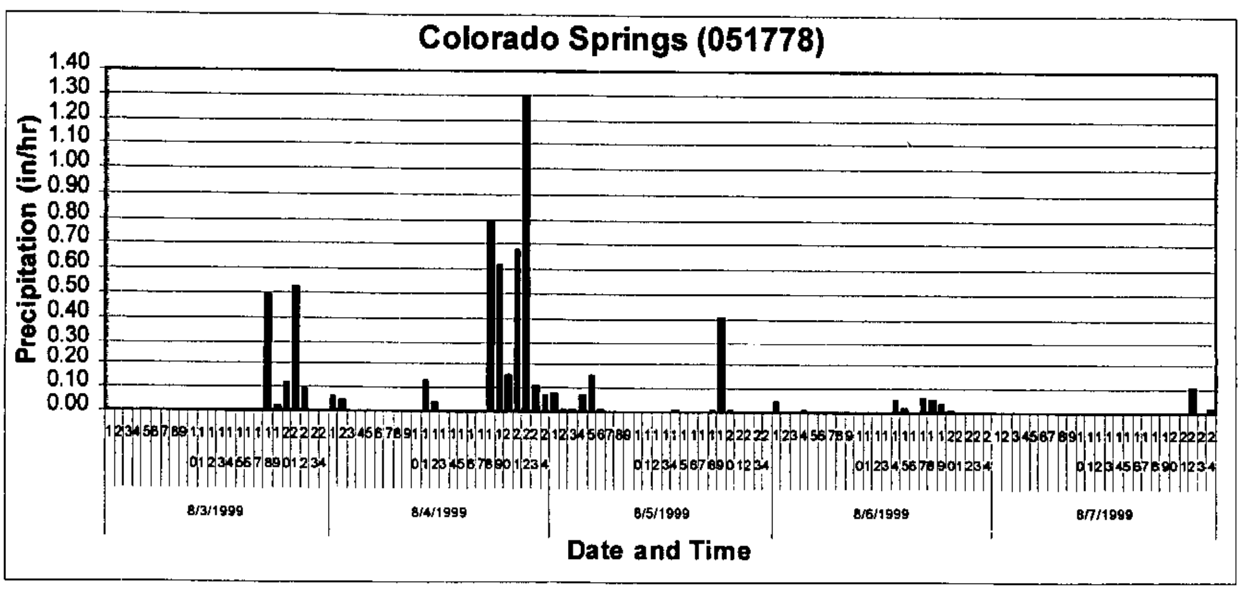


Figure 13a: Comparison of observed rainfall distribution over the duration of the event described in Section 5.1 of this report at the Colorado Springs NWS and Colorado College stations with the SCS Type IIA rainfall distribution suggested in the City of Colorado Springs and El Paso County Drainage Criteria Manual.

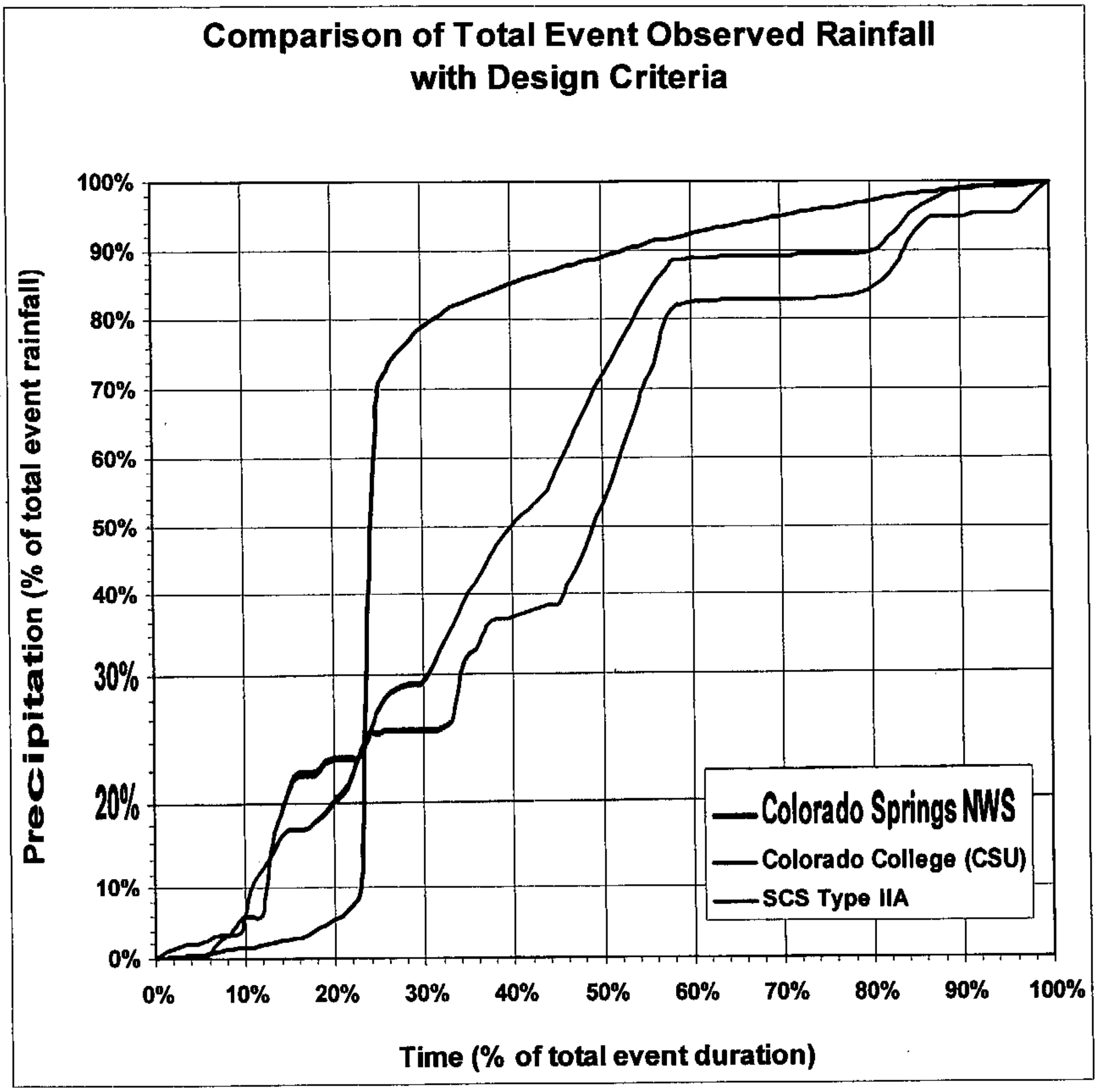
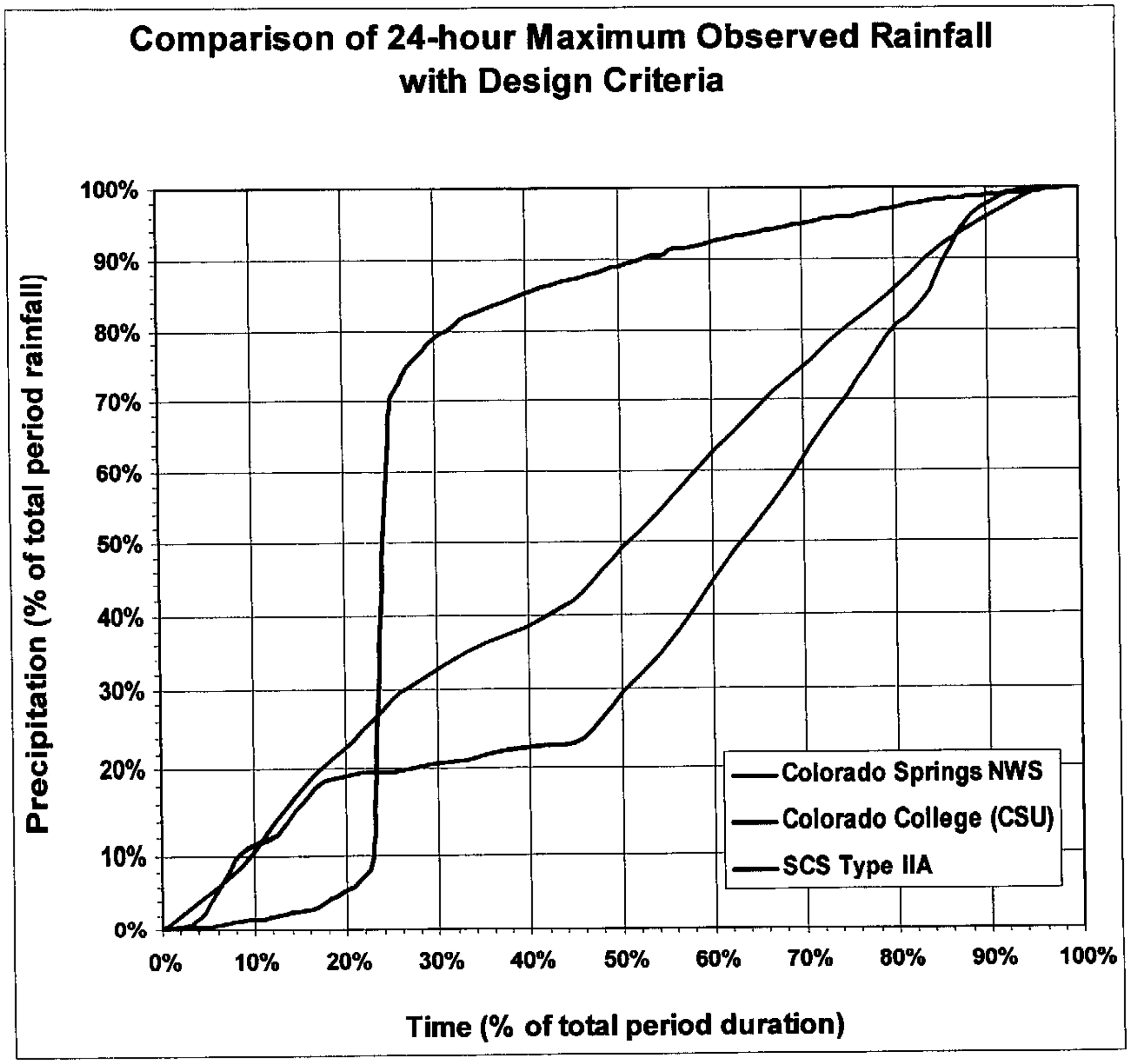


Figure 13b: Comparison of observed rainfall distribution during the period of maximum 24-hour rainfall (from 5 pm LST on April 29 to 5 pm LST on April 30 at the Colorado Springs NWS station, and from 4 pm LST on April 29 to 4 pm LST on April 30 at the Colorado College station) during the event described in Section 5.1of this report with the SCS Type IIA rainfall distribution suggested in the City of Colorado Springs and El Paso County Drainage Criteria Manual.



APPENDIX B

Tables

Table 1: Climatological monthly mean and extreme rainfall during 1948-2000, and monthly total rainfall observations during 1999 at the Colorado Springs NWS station, as compiled by the Western Regional Climate Center (*http://www.wrcc.dri.edu*). Liquid equivalent precipitation is indicated, for which trace amounts are excluded.

Month	Mean (1948-2000)	Standard deviation	Maximum monthly total	Maximum single day	1999 monthly total
April	1.37 in	1.34 in	7.50 in (1999)	2.63 in (4/30/1999)	7.50 in
May	2.28 in	1.44 in	5.67 in (1957)	2.23 in (5/18/1955)	3.57 in
June	2.31 in	1.69 in	8.00 in (1965)	2.65 in (6/20/1970)	1.36 in
July	2.94 in	1.35 in	5.27 in (1968)	3.63 in (7/29/1997)	4.70 in
August	2.96 in	1.64 in	7.04 in (1999)	3.98 in (8/4/1999)	7.04 in

Table 2: Daily total rainfall, in inches, at stations in the vicinity of Colorado Springs for the periods listed in the plaintiffs' complaint. Period totals exclude trace (T) amounts. A single asterisk (*) denotes the largest daily precipitation amount during April on record at the Colorado Springs NWS station. A double asterisk (**) denotes the largest single-day precipitation amount recorded during 1948-2000 at the Colorado Springs NWS station. The notation "PF" indicates missing data. The major storm events examined in Section 5 of this report are shaded.

Date	Colorado College (C.S. Utilities)	Colorado Springs (NOAA/NWS)	Manitou Springs (NOAA/NWS)
4/28/99	1.19	0.39	0.50
4/29/99	3.57	1.75	4.70
4/30/99	3.58	2.63*	1.60
5/1/99	0.96	0.82	0.60
5/2/99	0.06	0.16	0.40
5/3/99	0.00	T	0.00
5/4/99	0.00	T	0.00
5/5/99	0.00	T	0.00
5/6/99	0.00	0.00	0.00
5/7/99	0.00	0.00	0.00
5/8/99	0.00	0.00	0.00
5/9/99	0.00	0.00	0.00
5/10/99	0.02	0.02	0.00
Period Total	9.38	5.77	7.80

5/23/99	0.06	T	0.10
5/24/99	0.21	0.49	0.10
5/25/99	1.15	1.08	0.80
5/26/99	0.00	0.00	0.00
5/27/99	0.42	0.47	0.30
5/28/99	0.01	0.00	0.00
5/29/99	PF	0.05	0.00
5/30/99	PF	T	0.00
5/31/99	PF	0.10	0.00
6/1/99	0.09	T	0.00
6/2/99	0.02	T	0.00
6/3/99	0.01	0.00	0.00
6/4/99	0.00	0.00	0.00
Period Total	1.97	2.19	1.30

Table 2 (cont.): Daily total rainfall, in inches, at stations in the vicinity of Colorado Springs for the periods listed in the plaintiffs' complaint. Period totals exclude trace (T) amounts. A double asterisk (**) denotes the largest single-day precipitation amount recorded during 1948-2000 at the Colorado Springs NWS station. The major storm events examined in Section 5 of this report are shaded.

Date	Colorado College (C.S. Utilities)	Colorado Springs (NOAA/NWS)	Manitou Springs (NOAA/NWS)
7/8/99	0.23	0.21	0.00
7/9/99	0.00	0.00	0.00
7/10/99	0.00	0.00	0.00
7/11/99	0.00	T	0.00
7/12/99	0.00	T	0.00
7/13/99	0.00	0.00	0.00
7/14/99	0.00	T	0.00
7/15/99	0.07	0.01	0.00
7/16/99	0.49	0.91	0.00
7/17/99	0.04	0.52	0.00
7/18/99	0.50	0.00	0.00
7/19/99	0.07	0.01	0.00
7/20/99	0.00	0.00	0.00
7/21/99	0.00	T	0.00
7/22/99	0.00	T	0.00
7/23/99	0.00	T	0.00
7/24/99	0.20	0.00	0.00
7/25/99	0.00	T	0.00
7/26/99	0.00	0.00	0.00
7/27/99	0.00	0.00	0.00
7/28/99	0.19	0.51	0.00
7/29/99	0.00	T	0.00
7/30/99	0.98	0.07	0.00
7/31/99	0.70	2.36	0.00
8/1/99	0.00	0.19	0.00
8/2/99	0.01	0.00	0.00
8/3/99	0.24	1.26	0.00
8/4/99	1.72	3.98**	0.00
8/5/99	0.33	0.77	0.00
8/6/99	0.57	0.27	0.00
8/7/99	0.15	0.13	0.00
8/8/99	0.01	0.03	0.00
8/9/99	0.20	0.03	0.00
8/10/99	0.07	0.01	0.00
Period Total	6.77	10.49	0.00

Table 3: Names and locations of rainfall gauges shown in **Appendix A, Figure 8a**.

No. in Figure 8a	Station Name (COOP ID)	Station Agency	Lat. (North)	Long. (West)	Elev. (feet)
1	Colorado College	CSU[1]	38.85	104.83	6020
2	Colorado Springs (051778)	NWS[2]	38.82	104.72	6139
3	Eastonville 2 NNW (052494)	NWS	39.12	104.60	7208
4	Fort Carson AFB (053002)	NWS	38.68	104.77	5870
5	4 Diamonds	CSU[3]	38.90	104.82	N/A
6	Greenland 9 SE (053579)	NWS	39.10	104.73	7478
7	Manitou Springs (055352)	NWS	38.85	104.93	6628
8	Mesa Plant	CSU	38.88	104.87	N/A
9	Monument (055734)	NWS	39.10	104.87	7078
10	Monument Valley	CSU	38.85	104.83	N/A
11	Nixon Base	CSU[1]	38.63	104.72	5489
12	Old Farm	CSU	38.90	104.72	N/A
13	Piniello Ranch	CSU[1]	38.76	104.74	5730
14	Pueblo (056740)	NWS	38.28	104.50	4683
15	Quail Lake	CSU	38.80	104.80	N/A
16	Ruxton Park (057309)	NWS	38.85	104.97	9048
17	Woodland Park (059210)	NWS	39.07	105.17	7758

[1] These Colorado Springs Utilities (CSU) station locations were obtained from data provided by the City Attorney for Colorado Springs, Colorado.
[2] National Weather Service (NWS) station locations were obtained from the National Climatic Data Center (NCDC) website at *http://lwf.ncdc.noaa.gov/oa/ncdc.html*.
[3] Some Colorado Springs Utilities (CSU) station locations were obtained using addresses listed on the CSU website at *http://et.csu.org/*, via MapBlast at *http://www.mapblast.com/*.

Table 4: Comparison of 100-year 24-hour storms for the region of Colorado Springs, indicated by the references discussed in Section 3 of this report, with total rainfall observed in the vicinity of Colorado Springs during April 28-May 2, 1999, for the storm event described in Section 5.1 of this report. Rainfall totals are given in inches and are the maximum values observed during the storm event for the given duration, except where an asterisk (*) indicates total rainfall during the 84-hour event. The determination of reference values employed maps (m) and regression equations (r) given in the indicated references.

Duration of Rainfall	NOAA TP-40 (m)	NOAA TP-49 (m)	NOAA Atlas 2 (m/r)	Colorado College (C.S. Utilities)	Colorado Springs (NOAA/NWS)	Manitou Springs (NOAA/NWS)
1 hour	2.4 in	N/A	2.6 in	0.59 in	0.57 in	0.70 in
2 hours	2.7 in	N/A	2.9 in	0.83 in	0.78 in	1.20 in
3 hours	2.8 in	N/A	3.1 in	1.03 in	0.89 in	1.80 in
6 hours	3.4 in	N/A	3.5 in	1.78 in	1.51 in	2.50 in
12 hours	3.8 in	N/A	4.0 in	3.11 in	2.51 in	3.20 in
24 hours	4.3 in	N/A	4.4 in	5.55 in	3.30 in	4.80 in
48 hours	N/A	4.9 in	N/A	8.34 in	4.76 in	6.80 in
96 hours	N/A	5.5 in	N/A	9.36 in*	5.75 in*	7.80 in*

APPENDIX C

References

Adams, D.K., and A.C. Comrie, 1997: The North American monsoon. *Bulletin of the American Meteorological Society*, v. 78, pp. 2197-2213.

Bell, G.D., M.S. Halpert, C.F. Ropelewski, V.E. Kousky, A.V. Douglas, R.C. Schnell, and M.E. Gelman, 1999: Climate assessment for 1998. *Bulletin of the American Meteorological Society*, v. 80, pp. S1-S48.

Castro, C.L., T.B. McKee, and R.A. Pielke, Sr., 2001: The relationship of the North American monsoon to tropical and North Pacific sea surface temperatures as revealed by observational analyses. *Journal of Climate*, v. 14, pp. 4449-4473.

Doswell, C.A. III, 1980: Synoptic-scale environments associated with High Plains severe thunderstorms. *Bulletin of the American Meteorological Society*, v. 61, pp. 388-1400.

Knighton, D., 1998: Fluvial Forms and Processes: A New Perspective. Arnold (Hodder Headline Group). 383 pp.

Maddox, R.A., L.R. Hoxit, C.F. Chappell, and F. Caracena, 1978: Comparison of meteorological aspects of the Big Thompson and Rapid City flash floods. *Monthly Weather Review*, v. 106, pp. 375-389.

Maddox, R.A., F. Canova, and L.R. Hoxit, 1980: Meteorological characteristics of flash flood events over the western United States. *Monthly Weather Review*, v. 108, pp. 1866-1877.

NOAA Atlas 2, prepared by J.F. Miller, R.H. Frederick, and R.J. Tracey, 1973: Precipitation Frequency Atlas of the Western United States, Volume 3 (Colorado). U.S. Department of Commerce, NOAA, National Weather Service. 67 pp.

NOAA Technical Paper No. 40, prepared by D.M. Hershfield, 1961: Rainfall Frequency Atlas of the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years. U.S. Department of Commerce, Hydrologic Services Division. 61 pp.

NOAA Technical Paper No. 49, prepared by J.F. Miller, 1964: Two- to Ten-Day Precipitation for Return Periods of 2 to 100 Years in the Contiguous United States. U.S. Department of Commerce, U.S. Weather Bureau. 29 pp.

Petersen, W.A., L.D. Carey, S.A. Rutledge, J.C. Knievel, N.J. Doesken, R.H. Johnson, T.B. McKee, T. Vonder Haar, and J.F. Weaver, 1999: Mesoscale and radar observations of the Fort Collins flash flood of 28 July 1997. *Bulletin of the American Meteorological Society*, v. 80, pp. 191-216.

Pielke, R.A., Jr., 1999: Nine fallacies of floods. *Climatic Change*, v. 42, pp. 413-438.

Ropelewski, C.F., and M.S. Halpert, 1986: North American precipitation and temperature patterns associated with the El Niño/Southern Oscillation (ENSO). *Monthly Weather Review*, v. 114, pp. 2352-2362.

Toth, J.J., and R.H. Johnson, 1985: Summer surface flow characteristics over Northeast Colorado. *Monthly Weather Review*, v. 113, pp. 1458-1469.

USGS Water-Resources Investigations Report No. 88-4136, 1989: Suspended sediment and sediment source areas in the Fountain Creek drainage basin upstream from Widefield, southeastern Colorado. 36 pp.

Walesh, S.G., 1989: Urban Surface Water Management. John Wiley & Sons, Inc. 518 pp.

Weaver, J.F., E. Gruntfest, and G.M. Levy, 2000: Two floods in Fort Collins, Colorado: Learning from a natural disaster. *Bulletin of the American Meteorological Society*, v. 81, pp. 2359-2366.

Report No. 2 to the City Attorney for Colorado Springs, Colorado, in reference to El Paso County District Court case no. 01CV1290

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May 21, 2003

ABSTRACT

This report pertains to El Paso County District Court case no. 01CV1290, Speight *et al.* v. the City of Colorado Springs and El Paso County, Colorado. This is the second of four reports to the City Attorney for Colorado Springs, Colorado. The report addresses runoff from a major storm event that occurred in the Fountain and Monument Creek watershed during April 28-May 2, 1999. This storm event has been described and analyzed in detail in Report No. 1 of this series. This report describes the application of the U.S. EPA Stormwater Management Model (SWMM) to the simulation of runoff hydrographs in Monument and Fountain Creeks as a result of the storm event. Two scenarios are examined: (1) discharges that likely resulted at various locations in the stream system, and (2) discharges that would have been observed had the area currently occupied by the City of Colorado Springs remained undeveloped. The hydraulic conditions of discharges and flow velocities in a portion of Fountain Creek located downstream of Colorado Springs are then examined under the influence of current and historical channel configurations near the location of the KOA property south of Colorado Springs. Of primary significance in the findings presented here that (1) stream discharges at the location of the KOA property along Fountain Creek are increased by the combination of upstream development *and* nearby floodplain constriction, (2) constriction of the nearby floodplain exerts a far greater influence on increased stream flow velocity, and therefore the potential for stream bank erosion by hydraulic action, in the portion of Fountain Creek immediately upstream of and adjacent to the KOA property than is found for the development and urbanization of upstream areas in the watershed, and (3) stream discharges and, to a lesser degree, flow velocities at the location of the Greenview Ditch Headworks along Fountain Creek near Piñon, Colorado, are increased by development in the upstream area.

1. Introduction

The complaint filed by the above-named plaintiffs lists three periods in the spring and summer of 1999 during which storm events may have caused flood-related property damages in locations along Fountain Creek downstream of Colorado Springs, Colorado. Within these periods, the largest storm event occurred on April 28-May 2, 1999. As discussed in Report No. 1 of this series, that event was actually composed of several smaller storms with distinct underlying meteorological causes but occurring in succession over a short time period. In addition, winter storms prior to that event led to near-saturated soil conditions in the upstream portions of the Fountain and Monument Creek watershed.

The primary goals of the work presented here are to demonstrate *ex post facto* for the major storm event (1) the effects of development and urbanization in the area of the City of Colorado Springs on stream discharges and flow velocities in adjacent and downstream locations, and (2) the effects of floodplain constriction by a constructed levee on flow conditions in Fountain Creek downstream of Colorado Springs. These goals will be achieved using currently available programs for the mathematical modeling of hydrologic and hydraulic systems. A discussion included in Section 2 will address the methodology employed in the selection and application of available methods for this work.

The reader is referred to the Introduction of Report No. 1 for a description of the physical features of the Fountain and Monument and Creek watershed and stream reaches. This report addresses the magnitudes of observed and simulated stream discharges and flow velocities at sites along Fountain Creek downstream of Colorado Springs during the major storm event. The material and discussions included in this report also explore the effects of urbanization and development in the area of the City of Colorado Springs on the hydrologic production of runoff and stream discharge during such a sustained storm event. Additional results of hydraulic model simulations are provided in order to address the effects of floodplain constriction during this high-flow event along a portion of Fountain Creek in the vicinity of the KOA property south of Colorado Springs.

Report Organization

A discussion and justification of the modeling methodology employed for the simulations presented here is included in Section 2. The primary goal of this work is described in that section as the appropriate representation of hydrologic and stream flow production processes in the Fountain and Monument Creek watershed for use in the study of alternative scenarios of development and urbanization, specifically, for the simulation of "historical" stream discharges under equivalent rainfall conditions in the absence of development in the area of the City of Colorado Springs.

The sources of data employed in this report are listed in Section 3. These sources include maps and tables included in planning studies of the Monument and Fountain Creek basins performed by private engineering firms for the City of Colorado Springs, printed and on-line meteorological data, documentation of flood hazards in the vicinity of Fountain, Colorado, by the Federal Emergency Management Agency (FEMA), topographic maps of the Fountain and Monument Creek watersheds by the U.S. Geological Survey (USGS), and aerial photographs of portions of Fountain Creek in the vicinity of the KOA property provided by the City Attorney for Colorado Springs.

A brief description of the hydrologic model employed for the simulations and results presented in this report is included in Section 4. This description includes a list of data requirements for the successful use of the U.S. Environmental Protection Agency's (USEPA) SWMM RUNOFF model. Brief discussions regarding the extraction of relevant data from available sources for the delineation of watershed sub-basins and drainage network channels are included in that section.

The simulation of the calibration storm event is described in Section 5. This simulation was employed merely as a test of model function under the influence of realistic hyetograph input. However, the process by which this simulation was completed exposed deficiencies in the spatial coverage of available rainfall data and led to the establishment of supplemental hyetographs to cover specific geographical "zones" where gaps in the network of rainfall observations occurred in order to simulate accurately the observed hydrographs at USGS stream gauge locations.

The simulation using SWMM RUNOFF of the major storm event at issue in the complaint discussed above is described in Section 6. Again, the accurate simulation of observed stream discharge hydrographs at USGS stream gauge locations required the development of hyetographs for specific geographic zones where gaps in the network of rainfall observations occurred in the Fountain and Monument Creek watershed. The process by which these supplemental hyetographs were formulated for the accurate simulation of both the peak discharges and the overall shape and total flow volume of the observed hydrographs at two gauged locations along Fountain Creek are discussed there. The formulation of watershed sub-basin surface conditions and runoff routing parameters for the scenario involving pre-development conditions in the area of the City of Colorado Springs is also addressed in this section. The results of these simulations using only the RUNOFF portion of SWMM are discussed in Section 6.

Details of the hydraulic model employed for the simulation of flow conditions along a portion of Fountain Creek downstream of Colorado Springs are included in Section 7. The construction of this model for use in SWMM EXTRAN is described there. The determination of channel segment cross-sections for the current and historical configurations of Fountain Creek in the reaches downstream of the bridge at Colorado Highway 16, located some distance south of Colorado Springs, is addressed in detail in this section.

The simulation of channel discharge and flow velocity conditions at the location of USGS gauge 07105800 and in the modeled portions of Fountain Creek immediately upstream of and adjacent to the KOA property is discussed in Section 8. Extensive use of graphical results from the EXTRAN model is made here. These simulations address the flow conditions under current conditions of channel configuration and development in the upstream area, as well as alternative scenarios of historical channel configurations, pre-development conditions in upstream areas, and a combination of those. The potential for the erosion of the channel bed and banks at selected locations in the portion of Fountain Creek modeled here using SWMM EXTRAN is also addressed in this section.

A summary of this report and its conclusions relevant to the questions posed by the City Attorney for Colorado Springs is presented in Section 9. All referenced figures are included in **Appendix A**. Tables referenced in the discussions are included in **Appendix B**. Other established references employed here are identified further in **Appendix C**.

2. Modeling Methodology

Of all the data listed in Section 3, the two data sets of primary interest for this work are observations of spatially distributed observations of rainfall and stream discharge. During the major storm event on April 28-May 2, 1999, stream discharges in portions of Fountain and Monument Creeks (and several tributaries) were of such a magnitude that measurements at USGS gauges were unreliable. The available data were therefore inadequate for the diagnosis of storm-related response at locations of particular interest. Specifically, USGS gauge 07105800 ("Fountain Creek at Security, Colorado"), the stream flow gauge located closest to the KOA property south of Colorado Springs where much erosion damage was reportedly sustained during the major storm event, was inundated by the discharges in Fountain Creek.

Using such a flexible hydrologic model as SWMM RUNOFF, the methodology adopted here can best be described as an effort to fit the simulated hydrographs, especially their peak discharges and total flow volumes, to known USGS hydrographs at all corresponding locations on major streams where observations are available in the modeled watershed. For the major storm event addressed here, stream discharge data was available at only five USGS gauge locations in the Fountain and Monument Creek watershed where corresponding locations were appropriately represented in the RUNOFF and EXTRAN models described above. In other locations, such as along the upper and middle portions of Fountain Creek, USGS data was considered unreliable due to the high discharge conditions that occurred during the major storm event addressed here and was not released to the author for the purposes of this work.

This work focused on refining the interpretation of spatial variations in rainfall over the watershed until the hydrographs at USGS gauges 07105500 ("Fountain Creek at Colorado Springs, Colorado"), near the center of Colorado Springs, and 07105530 ("Fountain Creek below Janitell Road below Colorado Springs, Colorado"), near the southern edge of Colorado Springs, were simulated as closely as possible. These gauges are located along portions of Fountain Creek that are expected to be the most affected by typically high-intensity, short-response-time surface runoff from urbanized and developed upstream areas. Except in portions of the Sand Creek watershed, where the official National Weather Service rainfall gauge for Colorado Springs is located, little rainfall was found to occur in locations downstream of USGS gauge 07105530. This is an indication that the observed and simulated discharges and total flow volumes should remain largely unmodified in reaches of Fountain Creek downstream of USGS gauge 07105530.

It must be remembered that large portions of the Fountain and Monument Creek watersheds, especially in locations upstream of Colorado Springs and in the nearby foothills, remain ungauged with respect to rainfall and stream discharge measurements. The development of supplemental hyetographs for specific geographical zones, as described below, was the primary method by which these gaps were filled. In addition, efforts were made at the simulation of peak stream discharges during the major storm event at one location along Monument Creek (USGS gauge 07104000, "Monument Creek at Pikeview, Colorado," near the northern edge of the City of Colorado Springs) and two locations along tributaries to Fountain Creek in the southwestern region of Colorado Springs (USGS gauges 07105000, "Bear Creek near Colorado Springs, Colorado," and 07105490, "Cheyenne Creek at Evans Avenue at Colorado Springs, Colorado").

3. Data Sources

Rainfall data used as input for the hydrologic model described below were obtained primarily from two sources:

- Precipitation data and weather observations by the NOAA National Climatic Data Center (*http://lwf.ncdc.noaa.gov/oa/ncdc.html*). The City Attorney for Colorado Springs also provided certified copies of some of these data.
- Hourly and daily precipitation data at sites operated or maintained by the Colorado Springs Utilities Department.

Other data employed for the delineation of the hydrologic model in SWMM RUNOFF were extracted primarily from maps and tables provided in the following studies:

- Fountain Creek Drainage Basin Planning Study (including maps), prepared for the City of Colorado Springs, Colorado, by Muller Engineering Company, Inc. (dated 1994).
- Monument Creek Drainage Basin Planning Study (including maps), prepared for the City of Colorado Springs, Colorado, by CH2M HILL (dated 1994).

These studies will be designated FCDBPS and MCDBPS, respectively, for the remainder of this report. For previously studied areas, maps showing the delineation of the studied sub-basins are included in:

- FCDBPS Volume II (Drawings), Figure 4.3-1.

- MCDBPS Volume III, Appendix B, Attachment 1.

Maps of existing land use are included in:

- FCDBPS Volume II (Drawings), Figure 3.4-2.
- MCDBPS Volume I, Figure 2-6 (p. 2-28).

Data on watershed sub-basin impervious areas (as percentage of sub-basin area) and distributions of hydrologic soil groups are included in:

- FCDBPS Volume III, Appendix A, Table 4.7-2.
- MCDBPS Volume III, Appendix B, Attachment 1, Table 7.

Hydrologic routing and related parameters for these study areas were extracted from:

- HEC-1 input files included in FCDBPS Volume III, Appendix A.
- MCDBPS Volume III, Appendix B, Attachment 1, Figures 8-13.
- USGS topographic maps for the Fountain and Monument Creek watershed.

USGS topographic maps were also employed for delineation of watershed basins and routing in the regions east and south of previously studied areas. These regions include the drainage areas of Sand Creek and Fort Carson Military Reservation, as well as other smaller areas adjacent to Fountain Creek south of Colorado Springs. Information regarding hydrologic soil groups for these regions was extracted from U.S. Department of Agriculture (USDA) Soil Conservation Service (now the Natural Resources Conservation Service) maps of the study area.

Data employed for the delineation of the hydraulic model in SWMM EXTRAN were extracted primarily from FEMA Flood Insurance Rate Maps (FIRMs) and Flood Insurance Studies (FISs) for the community of Fountain, El Paso County, Colorado. Additional information was extracted from an aerial photograph of Fountain Creek in the vicinity of the KOA property south of Colorado Springs, provided by the City Attorney for Colorado Springs, and from photographs of bridge and bank structures in that area by the author.

Data used in the construction of observed hydrographs at several USGS stream gauge stations in the Fountain and Monument Creek watershed during the events discussed here were obtained by the author from the USGS National Water Information System database. These 15-minute stream discharge data were quality controlled by the Pueblo Subdistrict Office of the USGS Water Resources Division before release to the author. The stream discharge data thus contain several gaps where discharge measurements were incomplete or suspect, especially during the major storm event at issue here.

4. Hydrologic Model (SWMM RUNOFF)

Sub-basin surface and routing parameters extracted from the data sources listed above were compiled for use in the USEPA's Storm Water Management Model (SWMM). Hydrologic production and routing of surface runoff during a given rainfall event is handled by the RUNOFF block of SWMM.

4.1. RUNOFF Data Requirements

In addition to time step and general calculation parameters provided to the model, data requirements for the RUNOFF block include:

- Rainfall data (*i.e.* "hyetographs") at specified (regular or irregular) time intervals.
- Sub-basin surface parameters:
  - Name.

  - Applied rainfall hyetograph.
  - Hydraulic load point (name of receiving channel for routing).
  - Sub-basin width.
  - Sub-basin total area.
  - Sub-basin imperviousness, as a percentage of total sub-basin area.
  - Average sub-basin surface slope.
  - Manning's roughness coefficients ("n") for pervious and impervious areas.
  - Depth of storage in surface depressions for pervious and impervious areas.
  - Maximum and minimum infiltration rates, and the coefficient of exponential decay from maximum to minimum rate during rainfall events for the Horton infiltration equation.
- Runoff routing parameters:
  - Channel name.
  - Hydraulic load point (name of next channel in routing sequence).
  - Shape of channel (rectangular, trapezoidal, circular pipe, etc.).
  - Channel bottom width (or pipe diameter).
  - Channel length.
  - Average channel slope.
  - Left and right side slopes (for trapezoidal channels).
  - Manning's roughness coefficient ("n") for channel material.
  - Total channel depth.
  - Initial depth of water in channel.

In addition to the parameters employed by the model for the calculation of surface runoff and channel routing, sub-basin and channel coordinates (in feet or meters north and east of a reference point) may be provided in a separate file and are useful in spatial representations of the constructed model. It should be noted, however, that these coordinates are not employed in the calculation of sub-basin sizes, drainage channel lengths, or other physical parameters relevant to the processes of runoff production and routing in this model.

4.2. RUNOFF Procedure

Generally, SWMM RUNOFF treats sub-basin areas as planar surfaces that are divided between pervious areas, which allow infiltration of rainfall to occur, and impervious areas according to the designated impervious percentage. Runoff from the impervious areas, on which depression losses and evaporation are calculated but no infiltration is allowed to occur, is not directed over the pervious area but is placed directly into the designated channel or "hydraulic load point." Runoff from the pervious areas, following calculation of depression losses, evaporation (if applicable) and soil moisture deficit, is produced by infiltration-excess and saturation-excess processes. The infiltration-excess runoff, also known as Horton overland flow, is produced when the precipitation rate exceeds the soil infiltration rate, which is varied according to the maximum and minimum rates and decay parameters specified for the hydrologic soil groups present in each sub-basin. The saturation-excess runoff is produced when the incident precipitation over a specified time period exceeds the saturation deficit that can be created in the soil by its (variable) infiltration rate over the same time period. Regardless of the process by which surface runoff from the pervious areas occurs, all runoff is placed directly into the designated channel.

The combined runoff from pervious and impervious areas of a sub-basin is routed through the specified drainage network from channel to channel by Manning's equation, a well-known method for the calculation of flow depth and velocity in channels with specified geometry and surface roughness. Where no further channels are specified in the drainage network, the time series of inflow to a designated junction is saved by the SWMM RUNOFF program in a specified file for input to other portions of the program, such as SWMM EXTRAN (described below).

Further discussion of the information required for adequate representation of the watershed sub-basins and drainage channels in the SWMM RUNOFF model is included here.

4.3. Sub-basin Surface Parameters

For the model constructed here, data available for sub-basins in the previously studied areas of the FCDBPS and MCDBPS were aggregated where such surface parameters as land use and land cover, ground slope, applied hyetograph, basin width and hydraulic load point would remain consistent. This procedure allowed a reduction in the total number of sub-basins for which input parameters would be compiled. Specifically, the FCDBPS and MCDBPS delineated a total of 365 sub-basins covering an area of approximately 415.5 mi^2. Using the sub-basin aggregation procedure, this model represents a total area of more than 495 mi^2 (including areas outside of those previous studies) with 233 (for the case of current development) to 235 (for the pre-development case) sub-basins.

For each sub-basin delineated here, average parameters for imperviousness and hydrologic soil group were calculated using the tabular data listed above. A complete listing of the sub-basin surface parameters employed for simulation of the major storm event is given here in **Appendix B, Table 1**. Of some importance here is the naming convention for sub-basins in the RUNOFF model. The names of sub-basins in the model presented here were derived from basin names and numerical designators listed in the FCDBPS and MCDBPS tables listed above. This naming convention was then easily extrapolated to areas such as the Sand Creek watershed, for which sub-basin surface parameters were not extracted from previously published Drainage Basin Planning Studies.

4.3.1. Imperviousness

In the case of imperviousness, it should be recognized that SWMM RUNOFF relies on the *directly connected impervious area* (DCIA) for its calculations of surface runoff production. The DCIA is typically some fraction of the total impervious area in a developed basin, though *a priori* calculation of this fraction is often difficult or ambiguous. As a brief example, we may consider the effects of two components of imperviousness after the work of Schueler (1994): rooftops (e.g. homes, commercial buildings, etc.), and transport systems (e.g. driveways, sidewalks, streets and highways)

Though rooftops may present an impervious surface to rainfall, the resulting rooftop runoff is collected in gutters that direct the runoff typically onto a pervious surface, such as a lawn or other undeveloped surface. However, in densely urbanized areas, the rooftop runoff may be conveyed by gutter systems directly into the street or storm sewer system. For transport systems, which typically lie on or above ground, gutter systems most often direct surface runoff into the storm sewer system, whether that is a surface channel or subsurface conduit. The DCIA considers only that portion of impervious surfaces from which runoff is conveyed directly to the storm sewer system, and not across some intervening pervious surface where infiltration may occur. As such, the DCIA can be a much larger fraction of the total impervious area in a sub-basin that is densely developed with a high density of transport systems (e.g. ~90% total impervious area), such as a downtown commercial or municipal district, than in a sub-basin with more distributed development (e.g. ~40% total impervious area) such as a residential subdivision.

The procedure discussed here employs the lower end of each range of imperviousness listed in the tables of source data listed above. Thus, the portion of a sub-basin (as a percentage of sub-basin area, typically) that has been listed with 5-15% impervious area will be considered the same portion of the sub-basin area with 5% imperviousness. Similarly, the portion of a sub-basin that has been listed with 70-100% impervious area will be considered the same portion of the sub-basin area with 70% imperviousness. These systematic reductions from total impervious area to DCIA are thus generally consistent with the analysis of DCIA given here.

4.3.2. Infiltration Rates

The calculation of average parameters for hydrologic soil groups present in a given sub-basin proceeded as follows. First, the maximum and minimum infiltration rates and decay coefficients for each soil group present in the sub-basin were calculated using recommended Horton's equation parameters from Table RO-7 in Volume I of the Denver Urban Drainage and Flood Control District's (UDFCD) Urban Storm Drainage Criteria Manual (USDCM). The resulting parameters were then aggregated for each sub-basin based on the percentage of the sub-basin assigned to each soil group in the tables of source data listed above. A similar approach was employed for the additional areas south and east of Colorado Springs that are included in this model but for which published Drainage Basin Planning Studies were not employed. It was found upon consultation with U.S. Soil Conservation Maps (listed above) that the major portions of those sub-basins fell within single hydrologic soil groups.

It should be noted that the subsurface flow of infiltrated moisture is excluded from the simulations presented here. This subsurface flow typically occurs in two layers during a rainfall event: a near-surface, near-saturated layer of "through-flow" or "interflow" that moves slowly toward the stream, and a deeper layer of groundwater flow that typically occurs below the stream bottom. The through-flow has a relatively slow time of response to the infiltrated fraction of incident rainfall, adding to the hydrographs in downstream locations within several hours or days, and its magnitude is small. The contribution of through-flow to changes in the surface stream flow is generally neglected in flood studies, due to the significantly greater contribution of surface runoff to the stream discharge hydrograph.

The much slower process of groundwater flow is the mechanism by which the discharge in a stream or river may change in periods during which no contributing rainfall or snowmelt is recorded. The stream discharge during these dry periods is often termed "base flow" and is important to the accurate simulation of observed hydrographs for isolated storm events. In the simulations discussed here, the model hydrographs are added to a derived base flow function, which is based on the gauged discharges immediately prior to the beginning of the storm event and at least twelve hours following the end of the storm event. The combined (simulated discharge + base flow) hydrograph is then compared with that observed at the gauged locations for accuracy.

During the simulation of the major storm event at issue here, it was observed that the minimum infiltration rates calculated by the USDCM method for each sub-basin were still too large. Physically, this result suggested that watershed soils were saturated beyond the degree generally assumed for the design of urban drainage systems. For the too-large minimum infiltration rates, available rainfall data and supplemental hyetographs provided to the model produced too little runoff and stream discharge when compared with stream gauge measurements during the event. Consideration of the saturating effects of winter storms in the Fountain and Monument Creek watershed prior to the major storm event, as discussed in Report No. 1, suggested that these minimum infiltration rates should be much lower than first assumed. Tests of the model discussed here led to the reduction of minimum infiltration rates by 80% in all modeled sub-basins, such that observed stream discharges could be produced with observed and supplemental hyetographs that remained realistic according to the analyzed magnitude and morphology of the major storm event.

4.4. Runoff Routing Parameters

The delineation of runoff channels proceeded generally with the extraction of channel lengths and slopes from either HEC-1 input files for the FCDBPS area or USGS topographic maps of the remaining study area. Using the constructed basin plan, shown here in **Appendix A, Figure 1**, a value was assigned to each stream segment (runoff channel) according to the Strahler ordering scheme. An example schematic of this ordering scheme is shown in **Figure 2**. The general rules of this scheme are given here after Chow *et al.* (1988):

1) The smallest recognizable channels generally flow only during wet weather, and are designated order 1.
2) Where two (or more) channels of the same order join, the downstream channel is of the next higher order.
3) Where a channel of lower order joins a channel of any higher order, the downstream channel is of the higher order.

It should be noted that these rules, as applied to the network constructed here, do not consider sub-basin surface runoff to a particular stream (*i.e.* the orange drainage paths in **Figure 1**) to have channel order 1, but that a location where surface runoff from two or more sub-basins joins is considered the beginning of a stream channel of order 1. Many of the true order 1 streams, according to the morphology of the modeled basins, are incorporated into the representation of the basins themselves and are therefore not represented separately as stream channel segments in this model.

The assigned order of each stream channel was then employed in the determination of appropriate channel bottom width and total channel depth for the conveyance of expected surface runoff flows from the entire contributing (upstream) area. In the course of simulation, however, it was found that several channels were expected to convey much greater discharges and volumes than this system would permit. In order to prevent errors that could be attributed to the delayed or attenuated routing of channel overflows, the width and depth dimensions of these channels were alternately increased until it was found that they conveyed all required discharges. So as to simulate the effective widening of a given channel by bank erosion and overflow onto its floodplain before increasing its depth by process of scour and bed erosion, channel widths were increased before their depths. This sometimes resulted in the apparent shift of a channel's order to the next higher order entirely. The likelihood of realizing the need for such a shift of some stream orders *a priori* may be related to the imperviousness of the contributing area, but a systematic relationship remains unclear without further analysis that is beyond the scope of this report.

The overall results of the stream channel ordering process and determination of channel widths and depths from those orders are listed in **Appendix B, Table 2**. It is shown there that some stream channels with an assigned order 1 eventually required dimensions that were initially assigned to stream channels of order 2 or 3 in order to convey incident discharges without overflow losses during the major storm event addressed in this report.

The types of natural channels that may be simulated using the RUNOFF model include regular (e.g. rectangular, trapezoidal, parabolic) geometries. Where variations of channel geometry are of greater interest, such as at downstream locations near the KOA property, the SWMM EXTRAN model has been employed. For simplicity, and to approximate the natural configurations of stream channels as accurately as possible with the available methods, streams in the Fountain and Monument Creek watershed were represented in this RUNOFF model using trapezoidal channels with 45° side slopes. Manning's roughness coefficients indicate the channel's frictional resistance to flow and were extracted from HEC-1 input files for the FCDBPS area. For the remainder of the study area modeled here, the FCDBPS roughness coefficients were employed where an adequate analogy between likely channel morphology could be found.

As stated above, the overall plan of sub-basins and channels for the RUNOFF model constructed here are shown in **Appendix A, Figure 1**. Labeled portions of the plan are shown in **Figures 3a** through **3f**. A close-up view of the area of this model that includes the approximate extent of the City of Colorado Springs is shown in **Figure 3g**. Sub-basin positions shown in these figures should be considered only representative of geographical location, and were not employed in the calculation of basin sizes, channel length, or other physical parameters important to the proper simulation of runoff production and routing processes.

Of greater importance than for the sub-basin areas, the naming convention for channels in the RUNOFF model presented here was derived from stream orders and somewhat natural geographic divisions of watershed areas. For tributary streams, as examples, the designator TGgC labels the stream that runs adjacent to or through sub-basin TGg and is also known as the Templeton Gap Floodway. The designator SPCbC labels the portion of Spring Creek that runs adjacent to or through sub-basin SPCb, which is different from SBCbC (a portion of South Beaver Creek adjacent to sub-basin SBCb) and SCbC (a portion of Severy Creek adjacent to sub-basin SCb). For main streams, as examples, the designator UFCMR01 labels Upper Fountain Creek Mainstem Reach number 01; the designator MMCMR12 labels Middle Monument Creek Mainstem Reach number 12; the designator LFCMR04 labels Lower Fountain Creek Mainstem Reach number 04. As such, any channel designator is intended to help the modeler (and reader) identify the general geographic area and watershed basin or sub-basin in which that stream channel is placed.

A complete listing of the channel routing parameters employed for simulation of the major storm event is given here in **Appendix B, Table 3**.

5. Calibration Event in RUNOFF: October 27-28, 1998

A calibration event was selected for this work with the goal of demonstrating model operation and accuracy using realistic distributions of rainfall hyetographs as input and measured stream discharge hydrographs for verification of model results. For these purposes, a small event was selected for which (1) moderate rainfall totals were observed over much of the Fountain and Monument Creek watershed by both National Weather Service and Colorado Springs Utilities rainfall gauges, and (2) USGS stream gauge data was available at several locations along Fountain and Monument Creeks for verification of sub-basin and channel input parameters in individual (or small groups of) sub-basins.

The selected event occurred on October 27-28, 1998. Hyetographs constructed from observed hourly rainfall totals are shown in **Appendix A, Figure 4a**. These data show the occurrence of an event composed of two major storm cells, separated in time by approximately 6-7 hours but both affecting large portions of the watershed area. Comparing simulation results with observed stream discharges, it was found during the course of simulation for this event that the available rainfall data were inadequate for the proper representation of stream discharges and total volumes. That is, *the development of a spatial distribution of rainfall using only the observed hyetographs resulted in too little surface runoff, and the simulated stream discharges and total volumes were far below those observed during this event.* This was not surprising, considering the large gaps in rainfall observations in the areas of Middle and West Monument and Beaver Creeks (see **Figures 3b** and **3c**) and along portions of Upper and Middle Fountain Creek (see **Figure 3a**). Most significantly, these areas include some of the more mountainous sub-basins in the watershed, which are susceptible to larger rainfall totals in storm events where the topography plays a major role. Such types of storm events, including upslope and thunderstorm patterns, were discussed in detail in Report No. 1.

For the purposes of simulation, then, supplemental hyetographs were formulated to improve the spatial representation of rainfall totals, especially in those areas that are distant from rainfall gauges. Considering the reasonable spatial coverage to which each observed hyetograph could be applied, the supplemental hyetographs were formulated for representative zones based primarily on the locations of major topographical features (e.g. the east side of the Monument Creek valley, the foothills just west of that valley, the center of Colorado Springs, etc.). The observed hyetographs shown in **Figure 4a**, the supplemental hyetographs shown in **Figure 4b**, and the representative areas to which each of those hyetographs is applied (shown on a plan view of the modeled watershed in **Figure 5**) should be considered together as our best estimate of the spatial and temporal distribution of the rainfall that actually occurred over the watershed during this event.

It should be noted here that dry antecedent conditions were applied to the simulation of this event. This means that the minimum infiltration rates were left unmodified from their original calculated values for each sub-basin based on known soil types and the calculations described in the UDFCD USDCM (2001). Thus the supplemental hyetographs employed to fill spatial gaps in the network of available rainfall observations were the only aspect of "calibration" applied to the RUNOFF model for simulation of this minor storm event. Although the applied difference in minimum infiltration rates results in the simulation of a slightly different hydrological regime throughout the watershed than for the major storm event addressed here, it should be considered that antecedent conditions are particular for each event and that every effort was made to represent those as accurately as possible for each of the model event simulations discussed here.

For brevity, only the results of the simulated stream discharges at USGS gauge 07105800 ("Fountain Creek at Security, Colorado") are provided in **Figure 6**. It can be seen in that figure that the RUNOFF model accurately simulates the magnitudes of the two major stream discharge peaks at that gauge. In addition, the slopes of the rising and recession limbs of the observed hydrograph shown there are well simulated by the model, demonstrating the utility of the formulation for runoff drainage in developed and urbanized areas that was described above. The slight overestimation of resulting total flow volume could likely be corrected by minor adjustments to the rainfall in the supplemental hyetographs.

6. Major Event in RUNOFF: April 28-May 2, 1999

The meteorology of the major storm event was described in detail in Report No. 1. During this event, more than nine inches of rainfall was recorded at the Colorado College gauge operated by the Colorado Springs Utilities Department. The maps of daily total and event total rainfall prepared for that report demonstrated high concentrations of rainfall in the foothills and mountains that cover the western portions of the City of Colorado Springs and the Monument Creek and Lower Fountain Creek valleys. However, it is important to note that small-scale details in the spatial distribution of rainfall in some of these areas are poorly represented by the spatial coverage of available rain gauge observations.

The hydrographs of stream discharge at five gauges in the Fountain and Monument Creek watershed were available during this event from the U.S. Geological Survey's National Water Information System database. These hydrographs are shown in **Figures 7a** (for USGS gauge 07104000, "Monument Creek at Pikeview, Colorado"), **7b** (for USGS gauges 07105000, "Bear Creek near Colorado Springs, Colorado," and 07105490, "Cheyenne Creek at Evans Avenue at Colorado Springs, Colorado"), **7c** (for USGS gauge 0705500, "Fountain Creek at Colorado Springs, Colorado"), and **7d** (for USGS gauge 07105530, "Fountain Creek below Janitell Road below Colorado Springs, Colorado").

The observed hourly hyetographs at six rainfall gauges in and near the modeled watershed are shown in **Figure 8a**. Rainfall observations at an additional eight locations in the watershed for which only daily rainfall totals were available are also employed in this simulation. For these hyetographs, a pattern-based analogy was drawn between each daily station and a nearby hourly station for each datum of daily total rainfall. This pattern was based on comparisons of daily total rainfall as well as topography, including elevation and aspect, inferred storm spatial and temporal patterns, and the simple availability of nearby stations collecting hourly rainfall totals. The resulting hyetographs at these daily stations demonstrate a temporal distribution of rainfall on each day that is similar to that for a nearby (or otherwise analogous) hourly station on the same day. These hourly hyetographs at locations for which only daily rainfall totals were available are shown in **Figure 8b**.

As for the calibration event described earlier, it was found that hyetographs based only on observed rainfall data were inadequate for the accurate simulation of stream discharges and total volumes at the available USGS gauge locations. Even after the 80% reduction of minimum infiltration rates was applied across the watershed in order to account for antecedent soil moisture conditions as discussed above, far too little runoff reached the drainage network and gauge locations during the simulated event. Again, supplemental hyetographs were formulated in zone-based locations, each with a spatial coverage appropriate to the surrounding topography, available rainfall observations, and the inferred pattern of individual storms during this event. Aside from accounting for antecedent soil moisture conditions in formulation of the minimum infiltration rates for each sub-basin in the modeled watershed, the hour-by-hour adjustment of these supplemental hyetographs during the major storm event was the only "calibration" applied to the RUNOFF model described here. The five resulting supplemental hyetographs employed in simulation of this major event are shown in **Figure 8c**.

A complete list of the hyetographs employed in this simulation, along with the daily rainfall totals at locations for which only that data was available, is given in **Appendix B, Table 4**. As suggested above, daily rainfall totals where only that data was available represented a "constraint" on the derived hourly hyetographs for those locations. The representative spatial coverage of sub-basins to which each of the six hourly, eight daily and five supplemental hyetographs were applied for the simulation of the major storm event is shown on a plan view of the modeled watershed in **Appendix A, Figure 9**. The coverage zones shown there for each hyetograph can generally be classified according to topographical influences consistent with the pattern of upslope (topography-induced) and thunderstorm rainfall that was found to occur during this event. While the physical representation of the watershed remained the same here as for the simulation of the minor event described above, the patterns of storm evolution for the major event were somewhat different and required changes in the coverage of hyetograph zones for much of the available and supplemental rainfall data.

Despite physical consistency with observed storm patterns, it should be noted that rainfall totals indicated by the supplemental hyetographs employed here are significantly greater than those at locations where hourly or daily observations are available. This is indicated in **Appendix B, Table 5**, where the total event rainfall during a 120-hour period (April 28-May 2, 1999) for each hyetograph is ranked in order of magnitude. Supplementary hyetographs, those added to the simulation of the major storm event in order to account for rainfall in areas not adequately covered by existing observations and rainfall gauges, occupy the top three positions in that table, each with more than ten inches of total event rainfall. The rainfall total for hyetograph 13 ("Water Operations," a Colorado Springs Utilities gauge), located immediately west of Monument Creek in the lower elevations of the foothills, is the largest *observed* in the watershed. However, this rainfall total is only just more than half of that required in the zone assigned to hyetograph 15, covering primarily the higher elevations of the foothills just west of Colorado Springs, in order to simulate observed stream discharges and total flow volumes in that region and at downstream locations. This zone covers the western portions of the City of Colorado Springs as well as portions of the adjacent foothills, where the effects of topography-induced rainfall would be most noticeable.

Again, the modeling methodology employed here considers hyetograph patterns that are physically consistent with the observed storm event for the accurate simulation of recorded stream discharges and total flow volumes at available locations in the Fountain and Monument Creek watershed. By finding the spatial and temporal distribution of rainfall that produces those observed stream discharges and total flow volumes under the conditions represented in the RUNOFF model, and then by changing relatively few parameters of that model, the modeler can be confident in the results supplied by investigations of alternative scenarios and events.

6.1. Current Development Conditions

The procedure of adjustment for the supplemental hyetographs included for simulation of the major storm event proceeded as described here. First, hyetographs 17 and 18 were formulated with hourly rainfall totals according to a 5:3 ratio (respectively) in order to match, as closely as possible, the four major hydrograph peaks at USGS gauge 07104000 (see **Appendix A, Figure 7a**) during the storm event. The selection of this particular ratio for these two adjoining hyetograph zones was based on a comparison of likely topographical influences on the upslope periods of this major storm event. Specifically, for an upslope rainfall event in this region the area of forcing topography (mountains) is located primarily in the zone for hyetograph 17, and thus will likely receive more rainfall than the zone to which hyetograph 18 was applied. In the zone for hyetograph 18, the topography slopes generally downward in the direction of "upslope" (east-southeasterly) flow and thus exerts little influence on rain-producing processes that result from vertical forcing of near-surface winds. The influence of near-surface wind direction is important where the forcing topography will likely have the greatest influence on rainfall totals during the storm event. The data for these near-surface winds, obtained for the Colorado Springs NWS station from the National Climatic Data Center (see Section 3 above for the NCDC website), were thus considered in the comparison of rainfall totals for all hyetograph zones along the Monument Creek valley and nearby foothills.

In order to avoid ambiguity in the development of hyetographs for zones 17 and 18, both of which contribute to the measurements at a single stream discharge gauge station, the choice of this 5:3 ratio for hourly rainfall totals in these zones involved consideration of other ratios as well. For some ratios, e.g. 2:1, the resulting hourly rainfall totals in the zone for hyetograph 17 (in the foothills west of Monument Creek) might have exhibited an influence on rainfall patterns that was too large in relation to other zones that covered the foothills region, such as the zone for hyetograph 15. For other ratios, e.g. 3:2, the resulting hourly rainfall totals in the zone for hyetograph 18 (in the region east of Monument Creek) would have had an influence on the rainfall patterns in this region that was larger than the topography in that zone would suggest.

Hourly rainfall totals for hyetograph 19 were then developed with the goal of simulating, as accurately as possible, the four major hydrograph peaks at USGS gauge 07105490 (see **Figure 7b**) during the storm event. As the zone for hyetograph 19 also covers the contributing area for USGS gauge 07105000 (see **Figure 7b**), an attempt was made to simulate the hydrograph at that location as well. However, considering variations in soil types and ground slopes between the contributing areas for each of these two gauges as well as the relative magnitude of their contributions to stream discharges in Lower Fountain Creek, a greater effort was made at the accurate simulation of discharge peaks at USGS gauge 07105490.

With the establishment of hyetographs representing much of the contributing areas for Upper and Middle Monument Creek and Upper and Middle Fountain Creek, the hourly rainfall totals for hyetograph 15 were developed for that portion of the watershed area that contributed to Lower Monument and Lower Fountain Creeks. The goal for the development of hyetograph 15 was to account for the entire magnitude and shape of the hydrograph at USGS gauge 07105500. This hyetograph adjustment proceeded hour-by-hour through the storm event in order to simulate as accurately as possible the slopes of rising and recession hydrograph limbs and peak discharge magnitudes at that location. In order to account for the increase in base flow over the duration of the storm event, a linear function for base flow was derived from the observed hydrograph by considering the stream discharges at USGS gauge 07105500 immediately prior to the beginning of the first storm during this event and approximately twelve hours following the end of the last storm of the event. A constant base flow was determined for the period prior to the storm event, and this linear function was applied to the event period from about 7 pm on April 28, 1999, to midnight on May 2, 1999. Efforts at the adjustment of hyetograph 15 then applied to the simulation of the difference between recorded stream discharges and this calculated base flow rate.

The results of these efforts at the adjustment of hyetograph 15, along with the simulation of peak discharges in other upstream locations, for the simulation of stream discharges at USGS gauge 07105500 are shown here in **Figure 10a**. Differences between the observed and simulated hydrographs at that location are minor and isolated, as shown on the graph. A simplified evaluation of the correlation between observed discharges at that location and the simulated discharges at the same times is shown on the scatter plot included in that figure. The fitted trend line shown there demonstrates a slope only slightly different from the desired value of unity (*i.e.*, $\mathbf{Q_{sim} = 1.0\ Q_{obs}}$), which would indicate total consistency in the simulation of observed stream discharges at this location. Further statistical evaluation of the simulated hydrograph is discussed below.

The process for simulation of stream discharges and total flow volumes at USGS gauge 07105530 was similar to that for USGS gauge 07105500 but was accomplished by the adjustment of hourly rainfall totals for only hyetograph 16. The zone covered by this hyetograph includes some of the most heavily developed and urbanized portions of the City of Colorado Springs, and thus produces significant surface runoff. The contribution of runoff from this portion of the City is indicated by the difference of measured hydrograph peaks between USGS gauges 07105500 and 07105530. The results of the adjustment of hyetograph 16 for the simulation of stream discharges at USGS gauge 07105530 are shown in **Figure 10b**. Again, a simplified evaluation of the correlation between observed discharges at that location and the simulated discharges at the same times is shown on the scatter plot included in that figure. The fitted trend line shown there demonstrates a slope within approximately 3% of the desired value of unity.

Differences between the observed and simulated hydrographs at USGS gauge 07105530 are somewhat larger than for the results at USGS gauge 07105500, as shown on the graph, but are confined primarily to the stream discharge minima during the storm event. It should be noted that the minima in the hydrograph at USGS gauge 07105530 have values of stream discharge that are *equal to or less than* those of the corresponding minima in the hydrograph at USGS 07105500, several miles *upstream*. Nevertheless, peak stream discharges and the overall shape of the hydrograph at USGS gauge 07105530 are well simulated by the RUNOFF model presented here. Simulated stream discharges at all of the available gauges in the Monument and Fountain Creek watershed are evaluated in **Appendix B, Table 6**. It is shown there that the magnitude and time of individual simulated peak discharges are very close (typically within approximately 1% and 30 minutes, respectively) to those observed at the respective USGS gauges.

Results of these efforts to simulate both the magnitude and shape of observed hydrographs at USGS gauges 07105500 and 07105530 are evaluated at the bottom of **Table 6**. It is shown there that the simulated stream discharge mean and maximum and the total flow volume during the event are within 1% of those observed at USGS gauge 07105500. The serial correlation, which is a measure of the internal variability from one observation to the next observation 15 minutes later, is closely approximated as well, indicating that this internal variability is preserved in simulation of the stream discharges at this location. Overall, a comparison of observed and simulated stream discharges at the same times over the duration of the event leads to a measure of the "goodness of fit" produced by the simulation, and is better than 97% for the simulation of this event. When evaluated along with absolute error measures (after Legates and McCabe 1999) for these results such as differences in the discharge mean, standard deviation and maximum and the total flow volume during the period of simulation, it can be concluded with a high degree of confidence that the observed hydrograph is reproduced accurately in the simulations presented here.

It is also shown in **Table 6** that the simulated mean stream discharge and total flow volume during the event are approximately 8% higher than those observed at USGS gauge 07105530, despite very close approximation of the peak stream discharges. This difference can be attributed to the relatively low minimum stream discharges that were recorded during the event but are not well simulated here. However, this difference in mean discharge and total flow volume remains well within the expected accuracy of the stream discharge observations themselves, which is 10-15%. The results presented here can thus be considered both accurate and slightly conservative with respect to the evaluation of flow magnitudes (discharges) and depths in downstream locations. It should also be noted that the serial correlation for the observed hydrograph at USGS gauge 07105530 is preserved in the simulated hydrograph, and that the correlation between the two hydrographs is again better than 97%.

The simulated stream discharges near the mouth of Shooks Run at its confluence with Fountain Creek in Colorado Springs were also examined. This simulated hydrograph, at a location for which no observations were available, is shown in **Appendix A, Figure 10c**. The significance of this result will be discussed in the following sections.

In the course of fitting simulated hydrographs to observed stream discharges at various locations along Monument and Fountain Creeks by the method discussed here, an interesting aspect of the major storm event was found that did not appear in the analysis of event morphology discussed at length in Report No. 1 of this series. The analysis presented there was based on satellite photographs and regional surface analyses at 12-hour intervals, supplemented with sparse observations of rainfall at daily and hourly intervals. That analysis was unable to detect the occurrence and movement of a precipitation cell embedded within the larger storm system that can be traced through the Fountain and Monument Creek watershed during the afternoon of April 30, 1999. This trace is found by examination of wind observations at the Colorado Springs NWS station and by comparison of the magnitudes and timing of rainfall maxima in several of the hyetographs shown in **Figure 8**.

Specifically, though upslope conditions persist through much of the event with winds generally from the east and southeast sectors near the surface, a sharp reversal to westerly winds was observed at the Colorado Springs Municipal Airport around 1-3 pm on April 30, 1999. The accompanying drop in temperature, increase in surface pressure and intensification of rainfall observed there at the same time are primary indications of thunderstorm passage. In this case, the thunderstorm passed generally from west to east over the observation site. With the available (hourly) resolution of the observed and supplemental hyetographs, the intense rainfall of this embedded cell can be traced back in time through the morning of April 30, 1999, toward the west from that observation site. As a result, it can be inferred from the rainfall data and weather observations that this heavy rainfall cell was likely initiated during the late evening on April 29, 1999, and moved slowly east-southeastward out of the foothills during the morning of April 30. By the afternoon of that date, this storm cell seemed to have stalled and two heavy rainfall cells can be found in the data: one was located over the eastern portions of the City of Colorado Springs, and the other was located over the foothills immediately upstream of the confluence of Fountain and Monument Creeks. In the immediate vicinity of Lower Monument Creek, however, very little rainfall was observed after 3 pm on April 30, 1999. It is around this time that the peak stream discharges were observed at USGS gauges 07105500, located near downtown Colorado Springs, and 07105530 located in the southern portions of Colorado

Springs. Absent any radar observations of this event, which would have been complicated by the topography of the foothills themselves in the vicinity of Colorado Springs, a far more extensive examination and analysis of all available data would be necessary for the determination of storm formation and movement beyond this cursory discussion.

6.2. Pre-development Conditions

The formulation of pre-development conditions for the modeled portion of the Fountain and Monument Creek watershed involved two aspects of the modeling procedure described above: (1) the imperviousness (as a percentage of total sub-basin area) for all modeled sub-basins located partially or wholly within the City of Colorado Springs was reduced to 0%, and (2) the Templeton Gap Floodway (RUNOFF channel "TGfC") was removed and the upper portion of Shooks Run (in the Templeton Gap sub-basin) was routed into the Shooks Run sub-basin accordingly. A schematic plan of the SWMM RUNOFF sub-basins and channels in the area currently encompassed by the City of Colorado Springs for this alternative scenario is shown in **Figure 11**. This formulation was thus intended to represent natural or historical sub-basin surface and runoff routing conditions, as if the City of Colorado Springs had never existed.

Some aspects of the differences between this formulation and that for current development conditions, described above, are listed in the top portion of **Appendix B, Table 7**. The total numbers of simulated sub-basins and channels in SWMM RUNOFF are listed there, as well as the number of EXTRAN channel segments (discussed below in Section 7) and several measures of total and developed area in the modeled portion of the Monument and Fountain Creek watershed. Given that the total area of the modeled watershed does not change with the scenario, it is important to note the large increase in developed area that is contributed by the City of Colorado Springs.

The results of the SWMM RUNOFF simulation for the case of pre-development conditions in the watershed during the same major storm event are shown at the locations of USGS gauges 07105500 and 07105530 in **Appendix A, Figures 12a** and **12b**, respectively. These results are also compared with those for the previously described conditions of current development in **Appendix B, Table 7**. For accuracy regarding this comparison of stream discharges and total flow volumes, the statistics listed there for pre-development and current development conditions are both for the *simulated* hydrographs at the locations of the indicated USGS gauges. It is shown there that, *under the influence of development in the City of Colorado Springs, peak discharges in Fountain Creek increase by 12-14% and total flow volume over the duration of the event increases by 20-25%* at the locations of the USGS gauges.

6.3. The Templeton Gap Floodway

An examination of discharges and total flow volumes in portions of Shooks Run in Colorado Springs provides an interesting measure by which the accuracy of this SWMM RUNOFF model may be evaluated. As an alternative to the scenario presented above for complete pre-development conditions in the area of the City of Colorado Springs, an intermediate scenario was explored in which the RUNOFF channel representing the Templeton Gap Floodway was removed from the model and the surrounding sub-basins and channels were reconfigured in the historical route of Shooks Run through downtown Colorado Springs to its confluence with Fountain Creek. For this scenario, the levels of development (imperviousness) in sub-basins located wholly or partially within the City of Colorado Springs were *not* altered. The results of this simulation for the major storm event addressed here are shown in **Appendix A, Figure 13a**. It is demonstrated there, and in the tabulated results in **Appendix B, Table 7**, that the peak discharge near the mouth of Shooks Run would have been more than 50% higher during this major storm event if the Templeton Gap Floodway had not been constructed. It should also be noted that total flow volume at that location would have been more than 60% greater under this scenario.

Further examination of the discharges and total flow volumes in Shooks Run for pre-development conditions in the area of the City of Colorado Springs, as described above, yielded an interesting result. The hydrograph near the mouth of Shooks Run for these pre-development conditions during the major storm event addressed here is shown in **Appendix A, Figure 13b**. It is shown there, and in the results compiled in **Appendix B, Table 7**, that *the peak stream discharges and total flow volumes near the mouth of Shooks Run under conditions of current development and with the Templeton Gap Floodway are approximately the same as those for pre-development conditions*. This result is consistent with the common method of engineering design for flood control projects that involves the reduction of peak stream discharges in a developed basin to those for the same basin under pre-development conditions. Regarding the accuracy of the methods applied in the construction of this RUNOFF model, that such a simulation of changes in peak stream discharges under physically consistent scenarios of sub-basin development and stream channel routing in a densely urbanized portion of the watershed should agree *almost exactly* with established engineering design principles is encouraging.

7. Hydraulic Model (SWMM EXTRAN)

A portion of the hydraulic routing of surface runoff through channels and conduits was performed using SWMM EXTRAN. This procedure differs from the routing of channel flows in the RUNOFF program by providing additional options for channel types, configurations, boundary conditions, the computation of various flow regimes (*i.e.*, supercritical, subcritical, and mixed flow conditions), and the diagnosis of backwater conditions in channel segments (e.g. "choked" flow, flooding, etc.).

7.1. EXTRAN Data Requirements

In addition to time step, general calculation parameters, convergence tolerances for iterated calculations, and boundary conditions (including input hydrographs provided to the model from the RUNOFF block), data requirements for the EXTRAN block include:

- Junction parameters:
  - Junction name.
  - Invert elevation (bottom of junction).
  - Ground elevation (top of junction).
  - Constant discharge into junction (if desired).
  - Initial depth of water in junction.
  - Maximum surcharge elevation (if desired).
- Channel parameters:
  - Channel name.
  - Upstream junction name.

  - o Downstream junction name.
  - o Initial discharge in channel.
  - o Type or shape of channel (rectangular, trapezoidal, circular pipe, irregular, etc.).
  - o Total channel depth.
  - o Channel bottom width or pipe diameter (if not an irregular channel; see below).
  - o Channel length (if not an irregular channel; see below).
  - o Elevation offsets at upstream and downstream junctions (if necessary).
  - o Manning's roughness coefficient ("n") for channel material.
  - o Left and right side slopes (for trapezoidal channels).
  - o Cross-section identifier (for irregular channels; see below) or bridge segment identifier (for bridge sections; see below).
  - o Average channel slope (for irregular channels; see below).
- Irregular channel parameters:
  - o Cross-section identifier (corresponds to other channel parameters given as above)
  - o Manning's roughness coefficients for left over-bank area, right over-bank area, and channel.
  - o Number of stations in cross-section.
  - o Station at left side (looking downstream) of cross-section.
  - o Station at right side (looking downstream) of cross-section.
  - o Channel length.
  - o Horizontal expansion/contraction coefficient (if necessary).
  - o Cross-section station/elevation pairs.
- Bridge segment parameters:
  - o Bridge segment identifier (corresponds to other channel parameters given as above).
  - o Number of cross-section station/Manning's n pairs given.
  - o Number of cross-section station/elevation pairs given.
  - o Number of bridge piers for which station/pier width/low-chord elevation data given.
  - o Cross-section station (from left side of cross-section) and Manning's n pairs.
  - o Cross-section station/elevation pairs (as for irregular channels; see above).
  - o Pier centerline station, width, and low-chord elevation for each pier.

In addition to the parameters employed by the model for the calculation of hydraulic channel routing, junction coordinates (in feet or meters north and east of a reference point) may be provided and are useful in spatial representations of the constructed model.

7.2. EXTRAN Procedure

The EXTRAN model represents the physical system with a link/node (channel/junction) structure where inputs, storage, and outputs of flow volumes occur at the nodes (junctions). Junctions are thus employed where input hydrographs are required (e.g. from the RUNOFF program) and where changes in channel parameters (specified in the link definitions) are necessary (e.g. contractions, expansions, bridges). As mentioned above, the EXTRAN model provides for a greater variability of channel and junction configurations than does the channel routing procedure of RUNOFF. Specifically, junction elevations cannot be specified in RUNOFF. Of great interest here are the bridges and irregular channel cross-sections present along much of Fountain Creek in the vicinity of USGS gauge 07105800 and the KOA property. These cannot be specified in SWMM RUNOFF as accurately as with the EXTRAN program.

At each time step, the EXTRAN model calculates stored volume, head and surface area at each junction. In channels, the flow cross-section area, hydraulic radius, surface width, discharge and velocity are calculated at each time step. Calculations for channels employ the one-dimensional (in space) de St. Venant equation for unsteady, gradually varied flow. Manning's flow (discharge) equation is employed for the definition of friction (*i.e.*, flow specific energy) slope in this calculation. The EXTRAN model employs a modified Euler (forward-step) integration method for explicit solutions to time step calculations.

The EXTRAN model is inherently one-dimensional and therefore accounts for flow variables along only the primary axis of flow, *i.e.*, the upstream/downstream direction. While this reduction of flow dimension is acceptable and, generally, desirable for long prismatic channels, variations of flow behavior in the cross-stream direction can become important where channel widths change significantly or channel bends occur. Overall, EXTRAN is well suited for the handling of flow simulations in channels with gradually varied cross-sectional configurations, but secondary circulations and energy losses that are induced in significant channel expansions, contractions and bends (including stream meanders) are necessarily excluded from this model.

A notable exception to this simplified treatment of flow behavior includes the specification of bridges in this EXTRAN model. Bridge segments are treated as channels with additional consideration for energy losses due to bridge piers. Low-chord elevations are used in the determination and treatment of submerged bridge sections during a simulation, though that possibility does not occur in the simulations described below. None of the other flow control devices available in the EXTRAN model (e.g. orifices, weirs, tide gates, pump stations, etc.) are employed in the simulations discussed here. A free outfall, with a specified water surface boundary condition at normal depth, is employed at the downstream end of this EXTRAN model.

7.3. Junction Parameters

For the simulations described here, care was taken to adhere as closely as possible to the physical layout of the portion of Fountain Creek south of Colorado Springs. This reach extends from the location of the Widefield wastewater treatment plant (WWWTP), approximately ¾ of a mile upstream of USGS gauge 07105800, to a location approximately 1 mile downstream of the KOA property where a diversion of Fountain Creek flow volumes is indicated on USGS topographic maps. Within this reach, junctions are specified at specific locations where the flow behavior is affected primarily by bridges or changes in channel cross-section. It should be noted that the cross-sections themselves are specified in the definition of channel segments, described below. The two bridges parameterized here are located at Carson Boulevard (immediately downstream of USGS gauge 07105800) and Colorado Highway 16 (approximately ¼ mile downstream of the Carson Boulevard bridge). A high degree of detail was applied to the portion of Fountain Creek immediately upstream and adjacent to the KOA property, and many of the specified junctions are located in that portion of the model.

It has been concluded by the author that the levee adjacent to Fountain Creek downstream of the bridge at Colorado Highway 16 was not overtopped by the flood event examined here. There exists no evidence on the provided aerial photograph of areas where the levee was breached and reconstructed or where vegetation has been scoured away from the top or outside face of the levee, as would have occurred in an overtopping situation. Therefore, the elevation of the levee top has been taken as the ground elevation. The same elevation has been used for the right bank of Fountain Creek at EXTRAN junctions located in that reach.

Junction elevations were extracted from FEMA Flood Insurance Study flood elevation profiles at locations determined using USGS topographic maps and an aerial photograph provided by the City Attorney for Colorado Springs. These flood elevation profiles provide streambed elevations as well as the water surface elevations for various design floods as determined by FEMA and its study contractors. For the purposes of this work, and because the discharges that occurred along much of Fountain Creek during the major storm event addressed here have been described by the U.S. Army Corps of Engineers as a 30-year to 40-year event, the elevation of the 100-year flood water surface has been taken as the elevation of the ground (or levee crest) in channel cross-sections. These streambed and ground elevations are employed in the specification of junctions in the EXTRAN model.

It should be noted that the names of junctions in the reach of Fountain Creek immediately upstream of and adjacent to the KOA property are derived from distances upstream ("US") or downstream ("DS") of the location where the outfall from Fort Carson Military Reservation joins the Creek. For the purposes of this work, that reference location is marked "FCMRout" on plans of this reach.

A complete listing of the EXTRAN junction parameters employed for simulation of the major storm event is given here in **Table 4**. The overall plan of the EXTRAN model employed here is shown in **Appendix A, Figure 14**. A profile view of the portion of Fountain Creek modeled here using EXTRAN is shown in **Figure 15**. Detailed diagrams of the modeled reach of Fountain Creek immediately upstream of and adjacent to the KOA property are shown in plan view in **Figure 16** and in profile in **Figure 17**.

7.4. Channel Parameters

The parameters necessary for the specification of channels in EXTRAN are listed above. For the purposes of this work, channel parameters were derived from a variety of sources. Channel lengths and slopes were extracted from USGS topographic maps, FEMA Flood Insurance Rate Maps (FIRMs), FEMA flood elevations profiles, and an aerial photograph of the portion of Fountain Creek immediately upstream of and adjacent to the KOA property. Channel depths were based on the FEMA flood elevation profiles provided in Flood Insurance Studies (FISs) for the community of Fountain and El Paso County, Colorado.

Other channel parameters such as roughness, cross-section geometry, and horizontal expansion/contraction coefficients were derived from measurements using the provided aerial photograph and several ground-based photographs by the author. Cross-section geometry was inferred from these photographs using observed low-flow channel, bank, levee and apparent floodplain dimensions. It should be noted that cross-sectional geometry remains static throughout these simulations; the accurate treatment of erosion/deposition processes in the modeled stream reaches, especially along its banks, would require formulations of two- and three-dimensional flow variability that is beyond the capability of the EXTRAN model.

For ease of parameterization, portions of Fountain Creek between the upstream end of the EXTRAN model and a point (junction "US0255") approximately 250 feet upstream of the outfall from Fort Carson Military Reservation (junction "FCMRout") have been approximated as symmetrical channel segments for their current configurations. In that reach, a high degree of detail regarding floodplain geometry was not necessary for the adequate simulation of flow behavior in the reach immediately upstream of and adjacent to the KOA property. However, in simulations discussed below for which the left bank levee downstream of the bridge at Colorado Highway 16 was removed, this portion of the reach was specified with an asymmetrical channel and floodplain configuration.

For the portion of Fountain Creek extending from a point (junction "US0255") approximately 250 feet upstream of the outfall from Fort Carson Military Reservation (junction "FCMRout") to a point (junction "DS3130") near the downstream end of the KOA property, a high degree of detail in channel configuration was derived from the provided aerial photograph. In this reach, the channel is primarily asymmetrical with a steep bank on the right side and varying bed and bank configurations on the left (levee) side. In addition, the width of the channel under moderate and high discharge conditions would experience various expansions and contractions in this reach due to the configurations of the constructed levee and eroded right bank. That these asymmetries and expansions/contractions are represented adequately in the EXTRAN model of this reach is important for the accurate simulation of flow depths and velocities in the vicinity of the KOA property.

For the portion of Fountain Creek extending from a point (junction "DS3130") near the downstream end of the KOA property to a location approximately one mile further downstream, a regular trapezoidal channel with a constant bed slope and 2:1 (H:V) side slopes is included in the model. A partial listing of the EXTRAN channel parameters employed for simulation of the major storm event is given here in **Appendix B, Table 5**. This listing does not include the geometry and roughness configurations for the individual bridge segments (channel type 12) and designated irregular channels (channel type 8), which are addressed below.

For the purposes of determining flow conditions in the vicinity of the Greenview Ditch Headworks near Piñon, Colorado, two long channel segments were appended at the downstream end of the EXTRAN model discussed here. These segments are specified with regular (trapezoidal) geometry and constant slope over a total distance of approximately 28 miles in the downstream direction in order to determine the discharge hydrograph and flow velocities at that location. The specified parameters of these channel segments are also included in **Table 5**. Because the availability of rainfall, watershed and channel geometry data for the lower portion of the Fountain Creek watershed was severely limited, it would have been extremely difficult to specify a complete rainfall/runoff model downstream of the location of the KOA property. Instead, a detailed analysis of observed rainfall and stream discharges in the portion of the Fountain Creek watershed downstream of the KOA property provides some insight into the conditions that were found at locations such as the Greenview Ditch Headworks during the major event discussed here. This analysis is provided below in Section 8.1.1 in the context of simulation results for that location.

7.5. Bridge Cross-sections

Bridge segments are included in this EXTRAN model of Fountain Creek at the locations of Carson Boulevard and Colorado Highway 16, as described above. The details of bridge cross-section geometry were derived primarily from FEMA flood elevation profiles of Fountain Creek. These profiles provide streambed elevations as well as bridge deck (low-chord) elevations. Additional information on floodway width and cross-sectional area at these bridges was found in the FEMA Flood Insurance Studies to which these flood elevation profiles were attached. Various other parameters of the bridges such as roughness coefficients and pier configuration were derived from ground-based photographs of the bridge at Colorado Highway 16 by the author (e.g. **Appendix A, Figure 18**). It was assumed that the bridge at Carson Boulevard was similar in configuration to the bridge at Colorado Highway 16. Based on the photograph shown in **Figure 18**, it was also assumed that bed and bank cross-sections and pier placement at these bridges was symmetrical about the center axis of the channel.

7.6. Irregular Channel Cross-sections

Irregular channels are designated in all portions of the modeled reach of Fountain Creek upstream of a point (junction "DS3130") near the downstream end of the KOA property. This designation allows the specification of cross-sectional configurations that do not necessarily conform to those of more regular or constructed channels, which often have rectangular, trapezoidal or triangular cross-sectional geometry.

As described above, channel segments upstream of a point (junction "US0255") approximately 250 feet upstream of the outfall from Fort Carson Military Reservation (junction "FCMRout") have been approximated as symmetrical channel segments with irregular geometry. Channel segments between junction "US0255" and junction "DS3130" comprise the portion of Fountain Creek immediately upstream of and adjacent to the KOA property and have been parameterized here with irregular, primarily asymmetrical geometry. For each of these cross-sections, under present conditions, the left bank of the cross-section is formed by the levee that runs generally parallel to Fountain Creek downstream of the bridge at Colorado Highway 16. The right bank of these cross-sections is typically near vertical, according to the provided aerial photograph, and has been parameterized here as such.

Designation of irregular channels with specified cross-sectional geometry in this reach allows for the parameterization of reach segments where expansions and contractions of the horizontal dimensions occur, especially in the segments immediately adjacent to the KOA property where the left bank levee retreats from the channel of Fountain Creek in order to allow for an agricultural diversion structure in that portion of the reach. This EXTRAN model is thus able to represent the low bed areas between the main channel of Fountain Creek and the channel of the irrigation diversion as an intermediate floodplain area that was likely inundated during the high flow event discussed here.

Designation of irregular channel geometry in this portion of Fountain Creek also allows for the "removal" of the left bank levee downstream of the bridge at Colorado Highway 16, providing some ability to simulate the historical configuration of the floodplain in that reach before the construction of the levee. The modeling results for high-flow conditions under the historical and present conditions are thus easily compared. For the purposes of removing the levee from the cross-sections in this portion of Fountain Creek, left bank elevations were typically lowered and left bank stations were extended in order to conform with information regarding floodplain widths and elevations available in the FEMA Flood Insurance Studies mentioned above. It was assumed that Colorado Highway 85/87 would still be located in its present alignment, providing a likely ground level at the left-most station for these floodplain cross-sections.

The specified cross-sections for the irregular channel segments employed in this EXTRAN model are shown in **Figures 19a** through **19f**. In those figures, the channel segment cross-section specified for current conditions, *i.e.*, including the left bank levee downstream of the bridge at Colorado Highway 16, are given by the solid black line. The historical cross-sections, *i.e.*, without that levee, are shown in those figures with the solid gray line. No differences between the current and historical cross-sections were specified here for channel and bridge segments between the upstream end of the EXTRAN model and the bridge at Colorado Highway 16 (inclusive).

8. Major event in EXTRAN: April 28-May 2, 1999

Stream discharges occurring at the downstream end of the RUNOFF model, described above, for each of the simulated conditions of watershed development were stored by SWMM RUNOFF for use as input to the SWMM EXTRAN program. The stream discharges and flow velocities at USGS gauge 07105800, at the location of the KOA property, and at the location of the Greenview Ditch Headworks are discussed for four scenarios:

1. Current development conditions in the upstream watershed, and the current channel configuration, *i.e.*, with the left bank levee along much of this portion of Fountain Creek,
2. Current development conditions in the upstream watershed, and the presumed historical channel configuration with a nearly unrestricted floodplain along the left bank of this portion of Fountain Creek,
3. Historical (pre-development) conditions in the upstream watershed, and the current channel configuration along Fountain Creek, and
4. Historical (pre-development) conditions in the upstream watershed, and the presumed historical channel configuration with a nearly unrestricted floodplain along the left bank of Fountain Creek.

With regard to the importance of stream flow velocities found at the locations of interest during these simulations, the durations of flow velocities above specific thresholds are found for each scenario. These results are helpful in the determination of potential for erosion of specified soil types along the stream banks during a high-flow event.

The results for all of these scenarios are organized and compared in **Appendix B, Tables 10** (for discharges and flow velocities at the location of USGS gauge 07105800, "Fountain Creek at Security, Colorado"), **11** (for discharges and flow velocities at the location of the upstream end of the KOA property), and **12** (for discharges and flow velocities at the location of the Greenview Ditch Headworks).

8.1. Current Development Conditions in the Upstream Watershed

The results of flow simulations in the portion of Fountain Creek specified for the EXTRAN model under the influence of current development conditions in upstream areas are given here. Additional analysis regarding the occurrence of rainfall and observed stream discharges in the portion of the Fountain Creek watershed not simulated with the rainfall/runoff model described above is also given here.

8.1.1. Current Channel Configuration Along Fountain Creek

The simulated stream channel water surface profile for the portion of Fountain Creek modeled here with its current configuration using SWMM EXTRAN is shown in **Appendix A, Figure 20a**. A closer view of this stream channel water surface profile in the portions of Fountain Creek immediately upstream of and adjacent of the KOA property is shown in **Figure**

20b. It can be seen there that the water surface approaches the top of the levee in two locations in the vicinity of the KOA property. However, no overflow onto the adjacent floodplain was found to occur in the EXTRAN model of this portion of Fountain Creek.

The simulated hydrograph at the location of USGS gauge 07105800, which did not function during this event, for this scenario is shown in **Figure 21a**. The peak discharge at this location during the major storm event is noticeably greater than that recorded (and simulated) at the nearest upstream USGS gauge (07105530) discussed above. This large difference in peak stream discharge is due to contributions from the Sand Creek watershed, which encompasses much of the area in the immediate vicinity of the Colorado Springs NWS rainfall gauge. Runoff from Sand Creek reaches Fountain Creek downstream of USGS gauge 07105530, and is therefore not included in that hydrograph. The simulated flow velocities (positive in the downstream direction) at the location of USGS gauge 07105800 are shown in **Figure 21b**. The simulated discharges and flow velocities at a location near the upstream end of the KOA property along Fountain Creek are shown in **Figures 21c** and **21d**, respectively.

Figure 22a shows the recorded stream discharge hydrographs at three USGS stream gauge stations on Fountain Creek: USGS gauge 07105530 is that simulated and discussed at length above; USGS gauge 07106000 ("Fountain Creek near Fountain, Colorado") is located several miles downstream of the KOA property and the end of the detailed portion of the EXTRAN model described here; USGS gauge 07106500 ("Fountain Creek at Pueblo, Colorado") is located just upstream of the confluence of Fountain Creek with the Arkansas River in Pueblo, Colorado, and several miles downstream of the location of the Greenview Ditch Headworks. It should be noted that the two stream gauges along this reach of Fountain Creek for which data during the major storm event are missing or unreliable, gauges 07105800 ("Fountain Creek at Security, Colorado") and 07106300 ("Fountain Creek near Piñon, Colorado"), are those located closest to the properties of interest (KOA and the Greenview Ditch Headworks, respectively) in this study. As a proxy for the missing data at USGS gauge 07105800, the simulated hydrograph at that location is included in **Figure 22a**.

The extent of rainfall in the lower portion of the Fountain Creek watershed can be considered here only inferentially from the observed stream discharge in Jimmy Camp Creek at its confluence with Fountain Creek several miles upstream of USGS gauge 07106000, from the observations of rainfall at Nixon Base (located between the Jimmy Camp Creek confluence and USGS gauge 07106000) provided by the City Attorney for Colorado Springs, from the relative magnitudes of stream discharges observed in Fountain Creek between successive USGS gauges, and from official NWS rainfall observations at locations in Pueblo, Colorado, outside of the Fountain Creek watershed. A portion of the difficulty in specification of an accurate rainfall/runoff model for the lower portion of the Fountain Creek watershed arises from the lack of rainfall and observed stream discharge data at distributed locations in the watershed, that is, away from the course of Fountain Creek itself.

Data provided by the USGS showed that the peak discharge at USGS gauge 07105900 ("Jimmy Camp Creek at Fountain, Colorado") reached only 611 $ft^3 s^{-1}$ at 6:00 pm on April 30, 1999, and otherwise remained less than 50 $ft^3 s^{-1}$ for much of the major event discussed here. The rainfall gauge at Nixon Base recorded a total of 5.0 inches over the entire storm event, with a maximum of 2.1 inches of rainfall on April 30, 1999. Both of these observations are consistent with the passage of a large thunderstorm cell from northwest to southeast over the City of Colorado Springs and the surrounding watershed area on that afternoon, as indicated following the formulation of supplemental hyetographs for the foothills and central portions of the City of Colorado Springs and described in Section 6.1 of this report.

The hydrographs shown in **Figure 22a** indicate that, of the increases in mean and peak discharges and total flow volume that occurred between USGS gauges 07105530 and 07106000, significant portions (nearly 74%, 55% and 74%, respectively) actually occurred upstream of the location of USGS gauge 07105800. This area has been thoroughly represented in the rainfall/runoff model described in this report. The lesser portion of the demonstrated increase is not represented in the rainfall/runoff model because of the data limitations described above. The increase in stream discharge and total flow volume that occurred between USGS stream gauges 07105800 and 07106000, though large for the period of the major event around midnight on April 29-30, 1999, was relatively small for the period of highest discharge during the afternoon of April 30, 1999.

The observed peak stream discharge at USGS gauge 07106500 shown on **Figure 22a** in the afternoon of April 30, 1999, can be attributed to the occurrence of a thunderstorm in the vicinity of Pueblo, Colorado around that time. Overall, however, the mean and peak discharges and total flow volume are found to decrease by 12%, 6%, and 12% respectively between USGS gauges 07106000 and 07106500. This decrease can be attributed to several processes, including the downstream attenuation of flood peaks as well as the lateral spreading and floodplain loss of flows along this wide, shallow, generally braided and geomorphically variable portion of Fountain Creek.

The simulated hydrograph obtained by extension of the EXTRAN model to the location of the Greenview Ditch Headworks near Piñon, Colorado, is shown here in **Figure 22b**. The simulated flow velocities at this location are shown in **Figure 22c**. This location occurs just downstream of USGS gauge 07106300, for which stream discharge data was missing or unreliable during this event, and is found at a distance from USGS gauge 07106000 that is approximately 50% of the distance between USGS gauges 07106000 and 07106500. The simulations results demonstrate that, from USGS gauge 07106000 to the location of the Greenview Ditch Headworks, the mean and peak discharges and total flow volume are found to decrease by just more than 6%, 14%, and 6% respectively. With regard to the mean discharge and total flow volume, these results are consistent with a nearly linear decrease in flows over that reach of Fountain Creek. The large decrease in the peak discharge may be attributed to several factors related to the exclusion of the lower portion of the Fountain Creek watershed from the rainfall/runoff model described here, as well as errors relevant to the specification of channel configurations for Fountain Creek in the vicinity of the Greenview Ditch Headworks, but it should be noted that this perceived error remains within the expected accuracy of the stream discharge observations themselves, as discussed in Section 6.1 above.

8.1.2. Historical Channel Configuration Along Fountain Creek

The water surface profile along the modeled portion of Fountain Creek for the case in which the historical channel and floodplain configuration is specified is shown in **Figure 23a**. A closer view of the behavior of the water surface profile in the vicinity of the bridge at Colorado Highway 16 is shown in **Figure 23b**. It is apparent there that the absence of the levee on the left bank of Fountain Creek immediately downstream of that bridge allows a significant expansion of the stream channel, resulting in a large drop in water surface elevation through the bridge. A closer view of the water surface profile in the portions of Fountain Creek immediately upstream of and adjacent to the KOA property is shown in **Figure 23c**. By comparing this profile with that given in **Figure 20b**, it is found that the water surface elevation is lower by approximately 1-3 feet along much of this portion of Fountain Creek for historical floodplain conditions.

Figures 24a and **24b** demonstrate that the presence of the levee downstream of the bridge at Colorado Highway 16 has little effect on discharges and flow velocities at the location of USGS gauge 07105800. A similar result is found for the discharges at the upstream end of the KOA property as shown in **Figure 24c**, but **Figure 24d** reveals that the flow velocities at this location are significantly lower for historical floodplain conditions.

Comparisons of discharge and flow velocity statistics for these cases are given in **Appendix B, Tables 10** (at the location of USGS gauge 07105800) and **11** (at the upstream end of the KOA property). Included there are the non-scour flow velocities for the simulated (approximate) mean flow depths at those locations as determined by the Federal Highway Administration (FHWA) and the National Hydraulics Institute (NHI) for coarse sand and sandy loam soils (FHWA NHI 01-004, 2001). According to USDA Soil Conservation Service maps (referenced in Section 3 above), these are the two dominant soil types in this portion of the Fountain and Monument Creek watershed. It is shown by the tabulated results presented here that the duration of flow velocities greater than the threshold for scour and erosion of sandy loam soils in the vicinity of the KOA property is significantly less for the historical channel configuration with an unrestricted left-bank floodplain than for the current channel configuration under the influence of the left-bank levee.

8.2. Pre-development Conditions in the Upstream Watershed

The results of flow simulations in the portion of Fountain Creek specified for the EXTRAN model under the influence of historical or pre-development conditions (*i.e.*, in the absence of the City of Colorado Springs) in upstream areas are given here.

8.2.1. Current Channel Configuration Along Fountain Creek

For the case of the current channel configuration, the water surface profile in this portion of Fountain Creek is shown in **Appendix A, Figure 25**. Simulated discharges and flow velocities at the location of USGS gauge 07105800 are shown in **Figures 26a** and **26b**, respectively. The simulated discharges and flow velocities for this case at the upstream end of the KOA property are shown in **Figures 26c** and **26d**, respectively. These figures demonstrate a measurable difference in the discharges and flow velocities in this portion of Fountain Creek between the pre-development and current development conditions in the upstream areas. These differences are also compiled in **Appendix B, Tables 10** (at the location of USGS gauge 07105800) and **11** (at the upstream end of the KOA property).

8.2.2. Historical Channel Configuration Along Fountain Creek

For the case of the historical channel configuration in this portion of Fountain Creek, the resulting water surface profile is shown in **Appendix A, Figure 27**. The simulated discharges and flow velocities at the location of USGS gauge 07105800 for this case are shown in **Figures 28a** and **28b**, respectively. Simulated discharges and flow velocities at the upstream end of the KOA property along Fountain Creek for this case are shown in **Figures 28c** and **28d**, respectively. Statistics for these results are also included in **Appendix B, Tables 10** (at the location of USGS gauge 07105800) and **11** (at the upstream end of the KOA property).

8.3. Discussion

It is shown in **Tables 10** and **11** that the presence of the levee on the left bank of Fountain Creek downstream of the bridge at Colorado Highway 16 exerts little influence on discharges and flow velocities at USGS gauge 07105800, but has a significant influence on discharges and flow velocities in Fountain Creek in the immediate vicinity of the KOA property. The compiled results in **Table 10** show that, at USGS gauge 07105800, the primary influence on discharges and flow velocities (and therefore the potential for bed and bank erosion, after Knighton [1998]) is exerted by the development of the upstream areas in the Fountain and Monument Creek watershed. This influence, however, remains small. **Table 11** shows mixed results at the location of the KOA property along Fountain Creek: stream discharges are affected by the combination of upstream development *and* the presence of the left-bank levee, but flow velocities in that portion of Fountain Creek are affected *far* more by the presence of the left-bank levee than by the development and urbanization of upstream areas.

8.4. Greenview Ditch Headworks

The simulated hydrograph at the approximate location of the Greenview Ditch Headworks for the case of historical pre-development conditions in the upstream area is shown here in **Appendix A, Figure 29a**. The simulated flow velocities at this location and under this condition are shown in **Figure 29b**. Statistics for these results are included in **Appendix B, Table 12**. It is shown there that development and urbanization in the upstream area causes an increase in the peak discharge of nearly 30% and an increase in the total flow volume of more than 40% at this location. **Table 12** also indicates that development in upstream areas leads to increases in mean flow velocity at this location of less than 20% and increases in the duration of flow velocities above given erosion thresholds of less than 10%. As described in the analysis presented in Section 8.1 above, simulations of flows in Fountain Creek at this location are affected only slightly by the exclusion of rainfall/runoff processes in the lower portion of the Fountain Creek watershed from the model employed here.

9. Summary and Conclusions

The magnitudes of observed and simulated stream discharges and flow velocities at selected sites along Fountain Creek downstream of Colorado Springs during the major storm event that occurred on April 28-May 2, 1999, have been addressed here. The methodology for model construction and use employed here has been directed at the exploration of alternative scenarios regarding conditions of development and urbanization in the studied watershed.

The process by which a model of rainfall/runoff processes was specified for this work has been described. A test simulation of a minor storm event that occurred on October 27-28, 1998, in the Fountain and Monument Creek watershed revealed the necessity of supplemental hyetograph input so that areas of the watershed where rainfall observations were nonexistent, or where nearby observations were unreliable due to topography, could be adequately represented in the SWMM RUNOFF model for the accurate simulation of observed stream discharges and total flow volumes at various USGS stream gauge locations in the watershed. The formulation of supplemental hyetographs for the coverage of zones where rainfall observations proved inadequate was also employed in the simulation of the major storm event addressed in this work.

The process by which the major storm event that occurred on April 28-May 2, 1999, was simulated using the SWMM RUNOFF model constructed here has been described in detail. Of significant interest in the results of this work is the high degree of accuracy to which observed stream discharge hydrographs at USGS gauge locations along Fountain Creek in and downstream of Colorado Springs were simulated. The accuracy of these simulation results leads to confidence in the results of subsequent simulations that explored the alternative scenario of pre-development conditions in the area of the City of Colorado Springs. Incidental results regarding the simulation of stream discharges in the Shooks Run tributary of Fountain Creek in Colorado Springs are highly supportive of the modeling methods employed here. The goal of posing this alternative was to determine the effects of development and urbanization in Colorado Springs on stream discharges and total flow volumes in Fountain Creek in downstream reaches. It was found for this major storm event that development in the area of the City of Colorado Springs resulted in an increase of peak discharges in Fountain Creek of 12-14% and an increase in total flow volume in Fountain Creek of 20-25%.

The process by which a hydraulic model representing a portion of Fountain Creek downstream of Colorado Springs in the vicinity of USGS gauge 07105800, the KOA property, and the Greenview Ditch Headworks has also been described. The specification of stream channel segment cross-sections for current conditions, which include a levee along the left bank of Fountain Creek downstream of the bridge at Colorado Highway 16, and historical conditions (prior to levee construction, with a nearly unrestricted floodplain along that same portion of Fountain Creek) have been described. The hydraulic behavior of these flows in this portion of Fountain Creek were simulated with SWMM EXTRAN, using output hydrographs from the RUNOFF model for the scenarios of current development and pre-development conditions in upstream areas of the Fountain and Monument Creek watershed. Through an analysis of observed rainfall and stream discharge observations available for this portion of the Fountain Creek watershed, it was found that exclusion of that area from the rainfall/runoff model described here played an insignificant role in the simulation of stream discharges and flow velocities at the location of the Greenview Ditch Headworks.

The results of these simulations for the various specified scenarios and cases have been discussed in detail. Overall, comparisons of these simulation results show that:

1. Both the western and eastern portions of the City of Colorado Springs were subjected to heavy rainfall cells during the peak period of this storm event. The apparent dynamics of the storm during April 30, 1999, are indicated by examinations of surface weather observations and comparisons of observed and supplemental hyetographs and could not have been determined from the sparse (in space and time) observational information employed for the event analysis presented in Report No. 1. As a result of the present analysis, inferred maximum rainfall rates and event rainfall totals in the foothills and downtown areas of Colorado Springs were significantly larger than those discussed in the earlier report.
2. The presence of the levee along the left bank of Fountain Creek downstream of the bridge at Colorado Highway 16 exerts little influence on discharges and flow velocities at the

location of USGS gauge 07105800, but has a large influence on discharge and flow velocities in Fountain Creek in the immediate vicinity of the KOA property.

3. The largest influence on discharges and flow velocities, and therefore the potential for bed and bank erosion by hydraulic action (Knighton 1998), at the location of USGS gauge 07105800 along Fountain Creek is exerted by the development of the upstream areas in the Fountain and Monument Creek watershed.
4. Stream discharges at the location of the KOA property along Fountain Creek are affected by the combination of upstream development *and* the presence of the left-bank levee.
5. Flow velocities in the portion of Fountain Creek immediately upstream of and adjacent to the KOA property are affected to a far greater degree by the presence of the left-bank levee than by the development and urbanization of upstream areas.
6. Stream discharges and, to a lesser degree, flow velocities at the location of the Greenview Ditch Headworks near Piñon, Colorado, are affected by development and urbanization in upstream areas, but are likely also affected by the braided pattern and geomorphology of Fountain Creek in that vicinity. Simulations of flows in Fountain Creek at that location are affected to an only slight degree by the exclusion of rainfall/runoff processes in the lower portion of the Fountain Creek watershed from the model described here.

Figure 1: Schematic diagram of SWMM RUNOFF model sub-basins (with orange drainage paths attached) and stream channels (with black flow paths attached) within the Fountain Creek watershed in the region upstream of USGS stream flow gauge 07105800. The reference point (0,0) occurs at the confluence of Fountain and Monument Creeks in Colorado Springs. Scales on the axes shown here are given in feet north and east of the reference point. Additional color-coded reference points correspond to those shown on labeled portions of this schematic in **Figures 3a** through **3f** and **14**.

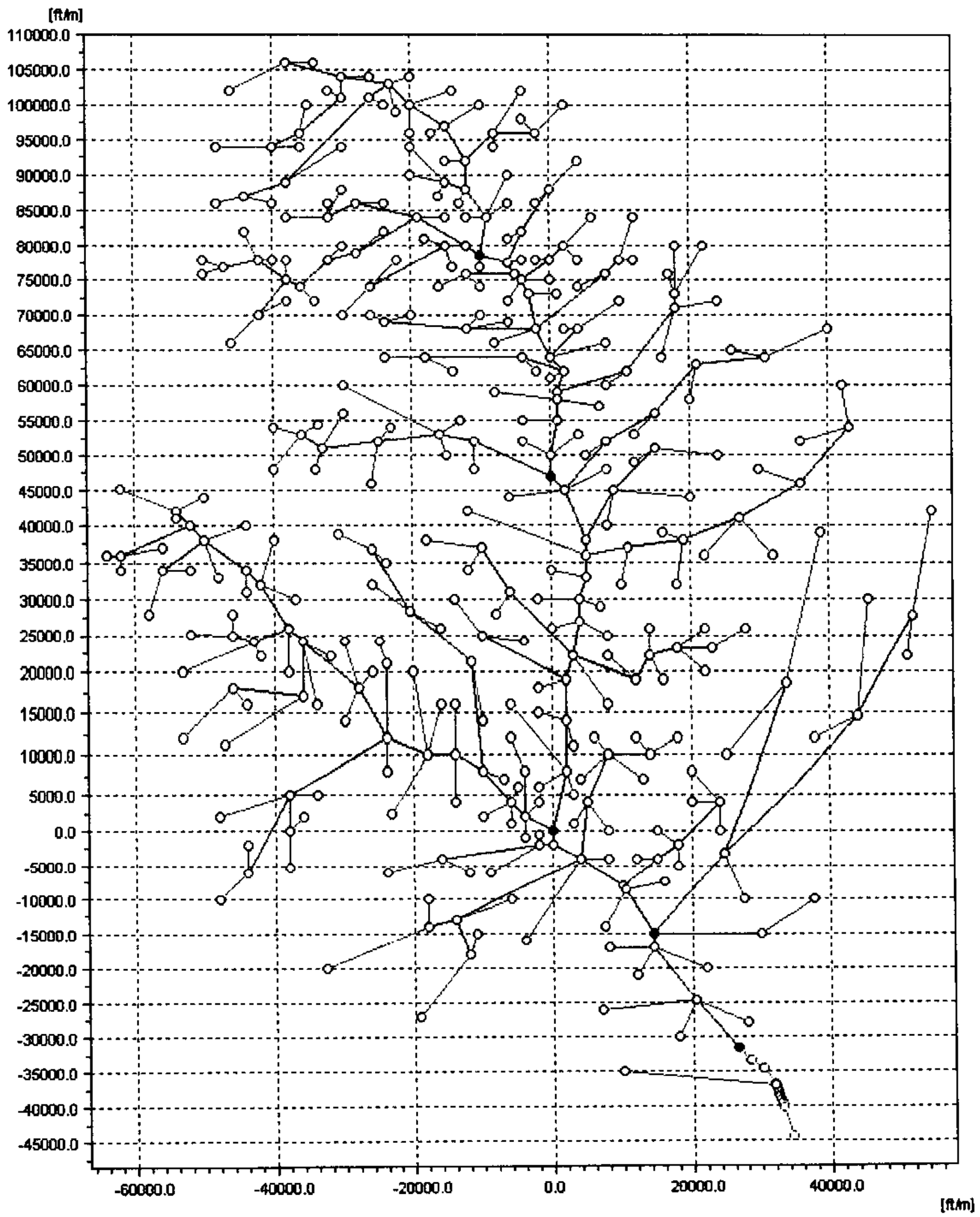


Figure 2: Example schematic demonstrating the assignment of numerical values to stream segments by the Strahler ordering scheme, from Figure 5.8.1 of Chow *et al.* (1988). The rules of the Strahler ordering scheme for stream channels are discussed in **Section 3** of this report.

