CHAPTER 5-- SURFACE WATER HYDROLOGY

5.1 General Snodgrass Mountain Hydrology

5.1.1 Key Surface Hydrology Characteristics

Snodgrass Mountain is located in west-central Colorado, near the town of Crested Butte. Generally, the Mountain encompasses elevations between 9,350 and 11,145 feet above mean sea level (amsl) and covers an area of approximately 2 mi^2. This relatively small area is drained by numerous ephemeral and perennial first and second order streams. Each of these nascent stream channels drains either to the East River to the east or Washington Gulch to the west. Annual discharge patterns for streams draining Snodgrass Mountain are dominated by spring snowmelt and typical of high elevation, montane climates. The peak runoff hydrograph typically shows a significant increase in discharge in March and April, a peak in discharge in May or June, and a steady reduction in June and July. Discharge during the remainder of the year remains relatively constant (August – February).

Snodgrass Mountain's geology plays an important role in the behavior of local surface hydrology. As discussed earlier in this report, local geology can generally be characterized as a massive cap of Snodgrass laccolith that overlays Mancos Shale. According to field observations made by GEO-HAZ Consulting, Inc. (GEO-HAZ) and Resource Engineering, Inc. (RESOURCE) there are not perennial streams or springs on the upper portion of Snodgrass Mountain that is underlain by the Snodgrass laccolith (i.e. generally above an elevation of 10,100 Ft.). This is because the upper portion of Snodgrass Mountain has a relatively small drainage area with correspondingly low potential perennial baseflow. The relatively small amount of available water infiltrates into surface soils and fractures in the laccolith. This water resurfaces below the laccolith-Mancos Shale contact as springs. Several perennial streams have also been observed below this geologic contact. Additionally, all wetland communities identified on Snodgrass during a 1995 survey of Snodgrass exist downslope of this point.

5.1.2 Proposed Snowmaking on Snodgrass Mountain

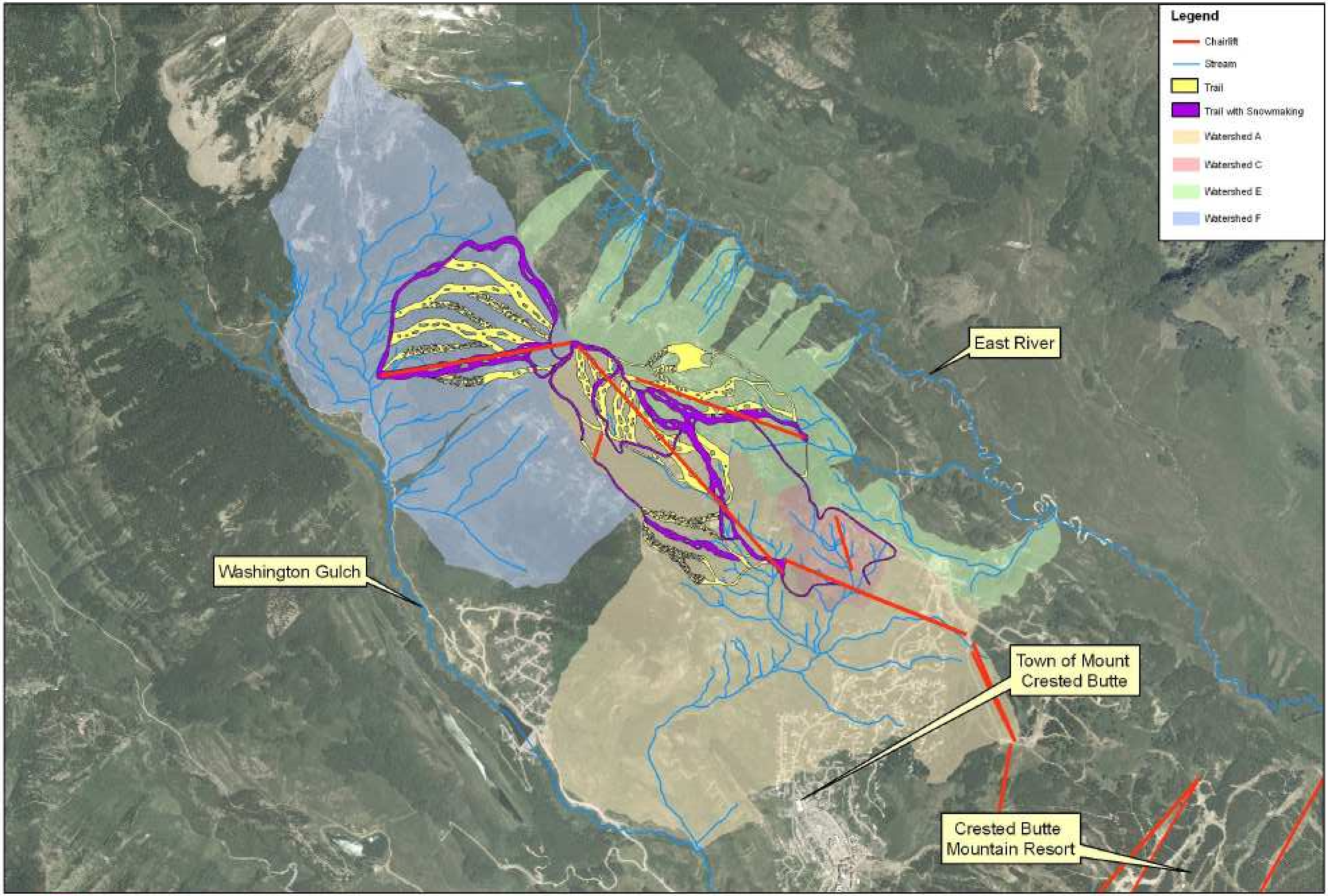
Artificial snow would be applied to selected trails as part of the Snodgrass Mountain Development Plan. The application of artificial snow allows Crested Butte Mountain Resort (CBMR) to maintain adequate snow depth in high traffic areas. This maintains skiability and protects skiers from ground hazards (i.e. rocks and trees) that may be exposed with insufficient snow cover. The Snodgrass Mountain Plan includes development of 297 acres of ski trails. Of this total, approximately 119 acres are proposed to receive snowmaking (see Figure 5.1). The historic, average application rate of snowmaking at Mount Crested Butte has been 1 acre foot per acre of ski trail. As such, CBMR anticipates applying approximately 119 acre feet of snowmaking water per year (119 acres of proposed snowmaking x 1 acre foot/acre application rate = 119 acre feet of snowmaking application). The proposed Snodgrass Mountain snowmaking operations will be supplied by CBMR's existing water rights and snowmaking diversion facility on the East River. Water diverted from the East River will be applied to Snodgrass Mountain and subsequently return to Washington Gulch and the East River during spring runoff.

5.1.3 Spatial Extent of Proposed Trail Clearing and Snowmaking in Relation to Microwatersheds

The proposed development contemplated in this study would develop ski terrain on Snodgrass Mountain that would be integrated with existing terrain on Mount Crested Butte. The proposed development would include development of infrastructure (e.g. lifts) and ski trails. Artificial snowmaking would be applied to some of the ski trails in order to improve skier safety. The most extensive development, as a percentage of watershed area, is proposed to occur in Watershed A. Trail clearing and snowmaking application will cover 13.17% and 4.89% of that watersheds total area, respectively. The extent of proposed trail clearing and snowmaking within each of the four major watersheds on Snodgrass Mountain (i.e. Watershed A, Watershed C, Watershed E, and Watershed F) is described in Table 5.1 and shown in Figure 5.1.

Table 5.1: Proposed Trail Clearing and Snowmaking Per Watershed, Snodgrass Mountain

				Percent Watershed Area	
Watershed ID	**Trail Area (Acres)**	**Snowmaking Area (Acres)**	**Watershed Area (Acres)**	**Trails**	**Snowmaking**
A	106.24	39.49	807.00	13.17%	4.89%
C	4.12	4.12	114.58	3.60%	3.60%
E	68.80	28.22	684.75	10.05%	4.12%
F	117.04	47.41	2307.17	5.07%	2.06%
Total	296.56	119.24	3913.50	7.58%	3.05%



RESOURCE
ENGINEERING, INC
909 Colorado Avenue
Glenwood Springs, CO 81601
(970) 945-6777 Voice (970) 945-1137 Facsimile

1 inch equals 3,000 feet

FIGURE 5.1: General Vicinity Map and Proposed Construction

Crested Butte Mountain Resort,
Snodgrass Expansion

Date: 10/15/07
File: 333-5.2
Drawn by: SJ
Approved by: GG

5.2 Methods - Snodgrass Mountain Surface Hydrology Analysis

The application of machine produced snow, in combination with vegetation removal for expanded ski terrain, may lead to an increase in the quantity of total annual snowmelt and the duration and/or intensity of spring peak flows. RESOURCE investigated the impacts of trail clearing and application of machine produced snow on the current and projected annual water balance for Snodgrass Mountain. This study focused on existing and proposed areas of disturbance, as well as terrain proposed to receive snowmaking coverage, as part of the Snodgrass Mountain development proposal.

The potential impacts of the proposed Snodgrass Development Plan are distributed among several watersheds that drain Snodgrass Mountain. These watersheds, along with proposed trails, are displayed in Figure 5.1. There are no historic records of stream discharge for these microwatersheds. As such, Snodgrass Mountain surface hydrology was evaluated using two methods. First, the annual water balance was modeled for average, dry and wet years, under existing and proposed conditions using water balance and snowmelt modeling techniques outlined in the following two publications: An Approach to Water Resources Evaluation of Non-Point Silvicultural Sources (WRENSS)[1] and the Water Management Research Project Handbook[2]. Second, modeling efforts were complimented with implementation of a stream flow monitoring program.

The WRENSS technique for modeling snowmelt and annual water balance was formed using the United States Forest Service (USFS) Supalpine Water Balance Model (SWBM).[3] The SWBM defines a study area based on its vegetative type, vegetative density and aspect. It then computes a water balance by identifying rates of precipitation and evapotranspiration in the area. The model then compares existing and proposed trail conditions by modifying evapotranspiration demand to reflect changes in vegetative density associated with trail clearing. The difference between precipitation and evapotranspiration is water available for surface runoff or ground water recharge. Decreased evapotranspiration associated with vegetative removal allows additional water from precipitation to be available for runoff.

The water balance modeling procedures in the WRENSS model used in this study were paired with snowmaking hydrology modeling techniques developed in the 1986 Water Management Research Project funded by Colorado Ski Country USA. This study evaluated water consumption during the production and use of man-made snow. The study found that, on average, 6% of water diverted for snowmaking is lost during the application process. This value varies according to relative humidity and temperature during the snowmaking process. For the purposes of this study, since snowmaking activities are proposed, the average loss rate of 6% was assessed on all snowmaking diversions.

---

[1] Troendle, Charles A., and C.F. Leaf. 1980. Hydrology, Chapter III. In: An Approach to Water Resources Evaluation of Non-point Silvicultural Sources (WRENSS). EPA60018-80-012, Environmental Research Laboratory. Athens, GA.

[2] Leaf, C.F., 1986. A Final Report on the Colorado Ski Country USA Water Management Research Project, Conducted by Wright Water Engineers, Inc. Denver, CO. February 1986.

[3] Leaf, C.F. and G.E. Brink. 1973. Computer Simulation of Snowmelt Within a Colorado Subalpine Watershed. USDA Forest Service Res. Paper RM-99. Rocky Mountain Forest and Range Experiment Station. Fort Collins, CO. Leaf, C.F. and G.E. Brink. 1973. Hydrologic Simulation Model of Colorado Subalpine Forest. USDA Forest Service Res. Paper RM-107. Rocky Mountain Forest and Range Experiment Station. Fort Collins, CO.

After its application, machine-produced snow is subject to a series of processes that diminish the volume of water available for runoff and return to the stream system. This includes consumption by sublimation, evaporation and evapotranspiration. These mechanisms were determined to occur as a function of aspect, elevation, vegetation type and vegetation density in the study area. Additional snowpack volume may be lost during spring snowmelt due to infiltration and subsequent recharge of soil moisture and groundwater. Together these processes remove volume from the snowpack and reduce water available for runoff during the spring snowmelt.

The WRENSS model requires the user to develop a series of site specific data inputs. These inputs include the following parameters: watershed characteristics, base flow hydrology, local climatic regimes and snowmaking operation plans. These inputs, along with key assumptions of the WRENSS model, are discussed in detail in Sections 5.2.1 through 5.2.4 below.

5.2.1 Defining Drainage Networks and Sub-Watersheds

There are several stream networks that drain Snodgrass Mountain. Generally, these streams are located in four major watersheds identified as Watershed A, Watershed C, Watershed E, and Watershed F. The watersheds drain from the east flank of the mountain to the East River or the west flank of the mountain to Washington Gulch, as shown in Figure 5.1. For the purposes of detailed ski area design, it was necessary to develop a highly detailed GIS database of Snodgrass Mountain streams and sub-watersheds. This high level of detail provides a basis for identifying results from the WRENSS model at specific locations on Snodgrass Mountain. Of particular interest was the ability to predict changes in surface and subsurface hydrology in the immediate vicinity of individual landslides. The steps taken to complete this detailed watershed mapping are discussed below.

Several sources of data were used to delineate watershed boundaries. The data sources include: 5 foot contours, high resolution aerial photography, and field observation. Initially, the 5 foot contours were converted into a digital elevation model (DEM). A predicted stream network was extracted from the DEM using hydrologic tools available in GIS. This network includes channels of perennial streams, channels of intermittent streams, and topographic swales that collect drainage. The predicted stream network was refined and validated based on aerial photography and field observations. Subsequently, the spatial hydrology tools noted above were used to identify microwatersheds along the stream network. Again, these results were validated based on aerial photography and field observations. Finally, a series of stream nodes were assigned to the stream network. The nodes represent key areas of interest based on their location on the stream network, proximity to proposed development and/or proximity to landslide areas. Next, each watershed was assigned a unique identification code that indicates to which node it directly contributes. For example, watersheds A8-1, A8-2, and A8-3 all flow to Node A8. The resulting product is a GIS database that provides a detailed representation of stream nodes, the stream network, and the 114 micro-watersheds that drain Snodgrass Mountain. These features are illustrated in Figure 5.2.

