THESIS

DISTRIBUTED SNOWMELT MODELING WITH GIS AND CASC2D

AT CALIFORNIA GULCH, COLORADO

Submitted by

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY **DO HYUK KANG** ENTITLED **DISTRIBUTED SNOWMELT MODELING WITH GIS AND CASC2D AT CALIFORNIA GULCH, COLORADO** BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

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ABSTRACT

DISTRIBUTED SNOWMELT MODELING WITH GIS AND CASC2D AT CALIFORNIA GULCH, COLORADO

Modeling snow hydrology in mountain streams such as California Gulch remains a problematic area of many hydrological models. Topographical effects such as altitude, aspect, slope, and landuse make snowmelt modeling more complicated. To solve these problems, this study develops a snowmelt module based on the Temperature Index method considers topographical effects and adds it into CASC2D model. The model considers snowmelt rates as equivalent rainfall. Taking topographical factors into consideration, the snowmelt module adjusts air temperature according to altitude, aspect, slope, and landuse. Using ArcGIS, the calculated aspect ratios and slopes are utilized in order to change air temperature. Additionally, due to vegetation factors against to solar radiation, the air temperature in some landuse areas such as forested regions must be adjusted. The results of CASC2D show consistency between observed discharges and simulated ones at various hydro stations in California Gulch, Colorado. The peak dates from the 13th to 16th of May are chosen to compare hydrographs. Furthermore, the movie maps of SWE, snowmelt rate, and flow depth, which are provided by ArcGIS, show considerable difference among the various slope, aspect, landuse, and altitude. In order to illustrate the difference in topographical effects on snowmelt schemes, two days in May (the 3rd and 23rd) are selected. While snow was still present in the upper California Gulch at the end of May, all of the snow had melted in downtown Leadville and lower California Gulch by mid-May. In addition, the sensitivity tests to the effects of altitude, landuse, and aspects are included to assess the uncertainties of their effects. The snowmelt modeling from Temperature Index with topographical considerations can be more improved with physically based melt equations and more atmospheric data assimilations

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LIST OF SYMBOLS

b – IDW exponent
c_{pa} - specific heat of air [J kg^{-1}]
D - sum of weighted distance
d_g – distance between samples [m]
D_h – momentum transfer coefficient [m/s]
$DULL$ – dullness factor unitless
E – evaporation rate [kg m^{-2} s^{-1}]
e_a – vapor pressure [mb]
E_o – eccentricity
e_{sat} – saturation vapor pressure [mb]
f_F - vegetative-cover factor
f_{sl} - slope factor
G – number of gages
i_{sc} – solar constant [W/m^2]
J – Julian day (e.g. Jan 1 is 1 and Dec 31 is 365.)
kv – Von Karmann constant
L_i – latent heat of fusion [J kg^{-1}]
L_w : latent heat of vaporization [J kg^{-1}]
M – melt rate [L/T]
M – melt rate [m s^{-1} ° C^{-1}]
p_g - value of sampled point
$\hat{p}_o$ - IDW value at the unknown point
Q – sum of energy flux [W/m^2]
Q_E – latent heat flux [W/m^2]
Q_G – ground heat flux [W/m^2]
Q_H – sensible heat flux [W/m^2]
Q_{kin} – incoming shortwave solar radiation [W/m^2]
Q_{long} – longwave solar radiation [W/m^2]
Q_{short} – shortwave solar radiation [W/m^2]
RH – relative humidity [%]
SM – snowmelt rate [m/s]
s_o – snow depth [m]
t_{sn} - time(hour) before(negative) or after (positive) solar noon

T^+ - air temperature above 0 ° C
T_a – air temperature [° C]
T_m – critical air temperature [° C]
T_z – air temperature adjusted with the lapse rate [° C]
u – wind velocity [m/s]
z' – height of anemometer [m]
z_o – roughness length [m]
ρ_{air} - air density [kgm^{-3}]
α - albedo
ω - angular velocity [radian/time]
Γ - day angle
ε - emissivity of snowpack
Λ - latitude
Δ - latitude where the sun is directly overhead
Δw - snowmelt [L]
σ - Stefan-Boltzman Constant [Wm^{-2} $°C^{-1}$]
Δt - time step depending on scales such as second, minute, or hour

LIST OF ACRONYMS

AGNPS – Agricultural Non-Point Source pollution model
APL – A Programming Language
CG – California Gulch
DDF – Degree Day Factor
DEM – Digital Elevation Model
EPA – Environmental Protection Agency
ESRI – Environmental Systems Research Institute
GRASS – Geographic Resources Analysis Support System
GWLR – Geographically Weighted Logistic Regression
HBV – Hydrological Bureau Waterbalance Model
HSPF – Hydrological Simulation Program - FORTRAN
IDW – Inverse Distance Weighting
KLXV – Leadville Airport Weather Station
LULC – Land Use and Land Cover
NRCS – Natural Resources Conservation Service
NWS – National Weather Service
OG – Oregon Gulch
OU – Operable Unit
SD – Star Ditch (tributary of Stray Horse Gulch)
SHE – System Hydrologic European
SNOTEL – Snowpack Telemetry
SWAT – Soil and water Assessment Tool
SWE – Snow Water Equivalence

CHAPTER 1:
INTRODUCTION

In mountainous and high altitude streams, snowmelt is a widely recognized source of discharge. A quantitative analysis of snowmelt to a stream from a watershed is usually difficult to perform because of the complexity of the physical processes involved with snowmelt and runoff generations. The snowmelt can be simulated using Degree-Days, Temperature Index, or Energy Balance method. This research focuses on Temperature Index Approach with the study applications to California Gulch, Colorado.

The main concepts of this research are to show and quantify the daily discharge fluctuations in watershed during snowmelt season. In watershed scales, the diurnal change of runoff based on air temperature occurs. Therefore, the basic approach of this study is to simulate snowmelt processes in mountainous streams using the distributed hydrological model, CASC2D. CASC2D allows the snowmelt procedure into distributed surface models because it is process oriented model and calculates the state variables based on cell at each time step with the consideration of snowmelt runoff. Snow melting occurs when the snow temperature is above 0 degree Celsius in Temperature Index method. Even though the Energy Balance Method is able to describe the most energy flux of snowmelt, it needs more concerns to collect and calculate the energy flux terms. It is why this research starts with the simple Temperature Index Approach.

But it is evenly hard to calculate the snow temperature directly. Additionally the change of snow temperature varies with elevation, slope, and terrain aspect especially in mountain areas. Therefore, the basic assumptions such as the critical air temperature to snowmelt, and terrain effects on air temperature to be met by snow melting procedures are necessary to analyze the snow melt procedures in mountainous watershed.

Julien and his students developed CASC2D in 1995. (Julien et al. 1995). Since then, CASC2D-SED was upgraded from CASC2D for sediment transport simulation (Johnson et al. 2000). Currently, a newer version of the physically based model CASC2D is developed including chemical transport as well as hydrology and sediment transport. In California Gulch case study, this research uses CASC2D for hydrology in simulating snowmelt. With the measured runoff data, the comparison with simulated ones is performed for the watershed scale snowmelt modeling.

For this case study of snow melting in California Gulch, the simulation period is chosen from 00:00 AM on the April 30th to 12:00 PM on the May 28th, 2003. Based on the SWE sampling dates from SourceWater data, above period is selected for the snow melting time scale. Within simulation period, the model uses the temperature index approach. The snowmelt module is added into the current CASC2D. For this method, the temperature, data are obtained from the meteorological station in Leadville airport. Holding other physical properties constant, this case study focuses on the temperature and related constants such as melting rate, and critical temperature to melt snow.

The examination of CASC2D running from the simulated snowmelt runoff from snowmelt module is performed by comparison with the measured runoff data from EPA the water stations during the simulation time. Discharge data comes from CG1 (upper gulch), CG4 (middle gulch), SD1, OG1 (tributaries), and CG6 (outlet). After comparing each simulated hydrograph with the measured one, the critical temperature indices to melt snow become the best fitted values to best represent hydrographs at most hydro stations. The duration of the hydrographs comparisons is from May 13 to May 16 for three days.

The objective of this thesis is to show possible extension of the model CASC2D for snowmelt processes and help for the research of the mountainous stream hydrology. The snowmelt sources for runoff in mountain streams are the main concepts for this study and can provide the future hydrological analyses in mountainous watersheds with respect to snowmelt runoff.

Toward this end, this research focuses on the four areas: 1) conceptualize snowmelt schemes considering altitude, slope, aspect, and landuse; 2) develop snowmelt module within CASC2D; 3) visualize the snowmelt processes with ArcGIS Movie Maps ('Movie Map' is used for mpeg files which ArcGIS manipulates based on GRID files) and 4) compare simulated hydrograph with measured one at the various hydro stations including outlet. Spatial Interpolations of SWE are conducted in Arcmap Inverse Distance Weight (IDW) procedure with the sampled SWE data from SourceWater by EPA in 2003 in California Gulch. Prior to the IDW procedure, the Jacknife statistical way is chosen to determine the most appropriate exponent value for IDW spatial interpolation. With the adjusted exponent value, the interpolation is performed with the sample time scale, from March 12th to May 28th, 2003. Based on the mean SWE from IDW, landuse factors and elevation are considered in order to calculate initial SWE for CASC2D. For example, in urban areas, the snow factor is lower than the vegetated or forested areas. With the initial data of SWE, CASC2D runs to simulate the snowmelt processes in order to represent Movie Maps of SWE, snowmelt rate, and flow depth and to compare simulated hydrographs with observed ones.

This thesis consists of six chapters. Chapter 1 is introduction. Chapter 2 reviews literature on snow hydrology, SWE analyses, and the IDW method. It also provides an overview of the physical characteristics of California Gulch such as site chronology, past landuse and climate. Chapter 3 provides a site description of California Gulch, explains the snowmelt method with respect to altitude, aspects and landuse types, and illustrates SWE distribution. Chapter 3 also represents snowmelt schemes with the considerations of altitude, slope, aspect, and landuse. Chapter 4 describes two sections of CASC2D set up such as overland and channel. The main properties of overland include Digital Elevation Model (DEM), soil, and landuse classification. The channel properties are geometry, roughness characteristics and link/node numbers. It also shows the numerical integration of state variables (SWE, flow depth) in CASC2D. Chapter 5 provides the ArcGIS movie maps of SWE, snowmelt rate, and flow depth, the comparisons of hydrographs, and the sensitivity tests to the effects of air temperature, landuse, and aspect on snowmelt rate. Chapter 6 contains a summary of results and conclusion.

CHAPTER 2:
LITERATURE REVIEW

2.1. Introduction

The Leadville Mining District, located about 60 miles southwest of Denver, Colorado, has been greatly affected by water and has struggled to keep its mines dewatered. California Gulch is the river across Leadville, and is a tributary of the Arkansas River. The elevation of Leadville is about 3094 meters (EPA 2001). The climate of Leadville is semi-arid continental. The runoff from snowmelt can be considered significant along the California Gulch (Gertson 2004, snow samples of SourceWater Consulting for EPA Report). There are three basic snowmelt approaches such as Degree-Days, Temperature Index, and Energy Balance methods. Theses three methods are reviewed here and Temperature Index method is chosen for this study. Based on SWE distribution in California Gulch and adjacent snow monitoring data, Inverse Distance Weighting method is used to interpolate SWE over the watershed. Additionally, landuse data is applied to add the factor in SWE value at each cell. Finally, CASC2D history is reviewed since the late 1980's. To assess the snowmelt concepts, SWE analysis, and application model to California Gulch, a literature review is performed.

2.2. Snow Hydrology

The studies of snow hydrology has evolved over the past 35 years, starting with the report *Snow Hydrology* (U.S. Army Corps of Engineers, 1956) and now described in most introductory hydrology texts (Linsley et al. 1975). The physical processes within a snowpack and involved in snowmelt are highly complex, involving mass and energy balances as well as heat and mass transport by conduction, vapor diffusion and meltwater drainage. (Tarboton and Luce, 1996). There is also an issue of ice layers which impede the downward propagation of infiltrating meltwater resulting in concentrated finger flow and sometimes lateral flow (Colbeck 1978;1991).

Figure 2-1 illustrates the energy exchages in snowmelt and snowpack ablation with respect to snowpack and surrounding atmospheric conditions such as air temperature, vapor pressure, and relative humidity (Tarboton and Luce, 1996). Figure 2-1 indicates that solar radiation fluxes are usually larger than sensible and latent heat fluxes which are in turn larger than fluxes to the ground (Male and Gray 1981). Anderson (1968) reports that 80% of solar radiation is absorbed in the top 5-15 cm of a snow pack, dependent on density. Additionally, the vegetation, forest cover, can affect the distribution of snow (McKay and Gray 1981; Troendle and Leaf 1981; Gary and Troendle 1982; Toews and Guns 1988). The various Q terms such as solar radiation, latent, sensible heat transfer, ground heat transfer, and heat transfer due to rainfall or snowfall will be explained with mathematical and physical definition in a later chapter.

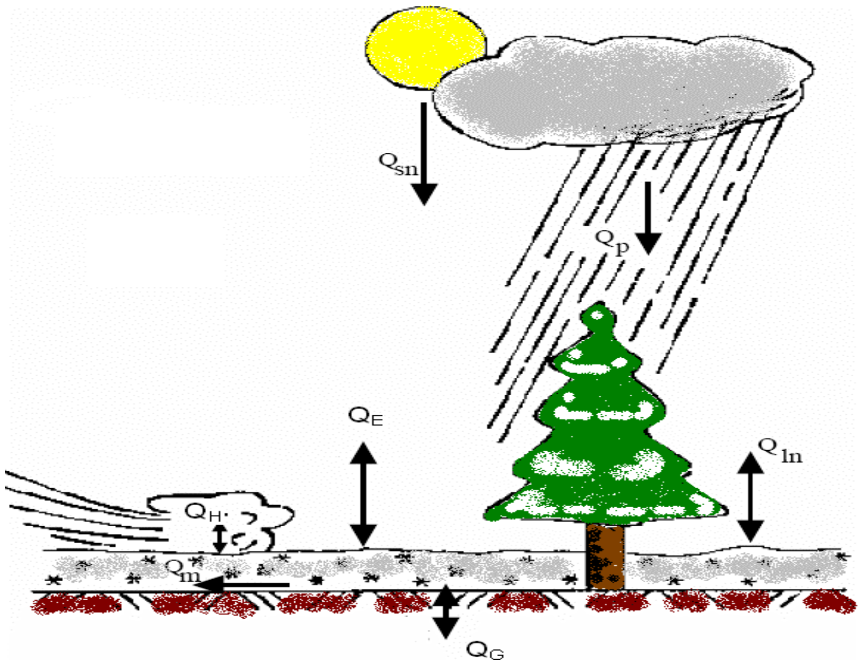

Figure 2-1 Illustrations of snow hydrological processes (Revised from Utah Energy Balance model Manual)

Snowmelt processes in Figure 2-1 is complex and operated on the snowmelt methods. Various approaches to snowmelt exist based on available data, and site characteristics. Degree-Days, Temperature Index, and Energy Balance methods are presented in the following chapters.

2.2.1. Degree Days Method

Degree-day methods are based on an assumed relationship between ablation and air temperature usually expressed in the form of positive temperature sums. The most basic formulation relates the amount of ice or snow melt, *M* (mm), during a period of n time intervals, Δt (d), to the sum of positive air temperatures of each time interval, T^{+} (°C), during the same period, the factor of proportionality being the degree-day factor, DDF, expressed in mm d^{-1}°C^{-1}.

$$\sum_{i=1}^{n} M = DDF \sum_{i=1}^{n} T^{+} \Delta t \qquad \textbf{(2-1)}$$

Commonly, daily time interval is used for temperature integration, although any other time interval, such as hourly or monthly can also be used for determining degree-day factors (Hock 2003). Degree-Day factor method can be included in Temperature Index Approach if the time scale can be reduced from day to hour, minutes or seconds.

2.2.2. Temperature Index Approach

Basically, Degree Day method can be classified into Temperature Index Approach because time scale is only a different point. Temperature index models have been the most common approach for melt modeling due to four reasons: (1) wide availability of air temperature data, (2) relatively easy interpolation and forecasting possibilities of air temperature, (3) generally good model performance despite their simplicity and (4) computational simplicity. Most operational runoff models, e.g. HBV-model (Bergstrom 1976), SRM-model (Martinec and Rango 1986), UBC-model (Quick and Pipes 1977), and HYMET-model (Tangborn 1984) use temperature-index methods for melt modeling (Hock 2003). Despite the well-established accuracy of process-based, energy budget snowmelt models (Anderson 1968; Marks and Dozier 1979, Morris 1982, Flerchinger and Saxton 1989, and Bloschl et al. 1991, and Barry 1992), there is a propensity towards using temperature-index or degree-day snowmelt relationships in hydrological models as especially those designed for water resource management purposes; SWAT (Fontaine et al. 2002), AGNPS (Young et al. 1989), and GWLR (Haith and Shoemaker 1987; Schneiderman 1999).

This approach estimates snowmelt, Δw, for a daily or longer time period as a linear function of average air temperature:

$$\Delta w = M \cdot (T_a - T_m), \qquad T_a \geq T_m;$$

$$\Delta w = 0, \qquad T_a < T_m; \qquad \textbf{(2-2)}$$

Where, *M* is called a melt coefficient, or melt factor. During melting, the snow-surface temperature is at or near 0°C, so that energy inputs from longwave radiation and turbulent exchange are approximately linear functions of air temperature, and that there is a general agreement between solar radiation and air temperature.

Many studies have revealed a high correlation between melt and air temperature. Braithwaite and Olsen (1998) found a correlation coefficient of 0.96 between annual ice ablation and positive air temperature sums. Although involving a simplification of snowmelt procedures that are more properly evaluated by the energy balance of the glacier surface, temperature-index models often match the performance of energy balance models on a catchment scale (Cavadias et al. 1986). It is because the melt energy is attributed to the high correlation of temperature with several energy balance components (Ambach 1988; Sato et al. 1983). Richard et al. (2001) concluded that air temperature is principle to determine the snowmelt in Snowmelt Runoff Model (SRM).

Male and Gray (1981) cited a study suggesting that, in the absence of site-specific data, M can be estimated as

$$M = 4.0 \cdot (1 - \alpha) \cdot \exp(-4 \cdot F) \cdot f_{sl} \qquad \textbf{(2-3)}$$

where *M* is in mm day^{-1} °C^{-1}, α is albedo, *F* is the fraction of forest cover, and f_{sl} is the slope factor, the ratio of solar radiation received on the site of interest to that on a horizontal surface. Snow albedo which is the snow reflectance against sun light is changing with snow surface characteristics and snow melt processes. The Hydrological Simulation Program – FORTRAN, HSPF mentioned the albedo of snowpack is varied with the dullness of snow surface (AQUA TERAA, 2001). Following EPA report of HSPF, the albedo or reflectivity of snowpack is a function of the dullness calculating albedo for the winter month is,

$$\alpha = 0.85 - 0.07 \cdot (DULL / 23.0)^{0.5} \qquad \textbf{(2-4)}$$

Where: *DULL* is decreased by one thousand times the snowfall for each interval. Otherwise, when snowfall does not occur, *DULL* is increased by one index unit per hour up to a maximum of 800.

Federer and Lash (1978) determined the melt factor for forests in the eastern United States as

$$M = f_F \cdot (0.7 + 0.0088 \cdot J) \cdot f_{sl}, \qquad J<183 \qquad \textbf{(2-5)}$$

where f_F is a vegetative-cover factor equal to 30.0 for open areas, 17.5 for hardwood forests, and 10.0 for conifer forests, and J is Julian Day (e.g. Jan 1 is 1, and Dec 31 is 365).

There are numerous kinds of melting factors to determine snowmelt processes. But, the melting factors should be determined with respect to the specific sites and watershed. Based on above equations, Leadville airport data were used to determine SWE at the lower gulch.

The value of degree-day factor varies with the melt period because of changes in the snow properties, such as snow density, and melting processes. By measuring temperature and melt water runoff from the snow, it is possible to calculate the degree-day factor at specific location and time (Singh et al. 2000).

The value of degree-day factor is used to change the degree-days to snowmelt in depth of water. The value of degree-day factor varies with the melt period because of changes in the snow properties, such as snow density, and melting processes. By measuring temperature and melt water runoff from the snow, it is possible to calculate the degree-day factor at specific location and time (Singh et al. 2000).

Anderson (1973) summarized the snow accumulation and ablation model and determined 5.40 mm°C^{-1} day^{-1}. Laumann and Reeh (1993) carried out the studies to estimate 4.0 mm°C^{-1} day^{-1} of degree day factor. Schytt (1964) found a broad agreement in degree-day factors for ice except for a high value of 13.8 mm°C^{-1} day^{-1}. Singh and Kumer (1996) determined the degree-day factor for snow by field investigations and reported to be 5.9 and 6.6 mm °C^{-1} day^{-1}.

Based on the fact that melt models generally fall into two categories: energy balance models, attempting to quantify melt as residual in the heat balance equation, ad temperature-index models assuming an empirical relationship between air temperatures and melt rates (Hock, 2003), Table 2-1 summarized reported degree-day factors from glaciers and snow-covered basins including site characteristics from Hock and Singh. Values are derived from different integration periods ranging from a few days (e.g. 3 days; Singh and Kumer, 1996) to several years (e.g. 512 days over a 6 year period; Braithwaite, 1995), limiting direct comparison. Temperature indexes are computed either from direct measurements or from melt obtained by energy balance computations (e.g. Arendt and Sharp, 1999). Even with the same sites, values can be different based on the way they are derived, for instance, how mean daily temperature is computed (Singh et al. 2000) or which temporal average is used (Arnold and MacKay 1964).

2.2.3. Energy and Mass Balance Method

Table 2-1 Degree Day Factors (Hock, 2003)

Site	DDF snow	DDF ice	Latitude	Elev. (m)	Period	Reference
Glaciers						
Alps/NewZealand/America						
Aletschgletscher (Switzerland)	5.3		46°27'N	3366	3 Aug ~ 19 Aug 1973	Lang, 1986
		11.7		2220	2 Aug ~ 27 Aug 1965	Lang, 1986
Morenoglacier (Argentina)		7.1	50°28'S	330	12 Nov 1993 ~ 1 Mar 1994	Takeuchi et al, 1996
John Evans Glacier (Canada)	5.5		79°40'N	260	27 Jun ~ 29 Jun 1996	Arendt and Sharp, 1999
	4.1			820	19 Jun ~ 14 Jul 1996	Arendt and Sharp, 1999
	3.9			820	23 May ~ 1 Jul 1998	Arendt and Sharp, 1999
	3.9			1180	25 Jun ~ 19 Jul 1996	Arendt and Sharp, 1999
	2.7			1180	31 May ~ 19 Jul 1998	Arendt and Sharp, 1999
		7.6		260	4 Jul ~ 16 Jul 1996	Arendt and Sharp, 1999
		8.1		820	15 Jul ~ 19 Jul 1996	Arendt and Sharp, 1999
		5.5		820	2 Jul ~ 19 Jul 1998	Arendt and Sharp, 1999
Scandinavia/Spitzbergen/Iceland						
Alfotbreen (Norway)	4.5[a]	6.0[a]	61°45'N	850-1400	1961 ~ 1990	Laumann and Reeh, 1993
Hellstugubreen (Norway)	3.5[a]	5.5[a]	61°34'N	1450-2200	1961 ~ 1990	Laumann and Reeh, 1993
Nigardsbreen (Norway)	4.0[a]	5.5[a]	61°41'N	300-2000	1961 ~ 1990	Laumann and Reeh, 1993
	4.4[a]	6.4[a]			1964 ~ 1990	Johannesson et al, 1995
Storglacia¨ren (Sweden)	3.2		67°55'N	1550	5 Jul ~ 7 Sep 1993	Hock, 1999
		6		1370	5 Aug ~12 Aug 1993	Hock, 1999
		6.4		1370	19 Jul ~ 27 Aug 1994	Hock, 1999
		5.4		1250	9 Jul ~ 4 Sep 1994	Hock, 1999
Vestfonna (Spitzbergen)		13.8[b]	~80°N	310-410	26 Jun ~ 5 Aug 1958	Schytt, 1964
Satujo¨kull (Iceland)	5.6[a]	7.7[a]	~65°N	800-1800	1987 ~ 1992	Johannesson et al, 1995
Himalaya						
Dokriani Glacier	5.9		31°45'N	4000	4 Jun ~ 6 Jun 1995	Singh and Kumer, 1996
	5.7	7.4		4000	4 days (1997 ~ 1998)	Singh and Kumer, 2000a,b
Glacier AX100	7.3	8.1	27°45'N	4956	Jun ~ Aug 1978[c]	Kayastha et al., 2000a
	8.7	8.8		5072	Jun ~ Aug 1978[d]	Kayastha et al., 2000a
	11.6			5245	1 Jun ~ 31 Aug 1978	Kayastha et al., 2000a
Khumbu Glacier		16.9	28°00'N	5350	21 May ~ 1 Jun 1999	Kayastha et al., 2000a
Rakhiot Glacier		6.6	35°22'N	3350	18 Jul ~ 6 Aug 1986	Kayastha et al., 2000a
Yala Glacier		9.3	28°14'N	5120	1 Jun ~ 31 Jul 1996[e]	Kayastha, 2001
		10.1		5270	1 Jun ~ 31 Jul 1996e	Kayastha, 2001

Site	DDF snow	DDF ice	Latitude	Elev. (m)	Period	Reference
Greenland						
Thule Ramp		12.0[b]	76°25'N	570	Jul-54	Schytt, 1955
		7.0[b]		570	Aug-54	Schytt, 1955
Camp IV-EGIG[f]		18.6	69°40'N	1013	Melt season 1959	Ambach, 1988a
GIMEX[g] Profile		8.7	67°06'N	341	10 Jun ~ 31 Jul 1991	Van del Wal, 1992
		9.2	67°06'N	519	15 Jun ~ 6 Aug 1991	Van del Wal, 1992
		20	67°04'N	1028	15 Jun ~ 6 Aug 1991	Van del Wal, 1992
Qamanarssup sermia	2.8[a]	7.3[a]	64°28'N	370-1410	1979 ~ 1987	Johannesson et al., 1995
		8.2		790	512 days (1980 ~ 86)	Braithwaite, 1995
Nordboglacier		7.5	61°28'N	880	415 days (1979 ~ 83)	Braithwaite, 1995
Kronprins Christian Land		9.8	79°54'N	380	8 Jul ~ 27 Jul 1999	Braithwaite et al., 1998
Hans Tausen Ice Cap		5.9	82°49'N	540	2 Jul ~ 5 Aug 1994	Braithwaite et al., 1998
Non-glaciated sites						
Gooseberry Creek, Utah	2.5		~38°N	2650	23 Apr ~ 9 May 1928	Clyde, 1931
Weissfluhjoch	4.5		46°48'N	2540	Snowmelt season	Zingg, 1951
3 basins in USA	2.7-4.9				Several seasnon	Corps of Engineers, 1956, p. 24
Former European USSR	5.5	7		1800-3700		Kuzmin, 1961, p. 117
12 sites in Finland	2.8-4.9	~60-68°N			1959 ~ 1978	Kuusisto, 1980
a	Best-fit values comparingdegree-day model to measured net balance.					
b	Surface ytpe not give, but probably partially snow.					
c	Averaged over 47 and 45 days for snow and ice, respectively.					
d	Averaged over 11 and 81 days for snow and ice, respectively.					
e	5120 and 5270 m, a.s.a. 5 and 10 % of ablation was snow ablation, respective					
f	Expedition glaciologique international au Gro¨nland.					
g	Greenland Ice Margin Experiment.					

Snowmelt is primarily driven by the energy exchange between air and snow temperature (Tarboton and Luce 1996). Contributions from all the heat fluxes are determined for the snowpack as energy exchange becomes larger. In addition, below mass and energy equations are based on Dingman (2002) and Abbott (1986).

$$Q = Q_* + Q_H + Q_E + Q_G \quad \textbf{(2-6)}$$

Where:

Q_* is net long and short wave solar radiation.

Q_H is the sensible heat flux.

Q_E is the latent heat flux.

Q_G is the ground heat flux.

$Q_* = Q_{long} + Q_{short}$

All units are W/m^2.

The longwave solar radiation, Q_{long} is determined by,

$$Q_{long} = (\varepsilon - 1) \cdot \sigma \cdot T_{air} \quad \textbf{(2-7)}$$

Where: σ is Stefan-Boltzmann constant (5.670 X 10^{-8} Wm^{-2} $°C^{-1}$)

T_{air} is the air temperature (°C)

ε is the emissivity of the snowpack.

Where $\varepsilon = 0.53 + 0.65 e_a^{0.5}$ **(2-8)**

Where e_a is vapor pressure in *mb.*

$$e_a = \frac{RH}{100} \cdot e_{sat} \quad \textbf{(2-9)}$$

Where e_{sat} is saturation vapor pressure in *mb*.

$$e_{sat} = 2.749 \cdot 10^{8\left(\frac{-4278.6}{(T_{air} + 247.79)}\right)} \quad \textbf{(2-10)}$$

The shortwave solar radiation, Q_{short} is obtained by,

$$Q_{short} = Q_{kin}(1-\alpha) \quad \textbf{(2-11)}$$

Where: α is albedo which is the reflectance against sunlight.

Q_{kin} is the incoming shortwave solar radiation and defined as,

$$Q_{kin} = i_{sc} \cdot E_o \cdot (\cos\Delta \cdot \cos\Lambda \cdot \cos(\omega \cdot t_{sn}) + \sin\Delta \cdot \sin\Lambda) \quad \textbf{(2-12)}$$

Where: i_{sc} is the solar constant (1367 Wm^{-2}).

E_0 is eccentricity (relative distance of the earth from the sun)

Where: $E_o = 1{,}000110 + 0.034221\cos\Gamma + 0.001280\sin\Gamma$

$+0.000719\cos 2\Gamma + 0.000077\sin 2\Gamma$, Eccentricity **(2-13)**

Γ is the day angle, defined as,

$\Gamma = \dfrac{2\pi(J-1)}{365}$, where J is Julian Day. **(2-14)**

Δ is declination which is the latitude where the sun is directly overhead.

Where: $\Delta = (180/\pi)\cdot(0.006918 - 0.399912\cos\Gamma + 0.070257\sin\Gamma$

$-0.006758\cos 2\Gamma + 0.000907\sin 2\Gamma + 0.000907\sin 2\Gamma$

$-0.002697\cos 3\Gamma + 0.00148\sin 3\Gamma)$, declination **(2-15)**

Λ is latitude at that point.

ω is the angular velocity of the earth's rotation (15 °/hour).

t_{sn} is the time(hour) before(negative) or after (positive) solar noon.

The sensible heat flux, Q_H , is determined by,

$$Q_H = \rho_{air} \cdot c_{pa} \cdot D_h \cdot T_{air} \quad \textbf{(2-16)}$$

Where: ρ_{air} is the air density, varied with the elevation (kgm^{-3}).

c_{pa} is the specific heat of air (J kg^{-1}).

T_{air} is air temperature in °C.

D_h is, the momentum transfer coefficient from the logarithmic wind velocity.

Where: $$D_h = \frac{k_v^2 \cdot u}{(\log(z' - \frac{s_o}{z_o})^2)} \quad \textbf{(2-17)}$$

Where: k_v is Von Karman constant (about 0.4, unitless).

Where: u is wind velocity (m/s).

z' is the height of anemometer (m).

z_o is roughness length (m).

s_o is snow depth (m).

The latent heat flux, Q_E, can be obtained from,

$$Q_E = (L_w + L_i) \cdot E \quad \textbf{(2-18)}$$

Where: L_w is latent heat of vaporization (typical value is 2260000 J kg^{-1}).

L_i is latent heat of fusion .(J kg^{-1}) (typical value is 334000 J kg^{-1}).

E is the evaporation rate in kg m^{-2} s^{-1}

Where $$E = \rho_{air} \cdot D_h \cdot [1 - \frac{RH}{100}] \quad \textbf{(2-19)}$$

Where: *RH* is relative humidity in *mb*.

The ground heat flux Q_G is assumed to be constant.

2.3. SWE Analysis in California Gulch

2.3.1. SWE Sampled Data in California Gulch

SourceWater Consulting sampled the snow water equivalence and snow depth in 2003 melting season, from 12th of March to 28th of May. The number of sample locations is 10, all of which are located in the upper California Gulch. They collected data such as snow water equivalence and snow depth along snow melting seasonInverse Distance Weighting Method (Arcmap Function)

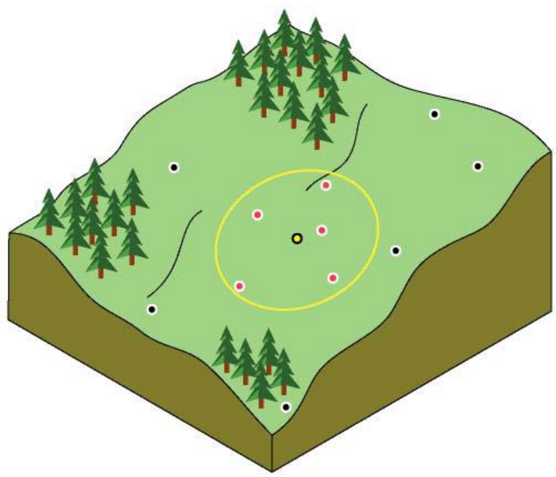

Figure 2-2Inverse Distance Weighting Method (from ESRI Help, 2002)

To determine snow water equivalence (SWE) in the California Gulch, the inverse distance weighting (IDW) method in Arcmap was used. IDW estimates cell values of SWE by averaging the values of sample data points in the vicinity of each cell. The closer a point is to the center of the cell being estimated, the more influence or weight it has in the averaging process. This method assumes that the variable being mapped decreased in influence with distance from its sampled location (ESRI 1999). With IDW, one can control the significance of known points upon the interpolated values, based on their distance from the output point. After locating the sampled data based on UTM

1983 Zone 13 x-y coordinate, the Arcmap Spatial Analyst can interpolate the sampled values to the entire watershed.

The first step in interpolating values with IDW, the first thing to do is to decide whether the exponent parameters should be inversely proportional to distance (b=1) for the distance to be squared (b=2) or etc (1.5, 2.5, and so on). The parameters used to determine the weighted values are the exponent (b) and maximum distance. The maximum distance was variable, the exponent value for weight was determined with Jacknife statistical method. Jacknife statistical method is used for bias removal (Beardwood 1990). Using Jacknife method, the exponent value is determined as 1.5.

To compute the IDW values, the following equation is used:

$$D = \sum_{g=1}^{G} d_g^{-b} \qquad \textbf{(2-20)}$$

Where: *G* is the number of gages.

d_g is the distance between sample point and unknown one.

b is the IDW exponent.

D is the sum of weighted distance.

To estimate the unknown point, the following equation is used:

$$\hat{p}_o = \frac{1}{D} \sum_{g=1}^{G} d_g^{-b} \cdot p_g \qquad \textbf{(2-21)}$$

Where: p_g is value of the sampled point.

$\hat{p}_o$ is IDW value at the unknown cell.

$\hat{p}_o$ values for unsampled area will be plotted in Arcmap.

2.4. CASC2D

CASC2D has been developed in the late 1980's by Julien in A Programming Language (APL). In 1990, the overland flow routing module in CASC2D was converted from APL to FORTRAN by Saghafian. In addition, Saghafian added the Green & Ampt infiltration, detention storage and diffusive-wave channel routing (Saghafian 1992). r.Hydro.CASC2D, the component of GRASS (Geographic Resources Analysis Support System), was developed to show the simulation of watershed response based on rainfall forcing function (Ogden et al. 1995). Engineering Computer Graphic Laboratory at Brigham Young University incorporated HEC-1, the surface runoff function in the two dimensional grid interface from CASC2D (Nelson et al. 1995). The comparison between CASC2D and lumped runoff models was conducted in the Goodwin Creek (Johnson et al. 1995). Additionally the landuse impact to the surface runoff and hydrological responses was tested (Doe et al. 1996). Furthermore, the two dimensional soil erosion simulation model, CASC2D-SED was developed as a following extension of CASC2D (Johnson et al. 2000). CASC2D was also applied to analyses of Colorado torrential rainfall in 1997 (Ogden et al. 2000). Currently, in CASC2D a chemical transport model is being developed. It is based on the previous CASC2D and CASC2D-SED functions and IPX data structures, which were made for the chemical transport modeling in EPA.

CASC2D is a process oriented model which deals with the state variables at each time and location by a cell basis. User has the input data such as overland/channel properties, simulation time characteristics, and cell sizes. Based on these data, CASC2D can reproduce GRID outputs such as water depth, sediment discharge, and chemical concentration. This research focuses on water depth results, which are resulted from snowmelt water into the domain.

2.5. Summary

Snow hydrology, water equivalence sampling, California Gulch overview, snow and CASC2D were reviewed based on historical and current literatures. Snow hydrology is the study of snowfall, snowmelt, and runoff in channel and overland. This research is focused on snowmelt processes and obtained the results of runoff simulation. Therefore, snow hydrology was explained by the snowmelt modeling as Degree Days method, Temperature Index method and Energy-Mass balance method. The Degree Day method is daily based snowmelt approach to determine average meltrate and amount of melt water. Temperature Index approach is the extension of Degree Day method to calculate change of the melt water at each time interval based on the air temperature above the critical one. The energy and mass balance methods are physically based approaches to calculate the amount of snowmelt considering the energy transport between snow and surrounding air.

The literature of SWE interpolation method is reviewed here. Inverse Distance Weight method is chosen to extrapolate SWE values from the sampled data in California Gulch. The distribution of SWE is plotted based on the normal distribution. The inverse weighted value from SWE will be used for the initial condition of numerical integration over the watershed. Additionally, SWE operated by IDW will be modified with the consideration of landuse and surface elevation.

CASC2D was reviewed since the late 1980's. The first version was developed for surface hydrological routing and runoff. The second version was to simulate sediment transport over the watershed. The last upgrade is under development and will be used for chemical transport. Finally,, this thesis work focused on the snowmelt module added into the last version of CASC2D. Temperature Index method will be used to simulate snowmelt over the California Gulch watershed. Analyses and comparison with the measured hydrographs will show the snowmelt processes and model appropriateness over the watershed.

CHAPTER 3:
SITE DESCRIPTION AND SNOWMELT METHOD

3.1. Introduction

This chapter describes California Gulch site and explains how snowmelt method applies into model. Topography, soil, landuse types, air temperature and runoff are illustrated for the application of snowmelt modeling. Snowmelt varies with altitude, aspects, and landuse types. Temperature rapes rate is chosen to decrease air temperature with elevation. Aspects data from Arcmap are used to change temperature based on north, south, east and west aspects. Landuse types are utilized for the variation of air temperature such that forest area has less air temperature than developed area. Additionally, the trends of SWE is explained by available Snow Telemetry (SNOTEL) near California Gulch are described during melting season. Based on the trends, the initial SWE over the watershed is provided considering altitude, and landuse characteristics. For the site description and snowmelt method, the following analyses are preformed.

- Illustrate topography, soil, lanuse types in California Gulch
- Plot the discharge and air temperature data in California Gulch
- Explain snowmelt methods with respect to altitude, aspects, and landuse
- Plot the SWE values in the near California Gulch from SNOTL data from Natural Resources Conservation Services (NRCS)
- Analyze SWE sampled data from SourceWater Consulting, 2003
- Provide the initial SWE based on altitude, and landuse types

3.2. California Gulch Site

Figure 3-1 shows the California Gulch watershed which includes downtown Leadville, California Gulch, and its tributaries. The stray horse Gulch flows across the downtown Leadville. In addition to the Stray horse Gulch, there are Malta Gulch, Airport Gulch, Pawnee Gulch and Georgia Gulch which are the small tributaries of the California Gulch. The Upper California Gulch is the starting point of the California Gulch. California Gulch itself is the tributary of the Upper Arkansas River. The California Gulch spans about 10 km from the Upper California to the outlet (CG6). The water basin area is approximately 16.5 square miles. Especially, Operable Unit 6 (OU6) which was made by EPA mining cleaning maintenances, have been cleared because of mining pollution and its environmental problems in Leadville. OU6 is located near the Stray Horse Gulch (Figure 3-2, Highlighted area) and includes the downtown of the Leadville. Therefore, OU6 has been historically sanitized by EPA since 1980's.

Malta Gulch is first tributary of California Gulch which comes from northeast. Airport, Pawnee, Oregon and Georgia Gulch come from the southeast. Oregon Gulch can be observed by hydro station, OG1. Stray horse Gulch also is measured by SD3 discharge facility. Stray horse Gulch flows across the Downtown Leadville and lots of mining sites.

