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A sensitivity analysis of the hydrology of the Bow Valley above Banff, Alberta using the UBC Watershed Model

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A Sensitivity Analysis of the Hydrology of the Bow Valley above Banff, Alberta using the UBC Watershed Model

by

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THESIS

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ABSTRACT

Snow and ice meltwater constitutes a significant portion of western Canada's water resources for residential, industrial and agricultural uses. As a consequence, temporal variations in climate will have a marked effect on the local hydrology of the Canadian Rocky Mountains, especially as glaciers, glacierettes and snow packs decrease in size or melt out. It is therefore very important for hydrologists to accurately understand the climatic sensitivity of glacierized watersheds in order to predict and prepare for potentially dramatic variations in the future water budget.

This thesis proposes a methodology for the estimation of the hydrological response of a large, temperate, glacierized basin to predicted climatic change. The historical hydrologic signature of the upper Bow Valley (2226 km^2) was estimated by calibrating the UBC Watershed Model to the basin using observed streamflows and meteorological data from 1950 to 1990. The areal glacier extents for the Upper Bow Valley between 1950 and 1990 were estimated based on observed trends of glacier recession in the Hector Basin. The calibration file for hydrologic year 1969 proved to be most successful, and thus was chosen for the climatic sensitivity analysis.

A series of climatic scenarios were drafted based on several general circulation model predictions. In addition, glacier areas were adjusted to simulate a 30% and 62% reduction (from 1993 estimates) in glacier area based on the observed trend in Hector Basin. The UBC Model was forced with the scenarios using the original 1969 calibration file. The scenarios were also tested against calibration files that had the glacier area adjusted to simulate estimated future extents. Results indicate that a shifting of the winter/summer discharge ratio of the Bow River above Banff will occur with a warmer climate. The reduction of glacier area reduces the potential for meltwater production in the summer, and warmer temperatures will cause earlier ablation of the winter snowpack and prolonged and enhanced evapotranspiration during the melt season.

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For my parents and Lucy.

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Chapter 1 - Introduction

1.1 The Changing Climate

Since pre-industrial times (about 1750 A.D.) accelerated greenhouse gas concentrations have caused a positive radiative forcing of the global climate (table 1.1) leading to increased surface temperatures, weather variability, and

Greenhouse Gas	Atmospheric Concentration Increase since 1750	Positive Radiative Forcing
carbon dioxide (CO_2)	30%	1.56 Wm^{-2}
methane (CH_4)	145%	0.47 Wm^{-2}
nitrous oxide (N_2O)	15%	0.14 Wm^{-2}

Table 1.1 - Increases in greenhouse gas concentrations and their influence on the earth-atmosphere energy balance - 1992 values (from Houghton *et al.,* 1996a).

other climatic anomalies (Houghton, *et al.*, 1996a; Leggatt, 1994). Despite the cooling effects of tropospheric aerosols (mainly from the combustion of fossil fuels and biomass and from volcanoes) global mean surface air temperatures have increased by between 0.3 and 0.6^{0}C since the late 19th century (Novelli, *et al.*, 1995), with the warmest temperatures in the human record occurring in the last decade. The Intergovernmental Panel on Climate Change (IPCC) have developed a range of future scenarios of atmospheric greenhouse gas and aerosol concentrations (Houghton, *et al.*, 1996b). From these scenarios, General

Circulation Models (GCM's) have been developed and refined to project future climate. GCM's use complex algorithms to simulate the most important large scale physical processes governing the global climate system. The most accurate climate models combine oceanic and atmospheric simulations (termed *coupled models*), and are the current focus of GCM research. Despite the uncertainties, of which there are many (Gates, 1987; Gates, *et al.*, 1996), GCM projections suggest that mean global temperatures will increase between 1^0C and 4^0C by 2100. The following is a list of the common predictions made by all GCM simulations (from Houghton *et al.*, 1996b):

- greater surface warming of the land than of the oceans in winter;
- minimal warming around Antarctica and in the North Atlantic as a result of deep ocean mixing;
- maximum warming in high northern latitudes in late autumn and winter resulting from decreased land surface albedo from reduced sea ice and snow cover;
- little warming over the Arctic in summer;
- little seasonal variation of the warming in low latitudes;
- reduction in the diurnal temperature range over land;
- increased snow precipitation in high latitudes ; and
- ***enhanced global mean hydrologic cycle***

1.2 Glaciers and a Changing Climate

The effects of the "Little Ice Age" on the global distribution of glaciers began to diminish around the middle to the end of the last century, when global temperatures began to increase. In response to this, alpine glaciers started to retreat to higher elevations (with some exceptions in Scandinavia and Patagonia (Holmlund and Fuenzalida, 1995)), as the hydrologic system was working towards an equilibrium with the changing climate (Meier, 1984; Oerlemans, 1987). Glaciers in the Canadian Cordillera were no exception (Henoch, 1971; Luckman, 1990).

Quantitative observations of the retreat of Yoho Glacier were first made in 1906 (Wheeler, 1934), and further recessional observations of Peyto, Chaba, Helmet, Sentinal and Sphinx glaciers were made in the 1920's and 1930's. (McCoubrey, 1937). Ice recession in this region has been extreme and virtually uninterrupted to the present day, however, this trend cannot continue indefinitely. If the climate continues to warm as predicted, then glaciers will retreat further to higher elevations or sheltered areas and the potential for glacier runoff will decrease as their extents decrease in size. This scenario has made water resources managers concerned about the future resource.

1.3 The Importance of Glaciers and the Annual Snowpack to Streamflow

Glaciers tend to regulate the flow of water in cold regions both seasonally and over longer periods of time. In the summer when the demand for water is highest, low stream flows are augmented by the melting of glaciers. Over a period of decades or centuries, glaciers will grow or diminish in size in accordance with summer temperatures and winter precipitation. At this scale glaciers act as long-term regulators by storing water during cool and wet periods, and releasing it during drier and hotter years. The exact cause for glacial cycles is not fully understood (Broecker and Denton, 1990), however, it is suspected that these cycles can be traced to massive reorganizations of the ocean-atmosphere system.

The most significant hydrologic component in most mountain systems is snowfall. The snowpack can be considered a seasonal aquifer that stores precipitation throughout the winter and releases it when temperatures increase in the spring. Spring melt is very important to groundwater recharge, and thus will affect streamflow throughout the summer. At high altitudes and sheltered areas, the perennial snowpack will contribute to the glacier system. GCM predictions suggest that winter precipitation in the Canadian Cordillera will intensify as a result of an enhanced Pacific orographic effect. If indeed this is the case, an important question is will precipitation increase enough in the winter to compensate for the potential extreme negative summer balance of Rocky Mountain glaciers caused by global warming.

1.4 The Hydrologic Importance of the Bow River Headwaters

The Bow River above Banff forms the headwaters of the South Saskatchewan River, which drains a basin roughly the size of Hungary. When considered spatially, the relatively small Bow River headwaters are unimportant relative to the entire South Saskatchewan River System. However, these headwaters are nourished by an extreme precipitation regime, and therefore are very significant hydrologically to the downstream hydrograph (figure 1.1). In the summer, Bow Valley glaciers continue to provide water once active snowmelt subsides, which flows into the dry grasslands of the prairies (figure 1.2).

The Upper Bow River is not regionally significant in providing potable water for the towns of Lake Louise and Banff, which rely on groundwater for their supply. However, downstream of Banff, water flowing from the Bow is extremely important to prairie farmers for irrigation purposes, particularly during arid periods when crops require excessive amounts of watering. Variation of the water resource during key periods of the growing season can have provincial and national effects as the South Saskatchewan River Basin sustains the majority of Canada's wheat industry.

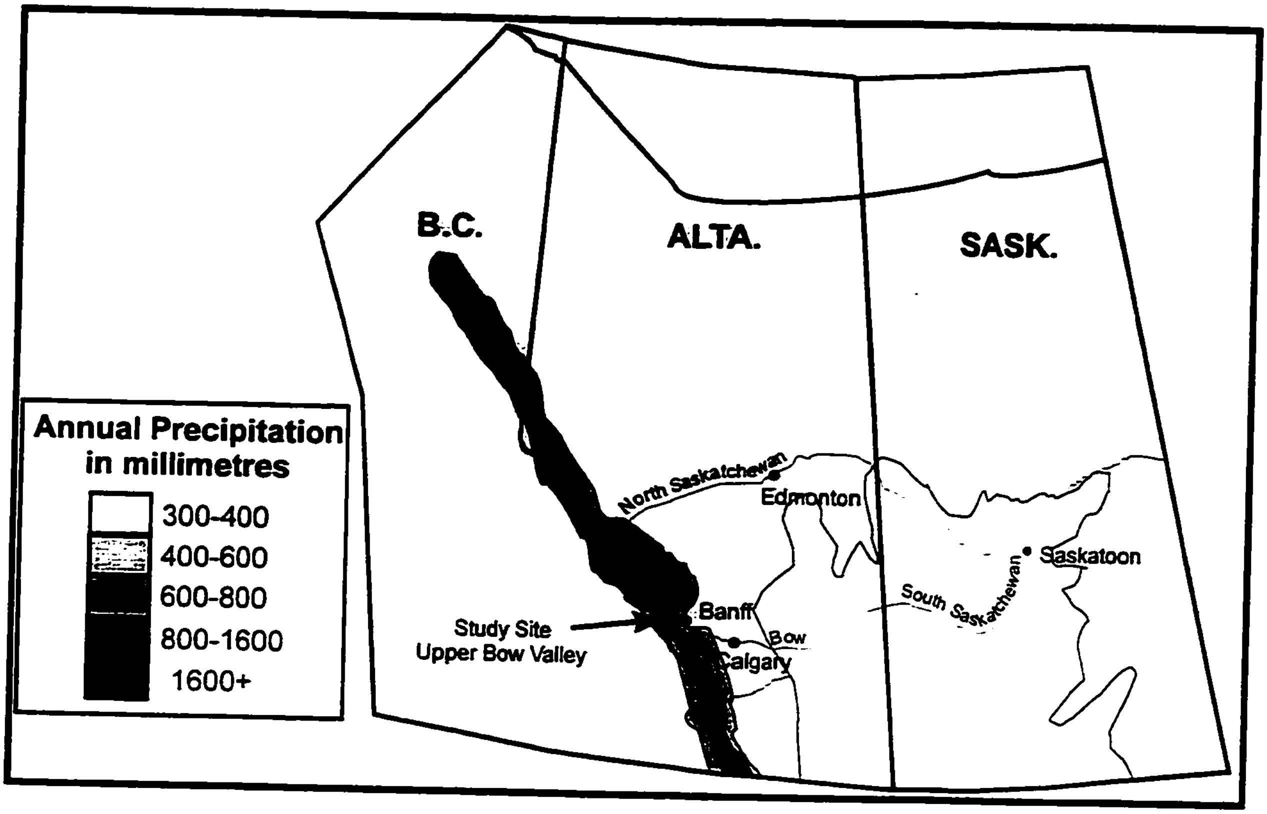


Figure 1.1 - Precipitation map of the western provinces.

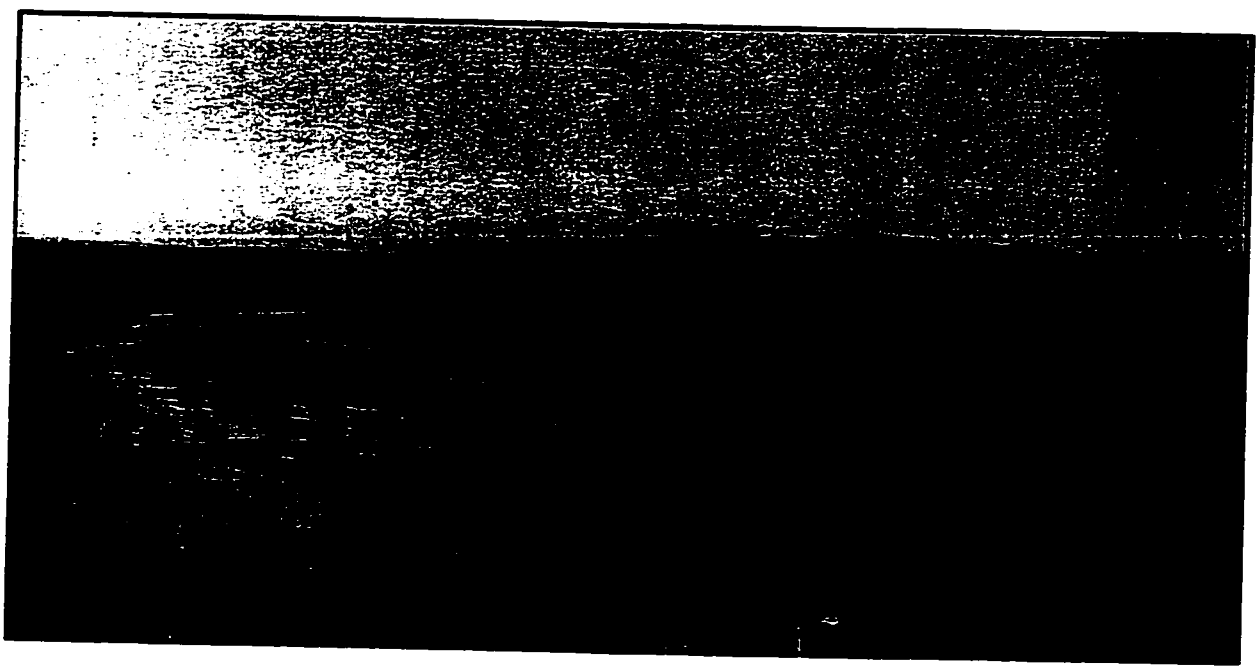


Figure 1.2 - The Upper Bow Valley (in background) provides runoff that is crucial for irrigation of the dry prairie provinces.

Intergovernmental agreements between Alberta and Saskatchewan insure that the water resource of the South Saskatchewan River is shared equally between the two provinces. Naturally, these agreements also state that in times of unusual low flow, the stress of water shortages is also shared between the provinces.

With the onset of global warming, water resource managers in Alberta and Saskatchewan are very concerned about the future of water availability in this region (Ron Bothe, pers. commun., 1997). The variation, modification and enhancement of the global hydrologic cycle is a feedback that requires heightened scientific attention, particularly in glaciated areas, if we are to prepare for the future. As recommended by the Climate-Hydrology-Ecosystems Interrelations in Mountainous Regions (CHESMO, 1994): "An intensification, coupling, and focusing of research activities in mountainous regions is urgently needed to achieve required progress in modelling the interrelations between climate, hydrology and ecosystems, as well as the effects of climatic changes and other impacts on natural resources, at different spatial and temporal scales."

In order to assess the effects of climate change on glacier basin hydrology and mass balance, one needs to identify two general parameters (Kuhn, 1993):

1) the present hydrometeorological conditions for runoff in a snow and ice covered basin must be established (daily and seasonal hydrographs need to be explained by the spatial and temporal variation of the snow and ice cover and energy input); and

2) the nature of the expected climate change needs to be defined with particular emphasis on the development of these climatic parameters that most influence current runoff patterns.

However, the solution is very complex. The exact physical parameters that determine runoff from a glacierized basin are still insufficiently understood (although a general understanding of the most influential components has been established) and detailed mountain hydrometeorological data is scarce in the Bow Valley. In addition, predicting the effects of climate change on the local meteorology of a given basin is not exact as GCM predictions are very coarse. A compromise between these two parameters must be calculated in order to estimate the effects of climate change on glacier hydrology and mass balance. A forecasting model consisting of limited inputs can still meet an acceptable level of reliability (Kuhn, 1993).

1.5 Goals and Objectives

There are two broad goals of this project:

1) The first is to identify the hydrologic signature of the Bow Basin above Banff through the following objectives:

    i) to assess the representativeness and accuracy of the regional hydrometeorologic data set;
    ii) to simulate the Bow River at Banff hydrograph using the UBC Watershed Model; and
    iii) to verify physical reality of model simulations using a regional hydrologic approach.

2) The second goal is to estimate the hydrologic response of the Bow Valley above Banff to climatic variation. This will be achieved by:

    i) establishing a series of climatic scenarios representing several GCM predictions; and
    ii) forcing the UBC model with these scenarios and comparing the model output with the observed hydrologic conditions.

1.6 Organization of the Thesis

The thesis is sub-divided into eight chapters. Following this introductory chapter, a review of mountain climate and hydrology is given and a brief overview of hydrologic modelling is included. Chapter three provides the logic for selecting the

UBC Watershed model, followed by a description of the model structure and algorithms. Chapter four is dedicated to describing the study area in terms of climate, land cover and hydrology, particularly as it pertains to hydrologic modelling. Chapter five describes the calibration process used to apply the UBC Watershed model to the Upper Bow Valley, while chapter six includes the calibration results and discussion. Chapter seven outlines the methodology and results of the application of climatic scenarios to the UBC Model, and chapter eight presents the key findings, discussion and suggestions for improvement.

Chapter 2 - Literature Review

2.1 High Mountain Climate

The study of high mountain climate is hindered by several inherent factors. First, the complexity and hazards of mountain terrain have historically deterred scientists from examining the regime of high altitude climate. Secondly, the meso and micro variability of mountain climate makes it difficult to draw basin-wide conclusions from point data sources, such as meteorological stations. In addition, the destructive nature of mountain environments, such as rockfalls, avalanches and high winds, make data collection using standard equipment problematic.

2.1.1 Effects of Altitude and Topography

Altitude and topography are the primary influences on climatic forcings in the mountains. The effects of these geographic parameters on radiation, wind and pressure, temperature, precipitation and evaporation will be discussed in the following section.

2.1.2 Radiation

Solar radiation reaches the earth's atmosphere at a relatively constant rate, known as the solar constant (I_o), and is the driving force of the planet's climate. The distribution of this energy on the earth's surface is strongly influenced by variations in topography, altitude and cloud cover. Net all-wave radiation Q^* is the sum of net shortwave and net longwave and can be generally described as (Whiteman, 1990):

$$Q^{*} = S + D + K\uparrow + L\downarrow + L\uparrow) \qquad (2.1)$$

where S = incoming direct shortwave radiation
D = incoming diffuse shortwave radiation
$K\uparrow$ = outgoing shortwave radiation
$L\downarrow$ = incoming longwave radiation
$L\uparrow$ = outgoing longwave radiation

Deficits or excesses in the net all-wave radiation budget must be compensated through fluxes of energy from non-radiative sources. These sources can be described as (Whiteman, 1990):

$$Q^{*} + Q_G + Q_H + Q_E = 0 \qquad (2.2)$$

where Q_G = ground heat flux
Q_H = surface sensible heat flux
Q_E = latent heat flux

Any excess radiative energy, typically during the day, may be used to warm the ground (or snow and ice) heat the atmosphere, or evaporate water. Nighttime radiative heat deficits are compensated by the condensation of water, radiative cooling from the air to the ground, and an upward heat flux from the ground to the air. The effect of increased altitude and topographical variation adds complexity to these processes.

Global solar radiation (shortwave) increases in intensity at higher altitudes as a result of a thinning atmosphere. Approximately one-half of the atmosphere's molecules (500 mb pressure level) is held in the lower 5000 m of the troposphere (Ahrens, 1991). Thus, as pressure decreases with elevation, so does the potential of radiation scattering, thereby allowing larger doses of direct shortwave radiation to reach the surface of high mountains as compared to surrounding lowlands. A net loss of terrestrial (longwave) radiation is experienced at high elevations because the low density of boundary layer air retards the potential of outgoing radiation absorption (Barry and Chorley, 1989).

Local topographical characteristics, such as slope and aspect, affect the thermal and radiative signature of the land surface (Young, 1985). The radiation intensity on a sloping surface can be described as (Barry and Chorley, 1989):

$$I_s = I_o \cos I \qquad (2.3)$$

where

i = the angle between the solar beam and a beam normal to the slope

High peaks in a basin will cause shading in mountain troughs and valleys, especially at low sun angles. A daily positive net radiation budget will allow radiative heating of sunlit peaks, causing air pressure differentials between sunlit peaks and shaded valleys.

2.1.3 Wind

Mountains act as a barrier to continental wind forcings. Air traveling over mountain obstacles are forced to rise often resulting in an orographic instability. The western Canadian mountain cordillera is particularly effective as a barrier to air flow as these mountains are orientated perpendicular to the direction of mass air flow. Characteristically, wind speeds at mid- and high latitude mountain peaks are usually strong - average speeds on Rocky Mountain summits in the winter are around 12-15 m s^1. This is a result of both the acceleration of air from the vertical compression of airflow, and the limited frictional resistance of terrain on high altitude winds (Barry, 1981; Young, 1985). In valley areas such as Crowsnest Pass, B.C., the funneling effect caused by surrounding mountain barriers can intensify wind speed considerably.

In addition, mountainous environments give rise to their own air flow regimes at the meso and micro scales. As valley air is warmed throughout the day, pressure differentials are created between the higher are lower altitudes (Whiteman, 1990, Barry, 1981). This causes air to expand vertically and flow both up-valley and up-slope. At night this process is reversed, and cold, dense air from higher elevations flows into surrounding lowlands. This phenomenon, termed katabatic, can also occur during the day as a result of boundary layer cooling from glacier ice (Barry and Chorley, 1989).