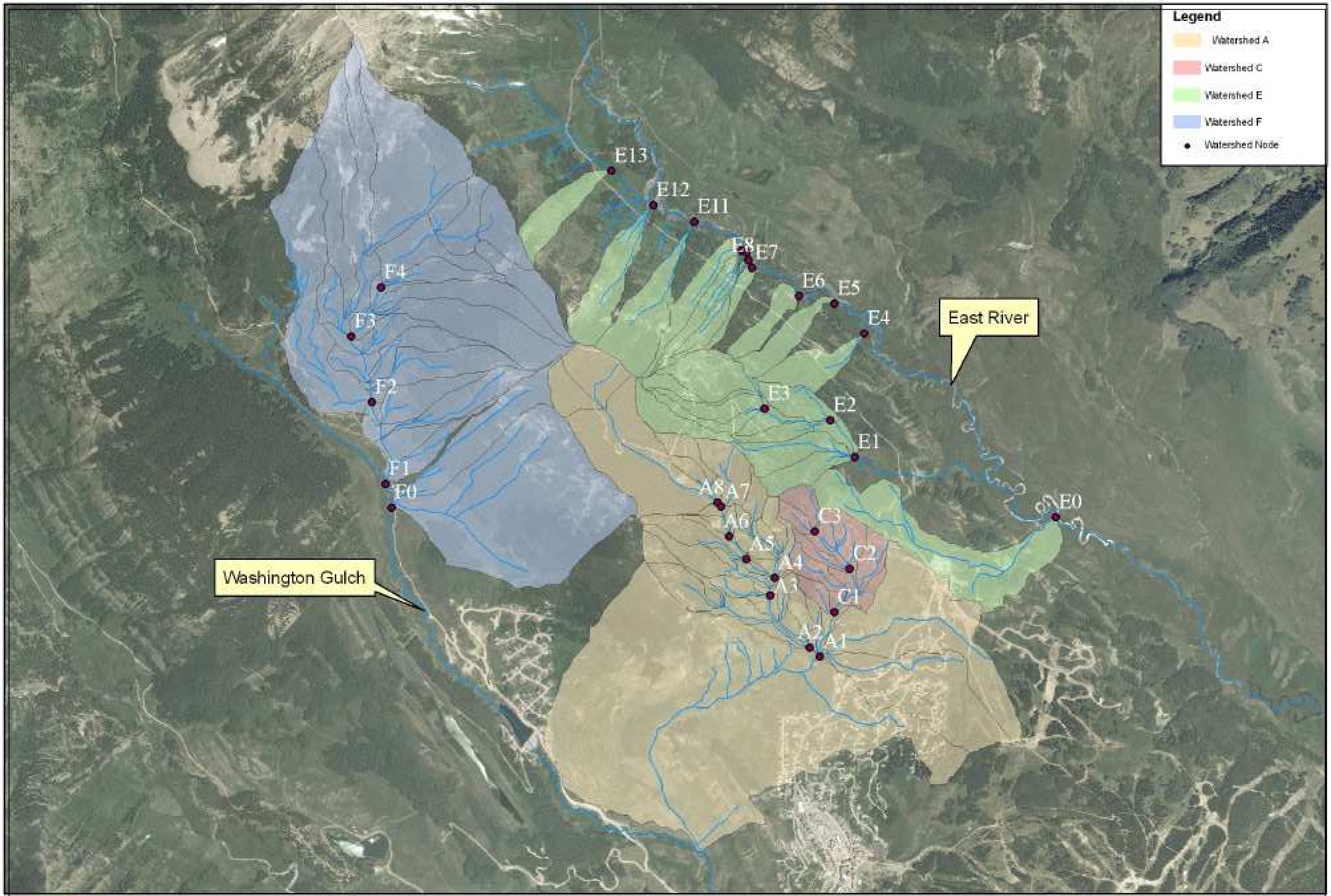
5.2.2 Analyzing Local Precipitation Trends

The WRENSS model requires local precipitation data for the Winter (October – February), Spring (March – June) and Summer/Fall (July – September) seasons. In order to estimate precipitation patterns at Snodgrass Mountain, RESOURCE reviewed regionally available climatic data collected by the National Oceanic and Atmospheric Administration (NOAA) and the Natural Resource Conservation Service (NRCS) SNOTEL data network. After an initial review, several stations were identified for detailed analysis based on their elevation and spatial proximity to Snodgrass Mountain. The selected stations are described in Table 5.2 and illustrated in Figure 5.3.

Table 5.2: Characteristics of Selected Weather Stations in the Vicinity of Snodgrass Mountain

Site Name	Elevation	Average Annual Precip.
Crested Butte, NOAA	9,380	24.42
Crested Butte, SNOTEL	10,007	26.96
Independence Pass, SNOTEL	10,600	31.00
Schofield Pass, SNOTEL	10,700	48.91

A coincident period of record of 1982-2005 was identified for the selected sites. This period of record includes several extreme wet and dry precipitation cycles and was used as the basis for further analysis. In particular, the selected sites were evaluated in detail by comparing the relationship between elevation and average annual precipitation. This comparison yielded a relatively linear relationship between elevation and precipitation at the Crested Butte NOAA,



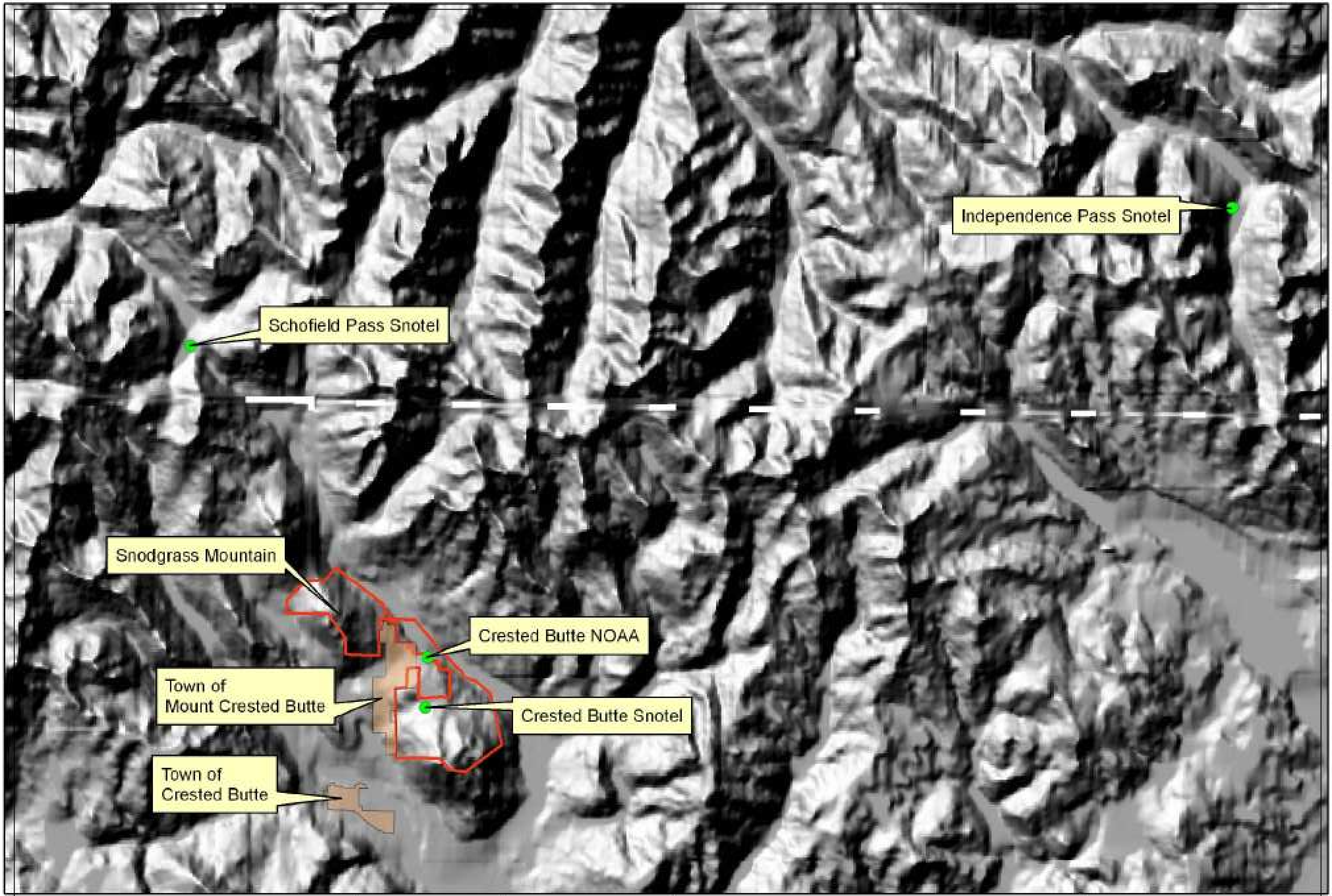
RESOURCE
ENGINEERING, INC
909 Colorado Avenue
Glenwood Springs, CO 81601
(970) 945-6777 Voice (970) 945-1137 Facsimile

1 inch equals 3,000 feet

FIGURE 5.2: Snodgrass Watersheds, Streams, and Stream Nodes

Crested Butte Mountain Resort,
Snodgrass Expansion

Date: 10/15/07
File: 333-5.2
Drawn by: SJ
Approved by: GG



RESOURCE
ENGINEERING, INC
909 Colorado Avenue
Glenwood Springs, CO 81601
(970) 945-6777 Voice (970) 945-1137 Facsimile

1 inch equals 15,000 feet

FIGURE 5.3: Weather Station Locations

Crested Butte Mountain Resort,
Snodgrass Expansion

Date: 10/15/07
File: 333-5.2
Drawn by: SJ
Approved by: GG

Crested Butte SNOTEL, and Independence Pass SNOTEL sites. That is, precipitation increased linearly with increases in elevation among the sites. Alternatively, the Schofield Pass SNOTEL site showed a sharp deviation from the linear relationship established between the other sites. This site was removed from further consideration due to this discrepancy. The relationship between the stations is shown in Figure 5.4.

For the watershed modeling of Snodgrass Mountain RESOURCE evaluated the following three types of years: dry, average, and wet. The average year was defined as the arithmetic mean of the study period of record (i.e. 1982 – 2005) at each station. For the wet period, 1995, the extreme wet year of record was selected. This was done because morphological changes resulting from landslide and fluvial processes are more likely to occur during extremely wet climatic cycles. Alternatively, 1994 was used as the dry year for modeling purposes. It was a relatively dry year; however, it was not the driest year over the study period of record. Nonetheless, it was deemed representative of water supplies that would occur in a dry year that could be expected to occur at a regular recurrence interval. More extreme dry years, like 2002, were excluded because they were assumed to have long recurrence intervals (i.e. a recurrence interval of longer than 1 year in 50 years). The percent of average precipitation for the dry (1994) and wet (1995) study years at the selected sites is summarized in Table 5.3.

Table 5.3: Percent of Average Precipitation During Extreme Years at Selected Study Sites

	Percent of Average	
Station	**Dry Year (1994)**	**Wet Year (1995)**
Crested Butte, NOAA	83%	145%
Crested Butte, SNOTEL	78%	143%
Independence Pass, SNOTEL	83%	141%

The elevations occupied by Snodgrass Mountain vary between approximately 9,350 feet and 11,150 feet. As illustrated in Figure 5.4, there is significant variability in annual precipitation in this 1,800 foot band. In order to account for this elevation driven precipitation variation, RESOURCE identified the mean watershed elevation of each microwatershed. Then, site specific precipitation patterns were calculated for each individual watershed based on an interpolation between the Crested Butte NOAA, Crested Butte SNOTEL, and Independence Pass SNOTEL weather stations. In the limited number of instances where the mean watershed elevation exceeded 10,600 feet, precipitation was predicted by extrapolating from the curve fit line used in the interpolation discussed above.

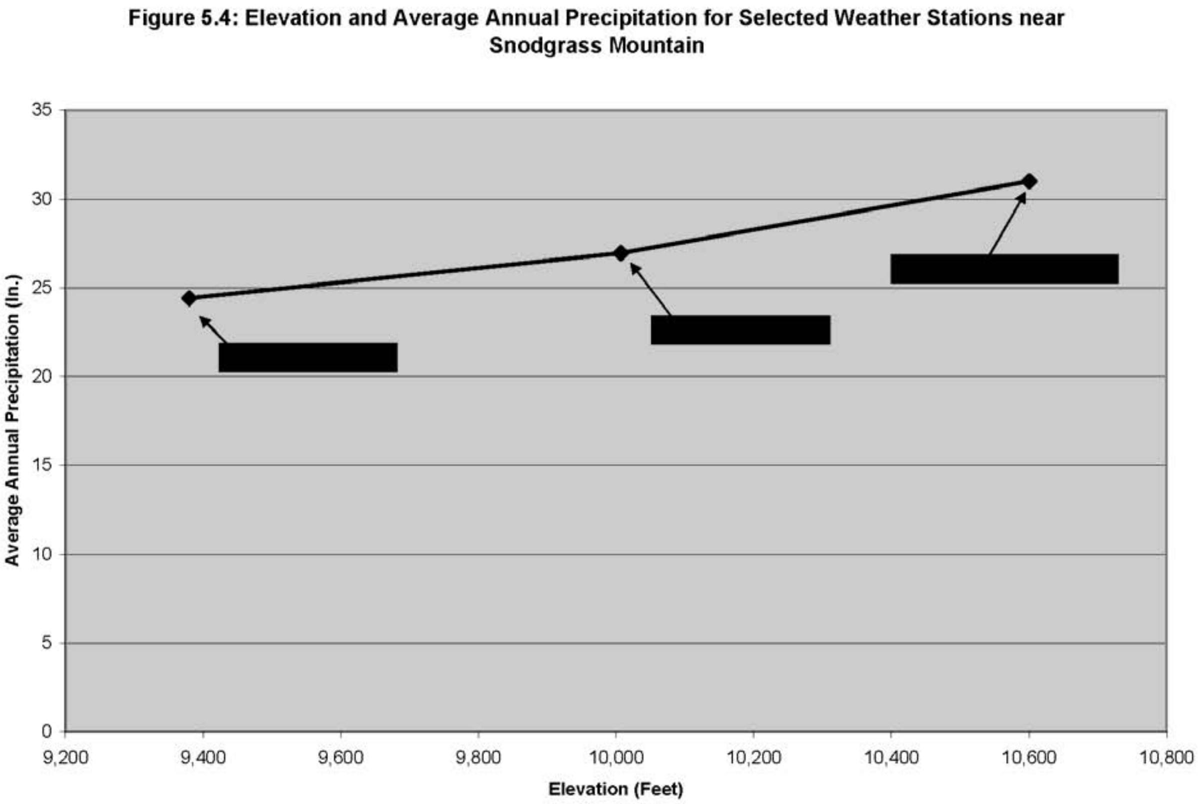
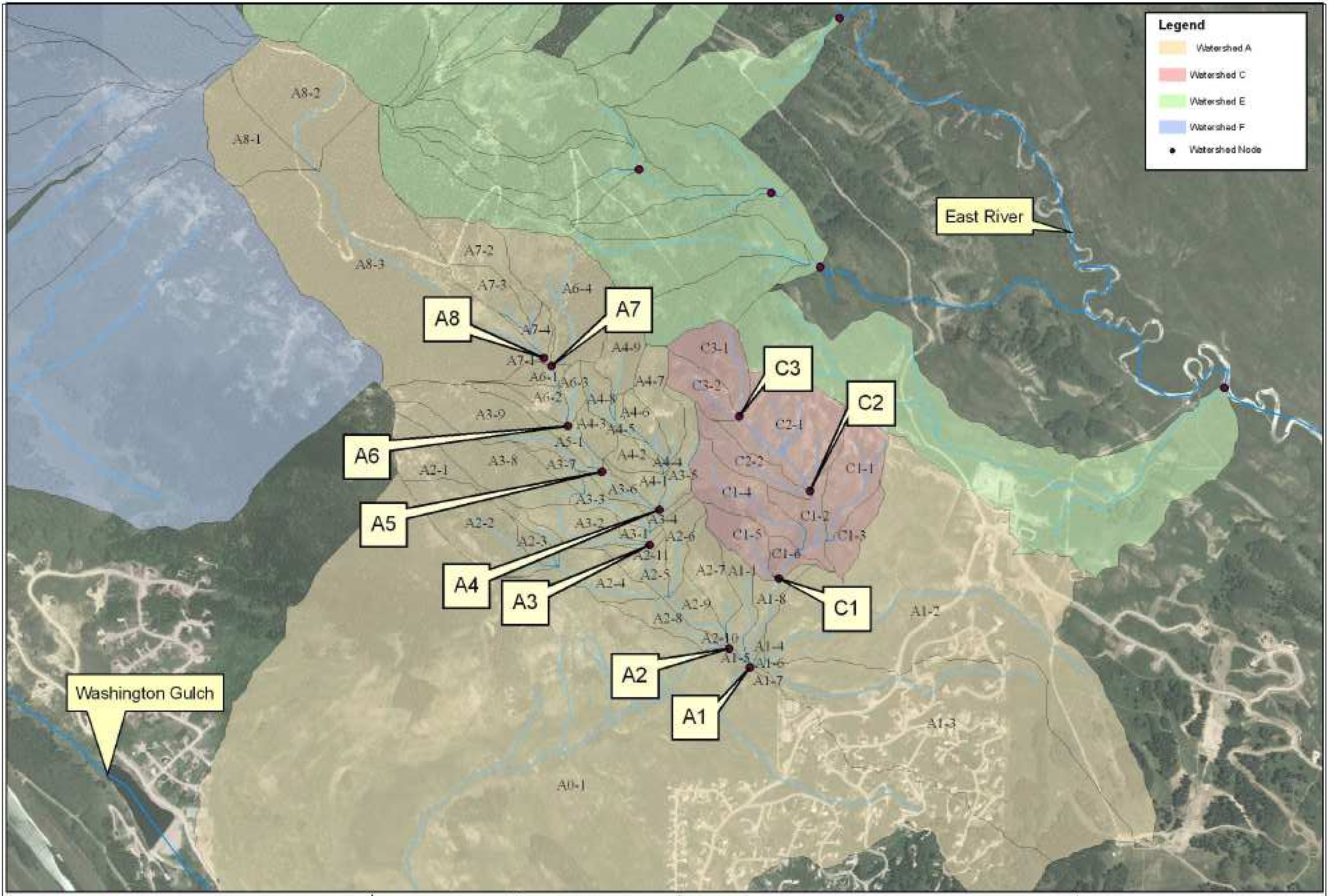