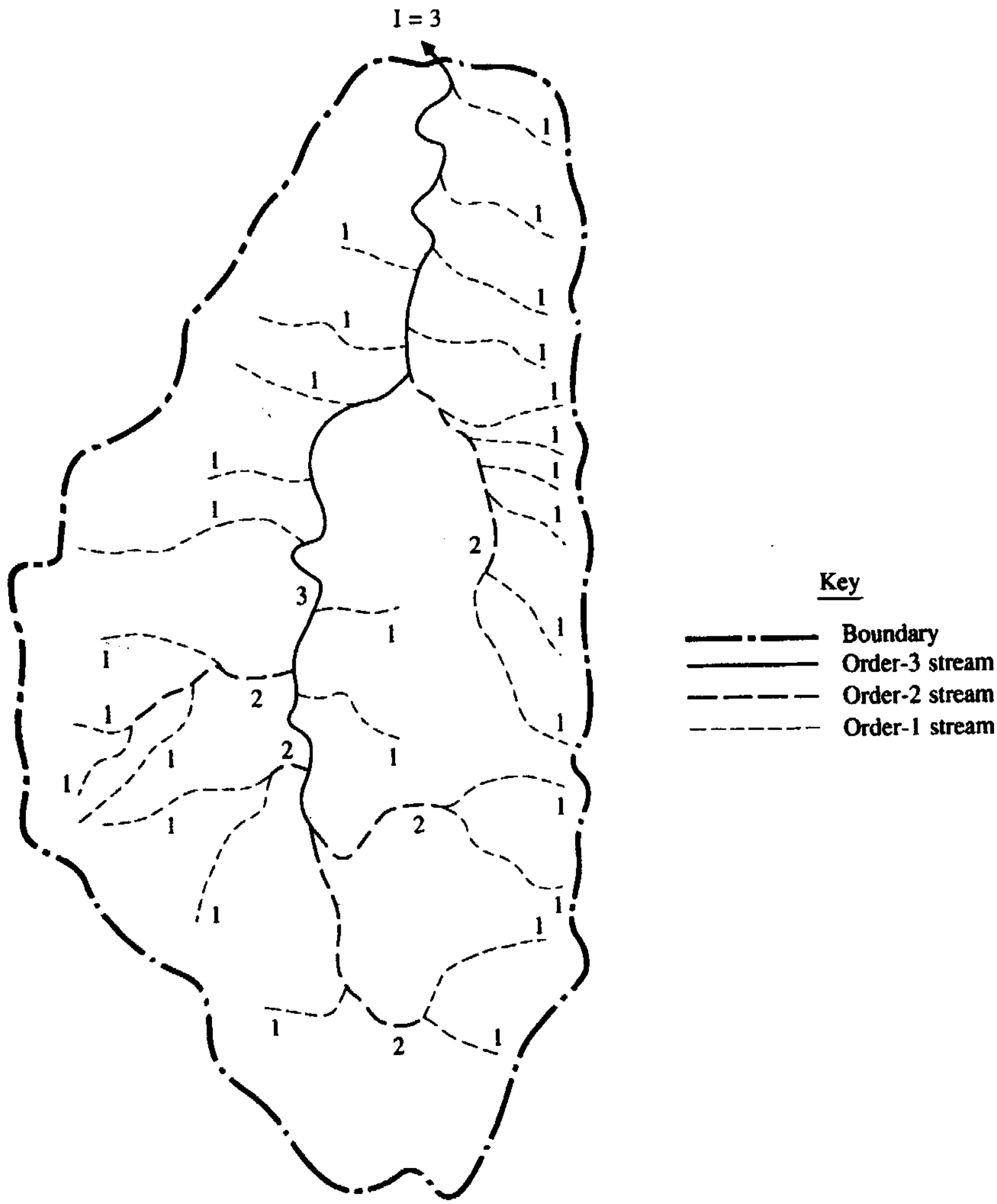


Figure 3a: Close-up view of SWMM RUNOFF model sub-basins (with orange drainage paths attached) and stream channels (with black flow paths attached) in the region of Upper and Middle Fountain Creek (UFC and MFC, respectively). The reference point (0,0) occurs at the confluence of Fountain and Monument Creeks in Colorado Springs. Scales on the axes shown here are given in feet north and east of the reference point. The color-coded reference point corresponds to that shown in **Figure 1**. Naming conventions for sub-basins and channels shown here are explained in **Section 4** of this report.

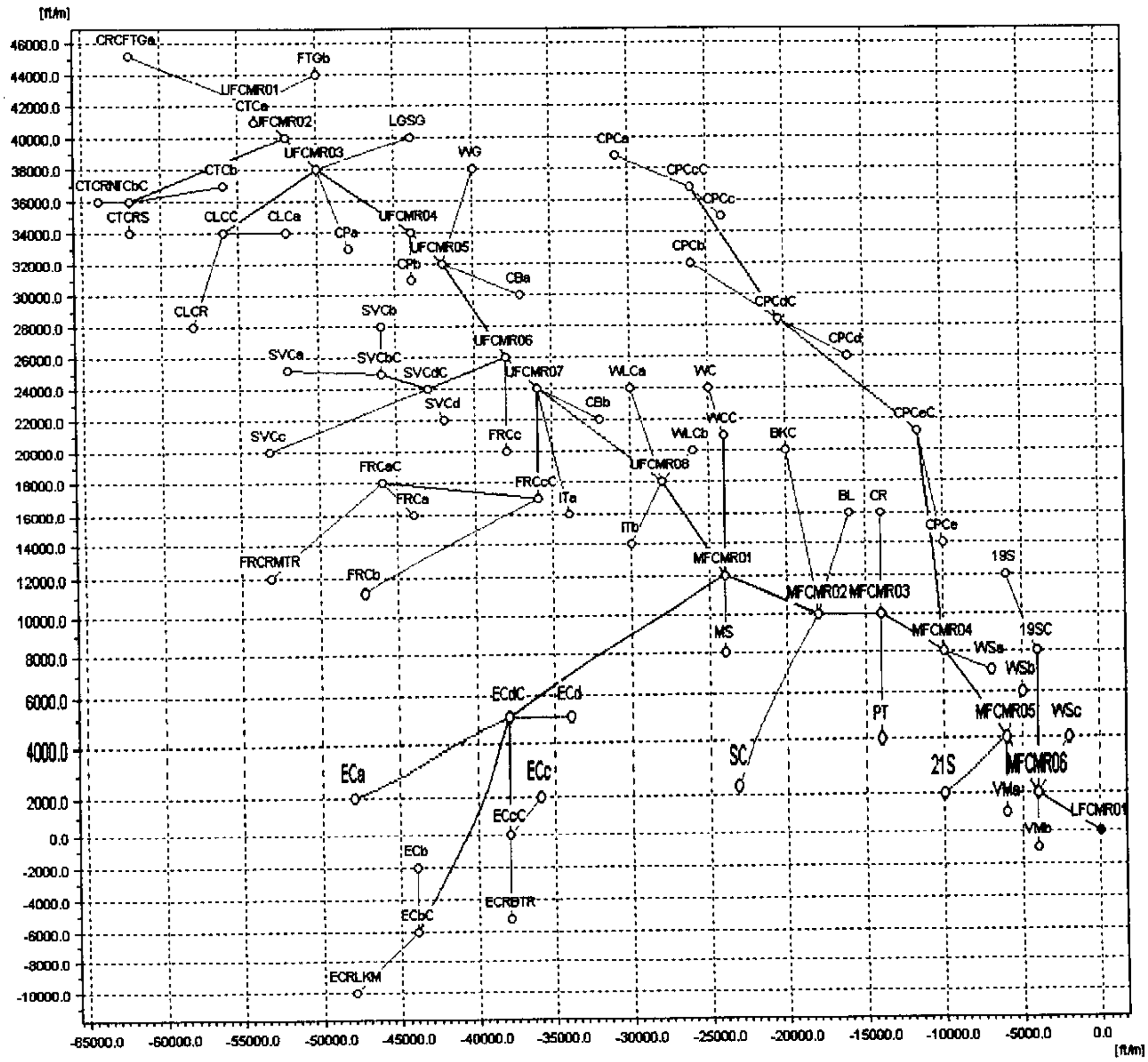


Figure 3b: Close-up view of SWMM RUNOFF model sub-basins (with orange drainage paths attached) and stream channels (with black flow paths attached) in the region of Upper Monument Creek (UMC). The reference point (0,0) occurs at the confluence of Fountain and Monument Creeks in Colorado Springs. Scales on the axes shown here are given in feet north and east of the reference point. The color-coded reference point corresponds to that shown in **Figures 1** and **3c**. Naming conventions for sub-basins and channels shown here are explained in **Section 4** of this report.

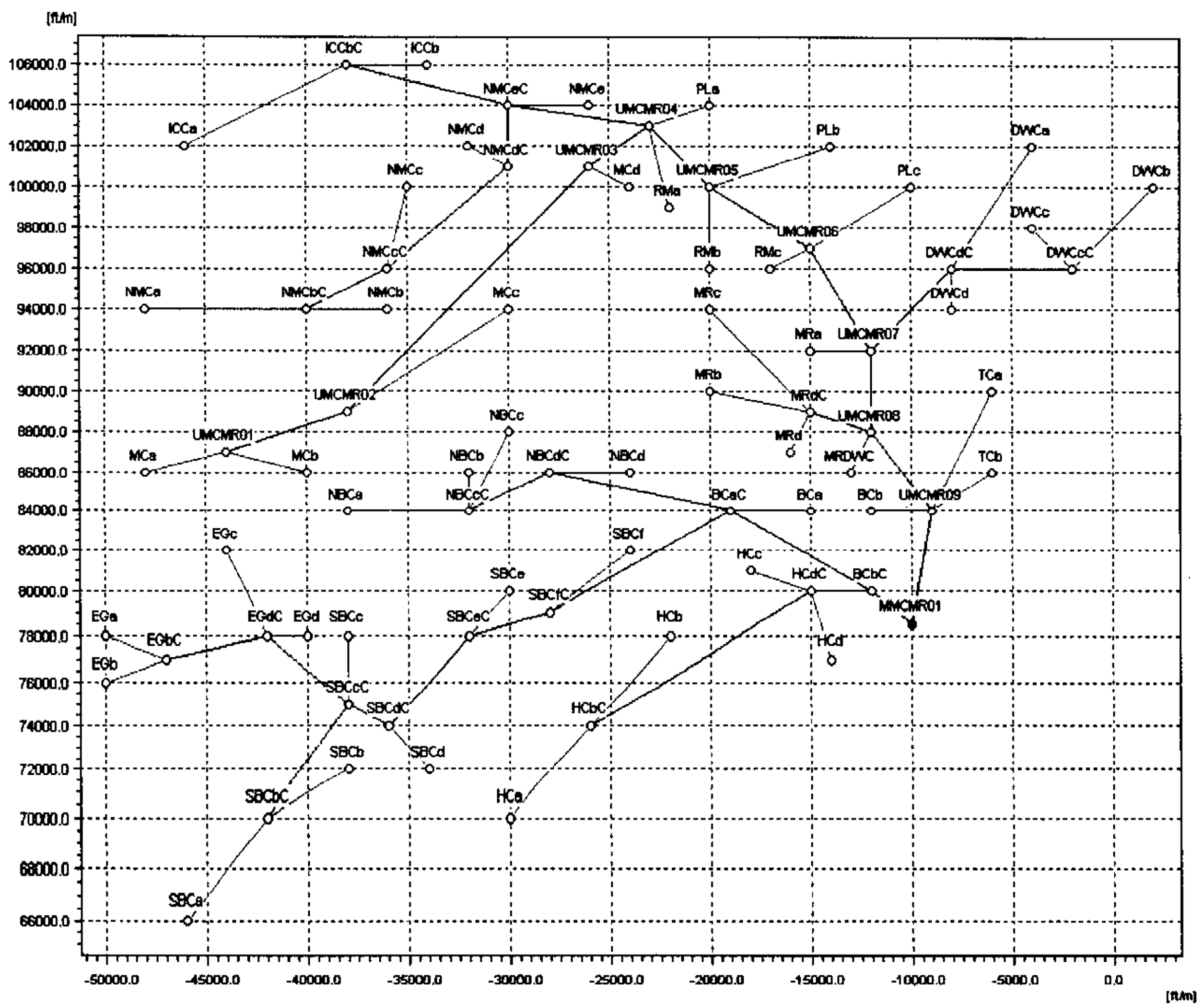


Figure 3c: Close-up view of SWMM RUNOFF model sub-basins (with orange drainage paths attached) and stream channels (with black flow paths attached) in the region of Middle Monument Creek (MMC), including West Monument Creek (WMC). The reference point (0,0) occurs at the confluence of Fountain and Monument Creeks in Colorado Springs. Scales on the axes shown here are given in feet north and east of the reference point. The color-coded reference points correspond to those shown in **Figures 1, 3b,** and **3d.** Naming conventions for sub-basins and channels shown here are explained in **Section 4** of this report.

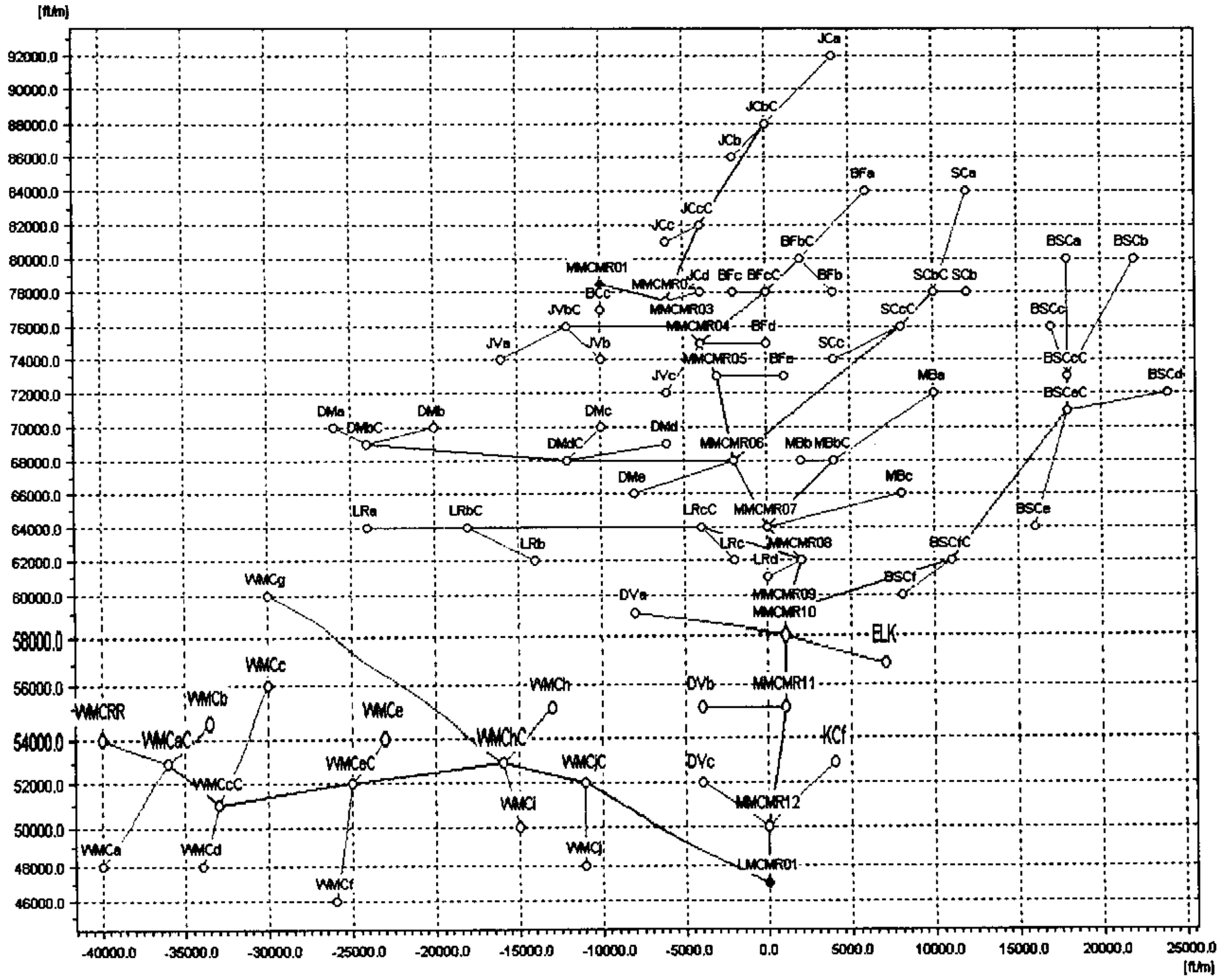


Figure 3d: Close-up view of SWMM RUNOFF model sub-basins (with orange drainage paths attached) and stream channels (with black flow paths attached) in the region of Lower Monument Creek (LMC). The reference point (0,0) occurs at the confluence of Fountain and Monument Creeks in Colorado Springs. Scales on the axes shown here are given in feet north and east of the reference point. The color-coded reference points correspond to those shown in **Figures 1**, **3c**, and **3e**. Naming conventions for sub-basins and channels shown here are explained in **Section 4** of this report.

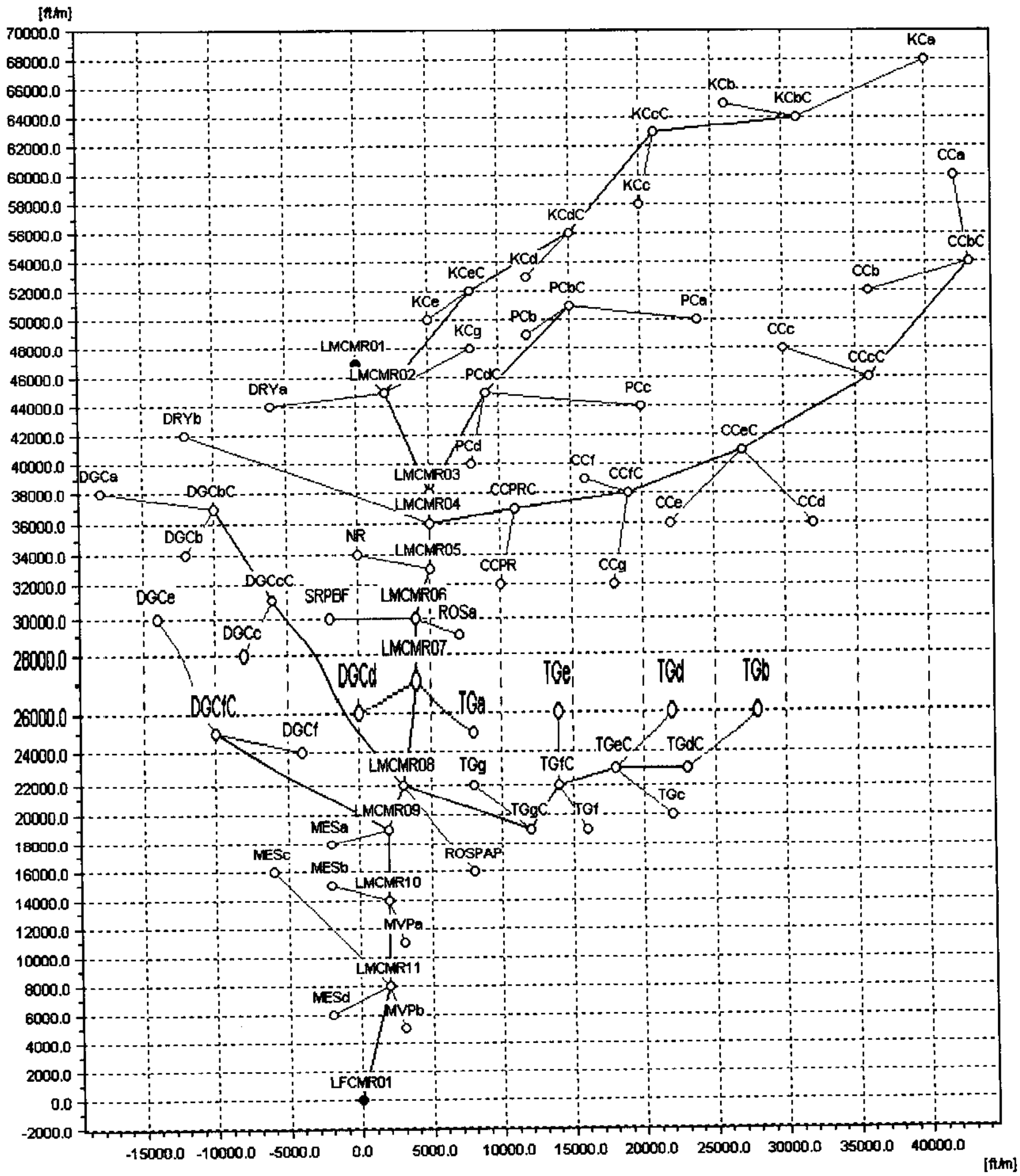


Figure 3e: Close-up view of SWMM RUNOFF model sub-basins (with orange drainage paths attached) and stream channels (with black flow paths attached) in the region of Lower Fountain Creek (LFC). The reference point (0,0) occurs at the confluence of Fountain and Monument Creeks in Colorado Springs. Scales on the axes shown here are given in feet north and east of the reference point. The color-coded reference points correspond to those shown in **Figures 1, 3a, 3d, 3f,** and **14.** Naming conventions for sub-basins and channels shown here are explained in **Section 4** of this report.

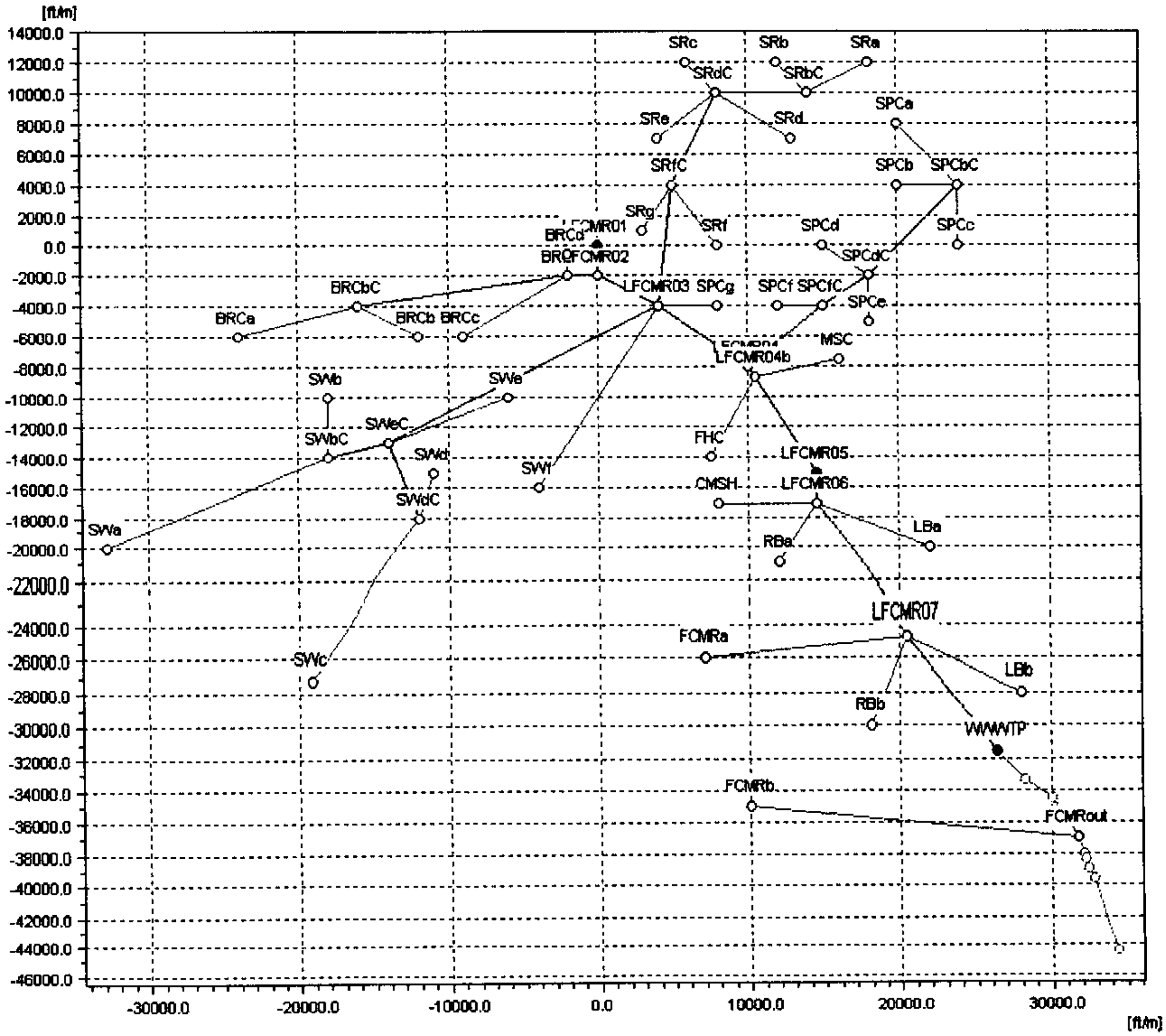


Figure 3f: Close-up view of SWMM RUNOFF model sub-basins (with orange drainage paths attached) and stream channels (with black flow paths attached) in the region of Sand Creek (SDC), east and south of Colorado Springs. The reference point (0,0) occurs at the confluence of Fountain and Monument Creeks in Colorado Springs. Scales on the axes shown here are given in feet north and east of the reference point. The color-coded reference points correspond to those shown in **Figures 1** and **3e**. Naming conventions for sub-basins and channels shown here are explained in **Section 4** of this report.

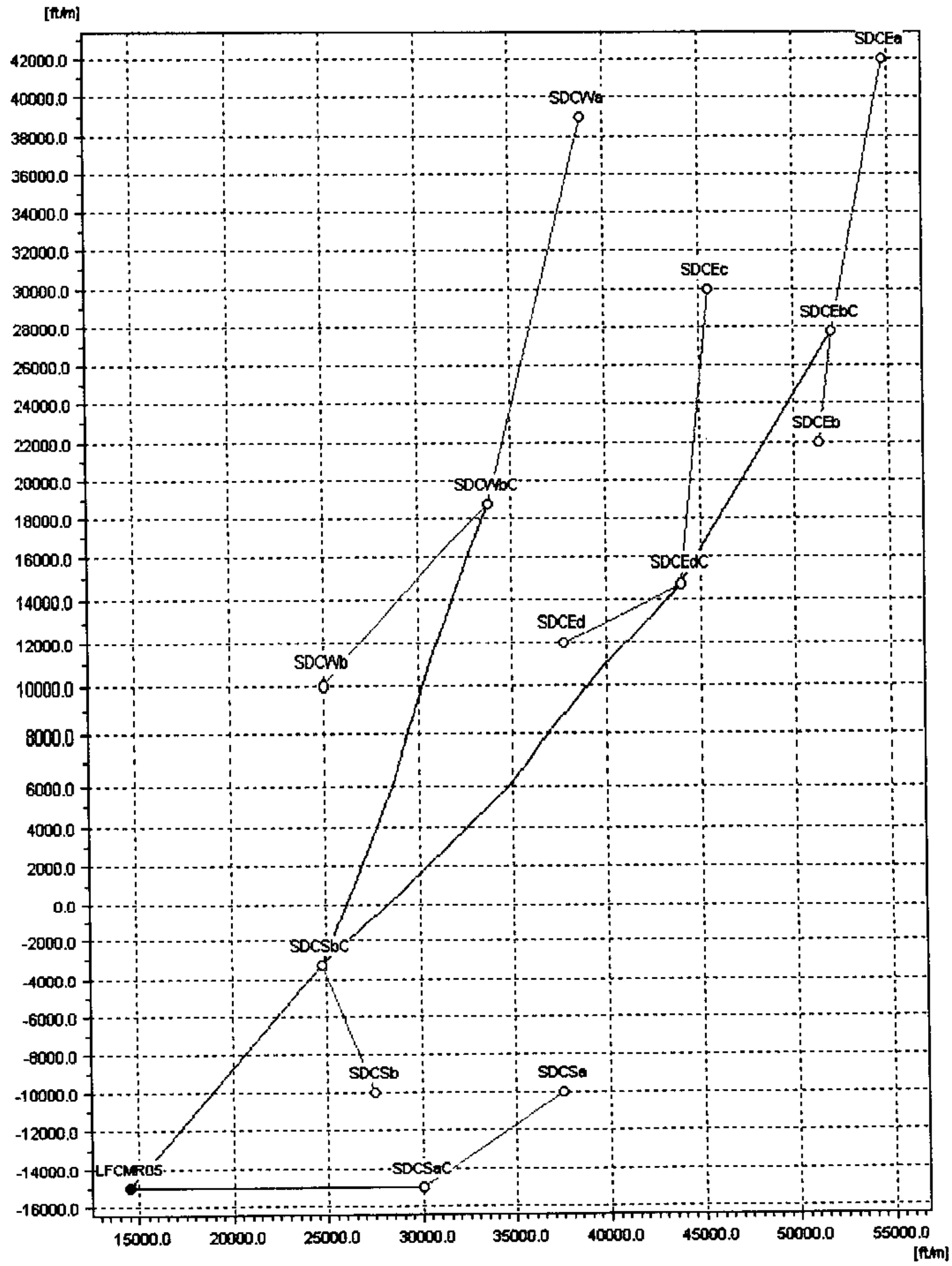


Figure 3g: Close-up view of SWMM RUNOFF model sub-basins (with orange drainage paths attached) and stream channels (with black flow paths attached) approximately within the region of the City of Colorado Springs. The reference point (0,0) occurs at the confluence of Fountain and Monument Creeks in Colorado Springs. Scales on the axes shown here are given in feet north and east of the reference point. The color-coded reference points correspond to those shown in **Figures 1, 3a, 3d, 3e,** and **3f**. Naming conventions for sub-basins and channels shown here are explained in **Section 4** of this report.

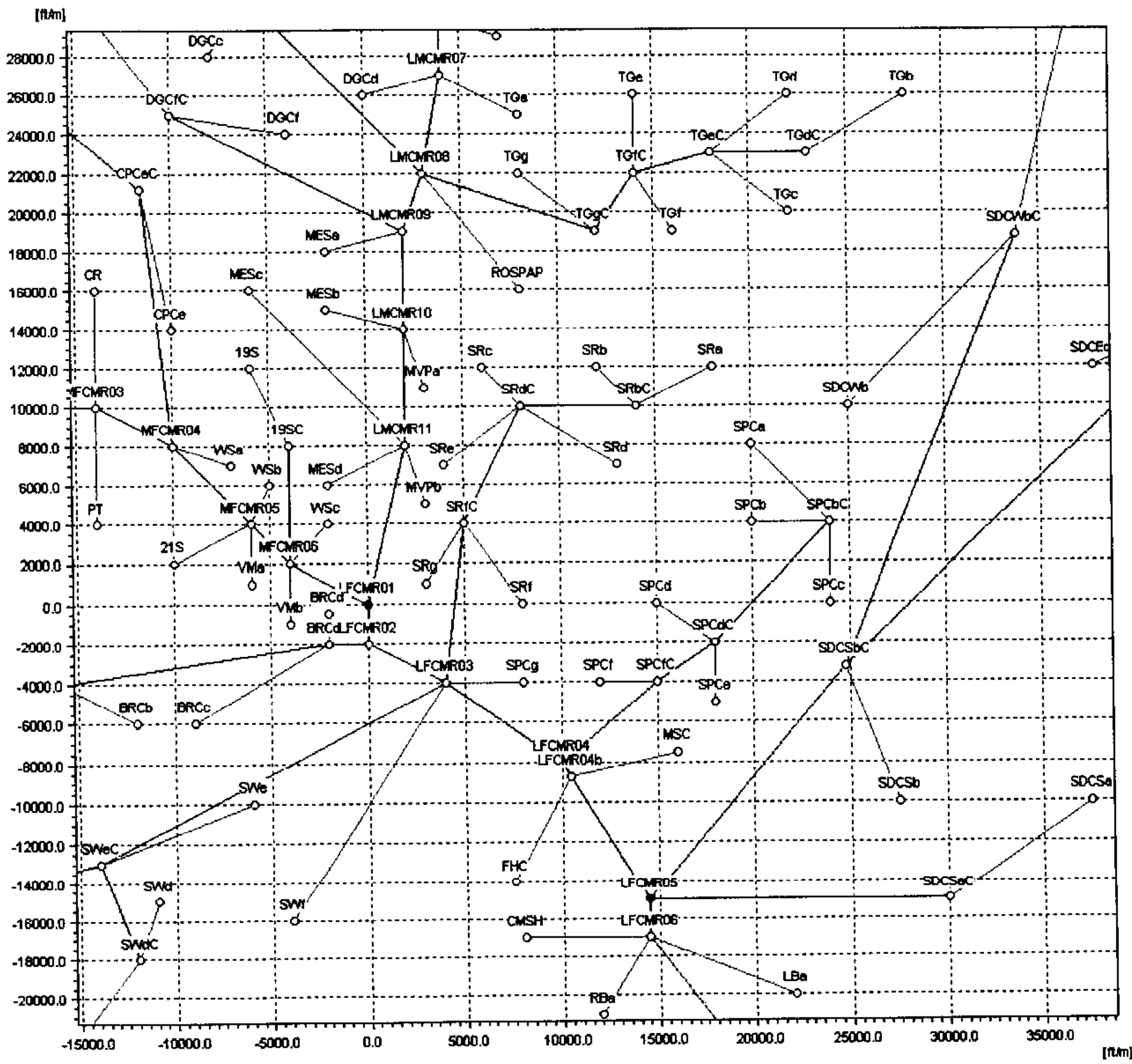


Figure 4a: Observed hourly hyetographs during the calibration event on October 27-28, 1998. These hyetographs are numbered 1-3 (top to bottom) on the left and 4-6 (top to bottom) on the right. The spatial distribution to which each hyetograph is applied for simulation of the calibration event is shown in **Figure 5**.

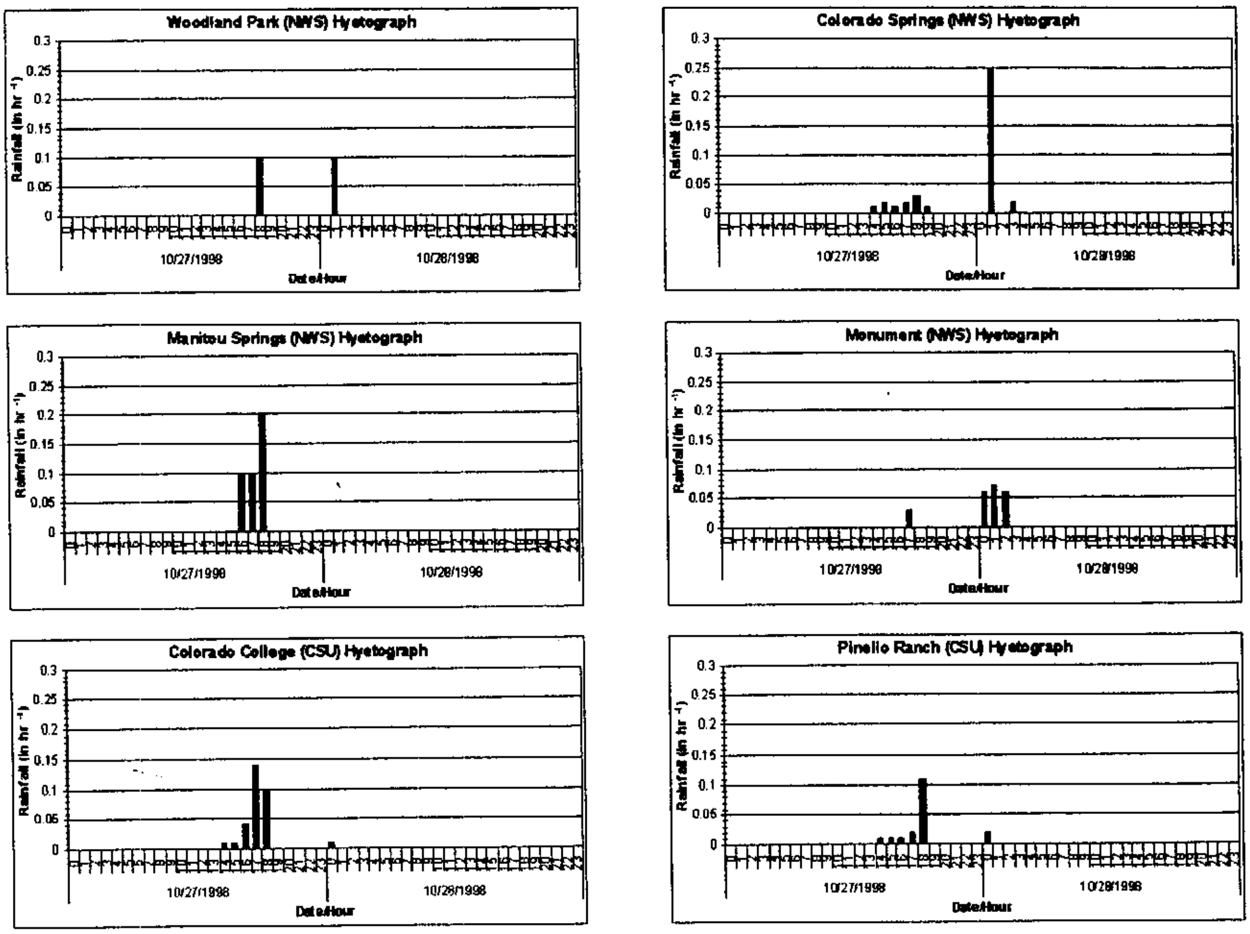


Figure 4b: Supplemental hourly hyetographs (numbered individually) developed for simulation of the calibration event during October 27-28, 1998. The spatial distribution to which each hyetograph is applied for simulation of the calibration event is shown in **Figure 5**.

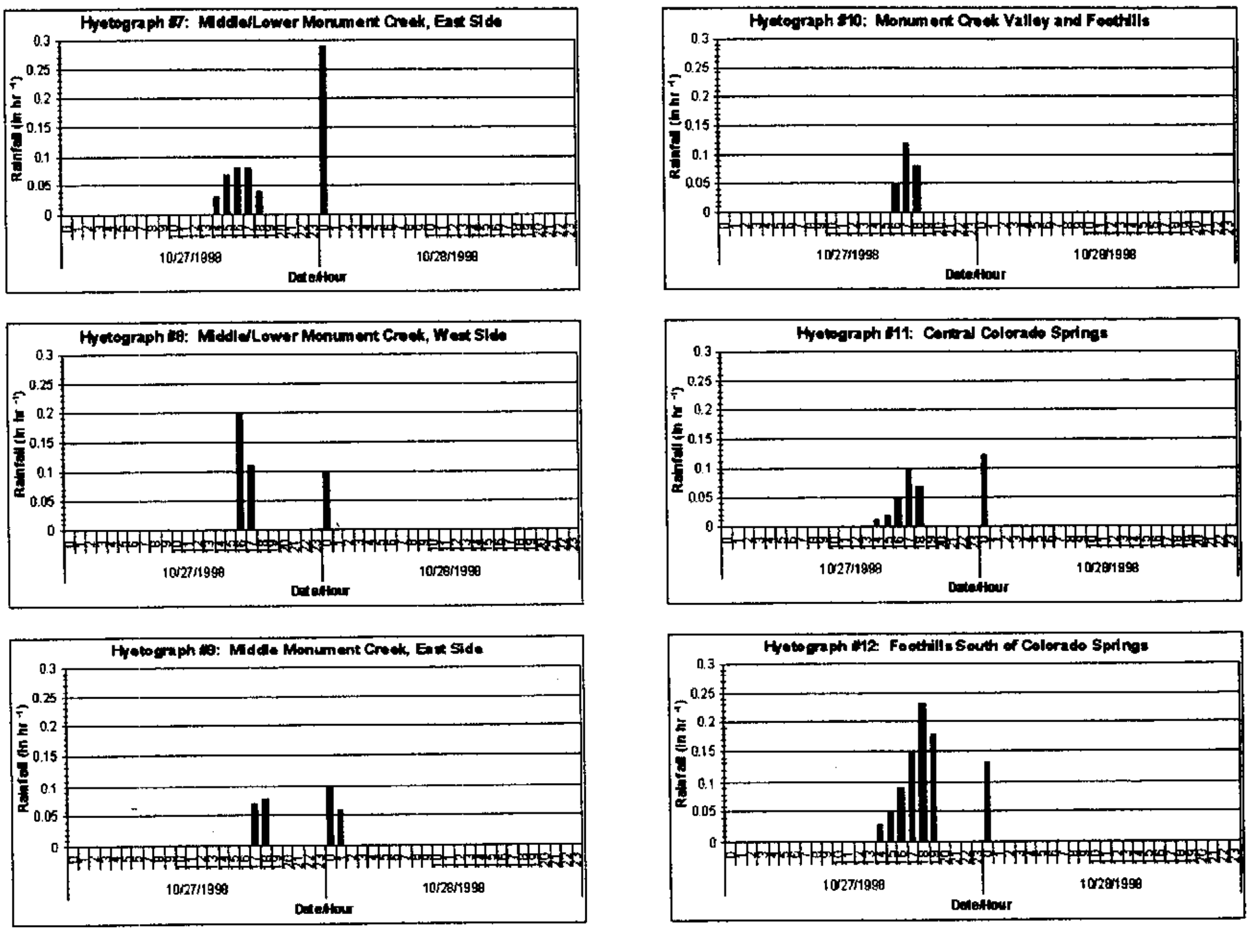


Figure 5: Schematic diagram showing the spatial distribution of hourly hyetographs given in **Figures 4a** and **4b** for simulation of the calibration event during October 27-28, 1998.

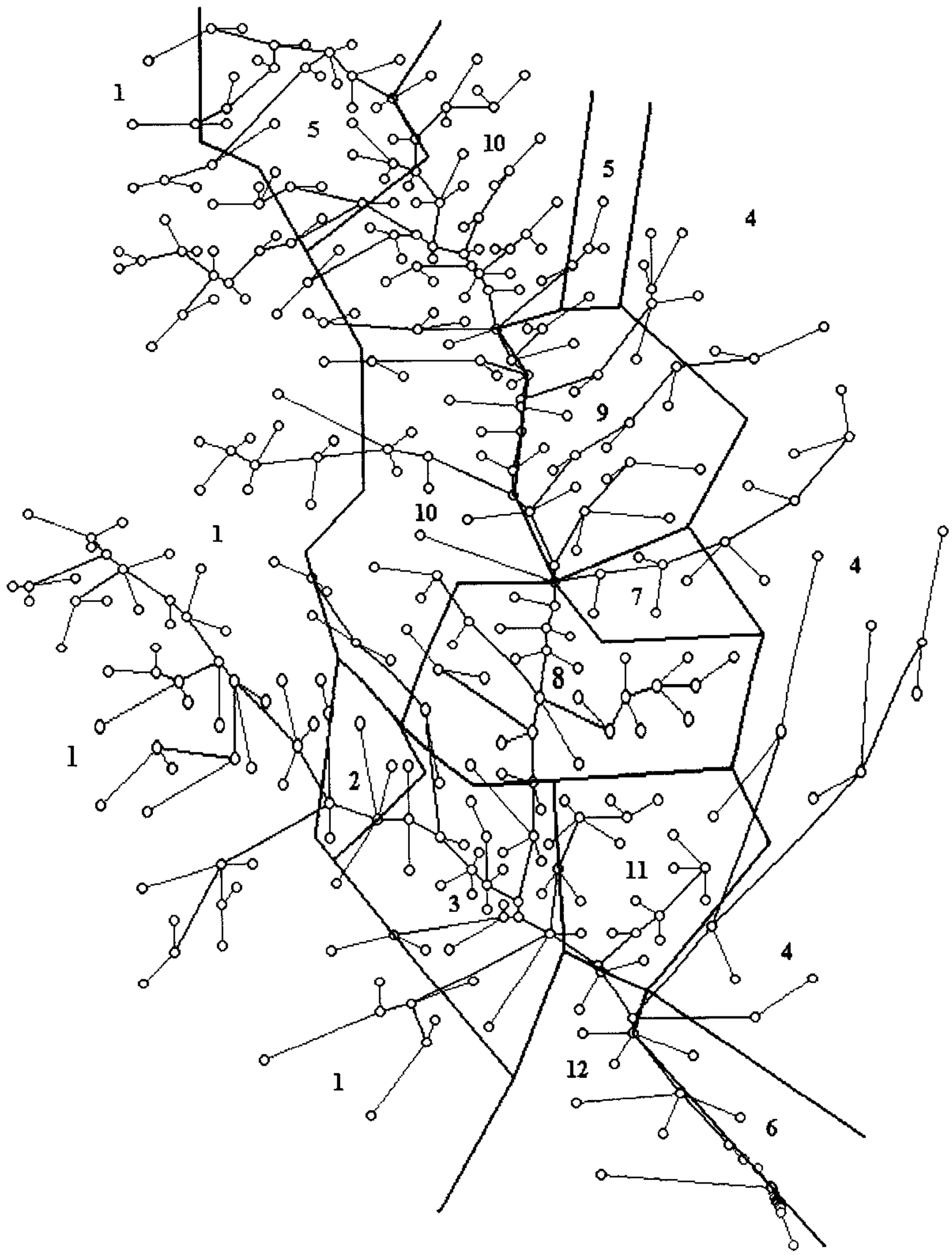


Figure 7a: Observed hydrograph for the major storm event during April 28-May 2, 1999, at USGS gauge 07104000 ("Monument Creek at Pikeview, Colorado").

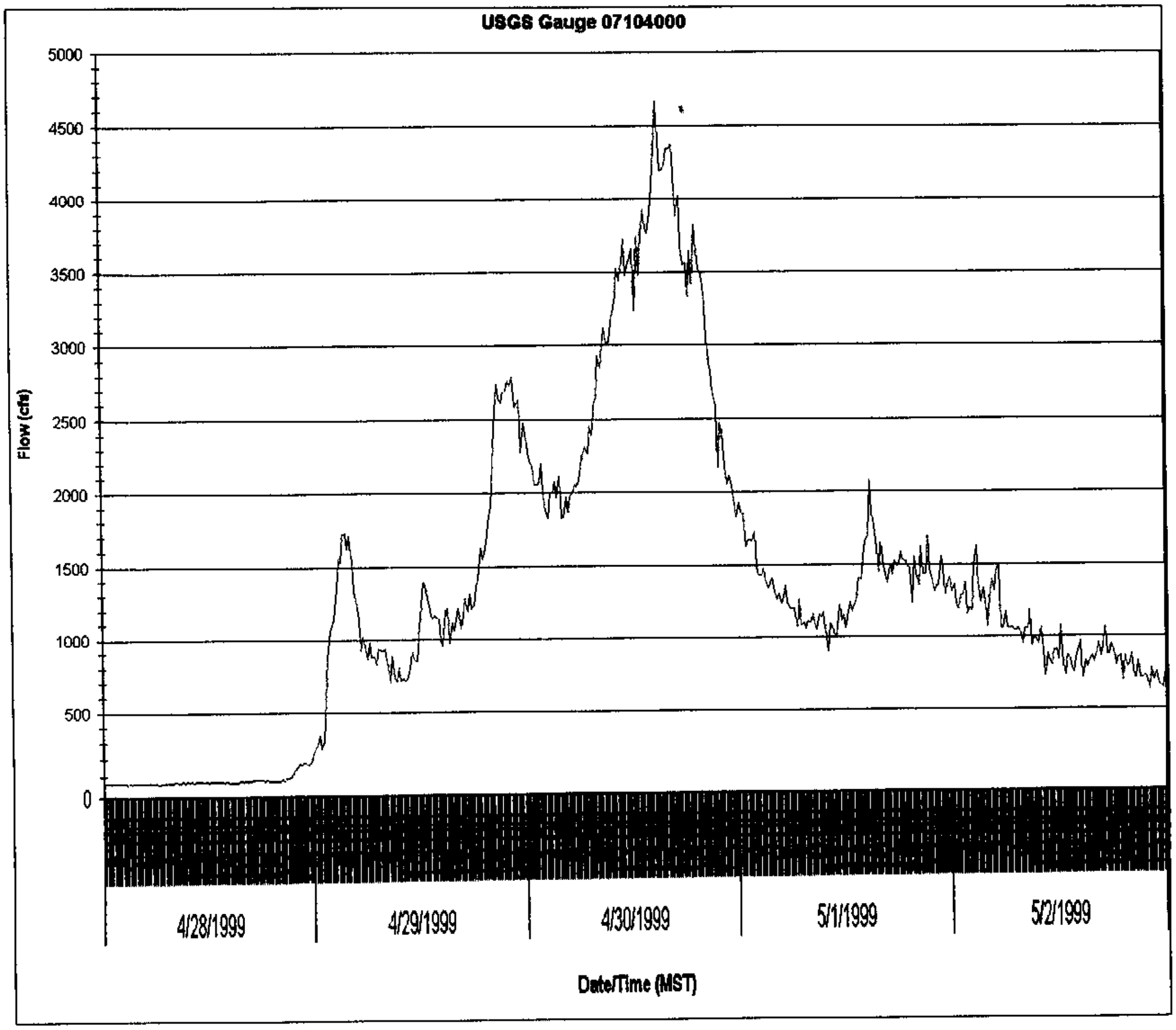


Figure 7b: Observed hydrographs for the major storm event during April 28-May 2, 1999, at USGS gauges 07105000 ("Bear Creek near Colorado Springs, Colorado") and 07105490 ("Cheyenne Creek at Evans Avenue at Colorado Springs, Colorado").

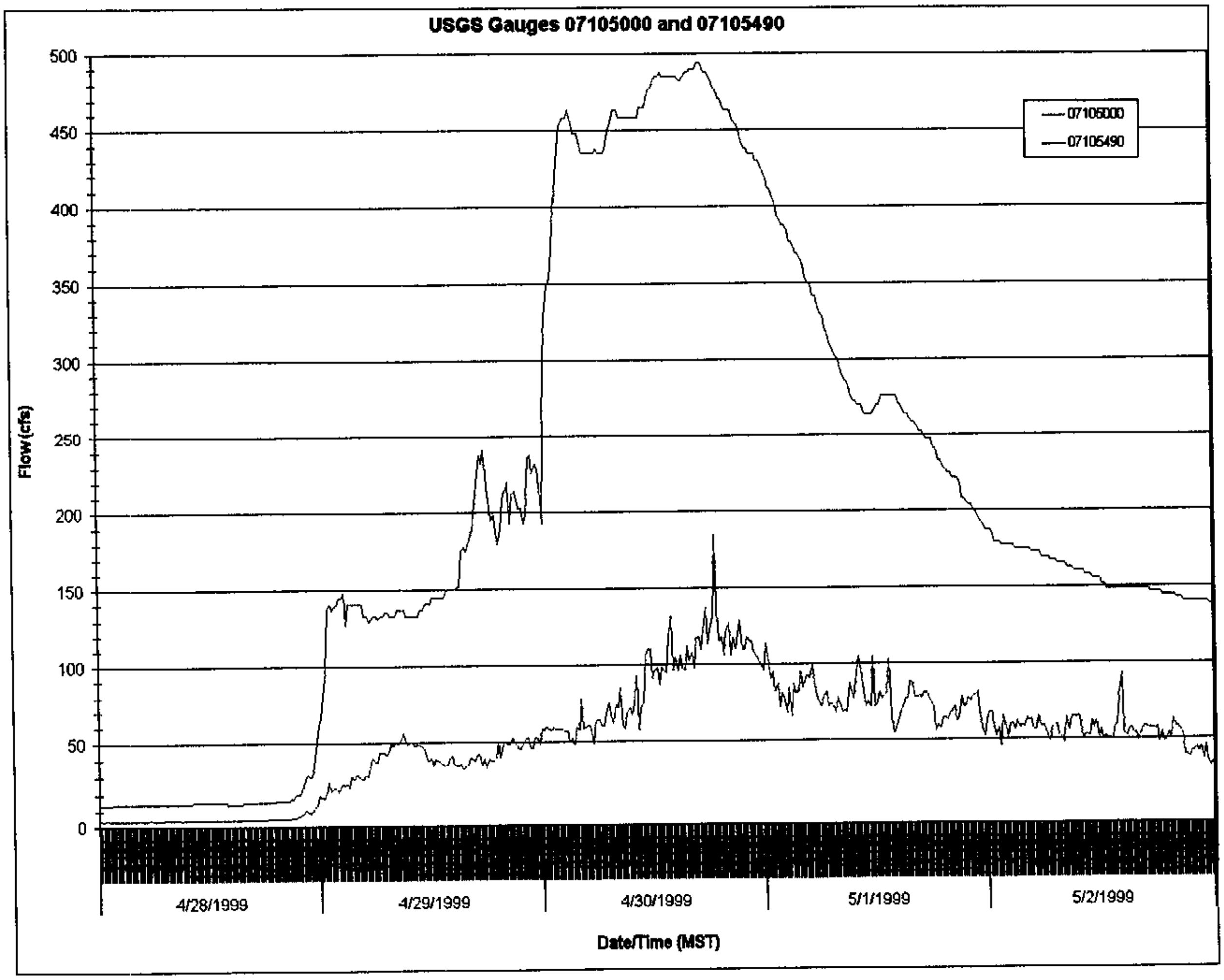


Figure 7c: Observed hydrograph for the major storm event during April 28-May 2, 1999, at USGS gauge 07105500 ("Fountain Creek at Colorado Springs, Colorado").

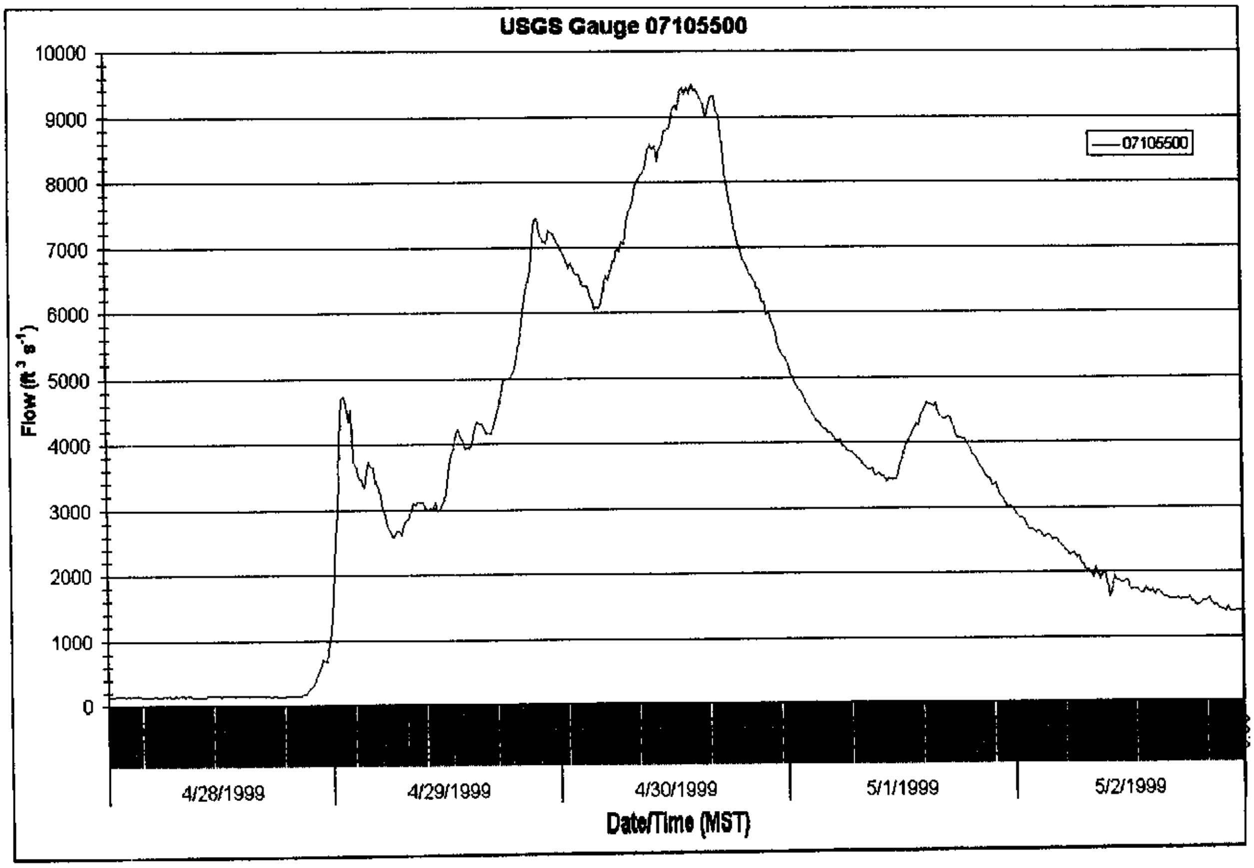


Figure 7d: Observed hydrograph for the major storm event during April 28-May 2, 1999, at USGS gauge 07105530 ("Fountain Creek below Janitell Road below Colorado Springs, Colorado").

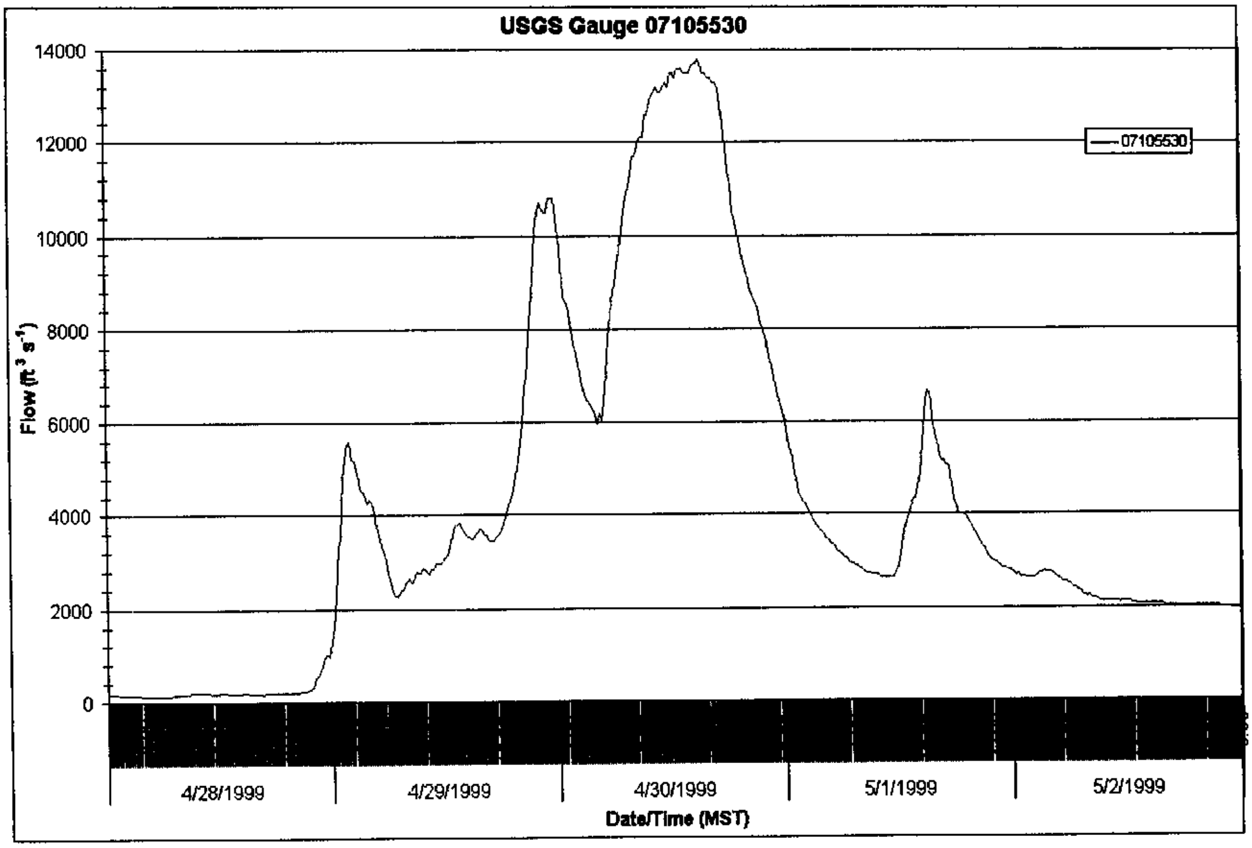


Figure 8a: Observed hourly rainfall during the major storm event on April 28-May 2, 1999. These hyetographs are numbered 1-3 (top to bottom), respectively. The spatial distribution to which each hyetograph is applied for simulation of the major storm event is shown in **Figure 9**.

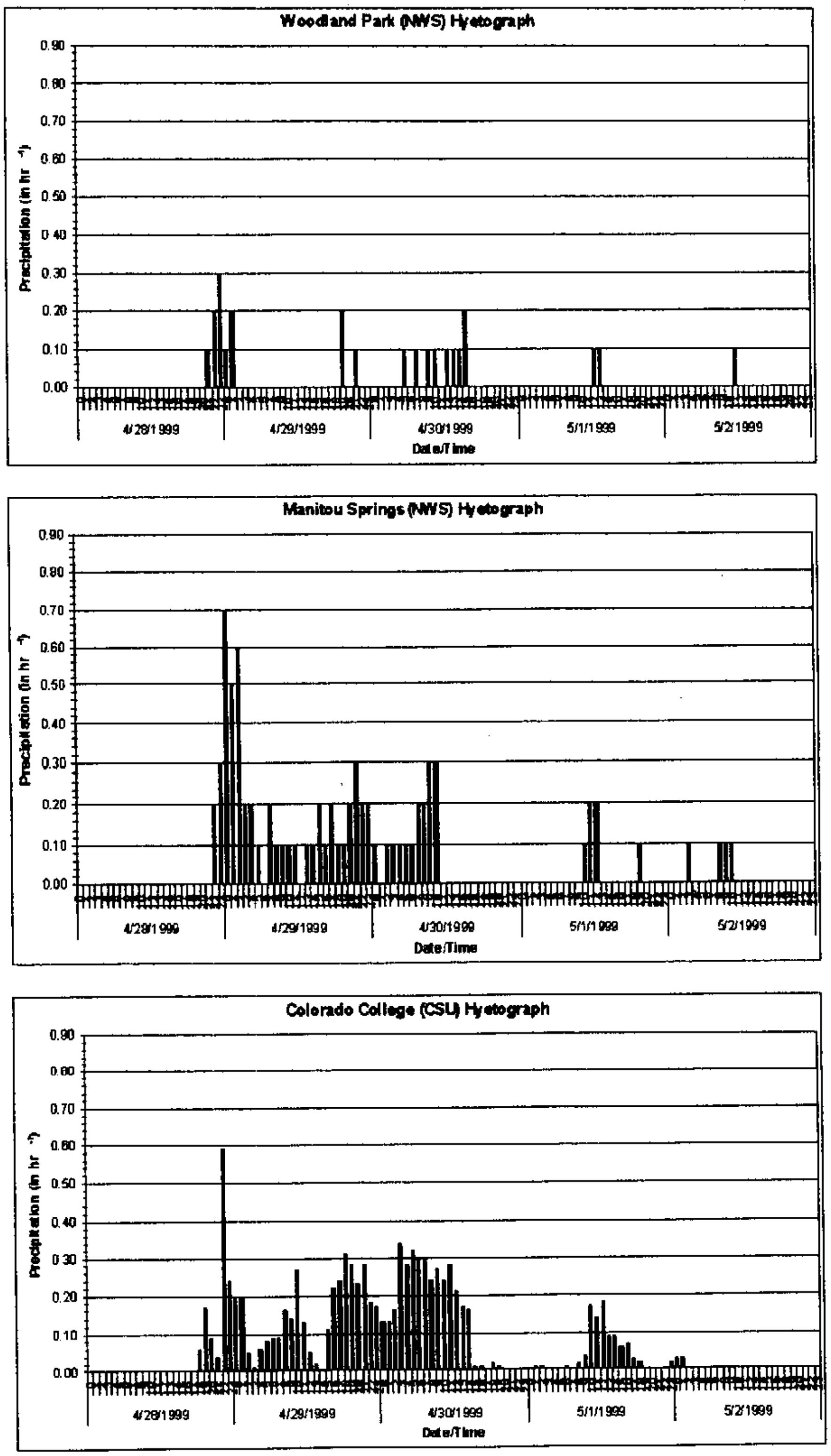
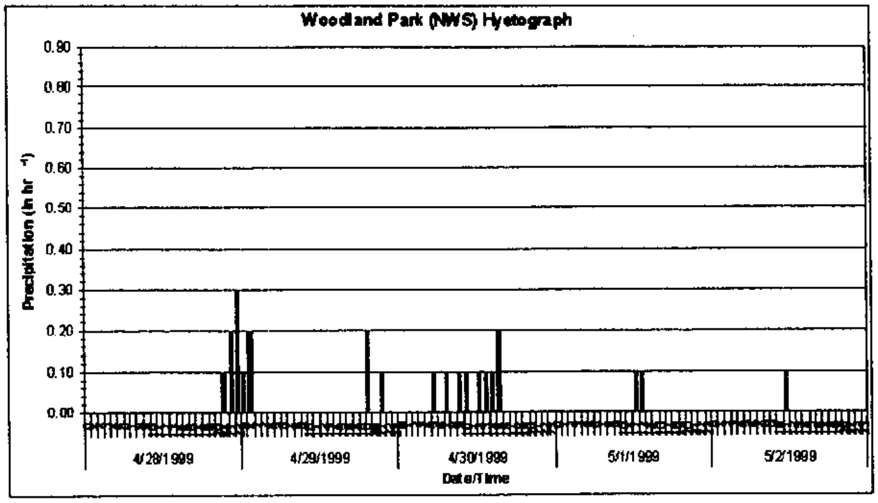
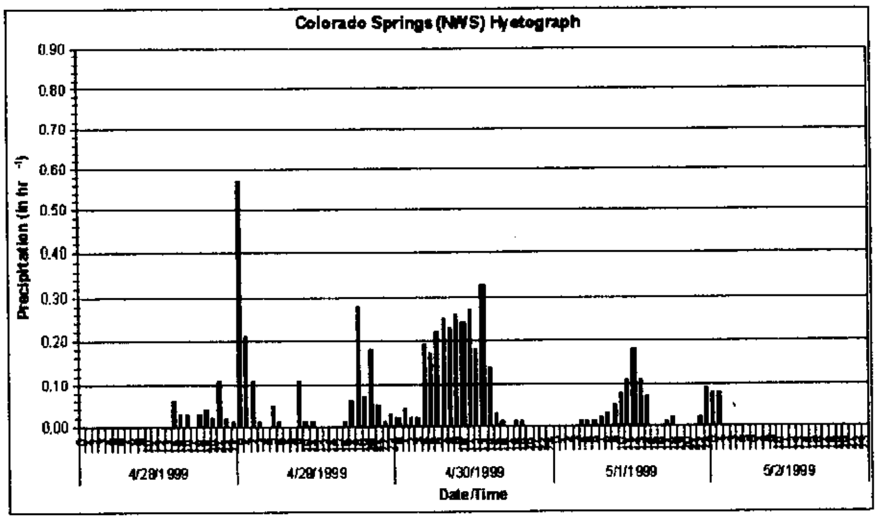


Figure 8a (continued): Observed hourly rainfall during the major storm event on April 28-May 2, 1999. These hyetographs are numbered 4-6 (top to bottom), respectively. The spatial distribution to which each hyetograph is applied for simulation of the major storm event is shown in **Figure 9**.





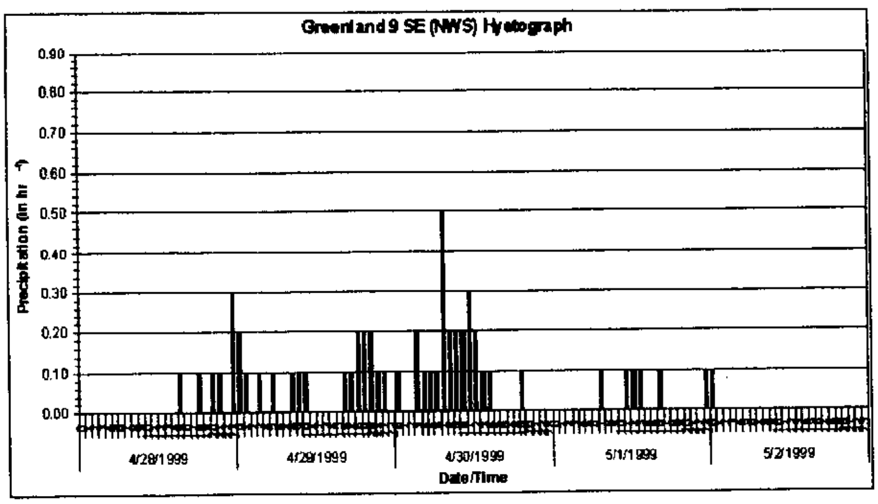
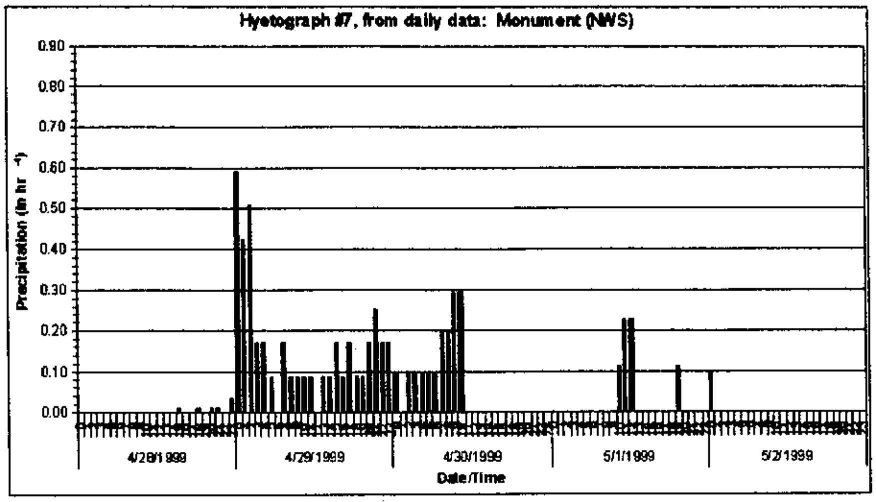
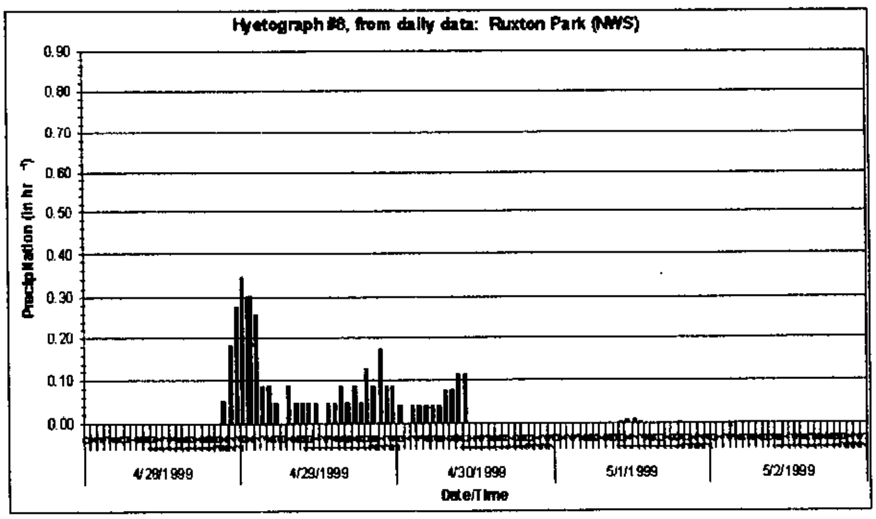


Figure 8b: Hourly hyetographs (numbered individually) derived from observed daily rainfall totals during the major storm event on April 28-May 2, 1999. The spatial distribution to which each hyetograph is applied for simulation of the major storm event is shown in **Figure 9**.





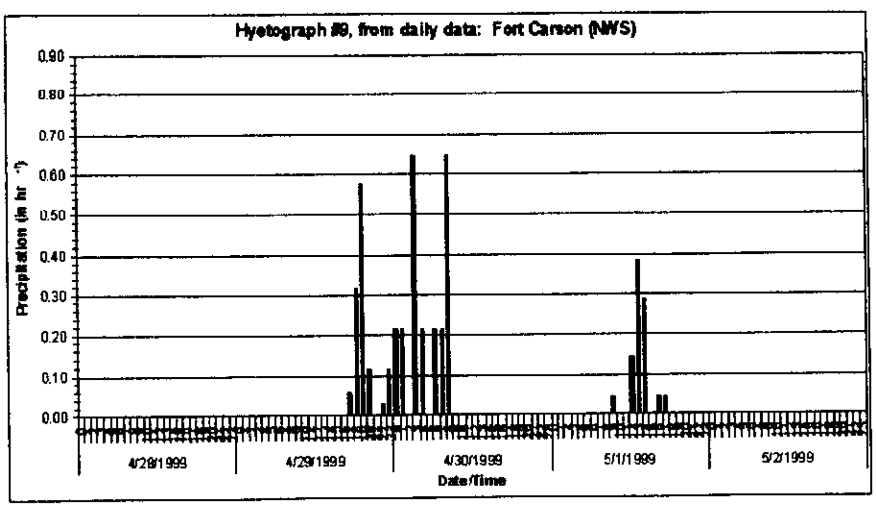


Figure 8b (continued): Hourly hyetographs (numbered individually) derived from observed daily rainfall totals during the major storm event on April 28-May 2, 1999. The spatial distribution to which each hyetograph is applied for simulation of the major storm event is shown in **Figure 9**.

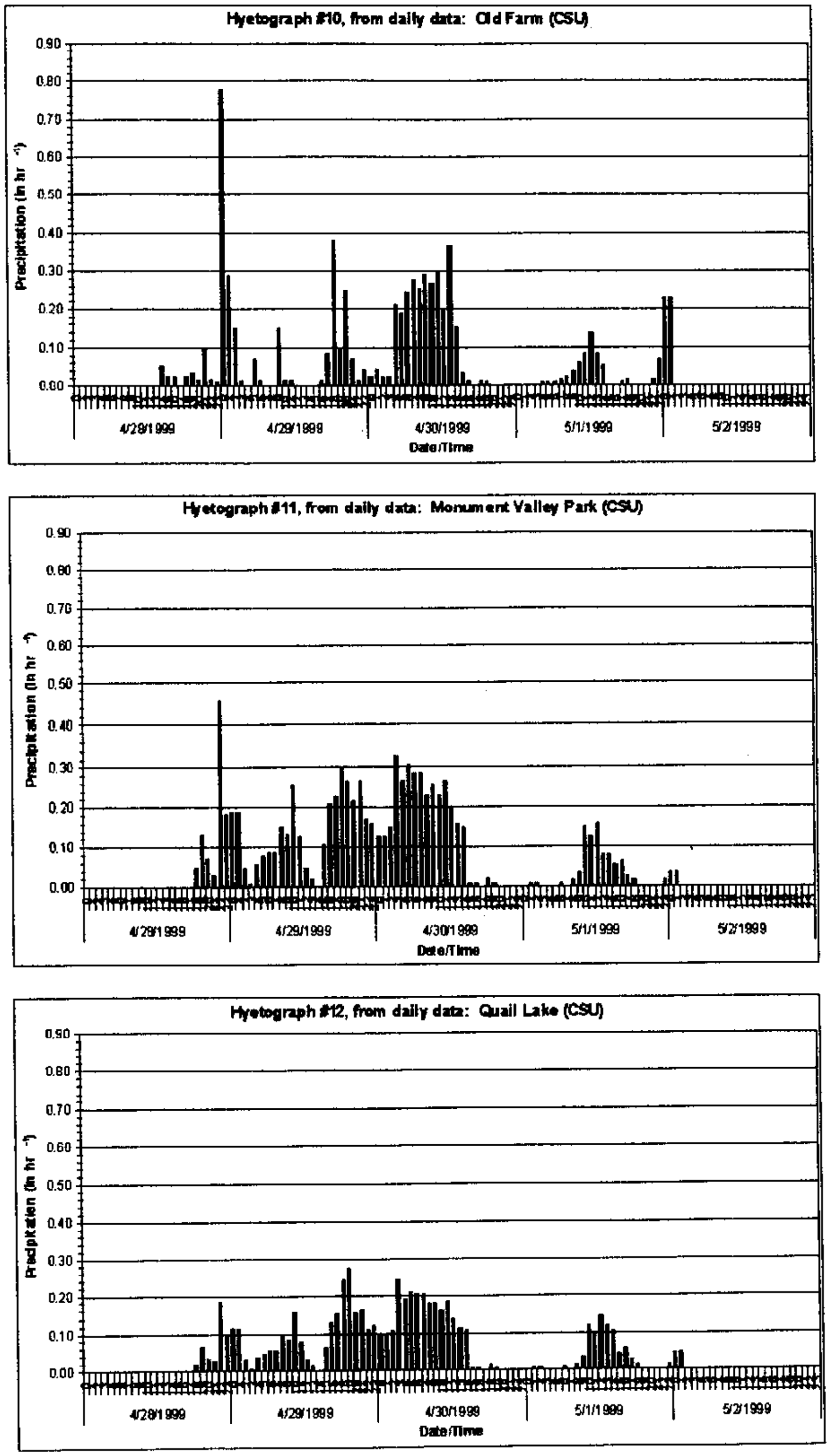
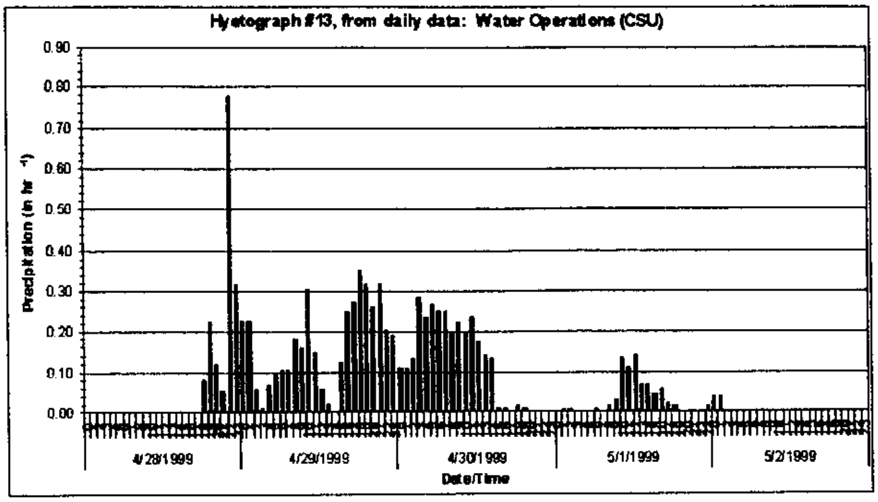


Figure 8b (continued): Hourly hyetographs (numbered individually) derived from observed daily rainfall totals during the major storm event on April 28-May 2, 1999. The spatial distribution to which each hyetograph is applied for simulation of the major storm event is shown in **Figure 9**.



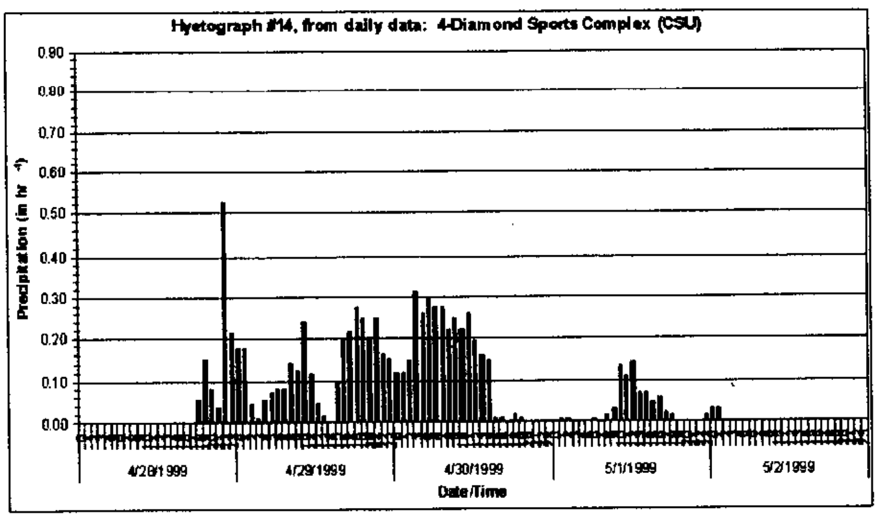
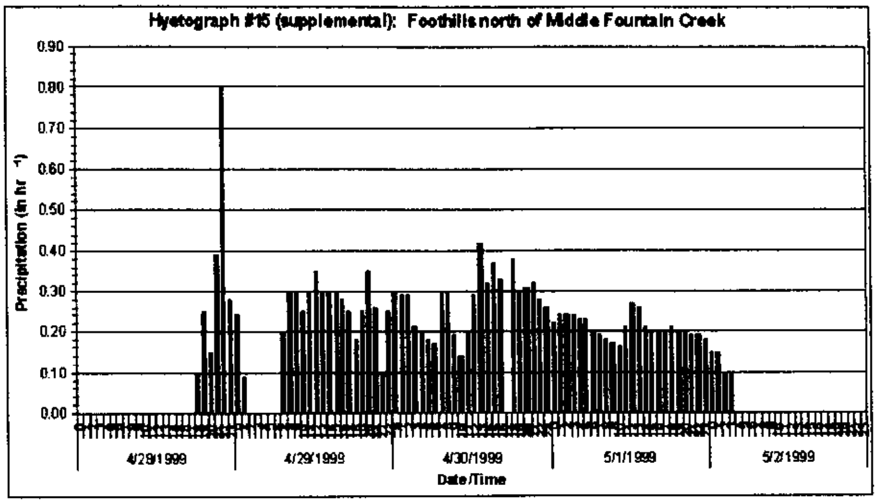
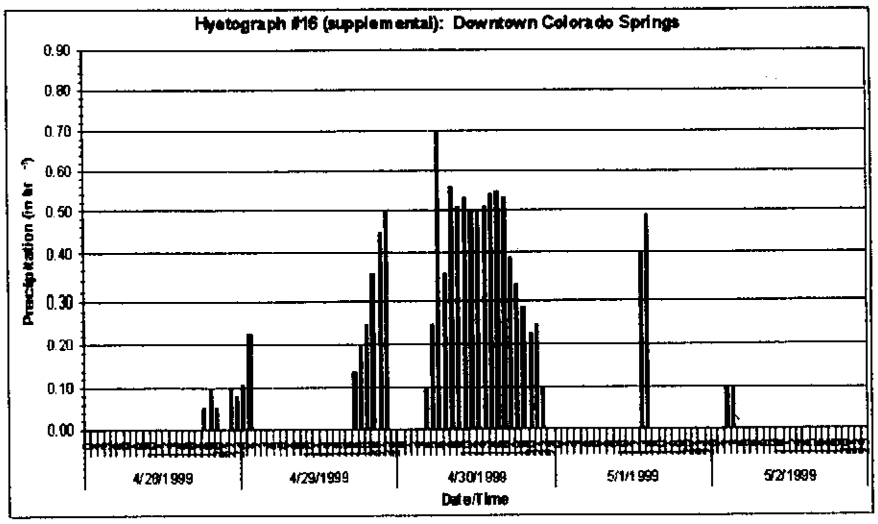


Figure 8c: Supplemental hourly hyetographs (numbered individually) employed for simulation of the major storm event on April 28-May 2, 1999. The spatial distribution to which each hyetograph is applied for simulation of the major storm event is shown in **Figure 9**.





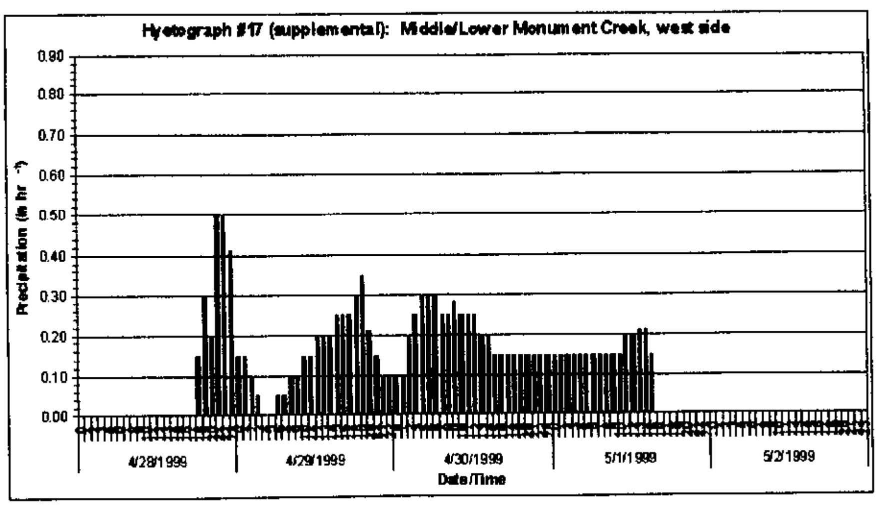
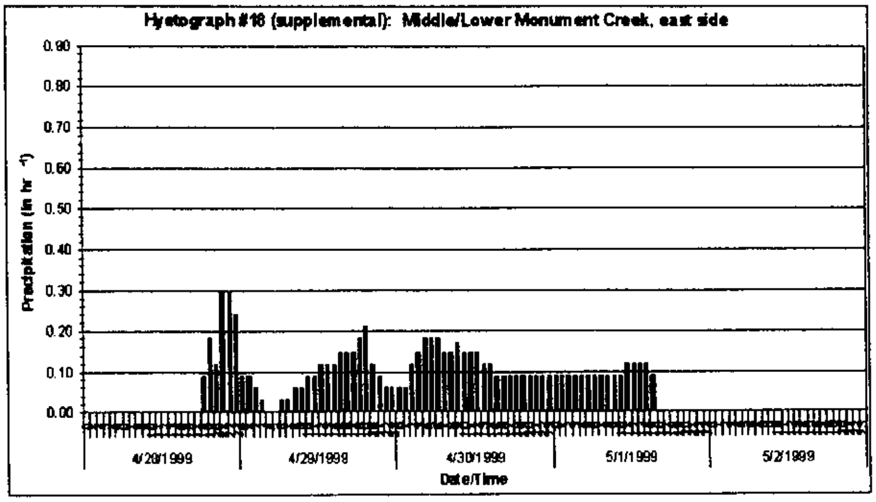


Figure 8c (continued): Supplemental hourly hyetographs (numbered individually) employed for simulation of the major storm event on April 28-May 2, 1999. The spatial distribution to which each hyetograph is applied for simulation of the major storm event is shown in **Figure 9**.



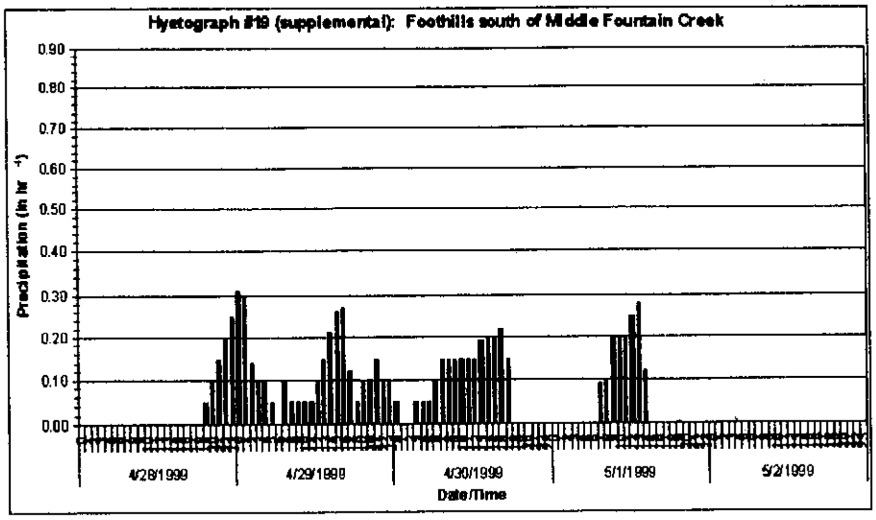


Figure 9: Schematic diagram showing the spatial distribution of hourly hyetographs given in **Figures 8a** through **8c** for simulation of the major storm event on April 28-May 2, 1999.

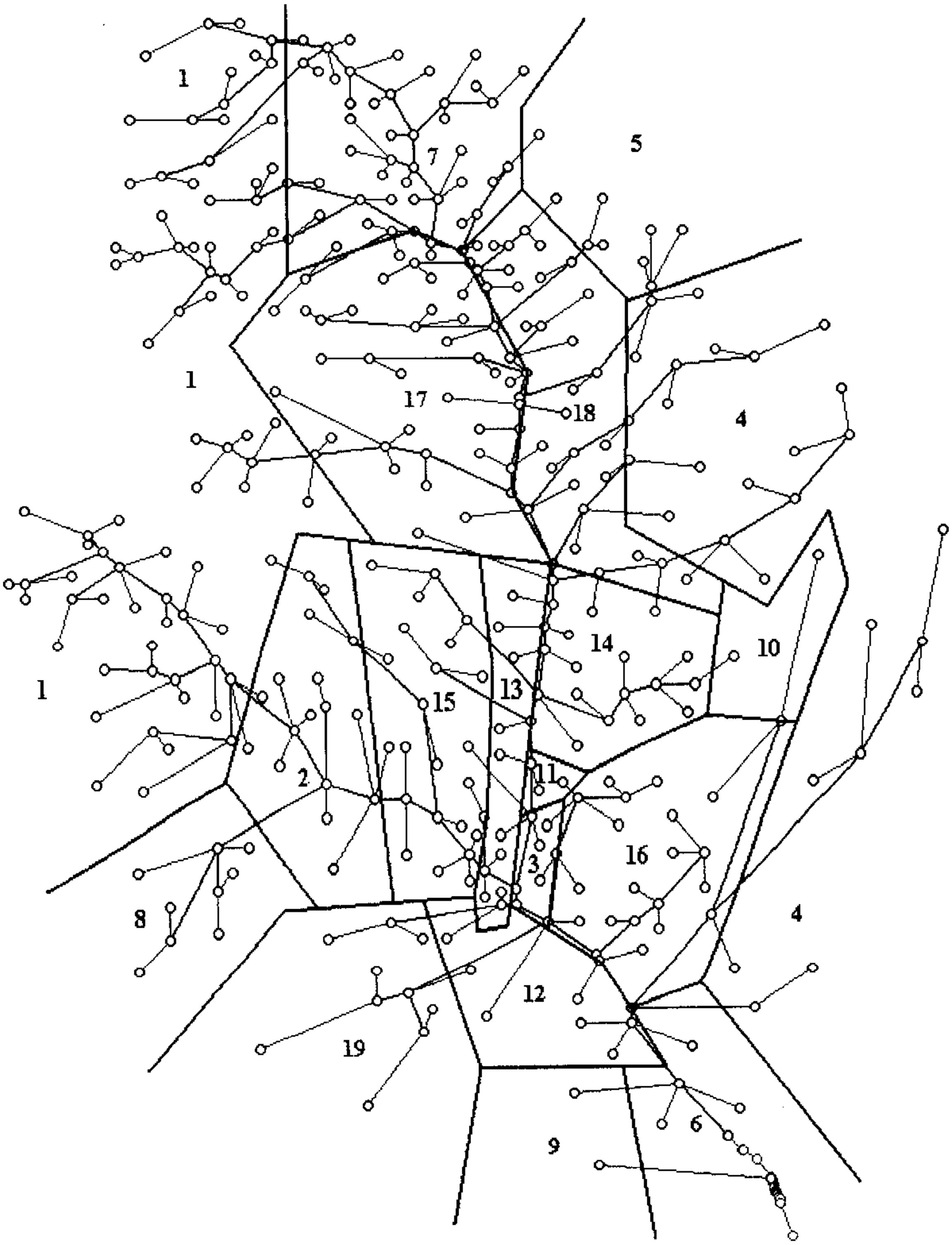
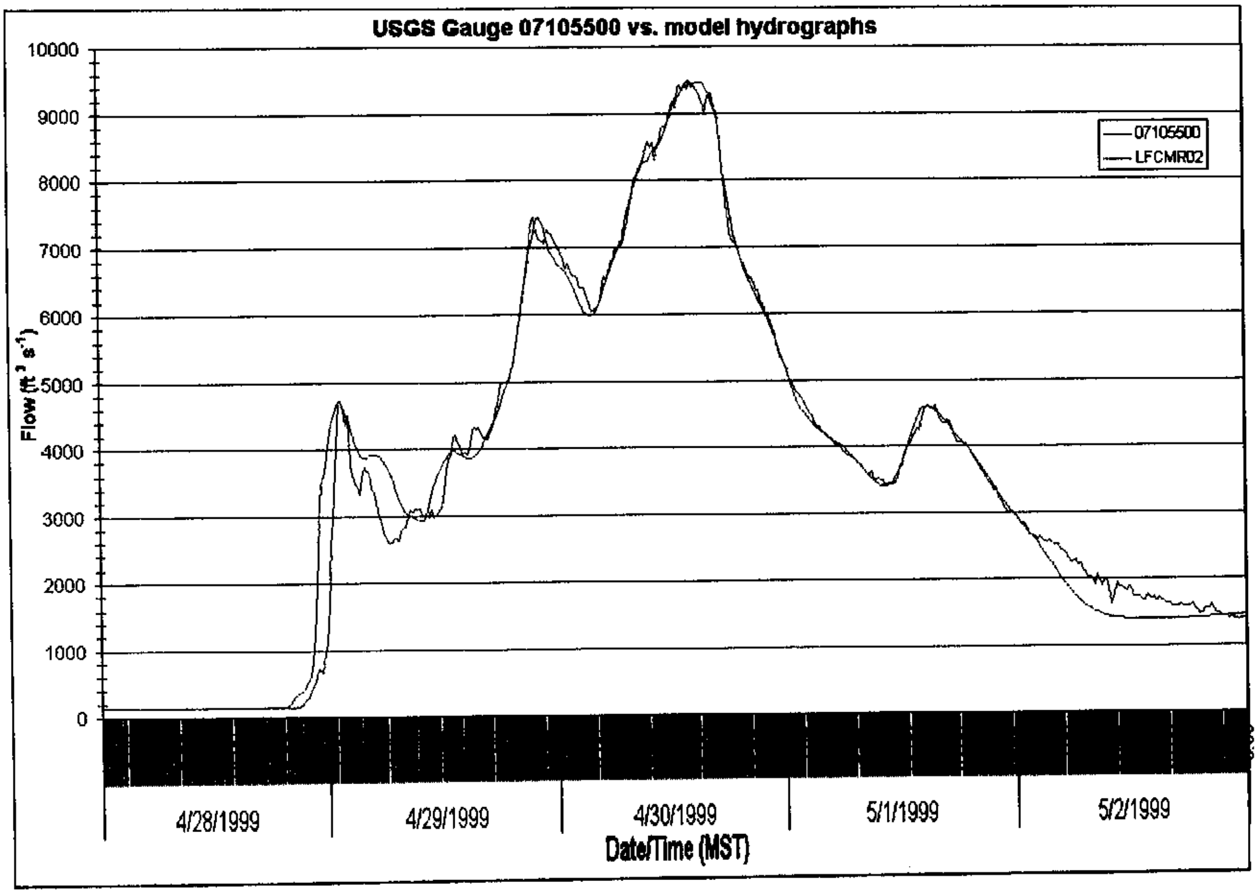


Figure 10a: Simulated hydrograph for the major storm event during April 28-May 2, 1999, at the location of USGS gauge 07105500, and a graph demonstrating the correlation between (concurrent) observed and simulated discharges at that location.



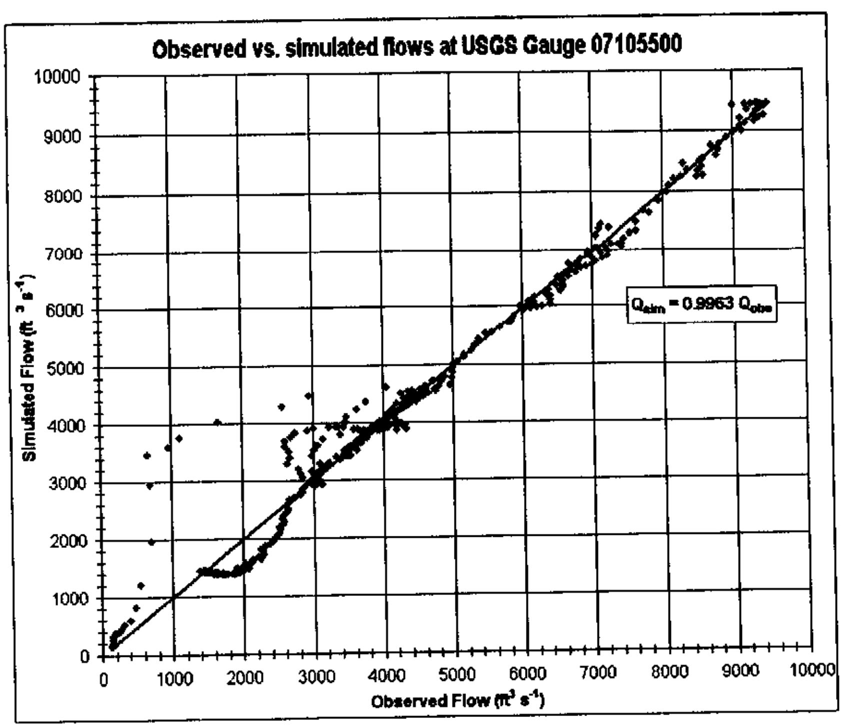
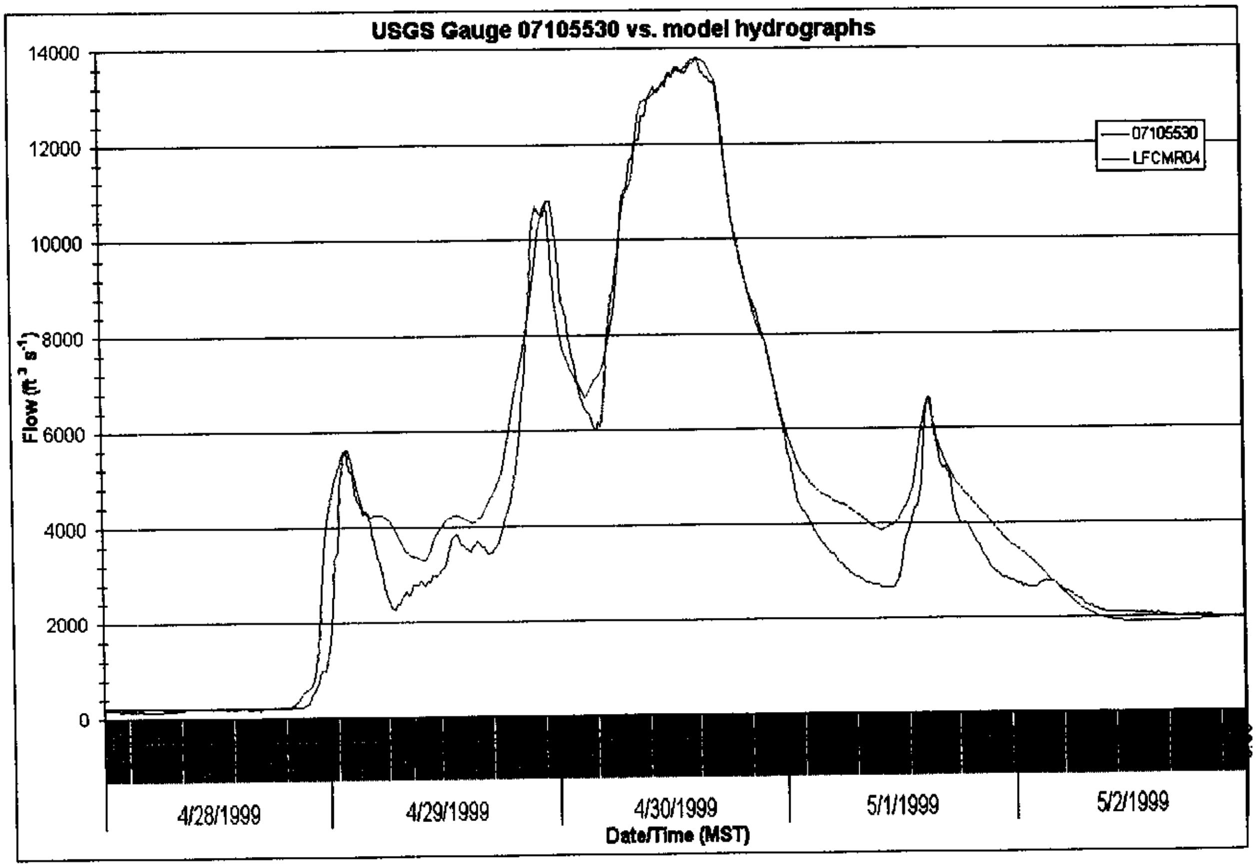


Figure 10b: Simulated hydrograph for the major storm event during April 28-May 2, 1999, at the location of USGS gauge 07105530, and a graph demonstrating the correlation between (concurrent) observed and simulated discharges at that location.



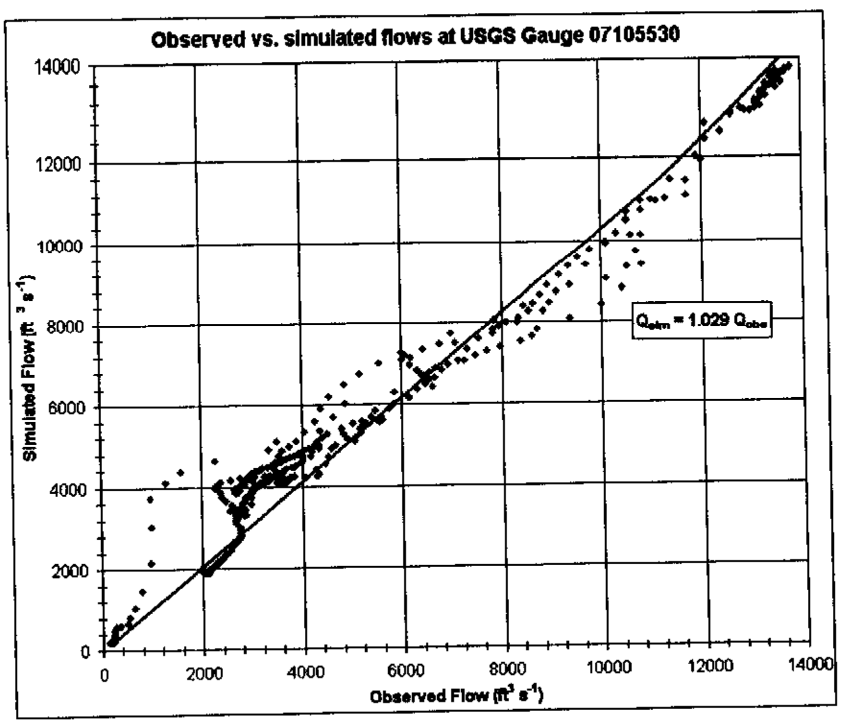


Figure 10c: Simulated hydrograph for the major storm event during April 28-May 2, 1999, near the mouth of Shooks Run in Colorado Springs.