2.1.4 Temperature

As a consequence of the poor thermal conductivity of air, vertical displacements of air masses give rise to adiabatic temperature fluctuations. As air molecules are forced upward, a decrease in pressure occurs which results in a simultaneous volume increase and temperature decrease. The rate at which this process occurs is termed the adiabatic lapse rate, and is highly dependent on the humidity and initial temperature of the air mass. If a rising volume of air retains it's moisture (no release of latent heat by condensation), then the air cools at a rapid rate of $9.8^{0}C\ km^{-1}$, known as the dry adiabatic lapse rate (DALR). Invariably, as air cools its moisture holding capacity decreases. When the temperature reaches the dew point clouds form and there is an exchange of latent heat by the condensing vapour. This process works to preserve the temperature of a rising air mass, and is termed the saturated adiabatic lapse rate (SALR). The rate at which this occurs is dynamically dependent on temperature, such that warmer air masses are able to retain moisture more effectively than cooler air. For higher temperatures, the SALR can be as low as $4^{0}C\ km^{-1}$, but at lower temperatures (below $-30^{0}C$), this rate can approach the level of the DALR.

2.1.5 Precipitation - The Orographic Regime

As air is forced vertically over mountain barriers and cools adiabaticaly, instabilities form and an increase in precipitation is observed. The intensity of orographic lifting is primarily dependent on the vertical profiles of moisture content and wind speed. Atmospheric humidity typically decreases with height, however the effects of vapour flux convergence, cloud-water content and wind speed can act to increase the moisture content with elevation. Typically, the orographic enhancement of precipitation increases steadily and then levels off at a maximum that is located near or just above the average lifting condensation level or alternatively termed the base level of cloud formation (Ahrens, 1991, Banta, 1990, Barry, 1981, Hasse and Dobson, 1986).

2.1.6 Evaporation and Transpiration

The rate of evaporation is a function of the ambient air conditions and the energy supply to the medium. More specifically, evaporation is controlled by the surface-air difference in vapour pressure and temperature, wind speed, incoming shortwave radiation, albedo of the evaporating medium, warm air advection, and the heat storage capacity of the medium (Nokes, 1995). Transpiration of water from vegetation is dependent on the physiological characteristics of the plant, such as the stomatal nature of the leaves and root structure, and also by the vapour pressure, which controls stomata size.

The effects of altitude on evapotranspiration is not fully understood (Barry, 1981). Theoretically, increases in altitude will increase the potential solar radiation and wind available for evaporation, however, the resultant decrease in temperature and pressure will reduce the overall potential for evapotranspiration. It is suggested that in a mid-latitude mountainous environment the single most important factor affecting evapotranspiration is wind (Barry, 1981). However, the complex and heterogeneous mountainous terrain make it difficult to draw conclusions about evaporation processes from point measurements.

2.2 Hydrology of a Glacierized Mountain Basin

The understanding and importance of high mountain hydrology is a high priority. The source of all major river systems on the planet are held within mountainous environments. Thus, the variability of mountain hydrological processes can have a significant effect on physical and social characteristics of surrounding regions. Despite this, high mountain hydrology suffers from a lack of scientific attention. Klemeš (1990a), former president of the International Association of Hydrological Science, writes "Hydrology of mountainous areas is lagging behind many other areas of hydrological inquiry, in proportion to its greater difficulty (in working such complex terrains)". This generalization can be interpreted as a symptom of the difficulty in collecting data in mountainous regions.

The following section will summarize some of the fundamental processes governing the hydrology of glacierized, high mountain basins.

2.2.1 Altitude and Topography

In general, altitude, and to a lesser extent topography, are the primary constituents that determine the distinction between nival and glacierized areas. The most productive hydrological areas of runoff are found in the mid- to lower elevation bands where temperatures are generally warmer. These regions collect solid water from higher altitudes by processes of blowing snow, avalanches, and ice transport (de Scally, 1989, Paterson, 1981, Takeuchi, 1980). The amount of solid water transport is also dependent on the surface topography. The steepness of slope will influence both the rate and magnitude of ice and snow transport, where as surface roughness will positively contribute to the surface detention of water. In higher elevation bands, runoff generation is thermally subdued for the majority of the year, and basin gains are the trend (provided that the precipitation and elevation is great enough to allow the formation of glaciers). Snow precipitation at these altitudes will be stored until the thermal regime allows for melting and/or the transformation into firn and ice.

2.2.2 The Role of Glaciers in Mountain Hydrology

Glaciers act as a standing high-altitude reservoir that store water for most of the year and release it when meteorological conditions allow. In Canada, this moderating effect produces water when flow is lowest: during the hot summer months. The following section elaborates on the processes of glacier accumulation, melt and their effects on high mountain hydrology.

2.2.2.1 - Glacier Mass Balance

The quantitative evaluation of glacier mass balance is imperative when determining climatic sensitivity of glacier dynamics. As described by Sugden and John (1976), "the mass balance of a glacier describes the input/output relationships of ice, firn and snow, and is usually measured in water equivalent". One balance year is defined as the time between the formation of two summer surfaces (UNESCO, 1970). The difference between accumulation and ablation for a balance year is the net balance. A positive net mass balance is the result of greater accumulation than ablation over one balance year, whereby the reverse is true for negative mass balance. Accumulation includes the input of solid and liquid precipitation, avalanching, aeolian redistribution of snow and the formation of superimposed ice (Müller, 1962, Østrem and Brugman, 1991, Palosuo, 1987, Sugden and John, 1991). Inputs of rime, hoar, and internal accumulation (refreezing of meltwater and/or rain), are generally not significant factors in the total accumulation of a glacier (Meier, 1965). Increases in seasonal snowfall and accumulation may result in a positive mass balance, which may increase flow rates and basil sliding (Paterson, 1981).

2.2.2.3 Ablation of Snow and Ice

Snow and ice will melt only when the surface temperature reaches 0°C (isothermal). The thermal heating of a snowpack or ice surface is retarded by the cold content of the medium. This results in thermal lag time between the temperature of the air and the snow/ice. The cold content of a snowpack is preserved longer when it is within contact with glacier ice.

The energy available for snow/ice melt can be theoretically described as:

$$Q_m = Q_{sn} + Q_{ln} + Q_h + Q_e + Q_g + Q_p - d_u/d_t \tag{2.4}$$

where Q_m is the energy flux available for melt; Q_{sn} is the net shortwave radiation absorbed by the snow; Q_{ln} is the net longwave radiation flux; Q_h is the convective or sensible heat flux; Q_e is the latent heat flux, Q_g is the conductive heat flux from the ground; Q_p is the heat provided from liquid precipitation; and d_u/d_t is the rate of change of internal (stored) energy per unit area. This equation, or variations of it, is discussed by the U.S. Army Corps of Engineers (1956), Male and Grey (1981); Morris (1985) and Lang (1986).

Given that all the components of Q_m are known, the melt rate of snow/ice can then be calculated using the equation

$$M = \frac{Q_m}{S} \tag{2.5}$$

where S = Latent heat of melt (333.7 J/gr at O°C).

Typically, shortwave net radiation is usually the most important parameter causing melt in unforested areas (Lang, 1986; Male and Grey, 1981), except under conditions of complete, dense cloud cover or of Chinook winds, where turbulent heat fluxes may become dominant (Marcus, 1985). Snow packs in forested areas are more sensitive to the longwave radiation budget (Quick and Pipes, 1977). Heat provided from rain is of minor importance (Lang, 1986, Sharp, 1960, cited in Sugden and John, 1976).

Utilizing the energy budget method to calculate melt rates requires extensive instrumentation, however it is highly recommended when forecasting river flow (Lang, 1986). Quick and Pipes (1994) found significant increase in efficiency when using a modified energy budget method over the simple degree-day option in the UBC Watershed Model. However, extrapolating point-source energy budget measurements to a macro-scale mountainous basin is problematic because of the spatial heterogeneity.

2.2.2.3 Runoff from Glaciers

Glaciers can be treated as a standing reservoir. During the ablation season, meltwater from the glacier surface is transported supra-, sub-, and en-glacially towards the terminus, where it emerges into one or several pro-glacial streams. Total discharge in a glacier stream is composed of water derived from groundwater (Q_g), snowmelt (Q_s), rainfall (Q_r) and icemelt (Q_i), where:

$$Q_i = Q_g + Q_s + Q_r + Q_i \qquad (2.6)$$

Early in the melt season, meltwater originating from snowpack ablation (Q_s) has been identified as the main component of discharge while summer runoff is derived mainly from icemelt (Q_i) and from rainfall (Q_r). As the heat for melting is mainly from net radiation and sensible heat, water inputs from rainfall (typically associated with cool, overcast conditions) compensate for reduced runoff from glaciers (Fountain and Tangborn, 1985; Krimmel and Tangborn, 1974).

2.2.2.4 Diurnal and Seasonal Cycles of Glacier Runoff

Glacier fed streams are extremely variable both diurnally and seasonally. These fluctuations are the result of interacting climatic and ablation processes. The presence of glaciers in a basin will influence the timing of peak discharge, the lag between precipitation and resultant runoff, runoff storage, and the total annual flows from the basin (Østrem, 1973, Collins, 1987, Fountain and Tangborn, 1985).

The diurnal runoff pattern from glaciers is controlled chiefly by the daily pattern of incoming net radiation and temperature. For glaciers that are clean-faced or supporting a thin debris cover, maximum runoff occurs shortly after the radiation maximum: roughly between 15:00 and 18:00 hours (Röthlisberger and Lang, 1987, Young, 1985). This lag is increased by the insulating properties of a thick debris cover or snowpack. As the melt season progresses and the en- and sub-glacial conduits mature and snow packs ablate, these lags become progressively shorter and the daily peak flows become more pronounced. Low flows, primarily nourished by groundwater sources and sub-glacier melt, are observed during the night and early morning when temperatures and incoming solar radiation are lowest.

Seasonal variations are the result of annual meteorological trends. Above average snowfall in a basin will retard the altitudinal migration of the snowline. In addition, a prolonged snowpack will absorb and store liquid precipitation, adding to the complexity of rainfall-runoff relationships. A year of positive mass balance will result in the water held within the snowpack being stored as part of the glacier rather than contributing to the downstream hydrograph.

In years displaying a high snowline, summer rainfall events have a pronounced effect on the hydrograph, displaying a significantly shorter lag time in comparison to a snow covered basin. This effect is partially counteracted by the porous, exposed firn aquifer, which will entrap liquid precipitation resulting in a longer rainfall-runoff lag.

2.2.2.5 Long Term Cycles of Glacier Mass Balance and Runoff

It is well known that glacier changes are among the clearest indicators of climatic variation (Haeberli *et al*, 1987; Meier, 1965; Oerlemans, 1994; Young, 1977). However, to assess the effects of climatic change on glaciers, an estimation of the response time must be done. The response time is the time it takes for a glacier to react to climate/mass balance perturbations (Sugden and John, 1976), and is related to the ratio between the glacier's maximum thickness and its annual ablation at the terminus (Jóhannesson *et al.*, 1989). Haeberli (1995) has suggested that the general trends of the signal characteristics of glacier length changes can be categorized based on size criteria (table 2.1). This broad classification is purely a generalization of globally observed trends in glacier fluctuations. More specifically, individual glacier response to climate is far more enigmatic: the product of an intricate web of interactions between latitude, altitude, topography, geology, aspect, climate, and glacier physics.

As a result of the cool climatic regime of the Little Ice Age (Ahrens, 1991), there was a global advance of alpine glaciers. Carbon dating of wood fragments found in morainic debris estimate the maximum extent of the Athabasca and Dome Glaciers (Columbia Icefield, Alberta) to have occurred in the mid-1840's (Luckman, 1988). Since that time, global temperatures have increased and the terminus of Rocky Mountain glaciers have migrated up-slope to cooler elevations. As these glaciers melt in size, their potential to produce runoff is reduced.

GLACIER SIZE	PHYSICAL CHARACTERISTICS	RESPONSE TO CLIMATE
Small - under 5 km^2 (cirque glaciers)	• somewhat static • low shear stress	• rapid response • reflect annual changes in climate
Medium - 5-25 km^2 (mountain glaciers)	• dynamic flow • high shear stress	• slower response • reflect decadal changes in climate
Large - over 25km^2 (valley glaciers)	• very dynamic flow • high shear stress • various ice inputs	• very slow response (except surges) • reflect changes in climate of several decades

Table 2.1 - Effect of glacier size on response time (from Haeberli, 1995)

2.3.3 Evaporation and Transpiration

Evaporation describes the process of a physical change of state between a liquid or solid to a gaseous form where enough energy is available for the water molecules to break through the threshold surface pressure and into the atmosphere (Barry and Chorley, 1987). Transpiration occurs primarily during the day, as the stomata of plants close up at night, and is a function of both atmospheric and biological parameters (Miller, 1990). The main factors controlling evaporation are solar energy and the vapour pressure gradient, which is dependent on other factors such as water and air temperatures, wind, atmospheric pressure, water quality, and the nature and shape of the evaporating surface (Raudkivi, 1979; Singh, 1989). Approximately 70-75 % of global precipitation on land surfaces is returned to the atmosphere by evapotranspiration.

The term *potential evapotranspiration* describes the rate of combined evaporation and transpiration that is not limited by water availability. The *actual evapotranspiration rate* describes the observed evapotranspiration rate, which is limited by the availability of water. The primary determinants of moisture availability in a soil medium are moisture content, vapour pressure, and the hydraulic conductivity (Huff and Swank, 1985).

2.3.6 Groundwater

Throughout this text, groundwater will be defined as all water contained within the ground medium (including the unsaturated zone of aeration). Groundwater occurs in all formations, and can be considered an aquifer if it is held within a stratum that is sufficiently porous and permeable. Water held within a formation that is porous, yet prohibits flow movement in significant quantities is termed an aquiclude. A geologic formation that contains no interconnected pores, and, therefore, can neither absorb nor transmit water is termed an aquifuge. Limestone beds, being highly impermeable, are not considered efficient at storing water, however, the karstic features associated with limestone deposits promote the rapid transit of underground flows.

Groundwater aquifers are seasonally recharged following periods of positive temperatures and wet weather. Inputs from snowmelt, icemelt, and rainfall contribute to the groundwater system. The groundwater flux decays as the active hydrologic system shuts down towards the start of the winter season. Groundwater flows are the primary sources of winter baseflow in rivers.

2.4 Mountain Watershed Modelling

Modelling can be considered the combination of observed empirical facts and their hydrological theoretical understanding described by a series of algorithms. Specifically, mountain hydrologic modelling requires an interdisciplinary approach, borrowing theory from hydrology, glaciology, climatology, boundary layer meteorology, geomorphology, geophysics and hydrogeology. As a result of the theoretical complexity that surrounds the alpine environment, mountain watershed modelling can be considered the pinnacle of the modeller's regime.

2.4.1 The Concept of Scale in Modelling

An important concept of modelling involves scale - both temporal and spatial. Short term forecasting over a period of hours or days is necessary for the monitoring and prediction of extreme flood events - such data are then used to protect the social regime of the basin. Medium term forecasting, over weeks or months, is important to reservoir management to ensure the integrity of hydroelectricity, irrigation and regional potable water resources. Long term forecasting focuses on seasonal, inter-annual or decadal variation in the water budget, and is the driving force behind issues of water allocation and long term management. Conditions of variable climate present long-term forecasters with the formidable task of estimating the water resource from coarse General Circulation Model (GCM) predictions.

2.4.2 Shades of Gray - Classifying Mathematical Models

Mathematical models can be categorized into 1) theoretical or physically based models, 2) conceptual models, and 3) empirical models. Each will be briefly discussed.

2.4.2.1 Empirical, Statistical or 'Black Box' Models

Models of this sort predict basin response but make no attempt at explaining the processes that govern physical hydrology. This is achieved by formulating a purely statistical relationship between basin input and output. Some successful statistical methodologies include the unit hydrograph (O'Donnell, 1986), extreme frequency analysis (Wood and O'Connell, 1985), regression analysis (Collins, 1988) and recursive estimation (Young, 1986). Black-box models can be efficient within a given operational range as strong statistical relationships are often supported by physical processes (Anderson and Burt, 1985). However, limitations arise when applying these models outside of the calibration data set, such as extreme events or extrapolating to other basins. These models are also limited when forecasting the output of a highly dynamic basin because they lack predictive capability.

2.4.2.2 Theoretical, Deterministic or Physical Models

These are models that try to mathematically represent the physical processes that govern the hydrology of a basin. Theoretical models consist of parameters that are physically significant in their contribution to basin hydrology and can be estimated by direct measurement. They characteristically have logical structure similar to that of the real system, and as a result, are better equipped to represent a dynamic system. In general, physically based models are data-intensive and require longer computational time, which can be problematic in technology-deficient regions, but they produce more information about the basin hydrology than other classes of models. However, all theoretical models simplify and therefore are subject to errors from abstraction (Singh, 1988). In addition, physical models are subject to errors that are held within the input data set, which can accumulate and multiply within the model algorithms to reveal inaccurate results.

2.4.2.3 Conceptual Models

Conceptual models are the compromise between theoretical and empirical models. The aim of the conceptual model is to consider the physical processes, but in a highly simplified format. Quasi-physical models include parameters that are physically significant but can be estimated from basic observations of various inputs and output. This approach is typically economically reasonable (when compared to the physically-based alternative), which makes it operationally advantageous in many situations. However, significant errors in the forecasting can persist. Model parameters such as snowmelt and icemelt may compensate each other to give plausible results that are deceivingly inaccurate. In addition, as these models are only weakly process-based (and therefore are not dynamically sensitive) they have a tendency to fail under conditions different to those represented in the calibration data set. Thus when used operationally these models require constant attention and often need re-calibration under varying meteorologic circumstances.

2.4.3 Paramaterization and Lumping

A lumped parameter simplifies model structure by ignoring the spatial or temporal distribution or variability, and therefore can be defined as a type of "black-box" approach. If spatial variability is acknowledged by a parameter (either vertically or areally), then it can be considered distributed. Lumped systems are based on ordinary differential equations, whereas distributed parameters are described by partial differential equations (Singh, 1988). Issues of spatial scale are important to consider both areally and vertically. The extent of altitudinal and spatial range will effect the model structure and the degree of parameterization or lumping.

Temporal scale is also important to consider in modelling. Some models, such as the UBC Model, are considered distributed as they represent spatial variability. If viewed temporally, these models can be considered lumped as they process data on a course temporal scale, especially if highly dynamic, glacierized basins are the focus of forecasting.

It can be argued that a highly physical approach that includes many parameters of varying altitudinal and spatial scale is an accurate method of mathematically simulating the hydrologic signature of a basin (Morris, 1985). However, a coarse paramaterization or lumped approach that includes parameters that blanket the effect of several causal factors can be equally effective. The lumped approach allows for the summation of minor hydrological forcings, both physically and spatially (Singh, 1988), which can be highly dynamic at the micro, meso and macro scale, and, therefore, be extremely difficult to model accurately. This is illustrated by the comparison of the Morin Model and the Martinec Model in the World Meteorological Organization's (WMO) report on the Intercomparison of Models of Snowmelt Runoff (WMO, 1986). Martinec's Model is the simplest in the study, consisting of coarse, physically based, empirical algorithms that model only six parameters (which were externally derived and needed no calibration). However, Martinec's forecasts compare well with the results of the Morin Model, which consists of a total of 31 parameters (28 of which require calibration). This suggests that some mountain basins may be sufficiently represented by a minimum of key "blanket parameters" - rather than a data-intensive approach. The minimalist approach can be widely applied without as much threat from data constraints, and also avoids errors involved in collecting complex calibration data (Klemeš, 1990b).

2.5 Error Analysis

The two main sources of error (of many) in hydrologic modelling are: 1) mathematical models are representations of physical systems, and therefore are subject to errors from abstraction, and 2) model parameters are estimated from historical or estimated data, and are therefore subject to errors in data collection and data representation (Singh, 1988; Bergström, 1991). Errors resulting from these sources can be either random or systematic. Random errors display an illogical perturbation in the expected output that are not consistent with the trends in computed flow. Random errors can be problematic to mitigate as the source of error can be either in the data collection or a computational fluke. Systematic errors are either over- or under-estimations that persist with re-occurring meteorological conditions. Typically these errors can be easily diagnosed and treated by conducting a sensitivity analysis on relevant parameters.

2.6 Principles and Confidence in Modelling

The field of hydrologic modelling has grown exponentially since the simple rainfall-runoff years of the 1950's and 60's, and expanded into a large number of hydrogeochemical applications. Operationally, hydrologic models are relied upon heavily to aid in the management of water resources. However, the confidence in model output is widely variable. This is perhaps because there are no universal guidelines for principles and ethics in the formulation or application of hydrologic models. From a management perspective, the implications of poor modelling can have devastating effects.

Essentially, it is important to maintain a critical and constructive attitude during all stages of the modelling process in order to instill confidence in the model as a predictive tool. Model results should be constantly and rigorously tested against high-quality observations. Unfortunately, forecasts into the future using climatic scenarios cannot be compared with observed data, and thus all assumptions, results and limitations must be clearly presented to the policy and decision makers.

Chapter 3 - Selection and Description of The UBC Watershed Model

3.0 Introduction

It is the objective of this chapter to provide a synopsis of the model selection process and a brief description of the UBC Model structure. Also included is a summary of the model calibration tools used in the calibration process. Detailed description of model algorithms is provided in appendix 1.