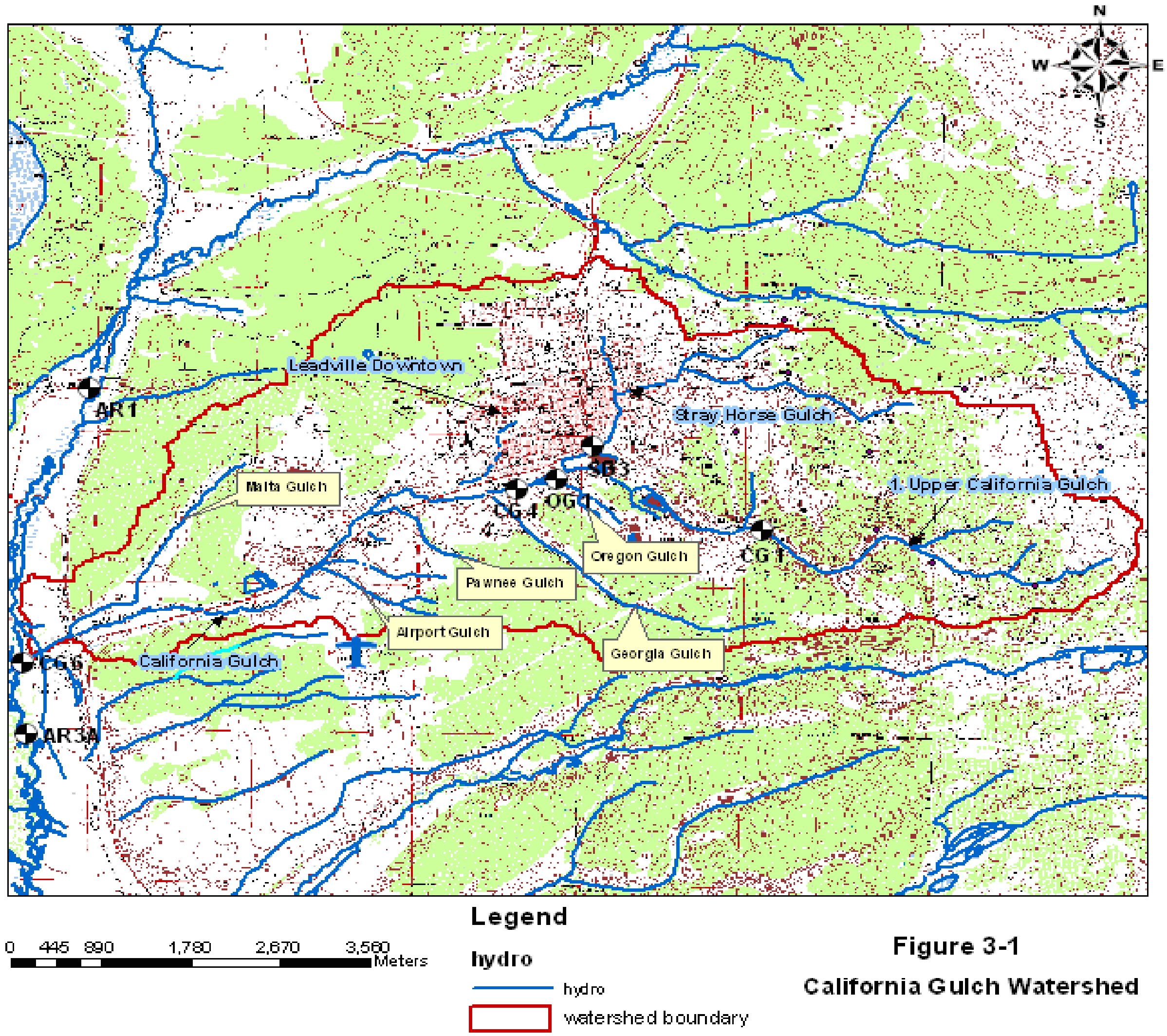

Figure 3-1 California Gulch Site Description

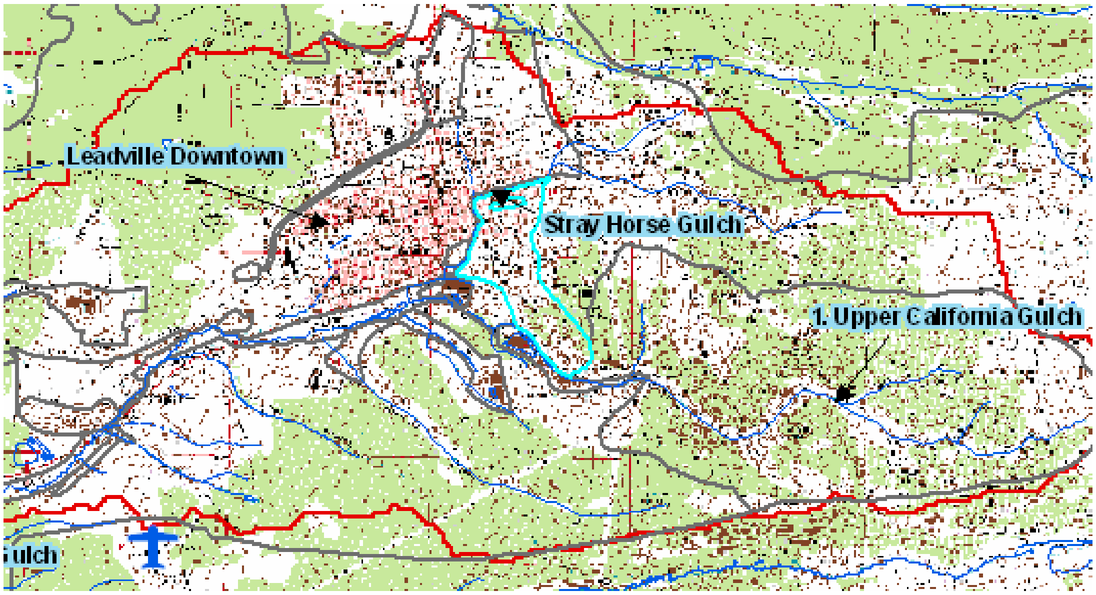

Figure 3-2 Downtown Leadville and Leadville Airport

Figure 3-2 shows the Leadville airport in lower left of the map. The Leadville airport has the North America's highest elevation (3025 meters) among all airports in U.S., and operates the weather station from National Weather Service (NWS). This can provide the meteorological data such as hourly temperature, pressure, and precipitation representing the Leadville area for snowmelt running in CASC2D, which is the lower part of the California Gulch watershed.

3.2.1. California Gulch Site Characteristics

California Gulch watershed is located across Leadville, and the tributary of the upper Arkansas River. The Site is located in a highly mineralized area of the Colorado Rocky Mountains. Mining, mineral processing, and smelting activities have produced gold, silver, lead and zinc for more than 140 years. Mining began in Leadville in 1859 when prospectors working the channels of Arkansas River tributaries discovered gold at the mouth of California Gulch (EPA 2001).

The topographic features of Lake County strongly influence the climatic variations in the Leadville area. The elevation of Leadville is about 3048 meters above mean sea level. The average minimum temperature is 21.9 degree F. Average annual precipitation is 18 inches with the wettest months being July and August and the driest motnths being December and January. Summer precipitation is usually associated with convective showers. The annual peak snowmelt usually occurs around June (Golder 1996). This California Gulch Site background is based on EPA Five Year Report made by TechLaw, Inc 2001.

EPA Second Five Year Report reviewed the California Gulch site chronology displayed in Table 3-1.

Table 3-1 California Gulch Site Chronology

Date	Event
1860	Placer gold discovered in California Gulch and mining began in the District.
1877-1894	The Harrison Reduction Wroks in Operable Unit (OU) 3., the only smleter reported to have Processed gold ores, opened on the northeast corner of Harrison Avenue and Elm Street in 1877, but closed in 1893.
1878-1882	The Grant Smelter operated from 1878 to 1882.
1878-1887	Berdell and Witherell Smelter operated near the La Plata slag pile in OU3.
1879-1882	Area comprising OU2 developed with placer claims.
1879-1886	The Cummings and Finn Smelter Works began operations at Big Evans Gulch in Ou3 1879. The plant, which also operated under the name of the Fryer Hill Smelting Company was dismantled in 1886. Other smleters that operatedin the Big Evanss Gulch Area included the Ohio and Missouri Smelter, the Gage-Hgaman Smelte, and the Raymond, Sherman, and McKay Smelter.
1879-1903	The Elgin Smelter operated intermittently from 1879 until 1903.
1879-1961	The Elgin, Grant, and Arkansas Valley Smelters in OU5 were constructed. The Arkansas Valley Smelter processes lead ore and reprocessed slag to produce lead, silver , and other metals and operated until 1961.
1882-1960	Arkansas Valley Smelter operated in OU3.
1892-1900	The Union Smelter operated from 1892 to 1900.
1892-1900	Bimetallic Smelting Company leased the La Plata area in OU3 for pyritic smelting of lowgrade ores.
1893-1902	The Elgin Smelter works in OU3 were leased and operated by several different companies.
1895	Yak Tunnel driven to dewater mines and to facilitate mineral exploration and development in OU1.
1900	American Smelting and Refining Company purchased the La Plata works in OU3 in 1900.
1914-1926	The Western Zinc Mining and Reducing Company constructed a smetler to the west of the City of Leadville in OU3 that extracted zinc from ores.
1917	Harrison Recovery Works was established to rework the Harriston Street slag pilein OU3.
1923	Last extension to Yak tunnel occurred - total length of tunnel measures 3-1/2 to 4 minles into Iron Hill and Breece Hill in OU1.
1925-1940	The Colorado Zince and Lead (CZL) site operated a floatation mill that processed zinc-lead ores sporadically between 1925-1940. The tailing impoundment at the CZL site is the only fluvial tailing impoundment in OU8.

Date	Event
1926-1938	In 1926, the Colorado Zinc-Lead Mill in OU5 began processing ores with a custom flotation process to produce zinc, lead, gold, silver, and some copper concentrations. The mill closed in 1930, but was remodeled in 1935. Between 1935 and 1938., when it closed for good, the mill procesed ores from several local mines and waste dumps. The history of the Arkansas Valley South Hillside Slag Pile is unknown. It is possible that either the Arkansas Valley or the Grant/Union Smlters disposed of slag at this site.
1939-1956	The mill that generated the tailing placed in the Main Impoundement, and possibly the North Impoundment in OU7, was located on the hillside northeast of the North Impundment. This mill was known as the Venir Mill, the California Gulch Mill, and the ASARCO Leadville Milling unit.
1945-1957	The Oregon Gulch Tailing Impoundment in OU10 received tailing from the Resurrection-ASARCO mill in California Gulch.
1943-1946	Ore & Chemical Companay (OCC) used OU2 as a disposal site.
1947-1987	Hecla Mining Company, which later purchased Day Mines (Hecla/Day), leased OU2 property.
1961	D&RGW purchased the Arkansas Valley (AV) slag pile in OU3f from ASARCO for use as ballast.
1968	Leadville Corporation purchased OU2 property.
1970	D&RGW purchased the La Plata slag pile in OU3 from the Leadville Sanitation District in 1970
970s-1980	The Apache Mill began operations in the late 1970s and continued operations into the 1980s.
970s-1986	A mill facility was in operation within the bounds of OU2 from the early. The mill unitilized a cyanide leach process to extract silver from ore obtained from the Sherman and Diamond Resurrection mines. The mill was purchased by the Leadville Corporation in the early 1980's and continued operations until the mill closed in 1986.
1983	D&RGW purchased the Harrison Street Slag Pilein OU3 from NL Industries for use as ballast production.
1983-1988	Leadivlle Silver & Gold operated a pyrite recovery process on OU2.
9/8/1983	California Gulch site placed on NPL.
1994	Sitewide Consent Decree.

Table 3-1 represents the historical events in the California Gulch site and Leadville mining operations since 1860. Figure 3-3 represents the location of the California Gulch area where is south west of Denver area in lake county in Colorado (EPA, 2001).

Since 1860, the California Gulch has been mined for gold, zinc, and lead and has been established by the facilities as smelters, and mills. In 1983, EPA placed the California Gulch on the National Priorities List, NPL, to clean and restore the Leadville area.

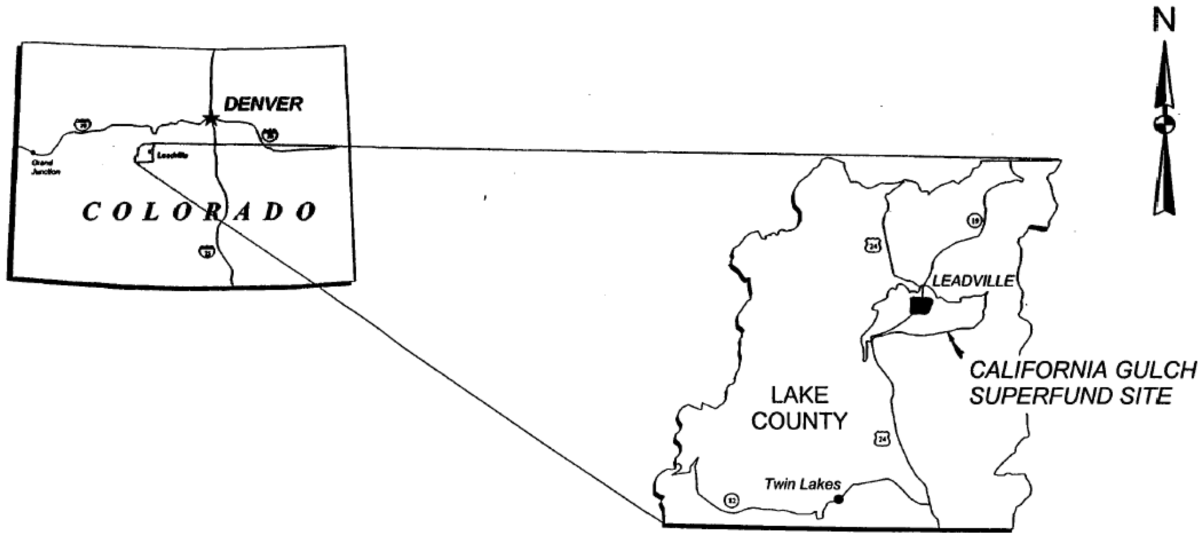

Figure 3-3 Location of California Gulch, TechLaw 2001

The California Gulch site includes the towns of Leadville and Stringtown, where has been the Leadville Historic Mining District, and a section of the Arkansas River from the confluence of California Gulch downstream to the confluence of Lake Fork Creek (TechLaw 2001). The elevation of the Site ranges from 9,448 feet at the confluence of Lake Fork Creek and the Arkansas River at the southwestern boundary of the site to over 12,000 feet near Ball Mountain east of Leadville, Colorado.

Since 1859, mining activity has almost been continuous, although there have been production cessations or slowdowns because of economic conditions or labor issues. An estimated 26 million tons of ore were brought out in the Leadville Mining District from 1859 through 1986 (Aquatics Associates 1991). Now, nearly approximately half of the mills and smelters have been either decommissioned or demolished.

Numerous mining skills were operated at the California Gulch site with placer mining, exposed fissure veins, and underground mining. Waste rocks were dumped near the mine entrances while metal ores were processed by crushing, milling, and smeltering resulting in the generation of several different types of waste such as waste rock piles, slag, acid rock drainage, and mill tailing. More than 2,000 mine waste piles have been recognized in the site, and 26 million tons of ore were produced over the history of mining operations.

The climate and hydrology of California Gulch is based on EPA, 2003. The climate of Lake County where the California Gulch is located is semi-arid continental. The average annual maximum temperature in the Leadville area is 50.5 degrees Fahrenheit and the minimum temperature is 21.9 degrees Fahrenheit. The mean temperature is 36.2 degrees Fahrenheit. The most significant precipitation occurs in the summer months of July and August. The annual normal precipitation in Leadville is 18.48 inches. The mean annual snowfall ranges from 134 inches at the lower gulch to 271 inches at the upper California Gulch. Surface runoff in upper California Gulch and its tributaries is intermittent and generally occurs as a result of snowmelt and high intensity rain storms events. The highest peak runoff was 12.4 cfs at the outlet hydro station between 1993 and 1996.

3.2.2. Topography

The elevation of California Gulch is from about 2900 meters to 3800 meters with a difference in elevation of 900 meters. The air temperature change depends on the air temperature rapes rate and terrain factors. The lower gulch has the range from 2900 m to 3200 m, and the upper gulch has up to 3800 m. The elevation of the gulch is lower than that of the near valley along California Gulch. (Figure 3-4)

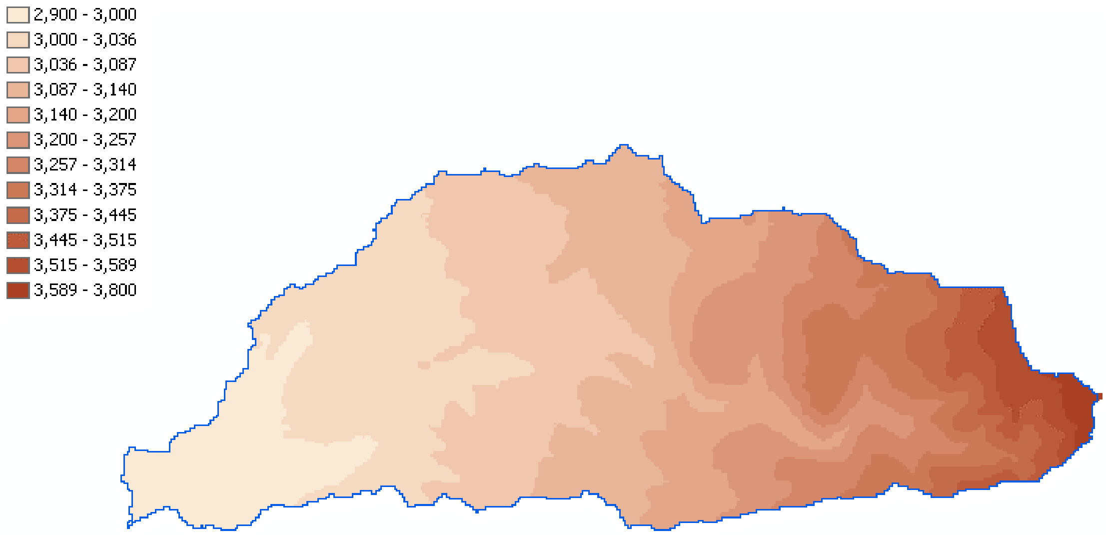

Figure 3-4 Elevation in California Gulch in meters (DEM from USGS)

In upper California Gulch, the slope is much steeper than the lower gulch. Channel flows through the lowest slope which makes the change on solar radiation due to slope factors. Figure 3-5 represents the slope over the watershed.

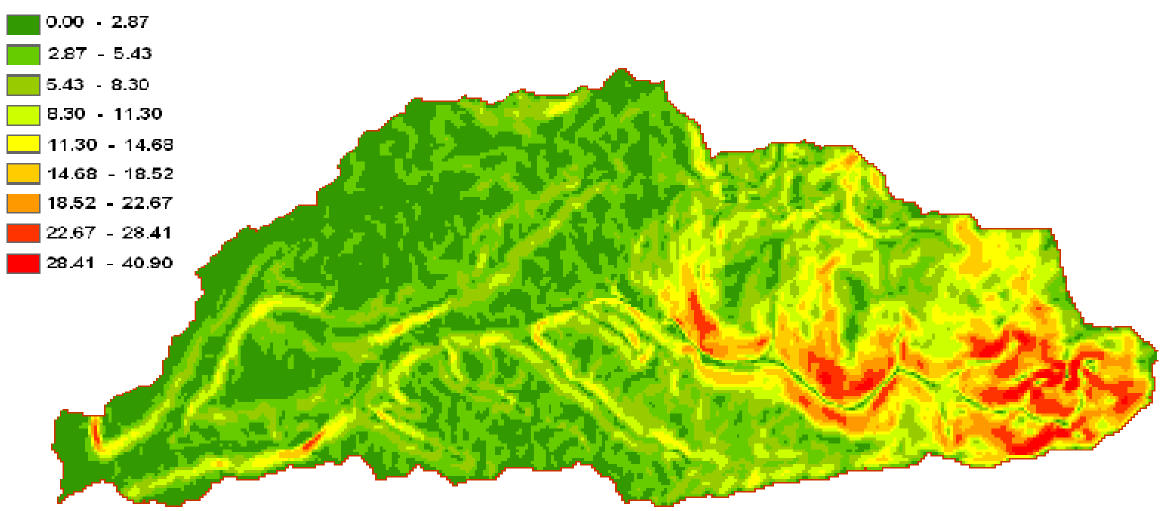

Figure 3-5 Slope in California Gulch in degrees

California Gulch flows to the west outlet. Therefore, the aspects to the sunlight are overall southwestern. It can also change the air temperature values based on sun's movement. Arcmap function generates the aspect values in degree (the direction is north, east, south, and west). Figure 3-6 shows the aspect ratios in California Gulch.

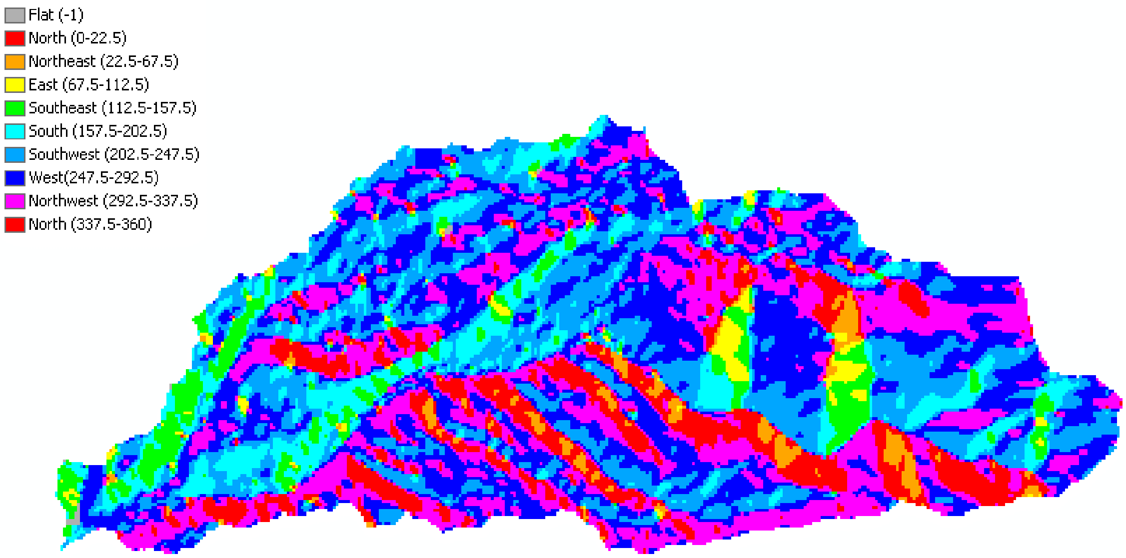

Figure 3-6 Aspects of North, South, East and West in California Gulch in degrees

3.2.3. Soil and Landuse Characteristics

Soil and Landuse data are available in Land Use and Land Cover site (LULC). Soil classification of the California Gulch divides three kinds of soils such as sandy loam, continuous sandy loam, and impervious soil. Figure 3-7 represents the soil classification in California Gulch. In downtown Leadville, the impervious soils are prevailing. Around downtown, the sandy loam is widespread over California Gulch.

Landuse classification is based on seven kinds of landuses such as Water, Developed, Barren, Forested, Shrubland, Grassland, and Planted. In downtown Leadville, Developed areas exist. Barren areas are along the gulch and below the downtown. In upper California Gulch, south of downtown Leadville and western parts of watershed, the forest areas spread. Overall, except for downtown Leadville, the barren and forest areas are dominant (Figure 3-8).

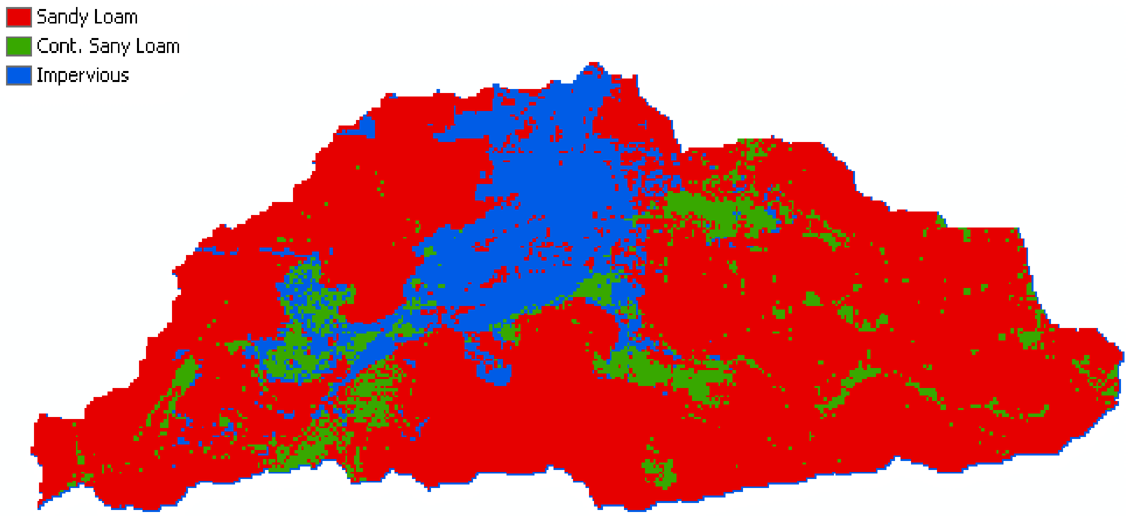

Figure 3-7 Soils of California Gulch

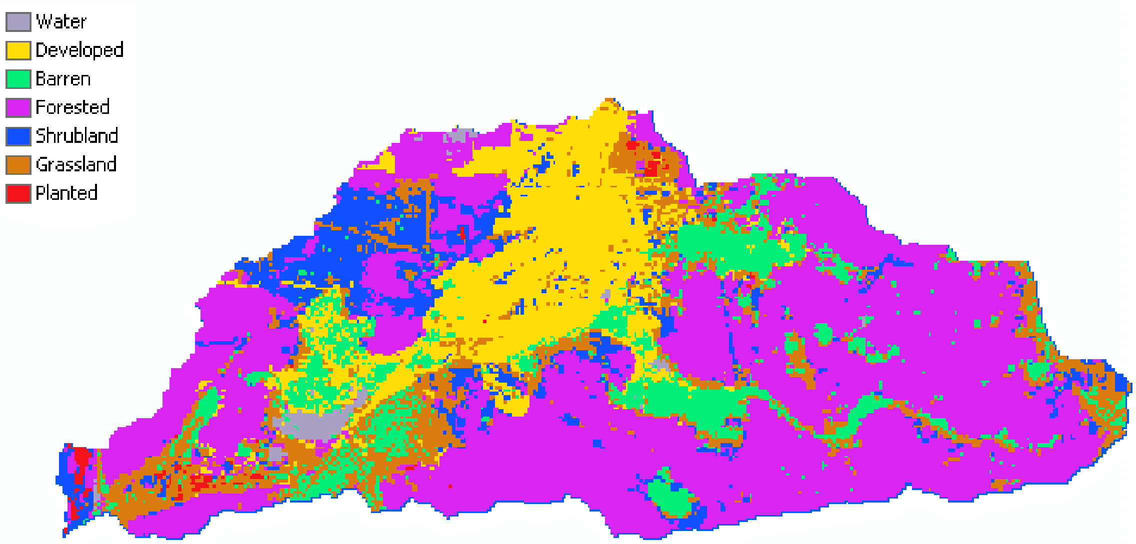

Figure 3-8 Landuse Classification in California Gulch

3.2.4. Air Temperature and Discharge in California Gulch

Air temperature and discharge data are obtained from April 30 to May 28. Leadville Airport weather station (3028 meters) provides hourly air temperature data. Various discharge data along California Gulch are presented from EPA hydro stations. The melting season, the runoff data follows the daily fluctuation of air temperature. Figure 3-9 shows air temperature (Leadville Airport) in California Gulch.

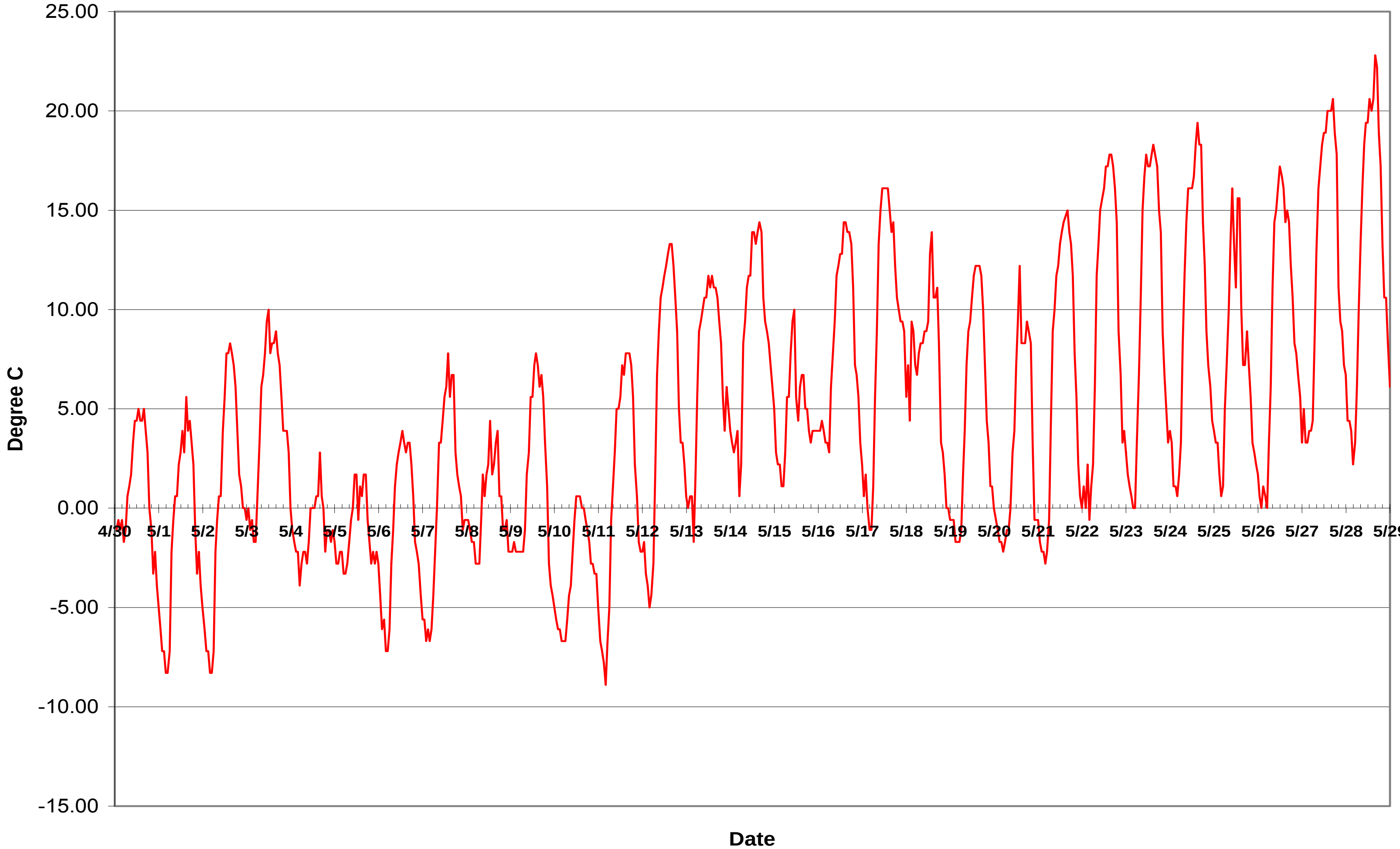

Figure 3-9 Air Temperatures in Leadville Airport

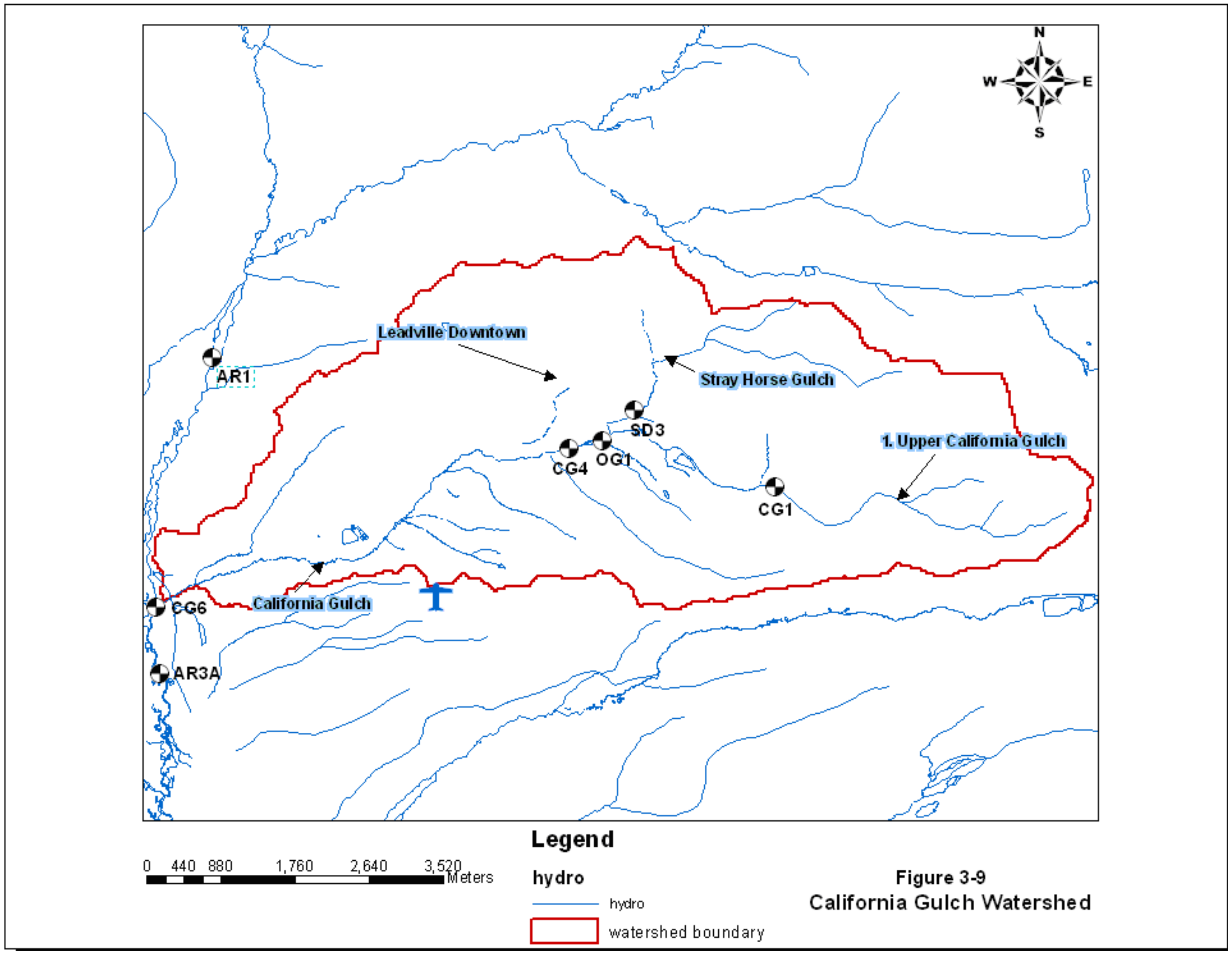

Figure 3-10 Location of Hydro Stations in California Gulch

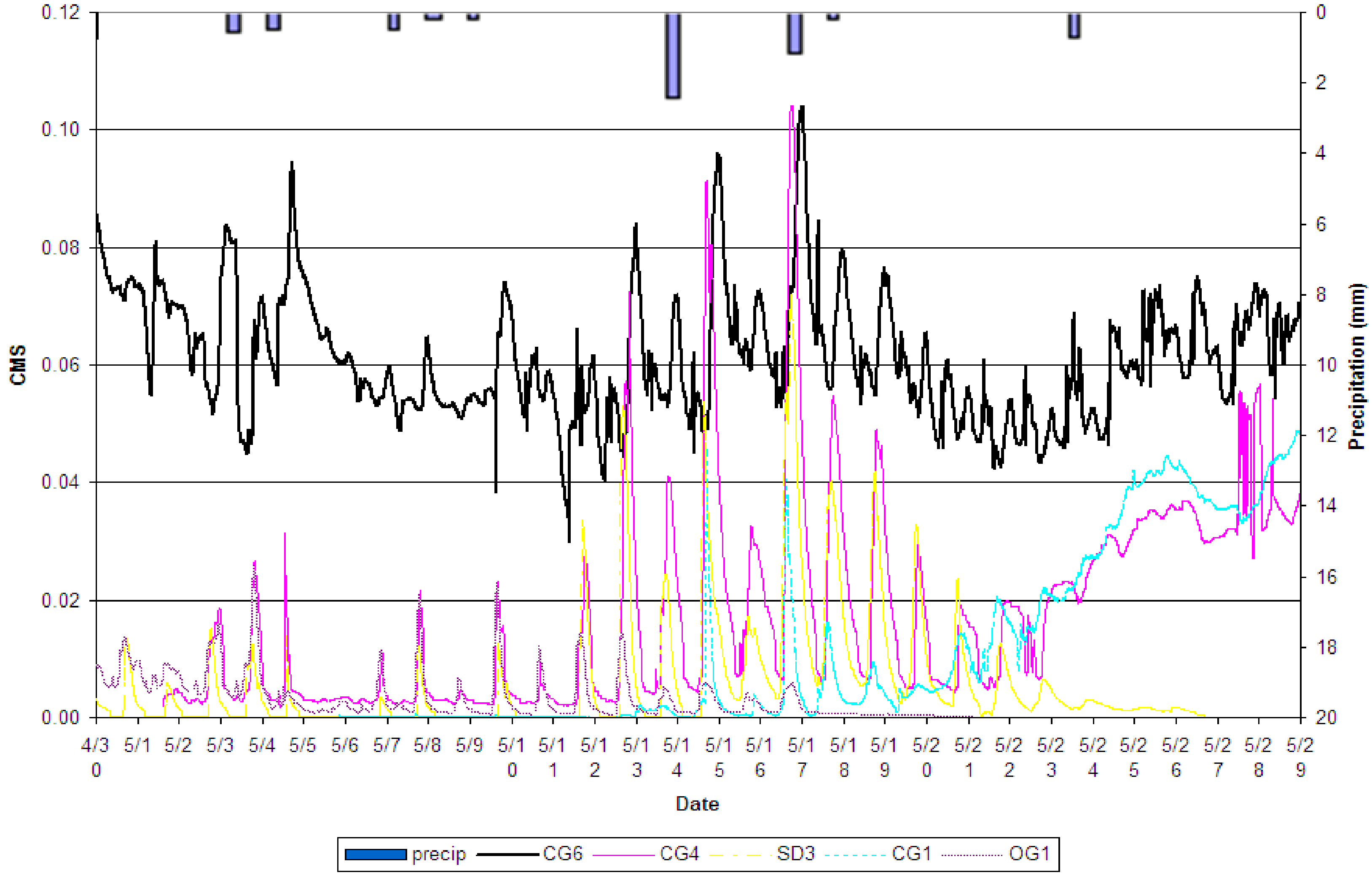

Figure 3-11 Discharge Data in California Gulch provided by EPA

CG6 is located in the outlet of California Gulch, and CG1 covers the upper California Gulch. Daily fluctuation of air temperature resulted in daily runoff change at outlet. All various stations are indicated in Figure 3-10. CG4 is located in the middle California Gulch, SD3 covers Stray Horse Gulch, and OG1 includes Oregon Gulch.

Until May 13, the air temperature goes from negative values to positive values in a daily basis. After that time, air temperature has become above 0 ° C. In upper California Gulch, the elevation is above 3400 meters, therefore snow in upper Gulch started to melt after mid May. The peak runoff at outlet was around May 17 whereas that of air temperature occurred at May 28. It implies that snow in upper California Gulch remained by the end of May and caused more runoff at the outlet. Even though the runoff of outlet at late May went down, the runoff at outlet went up again due to the contribution of snowmelt in the upper California Gulch.

3.3. Snowmelt Method

Recently the World Meteorological Organization (1986) compared 11 different snowmelt runoff models from several countries. The results were (Tarboton and Luce 1996):

- Most models used a temperature index approach, with monthly melt factor
- It is important to suppress melt during the ripening period, to account for the cold content and liquid water storage.
- Subdivision of basins into elevation zone is important.
- Further works on lapse rates are necessary.
- The interception of snow is important especially to forecast the effect of land use changes

Degree Day, Energy Balance, and Temperature-Index methods have been used to determine snowmelt. Degree Day method is the simplest way to determine snowmelt rate. The average temperatures are used to compute the snowmelt rate in Degree Day method. The counterpart of the plain Degree Day method is the Energy Balance method. Energy Balance method keeps the mass and energy transport on the snow surface. Data such as solar radiation, sensible/latent heat, precipitation heat, and ground heat should be obtained or calculated. Therefore, the mass and energy balance method is only as good as the goodness of available data.

For this reason, the thesis focuses on Temperature-Index Approach, which assumes that the temperature change will be the most dominant factor for melt snow. In spite of the simplicity, Temperature-Index methods have proven to be a powerful approach in watershed scales (Hock 2003). The various melting factors have a large variability from site to site. In this research, the melting rate will be adjusted based on the hydrographs, infiltration, and sublimation.

Based on Figure 3-4, the elevation of the California Gulch is range from 2900 m to 3800 m. In the Temperature Index approach, the temperature will be changed with the elevation, which follows a fixed temperature (wet adiabatic) lapse rate of 0.59 °C 100 m^{-1} (the rate could be adjusted with simulation results). Additionally, the temperature index equation is presented below,

$$SM = M \cdot (T_z - T_o) \qquad \textbf{(3-1)}$$

Where: *SM* is snowmelt rate (m/s).

M is melt rate ($ms^{-1}°C^{-1}$)

T_o is critical temperature to start to melt snow (°C).

T_z is air temperature adjusted with the wet adiabatic lapse rate (°C).

$$T_z = T_{air} - (0.59/100) \cdot (elevation_i - elevation_{weather})$$

Where: $elevation_i$ is the elevation at the cell, I (meter).

$elevation_{weather}$ is the elevation at weather station (meter).

Therefore, the temperature at each cell will vary with the elevation difference which has the maximum of 900 meters. It means 0 °C at the lowest point will be -5.31 °C at the highest point which is not still melting temperature.

Meltrate (*M*) can be altered with climate, hydrology, and specific watershed characteristics. In this research, the meltrate will be adjusted with the hydrographs such as CG1, CG4, OG1, SD3 (tributaries), and CG6 (outlet). Along the simulation time (the 30th of April to the 28th of May), the comparison and root mean square errors will be utilized to find the most appropriate meltrate constant.