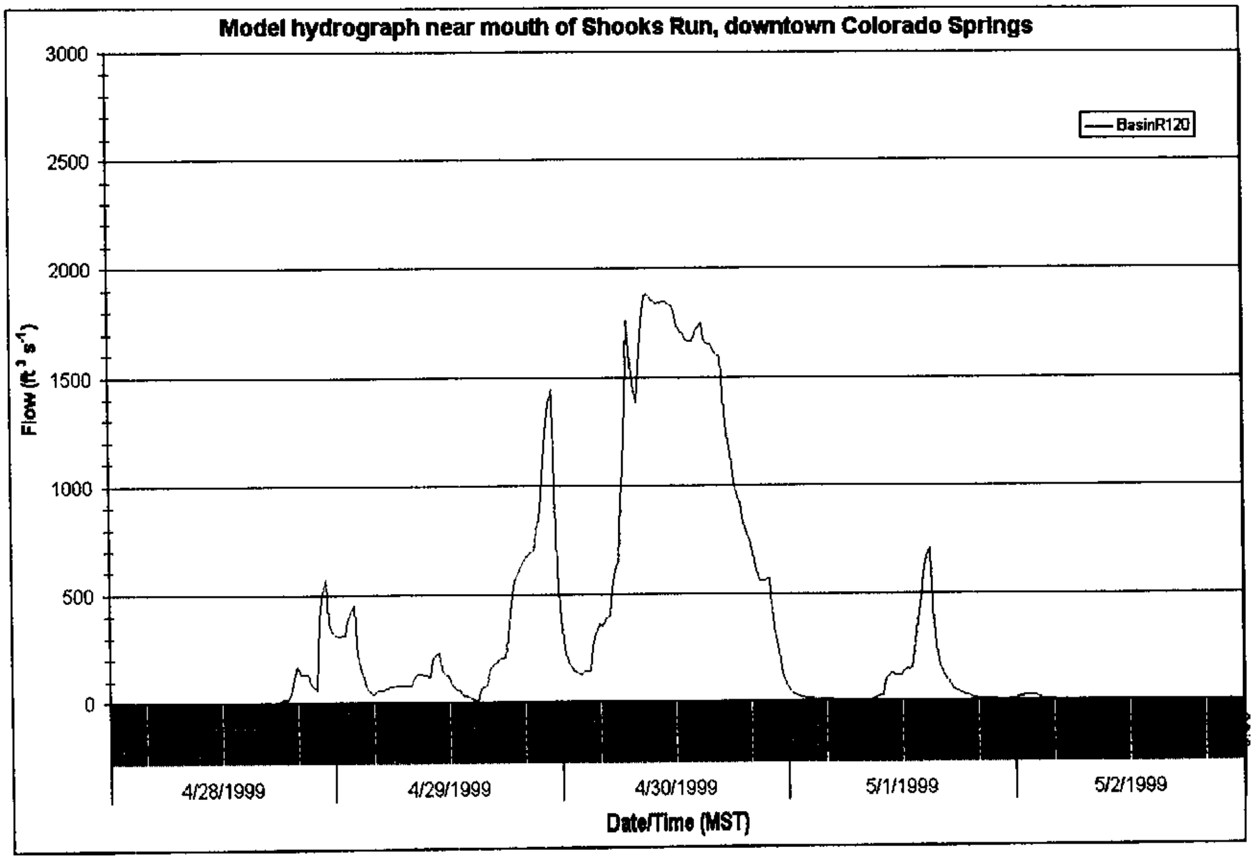


Figure 11: Close-up view of SWMM RUNOFF model sub-basins (with orange drainage paths attached) and stream channels (with black flow paths attached) approximately within the region of the City of Colorado Springs but for which the Templeton Gap Floodway is absent. This view should be compared with that given in **Figure 3g**, above. The reference point (0,0) occurs at the confluence of Fountain and Monument Creeks in Colorado Springs. Scales on the axes shown here are given in feet north and east of the reference point. The color-coded reference points correspond to those shown in **Figures 1, 3a, 3d, 3e,** and **3f.**

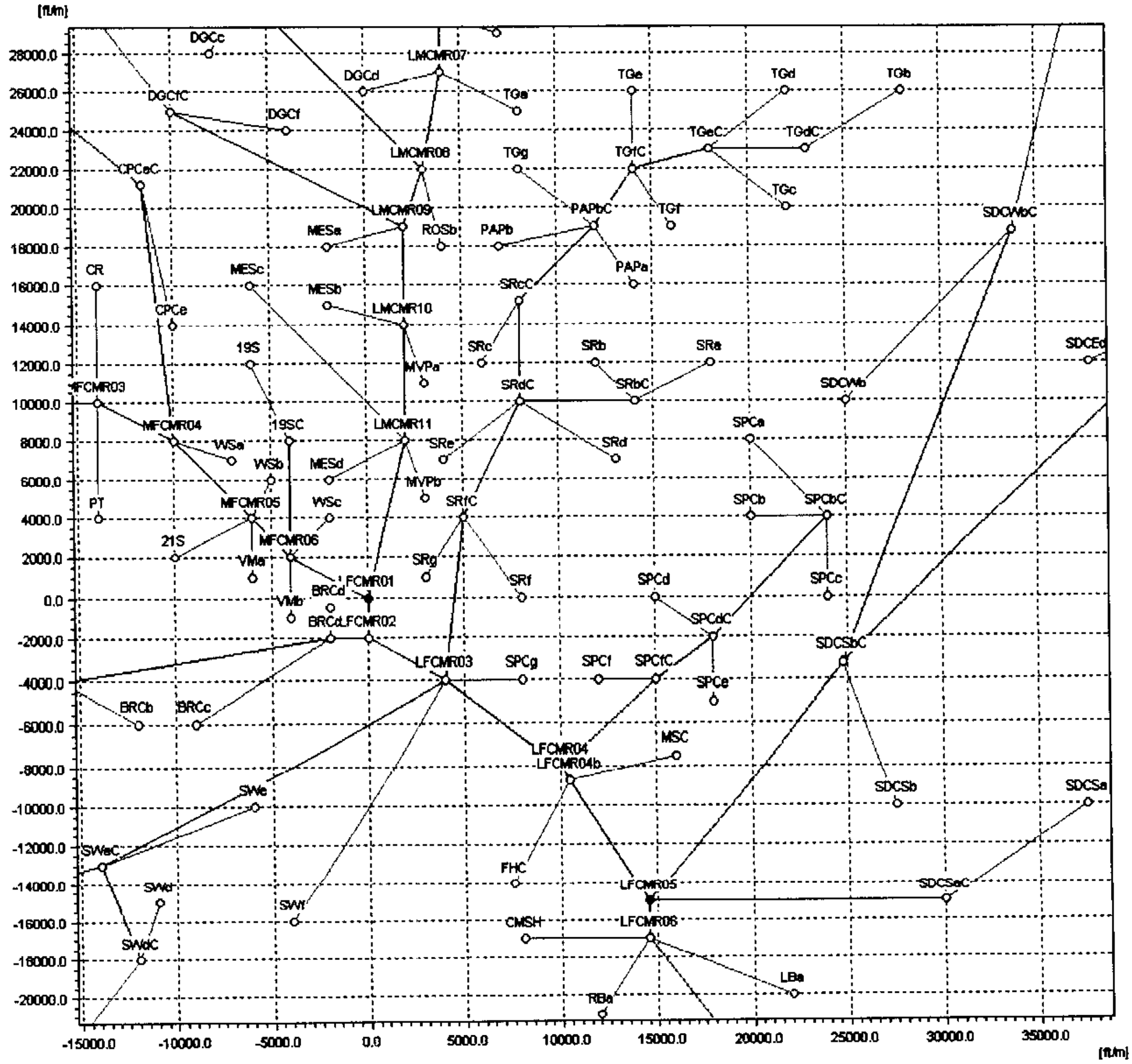


Figure 12a: Simulated hydrograph for the major storm event during April 28-May 2, 1999, at the location of USGS gauge 07105500, for the case of pre-development conditions in the area of the City of Colorado Springs.

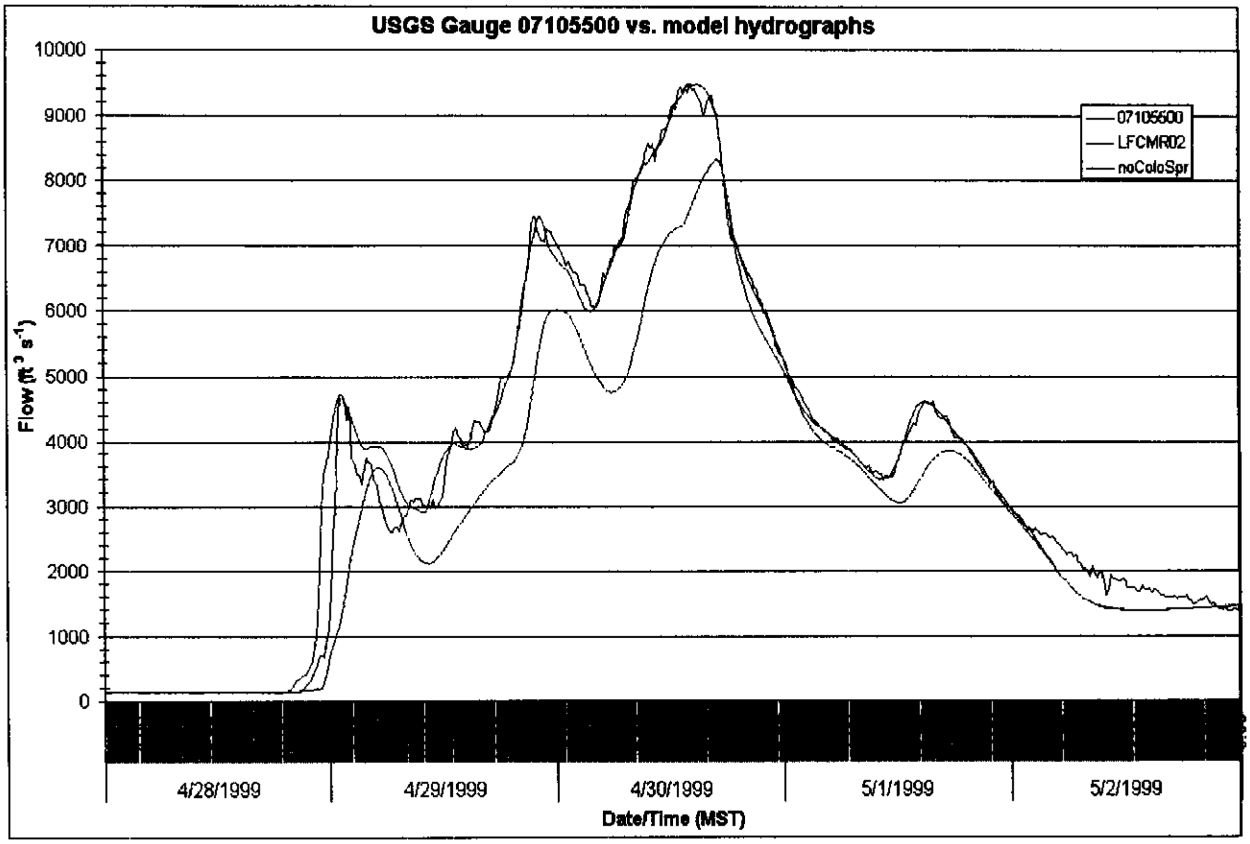


Figure 12b: Simulated hydrograph for the major storm event during April 28-May 2, 1999, at the location of USGS gauge 07105530, for the case of pre-development conditions in the area of the City of Colorado Springs.

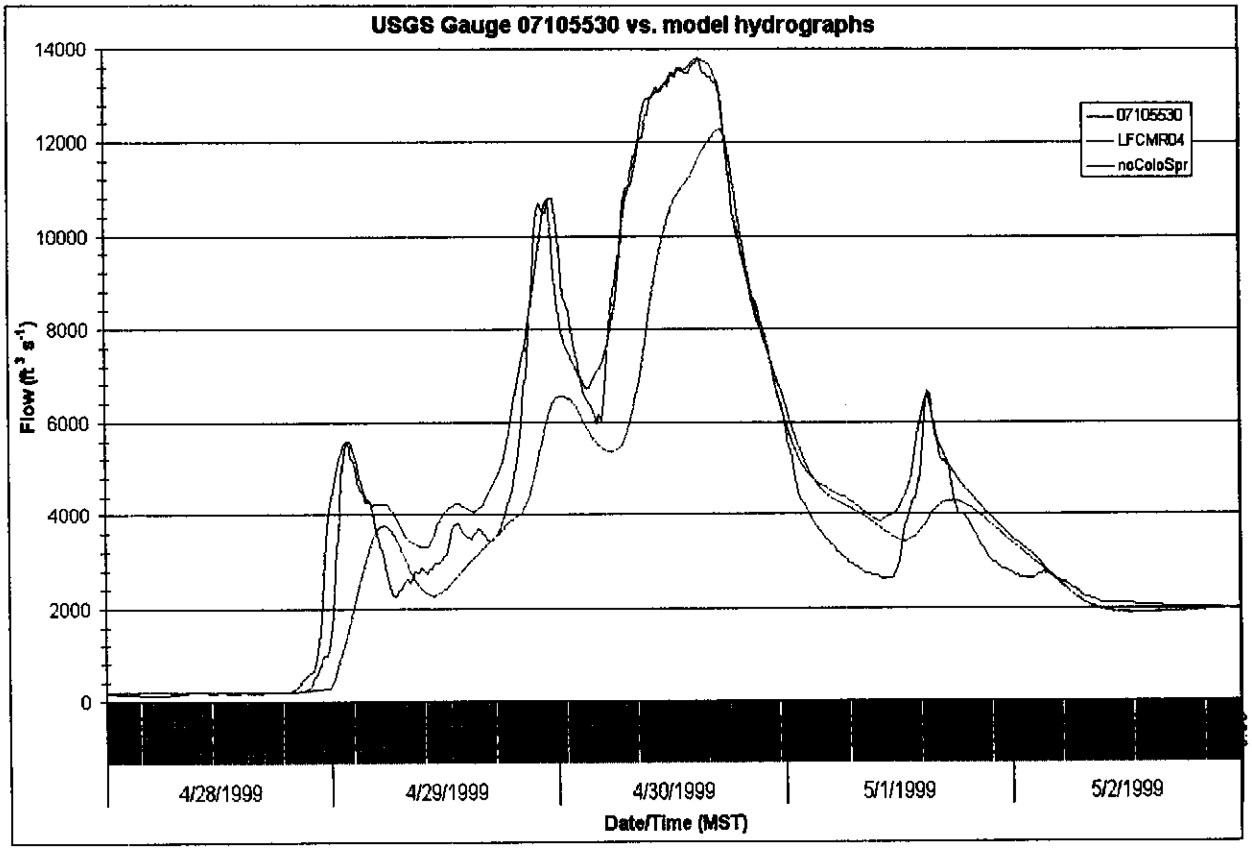


Figure 13a: Simulated hydrograph for the major storm event during April 28-May 2, 1999, near the mouth of Shooks Run in Colorado Springs, in the absence of the Templeton Gap Floodway.

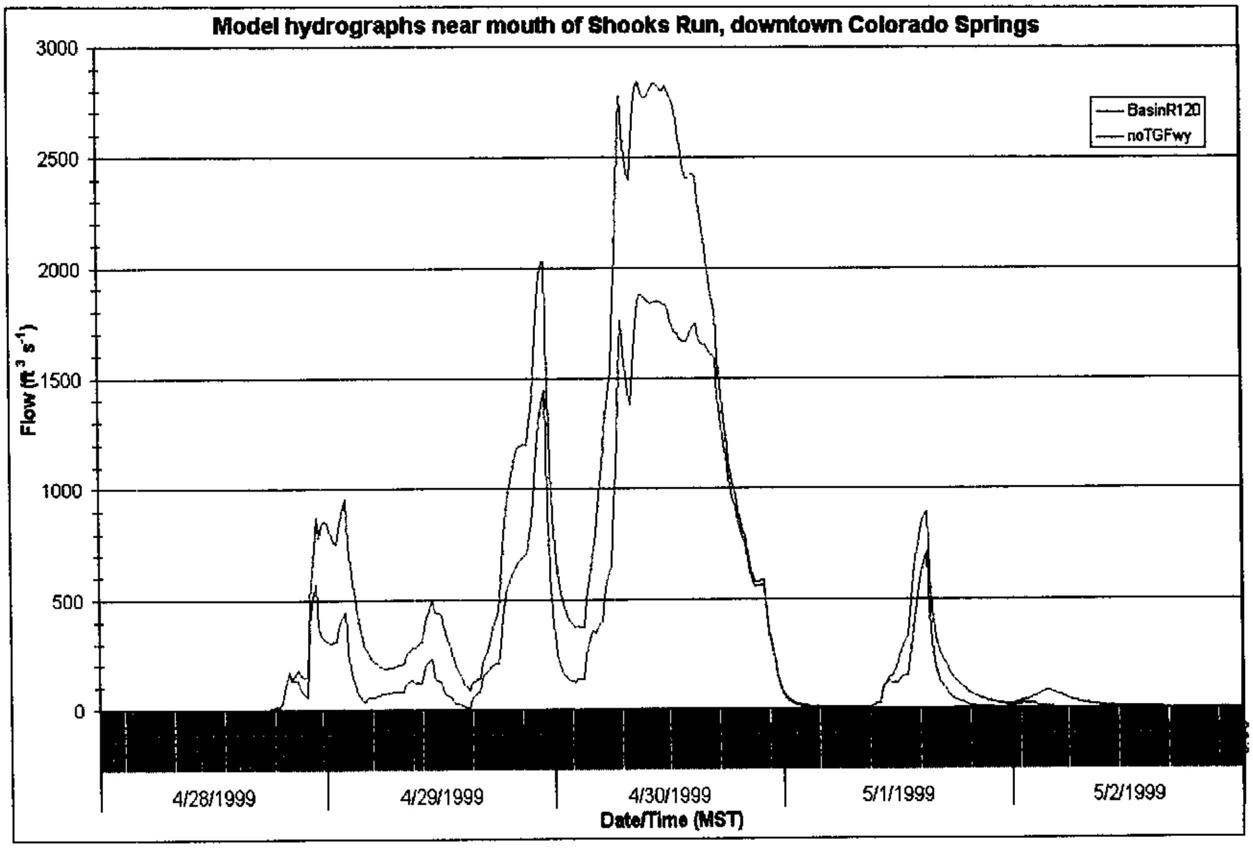


Figure 13b: Simulated hydrograph for the major storm event during April 28-May 2, 1999, near the mouth of Shooks Run in Colorado Springs, for the case of pre-development conditions (including the absence of the Templeton Gap Floodway) in the area of the City of Colorado Springs.

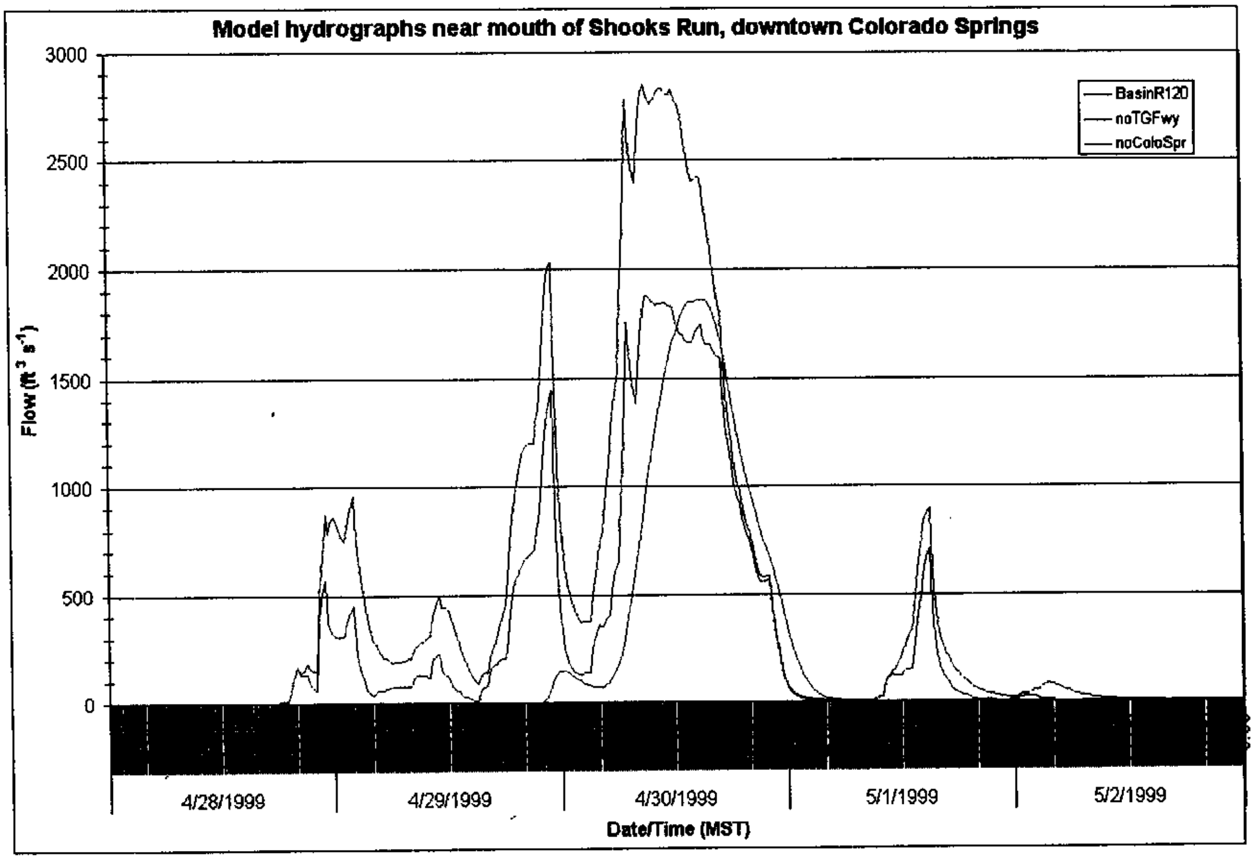


Figure 14: Expanded plan view of SWMM EXTRAN model stream channels for a portion of Fountain Creek downstream of Colorado Springs. The reference point (0,0) occurs at the confluence of Fountain and Monument Creeks in Colorado Springs. Scales on the axes shown here are given in feet north and east of the reference point. The color-coded reference point corresponds to that shown in **Figures 1** and **3e**. This portion of the model is shown as the gray segments at the lower right corner in those figures above. The KOA property is located along the highly detailed portion of this model near the center of the diagram, which is shown more clearly in **Figure 16**. The Greenview Ditch Headworks are located approximately 28 miles south (downstream) of this portion of Fountain Creek.

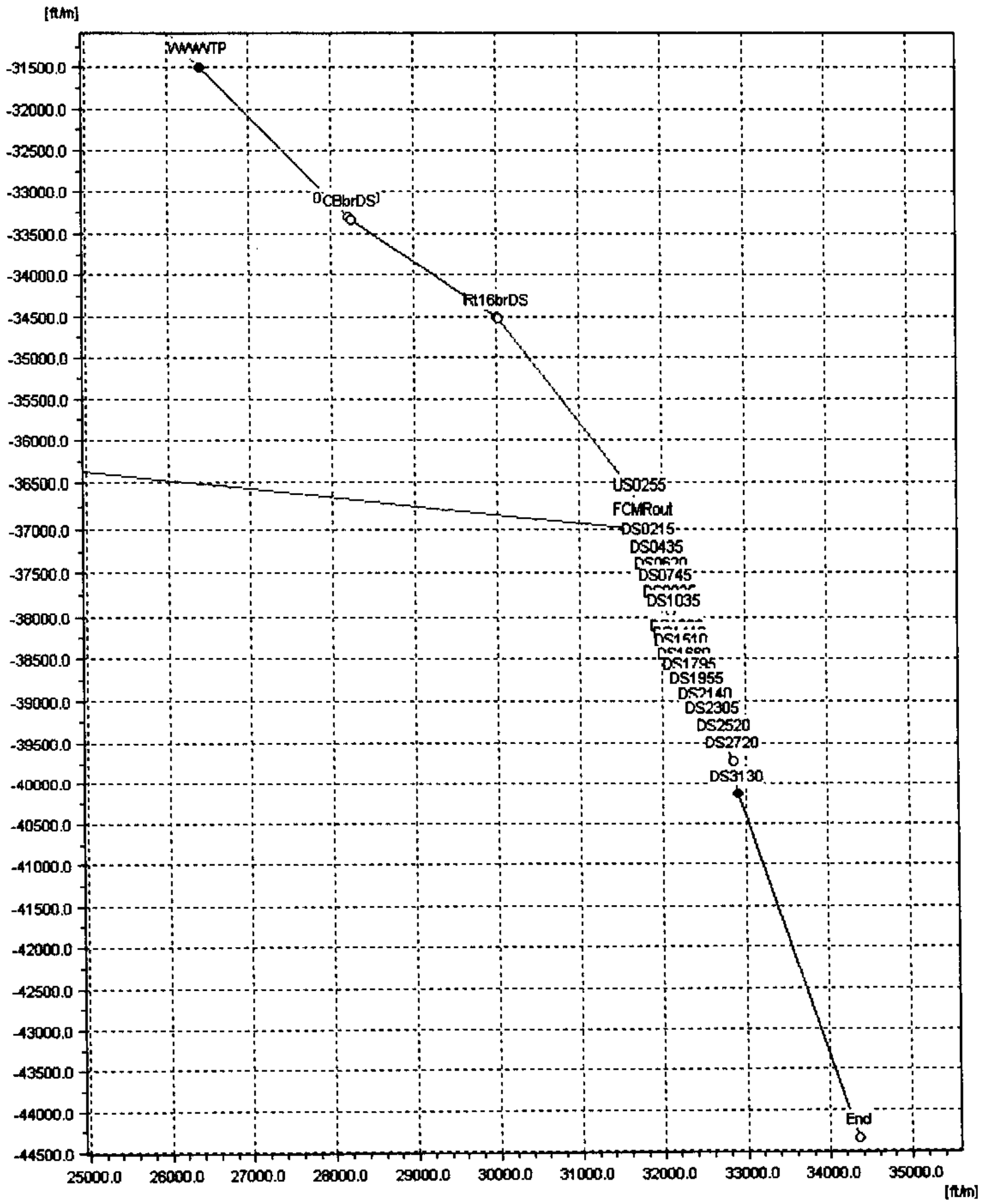


Figure 15: Profile view of SWMM EXTRAN model stream channels for a portion of Fountain Creek downstream of Colorado Springs, as shown above in **Figure 14**. The KOA property is located between the junctions marked "DS1955" and "DS3130," as shown below in **Figure 16**.

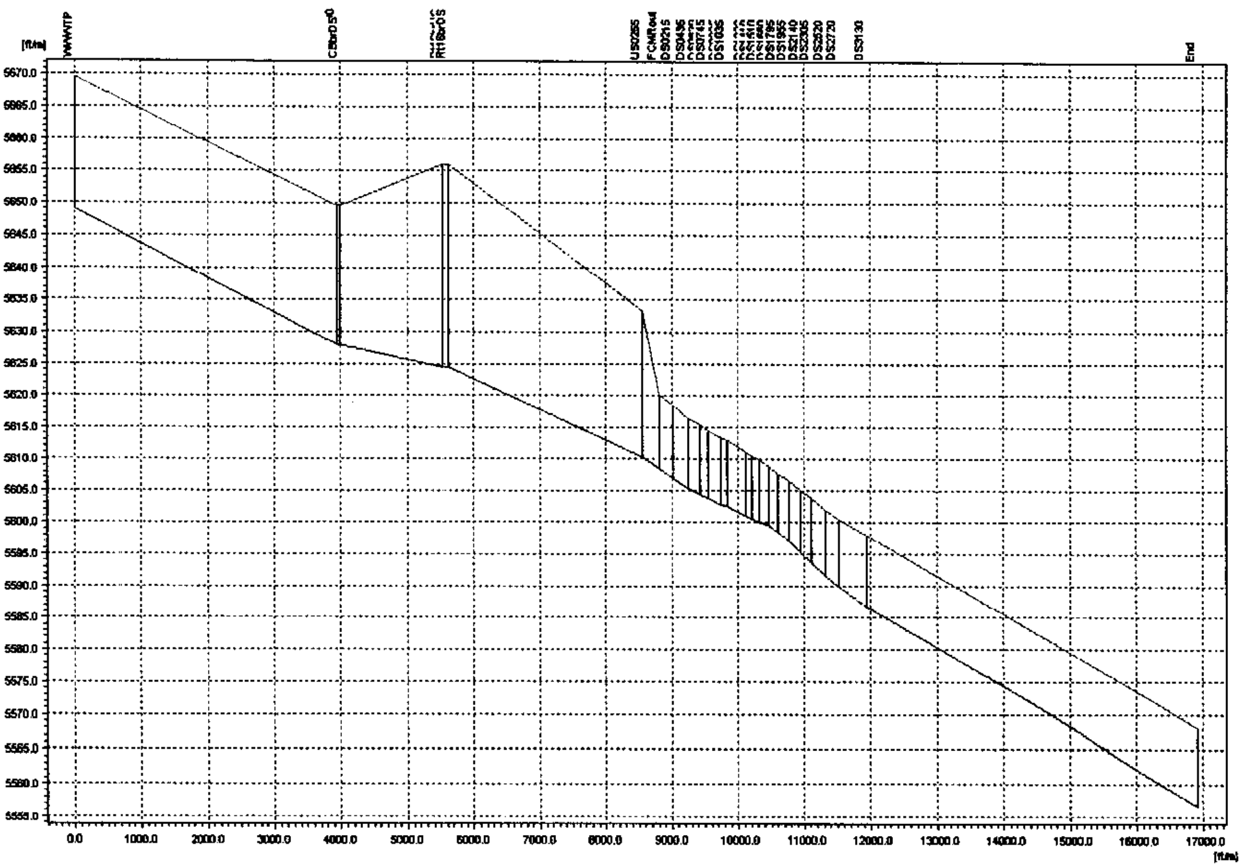


Figure 16: Detailed plan view of SWMM EXTRAN model stream channels for a portion of Fountain Creek downstream of Colorado Springs. The reference point (0,0) occurs at the confluence of Fountain and Monument Creeks in Colorado Springs. Scales on the axes shown here are given in feet north and east of the reference point. The KOA property is located along this portion of Fountain Creek between the color-coded points at junctions marked "DS1955" and "DS3130."

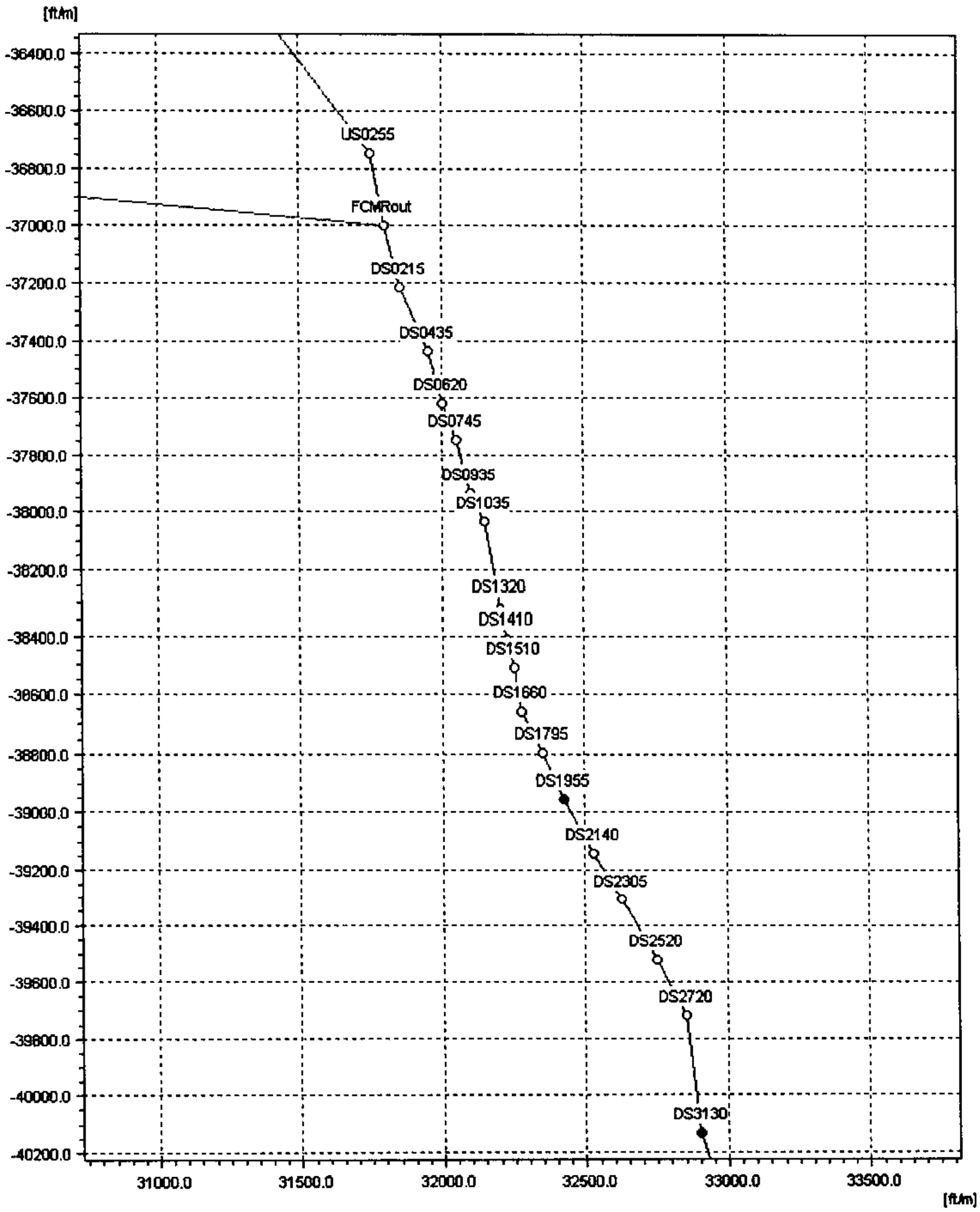


Figure 17: Detailed profile view of SWMM EXTRAN model stream channels for a portion of Fountain Creek downstream of Colorado Springs, as shown above in **Figure 16**. The KOA property is located along this portion of Fountain Creek between the junctions marked "DS1955" and "DS3130."

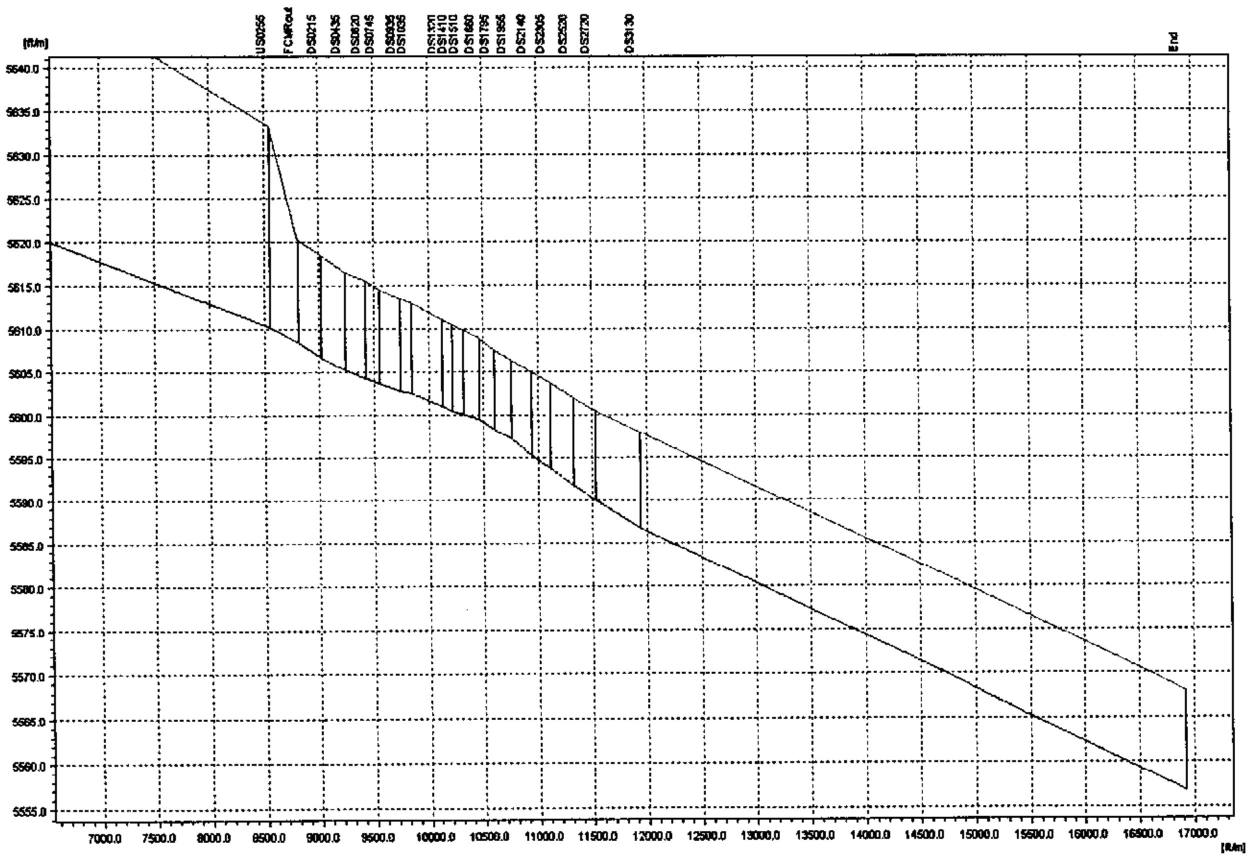


Figure 18: Photograph by the author of the Colorado Highway 16 bridge over Fountain Creek, downstream of Colorado Springs.

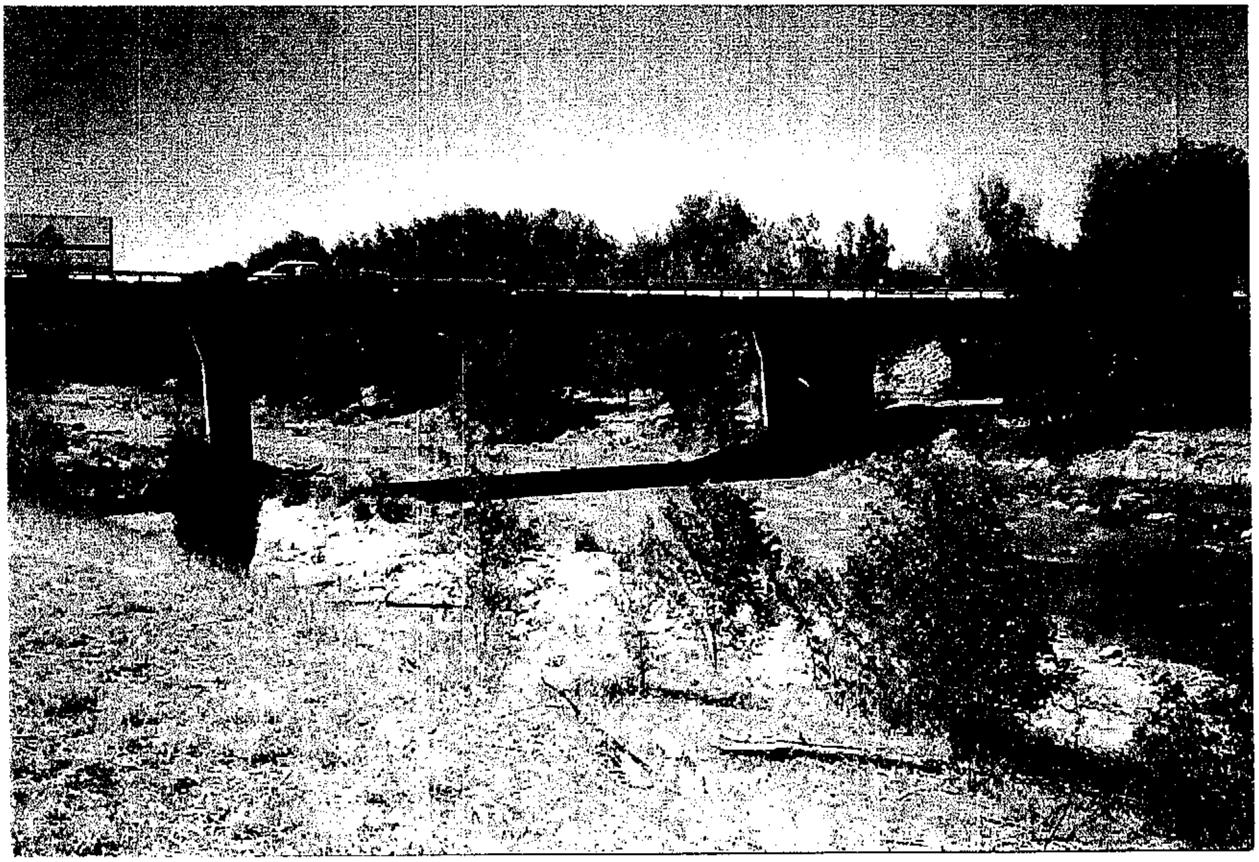


Figure 19a: EXTRAN model stream channel cross-sections for segments 1-4 and bridges 1 and 2, shown above in **Figures 14** and **15**. Historical cross-sections (i.e. without the left bank levee downstream of the Colorado Highway 16 bridge) are shown in gray, while current cross-sections are shown in black. Stations indicate distance in feet from the left bank (looking downstream).

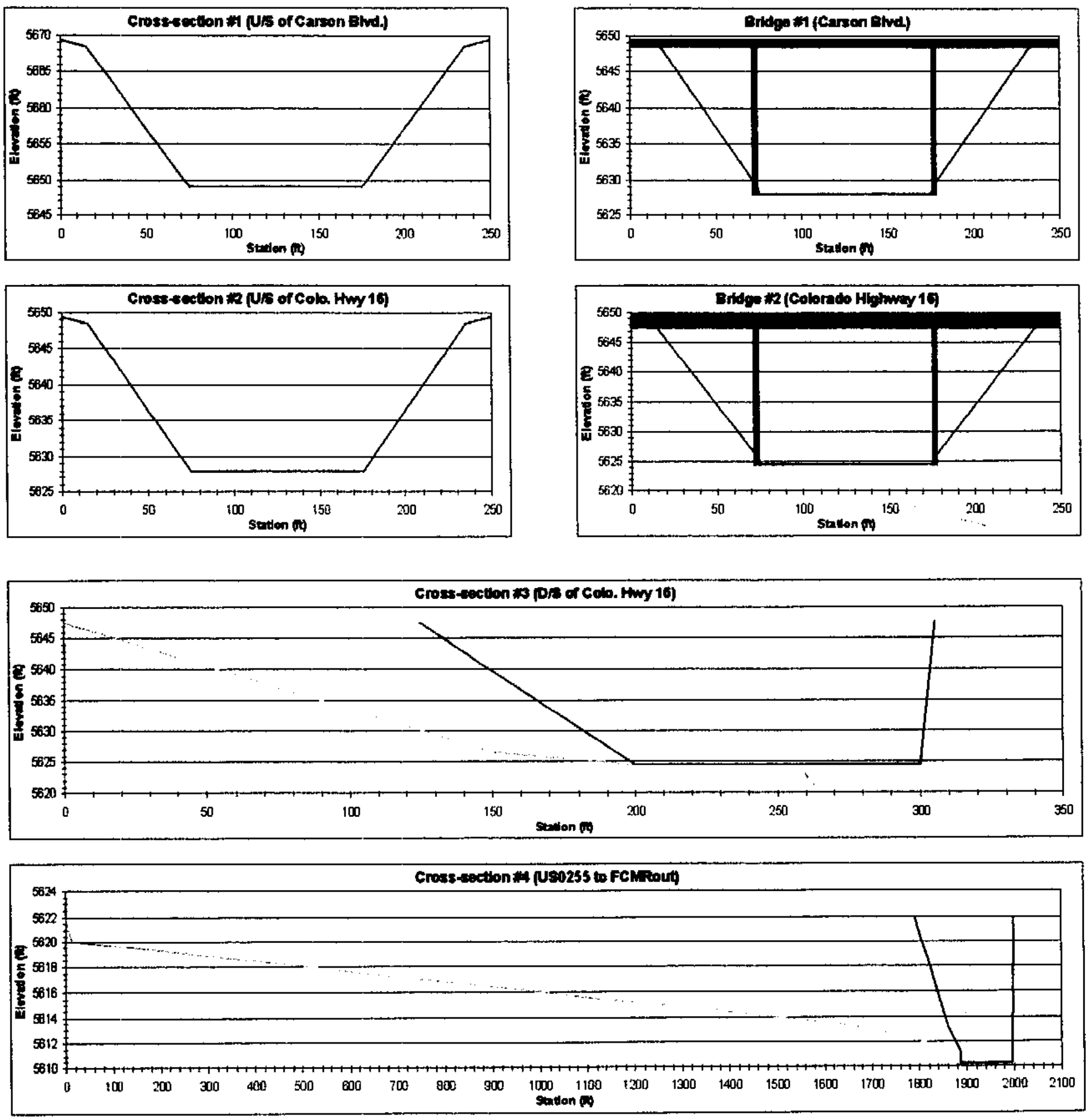


Figure 19b: EXTRAN model stream channel cross-sections for segments 5-8, shown above in **Figures 16** and **17**. Historical cross-sections (i.e. without the left bank levee downstream of the Colorado Highway 16 bridge) are shown in gray, while current cross-sections are shown in black. Stations indicate distance in feet from the left bank (looking downstream).

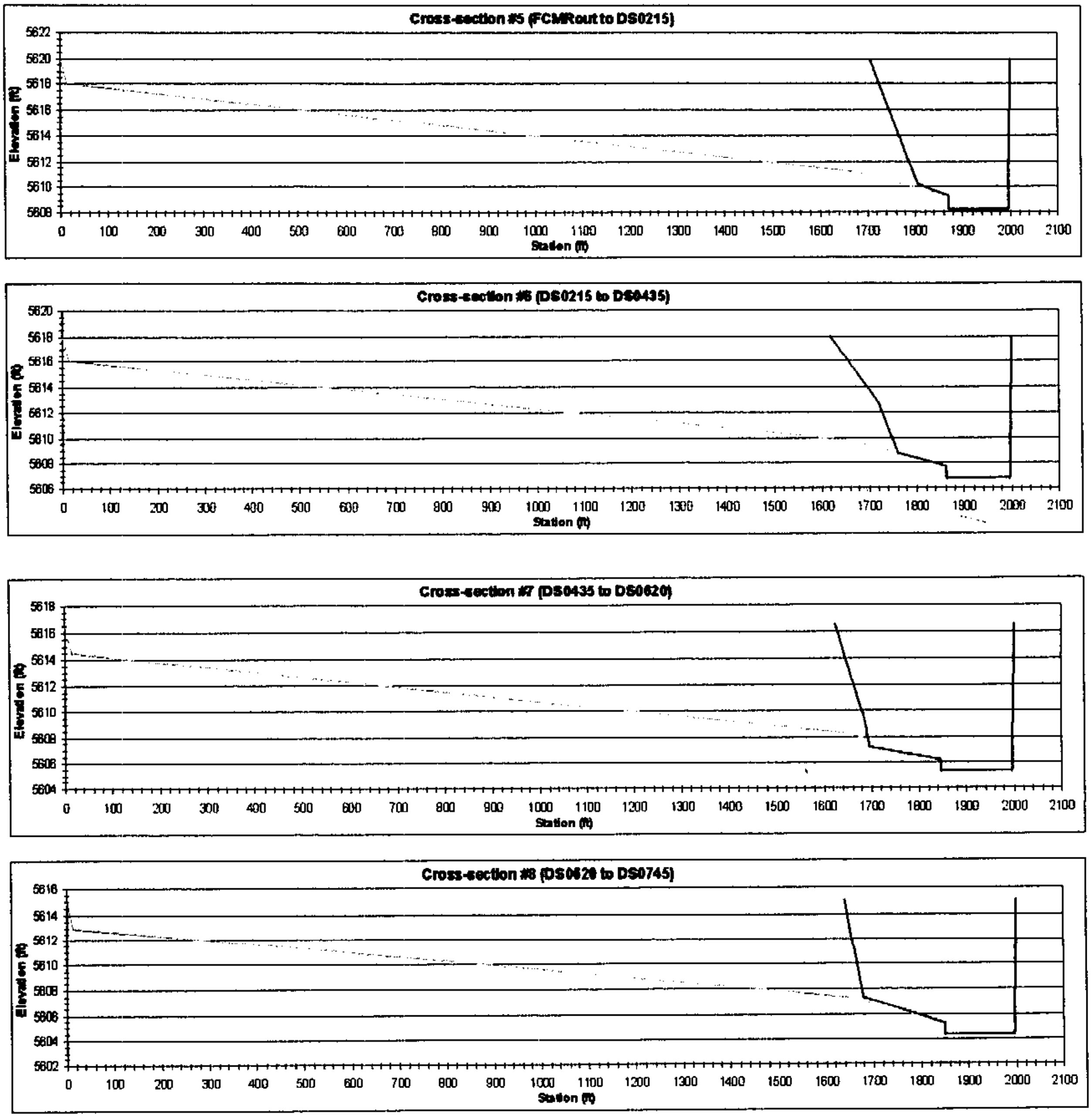


Figure 19c: EXTRAN model stream channel cross-sections for segments 9-12, shown above in **Figures 16** and **17**. Historical cross-sections (i.e. without the left bank levee downstream of the Colorado Highway 16 bridge) are shown in gray, while current cross-sections are shown in black. Stations indicate distance in feet from the left bank (looking downstream).

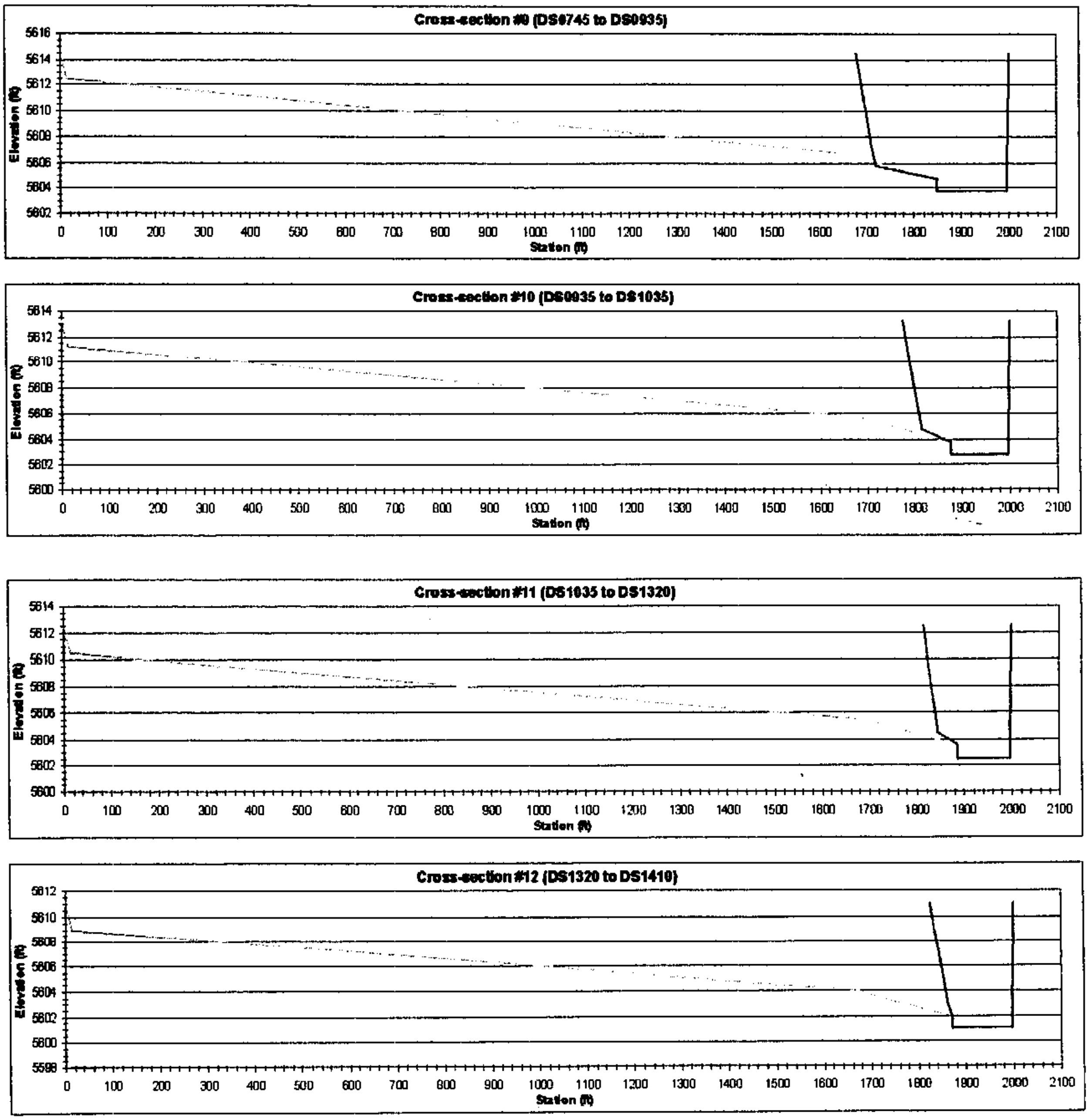


Figure 19d: EXTRAN model stream channel cross-sections for segments 13-16, shown above in **Figures 16** and **17**. Historical cross-sections (i.e. without the left bank levee downstream of the Colorado Highway 16 bridge) are shown in gray, while current cross-sections are shown in black. Stations indicate distance in feet from the left bank (looking downstream).

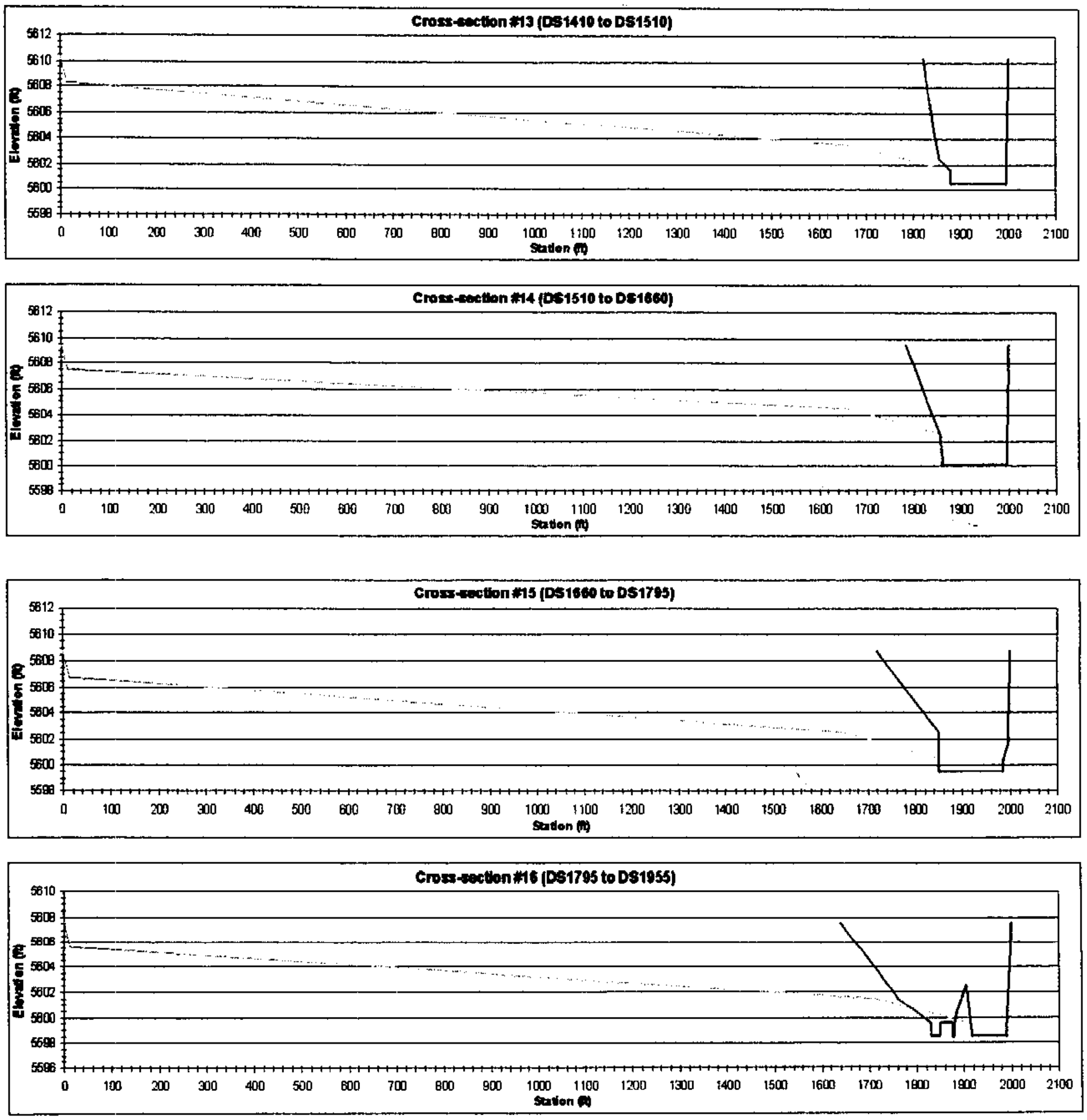


Figure 19e: EXTRAN model stream channel cross-sections for segments 17-20, shown above in **Figures 16** and **17**. Historical cross-sections (i.e. without the left bank levee downstream of the Colorado Highway 16 bridge) are shown in gray, while current cross-sections are shown in black. Stations indicate distance in feet from the left bank (looking downstream). The KOA property is located along this portion of Fountain Creek between the junctions marked "DS1955" and "DS3130."

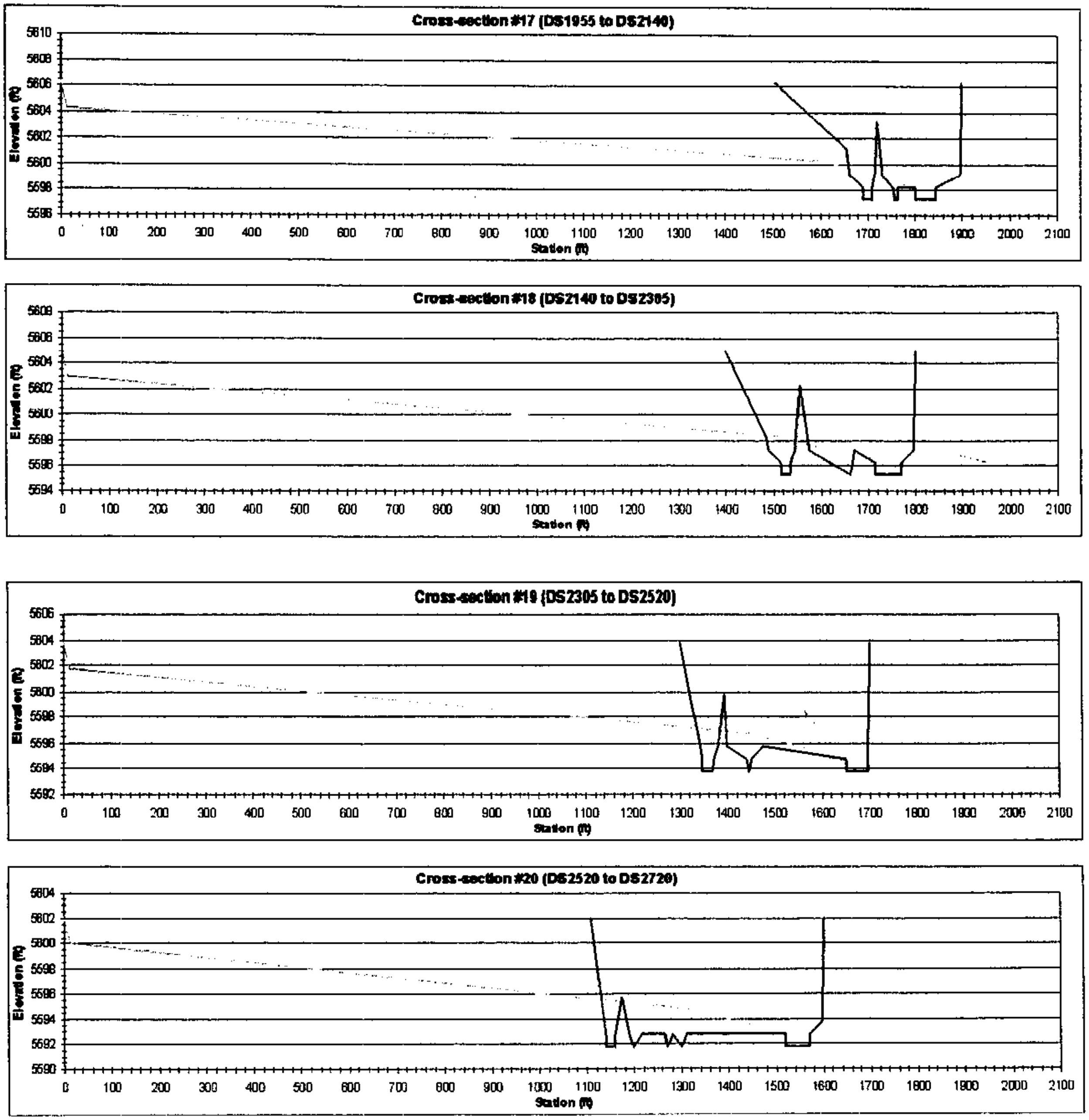


Figure 19f: EXTRAN model stream channel cross-sections for segment 21, shown above in **Figures 16** and **17**. The historical cross-section (i.e. without the left bank levee downstream of the Colorado Highway 16 bridge) is shown in gray, while the current cross-section is shown in black. Stations indicate distance in feet from the left bank (looking downstream). The KOA property is located along this portion of Fountain Creek between the junctions marked "DS1955" and "DS3130."

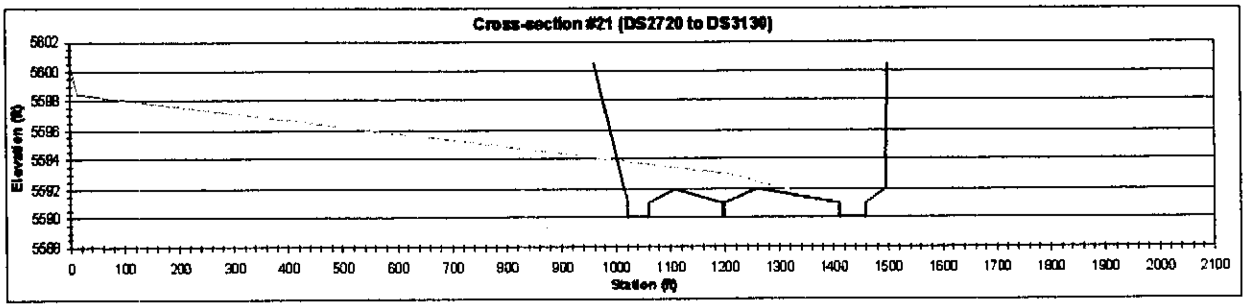


Figure 20a: Simulated stream channel water surface profile in the EXTRAN model segments along a portion of Fountain Creek for the major storm event during April 28-May 2, 1999. The profile shown corresponds to peak flow conditions near 3:30 pm on April 30, 1999. Junction names and discharges (in $ft^3\ s^{-1}$) for individual channel segments are shown near the top of the diagram. The KOA property is located along this portion of Fountain Creek between the junctions marked "DS1955" and "DS3130."

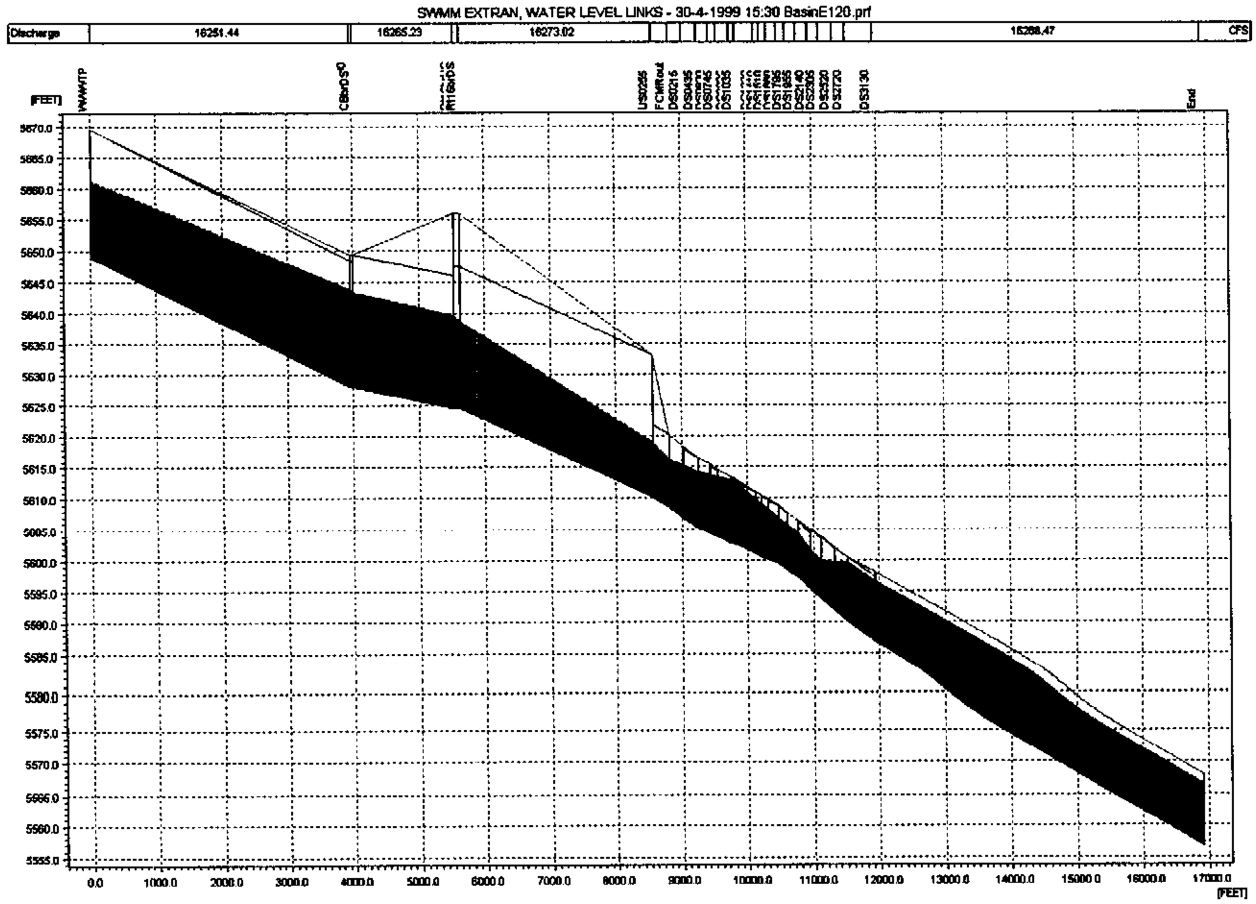


Figure 20b: Close-up view of simulated stream channel water surface profile in the EXTRAN model segments immediately upstream of and adjacent to the KOA property along Fountain Creek for the major storm event during April 28-May 2, 1999. The profile shown corresponds to peak flow conditions near 3:30 pm on April 30, 1999. Junction names and discharges (in $ft^3 s^{-1}$) for individual channel segments are shown near the top of the diagram. The KOA property is located along this portion of Fountain Creek between the junctions marked "DS1955" and "DS3130."

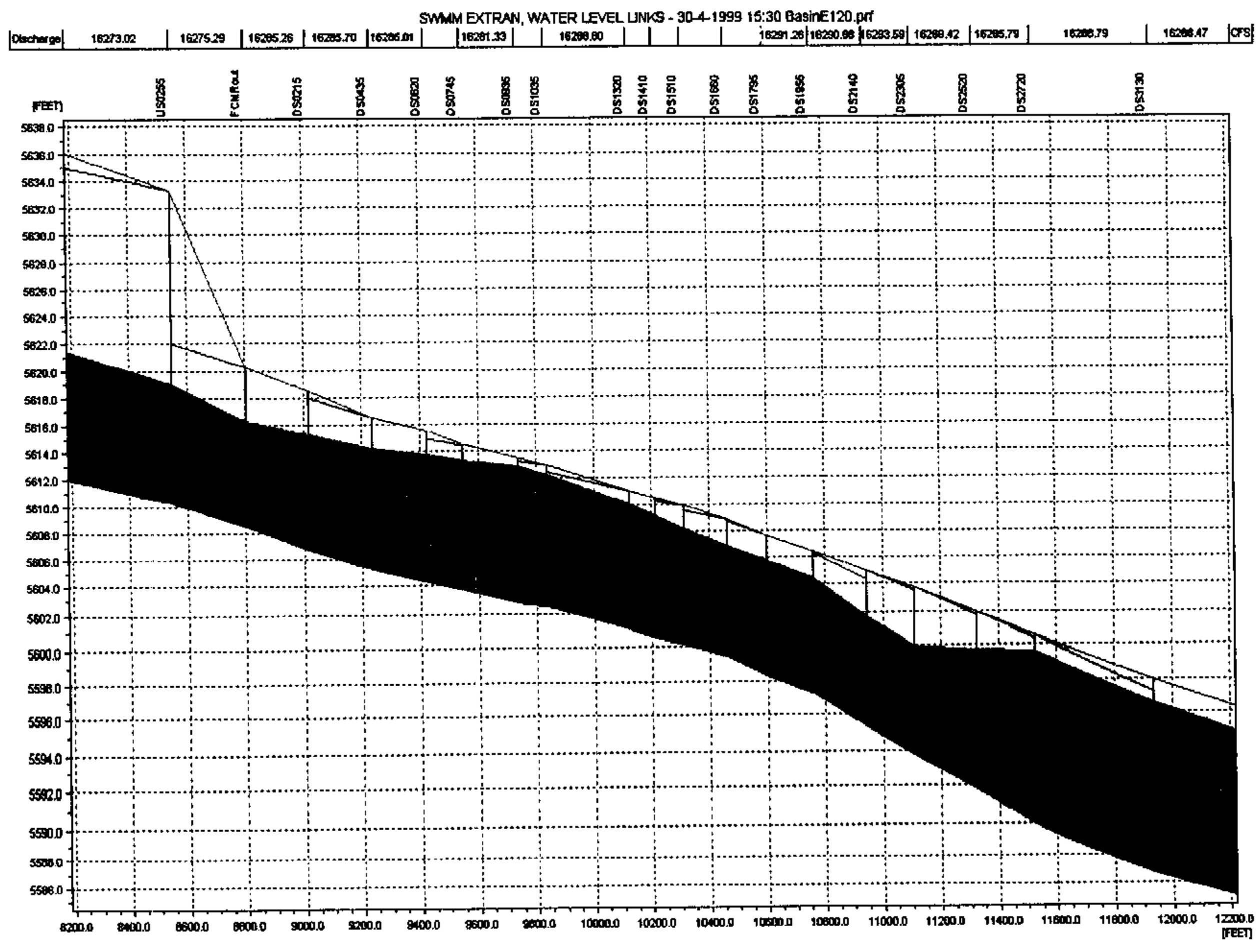


Figure 21a: Simulated hydrograph for the major storm event during April 28-May 2, 1999, at USGS gauge 07105800 (near the junction marked "CBbrDS" in **Figure 20a**). Statistics for these results are compiled in **Appendix B, Table 10.**

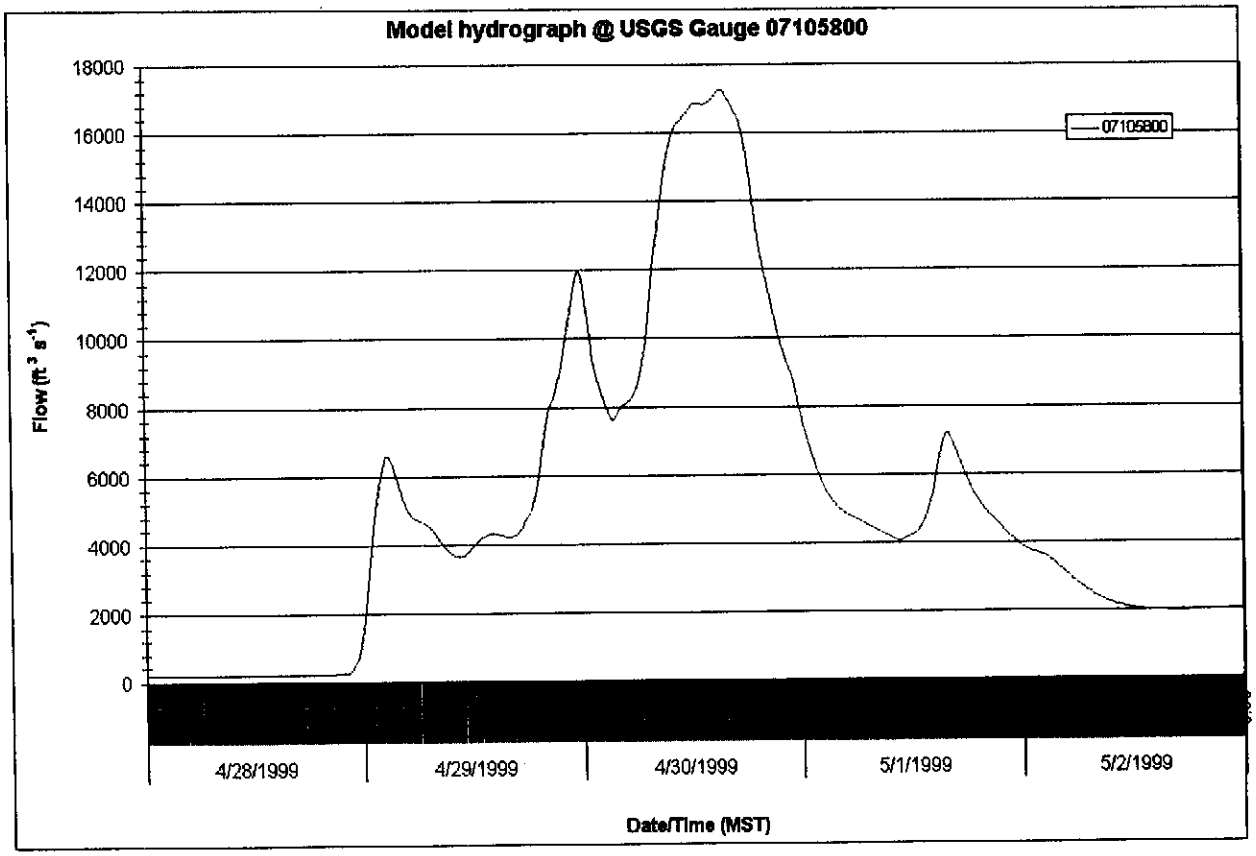


Figure 21b: Simulated flow velocities for the major storm event during April 28-May 2, 1999, at USGS gauge 07105800 (near the junction marked "CBbrDS" in **Figure 20a**). Statistics for these results are compiled in **Appendix B, Table 10.**

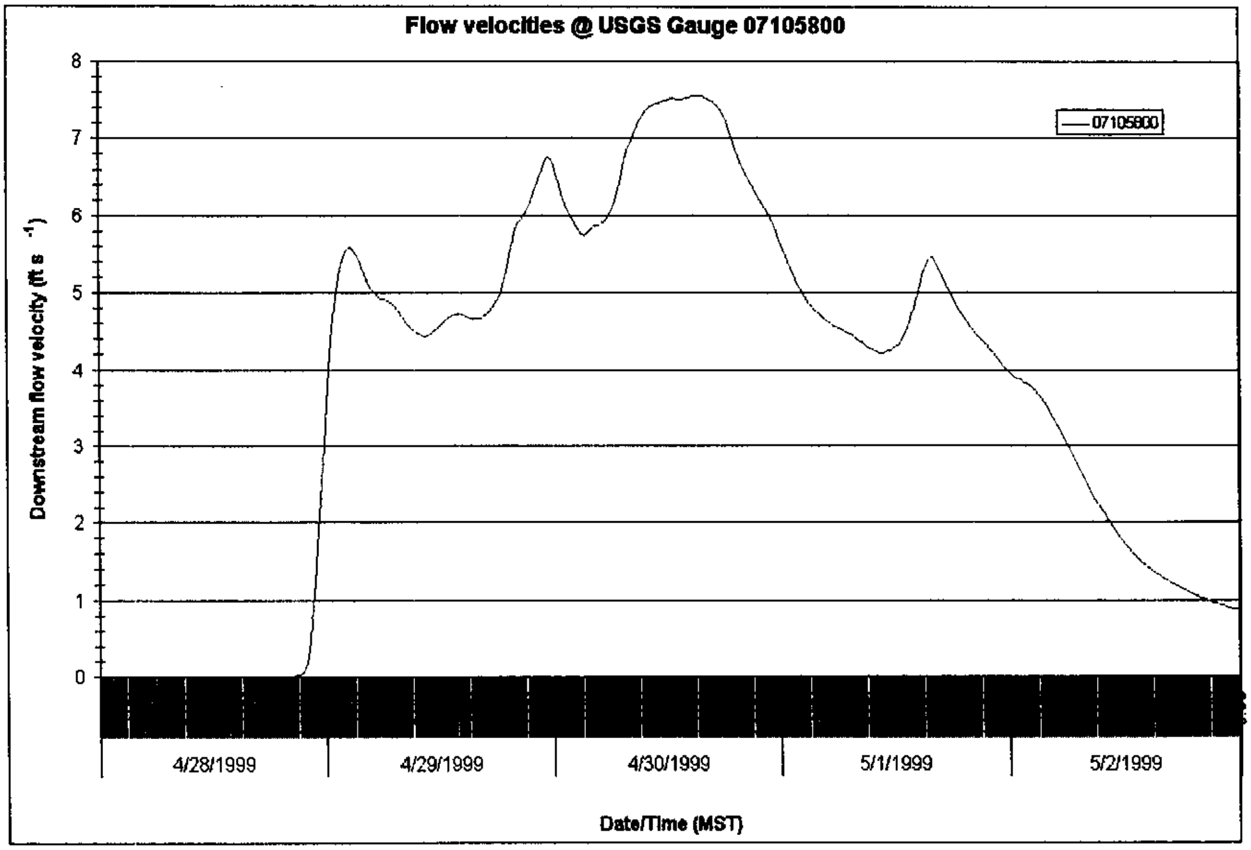


Figure 21c: Simulated hydrograph for the major storm event during April 28-May 2, 1999, at the upstream end of the KOA property (the junction marked "DS1955" in **Figures 20a** and **20b**) along Fountain Creek. Statistics for these results are compiled in **Appendix B, Table 11**.

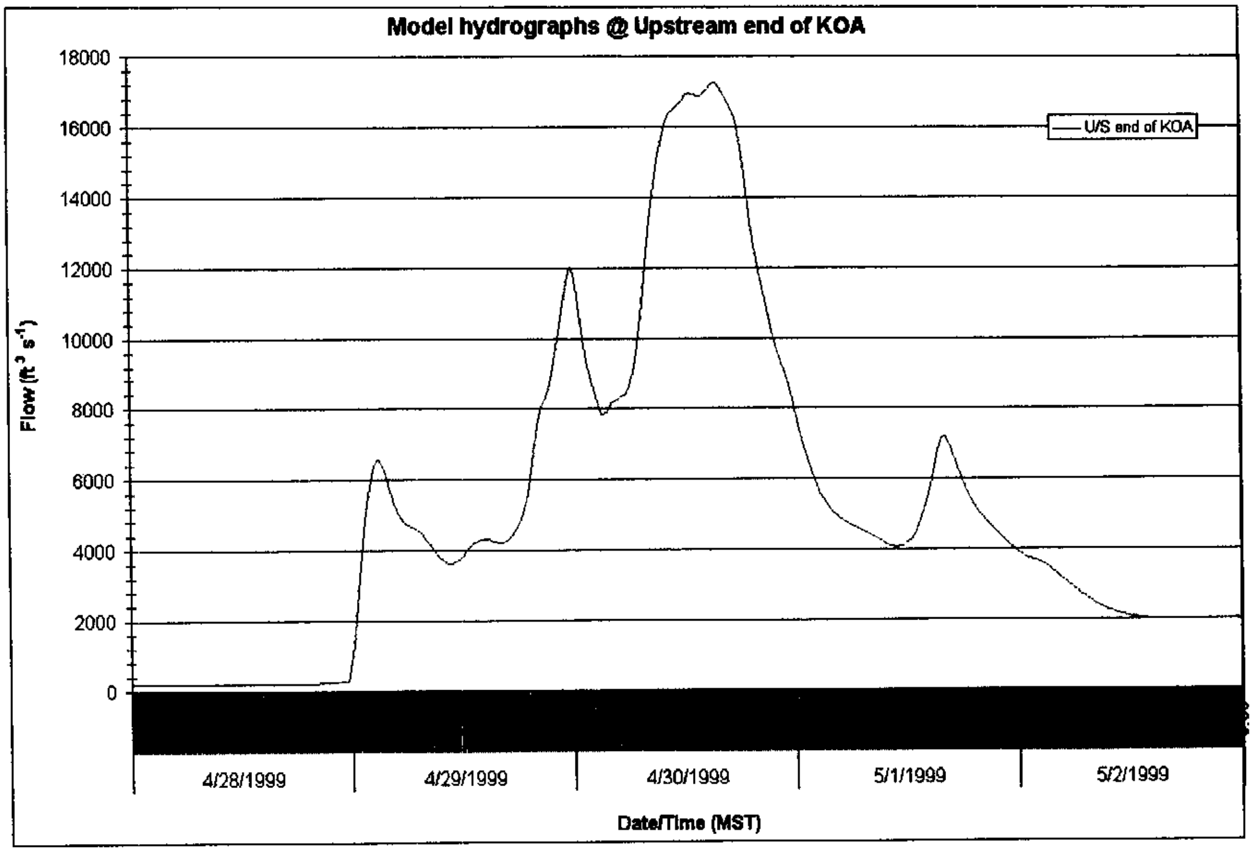


Figure 21d: Simulated flow velocities for the major storm event during April 28-May 2, 1999, at the upstream end of the KOA property (the junction marked "DS1955" in **Figures 20a** and **20b**) along Fountain Creek. Statistics for these results are compiled in **Appendix B, Table 11**.

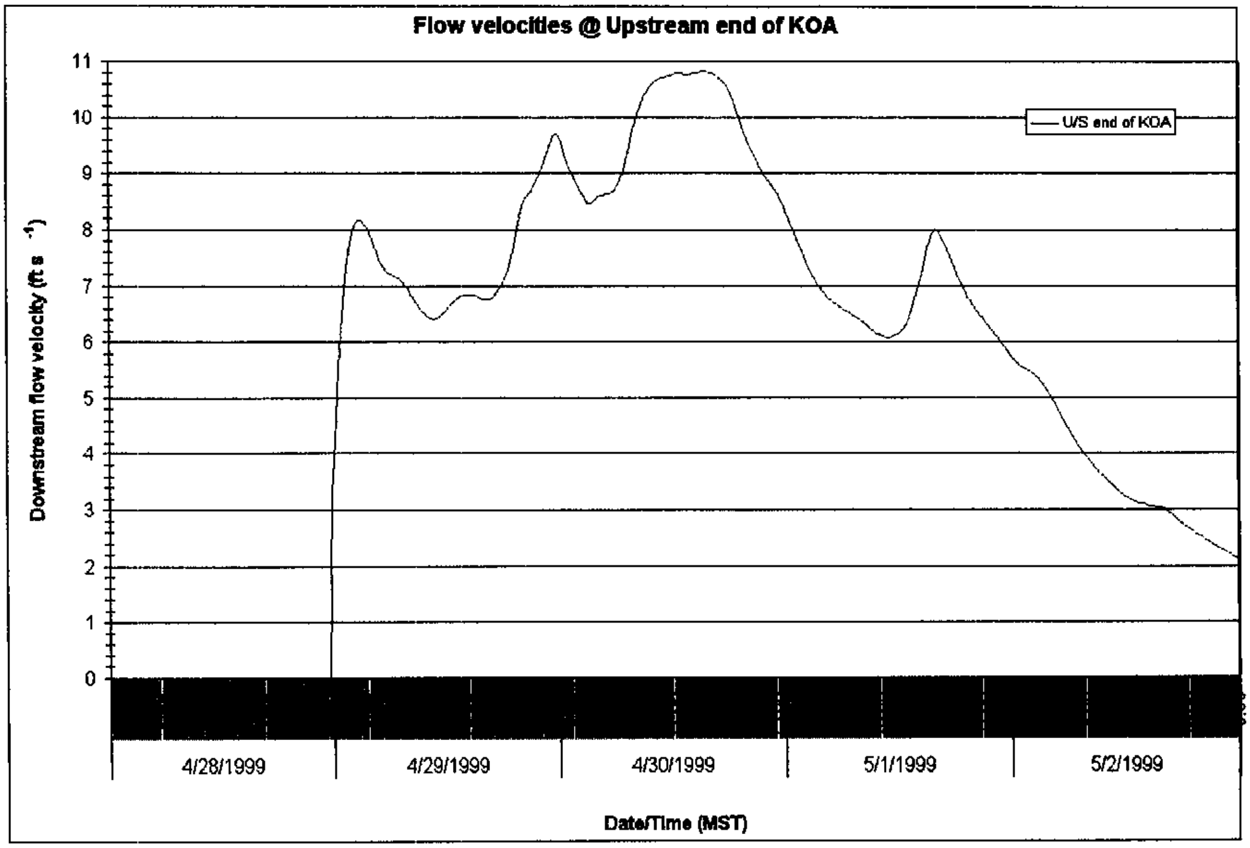


Figure 22a: Comparison of observed and simulated hydrographs for the major storm event during April 28-May 2, 1999, at USGS gauge locations along Fountain Creek between Colorado Springs and Pueblo, Colorado.

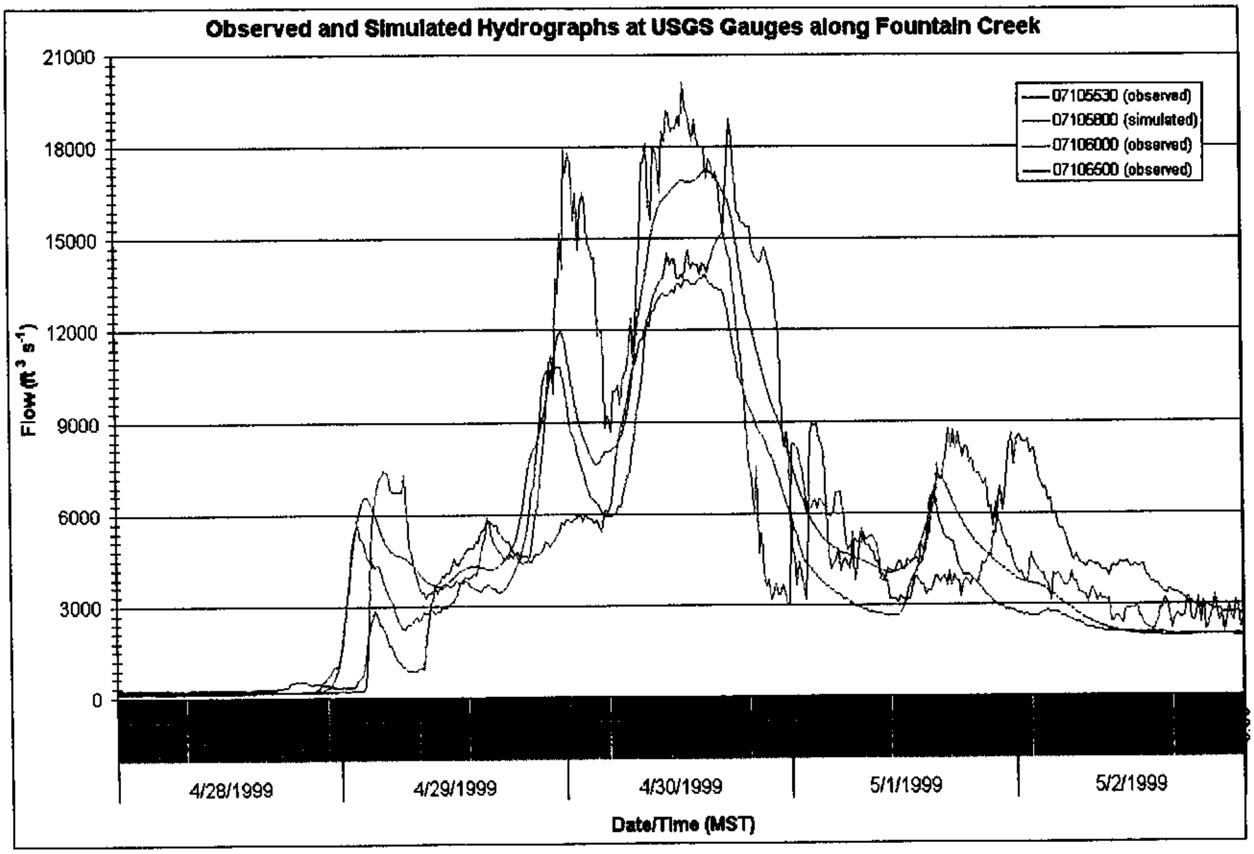


Figure 22b: Simulated hydrograph for the major storm event during April 28-May 2, 1999, at the location of the Greenview Ditch Headworks along Fountain Creek near Pueblo, Colorado. Statistics for these results are compiled in **Appendix B, Table 12.**

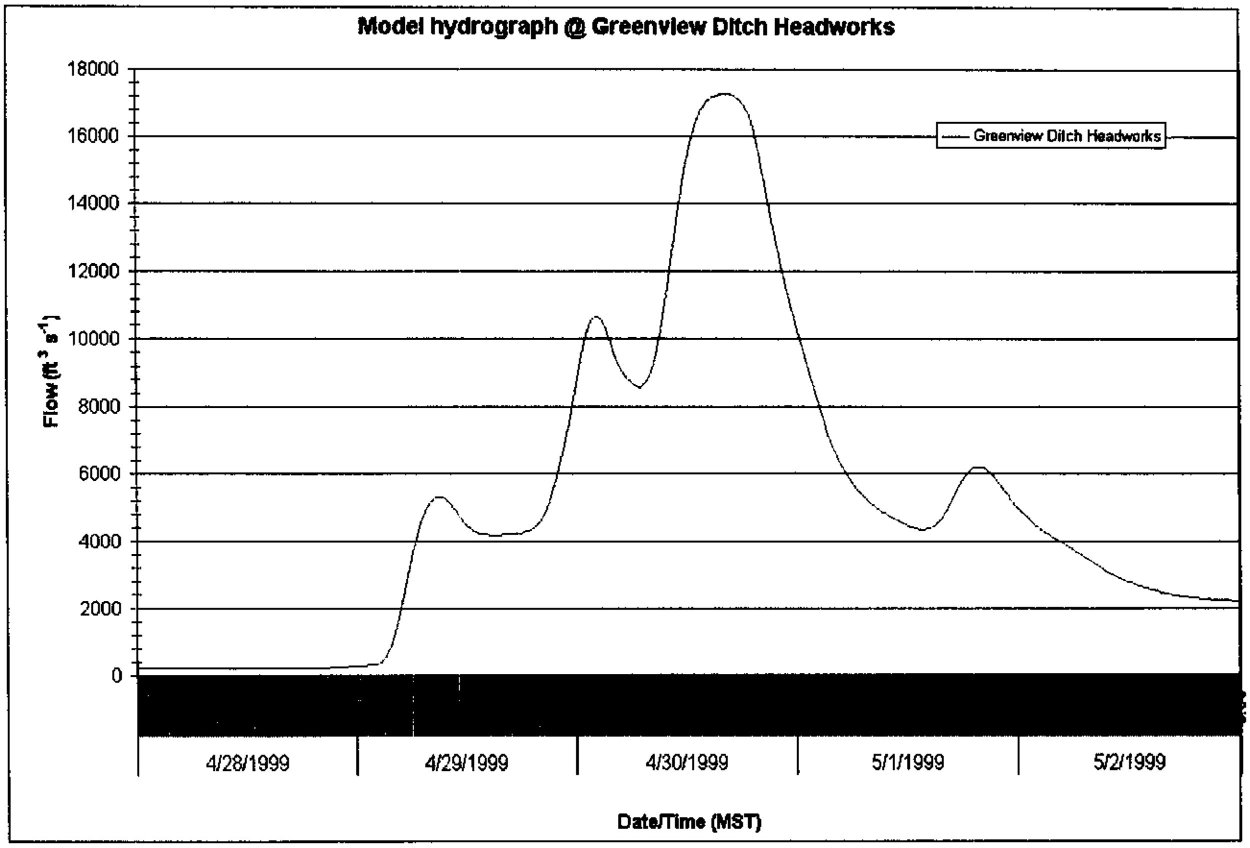


Figure 22c: Simulated flow velocities for the major storm event during April 28-May 2, 1999, at the location of the Greenview Ditch Headworks along Fountain Creek near Pueblo, Colorado. Statistics for these results are compiled in **Appendix B, Table 12.**

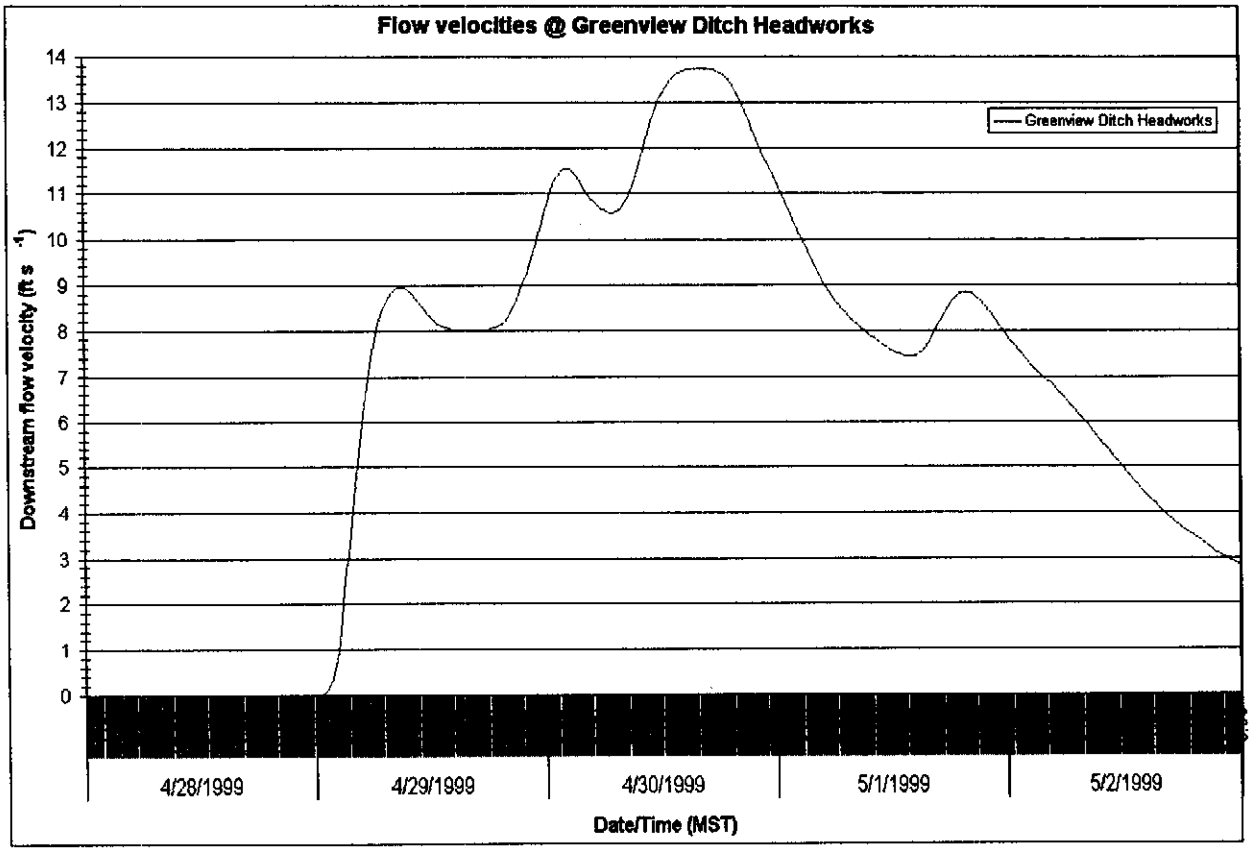


Figure 23a: Simulated stream channel water surface profile in the EXTRAN model segments along a portion of Fountain Creek for the major storm event during April 28-May 2, 1999, in the absence of the left bank levee downstream of the bridge at Colorado Highway 16 (the junction marked "Rt16brDS"). This result should be compared with that shown above in **Figure 20a.** The profile shown corresponds to peak flow conditions near 3:30 pm on April 30, 1999. Junction names and discharges (in $ft^3 s^{-1}$) for individual channel segments are shown near the top of the diagram. The KOA property is located along this portion of Fountain Creek between the junctions marked "DS1955" and "DS3130."

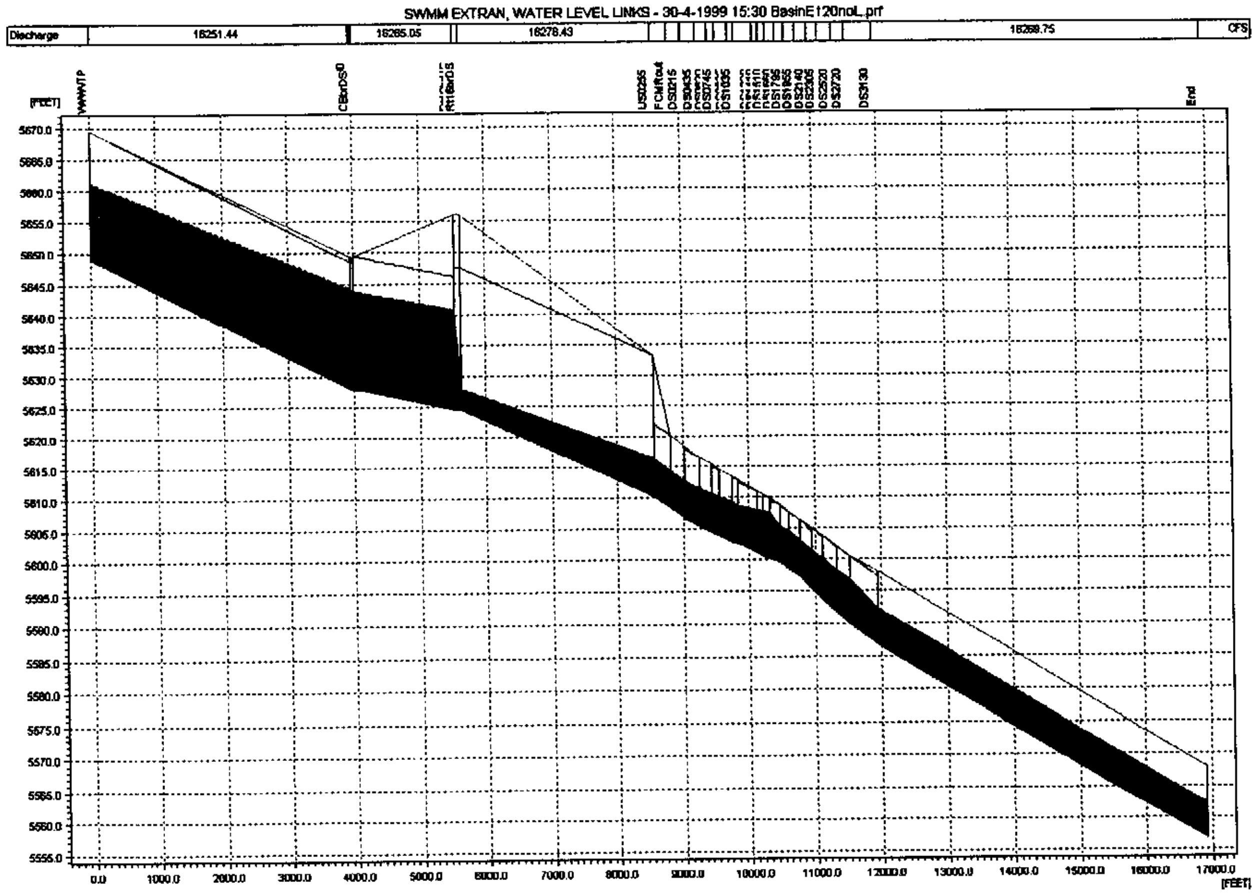


Figure 23b: Close-up view of simulated stream channel water surface profile in the EXTRAN model segments along a portion of Fountain Creek at and near the bridge at Colorado Highway 16 for the major storm event during April 28-May 2, 1999, in the absence of the left bank levee downstream of the bridge at Colorado Highway 16 (the junction marked "Rt16brDS"). The profile shown corresponds to peak flow conditions near 3:30 pm on April 30, 1999. Junction names and discharges (in ft^3 s^{-1}) for individual channel segments are shown near the top of the diagram.

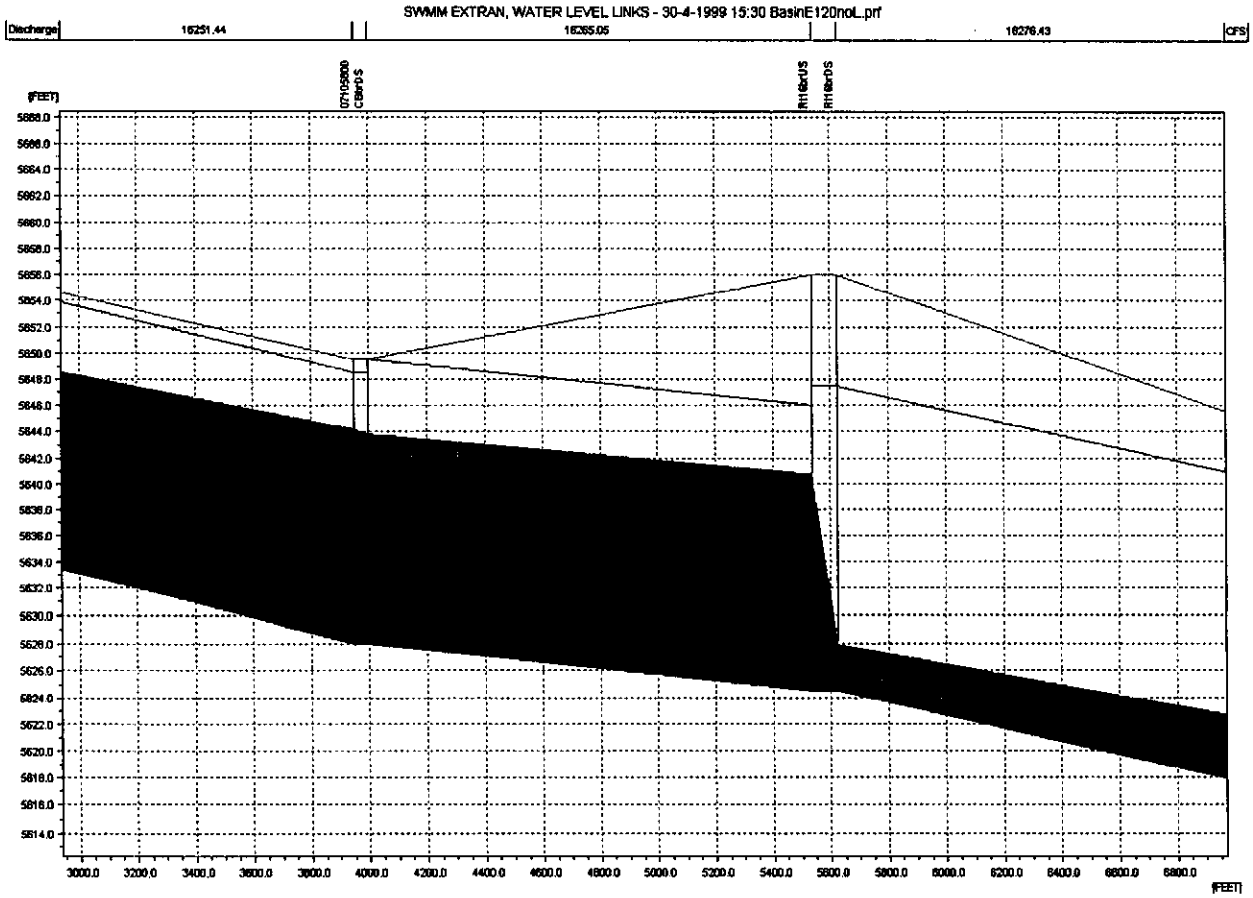


Figure 23c: Close-up view of simulated stream channel water surface profile in the EXTRAN model segments immediately upstream of and adjacent to the KOA property along Fountain Creek for the major storm event during April 28-May 2, 1999, in the absence of the left bank levee downstream of the bridge at Colorado Highway 16 (the junction marked "Rt16brDS" in **Figures 23a** and **23b**). This result should be compared with that shown above in **Figure 20b**. The profile shown corresponds to peak flow conditions near 3:30 pm on April 30, 1999. Junction names and discharges (in $ft^3 s^{-1}$) for individual channel segments are shown near the top of the diagram. The KOA property is located along this portion of Fountain Creek between the junctions marked "DS1955" and "DS3130."

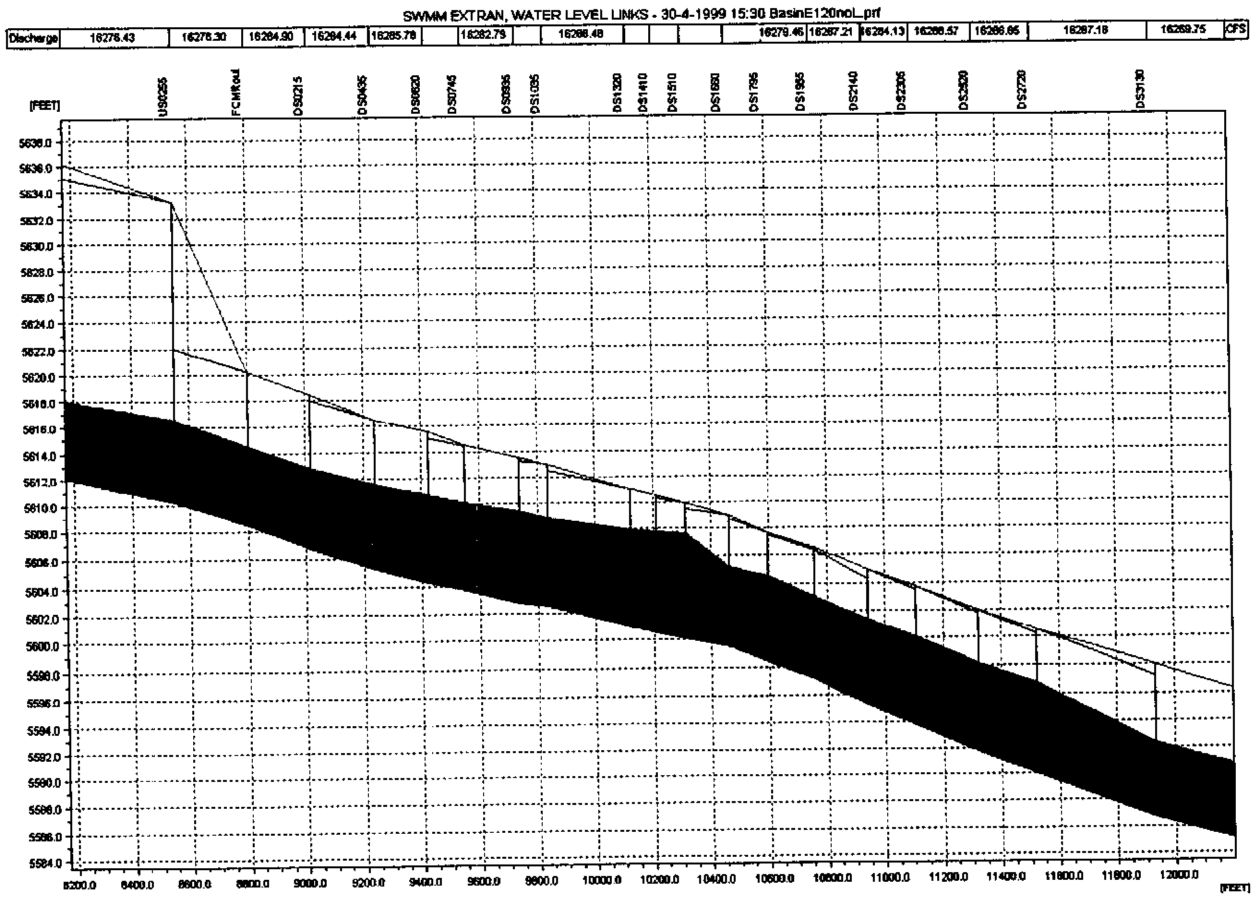


Figure 24a: Simulated hydrographs for the major storm event during April 28-May 2, 1999, at USGS gauge 07105800 (as marked in **Figure 23b**), in the absence of the left bank levee downstream of the bridge at Colorado Highway 16 (the junction marked "Rt16brDS" in **Figures 23a** and **23b**). This result is compared with that shown above in **Figure 21a**. Statistics for these results are compiled in **Appendix B, Table 10**.