Fig. 5.4. Precipitation in the vicinity of Snodgrass Mountain, as a function of elevation.



RESOURCE
ENGINEERING, INC
909 Colorado Avenue
Glenwood Springs, CO 81601
(970) 945-6777 Voice (970) 945-1137 Facsimile

N
W E
S

1 inch equals 1,500 feet

FIGURE 5.5: Microwatersheds A and C

Crested Butte Mountain Resort,
Snodgrass Expansion

Date: 10/15/07
File: 333-5.2
Drawn by: SJ
Approved by: GG

5.2.3 Analyzing Local Surface Hydrology Characteristics

The WRENSS model predicts runoff at the outlet of a given study watershed during a six month period. Snowmelt volume is predicted based on accumulated winter precipitation and the volume of artificially produced snow that was applied. Snowmelt timing is predicted by allocating accumulated snowpack according to empirical distributions developed in the Water Management Research Project. The streamflow values output by the model are calculated by adding an estimated baseflow to this predicted runoff.

RESOURCE reviewed regional stream gage data to calculate a baseflow that is appropriate for the microwatersheds on Snodgrass Mountain. Several gages were selected for analysis based on their relative similarity to the watersheds on Snodgrass Mountain (i.e. high watershed elevation and small watershed area). The average baseflow discharge *per square mile* for the selected, gaged watersheds was calculated to be 0.20 CFS. These gages are summarized in Table 5.4.

Table 5.4: Summary of Regionally Selected Stream Gages

Site	Elevation	Area (sq. mi)	Discharge per Sq. Mi. (CFS)
Coal Creek, Near Crested Butte, CO	9,495	8.65	0.24
Hunter Creek Above Midway Creek Near Aspen, CO	10,500	6.18	0.26
No Name Creek Near Aspen, CO	10,000	6.54	0.14
Midway Creek Near Aspen, CO	10,080	8.62	0.16
Average	**10,019**	**7.50**	**0.20**

Analysis of the selected gages identified significant variability in baseflow between dry, average, and wet years. This variability was accounted for by modifying the 0.20 CFS per square mile baseflow during average years to 0.15 CFS per square mile in dry years (75% of average) and 0.3 CFS per square mile in wet years (150% of average). Based on this analysis, each watershed on Snodgrass Mountain was assigned a baseflow by multiplying the appropriate base flow rate for the type of year (i.e. dry – 0.15 CFS per square mile, average - 0.20 CFS per square mile, or wet - 0.30 CFS per square mile) by the selected watershed’s area.

5.2.3.1 Monitoring Local Surface Hydrology

In anticipation of completing WRENSS surface hydrology modeling during the summer of 2007, a streamflow monitoring program was implemented in the spring of 2007. This data was intended to expand the hydrologic data available for Snodgrass Mountain and provide an empirical basis for calibration and validation of the WRENSS model. The program was targeted at monitoring the spring runoff hydrograph and peak flows which occur in response to snowmelt during April, May, and June. Initially, two sites were selected for monitoring. These sites correspond to Nodes A3 and A6. A third site, located at Node F2, was added to the monitoring program in early May (See Figure 5.2). This site was incorporated so that the program would include stream flow data from multiple Snodgrass Mountain watersheds. It was intended to help identify any potential variability in spring runoff patterns among the different watersheds draining Snodgrass Mountain.

HydroGeo, a subcontractor of GEO-HAZ, began weekly streamflow monitoring on March 22, 2007. Initially, Hydro-Geo collected measurements at Node A3 and Node A6 with a hand-held current meter. Discharge was calculated using the velocity-area methodology. As noted above, monitoring at Node F2 was included in the program beginning May 1, 2007. Weekly monitoring at Nodes A3 and A6 continued through July 3, 2007. On July 21st and 22nd, 2007, flumes were installed at both Node A3 and Node A6. Continuous recording pressure transducers were installed at the Upper Flume on July 21st, 2007 and at the Lower Flume on August 17th, 2007. The data collected by the pressure transducers replaced the weekly streamflow measurements. Flow monitoring at Node F2 continued through July 10, 2007. This monitoring duration was sufficient to watch the downward limb of the hydrograph return to approximate baseflow conditions.

5.2.4 Calculating Evapotranspiration and Infiltration Values

WRENSS is a water balance model; it calculates water available for streamflow by subtracting watershed losses attributable to a variety of physical processes (e.g. evapotranspiration and evaporation) from water available due to precipitation. In order to quantify the annual water balance, WRENSS developers reviewed literally hundreds of station years of data for the United States. The available data was distributed into geographic groupings defined by climatic similarity. The study site, Snodgrass Mountain, is located in the Rocky Mountain/Inland Intermountain Region. The annual water balance in this region is generally characterized by precipitative input, atmospheric and watershed losses and subsequent surface water runoff and recharge to soil and groundwater. The climate in the Rocky Mountain Region is generally characterized as semi-arid, with limited annual rainfall. The limited precipitation in this region is generally dominated by winter-time snowfall. The snowfall is typically complimented by periodic, often intense, late summer and early fall rain and thunderstorms.

These general climatic patterns significantly influence the physical processes that may consume precipitation input prior to its realization as streamflow. These potential watershed losses include interception, infiltration and evapotranspiration. A portion of rainfall may be intercepted by forest canopy. This water is retained in the canopy and may be directly consumed by vegetation or it may evaporate. In the Rocky Mountain Region, water that is not intercepted typically infiltrates the mantle and temporarily becomes part of the soil-water complex. Once incorporated into the soil, water may migrate along the ground water gradient, remain in place as storage, be consumed by evapotranspirational processes or percolate to greater depths as seepage. Potential evapotranspiration and soil moisture storage are subject to significant seasonal variation in the Rocky Mountain Region. During spring snowmelt soil moisture storage is at its annual maximum and there is sufficient water to satisfy all potential evapotranspiration. Alternatively, potential evapotranspiration may be limited during the late summer when transpirational demand is high and soil moisture has not been replenished.

The study plots and station data used to develop WRENSS were assumed to account for the amalgamated affect of the potential sources of watershed loss (i.e. interception, infiltration, evaporation, etc.). The data were used to develop a series of empirically based nomographs that predict watershed loss based on available precipitation. They include a unique set of empirically calculated evapotranspiration values and evapotranspiration modifier coefficients. The nomographs are designed to account for variability in factors like watershed energy and watershed aspect. For example, a watershed with a southern aspect will have high energy due to increased exposure to solar radiation. This exposure increases the rate at which snow melts and increases potential evapotranspiration.

The nomographs are tailored to an individual study watershed based on several inputs in the WRENSS modeling procedure. First, estimated seasonal precipitation is provided for the study watershed. Second, information related to vegetative extent and density is provided for the existing and proposed condition. Finally, the aspect of the study watershed is provided. Based on this information the model calculates actual watershed loss for the study watershed.

5.3 Results – Snodgrass Mountain Surface Hydrology

The WRENSS Model was paired with a stream flow monitoring program to evaluate Snodgrass Mountain surface hydrology. The results of these efforts are discussed in detail below.

5.3.1 WRENSS Modeling Results

RESOURCE developed several WRENSS modeling scenarios to facilitate review of the proposed Snodgrass Mountain development. To accomplish this a series of scenarios designed to evaluate the proposed development were created. This includes an Existing, Proposed, and Proposed with Snowmaking Scenario. The Existing Scenario characterizes the current conditions at Snodgrass Mountain with no ski trail and no snowmaking development. Alternatively, the Proposed Scenario models surface hydrology with the development of 296.2 acres of ski trails contemplated in this proposal. Finally, the Proposed with Snowmaking Scenario includes development of 296.2 acres of ski trail and the application of approximately 120 acre feet of water over 119.2 acres of ski trail for snowmaking purposes. These scenarios establish a baseline and provide for the assessment of hydrologic changes that may result from trail clearing and the application of artificial snowmaking.

After creating scenarios that characterize the proposed development, several scenarios representing different climatic regimes were developed. These include a scenario representing Dry, Average, and Wet precipitation years. As discussed in Section 5.2.2, the Dry Scenario is based on data collected during 1994 at selected weather stations. Precipitation during this year was approximately 81% of average. The Average Scenario is based on the arithmetic mean precipitation during the selected period of record at the selected weather stations. Finally, the Wet Scenario was approximately 143% of average precipitation. This was based on 1995 data at the selected weather stations. Evaluation of varied climatic regimes allows for a relative assessment of existing and proposed conditions under dry, average, and wet years. The proposed modifications on Snodgrass Mountain may alter surface hydrology. Proposed snowmaking will increase the annual volume of runoff and proposed trail clearing may alter the quantity and timing of snowmelt runoff.

In total, nine different modeling scenarios were identified (i.e. Existing-Dry Scenario, Existing-Average Scenario, Existing-Wet Scenario, Proposed-Dry Scenario, Proposed-Average Scenario, Proposed-Wet Scenario, Proposed with Snowmaking-Dry Scenario, Proposed with Snowmaking-Average Scenario and Proposed with Snowmaking-Wet Scenario). All of the 114 microwatersheds on Snodgrass Mountain were evaluated under each of the nine modeling scenarios. In total, 1,026 different model runs were completed for the watersheds on Snodgrass Mountain. Key model outputs from each watershed (e.g. maximum discharge, total runoff volume, existing/predicted vegetation extent, etc.) were exported into a tabular format. Then, data for each watershed was summarized based on the Node to which it contributes. These Nodes are illustrated in Figure 5.2. Key results for the nodes are described below.

5.3.1.1 Watershed A Results

Watershed A conveys water from the summit of Snodgrass Mountain west to Washington Gulch. Watershed A plays an important role in the WRENSS model because it is the sole conduit for skier traffic traveling between Snodgrass Mountain and Mount Crested Butte. As such, there are a number of ski trails, some with proposed snowmaking, located in Watershed A. Additionally, a few of the younger landslides identified in Section 2 are located in this watershed. The microwatersheds that contribute to Watershed A are shown in Figure 5.5.

Maximum discharge and annual runoff volume predicted for the nodes in Watershed A under each of the nine WRENSS modeling scenarios have been summarized. The annual runoff volume represents the quantity of water, in acre feet, discharged between approximately mid-March and the end of September. These values are shown in Table 5.5. Results for individual watersheds are provided in DIGITAL APPENDIX D5.1. Finally, average year hydrographs for the Existing, Proposed, and Proposed with Snowmaking Scenarios at Nodes A3 and A6 are illustrated in Figures 5.6 and 5.7.

Table 5.5: WRENSS Modeling Results, Watershed A

Moisture Regime	Node	Existing Max Q* (CFS)	Existing Volume (AF)	Proposed Max Q* (CFS)	Proposed Volume (AF)	Proposed + Snowmaking Max Q* (CFS)	Proposed + Snowmaking Volume (AF)	Max Q* % Change**	Volume % Change**
Average Year	A8	1.83	184.62	1.68	199.18	1.77	210.96	-3.24%	14.27%
	A7	0.27	28.13	0.33	30.12	0.37	33.74	35.78%	19.95%
	A6	2.18	254.34	2.18	272.48	2.35	292.61	8.09%	15.04%
	A5	2.23	261.15	2.25	279.84	2.42	300.37	8.82%	15.02%
	A4	0.46	45.52	0.48	46.44	0.51	49.25	12.03%	8.20%
	A3	3.05	388.00	3.50	412.51	3.74	443.69	22.58%	14.35%
	A2	3.77	488.07	4.32	501.71	4.56	533.43	21.01%	9.29%
	A1	7.37	839.66	8.20	853.32	8.39	885.54	13.84%	5.46%
Wet Year	A8	3.65	360.10	3.25	374.50	3.35	387.22	-8.12%	7.53%
	A7	0.49	50.79	0.58	52.75	0.62	56.66	27.53%	11.55%
	A6	4.34	488.53	4.05	506.46	4.23	528.18	-2.37%	8.12%
	A5	4.44	501.33	4.17	519.80	4.36	541.96	-1.74%	8.10%
	A4	0.84	83.43	0.88	84.34	0.91	87.37	8.76%	4.72%
	A3	5.98	736.45	6.37	760.65	6.62	794.33	10.84%	7.86%
	A2	7.07	891.87	7.83	917.73	8.08	951.89	14.29%	6.73%
	A1	12.93	1472.47	14.36	1498.35	14.56	1532.98	12.56%	4.11%
Dry Year	A8	1.32	133.85	1.24	146.99	1.32	157.90	0.17%	17.96%
	A7	0.20	20.38	0.24	22.13	0.28	25.47	40.84%	25.01%
	A6	1.56	183.98	1.61	200.24	1.76	218.86	13.11%	18.96%
	A5	1.60	188.81	1.65	205.55	1.82	224.55	13.88%	18.93%
	A4	0.33	33.10	0.35	33.89	0.38	36.49	13.98%	10.23%
	A3	2.19	281.87	2.60	303.79	2.82	332.66	28.37%	18.02%
	A2	2.71	355.56	3.20	370.11	3.43	399.46	26.59%	12.35%
	A1	5.55	624.00	6.19	638.56	6.37	668.38	14.90%	7.11%

* Max. Q represents the predicted annual peakflow.
**Percent change represents the percent change between the Existing and Proposed with Snowmaking Scenarios.