3.1 Selection of an Appropriate Model

Dodge (1972) outlined a rational methodology for the selection of hydrologic models for prediction purposes. The following variation of Dodge's methodology was used to determine the selection of a model for this project:

1) Define the problem.
2) Specify the objective.
3) Examine the data availability.
4) Specify the economic and computing constraints.
5) Choose a particular class of hydrologic model (statistical, conceptual or physical).
6) Select an appropriate model that functions well in a mountainous environment.

The problem and objectives of this project (as outlined in chapter 1) require a complex, distributed model structure (both areally and vertically) to account for the changes in glacier size within complex mountain terrain. Unfortunately, the Bow Valley data set contains only simple meteorological variables: daily maximum and minimum temperature, daily precipitation and periodic snowcourse data, which limit the model criteria to an empirical or conceptual model with little data requirements.

The UBC Model, designed specifically to provide a computational representation of mountain watershed behavior, satisfied the data constraints. It is a quasi-physical, coarsely distributed model designed primarily for short term hydrograph forecasting. However, because the model can operate continuously using successive meteorological data, it is feasible to use the model for long term forecasting. The model compared well with other watershed models in the World Meteorological Organization's Intercomparison of Models of Snowmelt Runoff (1986) and is used extensively by B.C. Hydro for operational flow forecasting of the Williston and Columbia watersheds. In addition, the model is available free of charge from Dr. M.C. Quick (Department of Civil Engineering, University of British Columbia) and can operate on a 486 personal computer. Thus, the UBC Model was selected for the project.

3.2 Data Requirements and Design Constraints

The model requires a minimum of input data, which includes daily minimum and maximum temperature and daily precipitation. From these data both the timing and quantity of streamflow resulting from snowmelt, icemelt, rainfall and groundwater is calculated. As a consequence of the minimal data requirements, the model inherently makes gross assumptions when computing output. The model interprets meteorological point data and extrapolates values for the entire watershed based on the operator's physical description of the basin.

In order to calibrate the model, high quality streamflow reference data are needed. It is desirable to use flow data from a meteorologically diverse number of years. This will sensitize the model to basin response to a variety of meteorological conditions. However, using a hydrologically extreme anomalous year to calibrate the model can muddle the forecast efficiency. This is because the model may process average storm events with an extreme event bias.

The estimation of snow packs by the model is accomplished by using two data sources: daily precipitation from meteorological stations and snow course measurements. Snow course measurements are not used as direct input, but rather as a reference to compare estimated snow accumulation. Daily precipitation values from meteorological stations are input directly into the model to estimate snow accumulation per elevation band.

3.3 Watershed Model Structure

The basic structure of the model contains four main sub-models:

1) Meteorological sub-model;
2) Snow and Glacier Melt sub-model
3) Soil Moisture sub-model; and
4) Flow Routing sub-model.

A schematic of the model is presented in figure 3.1. A brief description of each sub-model is provided below.

3.3.1 Meteorological Sub-Model

The model can interpret meteorological data from a maximum of three point sources (meteorological stations) at given elevations. The meteorological data from each point source is extrapolated to the mid-elevation of each band using a series of lapse rate calculations and estimated precipitation modification factors.

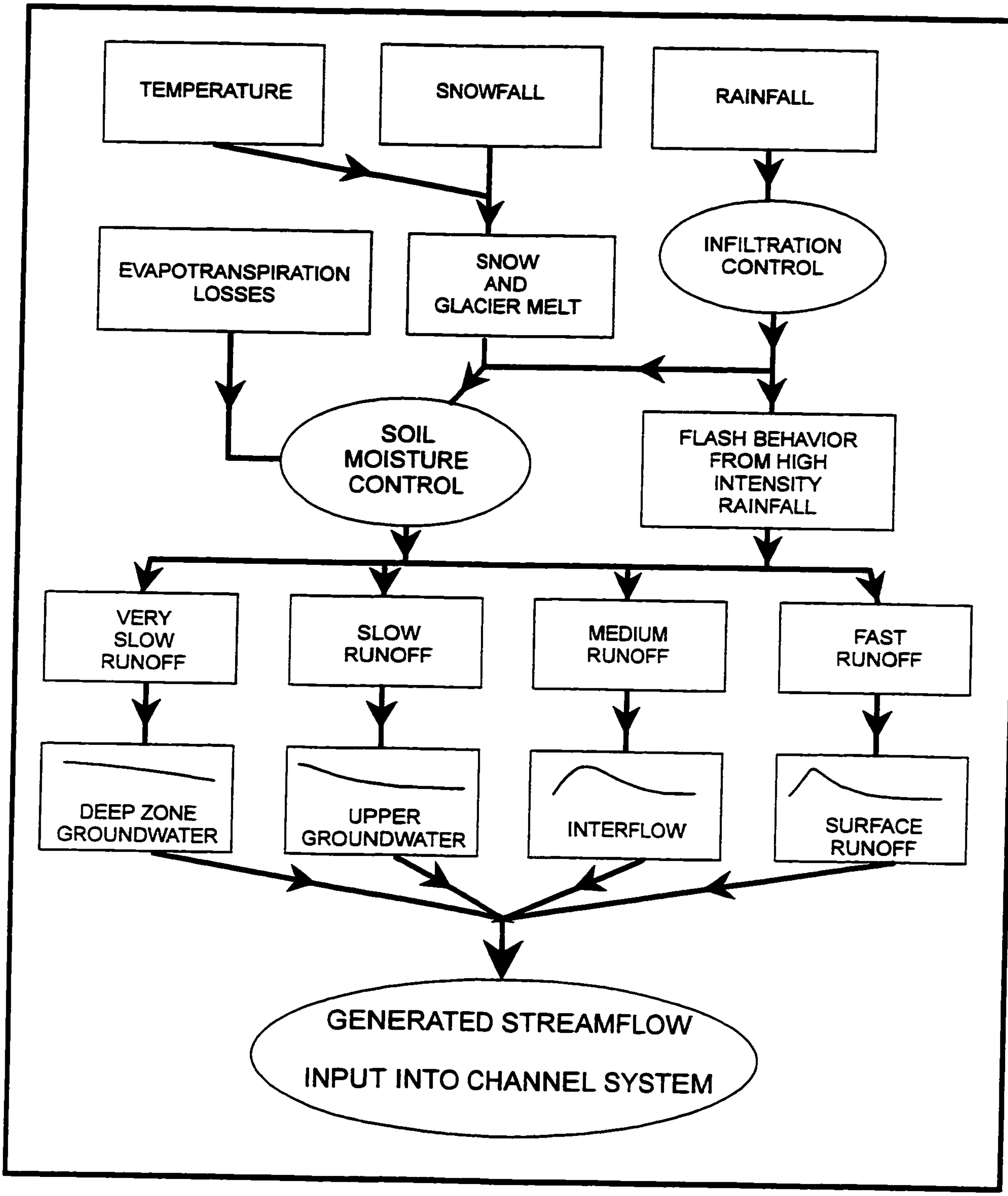


Figure 3.1 - Schematic of the UBC Watershed Model Structure (from Quick and Pipes, 1994).

3.3.1.1 Calculating Temperature Lapse Rates

The UBC model estimates temperature lapse rates primarily as a function of daily temperature range and precipitation. The temperature lapse rate under humid conditions will approximate the saturated adiabatic lapse rate (SALR), which is typically quite low. The model assumes humid conditions during periods of little diurnal temperature range and/or when precipitation is recorded. During periods of little cloud cover and low humidity, the lapse rate during the day will be quite high, and therefore closer to the dry adiabatic rate (DALR). These conditions are typified by a high diurnal temperature range. Based on the above assumptions and by using the daily temperature range as an index, the model calculates two daily lapse rates: one for maximum temperature and one for minimum temperature.

3.1.1.2 Precipitation Elevation Gradients

The orographic enhancement of precipitation is described by two independent algorithms. The first algorithm predicts the orographic effect on precipitation when the base elevation temperature is $0^{0}C$ or less. The logic behind this equation is that cold, moist air masses are very dependent on orographic lifting to produce precipitation (Quick and Pipes, 1994). Orographic enhancement of precipitation tends to decrease substantially at about ½ of the elevation range and levels off at about $^{2}/_{3}$ of the elevation range (Barry, 1981). To account for this process, this algorithm allows for a three-level modification of the orographic effect on precipitation (figure 3.2). This option is particularly useful in basins with a large elevation range, such as the Himalayas.

A second algorithm describes the distribution of precipitation for temperatures that are greater than 0°C by estimating the stability of the air mass. At warmer air temperatures, a large difference between SALR and DALR indicates an unstable air mass. As warm air is more likely to produce convective precipitation, and therefore is less dependent on orographic lifting, this algorithm decreases the orographic effect on precipitation. The combination of these two algorithms is responsible for the sensitivity of snowfall to orographic effect and the relative immunity of warm, summer rainfall to orographic enhancement.

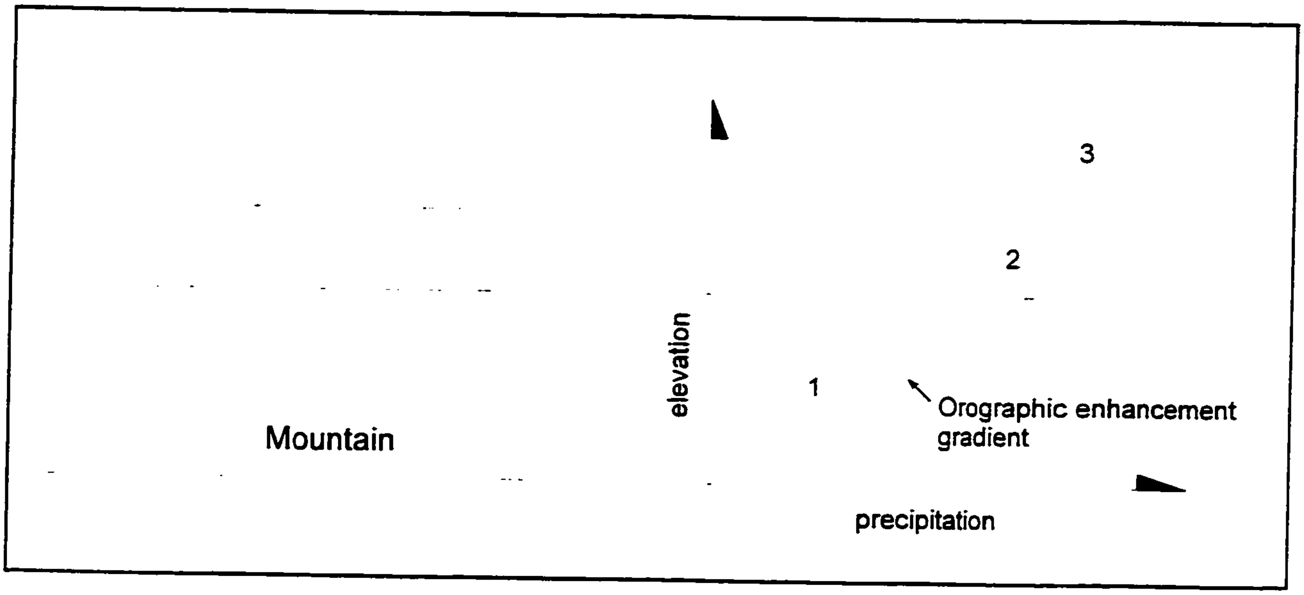


Figure 3.2 - Schematic of possible precipitation gradient factors in the UBC Model.

3.1.1.3 Form of Precipitation

For each elevation band, the model must calculate the physical state of precipitation as being either solid or liquid. Precipitation falling as snow is treated as a temporary aquifer until melted, where as rain is immediately processed by the soil moisture model. The differentiation between snow and rain is dictated by three logical assumptions:

if $T < 0^0C$ all precipitation is solid;
if $T >$ A0FORM all precipitation is liquid;
if A0FORM $\geq T \geq 0^0C$ then a portion of the precipitation will be rain.

A0FORM is also a model parameter that can be specified by the user. Typical values for most basins hover around the default setting of 2^0C. Although the model uses mean daily temperature when making these assumptions, the model can be calibrated to use daily maximum or minimum temperature.

3.1.1.4 Precipitation Representation Factors

The model extrapolates point precipitation values to cover the areal extent of the basin by assigning two precipitation representation factors (PRF) to each meteorological station: one for snow and one for rain (figure 3.3). The PRF adjusts point measurements from meteorological stations to correspond with the precipitation budget of the entire basin. The PRF values, ranging from -1 to 1, are input by the user and are determined by comparing long term discharge and snowcourse data to calculated data. A PRF of -1 will decrease precipitation by 100% at the meteorological site elevation. Snow precipitation (and ultimately accumulation) is likely to be far more variable than rainfall due to factors associated with redistribution, orographic enhancement, lake effects, vegetative cover and local exposure (Pomeroy and Gray, 1995; Quick and Pipes, 1994).

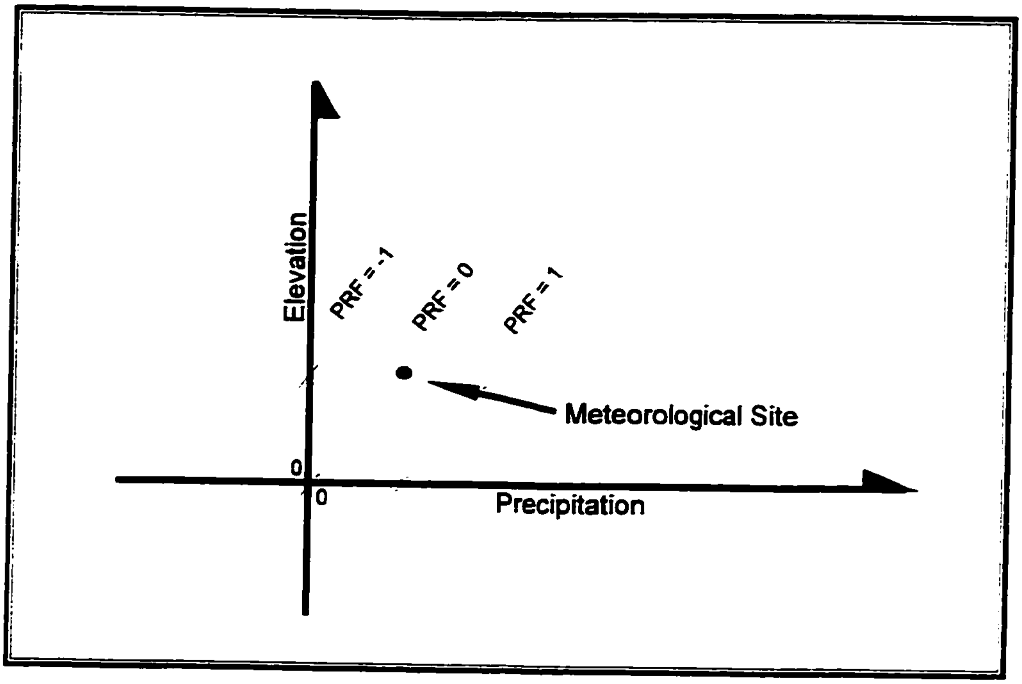


Figure 3.3 - Schematic displaying the effect of the model parameter Precipitation Representation Factor (PRF) on point precipitation measurements (from Quick and Pipes, 1994).

3.1.1.5 Evapotranspiration

The UBC Model calculates evaporation through a three stage approach. The first stage estimates the daily potential evapotranspiration for the elevation band of the reference meteorological station. This algorithm includes a monthly factor that accounts for the seasonal variation of evaporation. The second stage distributes the calculated daily potential evaporation rate for the reference meteorological station to the mid-elevation of the remaining elevation bands in the watershed using the calculated environmental lapse rate. The third stage estimates the actual evaporation rate per elevation band by processing the potential evaporation rate in conjunction with the calculated soil moisture deficit. This stage will be discussed as part of the soil moisture model.

As forest cover significantly influences the daily potential evapotranspiration rate (Strahler and Strahler, 1989), the model includes a forest cover modification algorithm. However, actual evapotranspiration rates are physically related to the density of vegetation cover, which decreases with increasing elevation. Thus, the model allows evapotranspiration to be modified by a canopy density factor which is entered by the user and describes the density of tree cover per band.

3.3.2 Soil Moisture Model

The UBC Model processes water inputs from snowmelt, icemelt and precipitation into non-linear subdivisions of evaporation loss and fast, medium, slow and very slow runoff components through a soil moisture deficit regime (figure 3.4). It is common for watershed models to operate under a soil moisture deficit rather than to describe the soil moisture capacity of the basin because it is less data intensive and ultimately less complicated (Bergstro[crrc1]m, 1991). The maximum runoff potential of the basin is reached when the soil moisture deficit has been satisfied, with the exception of flash runoff from high intensity rainfall.

This component of the model is non-linear because the soil moisture parameters are largely empirical, or more accurately, founded on the observed hydrograph and therefore history-based. By keeping non-linear computations within the soil moisture model, the flow routing model can be kept linear, and therefore much simpler computationally, which ultimately cuts down on computing time (Quick, M.C., pers. comm., 1997). The model prioritizes soil moisture components into four categories which will be explained individually.

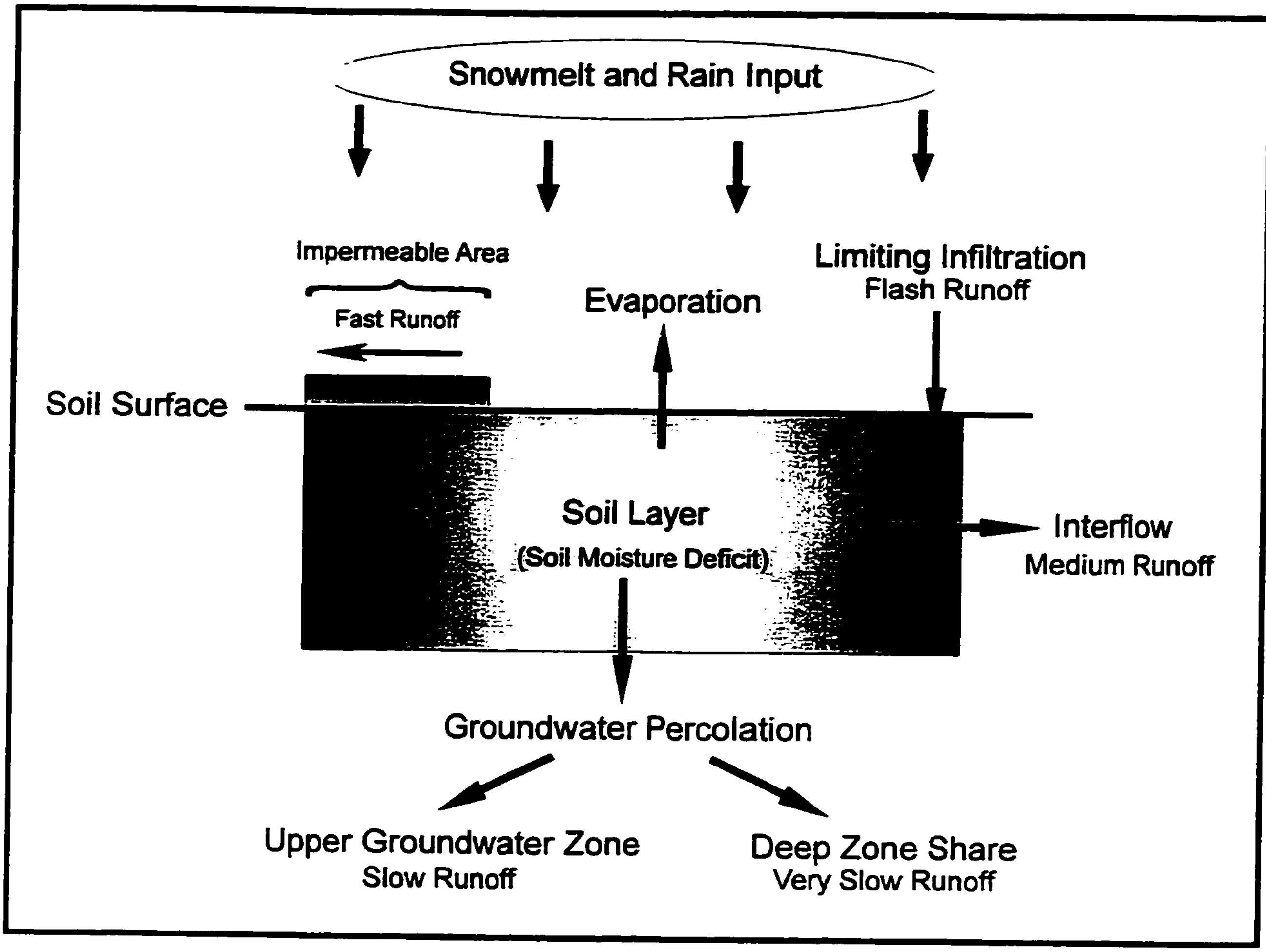


Figure 3.4 - Schematic of the UBC soil moisture model (from Quick and Pipes, 1994).