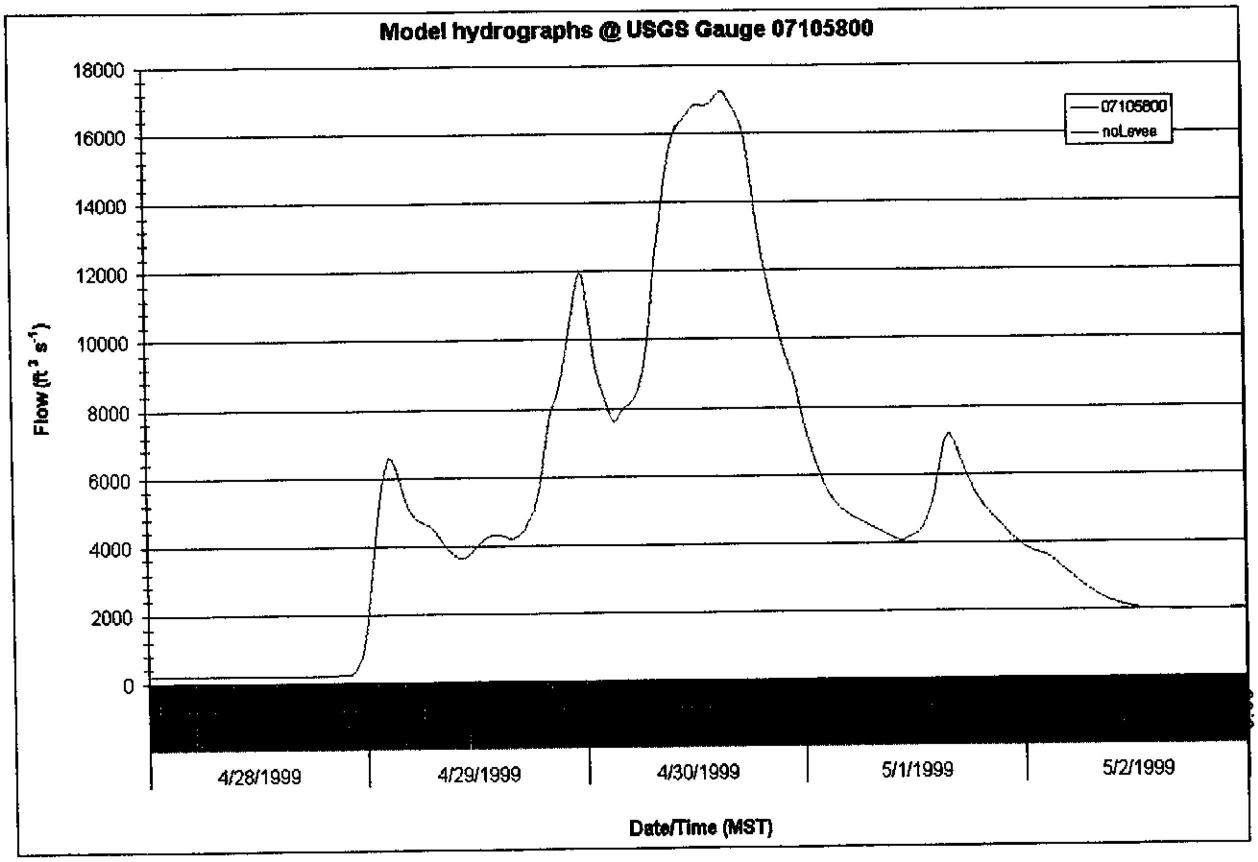


Figure 24b: Simulated flow velocities for the major storm event during April 28-May 2, 1999, at USGS gauge 07105800 (as marked in **Figure 23b**), in the absence of the left bank levee downstream of the bridge at Colorado Highway 16 (the junction marked "Rt16brDS" in **Figures 23a** and **23b**). This result is compared with that shown above in **Figure 21b**. Statistics for these results are compiled in **Appendix B, Table 10**.

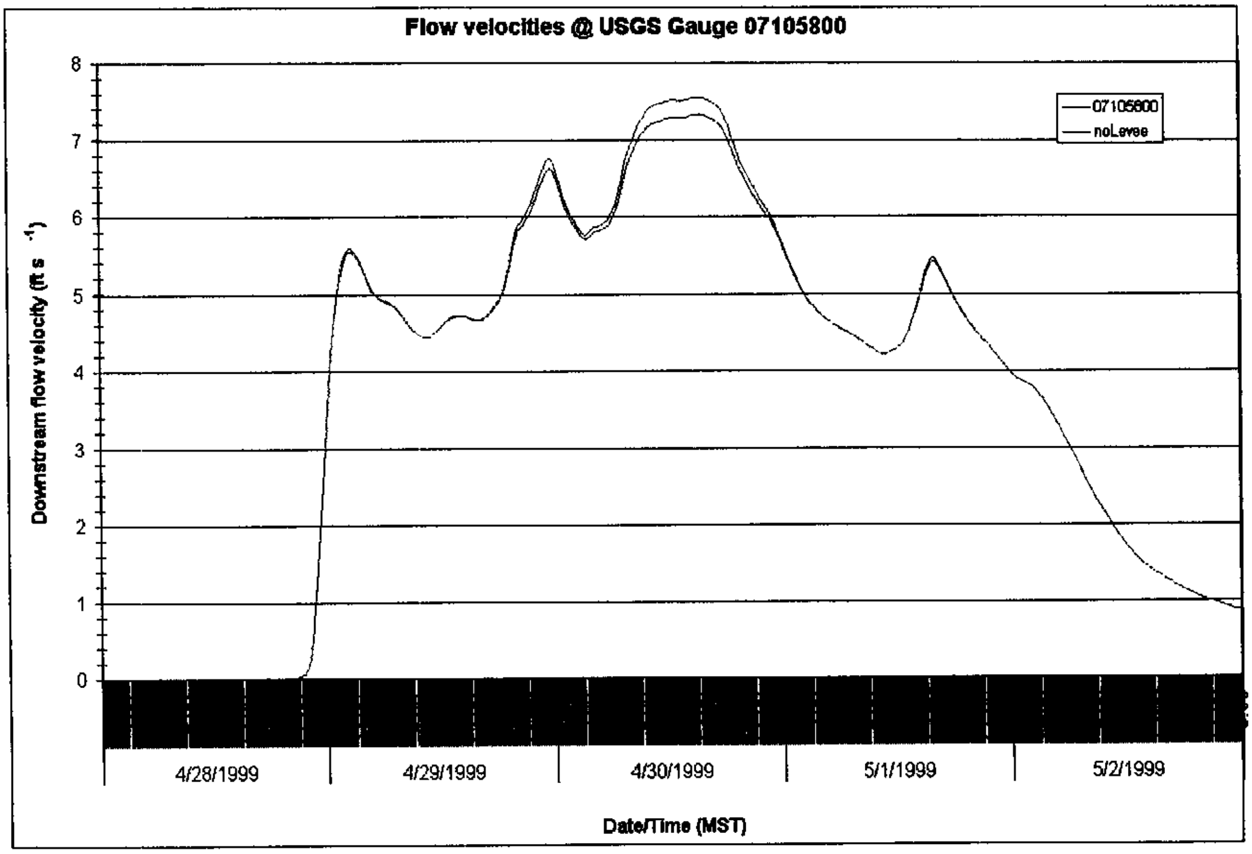


Figure 24c: Simulated hydrographs for the major storm event during April 28-May 2, 1999, at the upstream end of the KOA property (the junction marked "DS1955" in **Figures 23a** and **23c**) along Fountain Creek, in the absence of the left bank levee downstream of the bridge at Colorado Highway 16 (the junction marked "Rt16brDS" in **Figures 23a** and **23b**). This result is compared with that shown above in **Figure 21c**. Statistics for these results are compiled in **Appendix B, Table 11**.

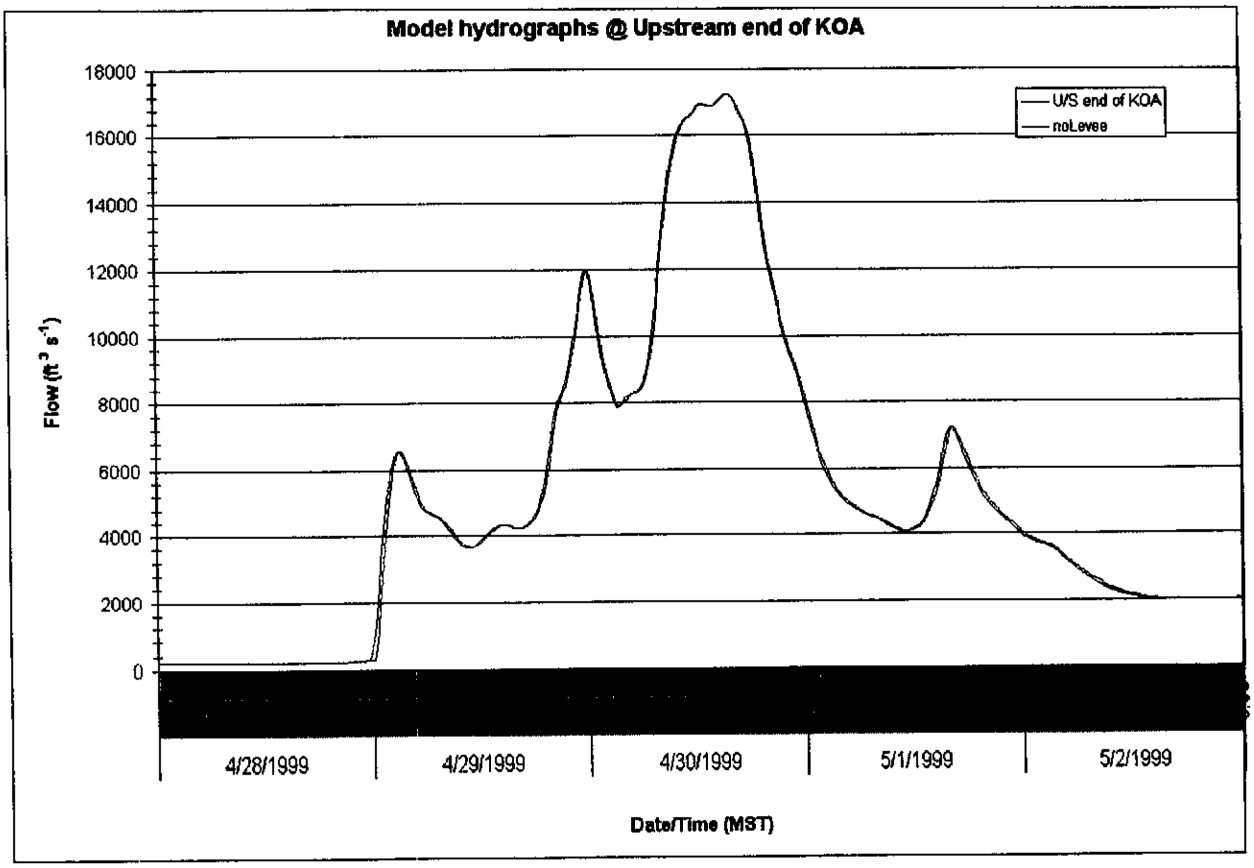


Figure 24d: Simulated flow velocities for the major storm event during April 28-May 2, 1999, at the upstream end of the KOA property (the junction marked "DS1955" in **Figures 23a** and **23c**) along Fountain Creek, in the absence of the left bank levee downstream of the bridge at Colorado Highway 16 (the junction marked "Rt16brDS" in **Figures 23a** and **23b**). This result is compared with that shown above in **Figure 21d**. Statistics for these results are compiled in **Appendix B, Table 11**.

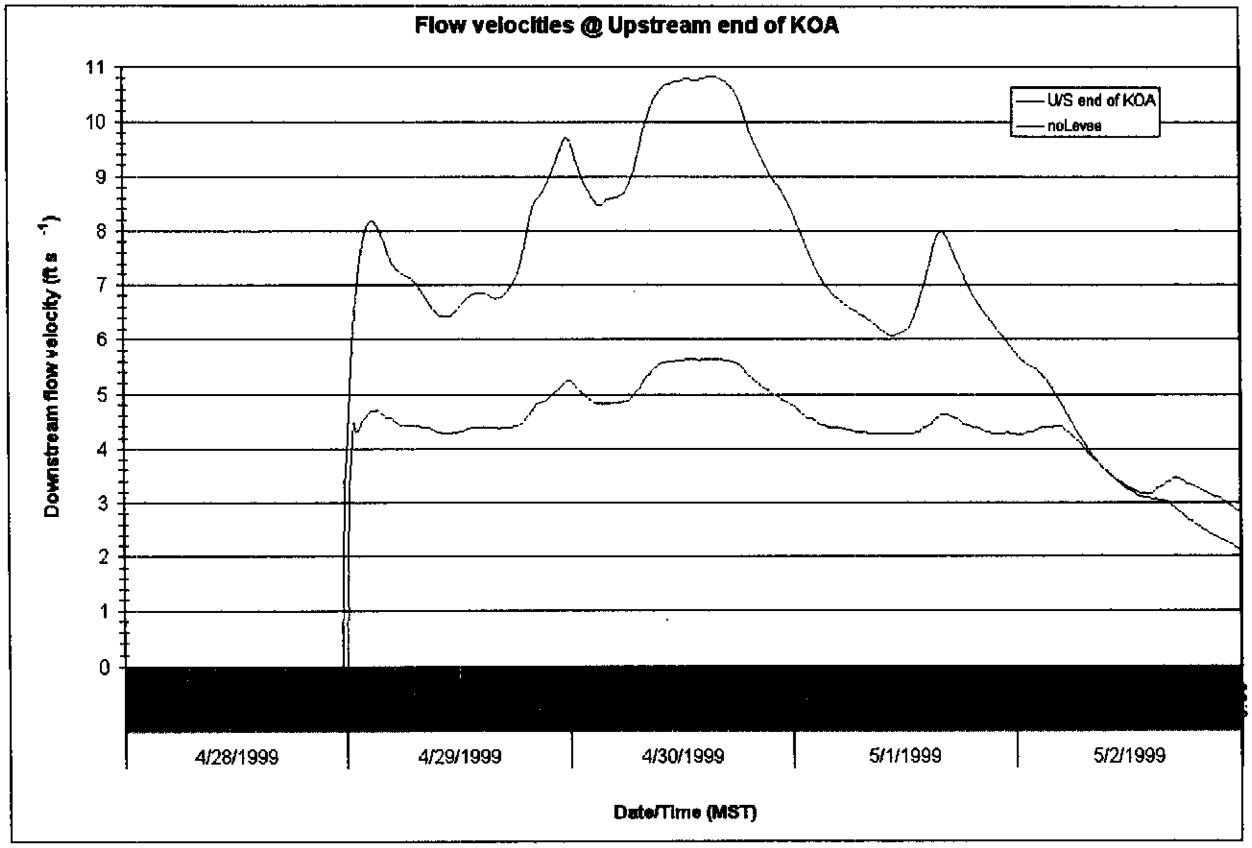


Figure 25: Simulated stream channel water surface profile in the EXTRAN model segments along a portion of Fountain Creek for the major storm event during April 28-May 2, 1999, in the absence of the developed area of the City of Colorado Springs in the upstream region. This result should be compared with that shown above in **Figure 20a**. The profile shown corresponds to peak flow conditions near 6:00 pm on April 30, 1999. Junction names and discharges (in ft^3 s^{-1}) for individual channel segments are shown near the top of the diagram. The KOA property is located along this portion of Fountain Creek between the junctions marked "DS1955" and "DS3130."

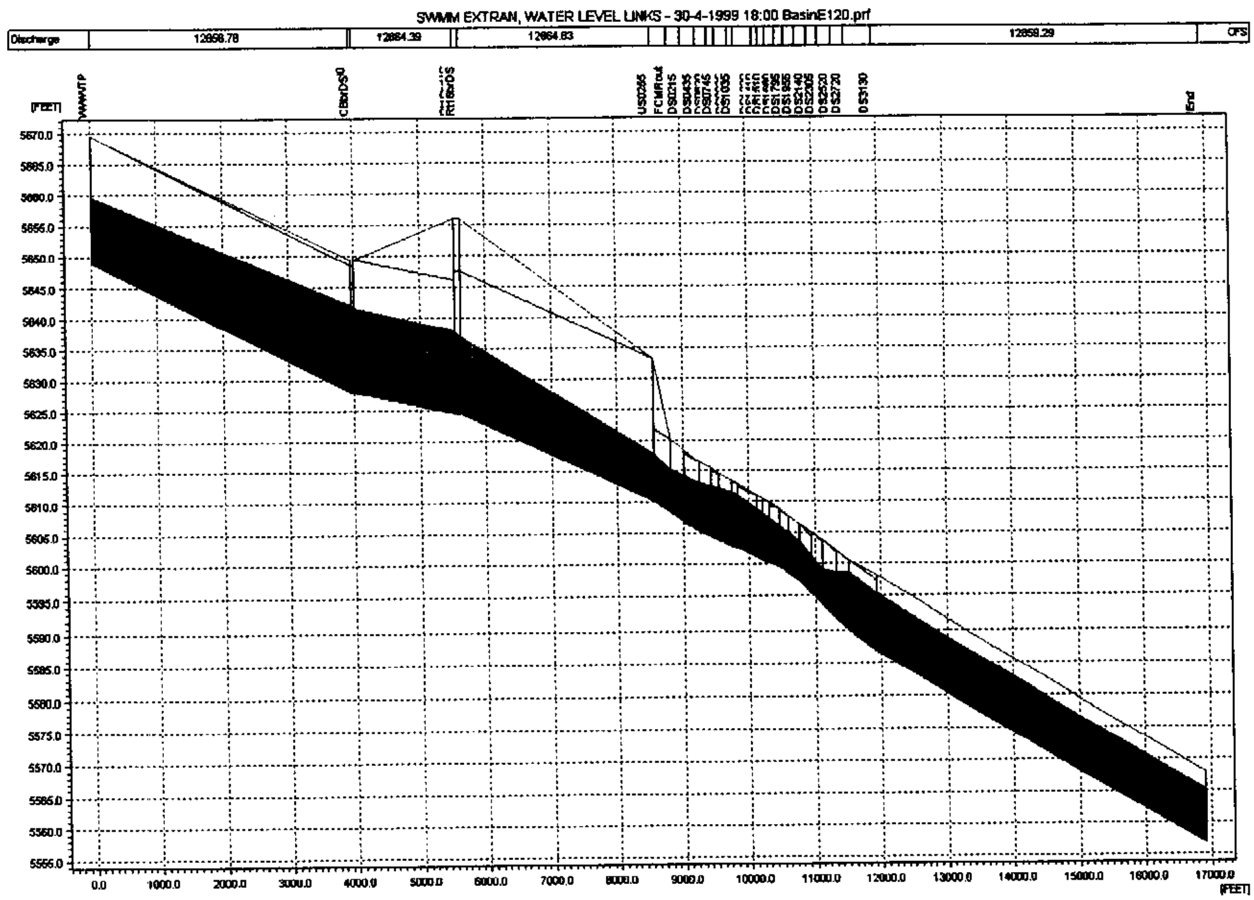


Figure 26a: Simulated hydrographs for the major storm event during April 28-May 2, 1999, at USGS gauge 07105800 (near the junction marked "CBbrDS" in **Figure 25**), in the absence of the developed area of the City of Colorado Springs in the upstream region. This result is compared with those shown above in **Figures 21a** and **24a**. Statistics for these results are compiled in **Appendix B, Table 10**.

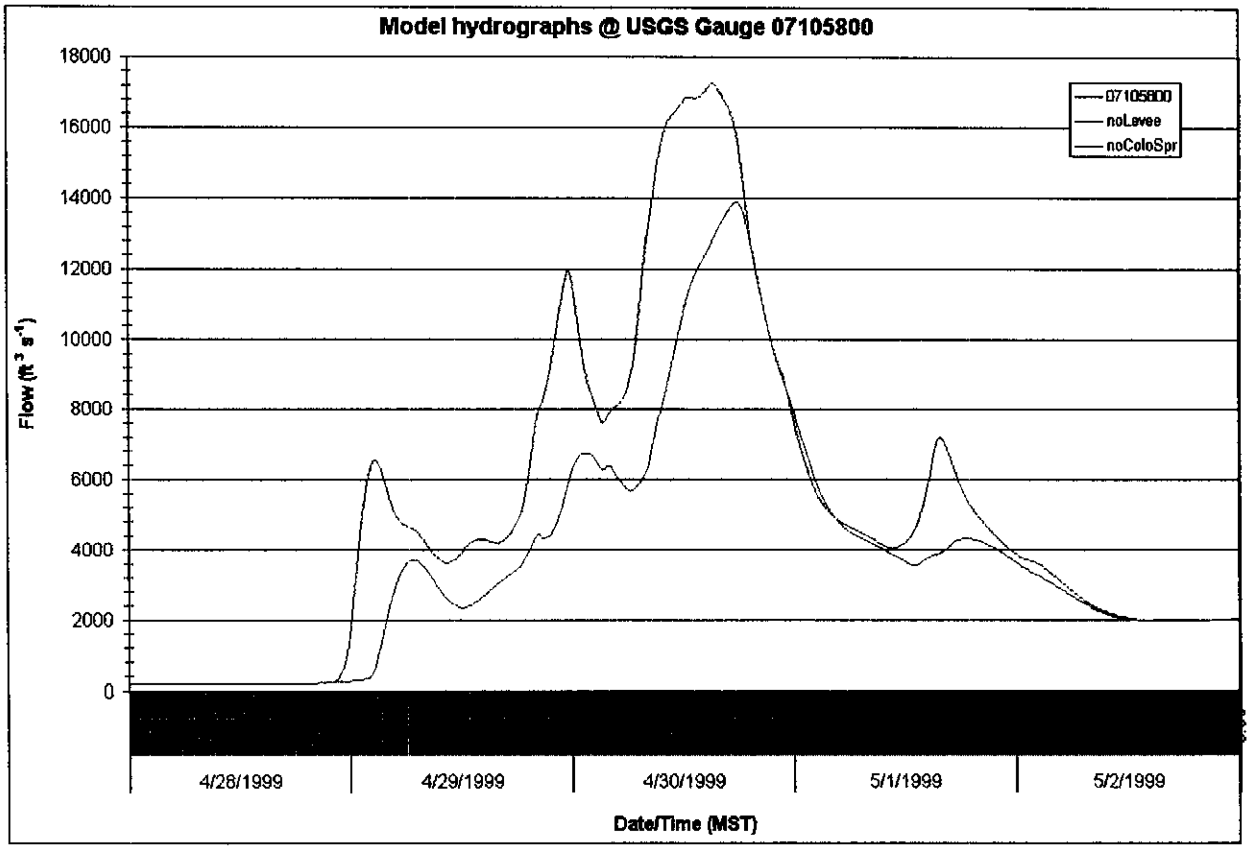


Figure 26b: Simulated flow velocities for the major storm event during April 28-May 2, 1999, at USGS gauge 07105800 (near the junction marked "CBbrDS" in **Figure 25**), in the absence of the developed area of the City of Colorado Springs in the upstream region. This result is compared with those shown above in **Figures 21b** and **24b**. Statistics for these results are compiled in **Appendix B, Table 10**.

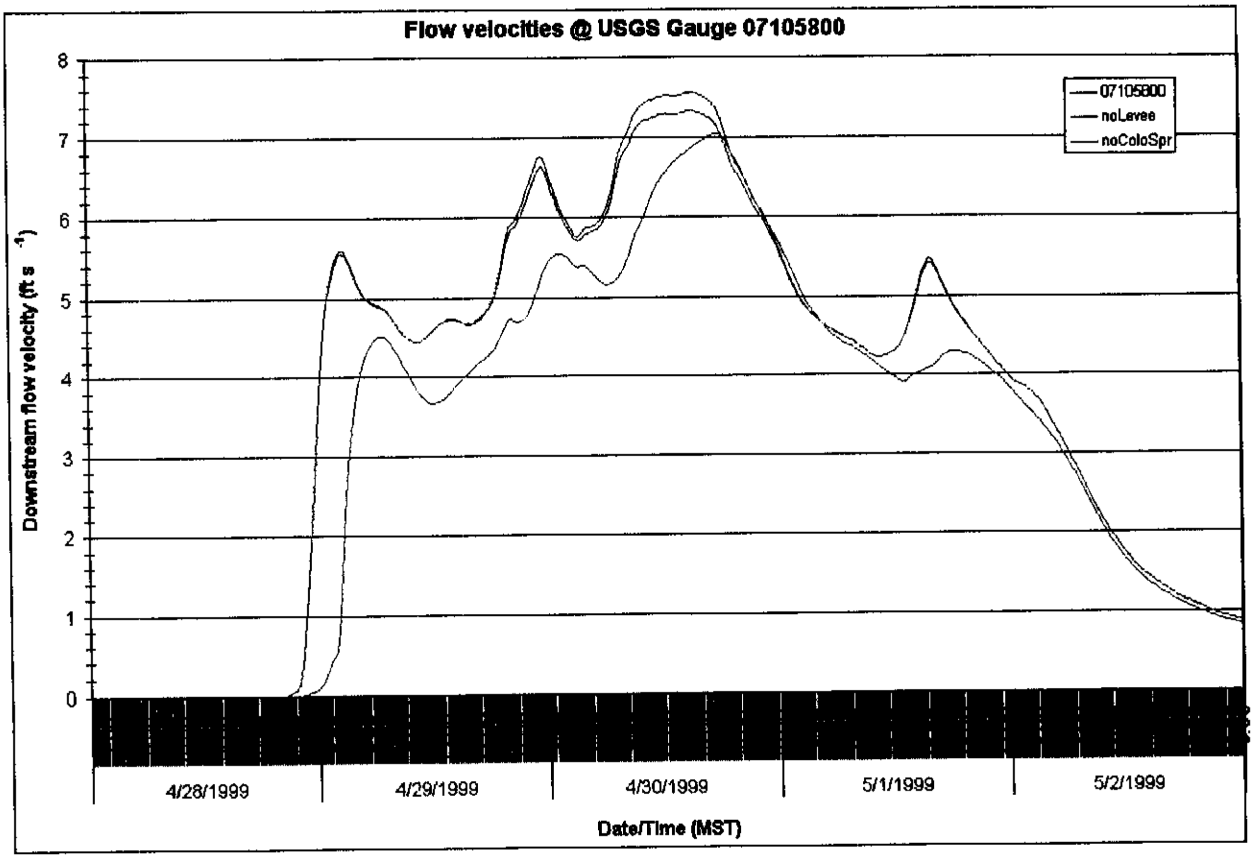


Figure 26c: Simulated hydrographs for the major storm event during April 28-May 2, 1999, at the upstream end of the KOA property (the junction marked "DS1955" in **Figure 25**) along Fountain Creek, in the absence of the developed area of the City of Colorado Springs in the upstream region. This result is compared with those shown above in **Figures 21c** and **24c.** Statistics for these results are compiled in **Appendix B, Table 11**.

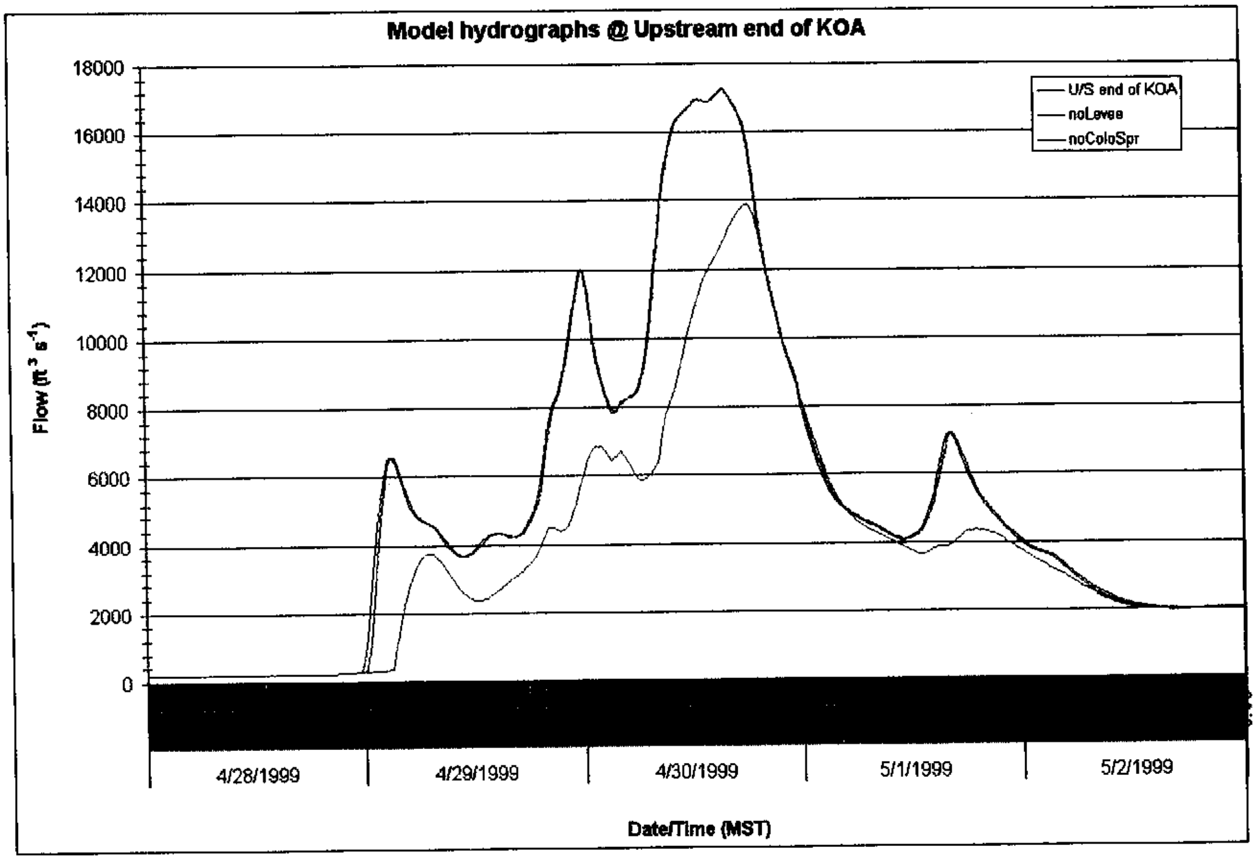


Figure 26d: Simulated flow velocities for the major storm event during April 28-May 2, 1999, at the upstream end of the KOA property (the junction marked "DS1955" in **Figure 25**) along Fountain Creek, in the absence of the developed area of the City of Colorado Springs in the upstream region. This result is compared with those shown above in **Figures 21d** and **24d.** Statistics for these results are compiled in **Appendix B, Table 11.**

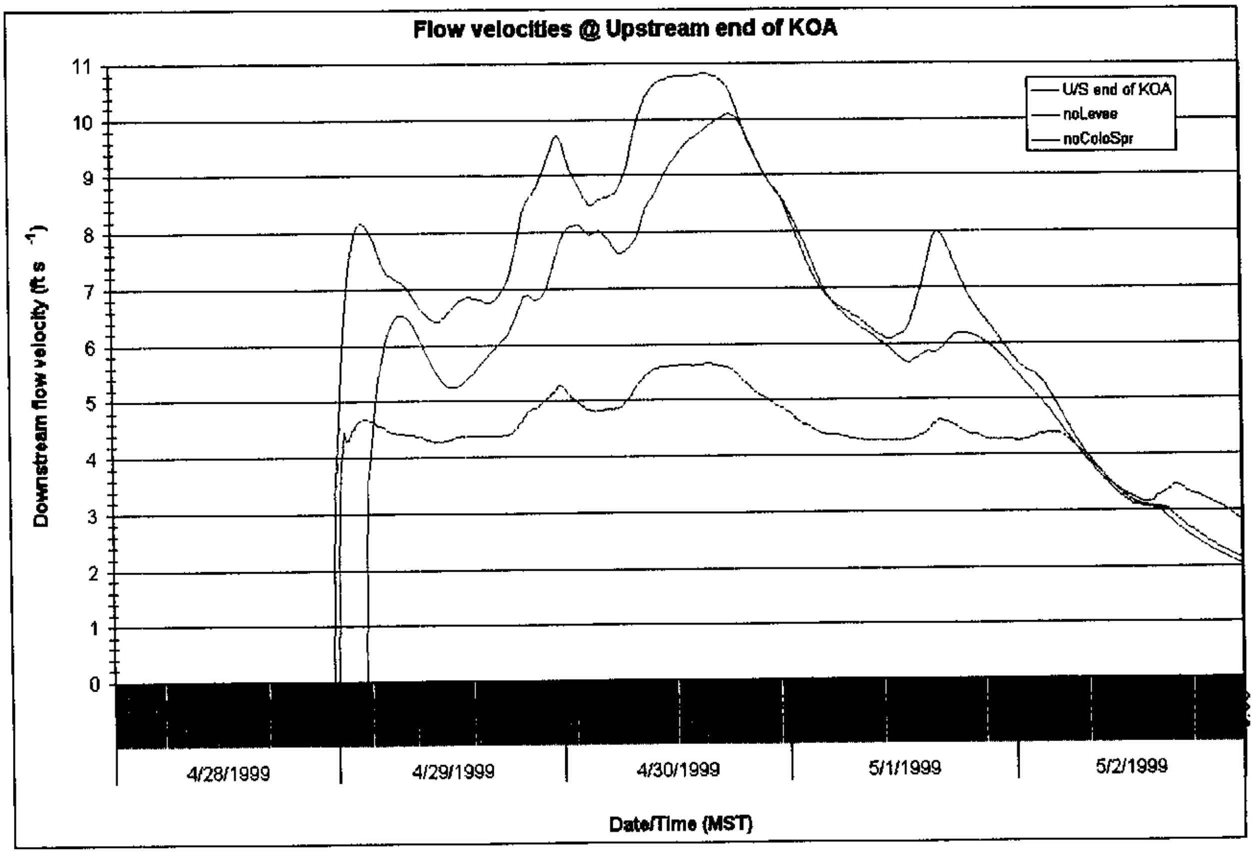


Figure 27: Simulated stream channel water surface profile in the EXTRAN model segments along a portion of Fountain Creek for the major storm event during April 28-May 2, 1999, in the absence of the developed area of the City of Colorado Springs in the upstream region as well as the left bank levee downstream of the Colorado Highway 16 bridge (the junction marked "Rt16brDS"). This result should be compared with those shown above in **Figures 23a** and **25**. The profile shown corresponds to peak flow conditions near 6:00 pm on April 30, 1999. Junction names and discharges (in $ft^3\ s^{-1}$) for individual channel segments are shown near the top of the diagram. The KOA property is located along this portion of Fountain Creek between the junctions marked "DS1955" and "DS3130."

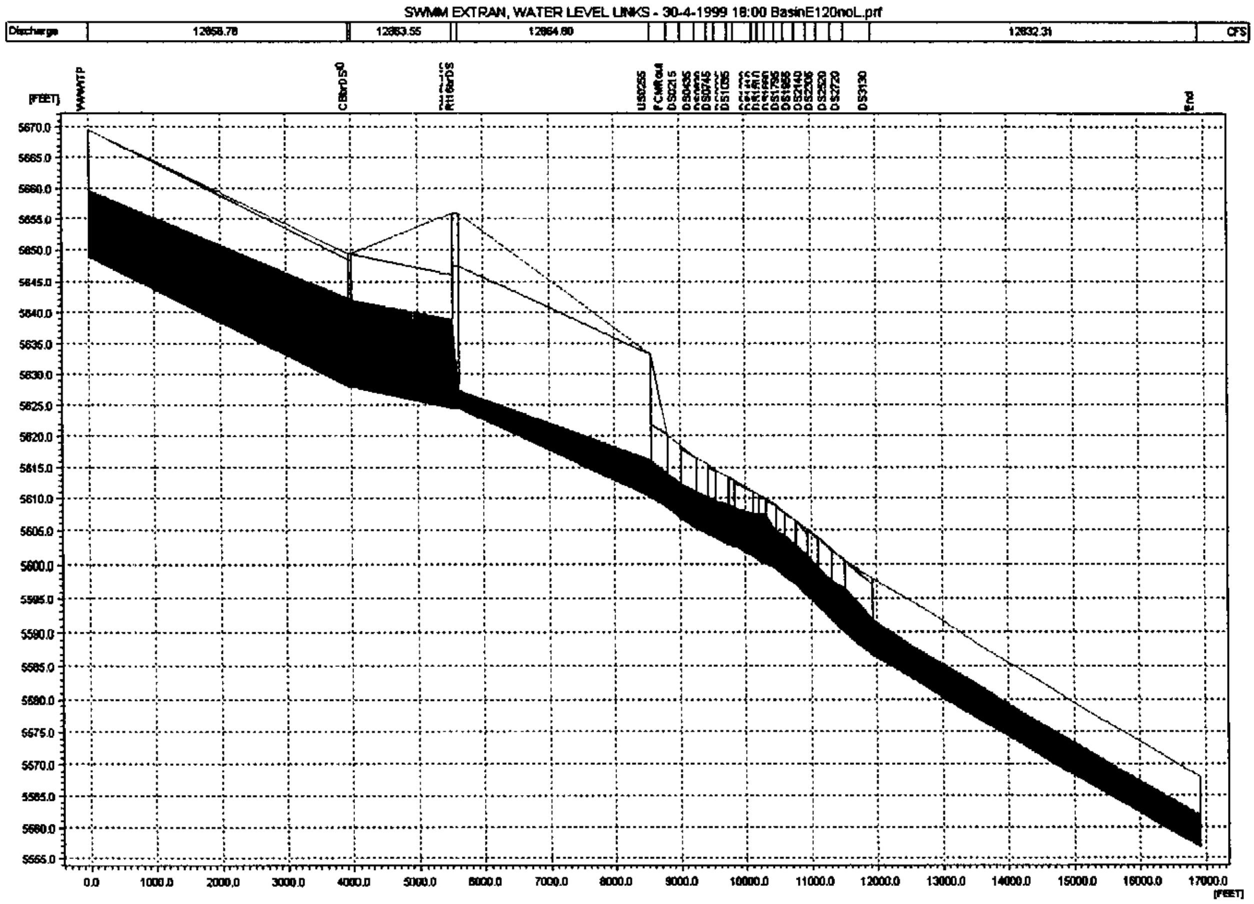


Figure 28a: Simulated hydrographs for the major storm event during April 28-May 2, 1999, at USGS gauge 07105800 (near the junction marked "CBbrDS" in **Figure 27**), in the absence of the developed area of the City of Colorado Springs in the upstream region as well as the left bank levee downstream of the bridge at Colorado Highway 16 (the junction marked "Rt16brDS" in **Figure 27**). This result is compared with those shown above in **Figures 21a, 24a,** and **26a**. Statistics for these results are compiled in **Appendix B, Table 10**.

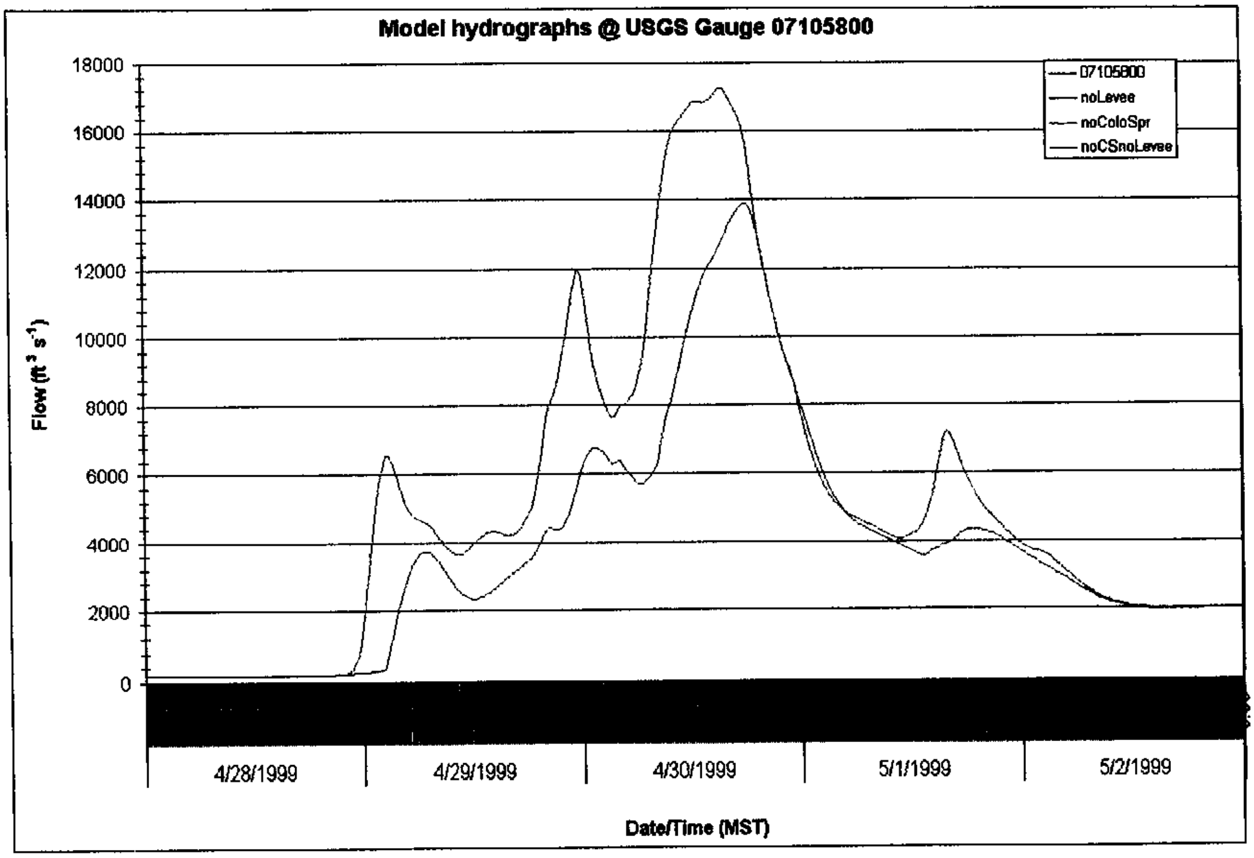


Figure 28b: Simulated flow velocities for the major storm event during April 28-May 2, 1999, at USGS gauge 07105800 (near the junction marked "CBbrDS" in **Figure 27**), in the absence of the developed area of the City of Colorado Springs in the upstream region as well as the left bank levee downstream of the bridge at Colorado Highway 16 (the junction marked "Rt16brDS" in **Figure 27**). This result is compared with those shown above in **Figures 21b, 24b,** and **26b**. Statistics for these results are compiled in **Appendix B, Table 10**.

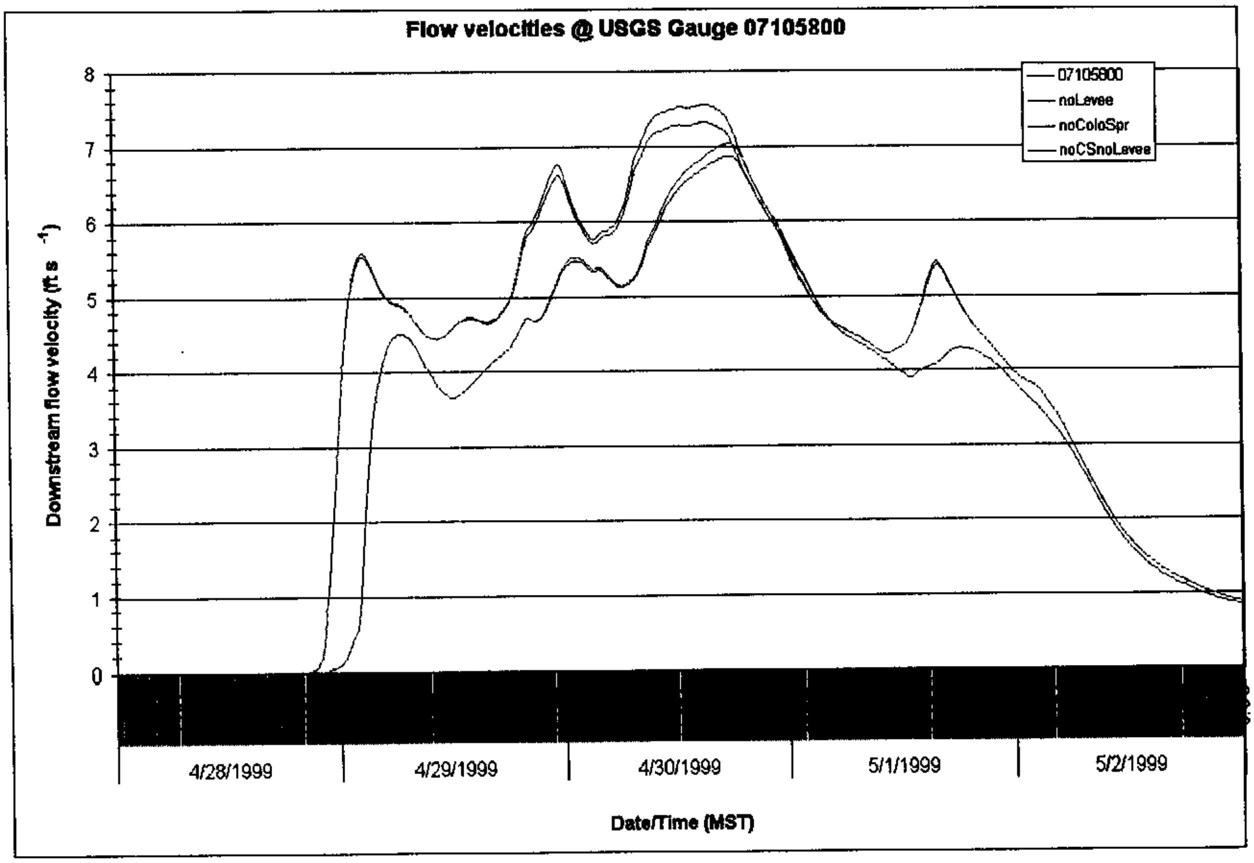


Figure 28c: Simulated hydrographs for the major storm event during April 28-May 2, 1999, at the upstream end of the KOA property (the junction marked "DS1955" in **Figure 27**) along Fountain Creek, in the absence of the developed area of the City of Colorado Springs in the upstream region as well as the left bank levee downstream of the bridge at Colorado Highway 16 (the junction marked "Rt16brDS" in **Figure 27**). This result is compared with those shown above in **Figures 21c, 24c,** and **26c**. Statistics for these results are compiled in **Appendix B, Table 11.**

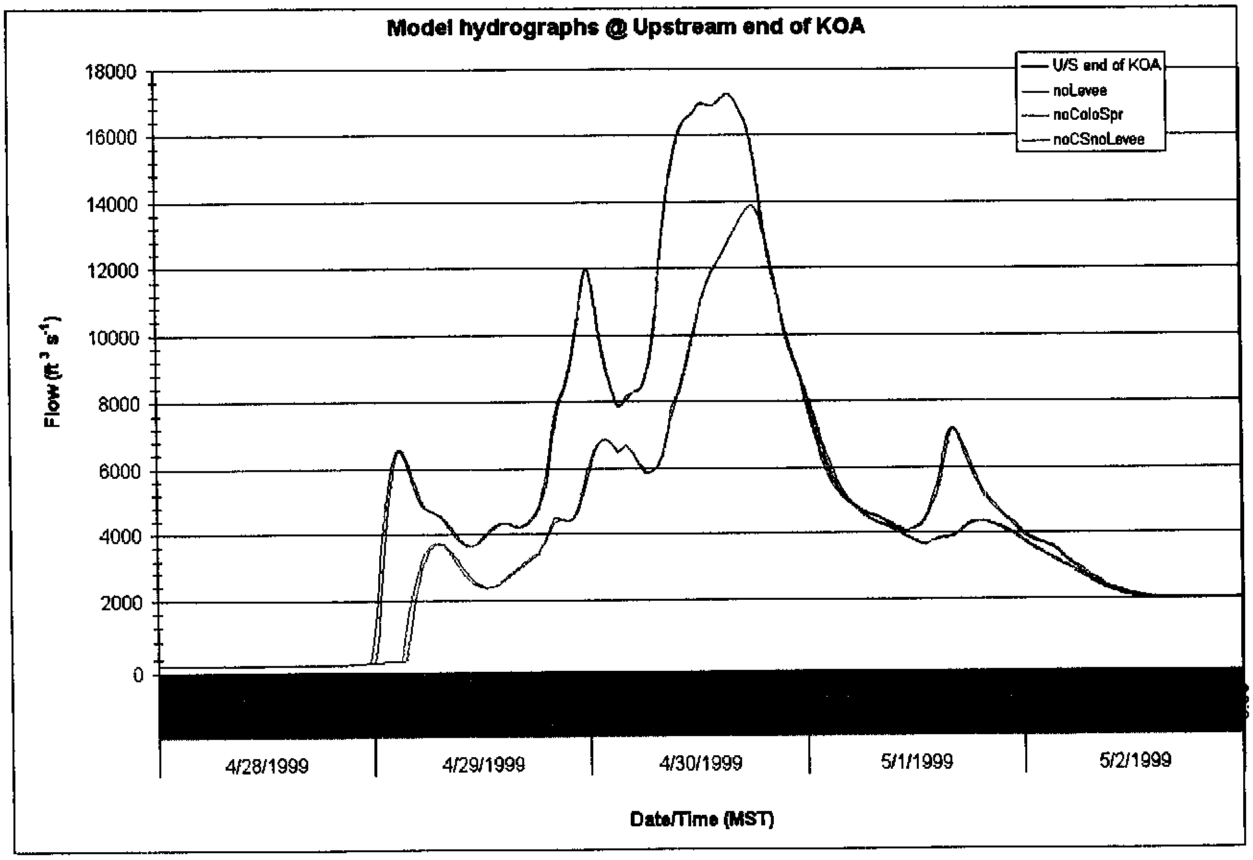


Figure 28d: Simulated flow velocities for the major storm event during April 28-May 2, 1999, at the upstream end of the KOA property (the junction marked "DS1955" in **Figure 27**) along Fountain Creek, in the absence of the developed area of the City of Colorado Springs in the upstream region as well as the left bank levee downstream of the bridge at Colorado Highway 16 (the junction marked "Rt16brDS" in **Figure 27**). This result is compared with those shown above in **Figures 21d, 24d,** and **26d**. Statistics for these results are compiled in **Appendix B, Table 11**.

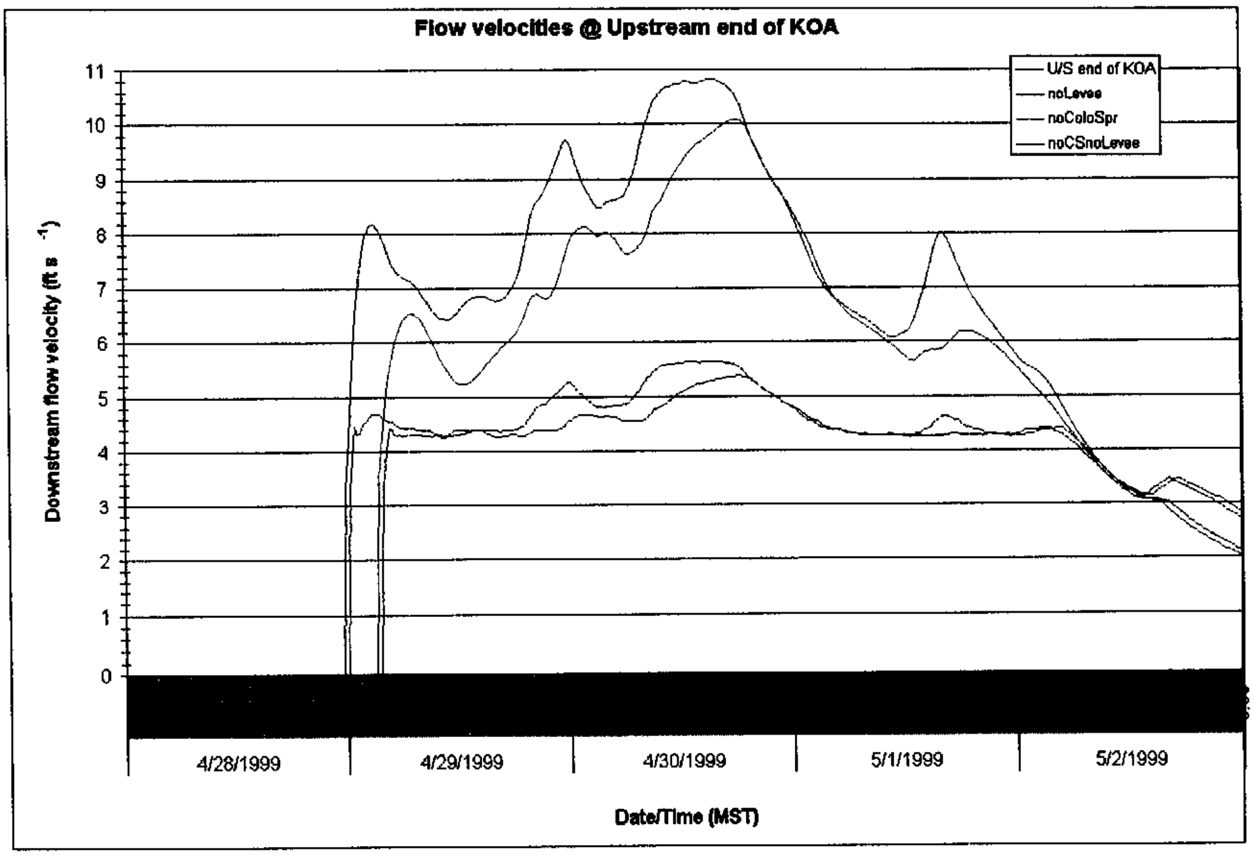


Figure 29a: Simulated hydrographs for the major storm event during April 28-May 2, 1999, at the location of the Greenview Ditch Headworks near Pueblo, Colorado, for the cases of current development and pre-development conditions in the area of the City of Colorado Springs in the upstream region. This result is compared with that shown above in **Figure 22a**. Statistics for these results are compiled in **Appendix B, Table 12.**

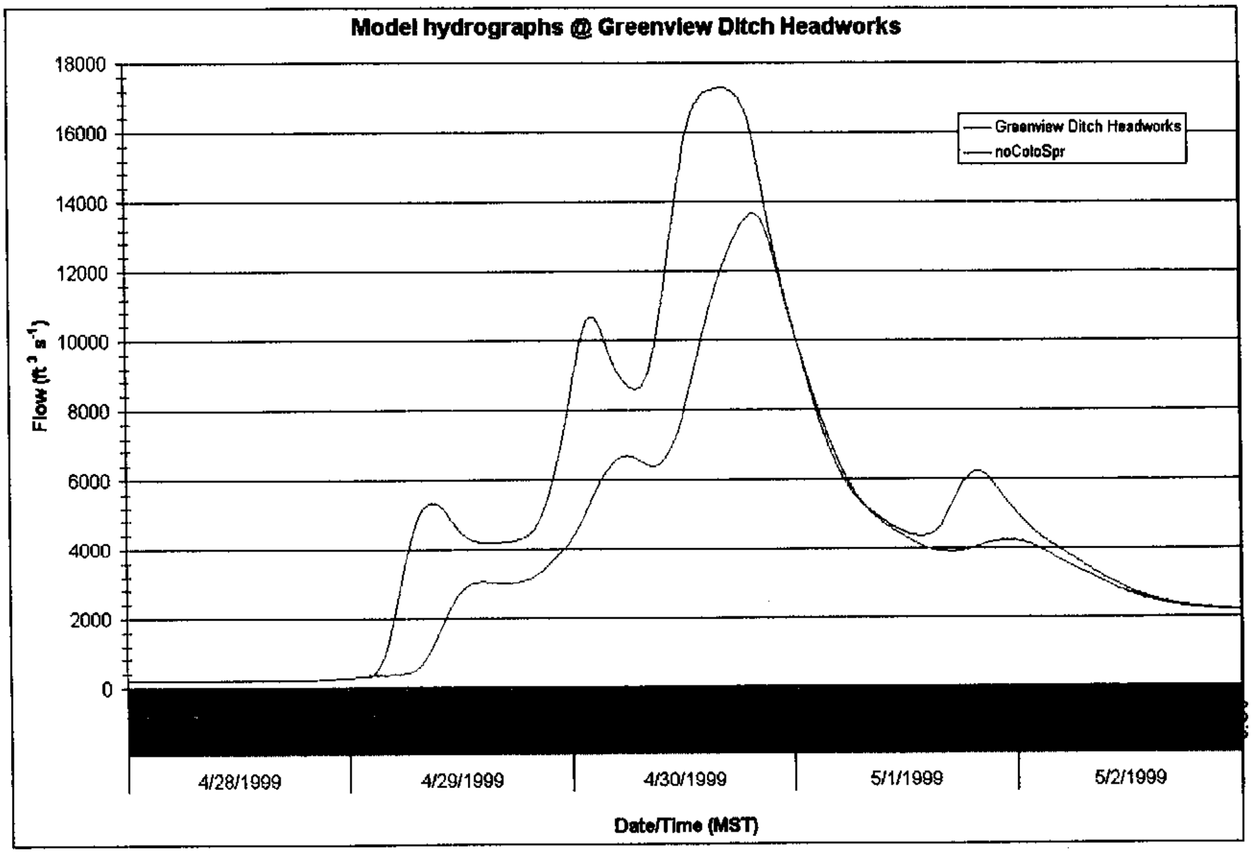


Figure 29b: Simulated flow velocities for the major storm event during April 28-May 2, 1999, at the location of the Greenview Ditch Headworks near Pueblo, Colorado, for the cases of current development and pre-development conditions in the area of the City of Colorado Springs in the upstream region. This result is compared with that shown above in **Figure 22b**. Statistics for these results are compiled in **Appendix B, Table 12**.

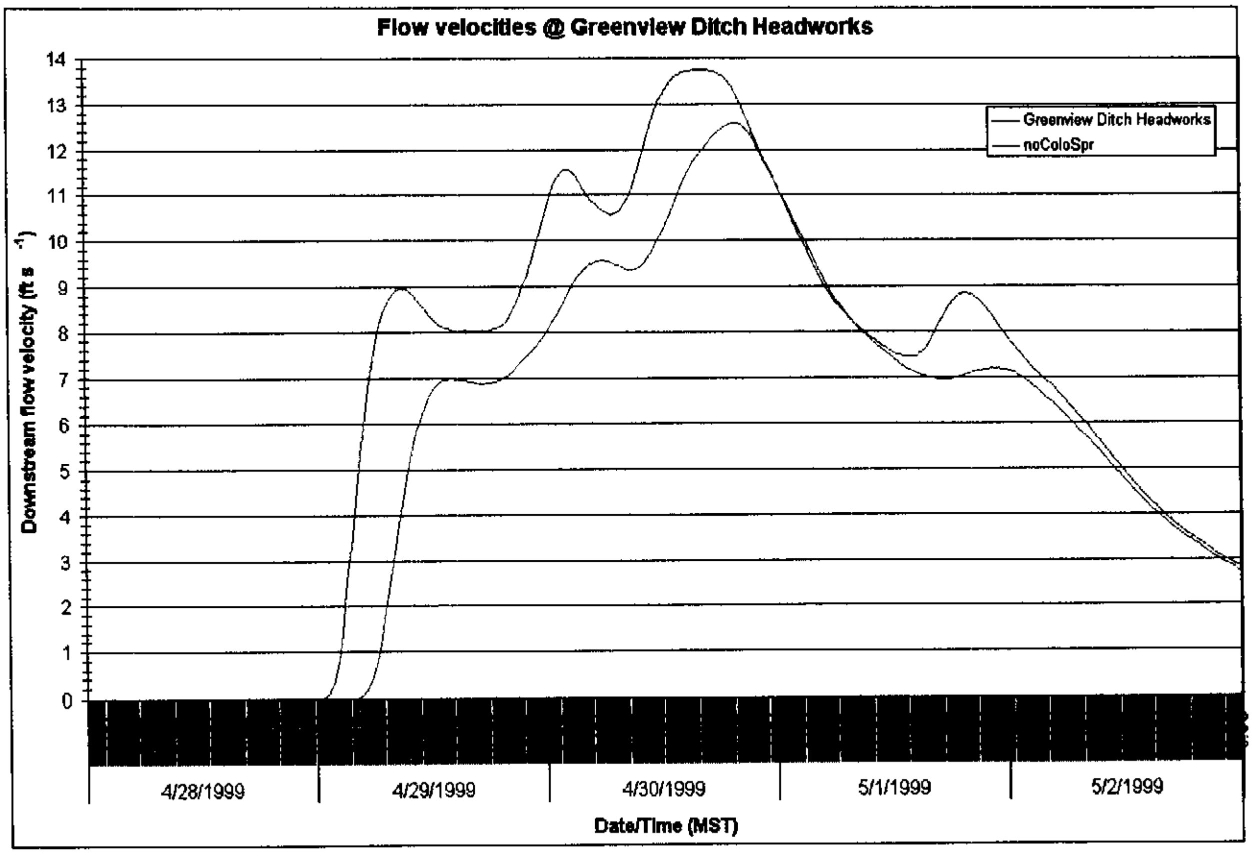


Table 1: Listing of SWMM RUNOFF sub-basin surface parameters for current development conditions. Sub-basins with names in **bold** type are located partially or wholly within the City of Colorado Springs. Explanations of data fields listed here are given in **Section 4** of this report.

	Hyeto-graph	Name	Hydraulic Load Pt	Width (ft)	Area (ac)	% Imp	Slope (ft/ft)	Imp n	Pv n	Imp D St (in)	Pv D St (in)	Max Inf (in/hr)	Min Inf (in/hr)	Inf Decay (s⁻¹)
H1	1	'CRCFTCa'	'UFCMR01'	45000	9451.2	7.13	0.1	0.015	0.8	0.1	0.4	3.51	0.109	0.0018
H1	1	'FTGc'	'UFCMR01'	9800	652.8	7.5	0.1772	0.015	0.8	0.1	0.4	4.13	0.110	0.0018
H1	1	'CTCa'	'UFCMR01'	3900	153.6	0	0.2182	0.015	0.8	0.1	0.4	3	0.1	0.0018
H1	1	'CTCRN'	'CTCbC'	14400	4300	0	0.2585	0.015	0.8	0.1	0.4	3	0.1	0.0018
H1	1	'CTCRS'	'CTCbC'	12800	3596.8	0	0.1407	0.015	0.8	0.1	0.4	3	0.1	0.0018
H1	1	'CTCb'	'CTCbC'	12800	1075.2	1.5	0.1407	0.015	0.8	0.1	0.4	3	0.1	0.0018
H1	1	'CLCR'	'CLCC'	14000	2873.6	0	0.1364	0.015	0.8	0.1	0.4	3	0.1	0.0018
H1	1	'CLCa'	'CLCC'	8000	355.4	0	0.2923	0.015	0.8	0.1	0.4	3	0.1	0.0018
H1	1	'LGSG'	'UFCMR03'	9200	2342.4	10.10	0.1073	0.015	0.8	0.1	0.4	3	0.1	0.0018
H1	1	'CPa'	'UFCMR03'	8000	805.2	4.5	0.3143	0.015	0.8	0.1	0.4	3	0.1	0.0018
H1	1	'WG'	'UFCMR05'	10000	1139.2	0.3	0.1484	0.015	0.8	0.1	0.4	3	0.1	0.0018
H1	1	'CPb'	'UFCMR04'	8000	805.2	4.5	0.38	0.015	0.8	0.1	0.4	3	0.1	0.0018
H1	1	'CBa'	'UFCMR05'	12000	1811.2	1.27	0.25	0.015	0.8	0.1	0.4	3	0.1	0.0018
H1	1	**'SVCa'**	'SVCbC'	21000	2435.4	0	0.1533	0.015	0.8	0.1	0.4	3	0.1	0.0018
H1	1	**'SVCb'**	'SVCbC'	4000	236.8	0	0.24	0.015	0.8	0.1	0.4	3	0.1	0.0018
H1	1	**'SVCc'**	'SVCdC'	8800	2103.2	0	0.16	0.015	0.8	0.1	0.4	3	0.1	0.0018
H1	1	**'SVCd'**	'SVCdC'	8000	416	0.3	0.32	0.015	0.8	0.1	0.4	4.5	0.12	0.0018
H1	1	**'FRCRMTR'**	'FRCaC'	10000	2240	0	0.1442	0.015	0.8	0.1	0.4	3	0.1	0.0018
H1	1	**'FRCa'**	'FRCaC'	8000	768	0	0.1333	0.015	0.8	0.1	0.4	3	0.1	0.0018
H1	1	**'FRCb'**	'FRCcC'	10000	3033.6	0	0.1532	0.015	0.8	0.1	0.4	3	0.1	0.0018
H1	1	**'FRCc'**	'UFCMR06'	12000	595.2	0	0.2143	0.015	0.8	0.1	0.4	3	0.1	0.0018
H1	2	'CBb'	'UFCMR07'	7000	355.4	0	0.32	0.015	0.8	0.1	0.4	3	0.1	0.0018
H1	2	'ITa'	'UFCMR07'	9000	960	0	0.3080	0.015	0.8	0.1	0.4	3	0.1	0.0018
H1	2	'WLCa'	'UFCMR08'	8800	1139.2	0	0.1833	0.015	0.8	0.1	0.4	3	0.1	0.0018
H1	2	'ITb'	'UFCMR08'	3400	832	1.5	0.2182	0.015	0.8	0.1	0.4	3	0.1	0.0018
H1	2	'WLCc'	'UFCMR08'	4000	275.2	0	0.2545	0.015	0.8	0.1	0.4	3	0.1	0.0018
H1	8	'ECa'	'ECdC'	16000	3392	0	0.2107	0.015	0.8	0.1	0.4	3	0.1	0.0018
H1	8	'ECb'	'ECbC'	12000	1536	0	0.1889	0.015	0.8	0.1	0.4	3	0.1	0.0018
H1	8	'ECRLKM'	'ECbC'	14000	1472	0	0.2207	0.015	0.8	0.1	0.4	3	0.1	0.0018
H1	8	'ECRBTR'	'ECcC'	10000	2042	0	0.1207	0.015	0.8	0.1	0.4	3	0.1	0.0018
H1	8	'ECc'	'ECcC'	5000	442	0	0.2118	0.015	0.8	0.1	0.4	3	0.1	0.0018
H1	8	'ECd'	'ECdC'	25000	2496	1.00	0.3333	0.015	0.8	0.1	0.4	3	0.1	0.0018
H1	2	'WC'	'WCC'	10000	1821.6	1.73	0.1217	0.015	0.8	0.1	0.4	3	0.1	0.0018
H1	2	'MS'	'MFCMR01'	5000	460.8	1.5	0.24	0.015	0.5	0.1	0.4	3	0.1	0.0018
H1	2	'BKC'	'MFCMR02'	10000	1472	4	0.11	0.015	0.8	0.1	0.4	3	0.1	0.0018
H1	2	'SC'	'MFCMR02'	12000	3712	0.02	0.2	0.015	0.8	0.1	0.4	3	0.1	0.0018
H1	15	'BL'	'MFCMR02'	4000	640	11	0.1150	0.015	0.8	0.1	0.4	3	0.1	0.0018
H1	15	'CR'	'MFCMR03'	4000	396.4	0.75	0.104	0.015	0.8	0.1	0.4	3	0.1	0.0018
H1	15	'PT'	'MFCMR03'	12000	1900	0.25	0.1007	0.015	0.8	0.1	0.4	3.9	0.112	0.0018
H1	1	'CPCa'	'CPCaC'	15224	2809.6	0	0.1294	0.015	0.8	0.1	0.4	3	0.1	0.0018
H1	2	'CPCb'	'CPCbC'	19564	922	0	0.1534	0.015	0.8	0.1	0.4	3	0.1	0.0018
H1	2	'CPCc'	'CPCcC'	19200	844.8	0	0.1	0.015	0.8	0.1	0.4	3	0.1	0.0018
H1	15	'CPCd'	'CPCdC'	22800	1315.4	7.5	0.0702	0.015	0.8	0.1	0.4	3	0.1	0.0018
H1	15	**'CPCe'**	'CPCeC'	244800	1516.8	27.25	0.0121	0.015	0.15	0.1	0.4	2.43	0.114	0.0017
H1	15	**'WSa'**	'MFCMR04'	125000	454.4	40	0.08	0.015	0.15	0.1	0.4	3	0.1	0.0018
H1	15	**'21S'**	'MFCMR05'	160000	409.6	40.5	0.0607	0.015	0.15	0.1	0.4	3	0.1	0.0018
H1	15	**'VMa'**	'MFCMR05'	102400	204.8	2.25	0.0471	0.015	0.15	0.1	0.4	3	0.1	0.0018
H1	15	**'WSb'**	'MFCMR05'	64000	601.6	40	0.0593	0.015	0.15	0.1	0.4	3	0.1	0.0018
H1	15	**'19S'**	'19SC'	232400	320	37.5	0.09	0.015	0.15	0.1	0.4	3	0.1	0.0018
H1	13	**'VMb'**	'MFCMR06'	96000	204.8	37.5	0.0941	0.015	0.15	0.1	0.4	3	0.1	0.0018
H1	13	**'WSc'**	'MFCMR06'	64000	320	40	0.0633	0.015	0.15	0.1	0.4	3	0.1	0.0018
H1	1	**'MCa'**	'UMCMR01'	15000	1190.4	0	0.076	0.015	0.8	0.1	0.4	3	0.1	0.0018
H1	1	**'MCb'**	'UMCMR01'	15400	928	0	0.152	0.015	0.8	0.1	0.4	3	0.1	0.0018
H1	1	**'MCc'**	'UMCMR02'	33400	2124.8	0	0.144	0.015	0.8	0.1	0.4	3.01	0.1	0.0018
H1	7	**'MCd'**	'UMCMR03'	9800	435.2	15.6	0.302	0.015	0.35	0.1	0.4	4.46	0.12	0.0018
H1	1	'NMCa'	'NMCaC'	27000	2976	0	0.079	0.015	0.8	0.1	0.4	3.04	0.1	0.0018
H1	1	'NMCb'	'NMCbC'	11000	819.2	0	0.28	0.015	0.8	0.1	0.4	3	0.1	0.0018
H1	1	'NMCc'	'NMCcC'	15400	1427.2	0	0.222	0.015	0.8	0.1	0.4	3	0.1	0.0018
H1	1	'NMCd'	'NMCdC'	6200	377.6	0	0.261	0.015	0.8	0.1	0.4	3	0.1	0.0018
H1	7	'NMCe'	'NMCeC'	13400	441.6	10	0.38	0.015	0.35	0.1	0.4	3	0.1	0.0018
H1	1	'ICCa'	'ICCbC'	33400	2707.2	0	0.152	0.015	0.8	0.1	0.4	3.02	0.1	0.0018
H1	1	'ICCb'	'ICCbC'	20000	1433.6	0	0.211	0.015	0.8	0.1	0.4	3	0.1	0.0018
H1	7	'RMa'	'UMCMR04'	7800	627.2	1.8	0.104	0.015	0.35	0.1	0.4	4.4	0.118	0.0018
H1	7	'PLa'	'UMCMR04'	3100	195.4	0	0.194	0.015	0.35	0.1	0.4	4.5	0.12	0.0018
H1	7	'PLb'	'UMCMR05'	15400	1555.2	5.00	0.051	0.015	0.35	0.1	0.4	4.43	0.12	0.0018
H1	7	'RMb'	'UMCMR05'	7600	684.8	2.4	0.157	0.015	0.35	0.1	0.4	4.42	0.12	0.0018
H1	7	'PLc'	'UMCMR06'	9000	1216	2.99	0.074	0.015	0.35	0.1	0.4	4.4	0.118	0.0018
H1	7	'RMc'	'UMCMR06'	3200	230.8	0	0.058	0.015	0.35	0.1	0.4	4.5	0.12	0.0018

Table 1 (continued): Listing of SWMM RUNOFF sub-basin surface parameters for current development conditions. Sub-basins with names in **bold** type are located partially or wholly within the City of Colorado Springs. Explanations of data fields listed here are given in **Section 4** of this report.

	Hydrograph	Name	Hydraulic Load Pt	Width (ft)	Area (ac)	% Imp	Slope (ft/ft)	Imp n	Pv n	Imp D St (in)	Pv D St (in)	Max Inf (in/hr)	Min Inf (in/hr)	Inf Decay (s^{-1})
H1	7	'DWCa'	'DWCcC'	5200	742.4	5	0.062	0.015	0.35	0.1	0.4	4.35	0.118	0.0018
H1	7	'DWCb'	'DWCcC'	12800	1331.2	2.29	0.05	0.015	0.35	0.1	0.4	4.41	0.118	0.0018
H1	7	'DWCc'	'DWCcC'	11400	499.2	6.43	0.007	0.015	0.35	0.1	0.4	4.35	0.118	0.0018
H1	7	'DWCd'	'DWCdC'	7800	755.2	15.1	0.031	0.015	0.35	0.1	0.4	4.45	0.12	0.0018
H1	7	'MRa'	'UMCMR07'	3900	332.2	0	0.041	0.015	0.35	0.1	0.4	4.43	0.12	0.0018
H1	7	'MRb'	'MRaC'	25200	1075.2	0	0.122	0.015	0.35	0.1	0.4	4.24	0.116	0.0018
H1	7	'MRc'	'MRaC'	31000	900	0.52	0.197	0.015	0.35	0.1	0.4	2.93	0.112	0.0018
H1	7	'MRd'	'MRaC'	5800	204.8	0	0.080	0.015	0.35	0.1	0.4	4.5	0.12	0.0018
H1	7	'MRDWC	'UMCMR08'	12400	313.6	1.76	0.062	0.015	0.35	0.1	0.4	4.22	0.116	0.0018
H1	7	'TCa'	'UMCMR09'	25200	1440	3.76	0.043	0.015	0.35	0.1	0.4	4.42	0.118	0.0018
H1	7	'TCb'	'UMCMR09'	5200	281.6	0	0.031	0.015	0.35	0.1	0.4	4.5	0.12	0.0018
H1	7	'BCa'	'BCaC'	19400	659.2	0	0.122	0.015	0.35	0.1	0.4	4.47	0.12	0.0018
H1	7	'BCb'	'UMCMR09'	5200	492.8	0	0.047	0.015	0.35	0.1	0.4	4.38	0.118	0.0018
H1	17	'HCa'	'HCbC'	25200	870.4	0	0.145	0.015	0.6	0.1	0.4	3	0.1	0.0018
H1	7	'HCb'	'HCbC'	25400	934.4	0	0.244	0.015	0.35	0.1	0.4	4.01	0.114	0.0018
H1	7	'HCc'	'HCaC'	20600	281.6	0	0.184	0.015	0.35	0.1	0.4	4.5	0.12	0.0018
H1	17	'HCd'	'HCaC'	15000	384	0	0.143	0.015	0.35	0.1	0.4	4.5	0.12	0.0018
H1	1	'NBCa'	'NBCbC'	15000	825.6	0	0.172	0.015	0.6	0.1	0.4	3	0.1	0.0018
H1	1	'NBCb'	'NBCbC'	7000	396.8	0	0.184	0.015	0.6	0.1	0.4	3	0.1	0.0018
H1	1	'NBCc'	'NBCbC'	5200	492.8	0	0.423	0.015	0.6	0.1	0.4	3	0.1	0.0018
H1	7	'NBCd'	'NBCbC'	25600	665.6	0	0.342	0.015	0.35	0.1	0.4	3.74	0.114	0.0018
H1	1	'SBCa'	'SBCbC'	25400	3206.4	0	0.042	0.015	0.6	0.1	0.4	3.2	0.102	0.0018
H1	1	'SBCb'	'SBCbC'	12800	925.6	0	0.113	0.015	0.6	0.1	0.4	3	0.1	0.0018
H1	1	'SBCc'	'SBCcC'	12800	409.6	0	0.183	0.015	0.6	0.1	0.4	3	0.1	0.0018
H1	1	'SBCd'	'SBCdC'	10400	1696.8	0	0.137	0.015	0.6	0.1	0.4	3	0.1	0.0018
H1	1	'SBCe'	'SBCeC'	10400	582.4	0	0.283	0.015	0.6	0.1	0.4	3	0.1	0.0018
H1	7	'SBCf'	'SBCfC'	22600	1171.2	0	0.227	0.015	0.35	0.1	0.4	3.42	0.116	0.0018
H1	1	'ECa'	'ECbC'	5200	793.6	0	0.092	0.015	0.6	0.1	0.4	3	0.1	0.0018
H1	1	'ECb'	'ECbC'	10400	1024	0	0.149	0.015	0.6	0.1	0.4	3	0.1	0.0018
H1	1	'ECc'	'ECaC'	15400	672.2	0	0.162	0.015	0.6	0.1	0.4	3	0.1	0.0018
H1	1	'ECd'	'ECaC'	6200	300.8	0	0.186	0.015	0.6	0.1	0.4	3	0.1	0.0018
H1	5	'JCa'	'JCbC'	15000	1325.2	0	0.082	0.015	0.35	0.1	0.4	4.23	0.116	0.0018
H1	7	'JCb'	'JCbC'	11400	896	0	0.046	0.015	0.35	0.1	0.4	4.5	0.12	0.0018
H1	7	'JCc'	'JCcC'	10400	925.6	0	0.023	0.015	0.35	0.1	0.4	4.5	0.12	0.0018
H1	17	'BCc'	'MMCMR01'	2500	249.6	0	0.102	0.015	0.35	0.1	0.4	4.52	0.124	0.0018
H1	18	'JCd'	'MMCMR02'	2500	153.6	0	0.029	0.015	0.35	0.1	0.4	4.5	0.12	0.0018
H1	17	'JVa'	'JVbC'	23600	1190.4	0	0.122	0.015	0.35	0.1	0.4	4.38	0.118	0.0018
H1	17	'JVb'	'JVbC'	15400	697.6	0	0.09	0.015	0.35	0.1	0.4	4.5	0.12	0.0018
H1	5	'BFa'	'BFbC'	12800	896	4.33	0.074	0.015	0.35	0.1	0.4	4.5	0.12	0.0018
H1	18	'BFb'	'BFbC'	7800	384	7.2	0.054	0.015	0.35	0.1	0.4	4.19	0.116	0.0018
H1	18	'BFc'	'BFcC'	10400	332.8	0	0.046	0.015	0.35	0.1	0.4	4.5	0.12	0.0018
H1	18	'BFd'	'MMCMR04'	12800	396.8	2.85	0.027	0.015	0.35	0.1	0.4	4.5	0.12	0.0018
H1	18	'BFe'	'MMCMR05'	3800	486.4	7.95	0.034	0.015	0.35	0.1	0.4	4.5	0.12	0.0018
H1	17	'DMa'	'DMbC'	7700	742.4	0	0.292	0.015	0.6	0.1	0.4	3.08	0.102	0.0018
H1	17	'DMb'	'DMbC'	25800	1705.2	5.13	0.14	0.015	0.35	0.1	0.4	4.09	0.114	0.0018
H1	17	'DMc'	'DMaC'	15000	615.4	0	0.094	0.015	0.35	0.1	0.4	4.37	0.118	0.0018
H1	17	'DMd'	'DMaC'	11800	355.4	0	0.197	0.015	0.35	0.1	0.4	4.56	0.13	0.0017
H1	17	'JVc'	'MMCMR04'	3900	704	0	0.100	0.015	0.35	0.1	0.4	4.52	0.124	0.0017
H1	5	'SCa'	'SCbC'	20500	2086.4	3.02	0.087	0.015	0.35	0.1	0.4	4.47	0.12	0.0018
H1	5	'SCb'	'SCbC'	11400	608	4.4	0.091	0.015	0.35	0.1	0.4	4.5	0.12	0.0018
H1	18	'SCc'	'SCcC'	20900	800	1.37	0.076	0.015	0.35	0.1	0.4	4.5	0.12	0.0018
H1	18	'MBa'	'MBbC'	20500	1006.4	0	0.087	0.015	0.35	0.1	0.4	4.5	0.12	0.0018
H1	18	'MBb'	'MBbC'	12800	851.2	0	0.035	0.015	0.35	0.1	0.4	4.5	0.12	0.0018
H1	17	'DMe'	'MMCMR06'	23200	985.6	0	0.082	0.015	0.35	0.1	0.4	4.51	0.12	0.0018
H1	18	'MBc'	'MMCMR07'	25800	940.8	0	0.047	0.015	0.35	0.1	0.4	4.5	0.12	0.0018
H1	17	'LRa'	'LRbC'	9000	720.8	0	0.27	0.015	0.35	0.1	0.4	3.15	0.102	0.0018
H1	17	'LRb'	'LRbC'	34000	1792	2.49	0.085	0.015	0.35	0.1	0.4	4.28	0.118	0.0018
H1	17	'LRc'	'LRcC'	14200	460.8	12.8	0.062	0.015	0.35	0.1	0.4	4.52	0.122	0.0018
H1	17	'LRd'	'MMCMR08'	3000	179.2	16.4	0.0377	0.015	0.35	0.1	0.4	4.5	0.12	0.0018
H1	17	'DVa'	'MMCMR10'	32000	1900.8	2.36	0.082	0.015	0.35	0.1	0.4	4.57	0.122	0.0018
H1	17	'DVb'	'MMCMR11'	20000	745.2	10.27	0.0765	0.015	0.35	0.1	0.4	4.5	0.12	0.0018
H1	17	'DVc'	'MMCMR12'	24000	691.2	7.95	0.0321	0.015	0.35	0.1	0.4	4.5	0.12	0.0018
H1	1	'WMCRR	'WMCaC'	24000	3555.4	0	0.1509	0.015	0.6	0.1	0.4	3.21	0.102	0.0018
H1	1	'WMCa'	'WMCaC'	7200	1056	0	0.2114	0.015	0.6	0.1	0.4	3	0.1	0.0018
H1	1	'WMCb'	'WMCaC'	4000	364.8	0	0.1208	0.015	0.6	0.1	0.4	3	0.1	0.0018
H1	1	'WMCc'	'WMCcC'	8000	1132.8	0	0.5774	0.015	0.6	0.1	0.4	3.14	0.102	0.0018
H1	1	'WMCd'	'WMCcC'	6000	1465.6	0	0.1509	0.015	0.6	0.1	0.4	3	0.1	0.0018
H1	17	'WMCe'	'WMCeC'	5000	697.6	0	0.4622	0.015	0.6	0.1	0.4	3.12	0.102	0.0018
H1	1	'WMCf'	'WMCeC'	12000	2022.4	0	0.4622	0.015	0.6	0.1	0.4	3	0.1	0.0018
H1	17	'WMCg'	'WMCfC'	44000	2304	0	0.0765	0.015	0.6	0.1	0.4	3.19	0.102	0.0018

Table 1 (continued): Listing of SWMM RUNOFF sub-basin surface parameters for current development conditions. Sub-basins with names in **bold** type are located partially or wholly within the City of Colorado Springs. Explanations of data fields listed here are given in **Section 4** of this report.

	Hyeto-graph	Name	Hydraulic Load Pt	Width (ft)	Area (ac)	% Imp	Slope (ft/ft)	Imp n	Pv n	Imp D St (in)	Pv D St (in)	Max Inf (in/hr)	Min Inf (in/hr)	Inf Decay (s⁻¹)
H1	17	'WMCh'	'WMCnC'	4800	256	0	0.1132	0.015	0.35	0.1	0.4	4.5	0.12	0.0018
H1	17	'WMCi'	'WMCnC'	3200	475.6	0	0.0900	0.015	0.35	0.1	0.4	4.02	0.114	0.0018
H1	17	'WMCj'	'WMCjC'	25000	1792	2.49	0.0377	0.015	0.35	0.1	0.4	3.92	0.112	0.0018
H1	5	'BSCa'	'BSCcC'	20000	1056	0	0.0604	0.015	0.35	0.1	0.4	4.5	0.12	0.0018
H1	5	'BSCb'	'BSCcC'	52000	972.8	0	0.0604	0.015	0.35	0.1	0.4	4.5	0.12	0.0018
H1	5	'BSCc	'BSCcC	4800	249.6	0	0.0226	0.015	0.35	0.1	0.4	4.5	0.12	0.0018
H1	4	'BSCd'	'BSCeC'	17000	2956.8	0	0.0453	0.015	0.35	0.1	0.4	4.5	0.12	0.0018
H1	4	'BSCe'	'BSCeC'	22000	1177.6	0	0.0579	0.015	0.15	0.1	0.4	4.5	0.12	0.0018
H1	18	'BSCf'	'BSCfC	20400	697.6	0	0.0302	0.015	0.15	0.1	0.4	4.5	0.12	0.0018
H1	18	'ELK'	'MMCMR10'	24000	1755.6	0	0.0204	0.015	0.15	0.1	0.4	4.82	0.172	0.0011
H1	4	'KCa'	'KCbC'	34000	4475.6	2.44	0.0453	0.015	0.35	0.1	0.4	4.5	0.12	0.0018
H1	4	'KCb'	'KCbC'	15400	3296	2.72	0.0377	0.015	0.35	0.1	0.4	4.5	0.12	0.0018
H1	4	'KCc'	'KCcC'	16000	1952	0	0.0377	0.015	0.15	0.1	0.4	4.5	0.12	0.0018
H1	18	**'KCd'**	'KCdC'	512000	710.4	11.1	0.0755	0.015	0.15	0.1	0.4	4.7	0.152	0.0014
H1	18	**'KCe'**	'KCeC'	20000	652.8	4.2	0.0264	0.015	0.15	0.1	0.4	4.88	0.18	0.001
H1	18	**'KCf'**	'MMCMR12'	6000	800	14.85	0.0189	0.015	0.15	0.1	0.4	4.93	0.182	0.0009
H1	18	'KCg'	'LMCMR02'	25000	675.4	4.05	0.0204	0.015	0.15	0.1	0.4	4.83	0.172	0.0011
H1	17	'DRYa'	'LMCMR02'	25000	1414.4	0	0.0755	0.015	0.15	0.1	0.4	3.83	0.114	0.0017
H1	17	**'DRYb'**	'LMCMR04	1792000	2220.8	1.05	0.0679	0.015	0.15	0.1	0.4	4.49	0.124	0.0017
H1	4	'PCa'	'PCbC	32000	1926.4	0	0.0604	0.015	0.15	0.1	0.4	4.02	0.144	0.0015
H1	18	'PCb'	'PCbC	12000	844.8	0	0.0453	0.015	0.15	0.1	0.4	4.74	0.188	0.0008
H1	4	**'PCc'**	'PCdC	1024000	2323.2	30.92	0.0604	0.015	0.15	0.1	0.4	4.96	0.194	0.0008
H1	18	**'PCd'**	'PCdC	384000	1088	31.00	0.0321	0.015	0.15	0.1	0.4	4.49	0.14	0.0015
H1	4	'CCa'	'CCcC'	20000	2163.2	1.1	0.0358	0.015	0.35	0.1	0.4	4.5	0.12	0.0018
H1	4	'CCb'	'CCcC'	6800	2301.6	0	0.0302	0.015	0.15	0.1	0.4	4.54	0.128	0.0017
H1	4	'CCc	'CCcC	13000	3116.8	0	0.0302	0.015	0.15	0.1	0.4	4.37	0.13	0.0015
H1	4	'CCd'	'CCeC'	13000	1971.2	0	0.0284	0.015	0.15	0.1	0.4	4.79	0.166	0.0012
H1	18	**'CCe'**	'CCeC'	537600	774.4	40	0.0377	0.015	0.15	0.1	0.4	4.31	0.132	0.0016
H1	18	**'CCf'**	'CCfC	426400	1344	40	0.0528	0.015	0.15	0.1	0.4	4.82	0.18	0.001
H1	14	**'CCg'**	'CCfC	172800	153.6	40	0.0755	0.015	0.15	0.1	0.4	4.40	0.150	0.0014
H1	14	**'CCPR'**	'CCPRC'	409000	736	14	0.0604	0.015	0.15	0.1	0.4	3.03	0.124	0.0016
H1	13	**'NR'**	'LMCMR05	296000	1408	4.74	0.0453	0.015	0.15	0.1	0.4	3.7	0.120	0.0015
H1	13	**'SRPBF'**	'LMCMR06	296000	1225.8	4.01	0.0906	0.015	0.15	0.1	0.4	3.2	0.102	0.0017
H1	15	'DGCa	'DGCbC'	25000	2086.4	0.18	0.1132	0.015	0.15	0.1	0.4	3.7	0.12	0.0016
H1	15	**'DGCb'**	'DGCbC'	384000	1011.2	1.47	0.1509	0.015	0.15	0.1	0.4	4.09	0.138	0.0014
H1	15	**'DGCc'**	'DGCcC'	179200	624.8	0.8	0.0396	0.015	0.15	0.1	0.4	4.37	0.134	0.0016
H1	13	**'DGCd'**	'LMCMR07	256000	774.4	42.75	0.0302	0.015	0.15	0.1	0.4	4.42	0.142	0.0014
H1	15	'DGCe'	'DGCfC'	8800	1004.8	0	0.0943	0.015	0.15	0.1	0.4	3.82	0.128	0.0016
H1	15	**'DGCf'**	'DGCfC'	256000	995.4	2.48	0.1585	0.015	0.15	0.1	0.4	3.99	0.13	0.0016
H1	14	**'TGa'**	'LMCMR07	335400	1065.8	5.90	0.0528	0.015	0.15	0.1	0.4	3.37	0.114	0.0017
H1	10	**'TGb'**	'TGdC	512000	1529.6	29.23	0.0453	0.015	0.15	0.1	0.4	4.05	0.122	0.0017
H1	14	**'TGc'**	'TGeC	384000	716.8	29.6	0.0453	0.015	0.15	0.1	0.4	4.04	0.182	0.0009
H1	14	**'TGd'**	'TGeC	691200	1331.2	40	0.0226	0.015	0.15	0.1	0.4	4.08	0.132	0.0015
H1	14	**'TGe'**	'TGfC'	256000	1184	27.51	0.0900	0.015	0.15	0.1	0.4	4.10	0.15	0.0013
H1	14	**'TGf'**	'TGfC'	115200	035.6	4.8	0.1094	0.015	0.15	0.1	0.4	3.88	0.122	0.0017
H1	14	**'TGg'**	'TGgC'	125000	569.6	45.9	0.0302	0.015	0.15	0.1	0.4	3.92	0.114	0.0018
H1	14	**'ROSa'**	'LMCMR08	256000	262.4	70	0.0377	0.015	0.15	0.1	0.4	3.74	0.122	0.0016
H1	14	**'ROSPAP'**	'LMCMR08	335400	2035.2	43.87	0.0208	0.015	0.15	0.1	0.4	4.73	0.166	0.0013
H1	13	**'MESa'**	'LMCMR09	96000	384	11.6	0.0943	0.015	0.15	0.1	0.4	3.36	0.104	0.0018
H1	13	**'MESb'**	'LMCMR10'	320000	355.4	27.6	0.0755	0.015	0.15	0.1	0.4	3.75	0.11	0.0018
H1	15	**'MESc'**	'LMCMR11'	1152000	1420.8	3.10	0.2228	0.015	0.15	0.1	0.4	3.59	0.108	0.0018
H1	13	**'MESd'**	'LMCMR11'	256000	537.6	40	0.0900	0.015	0.15	0.1	0.4	3.57	0.108	0.0018
H1	11	**'MVPa'**	'LMCMR10'	125000	172.8	40	0.0302	0.015	0.15	0.1	0.4	4.04	0.14	0.0014
H1	3	**'MVPb'**	'LMCMR11'	320000	307.2	40	0.0377	0.015	0.15	0.1	0.4	4.32	0.152	0.0013
H1	19	'BRCa'	'BRCbC'	55200	4396.8	0	0.1429	0.015	0.5	0.1	0.4	3	0.1	0.0018
H1	19	**'BRCb'**	'BRCbC'	25000	1971.2	12	0.0571	0.015	0.15	0.1	0.4	3	0.1	0.0018
H1	12	**'BRCc'**	'BRCdC	51200	524.8	15	0.0727	0.015	0.15	0.1	0.4	3	0.1	0.0018
H1	13	**'BRCd'**	'BRCdC	59500	147.2	55	0.025	0.015	0.15	0.1	0.4	3	0.1	0.0018
H1	16	**'SRa'**	'SRbC'	192000	812.8	32.55	0.025	0.015	0.15	0.1	0.4	4.9	0.184	0.0008
H1	16	**'SRb'**	'SRbC	211200	720.8	35.5	0.025	0.015	0.15	0.1	0.4	4.5	0.12	0.0018
H1	11	**'SRc'**	'SRdC	224000	761.6	40	0.025	0.015	0.15	0.1	0.4	4.55	0.128	0.0017
H1	16	**'SRd'**	'SRdC'	320000	1254.4	40	0.025	0.015	0.15	0.1	0.4	4.5	0.12	0.0018
H1	3	**'SRe'**	'SRdC'	172800	396.8	39.3	0.025	0.015	0.15	0.1	0.4	5	0.2	0.0007
H1	16	**'SRf'**	'SRfC'	192000	691.2	39.5	0.025	0.015	0.15	0.1	0.4	4.65	0.128	0.0017
H1	3	**'SRg'**	'SRfC'	125000	652.8	67	0.025	0.015	0.15	0.1	0.4	5	0.2	0.0007
H1	19	'SWa'	'SWbC	53000	5811.2	0	0.1840	0.015	0.5	0.1	0.4	3	0.1	0.0018
H1	19	'SWb	'SWbC	20000	1222.4	0	0.44	0.015	0.5	0.1	0.4	3	0.1	0.0018
H1	19	'SWc'	'SWdC	35000	5955.4	0	0.2222	0.015	0.5	0.1	0.4	3	0.1	0.0018
H1	19	'SWd	'SWdC	12000	565.2	0	0.4	0.015	0.5	0.1	0.4	3	0.1	0.0018
H1	12	**'SWe'**	'SWeC	256000	2425.2	5.4	0.0867	0.015	0.15	0.1	0.4	3	0.1	0.0018

Table 1 (continued): Listing of SWMM RUNOFF sub-basin surface parameters for current development conditions. Sub-basins with names in **bold** type are located partially or wholly within the City of Colorado Springs. Explanations of data fields listed here are given in **Section 4** of this report.

	Hyeto-graph	Name	Hydraulic Load Pt	Width (ft)	Area (ac)	% Imp	Slope (ft/ft)	Imp n	Pv n	Imp D St (in)	Pv D St (in)	Max Inf (in/hr)	Min Inf (in/hr)	Inf Decay (s⁻¹)
H1	12	**'SWF'**	'LFCMR03	1405000	2066	35.1	0.05	0.015	0.15	0.1	0.4	3	0.1	0.0018
H1	16	**'SPCa'**	'SPCbC'	256000	921.6	65.5	0.025	0.015	0.15	0.1	0.4	5	0.2	0.0007
H1	16	**'SPCb'**	'SPCbC'	204800	745.6	41.5	0.025	0.015	0.15	0.1	0.4	5	0.2	0.0007
H1	16	**'SPCc'**	'SPCbC'	384000	992	40.05	0.025	0.015	0.15	0.1	0.4	4.42	0.128	0.0017
H1	16	**'SPCd'**	'SPCdC'	125000	331.2	37	0.025	0.015	0.15	0.1	0.4	4.25	0.14	0.0012
H1	16	**'SPCe'**	'SPCdC'	153600	339.2	40	0.025	0.015	0.15	0.1	0.4	4.5	0.12	0.0018
H1	16	**'SPCf'**	'SPCfC	153600	902.4	20.5	0.025	0.015	0.15	0.1	0.4	4.55	0.128	0.0017
H1	16	**'SPCg'**	'LFCMR03'	125000	339.2	49.5	0.025	0.015	0.15	0.1	0.4	4.62	0.124	0.0017
H1	12	**'FHC'**	'LFCMR04b	704300	1604	32.7	0.025	0.015	0.15	0.1	0.4	3	0.1	0.0018
H1	16	**'MSC'**	'LFCMR04b'	160000	800	22	0.025	0.015	0.15	0.1	0.4	3	0.1	0.0018
H1	4	'SDCEa'	'SDCEbC'	27000	5404	0	0.024	0.015	0.35	0.1	0.4	5	0.2	0.0007
H1	4	'SDCEb'	'SDCEbC	25400	2524	0	0.0314	0.015	0.35	0.1	0.4	5	0.2	0.0007
H1	4	'SDCEc'	'SDCEdC'	25750	4352	0	0.0281	0.015	0.35	0.1	0.4	5	0.2	0.0007
H1	4	**'SDCEd'**	'SDCEdC'	1645000	4100	25	0.0291	0.015	0.15	0.1	0.4	5	0.2	0.0007
H1	10	**'SDCWa'**	'SDCWbC'	1235200	8900	1.5	0.02	0.015	0.15	0.1	0.4	5	0.2	0.0007
H1	16	**'SDCWb'**	'SDCWbC'	1005800	4800	50	0.0287	0.015	0.15	0.1	0.4	5	0.2	0.0007
H1	4	**'SDCSa'**	'SDCSaC'	9000	3200	7	0.0124	0.015	0.15	0.1	0.4	5	0.2	0.0007
H1	4	**'SDCSb'**	'SDCSbC'	570000	3520	57.3	0.0109	0.015	0.15	0.1	0.4	5	0.2	0.0007
H1	12	**'CMSH'**	'LFCMR06'	325000	1280	30	0.039	0.015	0.15	0.1	0.4	3	0.1	0.0018
H1	8	'LBa'	'LFCMR06'	10250	1024	10	0.0246	0.015	0.35	0.1	0.4	5	0.2	0.0007
H1	12	**'RBa'**	'LFCMR06'	9000	640	35	0.0357	0.015	0.15	0.1	0.4	3	0.1	0.0018
H1	9	'FCMRa'	'LFCMR07'	35000	2560	25	0.0321	0.015	0.35	0.1	0.4	3	0.1	0.0018
H1	8	'LBb'	'LFCMR07'	36000	3264	30	0.0208	0.015	0.35	0.1	0.4	5	0.2	0.0007
H1	8	'RBb'	'LFCMR07'	10250	768	0	0.0235	0.015	0.35	0.1	0.4	3	0.1	0.0018
H1	9	'FCMRb'	'FCMRout'	41000	3520	10	0.0140	0.015	0.35	0.1	0.4	3	0.1	0.0018

Table 2: Details and results of Strahler ordering scheme applied to RUNOFF stream channels shown in **Appendix A, Figures 1** and **3a** through **3f**. A discussion of the Strahler ordering scheme for stream channels is given in **Section 4** of this report.

Assigned Strahler order	# of channels	Total length (ft)	Initial width (ft)	Final width range (ft)	Initial depth (ft)	Final depth range (ft)
1	83	730974	5	5-20	5	5-20
2	23	174246	10	10-20	10	10-20
3	29	128125	20	20-40	20	20-40
4	8	46429	40	40	40	40
Total	**143**	**1079747**	---	---	---	---

Table 3: Listing of SWMM RUNOFF channel parameters for current development conditions. Explanations of data fields listed here are given in **Section 4** of this report.

	Name	Hydraulic Load Pt	Type	Width (ft)	Length (ft)	Slope (ft/ft)	L slope (ft/ft)	R slope (ft/ft)	Manning N	Depth (ft)	Init Dpth (ft)
G1	'UFCMR01'	'UFCMR02	1	10	2205	0.030	1	1	0.16	10	0
G1	'CTCbC'	'UFCMR02'	1	5	12916	0.1114	1	1	0.17	5	0
G1	'UFCMR02'	'UFCMR03'	1	10	4705	0.0212	1	1	0.16	10	0
G1	'CLCC'	'UFCMR03'	1	5	5833	0.2005	1	1	0.17	5	0
G1	'UFCMR03'	'UFCMR04	1	10	7003	0.0214	1	1	0.17	10	0
G1	'UFCMR04'	'UFCMR05	1	10	2583	0.0155	1	1	0.16	10	0
G1	'UFCMR05'	'UFCMR06	1	20	9024	0.0176	1	1	0.165	10	0
G1	'SVCbC'	'SVCdC	1	5	2917	0.0969	1	1	0.17	5	0
G1	'SVCdC'	'UFCMR06	1	5	4792	0.217	1	1	0.17	5	0
G1	'UFCMR06'	'UFCMR07	1	20	3875	0.0252	1	1	0.165	10	0
G1	'FRCaC'	'FRCcC'	1	5	5875	0.069	1	1	0.17	5	0
G1	'FRCcC'	'UFCMR07	1	5	4166	0.23	1	1	0.17	5	0
G1	'UFCMR07'	'UFCMR05	1	20	9292	0.043	1	1	0.165	10	0
G1	'UFCMR08'	'MFCMR01'	1	20	7792	0.0513	1	1	0.165	10	0
G1	'ECbC'	'ECdC'	1	5	10065	0.1124	1	1	0.17	5	0
G1	'ECcC'	'ECdC'	1	10	5205	0.0537	1	1	0.17	5	0
G1	'ECdC'	'MFCMR01'	1	10	15282	0.1510	1	1	0.17	10	0
G1	'WCC'	'MFCMR01'	1	5	15414	0.0522	1	1	0.17	5	0
G1	'MFCMR01'	'MFCMR02	1	20	5542	0.0306	1	1	0.175	20	0
G1	'MFCMR02'	'MFCMR03	1	20	3000	0.026	1	1	0.17	20	0
G1	'MFCMR03'	'MFCMR04	1	20	3875	0.0206	1	1	0.165	20	0
G1	'CPCcC'	'CPCdC'	1	10	12024	0.0728	1	1	0.16	10	0
G1	'CPCdC'	'CPCeC'	1	10	11457	0.0592	1	1	0.16	10	0
G1	'CPCeC'	'MFCMR04'	1	20	13900	0.0229	1	1	0.16	10	0
G1	'MFCMR04'	'MFCMR05'	1	20	5833	0.0137	1	1	0.165	30	0
G1	'MFCMR05'	'MFCMR06	1	20	3205	0.0214	1	1	0.16	30	0
G1	'19SC'	'MFCMR06	1	10	5205	0.0307	1	1	0.16	5	0
G1	'MFCMR06'	'LFCMR01'	1	20	4067	0.0128	1	1	0.15	30	0
G1	'UMCMR01'	'UMCMR02	1	5	7700	0.0259	1	1	0.17	5	0
G1	'UMCMR02'	'UMCMR03	1	5	18000	0.0506	1	1	0.17	5	0
G1	'UMCMR03'	'UMCMR04	1	5	5400	0.0701	1	1	0.17	5	0
G1	'NMCbC'	'NMCcC'	1	5	7100	0.0502	1	1	0.17	5	0
G1	'NMCcC'	'NMCdC	1	5	7700	0.057	1	1	0.17	5	0
G1	'NMCdC'	'NMCeC	1	5	3900	0.0414	1	1	0.17	5	0
G1	'ICCbC'	'NMCeC'	1	5	11000	0.0921	1	1	0.17	5	0
G1	'NMCeC'	'UMCMR04'	1	10	5800	0.0712	1	1	0.17	10	0
G1	'UMCMR04'	'UMCMR05	1	10	3900	0.0181	1	1	0.16	10	0
G1	'UMCMR05'	'UMCMR06	1	20	7100	0.0127	1	1	0.16	10	0
G1	'UMCMR06'	'UMCMR07'	1	20	7700	0.0104	1	1	0.16	10	0
G1	'DWCcC'	'DWCdC	1	10	5400	0.0249	1	1	0.16	5	0
G1	'DWCdC'	'UMCMR07	1	10	7200	0.018	1	1	0.16	10	0
G1	'UMCMR07'	'UMCMR05	1	20	3900	0.0072	1	1	0.16	20	0
G1	'MRdC'	'UMCMR05	1	10	5400	0.0407	1	1	0.17	10	0
G1	'UMCMR08'	'UMCMR09	1	20	5700	0.0082	1	1	0.16	20	0
G1	'UMCMR09'	'MMCMR01'	1	20	6700	0.0075	1	1	0.16	20	0
G1	'NBCcC'	'NBCdC'	1	5	5200	0.0854	1	1	0.17	5	0
G1	'NBCdC'	'BCaC'	1	5	10800	0.0925	1	1	0.17	5	0
G1	'SBCbC'	'SBCcC'	1	5	5700	0.0312	1	1	0.17	5	0
G1	'EGbC'	'EGdC'	1	5	5700	0.0177	1	1	0.17	5	0
G1	'EGdC'	'SBCcC'	1	5	5200	0.0117	1	1	0.17	5	0
G1	'SBCcC'	'SBCdC	1	10	4500	0.0444	1	1	0.17	10	0
G1	'SBCdC'	'SBCeC	1	10	5200	0.033	1	1	0.17	10	0
G1	'SBCeC'	'SBCfC'	1	10	5800	0.0539	1	1	0.17	10	0
G1	'SBCfC'	'BCaC'	1	10	10300	0.1049	1	1	0.16	10	0
G1	'BCaC'	'BCcC'	1	10	12400	0.0172	1	1	0.16	15	0
G1	'HCbC'	'HCdC	1	10	15700	0.107	1	1	0.17	10	0
G1	'HCdC'	'BCcC'	1	10	4400	0.5003	1	1	0.17	5	0
G1	'BCbC'	'MMCMR01'	1	10	800	0.0512	1	1	0.16	15	0
G1	'MMCMR01'	'MMCMR02'	1	20	4000	0.0151	1	1	0.15	20	0
G1	'JCbC'	'JCcC'	1	10	9700	0.0209	1	1	0.16	5	0
G1	'JCcC'	'MMCMR02'	1	10	5200	0.0194	1	1	0.16	10	0
G1	'MMCMR02'	'MMCMR03'	1	20	2100	0.0049	1	1	0.15	20	0
G1	'JVbC'	'MMCMR03'	1	10	7700	0.0311	1	1	0.16	10	0
G1	'MMCMR03'	'MMCMR04'	1	20	1900	0.0104	1	1	0.15	20	0
G1	'BFbC'	'BFcC	1	5	4000	0.0324	1	1	0.16	5	0

Table 3 (continued): Listing of SWMM RUNOFF channel parameters for current development conditions. Explanations of data fields listed here are given in **Section 4** of this report.