Furthermore, a sublimation term will be added to calculate the SWE value at each time and each cell. Based on the works of Montesi et al. (2004), the sublimation rate of snow can be calculated by the elevation at a U.S. continental site at each of two elevations (3230 and 2920 m). Using linear interpolation of snow sublimation rate, the interpolated values will be subtracted from the current SWE at each cell. By the way, the sublimation rate is not significant compared with other terms such as elevation, landuse, and slope.

Table 3-2 Sublimation rate of snow (Montesi et al. 2004)

	g/hour	m SWE/sec
Elevation and tree type		
Upper live	138	3.83E-08
Lower live	62	1.72E-08

In addition, the slope, aspect and landuse factors are considered to calculate the snowmelt at each cell. Following chapters explain how topography affects the snowmelt characteristics.

3.3.1. Temperature Change with Elevation

California Gulch varies from 2900 m to 3800 m is a significant factor to air temperature change. The terrain and shape effect on temperature should be considered. Based on the available data and Arcmap tools with grids data of DEM and aspect, the elevation was first pursued to change air temperature at each cell.

Air temperature is obtained from one weather station in one catchment, because air temperature decreases with higher elevation. A fixed temperature lapse rate of 2.11 ° C 100 m^{-1} could be chosen to make reduction of air temperature with the increase of elevation. Or, based on the specific condition of watershed, the adjusted value considering terrain effect with elevation can be assumed.

For example, if the air temperature is 4 ° C at 3048 m elevation (where is Leadville weather station) and lapse rate is 2.11 ° C decrease per 100 m, the temperature variations with location is represented in Figure 3-10.

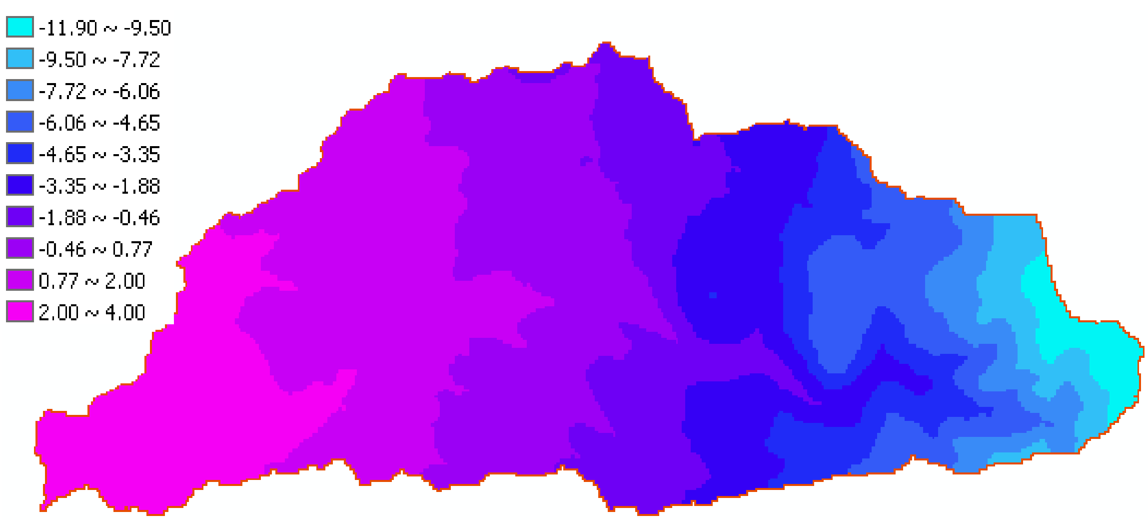

Figure 3-12 Temperature in California Gulch in Degree Celsius

Even though the temperature in lower gulch is above zero ° C, the air temperature in the upper gulch is below zero ° C which means that the snowpack in upper gulch would not be melted because of lower air temperature. In Figure 3-12, the air temperature in the lower gulch, is about 3 ° C, whereas that of upper gulch, is approximately -10 ° C. The air temperature difference (13 ° C) can be a dominant factor to change snowmelt processes. During melting season (April and May in California Gulch), usual air temperature changes around zero degree Celsius, so the geospatial variation of melting pattern can be changed with elevation.

3.3.2. Temperature Change with Aspect

In addition to elevation, the aspect to north, south, east, and west against sun light can be the factor to establish the air temperature. Gertson (2004) reported that the air temperature of north face is averagely 6 ° C lower than that of south face. It means that south face has 2 ° C whereas north face has - 4 ° C. It makes difference of snowmelt with respect to aspects.

Air temperature data were collected at two different locations or site that included a north facing aspect and a south facing aspect in *Pinus contorta* forest, east of Leadville (Gertson, 2004).

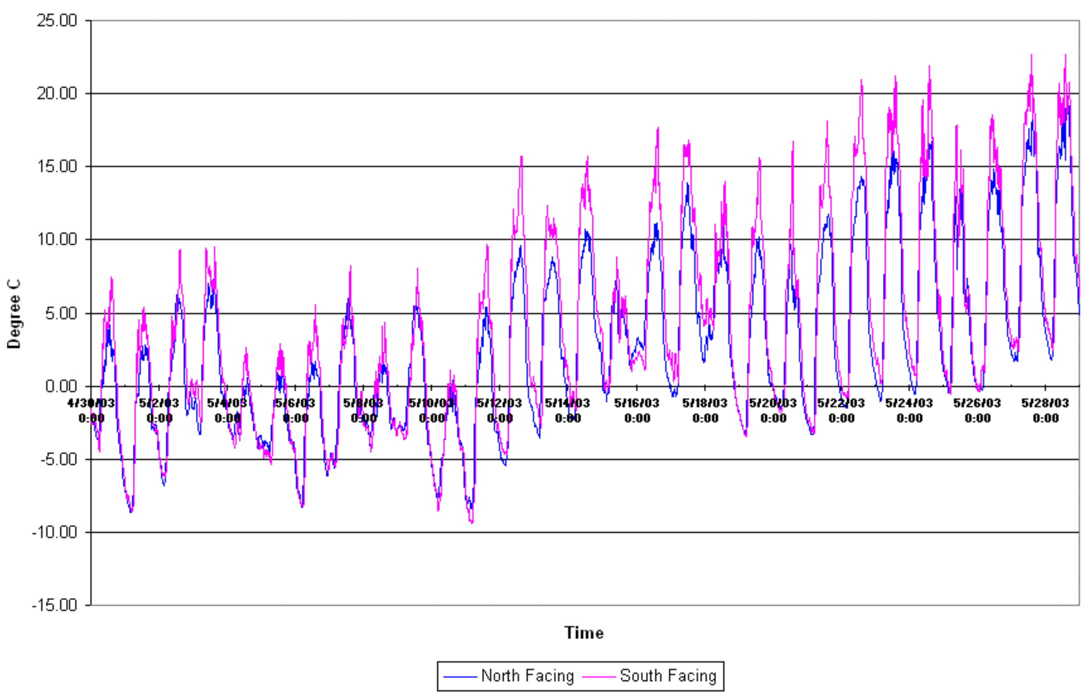

Figure 3-13 Temperature Difference with North and South Aspects, Gertson, 2004

During simulation time (the 30th of April to the 28th of May), the overall air temperature went up with time (Figure 3-9). Therefore, the daily fluctuations and the difference between at the northern and southern aspects could be the difference of the air temperature at each cell. As the time goes on, the difference increases up to about 9 ° C. Average discrepancy is approximately 6 ° C which will be used to calculate the temperature addition to each aspect over the watershed.

Aspect values can be obtained from Arcmap aspect function as grids type which varies from 0 ° to 365 °. Figure 3-6 shows the distribution of the aspect to sunlight. California Gulch watershed has the overall west aspect, but in northern area, the north aspect spans along the streams which are the tributaries of California Gulch. It makes the air temperature difference and will be added in Snowmelt module in CASC2D.

Temperature addition due to aspects is considered in addition to elevation. First of all, the temperature changes with elevation at each cell. Following the aspect value at that cell the air temperature factors will be determined. In direct north, the addition is - 3 ° C. In the part of northern facing, the addition is - 1.5 ° C. But, direct south is 3 ° C, and the part of south is 1.5 ° C. In east part, the sin function is applied to make the addition. In direct east aspect, the amplitude of sin curve is 2 ° C. In eastern part, the amplitude of sin curve is 1 ° C. In the opposite way, the direct west and western aspect have 2 and 1 ° C amplitudes (the amplitudes could be adjusted with model running) for sin curve, but negative values for temperature additions. Table 3-2 represents the addition values of air temperature based on aspect values. Additionally, θ is defined with respect to simulation time (*simtime*) in equation (3-1).

$$\theta = \frac{\pi}{12} \cdot simtime \qquad \textbf{(3-1)}$$

Where: *simtime* is simulation time in CASC2D (hours).

simtime is zero at mid night.

Table 3-3 Addition of Air Temperature with respect to Aspect Ratio

Aspect(Degree), θ	Temperature Addition (Kaspect)
0 or 360	-3.0
0 ~ 45	-1.5
45 ~ 90	(1.0)sinθ
90	(2.0)*sinθ
90 ~ 135	(1.0)*sinθ
135 ~ 180	1.5
180	3
180 ~ 225	1.5
225 ~ 270	(-1.0)sinθ
270	(-2.0)*sinθ
270 ~ 315	(-1.0)sinθ
315 ~ 360	-1.5

Table 3-3 shows that the temperature additions change with simulation time in hour which is only considered in western and eastern aspects in watershed. The sun rises from the east, therefore the temperature addition of eastern aspect of the watershed at 6:00 AM is the maximum, but temperature decreases as the sun sets. In the case of western aspect, the values are reverse. In California Gulch, the most aspects are on the western and northern aspects of the watershed. This temperature addition due to aspects can change the overall temperature and snowmelt characteristics within each cell.

3.3.3. Temperature Change with Slope

The slope factor, i.e., the ratio of solar radiation received on the site of interest to that on a horizontal surface, can be the factor to change snowmelt processes (Dingman 2002). In this study, the air temperature changes with slope values in California Gulch watershed. The contribution of slope factors makes the variation of air temperature based on slope map in California Gulch (Figure 3-5). The upper California Gulch has the highest elevation and slope in the watershed whereas downtown Leadville area has relatively flat surface. Solar radiation supplies more in flatter surface such as downtown Leadville, and lower gulch. Therefore, the reduction of air temperature with high slope factors is added to calculate the snowmelt.

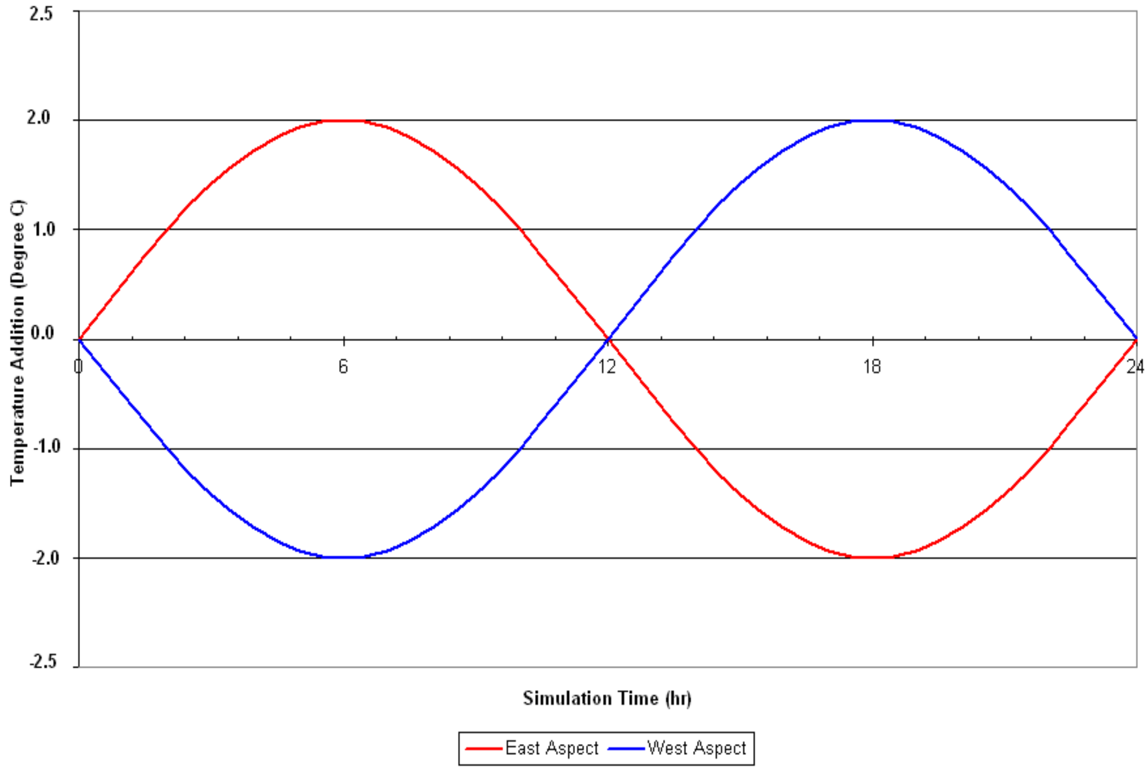

Figure 3-14 Temperature Difference with East and West Aspects

The slope factors contribute to the air temperature by the factor of slope based on 15 degrees (Gertson 2004). The equation 3-2 shows the contribution of final slope, aspect and elevation on air temperature at each cell.

$$T_z = \left(\frac{S_o}{15.0}\right) \cdot (K_{aspect}) + T_{elev} \qquad \textbf{(3-2)}$$

Where: T_z is adjusted air temperature with respect to slope, aspect, and elevation.

K_{aspect} is the addition of air temperature due to aspect ratio (Table 3-2).

S_o is slope in degrees.

T_{elev} is the air temperature changed with elevation.

Other researches on northness against solar radiation were conducted. Molotch et al. (2004) parameterized northness to substitute for solar radiation in a classified way. Northness was defined by the product between sin of aspect and cosine of slope value provided by ArcGIS. The index of northness is represented to modify solar radiation, linearly.

3.3.4. Temperature Change with Landuse

The surface snowmelt rate decreased as the forest density increased because both albedo and downward longwave radiation influenced net radiation (Suzuki et al. 1999). Figure 3-8 shows landuse characteristics in California Gulch where coniferous trees are dominant. In this study, the reduction of air temperature (-2 ° C) is considered in forest areas. Upper California Gulch, and southwest of downtown Leadville, the snowmelt rate is decreased based on the decline of air temperature. Additionally, there is still snow cover in upper California Gulch even at the late snowmelt season.

3.4. SWE Distribution

Natural Resources Conservation Service (NRCS) provides the hourly snow data such as SWE, snow depth, snow density, and air temperature which is called Snow Telemetry (SNOTEL). Around the California Gulch, there are four SNOTEL sites. SWE data based on four SNOTEL sites indicate how SWE changes in Colorado Mountain areas. Additionally, SourceWater (Gertson 2004) sampled SWE in 2003 snowmelt season around upper California Gulch. In addition to Leadville Airport weather station data, the sampled SWE and calculated one from weather station are interpolated over the watershed. Furthermore, the initial SWE for model running is provided based on IDW interpolated SWE, altitude, and landuse factors.

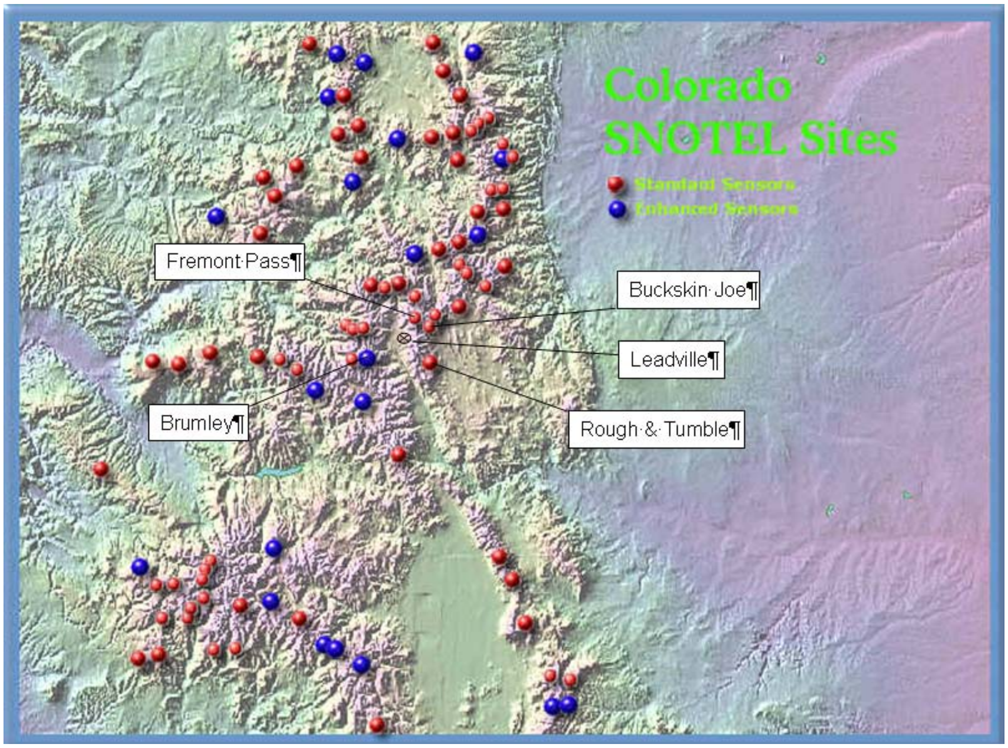

Figure 3-15 Location of SNOTEL sites near California Gulch

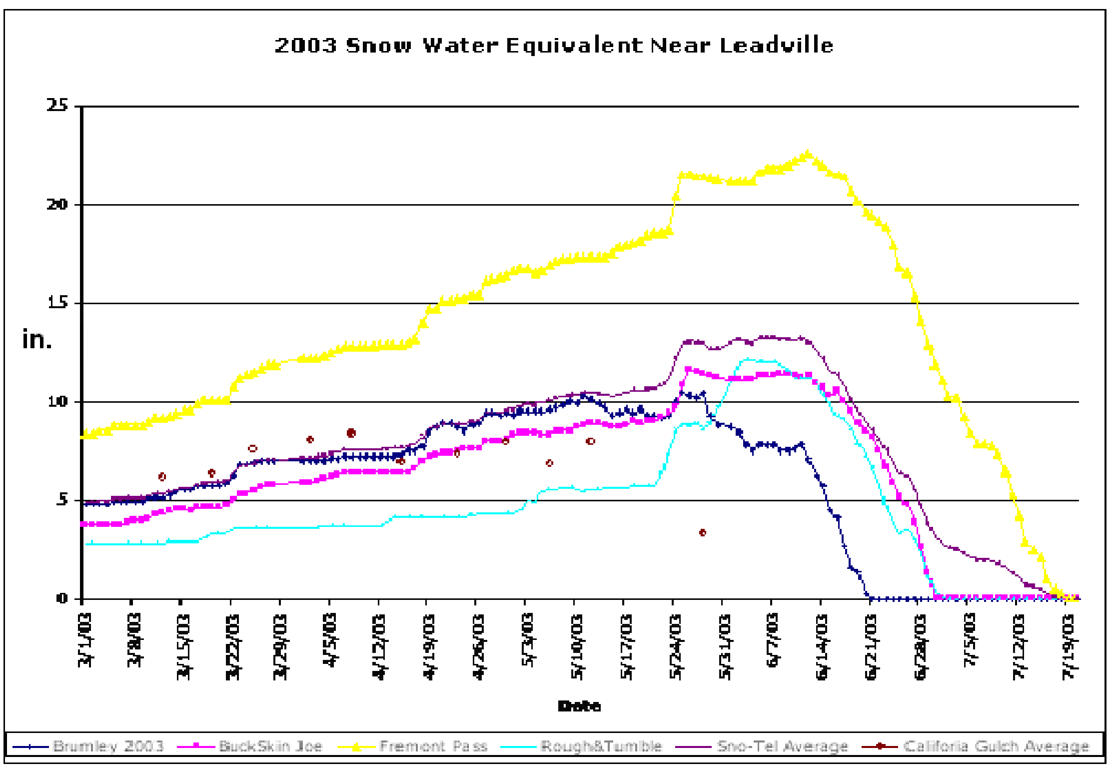

Figure 3-16 SWE change in SNOTEL sites

Table 3-4 SNOTEL Site Description

	Brumley	Fremont Pass	Buckskin Joe	Rough & Tumble
Latitude	39.09	39.38	39.3	39.03
Longitude	-106.54	-106.2	-106.11	-106.08
Elevation (ft)	10600	11400	11150	10360

3.4.1. SNOTEL around California Gulch

Natural Resources Conservation Survey, NRCS, has investigated snow samples, snow depth, snow density, and air temperature by hourly base which is called Snowpack Telemetry (SNOTEL). There are four SNOTEL sites near Leadville (Gertson, 2004) e.g. Brumley, Fremont Pass, Buckskin Joe, and Rough & Tumble (Figure 3-15).

Figure 3-16 shows the change of SWE at SNOTEL sites with peaks in May and early June. The peak values of SWE are from 22 inches to 11 inches (560 mm to 280 mm SWE). In Brumley, the peak occurs at the mid May where the elevation is 3230.88 meters. Buckskin Joe has the peak at the late may, Fremont Pass at mid June, and Rough & Tumble at the early June, respectively. Geomorphic effect on SWE such as terrain, slope, and slope aspect at each site could cause the peak SWE respectively. Figure 3-15 also represents the geographical locations of SNOTEL sites near California Gulch. Brumley is similar to elevation of Leadville area and has appropriate SWE value, 280 mm SWE at the peak. This is why the simulation time, the April 30 to May 28 has the same snow melting duration as that of Brumely.

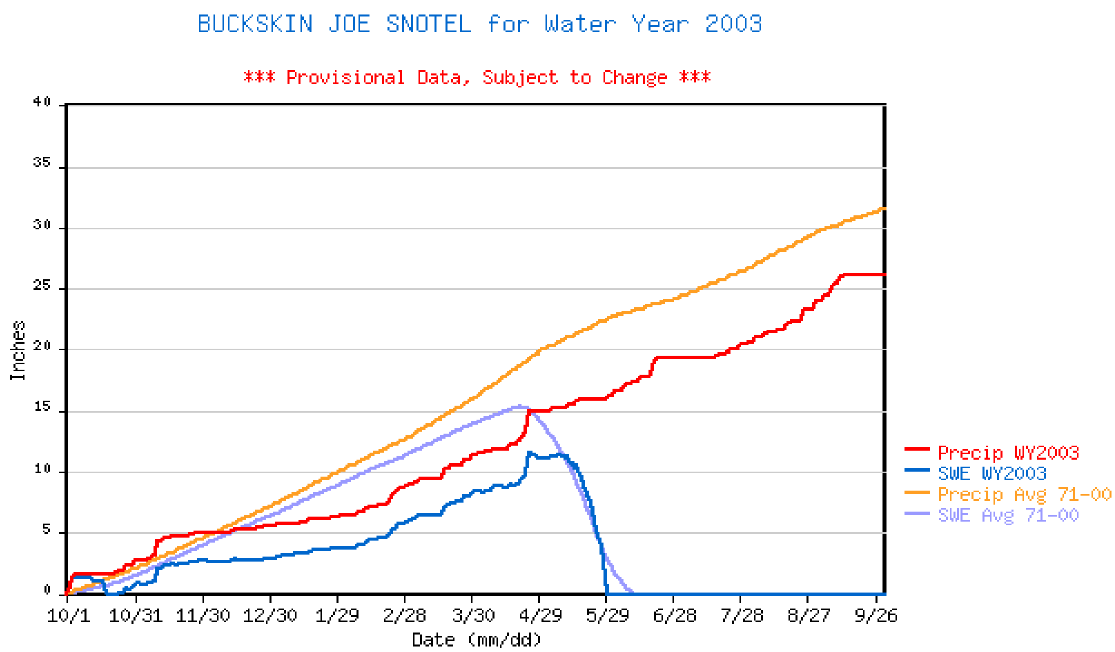

Figure 3-17 SWE Comparison with Average in 2003 Water year (from NRCS)

3.4.2. IDW Interpolation of SWE in California Gulch

Figure 3-17 shows 2003 water year SWE is not above the average. SourceWater Consulting worked for EPA to sample SWE in the California Gulch in 2003. SourceWater chose 10 points of sample locations, Fryer Hill, Strayhorse Gulch near the Highland Mary retention pond, Carbonate Hill, East Iron Hill, Nugget Gulch, Oro City, Upper California Gulch, Irene Mine, Famous Mine, and Upper Adelaide Park.

Figure 3-18 shows the sampling sites chosen by SourceWater. They cover the upper California Gulch. Therefore, to represent the lower gulch, the weather station at Leadville Airport is chosen to determine appropriate SWE value and characterize the lower parts of California Gulch.

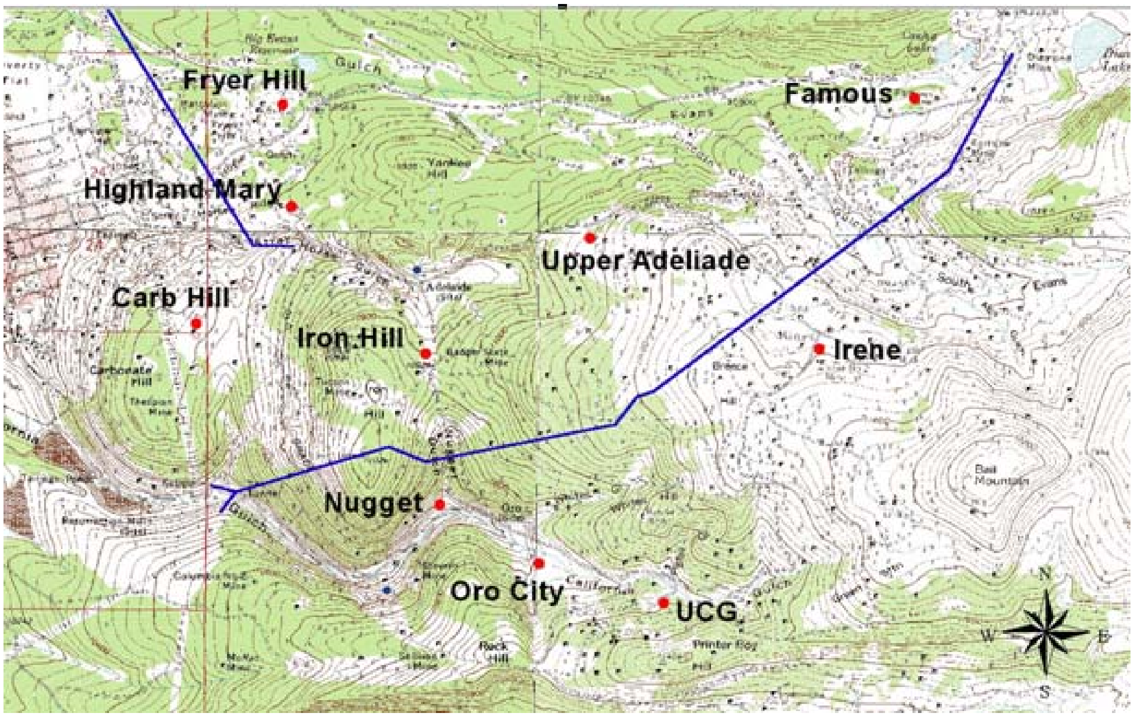

Figure 3-18 SWE Sampling Sites from SourceWater in upper California Gulch, 2004

Table 3-5 SWE Sampling Site Description

Station_id	UTM X (m)	UTM Y (m)	Elevation (m)
UCG	393086.21	4343114.58	3316.224
ORO City	392065.54	4343362.75	3267.456
Nugget	391516.76	4343721.03	3224.784
High Mary	390632.42	4345423.30	3230.88
Carb Hill	390106.36	4344776.65	3230.88
Iron Hill	391441.61	4344565.18	3328.416
Upper Adeliade	392388.87	4345239.79	3413.76
Irene	393724.12	4344610.62	3535.68
Famous	394316.59	4346033.25	3221.736
Fryer Hill	390602.71	4345991.31	3398.52
KLXV	386362.43	4342393.96	3028.6125

Including Leadville Airport weather station, this analysis produced 11 points of SWE (Leadville Airport, Fryer Hill, Highland Mary, Carb Hill, Iron Hill, Upper Adeliade, Famous, Nugget, Irene, Oro City, and UCG) at 11 times (3/12, 3/19, 3/25, 4/2, 4/8, 4/15, 4/23, 4/30, 5/6, and 5/12/2003). In addition, the Leadville airport has a meteorological station operated by National Climatological Data Center (NCDC). Hourly based temperature, precipitation, pressure, wind speed, wind direction, and sky condition were obtained from this station. Based on precipitation data, the snow water equivalences (SWE) were calculated and used for IDW SWE interpolation. Figure 3-19 represents the map of SWE sampling sites including the weather station in California Gulch.

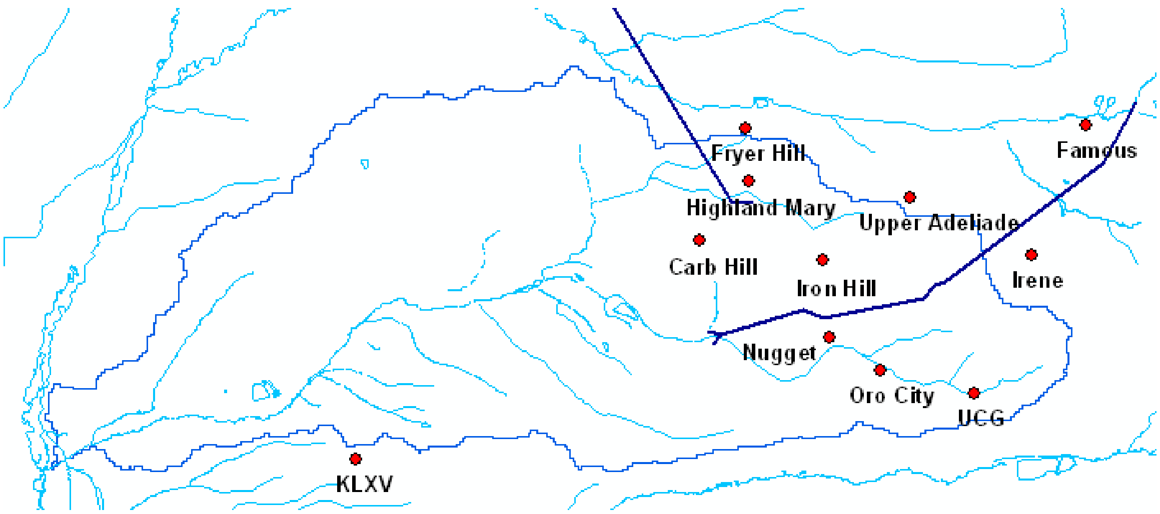

Figure 3-19 Locations of SWE Sampling and Calculation Points

Figure 3-19 represents the 11 sample points including the weather station which is located in the Leadville Airport. SWE at the weather station were calculated based on precipitation, air temperature, and albedo (snow reflectance against sun light). Detailed calculation is carried out using weather data from KLXV.

Based on SWE by SourceWater, IDW interpolated SWEs were mapped. The 12th, 19th, 25th of March, 2nd, 8th, 15th, 23rd, 30th of April, and 6th, 12th, 28th of May data were collected. SWE were calculated with snow depth and snow density using US federal sample methods. Additionally, the model simulation time is from the 30th of April to the 28th of May.

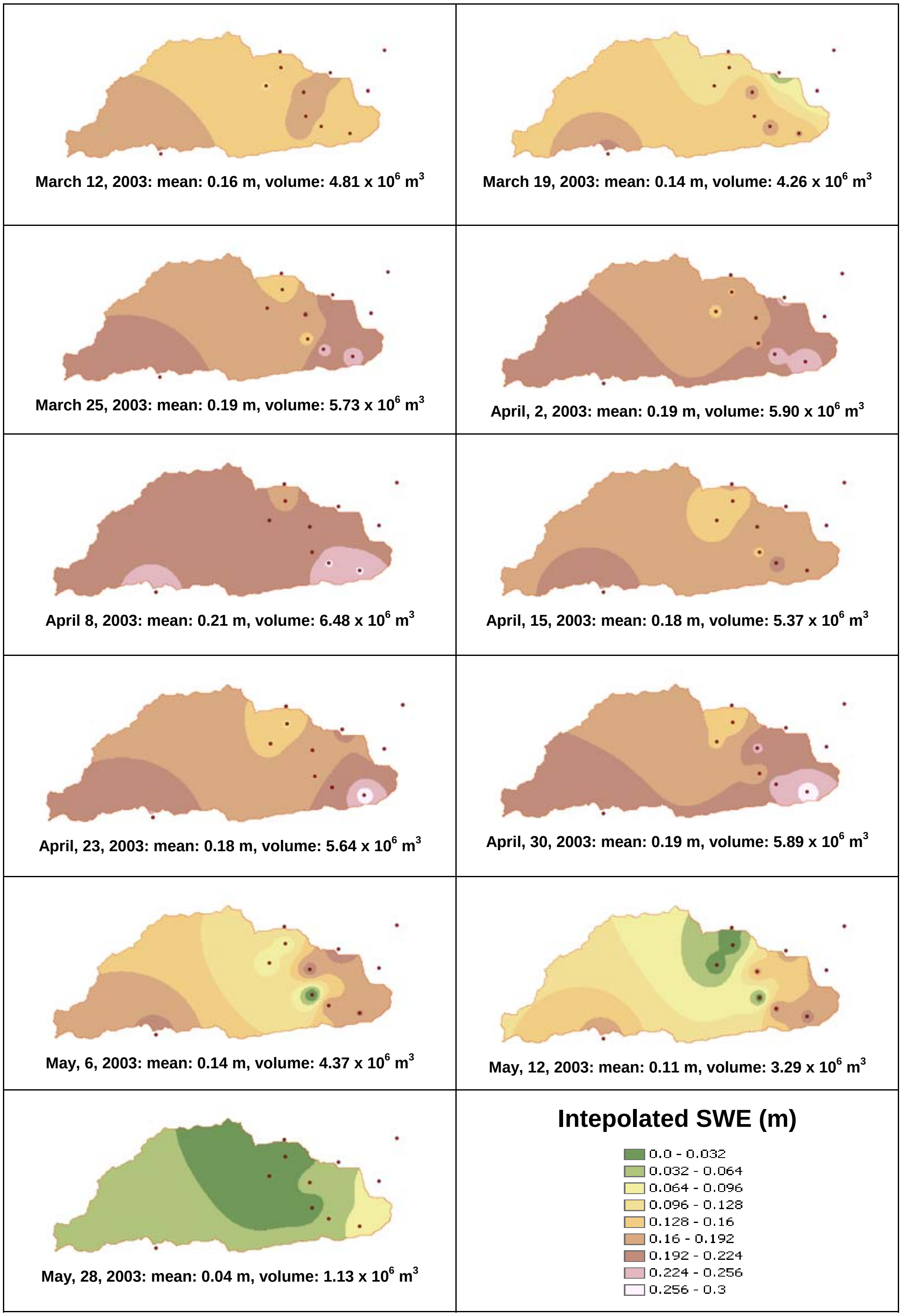

Figure 3-20 IDW Interpolation Map in California Gulch

3.4.3. Initial SWE with Altitude and Landuse

Based on IDW interpolation, SWE values were extrapolated over the watershed. This means that SWE values change with the simulation time (March 12 to May 28). Peak time occurs at the 8th of April, and the amount of SWE is 0.19 m. Figure 3-18 shows how the tendency of SWE is over the time scale SourceWater Consulting sampled in California Gulch after IDW interpolation over the watershed. Even though the average SWE peaks at the early April, UCG, Oro, and Fryer have the climax of SWE at the late April or early May. By the way, Nugget, Carbonate Hill, and High Mary were lost most SWE before the mid May. It could depend on the elevation, and geomorphological effect on snowmelt.

Although the SWE trend and IDW interpolation provide SWE value over the watershed, the landuse effect should also be considered in calculating SWE. In paved road or downtown area, snow on the ground can melt more than in forest or grassland areas. Considering snow factor based on landuse can provide new initial SWE for simulations of snowmelt. It is more reasonable than initial SWE only considering SWE reduction with elevation.

A landuse digital map (Figure 3-8) is used to manipulate initial SWE as well as to run CASC2D. Total number of land types is seven. Refer to Table 3-5 for the landuse application into the initial SWE. Based on the mean SWE value from IDW interpolation, each land type has the SWE factor values. Developed area such as downtown decreases SWE compared with forested area. This is because snow on paved areas can melt quicker than that on the vegetated areas. Furthermore, the trees in the forested areas intercept snow. Thus the forested sections have higher than average SWE.

In addition, the SWE values changed with altitude. At the highest elevation (3800 m), SWE is 0.508 m water equivalence whereas SWE is 0.01 m water equivalence at the lowest point. (Figure 3-21)

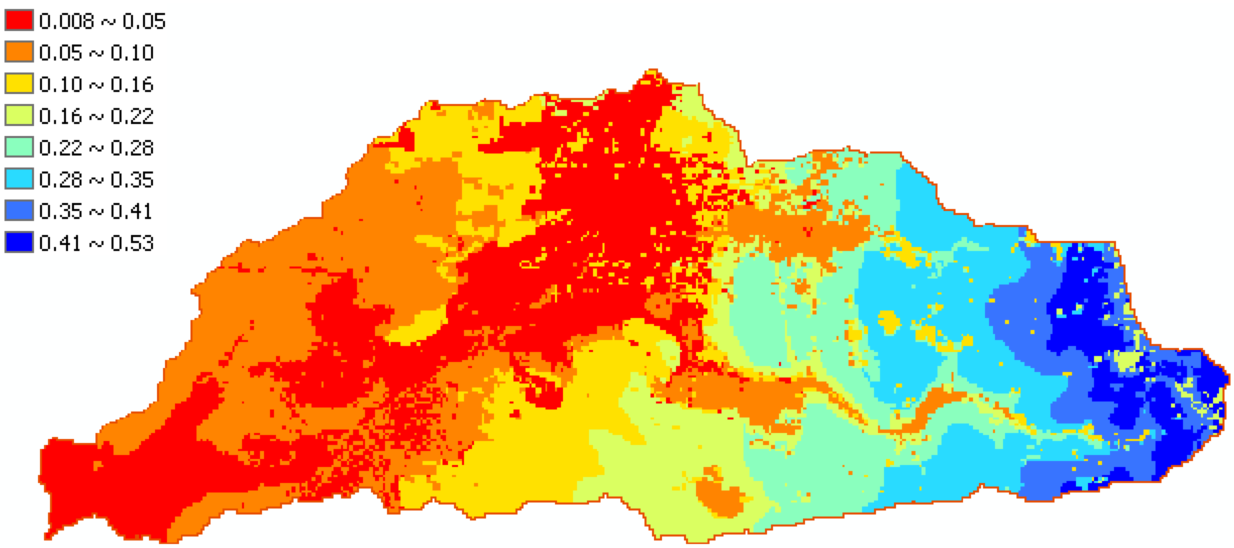

Figure 3-21 Initial SWE in meters

Table 3-6 SWE factor based on land type for the initial SWE

Land Type	Name	SWE Factor
1	water	1
2	developed	0.3
3	barren	0.5
4	forested	1.3
5	shrubland	1.1
6	grassland/herbaceous	1
7	planted/cultivated	1

Based on the linearization of SWE with elevation, the landuse factor is added to calculate the initial SWE over the watershed. Therefore, the SWE values in Downtown Leadville have less SWE than mean SWE whereas those on forest and shrubland have higher than mean SWE.

More comments on initial SWE are needed to adjust the initial SWE map (Figure 3-21). Erxleben et al. (2002) compared various spatial interpolation methods for estimating snow distribution in the Colorado Rocky Mountains such as IDW, ordinary kriging, modified residual kriging and cokriging and binary regression trees and geostatistical methods. They determined that binary regression trees and geostatistical methods are the best way to adjust initial SWE data. Figure 3-22 shows the determination of snow depth values based on elevation, vegetation cover, aspect, and slope at each cell. In addition, this research considers landuse characteristics, and elevation, which provides more sophisticated results in initial SWE. It shows only IDW interpolation of SWE is not enough to be a representative in a watershed. Furthermore, Erxleben et al. (2000) pointed that the combination of binary regression trees and kriging was determined to be the superior method for Rocky Mountains Snow areas. To account for the non-linear relationships between snow depth and variables such as elevation, slope, aspect, net solar radiation, and vegetation, more sophisticated interpolation ways should be pursued.