5.3.1.2 Watershed C Results

Watershed C is located on the eastern flank of Snodgrass Mountain in the 9,200 feet to 10,200 feet elevation range. This watershed is tributary to Watershed A and Washington Gulch. Watershed C was distinguished from Watershed A for several reasons. First, there is limited trail development and snowmaking application in this watershed. Next, Watershed C drains a mix of stable geologies and relatively old landslide complexes. The microwatersheds that contribute to Watershed C are shown in Figure 5.5.

Maximum discharge and annual runoff volume predicted for the nodes in Watershed C under each of the nine WRENSS modeling scenarios have been summarized. These values are shown in Table 5.6. Results for individual watersheds are provided in DIGITAL APPENDIX D5.1 . Finally, average year hydrographs for the Existing, Proposed, and Proposed with Snowmaking Scenarios at Node C1 are illustrated in Figure 5.8.

Table 5.6: WRENSS Modeling Results, Watershed C

Moisture Regime	Node	Existing Max Q* (CFS)	Existing Volume (AF)	Proposed Max Q* (CFS)	Proposed Volume (AF)	Proposed + Snowmaking Max Q* (CFS)	Proposed + Snowmaking Volume (AF)	Max Q* % Change**	Volume % Change**
Average	C3	0.22	21.50	0.22	21.51	0.22	22.09	2.08%	2.75%
	C2	0.76	65.17	0.76	65.19	0.77	66.59	1.75%	2.17%
	C1	1.33	123.71	1.34	123.81	1.36	127.17	2.45%	2.80%
Wet	C3	0.38	37.28	0.39	37.29	0.39	37.87	1.22%	1.59%
	C2	1.32	111.13	1.32	111.14	1.33	112.54	1.03%	1.27%
	C1	2.37	216.87	2.37	216.98	2.40	220.46	1.52%	1.65%
Dry	C3	0.17	16.40	0.17	16.41	0.17	16.99	2.71%	3.59%
	C2	0.57	50.23	0.57	50.24	0.59	51.64	2.26%	2.80%
	C1	1.03	96.88	1.03	96.97	1.06	100.28	3.04%	3.51%

* Max. Q represents the predicted annual peakflow
**Percent change represents the percent change between the Existing and Proposed with Snowmaking Scenarios.

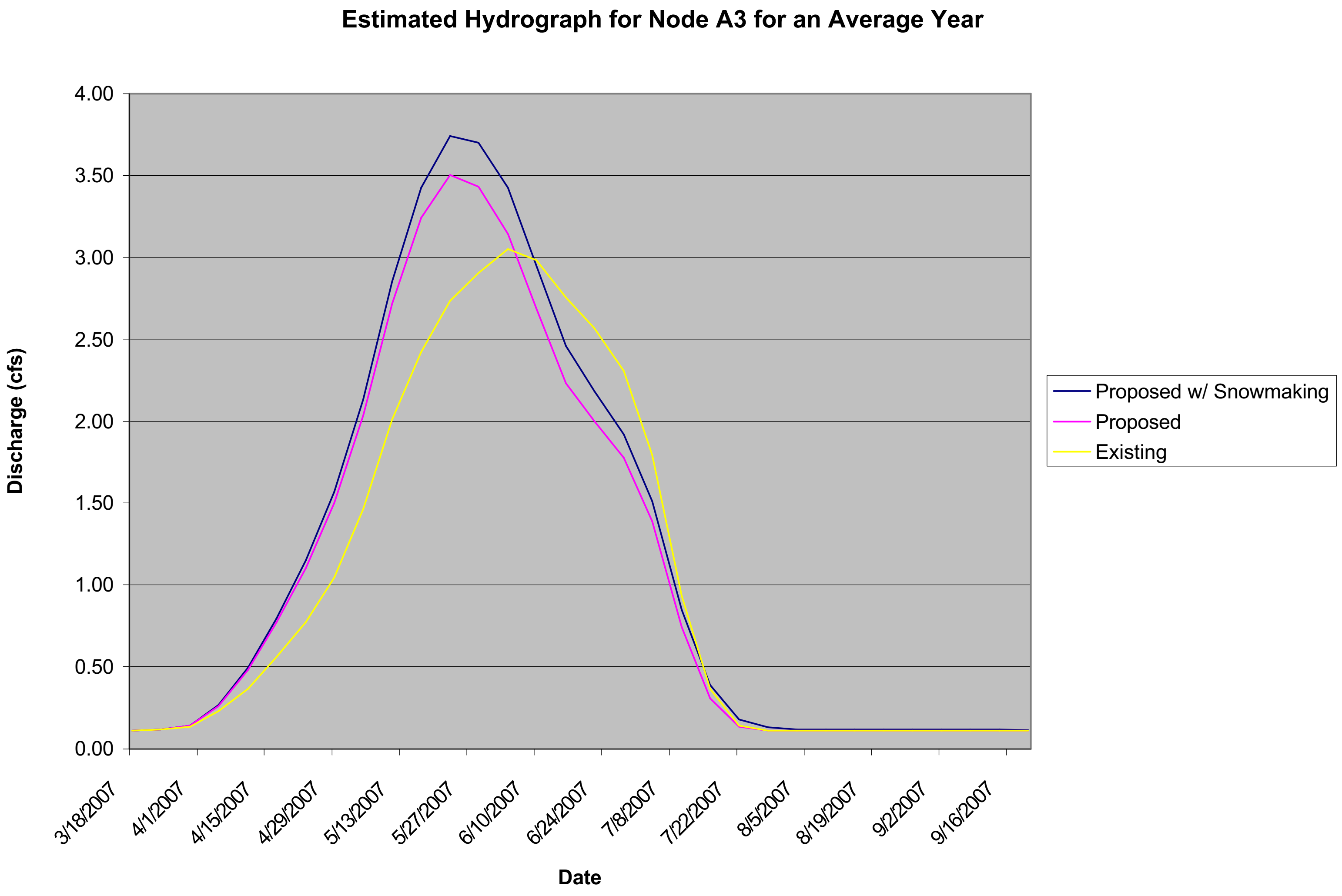


Fig. 5-6. Average year hydrographs for the Existing, Proposed, and Proposed with Snowmaking Scenarios at Node A3.

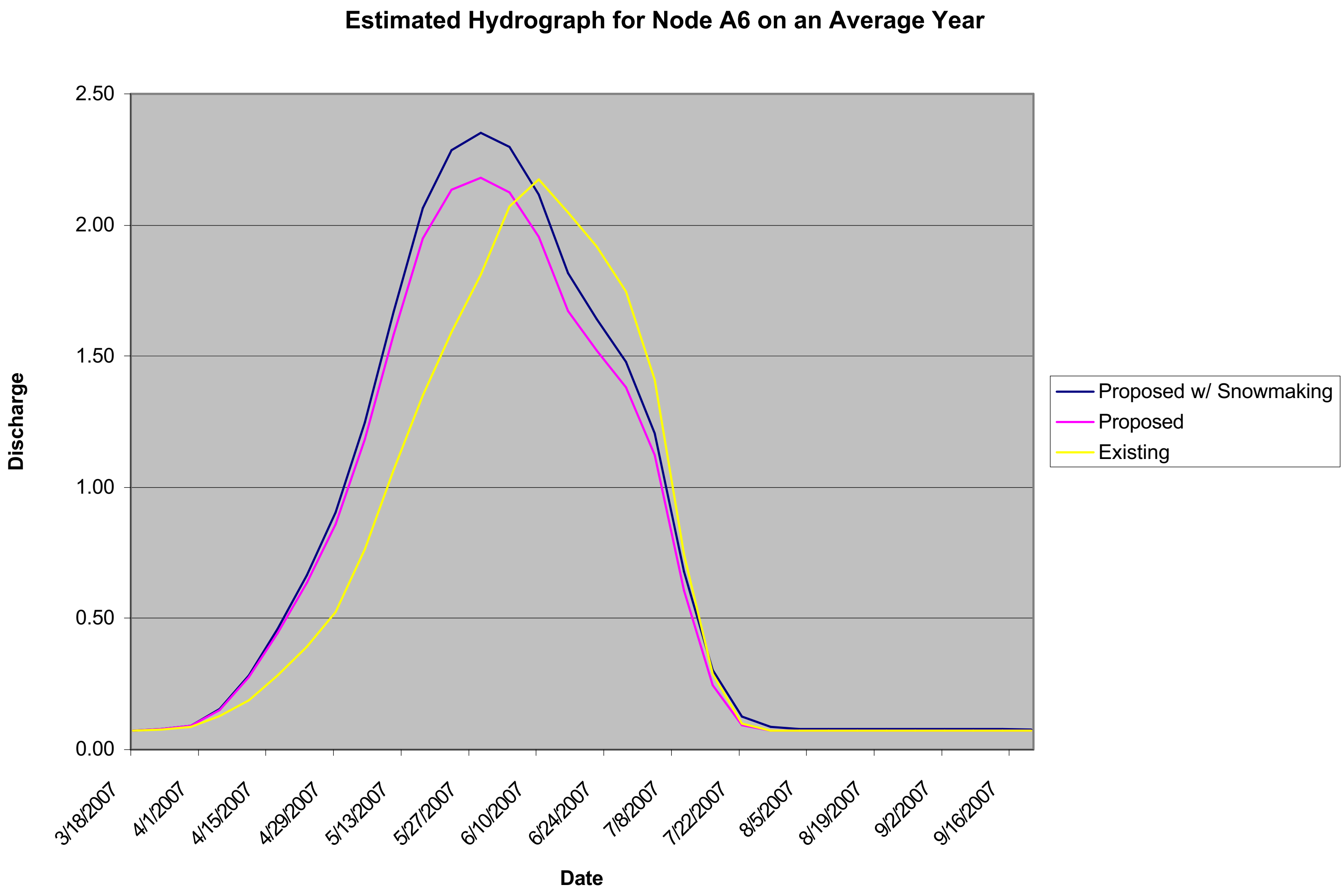


Fig. 5-7. Average year hydrographs for the Existing, Proposed, and Proposed with Snowmaking Scenarios at Node A6.

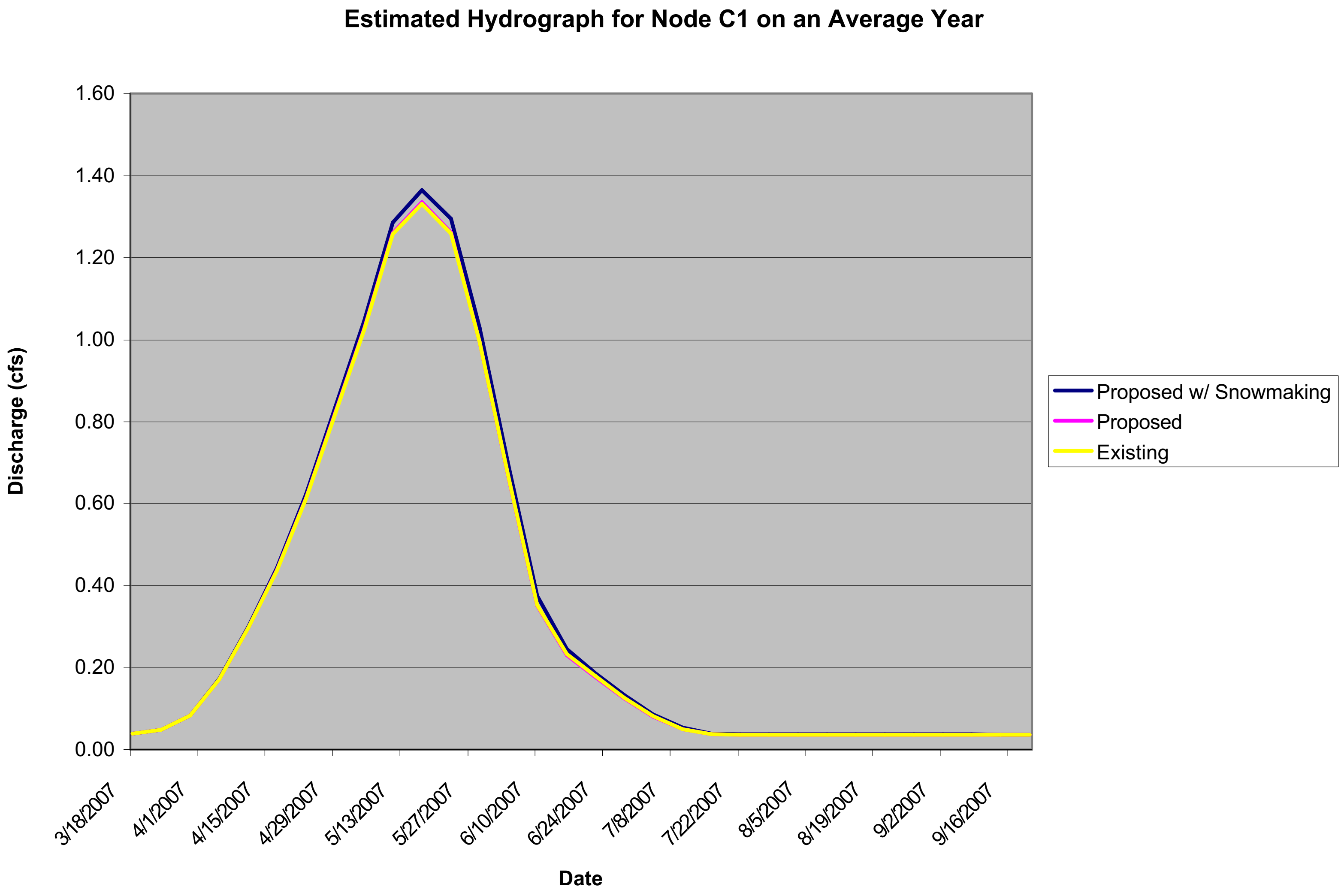


Fig. 5-8. Average year hydrographs for the Existing, Proposed, and Proposed with Snowmaking Scenarios at Node C1.