	Name	Hydraulic Load Pt	Type	Width (ft)	Length (ft)	Slope (ft/ft)	L slope (ft/ft)	R slope (ft/ft)	Manning N	Depth (ft)	Init Dpth (ft)
G1	'BFcC'	'MMCMR04'	1	10	5200	0.0291	1	1	0.16	5	0
G1	'MMCMR04'	'MMCMR05'	1	20	4000	0.0008	1	1	0.15	20	0
G1	'MMCMR05'	'MMCMR06'	1	20	5200	0.0078	1	1	0.15	20	0
G1	'DMbC'	'DMdC'	1	10	19700	0.0538	1	1	0.17	10	0
G1	'DMdC'	'MMCMR06'	1	10	10300	0.032	1	1	0.16	10	0
G1	'SCbC'	'SCcC'	1	10	5400	0.0269	1	1	0.16	10	0
G1	'SCcC'	'MMCMR06'	1	10	11000	0.0268	1	1	0.16	10	0
G1	'MMCMR06'	'MMCMR07'	1	40	5200	0.0062	1	1	0.15	20	0
G1	'MBbC'	'MMCMR07'	1	10	5400	0.0222	1	1	0.16	10	0
G1	'MMCMR07'	'MMCMR08'	1	40	5100	0.0078	1	1	0.15	20	0
G1	'LRbC'	'LRcC'	1	10	15400	0.0337	1	1	0.17	10	0
G1	'LRcC'	'MMCMR08'	1	10	7100	0.0254	1	1	0.16	10	0
G1	'MMCMR08'	'MMCMR09'	1	40	2600	0.0099	1	1	0.15	20	0
G1	'BSCcC'	'BSCeC'	1	10	3200	0.025	1	1	0.16	5	0
G1	'BSCeC'	'BSCfC'	1	10	11200	0.0147	1	1	0.16	10	0
G1	'BSCfC'	'MMCMR09'	1	10	10400	0.0226	1	1	0.16	10	0
G1	'MMCMR09'	'MMCMR10'	1	40	4100	0.0073	1	1	0.15	20	0
G1	'MMCMR10'	'MMCMR11'	1	40	3000	0.0083	1	1	0.15	20	0
G1	'MMCMR11'	'MMCMR12'	1	40	4000	0.0076	1	1	0.15	20	0
G1	'MMCMR12'	'LMCMR01'	1	40	4000	0.0075	1	1	0.15	20	0
G1	'WMCaC'	'WMCcC'	1	5	4000	0.02	1	1	0.17	5	0
G1	'WMCcC'	'WMCeC'	1	10	9200	0.0522	1	1	0.17	10	0
G1	'WMCeC'	'WMChC'	1	10	9000	0.1373	1	1	0.17	10	0
G1	'WMChC'	'WMCjC'	1	20	5200	0.0413	1	1	0.17	10	0
G1	'WMCjC'	'LMCMR01'	1	20	12000	0.0254	1	1	0.16	10	0
G1	'LMCMR01'	'LMCMR02'	1	40	3000	0.0009	1	1	0.14	40	0
G1	'KCbC'	'KCcC'	1	10	11000	0.02	1	1	0.16	10	0
G1	'KCcC'	'KCdC'	1	10	9200	0.0206	1	1	0.15	10	0
G1	'KCdC'	'KCeC'	1	10	8000	0.0109	1	1	0.15	10	0
G1	'KCeC'	'LMCMR02'	1	10	10400	0.0183	1	1	0.15	10	0
G1	'LMCMR02'	'LMCMR03'	1	40	8000	0.0106	1	1	0.14	40	0
G1	'PCbC'	'PCdC'	1	10	10000	0.025	1	1	0.15	5	0
G1	'PCdC'	'LMCMR03'	1	10	7500	0.024	1	1	0.15	10	0
G1	'LMCMR03'	'LMCMR04'	1	40	2800	0.0071	1	1	0.14	40	0
G1	'CCbC'	'CCcC'	1	10	10800	0.0231	1	1	0.16	5	0
G1	'CCcC'	'CCeC'	1	10	9200	0.0217	1	1	0.16	10	0
G1	'CCeC'	'CCfC'	1	10	9200	0.0185	1	1	0.16	10	0
G1	'CCfC'	'CCPRC'	1	10	7800	0.0179	1	1	0.15	10	0
G1	'CCPRC'	'LMCMR04'	1	10	9400	0.0234	1	1	0.15	10	0
G1	'LMCMR04'	'LMCMR05'	1	40	2800	0.0071	1	1	0.14	40	0
G1	'LMCMR05'	'LMCMR06'	1	40	4400	0.0045	1	1	0.15	40	0
G1	'LMCMR06'	'LMCMR07'	1	40	3200	0.0125	1	1	0.13	40	0
G1	'LMCMR07'	'LMCMR08'	1	40	4800	0.0083	1	1	0.13	40	0
G1	'DGCbC'	'DGCcC'	1	20	9800	0.0294	1	1	0.16	10	0
G1	'DGCcC'	'LMCMR08'	1	20	12800	0.025	1	1	0.15	10	0
G1	'TGdC'	'TGeC'	1	10	5200	0.0192	1	1	0.14	10	0
G1	'TGeC'	'TGfC'	1	20	3200	0.0150	1	1	0.14	10	0
G1	'TGfC'	'TGgC'	1	20	3800	0.0132	1	1	0.1	10	0
G1	'TGgC'	'LMCMR08'	1	20	9200	0.0103	1	1	0.05	10	0
G1	'LMCMR08'	'LMCMR09'	1	40	2000	0.0077	1	1	0.13	40	0
G1	'DGCfC'	'LMCMR09'	1	10	13200	0.0242	1	1	0.16	10	0
G1	'LMCMR09'	'LMCMR10'	1	40	9000	0.0075	1	1	0.12	40	0
G1	'LMCMR10'	'LMCMR11'	1	40	5000	0.0083	1	1	0.12	40	0
G1	'LMCMR11'	'LFCMR01'	1	40	9200	0.0065	1	1	0.12	40	0
G1	'LFCMR01'	'LFCMR02'	1	40	2205	0.0113	1	1	0.11	40	0
G1	'BRCbC'	'BRCdC'	1	20	19875	0.043	1	1	0.14	10	0
G1	'BRCdC'	'LFCMR02'	1	20	2583	0.002	1	1	0.14	10	0
G1	'LFCMR02'	'LFCMR03'	1	40	5876	0.0136	1	1	0.09	40	0
G1	'SRbC'	'SRdC'	1	10	8642	0.021	1	1	0.09	10	0
G1	'SRdC'	'SRfC'	1	20	4917	0.0071	1	1	0.11	20	0
G1	'SRfC'	'LFCMR03'	1	20	7624	0.0063	1	1	0.1	20	0
G1	'SWbC'	'SWeC'	1	20	11400	0.091	1	1	0.135	10	0
G1	'SWdC'	'SWeC'	1	20	9455	0.099	1	1	0.12	10	0
G1	'SWeC'	'LFCMR03'	1	20	14835	0.013	1	1	0.12	20	0
G1	'LFCMR03'	'LFCMR04'	1	40	9542	0.0153	1	1	0.125	40	0
G1	'SPCbC'	'SPCdC'	1	20	8600	0.021	1	1	0.14	10	0

Table 3 (continued): Listing of SWMM RUNOFF channel parameters for current development conditions. Explanations of data fields listed here are given in **Section 4** of this report.

	Name	Hydraulic Load Pt	Type	Width (ft)	Length (ft)	Slope (ft/ft)	L slope (ft/ft)	R slope (ft/ft)	Manning N	Depth (ft)	Init Dpth (ft)
G1	'SPCdC'	'SPCfC'	1	20	2792	0.0143	1	1	0.135	20	0
G1	'SPCfC'	'LFCMR04'	1	20	5250	0.0152	1	1	0.035	20	0
G1	'LFCMR04'	'LFCMR04c'	1	40	722	0.0061	1	1	0.05	40	0
G1	'LFCMR04b'	'LFCMR05'	1	40	7041	0.0061	1	1	0.05	40	0
G1	'SDCSaC'	'LFCMR05'	1	5	13390	0.0131	1	1	0.14	5	0
G1	'SDCEbC'	'SDCEcC'	1	5	17400	0.0121	1	1	0.16	5	0
G1	'SDCEdC'	'SDCSbC'	1	10	28325	0.0132	1	1	0.15	10	0
G1	'SDCWbC'	'SDCSbC'	1	20	20265	0.0152	1	1	0.15	20	0
G1	'SDCSbC'	'LFCMR06'	1	20	18025	0.0122	1	1	0.14	20	0
G1	'LFCMR05'	'LFCMR06'	1	40	2300	0.0087	1	1	0.05	40	0
G1	'LFCMR06'	'LFCMR07'	1	40	10250	0.0059	1	1	0.05	40	0
G1	'LFCMR07'	'WWWTP'	1	40	11430	0.0052	1	1	0.07	40	0

Table 4: Precipitation stations employed for simulation of hydrographs for the major storm event during April 28-May 2, 1999. Stations not highlighted are those for which hourly rainfall data was available for the entire event. Stations with yellow (light) shading are those for which only daily data was available during the event. Stations with green (dark) shading represent those supplemental data employed for hydrograph matching in simulation of the event. The "primary basin" listed is the RUNOFF model designator for the central or representative basin affected by the corresponding hyetograph.

April 28-May 2, 1999 event

Constraints: daily rainfall totals where hourly data unavailable

Hyetograph	Description/Location	Primary Basin	Daily Rainfall 28-Apr	29-Apr	30-Apr	1-May	2-May	Event Total
1	Woodland Park (Upper Fountain Creek and Rampart Range)	CRCFTGa						
2	Manitou Springs (Middle Fountain Creek and foothills)	MS						
3	Colorado College (near center of Colorado Springs)	MVPb						
4	Colorado Springs NWS (Municipal Airport)	SDCSa						
5	Greenland 9 SE NWS (NE of Middle Monument Creek Basin)	BSCb						
6	Pinello Ranch CSU (south of Colorado Springs)	RBb						
7	Monument NWS	PLc/RMc	0.08	3.98	1.57	0.68	0.1	6.42
8	Ruxton Park NWS	ECa/ECc	0.51	2.3	0.61	0.03	0	3.45
9	Fort Carson NWS	FCMRa	0	1.21	2.37	N/A	N/A	3.58
10	Old Farm (CSU)	TGb	0.3	2.43	2.93	0.62	0.46	6.74
11	Monument Valley Park (CSU)	MVPa	0.92	3.4	3.43	0.86	0.07	8.68
12	Quail Lake (CSU)	FHC	0.43	2.31	2.44	0.8	0.09	6.07
13	Water Operations (CSU)	MESa/MESc	1.57	4.05	2.98	0.75	0.08	9.43
14	4-Diamond Sports Complex (CSU)	TGa/TGg/ROSa	N/A	N/A	3.31	0.75	0.06	4.12
15	Foothills north of Fountain Creek	CPCe						
16	Downtown Colorado Springs	SRd/SPCd						
17	Middle/Lower Monument Creek, west side	DVa						
18	Middle/Lower Monument Creek, east side	ELK						
19	Foothills south of Fountain Creek	SWb						

Table 5: List of precipitation stations ("hyetographs") and the rank of corresponding rainfall totals for the major storm event during April 28-May 2, 1999. Shading of station information is as for **Table 4**, above.

RUNOFF Results for April 28-May 2, 1999 event

Hyetograph	Description/Location	Primary Basin
1	Woodland Park (Upper Fountain Creek and Rampart Range)	CRCFTGa
2	Manitou Springs (Middle Fountain Creek and foothills)	MS
3	Colorado College (near center of Colorado Springs)	MVPb
4	Colorado Springs NWS (Municipal Airport)	SDCSa
5	Greenland 9 SE NWS (NE of Middle Monument Creek Basin)	BSCb
6	Pinello Ranch CSU (south of Colorado Springs)	RBb
7	Monument NWS	PLc/RMc
8	Ruxton Park NWS	ECa/ECc
9	Fort Carson NWS	FCMRa
10	Old Farm (CSU)	TGb
11	Momument Valley Park (CSU)	MVPa
12	Quail Lake (CSU)	FHC
13	Water Operations (CSU)	MESa/MESc
14	4-Diamond Sports Complex (CSU)	TGa/TGg/ROSa
15	Foothills north of Fountain Creek	CPCe
16	Downtown Colorado Springs	SRd/SPCd
17	Middle/Lower Monument Creek, west side	DVa
18	Middle/Lower Monument Creek, east side	ELK
19	Foothills south of Fountain Creek	SWb

Total 120-hour rainfall		
largest	15	18.69
	17	13.12
	16	11.42
	13	9.43
	3	9.36
	11	8.68
	14	8.38
	18	7.85
	2	7.80
	19	7.36
	10	6.74
	7	6.42
	12	6.07
	4	5.75
	5	5.70
	9	4.53
	8	3.45
	1	2.40
smallest	6	0.95

Table 6: Results of RUNOFF simulation of the major storm event during April 28-May 2, 1999. See text in **Section 6** of this report for explanations of abbreviations, calculated statistics and shaded areas.

RUNOFF Results for April 28-May 2, 1999 event

Gauge	Location	Channel	Observed Peak 1			Modeled Peak 1 (BasinR31.dat)				
		Outflow	Base Flow	Total Flow	Time	Flow	Error	% Error	Time	Error
07104000	Lower Mon Ck	LMCMR04	146.31	1730	4/29/99 3:30	1592.81	9.12	0.6%	4/29/99 3:30	0:00
07105000	Bear Ck	BRCa (runoff)	0.00	56	4/29/99 8:45	44.99	-11.01	-19.7%	N/A	N/A
07105490	Cheyenne Ck	SWbC + dC	24.21	148	4/29/99 2:30	126.46	2.67	2.2%	4/29/99 3:00	0:30
07105500	Lower Ftn Ck	LFCMR02	210.95	4720	4/29/99 1:15	4504.52	-4.20	-0.1%	4/29/99 1:16	0:01
07105530	Lower Ftn Ck	LFCMR04	310.05	5600	4/29/99 1:45	5292.70	2.77	0.1%	4/29/99 1:47	0:02

Gauge	Location	Channel	Observed Peak 2			Modeled Peak 2 (BasinR58.dat)				
		Outflow	Base Flow	Total Flow	Time	Flow	Error	% Error	Time	Error
07104000	Lower Mon Ck	LMCMR04	269.69	2790	4/29/99 22:30	2516.09	-4.25	-0.2%	4/29/99 22:36	0:06
07105000	Bear Ck	BRCa (runoff)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
07105490	Cheyenne Ck	SWbC + dC	42.32	236	4/29/99 17:15	196.77	3.09	1.6%	4/29/99 17:00	-0:15
07105500	Lower Ftn Ck	LFCMR02	474.72	7450	4/29/99 21:45	6957.87	-17.41	-0.2%	4/29/99 22:19	0:34
07105530	Lower Ftn Ck	LFCMR04	684.33	10500	4/29/99 23:00	10092.89	-22.78	-0.2%	4/29/99 23:00	0:00

Gauge	Location	Channel	Observed Peak 3			Modeled Peak 3 (BasinR72.dat)				
		Outflow	Base Flow	Total Flow	Time	Flow	Error	% Error	Time	Error
07104000	Lower Mon Ck	LMCMR04	376.84	4890	4/30/99 15:05	4509.56	-3.60	-0.1%	4/30/99 15:03	-0:02
07105000	Bear Ck	BRCa (runoff)	0.00	185	4/30/99 18:35	156.39	-29.61	-16.0%	N/A	N/A
07105490	Cheyenne Ck	SWbC + dC	72.09	565	4/30/99 17:35	436.91	-57.00	-11.6%	4/30/99 18:00	0:25
07105500	Lower Ftn Ck	LFCMR02	687.01	9490	4/30/99 14:15	8796.13	-6.86	-0.1%	4/30/99 14:14	-0:01
07105530	Lower Ftn Ck	LFCMR04	986.12	13800	4/30/99 15:00	12843.81	9.73	0.1%	4/30/99 15:02	0:02

Gauge	Location	Channel	Observed Peak 4			Modeled Peak 4 (BasinR96.dat)				
		Outflow	Base Flow	Total Flow	Time	Flow	Error	% Error	Time	Error
07104000	Lower Mon Ck	LMCMR04	531.07	2070	5/1/99 14:45	1535.66	-3.27	-0.2%	5/1/99 15:00	0:15
07105000	Bear Ck	BRCa (runoff)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
07105490	Cheyenne Ck	SWbC + dC	97.56	276	5/1/99 14:15	179.80	1.36	0.8%	5/1/99 14:00	-0:15
07105500	Lower Ftn Ck	LFCMR02	1002.22	4610	5/1/99 14:45	3592.99	-14.79	-0.4%	5/1/99 15:00	0:15
07105530	Lower Ftn Ck	LFCMR04	1368.81	6660	5/1/99 15:00	5261.44	0.25	0.0%	5/1/99 15:00	0:00

	07105500	LFCMR02	Error	% Error	07105530	LFCMR04	Error	% Error
Flow Mean ($ft^3 s^{-1}$)	4172.6	4180.4	7.8	0.2%	4926.4	5306.6	380.2	7.7%
Flow St.D. ($ft^3 s^{-1}$)	2376.9	2361.7	-15.2	-0.6%	3659.2	3495.4	-163.8	-4.5%
Flow Max ($ft^3 s^{-1}$)	9490.0	9481.9	-8.1	-0.1%	13800.0	13810.4	10.4	0.1%
Flow Min ($ft^3 s^{-1}$)	133.0	137.0	4.0	3.0%	198.0	200.0	2.0	1.0%
Total Load (ac-ft)	35260.5	35326.3	65.8	0.2%	41630.3	44842.9	3212.6	7.7%
Serial correlation	0.9982	0.9989	0.0007	0.1%	0.9981	0.9987	0.0006	0.1%
Cross-correlation	0.9854				0.9856			
r^2=	0.9710				0.9714			
MAE ($ft^3 s^{-1}$)	214.1				521.7			
RMSE ($ft^3 s^{-1}$)	404.9				734.2			

Relative correlation measures
r = 1 indicates perfect direct linear correlation
r^2 indicates (1) "coefficient of determination"
(2) "goodness of fit"
(3) "portion of variance explained"

Absolute correlation measures
Simulation Errors in (1) Flow Mean
(2) Total Load
Mean Absolute Error (MAE)
Root-Mean-Squared Error (RMSE)

Table 7: Compiled changes of RUNOFF model specification and simulations of the major storm event addressed here for pre-development and current development conditions.

Basin Model Characteristics

	Pre-developed Case	Current Development	Change	% Change
Number of RUNOFF sub-basins	235	233	-2	---
Number of RUNOFF channels	144	143	-1	---
Number of EXTRAN channels	23	23	0	---
Total Basin Area (mi^2)	495.43	495.43	0.00	0.00%
Developed Basin Area (mi^2)	9.41	42.43	33.02	350.83%
Overall Basin Imperviousness	1.90%	8.56%	0.0666	350.83%

†From Bedient and Huber (2002) Figure 6.1, after Leopold (1968).
‡Using Equations (RO-6) and (RO-7) and Table RO-4 after UDFCD (2001).

RUNOFF Results for April 28-May 2, 1999 event

	USGS 07105500 (LFCMR02)			
	Pre-devel.	Current	Change	% Change
Flow Mean ($ft^3 s^{-1}$)	3482.8	4180.4	697.6	20.0%
Flow St.D. ($ft^3 s^{-1}$)	1999.7	2361.7	362.1	18.1%
Flow Max ($ft^3 s^{-1}$)	8328.0	9481.9	1153.9	13.9%
Flow Min ($ft^3 s^{-1}$)	137.0	137.0	0.0	0.0%
Total Load (ac-ft)	29431.0	35326.3	5895.3	20.0%

	USGS 07105530 (LFCMR04)			
	Pre-devel.	Current	Change	% Change
Flow Mean ($ft^3 s^{-1}$)	4259.0	5306.6	1047.6	24.6%
Flow St.D. ($ft^3 s^{-1}$)	2866.0	3495.4	629.4	22.0%
Flow Max ($ft^3 s^{-1}$)	12272.5	13810.4	1538.0	12.5%
Flow Min ($ft^3 s^{-1}$)	200.0	200.0	0.0	0.0%
Total Load (ac-ft)	35990.5	44842.9	8852.4	24.6%

	Mouth of Shooks Run (SRfC)			
	Pre-devel.	Current	Change	% Change
Flow Mean ($ft^3 s^{-1}$)	188.9	290.9	102.1	54.0%
Flow St.D. ($ft^3 s^{-1}$)	467.6	513.0	45.4	9.7%
Flow Max ($ft^3 s^{-1}$)	1862.5	1877.5	15.0	0.8%
Flow Min ($ft^3 s^{-1}$)	0.0	0.0	0.0	0.0%
Total Load (ac-ft)	1873.1	2885.3	1012.2	54.0%

	Mouth of Shooks Run (SRfC)			
	Current	w/o TGFwy	Change	% Change
Flow Mean ($ft^3 s^{-1}$)	290.9	469.9	179.0	61.5%
Flow St.D. ($ft^3 s^{-1}$)	513.0	758.4	245.4	47.8%
Flow Max ($ft^3 s^{-1}$)	1877.5	2845.6	968.1	51.6%
Flow Min ($ft^3 s^{-1}$)	0.0	0.0	0.0	0.0%
Total Load (ac-ft)	2885.3	4660.5	1775.1	61.5%

Table 8: Listing of SWMM EXTRAN junction parameters. Explanations of data fields listed here are given in **Section 7** of this report.

	Name	Grnd. Elev.	Invert Elev.	Base Flow	Initial Depth	X location	Y location	Surcharge
D1	'WWWTP'	5069.5	5049	0	0	25400	-31500	0
D1	'07105800'	5049.5	5028	0	0	25200	-33300	0
D1	'CBbrDS'	5049.5	5028	0	0	29225	-33350	0
D1	'Rt16brUS'	5055	5024.5	0	0	30000	-34500	0
D1	'Rt16brDS'	5055	5024.5	0	0	30025	-34590	0
D1	'US0255'	5033.25	5010.25	0	0	31750	-36745	0
D1	'FCMRout'	5020.25	5002.5	0	0	31800	-37000	0
D1	'DS0215'	5018.5	5000.75	0	0	31850	-37215	0
D1	'DS0435'	5019.5	5005.25	0	0	31950	-37425	0
D1	'DS0620'	5015.25	5004.3	0	0	32000	-37620	0
D1	'DS0745'	5014.5	5003.75	0	0	32050	-37745	0
D1	'DS0935'	5013.5	5002.75	0	0	32100	-37935	0
D1	'DS1035'	5013	5002.5	0	0	32150	-38035	0
D1	'DS1320'	5011	5001	0	0	32200	-38323	0
D1	'DS1410'	5010.5	5000.5	0	0	32225	-38410	0
D1	'DS1510'	5009.9	5000.1	0	0	32250	-38510	0
D1	'DS1660'	5009.9	5599.5	0	0	32275	-38660	0
D1	'DS1795'	5007.6	5592.4	0	0	32350	-38795	0
D1	'DS1955'	5000.45	5597.25	0	0	32425	-38955	0
D1	'DS2140'	5605	5595.25	0	0	32525	-39140	0
D1	'DS2305'	5603.75	5593.75	0	0	32625	-39305	0
D1	'DS2520'	5602	5591.75	0	0	32750	-39520	0
D1	'DS2720'	5600.5	5590	0	0	32850	-39723	0
D1	'DS3130'	5596	5586.75	0	0	32900	-40135	0
D1	'End'	5568	5550.75	0	0	34350	-44353	0

Table 9: Listing of SWMM EXTRAN channel parameters. Explanations of data fields listed here are given in **Section 7** of this report. Note that channel type 12 indicates a bridge segment, channel type 8 indicates an irregular cross-section, and channel type 6 indicates a regular trapezoidal cross-section with the indicated side slopes. Plotted cross-sections for the bridges and irregular channels are shown in **Appendix A, Figures 19a** through **19f.**

Irregular Channel Data

	Name	From Junct	To Junct	Initial Flow	Type	Full Area	Max Depth	Width	Length	U/S Invert	D/S Invert	Roughness	X-section #	Avg Slope
C1	'LFCMR08'	'WWWTP'	'07105800'	0	5	0	0	0	5949	0	0	0	1	0.00532
C1	'CBbridge'	'07105800'	'CBbrDS'	0	12	0	0	0	50	0	0	0.015	1	0.001
C1	'LFCMR09'	'CBbrDS'	'Rt16brUS'	0	5	0	0	0	1539	0	0	0	2	0.00229
C1	'Rt16bridge'	'Rt16brUS'	'Rt16brDS'	0	12	0	0	0	90	0	0	0.015	2	0.001
C1	'LFCMR10a'	'Rt16brDS'	'US0255'	0	5	0	0	0	2023	0	0	0	3	0.00489
C1	'LFCMR10b'	'US0255'	'FCMRout'	0	5	0	0	0	255	0	0	0	4	0.00080
C1	'LFCMR11a'	'FCMRout'	'DS0215'	0	5	0	0	0	215	0	0	0	5	0.00098
C1	'LFCMR11b'	'DS0215'	'DS0435'	0	5	0	0	0	220	0	0	0	6	0.00082
C1	'LFCMR11c'	'DS0435'	'DS0620'	0	5	0	0	0	185	0	0	0	7	0.00541
C1	'LFCMR11d'	'DS0620'	'DS0745'	0	5	0	0	0	125	0	0	0	8	0.004
C1	'LFCMR11e'	'DS0745'	'DS0935'	0	5	0	0	0	190	0	0	0	9	0.00522
C1	'LFCMR11f'	'DS0935'	'DS1035'	0	5	0	0	0	100	0	0	0	10	0.0025
C1	'LFCMR12a'	'DS1035'	'DS1320'	0	5	0	0	0	285	0	0	0	11	0.00526
C1	'LFCMR12b'	'DS1320'	'DS1410'	0	5	0	0	0	90	0	0	0	12	0.00556
C1	'LFCMR13a'	'DS1410'	'DS1510'	0	5	0	0	0	100	0	0	0	13	0.004
C1	'LFCMR13b'	'DS1510'	'DS1660'	0	5	0	0	0	150	0	0	0	14	0.004
C1	'LFCMR13c'	'DS1660'	'DS1795'	0	5	0	0	0	135	0	0	0	15	0.002148
C1	'LFCMR13d'	'DS1795'	'DS1955'	0	5	0	0	0	150	0	0	0	16	0.007167
C1	'LFCMR14a'	'DS1955'	'DS2140'	0	5	0	0	0	185	0	0	0	17	0.01081
C1	'LFCMR14b'	'DS2140'	'DS2305'	0	5	0	0	0	155	0	0	0	18	0.00909
C1	'LFCMR14c'	'DS2305'	'DS2520'	0	5	0	0	0	215	0	0	0	19	0.0093
C1	'LFCMR14d'	'DS2520'	'DS2720'	0	5	0	0	0	200	0	0	0	20	0.00575
C1	'LFCMR15'	'DS2720'	'DS3130'	0	5	0	0	0	410	0	0	0	21	0.00793

Regular Channel Data

	Name	From Junct	To Junct	Initial Flow	Type	Full Area	Max Depth	Bottom W	Length	U/S Invert	D/S Invert	Roughness	L side H:V	R side H:V
C1	'LFCMR16'	'DS3130'	'End'	0	6	0	11.25	120	4990	0	0	0.04	2	2
C1	'LFCMR17'	'End'	'GDHwks'	0	6	0	11.25	120	128375	0	0	0.03	2	2
C1	'LFCMR18'	'GD-Hwks'	'4850'	0	6	0	11.25	120	9500	0	0	0.03	2	2

Table 10: Compiled results of EXTRAN simulations of stream flows and flow velocities using current and historical configurations of channel segments in a portion of Fountain Creek under pre-development and current development conditions in upstream areas. These results are for the location of USGS gauge 07105800 ("Fountain Creek at Security, Colorado").

EXTRAN Results for April 28-May 2, 1999 event

	USGS 07105800 (CBbr)			
	Pre-devel.	Current	Change	% Change
Flow Mean ($ft^3 s^{-1}$)	3875.0	5172.8	1297.8	33.5%
Flow St.D. ($ft^3 s^{-1}$)	3403.2	4593.2	1189.9	35.0%
Flow Max ($ft^3 s^{-1}$)	13880.6	17251.6	3371.1	24.3%
Flow Min ($ft^3 s^{-1}$)	200.0	200.0	0.0	0.0%
Total Load (ac-ft)	38429.9	51300.5	12870.6	33.5%

	USGS 07105800 (CBbr)			
	Current	w/o Levee	Change	% Change
Flow Mean ($ft^3 s^{-1}$)	5172.8	5172.9	0.1	0.0%
Flow St.D. ($ft^3 s^{-1}$)	4593.2	4593.3	0.1	0.0%
Flow Max ($ft^3 s^{-1}$)	17251.6	17254.7	3.1	0.0%
Flow Min ($ft^3 s^{-1}$)	200.0	200.0	0.0	0.0%
Total Load (ac-ft)	51300.5	51301.4	0.9	0.0%

	USGS 07105800 (CBbr)			
	Pre-devel.	w/o Levee	Change	% Change
Flow Mean ($ft^3 s^{-1}$)	3875.0	3875.0	0.0	0.0%
Flow St.D. ($ft^3 s^{-1}$)	3403.2	3403.2	0.0	0.0%
Flow Max ($ft^3 s^{-1}$)	13880.6	13879.6	-1.0	0.0%
Flow Min ($ft^3 s^{-1}$)	200.0	200.0	0.0	0.0%
Total Load (ac-ft)	38429.9	38430.0	0.1	0.0%

From River Engineering for Highway Encroachments (Richardson *et al.* 2001)
Hydraulic Design Series No. 6, FHWA NHI 01-004, 2001
Table 3.5 (p. 3.44): Nonscour Velocities for Soils

Soil Type	Mean Depth	Nonscour V
Coarse sand (noncohesive, D_{50} = 0.5-1.0 mm)	9.8 ft	2.3 ($ft\ s^{-1}$)
Sandy loam (cohesive)	9.8 ft	4.9 ($ft\ s^{-1}$)

	USGS 07105800 (CBbr)			
	Pre-devel.	Current	Change	% Change
Velocity Mean ($ft\ s^{-1}$)	3.24	3.75	0.51	15.8%
Velocity St.D. ($ft\ s^{-1}$)	2.23	2.44	0.21	9.5%
Velocity Max ($ft\ s^{-1}$)	7.04	7.56	0.52	7.4%
Velocity Min ($ft\ s^{-1}$)	0.00	0.00	0.00	0.0%
Time above 2.3 $ft\ s^{-1}$ (h)	77.75	81.50	3.75	4.8%
Time above 4.9 $ft\ s^{-1}$ (h)	28.75	42.50	13.75	47.8%

	USGS 07105800 (CBbr)			
	Current	w/o Levee	Change	% Change
Velocity Mean ($ft\ s^{-1}$)	3.75	3.71	-0.04	-1.0%
Velocity St.D. ($ft\ s^{-1}$)	2.44	2.40	-0.05	-1.9%
Velocity Max ($ft\ s^{-1}$)	7.56	7.33	-0.23	-3.0%
Velocity Min ($ft\ s^{-1}$)	0.00	0.00	0.00	0.0%
Time above 2.3 $ft\ s^{-1}$ (h)	81.50	81.50	0.00	0.0%
Time above 4.9 $ft\ s^{-1}$ (h)	42.50	41.25	-1.25	-2.9%

	USGS 07105800 (CBbr)			
	Pre-devel.	w/o Levee	Change	% Change
Velocity Mean ($ft\ s^{-1}$)	3.24	3.22	-0.02	-0.8%
Velocity St.D. ($ft\ s^{-1}$)	2.23	2.20	-0.03	-1.2%
Velocity Max ($ft\ s^{-1}$)	7.04	6.87	-0.17	-2.4%
Velocity Min ($ft\ s^{-1}$)	0.00	0.00	0.00	0.0%
Time above 2.3 $ft\ s^{-1}$ (h)	77.75	77.75	0.00	0.0%
Time above 4.9 $ft\ s^{-1}$ (h)	28.75	28.75	0.00	0.0%

Table 11: Compiled results of EXTRAN simulations of stream flows and flow velocities using current and historical configurations of channel segments in a portion of Fountain Creek under pre-development and current development conditions in upstream areas. These results are for the location of the upstream end of the KOA property along Fountain Creek.

EXTRAN Results for April 28-May 2, 1999 event

	Upstream end of KOA property (LFCMR14a)			
	Pre-devel.	Current	Change	% Change
Flow Mean ($ft^3\ s^{-1}$)	3900.3	5198.2	1297.9	33.3%
Flow St.D. ($ft^3\ s^{-1}$)	3430.4	4632.6	1202.2	35.0%
Flow Max ($ft^3\ s^{-1}$)	13883.5	17265.6	3382.1	24.4%
Flow Min ($ft^3\ s^{-1}$)	200.0	200.0	0.0	0.0%
Total Load (ac-ft)	38681.0	51552.4	12871.4	33.3%

	Upstream end of KOA property (LFCMR14a)			
	Current	w/o Levee	Change	% Change
Flow Mean ($ft^3\ s^{-1}$)	5198.2	5196.9	-1.3	0.0%
Flow St.D. ($ft^3\ s^{-1}$)	4632.6	3430.4	-1202.2	-26.0%
Flow Max ($ft^3\ s^{-1}$)	17265.6	13883.5	-3382.1	-19.6%
Flow Min ($ft^3\ s^{-1}$)	200.0	200.0	0.0	0.0%
Total Load (ac-ft)	51552.4	38681.0	-12871.4	-25.0%

	Upstream end of KOA property (LFCMR14a)			
	Pre-devel.	w/o Levee	Change	% Change
Flow Mean ($ft^3\ s^{-1}$)	3900.3	3899.2	-1.2	0.0%
Flow St.D. ($ft^3\ s^{-1}$)	3430.4	3434.9	4.5	0.1%
Flow Max ($ft^3\ s^{-1}$)	13883.5	13881.5	-2.0	0.0%
Flow Min ($ft^3\ s^{-1}$)	200.0	200.0	0.0	0.0%
Total Load (ac-ft)	38681.0	38669.3	-11.7	0.0%

From River Engineering for Highway Encroachments (Richardson *et al.* 2001)
Hydraulic Design Series No. 6, FHWA NHI 01-004, 2001
Table 3.5 (p. 3.44): Nonscour Velocities for Soils

Soil Type	Mean Depth	Nonscour V
Coarse sand (noncohesive, D_{50} = 0.5-1.0 mm)	6.6 ft	2.1 ($ft\ s^{-1}$)
Sandy loam (cohesive)	6.6 ft	4.6 ($ft\ s^{-1}$)

	Upstream end of KOA property (LFCMR14a)			
	Pre-devel.	Current	Change	% Change
Velocity Mean ($ft\ s^{-1}$)	4.78	5.52	0.73	15.3%
Velocity St.D. ($ft\ s^{-1}$)	3.18	3.46	0.28	8.8%
Velocity Max ($ft\ s^{-1}$)	10.09	10.83	0.74	7.3%
Velocity Min ($ft\ s^{-1}$)	0.00	0.00	0.00	0.0%
Time above 2.1 $ft\ s^{-1}$ (h)	92.00	96.50	4.50	4.9%
Time above 4.6 $ft\ s^{-1}$ (h)	72.75	77.50	4.75	6.5%

	Upstream end of KOA property (LFCMR14a)			
	Current	w/o Levee	Change	% Change
Velocity Mean ($ft\ s^{-1}$)	5.52	3.55	-1.97	-35.6%
Velocity St.D. ($ft\ s^{-1}$)	3.46	1.88	-1.58	-45.6%
Velocity Max ($ft\ s^{-1}$)	10.83	5.65	-5.18	-47.8%
Velocity Min ($ft\ s^{-1}$)	0.00	0.00	0.00	0.0%
Time above 2.1 $ft\ s^{-1}$ (h)	96.50	96.00	-0.50	-0.5%
Time above 4.6 $ft\ s^{-1}$ (h)	77.50	32.50	-45.00	-58.1%

	Upstream end of KOA property (LFCMR14a)			
	Pre-devel.	w/o Levee	Change	% Change
Velocity Mean ($ft\ s^{-1}$)	4.78	3.30	-1.48	-30.9%
Velocity St.D. ($ft\ s^{-1}$)	3.18	1.88	-1.30	-41.0%
Velocity Max ($ft\ s^{-1}$)	10.09	5.38	-4.71	-46.7%
Velocity Min ($ft\ s^{-1}$)	0.00	0.00	0.00	0.0%
Time above 2.1 $ft\ s^{-1}$ (h)	92.00	92.50	0.50	0.5%
Time above 4.6 $ft\ s^{-1}$ (h)	72.75	22.00	-50.75	-69.8%

Table 12: Compiled results of EXTRAN simulations of stream flows and flow velocities in a portion of Fountain Creek under pre-development and current development conditions in upstream areas. These results are for the location of the Greenview Ditch Headworks along Fountain Creek near Pueblo, Colorado.

EXTRAN Results for April 28-May 2, 1999 event

	Greenview Ditch Headworks (LFCMR18)			
	Pre-devel.	Current	Chaage	% Change
Flow Mean ($ft^3 s^{-1}$)	3875.2	5172.1	1296.8	33.5%
Flow St.D. ($ft^3 s^{-1}$)	3463.6	4621.4	1157.7	33.4%
Flow Max ($ft^3 s^{-1}$)	13678.3	17279.3	3601.0	26.3%
Flow Min ($ft^3 s^{-1}$)	200.0	200.0	0.0	0.0%
Total Load (ac-ft)	38431.9	51293.1	12861.3	33.5%

From River Engineering for Highway Encroachments (Richardson *et al.* 2001)
Hydraulic Design Series No. 6, FHWA NHI 01-004, 2001
Table 3.5 (p. 3.44): Nonscour Velocities for Soils

Soil Type	Mean Depth	Nonscour V
Coarse sand (noncohesive, D_{50} = 0.5-1.0 mm)	6.6 ft	2.1 ($ft\ s^{-1}$)
Sandy loam (cohesive)	6.6 ft	4.6 ($ft\ s^{-1}$)

	Greenview Ditch Headworks (LFCMR18)			
	Pre-devel.	Current	Change	% Change
Velocity Mean ($ft\ s^{-1}$)	5.62	6.60	0.98	17.5%
Velocity St.D. ($ft\ s^{-1}$)	3.96	4.34	0.38	9.7%
Velocity Max ($ft\ s^{-1}$)	12.58	13.74	1.16	9.2%
Velocity Min ($ft\ s^{-1}$)	0.00	0.00	0.00	0.0%
Time above 2.1 $ft\ s^{-1}$ (h)	89.00	93.25	4.25	4.8%
Time above 4.6 $ft\ s^{-1}$ (h)	75.50	81.25	5.75	7.6%

APPENDIX C

References

Bedient, P.B., and W.C. Huber, 2002: Hydrology and Floodplain Analysis (3rd Ed.). Upper Saddle River, NJ: Prentice Hall. 763 pp.

Chow, V.T., D.R. Maidment, and L.W. Mays, 1988: Applied Hydrology. New York: McGraw-Hill, Inc. 572 pp.

Denver Urban Drainage and Flood Control District, 2001: Urban Storm Drainage Criteria Manual, Volume I.

Knighton, D., 1998: Fluvial Forms and Processes: A New Perspective. Arnold (Hodder Headline Group). 383 pp.

Legates, D.R., and G.J. McCabe, Jr., 1999: Evaluating the use of "goodness-of-fit" measures in hydrologic and hydroclimatic model validation. *Water Resources Research*, **35** (1), 233-241.

Maidment, D.R. (ed.), 1992: Handbook of Hydrology. New York: McGraw-Hill, Inc.

Richardson, E.V., D.B. Simons, and P.F. Lagasse, 2001: River Engineering for Highway Encroachments: Highways in the River Environment. Report No. FHWA NHI 01-004, HDS 6. 644 pp.

Rosgen, D.L., 1994: A classification of natural rivers. *Catena*, **22**, 169-199.

Schueler, T., 1994: The importance of imperviousness. *Watershed Protection Techniques*, **1** (3), 100-111.

Walesh, S.G., 1989: Urban Surface Water Management. John Wiley & Sons, Inc. 518 pp.

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Memorandum

To: Allen Leonard, Senior Litigation Specialist
and Shane White, Senior Litigation Attorney
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Colorado Springs, Colorado 80901-1575

From: Larry Roesner, Ph.D, P.E., P.H.
and Matthew Garcia, M.S.

Date: June 3, 2003

Re: El Paso County District Court case no. 01CV1290, Speight *et al.* v. the City of Colorado Springs and El Paso County, Colorado: Assessment of the City of Colorado Springs' ***Drainage Criteria Manual***

We have reviewed the ***Drainage Criteria Manual** ("the Manual")* adopted by the City of Colorado Springs and El Paso County and provided by your office. Our findings follow:

- The Manual is well written and clear.
- Its authors are up-to-date on current stormwater management issues and approaches.
- Use of the major drainageways as amenities is good practice.
- Adopting regional detention of stormwater as a policy, as indicated in the Manual, is better than requiring small local detention facilities. The storage volume sizing requirements are adequate (2-hour and 24-hour, 10-year and 100-year storms), and the emergency spillway requirements seem adequate. Design guidance provided in Section 11 is consistent with current design practice for flood control facilities.
- Structural best management practices (BMPs) for water quality are not addressed in the Manual. We would think that BMP criteria should be included in the Manual in order to facilitate compliance with your MS4 permit. However, the presence or absence of such facilities in a drainage system will have no significant effect on flood flows.

- Changing the design criterion from the use of a 10-yr initial design storm to the use of a 5-yr storm is good. It will result in a lower peak runoff rate for all storms larger than the 5-yr event, compared to the peak flow that would result from a system sized for a 10-yr initial design storm.

- There appears to be a conflict between the statement in Section 2.5.3, "No buildings or structures shall be constructed within the limits of the 100-year flood plain," and the statement in Section 2.8, "Any *proposed* structure located within the 100-year flood plain…" Although development in the flood plain is common in Front Range cities, it is not good practice unless compensating storage is provided.

- Section 4 ("Report Guidelines") is one of the better summaries on this topic that we have seen. These requirements force developers to reveal the basis of their design in a way that the City can insure that its requirements are met.

- It appears that the reference to page 5-14 on Figures 5-4a through 5-4c is incorrect.

To summarize, the ***Drainage Criteria Manual*** adopted by the City of Colorado Springs and El Paso County rates as one of the better storm drainage manuals that we have seen.

…LAR

Report No. 4 to the City Attorney for Colorado Springs, Colorado, in reference to El Paso County District Court case no. 01CV1290

Matthew Garcia, M.S., under the direction of
Prof. Larry Roesner, Ph.D., P.E., P.H.
Department of Civil Engineering
Colorado State University
Fort Collins, Colorado 80523

June 3, 2003

ABSTRACT

This report pertains to El Paso County District Court case no. 01CV1290, Speight *et al.* v. the City of Colorado Springs and El Paso County, Colorado. This is the fourth of four reports to the City Attorney for Colorado Springs, Colorado. The report addresses the materials and conclusions presented in the first three reports of this series.

1. Introduction

The complaint filed by the above-named plaintiffs lists three periods in the spring and summer of 1999 during which storm events may have caused flood-related property damages in locations along Fountain Creek downstream of Colorado Springs, Colorado. The primary goals of this report are to summarize the materials presented in the previous three reports of this series and draw relevant conclusions. The first two reports of this series addressed the meteorological, hydrologic and hydraulic circumstances of those storm and flood events, with an emphasis on the first and largest of those events. The third report of this series was an assessment of the *Drainage Criteria Manual* adopted by the City of Colorado Springs and El Paso County, Colorado

Report Organization

Report No. 1 presented a meteorological analysis of several storm events during the spring and summer seasons of 1999 and is discussed in Section 2. Report No. 2 presented a detailed hydrologic and hydraulic analysis of rainfall, runoff and streamflow during the major storm event of April 28-May 2, 1999, and is discussed in Section 3. Report No. 3 presented an assessment of the City of Colorado Springs' *Drainage Criteria Manual* and is discussed in Section 4.

2. Report No. 1: Meteorological Analyses of Storm Events

2.1. Report Summary

Report No. 1 addressed several rainfall events during April through August, 1999, from which runoff- and flood-related damages may have resulted at locations along Fountain Creek downstream of Colorado Springs, Colorado. The physical features of Monument and Fountain Creeks and the surrounding watershed were described briefly. A reference map of the Fountain Creek watershed, including several locations relevant to the work presented here, is shown in

Figure 1. Ten rainfall events during the periods specified in the plaintiffs' complaint were addressed, and the sources of data used to evaluate these events were also listed.

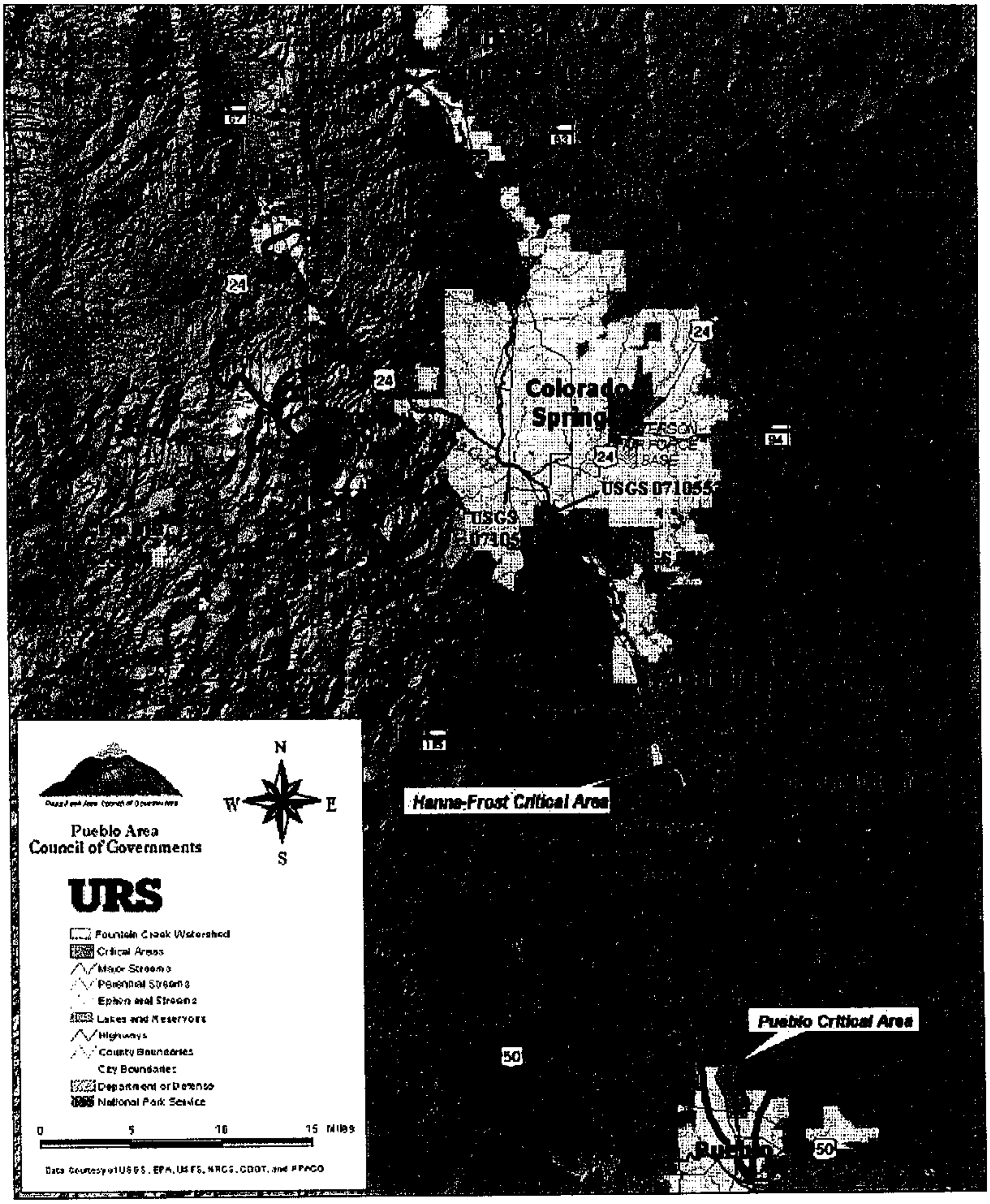


Figure 1: Colorado Springs and surrounding areas within the Fountain Creek watershed (outlined in black). The base map used here was created by the Pikes Peak Area Council of Governments (PPACG); location information was added by the author.

A brief examination of large-scale meteorological conditions and their influences on weather patterns in the vicinity of the Rocky Mountains was presented. Another large-scale factor of significant influence on weather and rainfall in the vicinity of Colorado Springs and the Fountain Creek basin is the Rocky Mountains. The Rocky Mountain Front Range lies immediately to the west of this region, and the Palmer Divide extends eastward from the Front Range to provide the northern boundary of this basin. The interactions between passing weather systems, at all levels of the atmosphere, and this topographic configuration are complex. However, we may classify two primary effects of the Rocky Mountains on such weather events: *solar heating of the land surface in a highly variable pattern*, which often leads to abrupt changes in wind speed and direction, and *upward forcing of near-surface winds* leading to large-scale areas of clouds and sometimes to sustained rainfall on the eastern slopes of the Front Range.

Heavy snowstorms were observed in portions of the Fountain Creek watershed during the spring of 1999. The meteorological conditions supporting the five largest storm events during the subsequent warm season were described and analyzed with regard to several specific weather patterns known to produce heavy rainfall and flash flood conditions along the Rocky Mountain Front Range. Hourly and daily total rainfall data were examined at several locations for each of these events. The daily total rainfall data at three stations in the vicinity of Colorado Springs are listed in **Table 1**.

The largest of these events, which occurred during the period April 28-May 2, 1999, was examined in detail in this report. Hourly rainfall data were analyzed for several stations in and near the Fountain Creek watershed (e.g. **Figures 2a** and **2b**), and daily total rainfall data were compiled and shown on schematic maps of the basin. The total event rainfall is shown in a schematic diagram of the Fountain Creek watershed in **Figure 3**. These data indicated the concentration of rainfall within the City of Colorado Springs during that event. It was also discussed that the meteorological conditions during this event were remarkably similar to those found by previous researchers for other Front Range heavy rainfall and flood events.

The total event rainfall at three stations in the vicinity of Colorado Springs were compared with the 100-year storm rainfall totals available in several references applicable to this region, most notably in the Drainage Criteria Manual that was adopted by the City of Colorado Springs and El Paso County, Colorado. The distributions of hourly rainfall throughout the event and during the peak 24-hour period of that event were compared with the storm rainfall distribution suggested for eastern Colorado in that Drainage Criteria Manual. These data are listed below in **Table 2**.

2.2. Conclusions

Conclusions regarding the largest rainfall events in the vicinity of Colorado Springs during the periods specified in the plaintiffs' complaint are listed here:

1. The period from April through August of 1999 can generally be characterized as a wet season with regard to rainfall in the vicinity of Colorado Springs, despite pre-season indications of a dry spring and summer due to La Niña conditions in the eastern equatorial Pacific Ocean. A portion of this large seasonal rainfall total can be attributed to an early extension of the North American monsoon to the Colorado region.

Table 1: Daily total rainfall, in inches, at stations in the vicinity of Colorado Springs for the periods listed in the plaintiffs' complaint. Period totals exclude trace (T) amounts. A single asterisk (*) denotes the largest daily precipitation amount during April on record at the Colorado Springs NWS station. A double asterisk (**) denotes the largest single-day precipitation amount recorded during 1948-2000 at the Colorado Springs NWS station. The notation "PF" indicates missing data. The major storm events examined in this work are shaded.

Date	Colorado College (C.S. Utilities)	Colorado Springs (NOAA/NWS)	Manitou Springs (NOAA/NWS)
4/28/99	1.19	0.39	0.50
4/29/99	3.57	1.75	4.70
4/30/99	3.58	2.63*	1.60
5/1/99	0.96	0.82	0.60
5/2/99	0.06	0.16	0.40
5/3/99	0.00	T	0.00
5/4/99	0.00	T	0.00
5/5/99	0.00	T	0.00
5/6/99	0.00	0.00	0.00
5/7/99	0.00	0.00	0.00
5/8/99	0.00	0.00	0.00
5/9/99	0.00	0.00	0.00
5/10/99	0.02	0.02	0.00
Period Total	9.38	5.77	7.80

5/23/99	0.06	T	0.10
5/24/99	0.21	0.49	0.10
5/25/99	1.15	1.08	0.80
5/26/99	0.00	0.00	0.00
5/27/99	0.42	0.47	0.30
5/28/99	0.01	0.00	0.00
5/29/99	PF	0.05	0.00
5/30/99	PF	T	0.00
5/31/99	PF	0.10	0.00
6/1/99	0.09	T	0.00
6/2/99	0.02	T	0.00
6/3/99	0.01	0.00	0.00
6/4/99	0.00	0.00	0.00
Period Total	1.97	2.19	1.30

Table 1 (cont.): Daily total rainfall, in inches, at stations in the vicinity of Colorado Springs for the periods listed in the plaintiffs' complaint. Period totals exclude trace (T) amounts. A double asterisk (**) denotes the largest single-day precipitation amount recorded during 1948-2000 at the Colorado Springs NWS station. The major storm events examined in Section 5 of this report are shaded.

Date	Colorado College (C.S. Utilities)	Colorado Springs (NOAA/NWS)	Manitou Springs (NOAA/NWS)
7/8/99	0.23	0.21	0.00
7/9/99	0.00	0.00	0.00
7/10/99	0.00	0.00	0.00
7/11/99	0.00	T	0.00
7/12/99	0.00	T	0.00
7/13/99	0.00	0.00	0.00
7/14/99	0.00	T	0.00
7/15/99	0.07	0.01	0.00
7/16/99	0.49	0.91	0.00
7/17/99	0.04	0.52	0.00
7/18/99	0.50	0.00	0.00
7/19/99	0.07	0.01	0.00
7/20/99	0.00	0.00	0.00
7/21/99	0.00	T	0.00
7/22/99	0.00	T	0.00
7/23/99	0.00	T	0.00
7/24/99	0.20	0.00	0.00
7/25/99	0.00	T	0.00
7/26/99	0.00	0.00	0.00
7/27/99	0.00	0.00	0.00
7/28/99	0.19	0.51	0.00
7/29/99	0.00	T	0.00
7/30/99	0.98	0.07	0.00
7/31/99	0.70	2.36	0.00
8/1/99	0.00	0.19	0.00
8/2/99	0.01	0.00	0.00
8/3/99	0.24	1.26	0.00
8/4/99	1.72	3.98**	0.00
8/5/99	0.33	0.77	0.00
8/6/99	0.57	0.27	0.00
8/7/99	0.15	0.13	0.00
8/8/99	0.01	0.03	0.00
8/9/99	0.20	0.03	0.00
8/10/99	0.07	0.01	0.00
Period Total	6.77	10.49	0.00

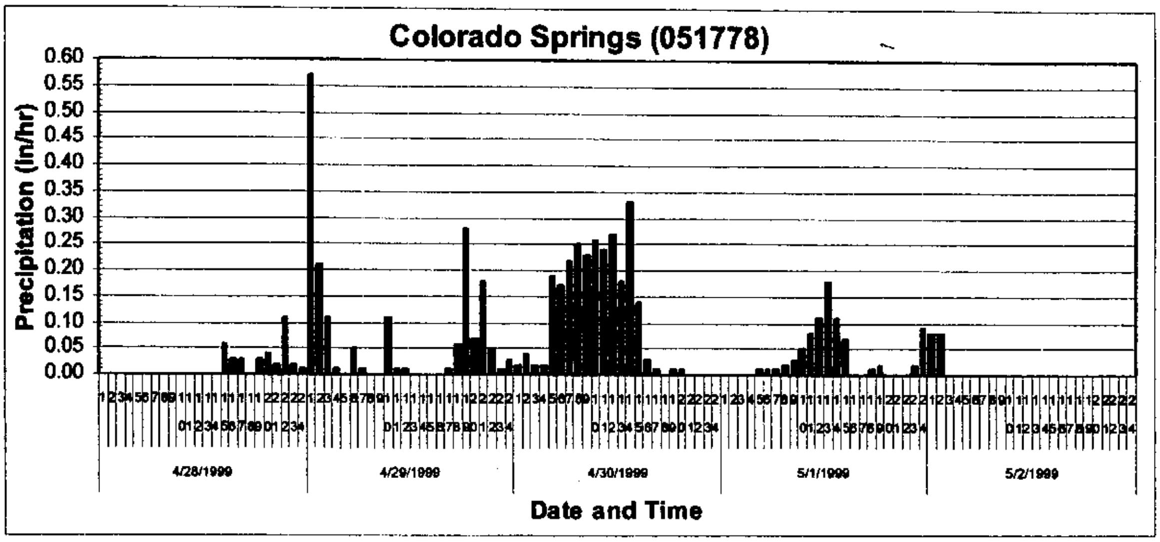


Figure 2a: Histogram of hourly rainfall, in inches, at the Colorado Springs NWS station during the period April 28-May 2, 1999, for the major storm event addressed in this work.

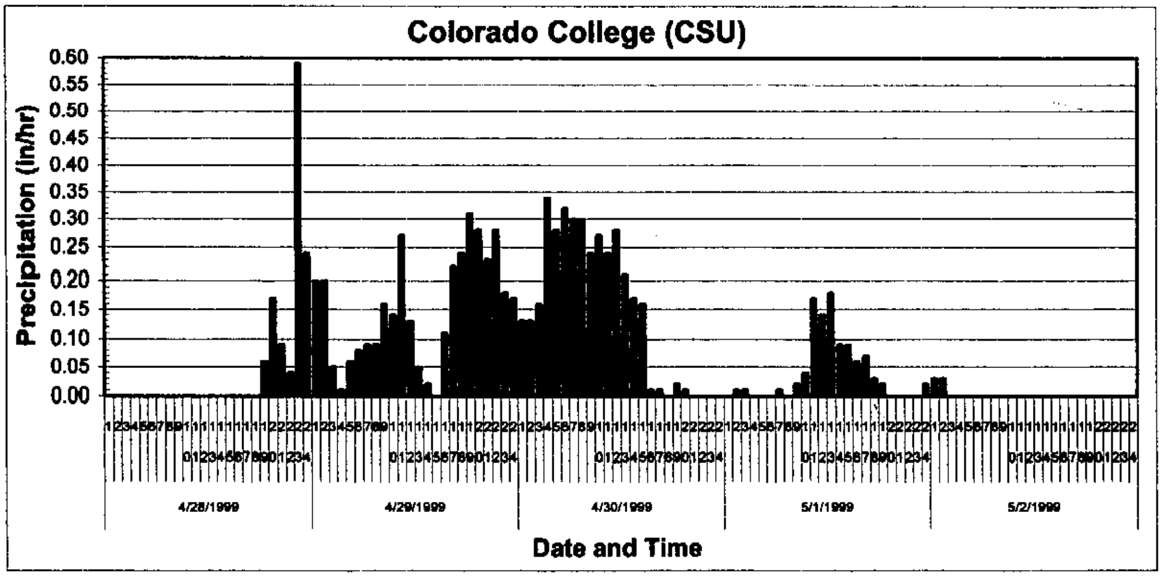


Figure 2b: Histogram of hourly rainfall, in inches, at the Colorado College (Colorado Springs Utilities) weather station during the period April 28-May 2, 1999, for the major storm event addressed in this work.

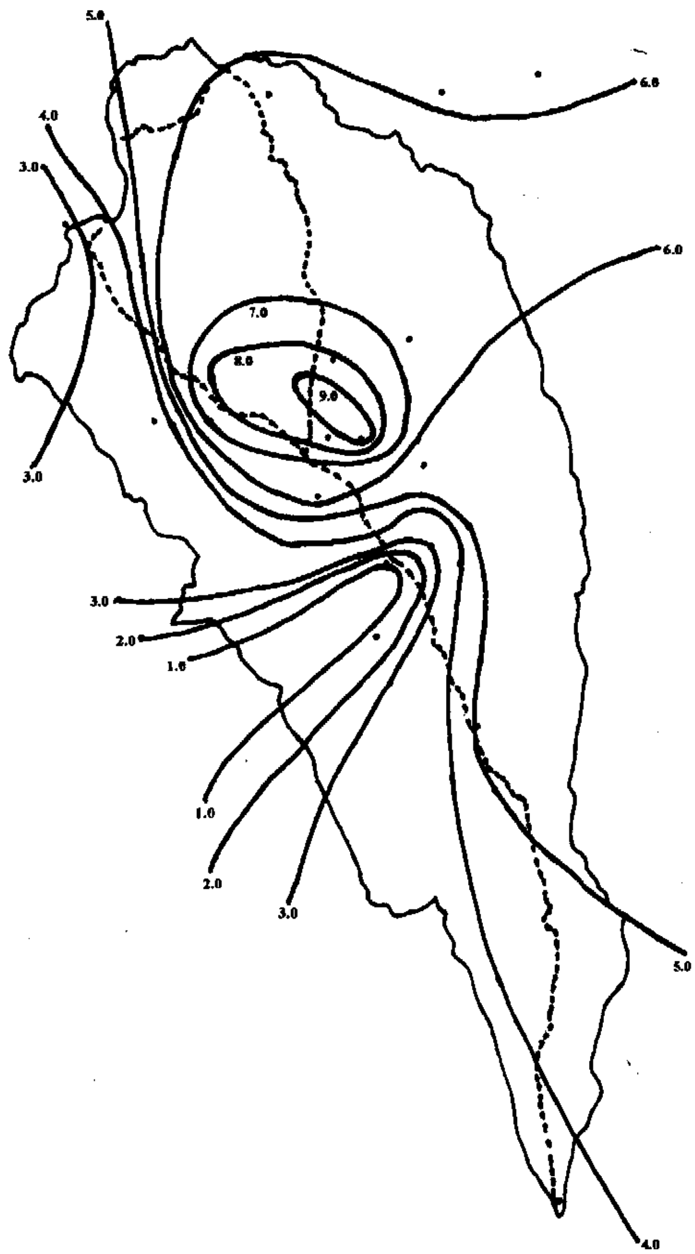


Figure 3: Schematic map of Fountain Creek watershed showing the distribution of total observed rainfall during the period April 28-May 2, 1999, for the major storm event addressed in this work. Contour lines indicate rainfall in inches.

Table 2: Comparison of 100-year 24-hour storms for the region of Colorado Springs, indicated by the references discussed in Section 3 of this report, with total rainfall observed in the vicinity of Colorado Springs during April 28-May 2, 1999, for the storm event described in Section 5.1 of this report. Rainfall totals are given in inches and are the maximum values observed during the storm event for the given duration, except where an asterisk (*) indicates total rainfall during the 84-hour event. The determination of reference values employed maps (m) and regression equations (r) given in the indicated references.

Duration of Rainfall	NOAA TP-40 (m)	NOAA TP-49 (m)	NOAA Atlas 2 (m/r)	Colorado College (C.S. Utilities)	Colorado Springs (NOAA/NWS)	Manitou Springs (NOAA/NWS)
1 hour	2.4 in	N/A	2.6 in	0.59 in	0.57 in	0.70 in
2 hours	2.7 in	N/A	2.9 in	0.83 in	0.78 in	1.20 in
3 hours	2.8 in	N/A	3.1 in	1.03 in	0.89 in	1.80 in
6 hours	3.4 in	N/A	3.5 in	1.78 in	1.51 in	2.50 in
12 hours	3.8 in	N/A	4.0 in	3.11 in	2.51 in	3.20 in
24 hours	4.3 in	N/A	4.4 in	5.55 in	3.30 in	4.80 in
48 hours	N/A	4.9 in	N/A	8.34 in	4.76 in	6.80 in
96 hours	N/A	5.5 in	N/A	9.36 in*	5.75 in*	7.80 in*

2. The weather patterns supporting each of the rainfall events discussed here were easily identified, even for the minor events not examined in detail, and the contribution of several of these patterns to heavy, sometimes flood-producing rainfall along the Colorado Front Range is well known.
3. Though the meteorological conditions supporting the April 28-May 2, 1999, event have been documented previously, a succession of these specific weather patterns is rare and, in previous known cases, has produced excessive rainfall and devastating flood and flash flood conditions. Specifically, similar conditions and flood events have been observed for the Big Thompson Canyon flood on July 31, 1976, and for the Fort Collins flood on July 27-29, 1997.
4. The April 28-May 2, 1999, event was preceded by heavy snowstorms in upstream portions of the Fountain Creek basin that likely led to near-saturated soil conditions in that portion of the basin. A combination of near-saturated soil conditions and heavy initial rainfall during the April 28-May 2, 1999, event led to greater runoff than would have occurred for dry antecedent conditions. Given the complete saturation of soils during the first storm of this event, all of the rainfall during the sustained and intense second storm of the event was likely converted to runoff.
5. Maximum 24-hour rainfall totals at the Colorado College and Manitou Springs NWS stations during the April 28-May 2, 1999, event exceeded all available measures of the regional 100-year 24-hour storm, including that provided in the Drainage Criteria Manual adopted by the City of Colorado Springs and El Paso County, Colorado. In addition, the total event (84-hour) rainfall at each of these two stations and at the Colorado Springs NWS station exceeded the 100-year 96-hour storm total rainfall as indicated in the only available reference for such data. It has been noted that the 2.63 inches of rainfall recorded at the Colorado Springs NWS station on April 30, 1999, is the largest daily precipitation amount during April on record for that location.

6. For the event described here during August 3-7, 1999, a maximum 24-hour rainfall total of 4.22 inches was recorded at the Colorado Springs NWS station around August 4, 1999. The total rainfall for this event also approached, but did not exceed, the 100-year 24-hour storm indicated for the region of Colorado Springs in the available references. However, it has been noted that the 3.98 inches of rainfall recorded at the Colorado Springs NWS station on August 4, 1999, is the largest single-day precipitation amount on record for that location.
7. References such as the NOAA Atlas 2 maps employed for the estimation of total storm rainfall in the Drainage Criteria Manual adopted by the City of Colorado Springs and El Paso County, Colorado, do not account for the rare succession of meteorological patterns that led to the April 28-May 2, 1999, event.
8. The observed rainfall distributions during the April 28-May 2, 1999, event differed significantly from the SCS Type IIA rainfall distribution suggested in the Drainage Criteria Manual. While the distribution suggested for the design of drainage facilities may accurately represent a type of High Plains thunderstorm that is common to the region of Colorado Springs, intense rainfall during the observed event resulted from nearly stationary convective storms that were supported by upslope flows.

3. Report No. 2: Hydrologic/Hydraulic Analysis of April 28-May 2, 1999, Event

3.1. Report Summary

Report No. 2 addressed the magnitudes of observed and simulated stream discharges and flow velocities at selected sites along Fountain Creek downstream of Colorado Springs during the major storm event that occurred on April 28-May 2, 1999. The methodology for model construction and use was oriented toward the exploration of alternative scenarios regarding conditions of development and urbanization in the studied watershed.

The major storm event that occurred on April 28-May 2, 1999, was simulated using a SWMM RUNOFF model. The physical layout of the hydrologic model is shown in **Figure 4**. A test simulation using a minor storm event revealed the necessity of supplemental hyetograph input so that areas where rainfall observations were nonexistent, or where nearby observations were unreliable due to changes in topography, could be represented in the SWMM RUNOFF model for the simulation of observed stream discharges and total flow volumes at various USGS stream gauge locations. Initial simulations of the major storm event, shown in **Figure 5**, revealed that the observed rainfall data produced discharge hydrographs at locations in and downstream of Colorado Springs that were much smaller than those observed. The formulation of supplemental hyetographs in areas where rainfall observations were inadequate was thus employed in order to develop an accurate simulation of the major storm event.

Observed stream discharge hydrographs at USGS gauge locations along Fountain Creek in and downstream of Colorado Springs were then simulated to a high degree of accuracy. The distribution of event total rainfall in the Fountain Creek watershed required for the simulation of observed flow hydrographs is shown in **Figure 6**. This should be compared with that obtained using only observed rainfall (**Figure 3**). The resulting simulated hydrographs at USGS gauges 07105500 and 07105530, in and near the City of Colorado Springs, are shown in **Figures 7a** and **7b**. Compiled data regarding the results and accuracy of this hydrologic simulation effort are listed in **Table 3**.

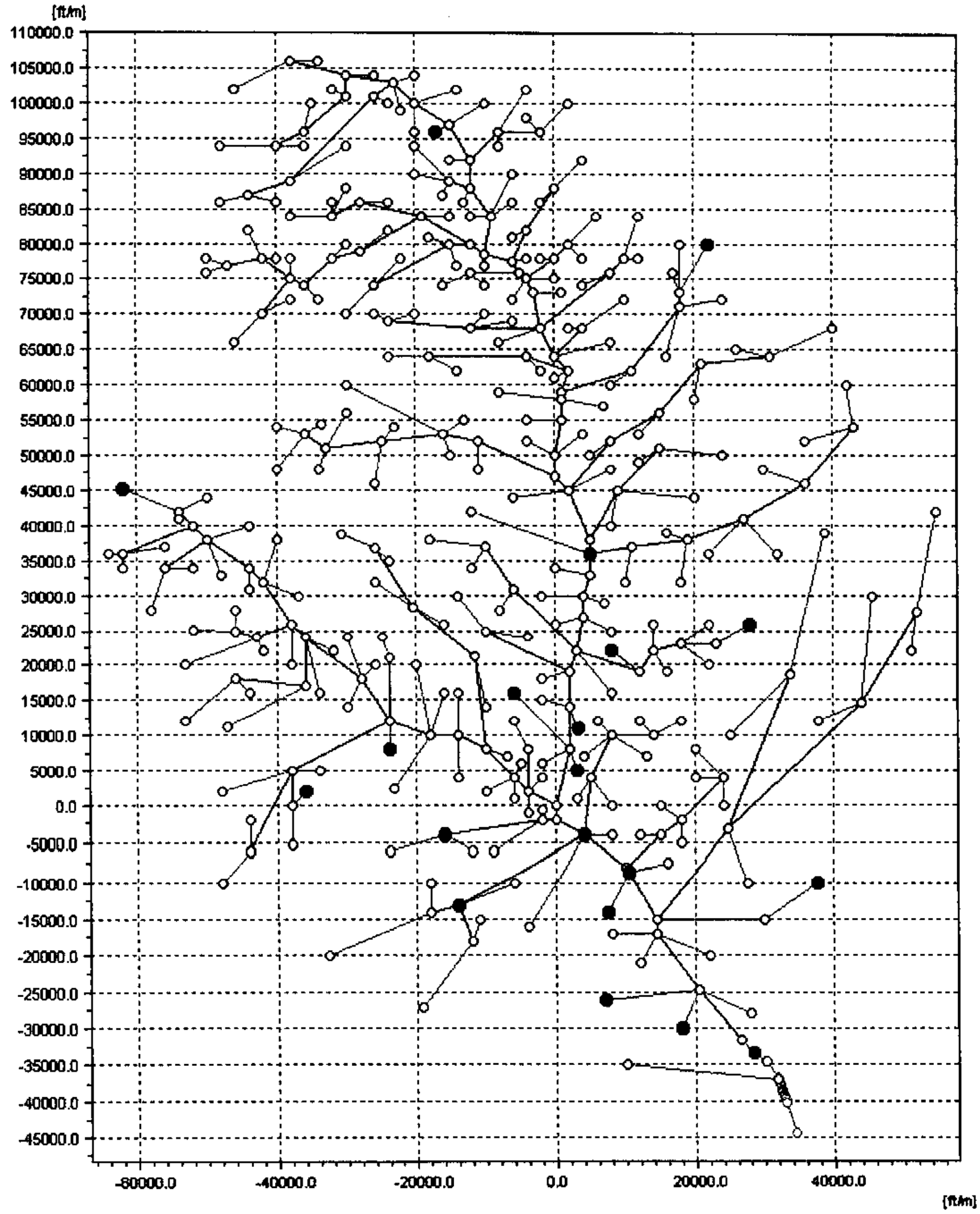


Figure 4: Schematic diagram of SWMM RUNOFF model sub-basins (with orange drainage paths attached) and stream channels (with black flow paths attached) within the Fountain Creek watershed in the region upstream of USGS stream flow gauge 07105800. The reference point (0,0) occurs at the confluence of Fountain and Monument Creeks in Colorado Springs. Scales on the axes shown here are given in feet north and east of the reference point. Additional color-coded reference points correspond to USGS stream gauge locations (red), rain gauges for which hourly rainfall data was available (dark blue), and rain gauges for which daily rainfall data was available (light blue).

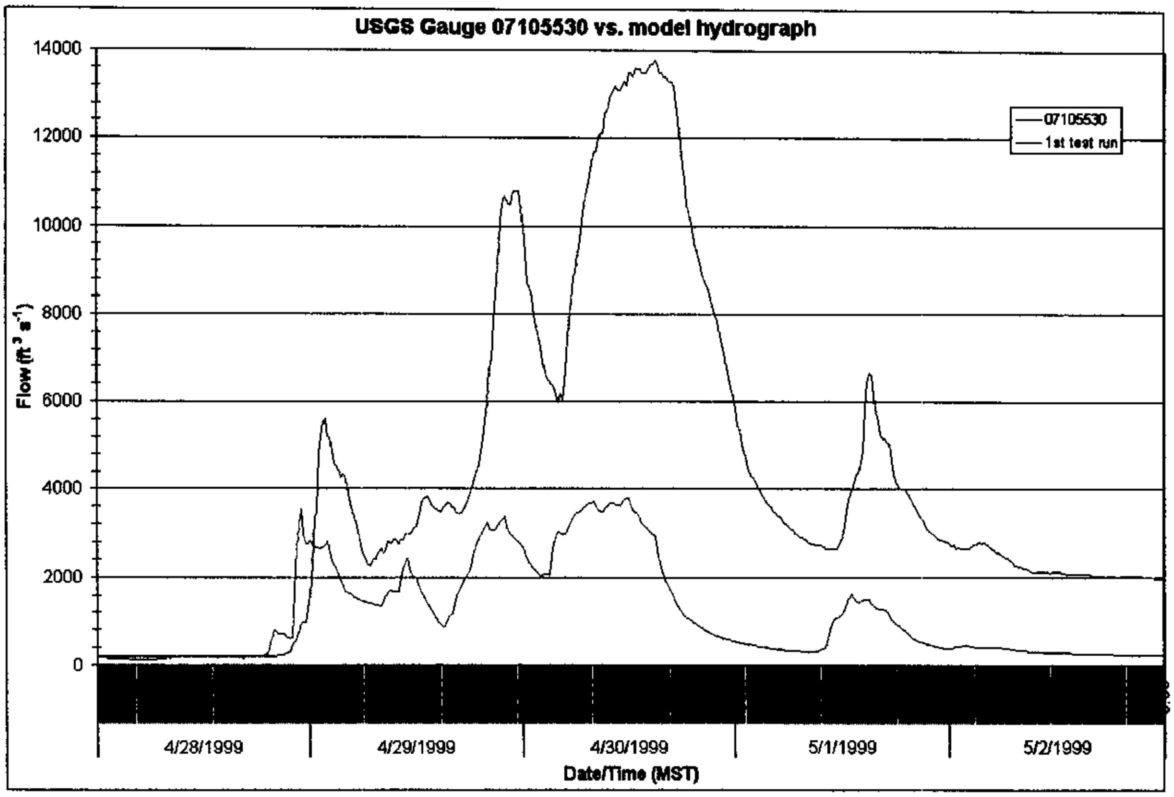


Figure 5: Simulated hydrograph for the major storm event during April 28-May 2, 1999, at the location of USGS gauge 07105530, using only observed rainfall at the gauge locations indicated in **Figure 4**.

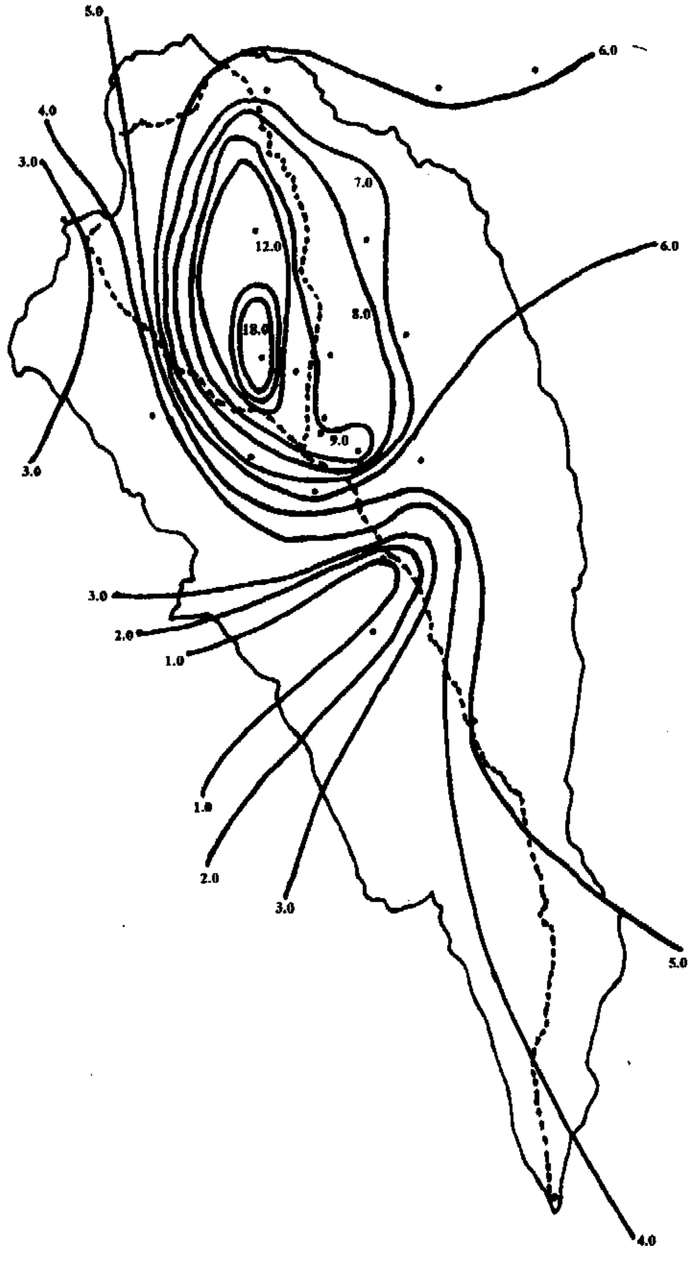
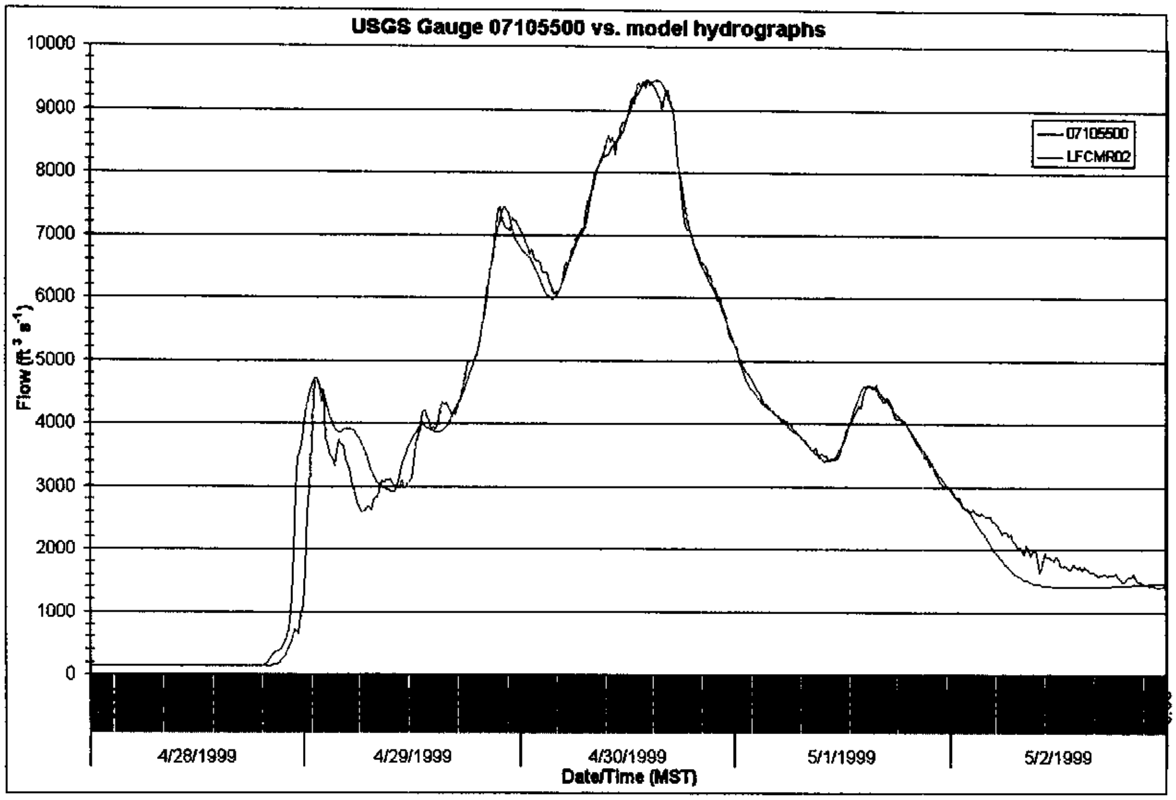


Figure 6: Schematic map of Fountain Creek watershed showing the distribution of total rainfall during the period April 28-May 2, 1999, required for accuracy in the simulation of streamflow hydrographs as shown below. Contour lines indicate rainfall in inches.



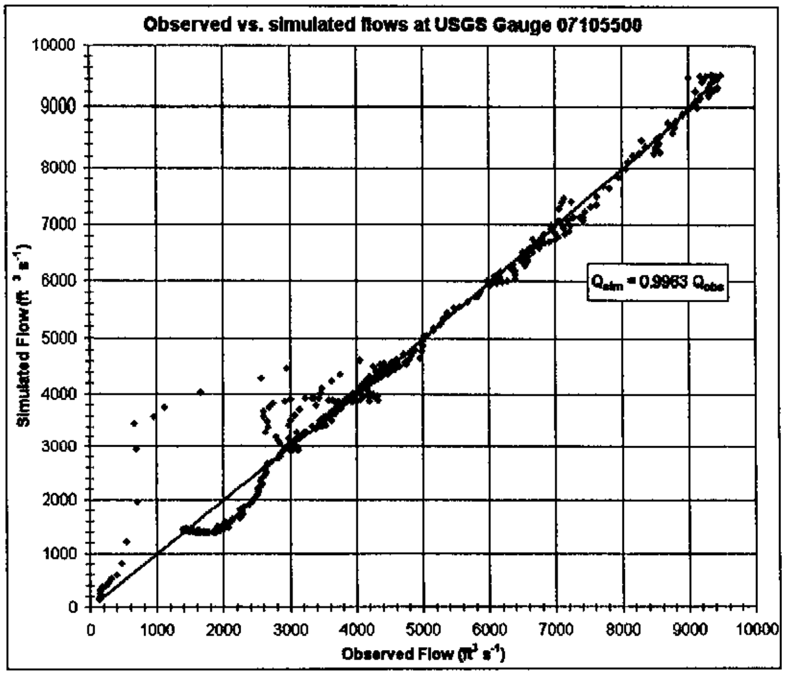
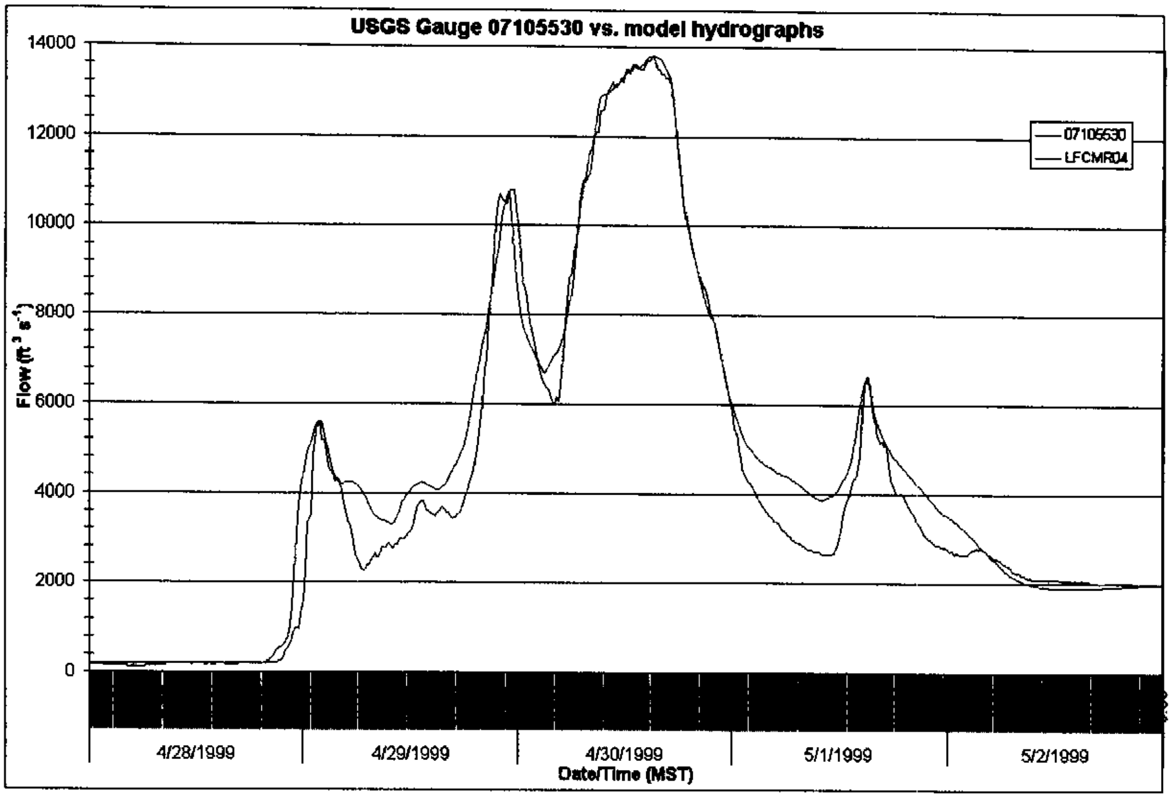


Figure 7a: Simulated hydrograph for the major storm event during April 28-May 2, 1999, at the location of USGS gauge 07105500, and a graph demonstrating the correlation between (concurrent) observed and simulated discharges at that location.



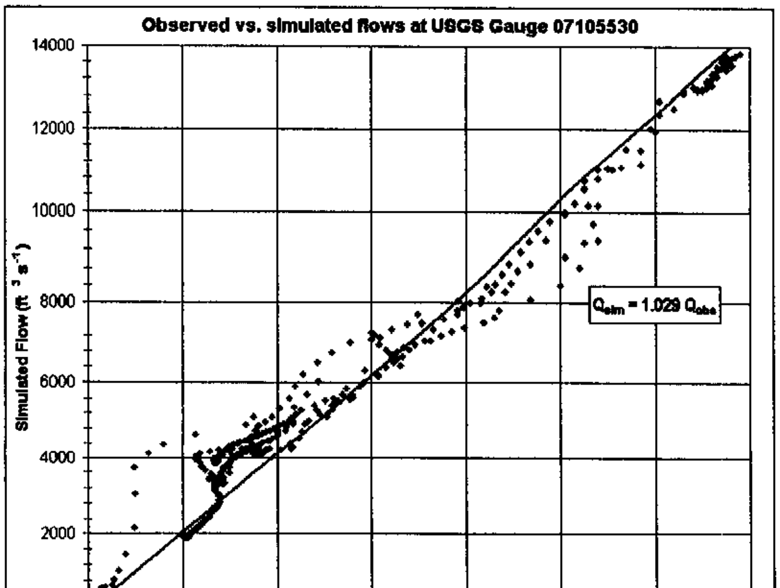


Figure 7b: Simulated hydrograph for the major storm event during April 28-May 2, 1999, at the location of USGS gauge 07105530, and a graph demonstrating the correlation between (concurrent) observed and simulated discharges at that location.

Table 3: Results of RUNOFF simulation of the major storm event during April 28-May 2, 1999.

RUNOFF Results for April 28-May 2, 1999 event

Gauge	Location	Channel Outflow	Observed Peak 1			Modeled Peak 1 (BasinR31.dat)				
			Base Flow	Total Flow	Time	Flow	Error	% Error	Time	Error
07104000	Lower Mon Ck	LMCVR04	146.31	1730	4/29/99 3:30	1592.61	3.12	0.6%	4/29/99 3:30	0.00
07105000	Bear Ck	BRCa (runoff)	0.00	66	4/29/99 8:45	44.99	-11.01	-19.7%	N/A	N/A
07105490	Cheyenne Ck	SWbC + dC	24.21	148	4/29/99 2:30	128.45	2.67	2.2%	4/29/99 3:00	0.50
07105500	Lower Ftn Ck	LFCVR02	213.98	4720	4/29/99 1:15	4504.93	-4.20	-0.1%	4/29/99 1:15	0.01
07105530	Lower Ftn Ck	LFCVR04	312.08	5600	4/29/99 1:45	5292.70	2.77	0.1%	4/29/99 1:47	0.03

Gauge	Location	Channel Outflow	Observed Peak 2			Modeled Peak 2 (BasinR50.dat)				
			Base Flow	Total Flow	Time	Flow	Error	% Error	Time	Error
07104000	Lower Mon Ck	LMCVR04	269.69	2790	4/29/99 22:30	2516.56	-4.25	-0.2%	4/29/99 22:36	0.06
07105000	Bear Ck	BRCa (runoff)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
07105490	Cheyenne Ck	SWbC + dC	42.35	238	4/29/99 17:15	198.77	3.09	1.6%	4/29/99 17:00	-0.15
07105500	Lower Ftn Ck	LFCVR02	474.75	7450	4/29/99 21:45	8957.67	-17.41	-0.2%	4/29/99 22:13	0.34
07105530	Lower Ftn Ck	LFCVR04	654.33	10800	4/29/99 23:00	10092.59	-22.75	-0.2%	4/29/99 23:02	0.03

Gauge	Location	Channel Outflow	Observed Peak 3			Modeled Peak 3 (BasinR72.dat)				
			Base Flow	Total Flow	Time	Flow	Error	% Error	Time	Error
07104000	Lower Mon Ck	LMCVR04	376.84	4890	4/30/99 15:05	4509.56	-3.50	-0.1%	4/30/99 15:03	-0.03
07105000	Bear Ck	BRCa (runoff)	0.00	185	4/30/99 18:35	155.39	-29.61	-16.0%	N/A	N/A
07105490	Cheyenne Ck	SWbC + dC	72.09	565	4/30/99 17:55	435.91	-57.00	-11.6%	4/30/99 18:02	0.25
07105500	Lower Ftn Ck	LFCVR02	657.01	9490	4/30/99 14:15	8798.15	-6.85	-0.1%	4/30/99 14:14	-0.01
07105530	Lower Ftn Ck	LFCVR04	966.12	13800	4/30/99 15:00	12843.51	2.73	0.1%	4/30/99 15:02	0.03

Gauge	Location	Channel Outflow	Observed Peak 4			Modeled Peak 4 (BasinR96.dat)				
			Base Flow	Total Flow	Time	Flow	Error	% Error	Time	Error
07104000	Lower Mon Ck	LMCVR04	521.07	2070	5/1/99 14:45	1535.56	-3.27	-0.2%	5/1/99 15:00	0.15
07105000	Bear Ck	BRCa (runoff)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
07105490	Cheyenne Ck	SWbC + dC	37.56	276	5/1/99 14:15	179.50	1.36	0.8%	5/1/99 14:00	-0.15
07105500	Lower Ftn Ck	LFCVR02	1202.22	4610	5/1/99 14:45	3592.99	-14.79	-0.4%	5/1/99 15:00	0.15
07105530	Lower Ftn Ck	LFCVR04	1355.81	5550	5/1/99 15:30	5261.44	0.25	0.0%	5/1/99 15:30	0.00

	07105500	LFCMR02	Error	% Error	07105530	LFCMR04	Error	% Error
Flow Mean ($ft^3 s^{-1}$)	4172.6	4180.4	7.8	0.2%	4926.4	5306.6	380.2	7.7%
Flow St.D. ($ft^3 s^{-1}$)	2376.9	2361.7	-15.2	-0.6%	3659.2	3495.4	-163.8	-4.5%
Flow Max ($ft^3 s^{-1}$)	9490.0	9481.9	-8.1	-0.1%	13800.0	13810.4	10.4	0.1%
Flow Min ($ft^3 s^{-1}$)	133.0	137.0	4.0	3.0%	195.0	[illegible]	2.0	1.0%
Total Load (ac-ft)	35262.5	35326.3	63.8	0.2%	41630.3	44842.9	3212.5	7.7%
Serial correlation	0.9982	0.9989	0.0007	0.1%	0.9981	0.9987	0.0006	0.1%
Cross-correlation	0.9854				0.9856			
r^2=	0.9710				0.9714			
MAE ($ft^3 s^{-1}$)	214.1				521.7			
RMSE ($ft^3 s^{-1}$)	424.9				734.2			

Relative correlation measures

r = 1 indicates perfect direct linear correlation

r^2 indicates (1) "coefficient of determination"
(2) "goodness of fit"
(3) "portion of variance explained"

Absolute correlation measures

Simulation Errors in (1) Flow Mean
(2) Total Load

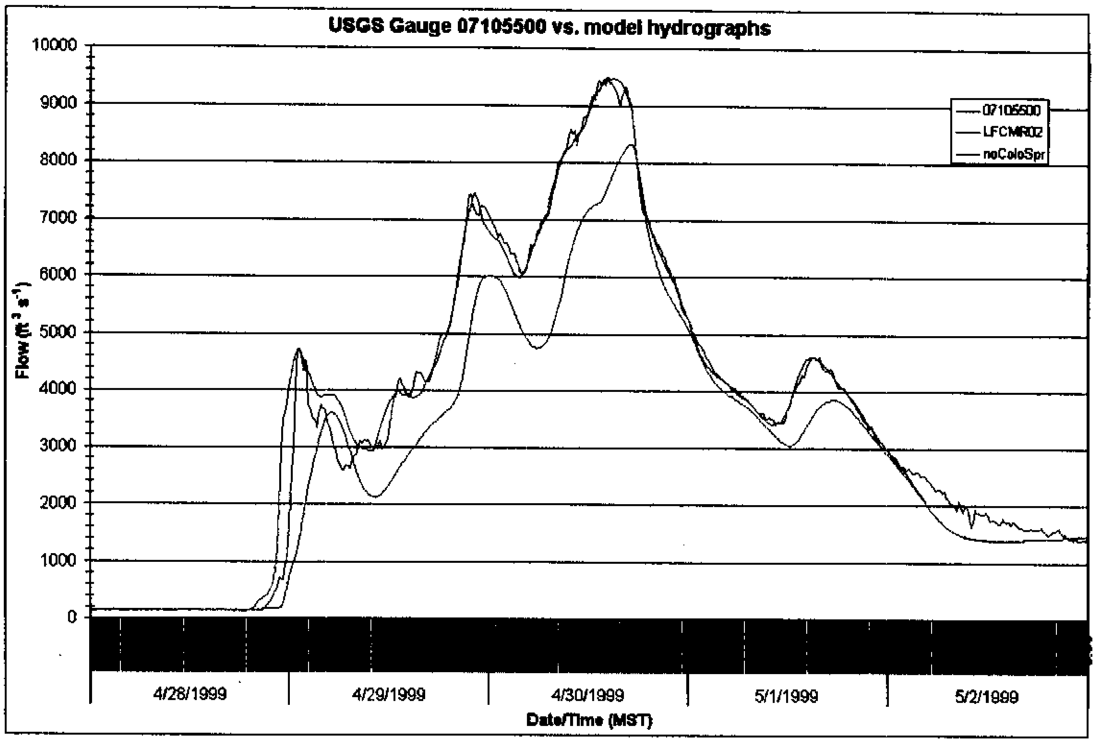
Mean Absolute Error (MAE)

Root-Mean-Squared Error (RMSE)

Subsequent simulations explored the alternative scenario of pre-development conditions in the area of the City of Colorado Springs. The goal of posing this alternative was to determine the effects of development and urbanization in Colorado Springs on the stream discharges and total flow volumes in downstream reaches of Fountain Creek. The stream discharge results at the two USGS gauge locations listed above for this alternative scenario are shown in **Figure 8**. It was found that development in the area of the City of Colorado Springs resulted in an increase of peak discharges in Fountain Creek of 12-14% and an increase in total flow volume in Fountain Creek of 20-25% during this major storm event.

A detailed hydraulic model representing a portion of Fountain Creek downstream of Colorado Springs in the vicinity of USGS gauge 07105800, the KOA property, and the Greenview Ditch Headworks was also applied. A close-up view of the portion of this model located near the KOA property is shown in **Figure 9**. The specification of stream channel cross-sections for existing conditions, which include a levee along the left bank of Fountain Creek downstream of the bridge at Colorado Highway 16, and historical conditions (prior to levee construction, with a nearly unrestricted floodplain along that same portion of Fountain Creek) were described. The hydraulic behavior of flows in this portion of Fountain Creek was simulated with SWMM EXTRAN, using output hydrographs from the RUNOFF model for the scenarios of current development and pre-development conditions in upstream areas of the Fountain and Monument Creek watershed. The water surface profiles at peak discharge near the KOA property during the major storm event for the current and historical channel/floodplain configurations are shown in **Figures 10** and **11**, respectively. Though these results apply specifically to the case of current development in the upstream area, the water surface profiles for pre-development conditions in the upstream area are little different for the respective channel/floodplain configurations and are not shown here. The simulated stream discharges and flow velocities at the location of the KOA property along Fountain Creek for these four cases are shown in **Figure 12**. Compiled data demonstrating the potential effects of upstream development and floodplain constriction at the location of the KOA property are included in **Table 4**.

Through an analysis of observed rainfall and stream discharge observations available for the lower portion of the Fountain Creek watershed, it was found that exclusion of that area from the rainfall/runoff model described here played an insignificant role in the simulation of stream discharges and flow velocities at the location of the Greenview Ditch Headworks. The simulated stream discharges and flow velocities at the location of the Greenview Ditch Headworks along Fountain Creek for the cases of current and pre-development conditions in the upstream area are shown in **Figure 13**. Compiled data demonstrating the potential effects of upstream development at the location of the Greenview Ditch Headworks are included in **Table 5**.



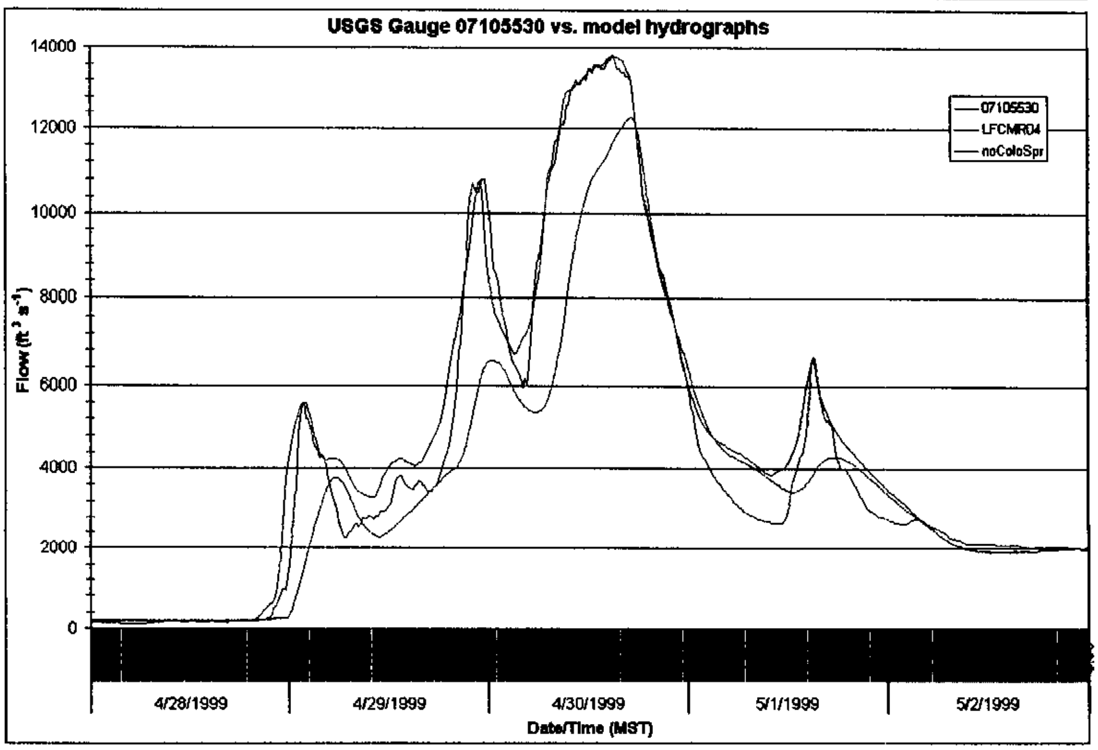


Figure 8: Simulated hydrographs for the major storm event during April 28-May 2, 1999, at the locations of USGS gauges 07105500 and 07105530, for the case of pre-development conditions in the area of the City of Colorado Springs.

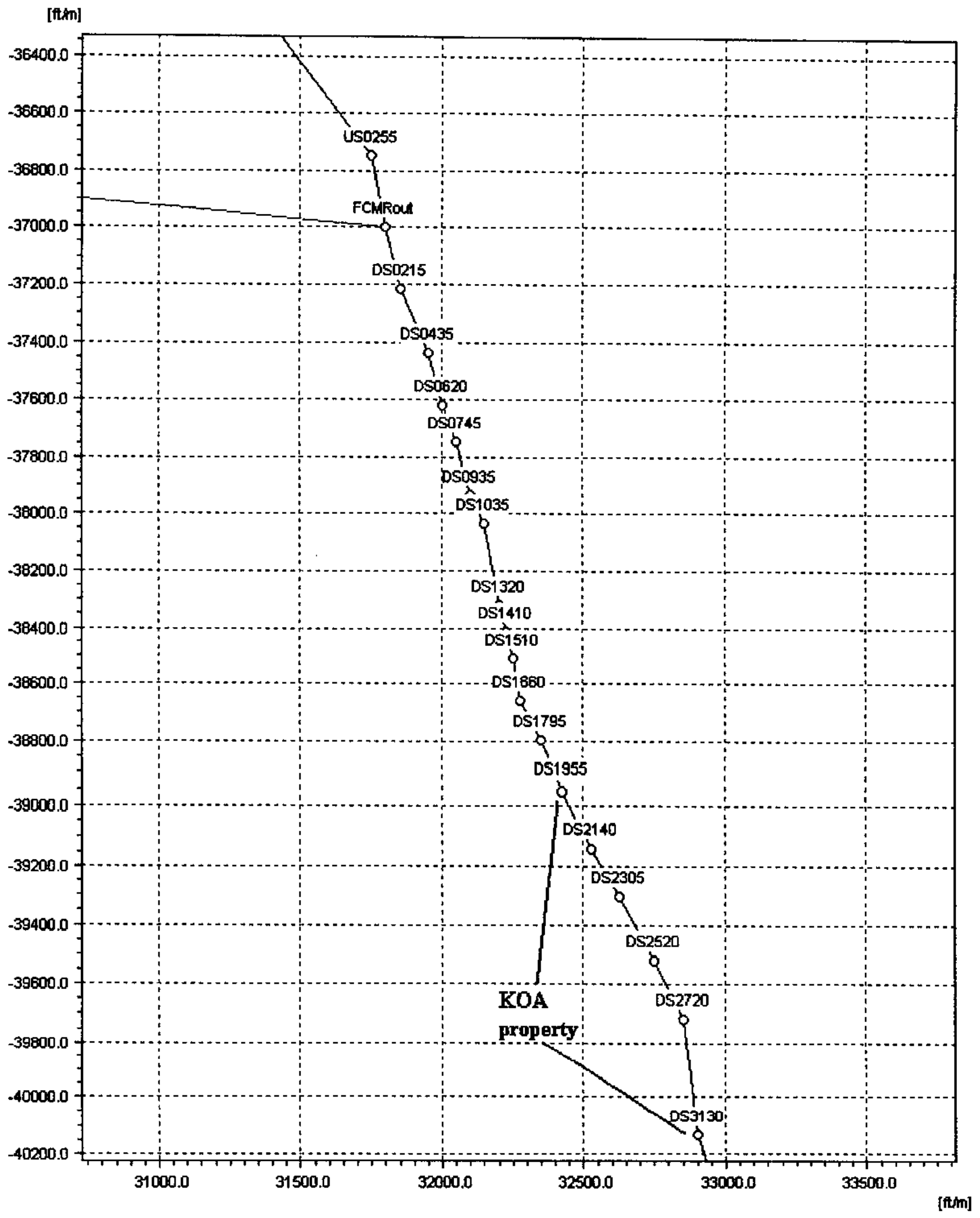


Figure 9: Detailed plan view of SWMM EXTRAN model stream channels for a portion of Fountain Creek downstream of Colorado Springs. The reference point (0,0) occurs at the confluence of Fountain and Monument Creeks in Colorado Springs. Scales on the axes shown here are given in feet north and east of the reference point.

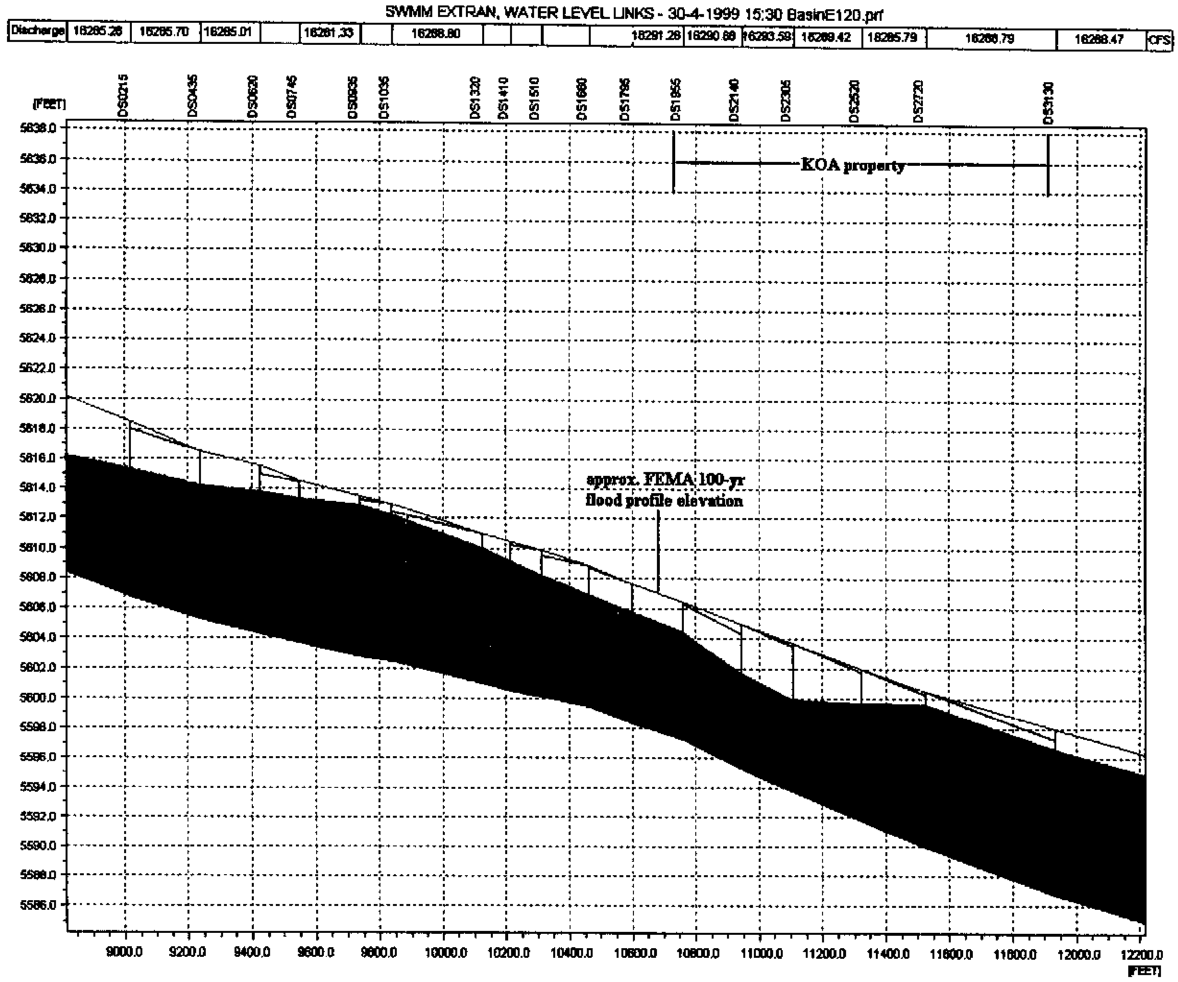


Figure 10: Close-up view of simulated stream channel water surface profile in the EXTRAN model segments immediately upstream of and adjacent to the KOA property along Fountain Creek for the major storm event during April 28-May 2, 1999. The profile shown corresponds to peak flow conditions near 3:30 pm on April 30, 1999. Junction names and discharges (in ft^3 s^{-1}) for individual channel segments are shown near the top of the diagram.