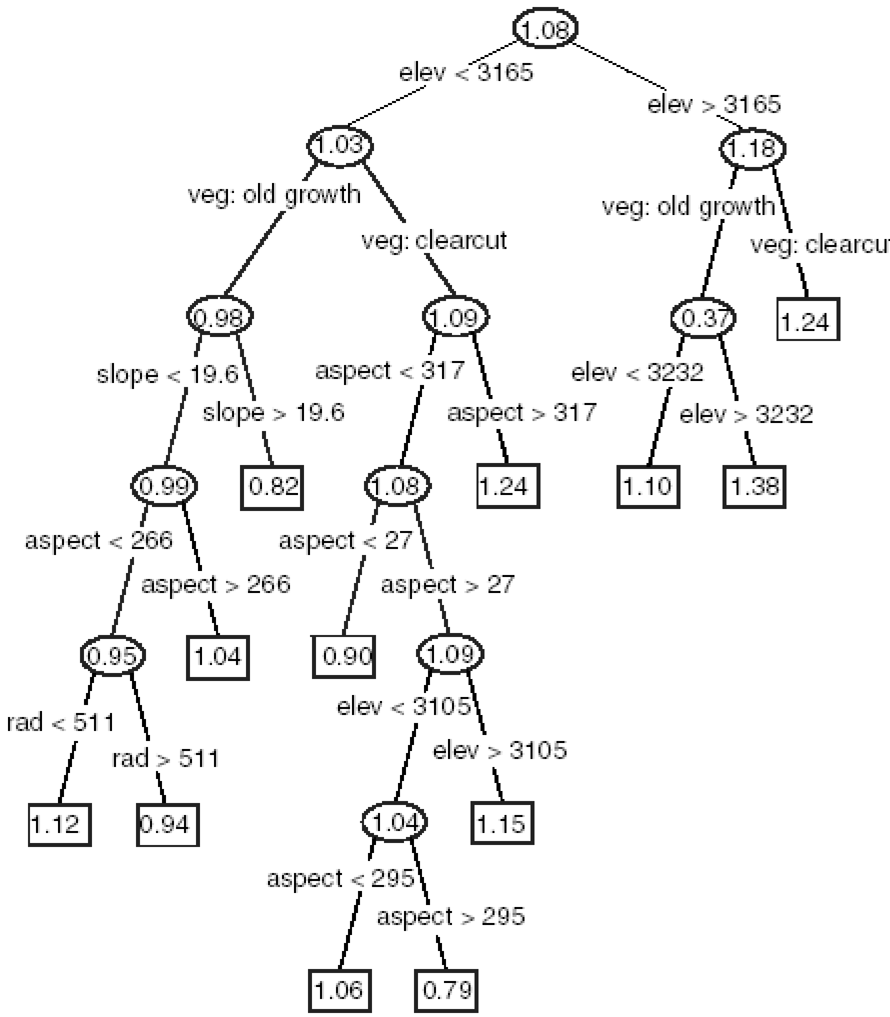

Figure 3-22 12 node tree for Fool Creek snow depth. Root node is the ellipse located at the top of the diagram and terminal nodes are represented by the rectangular boxes. The values contained within the ellipses and rectangles are the mean snow depth at that node. Units of snow depth are in meters, elevation is in meters, and aspect is in degrees (north=0, east=90, south=180, and west=270) (Erxleben et al. 2002)

Additionally, Fassnacht et al. (2003) evaluates inverse distance weighted and regression nonexact techniques for interpolating methods of snow water equivalences for the years 1993, 1998, and 1999 which are average, higher than average and lower than average than snow year. They concluded that regression multivariate method is superior to other methods such as IDW, Optimal Distance Averaging, and Hysopmetric method. It indicates that SWE interpolation and distribution requires more statistical determination considering time scales, and topographical conditions.

3.5. Summary

Chapter 3 demonstrates California Gulch site description such as topography, soil/landuse characteristics, air temperature, and discharge over the watershed. California Gulch is a reasonable example of mountain stream and can be one of representatives of snowmelt processes. Temperature and discharge data are correlated with respect to snowmelt. Various stations including outlet (CG6) can be compared with further model runs.

Snowmelt method is explained with regard to altitude, aspects, slope, and landuse. The adjusted rapes rate of air temperature will be chosen to snowmelt procedure in model. And, physically, the solar radiation on the sloping surface and aspect is changed, so alters the snowmelt processes at each point. Additionally, the forested areas have the negative factors in air temperature considering energy flux (Suzuki et al. 1999).

Furthermore, the initial SWE is manipulated based on IDW interpolation of SWE samples, altitude, and landuse. Before this, SWE trends in Colorado Mountain areas are explained by SNOTEL data which enable us to choose the snowmelt season (April 30 to May 28) and amount of peak SWE. This initial SWE will be the basic input for CASC2D model run in the following chapters.

CHAPTER 4:
CASC2D Setup

4.1. Introduction

After conceptualization of snowmelt processes, Chapter 3 implemented the SWE data analysis. To demonstrate concepts of snowmelt based on SWE, the CASC2D model is modified to simulate runoff from snowmelt procedures. CASC2D is operated by Temperature Index method. Additionally, the temperature changes with elevation and landuse types. Based on snowmelt using temperature, SWE values decreases with respect to time.

For snowmelt simulation, CASC2D needs a basic data set up such as a DEM, soil type, landuse, and channel characteristics. For Model set up, the following analyses are performed.

- Explain overland properties such as DEM, soil, and landuse types for numerical modeling
- Describe channel properties (link and node)
- Illustrate how snowmelt module operates in CASC2D model
- Identify numerical integration of state variables such as SWE and Water depth

4.2. Properties of Overland in California Gulch

Data on overland are composed of digital elevation model (DEM), soil, landuse, and other conditions such as initial water depth, infiltration, These data will be used to run snowmelt processes in this research. Additionally, the spatial domain is covered by mask file, and the spatial analyses set up comprises rows (147), columns (372) as the ASCII codes. The watershed domain comprises 34002 cells which is 62 % of entire domain. It is divided by two parts between overland and channel.

Figure 3-4, 3-7, and 3-8 show California Gulch's DEM, soil, and landuse classification, respectively. In addition, ArcGIS manipulates slope and aspect at each cell from DEM data which alters the snowmelt process in numerical calculation. Soil properties control the infiltration characteristics (Table 4-1).

Table 4-1 Soil Infiltration Characteristics (Land Use/Land Cover)

Soil Type	Soil	Hydr. Cond.	Suction Head	Moisture Deficit
	Index	[m/s]	[m]	[m/m]
Sandy Loam	1	2.50E-06	0.1	0.2
Con. Sandy Loam	2	3.33E-06	0.1	0.3
Impervious	3	1.39E-07	0.005	0

Sandy loam has larger hydraulic conductivity and suction head than impervious soil has. Infiltration rates will be calculated based on the above soil characteristics and the Green and Ampt infiltration equations.

Figure 3-8 shows the landuse classification which influence on interception and surface roughness (from Land Use/Land Cover in USGS). Roughness and interception handle water routing and flow depth calculation in the numerical integration of flow depth and SWE. To calculate the velocity of water in overland, CASC2D uses Manning's n value at each cell on the overland. Table 4-2 represents the summary of the interception depth and surface roughness based on landuse types. Forest area has the highest roughness and interception depth. In developed area, the pavement causes lower surface roughness, therefore water and melted snow flow fast as compared with the flow velocity in other areas.

Table 4-2 Landuse Characteristics

Landuse	n	Interception (mm)
Water	0.040	0.000
Developed	0.015	0.000
Barren	0.043	0.000
Forested	0.400	0.003
Shrubland	0.300	0.002
Grassland/Herbaceous	0.200	0.002
Planted/Cultivated	0.300	0.001

4.3. Properties of Channel in California Gulch

In the CASC2D, the channel links of the California Gulch are shown in Figure 4-1 (EPA STORET DATA). The channel geometry is rectangular shaped, the bottom width is 3 meters, and the bank height is 4 meters in most channels. Figure 4-1 shows the channel link number at each section.

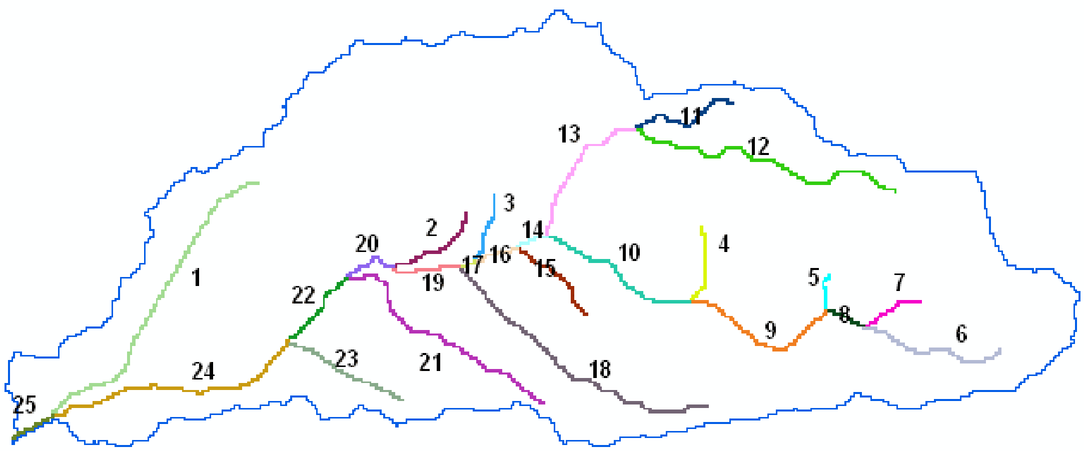

Figure 4-1 Links of California Gulch and its Tributaries

Nodes are the elements of each link, and numbered from upstream to downstream. Link number 25, 24, 22 and 20 are in the lower California Gulch. Link number 5, 6, 7, 8, and 9 comprise the upper California Gulch at which the vegetation is forest and the altitude is higher above 3400 meters. The Stray Horse Gulch is the part with link number 11, 12, and 13, and flows across downtown Leadville. Oregon Gulch occupies in the link number 15 where the upper gulch is forest, and most of Oregon Gulch is in the barren areas (Figure 3-8).

Based on landuse type and soil characteristics at each link and node, each stream has the specific properties such as channel geometry, roughness, sinuosity, and dead storage depth in channel (Table 4-3). The dead storage depth is assumed to be zero, channel geometry be rectangular shapes, and sinuosity be one.

For the discrepancies in geo-coding of channel link 2 and 3, and actual sites, user input in channel assigns the higher roughness values in link 2 and 3. The lower California Gulch has small cross section whereas upper gulch has larger or artificial channel cross section. That is why link number 1, 22, 23, and 24 have the smaller channel cross sectional area. The link number 25 includes the outlet of California Gulch which is the smallest one among all channel cross sections.

Table 4-3 Channel Properties based on Link Number

Link	Bottom Width (m)	Bank Height(m)	n
1	1.0	0.5	0.035
2	3.0	4.0	0.300
3	3.0	4.0	0.300
4	3.0	4.0	0.035
5	3.0	4.0	0.035
6	3.0	4.0	0.035
7	3.0	4.0	0.035
8	3.0	4.0	0.035
9	3.0	4.0	0.035
10	3.0	4.0	0.035
11	3.0	4.0	0.035
12	3.0	4.0	0.035
13	3.0	4.0	0.035
14	3.0	4.0	0.035
15	3.0	4.0	0.035
16	3.0	4.0	0.035
17	3.0	4.0	0.035
18	3.0	4.0	0.035
19	3.0	4.0	0.035
20	3.0	4.0	0.035
21	3.0	4.0	0.035
22	1.0	0.5	0.035
23	1.0	0.5	0.035
24	1.0	0.5	0.035
25	0.4	0.2	0.035

4.4. Numerical Integration in CASC2D

The basic cell size is 30 meter by 30 meter rectangular shape. At each cell, CASC2D numerically integrates state variables with the change of state variables at the previous time step. The total watershed domain comprises 34002 cells which is 60 % of entire domain. Projection type is based on North American Datum (NAD) 1983. ArcGIS projected the entire domain with x lower left point (382985 meters), and y lower left point (4349263 meters).

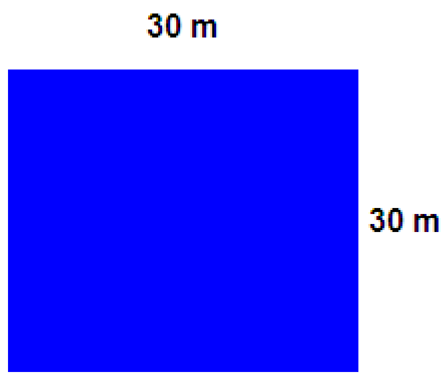

Figure 4-2 CASC2D Cell Size

The snowmelt module will be added into CASC2D which is focused only on the surface hydrological processes. The watershed domains are composed of the overland and channel to calculate the state variables. Previously, the state variable in CASC2D (hydrology) was only the water depth in overland and channel. SWE in overland cells will also be integrated in CASC2D hydrology version.

CASC2D can include a variety of special modules, which can be inserted such as sediment transport, chemical transport, and snowmelt units. CASC2D is modified with the addition of snowmelt components. The basic structure of CASC2D frame is presented below.

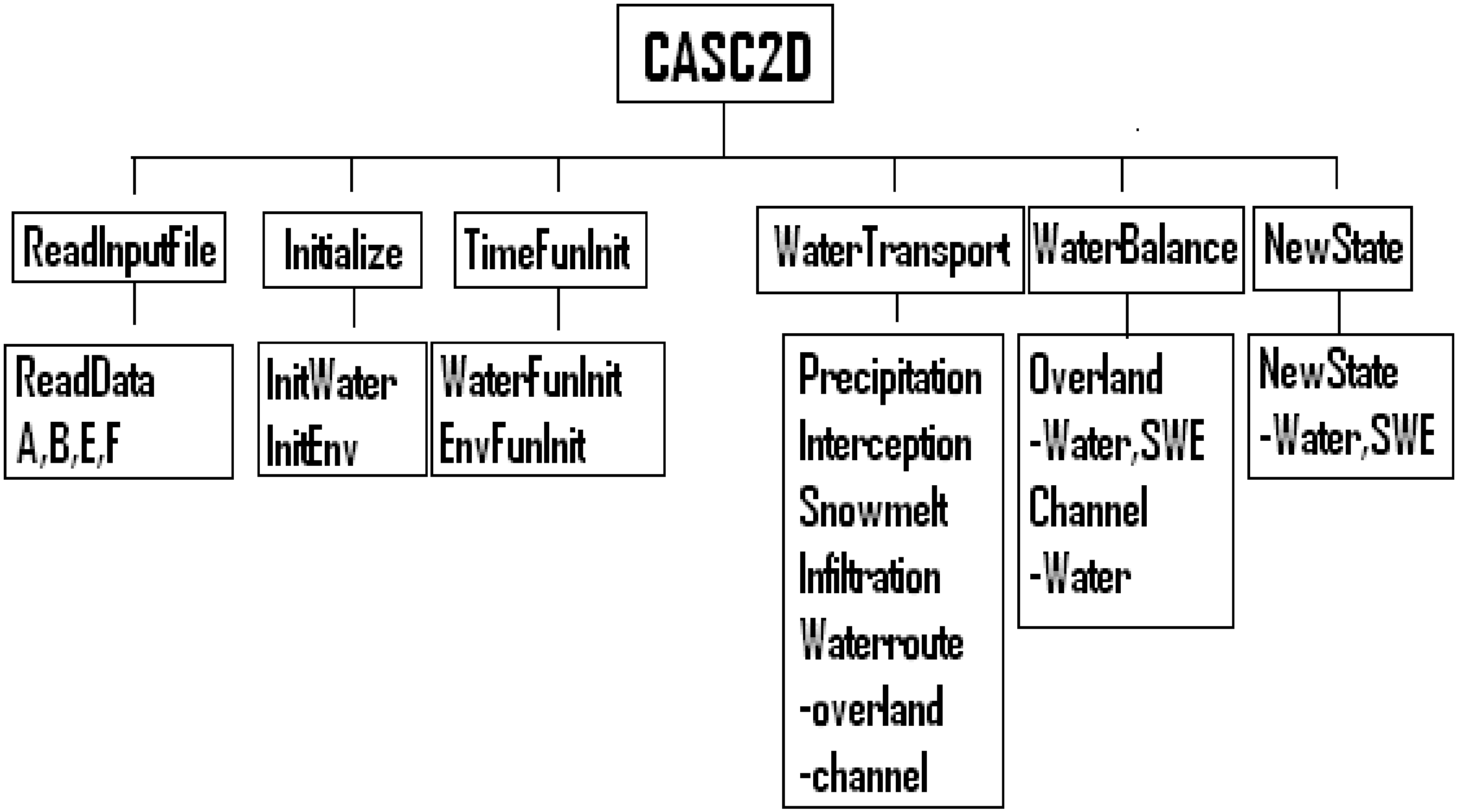

Figure 4-3 CASC2D Model Structure

The main module, CASC2D, controls all modules such as *ReadDataGroup*, *Initialize*, *TimefuncInit*, *WaterTransport*, *WaterBalance*, and *NewState*.

ReadDataGroupA reads the input for general controls like simulation type, grid characteristics, start time, time step function, print control, and making of echo file. *ReadDataGroupB* contains the mask, elevation, soils, landuse, snowmelt type, channel link/node, initial water depth/SWE, precipitation type, and reporting style/points. *ReadDataGroupE* has time functions for air temperature, wind speed, and relative humidity to use in snowmelt module. *ReadDataGroupF* deals with time series files of precipitation, water depth, and snow and summary files.

Initialize sets the initial value and memory allocation of hydrological variables and snow variables for computations. At the start of simulation, *TimeFunctionInit* set the starting values of parameters using control time series functions.

To compute derivative terms for water transport processes, precipitation, snowmelt, interception, infiltration, overland flow/routing, and channel flow/routing, *WaterTransport* function is called. *WaterBalance* module is to update water depths and SWE values in overland cells and channels for the next time step. Finally, *NewState* function stores new water depths and SWE in overland and channel cells for the next iteration.

CASC2D uses numerical integration to calculate the state variables, water depth, and SWE. Derivative terms and time steps are used to integrate state variables. The basic equation for numerical integration is

$$u(t+\Delta t) = u(t) + \frac{du}{dt}(t) \cdot \Delta t \qquad \textbf{(4-2)}$$

where t is time

Δt is time step.

u is state variables like water depth, and SWE.

$\frac{du}{dt}$ is derivative terms.

When the state variable is water depth, derivative terms will be the sum of precipitation rate, infiltration rate, interception rate, and snowmelt rate. In the case of SWE, the derivative terms will be the total snowmelt rate and snow sublimation rate. Especially, the snowmelt rate is a positive derivative to integrate water depth, and a negative value to calculate SWE in each cell.

4.5. Summary

CASC2D model integrates the state variables at each cell (30 by 30 meters) based on NAD 1983 GIS projection basis. California Gulch watershed is composed of overland and channel sections. To operate water routing in the domain, CASC2D uses overland and channel properties such as roughness, slope, soil, and landuse input data.

This study focuses on SWE change and snowmelt flow in overland and channel. Snowmelt module is plugged into CASC2D model. CASC2D provides the SWE and snowmelt rate as well as flow depth at each time step. The next chapter will include the simulation results and comparisons with actual runoff data.

CHAPTER 5:
SIMULATION RESULTS

5.1. Introduction

The snowmelt study in California Gulch demonstrates diurnal fluctuations of hydrographs at the various hydro stations including outlet. To simulate the change of SWE, snowmelt rate, and flow depth, ArcGIS Arc Macro Language (AML) provides Movie Maps during simulation time (from April 30 to May 28). This chapter utilizes the movie maps as GRID plots to illustrate the snowmelt processes. It also represents the comparisons between actual hydrographs and simulated ones on three peak days. Furthermore, the sensitivity tests based on the change of temperature from the entire air temperature, landuse, and aspect data are conducted.

5.2. Snowmelt Results

5.2.1. SWE Change

SWE changes with respect to the air temperature. Based on the initial condition of SWE, SWE is reduced as simulation time goes on. Because the initial SWE is distributed factored by the mean SWE from IDW, altitude and landuse, SWE in the lower gulch disappeared first. SWE in the downtown Leadville vanished faster than SWE at the same elevation in the forest or cultivated areas. In the late of simulation period (late May), there is still SWE in the upper California Gulch. SWE in the north aspect still exist whereas SWE in the south has gone. Figure 5-1 demonstrates the change of SWE during the simulation period (from April 30 to May 28).

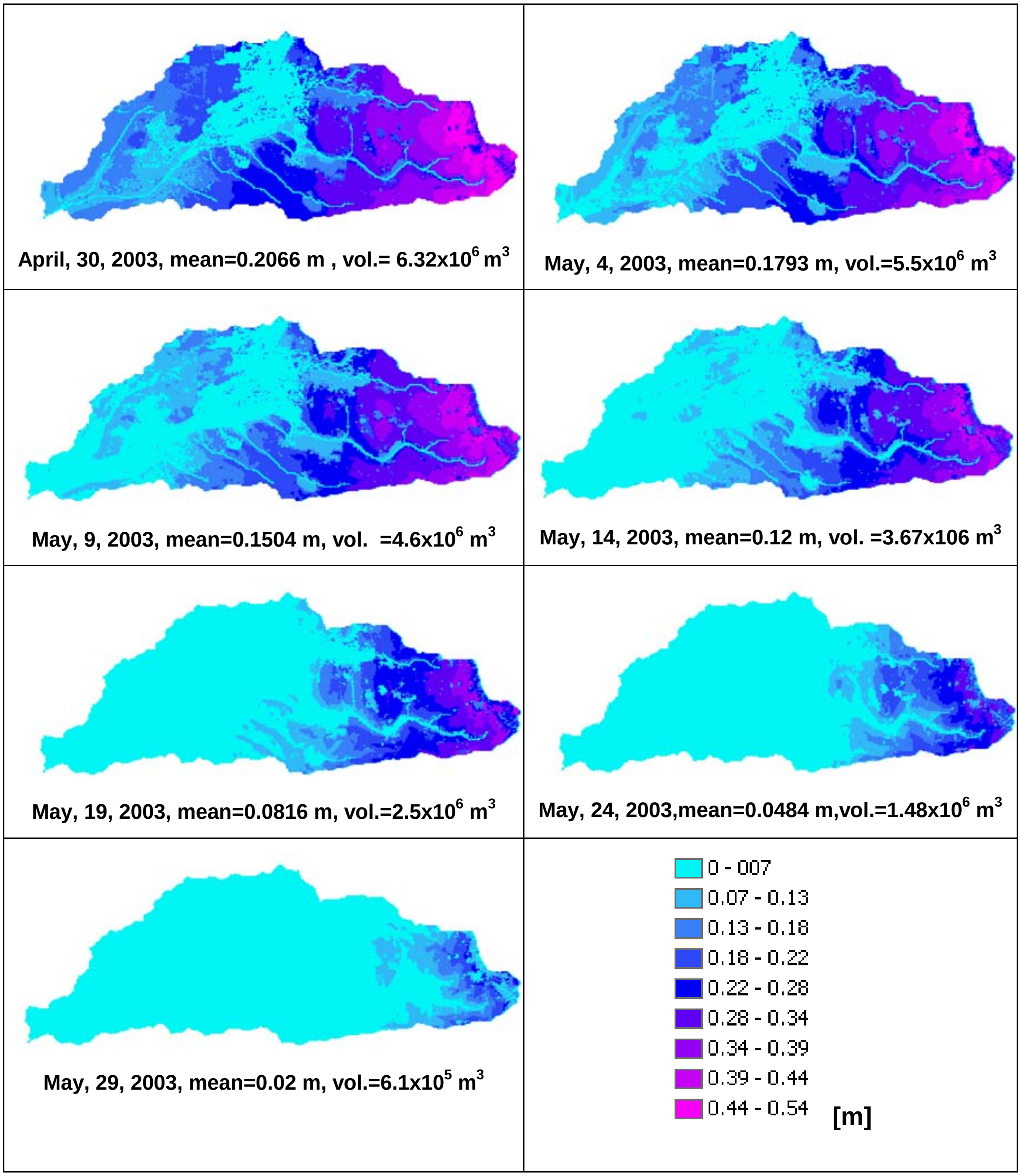

Figure 5-1 Snow Water Equivalence Frames with Time

In Figure 5-1, April 30 represents the initial SWE. Four days later, SWE in the lower gulch fades away. SWE in the developed area (downtown Leadville), and barren area (mid California Gulch) disappeared. Figure 3-8 shows that landuse classification of west downtown Leadville is forest. This is why the frame of May 9 still represents SWE in the west of downtown Leadville due to the negative air temperature forcing on forest. Fourteen days later, SWE downstream of the middle California Gulch disappeared whereas the north facing along the tributaries still exists. SWE in the upper California Gulch starts to melt on the May 19. Because the air temperature goes up to 15 ° C until the May 19, the lapse rate (about 2.11 ° C per 100 m) can not retreat the higher air temperature in the higher elevation. At the last day (May 29), SWE still remains in the highest elevation over the entire watershed.

5.2.2. Snowmelt Rate

Modified CASC2D calculates the snowmelt rate in mm per hour. Depending on the air temperature, SWE starts to melt and flow into each overland cell. If there is no SWE in a cell, the snowmelt rate becomes zero. It can show the processes how snow melts in a watershed. The melting processes are different with respect to altitude, aspect, and landuse. From the snowmelt method in Chapter 3, the lapse rate will change the air temperature with elevation. The south aspect has more snowmelt than the north aspect. In addition, the wooded areas have less snowmelt due to the negative forcing on air temperature.

Two days (May 3 and May 23) are chosen to characterize the early snowmelt and late snowmelt characteristics. Figure 5-2 represents the simulation results of May 3.

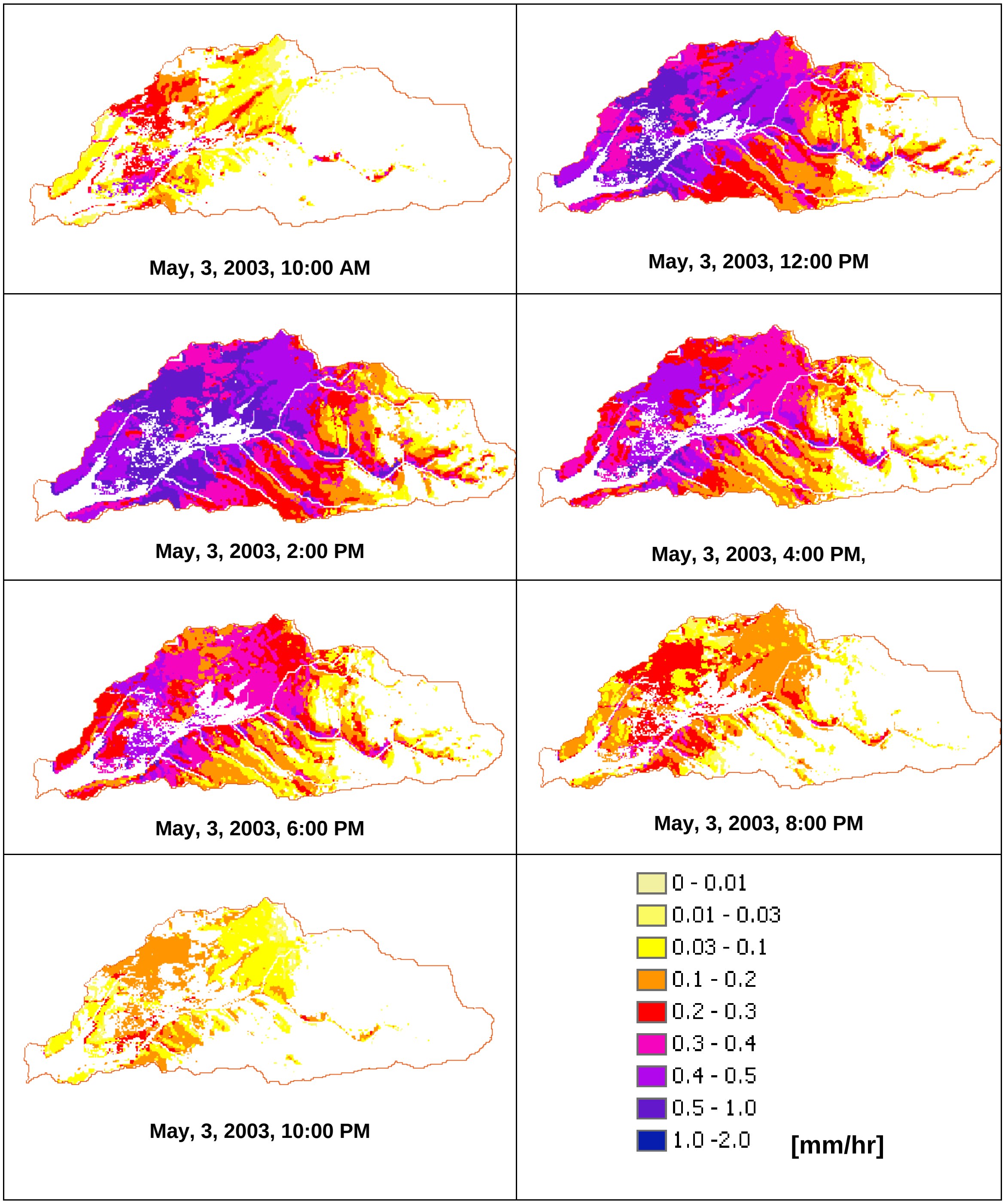

Figure 5-2 Snowmelt Rate Frames, May 3

At 10:00 AM, the SWE over the entire watershed still exist. It causes the possibility of the snowmelt in most of the California Gulch. At 12:00 PM, the snowmelt rate increases from the lower gulch. SWE at the lowest gulch and some parts of downtown Leadville, already vanished. At 2:00 PM, the snowmelt spans all of watershed without the upper California Gulch. Compared with SWE frames, the difference of snowmelt between north and south facing is better represented at 2:00 PM especially along the tributaries. From 4:00 PM, snowmelt starts to decrease from the higher altitudes. The reduction of snowmelt in north facing slope is faster than that of south face. Similar to the change of SWE, the snowmelt rate of the wooded areas of the west downtown Leadville, is less than adjacent regions despite of the lower elevation. At 10:00 PM, the snowmelt of partial downtown areas, and lower gulch still exist.

The reason why the lower gulch has no snowmelt, is because the first 3 days simulation melts most of snow cover in the lower gulch. To represent the snowmelt in the lower gulch and some parts of downtown Leadville, Figure 5-3 represents the significant snowmelt at 8:00 AM of the second day in the lower gulch and parts of downtown Leadville..

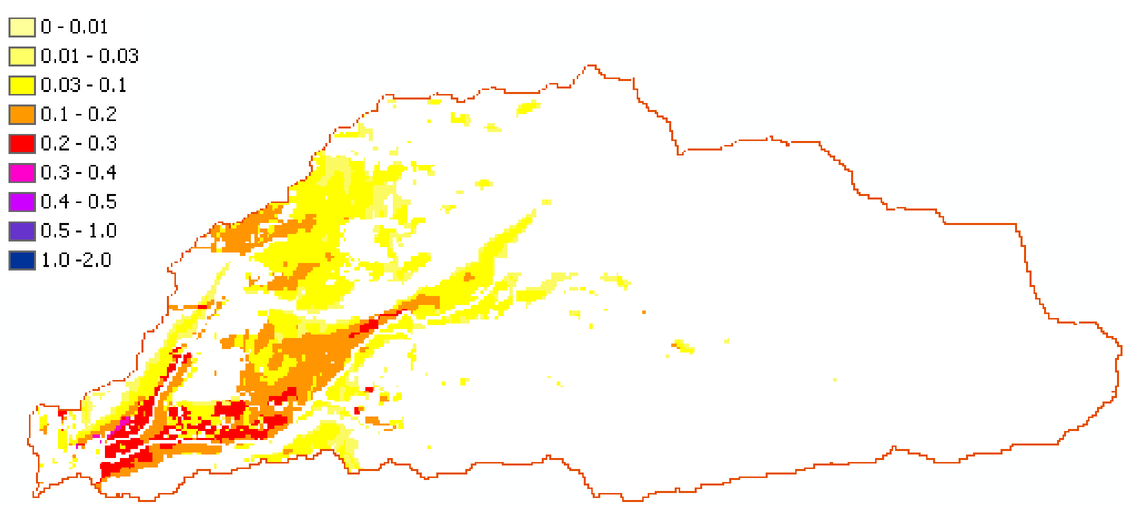

Figure 5-3 Snowmelt at 8:00 AM on the April 1st in mm/hour

Figure 5-4 shows the change of snowmelt rate on May 23. At this time, the snow cover downstream of middle California Gulch has disappeared, and SWE in the upper California Gulch still thaws even at the late snowmelt season.

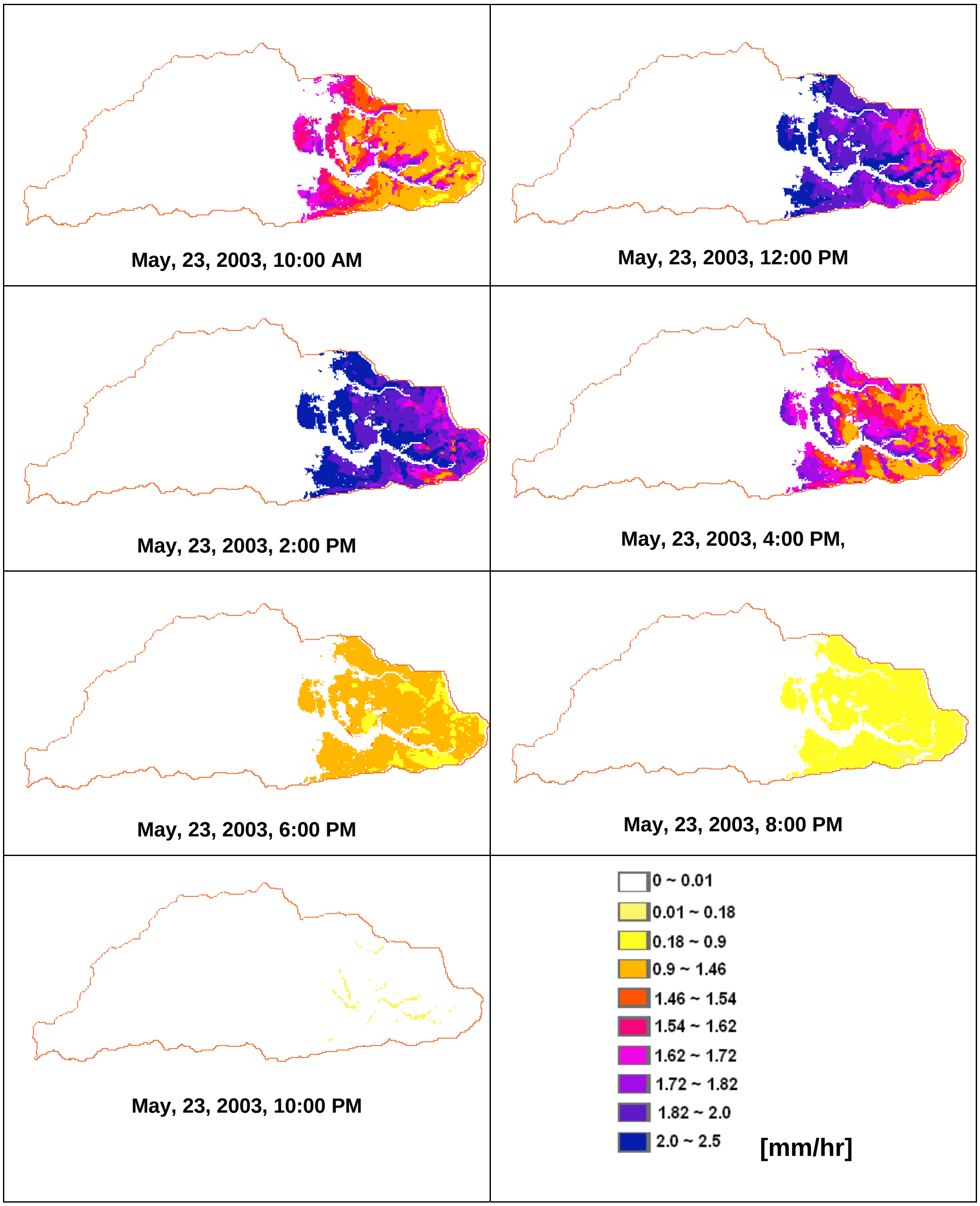

Figure 5-4 Snowmelt Rate Frames, May 23

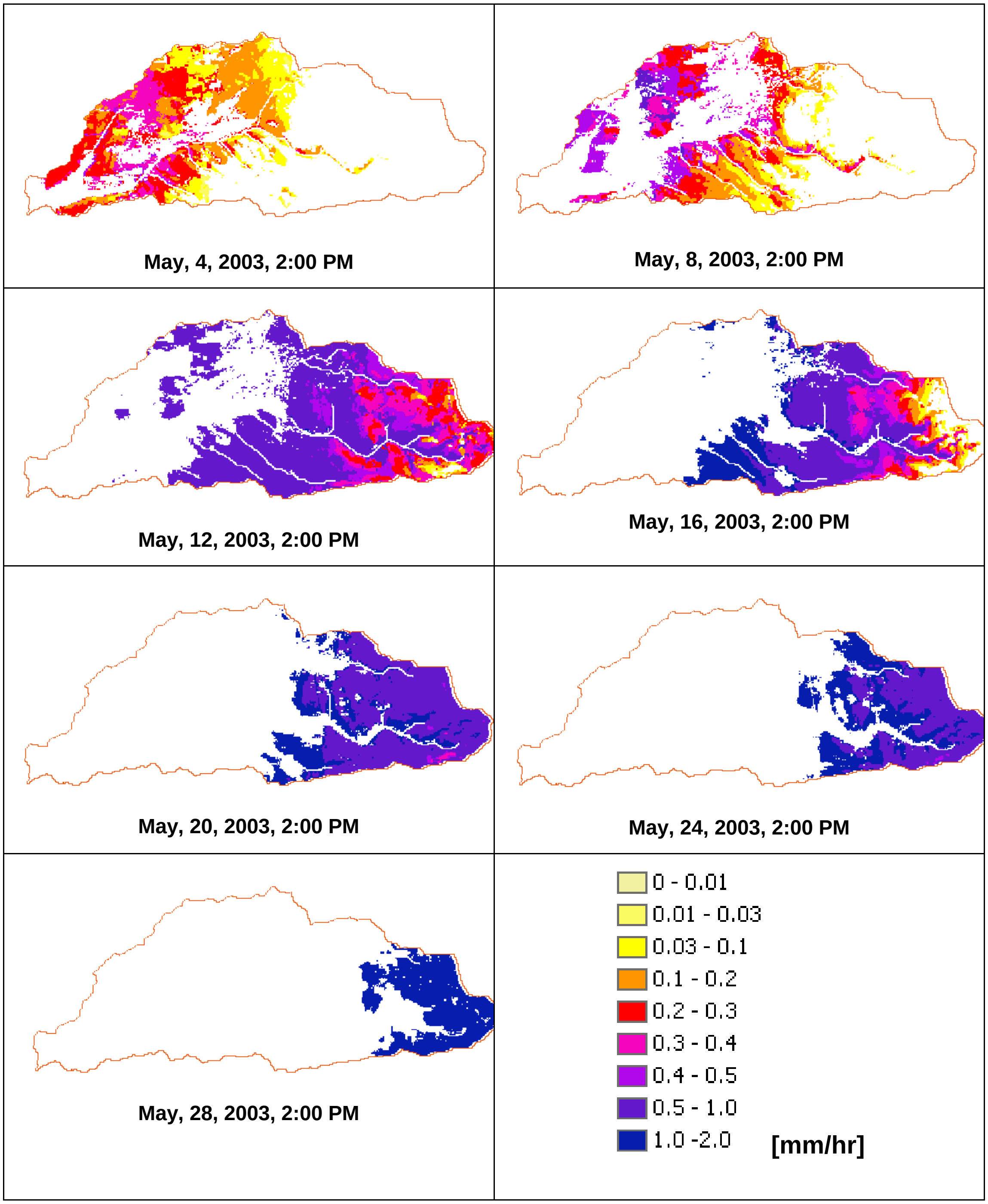

Figure 5-5 Monthly Snowmelt Rate Frames

At 10:00 AM, the SWE at the lowest elevation of the upper California Gulch starts to melt. Because the altitude along the gulch is lower than other mountain areas, SWE just near the gulch vanished. The snowmelt rate near the valley has above 2 mm/hr snowmelt rate. It causes more snowmelt in late May in California Gulch. After 4:00 PM, the snowmelt rate decreases from the upper mountain. Based on the effect of slope (Figure 3-5) and forested landuse, the mountain areas have less snowmelt rate. At night (10:00 PM), the snowmelt remains only at the lowest parts of the upper California Gulch.

Figure 5-5 shows the GRID plots of snowmelt rate in May. Considering the strength of color schemes, the snowmelt rate increases as the date go on. On May 4, the snow in the lower gulch only melts. Eight days later, the snowpack along the tributaries starts to melt with the melt difference between south and north aspect. After the May 12, the snowmelt intensity is above 0.5 mm/hr. After the May 24, the snowpack in the upper California Gulch still exists.

5.2.3. Flow Depth

Flow depth is scaled in meters, and dependent on available SWE and snowmelt rate at that time. It assumes that there is no precipitation during the simulation time. Therefore, water contents at each cell come only from the melted snow. Based on the snowmelt rate and SWE change, the flow depth frames represent how surface water flows in California Gulch watershed. Figure 5-6 represents how water from snowmelt flows in watershed on the May 3. In the early morning (8:00 AM), the flow appears at the lower gulch, in the west of downtown Leadville, and along the California Gulch. Even at the upper gulch, the altitude near streams is relatively low. It is why the flow emerges early in the morning at the high elevation.