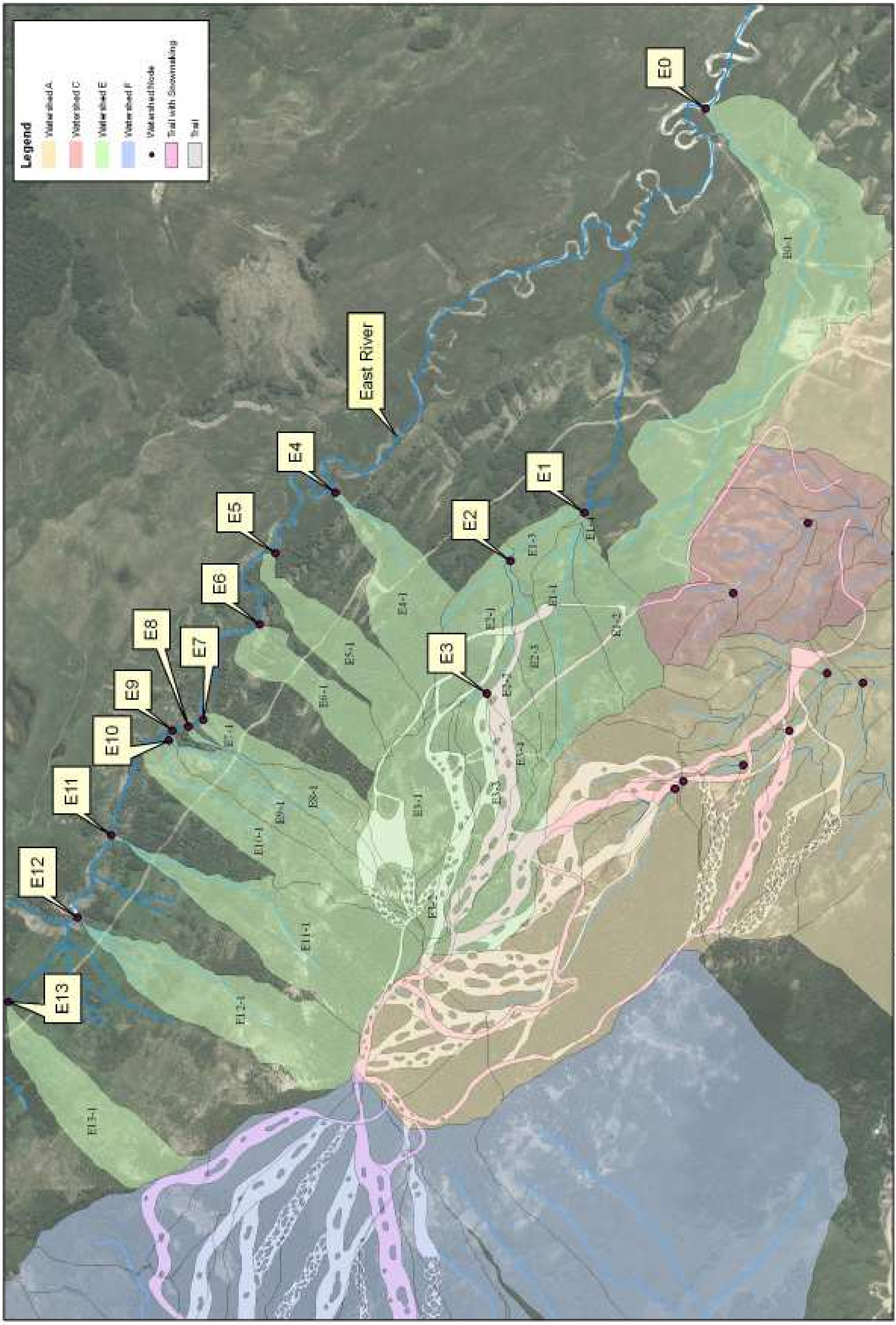


FIGURE 5.9: E Microwatersheds

Crested Butte Mountain Resort,
Snodgrass Expansion

1 inch equals 1,500 feet

Date: 10/15/07
File: 333-5.2
Drawn by: SJ
Approved by: GG

RESOURCE
ENGINEERING, INC
909 Colorado Avenue
Glenwood Springs, CO 81601
(970) 945-6777 Voice (970) 945-1137 Facsimile

5.3.1.3 Watershed E Results

Watershed E is a collection of microwatersheds that convey drainage from the north and east flanks of Snodgrass Mountain to the East River. Unlike the watersheds discussed above, there is not a single stream network associated with Watershed E. Rather, this watershed is comprised of a series of small streams and microwatersheds that drain directly to the East River. Several ski trails, some including snowmaking are proposed in Watershed E. The microwatersheds that compose this watershed are shown in Figure 5.9.

Maximum discharge and annual runoff volume predicted for the nodes in Watershed E under each of the nine WRENSS modeling scenarios have been summarized. These values are shown in Table 5.7. Results for individual watersheds are provided in DIGITAL APPENDIX D5.1. The analysis indicates that subwatersheds E4 through E13 will be minimally impacted by the proposed development. Watersheds E1 through E3 are located downstream of proposed trail clearing and snowmaking application and are expected to experience some hydrologic changes. Average year hydrographs for the Existing, Proposed, and Proposed with Snowmaking Scenarios at Node E2 are illustrated in Figure 5.10.

Table 5.7: WRENSS Modeling Results, Watershed E

Moisture Regime	Node	Existing Max Q* (CFS)	Existing Volume (AF)	Proposed Max Q* (CFS)	Proposed Volume (AF)	Proposed + Snowmaking Max Q* (CFS)	Proposed + Snowmaking Volume (AF)	Max Q* % Change**	Volume % Change**
Average	E13	0.47	43.71	0.47	43.71	0.47	43.71	0.02%	0.01%
	E12	0.83	82.45	0.83	82.49	0.83	82.59	0.30%	0.17%
	E11	1.89	193.15	1.87	193.84	1.88	194.40	-0.58%	0.64%
	E10	0.43	42.47	0.44	42.79	0.44	42.79	2.64%	0.77%
	E9	0.27	27.72	0.28	27.91	0.28	27.91	2.18%	0.70%
	E8	0.19	17.65	0.19	17.65	0.19	17.65	0.00%	0.00%
	E7	0.16	16.39	0.16	16.51	0.16	16.51	2.42%	0.74%
	E6	0.19	21.91	0.19	21.94	0.19	21.94	-0.01%	0.13%
	E5	0.24	27.94	0.24	28.14	0.24	28.14	-0.05%	0.70%
	E4	0.31	34.36	0.31	34.47	0.31	34.47	0.59%	0.33%
	E3	0.74	90.27	0.99	100.17	1.06	110.45	42.34%	22.36%
	E2	1.17	137.75	1.47	149.71	1.58	164.24	34.77%	19.23%
	E1	2.05	241.95	2.45	258.52	2.60	281.16	26.76%	16.21%
	E0	1.99	162.93	1.99	162.93	1.99	163.14	0.11%	0.13%

Wet	E13	0.79	74.54	0.79	74.54	0.79	74.54	0.02%	0.01%
	E12	1.43	144.24	1.43	144.28	1.43	144.39	0.25%	0.10%
	E11	1.34	141.73	1.33	142.40	1.34	143.00	-0.36%	0.89%
	E10	0.73	71.46	0.75	71.78	0.75	71.78	2.43%	0.45%
	E9	0.47	48.00	0.47	48.19	0.47	48.19	1.97%	0.40%
	E8	0.32	30.06	0.32	30.06	0.32	30.06	0.00%	0.00%
	E7	0.27	28.60	0.27	28.72	0.27	28.72	2.17%	0.42%
	E6	0.37	41.39	0.37	41.42	0.37	41.42	-0.06%	0.07%
	E5	0.48	52.96	0.48	53.15	0.48	53.15	-0.37%	0.36%
	E4	0.56	63.14	0.57	63.25	0.57	63.25	0.42%	0.18%
	E3	1.40	167.21	1.73	176.92	1.80	188.01	28.78%	12.44%
	E2	2.18	254.13	2.57	265.84	2.69	281.53	23.16%	10.78%
	E1	3.76	442.79	4.28	459.05	4.45	483.48	18.37%	9.19%
	E0	3.45	274.00	3.45	274.00	3.45	274.21	0.06%	0.08%
Dry	E13	0.34	31.69	0.34	31.70	0.34	31.70	0.02%	0.02%
	E12	0.66	64.68	0.66	64.72	0.66	64.81	0.33%	0.20%
	E11	0.52	56.48	0.52	57.09	0.52	57.60	0.56%	1.98%
	E10	0.32	31.49	0.33	31.78	0.33	31.78	2.74%	0.93%
	E9	0.20	19.95	0.20	20.11	0.20	20.11	2.26%	0.81%
	E8	0.14	12.78	0.14	12.78	0.14	12.78	0.00%	0.00%
	E7	0.11	11.77	0.12	11.87	0.12	11.87	2.51%	0.86%
	E6	0.14	16.46	0.14	16.49	0.14	16.49	0.00%	0.14%
	E5	0.18	20.99	0.18	21.15	0.18	21.15	0.00%	0.76%
	E4	0.23	25.64	0.23	25.74	0.23	25.74	0.62%	0.36%
	E3	0.54	66.00	0.74	74.51	0.81	84.02	48.23%	27.30%
	E2	0.86	100.77	1.10	110.98	1.20	124.43	39.78%	23.49%
	E1	1.51	177.02	1.83	191.34	1.97	212.30	30.73%	19.93%
	E0	1.56	126.92	1.56	126.92	1.56	127.12	0.13%	0.15%

* Max. Q represents the predicted annual peakflow
**Percent change represents the percent change between the Existing and Proposed with Snowmaking Scenarios.

5.3.1.4 Watershed F Results

Watershed F receives drainage from the north and east flanks of Snodgrass Mountain. Additionally, it collects water from the south side of Gothic Mountain.[4] Stream flow from Watershed F is tributary to Washington Gulch. Several proposed trails, some with artificial snowmaking application, are located in the upper portion of Watershed F. The individual microwatersheds that comprise Watershed F are shown in Figure 5.11.

Maximum discharge and annual runoff volume predicted for the nodes in Watershed F under each of the nine WRENSS modeling scenarios have been summarized. These values are shown

---

[4] Gothic Mountain is outside of the Mount Crested Butte Ski Resort Special Use Permit Boundary. None of the proposed development activities occur on Gothic Mountain.

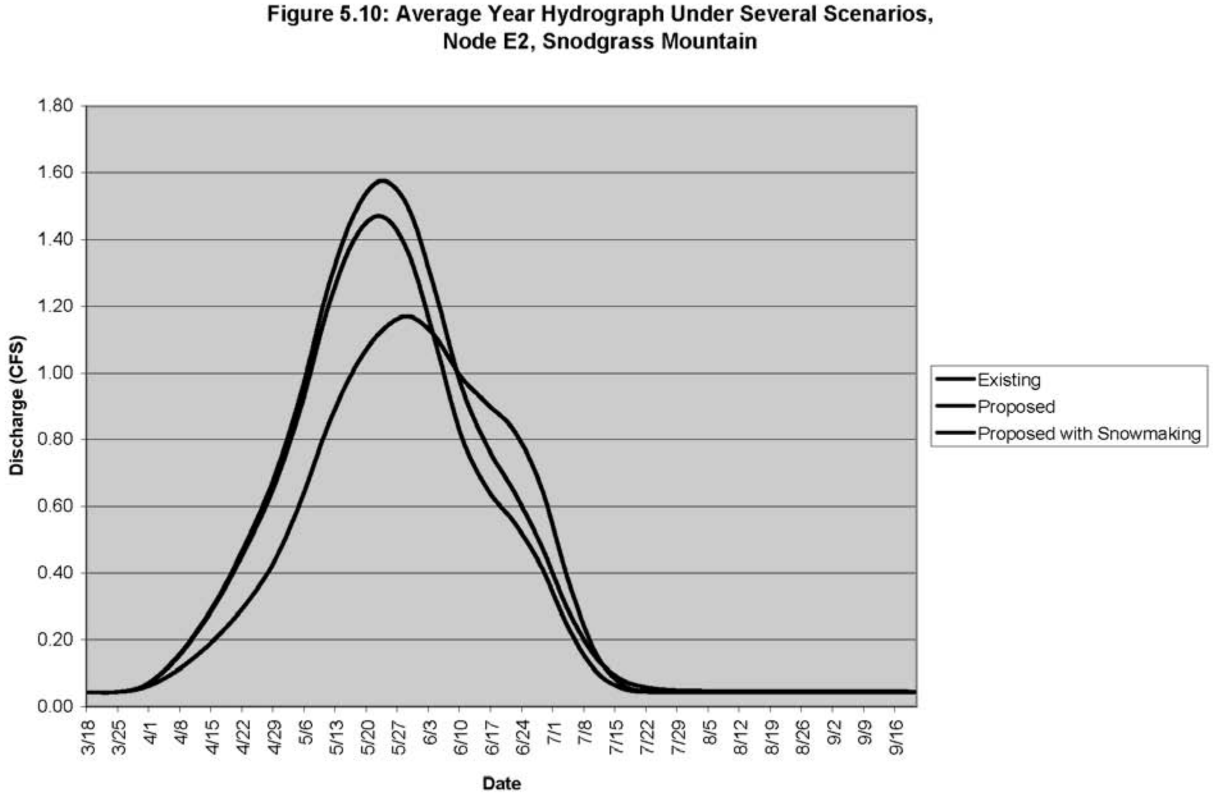
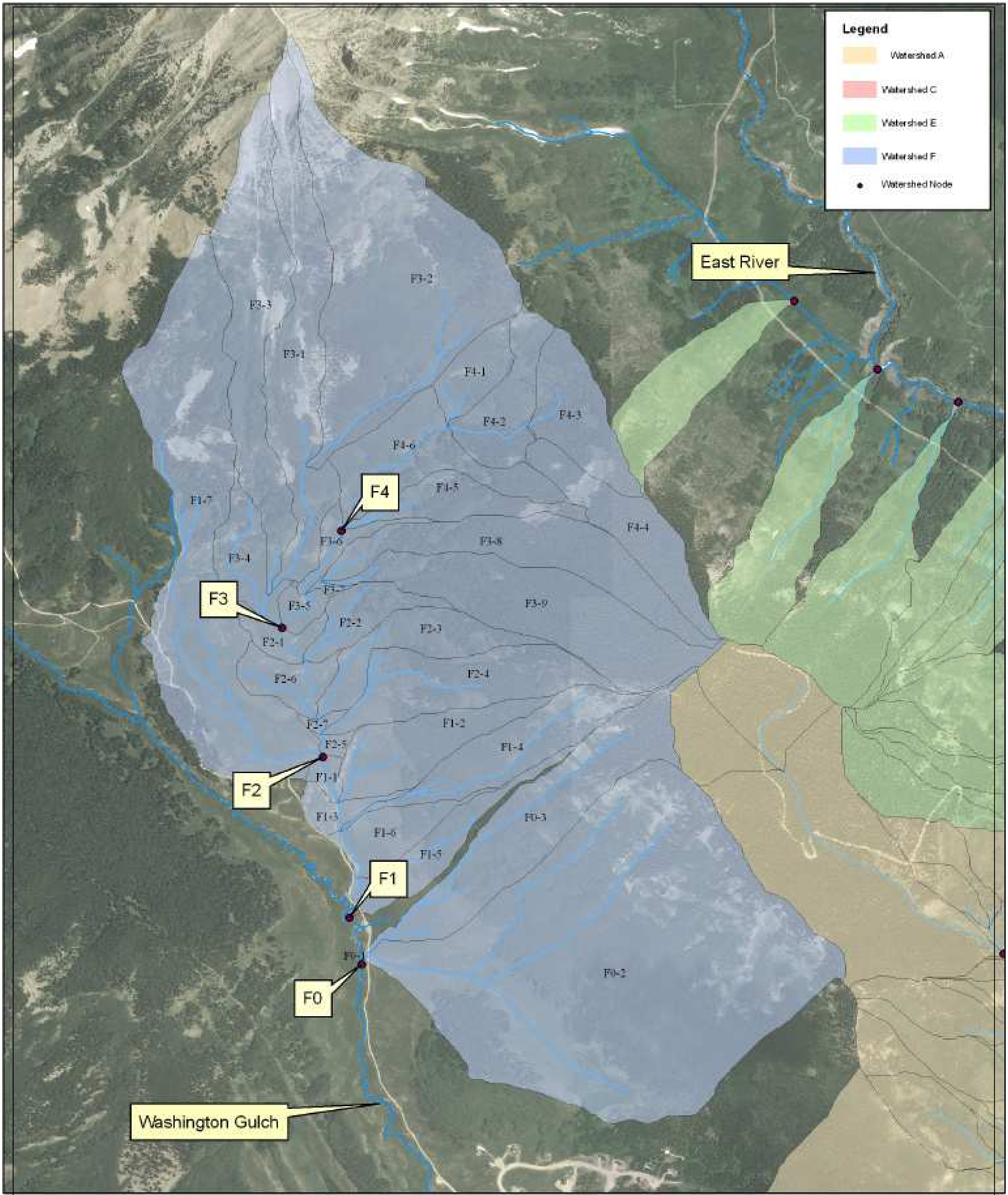