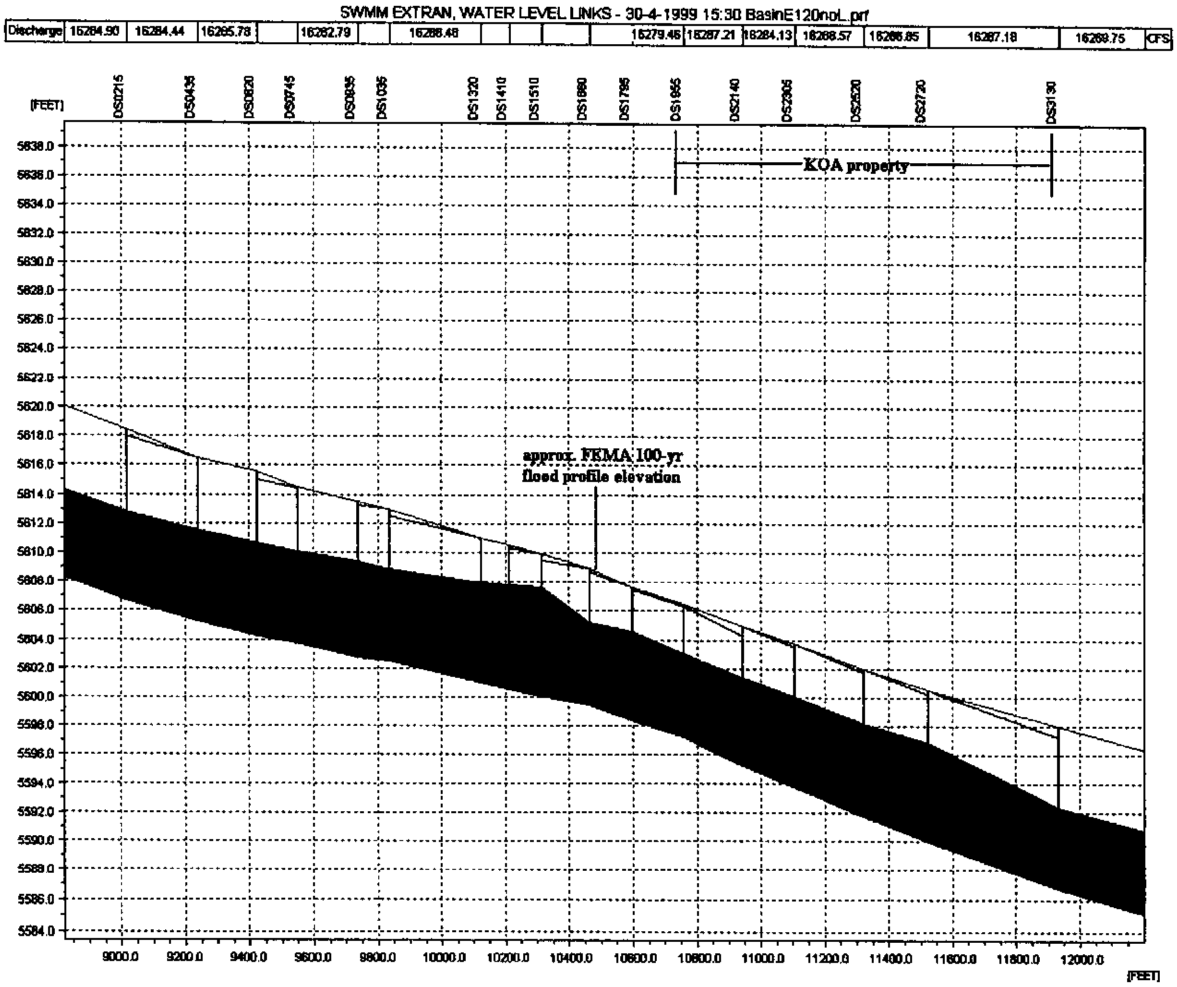


Figure 11: Close-up view of simulated stream channel water surface profile in the EXTRAN model segments immediately upstream of and adjacent to the KOA property along Fountain Creek for the major storm event during April 28-May 2, 1999, in the absence of the left bank levee downstream of the bridge at Colorado Highway 16. This result should be compared with that shown above in **Figure 10**. The profile shown corresponds to peak flow conditions near 3:30 pm on April 30, 1999. Junction names and discharges (in ft^3 s^{-1}) for individual channel segments are shown near the top of the diagram.

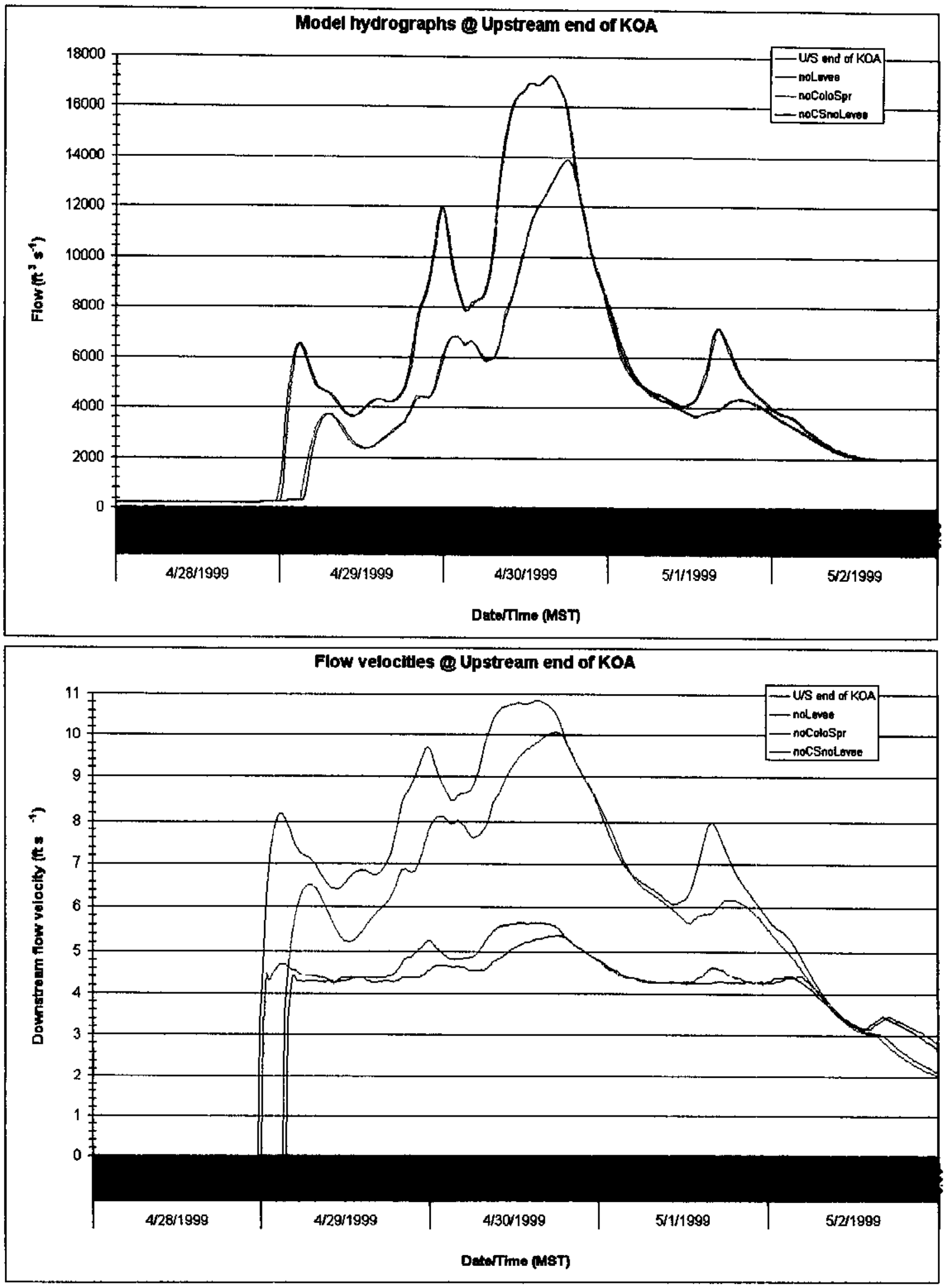


Figure 12: Simulated hydrographs and flow velocities for the major storm event during April 28-May 2, 1999, at the upstream end of the KOA property along Fountain Creek, for the four cases described in the text.

Table 4: Compiled results of EXTRAN simulations of stream flows and flow velocities using current and historical configurations of channel segments in a portion of Fountain Creek under pre-development and current development conditions in upstream areas. These results are for the location of the upstream end of the KOA property along Fountain Creek.

EXTRAN Results for April 28-May 2, 1999 event

	Upstream end of KOA property (LFCMR14a)			
	Pre-devel.	Current	Change	% Change
Flow Mean ($ft^3 s^{-1}$)	3900.3	5198.2	1297.9	33.3%
Flow St.D. ($ft^3 s^{-1}$)	3430.4	4632.6	1202.2	35.0%
Flow Max ($ft^3 s^{-1}$)	13883.5	17265.6	3382.1	24.4%
Flow Min ($ft^3 s^{-1}$)	200.0	200.0	0.0	0.0%
Total Load (ac-ft)	38681.0	51552.4	12871.4	33.3%

	Upstream end of KOA property (LFCMR14a)			
	Current	w/o Levee	Change	% Change
Flow Mean ($ft^3 s^{-1}$)	5198.2	5196.9	-1.3	0.0%
Flow St.D. ($ft^3 s^{-1}$)	4632.6	3430.4	-1202.2	-26.0%
Flow Max ($ft^3 s^{-1}$)	17265.6	13883.5	-3382.1	-19.6%
Flow Min ($ft^3 s^{-1}$)	200.0	200.0	0.0	0.0%
Total Load (ac-ft)	51552.4	38681.0	-12871.4	-25.0%

	Upstream end of KOA property (LFCMR14a)			
	Pre-devel.	w/o Levee	Change	% Change
Flow Mean ($ft^3 s^{-1}$)	3900.3	3899.2	-1.2	0.0%
Flow St.D. ($ft^3 s^{-1}$)	3430.4	3434.9	4.5	0.1%
Flow Max ($ft^3 s^{-1}$)	13883.5	13881.5	-2.0	0.0%
Flow Min ($ft^3 s^{-1}$)	200.0	200.0	0.0	0.0%
Total Load (ac-ft)	38681.0	38663.3	-17.7	0.0%

From River Engineering for Highway Encroachments (Richardson *et al.* 2001)
Hydraulic Design Series No. 6, FHWA NHI 01-004, 2001
Table 3.5 (p. 3.44): Nonscour Velocities for Soils

Soil Type	Mean Depth	Nonscour V
Coarse sand (noncohesive, D_{50} = 0.5-1.0 mm)	5.6 ft	2.1 ($ft\ s^{-1}$)
Sandy loam (cohesive)	5.6 ft	4.6 ($ft\ s^{-1}$)

	Upstream end of KOA property (LFCMR14a)			
	Pre-devel.	Current	Change	% Change
Velocity Mean ($ft\ s^{-1}$)	4.78	5.52	0.73	15.3%
Velocity St.D. ($ft\ s^{-1}$)	3.18	3.46	0.28	8.8%
Velocity Max ($ft\ s^{-1}$)	10.09	10.83	0.74	7.3%
Velocity Min ($ft\ s^{-1}$)	0.00	0.00	0.00	0.0%
Time above 2.1 $ft\ s^{-1}$ (h)	92.00	96.50	4.50	4.9%
Time above 4.6 $ft\ s^{-1}$ (h)	72.75	77.50	4.75	6.5%

	Upstream end of KOA property (LFCMR14a)			
	Current	w/o Levee	Change	% Change
Velocity Mean ($ft\ s^{-1}$)	5.52	3.55	-1.97	-35.6%
Velocity St.D. ($ft\ s^{-1}$)	3.46	1.88	-1.58	-45.6%
Velocity Max ($ft\ s^{-1}$)	10.83	5.65	-5.18	-47.8%
Velocity Min ($ft\ s^{-1}$)	0.00	0.00	0.00	0.0%
Time above 2.1 $ft\ s^{-1}$ (h)	96.50	96.00	-0.50	-0.5%
Time above 4.6 $ft\ s^{-1}$ (h)	77.50	32.50	-45.00	-58.1%

	Upstream end of KOA property (LFCMR14a)			
	Pre-devel.	w/o Levee	Change	% Change
Velocity Mean ($ft\ s^{-1}$)	4.78	3.30	-1.48	-30.9%
Velocity St.D. ($ft\ s^{-1}$)	3.18	1.88	-1.30	-41.0%
Velocity Max ($ft\ s^{-1}$)	10.09	5.38	-4.71	-46.7%
Velocity Min ($ft\ s^{-1}$)	0.00	0.00	0.00	0.0%
Time above 2.1 $ft\ s^{-1}$ (h)	92.00	92.50	0.50	0.5%
Time above 4.6 $ft\ s^{-1}$ (h)	72.75	22.00	-50.75	-69.8%

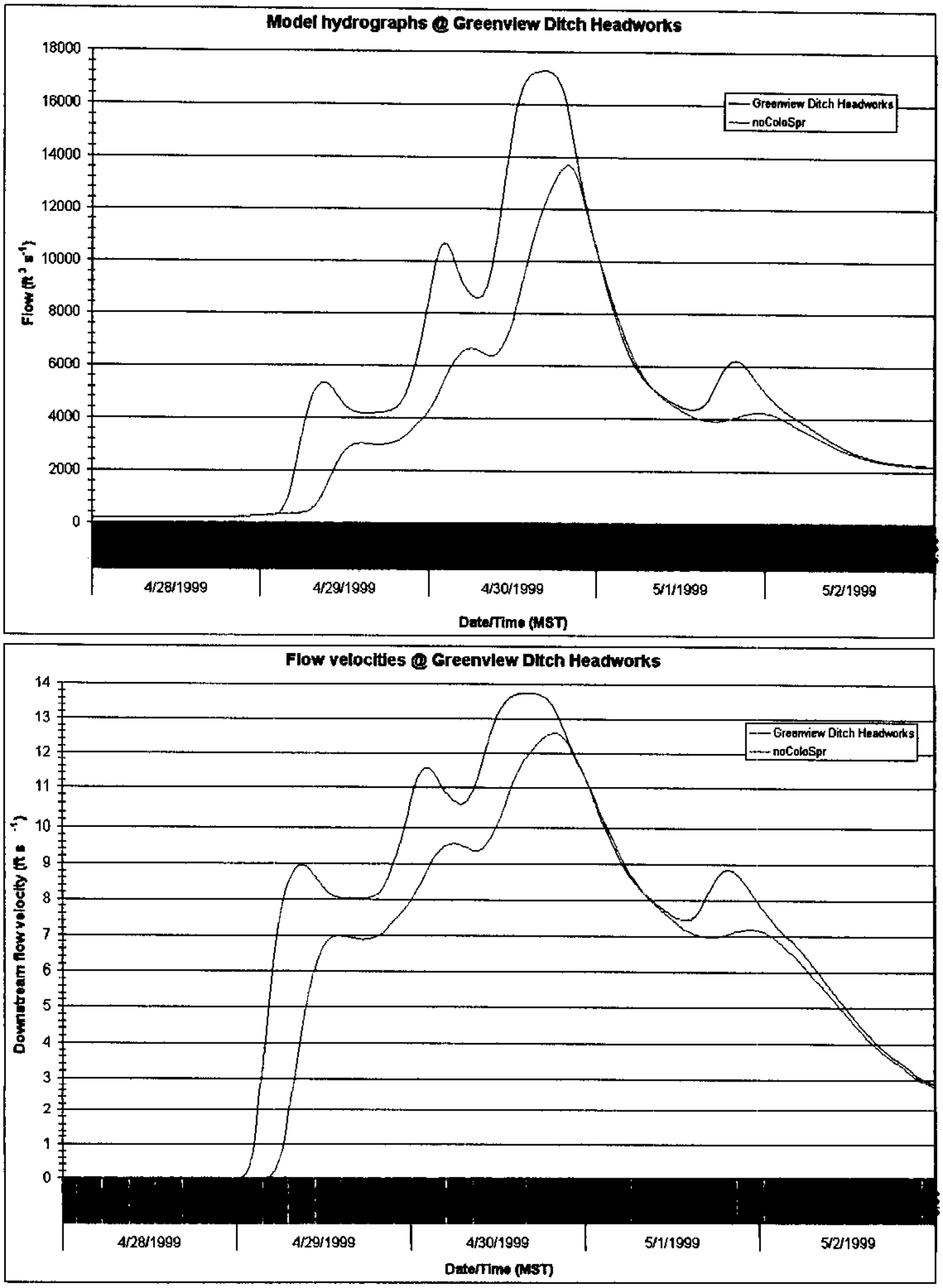


Figure 13: Simulated hydrographs and flow velocities for the major storm event during April 28-May 2, 1999, at the location of the Greenview Ditch Headworks near Pueblo, Colorado, for the cases of current and pre-development conditions in the area of the City of Colorado Springs.

Table 5: Compiled results of EXTRAN simulations of stream flows and flow velocities in a portion of Fountain Creek under pre-development and current development conditions in upstream areas. These results are for the location of the Greenview Ditch Headworks along Fountain Creek near Piñon, Colorado.

EXTRAN Results for April 28-May 2, 1999 event

	Greenview Ditch Headworks (LFCMR18)			
	Pre-devel.	Current	Change	% Change
Flow Mean ($ft^3 s^{-1}$)	[illegible]	[illegible]	[illegible]	[illegible]
Flow St.D. ($ft^3 s^{-1}$)	2463.6	[illegible]	[illegible]	[illegible]
Flow Max ($ft^3 s^{-1}$)	[illegible]	[illegible]	[illegible]	[illegible]
Flow Min ($ft^3 s^{-1}$)	[illegible]	[illegible]	0.0	0.0%
Total Load (ac-ft)	[illegible]	[illegible]	[illegible]	[illegible]

From River Engineering for Highway Encroachments (Richardson et al. 2001)
Hydraulic Design Series No. 6, FHWA NHI 01-004, 2001
Table 3.5 (p. 3.44): Nonscour Velocities for Soils

Soil Type	Mean Depth	Nonscour V
Coarse sand (noncohesive, [illegible] = 0.5-1.0 mm)	6.6 ft	2.1 ($ft s^{-1}$)
Sandy loam (cohesive)	6.6 ft	4.6 ($ft s^{-1}$)

	Greenview Ditch Headworks (LFCMR18)			
	Pre-devel.	Current	Change	% Change
Velocity Mean ($ft s^{-1}$)	[illegible]	6.60	[illegible]	[illegible]
Velocity St.D. ($ft s^{-1}$)	[illegible]	4.34	[illegible]	[illegible]
Velocity Max ($ft s^{-1}$)	[illegible]	[illegible]	[illegible]	[illegible]
Velocity Min ($ft s^{-1}$)	0.00	0.00	0.00	0.0%
Time above 2.1 $ft s^{-1}$ (h)	[illegible]	[illegible]	4.25	4.8%
Time above 4.6 $ft s^{-1}$ (h)	[illegible]	[illegible]	[illegible]	7.6%

3.2. Conclusions

The results of these simulations for the various specified scenarios and cases were examined in detail. Overall, comparisons of these simulation results showed that:

1. Both the western and eastern portions of the City of Colorado Springs were subjected to heavy rainfall cells during the peak period of this storm event. The apparent dynamics of the storm during April 30, 1999, are indicated by examinations of surface weather observations and comparisons of observed and supplemental hyètographs and could not have been determined from the sparse (in space and time) observational information employed for the event analysis presented in Report No. 1. As a result, in Report No. 2 analyses, the maximum rainfall rates and event rainfall totals applied to the foothills and downtown areas of Colorado Springs were significantly larger than those discussed in the earlier report.
2. The presence of the levee along the left bank of Fountain Creek downstream of the bridge at Colorado Highway 16 exerts little influence on discharges and flow velocities at the location of USGS gauge 07105800 upstream of the KOA property, but has a large influence on discharge and flow velocities in Fountain Creek in the immediate vicinity of the KOA property.
3. At the location of USGS gauge 07105800 along Fountain Creek, development in the upstream areas of the Fountain and Monument Creek watershed does increase discharges and flow velocities and, therefore, the potential for bed and bank erosion by hydraulic action.

4. Stream discharges at the location of the KOA property along Fountain Creek are affected by the combination of upstream development *and* the presence of the left-bank levee.
5. Flow velocities in the portion of Fountain Creek immediately upstream of and adjacent to the KOA property are affected to a far greater degree by the presence of the left-bank levee than by the development and urbanization of upstream areas.
6. Stream discharges and, to a lesser degree, flow velocities at the location of the Greenview Ditch Headworks near Piñon, Colorado, are affected by development and urbanization in upstream areas, but are likely also affected by the braided pattern and geomorphology of Fountain Creek in that vicinity. The simulated increases in flow velocity due to development in upstream areas remain less than 10%, leading to only small increases in the potential for bed and bank erosion by hydraulic action. Simulations of flows in Fountain Creek at that location are affected to an only slight degree by the exclusion from the simulations of rainfall/runoff processes in the lower portion of the Fountain Creek watershed.

4. Report No. 3: Assessment of the City of Colorado Springs' *Drainage Criteria Manual*

Report No. 3 was issued as a memorandum in review of the *Drainage Criteria Manual* ("the Manual") adopted by the City of Colorado Springs and El Paso County. Pertinent findings listed there are:

1. The Manual is well written and clear.
2. Its authors are up-to-date on current stormwater management issues and approaches.
3. Use of the major drainageways as amenities is good practice.
4. Adopting regional detention of stormwater as a policy, as indicated in the Manual, is better than requiring small local detention facilities. The storage volume sizing requirements are adequate (2-hour and 24-hour, 10-year and 100-year storms), and the emergency spillway requirements seem adequate. Design guidance provided in Section 11 is consistent with current design practice for flood control facilities.
5. Changing the design criterion from the use of a 10-yr initial design storm to the use of a 5-yr storm is good. It will result in a lower peak runoff rate for all storms larger than the 5-yr event, compared to the peak flow that would result from a system sized for a 10-yr initial design storm.
6. Section 4 ("Report Guidelines") is one of the better summaries on this topic that we have seen. These requirements force developers to reveal the basis of their design in a way that the City can insure that its requirements are met.

APPENDIX A

Figures

Figure 1: Colorado Springs and surrounding areas within the Fountain Creek basin. This map was created by the Pikes Peak Area Council of Governments (*http://www.ppacg.org*).

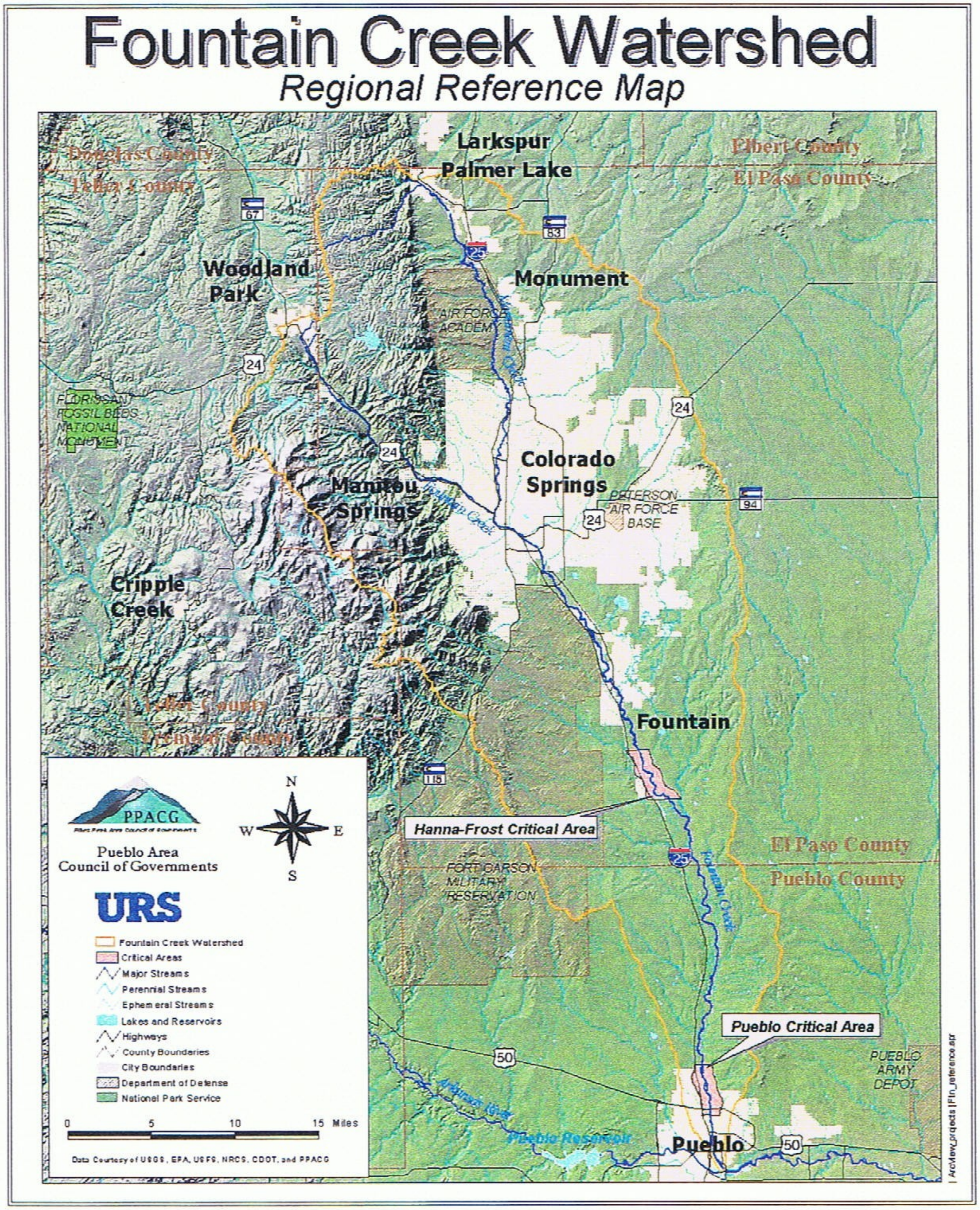


Figure 2: A portion of the NOAA Atlas 2 (Volume III: Colorado) map for Colorado Springs and the surrounding area showing rainfall totals for the 100-year 24-hour storm. Blue contour lines indicate surface elevation in thousands of feet. Black contour lines indicate 100-year 24-hour rainfall in tenths of an inch.

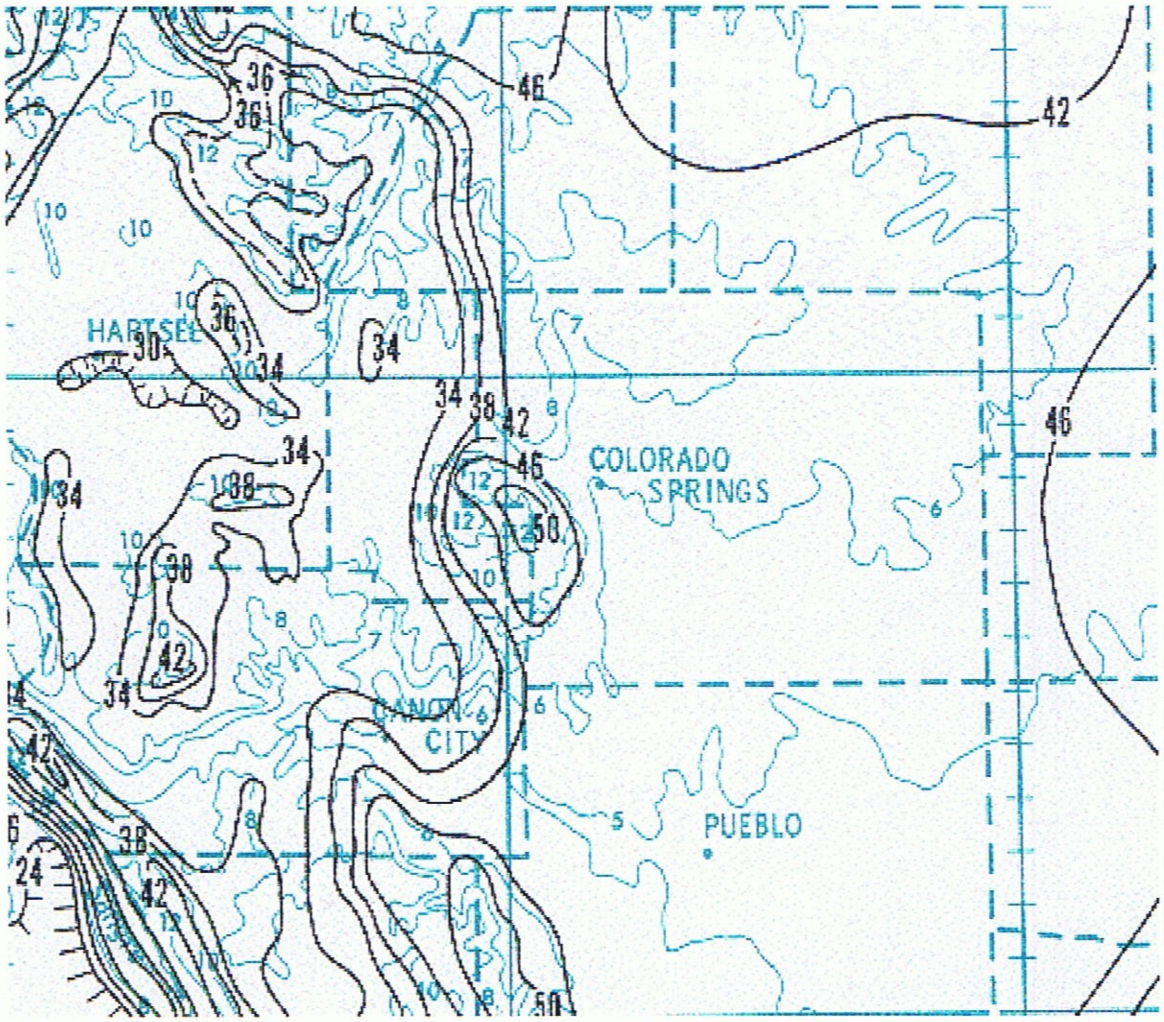


Figure 3: Charts showing the correlation of La Niña conditions in the eastern equatorial Pacific Ocean and seasonal precipitation along the Rocky Mountain Front Range, from the NOAA-CIRES Climate Diagnostic Center (*http://www.cdc.noaa.gov/Climaterisks*). Months are abbreviated: "DJF" indicates December-January-February, "MAM" indicates March-April-May, etc. The Southern Oscillation Index (SOI) is an indicator of El Niño/La Niña status that employs surface pressure observations in the tropical Pacific Ocean. These charts apply to the observation of precipitation extremes along the Rocky Mountain Front Range following La Niña events only; charts for precipitation extremes following El Niño events can also be found at the above website. To use these charts:

1. Select the chart corresponding to the season or period of the precipitation extreme (listed at the top of each chart).
2. On that chart, select the pair of histogram bars corresponding to the season or period of the most recent extreme La Niña event (listed on the horizontal axis of each chart).

The numbers of observed wet and dry seasonal precipitation extremes are then read from the selected pair of histogram bars.

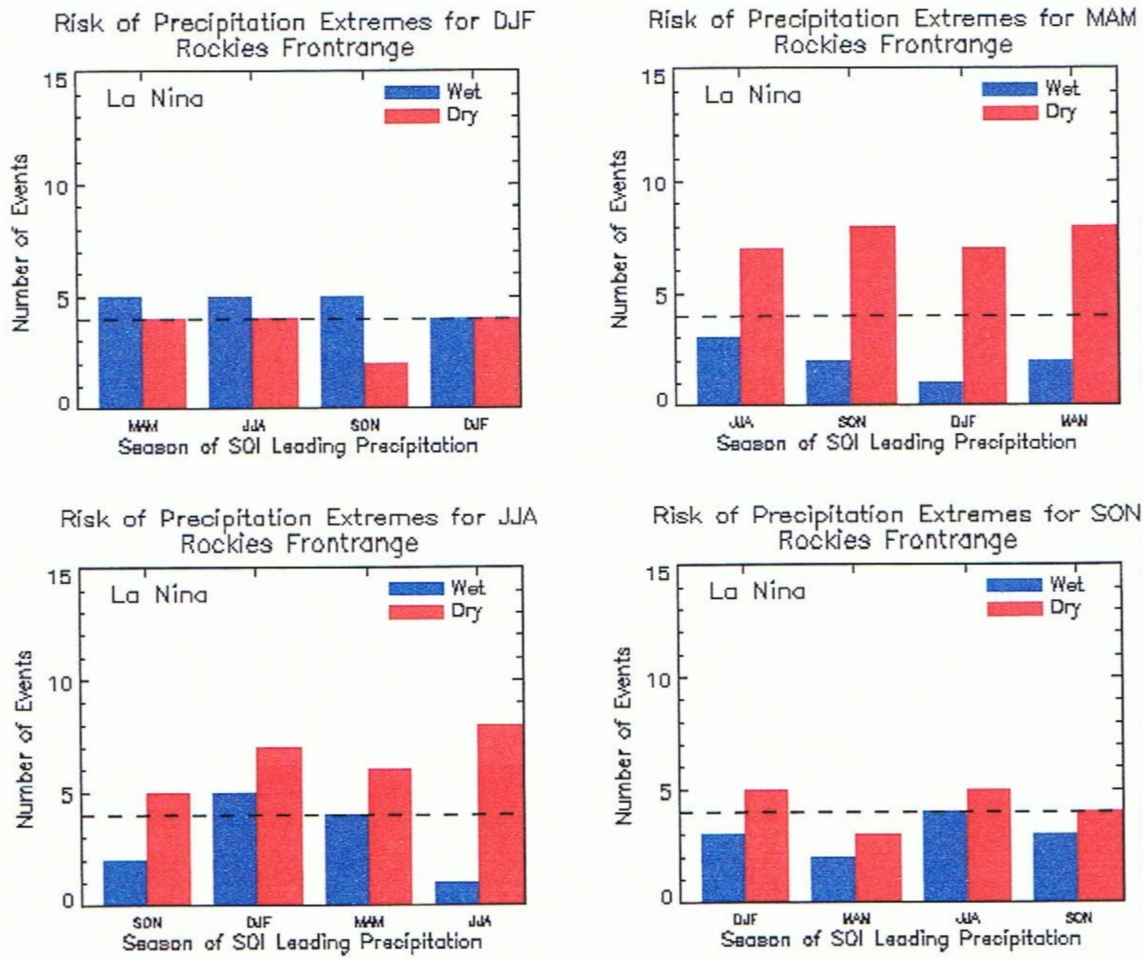


Figure 13a: Comparison of observed rainfall distribution over the duration of the event described in Section 5.1 of this report at the Colorado Springs NWS and Colorado College stations with the SCS Type IIA rainfall distribution suggested in the City of Colorado Springs and El Paso County Drainage Criteria Manual.

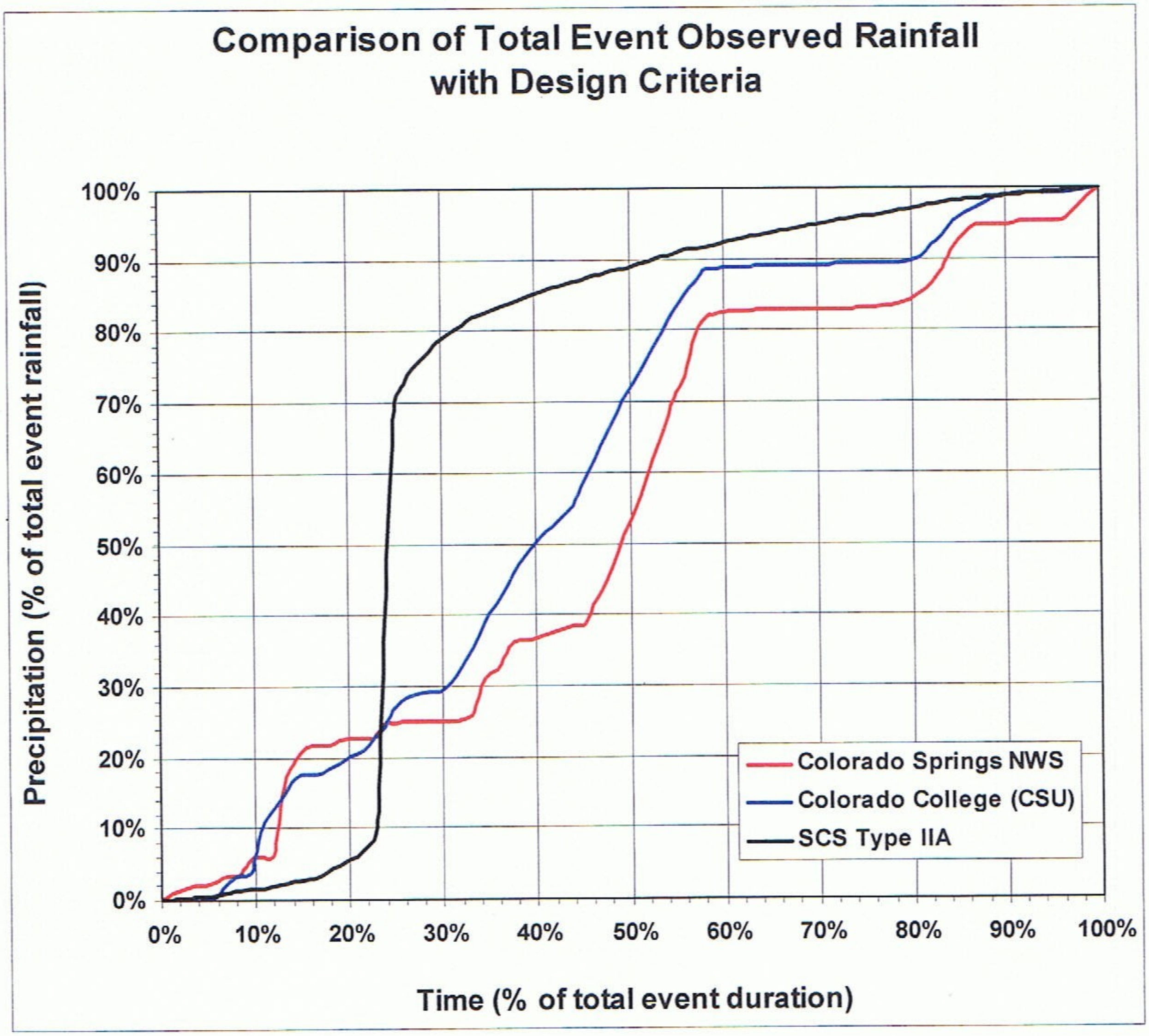


Figure 13b: Comparison of observed rainfall distribution during the period of maximum 24-hour rainfall (from 5 pm LST on April 29 to 5 pm LST on April 30 at the Colorado Springs NWS station, and from 4 pm LST on April 29 to 4 pm LST on April 30 at the Colorado College station) during the event described in Section 5.1of this report with the SCS Type IIA rainfall distribution suggested in the City of Colorado Springs and El Paso County Drainage Criteria Manual.

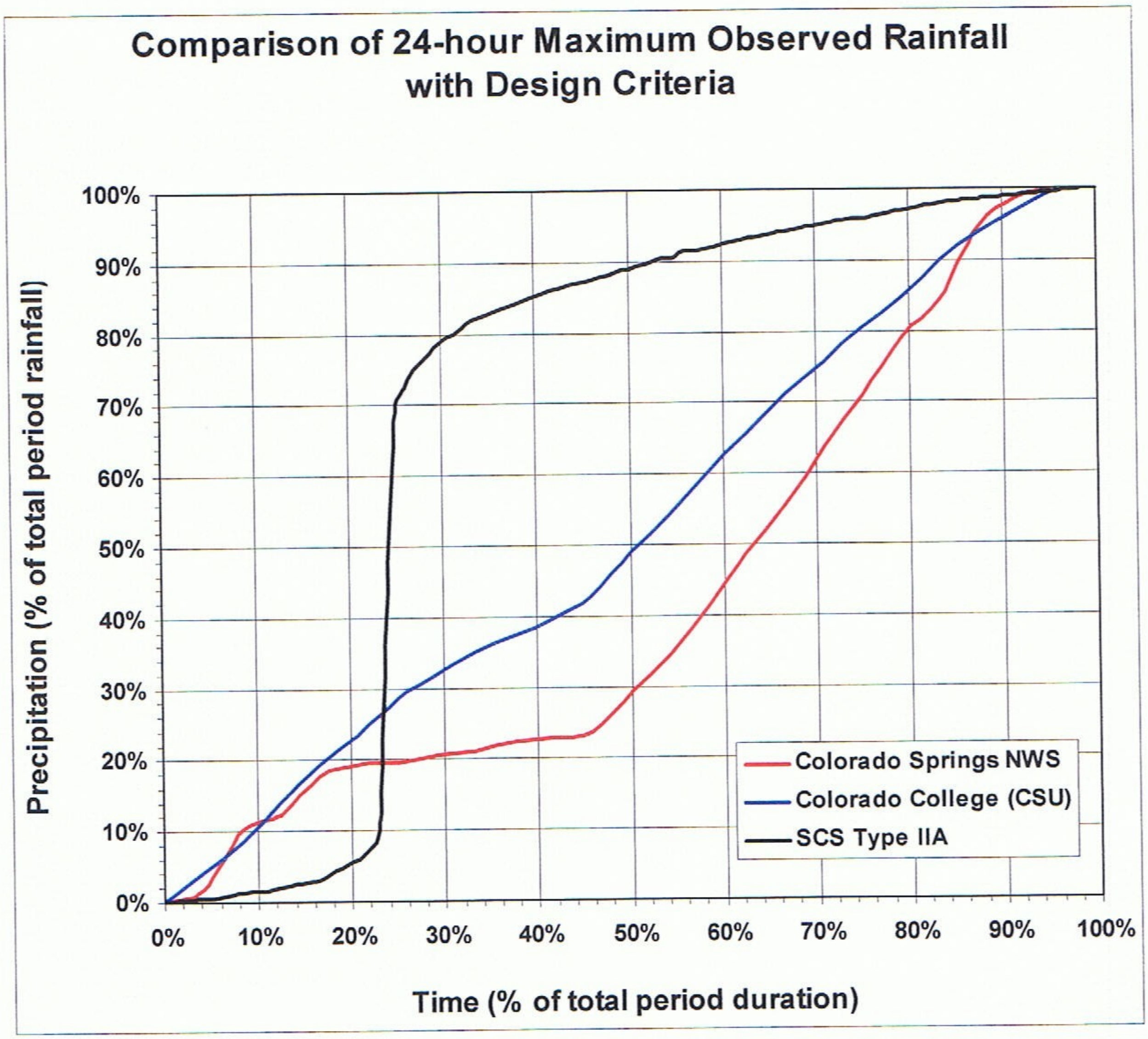


Figure 1: Schematic diagram of SWMM RUNOFF model sub-basins (with orange drainage paths attached) and stream channels (with black flow paths attached) within the Fountain Creek watershed in the region upstream of USGS stream flow gauge 07105800. The reference point (0,0) occurs at the confluence of Fountain and Monument Creeks in Colorado Springs. Scales on the axes shown here are given in feet north and east of the reference point. Additional color-coded reference points correspond to those shown on labeled portions of this schematic in **Figures 3a** through **3f** and **14**.

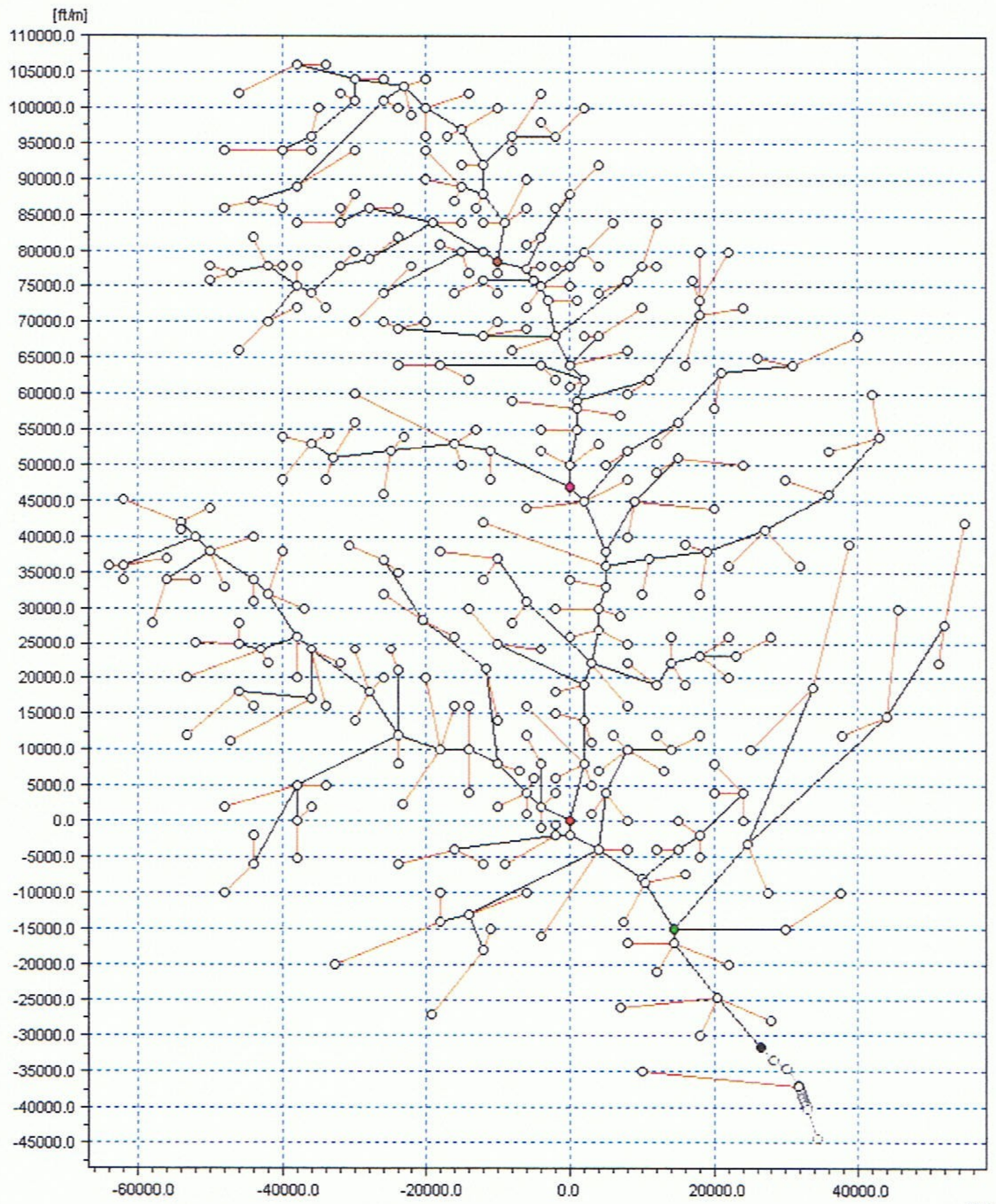


Figure 3a: Close-up view of SWMM RUNOFF model sub-basins (with orange drainage paths attached) and stream channels (with black flow paths attached) in the region of Upper and Middle Fountain Creek (UFC and MFC, respectively). The reference point (0,0) occurs at the confluence of Fountain and Monument Creeks in Colorado Springs. Scales on the axes shown here are given in feet north and east of the reference point. The color-coded reference point corresponds to that shown in **Figure 1**. Naming conventions for sub-basins and channels shown here are explained in **Section 4** of this report.

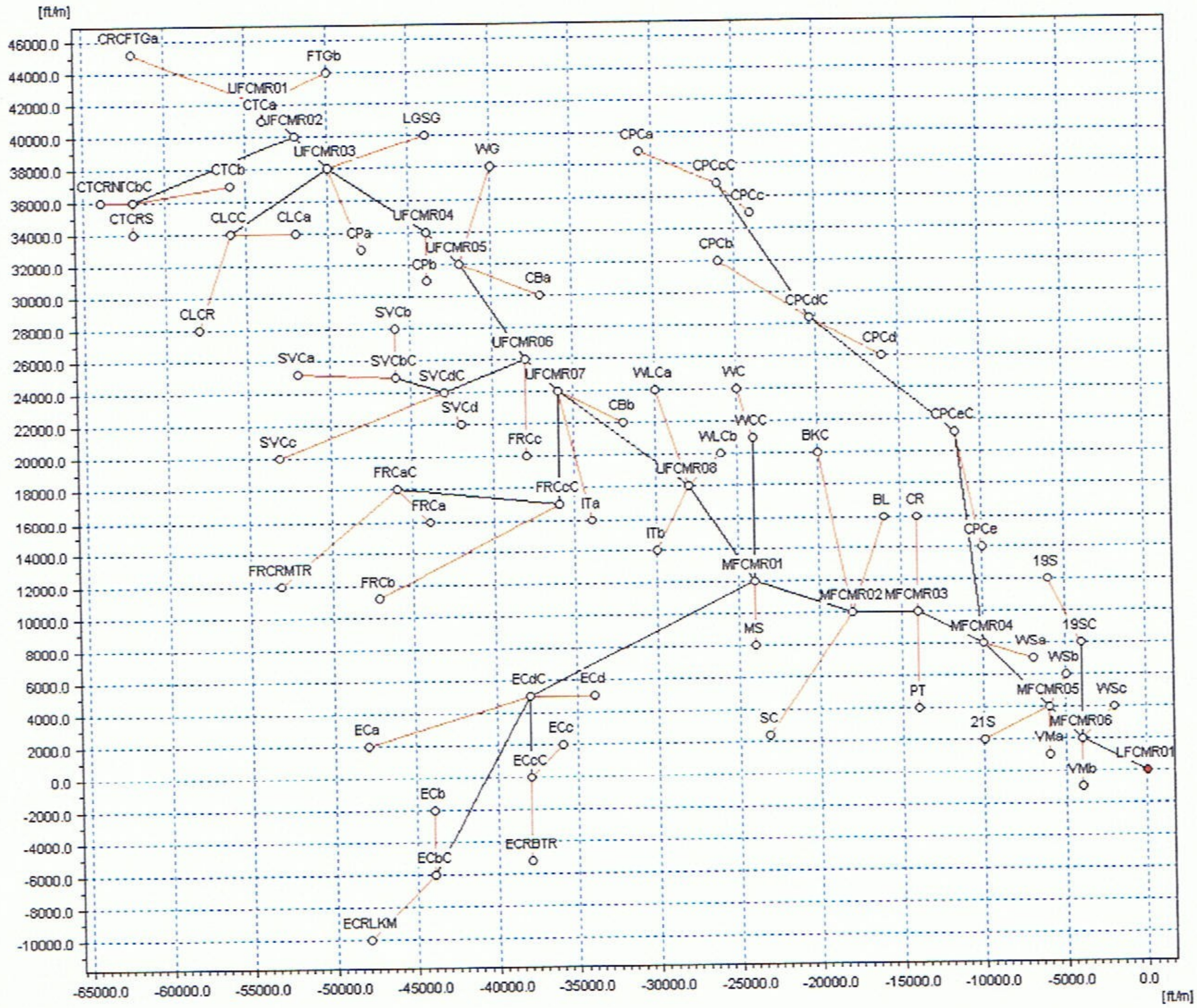


Figure 3b: Close-up view of SWMM RUNOFF model sub-basins (with orange drainage paths attached) and stream channels (with black flow paths attached) in the region of Upper Monument Creek (UMC). The reference point (0,0) occurs at the confluence of Fountain and Monument Creeks in Colorado Springs. Scales on the axes shown here are given in feet north and east of the reference point. The color-coded reference point corresponds to that shown in **Figures 1** and **3c**. Naming conventions for sub-basins and channels shown here are explained in **Section 4** of this report.

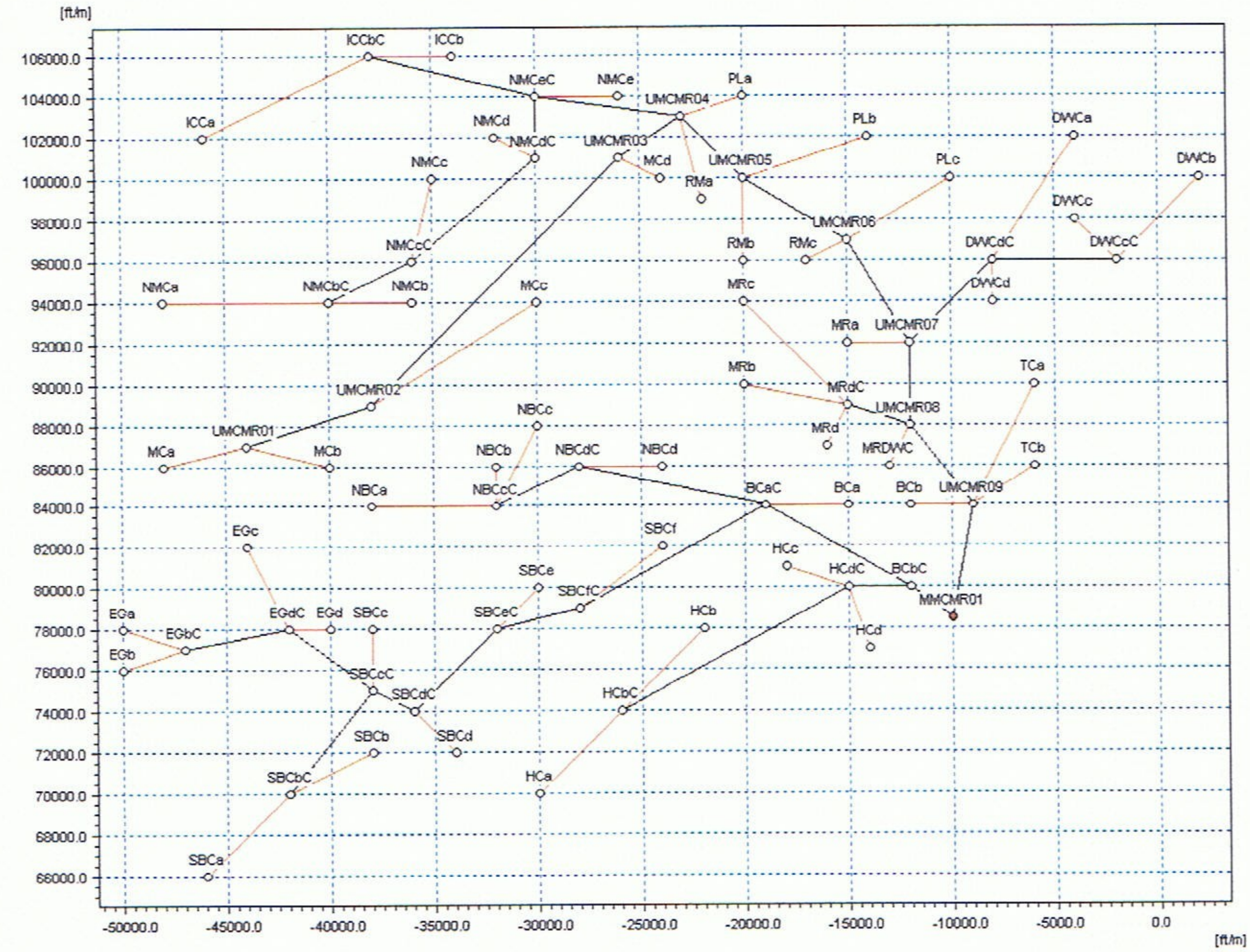


Figure 3c: Close-up view of SWMM RUNOFF model sub-basins (with orange drainage paths attached) and stream channels (with black flow paths attached) in the region of Middle Monument Creek (MMC), including West Monument Creek (WMC). The reference point (0,0) occurs at the confluence of Fountain and Monument Creeks in Colorado Springs. Scales on the axes shown here are given in feet north and east of the reference point. The color-coded reference points correspond to those shown in **Figures 1, 3b,** and **3d**. Naming conventions for sub-basins and channels shown here are explained in **Section 4** of this report.

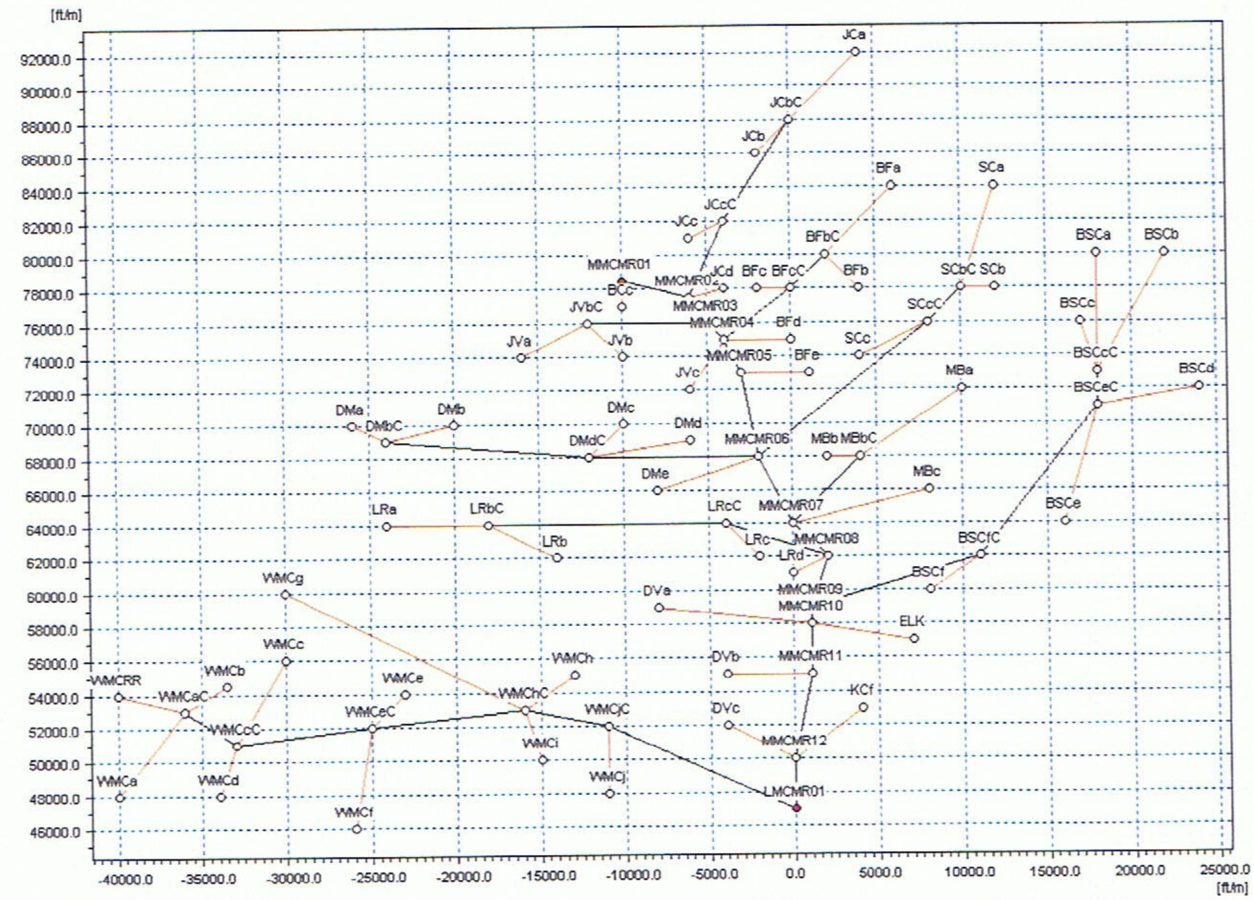


Figure 3d: Close-up view of SWMM RUNOFF model sub-basins (with orange drainage paths attached) and stream channels (with black flow paths attached) in the region of Lower Monument Creek (LMC). The reference point (0,0) occurs at the confluence of Fountain and Monument Creeks in Colorado Springs. Scales on the axes shown here are given in feet north and east of the reference point. The color-coded reference points correspond to those shown in **Figures 1**, **3c**, and **3e**. Naming conventions for sub-basins and channels shown here are explained in **Section 4** of this report.

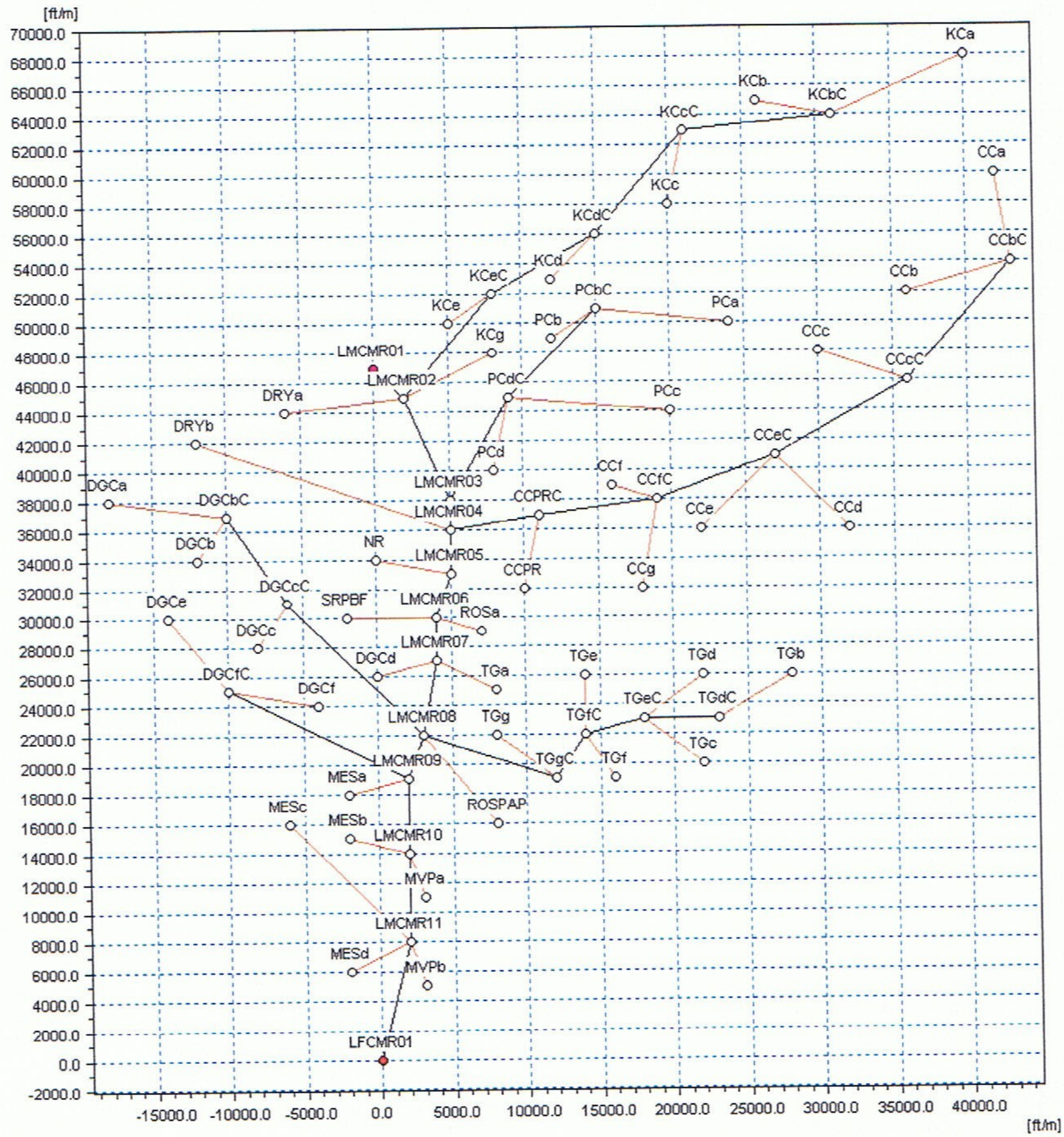


Figure 3e: Close-up view of SWMM RUNOFF model sub-basins (with orange drainage paths attached) and stream channels (with black flow paths attached) in the region of Lower Fountain Creek (LFC). The reference point (0,0) occurs at the confluence of Fountain and Monument Creeks in Colorado Springs. Scales on the axes shown here are given in feet north and east of the reference point. The color-coded reference points correspond to those shown in **Figures 1, 3a, 3d, 3f,** and **14.** Naming conventions for sub-basins and channels shown here are explained in **Section 4** of this report.

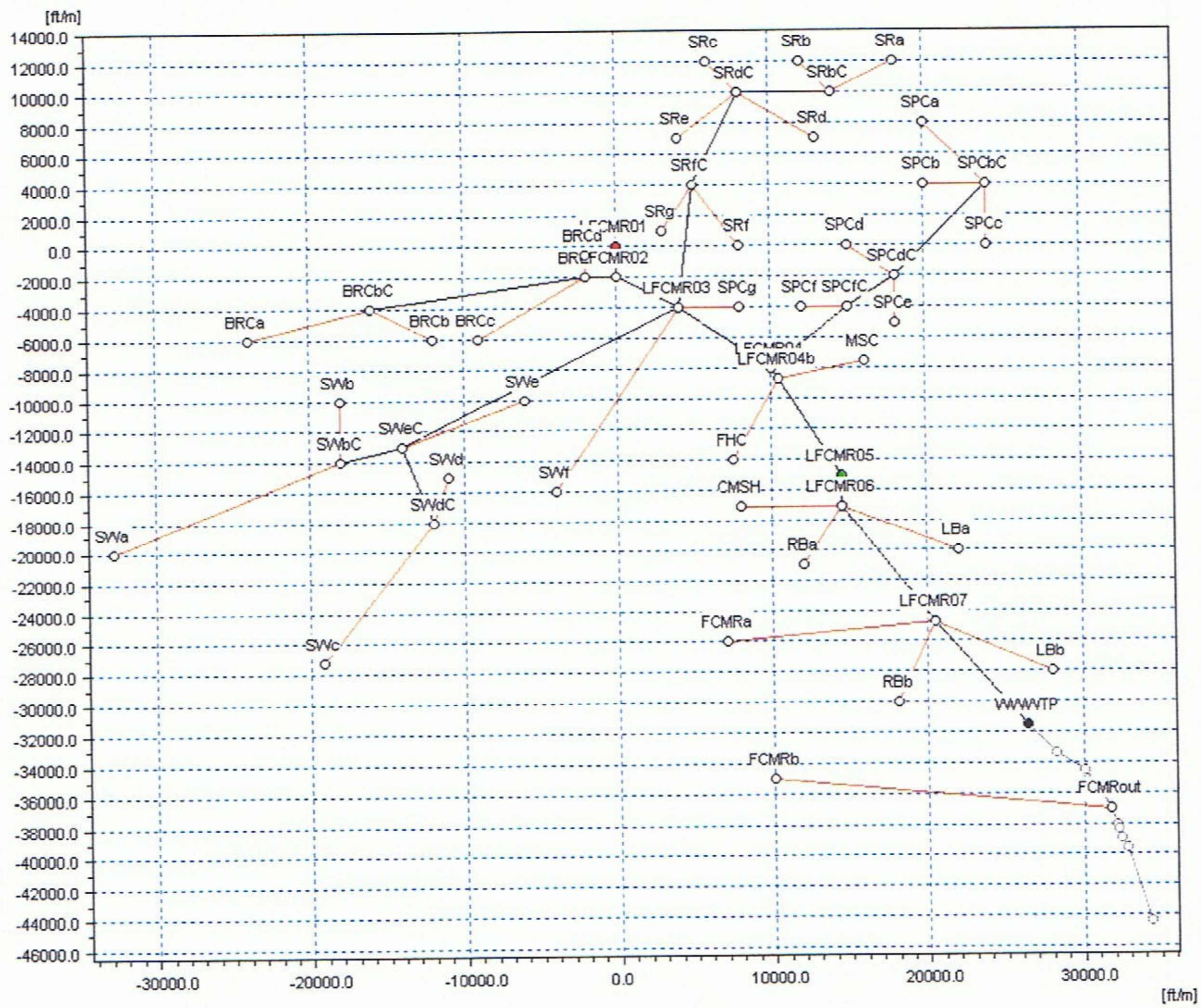


Figure 3f: Close-up view of SWMM RUNOFF model sub-basins (with orange drainage paths attached) and stream channels (with black flow paths attached) in the region of Sand Creek (SDC), east and south of Colorado Springs. The reference point (0,0) occurs at the confluence of Fountain and Monument Creeks in Colorado Springs. Scales on the axes shown here are given in feet north and east of the reference point. The color-coded reference points correspond to those shown in **Figures 1** and **3e**. Naming conventions for sub-basins and channels shown here are explained in **Section 4** of this report.

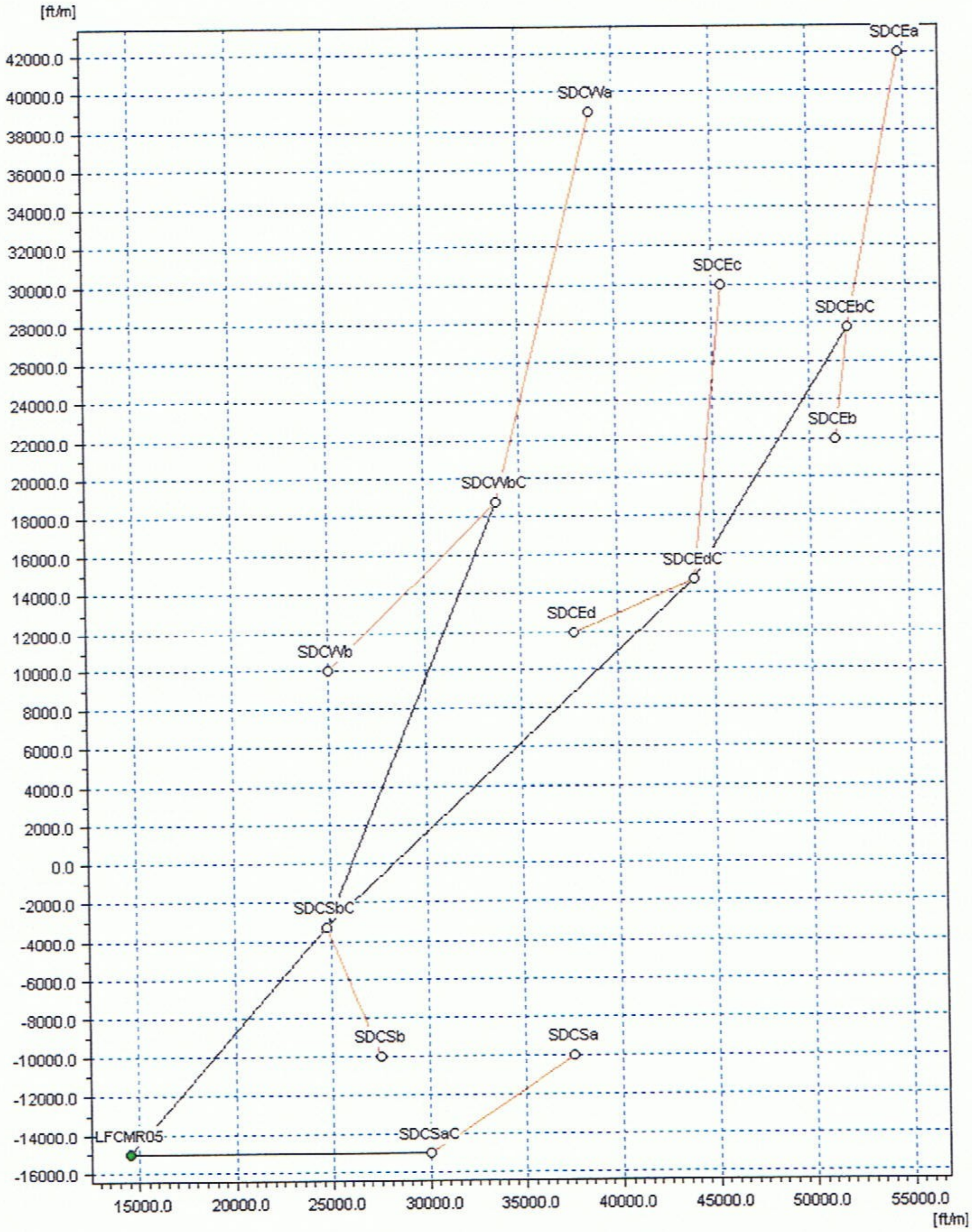


Figure 3g: Close-up view of SWMM RUNOFF model sub-basins (with orange drainage paths attached) and stream channels (with black flow paths attached) approximately within the region of the City of Colorado Springs. The reference point (0,0) occurs at the confluence of Fountain and Monument Creeks in Colorado Springs. Scales on the axes shown here are given in feet north and east of the reference point. The color-coded reference points correspond to those shown in **Figures 1, 3a, 3d, 3e,** and **3f.** Naming conventions for sub-basins and channels shown here are explained in **Section 4** of this report.

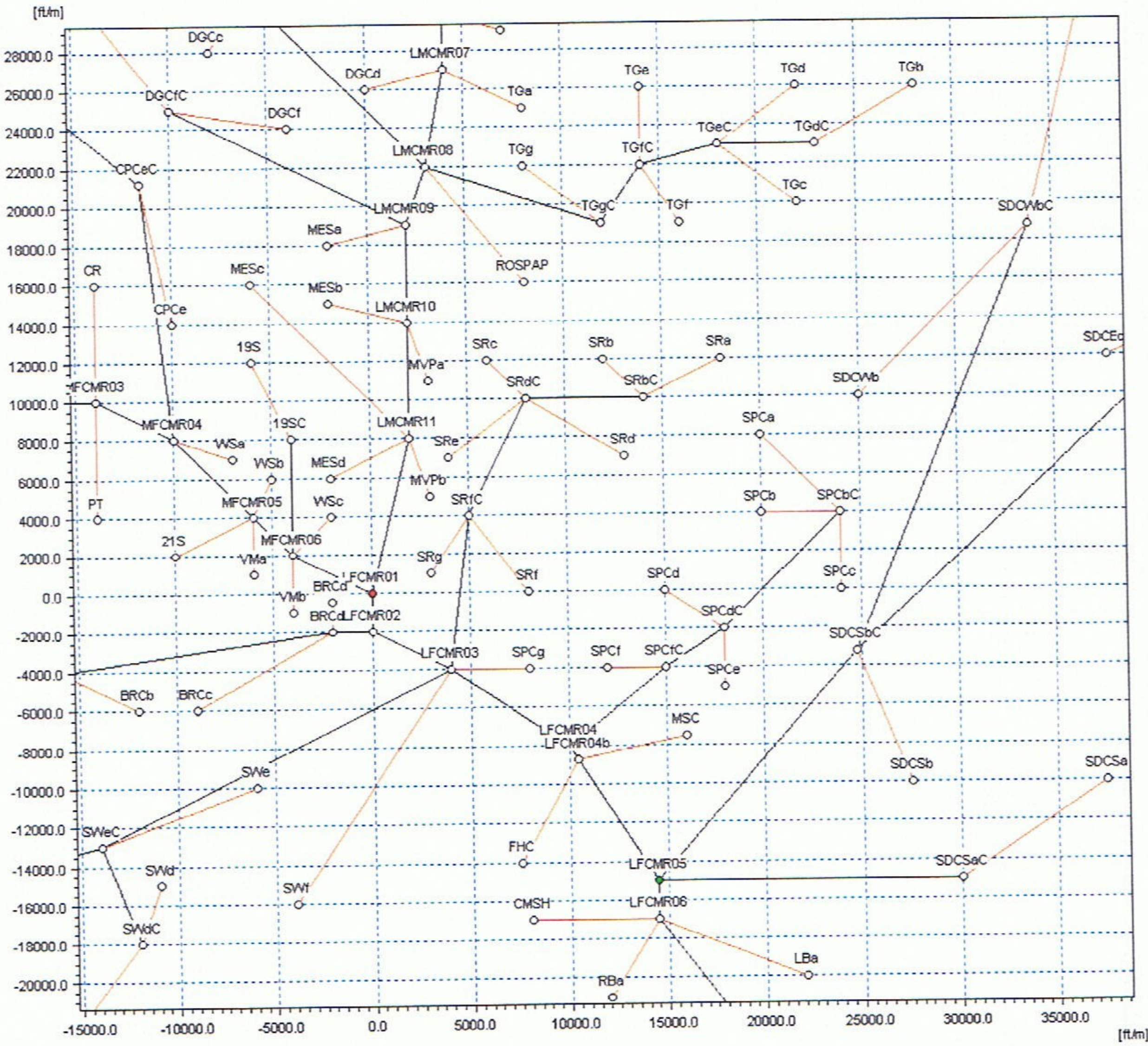


Figure 5: Schematic diagram showing the spatial distribution of hourly hyetographs given in **Figures 4a** and **4b** for simulation of the calibration event during October 27-28, 1998.

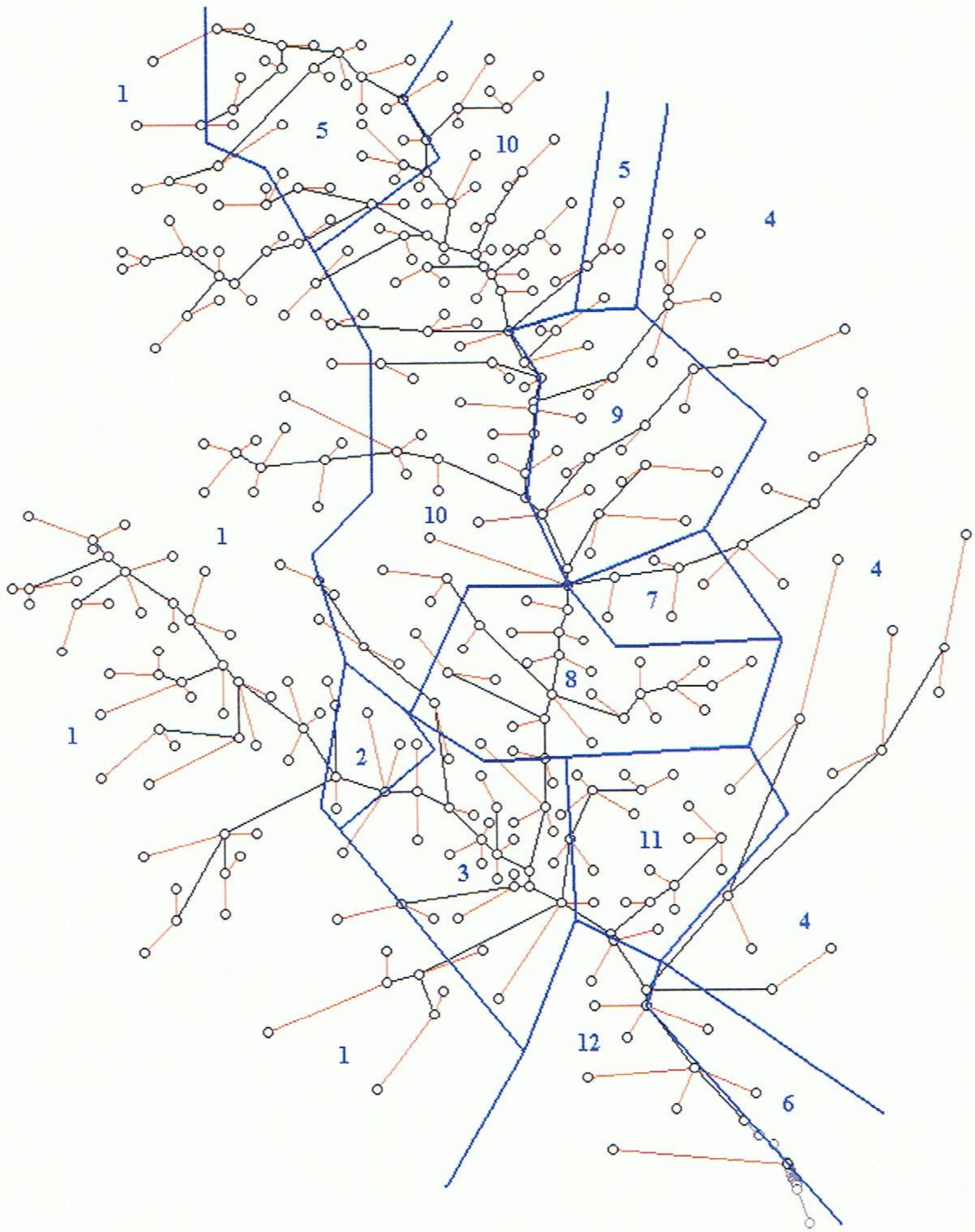


Figure 7a: Observed hydrograph for the major storm event during April 28-May 2, 1999, at USGS gauge 07104000 ("Monument Creek at Pikeview, Colorado").

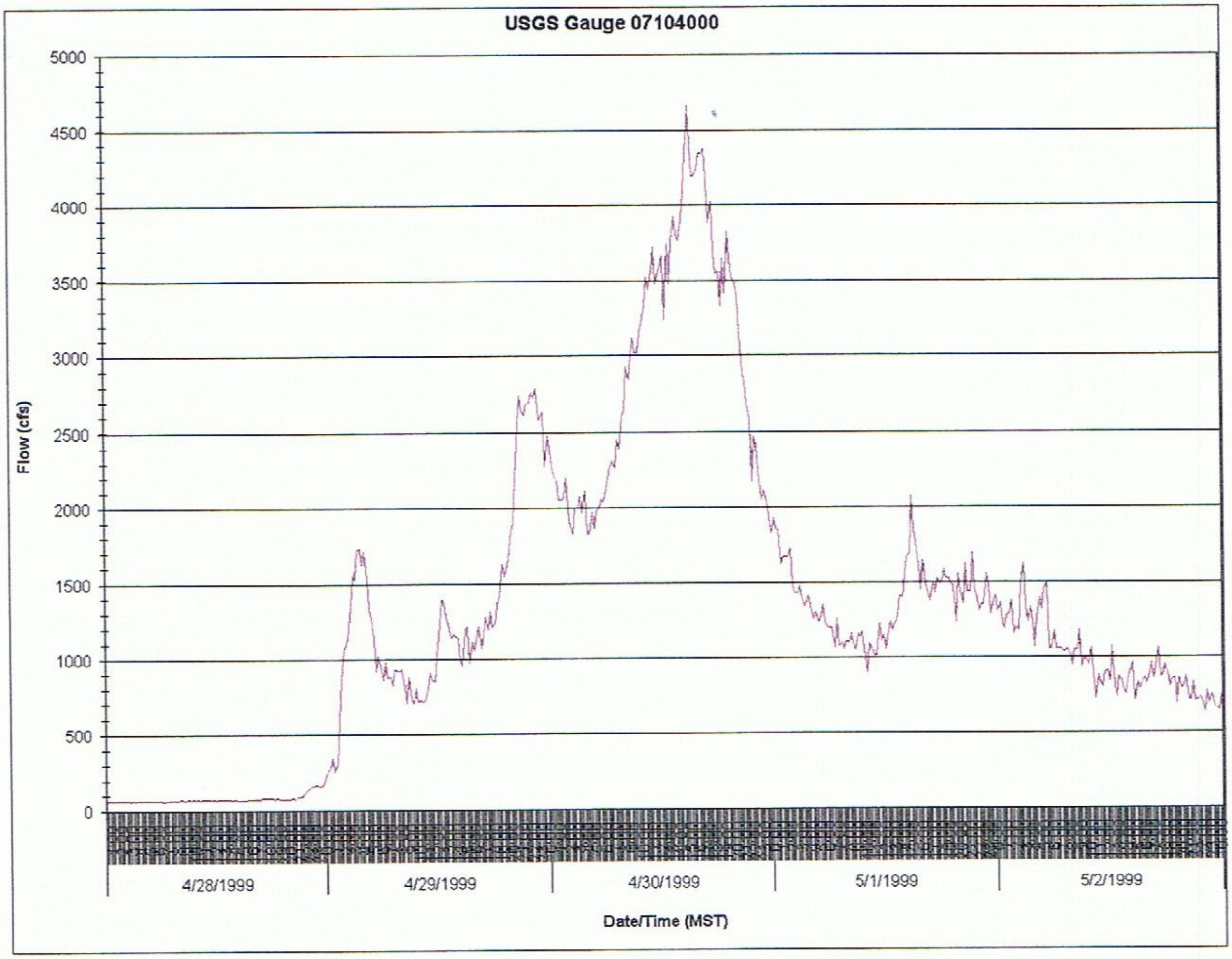


Figure 7b: Observed hydrographs for the major storm event during April 28-May 2, 1999, at USGS gauges 07105000 ("Bear Creek near Colorado Springs, Colorado") and 07105490 ("Cheyenne Creek at Evans Avenue at Colorado Springs, Colorado").

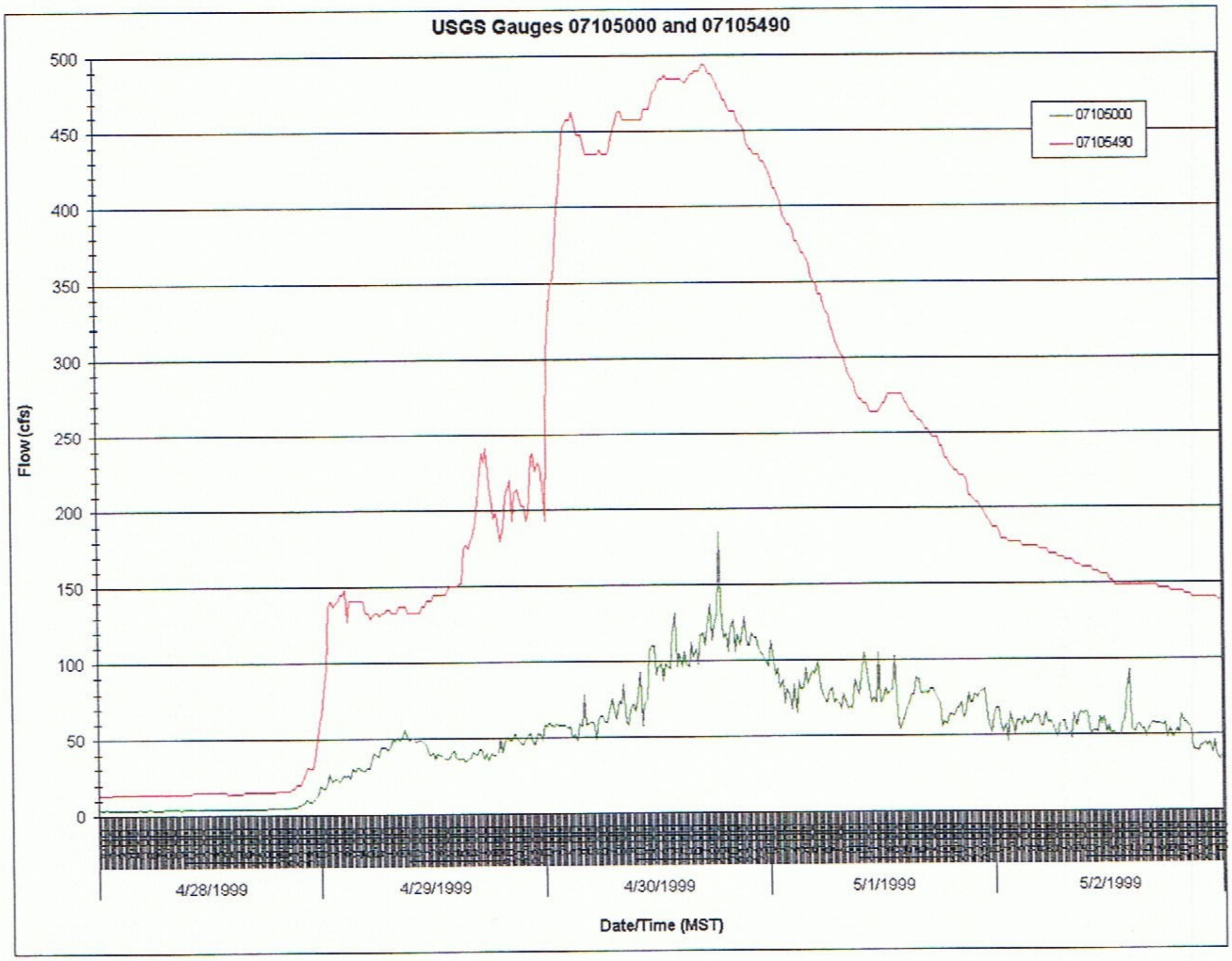


Figure 7c: Observed hydrograph for the major storm event during April 28-May 2, 1999, at USGS gauge 07105500 ("Fountain Creek at Colorado Springs, Colorado").

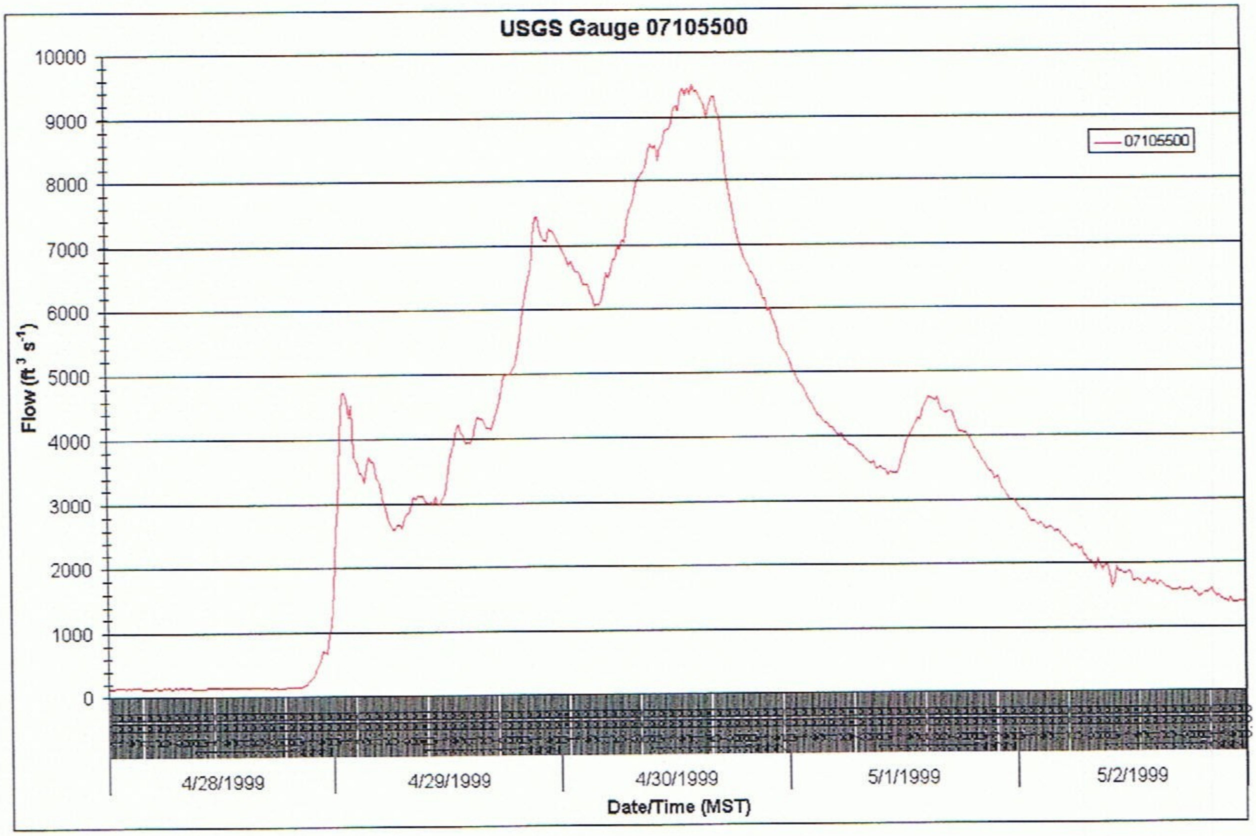


Figure 7d: Observed hydrograph for the major storm event during April 28-May 2, 1999, at USGS gauge 07105530 ("Fountain Creek below Janitell Road below Colorado Springs, Colorado").

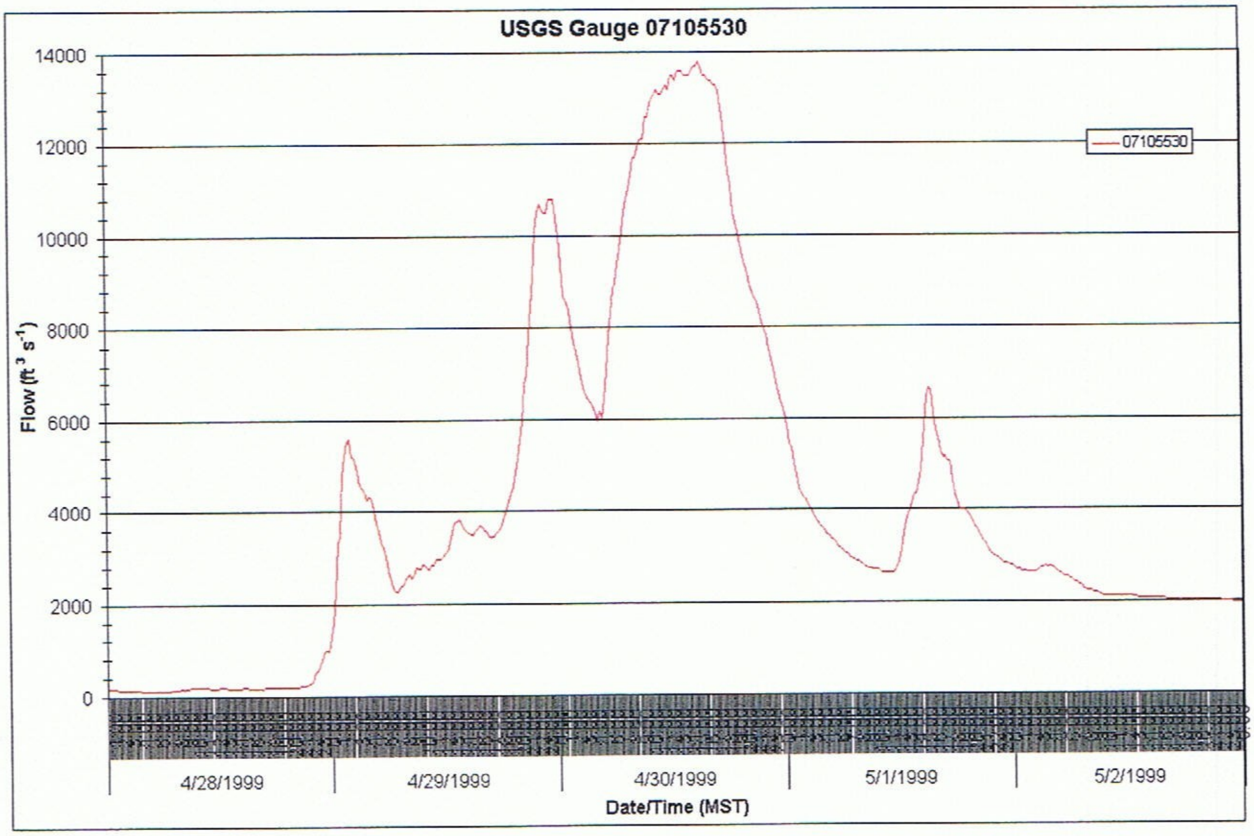


Figure 9: Schematic diagram showing the spatial distribution of hourly hyetographs given in **Figures 8a** through **8c** for simulation of the major storm event on April 28-May 2, 1999.

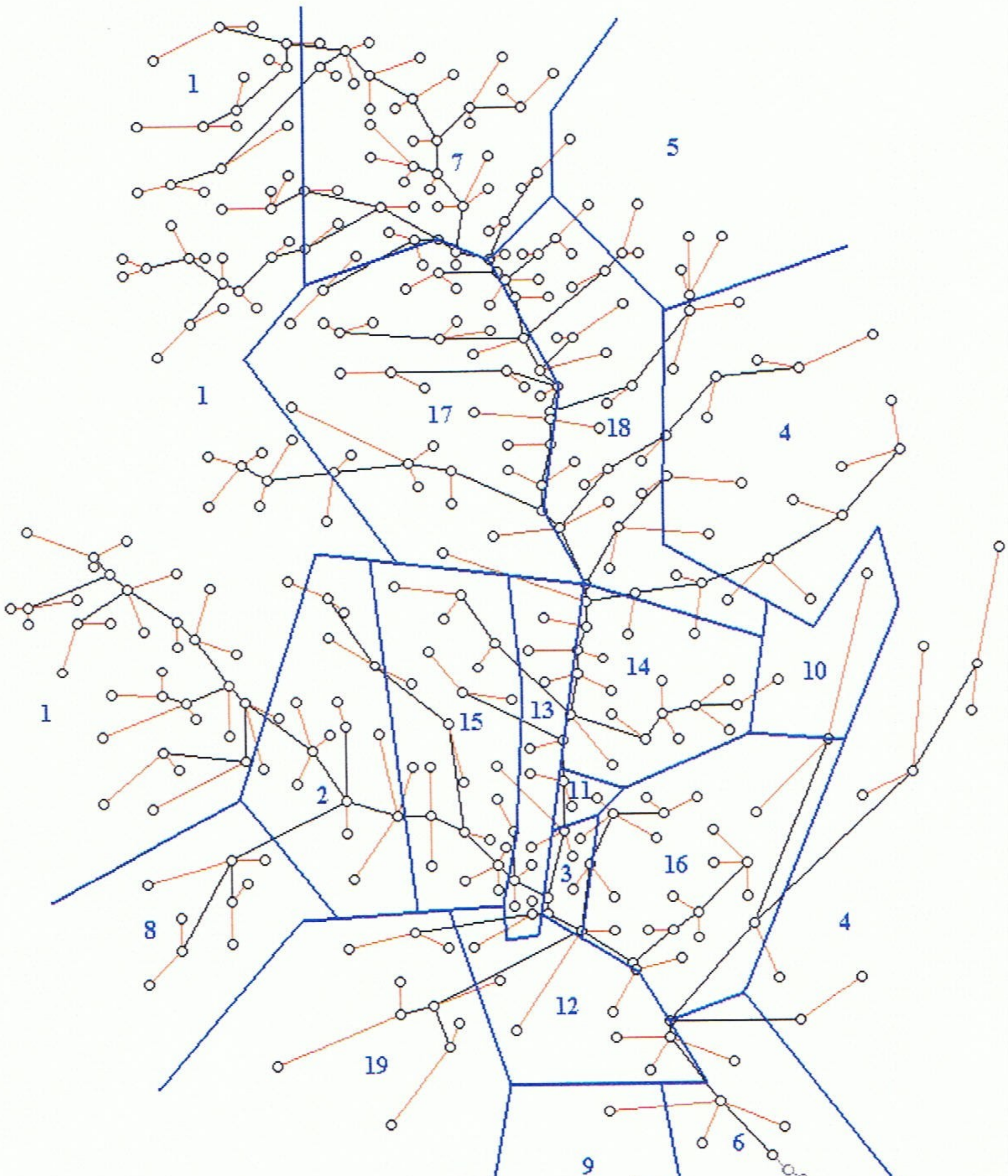
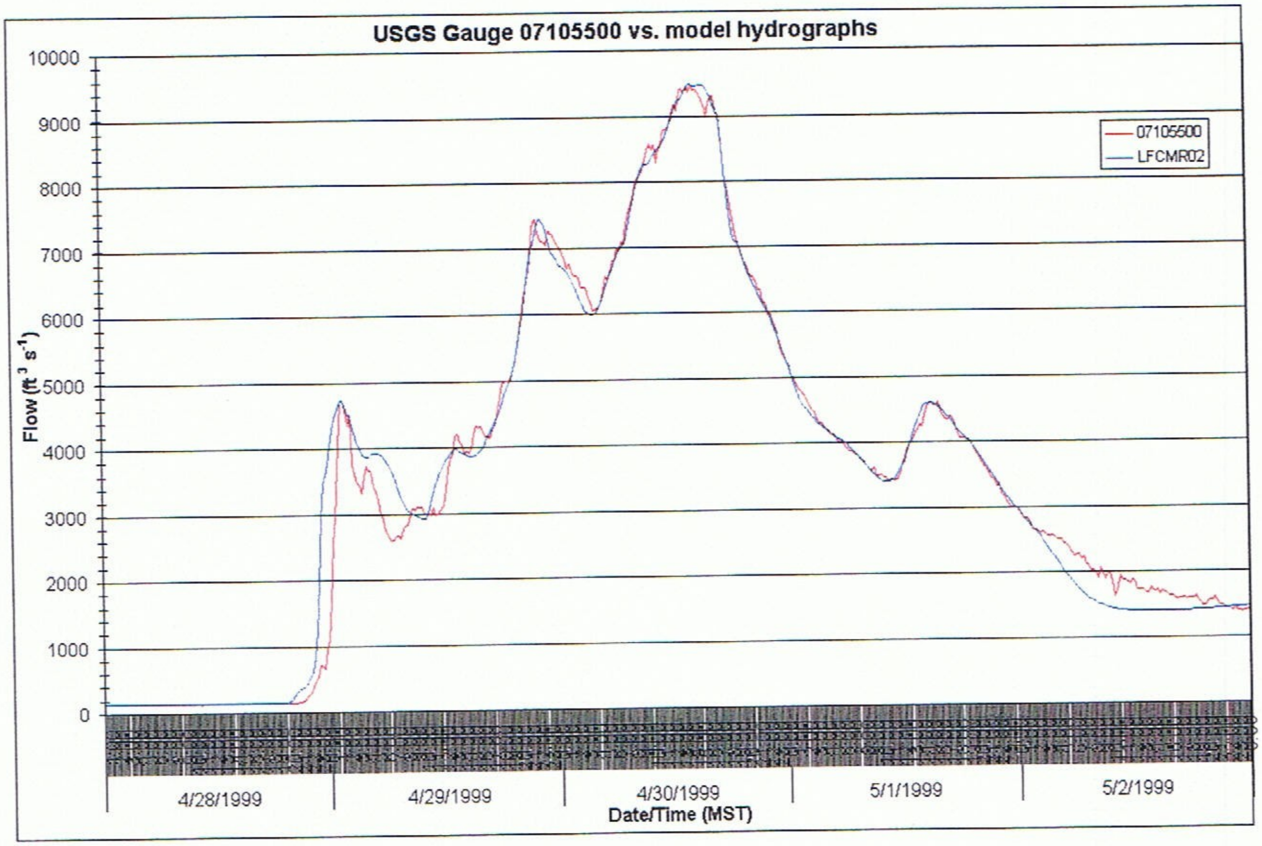


Figure 10a: Simulated hydrograph for the major storm event during April 28-May 2, 1999, at the location of USGS gauge 07105500, and a graph demonstrating the correlation between (concurrent) observed and simulated discharges at that location.



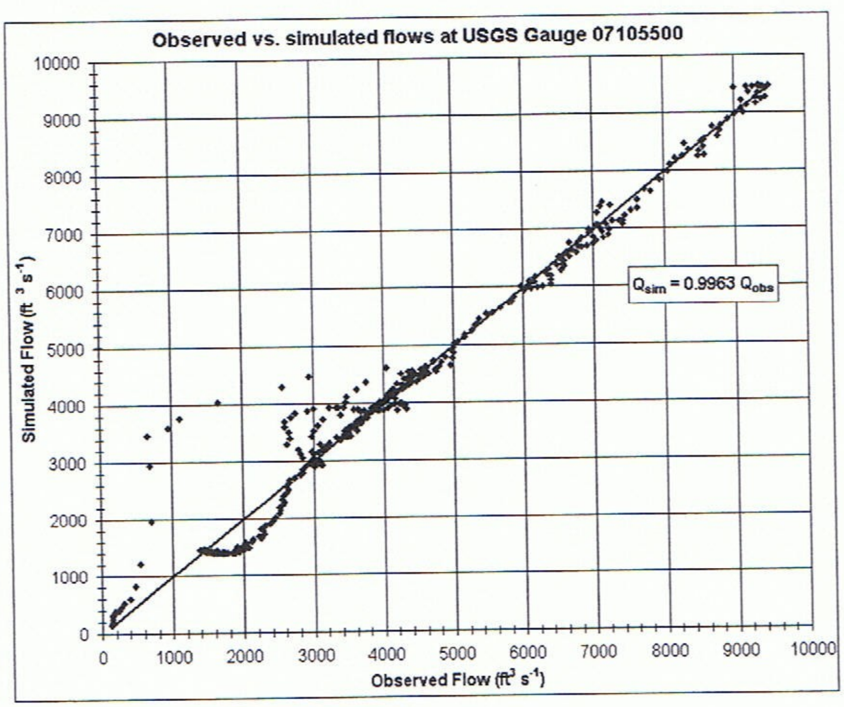
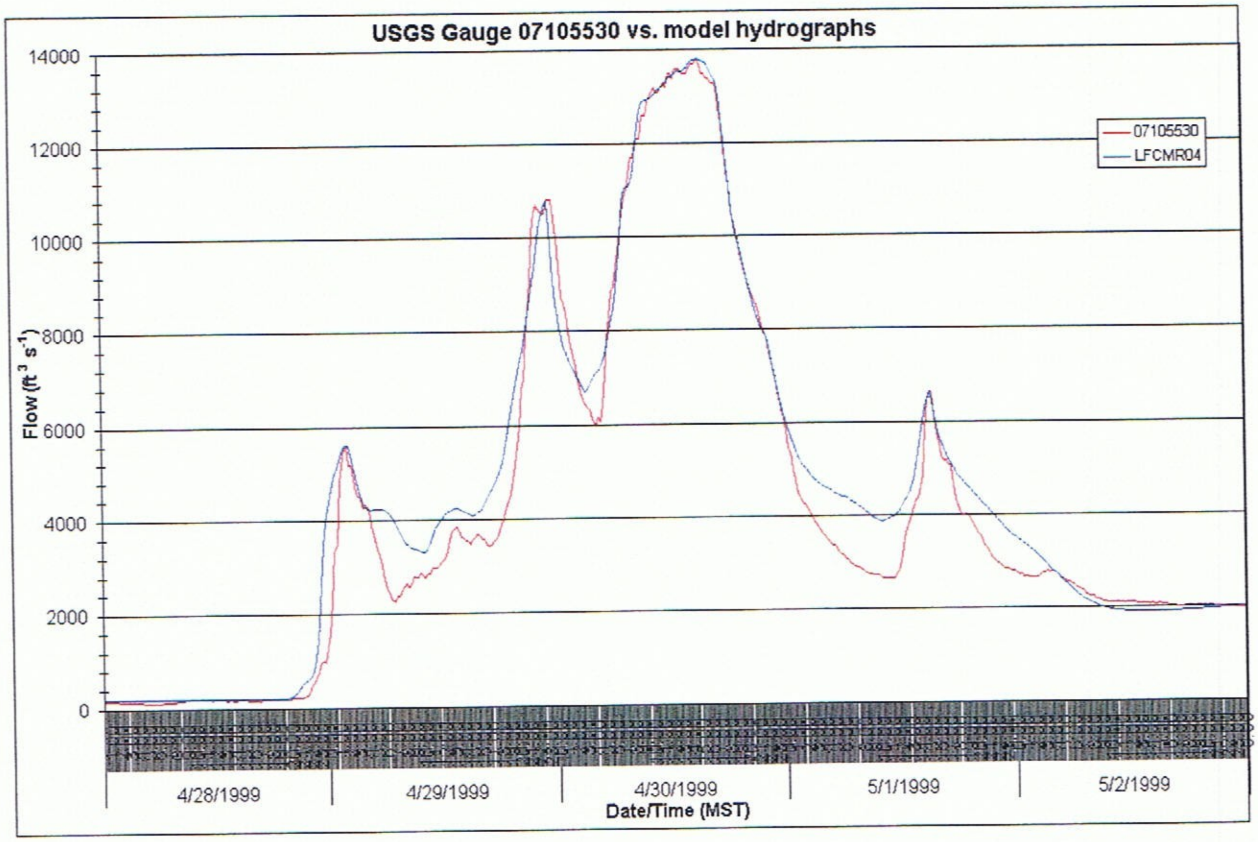


Figure 10b: Simulated hydrograph for the major storm event during April 28-May 2, 1999, at the location of USGS gauge 07105530, and a graph demonstrating the correlation between (concurrent) observed and simulated discharges at that location.