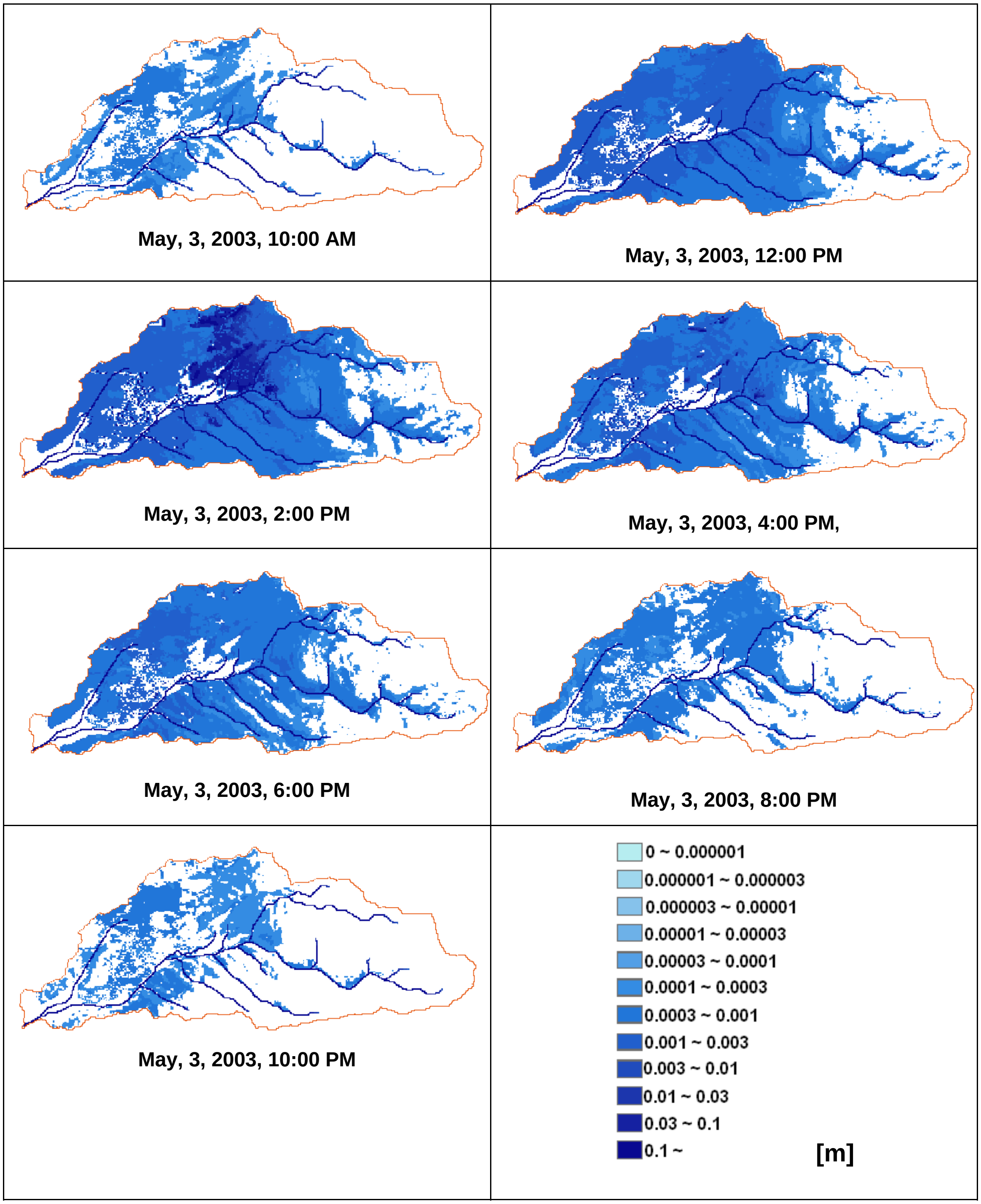

Figure 5-6 Flow Depth Frames, May 3

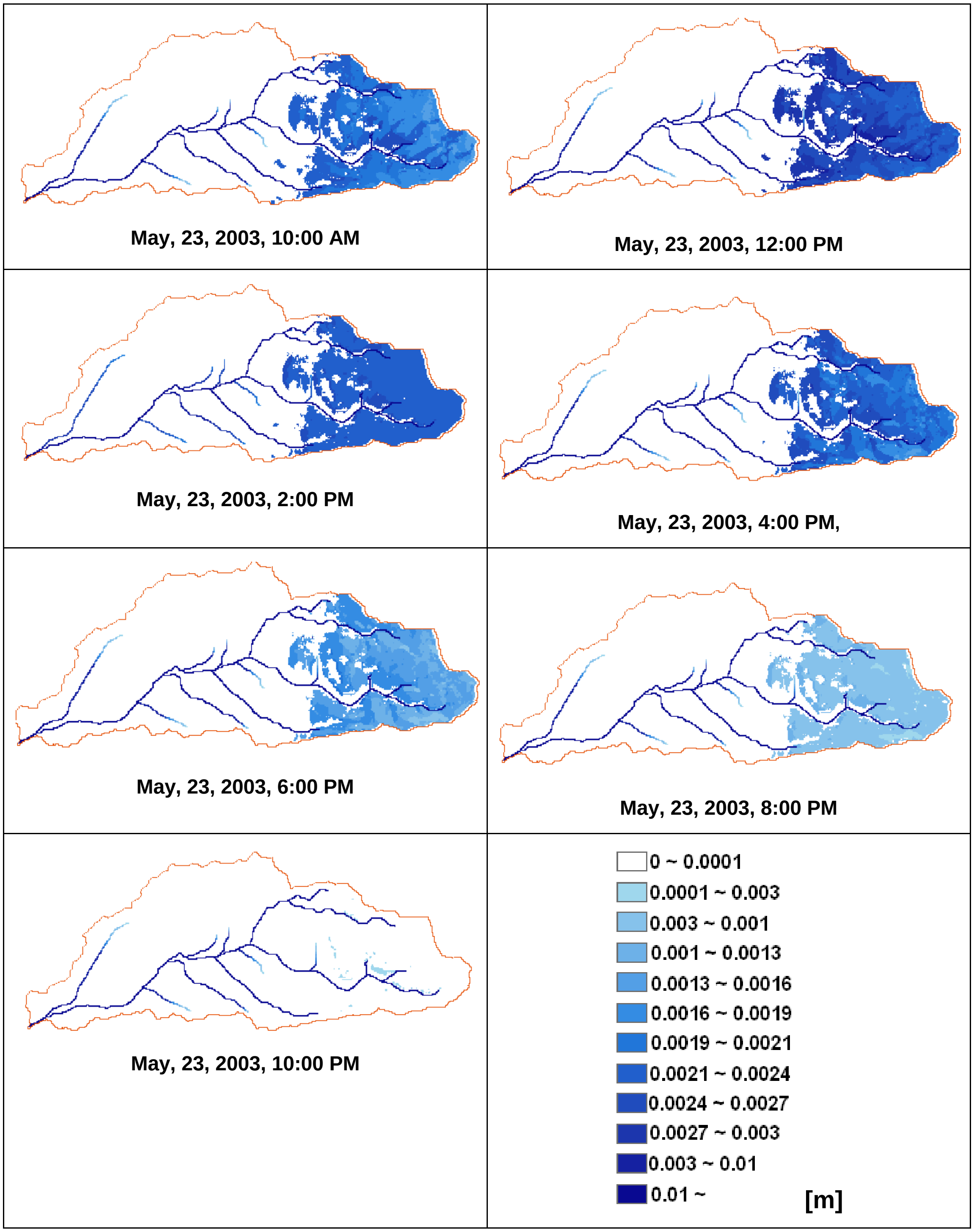

Figure 5-7 Flow Depth Frames, May 23

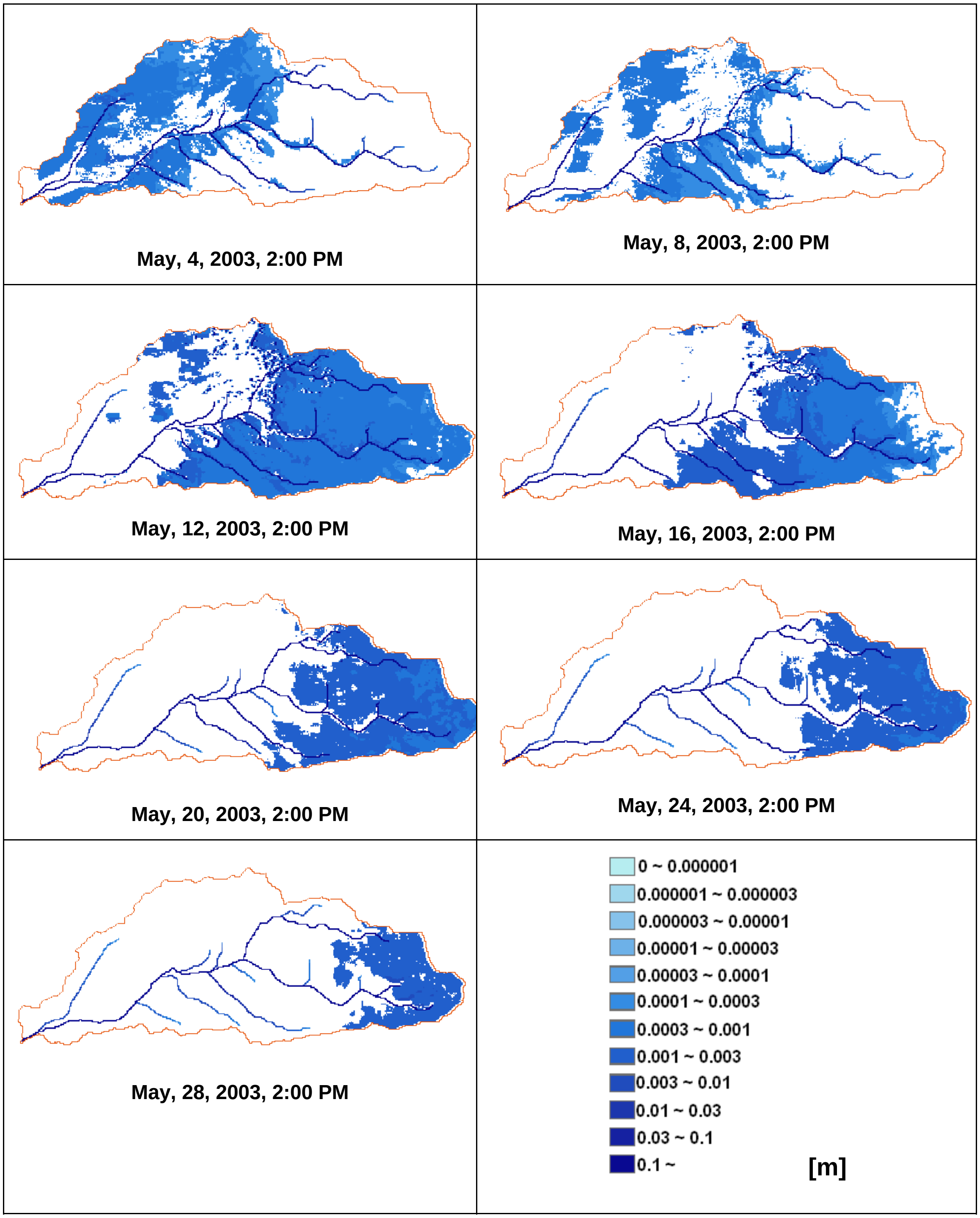

Figure 5-8 Monthly Snowmelt Rate Frames

After 12:00 AM, most regions except the upper California Gulch have more than 0.001 m flow. Some parts of downtown Leadville and lower gulch cannot have much snowmelt because there is no snow cover. At 4:00 PM, one can recognize that the south aspect along tributaries has more water than north aspect. This is because the air temperature of south aspect has positive addition of air temperature whereas north aspect has negative addition. After 8:00 PM, the flow depth starts to decrease. Finally, the frame of 10:00 PM is relatively similar to that of 10:00 AM.

Figure 5-7 shows the simulation of the flow depth on the May 23. The water only comes from the upper California Gulch because the snow cover downstream from the higher elevation already vanished. The change of blue index in Figure 5-6 represents the diurnal fluctuation of the snowmelt runoff even in the upper California Gulch.

Figure 5-8 represents how the water flows from which the snow melts in Figure 5-5. Similar to the snowmelt rate, the water spawns only in the lower gulch until May 8. After the snowpack vanishes, the water flows from the upper California Gulch. At last, the flow due to snowmelt still exists from the highest mountain in California Gulch.

5.3. Hydrograph Results

Figure 3-11 shows the comparisons between the actual runoff data and simulated ones at CG1, SD3, OG1, CG4 and CG6. Among 5 hydro stations, OG1, SD3, and CG6 are shown here whereas the remaining ones are represented in Appendix C. Basic model standard is that melt rate is 0.000000025 m/s, North/South temperature difference is 6 and 3 ° C, East/West temperature difference is 4 and 2 ° C, and the forested areas have -2 ° C (Chapter 3.3).

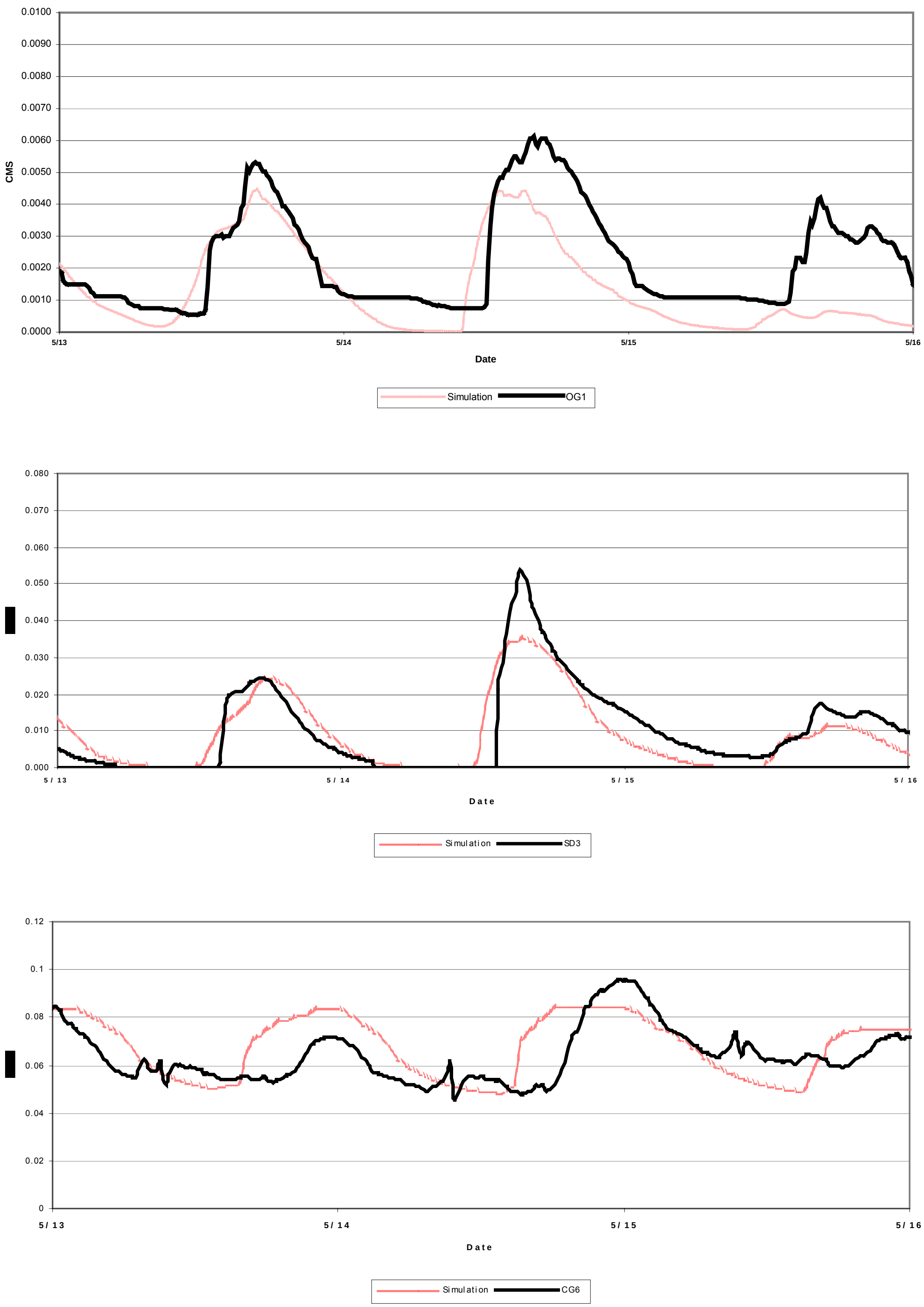

Figure 5-9 Three Days Hydrographs at OG1, SD3, and CG6 (outlet)

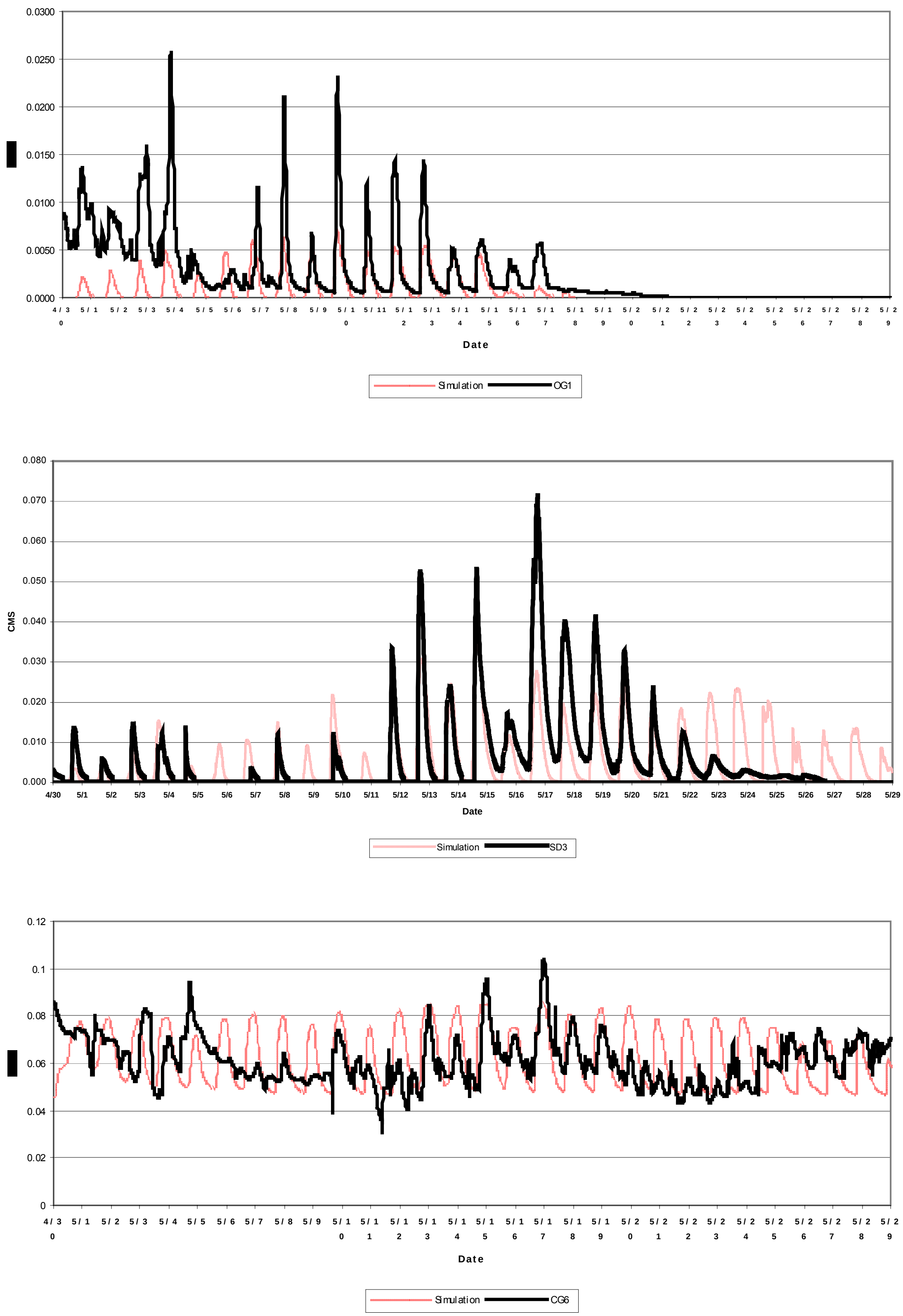

Figure 5-10 Thirty Days Hydrographs at OG1, SD3, and CG6 (outlet)

Figure 5-9 and 5-10 represent the three days and thirty days simulation, respectively. The order is Oregon Gulch (OG1), Stray Horse Gulch (SD3) and California Gulch (CG6).

The upstream of Oregon Gulch flows from the south east of the downtown Leadville. Its flood plain is composed of barren, woods, and some planted areas. The base flow is assumed to be zero m^3. The magnitudes of simulation are not consistent with measurements during 30 days simulation, whereas the peak time and fluctuations have good agreements. After May 18, the observation has no runoff. The simulation shows that there is no snowmelt after the 18^{th} of May. In 3 days of simulation, the simulated volume of runoff fits well with measurement of peak time and magnitude.

Stray horse Gulch flows through the downtown Leadville while the upstream of the gulch is barren and wooded areas. The base flow is assumed to be zero m^3 which to the same as Oregon Gulch. In the late May, the measured snowmelt runoff in the basin of Stray Horse Gulch comes to an end. The model overestimates the snowmelt in the late simulation times, although the discharge is decreased. By the way, 3 days simulation has a good agreement with the measurements (Figure 5-9). The investigation of air temperature change in the urban areas should be necessary to calibrate the discrepancies in SD3 simulation

Base flow is 0.046 m^3 in the simulation of CG6. Figure 5-9 represents the 3 days simulation. Despite of peak time difference and some discharge magnitude, the simulation is relatively correspondent to the measurements. From May 13 to 16, the actual runoff has the highest discharge during simulation times (Figure 5-9).

Figure 5-10 represents the 30 days simulation, which demonstrates the diurnal fluctuations due to snowmelt. From Appendix C, one can investigate that there are much differences between peaks and dips from the previous runs. This was caused by the set up for the wide lower gulch. In California Gulch, the lower gulch has the narrow and natural channel while the upper gulch is relatively wide and some are artificial channels. After changing the width of the lower gulch, simulation can reduce the peak's magnitudes. By the way, still the peak's difference is larger than that of measured hydrograph. The uncertainty of ground water, infiltration, and reservoir such as Leadville Water Treatment Plant, can cause the discrepancies between simulation and measurements. Table 5-1 shows the comparison of discharges between observation and simulation. Except for OG1 (due to the early May), CG6 and SD3 presents reasonable agreements between them.

Table 5-1 Comparison of runoff between observation and simulation

unit:m^3	CG6	OG1	SD3
Observation	153114	6297	14222
Simulation	155797	1952	13340

5.4. Sensitivity Test

The uncertainties of Temperature Index Approach are mainly caused by the air temperature distribution over the watershed. This study conducts the sensitivity tests with respect to the temperature variation of the entire air temperature, the forest factors, and aspect effects. Simulation is based on the same as the hydrograph in Chapter 5.3. Additionally, this chapter only focuses on the dependency of air temperature whereas the sensitivities to landuse and aspects are contained in Appendix C.

5.4.1. Sensitivity to Air temperature

To test the dependency on air temperature, the sensitivity tests are conducted by the increased and decreased of 2 ° C. The results are compared at the 5 hydro stations in the series of Figures during three days (May 13 to May 16, and T+2: add 2 ° C, T-2:subtract 2° C). Similar to the hydrograph results, OG1, SD3 and CG6 are shown here but, the remaining ones are in Appendix C.

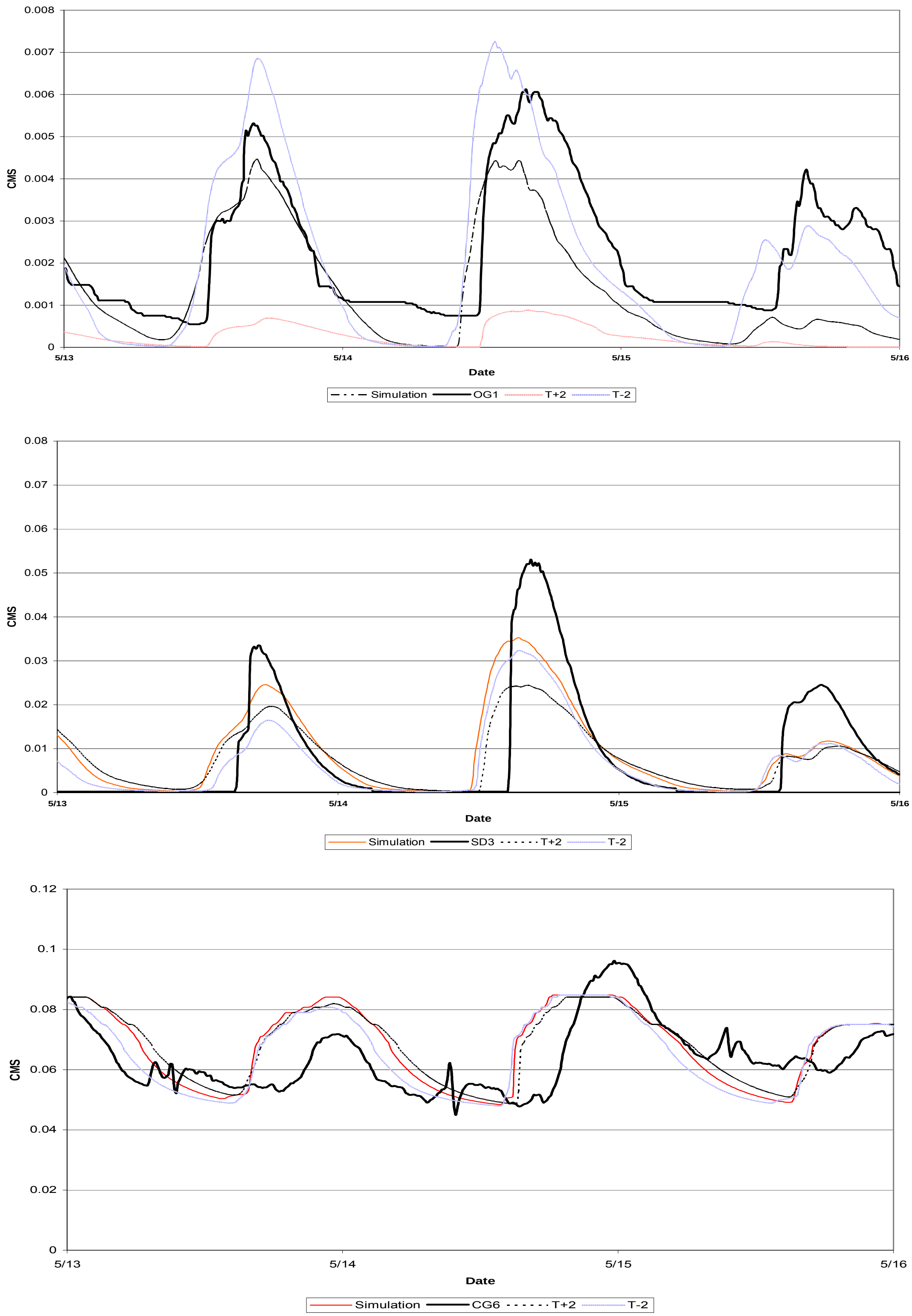

Figure 5-11 Sensitivity Tests to Air temperature at OG1, SD3, and CG6 (outlet)

Figure 5-11 shows that runoff volume of the decreased air temperature is larger than that of the increased air temperature (OG1). This could be due to the fact that there is more snowmelt in the early simulation times in the barren areas which is the flood plain of Oregon Gulch while at CG6, the higher runoff of the increased air temperature occurs during the recession times.

The sensitivity test of SD3 implies that decreased air temperature shows more reasonable results compared with measured hydrographs. It means that the melting rate on the SD3 was overestimated and it caused more snowmelt in the early snowmelt season and lower runoff in the late simulation dates. Except for this, the boom and recession of diurnal fluctuations among simulations are consistent reasonably with the measurements data.

5.5. Summary

This chapter includes the snowmelt, hydrographs, and sensitivity tests. The snowmelt results represent the change of SWE, snowmelt rate, and flow depth during the simulation times using ArcGIS. In the case of snowmelt and flow depth, one can see the effect of altitude, aspect, and landuse on snowmelt. In addition, there is still snowmelt rate and flow depth in the upper California Gulch at the late simulation times.

Simulated hydrographs were compared with the observed ones during thirty days and three days. The peak times of three days, CG4, OG1, and SD3 have the good agreements with the observed ones. However, there are still uncertainties in the effects of air temperature lapse rate, landuse, and aspects on the snowmelt schemes.

The sensitivity tests were performed with the individual parameters such as air temperature, forest factor and aspect effect. The air temperature has dominant effect on the runoff volume at the most hydro stations. However, the landuse and aspect effects are still ambiguous with the hydrological responses of water basin in the snowmelt procedures.

For future research on snowmelt modeling, the following subjects should be considered. First thing to understand is the importance of the initial SWE over the watershed. This study utilizes the altitude and landuse to provide the initial SWE. In addition, more topographical effects on the first SWE such as slope, aspect and shades should be adjusted. Besides the initial SWE, the air temperature is significant to the snowmelt. Air temperature should be distributed over the watershed with respect to altitude, landuse, and slope in addition to the time scales. This research tries to represents the topographical factor on air temperature. More sophisticated energy flux approach is necessary to adjust the spatial variation of air temperature. The energy and mass balance method can be an alternative approach to detect the energy fluxes with snowmelt whereas it requires more input data and parameters which are not commonly available. Indirect means to determine various input data for energy balance method still have a great degree of uncertainties. With the solar radiation data from the weather agency, the model can be more applicable to different watersheds. In snow hydrology, the movements of snow due to wind effect, interception, and infiltration are still ambiguous. The wind distributes more snow just under the hill, but little over the hill. Without the understanding of wind flow, the exact distribution of snow is still difficult to determine. The vegetation effect on snow should be considered to make snowmelt model. The sampling of snow may be conducted without consideration of the covered snow on the trees. In the case of deciduous trees, the snow on the leaves and stems are significant even compared with snow on surface. The retention of snow is complex especially during the snowmelt season. The melting snow can absorb water or adjacent snow which probably causes the snowmelt to retard. Research about snow absorbing of water contents is not enough to quantify the processes in the model.

As a result, a quantitative approach to snowmelt is a progressive work not only with previous modeling approaches but also this current research. Despite of the complexities of snowmelt procedures, the possible trials of models, and the continued tests should be carried out.

CHAPTER 6:
SUMMARY AND CONCLUSION

The Temperature Index Method is utilized to apply snowmelt procedures in California Gulch, Colorado. The snowmelt subroutine allows the air temperature to change with considerations of altitude, slope, aspect, and landuse. This subroutine is involved with the numerical model CASC2D to update SWE, and to produce snowmelt rate, and flow depth. The application into California Gulch, Colorado shows the reasonable results such as Movie Maps of SWE, snowmelt rate, and flow depth, and produces well fitted hydrographs at various stations.

6.1. Concepts of Snowmelt Procedures

Air temperature is the most significant parts to produce snowmelts in mountainous streams. During snowmelt season, the diurnal fluctuations of air temperature will change the snowmelt schemes. In addition to this, the topographical effects such as elevation, slope, aspect, and landuse influence the change of snowmelt procedures. The air temperature in this research is the function of the topographical factors. It changes the snowmelt processes at each location. The lapse rate of air temperature in elevation provides the decrease of air temperature in high altitude. The aspect values of north, south, east, and west adjust the air temperature at each location. Slope can also be applied into the consideration of aspect values. In addition, landuse such as forested regions controls the negative forcing on the air temperature.

6.2. Implementation of Snowmelt Subroutine

The numerical model CASC2D calculates the water depth at each cell within the watershed. To this end, it needs DEM, channel properties, landuse, and soil types GRID input data. The snowmelt subroutine is connected with CASC2D model. The subroutine calculates the amount of snowmelt and CASC2D routes the water into the watershed. The updated SWE is represented with GRID outputs. The melt water depth is plotted with flow depth within the watershed. In addition, the snowmelt rate in mm/hour is calculated inside the modified CASC2D. Other routing algorithms using slope, roughness, and soil types are followed by the previous CASC2D.

6.3. Tests of Snowmelt Subroutine in California Gulch

ArcGIS AMLs allow us to provide the Movie Maps with the ASCII tables of the snow water equivalence, snowmelt rate, and flow depth which are calculated from CASC2D. The visualization of the snowmelt rate could illustrate the topographical effects of altitude, slope, and aspect in the mountainous stream. One can see the long term snowmelt processes as well as the diurnal fluctuations using Movie Maps. In addition, ArcGIS utilizes DEM to make slope, and aspect values at each points. They could provide the input data for the distributed model, CASC2D. Doing so, CASC2D considers the topographical effects on snowmelts.

Additionally, the modified CASC2D simulates the hydrographs at CG6, OG1, and SD3. The comparison between simulated discharges and observed ones shows the reasonable agreements. The base flow at CG6 is 1.61 cfs, and others at OG1 and SD3 are zero. In addition to the 30 days simulations, the three peak days (from 13th to 16th of May) are compared with the actual discharge. In the case of peak days, the peak time and magnitudes are resonablly fitted well with the observations.

6.4. Concluding Remarks

The distributed hydrologic model CASC2D was modified to apply to snowmelt in mountainous watersheds. The surface runoff processes and hydrographs due to snowmelt are described using GIS and numerical modeling.

Because the Temperature Index method is based on an empirical equation, the melt rate should be adjusted to the specific watershed. In the case of landuse, the urban area, and forested regions could be more adjusted with the reasonable air temperature forcing. Considering topographical effects on air temperature can allow the Temperature Index Approach to estimate the snowmelt in a more realistic way.

Additionally, CASC2D model can be applied to the snowmelt schemes with the consideration of an energy balance model with more available data such as solar radiation, wind speed, and saturation vapor pressure over the watershed. With the understandings of the initial SWE, spatial distribution of air temperature, snow movements such as interception, and wind redistribution, the quantitative approach to snowmelt can be improved. Furthermore, the direct observations of the solar radiation or indirect ways to determine them, allow the physically based energy balance models which can be applied into any watershed for snowmelt estimations. Furthermore, CASC2D can adopt the updated erosion and sediment model with the consideration of snowmelt runoff. Higher snowmelt runoff due to the abrupt increase of air temperature can rigorously produce the sediment transport. It can be the next challenge with the distributed model CASC2D.

The empirical equation to calculate the amount of snowmelt was applied to California Gulch, Colorado. More investigation of topographical effects such as altitude, slope, aspect, and landuse/soil types on the mountainous stream will help to more accurately estimate snowmelt runoff in the mountainous basin.

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APPENDIX A:

SourceWater Snow Samples & D'statics

Table A-1 SourceWater Snow Samples

			Date	3/12/2007				
Samplers:	SWE	Justin Severyn, Craig Mueller				Start Time	900	
Dan Stephens	NOTES	Dan Stephens, Nick Wieland				End Time	1830	
Severyn, Nick Wieland								
er Observerth 10 mph (Leadville weather station)								
		All measurements in INCHES						
Site	Time	Snow Depth	Core Length	Wt. of Core and Tube	Wt. Of Empty Tube	Water Content	Density Percent	NOTES
UCG	957	NA	21.75	36	30	6	#VALUE!	
UCG	957	36	22	36	60	6	0.17	
						6	0.17	
ORO City	1047	35	19.25	36	30	6	0.17	
ORO City	1047	35	20.75	36.5	30.5	6	0.17	
						6	0.17	
NUGGET	1110	31	21.5	40	30	10	0.32	signs of wind loading
NUGGET	1119	30.5	17	36	30	6	0.20	this is a south facing slope
NUGGET	1121	30	13	35.5	30	5.5	0.18	
						7.17	0.23	
HIGH MARY	1154	24	13.5	35	30	5	0.21	
HIGH MARY	1154	25.5	15.25	35	30	5	0.20	
HIGH MARY	1154	27	18.5	35	30	5	0.19	
						5.00	0.20	
CARB HILL	1310	26.5	12.5	35	30	5	0.19	
CARB HILL	1312	26.5	14	35	30	5	0.19	
CARB HILL	1315	26.5	12	34.5	30	4.5	0.17	
						4.83	0.18	
IRON HILL	1352	30	19	37	30	7	0.23	1" dirt
IRON HILL	1353	29.5	21	37	30	7	0.24	.5" dirt
IRON HILL	1355	30.5	20.5	37	30	7	0.23	.5" dirt
						7.00	0.23	
PPER ADELAI	1426	21.5	19.5	36	30	6	0.28	No Dirt
PPER ADELAI	1430	30	21.5	37.5	30	7.5	0.25	Snow depth was Est. No Dirt
PPER ADELAI	1433	30	18	37	30	7	0.23	No Dirt
PPER ADELAI	1436	29.5	21.5	37	30	7	0.24	No Dirt
						6.88	0.25	
IRENE	1515	23	14	34.5	30	4.5	0.20	.5" dirt
IRENE	1518	21	13	34	30	4	0.19	1" dirt
IRENE	1520	13.5	15	35	30	5	0.37	.5" dirt
						4.50	0.25	
FAMOUS	1608	40	28.5	39.5	30	9.5	0.24	Snow depth was Est.
FAMOUS	1611	40.5	18.5	38.5	30	8.5	0.21	
FAMOUS	1615	40.5	26.5	38	30	8	0.20	
FAMOUS	1617	40	27.5	39	30	9	0.23	
						8.75	0.22	
FRYER HILL	1648	28.5	15	35	30	5	0.18	
FRYER HILL	1650	28.5	13	35	30	5	0.18	
FRYER HILL	1652	29	17.5	36.5	30	6.5	0.22	
FRYER HILL	1654	28.5	16.5	36	30	6	0.21	
						5.63	0.20	
COMMENTS:								
							0.21	

Table A-2 SourceWater Snow Samples (Continued)

			Date	3-18-09 / 3-19-09				
Samplers:	SWE	Craig Martel, Ryan Gustafson, Nick Wieland				Start Time	[8:00:00 3-18-09] [1300 3-19-09]	
	NOTES	Craig Martel				End Time	[1645 3-18-09] [1530 3-19-09]	
er Observations:								
f new snow, according to the Leadville bank the temp. was 20°F.								
ak RH 00% according to the Leadville airport weather station.								
		All measurements in INCHES						
Site	Time	Snow Depth	Core Length	Wt. of Core and Tube	Wt. Of Empty Tube	Water Content	Density Percent	NOTES
UCG	1030	45.5	16.5	35	30	5	0.11	
UCG	1035	46.5	20	36	30	6	0.13	
UCG	1038	46	20.5	39	30	9	0.20	
UCG	1041	45.5	21.5	36	30	6	0.13	
						6.5	0.14	
Granity	1140	45	20.5	38	30	8	0.18	
Granity	1143	42.5	12	33	30	3	0.07	
Granity	1146	45.5	29.5	39	30	9	0.20	
Granity	1149	46	29	39	30	9	0.20	
						7.25	0.16	
Haggel	1303	32	17	34.5	30	4.5	0.14	
Haggel		34	22	37	30	7	0.21	
Haggel		15	14.5	32	30	2	0.13	
Haggel		31	22	37	30	7	0.23	
Haggel	1330	31.5	19.5	36	30	6	0.19	
						5.3	0.18	
High Marg	1420	33.5	20	35.5	30	5.5	0.16	.5 dirt, found trouble but on fla
High Marg		31.5	18	33	30	3	0.10	.5 air
High Marg		33.5	29	35	30	5	0.15	flash
High Marg	1440	32.5	20	34.5	30	4.5	0.14	1.0 air
						4.5	0.14	
Carb hill	1507	34	17.5	36	30	6	0.18	No Dirt
Carb hill		33	16.5	35	30	5	0.15	
Carb hill		34.5	26.5	37	30	7	0.20	
Carb hill		34	18.5	33	30	3	0.09	
Carb hill		35	19	34.5	30	4.5	0.13	
Carb hill		33	18.5	32.5	30	2.5	0.08	
Carb hill	1525	35.5	14.5	35	30	5	0.14	
						4.71	0.14	
Iron Hill	1611	39.5	24.5	38	30	8	0.20	
Iron Hill		39.5	24.5	37	30	7	0.18	
Iron Hill	1624	40	24	37.5	30	7.5	0.19	
						7.5	0.19	
Fryer Hill	1320	33	12.5	35	30	5	0.15	
Fryer Hill		34	9	33	30	3	0.09	
Fryer Hill		35	21	37.5	30	7.5	0.21	
Fryer Hill		35	18.5	36	30	6	0.17	
Fryer Hill		34	14	33	30	3	0.09	
Fryer Hill		35	11.5	33	30	3	0.09	
Fryer Hill		35	22	37	30	7	0.20	
Fryer Hill	1400	35	20.5	37	30	7	0.20	
						5.1875	0.15	
Famous	1426	49.5	20	40	30	10	0.20	
Famous		49.5	20	39	30	9	0.18	.5 Dirt
Famous	1440	39.5	20	40	30	10	0.25	
						9.67	0.21	
						5.52	0.16	
ed through two consecutive days, data for 3-18-09 is recorded on sheet 1								
s located on sheet 2 of this spread sheet.								