3.3.2.1 First Priority - Impermeable Percentage (Fast Runoff)

The model allows the user to ascribe a certain percentage of each elevation band as being impermeable. Any input of water to these areas will be equivocally treated as fast runoff, representing Hortonian flow conditions. However, as the rates of the aforementioned processes are a function of the antecedent moisture conditions of the soil (Römkens, et. al, 1990), the model contains an algorithm that modifies the impermeable percentage (areas of bare rock land cover) of the watershed with changes in the soil moisture deficit.

3.3.2.2 Second Priority - Soil Moisture and Actual Evapotranspiration

The second priority satisfies the soil moisture deficit by allowing water inputs from snowmelt and rainfall. After entering the soil layer budget, a portion of the soil water is routed out of the soil moisture model as a result of daily estimates of actual evapotranspiration. Only permeable areas of the watershed are affected by the evapotranspiration demand. The model calculates a new value of soil moisture deficit for every day. All water input flowing into the soil layer is stored until the soil moisture deficit reaches zero, at which point water will overflow into other priorities.

3.3.2.3 Third Priority - Groundwater Percolation - Slow Runoff

Discharge from the soil layer aquifer is directed into the groundwater component until satisfied, at which point water is directed to the next priority (medium runoff). The groundwater percolation rate is a constant set by the user. The model processes water entering the groundwater component into two subdivisions: upper and lower groundwater. This separation simulates two rates of groundwater flow which can be adjusted independently to allow for a more accurate representation of watershed behavior.

3.3.2.4 Fourth Priority - Medium Runoff

The excess flowing from groundwater storage's is filtered into the medium runoff component (termed interflow), with the exception of glacier melt, which is re-routed to flow into the fast component of glacier meltwater production. Despite being categorized as the lowest priority, medium runoff is the most significant component of the soil moisture model during times of high volume snowmelt and rainfall.

The model treats the medium runoff component as a large "bath" which is nourished daily by excess snowmelt and rainfall. The algorithm releases a portion of this storage per day which is offset by a temporal value entered by the user.

3.3.3 Runoff Generated From High Intensity Rain

The model contains a sub-routine to estimate the runoff produced from high intensity rainfall events. The model assumes that during intense rainfall events a small percentage of runoff percolates into the soil moisture routine and the remainder, termed *flash share*, is directed entirely to the fast runoff component. The flash share is a function of the daily water inputs (rainfall, snowmelt and icemelt) and from two user-inputted parameters that describe: 1) the threshold value of total precipitation for flash runoff, and 2) the maximum flash runoff range. Snowmelt is only added to the flash share component during periods of high intensity rainfall.

3.3.4 Watershed Routing

The watershed routing procedure is based on a series of linear storage reservoirs. This procedure allots a time distribution factor to the quantity of water estimated within each component of runoff: fast, medium, slow and very slow (figure 3.5). Programming the routing algorithms in a linear fashion allows for faster computations and dissolves the need for calculating the antecedent conditions during the routing process (Quick, M.C, pers. comm., 1997). As a result of this

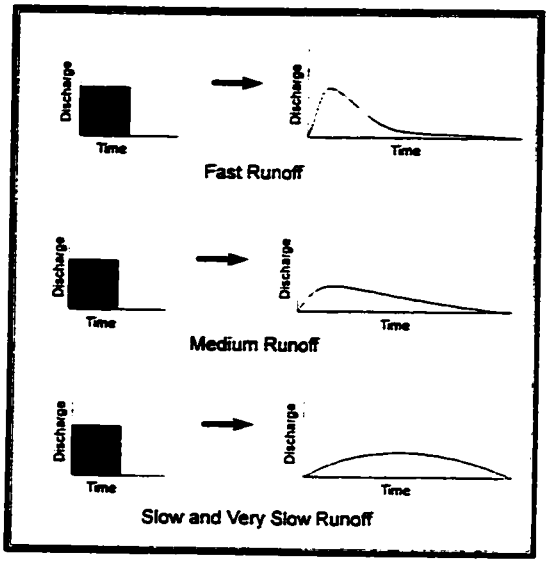


Figure 3-5 - Schematic of watershed routing model timing transformations on fast, medium, slow and very slow runoff (from Quick and Pipes, 1994).

linear programming, the model has the potential to be turned off and on at any given time and still provide accurate results regardless of the antecedent conditions.

3.3.5 Snow and Ice Melt Model

The model accumulates snowfall per elevation band based on the precipitation data. The model melts the snowpack using a simplified energy budget method based entirely on temperature-related assumptions (explained in appendix 1). This method has proven to be reasonably accurate in areas dominated by the longwave heat exchange, such as forests (Quick and Pipes, 1994). However, open area melt is not as well estimated as it is more a function of shortwave radiation, snowpack albedo, and turbulent mixing (Lang, 1986). Temperature alone is not an accurate indication of these variables as they are physically dependent on other factors, such as wind speed, cloud cover, and local topography (Quick and Pipes, 1994). However, Quick and Pipes approach this problem with a simplified energy budget theory that uses both minimum and maximum temperature and the diurnal temperature range to estimate the energy exchange at the surface of the snowpack. The model separates the traditional energy budget method into five main components, net shortwave radiation, net longwave radiation, convective heat transfer, advective heat transfer, and rainmelt, and calculates melt in mm/day produced by each component. The model includes algorithms to account for snow albedo decay and for a negative melt budget (cold content). Ice melt is calculated using the same equations but assuming an albedo of 0.3 for all glacierized areas.

3.4 UBC Model Calibration Tools

Several tools were used to calibrate the UBC Model. These include statistical analysis, graphical output, sensitivity analysis and an optimization routine. The procedure for model calibration is a cyclical one that involves both the objective description of evaluation statistics and the subjective visual interpretation of calculated hydrographs. Each will be briefly discussed.

3.4.1 Statistical Analysis

In the early stages of calibration, statistical output is primarily relied upon to estimate annual runoff volume. Three statistical algorithms are used: coefficient of efficiency, coefficient of determination, and the absolute value of difference. The coefficient of efficiency (*e!*) compares the timing and volume of the estimated with the observed hydrograph, and is calculated as follows:

$$e! = 1 - \frac{\sum_{i=1}^{n}(Qobs_i - Qest_i)^2}{\sum_{i=1}^{n}(Qest_i - \overline{Qobs})^2} \tag{3.1}$$

where

$$\overline{Qobs} = \frac{1}{n}\sum_{i=1}^{n} Qobs \tag{3.2}$$

$n =$ the number of days for daily runs or hours for hourly runs

$Qobs_i =$ the observed flow on day/hour i

$Qest_i =$ the calculated flow on day/hour i

An efficiency of 1 translates to a perfect estimation. Values deviating from 1 indicate problems associated with volume and/or timing. This statistic is more sensitive to exaggerated peaks rather than small underlying flows.

The coefficient of determination (r^2) is a function that describes how well the shape (timing) of the calculated hydrograph corresponds to the shape of the observed hydrograph - it is independent of volume representation. The coefficient of determination is calculated as follows:

$$r^2 = 1 - \frac{\sum_{i-1}^{n}(Qobs_i - (b \cdot Qest_i + a))^2}{\sum_{i=1}^{n}(Qobs_i - \overline{Qobs})^2} \tag{3.3}$$

where

$$a = \frac{1}{n}\sum_{i=1}^{n} Qobs_i - b\sum_{i=1}^{n} Qest_i \tag{3.4}$$

$$b = \frac{\sum_{i=1}^{n}(Qobs_i)(Qest_i) - \frac{1}{n}\sum_{i=1}^{n}Qest_i\sum_{i=1}^{n}Obs_i}{\sum_{i=1}^{n}(Qest_i)^2 - \frac{1}{n}\sum_{i=1}^{n}Qest_i} \quad (3.5)$$

The statistic that describes the volume error between calculated and observed flows is the absolute value of the difference (V), and is calculated by

$$V = \left|\frac{Qobs - Qest}{Qobs}\right| \quad (3.6)$$

This statistic is independent of hydrograph shape. Overestimation of total volume indicates that precipitation estimation is exaggerated. Visual examination of the graphical output is necessary to determine the timing of precipitation misrepresentation.

3.4.2 Graphical Output

Once the annual yield has been characterized, the temporal resolution is reduced to a seasonal level, and then further to a monthly or weekly scale. This fine tuning process relies on adjusting the timing and volume of runoff based on visual graphical output. The model is capable of displaying a graphical output for all components of the hydrograph (icemelt, snowmelt, rainfall, groundwater) produced in each elevation band or the total value for all bands.

3.4.3 Sensitivity Analysis

In order to approximate the model parameters, the model includes a sensitivity analysis option. After selecting the parameters to investigate, a range of values to be tested are entered into the program. Keeping all other parameters static, the program will then run the range of each parameter through the model and calculate the efficiency, coefficient of determination and the volume error for each value. This option is useful in approximating the values of model parameters, however, further adjustment is typically necessary.

3.4.4 Optimization Routine

The model also includes an automated optimization routine, which can be used to fine tune approximate parameter values without the tedium of having to manually vary model parameters and re-run the model. The user enters a range of ballpark values for up to three parameters. The optimization routine then randomly selects a value within this range, runs the model, and automatically calculates performance. Optimum parameter values are then recorded. This tool was not relied upon, as it is purely based on statistical analysis, and tends to ignore physical reality.

4 Chapter 4 - The Study Area

4.1 The Study Area

The Upper Bow Valley (2226 km^2) lies on the eastern side of the Great Divide of the Canadian Rocky Mountains, from latitude 51° 30' to 50° 40' North, and longitude 116° 35' to 115° 20' West (figure 4.1). The topography is rugged and mountainous, with ridges running generally north/south and separated by U-shaped valleys that confine the Bow River and its tributaries. The glacierized area was estimated at 73km^2 in 1978 (Young, 1995), of which most are perched on the western slopes of the valley above Lake Louise (figure 4.2). The Bow Valley has an altitudinal range of approximately 2200 meters, from 1200 masl to over 3400 masl, and can be separated into nine sub-basins. Table 4.1 summarizes the land covers of the Upper Bow Valley, including the sub-basins.

BASIN		Area	Forest	Glacier	Lake	Rock	%	%	%	%
	Gauge	km. sq.					Forest	Glacier	Lake	Rock
Bow River at Banff	BB001	2226.66	1160.06	72.86	15.06	978.68	52.10	3.27	0.68	43.95
Lake Louise	BA001	425.55	174.78	45.13	9.04	196.60	41.07	10.61	2.12	46.20
Pipestone River	BA002	307.79	119.71	9.79	0.35	177.94	38.89	3.18	0.11	57.81
Johnson Creek	BA006	124.17	50.94	0.00	0.31	72.92	41.02	0.00	0.25	58.73
Baker Creek	BA007	125.49	40.34	0.09	0.59	84.47	32.15	0.07	0.47	67.31
Hector Lake	BA008	281.41	83.81	33.20	9.04	155.36	29.78	11.80	3.21	55.21
Forty Mile Creek	BB003	133.41	64.95	0.00	0.13	68.33	48.68	0.00	0.10	51.22
Brewster Creek	BB004	107.15	48.73	0.49	0.25	57.68	45.48	0.46	0.23	53.83
Redearth Creek	BB005	154.16	94.12	1.71	1.23	57.10	61.05	1.11	0.80	37.04
Rest of basin		848.97	566.48	15.65	3.18	263.66	66.73	1.84	0.37	31.06
COMPARATIVE BASIN										
Peyto Creek		22.25	0.00	12.12	0.00	10.13	0.00	54.50	0.00	45.50

Table 4.1 - Summary of basin land cover characteristics for the Upper Bow Valley and sub-basins.

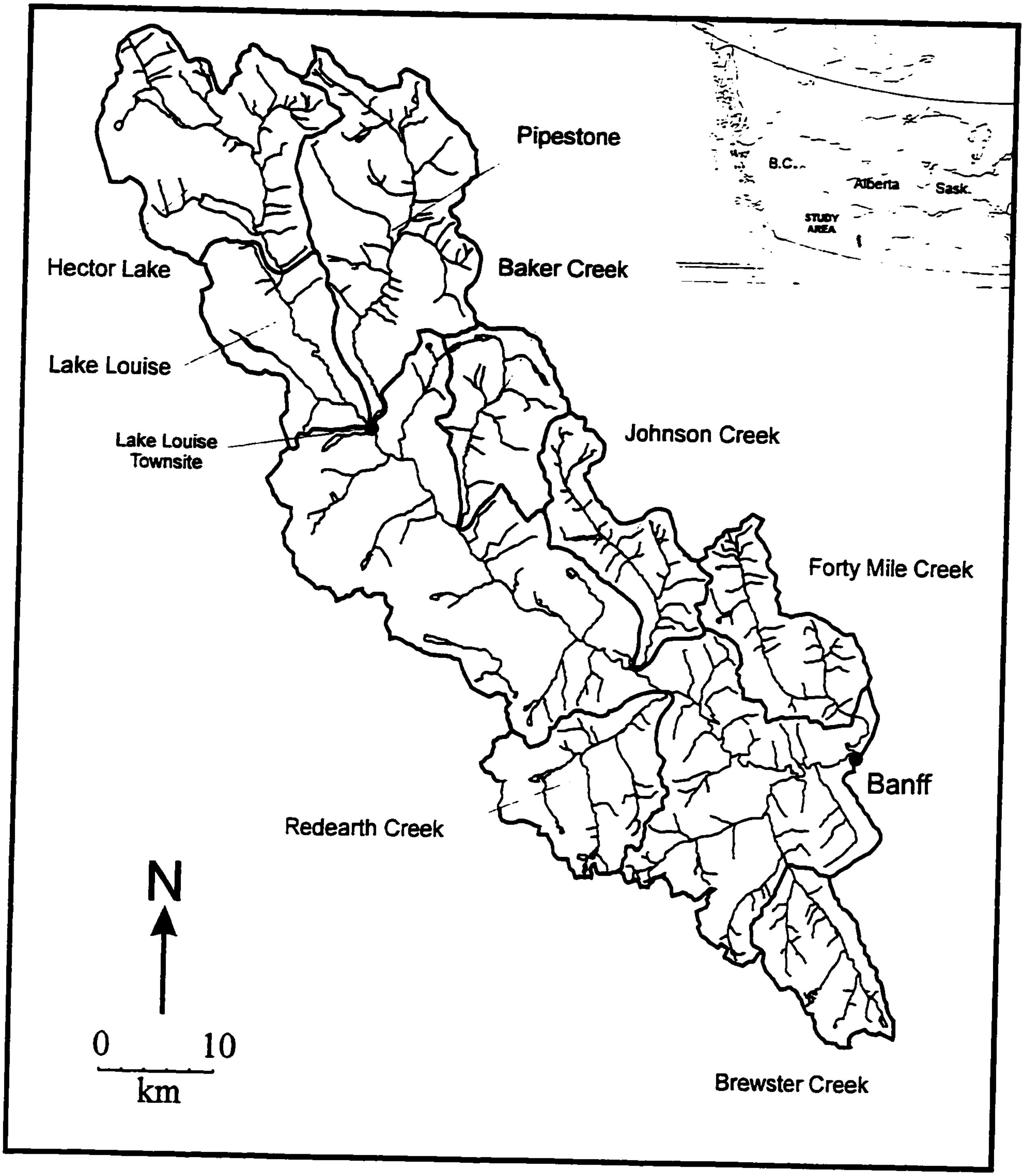


Figure 4.1 - The Bow Valley above Banff with sub-basins and rivers delineated.

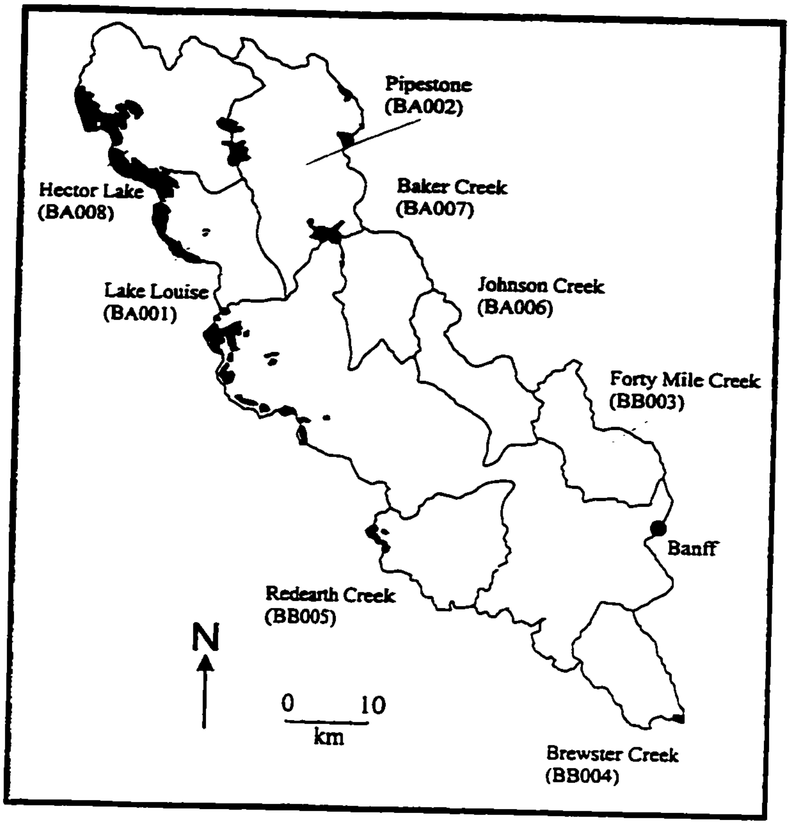


Figure 4.2 - Glacier distribution within the Upper Bow Valley (digitized from 1977 NTS maps).

Gadd (1995) provides an excellent overview of the ecological communities that flourish in the Bow Valley. Forest cover is extensive and dense over most of the basin under 2400 masl, and consists of mostly montane and subalpine woodlands supporting species of lodgepole pine (*Pinus contorta*), subalpine fir (*Abies lasiocarpa*), white spruce (*Pinus monticola*), Douglas-fir (*Pseudotsuga menziesii*) , aspen (*Populus tremuloides*) and white birch. The moist forest floor of the subalpine region is typically blanketed with thick mosses, such as stairstep moss (*Hylocomnium splendens*), Big red-stem (*Pleuroziumschreberi*) and knight's-plume

(*Ptilium cristacastrensis*). These mosses can act as a significant surface reservoir in the forest hydrology.

Mountain building, or more accurately up-piling, in the Canadian Rockies began in the late Jurassic Period, about 140 million years ago and tapered off about 45 million years ago (Gadd, 1995). The geology of the Bow Valley is primarily composed of sedimentary carbonate rock (dolomite and limestone) and clastics (sandstone, shale, quartzite, siltstone and gritstone). The Middle Carbonate Unit (limestone, dolomite, shale and slate) composes the majority of the Upper Bow Valley, formed in the middle Cambrian to Permian periods. The sedimentary layers found in the Middle Carbonate Unit are highly fractured and interbedded, resulting in a complex hydrogeological regime.

4.2 Climate of the Study Area

The Bow Valley above Banff experiences a moist, continental climate with meteorological forcings primarily from the Pacific Ocean and less frequently from the Gulf of Mexico and central Canada. Most of the atmospheric moisture from Pacific storms falls on the ranges west of the Bow Valley, however typical annual valley floor precipitation is still high, averaging about 450mm/annum. Meteorological forcings coming from the prairies occur mostly in early summer and during mid-winter cold snaps, and bring cool, wet conditions known as upslope weather which can last for up to a week at a time.

Climatic trends in the Bow are highly variable: my first summer in the Rockies greeted me with 31 straight days of full sunshine in 1994. When I returned in the summer of 1995, we had about 5 days of sun in 6 weeks. The Koeppen climate classification system terms the Canadian Rockies as Dfc: cold, snowy forest climate with no distinct dry season and short, cool summers (Strahler and Strahler, 1989). The hottest month is July, with typical daily maximums reaching 20° to 25°C in the valleys, while the coldest month is January, having an average overnight low of between -15° to -20°C. Years of El Niño influence display milder winters with decreased snow accumulation (Gadd, 1995). A brief summary of climatic data for Banff, Castle Mountain and Lake Louise from 1961-90 is presented in Table 4.2.

Location	Elev. (m)	Mean Temp °C	Days above 0 °C	Daily July High	Daily Jan Low	All-time High	All-time Low	An. Ppt (mm)	An. Snow (cm)	Days with rn/sn
Banff	1397	2.9	158	22.2	-14.9	34.4	-51.2	468	244	78/74
Castle Mt.	1360	3.0	149	22.9	-15.7	34.4	-43.9	866	459	67/67
Lake Louise	1524	-0.4	94	20.4	-21.4	34.4	-52.8	602	329	69/63

Table 4.2 - Climatic data for Banff, Lake Louise and Castle Mountain Ranger Station 1960-1991 (Source: Atmospheric Environment Service,1993).

4.2.1 Trends in the Climatic Record

Throughout the Banff climatic record, it is possible to distinguish several trends in both temperature and precipitation. It is interesting that these trends are in agreement with other global observations. The following is a brief overview of the major climatic trends of the Banff record.