Fig. 5.10. Annual hydrograph under several precipitation scenarios, Stream Node E2, axial stream.



RESOURCE
ENGINEERING, INC
909 Colorado Avenue
Glenwood Springs, CO 81601
(970) 945-6777 Voice (970) 945-1137 Facsimile

N
W E
S

1 inch equals 1,500 feet

Figure 5.11:
F Microwatersheds
Crested Butte Mountain Resort,
Snodgrass Expansion

Date: 10-17-2007
File: 333-5.2
Drawn by: SJ
Approved by: GG

in Table 5.8. Results for individual watersheds are provided in DIGITAL APPENDIX D5.1. Finally, average year hydrographs for the Existing, Proposed, and Proposed with Snowmaking Scenarios at Node F2 are illustrated in Figure 5.12.

Table 5.8: WRENSS Modeling Results, Watershed F

Moisture Regime	Node	Existing Max Q* (CFS)	Existing Volume (AF)	Proposed Max Q* (CFS)	Proposed Volume (AF)	Proposed + Snowmaking Max Q* (CFS)	Proposed + Snowmaking Volume (AF)	Max Q* % Change**	Volume % Change**
Average	F4	1.26	144.02	1.35	150.82	1.45	164.48	15.24%	14.20%
	F3	4.52	528.80	5.11	543.42	5.33	571.37	18.03%	8.05%
	F2	5.47	633.26	6.14	641.23	6.62	698.80	20.97%	10.35%
	F1	7.65	875.59	8.38	884.60	8.80	942.21	15.09%	7.61%
	F0	11.16	1351.23	11.87	1360.53	12.35	1418.88	10.59%	5.01%
Wet	F4	4.37	478.70	4.60	486.37	4.71	501.15	7.75%	4.69%
	F3	11.51	1311.56	13.01	1336.70	13.16	1359.60	14.38%	3.66%
	F2	13.46	1525.96	15.32	1558.65	15.62	1599.56	16.02%	4.82%
	F1	18.33	2069.11	20.25	2103.57	20.53	2144.53	11.99%	3.64%
	F0	25.98	3110.47	27.90	3145.25	28.20	3187.01	8.55%	2.46%
Dry	F4	1.03	117.65	1.13	124.66	1.23	137.32	19.26%	16.72%
	F3	3.84	440.64	4.44	462.58	4.57	482.20	19.22%	9.43%
	F2	4.70	533.02	5.48	561.41	5.78	599.05	22.88%	12.39%
	F1	6.67	742.11	7.52	771.50	7.74	809.18	15.95%	9.04%
	F0	10.01	1197.59	10.82	1227.26	11.12	1265.67	11.07%	5.68%

* Max. Q represents the predicted annual peakflow
**Percent change represents the percent change between the Existing and Proposed with Snowmaking Scenarios.

5.3.2 Streamflow Monitoring Results and WRENSS Model Validation

Stream flow monitoring data was collected at Nodes A3, A6, and F2 during Spring, 2007. This information was used to assess whether the WRENSS model results predicted for Snodgrass Mountain are reasonable. Due to the limited amount of continuously recorded data during most of the summer, RESOURCE could not validate total runoff volume. However, sufficient information was available to assess projected peak discharge and baseflow conditions. The results at each of these locations are discussed in detail below.

5.3.2.1 Node A6/Upper Flume Monitoring Data

As discussed above, the location of the Upper Flume Monitoring Site corresponds with Node A6 (see Figure 5.5). Streamflow during the last week of March at this site was measured at approximately 17 GPM (0.04 CFS). This suggests that spring snowmelt had not yet initiated and that the stream was measured under baseflow conditions. Shortly thereafter, in early April,

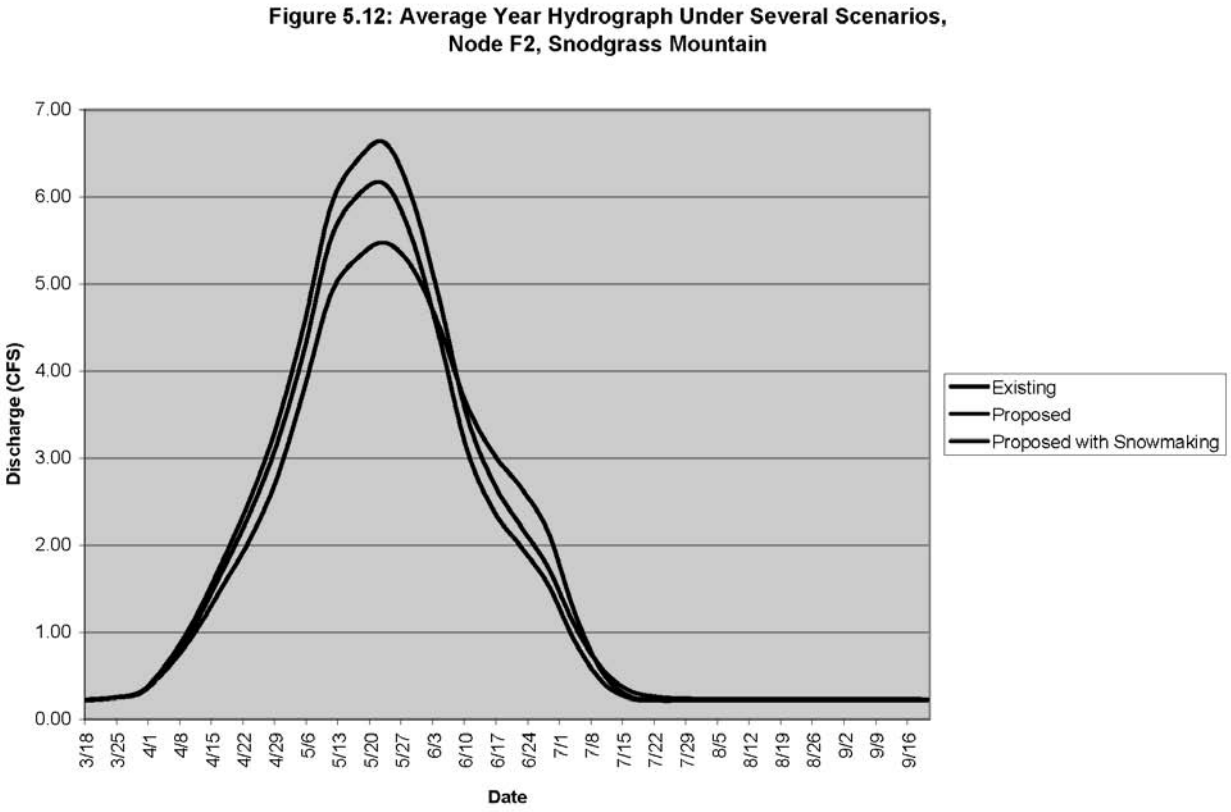


Fig. 5.12. Annual hydrograph under several precipitation scenarios, Stream Node F2, axial stream

snowmelt began and the hydrograph quickly began to ascend. Streamflow peaked at Node A6 on approximately May 1, 2007 at a rate of 509.8 GPM (1.14 CFS). Subsequent measurements display diminishing flows on the downward limb of the hydrograph. Weekly measurements ceased on July 3, 2007 and continuous pressure transducer measurements commenced on July 21st, 2007. The continuous measurements during the month of August were approximately 21 GPM (0.05 CFS) by late August. These values indicate that the stream had returned to baseflow conditions. The 2007 runoff hydrograph measured at the Upper Flume Site is illustrated in Figure 5.13.

5.3.2.2 Node A3/Lower Flume Monitoring Data

The location of the Lower Flume Monitoring Site corresponds with Node A3 (see Figure 5.5). The first measurement for this site, collected on March 22, 2007, recorded streamflow at 316.8 GPM (0.71 CFS). This value indicates that snowmelt and runoff at the Lower Site had already begun. Runoff at the Lower Site began before runoff at the Upper Site. This is because the Lower Site is approximately 400 feet below the Upper Site and temperatures are slightly warmer, which allows runoff to initiate at an earlier date. The hydrograph ascended through March and April until its peak on May 1, 2007. Discharge on that date was measured at 830.2 GPM (1.85 CFS). After the peak, streamflows steadily decreased until the last weekly measurement was collected on July 3, 2007. A pressure transducer was installed at the Lower Flume on August 17th, 2007 at which point measurements resumed. The pressure transducer data indicates that stream flow at the Lower Flume site returned to base flow levels of approximately 21 GPM (0.05 CFS). Figure 5.14 illustrates the 2007 runoff hydrograph at Node A3.

5.3.2.3 Washington Gulch at Node F2 Monitoring Data

The final streamflow monitoring site corresponds with Node F2 and is located on the northwest side of Snodgrass Mountain. As discussed above, monitoring at this site did not commence until May 1, 2007. Thus, early spring baseflow and the rising limb of the hydrograph were not measured. However, since the peak at the other two sites occurred on May 1, 2007, an approximate peak flow was recorded. The peak streamflow measured by HydroGeo was 4655.7 GPM (10.37 CFS). Subsequent streamflow measurements track the denouement of the hydrograph. A final measurement was collected at Node F2 on July 10, 2007. The stream was dry on this date. The available 2007 discharge data for Node F2 is illustrated in Figure 5.15.

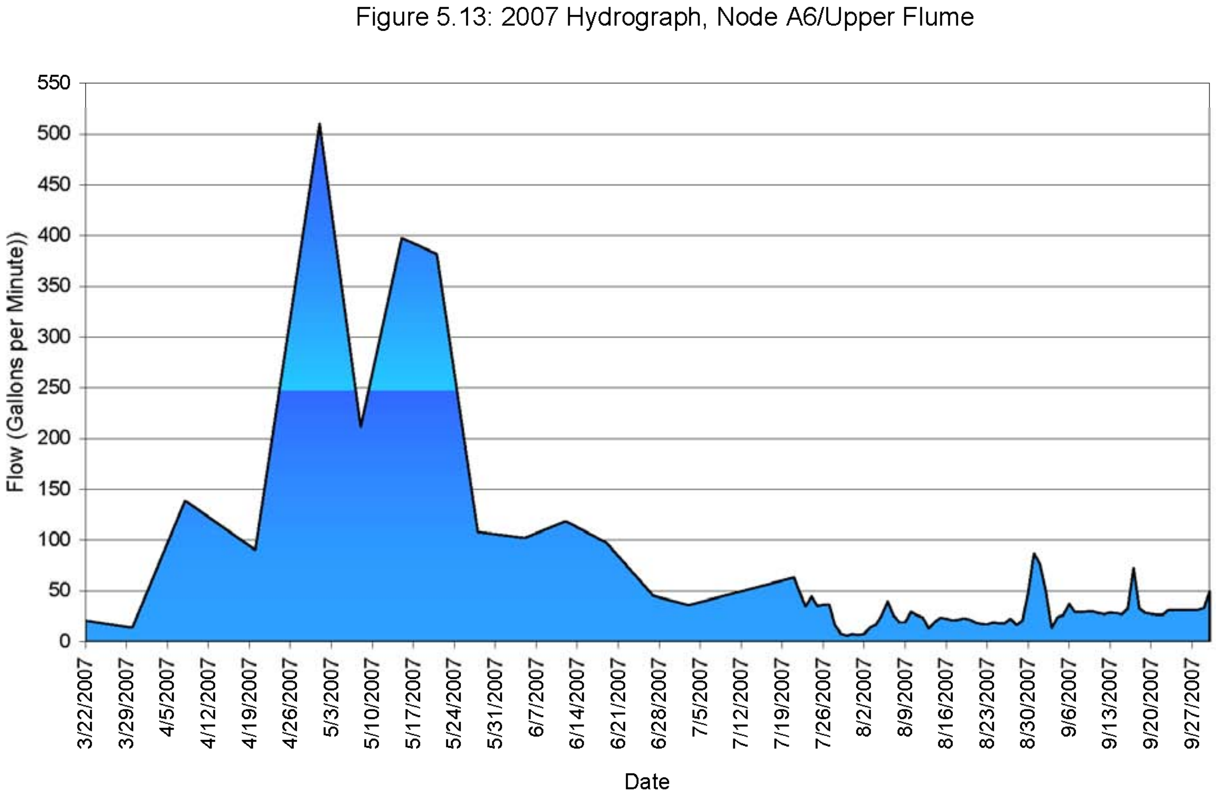


Fig. 5.13. 2007 hydrograph of the axial stream at Stream Node A6 (upper flume).