Table A-3 SourceWater Snow Samples (Continued)

SWE Data for Leadville Superfund Site Snowpack Sampling Sites

			Date	3/26/2007				
Samplers:	SWE	Craig Markel				Start Time	915	
	NOTES	High Weiland				End Time	1600	
...Observations:								
55X, 1.5-2" of new snow in past 24hr,								

Site	Time	Snow Depth	Core Length	Wt. of Core and Tube	Wt. Of Empty Tube	Water Content	Density Percent	NOTES
		All measurements in INCHES						
UCG	930	44	27	39.5	30	9.5	0.22	
UCG		43.5	27	39	30	9	0.21	
UCG	935	43.5	26.5	40	30	10	0.23	
						9.50	0.22	
ORO	1005	40.5	20.5	39	30	9	0.22	
ORO		42	27	40	30	10	0.24	
ORO	1020	41.5	22.5	40	30	10	0.24	0.5 Dirt
						9.67	0.23	
HUGG	1036	31.5	19	37.5	30	7.5	0.24	
HUGG		29.5	16	36	30	6	0.20	
HUGG		32	8	33	30	3	0.09	
HUGG		31.5	12	34.5	30	4.5	0.14	
HUGG	1046	32	19.5	35	30	5	0.16	
						5.20	0.17	
HIGH MARY	1125	30.5	19	37	30	7	0.23	1.0 Dirt
HIGH MARY		31.5	9.5	34.5	30	4.5	0.14	
HIGH MARY		32	10.5	34	30	4	0.13	
HIGH MARY	1134	31.5	10	34	30	4	0.13	
						4.88	0.16	
CARR HILL	1152	34	22	39	30	9	0.26	0.5 Dirt
CARR HILL		34	14.5	35	30	5	0.15	0.5 Dirt
CARR HILL		31.5	21	37.5	30	7.5	0.24	0.5 Dirt
CARR HILL	1235	31.5	21	37	30	7	0.22	0.5 Dirt
						7.13	0.22	
IRON HILL	1247	35	29	38	30	8	0.23	0.5 Dirt
IRON HILL		35.5	16.5	37	30	7	0.20	
IRON HILL		37	22.5	38	30	8	0.22	
						7.67	0.21	
UP ADD	1311	38	29	38	30	8	0.21	
UP ADD		37.5	27.5	40	30	10	0.27	
UP ADD	1316	38.5	24.5	39	30	9	0.23	
						9.00	0.24	
IRENE	1350	35	20	37	30	7	0.20	Heavy Snowmobile tracks
IRENE		34	29	36.5	30	6.5	0.19	Heavy Snowmobile tracks
IRENE	1356	34	26.5	37.5	30	7.5	0.22	Heavy Snowmobile tracks
						7.00	0.20	
FRYER HILL	1432	31	20.5	37	30	7	0.23	
FRYER HILL		29	9.5	33	30	3	0.10	
FRYER HILL		30.5	21	37.5	30	7.5	0.25	
FRYER HILL		29	12	34.5	30	4.5	0.16	
FRYER HILL		29	12	34.5	30	4.5	0.16	
FRYER HILL	1440	29	12	34.5	30	4.5	0.16	
						5.17	0.17	
FAMOUS	1509	46	20.5	40	30	10	0.22	
FAMOUS		40	31	41	30	11	0.28	
FAMOUS	1516	46.5	31	41	30	11	0.24	
Comments:						10.67	0.24	
							0.20	

Table A-4 SourceWater Snow Samples (Continued)

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[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
						[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
						[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
						[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
						[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
						[illegible]	[illegible]	
						[illegible]	[illegible]	

Table A-5 SourceWater Snow Samples (Continued)

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table A-6 SourceWater Snow Samples (Continued)

[illegible]

Table A-7 SourceWater Snow Samples (Continued)

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table A-8 SourceWater Snow Samples (Continued)

[illegible]

Table A-9 SourceWater Snow Samples (Continued)

[illegible]

Table A-10 SourceWater Snow Samples (Continued)

uperfund Site Snowpack Sampling Sites

5/15/2007

Start Time 9:30
End Time 13:30

.4° F. RH 45%

easurements in INCHES				
Wt. of Core and Tube	Wt. of Empty Tube	Water Content	Density Percent	NOTES
43	34	9	0.28	Hard Ice Layers
41.5	34	7.5	0.25	
43	34	9	0.29	
43	34	9	0.30	
42	34	8	0.26	
43	34	9	0.30	
44	34	10	0.34	
41	34	7	0.26	
43	34	9	0.34	
[illegible]	[illegible]	[illegible]	[illegible]	
		[illegible]	[illegible]	
43	34	9	0.36	
43	34	9	0.37	
42	34	8	0.33	
43	34	9	0.33	
42	34	8	0.36	
42	34	8	0.33	
41	34	7	0.35	
42	34	8	0.33	
42	34	8	0.30	
[illegible]	[illegible]	[illegible]	[illegible]	
		[illegible]	[illegible]	
41	34	7	0.30	
41	34	7	0.37	
41	34	7	0.30	
41	34	7	0.37	
41	34	7	0.36	
41	34	7	0.36	
[illegible]	[illegible]	[illegible]	[illegible]	
		[illegible]	[illegible]	
			0.00	No Snow In Sample
			0.00	No Snow In Sample
42	34	8	0.45	
42	34	8	0.45	
41	34	7	0.37	
41	34	7	0.30	
41.5	34	7.5	0.30	
42	34	8	0.41	
41.5	34	7.5	0.30	
42	34	8	0.40	
41.5	34	7.5	0.33	
[illegible]	[illegible]	[illegible]	[illegible]	
		[illegible]	[illegible]	
41.5	34	7.5	0.27	
42	34	8	0.27	
42	34	8	0.28	
42	34	8	0.28	.5 dirt
42.5	34	8.5	0.30	
42.5	34	8.5	0.31	
42.5	34	8.5	0.30	.5 dirt
42	34	8	0.29	
42	34	8	0.29	
[illegible]	[illegible]	[illegible]	[illegible]	Ice Layer
		[illegible]	[illegible]	
43.5	34	9.5	0.40	
44	34	10	0.45	
42	34	8	0.34	
42	34	8	0.35	
40	34	6	0.25	
43	34	9	0.30	
43.5	34	9.5	0.41	
43	34	9	0.33	
43.5	34	9.5	0.40	
[illegible]	[illegible]	[illegible]	[illegible]	
		[illegible]	[illegible]	
				No snow In Sample
		[illegible]	[illegible]	

Table A-11 SourceWater Snow Samples (Continued)

lle Superfund Site Snowpack Sampling Sites

Date 5/29/2007

Start Time 9:30
End Time 13:30

Calm and clear, 35.1 F, RH 45%

All measurements in INCHES

Core Length	Wt. of Core and Tube	Wt. Of Empty Tube	Water Content	Density Percent	NOTES
4.5	19	17	2	0.36	
5.5	20	17	3	0.50	
7	20.5	17	3.5	0.49	
7.5	21	17	4	0.53	
7	20	17	3	0.26	
7	20	17	3	0.26	
7	20	17	3	0.26	
5	19	17	2	0.19	
9.5	22	17	5	0.30	
11	22	17	5	0.26	
12	23	17	6	0.27	
			3.55	0.31	
3.5	19.5	17	2.5	0.51	
3	18	17	1	0.22	
5	19	17	2	0.33	
5	19	17	2	0.33	
6	20	17	3	0.39	
5.5	19	17	2	0.25	
5	19	17	2	0.26	
7	20	17	3	0.31	
			2.19	0.32	
4	18.5	17	1.5	0.31	
4	19	17	2	0.41	
3	18	17	1	0.21	
3.5	18	17	1	0.31	
4.5	19	17	2	0.35	
5	19.5	17	2.5	0.24	
5	19	17	2	0.24	
7	20	17	3	0.24	
4	18.5	17	1.5	0.16	
			1.89	0.29	
5	19	17	2	0.33	
3.5	18	17	1	0.12	
3	18	17	1	0.12	
3	18	17	1	0.14	
3.5	18.5	17	1.5	0.24	
3.5	18.5	17	1.5	0.24	
4	19	17	2	0.23	
3	18	17	1	0.19	
			1.50	0.23	
9	21.5	17	4.5	0.26	
8	21	17	4	0.29	
9	21.5	17	4.5	0.29	
13	22.5	17	5.5	0.21	
13	25	17	8	0.36	
11.5	22	17	5	0.23	
11	22	17	5	0.22	
12	24	17	7	0.32	
13.5	23	17	6	0.22	
13	24	17	7	0.21	
14.5	23	17	6	0.29	
14.5	23	17	6	0.29	
			5.71	0.28	
11	23	17	6	0.31	
9	22	17	5	0.39	
8.5	22	17	5	0.39	
9.5	22	17	5	0.36	
9	21.5	17	4.5	0.33	
9.5	22	17	5	0.36	
8.5	21.5	17	4.5	0.35	
			5.00	0.35	

D-test (D'Agostino, 1971) [see Gilbert, 1987]	
D	2.80E-01
Y	-5.63E-03
alpha	0.05
apha/2	0.025
1-apha/2	0.975
Accept or Reject?	***Accept***
N	$Y_{0.025}$
100	-2.552
150	-2.452
119	-2.514

$$D = \frac{\sum_{i=1}^{n} [i - 0.5(n+1)] x_i}{n^2 \sigma}$$

$$Y = \frac{D - 0.28209479}{0.02998598\sqrt{n}}$$

Figure A-0-1 D Test Result

APPENDIX B:

CASC2D Snowmelt & AML CODES

```
/*---------------------------------------------------------------------
C-  Function:     Snowmelt.c
C-
C-  Purpose/    Snowmelt.c computes the snowmelt rate
C-  Methods:    for each cell in the overland plane
C-                      based on energy balance equations and
C-                      snow water equivalent (SWE).
C-
C-  Inputs:     sweov[][] (at time t),
C-              netsolarradiation[][] (at time t),
C-                      airtemp[][] (at time t),
C-                      windspeed (at time t),
C-                      relativehumidity[][] (at time t),
C-                      barometricpressure[][] (at time t),
C-
C-  Outputs:    snowmeltrate[][] (at time t)
C-
C-  Controls:   imask[][],
C-                      sweov[][] (at time t)
C-
C-  Calls:      None
C-
C-  Called by:  WaterTransport
C-
C-  Created:      Do-Hyuk Kang (CSU)
C-
C-  Date:       14-FEB-2005
C-
C-  Revised:
C-
C-  Date:
C-
C---------------------------------------------------------------------
*/

//casc2d global variable declarations
#include "casc2d_general_declarations.h"

//casc2d global variable declarations for water transport
#include "casc2d_water_declarations.h"

//casc2d global variable declarations for environmental conditions
#include "casc2d_environment_declarations.h"

void Snowmelt()
{
      //local variable declarations/definitions
      int
            chanlink,   //channel link number
            channode;   //channel node number

      float
            airtempz,         //air temperature adjusted with elevation
            cairtemp,         //critical air tempeature to calculate
snowmelt with tempeature index method
            lch,              //channel length (m) (includes sinuosity)
            twch,             //top width of channel at flow depth (m)
```

```
            achsurf,          //surface area of channel (m2)

            eat,              //integrated effective emissivity of the
atmosphere
            vaporpressure,    //vapor pressure (mb)
            sigma,                  //Stefan-Boltzmann constant
W/m^2/K^4
            qlongnet,         //Longwave radiation w/m^2

            isc,              //solar constant W/m^2

            gamma,                  //Day angle (radians) (position of
the earth as it orbits the sun (gamma = 0 on Jan 1)
            enot,             //Eccentricity, relative distance of the
earth from the sun
            delta,                  //Declination of sun (radians)
            latitude,         //latitude at which the sun is directly
overhead
            omega,                  //omega 15 degree over hour
(Radian/hour)
            tsn,              //tsn is them time before (negative) or
after (positive) solar noon (hour)
            albedo,                 //approximated albedo during melt
            qkin,             //shortwave radiation
            qshortnet,        //net short wave radiation (W/m2)
            qstar,                        //net solar radiation (W/m2)

            densitya,         //density of air for a cell (varies with
elevation) (kg/m3)
            cpa,              //specific heat of air KJ/kg/degree
celsius
            kv,                     //Von Karman constant = 0.4
(dimensionless)
            zprime,                //height of anemometer above ground,
user's option (m)

            snowpackdepth,    //depth of snow pack, used for sensible
heat calculation (m)
            snowfalldepth,    //depth of snow fall, used for
dullness/abedo calculations (m)
            densitys,         //density of snow (kg/m3) (assumed
constant, 100 kg/m3)

            znot,             //roughness height (m)
            turbcoef,         //momentum transfer coefficient from
logarithmic wind file
            sheat,                  //sensible heat transfer
            //sphumid,        //specific humidity of atmosphere
            esat,             //saturation vapor pressure
            evaporate,        //latent heat transfer
            lhvapor,          //latent heat of vaporization (J/kg)
            lhfusion,         //latent heat of fusion (J/kg)
            cpice,                  //specific heat of ice (J/kg/degree
C)
            lhtransfer,       //latent heat transfer (W/m2)
            gheat,                  //heat flux due to the ground
(J/m^2/s)
```

```
            hflux,                  //heat flux determined by energy
budget method
            densityw,         //water density (kg/m^3)
            tempadd,          //temperature addition from aspect
            tempadd1;
double
            pi = 3.141592;                        //pi = 3.141927
            //meltrate;       //snowmelt rate for degree day method

      //meltrate = (float)(0.000000002525);

      //Choose Degree Day method(1) or Energy Balance Method(2)
      if(meltopt == 0)  //Degree Day method (1)
      {

            //Loop over rows
            for(i=1; i<=nrows; i++)
            {
                  //Loop over columns
                  for(j=1; j<=ncols; j++)
                  {
                        //if the cell is in the domain
                        if(imask[i][j] != nodatavalue)
                        {
                              //check if swe[][] > 0.0
                              if(sweov[i][j] > 0.0)
                              {

                                    //water density (kg/m3)
                                    densityw = (float)(1000.0);

                                    //snow density (kg/m3) ==> global
variable (DK)
                                    densitys = (float)(100.0);

                                    //if simtime is 04/30/03
                                    if(simtime >= 0.0 && simtime <
24.0)
                                    {
                                          //air temperature considering
elevation and from degree Celsius
                                          airtempz =
(float)(((elevationov[i][j] - airtempelev[1])
                                          * (-2.150198)/ 100.0 +
atinterp[1]));

                                    }     //end if 04/30/03

                                    //if simtime is 05/01/03
                                    if(simtime >= 24.0 && simtime <
48.0)
                                    {
                                          //air temperature considering
elevation and from degree Celsius
                                          airtempz =
(float)(((elevationov[i][j] - airtempelev[1])
```

```
                                        * (-2.13834)/ 100.0 +
atinterp[1]));

                                }       //end if 05/01/03

                                //if simtime is 05/02/03
                                if(simtime >= 48.0 && simtime <
72.0)
                                {
                                        //air temperature considering
elevation and from degree Celsius
                                        airtempz =
(float)(((elevationov[i][j] - airtempelev[1])
                                        * (-2.150198)/ 100.0 +
atinterp[1]));

                                }       //end if 05/02/03

                                //if simtime is 05/03/03
                                if(simtime >= 72.0 && simtime <
96.0)
                                {
                                        //air temperature considering
elevation and from degree Celsius
                                        airtempz =
(float)(((elevationov[i][j] - airtempelev[1])
                                        * (-1.347826)/ 100.0 +
atinterp[1]));

                                }       //end if 05/03/03

                                //if simtime is 05/04/03
                                if(simtime >= 96.0 && simtime <
120.0)
                                {
                                        //air temperature considering
elevation and from degree Celsius
                                        airtempz =
(float)(((elevationov[i][j] - airtempelev[1])
                                        * (-2.521739)/ 100.0 +
atinterp[1]));

                                }       //end if 05/04/03

                                //if simtime is 05/05/03
                                if(simtime >= 120.0 && simtime <
144.0)
                                {
                                        //air temperature considering
elevation and from degree Celsius
                                        airtempz =
(float)(((elevationov[i][j] - airtempelev[1])
                                        * (-2.952969)/ 100.0 +
atinterp[1]));

                                }       //end if 05/05/03
```

```
                                    //if simtime is 05/06/03
                                    if(simtime >= 144.0 && simtime <
168.0)
                                    {
                                          //air temperature considering
elevation and from degree Celsius
                                          airtempz =
(float)(((elevationov[i][j] - airtempelev[1])
                                          * (-2.988142)/ 100.0 +
atinterp[1]));

                                    }     //end if 05/06/03

                                    //if simtime is 05/07/03
                                    if(simtime >= 168.0 && simtime <
192.0)
                                    {
                                          //air temperature considering
elevation and from degree Celsius
                                          airtempz =
(float)(((elevationov[i][j] - airtempelev[1])
                                          * (-1.980237)/ 100.0 +
atinterp[1]));

                                    }     //end if 05/07/03

                                    //if simtime is 05/08/03
                                    if(simtime >= 192.0 && simtime <
216.0)
                                    {
                                          //air temperature considering
elevation and from degree Celsius
                                          airtempz =
(float)(((elevationov[i][j] - airtempelev[1])
                                          * (-2.565217)/ 100.0 +
atinterp[1]));

                                    }     //end if 05/08/03

                                    //if simtime is 05/09/03
                                    if(simtime >= 216.0 && simtime <
240.0)
                                    {
                                          //air temperature considering
elevation and from degree Celsius
                                          airtempz =
(float)(((elevationov[i][j] - airtempelev[1])
                                          * (-1.533597)/ 100.0 +
atinterp[1]));

                                    }     //end if 05/09/03

                                    //if simtime is 05/10/03
                                    if(simtime >= 240.0 && simtime <
264.0)
                                    {
```

```
                                        //air temperature considering
elevation and from degree Celsius
                                        airtempz =
(float)(((elevationov[i][j] - airtempelev[1])
                                        * (-3.209486)/ 100.0 +
atinterp[1]));

                                  }     //end if 05/10/03

                                  //if simtime is 05/11/03
                                  if(simtime >= 264.0 && simtime <
288.0)
                                  {
                                        //air temperature considering
elevation and from degree Celsius
                                        airtempz =
(float)(((elevationov[i][j] - airtempelev[1])
                                        * (-1.992095)/ 100.0 +
atinterp[1]));

                                  }     //end if 05/11/03

                                  //if simtime is 05/12/03
                                  if(simtime >= 288.0 && simtime <
312.0)
                                  {
                                        //air temperature considering
elevation and from degree Celsius
                                        airtempz =
(float)(((elevationov[i][j] - airtempelev[1])
                                        * (-1.399209)/ 100.0 +
atinterp[1]));

                                  }     //end if 05/12/03

                                  //if simtime is 05/13/03
                                  if(simtime >= 312.0 && simtime <
336.0)
                                  {
                                        //air temperature considering
elevation and from degree Celsius
                                        airtempz =
(float)(((elevationov[i][j] - airtempelev[1])
                                        * (-2.426877)/ 100.0 +
atinterp[1]));

                                  }     //end if 05/13/03

                                  //if simtime is 05/14/03
                                  if(simtime >= 336.0 && simtime <
360.0)
                                  {
                                        //air temperature considering
elevation and from degree Celsius
                                        airtempz =
(float)(((elevationov[i][j] - airtempelev[1])
```

```
                                    * (-2.391304)/ 100.0 +
atinterp[1]));

                                }     //end if 05/14/03

                                //if simtime is 05/15/03
                                if(simtime >= 360.0 && simtime <
384.0)
                                {
                                    //air temperature considering
elevation and from degree Celsius
                                    airtempz =
(float)(((elevationov[i][j] - airtempelev[1])
                                    * (-2.438735)/ 100.0 +
atinterp[1]));

                                }     //end if 05/15/03

                                //if simtime is 05/16/03
                                if(simtime >= 384.0 && simtime <
408.0)
                                {
                                    //air temperature considering
elevation and from degree Celsius
                                    airtempz =
(float)(((elevationov[i][j] - airtempelev[1])
                                    * (-3.110672)/ 100.0 +
atinterp[1]));

                                }     //end if 05/16/03

                                //if simtime is 05/17/03
                                if(simtime >= 408.0 && simtime <
432.0)
                                {
                                    //air temperature considering
elevation and from degree Celsius
                                    airtempz =
(float)(((elevationov[i][j] - airtempelev[1])
                                    * (-3.193676)/ 100.0 +
atinterp[1]));

                                }     //end if 05/17/03

                                //if simtime is 05/18/03
                                if(simtime >= 432.0 && simtime <
456.0)
                                {
                                    //air temperature considering
elevation and from degree Celsius
                                    airtempz =
(float)(((elevationov[i][j] - airtempelev[1])
                                    * (-1.822134)/ 100.0 +
atinterp[1]));

                                }     //end if 05/18/03
```

```
                                    //if simtime is 05/19/03
                                    if(simtime >= 456.0 && simtime <
480.0)
                                    {
                                          //air temperature considering
elevation and from degree Celsius
                                          airtempz =
(float)(((elevationov[i][j] - airtempelev[1])
                                          * (-1.312253)/ 100.0 +
atinterp[1]));

                                    }     //end if 05/19/03

                                    //if simtime is 05/20/03
                                    if(simtime >= 480.0 && simtime <
504.0)
                                    {
                                          //air temperature considering
elevation and from degree Celsius
                                          airtempz =
(float)(((elevationov[i][j] - airtempelev[1])
                                          * (-1.426877)/ 100.0 +
atinterp[1]));

                                    }     //end if 05/20/03

                                    //if simtime is 05/21/03
                                    if(simtime >= 504.0 && simtime <
528.0)
                                    {
                                          //air temperature considering
elevation and from degree Celsius
                                          airtempz =
(float)(((elevationov[i][j] - airtempelev[1])
                                          * (-1.620553)/ 100.0 +
atinterp[1]));

                                    }     //end if 05/21/03

                                    //if simtime is 05/22/03
                                    if(simtime >= 528.0 && simtime <
552.0)
                                    {
                                          //air temperature considering
elevation and from degree Celsius
                                          airtempz =
(float)(((elevationov[i][j] - airtempelev[1])
                                          * (-1.656126)/ 100.0 +
atinterp[1]));

                                    }     //end if 05/22/03

                                    //if simtime is 05/23/03
                                    if(simtime >= 552.0 && simtime <
576.0)
                                    {
```

```
                                        //air temperature considering
elevation and from degree Celsius
                                        airtempz =
(float)(((elevationov[i][j] - airtempelev[1])
                                        * (-1.762846)/ 100.0 +
atinterp[1]));

                                }       //end if 05/23/03

                                //if simtime is 05/24/03
                                if(simtime >= 576.0 && simtime <
600.0)
                                {
                                        //air temperature considering
elevation and from degree Celsius
                                        airtempz =
(float)(((elevationov[i][j] - airtempelev[1])
                                        * (-1.822134)/ 100.0 +
atinterp[1]));

                                }       //end if 05/24/03

                                //if simtime is 05/25/03
                                if(simtime >= 600.0 && simtime <
624.0)
                                {
                                        //air temperature considering
elevation and from degree Celsius
                                        airtempz =
(float)(((elevationov[i][j] - airtempelev[1])
                                        * (-1.893281)/ 100.0 +
atinterp[1]));

                                }       //end if 05/25/03

                                //if simtime is 05/26/03
                                if(simtime >= 624.0 && simtime <
648.0)
                                {
                                        //air temperature considering
elevation and from degree Celsius
                                        airtempz =
(float)(((elevationov[i][j] - airtempelev[1])
                                        * (-1.628458)/ 100.0 +
atinterp[1]));

                                }       //end if 05/26/03

                                //if simtime is 05/27/03
                                if(simtime >= 648.0 && simtime <
672.0)
                                {
                                        //air temperature considering
elevation and from degree Celsius
                                        airtempz =
(float)(((elevationov[i][j] - airtempelev[1])
```

```
                                    * (-1.695652)/ 100.0 +
atinterp[1]));

                              }     //end if 05/27/03

                              //if simtime is 05/28/03
                              if(simtime >= 672.0 && simtime <
696.0)
                              {
                                    //air temperature considering
elevation and from degree Celsius
                                    airtempz =
(float)(((elevationov[i][j] - airtempelev[1])
                                    * (-2.126482)/ 100.0 +
atinterp[1]));

                              }     //end if 05/28/03


                                    //Considering aspect, air
temperature will be added by the factor
                                    //Initialize tempadd, zero
                                    tempadd = (float)(0.0);

                                    //considering direct north
aspect
                                    if((aspect[i][j] == 0.0) ||
(aspect[i][j] == 360.0))
                                    {
                                          //temperature addition
                                          tempadd =
(float)((demslope[i][j]/12.0)*(-3.0));

                                    }

                                    //considering north aspect
                                    if(((aspect[i][j] > 315.0) &&
(aspect[i][j] < 360.0)) || ((aspect[i][j] > 0.0) && (aspect[i][j] <
45.0)))
                                    {
                                          //temperature addition
                                          tempadd =
(float)((demslope[i][j]/12.0)*(-1.5));

                                    }

                                    //considering south aspect
                                    if((aspect[i][j] > 135.0) &&
(aspect[i][j] < 225.0))
                                    {
                                          //temperature addition
                                          tempadd =
(float)((demslope[i][j]/12.0)*(1.5));

                                    }
```

```
                                        //considering direct south
aspect
                                        if(aspect[i][j] == 180.0)
                                        {
                                              //temperature addition
                                              tempadd =
(float)((demslope[i][j]/12.0)*(3.0));

                                        }

                                        //considering direct east
                                        if(aspect[i][j] == 90.0)
                                        {
                                              //temperature addition
                                              tempadd =
(float)((demslope[i][j]/12.0)*(3.0)*sin(pi/12.0*simtime));
                                        }

                                        //considering east sections
                                        if(((aspect[i][j] >= 45.0) &&
(aspect[i][j] < 90.0)) || ((aspect[i][j] > 90.0) && (aspect[i][j]<=
135.0)))
                                        {
                                              //temperature addition
                                              tempadd =
(float)((demslope[i][j]/12.0)*(1.5)*sin(pi/12.0*simtime));
                                        }

                                        //considering direct west
                                        if(aspect[i][j] == 270.0)
                                        {
                                              //temperature addition
                                              tempadd =
(float)((demslope[i][j]/12.0)*(-3.0)*sin(pi/12.0*simtime));
                                        }

                                        //considering west parts
                                        if(((aspect[i][j] >= 225.0)
&& (aspect[i][j] < 270.0)) || ((aspect[i][j] > 270.0) &&
(aspect[i][j]<= 315.0)))
                                        {
                                              //temperature addition
                                              tempadd =
(float)((demslope[i][j]/12.0)*(-1.5)*sin(pi/12.0*simtime));
                                        }

                                        //considering flat surface
                                        if(aspect[i][j] == -1.0)
                                        {
                                              //temperature addition
is zero
                                              tempadd = (float)(0.0);
                                        }

                                        tempadd1 = (float)(0.0);
                                        //tempadd1 : temperature
addition based on landuse
```

```
//
//2:developed--> add 0.5 degree
if(landuse[i][j] == 2)
{
      tempadd1 = (float)(0.0);
}
//3:barren--> add 0.2 degree
if(landuse[i][j] == 3)
{
      tempadd1 = (float)(0.0);
}
//4:forest--> reduce 3 degree
//simtime control (before 14th day and after 14th day)
//if(simtime < 336.0)
//{
//    if(landuse[i][j] == 4)
//    {
//          tempadd1 = (float)(-3.0);
//    }
//}
//else
//{
      if(landuse[i][j] == 4)
      {
            tempadd1 = (float)(-2.0);
      }
//}
//5:shrubland--> reduce 1 degree
if(landuse[i][j] == 5)
{
      tempadd1 = (float)(0.0);
}
//5:grassland--> reduce 1 degree
if(landuse[i][j] == 5)
{
      tempadd1 = (float)(0.0);
}
//airtemperature adjustment
//airtempz = (float)(airtempz + tempadd + tempadd1);
```

```
                                    //airtemperature adjustment
                                    airtempz = (float)(airtempz  +
tempadd + tempadd1);

                                    //Calculate dullness index for snow
pack albedo
                                    //
                                    //if snow is falling
(grossswerate[][] > 0.0)
                                    if(grossswerate[i][j] > 0.0)
                                    {
                                          //Snowpack dullness
decreases...
                                          //
                                          //Note:  When snow falls, the
dullness index of the snowpack
                                          //       decreases by 1.0
dullness units for each meter of
                                          //       snow depth (not
SWE!!!) that falls during the time
                                          //       step.   SWE is
converted to snow depth using as
                                          //       assumed snow density
value of 100 kg/m3...
                                          //
                                          //Compute depth of snow fall
(m)
                                          snowfalldepth =
(float)((densityw / densitys) * grossswerate[i][j] * dt[idt]);

                                          //compute the dullness of the
snow pack in this cell
                                          dullness[i][j] =
(float)(dullness[i][j] - 1.0 * snowfalldepth);

                                          //Check dullness for minimum
value...
                                          //
                                          //if dullness[][] < 0.0
                                          if(dullness[i][j] < 0.0)
                                          {
                                                //reset the dullness to
zero
                                                dullness[i][j] =
(float)(0.0);

                                          }     //end if dullness < 0.0
                                    }
                                    else  //else, snow is not falling
(grossswerate[][] = 0.0)
                                    {
                                          //Snowpack dullness
increases...
                                          //
```

```
                                        //Note:  Between snow fall
events, the snow pack dullness
                                        //       increases by one
dullness unit per hour up to a
                                        //       maximum value of 800
dullness units.
                                        //
                                        //if dullness[][] < 800.0
                                        if(dullness[i][j] <= 800.0)
                                        {
                                              //increment the
dullness over time (1 dullness unit per hour)
                                              dullness[i][j] =
(float)(dullness[i][j] + 2.778e-4 * dt[idt]);

                                        }     //end if dullness[][] <
800.0

                                        //Check dullness for maximum
value...
                                        //
                                        //if dullness[][] > 800.0
                                        if(dullness[i][j] > 800.0)
                                        {
                                              //reset the dullness to
800.0
                                              dullness[i][j] =
(float)(800.0);

                                        }     //end if dullness[][] >
800.0

                                  }     //end if grossswerate[][] >
0.0

                                  //reflectance (albedo) of snow pack
(dimensionless)
                                  albedo = (float)(0.85 - 0.07*
pow((dullness[i][j] / 24.0 ),0.5));

                                  //evaporation rate (kg/m2/s)
                                  //evaporate =
(float)((0.0001)*densitya*turbcoef*(1.0-rhuinterp[1]/100.0));

                                  //air temperature is less than 0
degree celsius
                                  if(airtempz <= 0.0)
                                  {
                                        //critical airtemp = 0.0
                                        cairtemp = 0.0;

                                  }     //end if air temperature is
less than 0 degree celsius

                                  //air temparature is larger than 0
degree celsius
                                  else
```

```
					{
						//crtical airtemp = air
temperature
						cairtemp = (float)(airtempz);

					}	//end else air temperature is
larger than 0.0 degree celsius

					//calculate meltrate (from day to
seconds, 10 hours based)
					//meltrate = (float)(4.0*(1-
albedo)*exp(-4.0*0.6)/10.0/36000/100.0);

					//Calculate snowmelt rate
					snowmeltrate[i][j] = cairtemp *
meltrate;

					//check if the snowmelt potential
exceeds the available swe
					if(snowmeltrate[i][j]*dt[idt] >
sweov[i][j])
					{
						//limit snowmelt rate to
available swe supply
						snowmeltrate[i][j] =
sweov[i][j] / dt[idt];

					}	//end check of snowmelt
potential

				}	//end if sweov[][] > 0.0

				else	//else sweov[][] = 0.0 (no snowpack
in cell)
				{
					//set the snowmelt rate to zero
					snowmeltrate[i][j] = 0.0;

				}	//end if sweov[][] > 0.0

				//Compute the cell surface area
				//
				//if the cell is a channel cell
				if(imask[i][j] > 1)
				{
					//Get channel link and node
					chanlink = link[i][j];
					channode = node[i][j];

					//Compute area of channel within
cell...
					//
					//Assign channel characteristics
					lch =
chanlength[chanlink][channode];		//channel length (m)
(includes sinuosity)
```

```
                                    twch = twidth[chanlink][channode];
            //channel top width at bank height (m)

                                    //Surface area of channel portion
of cell (m2)

                                    achsurf = twch * lch;
                              }
                              else  //cell is not a channel cell
(overland only)
                              {
                                    //no channel present, surface area
is zero

                                    achsurf = 0.0;

                              }     //end if imask > 1

                              //Compute cumulative snowmelt volume for
this cell (m3)
                              snowmeltvol[i][j] = snowmeltvol[i][j]
                                    + snowmeltrate[i][j] * dt[idt] * (w
* w - achsurf);


                        }     //end loop over columns

                  }     //end loop over rows

            }     //end if meltopt = 1

      }     //end Degree Day method


      else if (meltopt == 1)
      {

            //Initialize local variables
            //
            //pi = 3.1415927
            pi = (float)(3.1415927);

            //water density (kg/m3)
            densityw = (float)(1000.0);

            //snow density (kg/m3) ==> global variable (DK)
            densitys = (float)(100.0);

            //latent heat of vaporization (J/kg)
            lhvapor = (float)(2260000.0);

            //latent heat of fusion (J/kg)
            lhfusion = (float)(334000.0);

            //specific heat of ice (J/kg/degree C)
            cpice = (float)(2100.0);

            //heat flux from the underlying ground (W/m2)
            gheat = (float)(2.0);
```

```
            //specific heat of air J/kg/degree celcius
            cpa = 1010.0;

            //Von Karman constant
            kv = (float)(0.4);

            //anmometer above ground, user's option (m)
            zprime = 2.0;

            //Loop over rows
            for(i=1; i<=nrows; i++)
            {
                  //Loop over columns
                  for(j=1; j<=ncols; j++)
                  {
                        //if the cell is in the domain
                        if(imask[i][j] != nodatavalue)
                        {
                              //if the cell has snowpack (sweov[][] >
0.0)
                              if(sweov[i][j] > 0.0)
                              {
                                    //Below are the equations to make
snowmelt processes with net radiation
                                    //,sensible heat, latent heat, and
heat due to ground.
                                    //It can make the snowmeltrate[][]
(m/s)
                                   //Net solar radiation calculation...
                                    //

                                    //air temperature varied with
elevation in degree Celsius
                                    //==>need to modify airtempelev
array (DK)
                                    airtempz =
(float)(((elevationov[i][j] - airtempelev[1])
                                          * (-0.098)/ 100.0 +
atinterp[1]));

                                    //solar constant W/m^2
                                    isc = 1367.0;

                                    //Julian Day of year Global
Variable (user input)
                                    jday = (int)(jday + simtime/24.0);

                                    //Day angle (Radians)
                                    gamma = (float)(2*pi*(jday-
1)/365.0);

                                    //Eccentricity, relative distance
of the earth from the sun
                                    enot = (float)(1.000110 +
0.034221*cos(gamma) + 0.001280*sin(gamma)
```

```
                                        +
0.000719*cos(2*gamma)+0.000077*sin(2*gamma));

                                    //latitude at which the sun is
directly overhead (declination)
                                    delta = (float)((0.006918-
0.399112*cos(gamma) +
                                          0.070257*sin(gamma) -
0.006758*cos(2*gamma)+0.000907*sin(2*gamma) -
                                          0.002697*cos(3*gamma) +
0.00148*sin(3*gamma)));

                                    //Latitude- in the case of small
scale, user's option (radian)
                                    latitude =
(float)((39.0+14.0/60)/180.0*pi);

                                    //omega 15 degree over hour
(Radian/hour)
                                    omega = (float)((pi/180*15));

                                    //tsn is them time before
(negative) or after (positive) solar noon (hour)
                                    tsn = (float)((simtime-
((int)(simtime/24.0))*24.0)-12.0);

                                    // shortwave radiation (W/m^2)
                                    qkin =
(float)(isc*enot*(cos(delta)*cos(latitude)*cos(omega*tsn)+sin(delta)*si
n(latitude)));

                                    //Calculate dullness index for snow
pack albedo
                                    //
                                    //if snow is falling
(grossswerate[][] > 0.0)
                                    if(grossswerate[i][j] > 0.0)
                                    {
                                          //Snowpack dullness
decreases...
                                          //
                                          //Note:  When snow falls, the
dullness index of the snowpack
                                          //       decreases by 1.0
dullness units for each meter of
                                          //       snow depth (not
SWE!!!) that falls during the time
                                          //       step.   SWE is
converted to snow depth using as
                                          //       assumed snow density
value of 100 kg/m3...
                                          //
                                          //Compute depth of snow fall
(m)
                                          snowfalldepth =
(float)((densityw / densitys) * grossswerate[i][j] * dt[idt]);
```

```
                                        //compute the dullness of the
snow pack in this cell
                                        dullness[i][j] =
(float)(dullness[i][j] - 1.0 * snowfalldepth);

                                        //Check dullness for minimum
value...
                                        //
                                        //if dullness[][] < 0.0
                                        if(dullness[i][j] < 0.0)
                                        {
                                              //reset the dullness to
zero
                                              dullness[i][j] =
(float)(0.0);

                                        }     //end if dullness < 0.0
                                  }
                                  else  //else, snow is not falling
(grossswerate[][] = 0.0)
                                  {
                                        //Snowpack dullness
increases...
                                        //
                                        //Note:  Between snow fall
events, the snow pack dullness
                                        //       increases by one
dullness unit per hour up to a
                                        //       maximum value of 800
dullness units.
                                        //
                                        //if dullness[][] < 800.0
                                        if(dullness[i][j] <= 800.0)
                                        {
                                              //increment the
dullness over time (1 dullness unit per hour)
                                              dullness[i][j] =
(float)(dullness[i][j] + 2.778e-4 * dt[idt]);

                                        }     //end if dullness[][] <
800.0

                                        //Check dullness for maximum
value...
                                        //
                                        //if dullness[][] > 800.0
                                        if(dullness[i][j] > 800.0)
                                        {
                                              //reset the dullness to
800.0
                                              dullness[i][j] =
(float)(800.0);

                                        }     //end if dullness[][] >
800.0
```

```
                                    }     //end if grossswerate[][] >
0.0

                                    //reflectance (albedo) of snow pack
(dimensionless)
                                    albedo = (float)(0.85 - 0.07*
pow((dullness[i][j] / 24.0 ),0.5));

                                    //net short wave radiation (W/m2)
                                    qshortnet = (float)(qkin * (1.0 -
albedo)/300000000);

                                    //saturation vapor pressue by air
temperature (mb)
                                    //esat =
(float)(2.749*pow(10.0,(8*(-4278.6/(airtempz + 242.79)))));
                                    esat =
(float)(6.11*exp((17.3*airtempz)/(airtempz+237.3)));

                                    //vapor pressure (mb) determined by
saturation vapor pressure and relative humidity
                                    vaporpressure =
(float)(rhuinterp[1]/100.0*esat);

                                    //integrated effective emissivity
of the atmosphere (unitless)
                                    eat =
(float)((0.53+0.065*pow(vaporpressure,0.5))*1.0);

                                    //Stefan-Boltzmann constant
(W/m^2/K^4)
                                    sigma = (float)(5.6697*pow(10,-7));

                                    //net longwave radiation & air
temperature Kelvin (W/m^2)
                                    qlongnet = (float)((eat-
1.0)*sigma*(pow(airtempz,4.0)));

                                    //net solar radiation (W/m2)
                                    qstar = qlongnet + qshortnet;

                                    //sensible heat transfer

                                    //compute air density (kg/m3)
                                    densitya = (float)(1.225 - 0.000109
* elevationov[i][j]);

                                    //use with 350kg/m3 snow density
(peak swe)(m) vs 1000kg/m3 water density
                                    snowpackdepth =
(float)(sweov[i][j]*2.86);

                                    //roughness length (m)
                                    znot = (float)(0.01);

                                    //momentum transfer coefficient
from logarithmic wind profile (m/s)
```

```
					turbcoef =
(float)((pow(kv,2.0)*windinterp[1]
						/(pow((log((zprime-
snowpackdepth)/znot)),2.0))));

					//sensible heat transfer
(J/m^2/s==> W/m^2)
					sheat =
(float)(densitya*cpa*turbcoef*(airtempz)/1000);

					//latent heat transfer
					//
					//calculated from the saturated
snow humidity (=1) and Relative Humidity form met data

					//specific humidity
					//sphumid =
(float)(0.22*vaporpressure/apinterp[1]);

					//evaporation rate (kg/m2/s)
					evaporate =
(float)((0.0001)*densitya*turbcoef*(1.0-rhuinterp[1]/100.0));

					//latent heat transfer (includes
units conversion: J/m2/s to W/m2)
					lhtransfer = (lhvapor + lhfusion -
cpice) * evaporate;

					//heat flux determined by energy
budget method(W/m^2)
					hflux = qstar + sheat + lhtransfer
+ gheat;

					//if ambient temperature >= zero
					if (airtempz >= 0.0)
					{
						//compute snowmelt rate (m/s)
						snowmeltrate[i][j] =
hflux/densityw/lhfusion;
					}
					else	//else airtemp <= 0.0
					{
						//set snowmelt rate to zero
						snowmeltrate[i][j] = 0.0;

					}	//end if airtemp > 0.0

					//check if the snowmelt potential
exceeds the available swe
					if(snowmeltrate[i][j]*dt[idt] >
sweov[i][j])
					{
						//limit snowmelt rate to
available swe supply
						snowmeltrate[i][j] =
sweov[i][j] / dt[idt];
```

```
                                    }     //end check of snowmelt
potential

                              }     //end if sweov[][] > 0.0

                              else  //else sweov[][] = 0.0 (no snowpack
in cell)
                              {
                                    //set the snowmelt rate to zero
                                    snowmeltrate[i][j] = 0.0;

                              }     //end if sweov[][] > 0.0

                              //Compute the cell surface area
                              //
                              //if the cell is a channel cell
                              if(imask[i][j] > 1)
                              {
                                    //Get channel link and node
                                    chanlink = link[i][j];
                                    channode = node[i][j];

                                    //Compute area of channel within
cell...
                                    //
                                    //Assign channel characteristics
                                    lch =
chanlength[chanlink][channode];           //channel length (m)
(includes sinuosity)
                                    twch = twidth[chanlink][channode];
            //channel top width at bank height (m)

                                    //Surface area of channel portion
of cell (m2)
                                    achsurf = twch * lch;
                              }
                              else  //cell is not a channel cell
(overland only)
                              {
                                    //no channel present, surface area
is zero
                                    achsurf = 0.0;

                              }     //end if imask > 1

                              //Compute cumulative snowmelt volume for
this cell (m3)
                              snowmeltvol[i][j] = snowmeltvol[i][j]
                                    + snowmeltrate[i][j] * dt[idt] * (w
* w - achsurf);

                        }     //end if cell is in domain

                  }     //end loop over columns

            }     //end loop over rows
```

```
      }      //end Energy Balance Method

//End of function: Return to WaterBalance
}
```

```
/* ####################################################################
/* #################            DS.AML          #####################
/* ####################################################################

/* ====================================================================
/* PURPOSE:
/* Animates a time series from Arc Info ASCII grids created by
/* the CASC2D-SED hydrological model.   The user has the possibility
/* of creating an animated MPEG file (movie) from the ArcPlot
/* display window by creating a screenshot of each display.
/* In general, this AML can be used to create a movie from any
/* time series of Arc Info ASCII grids if these ASCII grids have
/* the same Prefix (root) name and the Sufix (file extension) in
/* an ordered sequence of arabic numbers.
/*
/* ====================================================================
/* INPUT
/* 1.  A time series of Arc Info ASCII grids:
/*    Example 1: one map per frame and n number of frames are shown
/*      depth.1; depth.2; ....; depth.n;
/*    Example 2: four maps per frame and n number of frames are shown
/*      depth.1; depth.2; ....; depth.n;
/*      erosion.1; erosion.2; ....erosion.n;
/*      flow.1; flow.2; ....; flow.n;
/*      rain.1; rain.2; ....; rain.n;
/* 2.  A parameter file that will control the display of the grids or
/*  map composition.   Optionally, this parameter file might not be
```

```
/*  given but the user needs to enter data manually.
/*
/* ==================================================================
/* OUTPUT:
/*   1.  A series of Arc Info grids (if user doesn't opt to kill them)
/*      after making the movie)
/*  Example: User chooses to show every other grid in his input
/*    series, starting in grid 6 and ending in grid 10:
/*    depth6; depth8; depth10
/*   2.  An MPEG file (if user decides to create a movie using the
/*      generated grids)
/*
/* ==================================================================
/* USAGE:
/* Arc: &run ds <ParameterFile>
/*
/* ==================================================================
/* ARGUMENTS:
/*  ParamFile: Name of the input data file.  If not specified,
/*       the user must enter the input data interactively.
/*
/* ==================================================================
/* VARIABLES:
/*   Globals:
/*  .CreateMovie: Index: 1: Movie is created; 0: not created
/*  .ElapsedTime: Elapsed time (secs) between CASC2D generated maps
/*  .EndFrame: Frame in which the display or movie will end
/*  .FrameStep: Number of frames to skip when displaying series
```

```
/*  .iter: Counter used to name multiple sequential images
/*  .MapTitleXX: Title for each of the displayed maps
/*  .MovieName: Name given to the final MPEG file (movie)
/*  .NameXX: Prefix (root) given to each of the thematic series
/*  .RMTXX: Remap table for each of the thematic series
/*  .SecsPause: Seconds to halt the series display
/*  .ShdSetXX: Shade set for each of the thematic series
/*  .StartFrame: Frame in which the display or movie will end
/*  .wPath: workspace location.   Enter full path if the workspace
/*         is in another location
/*
/* ==================================================================
/* CALLS:
/*  APdisplay.aml;
/*
/* ==================================================================
/* ROUTINES:
/*   GetUserInputData -- Prompts the user to enter input data
/*   GetFileInputData -- Input data is read from a file
/*   CreateGrids      --
/*      1.  Creates the grids from the ArcInfo
/*         ASCII files if they don't exists.
/*         They will be named as: PrefixSufix
/*         Example: depth1; depth2; ....depthn;
/*      2.  Writes grid stats.  in text files
/*    DisplayGrids    -- Displays the series of grids in an Arc Plot
/*         display window according to the specified
/*         remap table and shadesets defined previously
```

```
/*        by the user.
/*   Animate         -- Executes the MPEG encoder
/*   KillAllGrids     -- Created grids can be cleaned once the screen
/*        shot has been taken if the user decides so.
/*   GetUserSpecs     -- Get the user's ArcPlot configuration
/*   PutUserSpecs     -- Restores the user's AP configuration
/*   bailout         -- bails of of aml
/* ===================================================================
/* NOTES:
/* Must have the Berkeley MPEG encoder in:
/*                              $ARCHOME\bin\mpeg_encode.exe
/*
/* ===================================================================
/* HISTORY:
/* 9 Aug 1996 Original coding - Ian DeMerchant
/*   (as mpeg_encode.aml in ArcTools)
/* 15 Nov 2000 Major revision - Stephen Lead (slead@esriau.com.au)
/*   (as movie.aml)
/* 15 Jul 2001 Revision  -- Rosalia Rojas (CSU)
/*     (as DisplaySeries.aml)
/*  This AML has been rewriten for handling different options.
/*  The movie can display 1, 2, 3, 4 or 6 maps per frame
/*  User is able to define the remap table and color scheme
/*  for each of the maps in the frame.
/*  User is able to define a starting and ending frame and
/*  show them in a predefined interval.
/*
/* ===================================================================
```

```
&ARGS DSParamFile

&IF [NULL %DSParamFile%] &THEN
  &CALL GetUserInputData
&ELSE
  &CALL GetFileInputData
&CALL CheckInputErrors
&CALL CreateGrids

/* IN CASE THAT A MOVIE IS NOT TO BE CREATED, THE USER IS GIVEN THE
/* POSIBILITY OF DISPLAYING THE GRIDS AS MANY TIMES AS (S)HE WISHES

&SV ShowSeriesAgain = .FALSE.

&do &until ^ %ShowSeriesAgain%
  &CALL DisplayGrids
  &IF %.CreateMovie% = 0 &THEN
    &DO
      &TYPE
      &TYPE !!! Hello there !!!
      &SV ShowSeriesAgain = ~
      [QUERY 'Do you want to display again the time series' .FALSE.]

      /* Include the next line in case that you changed your mind
      /* after displaying the series (ex.  you decide to kill grids)
      &IF  %ShowSeriesAgain% &THEN &CALL GetFileInputData
```

```
    &TYPE
   &END
&end

&IF %.CreateMovie% = 1 &THEN ;  &CALL Animate

&CALL KillAllGrids

&RETURN


/* ######################################################################
/* ############   ROUTINE GET_USER_INPUT_DATA    ###################
/* ######################################################################

&ROUTINE GetUserInputData

/* GET THE NUMBER OF MAPS PER FRAME */

&TYPE
&SV .MapsPerFrame = ~
        [RESPONSE 'How many maps per frame? 1,2,3,4 or 6?']
&TYPE

/* DEFINE WHICH FRAMES WILL BE SHOWN

&SV .StartFrame = [RESPONSE 'Start movie in frame number']
&TYPE
```

```
&SV .EndFrame =   [RESPONSE 'End movie in frame number']
&TYPE

&SV .ElapsedTime =  ~
          [RESPONSE 'Elapsed show time between frames (sec.)']
&TYPE

&SV .FrameStep =  [RESPONSE 'Show frame step']
&TYPE

&SV .SecsPause = [RESONSE 'Seconds to pause frames display in AP']

/* Ask for the location of the folder where the ASCII grids are
&SV .wPath =  [RESPONSE 'ASCII grids location (full path)']
&TYPE

/* GET THE NAMES OF THOSE MAPS

 &DO MapNumber = 1 &TO %.MapsPerFrame%
   &sv .Name%MapNumber% = ~
      [RESPONSE 'Name (prefix) of map no.  '%MapNumber% :']
 &END
 &TYPE

/* ASK THE USER TO ENTER THE REMAP TABLE NAME FOR EACH OF
/* THE MAPS (S)HE WANTS TO DISPLAY
```

```
 &DO MapNum = 1 &TO %.MapsPerFrame%
  &sv .RMT%MapNum% = ~
   [RESPONSE 'Remap table name for the '[value Name%MapNum%]' map']
 &END
 &TYPE

/* ASK THE USER TO ENTER THE SHADESET FILE NAME FOR EACH OF
/* THE MAPS (S)HE WANTS TO DISPLAY

 &DO MapNo = 1 &TO %.MapsPerFrame%
  &sv .ShdSet%MapNo% = ~
   [RESPONSE 'Shadeset file name for the '[value Name%MapNo%]' map']
 &END
 &TYPE

/* ASK THE USER TO ENTER THE TITLE TO DISPLAY FOR EACH OF
/* THE MAPS (S)HE WANTS TO DISPLAY

 &DO MapNo = 1 &TO %.MapsPerFrame%
  &sv .MapTitle%MapNo% = ~
   [RESPONSE 'Title to display for the '[value Name%MapNo%]' map']
 &END
 &TYPE

/* ASK WHETHER THE USER WANTS TO CLEAN THE WORKSPACE
/* AFTER THE MOVIE IS DONE.

&SV OrderToKill = ~
```

```
  [RESPONSE 'Kill grids after they are displayed (1:yes;0:no) ?']
&TYPE

/* SCARE THE USER IF (S)HE WANTS TO CREATE THE MPEG FILE
 &TYPE
 &TYPE WARNING !!!!
 &TYPE Be aware that creating a movie will take for about
 &TYPE a minute per frame.   Make sure that this time series
 &TYPE is what you want to be displayed.
 &TYPE
 &TYPE
 &TYPE

&SV .CreateMovie = ~
  [RESPONSE 'would you like to create a movie (1:yes;0:no) ?']
&TYPE

&IF %CreateMovie% = 1 &THEN
   &SV .MovieName = [RESPONSE 'Movie name']
&TYPE

/*&SV .3Drendering = ~
/*   [RESPONSE 'would you like a 3-D representation (1:yes;0:no) ?']
/*&TYPE

/*&SV .SurfaceModel = ~
/*   [RESPONSE 'Name of the surface model (include path) ?']
/*&TYPE
```

```
/*&SV .Zscale = ~
/*   [RESPONSE 'Vertical scale (>1 exaggeration; <1 reduccion):']
/*&TYPE

&RETURN



/* ##################################################################
/* ############    ROUTINE GET_FILE_INPUT_DATA    ###################
/* ##################################################################

&ROUTINE GetFileInputData

&SV AMLunit = [open %DSParamFile% openstat -read]

/* First four lines are comments
&SV line1 = [read %AMLunit% readstat]  /* comment line
&SV line2 = [read %AMLunit% readstat]  /* comment line
&SV line3 = [read %AMLunit% readstat]  /* comment line
&SV line4 = [read %AMLunit% readstat]  /* comment line
&TYPE

&SV line5 = [unquote [read %AMLunit% readstat]]
&SV .MapsPerFrame = [extract 2 %line5%]
&TYPE Maps Per Frame: %.MapsPerFrame%
&TYPE
```

```
&SV line6 = [unquote [read %AMLunit% readstat]]
&SV .StartFrame = [extract 2 %line6%]
&TYPE Starting Frame = %.StartFrame%
&TYPE

&SV line7 = [unquote [read %AMLunit% readstat]]
&SV  .EndFrame = [extract 2 %line7%]
&TYPE Ending Frame = %.EndFrame%
&TYPE

&SV line8 = [unquote [read %AMLunit% readstat]]
&SV  .ElapsedTime = [extract 2 %line8%]
&TYPE Elapsed time between frames = %.ElapsedTime%
&TYPE

&SV line9 = [unquote [read %AMLunit% readstat]]
&SV  .FrameStep = [extract 2 %line9%]
&TYPE Frame Step = %.FrameStep%
&TYPE

&SV line10 = [unquote [read %AMLunit% readstat]]
&SV  .SecsPause = [extract 2 %line10%]
&TYPE Seconds to pause frame display in AP = %.SecsPause%
&TYPE

&SV line11 = [read %AMLunit% readstat]  /* blank line

&SV line12 = [UNQUOTE [READ %AMLunit% readstat] ]
```

```
&SV  .wPath = [extract 2 %line12%]
&TYPE Time series grids location = %.wPath%
&TYPE

&SV line13 = [unquote [read %AMLunit% readstat]]
&DO MapNumber = 1 &TO %.MapsPerFrame%
  &SV .Name%MapNumber% = ~
     [EXTRACT [CALC %MapNumber% + 1] %line13%]
  &TYPE Map No.  %MapNumber%: [VALUE .Name%MapNumber%]
&END
&TYPE

&SV line14 = [unquote [read %AMLunit% readstat]]
&DO MapNumber = 1 &TO %.MapsPerFrame%
  &sv .RMT%MapNumber% = ~
     [EXTRACT [CALC %MapNumber% + 1] %line14%]
  &TYPE Map No.  %MapNumber% Remap Table: [VALUE .RMT%MapNumber%]
&END
&TYPE

&SV line15 = [unquote [read %AMLunit% readstat]]
&DO MapNumber = 1 &TO %.MapsPerFrame%
  &sv .ShdSet%MapNumber% = ~
     [EXTRACT [CALC %MapNumber% + 1] %line15%]
  &TYPE Map No.  %MapNumber% shadeset: [VALUE .ShdSet%MapNumber%]
&END
&TYPE
```

```
&SV line16 = [unquote [read %AMLunit% readstat]]
&DO MapNumber = 1 &TO %.MapsPerFrame%
  &sv .MapTitle%MapNumber% = ~
     [EXTRACT [CALC %MapNumber% + 1] %line16%]
  &TYPE Map No.  %MapNumber% title: [VALUE .MapTitle%MapNumber%]
&END
&TYPE

&SV line17 = [unquote [read %AMLunit% readstat]]
&DO MapNumber = 1 &TO %.MapsPerFrame%
  &sv .MapSubTitle%MapNumber% = ~
     [EXTRACT [CALC %MapNumber% + 1] %line17%]
  &TYPE Map No.  %MapNumber% subtitle: [VALUE .MapSubTitle%MapNumber%]
&END
&TYPE

&SV line18 = [unquote [read %AMLunit% readstat]]
&SV .OrderToKill = [extract 2 %line18%]
&IF %.OrderToKill% = 1 &THEN; &TYPE Grids deleted after displayed
&ELSE &TYPE Generated grids will not be deleted
&TYPE

&SV line19 = [unquote [read %AMLunit% readstat]]
&SV .CreateMovie = [extract 2 %line19%]
&IF %.CreateMovie% = 1 &THEN; &TYPE An MPEG file will be created
&ELSE &TYPE No MPEG file will be created
&TYPE
```

```
&SV line20 = [unquote [read %AMLunit% readstat]]
&SV .MovieName = [extract 2 %line20%]
&TYPE Movie Name = %.MovieName%
&TYPE

&SV line21 = [read %AMLunit% readstat]  /* comment line
&SV line22 = [read %AMLunit% readstat]  /* comment line

&SV line23 = [unquote [read %AMLunit% readstat]]
&SV .3Drendering = [extract 2 %line23%]
&IF %.3Drendering% = 1 &THEN; &TYPE 3-D grids will be displayed
&ELSE &TYPE 2-D grids will be displayed
&TYPE

/*&IF %.3Drendering% = 1 &THEN
/*  &DO
/*     &SV line24 = [unquote [read %AMLunit% readstat]]
/*     &SV .SurfaceModel = [extract 2 %line24%]
/*     &TYPE Surface Model: %.SurfaceModel%
/*     &TYPE
/*     &SV line25 = [unquote [read %AMLunit% readstat]]
/*     &SV .Zscale = [extract 2 %line25%]
/*     &TYPE Z scale:  %.Zscale%
/*     &TYPE
/*  &END

&SV closestat = [CLOSE %AMLunit%]
```

```
&RETURN

/* ######################################################################
/* ############      ROUTINE CREATE_GRIDS        ###################
/* ######################################################################

&routine CreateGrids

/* OPEN AND WRITE TITLES IN THE FILES THAT WILL HOLD THE GRIDS STATS.

&DO i = 1 &TO %.MapsPerFrame%
  &SV filexists = [EXIST %.wPath%[value .Name%i%]_desc.txt -FILE]
  &IF %filexists% &THEN
  &SV NULL [DELETE %.wPath%[value .Name%i%]_desc.txt]
  &SV fileunit%i% ~
        [open %.wPath%[value .Name%i%]_desc.txt openstat -WRITE]
  &SV NULL [WRITE [value fileunit%i%] ~
  'GridName       Min.          Max.          Mean          StdDev']
  &SV NULL [WRITE [value fileunit%i%] ~
  '----------------------------------------------------------------']
&END

&FORMAT 3

/* THE INPUT ASCII GRIDS (FROM CASC2D_SED) ARE CALLED
/*      ex.  depth.1, depth.2, AND SO ON
/* GRIDS ARE GOING TO BE CALLED ex.  depth1, depth2 AND SO ON
```

```
/* IF OLD GRIDS ARE PRESENT, THEY WILL BE REUSED, OTHERWISE, THEY
/* WILL BE CREATED.   MAKE SURE THAT THOSE OLD GRIDS ARE THE ONES YOU
/* WANT TO USE, OTHERWISE, KILL THEM BEFORE STARTING THE CURRENT
AML

&DO FrameNumber = %.StartFrame% &TO %.EndFrame% &BY %.FrameStep%

  &TYPE Frame Number: %FrameNumber%

  &DO MapNumber = 1 &TO %.MapsPerFrame%
   &SV String := %.wPath%[value  .Name%MapNumber%]
   &SV gridexist = [EXISTS %String%%FrameNumber% -grid]
   &IF %gridexist% eq .FALSE.  &THEN
     &DO
       &TYPE Creating grid
       ASCIIGRID ~
           %String%.%FrameNumber% %String%%FrameNumber% FLOAT
       &TYPE Calculating statistics
       &DESCRIBE %String%%FrameNumber%
       &SV DataLine := ~
        [FORMAT '%1,10% %2,-15% %3,-15% %4,-15% %5,-15%' ~
        %GRD$GRID%       %GRD$ZMIN%       %GRD$ZMAX%       %GRD$MEAN%
%GRD$STDV%]
       &SV NULL [WRITE [value fileunit%MapNumber%] %DataLine%]
       /*&CALL ComputeStats
     &END
  &END
```

```
&END

&DO i = 1 &TO %.MapsPerFrame%   /* Closing the stats.  files
  &SV NULL [CLOSE [value fileunit%i%]]
&END

&RETURN



/* ######################################################################
/* ############       ROUTINE DISPLAY_GRIDS       ###################
/* ######################################################################

&ROUTINE DisplayGrids

/* THE VARIABLE iter WAS ORIGINALLY INSIDE THE animate.aml
/* WE INITIALIZE IT OUTSIDE THE LOOP THAT CREATES THE GRIDS

&SV .iter -1

AP

&CALL GetUserSpecs

&SV timesec 0  /* Inititalize total time to zero before displaying

&FORMAT 1
```

```
/*&IF %.MapsPerFrame% = 1 &THEN
/*  &RUN DS1.AML
/*&ELSE
  &RUN APdisplay.aml

&CALL PutUserSpecs

QUIT

&RETURN



/* ####################################################################
/* ############          ROUTINE ANIMATE      ###################
/* ####################################################################

/* THIS PART OF THE CODE IS A MODIFIED COPY OF THE animate
/* routine WRITEN BY STEPHEN LEAD IN THE animate.aml

&ROUTINE animate

/* TO CREATE THE ANIMATED MPEG FILE, WE USE THE BERKELEY MPEG ENCODER
/* WITH THE DEFAULT MPEG PARAMETER FILE DEFINED IN THIS AML.

/* THE USER CAN CHANGE THESE PARAMETER VALUES TO HIS/HER LIKING
/* ACCORDING TO THE USERS-GUIDE.PS CREATED AT THE BERKELEY MULTIMEDIA
```

```
/* RESEARCH CENTER, WHICH CAN BE FOUND AT:
/* http://bmrc.berkeley.edu/frame/research/mpeg/mpeg_encode.html

/* A GOOD EXPLANATION AND EXAMPLE OF THE MPEG PARAMETER FILE IS
FOUND
/* AT: http://www.math.arizona.edu/swig/animation/MPEG/(by Mark Hays)

 /* Calculate the first and last images - the temporary files
 /* contain a prefix with 5 trailing digits.  We need to substitute
 /* zeros for any leading blank values.

 &s first 00000
 &s last %.iter%
   &do i = 1 &to [calc 5 - [length %.iter%]]
     &s last 0%last%
   &end

  /* Write out a parameter file for this animation.
  &s param_file [scratchname -file]
  &s fileunit [open %param_file% openstat -write]
  &if %openstat% <> 0 &then
    &do
    &s str Could not create %param_file%...; &call bailout
    &end

  &s null [write %fileunit% 'PATTERN IBBPBBPBBPBB']
  &s null [write %fileunit% 'INPUT']
  &setchar &function '|*' '*|'
```

```
&s null |* write %fileunit% ~
        |* quote %.MovieName%* [%first%-%last%] *| *|
&setchar &function [ ]
&s null [write %fileunit% 'END_INPUT']
&s null [write %fileunit% [quote OUTPUT %.wPath%%.MovieName%]]
&s null [write %fileunit% [quote INPUT_DIR [show work]]]
&s null [write %fileunit% ~
 [quote INPUT_CONVERT [joinfile [joinfile ~
 [pathname $ARCHOME] bin -SUB] rasttopnm -FILE] *]]
&s null [write %fileunit% 'BASE_FILE_FORMAT PNM']
&s null [write %fileunit% 'SLICES_PER_FRAME 1']
&s null [write %fileunit% 'PIXEL HALF']
&s null [write %fileunit% 'RANGE 9']
&s null [write %fileunit% 'PSEARCH_ALG TWOLEVEL']
&s null [write %fileunit% 'BSEARCH_ALG CROSS2']
&s null [write %fileunit% 'GOP_SIZE 12']
&s null [write %fileunit% 'PQSCALE 10']
&s null [write %fileunit% 'IQSCALE 10']
&s null [write %fileunit% 'BQSCALE 10']
&s null [write %fileunit% 'REFERENCE_FRAME ORIGINAL']
&s null [write %fileunit% 'FORCE_ENCODE_LAST_FRAME']
&s null [close %fileunit%]

/* EXECUTE THE ENCODER
&sys [joinfile [joinfile [pathname $ARCHOME] bin -SUB] ~
    mpeg_encode -FILE] %param_file%
```

```
  /* DELETE THE TEMPORARY FILES

  &s deletestat [DELETE %param_file% -file]

    &DO i = 0 &TO %.iter%

    &SV value %i%

      &DO a = 1 &TO [calc 5 - [LENGTH %i%]]

        &S value 0%value%

        &S delstat [DELETE %.MovieName%%value% -file]

      &END

    &END

&RETURN



/* ##################################################################

/* ############      ROUTINE KILL_ALL_GRIDS      ##################

/* ##################################################################


/* KILL THE INPUT GRIDS IF THE USER DECIDED SO


&ROUTINE KillAllGrids


&IF %.OrderToKill% = 1 &THEN


 &DO FrameNumber = %.StartFrame% &TO %.EndFrame% &BY %.FrameStep%


   &type Killing Grids Number: %FrameNumber%


   &DO MapNumber = 1 &TO %.MapsPerFrame%
```

```
    &sv String := %.wPath%[value  .Name%MapNumber%]
    &sv gridexist = [exists %String%%FrameNumber% -grid]
    &if %gridexist% &then
    KILL %String%%FrameNumber% ALL
   &END

  &END
&RETURN

/* ##################################################################
/* ###########        ROUTINE GET_USER_SPECS    ###################
/* ##################################################################

/* DETERMINES THE USERS SPECIFICATIONS BEFORE IMPLEMENTING NEW
ONES
/* WITH THIS AML

&ROUTINE GetUserSpecs

  /* GET THE NUMBER OF DECIMALS
  &SV UsersDecimals [SHOW &FORMAT]
  &TYPE UsersDecimals %UsersDecimals%

  /* GET THE DISPLAY WINDOW SPECIFICATION
  &SV UsersAPdisplay [SHOW DISPLAY]
  &TYPE UsersAPdisplay %UsersAPdisplay%

  /* GET THE SHADESET
```

```
  &SV UsersShadeSet [SHOW SHADESET]
  &TYPE UsersShadeSet %UsersShadeSet%

  /* GET THE TEXT SPECIFICATIONS
  &SV UserTextFont [SHOW TEXTFONT]
  &SV UserTextQuality [SHOW TEXTQUALITY]
  &SV UserTextSpacing [SHOW TEXTSPACING]
  &SV UserTextSize [SHOW TEXTSIZE]

&RETURN
/* ######################################################################
/* ############         ROUTINE PUT_USER_SPECS    ###################
/* ######################################################################

/* RESTORES THE USER'S SPECIFICATIONS

&ROUTINE PutUserSpecs

  /* RESTORE THE USER'S NUMBER OF DECIMALS
  &FORMAT %UsersDecimals%

  /* RESTORE THE USER'S DISPLAY WINDOW SPECIFICATION
  DISPLAY %UsersAPdisplay%

  /* RESTORE THE USER'S SHADESET
  SHADESET %UsersShadeSet%

  /* RESTORE THE USER'S TEXT SPECIFICATIONS
```

```
  TEXTFONT %UserTextFont%

  TEXTQUALITY %UserTextQuality%

  TEXTSPACING %UserTextSpacing%

  TEXTSIZE %UserTextSize%


&RETURN


/* ##################################################################

/* ##########    ROUTINE CHECK_INPUT_ERRORS        ################

/* ##################################################################


&ROUTINE CheckInputErrors


/* TODO: this is just one of the errors.   I should check for the rest


&IF %.MapsPerFrame% NE 1 AND  ~

   %.MapsPerFrame% NE 2 AND ~

   %.MapsPerFrame% NE 3 AND ~

   %.MapsPerFrame% NE 4 AND ~

   %.MapsPerFrame% NE 6 &THEN

 &DO

   &TYPE WARNING !!!!

   &TYPE You have chosen to display %.MapsPerFrame% grids per frame

   &TYPE Please, Choose to display 1, 2, 3, 4 or 6 grids per frame

   &TYPE

   &CALL bailout

 &END
```

```
&RETURN

/* ######################################################################
/* ############        ROUTINE BAIL_OUT        ###################
/* ######################################################################

&ROUTINE bailout

  &IF NOT [variable str] &THEN &S str Bailing out of %aml$file%
  &RETURN; &RETURN &WARNING %str%
  &TYPE

&RETURN
```

```
/* ####################################################################
/* ############        APDISPLAY.AML          ###################
/* ####################################################################

/* =====================================================================
/* PURPOSE:
/* Displays different thematic map series in AP.   Legends are
/* displayed, with the key files being generated automatically if
/* they are not created yet.
/* Titles for each thematic series can be shown.   Time is also
/* displayed.   This time is computed from the elapsed time between
/* CASC2D maps, and the map number in the series.
/*
/* =====================================================================
/* ARGUMENTS:
/*  None
/*
/* =====================================================================
/* VARIABLES:
/*  Passed from the main program (DS.aml) as global
/*  variables.
/*
/* =====================================================================
/* CALLS:
/*  TakeScreenShot.aml
/*
/* =====================================================================
/* ROUTINES:
```

```
/*   Legend    -- Creates key files and displays map legends
/*      according to the given remap table and shadeset
/*   TitleText -- Writes map titles (specified in the Parameter file)
/*   TimeText  -- Writes the event simulation time
/*   SetLayoutVariables -- Specifies position of legend, title, sub-
/*      title, simulation time and maps in a given layout
/*
/* ===================================================================
/* HISTORY:
/*   August 18, 2001:  This part of the code is taken from the main
/*  program (DisplaySeries.aml) and becomes a stand alone aml.
/*  November 16, 2001: Display2.aml, Display3.aml....Display6.aml
/*  are re-writen more generically in only one AML (Display.aml).
/*
/* ===================================================================

/* Displays a red line around the AP window
LINECOLOR 0
LINESIZE 0.05

/* I want a white background.   Instead of changing the canvas color
/* I will just put a white patch as background
SHADETYPE COLOR
SHADECOLOR 1
&SV CanvasColor = [SHOW CANVASCOLOR]
&TYPE Canvas Color is %CanvasColor%

/* SPECIFY ARCPLOT DISPLAY CONFIGURATION
```

```
&IF %.MapsPerFrame% EQ 1 OR %.MapsPerFrame% EQ 4 &THEN
  &DO
    DISPLAY 9999 SIZE CANVAS 720 600    /* Landscape
    PAGESIZE 11 8.5                     /* Landscape
     &IF %CanvasColor% EQ BLACK &THEN PATCH 0 0 11 8.5
    BOX 0 0 11 8.5                      /* Landscape
  &END
&ELSE
  &DO
    DISPLAY 9999 SIZE CANVAS 400 300    /* Portrait
    PAGESIZE 8.5 11                     /* Portrait
    &IF %CanvasColor% EQ BLACK &THEN PATCH 0 0 8.5 11
    BOX 0 0 8.5 11                      /* Portrait
  &END

/* LEGEND AND TITLES WILL NOT CHANGE ALONG THE SIMULATION SO THEY
ARE
/* DISPLAYED ONLY ONCE AT THE BEGINING (they won't flicker every time
/* the display is refreshed and the display will be faster)

/* Set variables depending on the number of maps per frame
&CALL SetLayoutVariables

/* Creates Legends and Titles in layout
&CALL Legend
&CALL TitleText

/* DISPLAY THEMATIC MAP SERIES
```

```
&DO FrameNumber = %.StartFrame% &TO %.EndFrame% &BY %.FrameStep%

 GNDS TRANSPARENT  /* NODATA cells will be displayed transparently.
                /* that I can see the map legend

 &SV timesec [calc %FrameNumber% * %.ElapsedTime%]
 &SV timemin [calc %timesec% / 60]
 /*DK added time in hour and in day
 &SV timehour [calc %timesec% / 3600]
 &SV timeday [calc %timesec% / 86400]
 &CALL TimeText

 &TYPE Displaying frame Number: %FrameNumber%

 &DO n = 1 &TO %.MapsPerFrame%
  MAPLIMITS [UNQUOTE[VALUE MLimits%n%]]
  MAPEXTENT %.wPath%[VALUE .Name%n%]%FrameNumber%
  MAPPOSITION LR LR
  SHADEDELETE ALL
  SHADESET [VALUE .ShdSet%n%]
  GRIDSHADES ~
     %.wPath%[VALUE .Name%n%]%FrameNumber% VALUE [VALUE .RMT%n%]
  LINECOLOR 0
  LINESIZE 0.02
  /* DK: line below is used specified the watershed outline
  ARCS C:\Movie\flow062405\mask_poly
```

```
  &END

  &PAUSE &SECONDS %.SecsPause%

  &IF %.CreateMovie% = 1 &THEN &DO
    &RUN TakeScreenShot
    &TYPE Done: Screen shot of frame Number: %FrameNumber%
  &END

&END

&RETURN

/* ##################################################################
/* ############      ROUTINE LEGEND          ###################
/* ##################################################################

/* CREATES FILES TO STORE THE KEY FILES.
/* KEY FILES ARE DERIVED FROM REMAP TABLES

&ROUTINE Legend

&DO k = 1 &TO %.MapsPerFrame%

  &SV fileunit%k% [OPEN %.wPath%[value .Name%k%].key openstat -write]

  &IF %openstat% <> 0 &THEN
   &DO
```

```
    &SV str Could not create key_file ...; &CALL bailout
  &END

/* DATA WILL BE TAKEN FROM THE REMAP TABLE (DEFINED BY THE USER)
/* AND WRITEN TO THE TEMPORAL KEY FILE WITH THE CORRESPONDING
/* KEY FILE FORMAT (see "Drawing Key Legend" help)

&SV eof 0
&SV RemapFile%k% [open [value .RMT%k%] openstat -read]
&SV line [UNQUOTE [READ [value RemapFile%k%] eof]]

/* I ASSUME THAT THE USER DOESN'T HAVE MORE THAN 100 CLASSES!!!
/* I WILL ONLY WRITE THE UPPER LIMIT AS THE TEXT CLOSE TO THE KEY
/* IF YOU WANT TO WRITE THE WHOLE INTERVAL --> CHANGE NEXT LINES
/* OF CODE TO READ AND WRITE THE 1st AND 2nd ARGUMENT OF %line%

&DO i = 1 &TO 100 &WHILE %eof% NE 102
  /* 102 is returned value for EOF
  &SV NULL [WRITE [VALUE fileunit%k%] .%i% ]
    &SV key%i% := [QUOTE < [EXTRACT 2 %line%]]
  &SV NULL [WRITE [VALUE fileunit%k%] [value key%i%]]
  &SV line [UNQUOTE [READ [value RemapFile%k%] eof]]
&END

&SV NULL [CLOSE [VALUE fileunit%k%]]

&SV closestat = [CLOSE [VALUE RemapFile%k%]]
&END
```

```
/* TODO:CHANGE THE NEXT LINES WITH THE FONTS AND SIZES OF YOUR LIKING
/* NEXT SPECIFICATIONS WILL BE COMMON FOR ALL LEGENDS

/* Standandard hardware device color index:
/* 1:white; 2:red; 3:green; 4:blue; 5:cyan; 6:magenta; 7:yellow

SHADETYPE COLOR
TEXTCOLOR 0            /* Legend text color: black
TEXTFONT 'Times Bold'   /* Legend Font:smooth panel
TEXTSIZE 0.23 0.23      /* Legend text size: .2 inches
TEXTSPACING 0
TEXTQUALITY PROPORTIONAL
LINESIZE 0.01          /* Line width around key box
LINECOLOR 0            /* Line color (black) around key box
KEYBOX .25 .18         /* Key box width and height (inches)
KEYSEPARATION 0.05 0.03 /* Key dist.  to text and between keys

&DO j = 1 &TO %.MapsPerFrame%
  /*BOX [UNQUOTE[VALUE Area%j%]]
  SHADEDELETE ALL
  KEYAREA [UNQUOTE [value Area%j%]]
  SHADESET [value .ShdSet%j%]
  KEYSHADE %.wPath%[value .Name%j%].key
  &SV NULL [DELETE %.wPath%[value .Name%j%].key]  /* Delete key file
&END
```

```
&RETURN

/* ####################################################################
/* ############      ROUTINE TITLE_TEXT        ###################
/* ####################################################################

/* CREATES THE TITLES AND SUBTITLES CORRESPONDING TO EACH OF THE
/* THEMATIC SERIES -- TITLES ARE USER DEFINED IN THE PARAMETER FILE

&ROUTINE TitleText

TEXTCOLOR 4             /* Title in red
TEXTSIZE 0.4 0.4        /* Title font height & width: 0.4 inches
TEXTFONT 'Courier bold'   /*
TEXTSPACING 0
TEXTQUALITY PROPORTIONAL

/* MOVE: specifies a coordinate point used to position the cursor and
/* to position text drawn with TEXT and TEXTFILE.  Specify only the
/* lower left corner of the title and subtitle block.

&DO m = 1 &TO %.MapsPerFrame%
  MOVE [VALUE xTitlePos%m%] [VALUE yTitlePos%m% ]
  TEXT [value .MapTitle%m%]
  MOVE [VALUE xTitlePos%m%] [CALC [VALUE yTitlePos%m%] - 0.4]
  TEXT [value .MapSubTitle%m%]
&END
```

```
&RETURN

/* ##################################################################
/* ############       ROUTINE TIME_TEXT         ####################
/* ##################################################################

/* CALCULATES SIMULATION TIME AND DISPLAYS IT ON THE LAYOUT

&ROUTINE TimeText

/* Needed to put a black box on top of the time so that the last
/* time is not shown (the display window is not being refreshed )

SHADETYPE COLOR
SHADECOLOR 1

/* (xmin, ymin) has been specified in the SetVariables routine
&SV xmax = [CALC %xmin% + 2]
&SV ymax = [CALC %ymin% + 0.55]

PATCH %xmin% %ymin% %xmax% %ymax%

MOVE [CALC %xmin% + 0.25] [CALC %ymin% + 0.25]

TEXTSIZE 0.40 0.40
TEXTSPACING 0
TEXTQUALITY PROPORTIONAL
TEXTFONT 'omega bold'
```

```
TEXT 't =  '

TEXT [QUOTE [format '%1%' %timeday%]]

MOVE [CALC %xmin% + 1.8] [CALC %ymin% + 0.25]

TEXTFONT 'times'          /* ?????????????????????

TEXT '  day.'             /* How to write the whole thing

                          /* with only one TEXT command ?




/*MOVE [CALC %xmin% + 0.35] [CALC %ymin% - 0.1]


/*TEXTSIZE 0.40 0.40

/*TEXTSPACING 0

/*TEXTQUALITY PROPORTIONAL

/*TEXTFONT 'omega bold'

/*TEXT 't =  '

/*TEXT [QUOTE [format '%1%' %timeh%]]

/*MOVE [CALC %xmin% + 1.8] [CALC %ymin% - 0.1]

/*TEXTFONT 'times'          /* ?????????????????????

/*TEXT '  hour.'            /* How to write the whole thing

                          /* with only one TEXT command ?


&RETURN


/* ##################################################################

/* ###########       ROUTINE SET_VARIABLES      ###################

/* ##################################################################
```

```
&ROUTINE SetLayoutVariables
/*
/* modified JFE 04-17-2003 One MapsPerFrame
/* xTitlePos and yTitlePos for Title locations
/* xmin, ymin for time locations
/* modified JFE 01-29-2004 for Cal Gulch 150m grid
/*   to fix location of time - shifted to right

&IF %.MapsPerFrame% EQ 1 &THEN
  &DO
    &SV MLimits1 = ' 0 0 11 8.5 '
    &SV Area1 = '0.2 5.0 4.3 8.4'
/*    &SV xTitlePos1 = 3.5 Rosalia value original modified jfe
    &SV xTitlePos1 = 3.2
    &SV yTitlePos1 = 6.3
/*    &SV xmin = 6.75 Rosalia value original modified jfe
/*       for Arkansas River used 2.50 for Cal Gulch use 6.75
    &SV xmin = 3.5
    &SV ymin = 5
  &END

&IF %.MapsPerFrame% EQ 2 &THEN        /*  _____________
  &DO                            /*  |           |
    &SV MLimits1 = '0.1 5.4 8.4 10.9' /*  |     1     |
    &SV MLimits2 = '0.1 0.1 8.4 5.5'  /*  |___________|
    &SV Area1 = '0.1 8.9 2.85 10.65'  /*  |           |
    &SV Area2 = '0.1 3.6 2.85 5.35'   /*  |     2     |
    &SV xTitlePos1 = 2.4              /*  |___________|
```

```
    &SV yTitlePos1 = 10.6
    &SV xTitlePos2 = %xTitlePos1%
    &SV yTitlePos2 = [CALC %yTitlePos1% - 5.3 ]
    &SV xmin = 4.20
    &SV ymin = 0.1
  &END

/* this one needs more work.  Check values
&IF %.MapsPerFrame% EQ 3 &THEN
  &DO
    &SV MLimits1 = '0.0 7.4 8.5 11.0'
    &SV MLimits2 = '0.0 3.7 8.5 7.3'
    &SV MLimits3 = '0.0 0.0 8.5 3.6'
    &SV Area1 = '0.1 8.9 2.85 10.65'
    &SV Area2 = '0.1 3.6 2.85 5.35'
    &SV Area3 = '0.1 3.6 2.85 5.35'
    &SV xTitlePos1 = 5.75     /*   ____________
    &SV yTitlePos1 = 0.9      /*  |            |
    &SV xTitlePos2 = 5.75     /*  |     1      |
    &SV yTitlePos2 = 6.3      /*  |____________|
    &SV xTitlePos3 = 6.3      /*  |            |
    &SV yTitlePos3 = 5        /*  |     2      |
    &SV xmin = 2.20           /*  |____________|
    &SV ymin = 0.1            /*  |            |
  &END                        /*  |     3      |
                              /*  |____________|
&IF %.MapsPerFrame% EQ 4 &THEN
  &DO
```

```
  &SV MLimits1 = '0 4.25 5.5 8.5'
  &SV MLimits2 = '5.5 4.25 11 8.5'
  &SV MLimits3 = '0 0 5.5 4.25'
  &SV MLimits4 = '5.5 0 11 4.25'
  &SV Area1 = '0.05 6.95 2.05 8.45'
  &SV Area2 = '5.40 6.95 7.40 8.45'
  &SV Area3 = '0.05 2.75 2.05 4.25'
  &SV Area4 = '5.40 2.75 7.40 4.25'
  &SV xTitlePos1 = 2.70
  &SV yTitlePos1 = 8.05    /*  _________________________|
  &SV xTitlePos2 = 8.10    /*  |           |           |
  &SV yTitlePos2 = 8.05    /*  |     1     |     2     |
  &SV xTitlePos3 = 2.70    /*  |___________|___________|
  &SV yTitlePos3 = 3.85    /*  |           |           |
  &SV xTitlePos4 = 8.10    /*  |     3     |     4     |
  &SV yTitlePos4 = 3.85    /*  |___________|___________|
  &SV xmin = 3.0
  &SV ymin = 0.05
 &END

&IF %.MapsPerFrame% EQ 6 &THEN
 &DO
  &SV MLimits1 = '0.0 7.2 4.2 10.8'  /*Landscape: 0 4.2 3.6 8.4
  &SV MLimits2 = '4.2 7.2 8.4 10.8'  /*Landscape: 3.6 4.2 7.2 8.4
  &SV MLimits3 = '0.0 3.6 4.2 7.2'   /*Landscape: 7.2 4.2 10.8 8.4
  &SV MLimits4 = '4.2 3.6 8.4 7.2'   /*Landscape: 0 0 3.6 4.2
  &SV MLimits5 = '0.0 0.0 4.2 3.6'   /*Landscape: 3.6 0 7.2 4.2
  &SV MLimits6 = '4.2 0.0 8.4 3.6'   /*Landscape: 7.2 0 10.8 4.2
```

```
  &SV Area1 = '0.05 9.15 1.65 10.85'
  &SV Area2 = '4.2 9.15 5.8 10.85'
  &SV Area3 = '0.05 5.55 1.65 7.25'
  &SV Area4 = '4.2 5.55 5.8 7.25'
  &SV Area5 = '0.05 1.95 1.65 3.65'
  &SV Area6 = '4.2 1.95 5.8 3.65'
  &SV xTitlePos1 = 2      /*  _________________________
  &SV yTitlePos1 = 10.2   /*  |           |           |
  &SV xTitlePos2 = 6.15   /*  |     1     |     2     |
  &SV yTitlePos2 = 10.2   /*  |___________|___________|
  &SV xTitlePos3 = 2      /*  |           |           |
  &SV yTitlePos3 = 6.6    /*  |     3     |     4     |
  &SV xTitlePos4 = 6.15   /*  |___________|___________|
  &SV yTitlePos4 = 6.6    /*  |           |           |
  &SV xTitlePos5 = 2      /*  |     5     |     6     |
  &SV yTitlePos5 = 3.0    /*  |___________|___________|
  &SV xTitlePos6 = 6.15
  &SV yTitlePos6 = 3.0
  &SV xmin = 1.80
  &SV ymin = 0.05
 &END

&RETURN
```

```
/* animate.aml
/*
/* Animates a series of grids or images, by creating a screenshot of each
/* dataset, and compiling them into an MPEG movie file.  All grids should have
/* the same mapextent.
/*
/* Uses the core functionality of the ArcTools Animate program, although much
/* of the code is re-written.
/*
/* This version requires that the grids be numbered sequentially with a common
/* prefix, eg grid1, grid2.  Another approach might be to use a file containing
/* a list of grids, using the [OPEN] and [READ] functions to obtain the
/* grid names.
/*
/* History
/* 9 Aug 1996 Original coding - Ian DeMerchant (as mpeg_encode.aml in ArcTools)
/* 15 Nov 2000 Major revision - Stephen Lead
/*
/* Please report any problems or comments to slead@esriau.com.au
/*
/* THIS SCRIPT IS PROVIDED "AS IS", WITHOUT WARRANTY OF ANY KIND.
/* ESRI does not assume responsibility for the accuracy or reliability of the
/* script and recommends you test it thoroughly before implementation.
/*
/*=================================================================
========
/* Prefix is the grid prefix, Start and End refer to the suffix numbers.
/* Output is the mpeg movie file.
```

```
&args prefix start end output

/* Set the approximate number of frames per second - 40 frames seems to
/* result in each image lasting about 1 second.  (This is probably not the most
/* efficient way to achieve this - please let me know if you are aware of a
/* better way to approach this problem, perhaps by tweaking the parameters
/* file, etc)

&s repeats 40

&call checkargs
&call createimages
&call animate

&return

/*==============================================================
========
&routine createimages

  arcplot
  display 9999
  mapextent %prefix%%start%
  &s iter -1

    /* Iterate through each grid in the series.
    &do i = %start% &to %end%
```

```
clear

/* replace this next line with the applicable drawing command, eg
/* use GRIDSHADES with remap table, etc.

/* gridpaint %prefix%%i% # identity wrap gray
/* gridshades %prefix%%i%
image %prefix%%i%

/* Create a temporary screenshot image, convert to SUNRASTER.  Omit the
/* conversion stage if you are not using Windows NT.
&s tempimage [scratchname -file]
screensave %tempimage%
&s rsimage [scratchname -file]
arc convertimage %tempimage% %rsimage% sunraster none
&s delstat [delete %tempimage% -file]
&s delstat [delete %tempimage%w -file]

/* Copy this image a number of times to provide multiple frames, else
/* the image only appears for a split second in the mpeg file.  See
/* comments at the start of the script.

  &do a = 1 &to %repeats%
  &s iter [calc %iter% + 1]
  &s image%iter% [scratchname -prefix %prefix% -file]
  &s copystat [copy %rsimage% [value image%iter%] -file]
  &if %copystat% > 0 &then
    &do
```

```
      &s str Error copying image file...; &call bailout
      &end
    &end
  &s delstat [delete %rsimage% -file]
  &s delstat [delete %rsimage%w -file]

  &end

quit

&return

/*==================================================================
========
&routine animate

  /* Calculate the first and last images - the temporary files contain
  /* a prefix with 5 trailing digits.  We need to substitute zeros for any
  /* leading blank values.
  &s first 00000
  &s last %iter%
    &do i = 1 &to [calc 5 - [length %iter%]]
    &s last 0%last%
    &end

  /* Write out a parameter file for this animation.
  &s param_file [scratchname -file]
  &s fileunit [open %param_file% openstat -write]
```

```
&if %openstat% <> 0 &then
  &do
  &s str Could not create %param_file%...; &call bailout
  &end

&s null [write %fileunit% 'PATTERN IBBPBBPBBPBB']
&s null [write %fileunit% 'INPUT']
&setchar &function '|*' '*|'
&s null |* write %fileunit% |* quote %prefix%* [%first%-%last%] *| *|
&setchar &function [ ]
&s null [write %fileunit% 'END_INPUT']
&s null [write %fileunit% [quote OUTPUT %output%]]
&s null [write %fileunit% [quote INPUT_DIR [show work]]]
&s null [write %fileunit% [quote INPUT_CONVERT [joinfile [joinfile ~
  [pathname $ARCHOME] bin -SUB] rasttopnm -FILE] *]]
&s null [write %fileunit% 'BASE_FILE_FORMAT PNM']
&s null [write %fileunit% 'SLICES_PER_FRAME 1']
&s null [write %fileunit% 'PIXEL HALF']
&s null [write %fileunit% 'RANGE 9']
&s null [write %fileunit% 'PSEARCH_ALG TWOLEVEL']
&s null [write %fileunit% 'BSEARCH_ALG CROSS2']
&s null [write %fileunit% 'GOP_SIZE 12']
&s null [write %fileunit% 'PQSCALE 10']
&s null [write %fileunit% 'IQSCALE 10']
&s null [write %fileunit% 'BQSCALE 10']
&s null [write %fileunit% 'REFERENCE_FRAME ORIGINAL']
&s null [write %fileunit% 'FORCE_ENCODE_LAST_FRAME']
&s null [close %fileunit%]
```

```
/* Execute the encoder.
&sys [joinfile [joinfile [pathname $ARCHOME] bin -SUB] mpeg_encode -FILE] ~
  %param_file%

/* Delete the temporary files
&s deletestat [delete %param_file% -file]
  &do i = 0 &to %iter%
  &s value %i%
    &do a = 1 &to [calc 5 - [length %i%]]
    &s value 0%value%
    &s delstat [delete %prefix%%value% -file]
    &end
  &end

&return

/*================================================================
========
&routine checkargs

&if [null %prefix%] | [quote %prefix%] = '#' &then &call usage
&if [locase [quote %prefix%]] = 'usage' &then &call usage
&if [null %start%] | [quote %start%] = '#' &then &call usage
&if [null %end%] | [quote %end%] = '#' &then &call usage
&if [null %output%] | [quote %output%] = '#' &then &call usage
&if [type %start%] <> -1 | [type %end%] <> -1 &then &call usage
&s output [before %output% .].mpg
```

```
&if [exist %output% -file] &then
  &do
  &s str Output file %output% already exists...; &call bailout
  &end

/* Check that each input grid exists.
  &do i = %start% &to %end%
  &if not [exist %prefix%%i% -grid] &then
    &do
    &s str Grid %prefix%%i% does not exist...; &call bailout
    &end
  &end

&return

/*=================================================================
===========
&routine usage

  &s str Usage &r %aml$file% <prefix> <start> <end> <output>
  &call bailout

/*=================================================================
===========
&routine bailout

  &if not [variable str] &then &s str Bailing out of %aml$file%
  &return; &return &warning %str%
```

```
&return

/*=================================================================
========
/* END OF FILE
/*=================================================================
========
```

```
/* ###################################################################
/* ############       ROUTINE TAKE_SCREEN_SHOT    ###################
/* ###################################################################

/* THIS PART OF THE CODE IS A PARTIAL COPY OF THE createimages
/* routine WRITEN BY STEPHEN LEAD IN THE animate.aml

/* IMPORTANT: I HAD TO CHANGE MY SCREEN DISPLAY TO 'TRUE COLORS'
/* (NOT 256 OR 65536 COLORS)
/* CREATE A TEMPORARY SCREENSHOT IMAGE, CONVERT TO SUNRASTER.
/* OMIT THE CONVERSION STAGE IF YOU ARE NOT USING WINDOWS NT.

&SV tempimage [scratchname -file]

/* screensave command:IN WINDOWS NT THE IMAGE IS SAVED AS A BMP FILE
/* UNLESS OTHERWISE SPECIFIED.   SINCE JPEG IS ALREADY A COMPRESSED
/* IMAGE, AND THIS IMAGE WILL BE FURTHER COMPRESSED IN THE MPEG
/* ENCODER (THUS, LOOSING RESOLUTION) WE SAVE THE FILES AS
SUNRASTER

SCREENSAVE %tempimage%
&SV rsimage [scratchname -file]
ARC CONVERTIMAGE %tempimage% %rsimage% sunraster none
&SV delstat [delete %tempimage% -file]
&SV delstat [delete %tempimage%w -file]

/* NOTE: ANOTHER WAY TO CREATE AN ANIMATED FILE IS TO CREATE GIF
/* OR JPEG FILES AND TO USE A PROGRAM TO CREATE AN ANIMATED GIF.
```

```
/* ADVANTAGE: EASY TO USE, VERY VERSATIL.  DISADVANTAGE: SOFTWARE
/* NOT FOR FREE.  A GOOD STARTING POINT TO LEARN ABOUT ANIMATED GIFs
/* AND COMPARE SOFTWARE: http://www.webreference.com/dev/gifanim/
/* IN CASE THAT YOU DECIDE TO CREATE AN ANIMATED GIF,YOU CAN END
/* THE AML HERE.   NO NEED TO EXECUTE THE animate SUBROUTINE.

/* COPY THIS IMAGE A NUMBER OF TIMES TO PROVIDE MULTIPLE FRAMES,
/* ELSE THE IMAGE ONLY APPEARS FOR A SPLIT SECOND IN THE MPEG FILE.
/* SETTING THE APPROXIMATE NUMBER OF FRAMES PER SECOND TO 40
FRAMES
/* SEEMS TO RESULT IN EACH IMAGE LASTING ABOUT 1 SECOND.
/* THE LARGER NUMBER OF repeats --> THE MOVIE DOES NOT GO SO FAST
/* BUT THE TIME IT TAKES TO CREATE THE MOVIE IS BIGGER AND THE
/* MPEG FILE WILL ALSO BE LARGER

&SV repeats 2

&TYPE Copying the image 2 times

&do a = 1 &to %repeats%
  &SV .iter [calc %.iter% + 1]
  &SV image%.iter% [scratchname -prefix %.MovieName% -file]
  &SV copystat [copy %rsimage% [value image%.iter%] -file]
  &if %copystat% > 0 &then
        &do
          &s str Error copying image file...; &call bailout
        &end
&end
```

```
/* DELETE TEMPORARY FILES

&s delstat [delete %rsimage% -file]

&s delstat [delete %rsimage%w -file]



&RETURN


/* ##################################################################

/* ###########        ROUTINE BAIL_OUT        ##################

/* ##################################################################



&ROUTINE bailout


   &IF NOT [variable str] &THEN &S str Bailing out of %aml$file%

   &RETURN; &RETURN &WARNING %str%


&RETURN
```