4.2.1.1 Temperature

Meteorological data for Banff (1887-1991) are presented in figure 4.3. Throughout the Banff temperature record, it is possible to distinguish five distinct periods (table 4.3). The start of the record indicates a period of transition: a gradual warming of temperatures from those typical of the Little Ice Age. It is interesting to note that this period displays very little inter-annual temperature variability typical of transitional periods in climate (Sreenath, 1993). The next period, from about 1904 to 1946, displays warmer temperatures (2.3^{0}C) with a slightly higher variance (0.8). A slight warming trend can be observed over this period. A distinct cooling

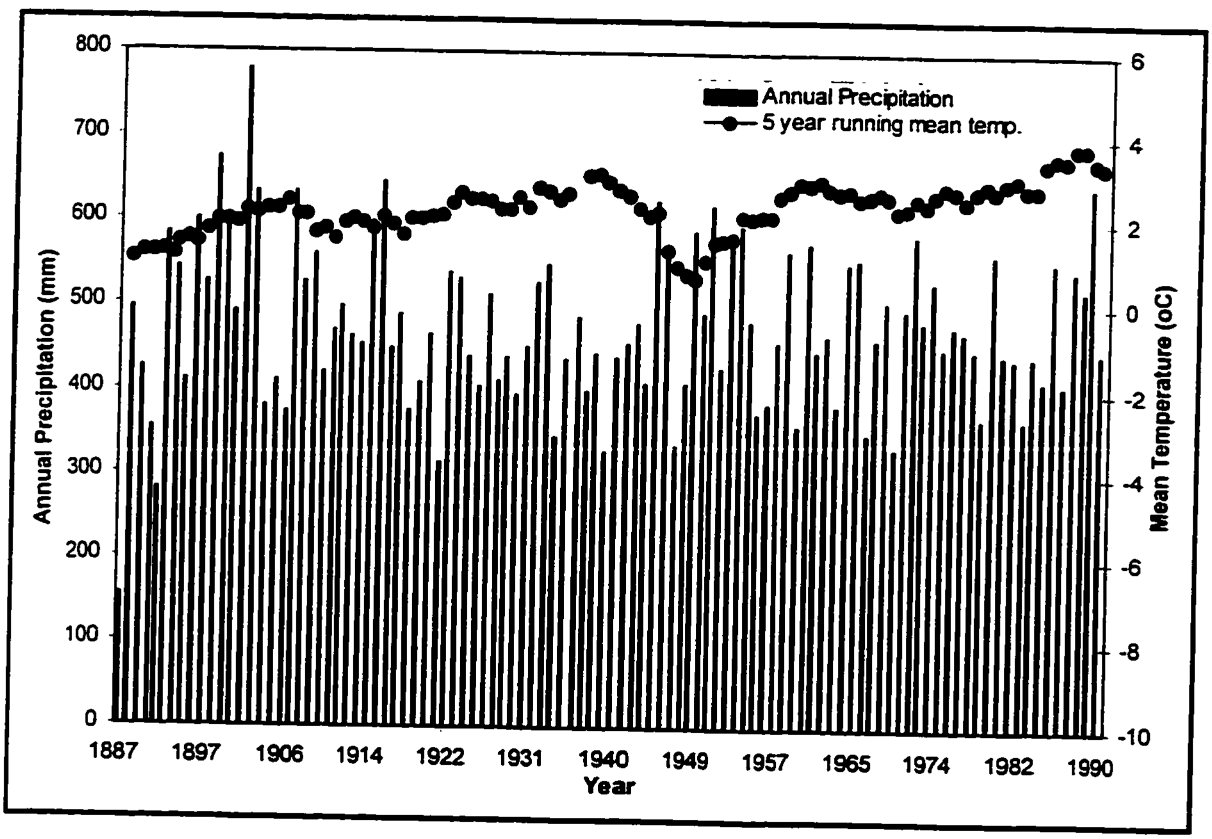


Figure 4.3 - Banff annual meteorological data 1887-1991.

period took place from 1947 to 1957. Average temperatures for this decade sank to 1.2^{0}C. In addition, inter-annual variability was the greatest in the observed record. By the late 1950's the temperature rose significantly and remained relatively stable until about 1980, when a distinct increase occurred. Fountain and McCabe (1996) have noted that there was a shift in the atmospheric circulation pattern at the 700mb level in the mid-1970's, however, the effects from this anomaly do not become detectable until about 1980. From 1980 to 1991, the mean temperature was 3.3^{0}C - the warmest in record.

Years	Mean Temp °C	Variance
1887-1903	1.7	0.3
1904-1946	2.3	0.8
1947-1957	1.2	2.8
1958-1979	2.7	0.4
1980-1991	3.3	0.8

Table 4.3 - Statistical trends in the Banff temperature record.

Nicholls *et. al.* (1996) have addressed the importance of examining the daily temperature range when assessing the observed climate variability. In the Banff record, a gradual increase in both annual maximum (T_{max}) and annual minimum temperature (T_{min}) is evident (figure 4.4). What is interesting to note is that T_{min} displays a greater linear increase than T_{max}. The trendline slope for T_{min} is 0.0014, compared the T_{max} trendline slope of 0.0009 (roughly double). Although this relationship is fairly insignificant, it nonetheless substantiates the findings of Karl *et al.* (1993), which suggest that worldwide increases in minimum land-surface air temperature have been increasing more than the maximum. This increase is mostly due to a faster rise in night temperatures, as dew-point temperatures are more sensitive to longwave radiation fluxes.

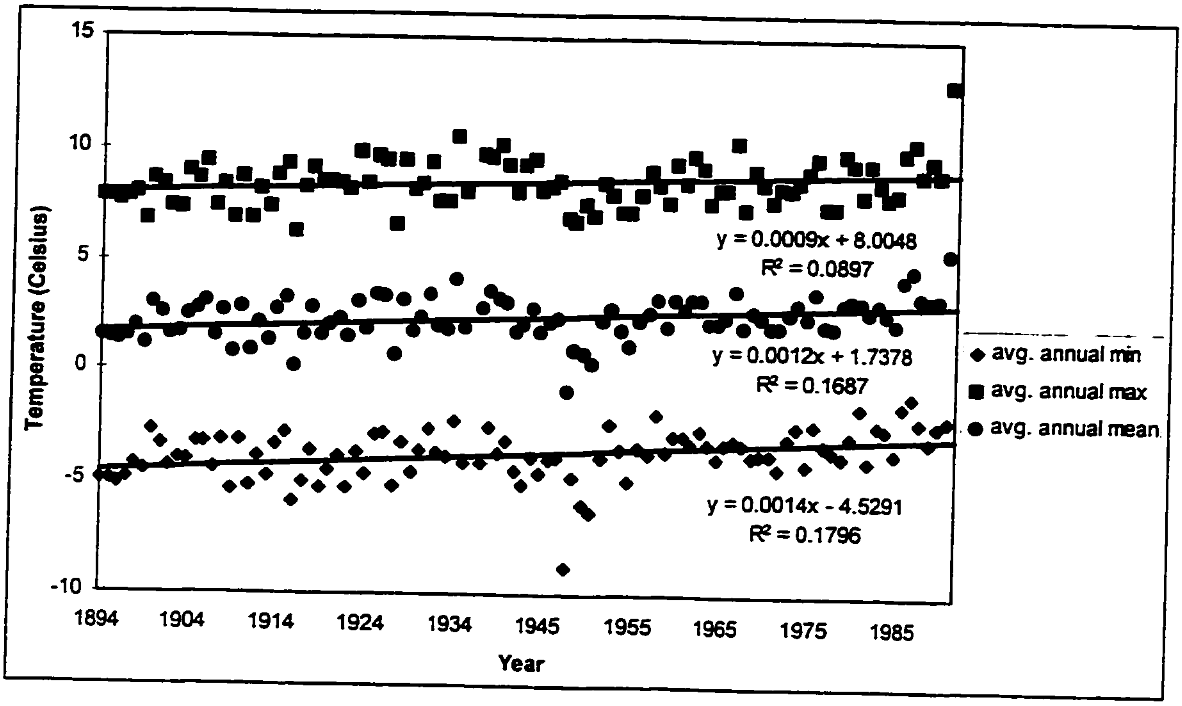


Figure 4.4 - Annual Banff maximum, minimum and mean temperatures for Banff 1894-1991.

4.2.1.2 Trends in Precipitation

Perhaps the only observable trend in the precipitation record is that it is highly variable. The inter-annual noise associated with the precipitation regime of the Upper Bow Valley makes it difficult to discern decadal or inter-decadal trends. Banff receives an average 450 mm per annum, although inter-annual variability can be up to 60%. Gadd (1995) has suggested that years of El Niño Southern Oscillation display a marked decrease in annual precipitation in the Upper Bow Valley. Major El Niños occurred in 1925-6, 1939-41, 1957-8, 1972-3 and 1982-3 (Barry and Chorley, 1987). Although it is difficult to separate El Niño influence from the inter-annual noise, most of these years are associated with typically lower annual precipitation.

4.3 Bow River above Banff Discharge Record

The uninterrupted discharge record of the Bow River at Banff extends back to 1911 (figure 4.4). Discharge patterns observed at the Bow River at Banff display extreme inter-annual variability (table 4.4). The record suggests no obvious trends in the 82 year period. There was an interval of generally low flows during the late 1930's to about 1950, and again from 1970 to 1991, whereas the 1960's experienced higher than average discharge. It is interesting to note that the variability of discharge has been increasing. The variance for years between 1910 and 1991 is 28.02 $m^3 \times 10^6$. For years between 1910 and 1970, the variance stays beneath the record average, however, between 1970 and 1991, the variance jumps to 33.44 $m^3 \times 10^6$. This may suggest that there is a tendency for increased variability in Bow River Discharge as the climate shifts to a warmer regime, although this is difficult to ascertain based on this cursory analysis.

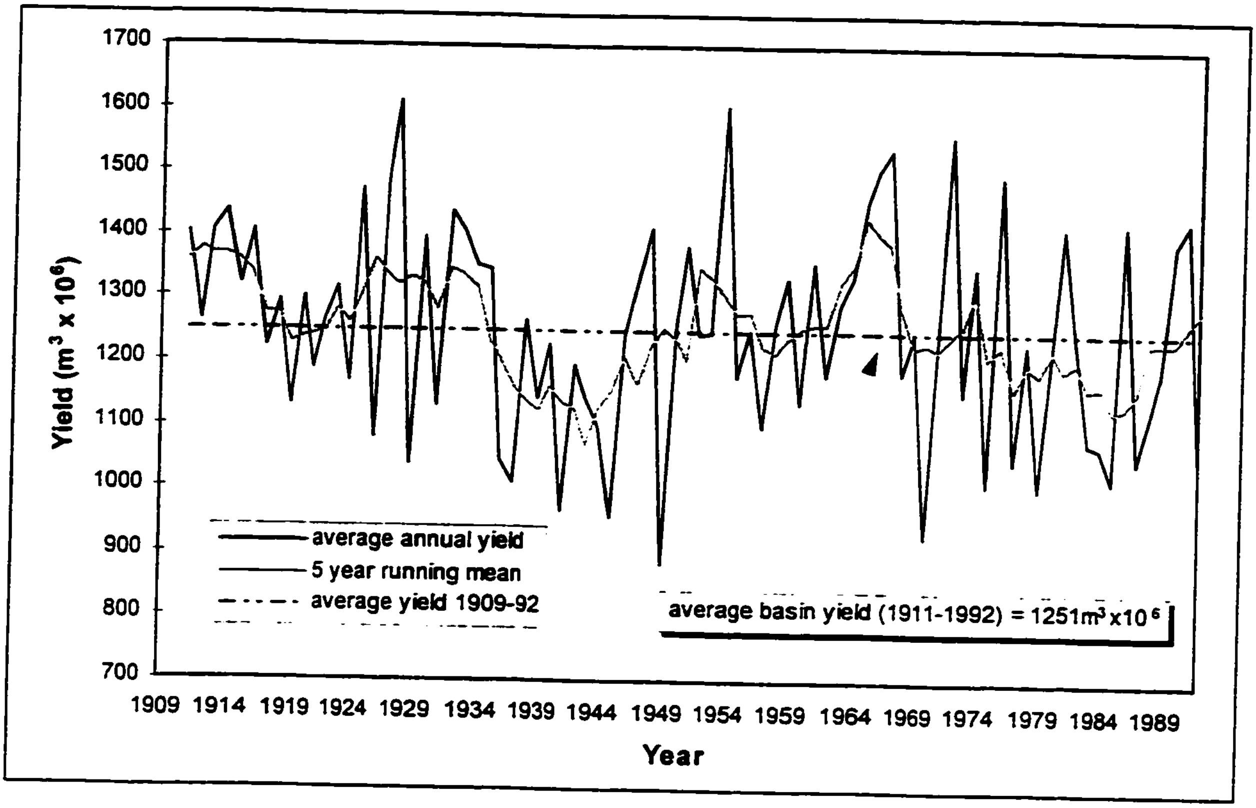


Figure 4.4 - Bow River Hydrograph at Banff 1911 -1992.

Years	Mean *Q* in $m^3 \times 10^6$	Variance
1911-1991	1251.16	28.02
1911-1936	1304.98	21.98
1937-1954	1201.35	26.24
1954-1969	1290.87	22.77
1970-1991	1203.85	33.44

Table 4.4 - Mean annual discharge and variance figures for Bow River at Banff discharge.

Chapter 5 - Calibration of the UBC Watershed Model to the Upper Bow Valley

5.1 Calibration Approach

Model calibrations were performed for years 1950-1990, however the calibration process described below was specifically optimized for hydrologic year 1969. It was found that 1969 displayed the most accurate calibration results (although several other years were also highly efficient) and was a typical climatic year (figure 5.1), and thus was chosen to be used for the climatic sensitivity analysis. In addition, a great amount of hydrological data was collected during this period at the Peyto Glacier Basin as part of the research initiatives of the International Hydrological Decade. With a few exceptions, the application of this calibration file to other years proved largely unsuccessful; the calibration file had to be manipulated in order to produce optimum results for other years. The reasons for this will be discussed at the end of this chapter.

5.1.1 Spatial Resolution of the Calibration

Ideally, calibrating the model to each sub-basin in the Upper Bow Valley would lead to a better understanding of the seasonal discharge variation of the basin. However, it is problematic to assume that the Lake Louise and Banff meteorological data would be representative of the smaller basins located around the periphery of the Upper Bow Valley. In addition, it is assumed that the basin-wide hydrologic signature overrides the sub-basin idiosyncrasies. Thus, the entire basin was calibrated as a single hydrologic unit.

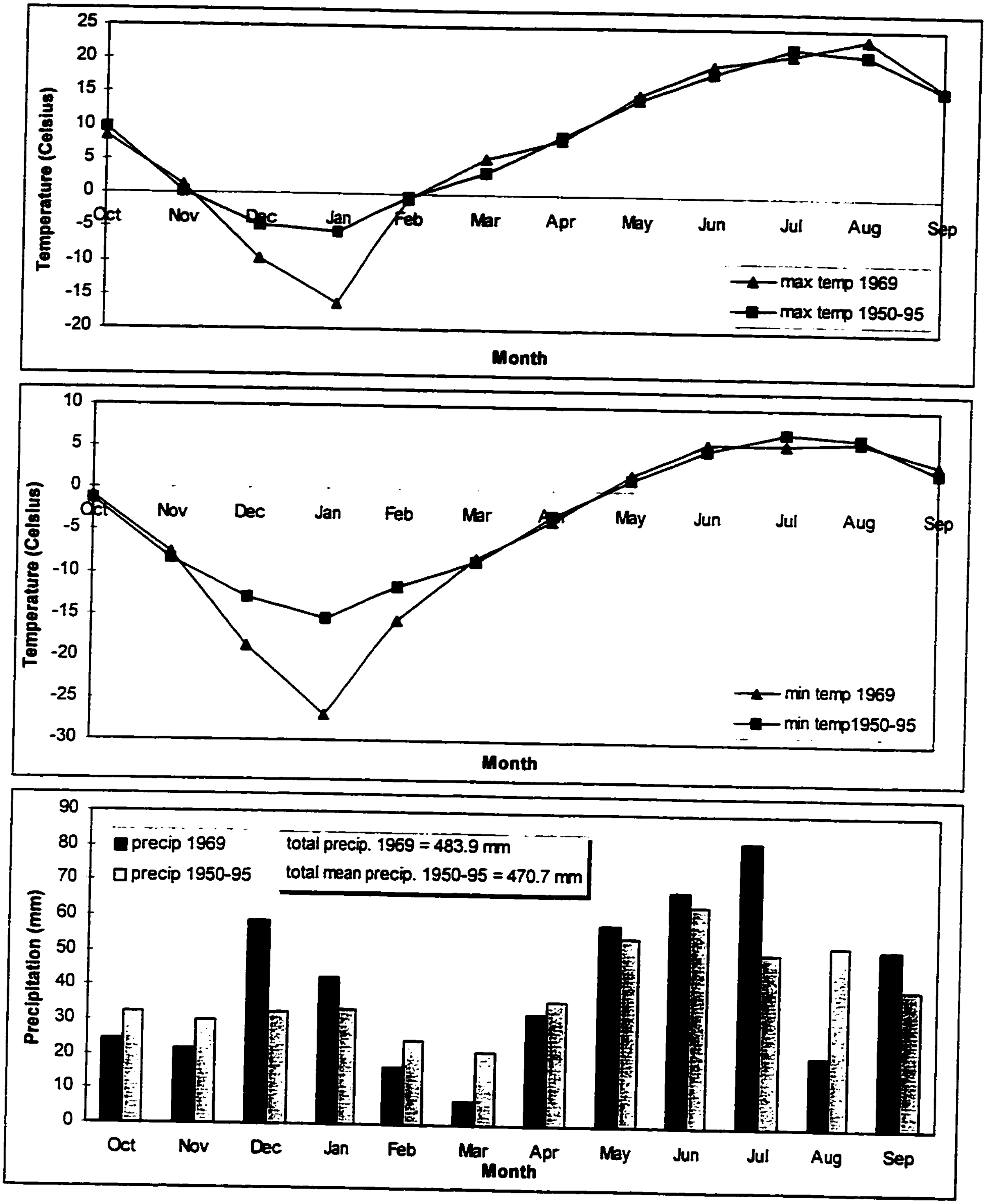


Figure 5.1 - Comparison of the mean 1950-95 precipitation and maximum and minimum temperature with observed values for hydrologic year 1969.

5.1.2 Estimating Glacier Recession

To extend the record backwards and forwards, the work of Hopkinson (1997) was used. Detailed photogrammetric analysis was conducted by Hopkinson (1997) on the glacier extents in 1951 and 1993 in the Hector Lake basin. Hopkinson then estimated the yearly recession values from 1951 to 1993 based on the modelled (1951-1966) and observed (1967-93) Peyto Glacier mass balance record. The rates of areal glacier recession per elevation band in the Hector Basin (as estimated by Hopkinson) were extrapolated to the entire Bow Valley above Banff (appendix 2). A hypsographic curve summarizing the assumed glacier retreat between 1951 to 1993 is presented in figure 5.2.

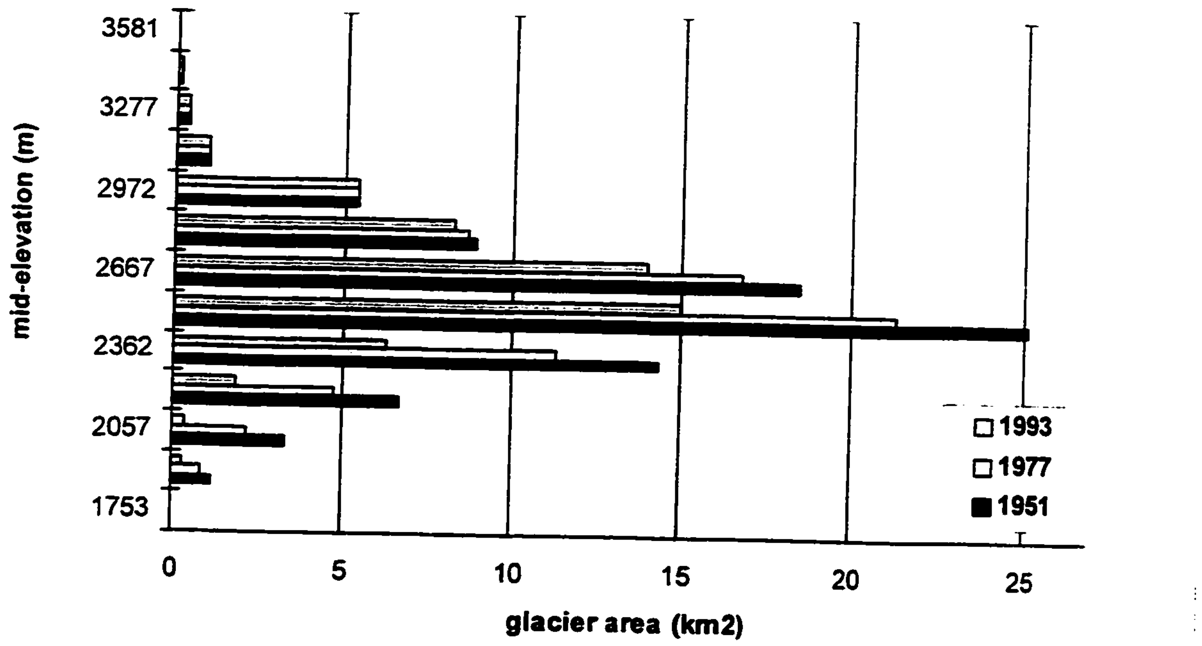


Figure 5.2 - Hypsographic curve of estimated glacier areas in the Upper Bow Valley.