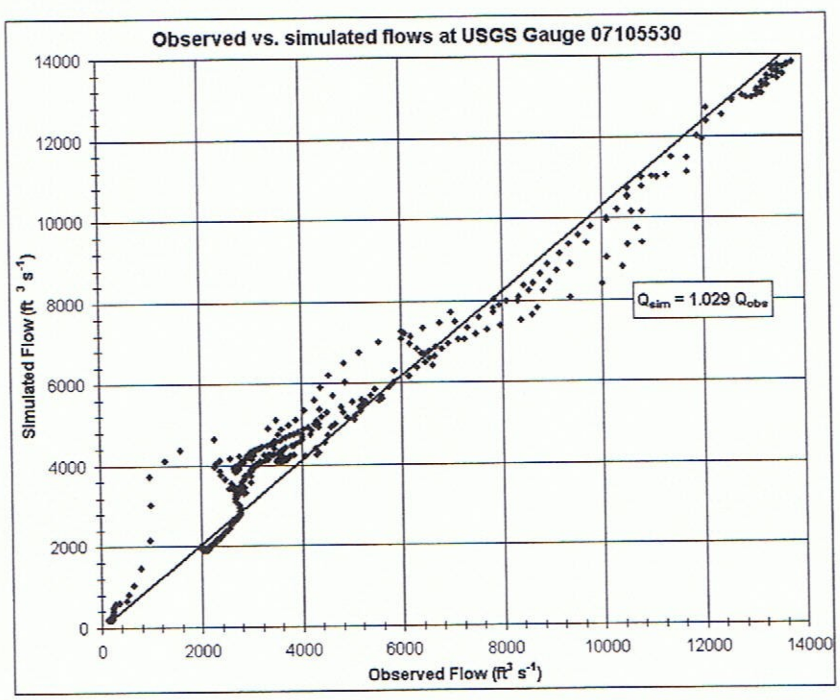


Figure 10c: Simulated hydrograph for the major storm event during April 28-May 2, 1999, near the mouth of Shooks Run in Colorado Springs.

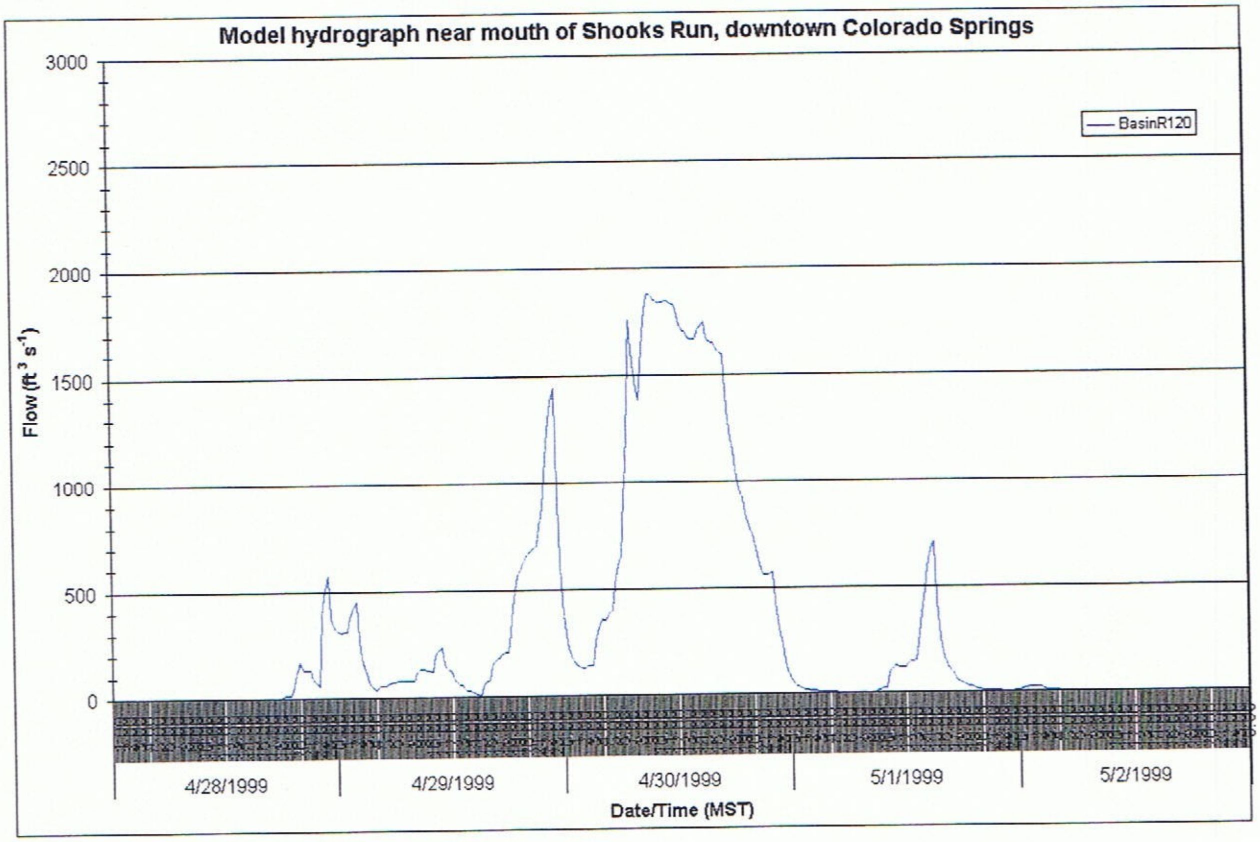


Figure 11: Close-up view of SWMM RUNOFF model sub-basins (with orange drainage paths attached) and stream channels (with black flow paths attached) approximately within the region of the City of Colorado Springs but for which the Templeton Gap Floodway is absent. This view should be compared with that given in **Figure 3g**, above. The reference point (0,0) occurs at the confluence of Fountain and Monument Creeks in Colorado Springs. Scales on the axes shown here are given in feet north and east of the reference point. The color-coded reference points correspond to those shown in **Figures 1**, **3a**, **3d**, **3e**, and **3f**.

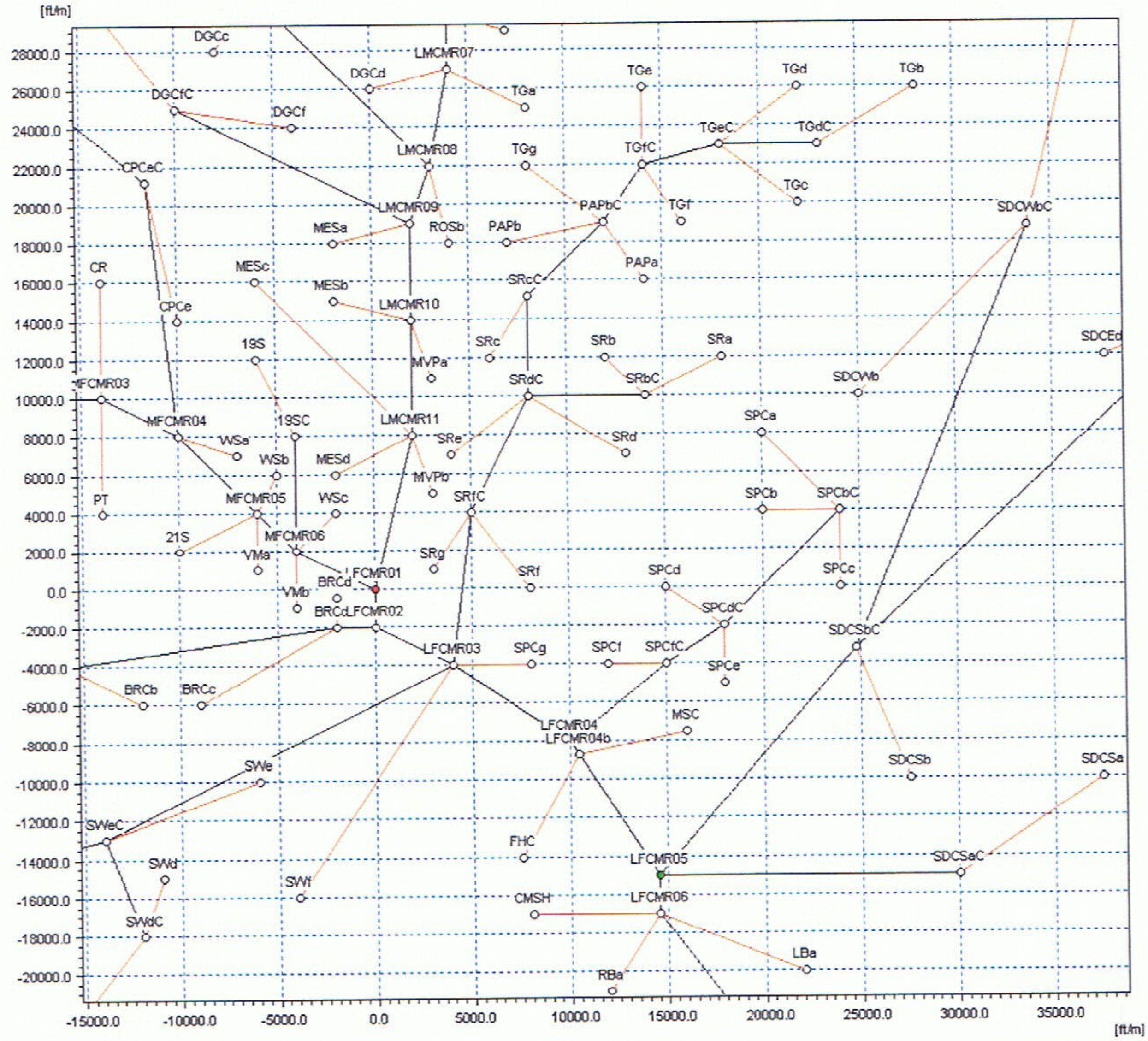


Figure 12a: Simulated hydrograph for the major storm event during April 28-May 2, 1999, at the location of USGS gauge 07105500, for the case of pre-development conditions in the area of the City of Colorado Springs.

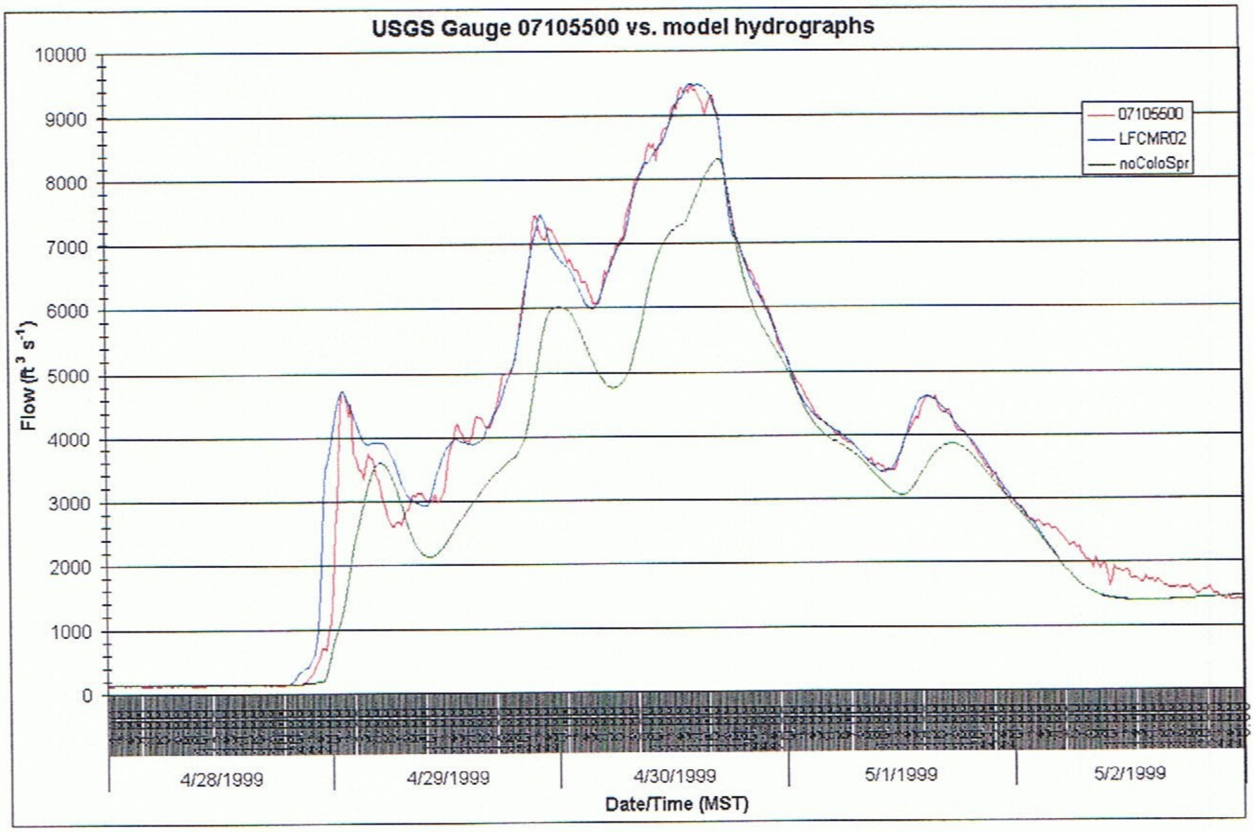


Figure 12b: Simulated hydrograph for the major storm event during April 28-May 2, 1999, at the location of USGS gauge 07105530, for the case of pre-development conditions in the area of the City of Colorado Springs.

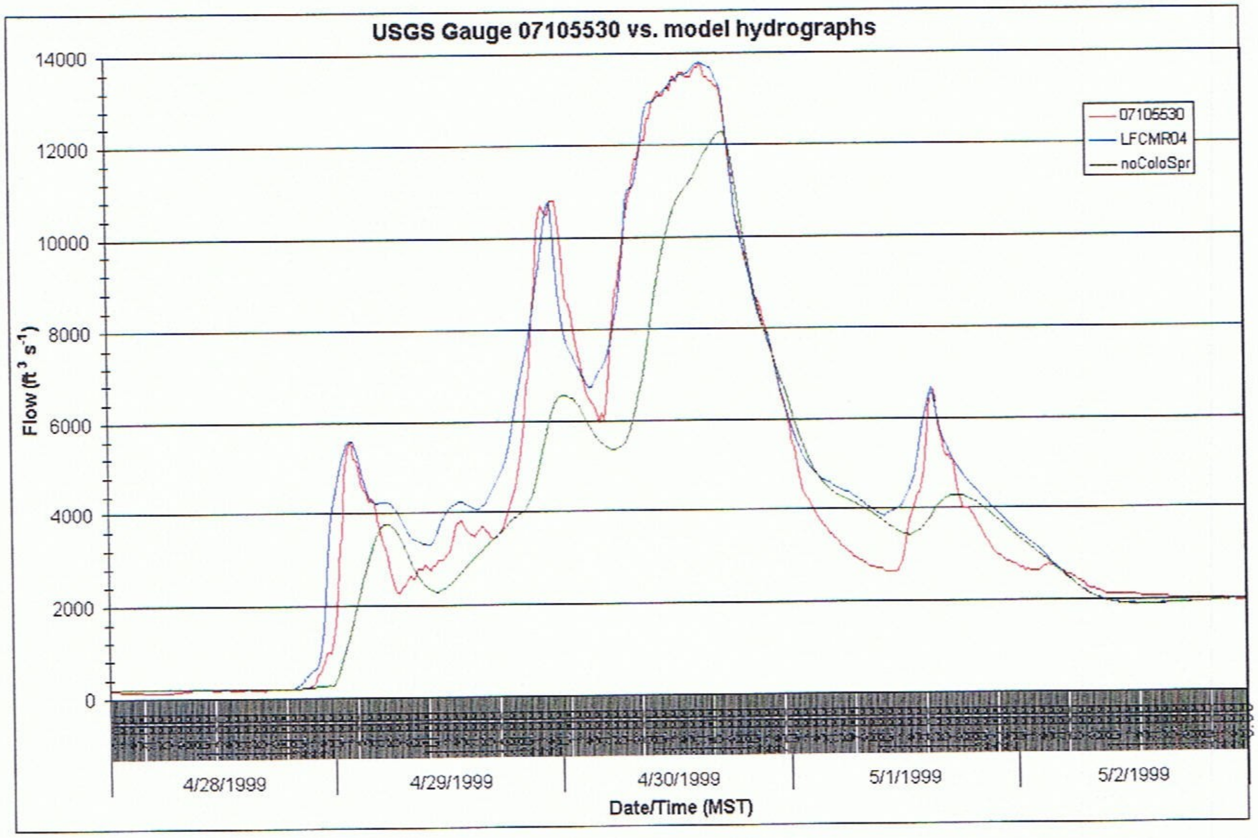


Figure 13a: Simulated hydrograph for the major storm event during April 28-May 2, 1999, near the mouth of Shooks Run in Colorado Springs, in the absence of the Templeton Gap Floodway.

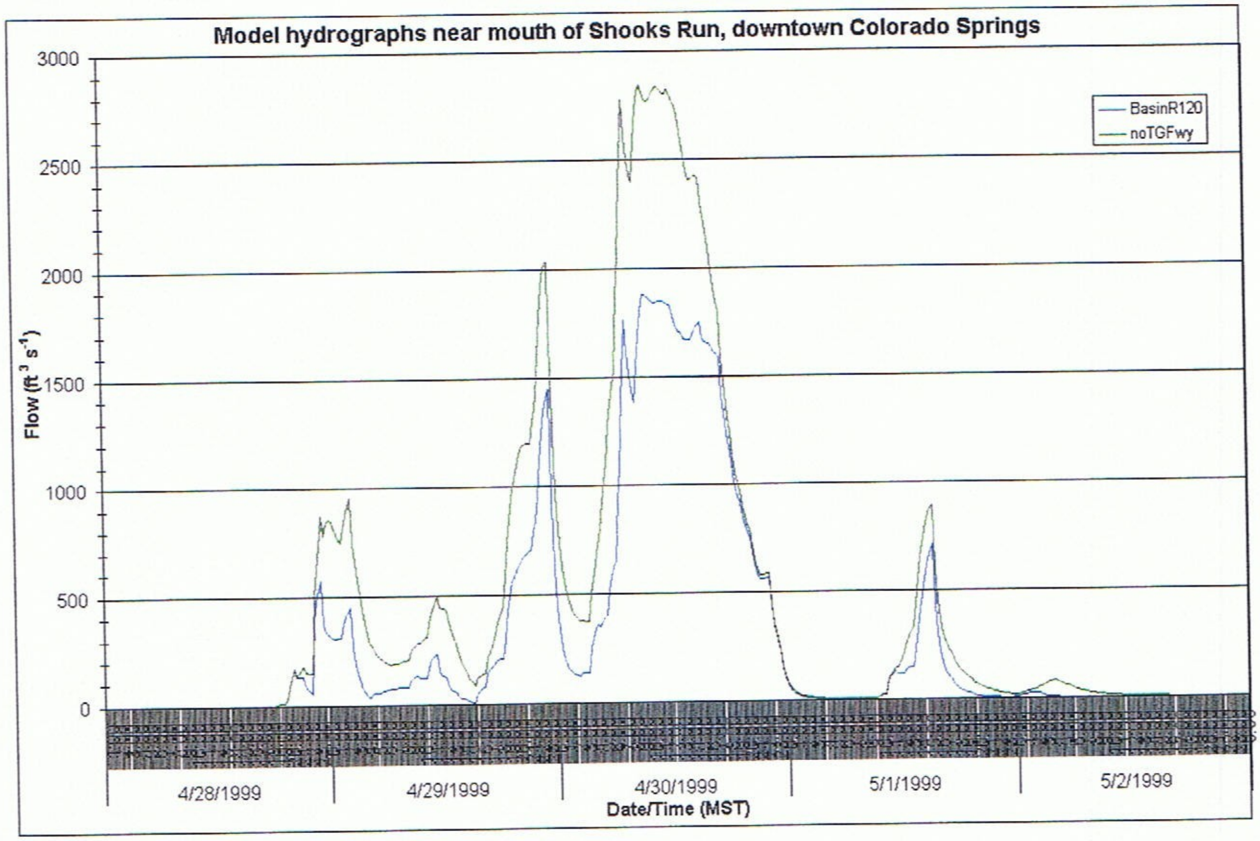


Figure 13b: Simulated hydrograph for the major storm event during April 28-May 2, 1999, near the mouth of Shooks Run in Colorado Springs, for the case of pre-development conditions (including the absence of the Templeton Gap Floodway) in the area of the City of Colorado Springs.

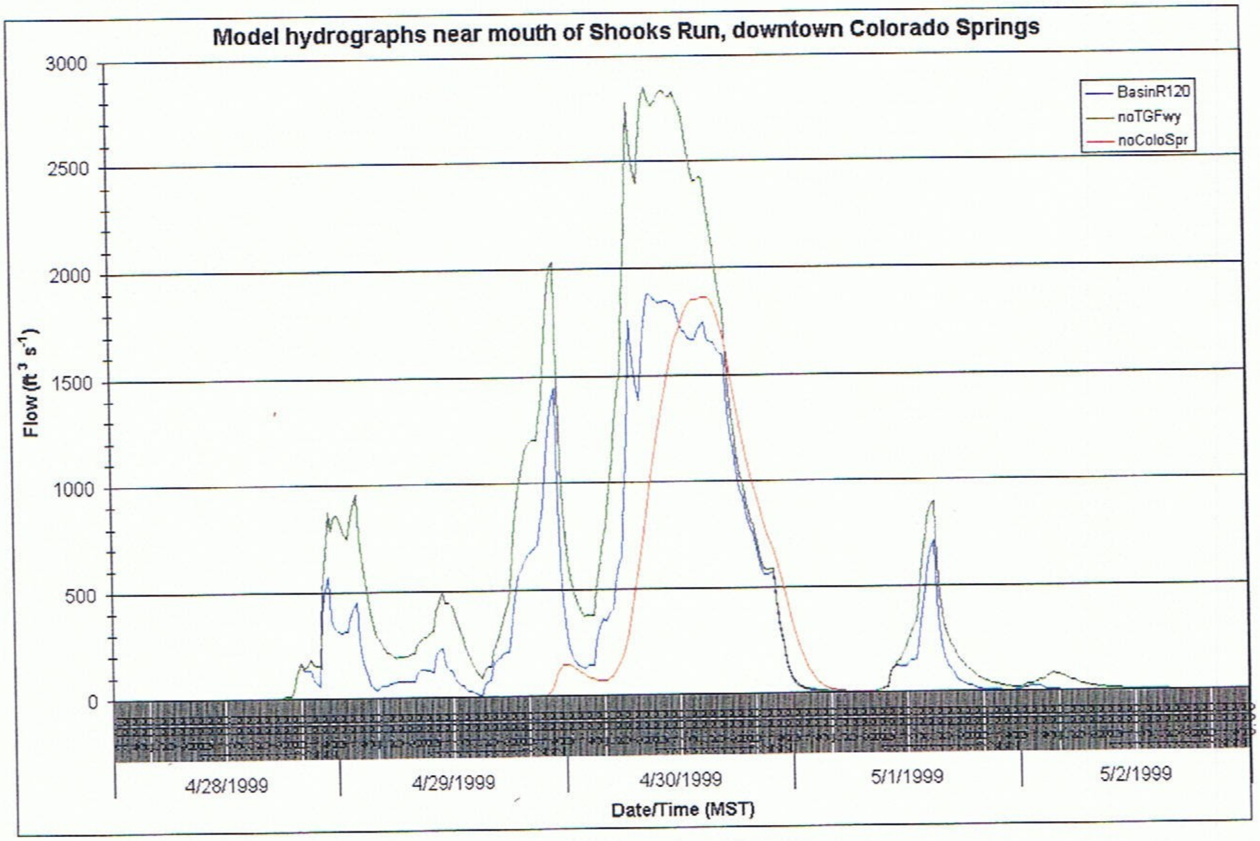


Figure 14: Expanded plan view of SWMM EXTRAN model stream channels for a portion of Fountain Creek downstream of Colorado Springs. The reference point (0,0) occurs at the confluence of Fountain and Monument Creeks in Colorado Springs. Scales on the axes shown here are given in feet north and east of the reference point. The color-coded reference point corresponds to that shown in **Figures 1** and **3e**. This portion of the model is shown as the gray segments at the lower right corner in those figures above. The KOA property is located along the highly detailed portion of this model near the center of the diagram, which is shown more clearly in **Figure 16**. The Greenview Ditch Headworks are located approximately 28 miles south (downstream) of this portion of Fountain Creek.

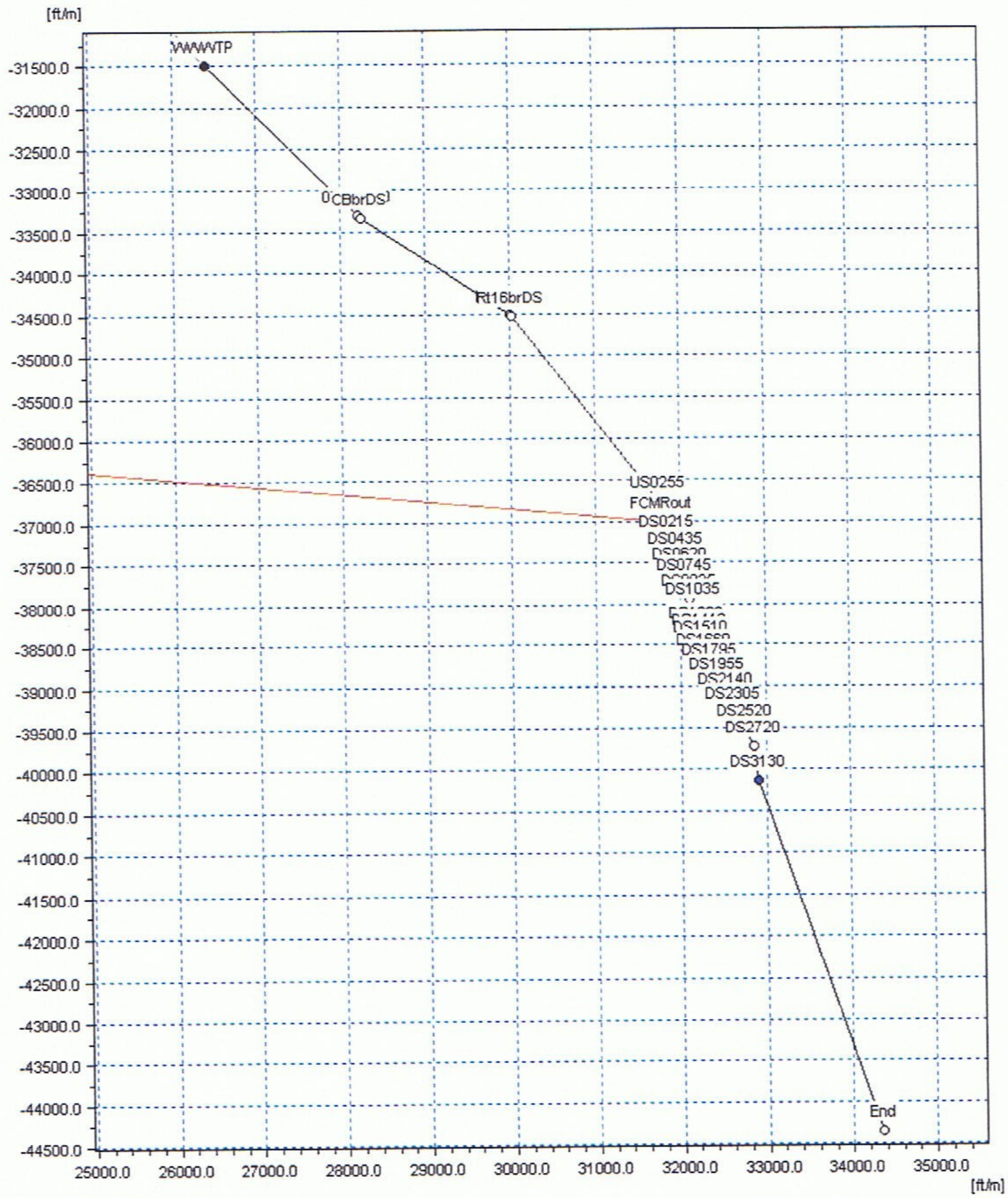


Figure 15: Profile view of SWMM EXTRAN model stream channels for a portion of Fountain Creek downstream of Colorado Springs, as shown above in **Figure 14**. The KOA property is located between the junctions marked "DS1955" and "DS3130," as shown below in **Figure 16**.

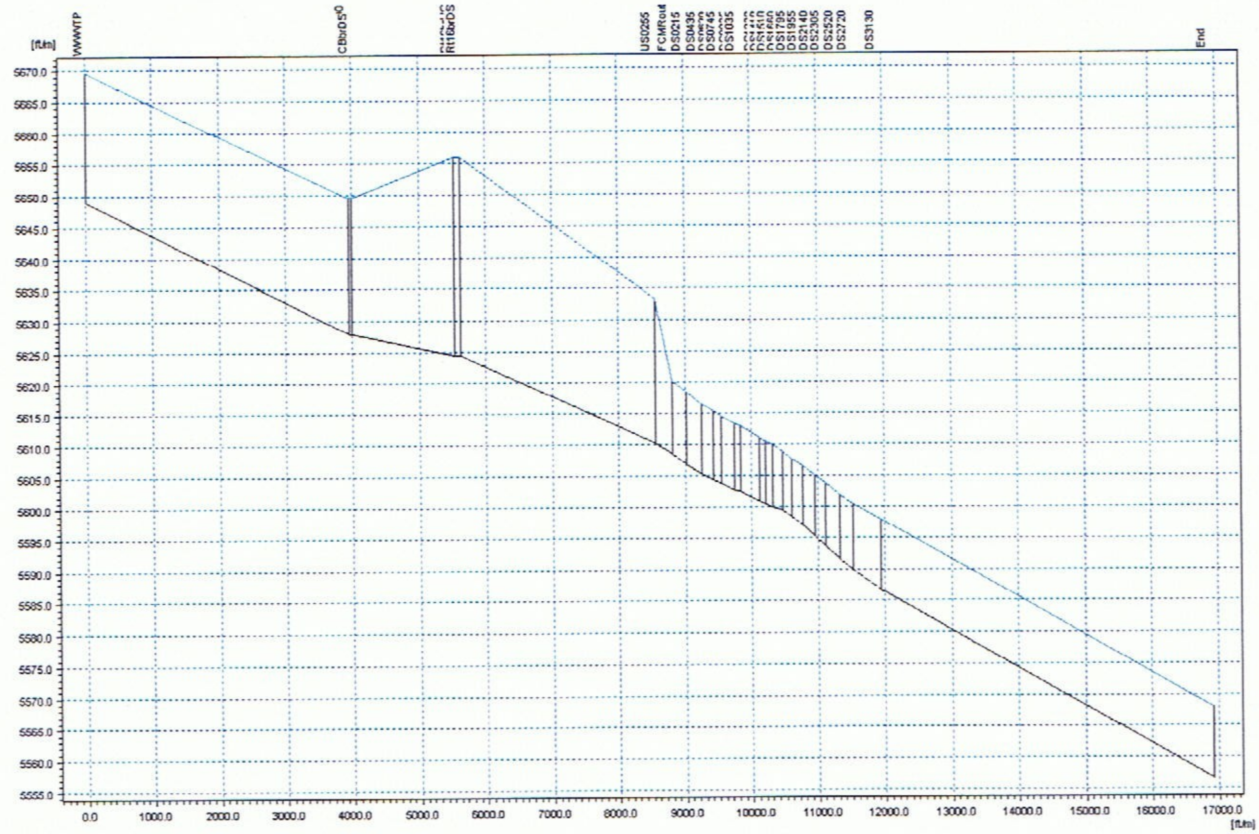


Figure 16: Detailed plan view of SWMM EXTRAN model stream channels for a portion of Fountain Creek downstream of Colorado Springs. The reference point (0,0) occurs at the confluence of Fountain and Monument Creeks in Colorado Springs. Scales on the axes shown here are given in feet north and east of the reference point. The KOA property is located along this portion of Fountain Creek between the color-coded points at junctions marked "DS1955" and "DS3130."

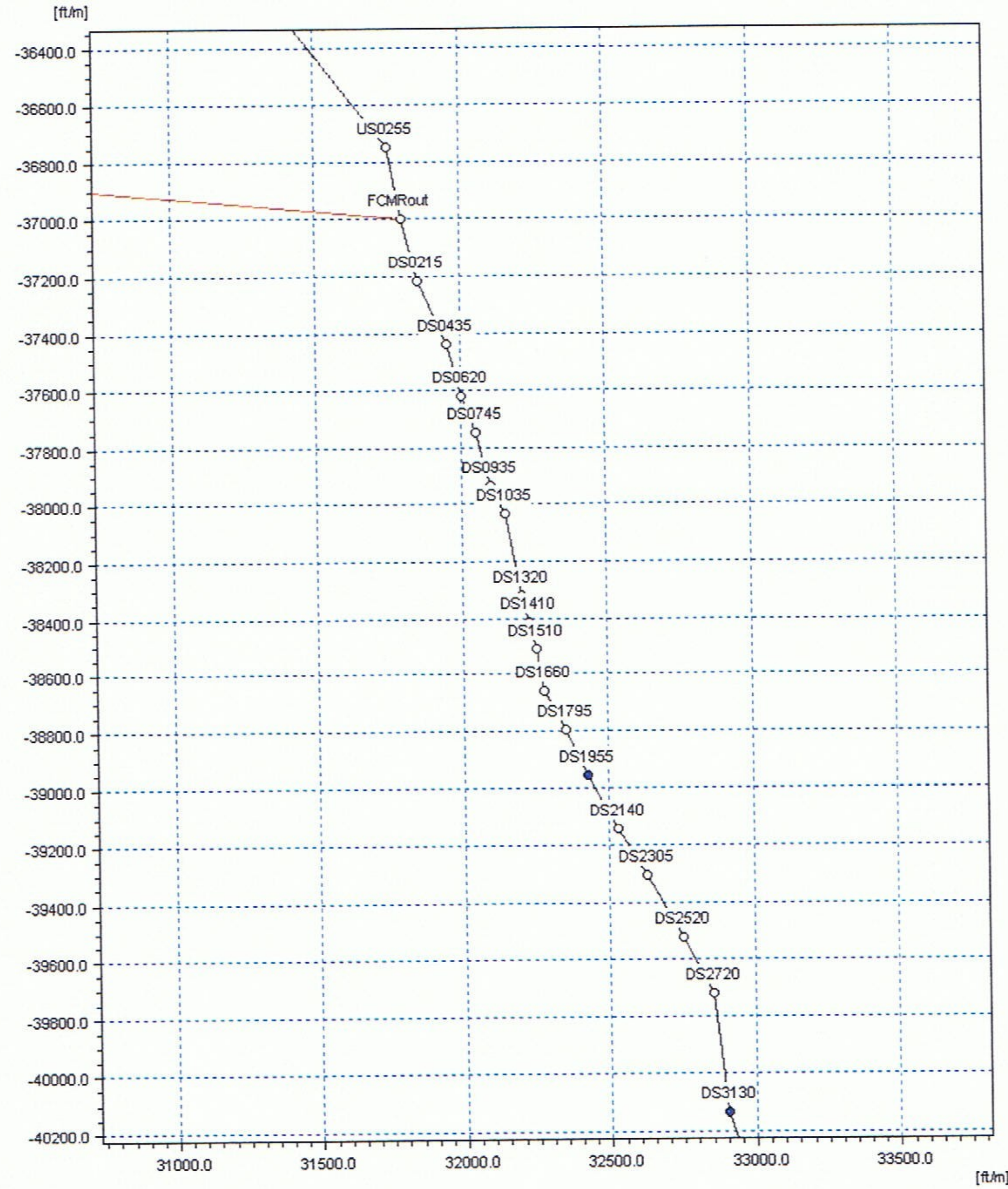


Figure 17: Detailed profile view of SWMM EXTRAN model stream channels for a portion of Fountain Creek downstream of Colorado Springs, as shown above in **Figure 16**. The KOA property is located along this portion of Fountain Creek between the junctions marked "DS1955" and "DS3130."

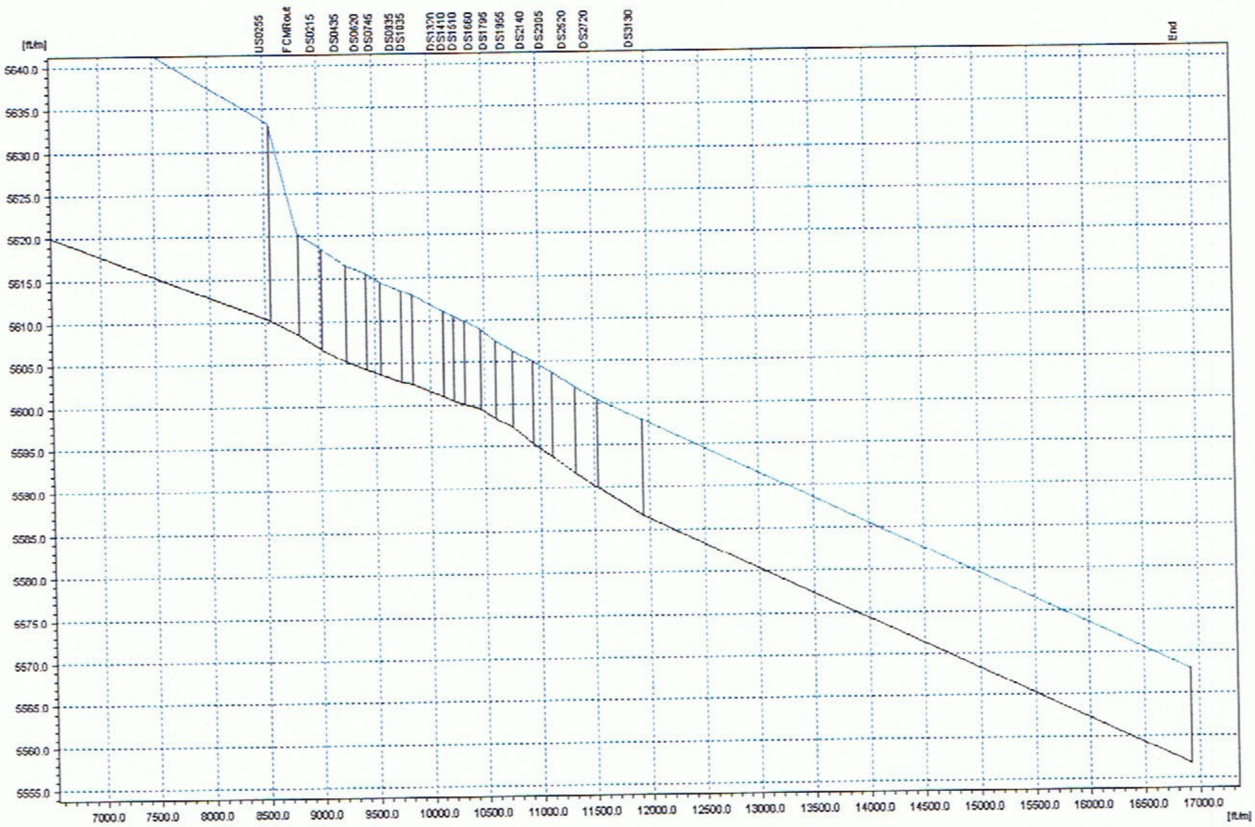


Figure 18: Photograph by the author of the Colorado Highway 16 bridge over Fountain Creek, downstream of Colorado Springs.

Figure 20a: Simulated stream channel water surface profile in the EXTRAN model segments along a portion of Fountain Creek for the major storm event during April 28-May 2, 1999. The profile shown corresponds to peak flow conditions near 3:30 pm on April 30, 1999. Junction names and discharges (in $ft^3\ s^{-1}$) for individual channel segments are shown near the top of the diagram. The KOA property is located along this portion of Fountain Creek between the junctions marked "DS1955" and "DS3130."

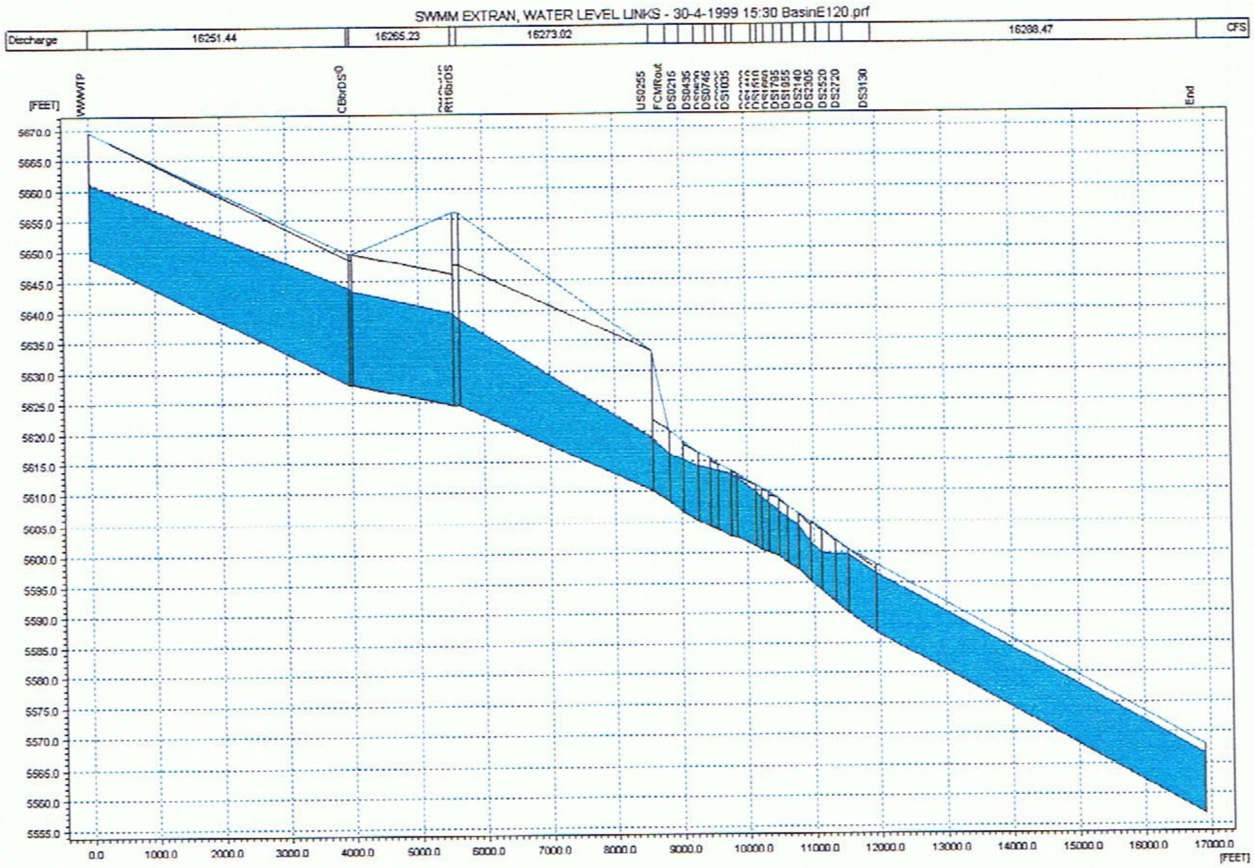


Figure 20b: Close-up view of simulated stream channel water surface profile in the EXTRAN model segments immediately upstream of and adjacent to the KOA property along Fountain Creek for the major storm event during April 28-May 2, 1999. The profile shown corresponds to peak flow conditions near 3:30 pm on April 30, 1999. Junction names and discharges (in $ft^3 s^{-1}$) for individual channel segments are shown near the top of the diagram. The KOA property is located along this portion of Fountain Creek between the junctions marked "DS1955" and "DS3130."

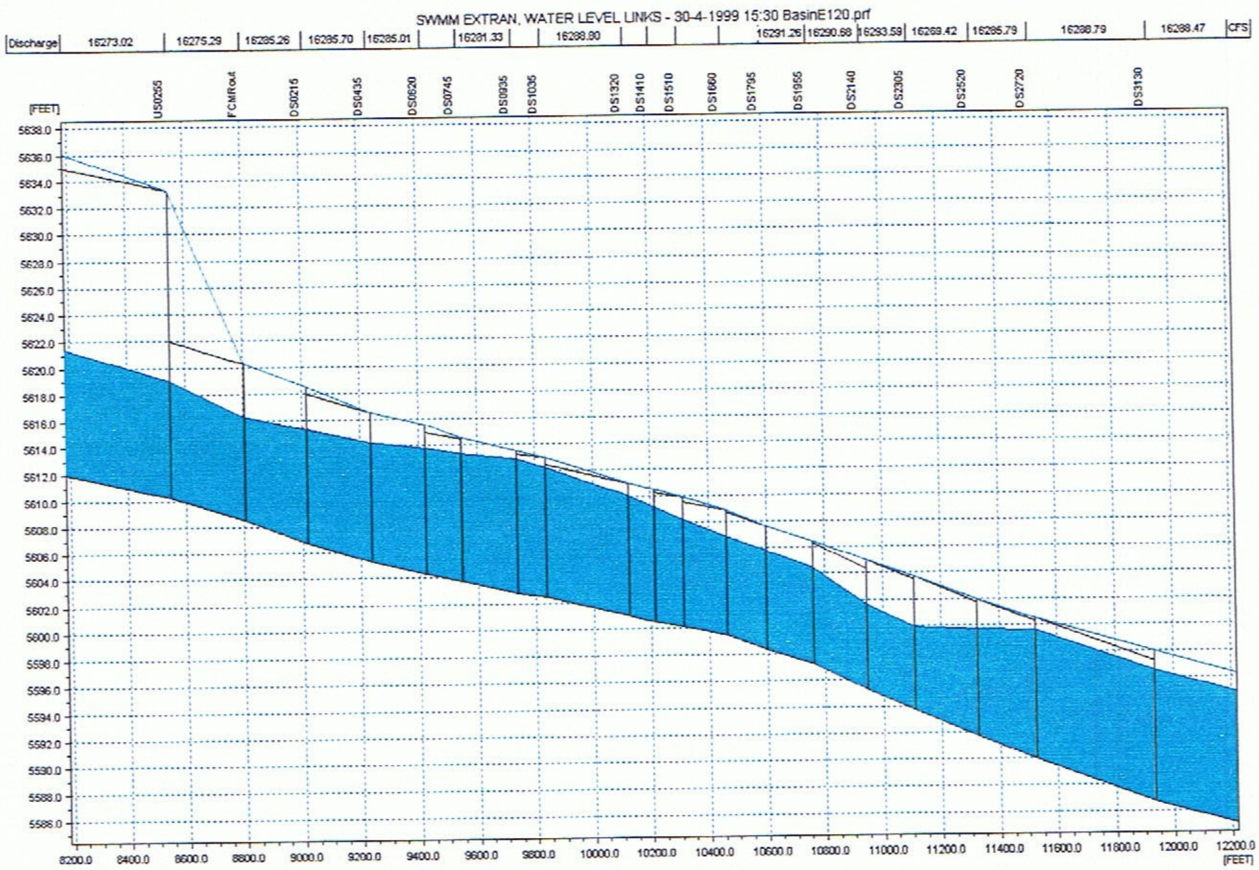


Figure 21a: Simulated hydrograph for the major storm event during April 28-May 2, 1999, at USGS gauge 07105800 (near the junction marked "CBbrDS" in **Figure 20a**). Statistics for these results are compiled in **Appendix B, Table 10**.

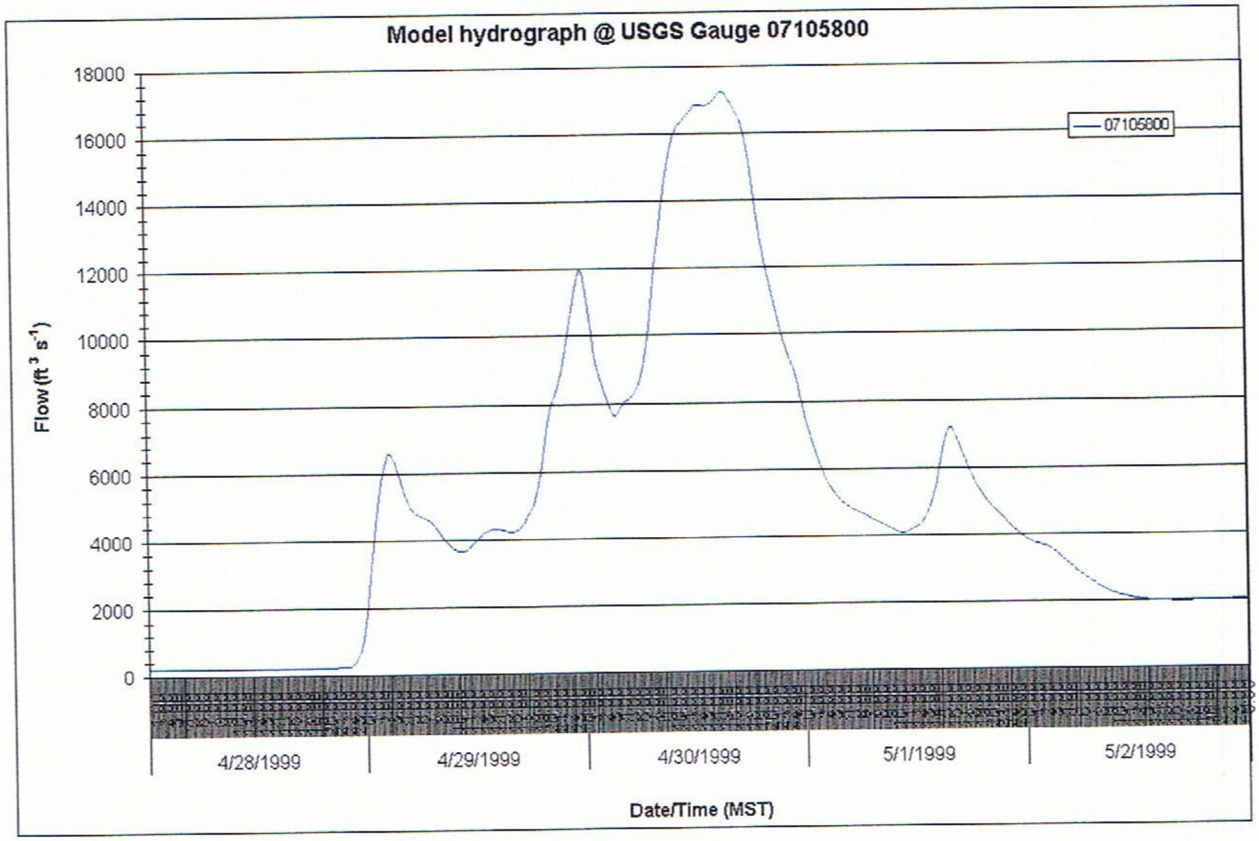


Figure 21b: Simulated flow velocities for the major storm event during April 28-May 2, 1999, at USGS gauge 07105800 (near the junction marked "CBbrDS" in **Figure 20a**). Statistics for these results are compiled in **Appendix B, Table 10**.

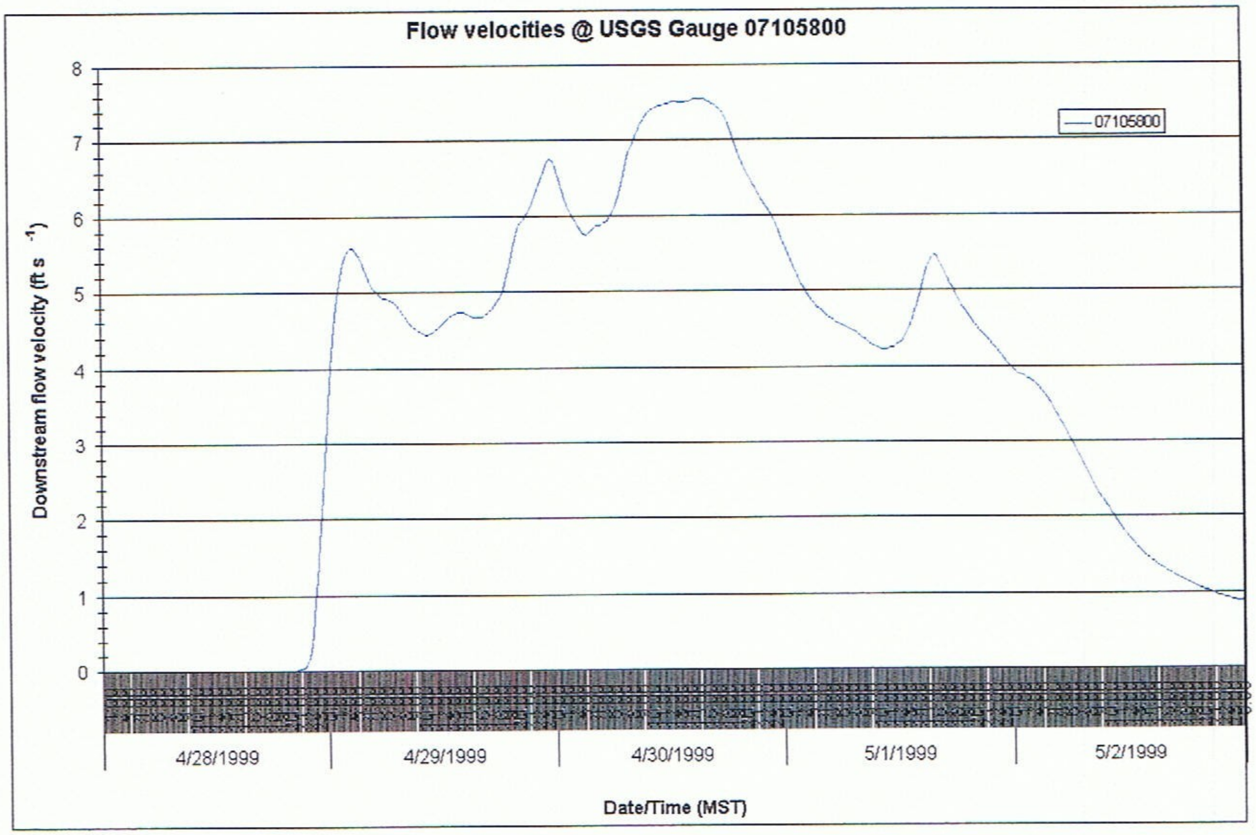


Figure 21c: Simulated hydrograph for the major storm event during April 28-May 2, 1999, at the upstream end of the KOA property (the junction marked "DS1955" in **Figures 20a** and **20b**) along Fountain Creek. Statistics for these results are compiled in **Appendix B, Table 11**.

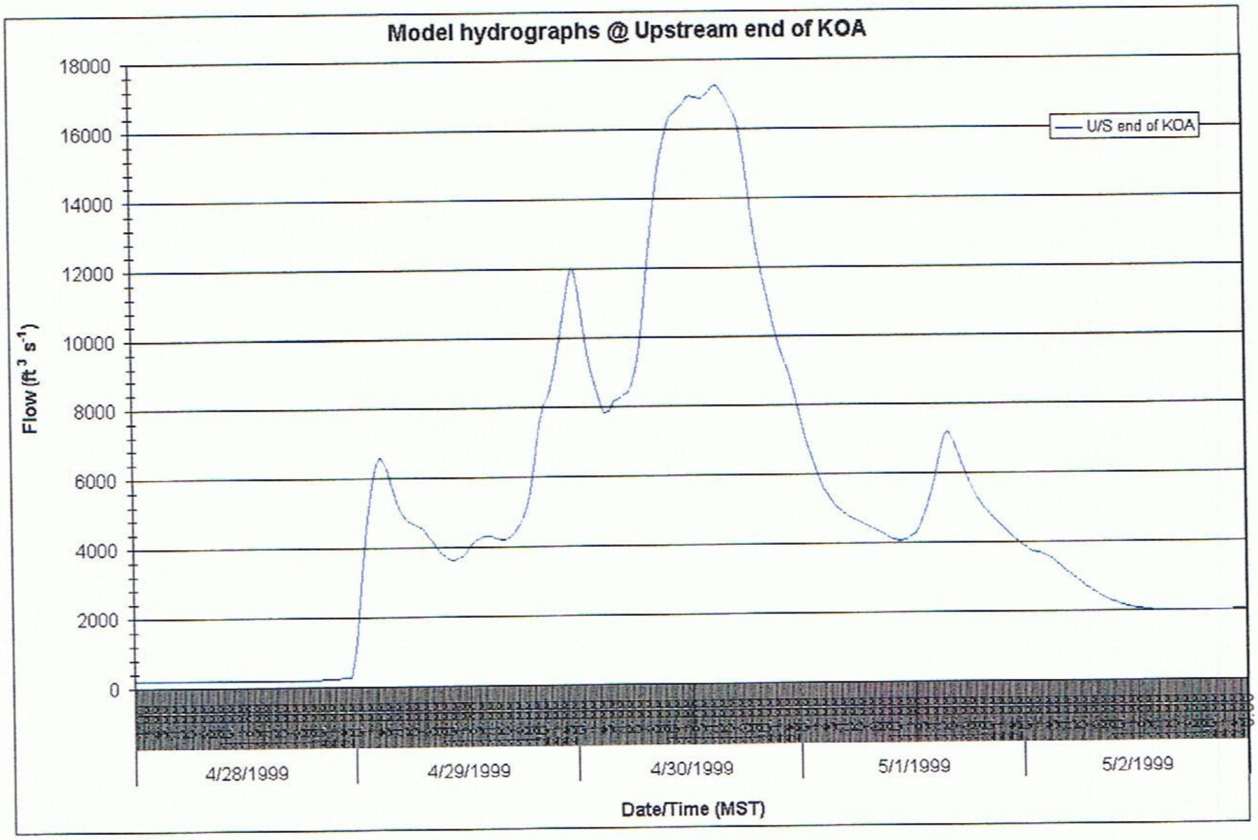


Figure 21d: Simulated flow velocities for the major storm event during April 28-May 2, 1999, at the upstream end of the KOA property (the junction marked "DS1955" in **Figures 20a** and **20b**) along Fountain Creek. Statistics for these results are compiled in **Appendix B, Table 11**.

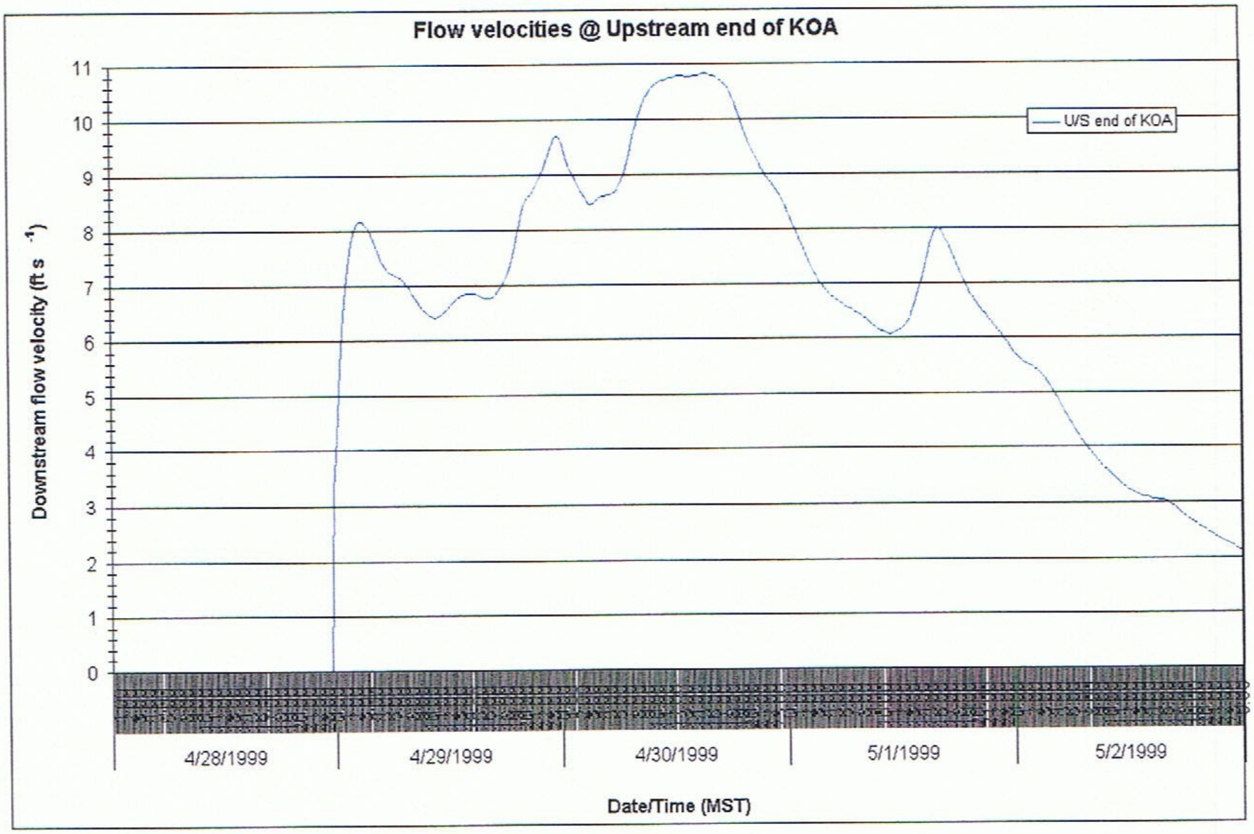


Figure 22a: Comparison of observed and simulated hydrographs for the major storm event during April 28-May 2, 1999, at USGS gauge locations along Fountain Creek between Colorado Springs and Pueblo, Colorado.

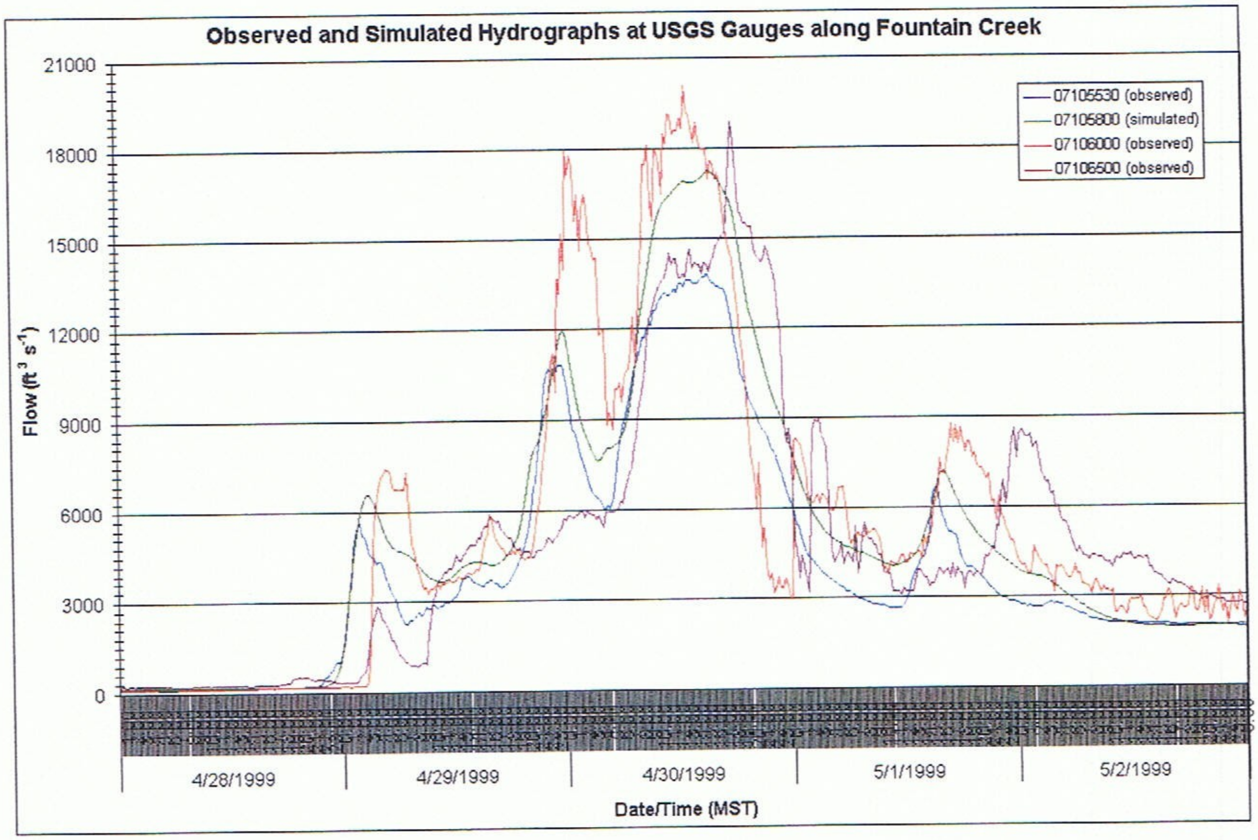


Figure 22b: Simulated hydrograph for the major storm event during April 28-May 2, 1999, at the location of the Greenview Ditch Headworks along Fountain Creek near Pueblo, Colorado. Statistics for these results are compiled in **Appendix B, Table 12.**

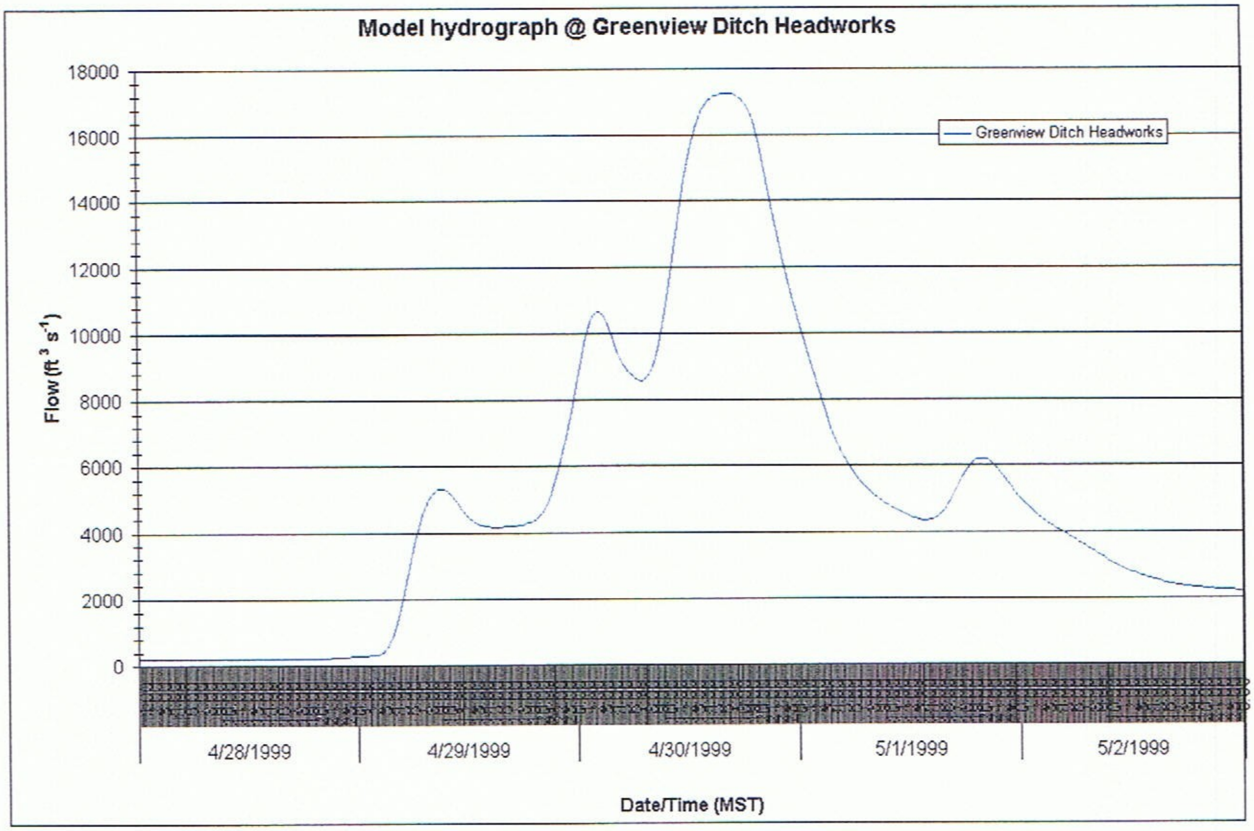


Figure 22c: Simulated flow velocities for the major storm event during April 28-May 2, 1999, at the location of the Greenview Ditch Headworks along Fountain Creek near Pueblo, Colorado. Statistics for these results are compiled in **Appendix B, Table 12**.

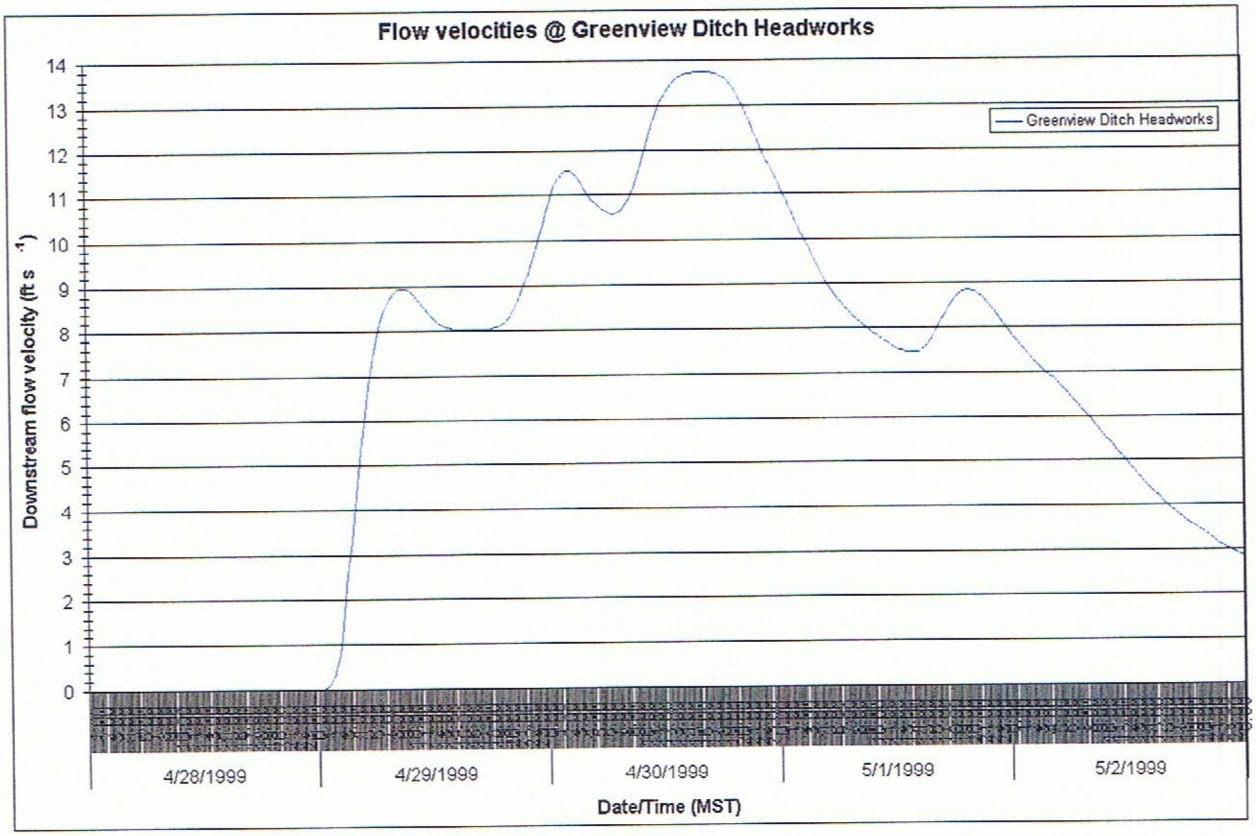


Figure 23a: Simulated stream channel water surface profile in the EXTRAN model segments along a portion of Fountain Creek for the major storm event during April 28-May 2, 1999, in the absence of the left bank levee downstream of the bridge at Colorado Highway 16 (the junction marked "Rt16brDS"). This result should be compared with that shown above in **Figure 20a**. The profile shown corresponds to peak flow conditions near 3:30 pm on April 30, 1999. Junction names and discharges (in $ft^3 s^{-1}$) for individual channel segments are shown near the top of the diagram. The KOA property is located along this portion of Fountain Creek between the junctions marked "DS1955" and "DS3130."

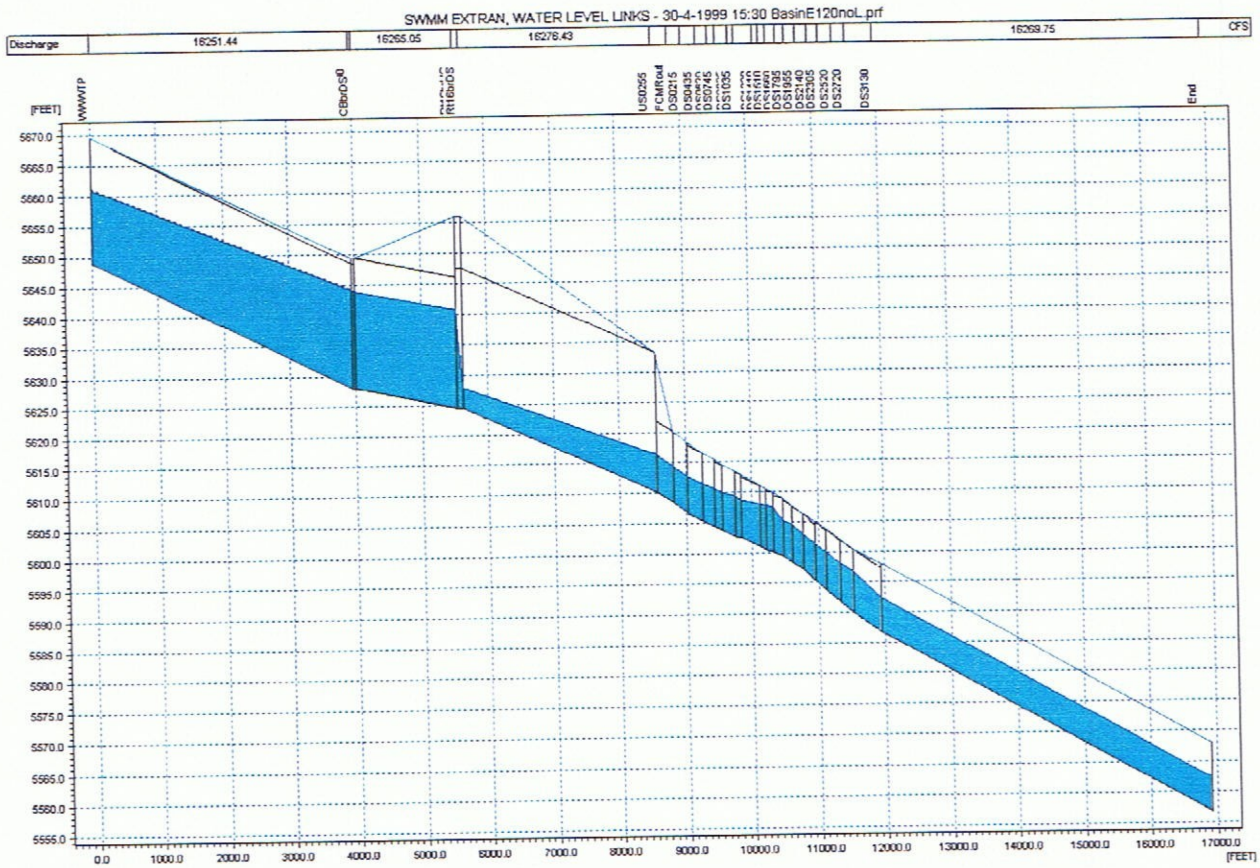


Figure 23b: Close-up view of simulated stream channel water surface profile in the EXTRAN model segments along a portion of Fountain Creek at and near the bridge at Colorado Highway 16 for the major storm event during April 28-May 2, 1999, in the absence of the left bank levee downstream of the bridge at Colorado Highway 16 (the junction marked "Rt16brDS"). The profile shown corresponds to peak flow conditions near 3:30 pm on April 30, 1999. Junction names and discharges (in $ft^3 s^{-1}$) for individual channel segments are shown near the top of the diagram.

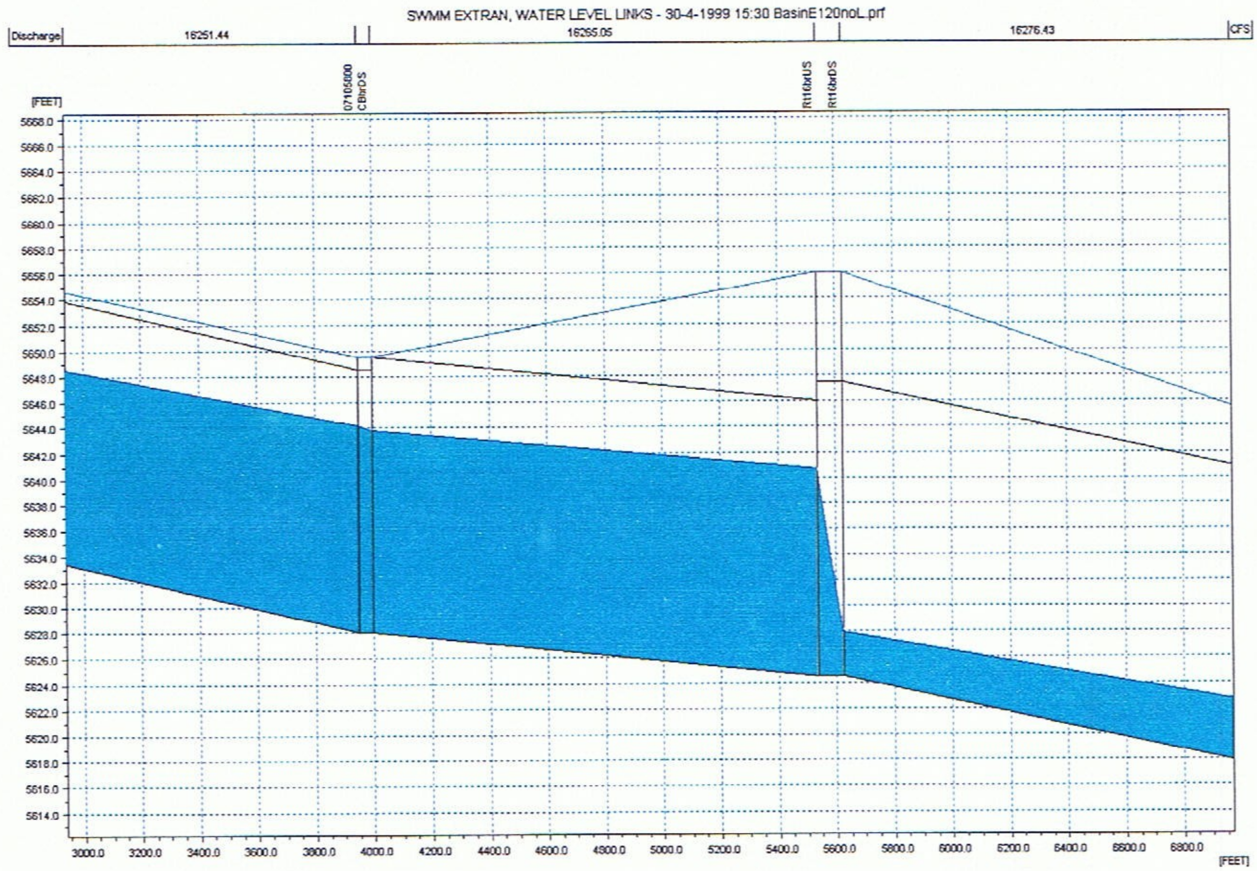


Figure 23c: Close-up view of simulated stream channel water surface profile in the EXTRAN model segments immediately upstream of and adjacent to the KOA property along Fountain Creek for the major storm event during April 28-May 2, 1999, in the absence of the left bank levee downstream of the bridge at Colorado Highway 16 (the junction marked "Rt16brDS" in **Figures 23a** and **23b**). This result should be compared with that shown above in **Figure 20b**. The profile shown corresponds to peak flow conditions near 3:30 pm on April 30, 1999. Junction names and discharges (in $ft^3 s^{-1}$) for individual channel segments are shown near the top of the diagram. The KOA property is located along this portion of Fountain Creek between the junctions marked "DS1955" and "DS3130."

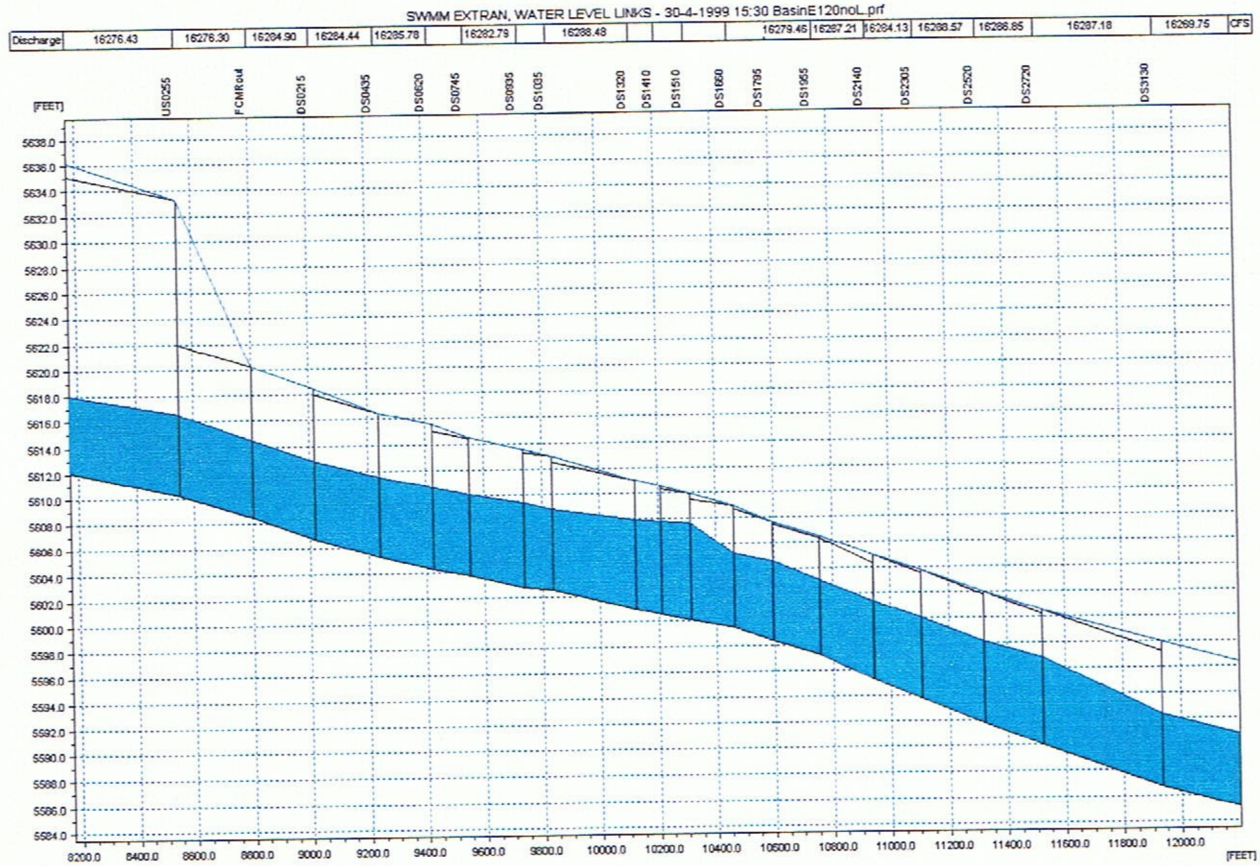


Figure 24a: Simulated hydrographs for the major storm event during April 28-May 2, 1999, at USGS gauge 07105800 (as marked in **Figure 23b**), in the absence of the left bank levee downstream of the bridge at Colorado Highway 16 (the junction marked "Rt16brDS" in **Figures 23a** and **23b**). This result is compared with that shown above in **Figure 21a**. Statistics for these results are compiled in **Appendix B, Table 10**.

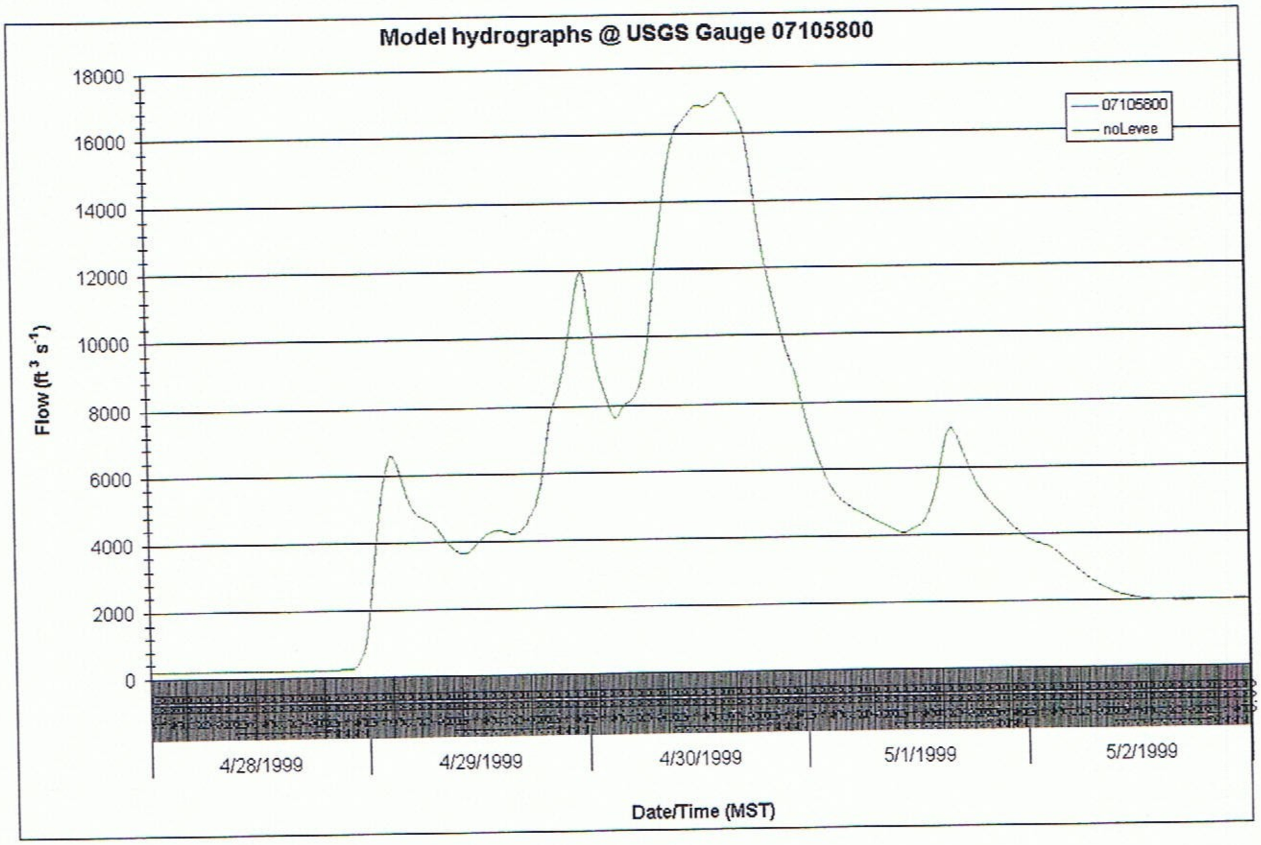


Figure 24b: Simulated flow velocities for the major storm event during April 28-May 2, 1999, at USGS gauge 07105800 (as marked in **Figure 23b**), in the absence of the left bank levee downstream of the bridge at Colorado Highway 16 (the junction marked "Rt16brDS" in **Figures 23a** and **23b**). This result is compared with that shown above in **Figure 21b**. Statistics for these results are compiled in **Appendix B, Table 10**.

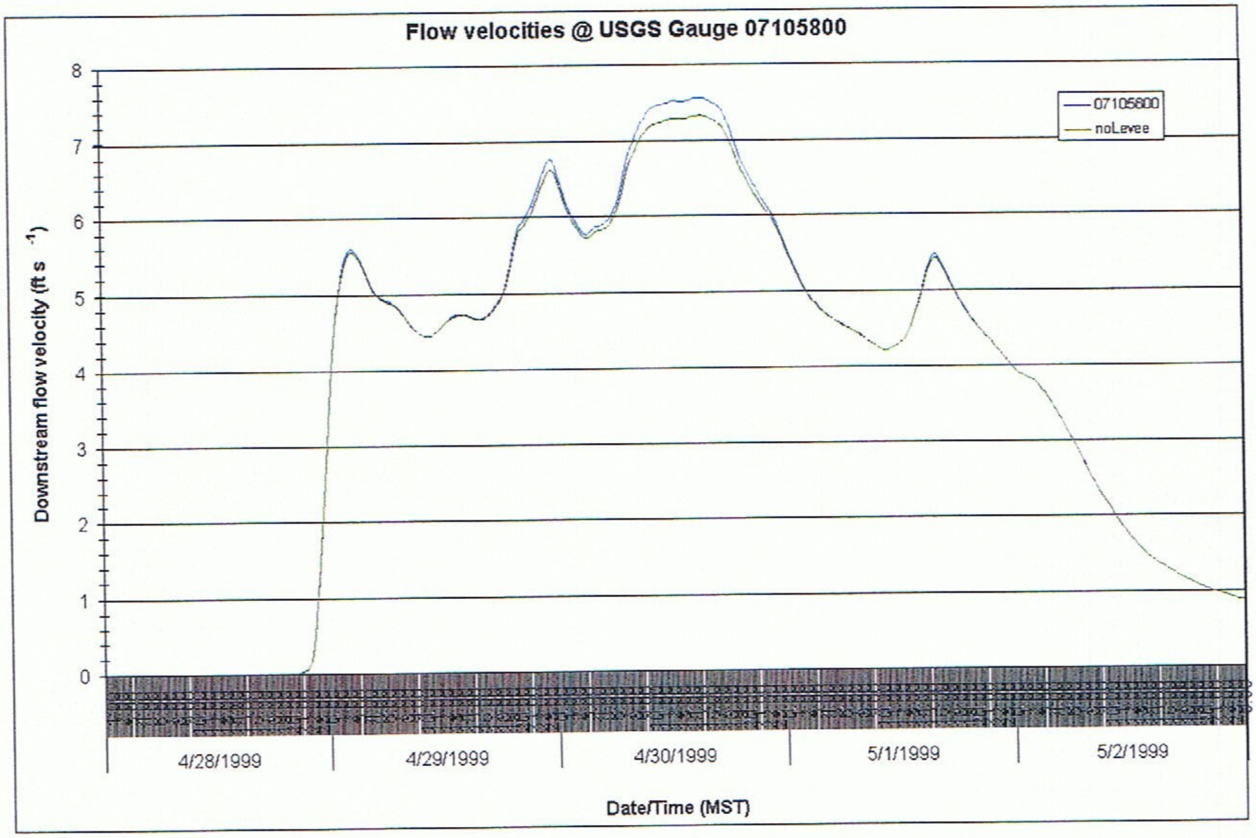


Figure 24c: Simulated hydrographs for the major storm event during April 28-May 2, 1999, at the upstream end of the KOA property (the junction marked "DS1955" in **Figures 23a** and **23c**) along Fountain Creek, in the absence of the left bank levee downstream of the bridge at Colorado Highway 16 (the junction marked "Rt16brDS" in **Figures 23a** and **23b**). This result is compared with that shown above in **Figure 21c**. Statistics for these results are compiled in **Appendix B, Table 11**.

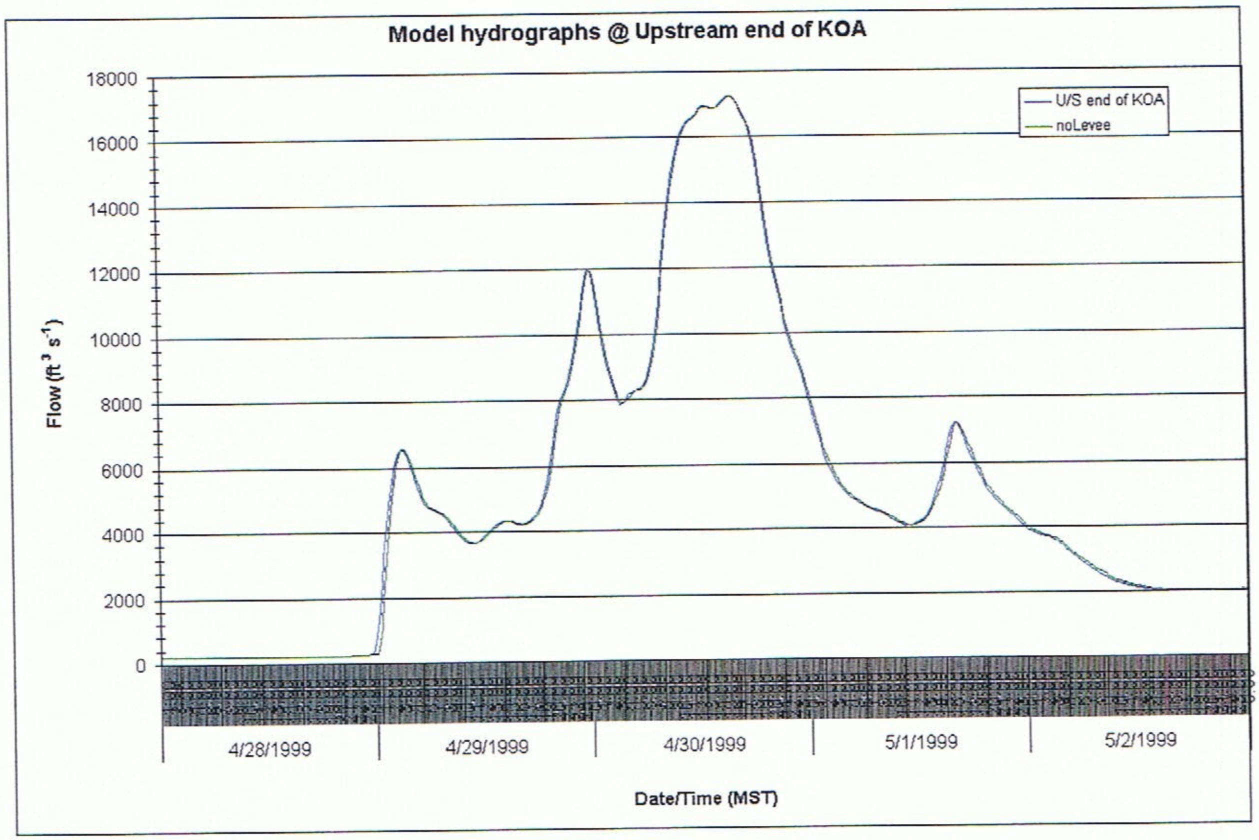


Figure 24d: Simulated flow velocities for the major storm event during April 28-May 2, 1999, at the upstream end of the KOA property (the junction marked "DS1955" in **Figures 23a** and **23c**) along Fountain Creek, in the absence of the left bank levee downstream of the bridge at Colorado Highway 16 (the junction marked "Rt16brDS" in **Figures 23a** and **23b**). This result is compared with that shown above in **Figure 21d**. Statistics for these results are compiled in **Appendix B, Table 11**.

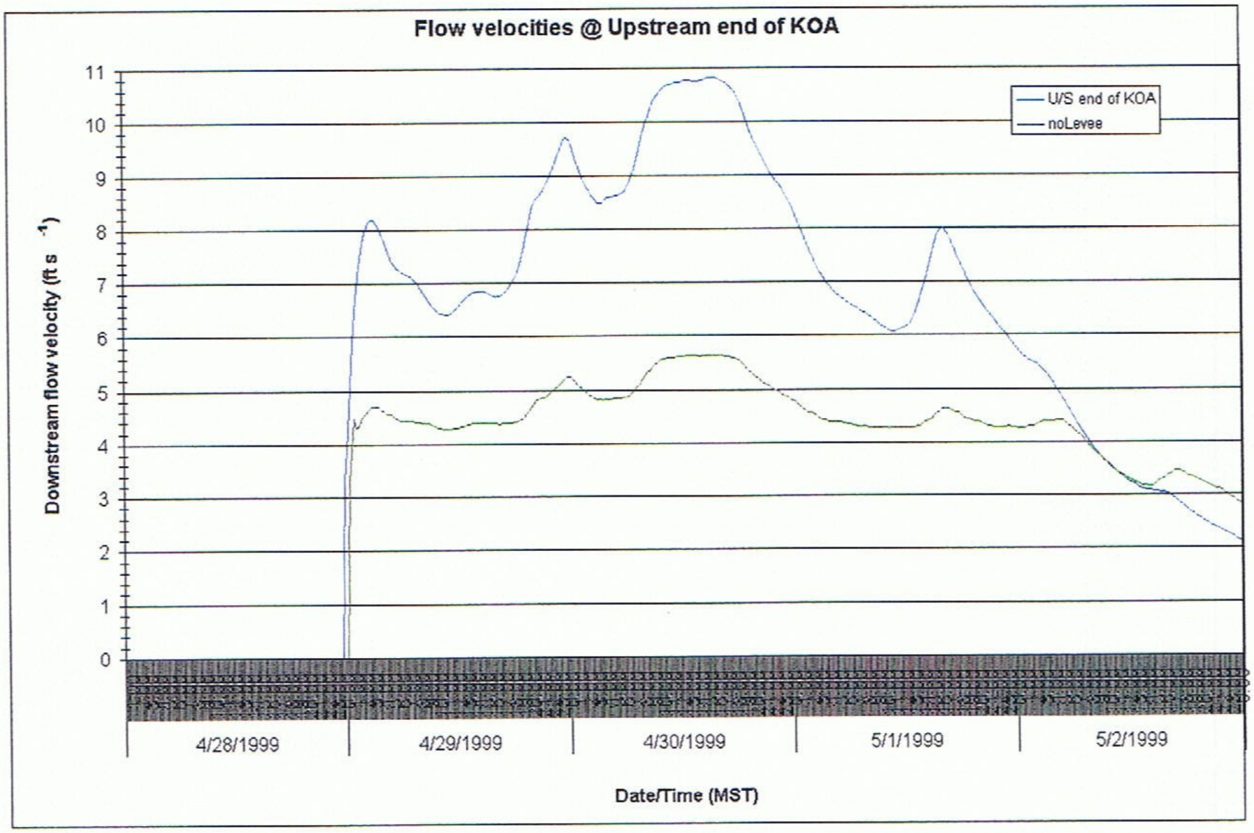


Figure 25: Simulated stream channel water surface profile in the EXTRAN model segments along a portion of Fountain Creek for the major storm event during April 28-May 2, 1999, in the absence of the developed area of the City of Colorado Springs in the upstream region. This result should be compared with that shown above in **Figure 20a**. The profile shown corresponds to peak flow conditions near 6:00 pm on April 30, 1999. Junction names and discharges (in $ft^3 s^{-1}$) for individual channel segments are shown near the top of the diagram. The KOA property is located along this portion of Fountain Creek between the junctions marked "DS1955" and "DS3130."

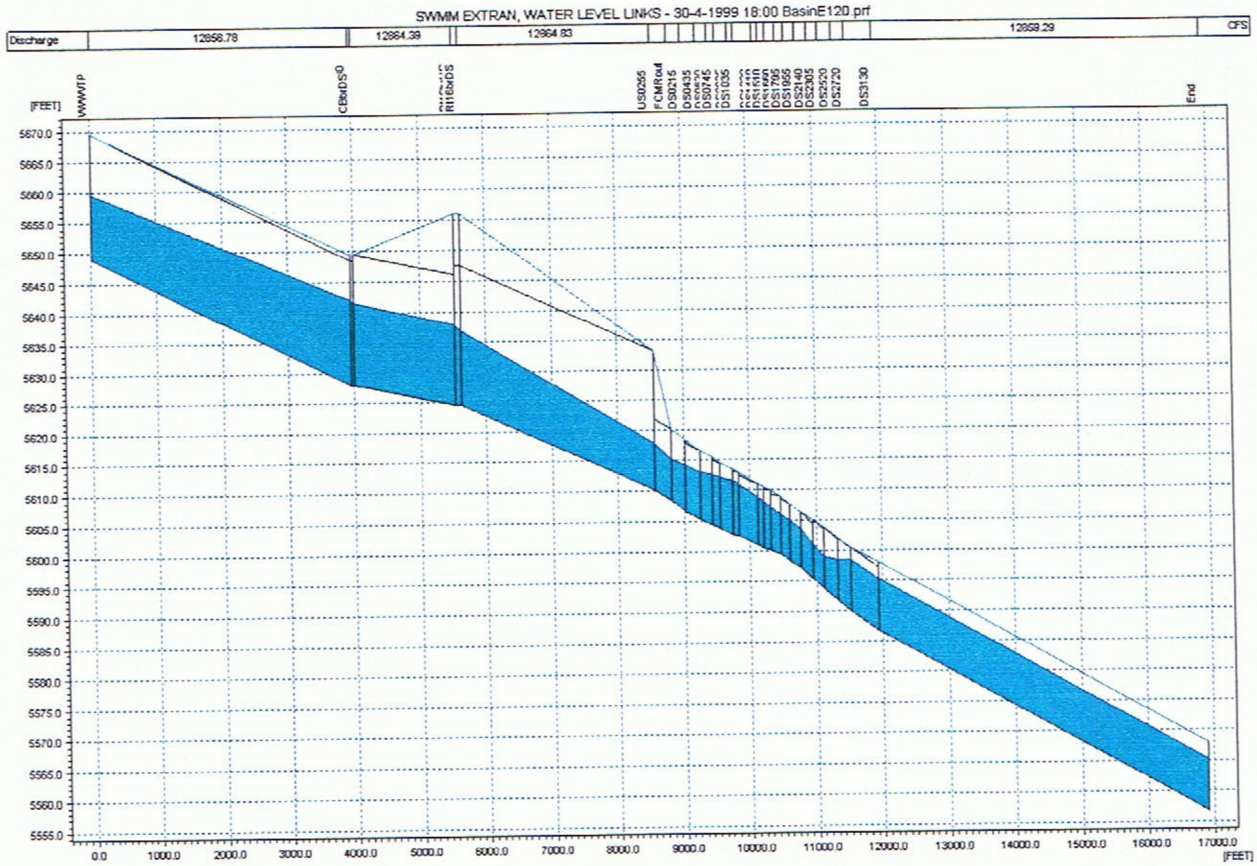


Figure 26a: Simulated hydrographs for the major storm event during April 28-May 2, 1999, at USGS gauge 07105800 (near the junction marked "CBbrDS" in **Figure 25**), in the absence of the developed area of the City of Colorado Springs in the upstream region. This result is compared with those shown above in **Figures 21a** and **24a**. Statistics for these results are compiled in **Appendix B, Table 10**.

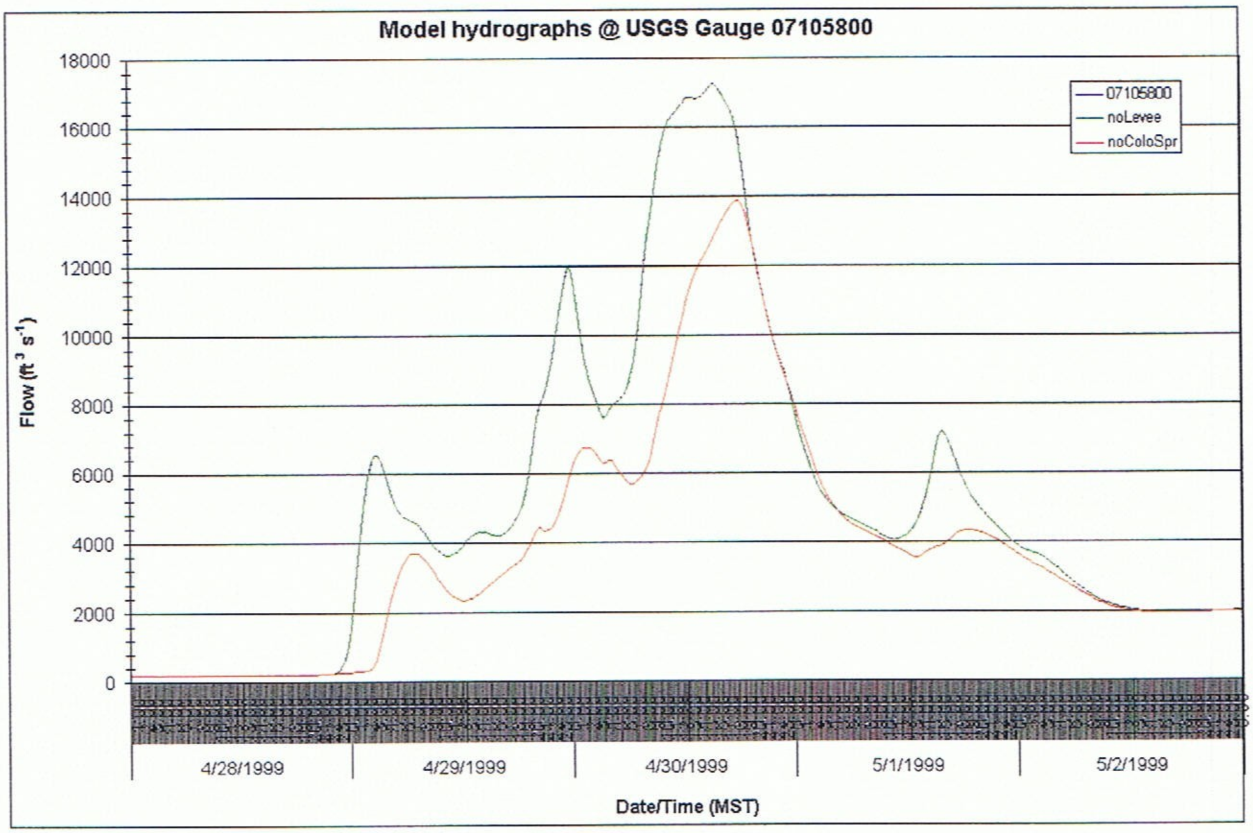


Figure 26b: Simulated flow velocities for the major storm event during April 28-May 2, 1999, at USGS gauge 07105800 (near the junction marked "CBbrDS" in **Figure 25**), in the absence of the developed area of the City of Colorado Springs in the upstream region. This result is compared with those shown above in **Figures 21b** and **24b**. Statistics for these results are compiled in **Appendix B, Table 10**.