APPENDIX C:

HYDROGRAPH RESULTS AT CG1, AND CG4

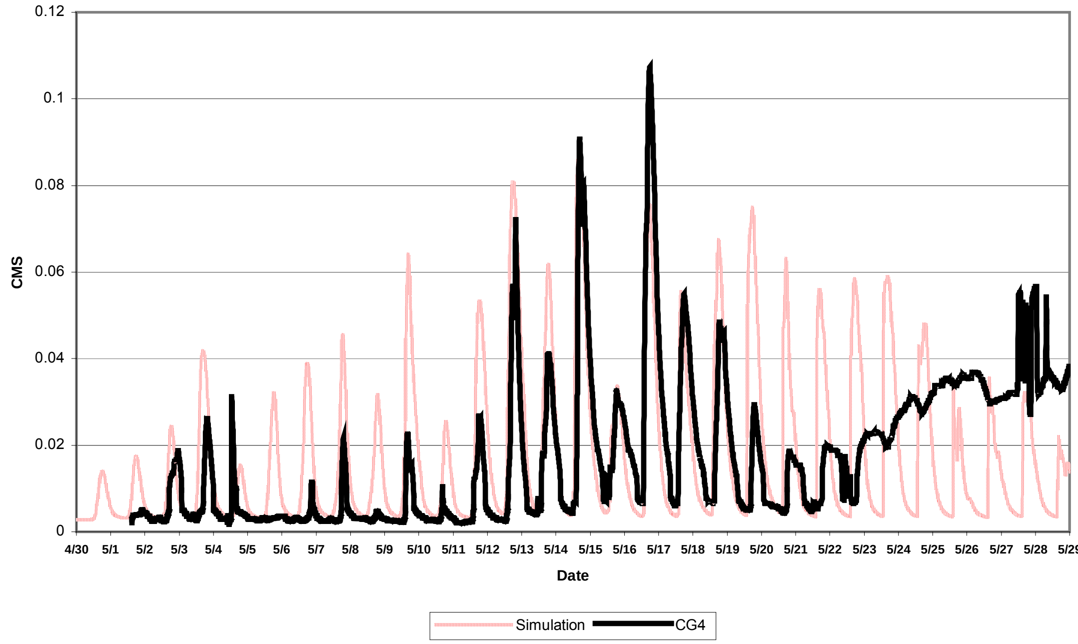

Figure C-1 Thirty Days Simulation Result at CG4

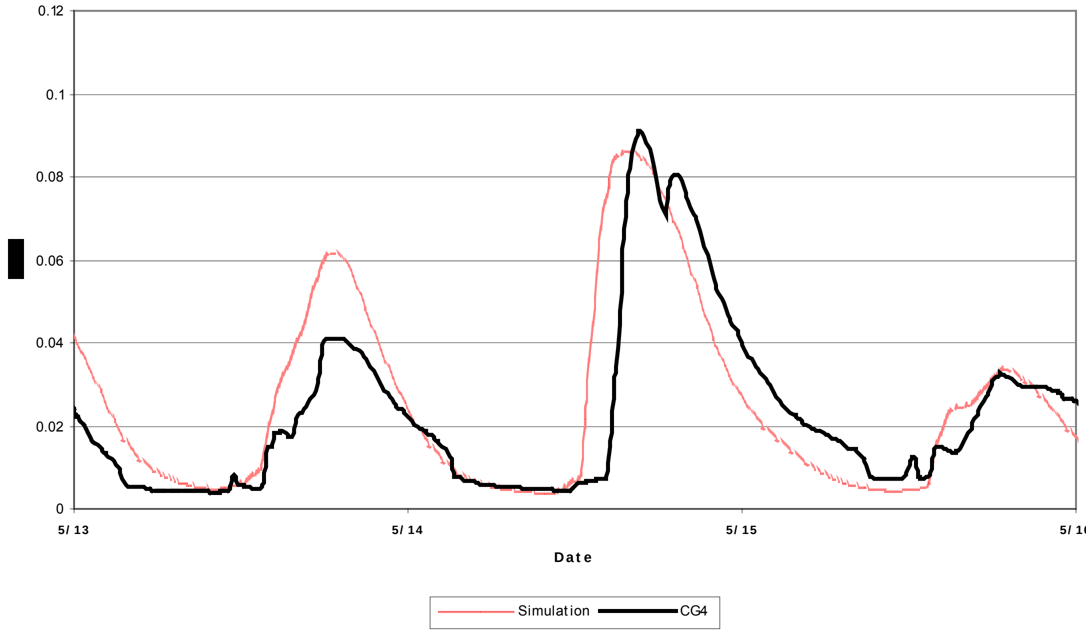

Figure C-2 Three Days Simulation Result at CG4

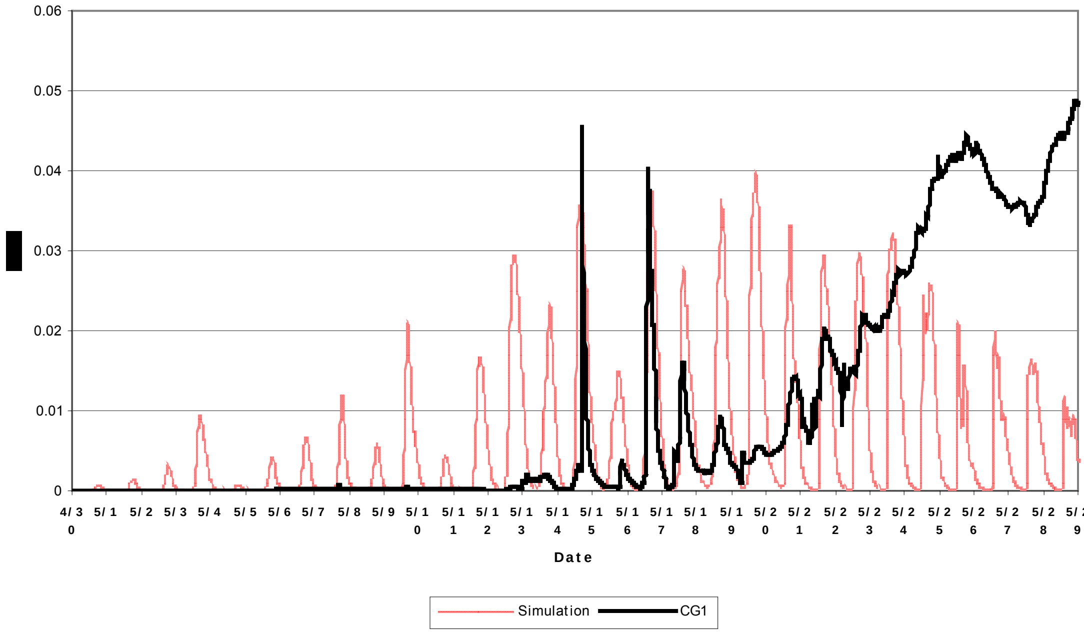

Figure C-3 Thirty Days Simulation Result at CG1

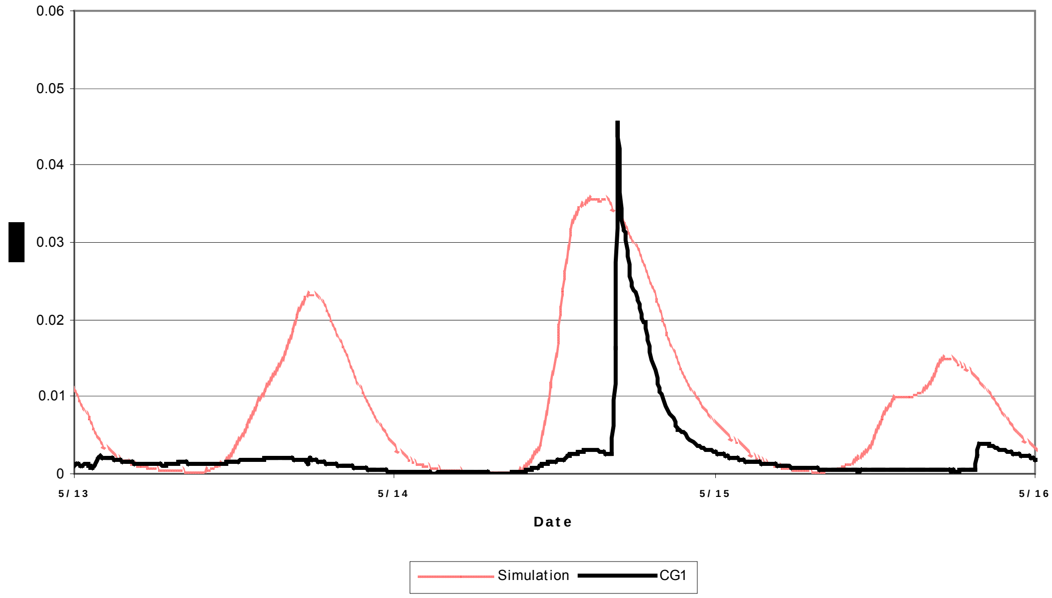

Figure C-4 Three Days Simulation Result at CG1

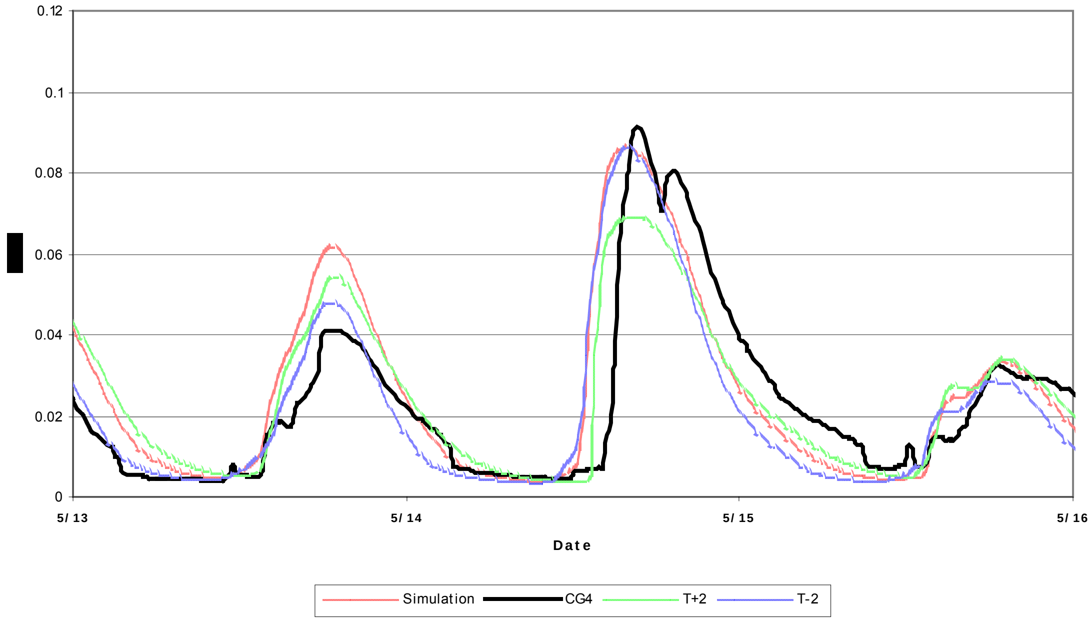

Figure C-5 Sensitivity to Air temperature at CG4

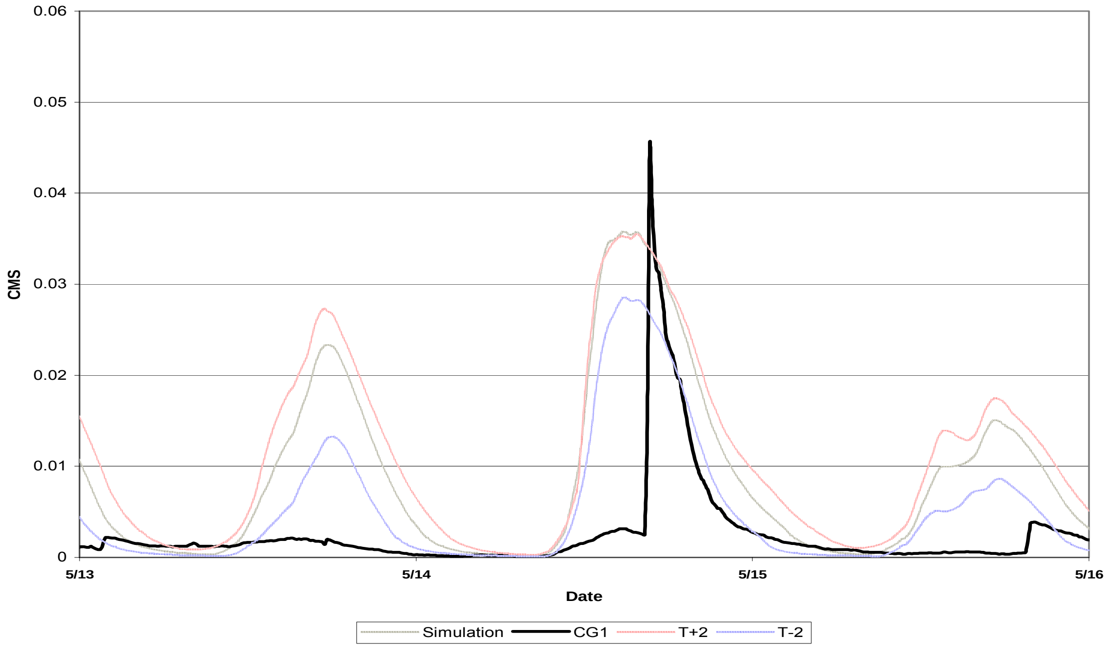

Figure C-6 Sensitivity to Air temperature at CG1

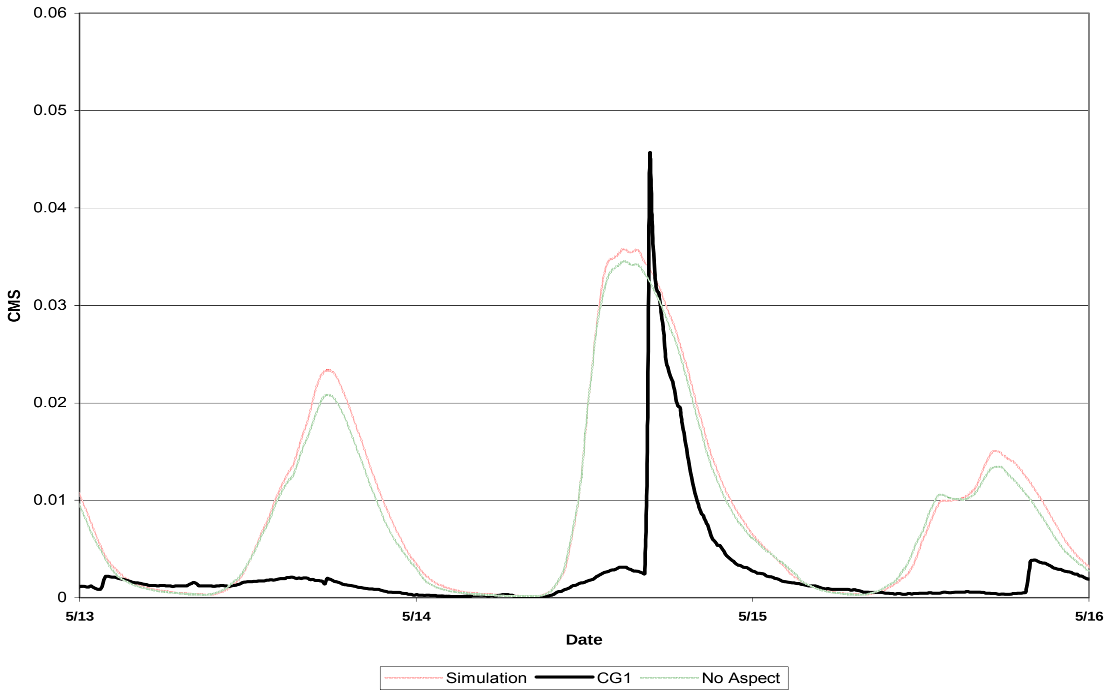

Figure C-7 Sensitivity to Aspect at CG1

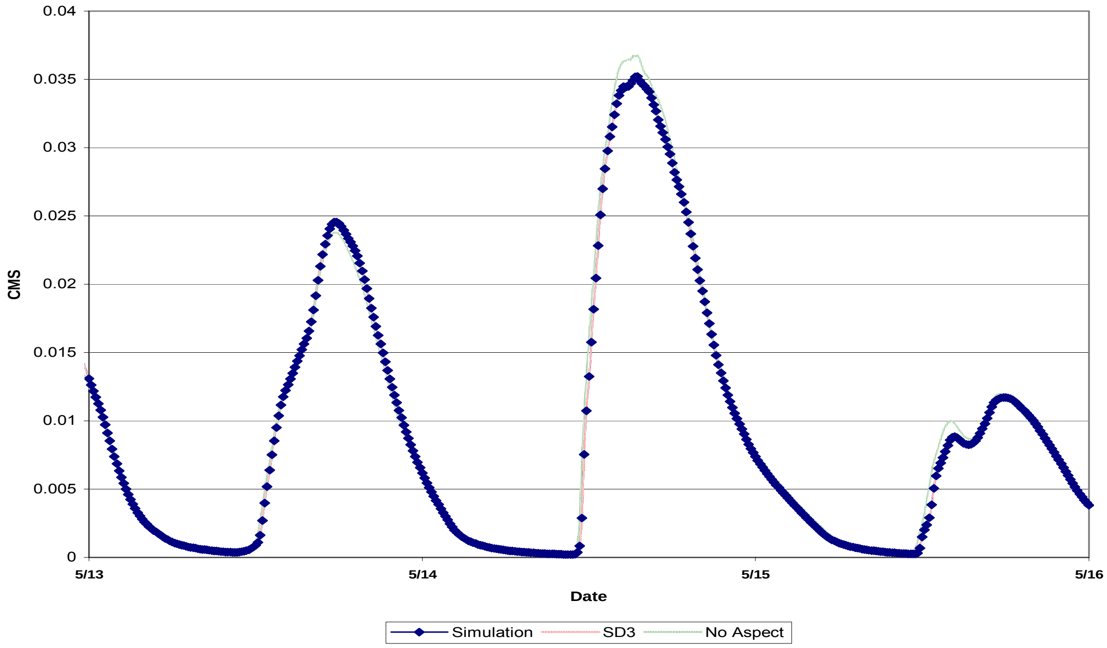

Figure C-8 Sensitivity to Aspect at SD3

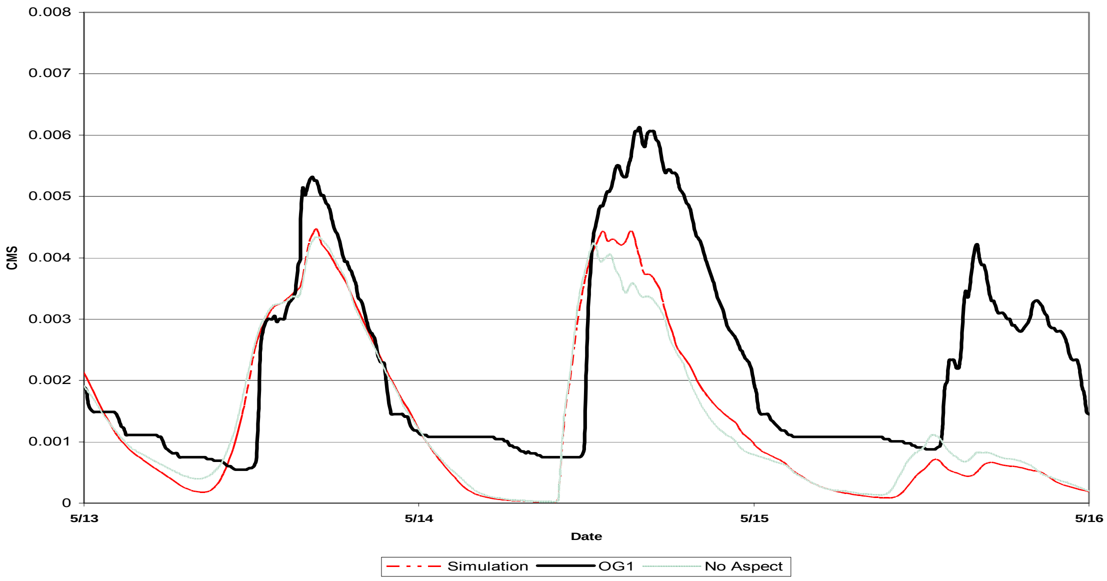

Figure C-9 Sensitivity to Aspect at OG1

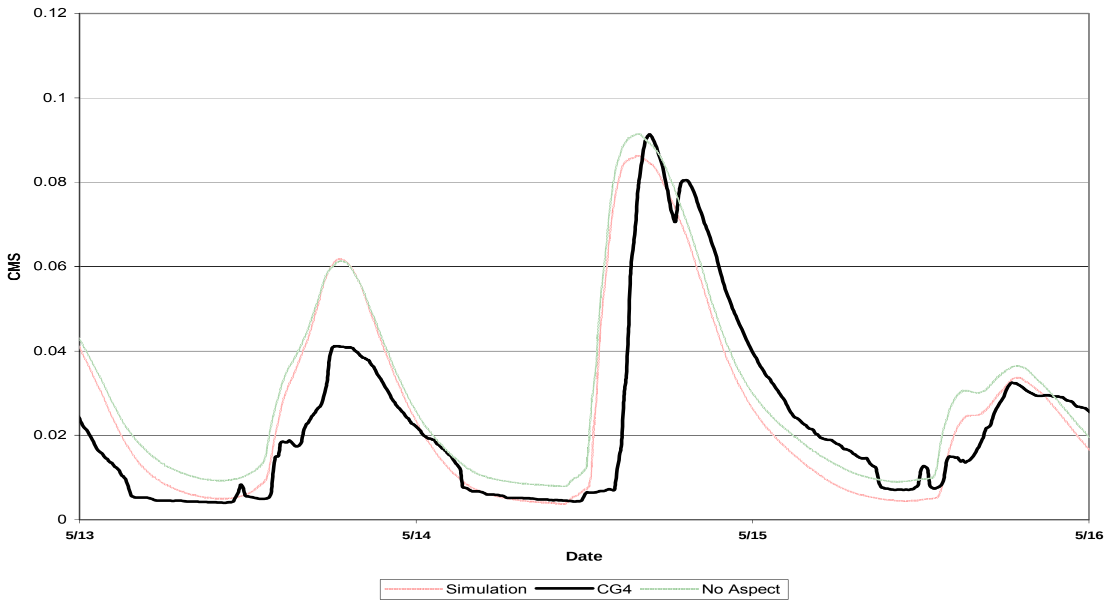

Figure C-10 Sensitivity to Aspect at CG4

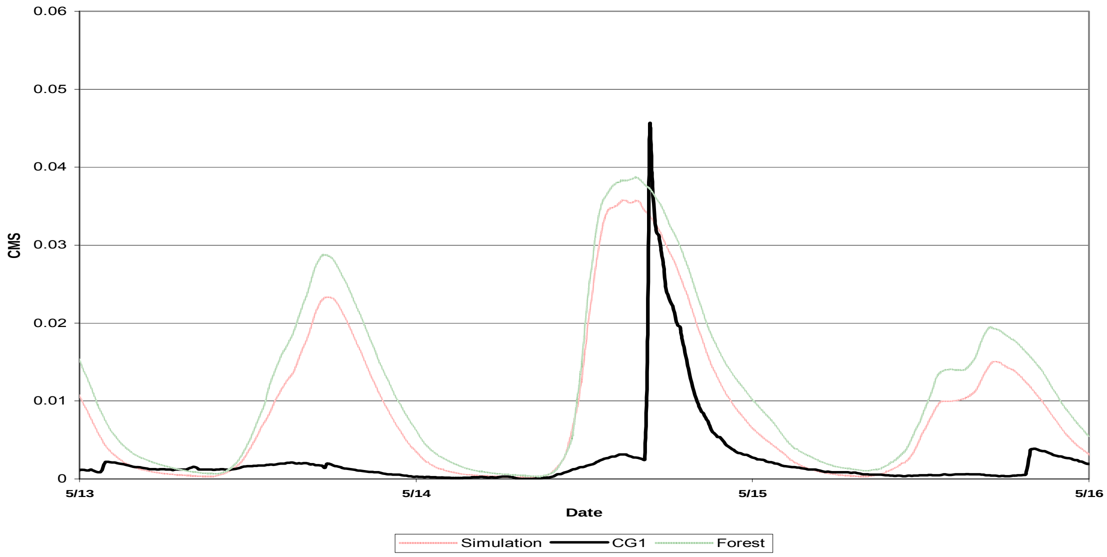

Figure C-11 Sensitivity to Forest at CG1

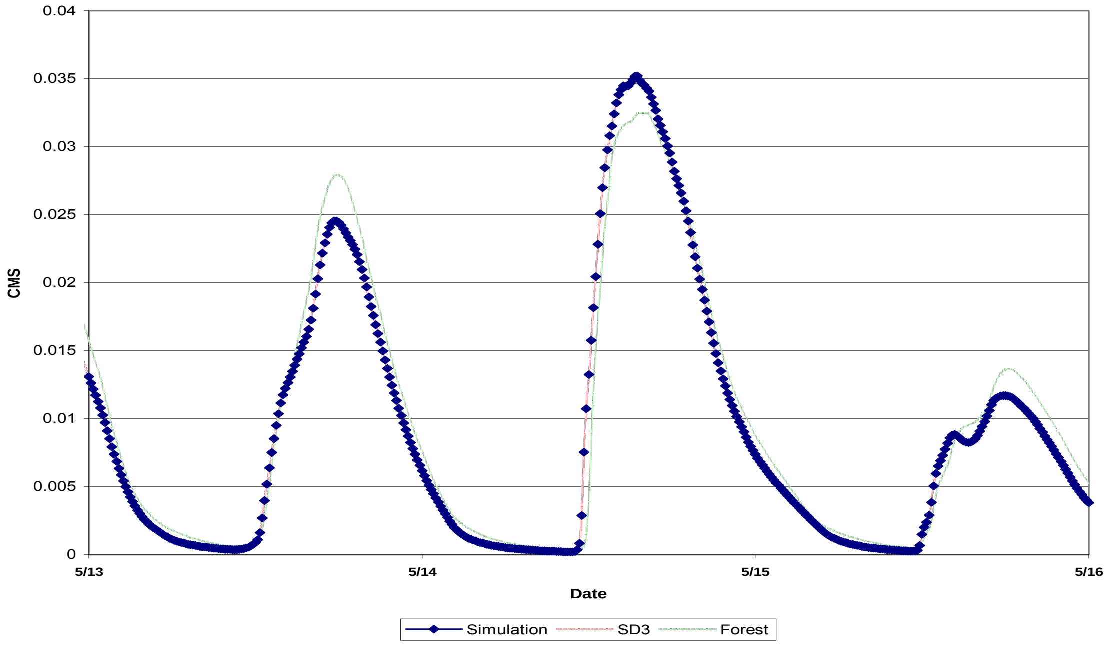

Figure C-12 Sensitivity to Forest at SD3

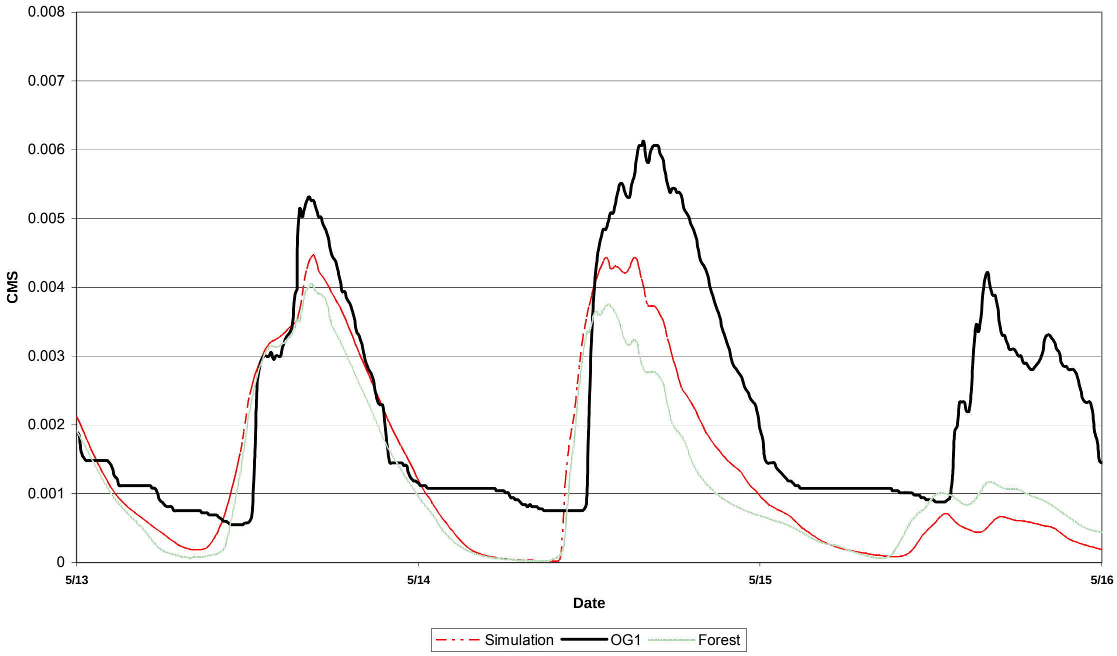

Figure C-13 Sensitivity to Forest at OG1

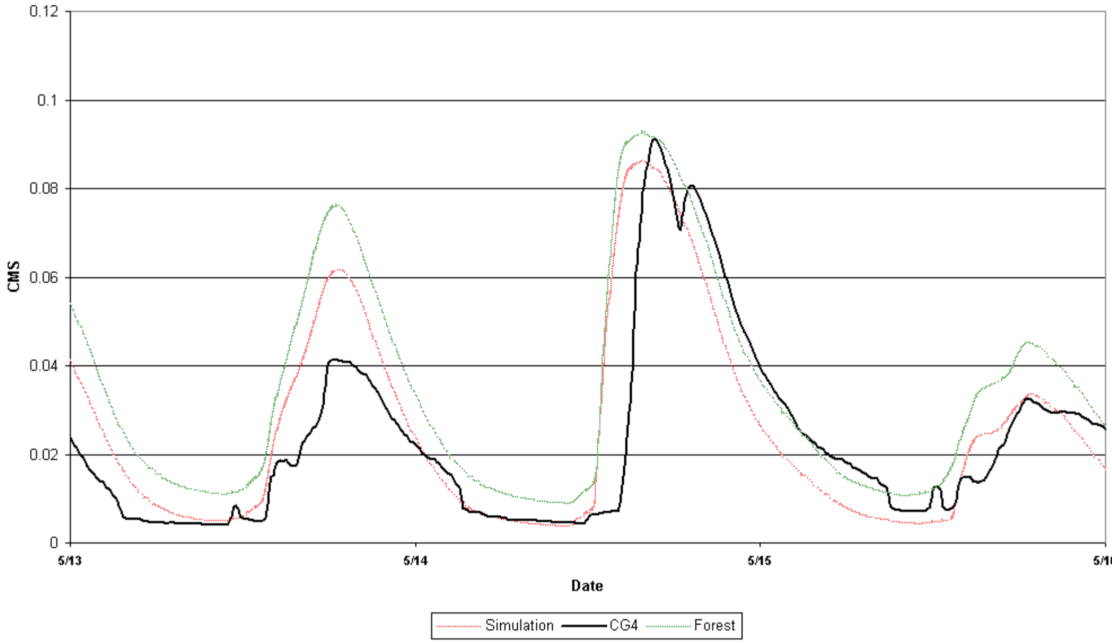

Figure C-14 Sensitivity to Forest at CG4