In so doing, spatial variability in topography, aspect, hydrometeorology, and glacier flow within the Upper Bow Valley will give rise to large errors in the these recession assumptions.

5.1.3 Estimating Model Parameters

Rigorous attempts were made to estimate model parameters based on the physical reality as represented by the regional hydrologic data set. However, because this model is not strongly physically based and because of the scarcity of hydrometeorologic data within the basin, some parameters had to be estimated based on the model assumptions.

5.2 Overview of the Calibration Procedure

The calibration process for the UBC Watershed Model will be discussed in the following stages:

1) Preliminary review and selection of calibration data;
2) Description of the watershed;
3) Calibration of the meteorological data distribution parameters;
4) Calibration of the snow and ice melt routine;
5) Calibration of the evapotranspiration routine;
6) Calibration of the groundwater seepage and routing parameters; and
7) Calibration of the watershed routing parameters.

5.3 Stage One - Preliminary Review and Selection of Calibration Data

For the purposes of the study four criteria were established for meteorological data selection:

1) A complete and accurate record from 1950 to 1991;

2) Station must be located within or near the boundary of the Upper Bow Valley;

3) Data must be representative of the general meteorological conditions of the entire Upper Bow Valley; and

4) Record must contain daily maximum and minimum temperature and daily precipitation for the entire year.

Using these criteria, meteorological data sets were narrowed to Lake Louise and Banff.

5.3.1 Rationale and Confidence in Calibration Data Selection

Correlation analysis between Banff and Lake Louise daily minimum and maximum temperature, precipitation and Bow at Banff daily discharge was conducted using 1967-1975 data (appendix 3). This analysis revealed that overall, Banff and Lake Louise daily hydrometeorological data did not display a strong relationship with Bow at Banff discharge. Lake Louise May and June daily maximum temperatures typically held a slightly stronger positive relationship than Banff with Bow at Banff discharge. Spatially, Lake Louise is located in a more central position than Banff, and therefore may explain the stronger relationship. Late summer maximum temperature typically did not display strong correlation coefficients with Bow River at Banff discharge, although they were slightly greater in years displaying high negative mass balance, such as 1970, but were still not significant.

Summer precipitation typically did not did not display any relationship with Bow at Banff discharge. This suggests that either: 1) summer precipitation is not a significant factor in Bow River at Banff total discharge; or, 2) both Lake Louise and

Banff are not representative of the Bow Valley precipitation regime. It is probable that both these factors contribute to the poor correlation relationships.

In order to determine the spatial relationships between hydrometeorological data from sites in the Upper Bow Valley, a correlation matrix consisting of daily precipitation and daily mean temperature between Banff and Lake Louise was formulated (table 5.1). Winter maximum and minimum temperatures display strong spatial relationships between all sites, having correlation coefficients of 0.98 and 0.94 respectively. Summer maximum temperatures display slightly lower relationships, and minimum temperatures are even less. A very weak relationship exists between both summer and winter precipitation, suggesting that the spatial variation of precipitation is extremely high in the Upper Bow Valley.

	LLmax5-9	LLmax10-4	LLmin5-9	LLmin10-4	LLppt10-4	LLppt5-9
Bmax5-9	0.862					
Bmax10-4		0.984				
Bmin5-9			0.673			
Bmin10-4				0.940		
Bppt10-4					0.491	
Bppt5-9						0.409

Table 5.1 - Correlation coefficients between Banff and Lake Louise hydrometeorological data for years 1967-1975. Numbers indicate months (i.e. 5-9 = May to September); max. indicates maximum daily temperature; min. indicates minimum daily temperature; ppt. indicates daily precipitation.

A scatterplot is presented in figure 5.3 displaying the weak relationship between Banff and Lake Louise daily precipitation for hydrologic year 1969 (r^2 = 0.1532). The r^2 increases to 0.2632 for period May-August, probably a result of the convective nature of rainfall. It is interesting to note the proliferation of data

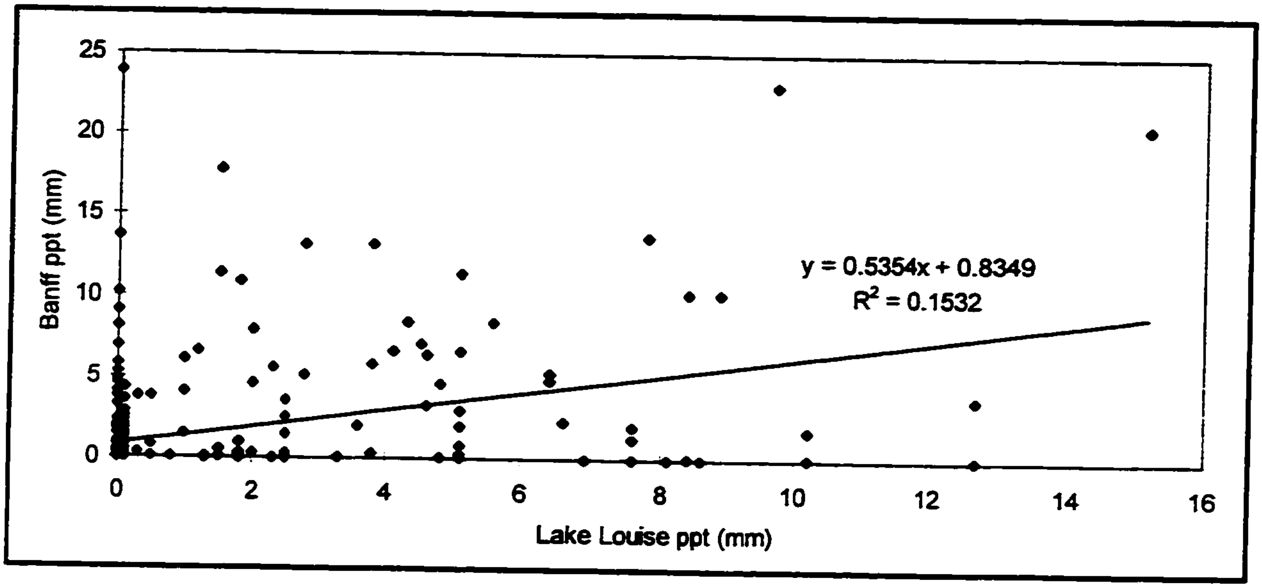


Figure 5.3 - Scatterplot of Banff and Lake Louise daily precipitation for year 1969.

points lying on the x and y axis, suggesting that either station can receive precipitation independent of each other. On one occasion, Banff received 23.9 mm of snow when Lake Louise recorded nothing. This variable pattern makes precipitation estimation extremely problematic in the Bow Valley above Banff. Essentially, the heterogeneity of the topography of the Upper Bow Valley inherently renders any point source data unrepresentative of the entire valley. Despite this, confidence in using these data is improved after it is subjected to the climatic modification routines of the UBC Model (see section 5.5).

5.3.2 Snow Course Data Selection

Snow course data from all stations within the upper Bow displayed significant positive relationships with Bow at Banff spring-summer yield (table 5.2). Correlation coefficients became stronger if July yield was included, suggesting that runoff from snowmelt is still a significant component of July discharge. The strongest positive

Snow Course	Elevation (m)	Years of Record	May - June Yield	May - July Yield
Bow River	1580	1940 - 1991	0.63	0.76
Upper Pipestone	1615	1940 - 1991	0.75	0.84
Chateau Lawn	1740	1940 - 1991	0.42	0.57
Mirror Lake	2030	1940 - 1991	0.83	0.96
Bow Summit	2080	1967 - 1991	0.56	0.82
Ptarmigan	2190	1967 - 1991	0.71	0.85
Sunshine Village	2230	1967 - 1991	0.65	0.81

Table 5.2 - Correlation coefficients between Bow Valley snow courses and Bow River at Banff spring discharge yields.

relationships with Bow at Banff May-July yield were displayed by Mirror Lake, Upper Ptarmigan, Pipestone and Bow Summit, and thus these snow courses were chosen to estimate the precipitation gradient parameters of the model.

It is unfortunate that the highest snow course (Sunshine) is located at a relatively low elevation of 2230 masl. Snow course data from stations located above 2200 masl would reveal the influence of the barrier effect of the topography on precipitation (explained in chapter 2). As a surrogate for a high altitude snow course, the winter balance record for Peyto Glacier was examined. Very low correlation coefficients suggest that snow accumulation on Peyto Glacier does not hold a strong relationship with Bow River discharge (table 5.3). Several reasons can account for this. First, Peyto Glacier is located just north of the Bow Valley, and thus the low correlation coefficients may be a result of distance. However, Bow Summit is located on the northern boundary of the Bow Valley and displays a high correlation coefficient with May-July Bow River at Banff discharge, and thus the poor

Peyto Glacier Specific Winter Balance Elevation Band (m.a.s.l.)	May - June	May - July
3100-3200	0.20	0.31
3000-3100	0.25	0.34
2900-3000	0.26	0.37
2800-2900	0.27	0.38
2700-2800	0.29	0.39
2600-2700	0.32	0.41
2500-2600	0.37	0.44
2400-2500	0.38	0.45
2300-2400	0.42	0.45
2200-2300	0.41	0.43
2100-2200	0.41	0.40

Table 5.3 - Correlation coefficients between Peyto Glacier winter balance per 100 m elevation band and Bow River at Banff discharge for years 1966-1990.

relationship with Peyto Glacier is probably not a result of geography. A more plausible reason is that Peyto Glacier forms a natural collection area for snow drifting over Mt. Rhonda, and thus preferentially accumulates at rates dependent on the extent of annual snow redistribution. The winter balance record for Peyto Glacier displays a highly variable inter-annual orographic precipitation enhancement rate: anywhere from 5.7% per 100m to 15.3% per 100m between 2100 to 3200 m.a.s.l. (appendix 5). These extreme rates of 'orographic precipitation enhancement' are not in agreement with accepted orographic theory (Quick and Pipes, 1994), which states that precipitation levels off at between one half and two thirds of the barrier height. Therefore it is highly probable that the heightened snow packs on Peyto Glacier result from preferential snow accumulation. As a result of this conclusion, the decision was made not to use Peyto Glacier winter balance data to estimate snowpack accumulation above 2200 masl, but rather to estimate it based on the more reliable spring discharge record.

5.4 Stage Two - Description of the Bow above Banff Watershed

5.4.1 Hypsographic Data

In order to produce a watershed description file for the Upper Bow Valley, hypsographic data (digitized from 1978 NTS maps) from the Bow Valley Study (Young, 1995) were used. These data are presented in figure 5.4. In using these data, problems in estimating land cover classifications arise from inaccurate mapping techniques, which will be discussed in the next chapter.

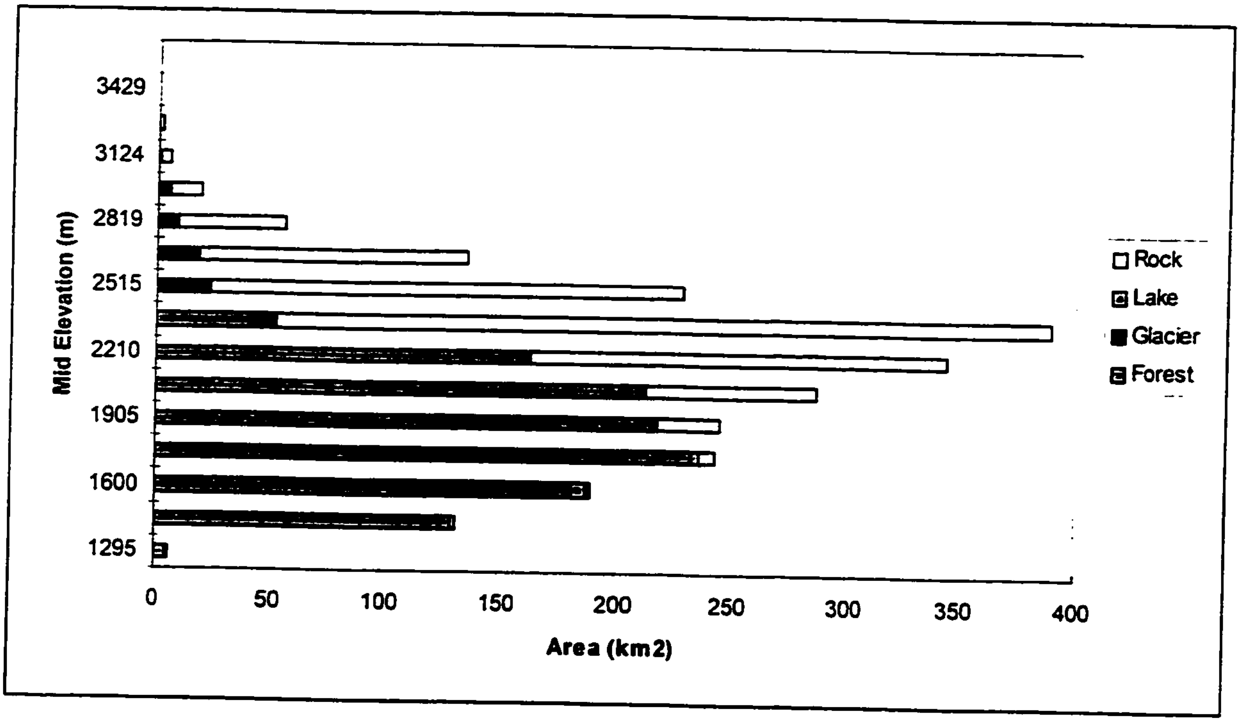


Figure 5.4 - Hypsographic curve of the Bow Valley above Banff.

5.4.2 Elevation Band Land Cover Description

The UBC Model allows for the description of various components within each elevation band. The values for these parameters are presented in table 5.4. Values for the mean area (C0ALEM), forested fraction (C0TREE), and the glaciated area (C0AGLA) of each elevation band were determined directly from the hypsographic curve data. A brief explanation of the remaining values is presented below.

5.4.2.1 Forest Cover Density

The values for forest cover density (C0CANY) were based on both theory and observation. It is know that the density and biomass of forests logarithmically decreases with increasing altitude (Brown and Gibson, 1983), and thus model parameter C0CANY was adjusted respectively. After having the opportunity to fly

	Elevation Band								
Parameter	1	2	3	4	5	6	7	8	9
C0ELEM (m)	1371	1676	1905	2133	2362	2590	2895	3200	3505
C0ALEM (km^2)	137.14	433.35	246.3	631.8	389.54	363.5	74.57	6.92	0.51
C0TREE (%)	0.985	0.958	0.875	0.581	0.102	0.008	0	0	0
C0CANY (%)	80	80	80	70	60	50	0	0	0
C0RIEN	0.2	0.2	0.5	0.5	0.5	0.5	0.7	0.7	0.7
C0AGLA (km^2)	0	0.014	0.83	7.05	11.32	38.05	14.08	1.292	1
C0AGOR (%)	0	0	100	100	100	100	100	100	100
C0IMPA (%)	0	.05	.15	.2	.3	.7	.72	.735	.743

Table 5.4 - Summary of Upper Bow Valley watershed description (C0ELEM = mid elevation of band; C0ALEM = Mean area of the band; C0TREE = forested fraction; C0CANY = density of the forest canopy; C0RIEN = orientation index; C0AGLA = glacier area; C0AGOR = fraction of glaciated area with south orientation; C0IMPA = fraction of impermeable area).

from Hector Lake to Banff, I noted that the density of forests in the valley bottom was approximately 80%, mottled by patches of wetland and meadow. Further quantification with air photographs or remote sensing analysis would aid in estimating this figure.

5.4.2.2 Orientation Index

Model parameter C0RIEN (orientation of the elevation band) was estimated from visual interpretation of the topographical maps. The lower portions of the basin were given little southern orientation as it is assumed that they will experience significant shadowing from upland areas. The mid-elevations of the Upper Bow Valley average a neutral tendency between north-south aspect. The highest elevation bands (7,8 and 9) were assigned values of 0.7 to represent the lack of shadowing in these regions. The errors resulting from these estimations are not considered high, although increased accuracy can be obtained through the use of a GIS package that estimates orientation, such as *IDRISI*® or *Surfer*®.

5.4.2.3 Glacier Orientation Index

For all bands the glacier orientation index (C0AGOR) was assigned a southern exposure to maximize water production from glaciers. In reality, this is not the scenario; approximately 70% of the glaciers in the Upper Bow Valley display an eastern, western or southern exposure. Despite this, it was decided to compromise the physical reality in order to maximize model efficiency. Admittedly, this contradicts the accepted philosophy of maintaining a physical basis in the calibration process, however, this exception is justified because of the poor ice melt component of the model. Assuming a southern exposure for all glaciers consistently increased model performance for multiple year runs, and thus, it is probable that the parameter values chosen are compensating for other problems inherent in the melt component of the model.

5.5 Stage Three - Calibration of the Meteorological Data Distribution Parameters

The calibration of the meteorological representation factors include P0RREP, P0SREP, E0LMID, E0LHI, P0GRADL, and P0GRADM (table 5.5).

Model Parameter	Description
P0RREP	liquid precipitation representation factor
P0SREP	snow precipitation representation factor
P0GRADL	orographic enhancement factor under 2200m
P0GRADM	orographic enhancement factor over 2200m
E0LMID	elevation to which P0GRADL applies
E0LHI	elevation over which P0GRADM applies

Table 5.5 - Description of the UBC Model meteorological data distribution parameters.

5.5.1 Precipitation

The model includes several parameters that can be used to adjust point source data to make it more representative of the basin-wide regime. Each will be discussed individually.

5.5.2 Meteorological Station Assignment per Elevation Band

Optimum efficiencies for UBC Model flow estimations were obtained when using Banff precipitation data for elevation bands 1 and 2 (elevations 1219 - 1790 masl) and Lake Louise precipitation data for bands 3 - 9 (elevation1790 - 3657 masl).

5.5.2.1 Rationale and Confidence

The rationale in preferentially weighting Lake Louise precipitation data is principally based on its central location within the basin, and partially on the fact that Louise displayed slightly higher correlations with Bow at Banff discharges (but not significantly). Confidence in this decision is reasonably high as the efficiency of UBC Model flow estimations consistently increased for multiple year runs.

5.5.3 Form of Precipitation

The model must distinguish between precipitation as either snow or rain in each elevation band. This is computed using the model parameter A0FORM, which was kept at the default value of $2^{0}C$. Thus, when the mean daily temperature in a given elevation band is over $2^{0}C$, then all precipitation is rain. If the mean daily temperature is between $0^{0}C$ and $2^{0}C$, a proportion of the precipitation will be specified as rain. This proportion is dependent on the mean daily temperature. All precipitation falling at temperatures below $0^{o}C$ is considered snow.

5.5.4 Orographic Enhancement of Precipitation

An orographic enhancement factor (P0GRADL) of 10% per 100m was used for elevations up to 2200 masl (E0LMID). This precipitation gradient was lowered to

3% per 100m (P0GRAM) for elevations over 2200 masl (E0LHI). A schematic of precipitation modelling for the Bow Valley above Banff is presented in figure 5.5.

5.5.4.1 Rationale and Confidence

This value was determined by examining the altitudinal variation of snow course data (figure 5.6). Rainfall data over a significant altitudinal range does not exist in the Upper Bow Valley, and therefore snow course data had to be used to

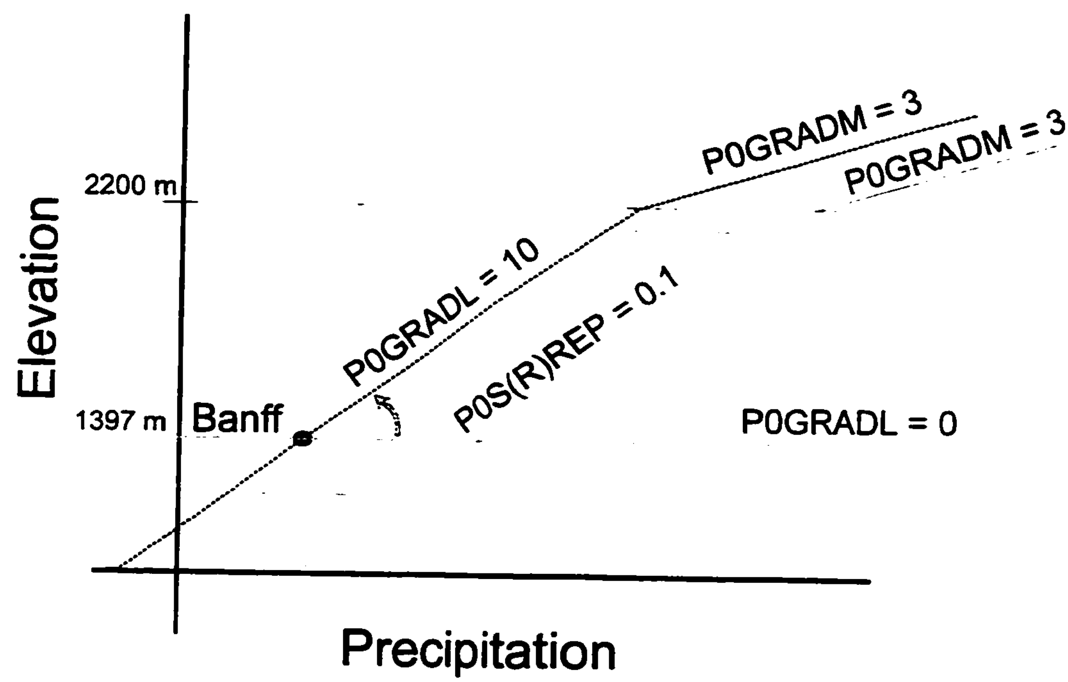


Figure 5.5 - Schematic of precipitation modelling.