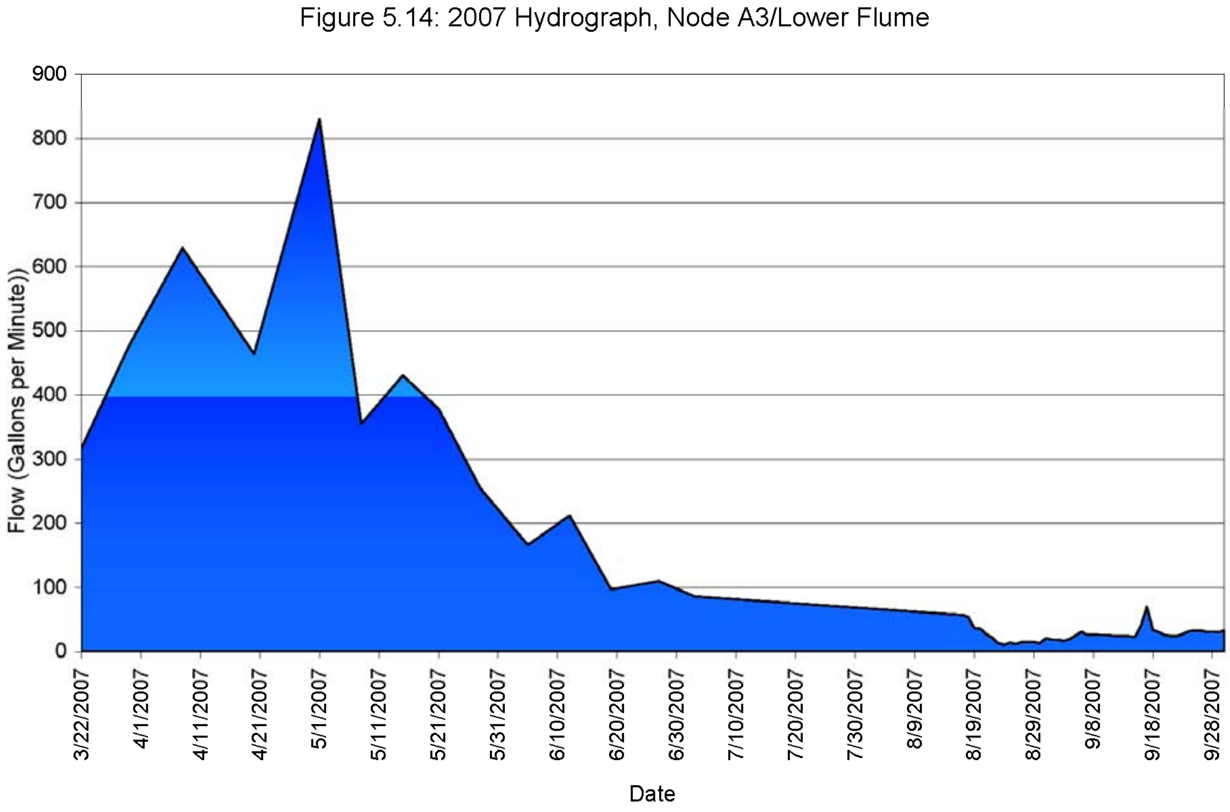


Fig. 5.14. 2007 hydrograph of the axial stream at Stream Node A3 (lower flume).

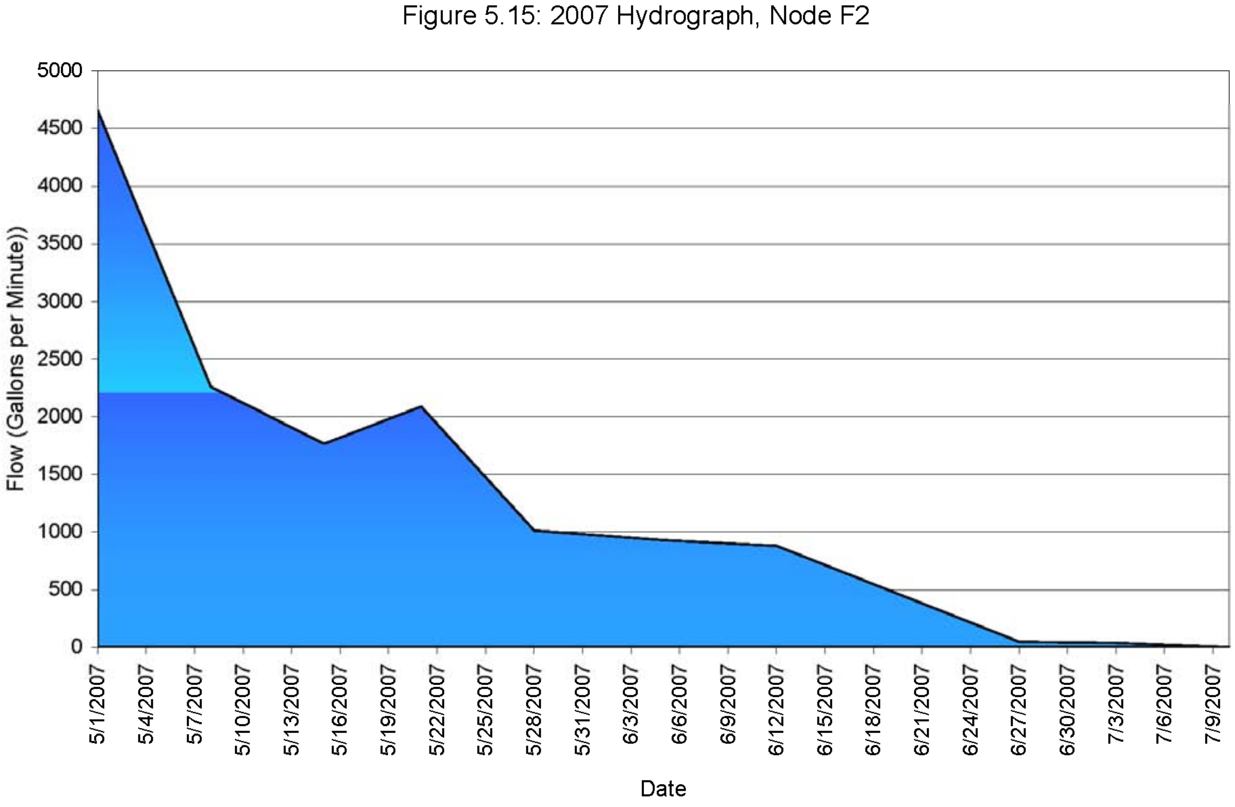


Fig. 5.15. 2007 hydrograph of the tributary to Washington Gulch, Stream Node F2.

5.3.2.4 WRENSS Validation Results

Based on data availability, the WRENSS model was verified by comparing data collected during 2007 at Nodes A3 and A6 with a 2007 model run. The 2007 Validation Scenario was developed using the modeling methodologies discussed in Section 5.2. The development assumptions used in the 2007 Validation Scenario correspond to the Existing Scenario. That is, the scenario does not include any trail clearing or snowmaking application. The 2007 Validation Scenario required the development of additional precipitation inputs. The methodology for developing this data varied from that disclosed in Section 5.2.2 because NOAA has not published 2007 data for the Crested Butte weather station. As such, the 2007 climate was first characterized based on data available from the SNOTEL data network. This data indicated that, for the period between October 1 and September 1, 2007 was an extremely dry year in the Crested Butte area. Based on this analysis, climatic data from 2002, another extremely dry year, was used as the basis for climatic input in the 2007 Validation Scenario.

The predictions generated by the WRENSS 2007 Validation Scenario were very similar to data collected at Nodes A3 and A6. The results for several key parameters are summarized in Table 5.9.

Table 5.9: Selected Modeled and Measured Results, WRENSS Model Validation

		Scenario	
Node	**Parameter**	**Modeled**	**Measured**
Node A3	Maximum Discharge	2.19	1.85
	Baseflow (CFS/Sq. Mile)	0.14	0.155
Node A6	Maximum Discharge	1.56	1.14
	Baseflow (CFS/Sq. Mile)	0.135	0.13

Generally, the predicted and measured results compare very closely for maximum discharge and baseflow and less closely for total runoff volume. The results suggest that the surface hydrology predictions produced by the WRENSS model are reasonable and reflect actual basin conditions. Further validation; including validation of annual runoff volume, can be made following collection of additional data through the Snodgrass Mountain stream flow monitoring program.

5.4 Methods – Snodgrass Mountain Stream Channel/Stream Stability Survey

Proposed activities, including trail clearing and snowmaking may impact the dynamic equilibrium of the current stream channel network draining

Snodgrass Mountain. In order to identify at-risk stream reaches, RESOURCE reviewed wet year maximum discharge and annual runoff volume predicted by the WRENSS model. Past experience has indicated that analysis should focus on changes in maximum discharge or annual runoff volume larger than 15%. Generally, these analyses have shown that changes of less than 15% are unlikely to be detrimental to stream morphology. Stream nodes with a predicted increase, under either metric, of more than 15% were selected for further evaluation.

At each selected node RESOURCE surveyed a cross section in a typical riffle reach. The surveyed data was then evaluated to determine key cross section characteristics including channel entrenchment, bank height, and width-depth ratios. RESOURCE also surveyed a longitudinal profile to determine channel slope; these slopes were verified with an inclinometer. Following the survey a pebble count was performed along the cross-section. The Wolman Pebble Count methodology was used to determine the size of the channel's bed and bank material, which is a very important indicator of channel stability. Finally, based on this quantitative data, RESOURCE was able to determine a Rosgen stream classification at each surveyed node.

RESOURCE also developed a qualitative assessment of riparian vegetation and stream bank stability within each survey reach. Existing stream channel stability was classified by inputting the quantitative and qualitative data collected into the Pfankuch Stream Stability Rating, as Modified by Rosgen. Vegetation was surveyed based on vegetation type, vegetative density, and root mass. High quality riparian vegetation protects stream banks from erosion by providing a dense root mass which holds soil together. Existing stream bank stability was evaluated by looking for indicators of bank instability such as sloughing, cracking, rills, and undercutting. The stream stability survey methodology for Snodgrass Mountain was developed based on Dave Rosgen's Watershed Assessment of River Stability and Sediment Supply (WARSSS).[5]

5.5 Results – Snodgrass Mountain Stream Channel Survey/Stream Stability Survey

Based upon review of the modeled results, RESOURCE stream nodes identified several nodes with predicted increases in maximum discharge and/or annual runoff volume of more than 15%. The identified nodes were in Watersheds A, E, and F; none of the nodes in Watershed C had a predicted increase of more than 15%. Only one location in Watershed F, Node F2, satisfied the 15% criteria. Additionally, there was only one node, Node A7, in Watershed A that met the 15% increase threshold. Despite this, Node A3 was also selected for further analysis. Maximum discharge and runoff volume are predicted to increase at this node by 110.8% and 107.9%, respectively. A second site was selected because Watershed A plays a pivotal role in the

---

[5] Rosgen, Dave. 2006. Watershed Assessment of River Stability and Sediment Supply (WARSS). Wildlands Hydrology. Fort Collins, CO.

development proposal. Watershed A is critical to the development proposal because it drains a significant portion of Snodgrass Mountain, it contains several of the relatively young landslides, and it is a key conduit for skier traffic traveling between Snodgrass Mountain and Mount Crested Butte.

As noted in Section 5.3.1.3, Watershed E includes a number of individual watersheds that are all directly tributary to the East River. Generally, the proposed development does not impact the microwatersheds in Watershed E. However, proposed trail numbers 13 – 18 are located in part of Watershed E. The microwatersheds influenced by these proposed trails are located on Stream E and summarized at Nodes E1, E2, and E3 (See Figure 5.9). The WRENSS model predicts that maximum discharge will increase by more than 15% at these nodes. The majority of the proposed trail development is located above Node E3 (See Figure 5.9). As such, the largest changes in maximum discharge and runoff volume predicted by the model are realized at Node E3. The predicted changes attenuate moving downstream to Nodes E2 and E1 as the percent of watershed area occupied by the proposed development diminishes.

Node E2 was selected to assess how stream stability at Nodes E1 – E3 may be affected by predicted changes in surface hydrology. Node E2 was chosen for detailed analysis for several reasons. First, there is a distinct break in the Stream E's slope immediately below Node E2. The slope above the break is very high (~14%) while the slope below the break is moderate (~4%). The moderate gradient portion of Stream E below Node E2 has a broad floodplain populated by extensive wetland vegetation, including willows. Moreover, there are several beaver ponds through this reach. Field observations indicated that this reach was extremely stable and capable of accommodating increased peak flows. Second, both Node E3 and E2 are located in the high gradient, upper portion of Stream E. As such, it was assumed that they would have similar characteristics. Finally, data at Node E2 reflects all of the proposed trail development whereas some of the proposed development occurs downstream of Node E3.

Ultimately, the nodes selected for stream channel survey were Nodes A3, A7, E2, and F2. The survey data provided quantitative (D50 particle size, width-depth ratio, etc.) and qualitative (vegetation type and density, existing bank stability, etc.) metrics for assessing stream stability. The results of the survey are discussed in detail below.

5.5.1 Node A7 Stream Channel Survey Results

Node A7 is located in a forested area with an abundance of willows and fir trees. This channel has low sinuosity and was classified as a Rosgen A5 stream type. There are significant amounts of downfall along the banks of the stream, and the fir and willow communities provide significant bank protection. There is some minor stream bank instability resulting from minor undercutting; however, this comprises of less than five percent of the banks within the survey reach. This instability occurs in segments where there is insufficient vegetation to stabilize the fine sized sediment in the channel. The Modified Pfankuch Stability Rating for this reach was determined to be Stable.

5.5.2 Node A3 Stream Channel Survey Results

The survey results for Node A3 were very different from A7. While it was still determined to be an A stream type, the sediment was much finer, resulting in classification as a Rosgen A6 stream type. The vegetation communities differed on each side of the channel, with the left bank densely covered in willows and alders. This vegetation protected much of the left bank from erosion. The right bank's riparian vegetation consists mostly of annual grasses that offer only a shallow root mass which makes the bank more susceptible to erosion. There were large bank failures found on the outside of meander bends on the right bank. Because of the fine particles, annual vegetation, and observed instabilities, this channel ranked Fair according to the Modified Pfankuch Rating procedure.

5.5.3 Node E2 Stream Channel Survey Results

The channel material at Node E2 contained coarse gravels, cobbles, and boulders and had the steepest slope of the four surveyed reaches. Because this channel was relatively steep and had large substrate its Rosgen classification was A4. This channel's vegetation consists of large stands of willows surrounded by annual grasses. The banks along this reach are low angled and fairly well protected by grasses, willows, and cobbles. There are some minor bank failures in places where the bank's slope is steeper. These failures are primarily sloughs resulting from undercutting; however, failures were very limited in this reach. The Modified Pfankuch Stability Rating procedure classified this reach as Stable.

5.5.4 Node F2 Stream Channel Survey Results

Node F2 has a very low gradient. The Rosgen stream classification is E6 because the channel material is primarily very fine sediment. The area around Node F2 was a marshy wetland complex with many willows and aquatic grasses. Visual observation suggests that streamflow regularly overtops bankfull and inundates adjacent wetland complexes. There is some evidence of bank instability but this appears to be a direct result of cattle grazing along the channel. The Modified Pfankuch Rating for this channel was Stable because of the low slope and the presence of dense annual grasses and willows along the channel.