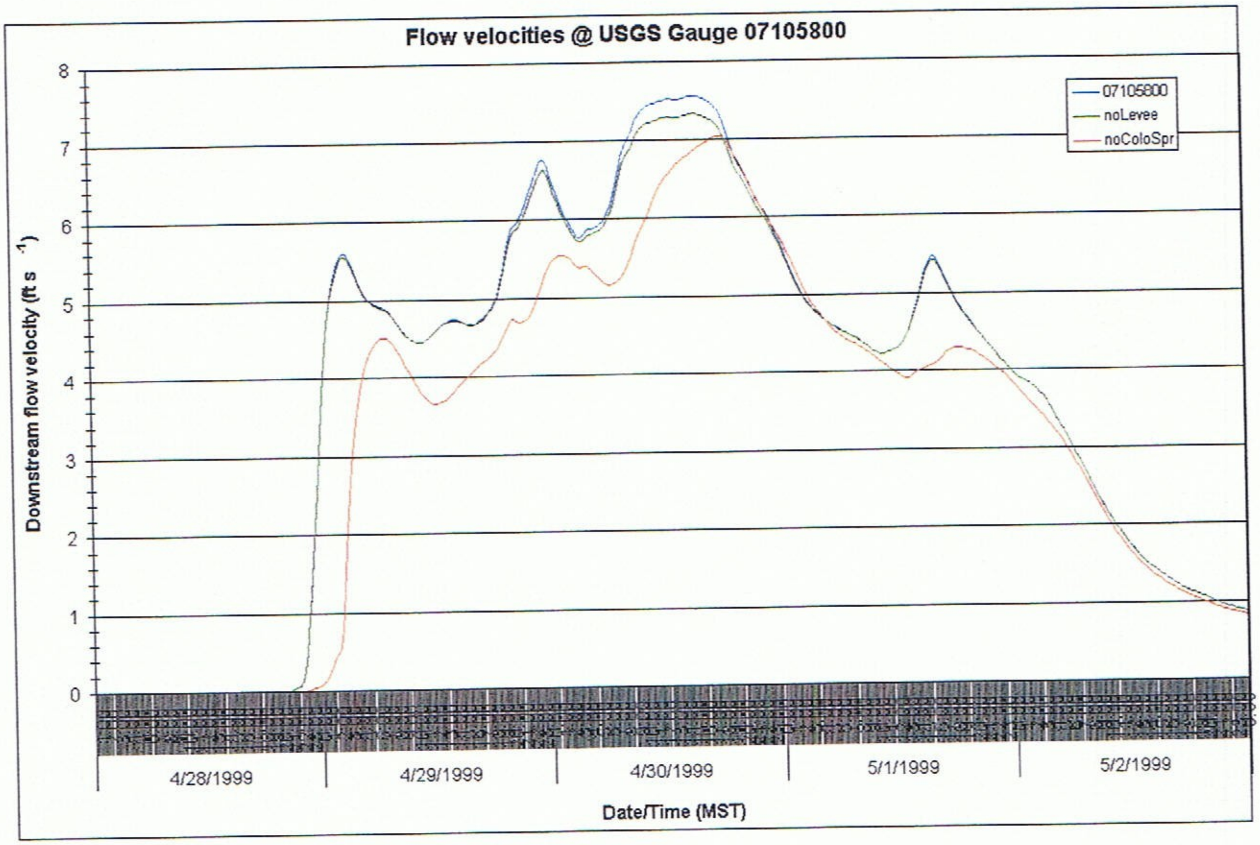


Figure 26c: Simulated hydrographs for the major storm event during April 28-May 2, 1999, at the upstream end of the KOA property (the junction marked "DS1955" in **Figure 25**) along Fountain Creek, in the absence of the developed area of the City of Colorado Springs in the upstream region. This result is compared with those shown above in **Figures 21c** and **24c.** Statistics for these results are compiled in **Appendix B, Table 11**.

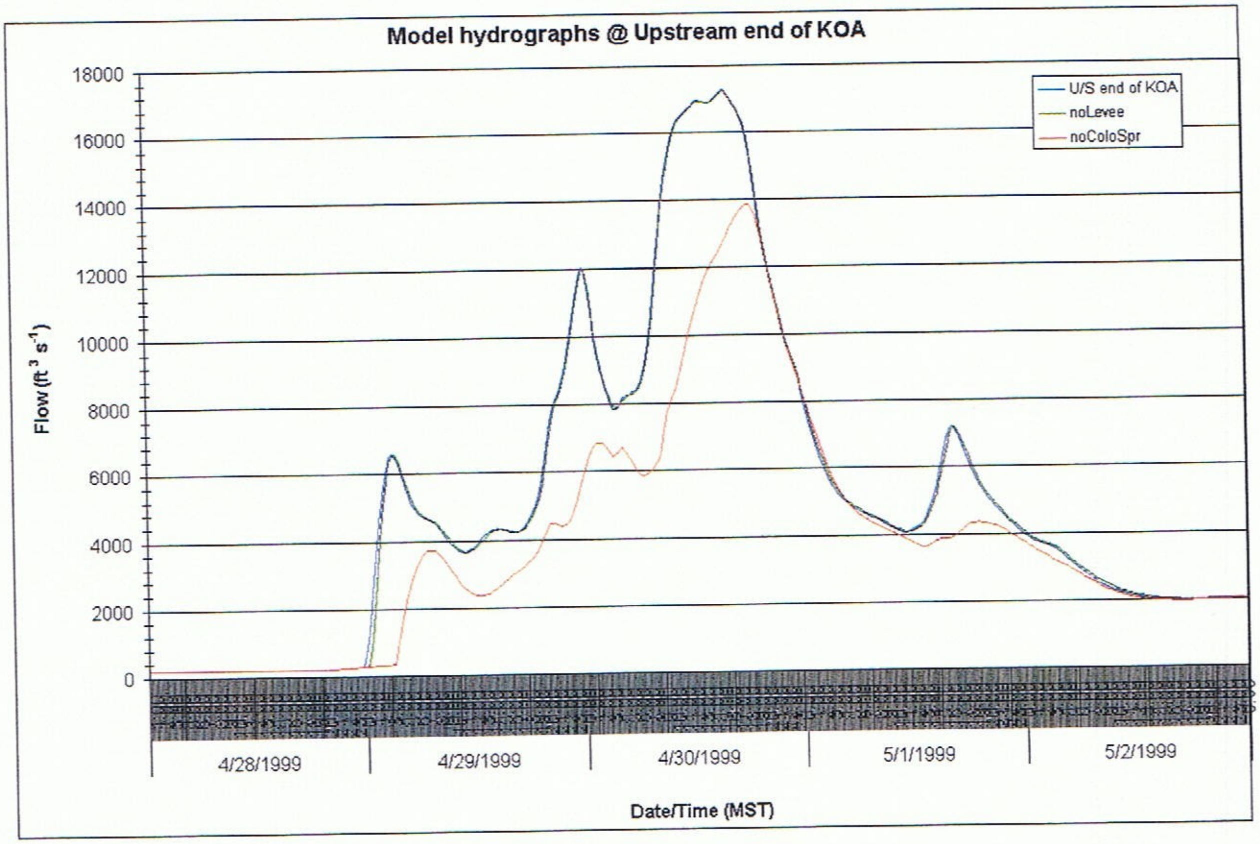


Figure 26d: Simulated flow velocities for the major storm event during April 28-May 2, 1999, at the upstream end of the KOA property (the junction marked "DS1955" in **Figure 25**) along Fountain Creek, in the absence of the developed area of the City of Colorado Springs in the upstream region. This result is compared with those shown above in **Figures 21d** and **24d**. Statistics for these results are compiled in **Appendix B, Table 11**.

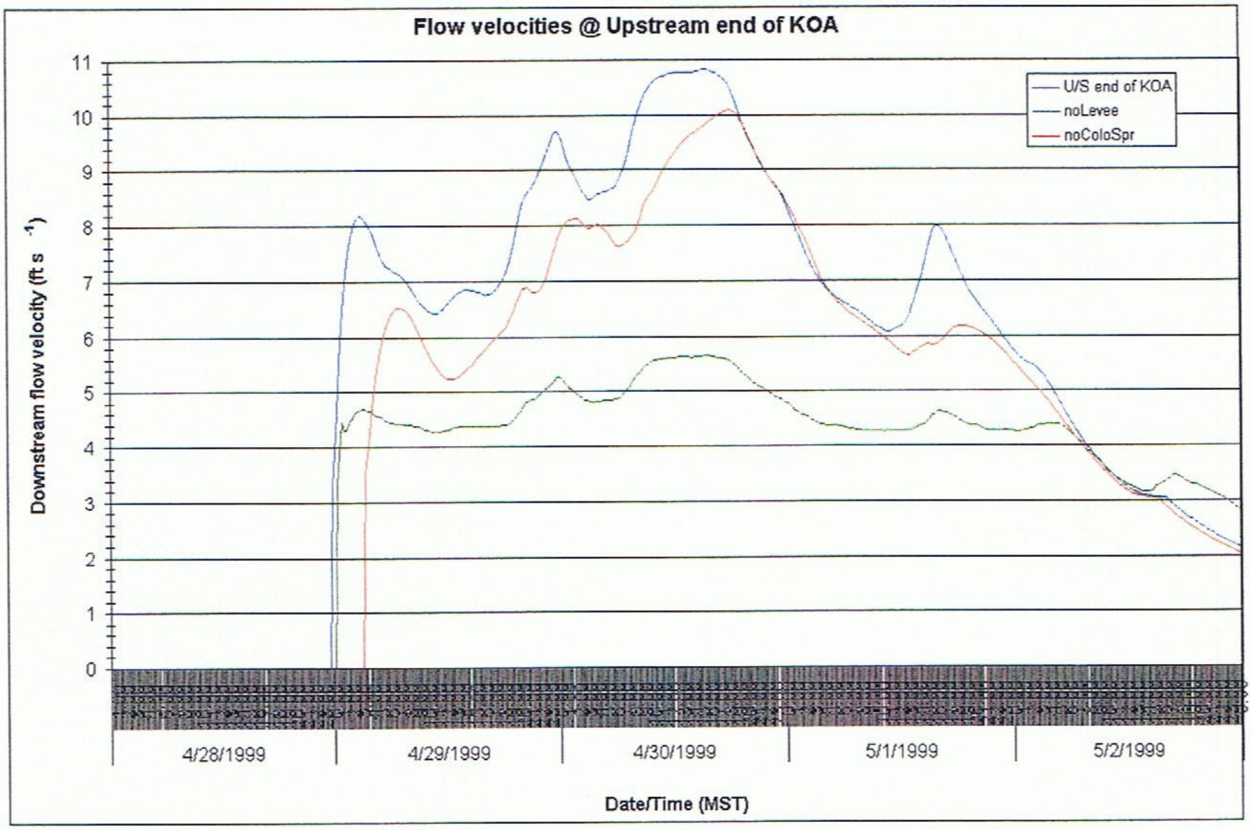


Figure 27: Simulated stream channel water surface profile in the EXTRAN model segments along a portion of Fountain Creek for the major storm event during April 28-May 2, 1999, in the absence of the developed area of the City of Colorado Springs in the upstream region as well as the left bank levee downstream of the Colorado Highway 16 bridge (the junction marked "Rt16brDS"). This result should be compared with those shown above in **Figures 23a** and **25**. The profile shown corresponds to peak flow conditions near 6:00 pm on April 30, 1999. Junction names and discharges (in $ft^3 s^{-1}$) for individual channel segments are shown near the top of the diagram. The KOA property is located along this portion of Fountain Creek between the junctions marked "DS1955" and "DS3130."

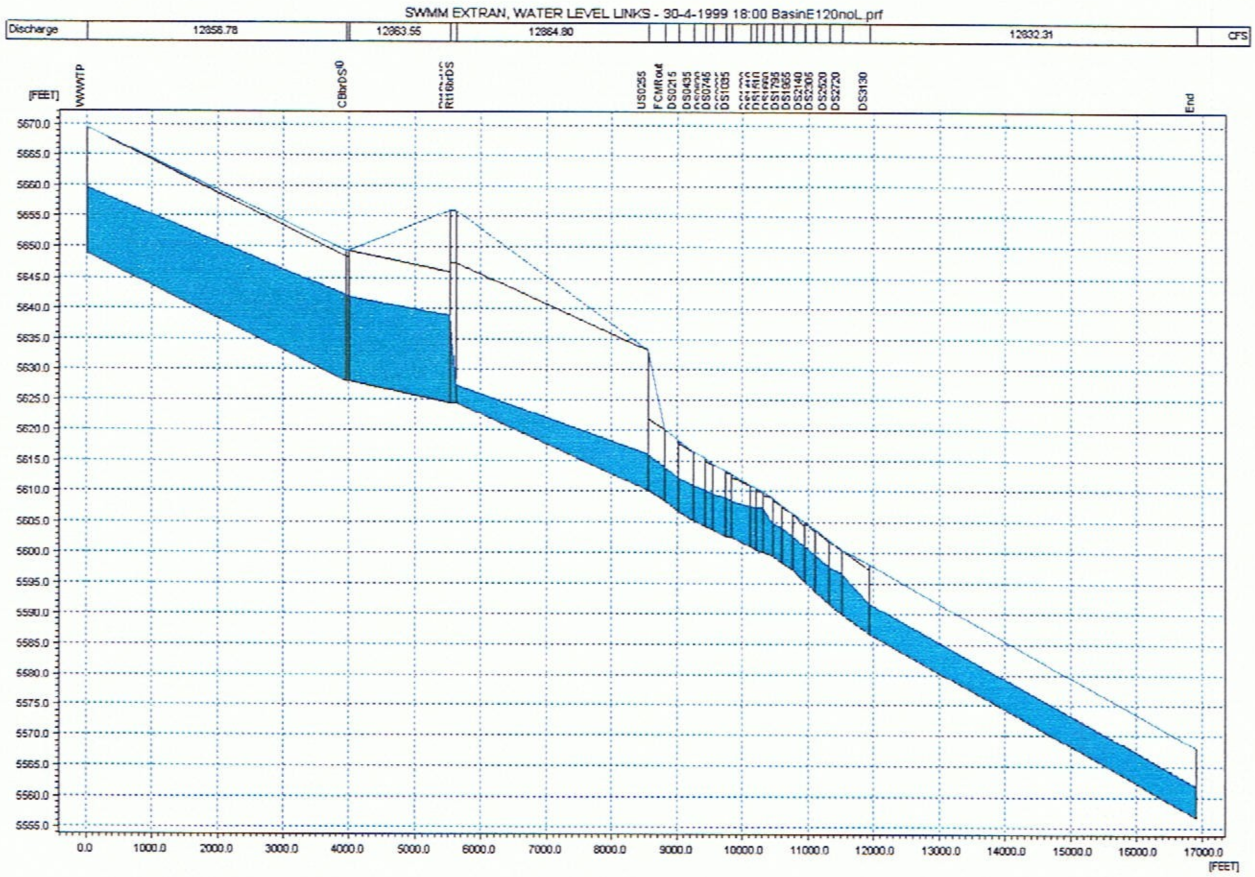


Figure 28a: Simulated hydrographs for the major storm event during April 28-May 2, 1999, at USGS gauge 07105800 (near the junction marked "CBbrDS" in **Figure 27**), in the absence of the developed area of the City of Colorado Springs in the upstream region as well as the left bank levee downstream of the bridge at Colorado Highway 16 (the junction marked "Rt16brDS" in **Figure 27**). This result is compared with those shown above in **Figures 21a**, **24a**, and **26a**. Statistics for these results are compiled in **Appendix B, Table 10**.

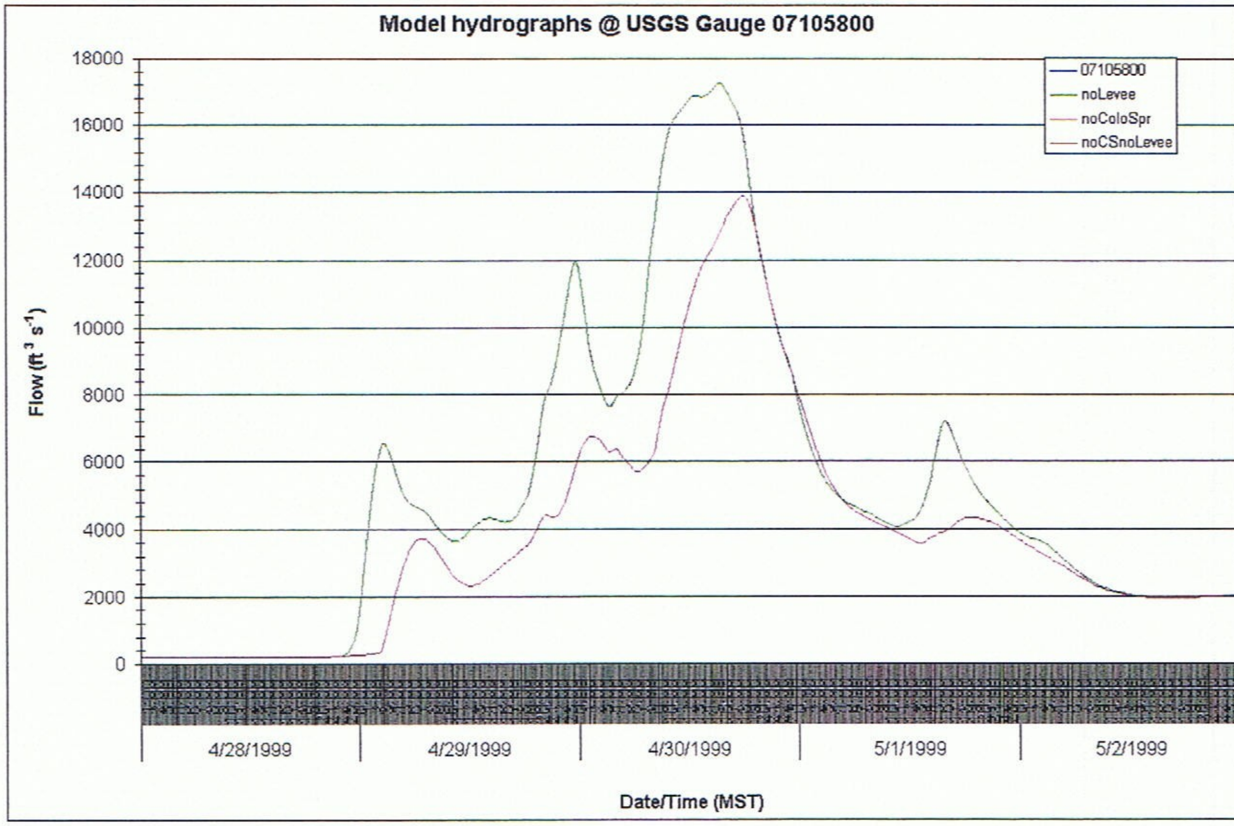


Figure 28b: Simulated flow velocities for the major storm event during April 28-May 2, 1999, at USGS gauge 07105800 (near the junction marked "CBbrDS" in **Figure 27**), in the absence of the developed area of the City of Colorado Springs in the upstream region as well as the left bank levee downstream of the bridge at Colorado Highway 16 (the junction marked "Rt16brDS" in **Figure 27**). This result is compared with those shown above in **Figures 21b**, **24b**, and **26b**. Statistics for these results are compiled in **Appendix B, Table 10**.

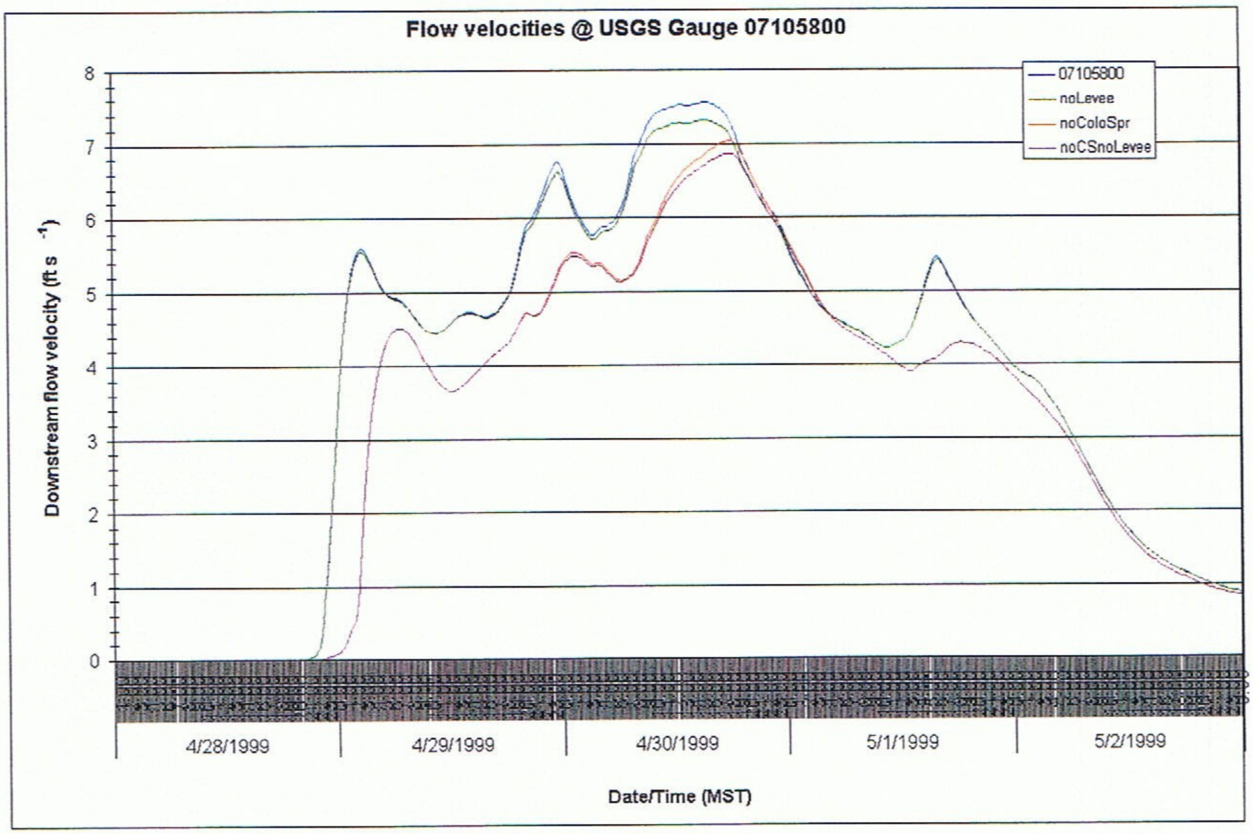


Figure 28c: Simulated hydrographs for the major storm event during April 28-May 2, 1999, at the upstream end of the KOA property (the junction marked "DS1955" in **Figure 27**) along Fountain Creek, in the absence of the developed area of the City of Colorado Springs in the upstream region as well as the left bank levee downstream of the bridge at Colorado Highway 16 (the junction marked "Rt16brDS" in **Figure 27**). This result is compared with those shown above in **Figures 21c**, **24c**, and **26c**. Statistics for these results are compiled in **Appendix B, Table 11**.

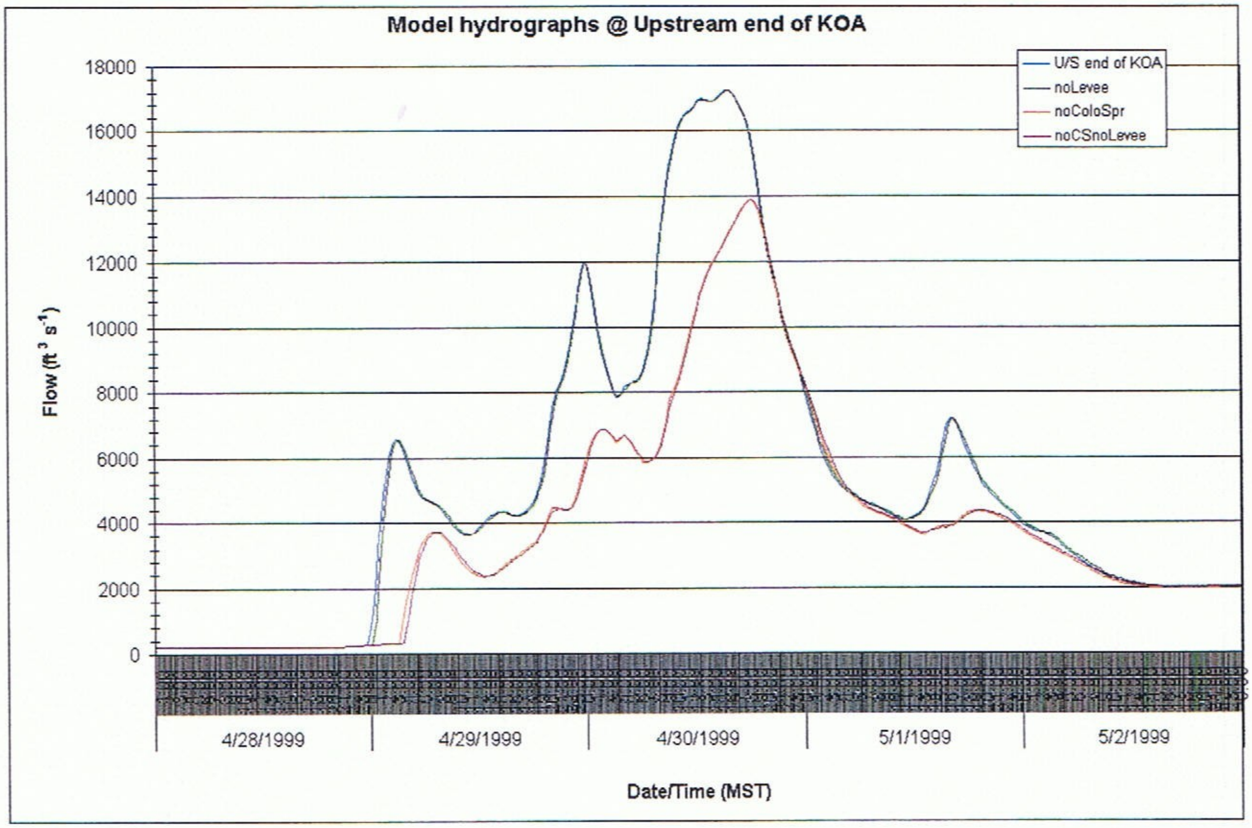


Figure 28d: Simulated flow velocities for the major storm event during April 28-May 2, 1999, at the upstream end of the KOA property (the junction marked "DS1955" in **Figure 27**) along Fountain Creek, in the absence of the developed area of the City of Colorado Springs in the upstream region as well as the left bank levee downstream of the bridge at Colorado Highway 16 (the junction marked "Rt16brDS" in **Figure 27**). This result is compared with those shown above in **Figures 21d**, **24d**, and **26d**. Statistics for these results are compiled in **Appendix B, Table 11**.

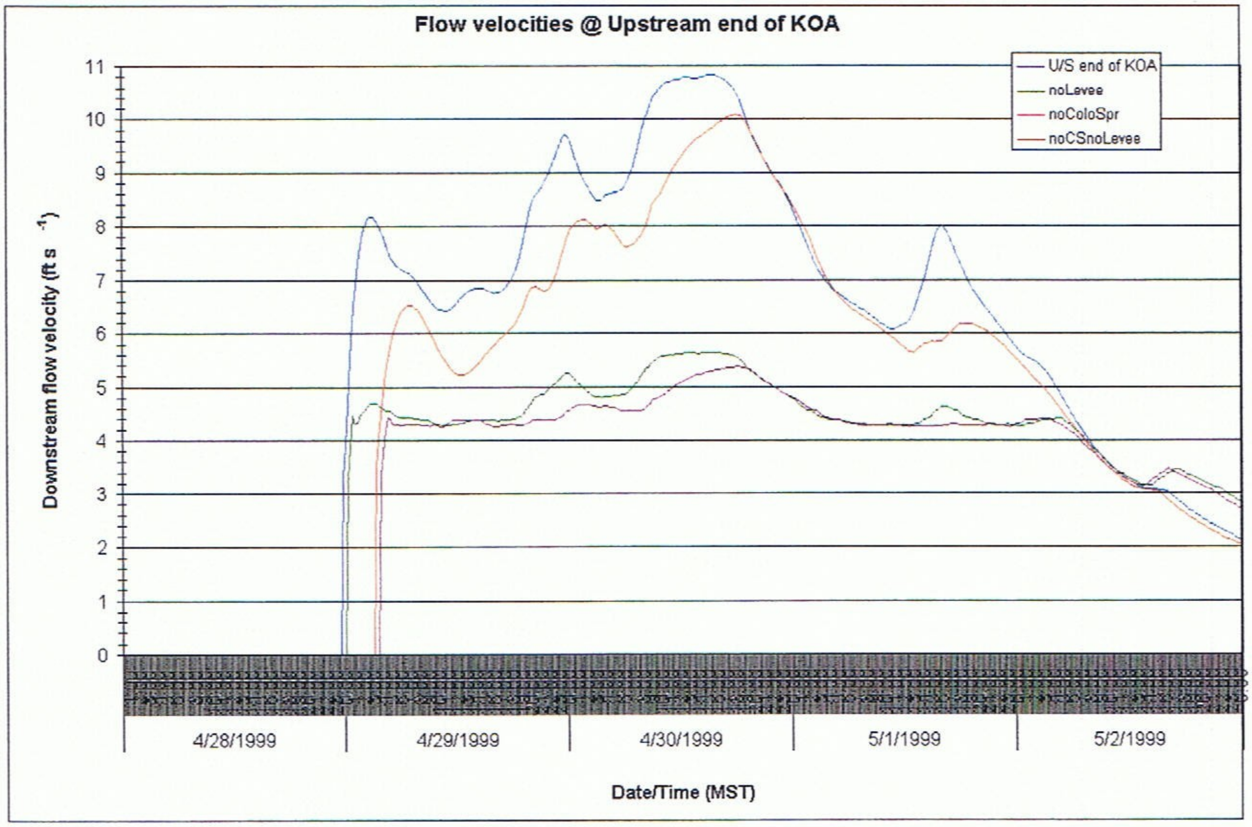


Figure 29a: Simulated hydrographs for the major storm event during April 28-May 2, 1999, at the location of the Greenview Ditch Headworks near Pueblo, Colorado, for the cases of current development and pre-development conditions in the area of the City of Colorado Springs in the upstream region. This result is compared with that shown above in **Figure 22a**. Statistics for these results are compiled in **Appendix B, Table 12**.

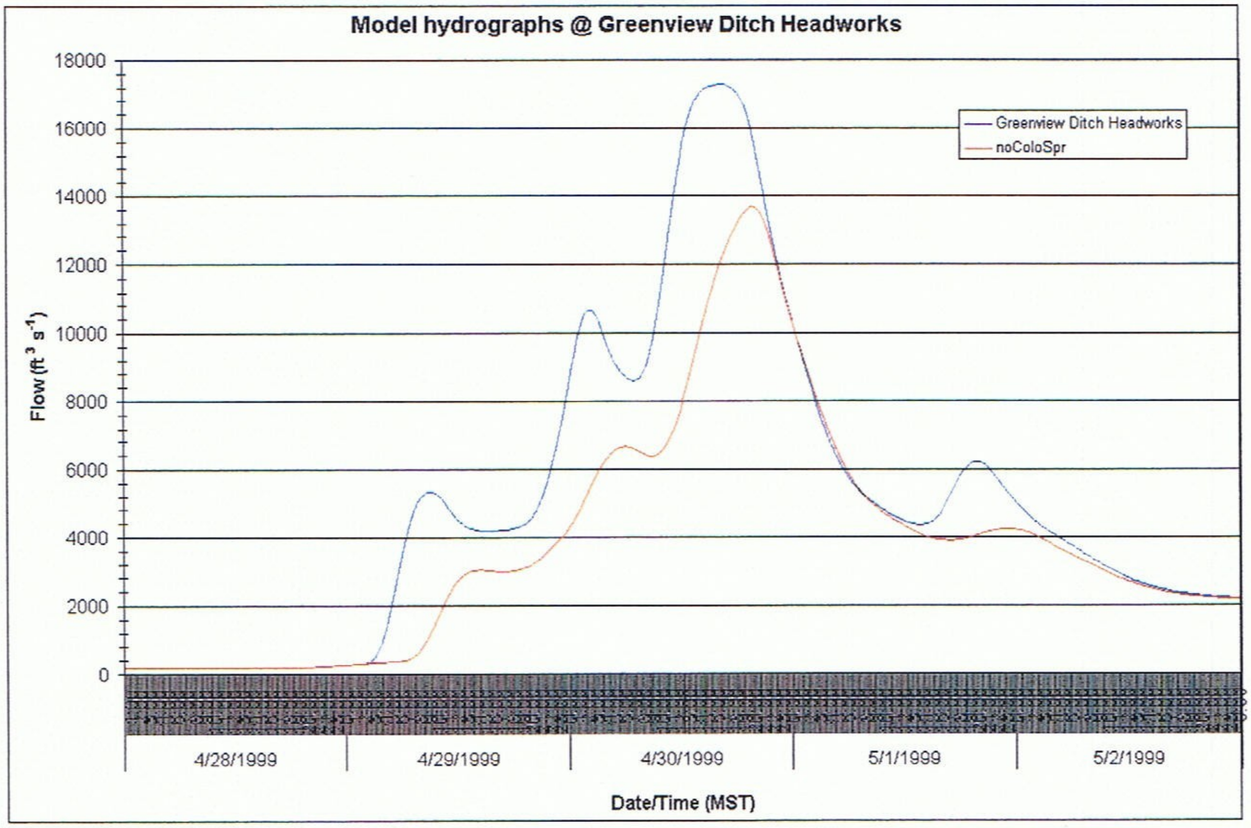


Figure 29b: Simulated flow velocities for the major storm event during April 28-May 2, 1999, at the location of the Greenview Ditch Headworks near Pueblo, Colorado, for the cases of current development and pre-development conditions in the area of the City of Colorado Springs in the upstream region. This result is compared with that shown above in **Figure 22b**. Statistics for these results are compiled in **Appendix B, Table 12**.

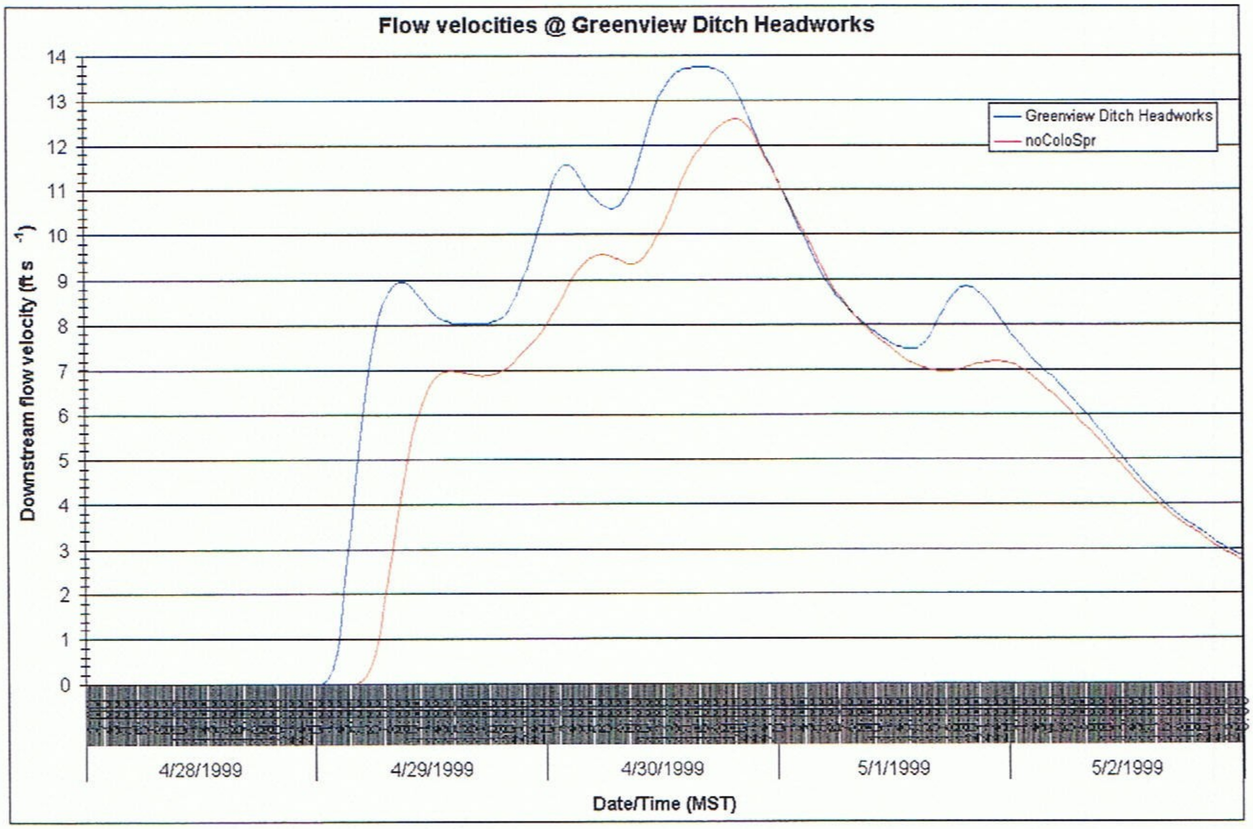


Table 4: Precipitation stations employed for simulation of hydrographs for the major storm event during April 28-May 2, 1999. Stations not highlighted are those for which hourly rainfall data was available for the entire event. Stations with yellow (light) shading are those for which only daily data was available during the event. Stations with green (dark) shading represent those supplemental data employed for hydrograph matching in simulation of the event. The "primary basin" listed is the RUNOFF model designator for the central or representative basin affected by the corresponding hyetograph.

April 28-May 2, 1999 event

Hyetograph	Description/Location	Primary Basin
1	Woodland Park (Upper Fountain Creek and Rampart Range)	CRCFTGa
2	Manitou Springs (Middle Fountain Creek and foothills)	MS
3	Colorado College (near center of Colorado Springs)	MVPb
4	Colorado Springs NWS (Municipal Airport)	SDCSa
5	Greenland 9 SE NWS (NE of Middle Monument Creek Basin)	BSCb
6	Pinello Ranch CSU (south of Colorado Springs)	RBb
7	Monument NWS	PLc/RMc
8	Ruxton Park NWS	ECa/ECc
9	Fort Carson NWS	FCMRa
10	Old Farm (CSU)	TGb
11	Momument Valley Park (CSU)	MVPa
12	Quail Lake (CSU)	FHC
13	Water Operations (CSU)	MESa/MESc
14	4-Diamond Sports Complex (CSU)	TGa/TGg/ROSa
15	Foothills north of Fountain Creek	CPCe
16	Downtown Colorado Springs	SRd/SPCd
17	Middle/Lower Monument Creek, west side	DVa
18	Middle/Lower Monument Creek, east side	ELK
19	Foothills south of Fountain Creek	SWb

Constraints: daily rainfall totals where hourly data unavailable

Daily Rainfall					Event
28-Apr	29-Apr	30-Apr	1-May	2-May	Total
0.08	3.99	1.57	0.68	0.1	6.42
0.51	2.3	0.61	0.03	0	3.45
0	1.21	2.37	N/A	N/A	3.58
0.3	2.43	2.93	0.62	0.46	6.74
0.92	3.4	3.43	0.86	0.07	8.68
0.43	2.31	2.44	0.8	0.09	6.07
1.57	4.05	2.98	0.75	0.08	9.43
N/A	N/A	3.31	0.75	0.06	4.12

Table 5: List of precipitation stations ("hyetographs") and the rank of corresponding rainfall totals for the major storm event during April 28-May 2, 1999. Shading of station information is as for **Table 4**, above.

RUNOFF Results for April 28-May 2, 1999 event

Hyetograph	Description/Location	Primary Basin
1	Woodland Park (Upper Fountain Creek and Rampart Range)	CRCFTGa
2	Manitou Springs (Middle Fountain Creek and foothills)	MS
3	Colorado College (near center of Colorado Springs)	MVPb
4	Colorado Springs NWS (Municipal Airport)	SDCSa
5	Greenland 9 SE NWS (NE of Middle Monument Creek Basin)	BSCb
6	Pinello Ranch CSU (south of Colorado Springs)	RBb
7	Monument NWS	PLc/RMc
8	Ruxton Park NWS	ECa/ECc
9	Fort Carson NWS	FCMRa
10	Old Farm (CSU)	TGb
11	Momument Valley Park (CSU)	MVPa
12	Quail Lake (CSU)	FHC
13	Water Operations (CSU)	MESa/MESc
14	4-Diamond Sports Complex (CSU)	TGa/TGg/ROSa
15	Foothills north of Fountain Creek	CPCe
16	Downtown Colorado Springs	SRd/SPCd
17	Middle/Lower Monument Creek, west side	DVa
18	Middle/Lower Monument Creek, east side	ELK
19	Foothills south of Fountain Creek	SWb

	Total 120-hour rainfall	
largest	15	18.69
	17	13.12
	16	11.42
	13	9.43
	3	9.36
	11	8.68
	14	8.38
	18	7.85
	2	7.80
	19	7.36
	10	6.74
	7	6.42
	12	6.07
	4	5.75
	5	5.70
	9	4.53
	8	3.45
	1	2.40
smallest	6	0.95

Table 6: Results of RUNOFF simulation of the major storm event during April 28-May 2, 1999. See text in **Section 6** of this report for explanations of abbreviations, calculated statistics and shaded areas.

RUNOFF Results for April 28-May 2, 1999 event

Gauge	Location	Channel Outflow	Observed Peak 1			Modeled Peak 1 (BasinR31.dat)				
			Base Flow	Total Flow	Time	Flow	Error	% Error	Time	Error
07104000	Lower Mon Ck	LMCMR04	146.31	1730	4/29/99 3:30	1592.51	9.12	0.6%	4/29/99 3:30	0.00
07105000	Bear Ck	BRCa (runoff)	0.00	56	4/29/99 8:45	44.99	-11.01	-19.7%	N/A	N/A
07105490	Cheyenne Ck	SWbC + dC	24.21	148	4/29/99 2:30	126.46	2.67	2.2%	4/29/99 3:00	0.30
07105500	Lower Ftn Ck	LFCMR02	210.95	4720	4/29/99 1:15	4504.82	-4.20	-0.1%	4/29/99 1:16	0.01
07105530	Lower Ftn Ck	LFCMR04	310.08	5500	4/29/99 1:45	5292.70	2.77	0.1%	4/29/99 1:47	0.02

Gauge	Location	Channel Outflow	Observed Peak 2			Modeled Peak 2 (BasinR50.dat)				
			Base Flow	Total Flow	Time	Flow	Error	% Error	Time	Error
07104000	Lower Mon Ck	LMCMR04	269.69	2790	4/29/99 22:30	2516.05	-4.25	-0.2%	4/29/99 22:36	0.06
07105000	Bear Ck	BRCa (runoff)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
07105490	Cheyenne Ck	SWbC + dC	42.32	238	4/29/99 17:15	198.77	3.09	1.6%	4/29/99 17:00	-0.15
07105500	Lower Ftn Ck	LFCMR02	474.72	7450	4/29/99 21:45	6957.87	-17.41	-0.2%	4/29/99 22:19	0.34
07105530	Lower Ftn Ck	LFCMR04	684.33	10600	4/29/99 23:00	10092.59	-22.78	-0.2%	4/29/99 23:00	0.00

Gauge	Location	Channel Outflow	Observed Peak 3			Modeled Peak 3 (BasinR72.dat)				
			Base Flow	Total Flow	Time	Flow	Error	% Error	Time	Error
07104000	Lower Mon Ck	LMCMR04	376.84	4890	4/30/99 15:05	4509.56	-3.60	-0.1%	4/30/99 15:03	-0.02
07105000	Bear Ck	BRCa (runoff)	0.00	186	4/30/99 18:35	156.39	-29.61	-16.0%	N/A	N/A
07105490	Cheyenne Ck	SWbC + dC	72.09	565	4/30/99 17:35	435.91	-57.00	-11.6%	4/30/99 18:00	0.25
07105500	Lower Ftn Ck	LFCMR02	687.01	9490	4/30/99 14:15	8796.13	-6.86	-0.1%	4/30/99 14:14	-0.01
07105530	Lower Ftn Ck	LFCMR04	966.12	13800	4/30/99 15:00	12843.61	9.73	0.1%	4/30/99 15:02	0.02

Gauge	Location	Channel Outflow	Observed Peak 4			Modeled Peak 4 (BasinR96.dat)				
			Base Flow	Total Flow	Time	Flow	Error	% Error	Time	Error
07104000	Lower Mon Ck	LMCMR04	531.07	2070	5/1/99 14:45	1535.65	-3.27	-0.2%	5/1/99 15:00	0.15
07105000	Bear Ck	BRCa (runoff)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
07105490	Cheyenne Ck	SWbC + dC	97.56	276	5/1/99 14:15	179.80	1.36	0.8%	5/1/99 14:00	-0.15
07105500	Lower Ftn Ck	LFCMR02	1002.22	4610	5/1/99 14:45	3592.99	-14.79	-0.4%	5/1/99 15:00	0.15
07105530	Lower Ftn Ck	LFCMR04	1388.51	6660	5/1/99 15:00	5261.44	0.29	0.0%	5/1/99 15:00	0.00

	07105500	LFCMR02	Error	% Error	07105530	LFCMR04	Error	% Error
Flow Mean ($ft^3 s^{-1}$)	4172.6	4180.4	7.8	0.2%	4926.4	5306.6	380.2	7.7%
Flow St.D. ($ft^3 s^{-1}$)	2376.9	2361.7	-15.2	-0.6%	3659.2	3495.4	-163.8	-4.5%
Flow Max ($ft^3 s^{-1}$)	9490.0	9481.9	-8.1	-0.1%	13800.0	13810.4	10.4	0.1%
Flow Min ($ft^3 s^{-1}$)	133.0	137.0	4.0	3.0%	198.0	200.0	2.0	1.0%
Total Load (ac-ft)	35260.5	35326.3	65.8	0.2%	41630.3	44842.9	3212.6	7.7%
Serial correlation	0.9982	0.9989	0.0007	0.1%	0.9981	0.9987	0.0006	0.1%
Cross-correlation	0.9854				0.9856			
r^2=	0.9710				0.9714			
MAE ($ft^3 s^{-1}$)	214.1				521.7			
RMSE ($ft^3 s^{-1}$)	404.9				734.2			

Relative correlation measures
r = 1 indicates perfect direct linear correlation
r^2 indicates (1) "coefficient of determination"
(2) "goodness of fit"
(3) "portion of variance explained"

Absolute correlation measures
Simulation Errors in (1) Flow Mean
(2) Total Load
Mean Absolute Error (MAE)
Root-Mean-Squared Error (RMSE)

Table 7: Compiled changes of RUNOFF model specification and simulations of the major storm event addressed here for pre-development and current development conditions.

Basin Model Characteristics

	Pre-developed Case	Current Development	Change	% Change
Number of RUNOFF sub-basins	235	233	-2	---
Number of RUNOFF channels	144	143	-1	---
Number of EXTRAN channels	23	23	0	---
Total Basin Area (mi^2)	495.43	495.43	0.00	0.00%
Developed Basin Area (mi^2)	9.41	42.43	33.02	350.83%
Overall Basin Imperviousness	1.90%	8.56%	0.0666	350.83%

†From Bedient and Huber (2002) Figure 6.1, after Leopold (1968).
‡Using Equations (RO-6) and (RO-7) and Table RO-4 after UDFCD (2001).

RUNOFF Results for April 28-May 2, 1999 event

	USGS 07105500 (LFCMR02)			
	Pre-devel.	Current	Change	% Change
Flow Mean ($ft^3 s^{-1}$)	3482.8	4180.4	697.6	20.0%
Flow St.D. ($ft^3 s^{-1}$)	1999.7	2361.7	362.1	18.1%
Flow Max ($ft^3 s^{-1}$)	8328.0	9481.9	1153.9	13.9%
Flow Min ($ft^3 s^{-1}$)	137.0	137.0	0.0	0.0%
Total Load (ac-ft)	29431.0	35326.3	5895.3	20.0%

	USGS 07105530 (LFCMR04)			
	Pre-devel.	Current	Change	% Change
Flow Mean ($ft^3 s^{-1}$)	4259.0	5306.6	1047.6	24.6%
Flow St.D. ($ft^3 s^{-1}$)	2866.0	3495.4	629.4	22.0%
Flow Max ($ft^3 s^{-1}$)	12272.5	13810.4	1538.0	12.5%
Flow Min ($ft^3 s^{-1}$)	200.0	200.0	0.0	0.0%
Total Load (ac-ft)	35990.5	44842.9	8852.4	24.6%

	Mouth of Shooks Run (SRfC)			
	Pre-devel.	Current	Change	% Change
Flow Mean ($ft^3 s^{-1}$)	188.9	290.9	102.1	54.0%
Flow St.D. ($ft^3 s^{-1}$)	467.6	513.0	45.4	9.7%
Flow Max ($ft^3 s^{-1}$)	1862.5	1877.5	15.0	0.8%
Flow Min ($ft^3 s^{-1}$)	0.0	0.0	0.0	0.0%
Total Load (ac-ft)	1873.1	2885.3	1012.2	54.0%

	Mouth of Shooks Run (SRfC)			
	Current	w/o TGFwy	Change	% Change
Flow Mean ($ft^3 s^{-1}$)	290.9	469.9	179.0	61.5%
Flow St.D. ($ft^3 s^{-1}$)	513.0	758.4	245.4	47.8%
Flow Max ($ft^3 s^{-1}$)	1877.5	2845.6	968.1	51.6%
Flow Min ($ft^3 s^{-1}$)	0.0	0.0	0.0	0.0%
Total Load (ac-ft)	2885.3	4660.5	1775.1	61.5%

Table 10: Compiled results of EXTRAN simulations of stream flows and flow velocities using current and historical configurations of channel segments in a portion of Fountain Creek under pre-development and current development conditions in upstream areas. These results are for the location of USGS gauge 07105800 ("Fountain Creek at Security, Colorado").

EXTRAN Results for April 28-May 2, 1999 event

	USGS 07105800 (CBbr)			
	Pre-devel.	Current	Change	% Change
Flow Mean ($ft^3 s^{-1}$)	3875.0	5172.8	1297.8	33.5%
Flow St.D. ($ft^3 s^{-1}$)	3403.2	4593.2	1189.9	35.0%
Flow Max ($ft^3 s^{-1}$)	13880.6	17251.6	3371.1	24.3%
Flow Min ($ft^3 s^{-1}$)	200.0	200.0	0.0	0.0%
Total Load (ac-ft)	38429.9	51300.5	12870.6	33.5%

	USGS 07105800 (CBbr)			
	Current	w/o Levee	Change	% Change
Flow Mean ($ft^3 s^{-1}$)	5172.8	5172.9	0.1	0.0%
Flow St.D. ($ft^3 s^{-1}$)	4593.2	4593.3	0.1	0.0%
Flow Max ($ft^3 s^{-1}$)	17251.6	17254.7	3.1	0.0%
Flow Min ($ft^3 s^{-1}$)	200.0	200.0	0.0	0.0%
Total Load (ac-ft)	51300.5	51301.4	0.9	0.0%

	USGS 07105800 (CBbr)			
	Pre-devel.	w/o Levee	Change	% Change
Flow Mean ($ft^3 s^{-1}$)	3875.0	3875.0	0.0	0.0%
Flow St.D. ($ft^3 s^{-1}$)	3403.2	3403.2	0.0	0.0%
Flow Max ($ft^3 s^{-1}$)	13880.6	13879.6	-1.0	0.0%
Flow Min ($ft^3 s^{-1}$)	200.0	200.0	0.0	0.0%
Total Load (ac-ft)	38429.9	38430.0	0.1	0.0%

From River Engineering for Highway Encroachments (Richardson *et al.* 2001)
Hydraulic Design Series No. 6, FHWA NHI 01-004, 2001
Table 3.5 (p. 3.44): Nonscour Velocities for Soils

Soil Type	Mean Depth	Nonscour V
Coarse sand (noncohesive, D_{50} = 0.5-1.0 mm)	9.8 ft	2.3 ($ft s^{-1}$)
Sandy loam (cohesive)	9.8 ft	4.9 ($ft s^{-1}$)

	USGS 07105800 (CBbr)			
	Pre-devel.	Current	Change	% Change
Velocity Mean ($ft s^{-1}$)	3.24	3.75	0.51	15.6%
Velocity St.D. ($ft s^{-1}$)	2.23	2.44	0.21	9.5%
Velocity Max ($ft s^{-1}$)	7.04	7.56	0.52	7.4%
Velocity Min ($ft s^{-1}$)	0.00	0.00	0.00	0.0%
Time above 2.3 $ft s^{-1}$ (h)	77.75	81.50	3.75	4.8%
Time above 4.9 $ft s^{-1}$ (h)	28.75	42.50	13.75	47.8%

	USGS 07105800 (CBbr)			
	Current	w/o Levee	Change	% Change
Velocity Mean ($ft s^{-1}$)	3.75	3.71	-0.04	-1.0%
Velocity St.D. ($ft s^{-1}$)	2.44	2.40	-0.05	-1.9%
Velocity Max ($ft s^{-1}$)	7.56	7.33	-0.23	-3.0%
Velocity Min ($ft s^{-1}$)	0.00	0.00	0.00	0.0%
Time above 2.3 $ft s^{-1}$ (h)	81.50	81.50	0.00	0.0%
Time above 4.9 $ft s^{-1}$ (h)	42.50	41.25	-1.25	-2.9%

	USGS 07105800 (CBbr)			
	Pre-devel.	w/o Levee	Change	% Change
Velocity Mean ($ft s^{-1}$)	3.24	3.22	-0.02	-0.6%
Velocity St.D. ($ft s^{-1}$)	2.23	2.20	-0.03	-1.2%
Velocity Max ($ft s^{-1}$)	7.04	6.87	-0.17	-2.4%
Velocity Min ($ft s^{-1}$)	0.00	0.00	0.00	0.0%
Time above 2.3 $ft s^{-1}$ (h)	77.75	77.75	0.00	0.0%
Time above 4.9 $ft s^{-1}$ (h)	28.75	28.75	0.00	0.0%

Table 11: Compiled results of EXTRAN simulations of stream flows and flow velocities using current and historical configurations of channel segments in a portion of Fountain Creek under pre-development and current development conditions in upstream areas. These results are for the location of the upstream end of the KOA property along Fountain Creek.

EXTRAN Results for April 28-May 2, 1999 event

	Upstream end of KOA property (LFCMR14a)			
	Pre-devel.	Current	Change	% Change
Flow Mean ($ft^3 s^{-1}$)	3900.3	5198.2	1297.9	33.3%
Flow St.D. ($ft^3 s^{-1}$)	3430.4	4632.6	1202.2	35.0%
Flow Max ($ft^3 s^{-1}$)	13883.5	17265.6	3382.1	24.4%
Flow Min ($ft^3 s^{-1}$)	200.0	200.0	0.0	0.0%
Total Load (ac-ft)	38681.0	51552.4	12871.4	33.3%

	Upstream end of KOA property (LFCMR14a)			
	Current	w/o Levee	Change	% Change
Flow Mean ($ft^3 s^{-1}$)	5198.2	5196.9	-1.3	0.0%
Flow St.D. ($ft^3 s^{-1}$)	4632.6	3430.4	-1202.2	-26.0%
Flow Max ($ft^3 s^{-1}$)	17265.6	13883.5	-3382.1	-19.6%
Flow Min ($ft^3 s^{-1}$)	200.0	200.0	0.0	0.0%
Total Load (ac-ft)	51552.4	38681.0	-12871.4	-25.0%

	Upstream end of KOA property (LFCMR14a)			
	Pre-devel.	w/o Levee	Change	% Change
Flow Mean ($ft^3 s^{-1}$)	3900.3	3899.2	-1.2	0.0%
Flow St.D. ($ft^3 s^{-1}$)	3430.4	3434.9	4.5	0.1%
Flow Max ($ft^3 s^{-1}$)	13883.5	13881.5	-2.0	0.0%
Flow Min ($ft^3 s^{-1}$)	200.0	200.0	0.0	0.0%
Total Load (ac-ft)	38681.0	38669.3	-11.7	0.0%

From River Engineering for Highway Encroachments (Richardson *et al.* 2001)
Hydraulic Design Series No. 6, FHWA NHI 01-004, 2001
Table 3.5 (p. 3.44): Nonscour Velocities for Soils

Soil Type	Mean Depth	Nonscour V
Coarse sand (noncohesive, D_{50} = 0.5-1.0 mm)	6.6 ft	2.1 ($ft\ s^{-1}$)
Sandy loam (cohesive)	6.6 ft	4.6 ($ft\ s^{-1}$)

	Upstream end of KOA property (LFCMR14a)			
	Pre-devel.	Current	Change	% Change
Velocity Mean ($ft\ s^{-1}$)	4.78	5.52	0.73	15.3%
Velocity St.D. ($ft\ s^{-1}$)	3.18	3.46	0.28	8.8%
Velocity Max ($ft\ s^{-1}$)	10.09	10.83	0.74	7.3%
Velocity Min ($ft\ s^{-1}$)	0.00	0.00	0.00	0.0%
Time above 2.1 $ft\ s^{-1}$ (h)	92.00	96.50	4.50	4.9%
Time above 4.6 $ft\ s^{-1}$ (h)	72.75	77.50	4.75	6.5%

	Upstream end of KOA property (LFCMR14a)			
	Current	w/o Levee	Change	% Change
Velocity Mean ($ft\ s^{-1}$)	5.52	3.55	-1.97	-35.6%
Velocity St.D. ($ft\ s^{-1}$)	3.46	1.88	-1.58	-45.8%
Velocity Max ($ft\ s^{-1}$)	10.83	5.65	-5.18	-47.8%
Velocity Min ($ft\ s^{-1}$)	0.00	0.00	0.00	0.0%
Time above 2.1 $ft\ s^{-1}$ (h)	96.50	96.00	-0.50	-0.5%
Time above 4.6 $ft\ s^{-1}$ (h)	77.50	32.50	-45.00	-58.1%

	Upstream end of KOA property (LFCMR14a)			
	Pre-devel.	w/o Levee	Change	% Change
Velocity Mean ($ft\ s^{-1}$)	4.78	3.30	-1.48	-30.9%
Velocity St.D. ($ft\ s^{-1}$)	3.18	1.88	-1.30	-41.0%
Velocity Max ($ft\ s^{-1}$)	10.09	5.38	-4.71	-46.7%
Velocity Min ($ft\ s^{-1}$)	0.00	0.00	0.00	0.0%
Time above 2.1 $ft\ s^{-1}$ (h)	92.00	92.50	0.50	0.5%
Time above 4.6 $ft\ s^{-1}$ (h)	72.75	22.00	-50.75	-69.8%

Table 12: Compiled results of EXTRAN simulations of stream flows and flow velocities in a portion of Fountain Creek under pre-development and current development conditions in upstream areas. These results are for the location of the Greenview Ditch Headworks along Fountain Creek near Pueblo, Colorado.

EXTRAN Results for April 28-May 2. 1999 event

	Greenview Ditch Headworks (LFCMR18)			
	Pre-devel.	Current	Change	% Change
Flow Mean ($ft^3 s^{-1}$)	3875.2	5172.1	1296.8	33.5%
Flow St.D. ($ft^3 s^{-1}$)	3463.6	4621.4	1157.7	33.4%
Flow Max ($ft^3 s^{-1}$)	13678.3	17279.3	3601.0	26.3%
Flow Min ($ft^3 s^{-1}$)	200.0	200.0	0.0	0.0%
Total Load (ac-ft)	38431.9	51293.1	12861.3	33.5%

From River Engineering for Highway Encroachments (Richardson *et al.* 2001)
Hydraulic Design Series No. 6, FHWA NHI 01-004, 2001
Table 3.5 (p. 3.44): Nonscour Velocities for Soils

Soil Type	Mean Depth	Nonscour V
Coarse sand (noncohesive, D_{50} = 0.5-1.0 mm)	6.6 ft	2.1 ($ft\ s^{-1}$)
Sandy loam (cohesive)	6.6 ft	4.6 ($ft\ s^{-1}$)

	Greenview Ditch Headworks (LFCMR18)			
	Pre-devel.	Current	Change	% Change
Velocity Mean ($ft\ s^{-1}$)	5.62	6.60	0.98	17.5%
Velocity St.D. ($ft\ s^{-1}$)	3.96	4.34	0.38	9.7%
Velocity Max ($ft\ s^{-1}$)	12.58	13.74	1.16	9.2%
Velocity Min ($ft\ s^{-1}$)	0.00	0.00	0.00	0.0%
Time above 2.1 $ft\ s^{-1}$ (h)	89.00	93.25	4.25	4.8%
Time above 4.6 $ft\ s^{-1}$ (h)	75.50	81.25	5.75	7.6%

Figure 1. Ten rainfall events during the periods specified in the plaintiffs' complaint were addressed, and the sources of data used to evaluate these events were also listed.

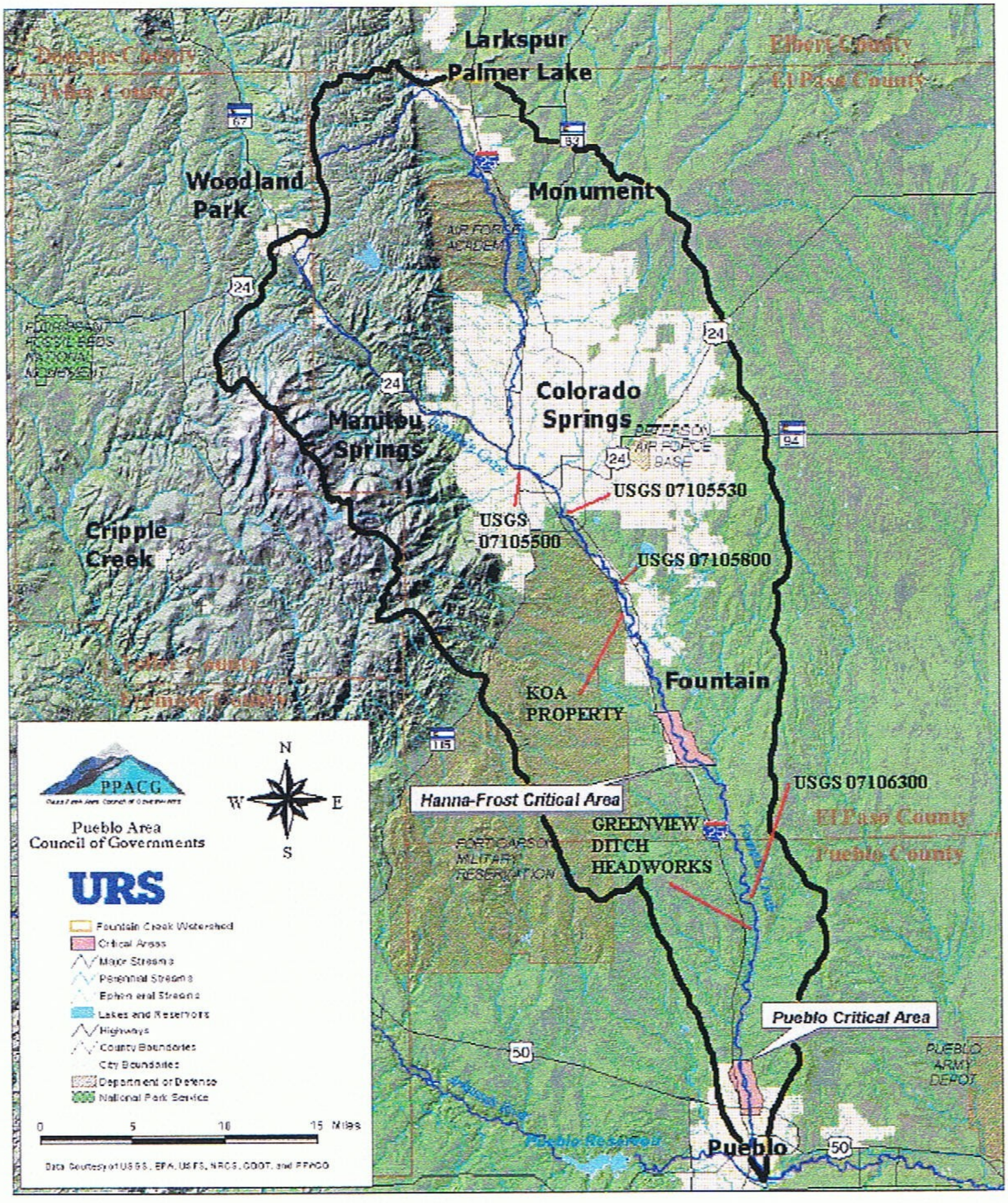


Figure 1: Colorado Springs and surrounding areas within the Fountain Creek watershed (outlined in black). The base map used here was created by the Pikes Peak Area Council of Governments (PPACG); location information was added by the author.

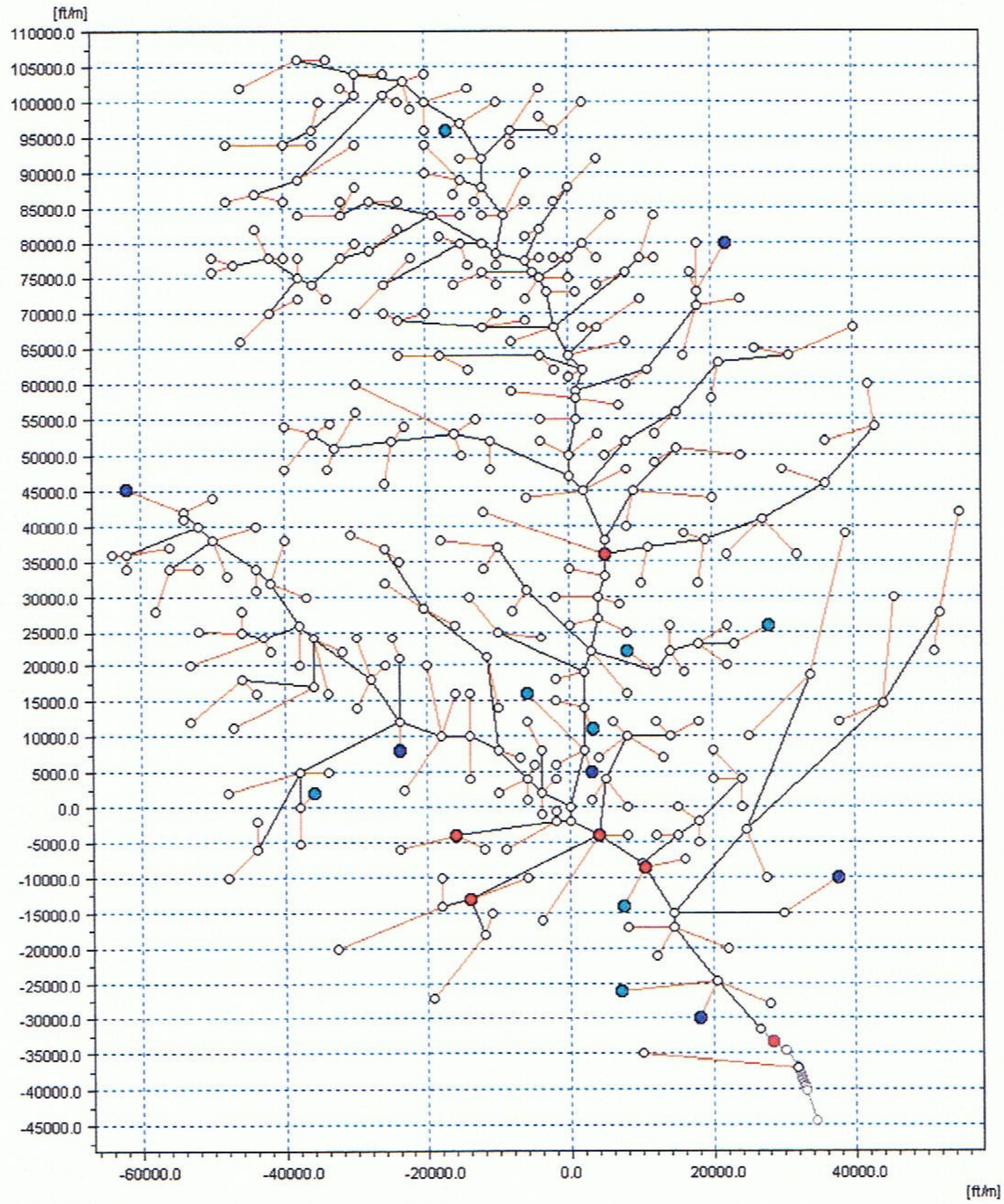


Figure 4: Schematic diagram of SWMM RUNOFF model sub-basins (with orange drainage paths attached) and stream channels (with black flow paths attached) within the Fountain Creek watershed in the region upstream of USGS stream flow gauge 07105800. The reference point (0,0) occurs at the confluence of Fountain and Monument Creeks in Colorado Springs. Scales on the axes shown here are given in feet north and east of the reference point. Additional color-coded reference points correspond to USGS stream gauge locations (red), rain gauges for which hourly rainfall data was available (dark blue), and rain gauges for which daily rainfall data was available (light blue).

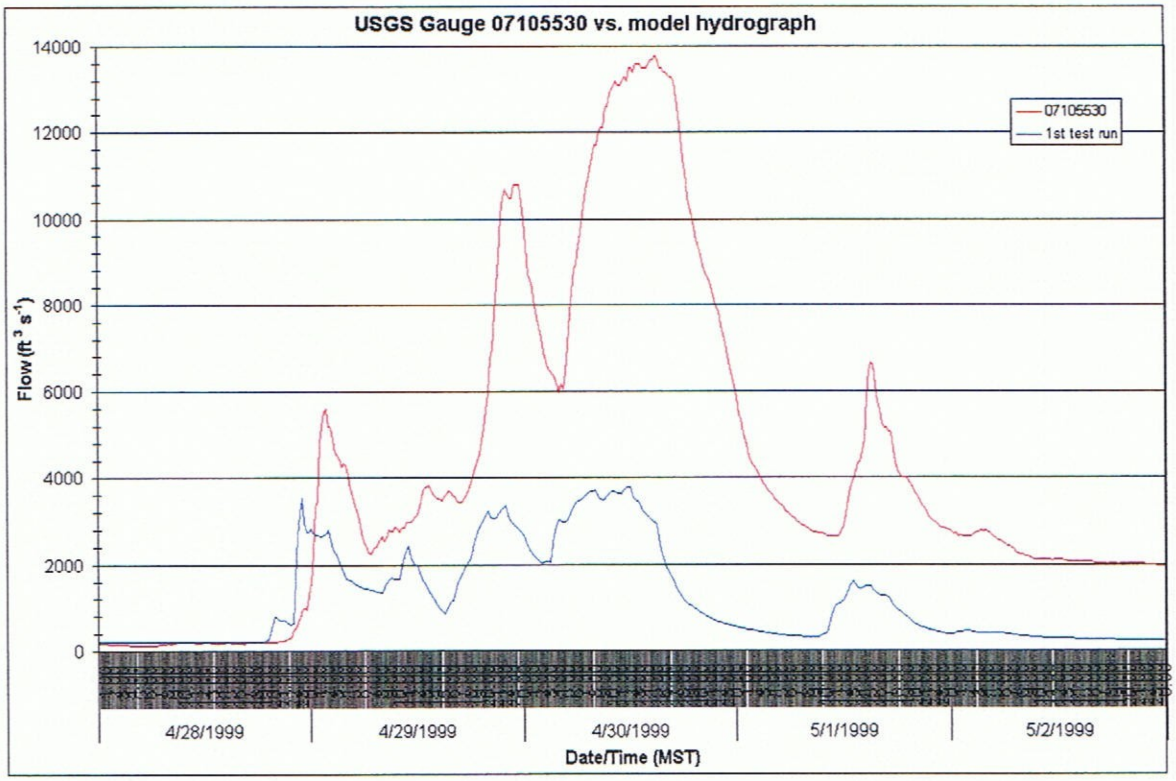
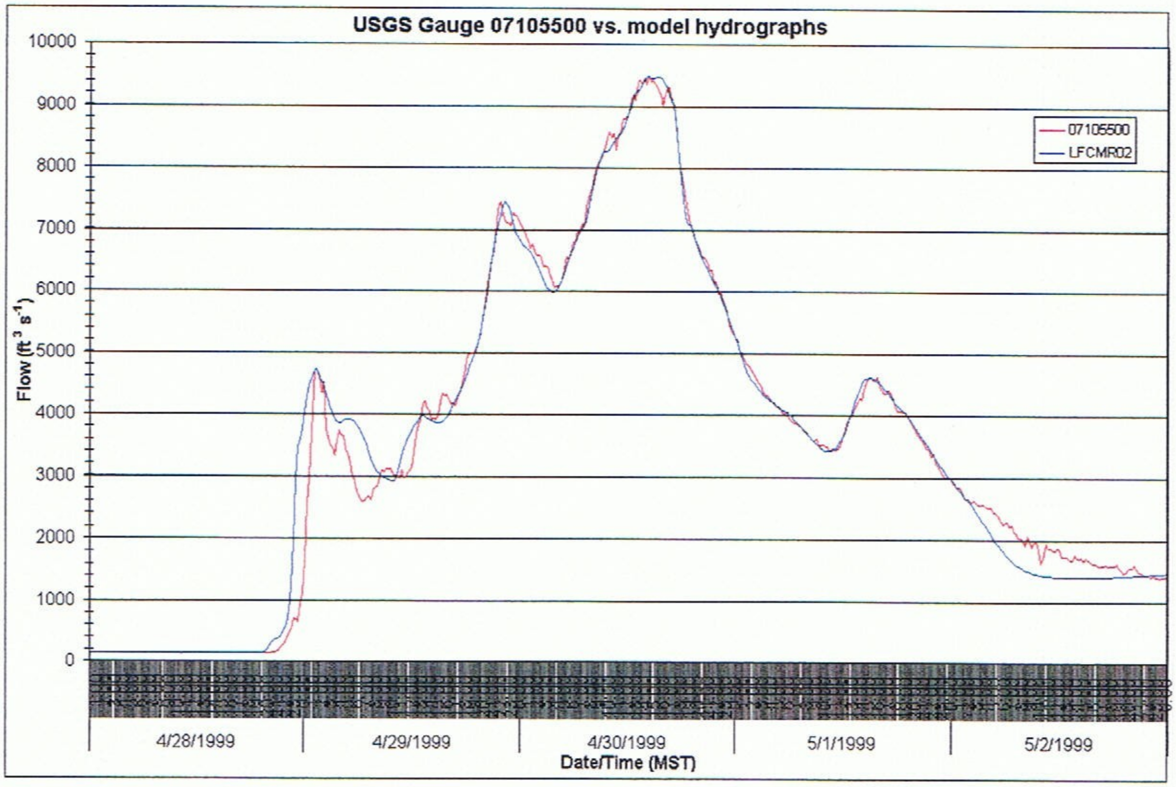


Figure 5: Simulated hydrograph for the major storm event during April 28-May 2, 1999, at the location of USGS gauge 07105530, using only observed rainfall at the gauge locations indicated in **Figure 4**.



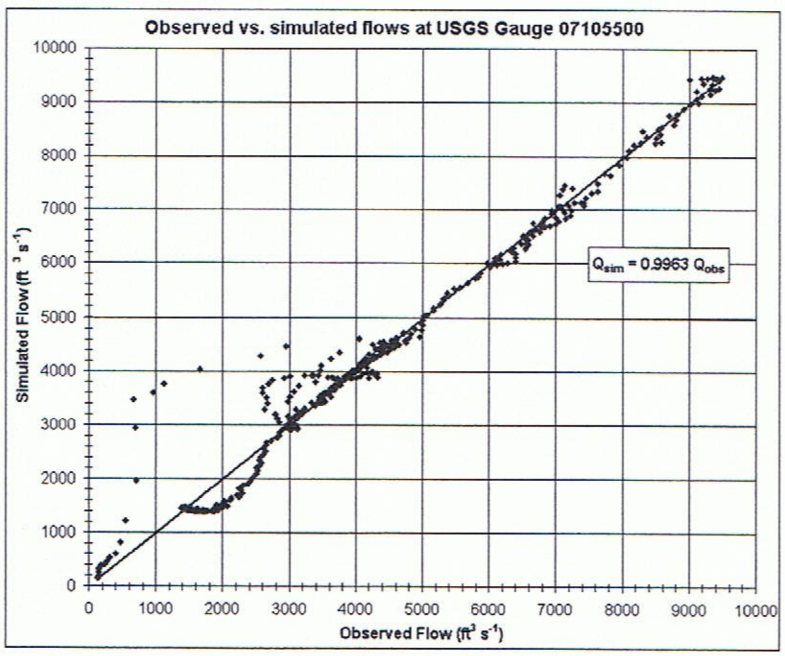
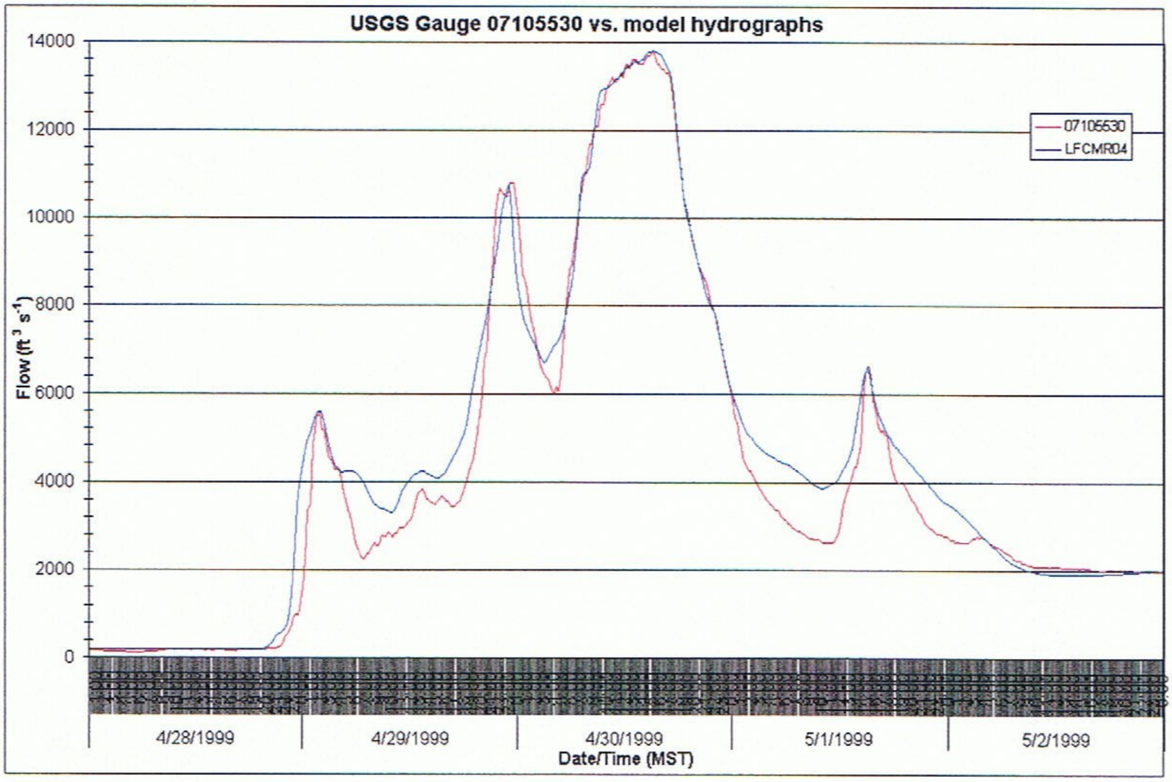


Figure 7a: Simulated hydrograph for the major storm event during April 28-May 2, 1999, at the location of USGS gauge 07105500, and a graph demonstrating the correlation between (concurrent) observed and simulated discharges at that location.



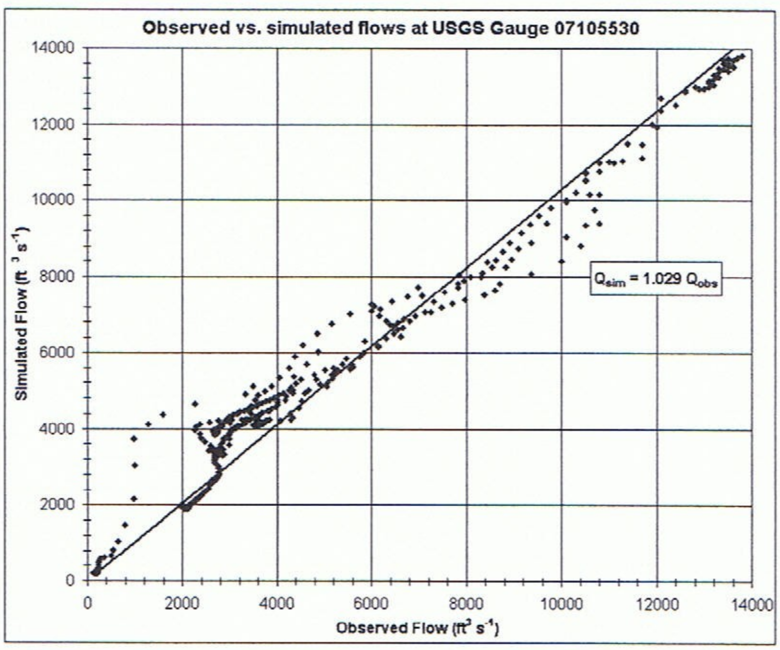


Figure 7b: Simulated hydrograph for the major storm event during April 28-May 2, 1999, at the location of USGS gauge 07105530, and a graph demonstrating the correlation between (concurrent) observed and simulated discharges at that location.

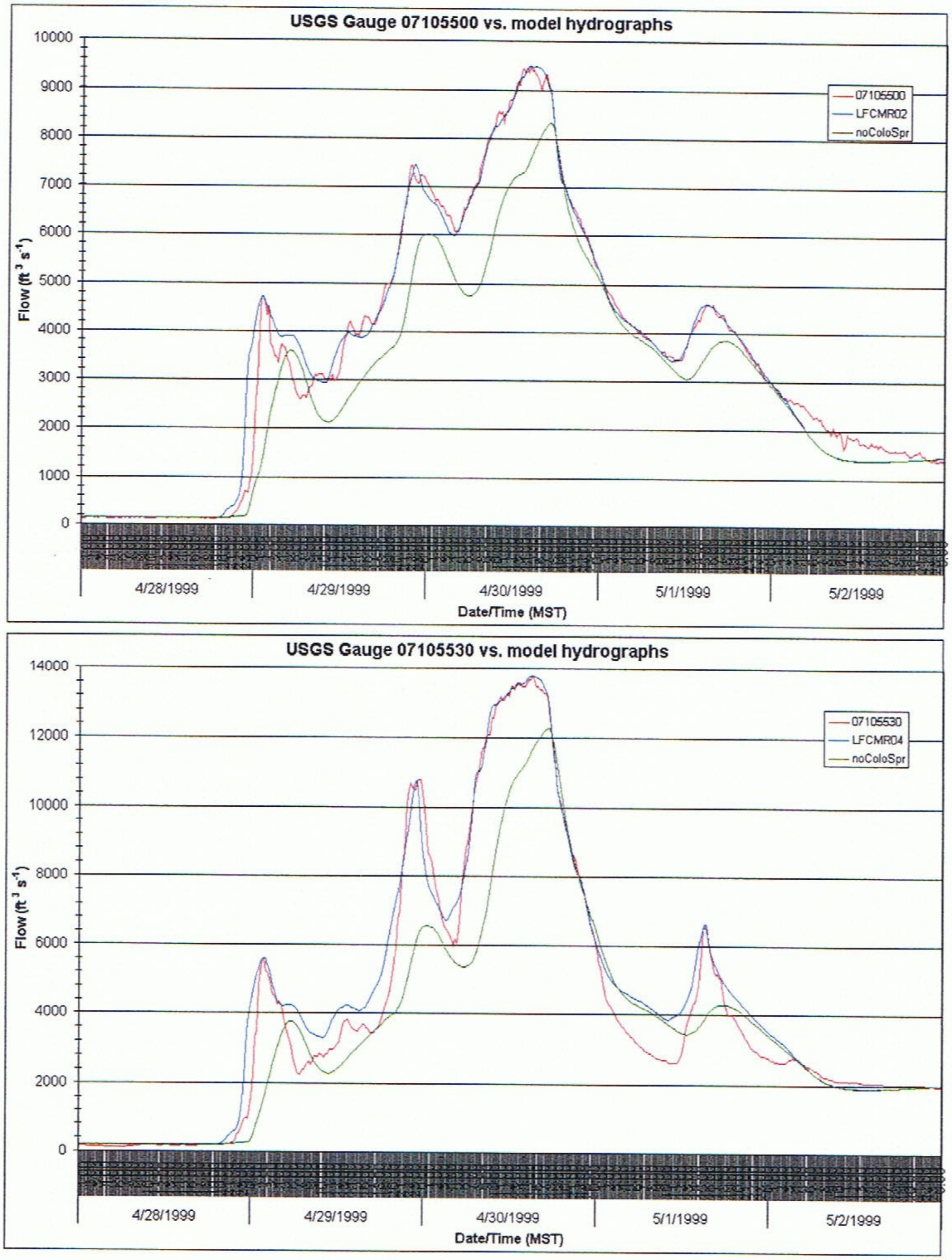


Figure 8: Simulated hydrographs for the major storm event during April 28-May 2, 1999, at the locations of USGS gauges 07105500 and 07105530, for the case of pre-development conditions in the area of the City of Colorado Springs.

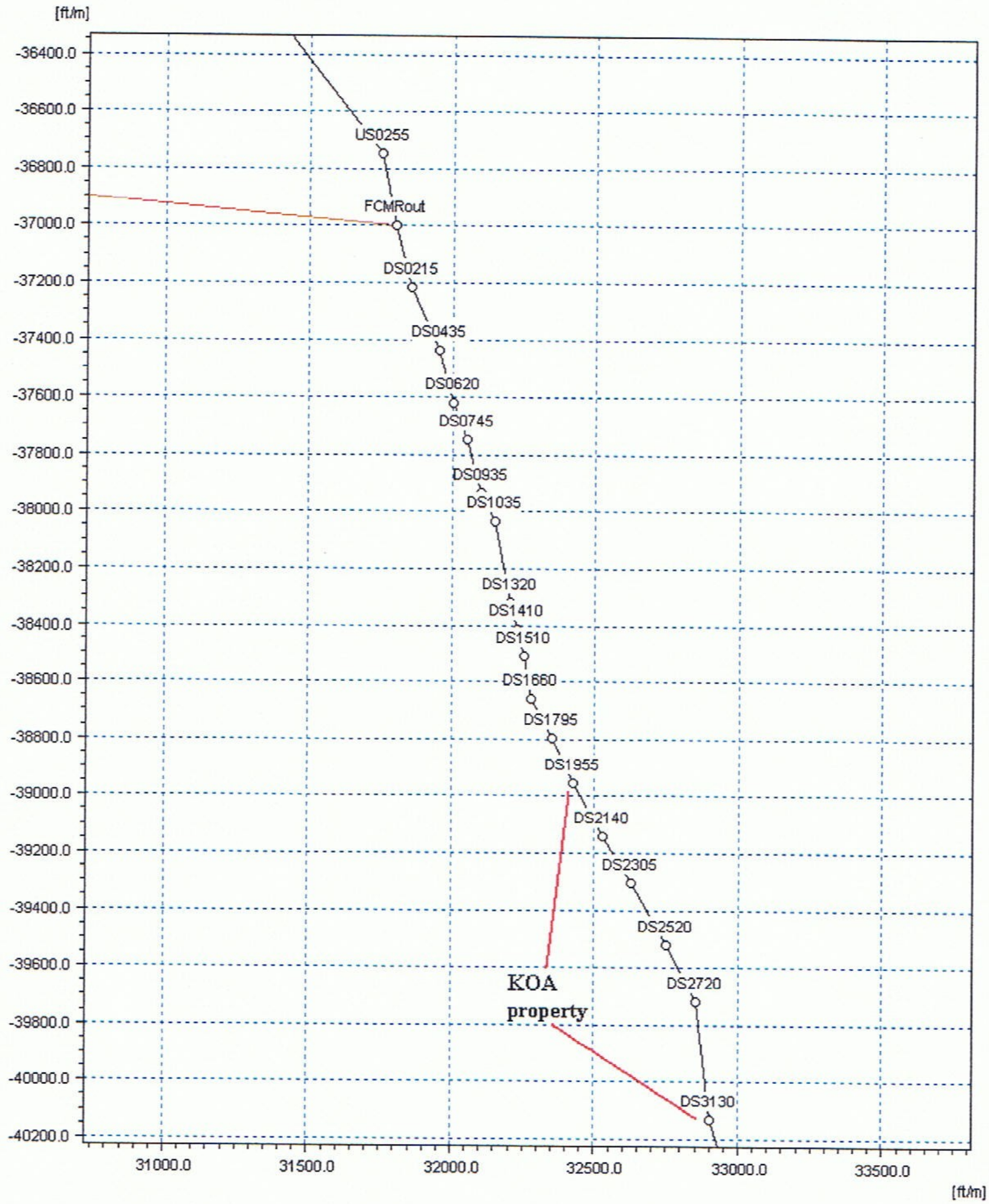


Figure 9: Detailed plan view of SWMM EXTRAN model stream channels for a portion of Fountain Creek downstream of Colorado Springs. The reference point (0,0) occurs at the confluence of Fountain and Monument Creeks in Colorado Springs. Scales on the axes shown here are given in feet north and east of the reference point.

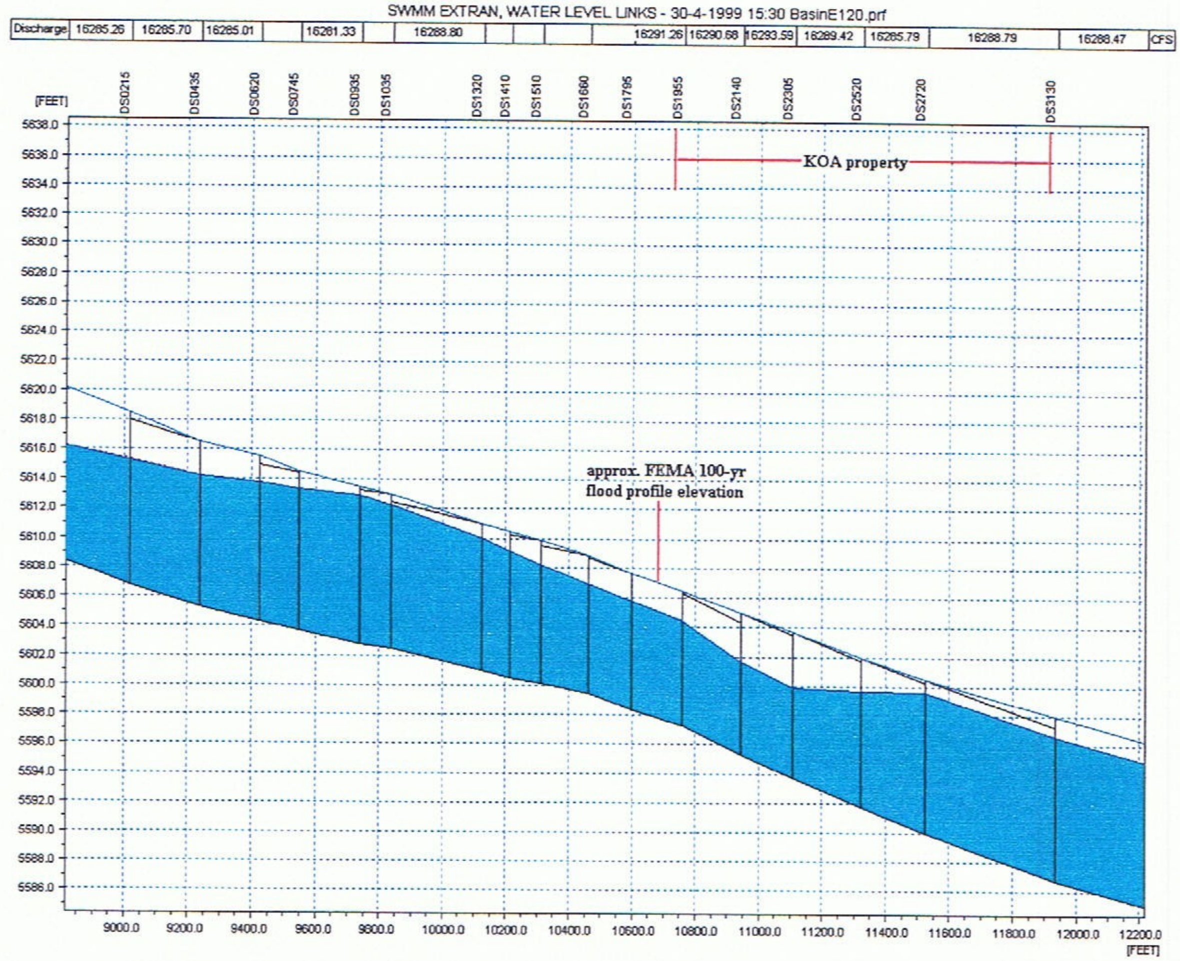


Figure 10: Close-up view of simulated stream channel water surface profile in the EXTRAN model segments immediately upstream of and adjacent to the KOA property along Fountain Creek for the major storm event during April 28-May 2, 1999. The profile shown corresponds to peak flow conditions near 3:30 pm on April 30, 1999. Junction names and discharges (in $ft^3\ s^{-1}$) for individual channel segments are shown near the top of the diagram.

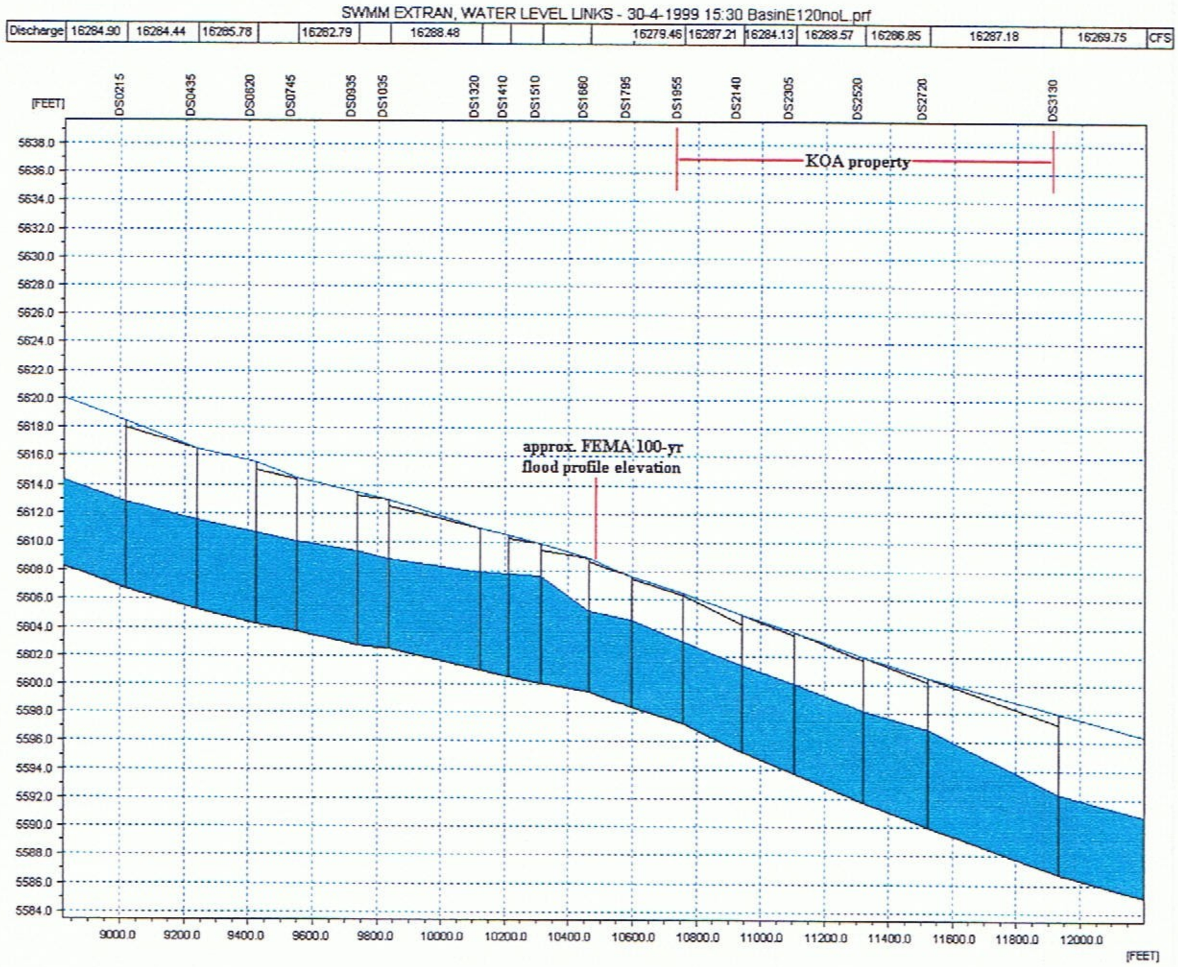


Figure 11: Close-up view of simulated stream channel water surface profile in the EXTRAN model segments immediately upstream of and adjacent to the KOA property along Fountain Creek for the major storm event during April 28-May 2, 1999, in the absence of the left bank levee downstream of the bridge at Colorado Highway 16. This result should be compared with that shown above in **Figure 10**. The profile shown corresponds to peak flow conditions near 3:30 pm on April 30, 1999. Junction names and discharges (in $ft^3\ s^{-1}$) for individual channel segments are shown near the top of the diagram.

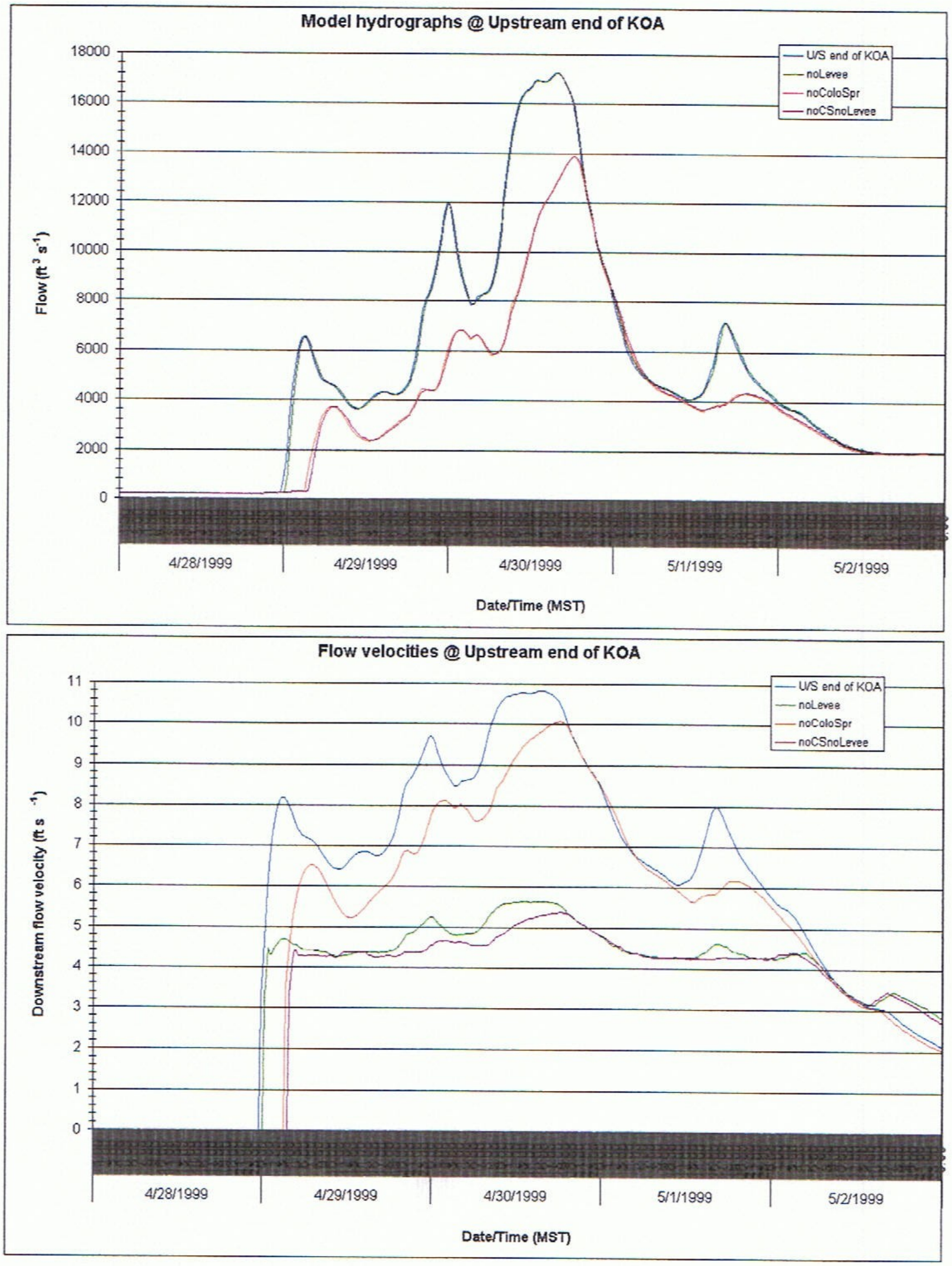


Figure 12: Simulated hydrographs and flow velocities for the major storm event during April 28-May 2, 1999, at the upstream end of the KOA property along Fountain Creek, for the four cases described in the text.

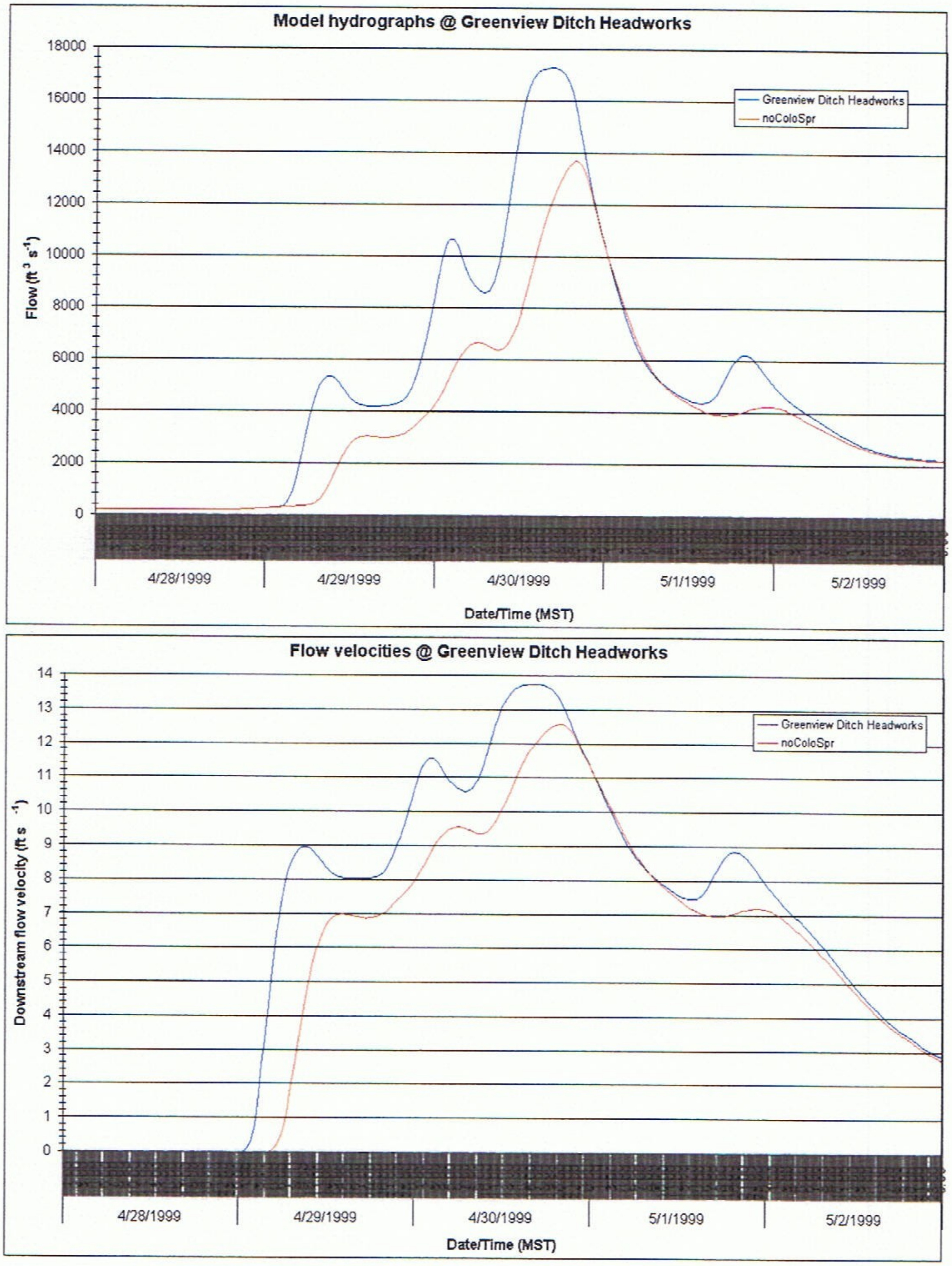


Figure 13: Simulated hydrographs and flow velocities for the major storm event during April 28-May 2, 1999, at the location of the Greenview Ditch Headworks near Pueblo, Colorado, for the cases of current and pre-development conditions in the area of the City of Colorado Springs.