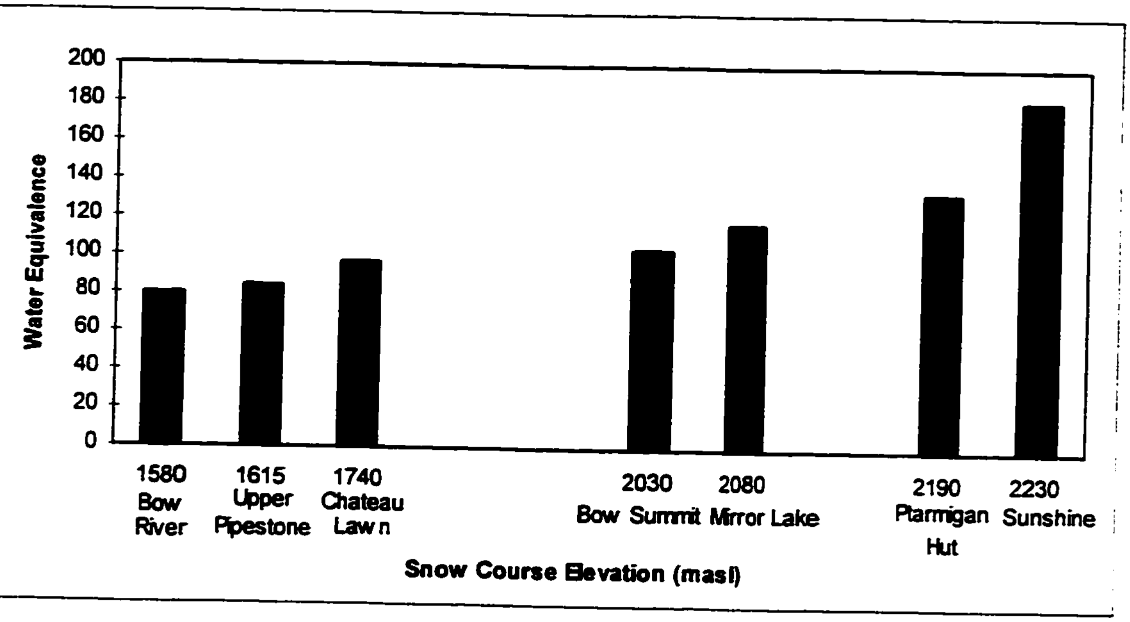


Figure 5.6 - Average 1967-1994 water equivalence (mm) and elevation for Upper Bow Valley snow courses.

estimate the orographic enhancement of precipitation. By examining the 1967-1994 record for Bow River, Bow Summit, Chateau Lawn, Mirror Lake, Ptarmigan Hut, Upper Pipestone and Sunshine snow courses, it was discovered that there is a significant vertical precipitation gradient within the Upper Bow Valley. Average snow course data from all stations between 1967 and 1994 reveal a vertical gradient in mean snow water equivalence of about 11.25% per 100m (figure 5.7). This figure is significantly higher than the average gradient of 4% per 100m as suggested by Quick and Pipes (1994). It is problematic to compare these values with full confidence given their spatial variability and the inherent variability in snow distribution and re-distribution, however, the basin wide trends are strong and consistent with each other (except for Sunshine, which displays an even greater vertical precipitation gradient). Thus, it was determined to estimate P0GRADL on the snow course data.

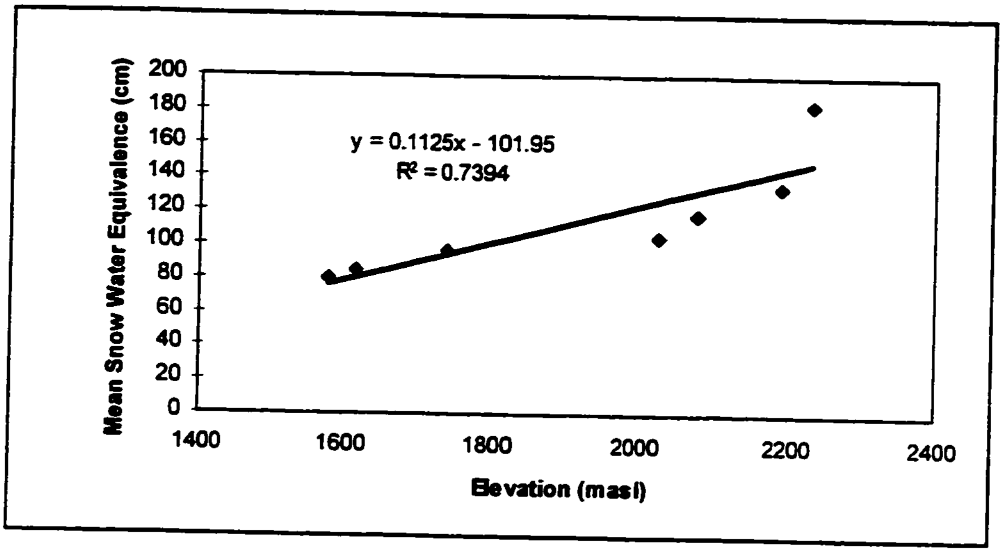


Figure 5.7 - Scatterplot displaying the altitudinal variation of mean 1967-1994 water equivalence for Upper Bow Valley snow courses.

It is known that the vertical precipitation gradient tends to level off at between one half and two thirds of the average mountain height (Barry, 1981), which for the Upper Bow Valley is approximately between 1800 masl and 3000 masl depending on basin

location. However, as the snow course data only covers an altitudinal range of 650 m (1580 - 2230 masl), there is no physical data to suggest the elevation of precipitation leveling, (E0LHI) or the degree of precipitation leveling (P0GRADM). Thus, a sensitivity analysis (figure 5.8 and 5.9) was executed to estimate the values of E0LHI (2200 m) and P0GRADM (3%). It is possible that significant errors may exist in this assumption, especially as elevations over 2200 account for over 36% of basin area. It is also reasonable to assume that the trendline representing the vertical gradient of orographic precipitation is logarithmic, rather than linear, as suggested by the model.

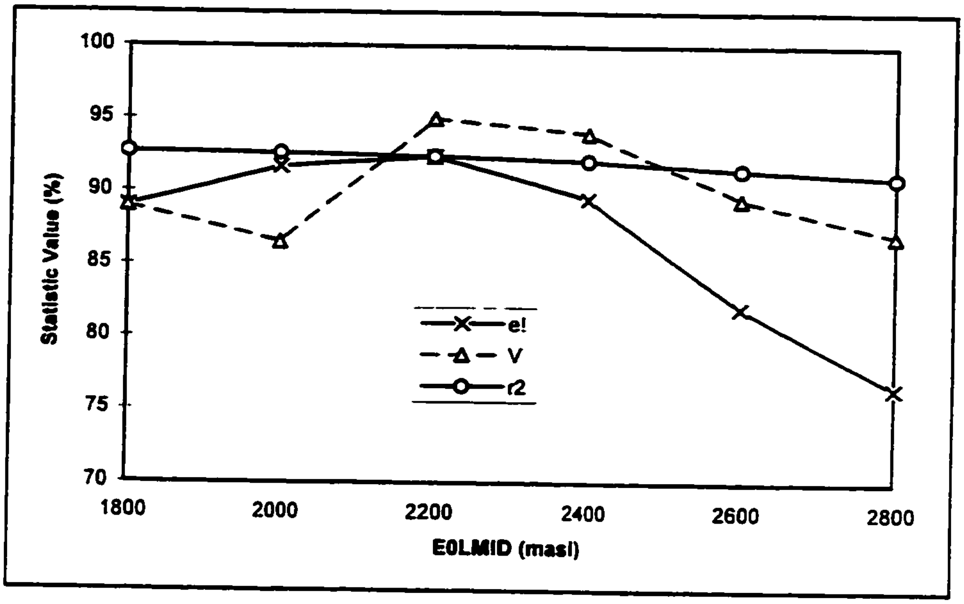


Figure 5.8 - Sensitivity analysis for model parameter E0LMID for year 1969 (e! = efficiency; V = absolute value of the difference; r^2 = coefficient of determination).

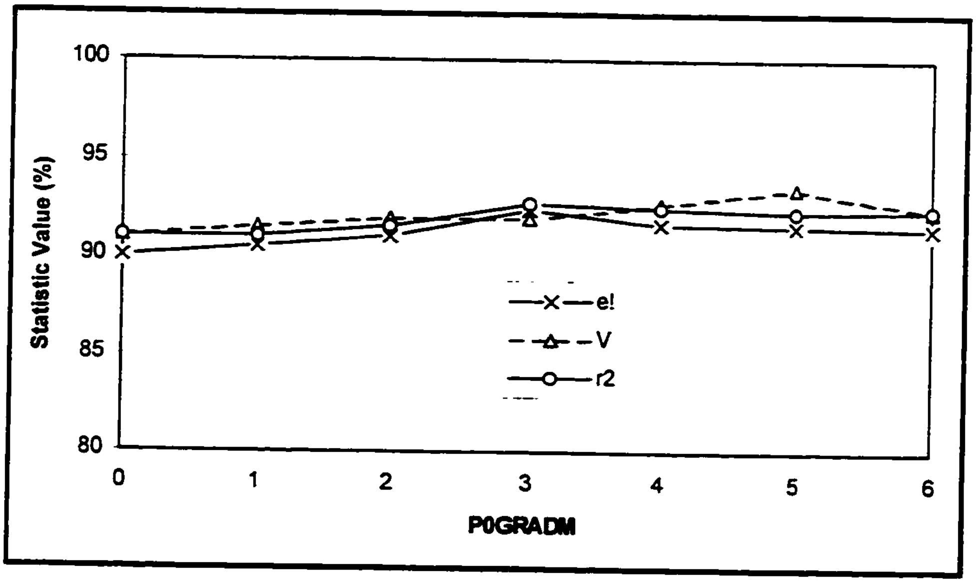


Figure 5.9 - Sensitivity analysis for model parameter P0GRADM for year 1969(e! = efficiency; V = absolute value of the difference; r^2 = coefficient of determination).

5.5.5 Estimating Snowpacks

The model contains a snow precipitation representation factor (P0SREP) that allows the modification of point source snow precipitation data to become more representative of basin wide conditions. It was found that both Banff and Lake Louise snow precipitation data performed best when assigned a P0SREP value of 0.1, which essentially increases precipitation by 10%. This value was determined from the examination of the regional snow course data set and from the model calibration statistics.

5.5.6 Estimating Rainfall

Rainfall is estimated using the same logic as snowfall, however this requires that a separate precipitation representation factor is used for rain. A liquid precipitation representation factor (P0RREP) of 0.1 proved most efficient for both Banff and Lake Louise meteorological station data. This value for P0RREP was concluded by examining late spring and summer Bow at Banff discharge and rainfall data, and by conducting a sensitivity analysis for a range of values. Fine tuning of this parameter was achieved by using the optimization routine

5.5.7 Assigning Meteorological Stations to Represent Elevation Bands

After running the model several dozen times using varying combinations of temperature data from Banff and Lake Louise for each elevation band, it was determined that optimum efficiencies were obtained when using only Banff data for all elevation bands. After examining the climatic normals for both sites between years 1961 and 1990, it was found that Lake Louise (1524 masl) had a mean annual temperature of -0.4°C, in comparison to Banff (1397 masl) at 2.9°C and Castle Mountain (1360 masl) at 3.0°C. The mean annual temperature at Lake Louise is more closely related to that of the Columbia Icefield (1981 masl) at -1.8°C. The minor differences between elevation (127 m) and location (45 km north-south) can not alone account for the great temperature variation. A more reasonable assumption is that Lake Louise, located at the base of the Plain of the Six Glaciers, experiences significant cooling from katabatic influences from upland glaciers, and as a result, is not representative of the basin-wide temperature regime.

5.5.8 Temperature Lapse Rates

The lapse rates for temperature were calculated using the default settings of the model, and are summarized in table 5.6. The threshold amount of precipitation for moist temperature lapse rate (A0PPTP) remained at the model default of 6 mm.

Model Parameter	Temperature Lapse Rate Conditions	Temperature Lapse Rate (°C/1000m)
A0TLZZ	moist adiabatic lapse rate	6.4
A0TLZP	lapse rate when ppt > A0PPTP	6.4
A0TLXM	lapse rate of Tmax when elevation of meteorological station < 2000m	10
A0TLNM	lapse rate of Tmin when elevation of meteorological station < 2000m	0.5

Table 5.6 - Default lapse rates used in the calibration of the UBC Model to the Upper Bow Valley.

5.6 Stage 4 - Snow and Ice Melt Calculation

The default snowmelt algorithms in the model were not adjusted (appendix 1). However, the albedo of ice was lowered from 0.3 to 0.23 in order to more reasonably represent the albedo of glacier ice.

5.6.1 Rationale for Ice Melt Modelling Adjustment

The calculated summer flows for the Bow River are typically lower than the observed flows for most years (by about 5%-10%), suggesting that the discharge calculated from icemelt could be underestimated. As a basis for comparison, the discharge from the Peyto Glacier basin (12km^2 glacierized) was compared to the UBC calculated discharge from icemelt for the entire Bow Valley (72km^2). It was discovered that the calculated discharge from icemelt for the entire upper Bow basin was modest when compared to Peyto Glacier for that same time period (figure 5.10). This relationship is somewhat misleading; the observed Peyto Glacier Basin discharge includes groundwater, snowmelt, rainfall and icemelt components. Keeping this in mind however, it would be expected that the discharge from icemelt for the entire Upper Bow Valley (72km^2 glacierized) would be an order of magnitude larger than the discharge from Peyto Glacier (12km^2 glacierized). From this cursory analysis it was decided to calibrate the UBC Model to the Peyto Glacier Basin to determine the efficiency of the model on a highly glacierized basin. Although it is problematic to use Banff and Lake Louise data to represent Peyto Glacier Basin hydrometeorological conditions, the results from the calibration revealed that icemelt was being underestimated (see appendix 6). Thus the albedo was lowered to a more reasonable value of 0.23.

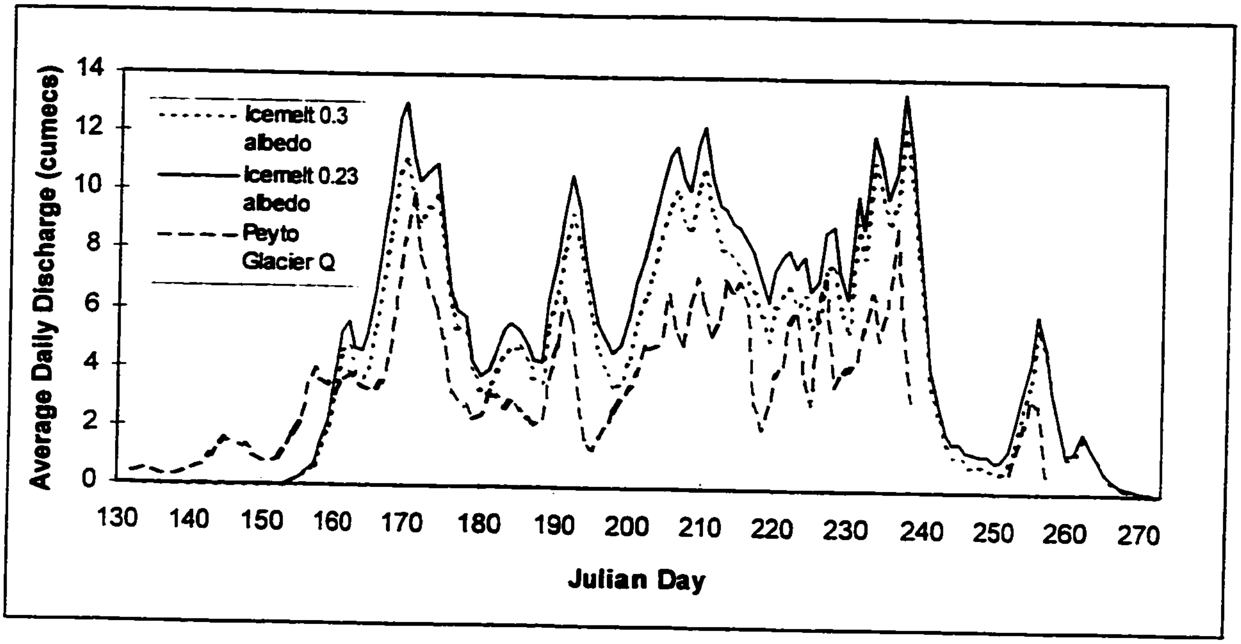


Figure 5.10 - Comparison of UBC Model calculated discharge from icemelt for the Upper Bow Valley assuming a glacier albedo of 0.3 and 0.23, and observed discharge from the Peyto Glacier Basin for 1969.

5.7 Stage 5 - Evapotranspiration, Wind and Cloud Cover Modelling

Evapotranspiration, wind and cloud cover for the basin are calculated using the default settings suggested in the model. Confidence in this assumption is discussed in the next chapter.

5.8 Stage 6 - Groundwater Estimation and Routing

Groundwater percolation (P0PERC) was assigned a value of 40mm/day. Of this, 35.5% is routed to the deep zone share (P0DZSH). Upper groundwater was given a flow time constant of 30 days (P0UGTK), while the time constant for deep groundwater was assigned a value of 140 days (P0DZTK). The release times are routed through a single linear reservoir assumed as default by the model. These figures were entirely derived from the optimization routine within the model as there are no calibration data available for the study area. Confidence in these figure is discussed in the next chapter.

5.9 Stage 7 - Water Routing from Glaciers, Snowmelt and Rainfall

The number of fast reservoirs assumed for rainfall, snowmelt and glacier runoff (N0FASR, N0FASS and N0GLAC) is two. The fast runoff time constants for rainfall, snowmelt and glacier runoff (P0FRTK, P0STK, and P0GLTK) were assumed as being two days. The interflow time constant was estimated at 3.8 days for rainfall and 4.8 days for snowmelt. No lags were assumed for either rainfall or snowmelt (the model does not offer a glacier lag option).

Chapter 6 - Calibration Results and Discussion

6.1 Results for the 1969 Calibration

The statistical calibration results for hydrologic 1969 are presented in table 6.1 and the observed and calculated hydrograph is displayed in figure 6.1. Overall, the calibration results for hydrologic year 1969 are very good (meteorological data presented in appendix 7); 99% of the total yield was estimated. The coefficient of efficiency (*e!)* for the year is 0.926, and coefficient of determination (r^2) is 0.933. These values do not drop considerably for the April-September period when the basin is most hydrologically active. The winter efficiency (0.75) is deceiving as the statistic is based on relative values; visual analysis of the hydrograph confirms that winter base flow errors are minimal. As the coefficient of determination indicates in figure 6.2, the overall shape of the calculated hydrograph is accurate, suggesting that the model performs well in representing the general hydrologic trends of the basin. However, there are some obvious errors which will be discussed in sequence.

Period (1968-69)	Observed Avg. Daily *Q* (cumecs)	Estimated Avg. Daily *Q* (cumecs)	Observed Yield ($m^3 \times 10^6$)	Estimated Yield ($m^3 \times 10^6$)	Coefficient of Efficiency	Coefficient of Determination
Oct 1 - Sept 31	39.8	40.1	1254.96	1266.85	0.926	0.933
Apr 1 - Sept 31	67.1	66.8	1060.62	1052.68	0.872	0.893
Oct 1 - Mar 31	12.3	13.5	194.34	214.17	0.7504	0.903

Table 6.1 - Statistical results for the calibration file applied to hydrologic year 1969.