5.6 Methods – Snodgrass Mountain Hydraulic Modeling

Once existing stream channel stability was identified, RESOURCE projected impacts to the stream channels due to the proposed development using hydraulic modeling techniques. RESOURCE generated inputs for the hydraulic model by pairing predictions from the WRENSS model with survey data collected at Nodes A3, A7, E2, and F2. This yielded critical information, including a cross sectional profile, channel slope, and discharge (Note: the peak discharge predicted in the WRENSS model was used) that was input into a two dimensional hydraulic modeling program called FlowMaster. Based on the inputs noted above, FlowMaster performs open channel hydraulic calculations and outputs various parameters including water surface elevation, wetted perimeter, flow velocity, etc. By comparing existing hydraulic variables to projected post-development conditions, RESOURCE was able to identify probable channel impacts due to trail clearing and snowmaking.

5.7 Results – Snodgrass Mountain Hydraulic Modeling

FlowMaster modeling software was used to predict hydraulic changes at channel cross sections surveyed at Nodes A3, A7, E2, and F2 during wet year maximum predicted discharge. Each cross section was evaluated under the Existing Scenario and the Proposed with Snowmaking Scenarios. Of the four selected nodes, the maximum change in discharge is predicted to occur during a wet year at Node F2. Discharge at Node F2 is predicted to increase by about 2.16 CFS between the Existing and Proposed with Snowmaking Scenarios (15.62 CFS – 13.46 CFS = 2.16 CFS). This represents a 16% increase in peak discharge under the Proposed with Snowmaking Scenario. The corresponding increase in water surface elevation is estimated to be 0.03 feet (i.e. 0.36 inches). The predicted changes in discharge at the other surveyed nodes are all less than 1 CFS. Additionally, the predicted increase in water surface elevation associated with increased discharge at those nodes is less than 0.03 feet. The maximum predicted change in velocity occurs at Node A3. During a wet year velocity during peak discharge is estimated to increase by 0.34 Ft./s from 4.27 Ft./s to 4.61 Ft./s. This is an increase of approximately 8%. The hydraulic changes modeled between the baseline and proposed scenarios are summarized in Table 5.10.

Table 5.10: Selected FlowMaster Hydraulic Modeling Results for Nodes A3, A7, E2, F2, Snodgrass Mountain

Site	Year Type	Condition	Discharge (cfs)	Water Surface Elevation (Ft.)	Wetted Perimeter (Ft.)	Velocity (Ft./s)
Node A3	Average	Existing	3.05	0.23	4.86	5.50
		Proposed + Snowmaking	3.74	0.25	4.91	5.71
		Difference	***0.69***	***0.02***	***0.05***	***0.21***
	Wet	Existing	5.98	0.31	5.06	4.27
		Proposed + Snowmaking	6.62	0.32	5.10	4.61
		Difference	***0.64***	***0.01***	***0.04***	***0.34***
Node A7	Average	Existing	0.27	0.12	2.03	2.42
		Proposed + Snowmaking	0.37	0.13	2.20	2.65
		Difference	***0.10***	***0.01***	***0.17***	***0.23***
	Wet	Existing	0.49	0.15	2.49	2.83
		Proposed + Snowmaking	0.62	0.16	2.55	3.08
		Difference	***0.13***	***0.01***	***0.06***	***0.25***
Node E2	Average	Existing	1.17	0.15	6.31	1.81
		Proposed + Snowmaking	1.58	0.17	7.39	1.91
		Difference	***0.41***	***0.02***	***1.08***	***0.10***
	Wet	Existing	2.18	0.20	7.49	2.16
		Proposed + Snowmaking	2.69	0.22	7.56	2.34
		Difference	***0.51***	***0.02***	***0.07***	***0.18***
Node F2	Average	Existing	5.47	0.88	22.05	1.36
		Proposed + Snowmaking	6.62	0.91	22.79	1.45
		Difference	***1.15***	***0.03***	***0.74***	***0.09***
	Wet	Existing	13.46	1.03	29.58	1.74
		Proposed + Snowmaking	15.62	1.06	30.85	1.81
		Difference	***2.16***	***0.03***	***1.27***	***0.07***

5.8 Conclusions –Predicted Effects of the Proposed Action on Surface Hydrology

5.8.1 Quantitative Effect of Trail Clearing and Snowmaking on Runoff and Stream Stability

The WRENSS modeling effort for Snodgrass Mountain generated extensive, detailed predictions for surface water behavior in individual microwatersheds. In particular, these microwatersheds were evaluated under three different development scenarios (i.e. Existing, Proposed, and Proposed with Snowmaking Scenarios) and three different climatic scenarios (i.e. Dry, Average, and Wet Year Scenarios). Analysis of the model's results focused on the predictions generated for the Wet Year Scenarios. Wet years are of particular interest because the significant amounts of available water generate large amounts of surface flow and hydraulic energy. This may result in phenomena like flooding, saturation of surface soils, stream network extension, etc. These are the physical processes that are most likely to influence stream stability and slope stability, which together constitute the focus of this study.

In order to evaluate the predicted effects of trail clearing and snowmaking on runoff and stream stability, this study focused on stream nodes with a predicted increase of more than 15% in maximum discharge and/or annual runoff volume in a wet year.[6] The selected nodes are discussed in detail in Section 5.5. These nodes were selected because the relatively significant increase in stream flow makes them most susceptible to changes in stream stability. The predicted changes in channel stability at each node, based on the integrated results of the WRENSS model, channel survey, and hydraulic model are discussed below.

5.8.1.1 Watershed A – Predicted Effects of Trail Clearing and Snowmaking

Node A7 is the only node in Watershed A predicted to have greater than a 15% increase in maximum discharge. None of the Watershed A nodes are predicted to have greater than a 15% increase in runoff volume. However, Node A3 was also analyzed in additional detail. This was done to increase available data in Watershed A and is discussed in detail in Section 5.5.

Peak discharge at Node A7 is predicted to increase from 0.49 CFS under the Existing Scenario to 0.62 CFS under the Proposed Scenario. This is an increase of 27.53%. Increases in other selected parameters at Node A7 are displayed in Table 5.11.

Table 5.11: Selected Hydrologic and Hydraulic Parameters Predicted at Node A7

	Scenario		
Parameter	**Existing**	**Proposed With Snowmaking**	**Percent Change**
Discharge (CFS)	0.49	0.62	27.53
Volume (AF)	50.79	56.66	11.55
Water Surface Elevation (Ft.)	0.15	0.16	6.66
Velocity (Ft./s)	2.83	3.08	8.83

Despite the relatively large increases in discharge predicted at Node A7, the predicted hydraulic changes are relatively modest. The stream channel at Node A7 is able to accommodate increased flow with moderate hydraulic change because of its steep gradient and low sinuosity.

A field assessment using the Modified Pfankuch Stability Rating classified the surveyed reach at Node A7 as stable under existing conditions. The stream banks in this reach are extremely stable due to a healthy, varied community of perennial riparian vegetation (e.g. fir trees and willows). It is predicted that this reach will remain stable under the conditions calculated for the Proposed with

---

[6] The 15% change is calculated based on a comparison of wet year modeling results for the Existing and Proposed with Snowmaking Scenarios.

Snowmaking Scenario. The limited changes in channel hydraulics are unlikely to destabilize the stream banks which are protected by dense root mats and large woody debris.

The peak discharge at Node A3 under the Proposed with Snowmaking Scenario is predicted to be 110.84% of the Existing Scenario. This, along with other selected changes at Node A3, shown in Table 5.12.

Table 5.12: Selected Hydrologic and Hydraulic Parameters Predicted at Node A3

	Scenario		
Parameter	**Existing**	**Proposed With Snowmaking**	**Percent Change**
Discharge (CFS)	5.98	6.62	10.84
Volume (AF)	736.45	794.33	7.86
Water Surface Elevation (Ft.)	0.31	0.32	3.23
Velocity (Ft./s)	4.27	4.61	7.96

The predicted change in peak discharge between the Existing and Proposed with Snowmaking Scenarios is calculated to have a limited impact on the hydraulic characteristics at Node A3. The water surface elevation and velocity are predicted to increase by 3.23% and 7.96%, respectively. Changes in channel hydraulics at Node A3 are predicted to be relatively small because of the channel's steep gradient and low sinuosity.

Channel stability at Node A3 was classified as fair, or moderately unstable, based on a field review using the Modified Pfankuch Stability Rating. The channel and bank material measured at the study reach for Node A3 was extremely fine and generally characterized as silt. Additionally, the left and right stream banks had significantly different riparian communities. The left bank was populated by a mix of willows, alders and annual grasses and was generally in stable condition. Alternatively, the right bank was populated exclusively by annual grasses. The root mats associated with these grasses appear to be unable to provide stability for the fine stream bank soils. As such, there are several zones of bank failure on the right bank in the study reach. It is possible that predicted increases in maximum discharge and runoff volume may exacerbate existing stream bank instabilities or cause new instabilities without mitigation.

5.8.1.2 Watershed C – Predicted Effects of Trail Clearing and Snowmaking

The proposed development in Watershed C is limited. Trails and snowmaking application will only affect 3.6% of the watershed area. As such, predicted changes in maximum discharge and runoff volume at Nodes C1 – C3 were approximately 1 – 2%. None of these nodes were selected for further analysis.

5.8.1.3 Watershed E – Predicted Effects of Trail Clearing and Snowmaking

Node E2 was selected to assess how stream stability at Nodes E1 – E3 may be affected by predicted changes in surface hydrology. The WRENSS model predicts that peak discharge at Node E2 will increase from 2.18 CFS under the Existing Scenario to 2.69 CFS under the Proposed with Snowmaking Scenario. This is an increase of 23.16%. Increases in other selected parameters predicted at Node E2 are displayed in Table 5.13.

Table 5.13: Selected Hydrologic and Hydraulic Parameters Predicted at Node E2

	Scenario		
Parameter	**Existing**	**Proposed With Snowmaking**	**Percent Change**
Discharge (CFS)	2.18	2.69	23.16
Volume (AF)	254.13	281.53	10.78
Water Surface Elevation (Ft.)	0.20	0.22	10.00
Velocity (Ft./s)	2.16	2.34	8.33

As shown in Table 5.13, the hydraulic changes predicted at Node E2 are relatively small. Water surface elevation at peak flow is predicted to increase by 0.02 ft. (0.24 inches) and peak flow velocities are expected to increase by 0.34 ft./s. The hydraulic changes at Node E2 are relatively small because the channel's steep grade and low sinuosity are able to convey increased flow very efficiently.

The stream reach surveyed at Node E2 was characterized as stable using the Modified Pfankuch Stability Rating procedure. The stream channel shape in this reach is generally trapezoidal. Riparian vegetation in the study reach includes dense clusters of willows and annual grasses. The riparian vegetation is complemented by some cobble sized bank material. The combination of channel shape, robust riparian vegetation and cobbles results in stable bank conditions. It is unlikely that the predicted hydraulic and streamflow changes will result in increased streambank erosion in this reach.

5.8.1.4 Watershed F – Predicted Effects of Trail Clearing and Snowmaking

Several ski trails, some with artificial snowmaking, are proposed in Watershed F. The only node in Watershed F with a significant change predicted in maximum discharge or annual runoff is Node F2. Maximum discharge at this node is predicted to increase by 16.02% from 13.46 CFS under existing conditions to 15.62 CFS under the Proposed with Snowmaking Scenario. Increases in other selected parameters at Node F2 are shown in Table 5.14.

Table 5.14: Selected Hydrologic and Hydraulic Parameters Predicted at Node F2

	Scenario		
Parameter	**Existing**	**Proposed With Snowmaking**	**Percent Change**
Discharge (CFS)	13.46	15.62	16.02
Volume (AF)	1525.96	1599.56	4.82
Water Surface Elevation (Ft.)	1.03	1.06	2.91
Velocity (Ft./s)	1.74	1.81	4.02

The channel slope in the Node F2 survey reach is very low. Additionally, the defined portion of the channel is relatively small. As such, it is anticipated that spring peak flows regularly overtop the streambanks in this reach and inundate the adjacent floodplain. Since the predicted increase in maximum discharge is spread over a relatively large area, the predicted increases in water surface elevation and peak flow velocity are very small.

The floodplain inundated by annual peak flows can generally be characterized as a marshy, wetlands complex. The floodplain vegetation is dominated by dense communities of willows and wetland grasses. These riparian and floodplain vegetation communities appear to provide significant stability to the fine grained channel and bank materials surveyed in this reach. Zones of instability observed in the survey reach appear to be the direct result of cattle grazing. Despite the segments of grazing induced instability, this reach was given a rating of stable based on the Modified Pfankuch Stability Rating methodology. It is expected that the streamflow modifications predicted by the WRENSS model will not result in increased streambank instability in this reach. The stream adjacent wetland complexes surveyed in this reach appear to be capable of accommodating annual inundation of the floodplain while remaining stable. It is recommended that the Forest Service and CBMR work with grazing lease holders to implement Best Management Practices that will reduce the impacts of grazing activities.

5.8.2 Mitigation of Any Predicted Adverse Impacts of Runoff

Generally, the stream channels draining Snodgrass Mountain are expected to maintain their current, relatively stable condition after implementation of the proposed development. The one exception to this conclusion is lower Stream A. The stream channel survey completed at Node A3 identified several existing zones of bank instability. The primary cause of the instability is that there is insufficient vegetative cover to stabilize the silty soils that comprise the bank. It is probable that the increased peak flow and runoff duration predicted by the WRENSS model under the Proposed and Proposed with Snowmaking Scenarios may exacerbate existing instability in the Node A3 survey reach.

The predicted impacts to stream channel stability near Node A3 may be managed with the implementation of mitigation measures. First, it is necessary to quantify the extent of the predicted impacts. Existing survey data focused on a 100 foot stream reach immediately upstream of Node A3. This data would be expanded by surveying stream channel stability upstream and downstream of Node A3.

Appropriate mitigation measures for lower Stream A will be selected based on the length of channel that is characterized as susceptible to increased bank erosion. Generally, the mitigation measures will include integrated streambank protection techniques, flow management techniques, or a combination of the two. Integrated streambank protection measures would use a combination of flow-redirection techniques (i.e. groins, barbs, etc.), structural techniques (i.e. riprap, log toes, etc.) and/or biotechnical techniques (i.e. woody plantings, soil reinforcement, etc.) to enhance bank stability. These applications would be designed to create streambanks that would remain stable under the conditions predicted for the Proposed Scenarios. Alternatively, flow management techniques would attempt to preclude development of stream bank instability by managing increased peak flow and runoff volume. This may be accomplished by construction of a detention pond that can capture peak discharge. The captured discharge would be released at a measured rate at a later time, thereby reducing the annual maximum discharge. Or, a diversion structure may be built to divert peak flows from lower Stream A. These flows would be delivered to a stable downstream reach via a pipeline. These measures have been successfully implemented at Snowmass Ski Resort and Copper Mountain Ski Resort.