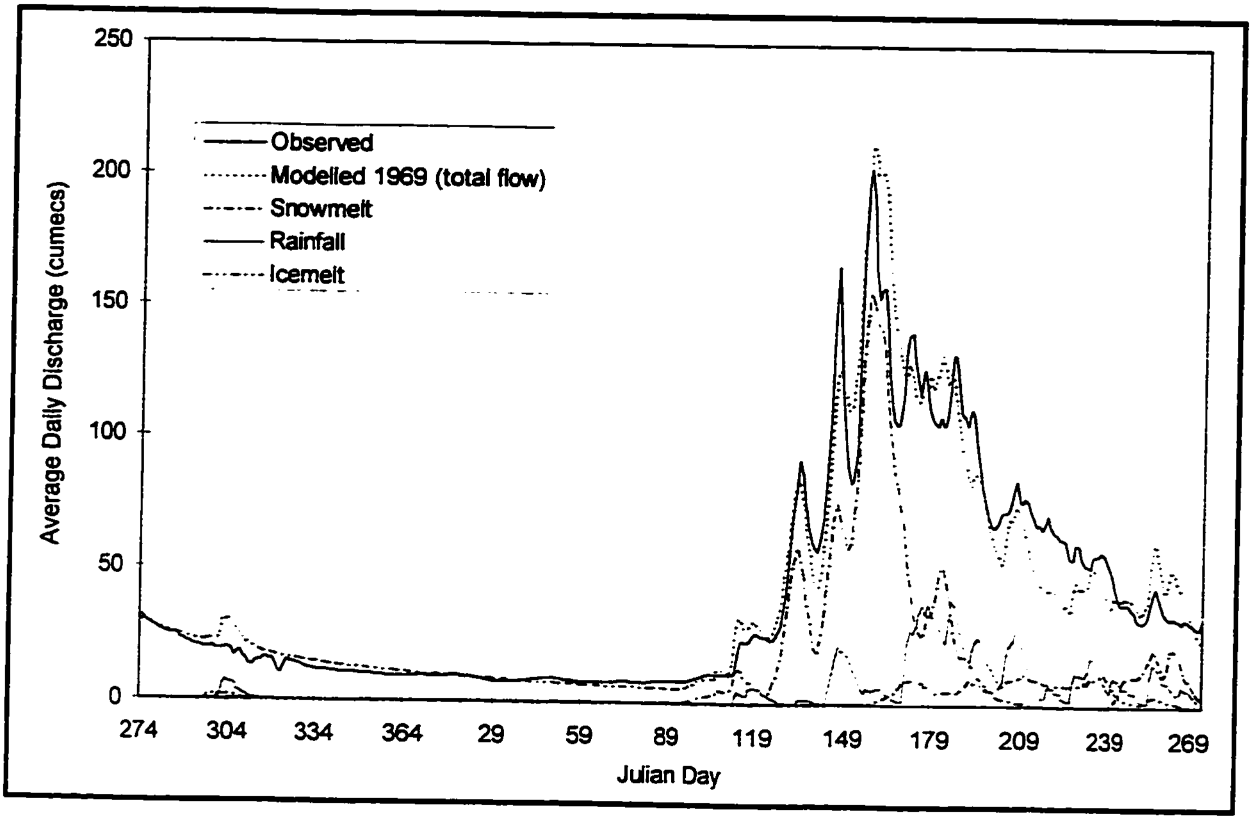


Figure 6.1 - Observed and modelled hydrograph for hydrologic year 1969.

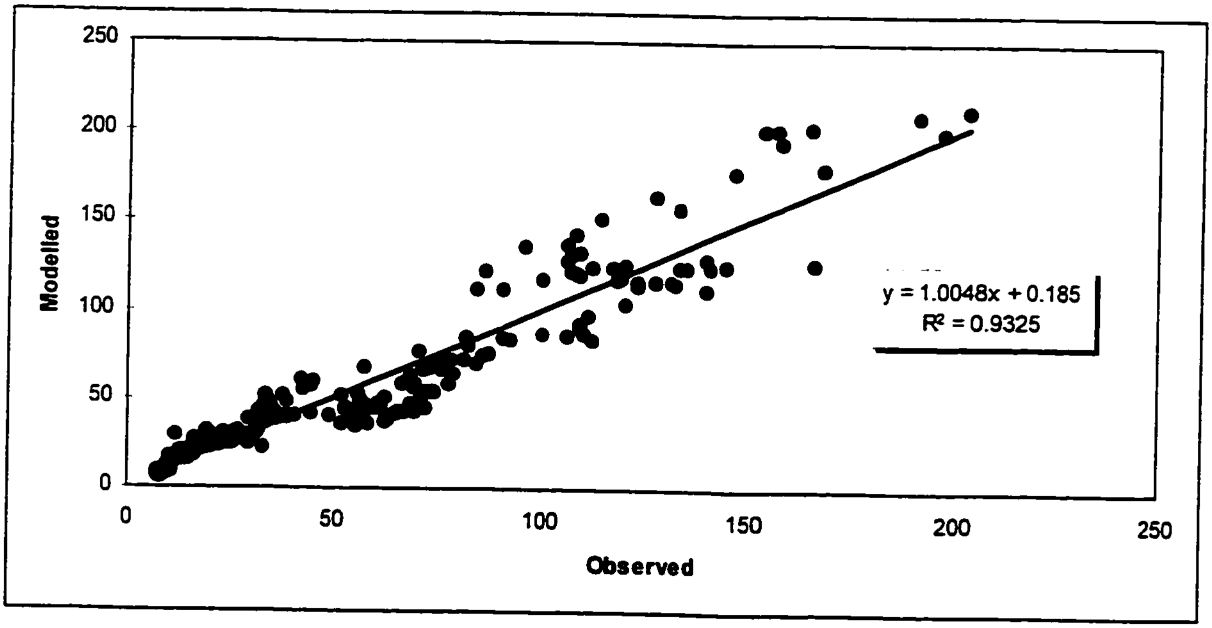


Figure 6.2 - Scatterplot between observed and modelled average daily discharges for Bow River at Banff for year 1969.

6.1.1 Snow Pack Accumulation and Ablation

In order to estimate the value for P0SREP (precipitation representation factor for snow), Bow River, Chateau Lawn, Upper Pipestone, Mirror Lake, Bow Summit, Ptarmigan Hut, and Sunshine Village snow course data (locations of snow courses displayed in appendix 4) was used as reference (figures 6.3 to 6.5). It was found that a P0SREP value of 0.1 for both Banff and Lake Louise provided reasonable estimation of recorded snow water equivalence of these snow courses.

Snowpack water equivalence estimation for elevation band 2 is imprecise in the early accumulation period, however, the total accumulation estimate is very good in comparison to Bow River and Upper Pipestone snow course data, which is ultimately most important. The values for the Chateau Lawn snow course data are

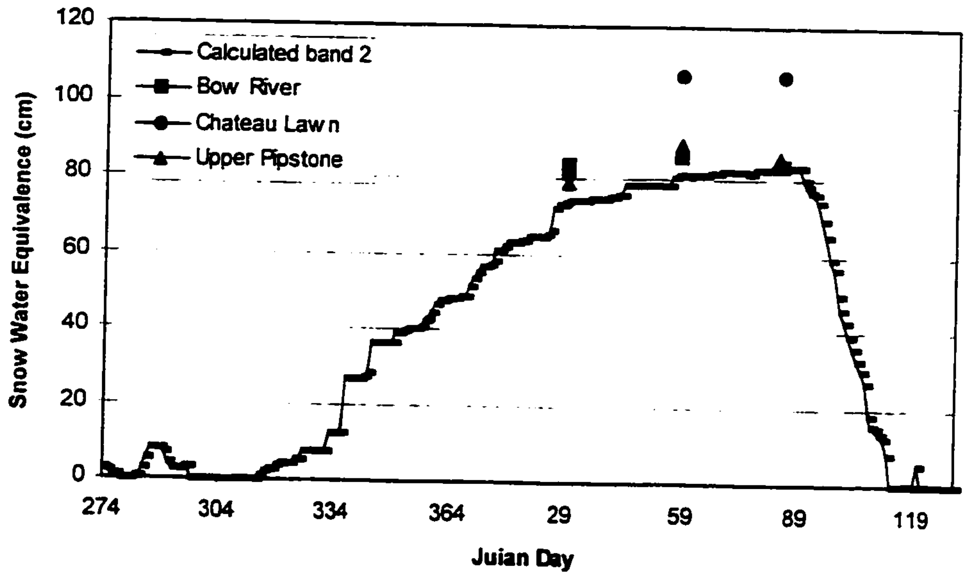


Figure 6.3 - Calculated snowpack water equivalence for band 2 (1523-1790 masl) compared to observed values from Bow River, Chateau Lawn, and Upper Pipestone for 1969 (using P0SREP 0.1).

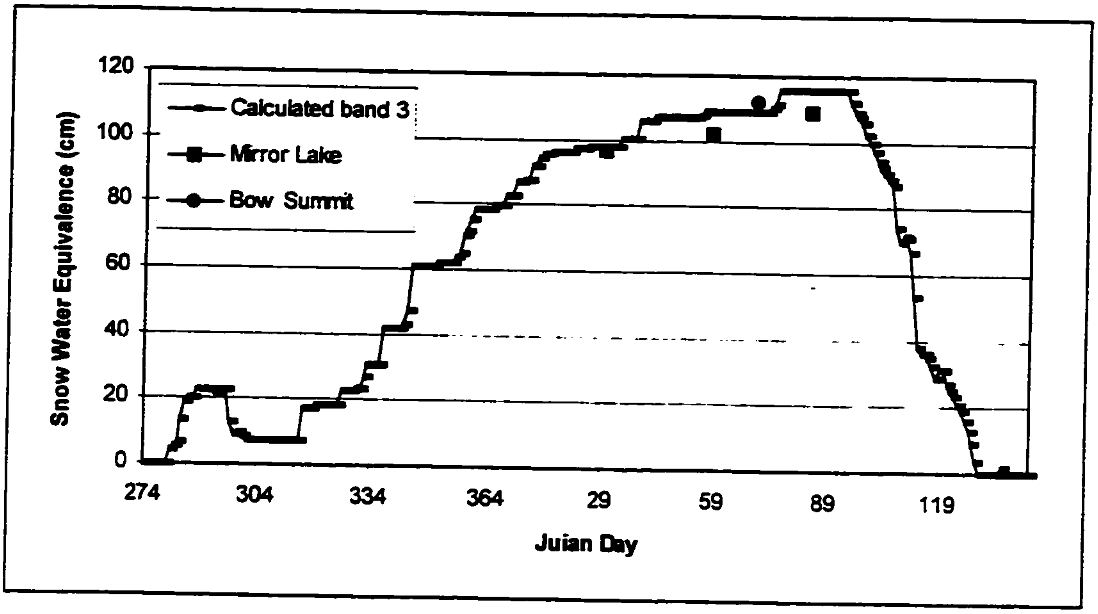


Figure 6.4 - Calculated snowpack water equivalence for band 3 (1790 -2020 masl) compared to observed values from Mirror Lake and Bow Summit for 1969 (using POSREP 0.1).

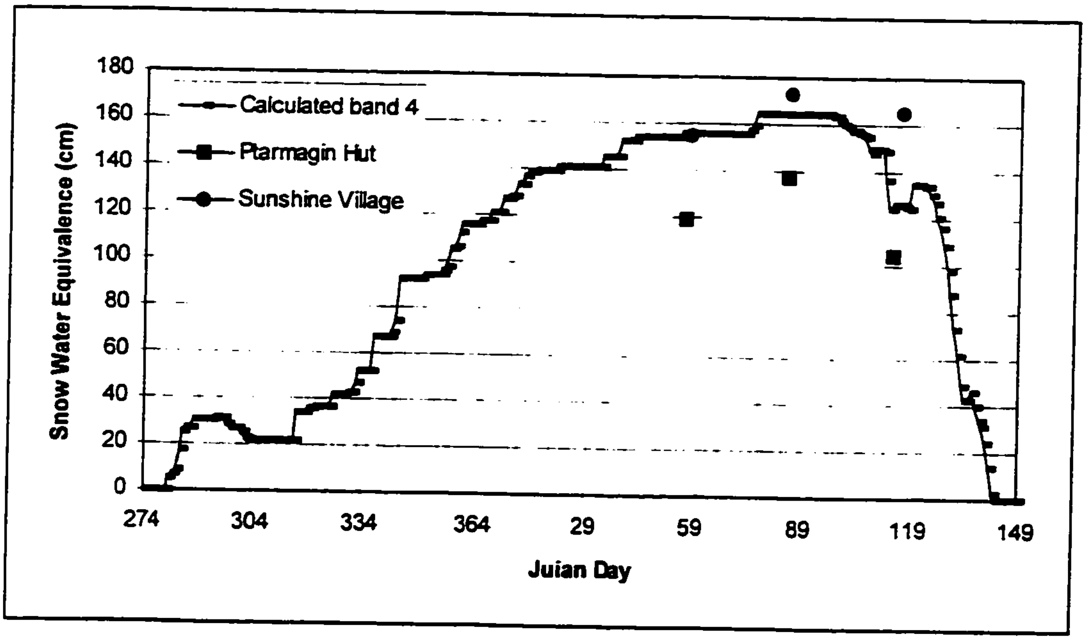


Figure 6.5 - Calculated snowpack water equivalence for band 4 (2020-2247 masl) compared to observed values from Ptarmigan Hut and Sunshine village for 1969 (using POSREP 0.1).

significantly greater than the model estimates. The correlation coefficient between the Chateau Lawn snow course data and Bow River above Banff May-July discharge for years 1967-1994 is 0.57, in contrast to Bow River at 0.76 and Upper Pipestone at 0.84. Thus, more confidence is placed on the Bow River and Upper Pipestone data as being representative of basin-wide conditions. Snow measurements are likely to be greatly distorted by local exposure, topography and snow redistribution, which will account for this variation.

To further quantify the accuracy of snowpack estimation, visual analysis of the graphical output of observed discharge, estimated discharge and calculated snowmelt discharge was conducted (figure 6.6). The initial stages of snowmelt are estimated well, but as melt continues errors progressively develop. The

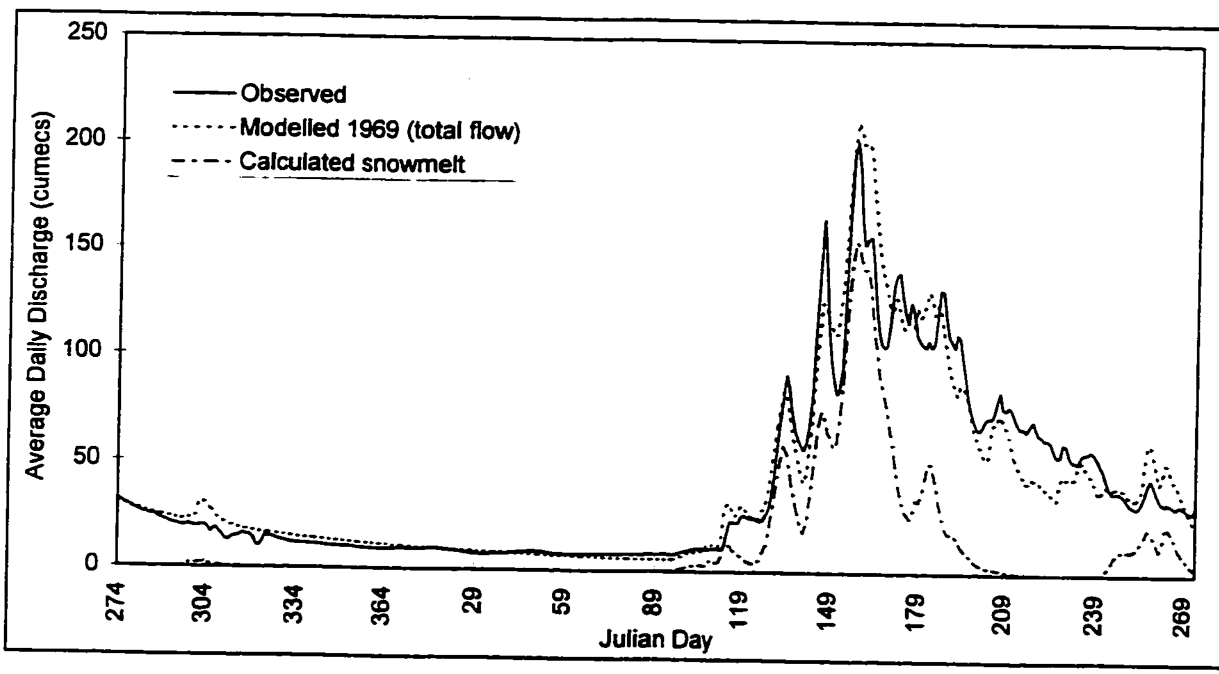


Figure 6.6 - Hydrograph displaying observed, modelled and calculated snowmelt discharge for the Upper Bow Valley for hydrologic year 1969.

second peak melt is significantly underestimated while the following trough is overestimated. Although the extreme peak melt is calculated accurately, the final stages of snowmelt are completely misrepresented.

There are two possible explanations for these errors. First, these errors may be a result of the model's deficiency in estimating the dynamic seasonal properties of snowmelt routing. It is known that as the snowpack warms and ablates, it becomes progressively responsive to meteorologic forcings. As the model assumes an isotrophic flow rate for snowmelt, the dynamic snowmelt responses are loosely represented. Another explanation revolves around the rainfall events that occur concurrently during the snowmelt period. The model is assuming that the precipitation recorded at Lake Louise is blanketing the basin when in reality these events may be site specific. The precipitation events just before and after julian day 149 were recorded at Banff, Lake Louise and Castle Mountain in similar intensities. However, precipitation received between julian days 170 to 186 was spatially variable: Banff recorded 131.5 mm while Lake Louise recorded only 63.6 mm. Thus it is probable that during this period the peaks on the observed hydrograph are really a result of rainfall runoff rather than snowmelt, and as the precipitation is represented primarily from the Lake Louise meteorological station, these peaks are underestimated.

Another problem with the snowmelt component of the hydrograph is late summer snow melt. The model is calculating a surplus of snowmelt starting from late August and continuing through September. Although the observed hydrograph does register a small increase in flow during early September, it is not nearly as significant as the model estimates. It is highly likely that this problem is a result of inaccurate temperature lapse rate estimation combined with an overestimation of the basin-wide precipitation budget. The nighttime temperatures during late August fell to near the freezing point in Banff, and thus a percentage of the precipitation falling at higher elevations is modelled as snow. This period could have been experiencing upslope weather patterns, resulting in inversion conditions, which would inhibit snow precipitation. It is also possible that these precipitation events fell as rain during the day when temperatures were considerably warmer. In addition, the precipitation recorded at Lake Louise in August 1969 was above the basin average: Lake Louise recorded approximately 30% more precipitation than Banff, and as a result, discharge from precipitation is probably overestimated during this time.

6.1.2 Summer Discharge

July and August flows are considerably underestimated in the 1969 calibration. The source of this error lies in either the underestimation of rainfall calculation, glacier melt, or river flow augmentation from groundwater inputs. Each will be addressed in sequence.

6.1.2.1 Rainfall Estimation

The most probable explanation for the low summer calculated discharge may revolve around the spatial distribution of rainfall in the Upper Bow Valley. As discussed, rainfall in the basin is highly spatially variable. Between April to July, Banff received roughly 43% more precipitation than Lake Louise, and therefore it is reasonable to assume that the large residual error between observed and calculated flows is a result of unrepresentative rainfall data in the upper elevation bands (where fast Hortonian flow dominates). To mitigate this problem, Banff meteorological data was assigned representation in all elevation bands. This resulted in higher summer flows, but at the cost of severe snowpack estimation errors. Thus it was decided to resort back to Lake Louise precipitation data for elevation bands 3-9 and accept the error in summer flow estimation.

6.1.2.2 Estimation of Ice Melt

Another explanation for the poor summer flow prediction is potential underestimation of ice melt. As discussed in section 5.6.1, it is thought that the ice melt routine of the model systematically underestimates icemelt. However, it is extremely difficult to quantify the absolute icemelt contribution to the Bow at Banff observed hydrograph. Hopkinson (1997) estimated the monthly ice wastage component at the Bow at Banff using an idealized ice melt hydrograph and modelled mass balance approach. The results of Hopkinson's methods are compared to the UBC technique in table 6.2. It is problematic to directly compare the absolute values from Hopkinson's analysis and the UBC method as they are measuring two different volumes. Hopkinson's figures estimate the volume of water resulting from glacier ice and firn melt above the equilibrium balance, where as the model calculates total ice and firn melt (which will be much greater). The difference between these two values is not absolutely known. Even in a positive mass balance year, there still can be a significant contribution of glacier ice melt to the downstream hydrograph.

Nonetheless, the relative seasonal proportions are compared. The monthly proportions between the UBC Model estimates and Hopkinson's results are in

	% of glacier wastage/total ice melt of basin yield			
Method	**June**	**July**	**August**	**September**
modelled mass balance	0.4	2.5	7.5	7.1
idealized hydrograph	0.11	2.34	8.93	6.21
UBC Model	3.9	12.6	20.38	4.45

Table 6.2 - Comparison of methodologies for estimating total glacier ice melt (UBC Model) and glacier wastage (Hopkinson) contribution to the Bow at Banff hydrograph for 1969.

contradiction. The particularly low September ice melt percentage estimated by the UBC Model is a result of inaccurate estimation of late season snow melt, presumably blanketing the glaciers and prematurely terminating the melt season, and thus is not considered to be comparable.

The idealized ice melt hydrograph method was based on an average of Young's (1982) calculated ice and firn melt discharges for Peyto Glacier from 1967 to 1974 (table 6.3) and thus error is introduced from abstraction. Nonetheless, the 1969 monthly melt proportions estimated by Young for Peyto Glacier and the UBC Model estimates for the Upper Bow Valley are in disagreement (table 6.4). The UBC Model calculates ice melt uniformly among the summer months, where as in reality, there is a distinct monthly variation in ice melt production, as Young's estimation suggests.

A portion of the disagreement can be blamed on the physical and spatial variability of the glaciers is question: Peyto Glacier may not be representative of all

Year	Monthly Melt ($m^3 \times 10^3$)			
	June	July	August	September
1967	16.3	1391.0	4799.1	6144.7
1968	18.9	1390.0	2669.3	1947.6
1969	[illegible]	[illegible]	[illegible]	[illegible]
1970	1000.5	6327.0	12069.0	852.5
1971	13.9	2144.2	6358.1	1700.0
1972	9.9	1218.8	4409.5	970.0
1973	98.1	2107.9	5405.9	
1974	12.0	1435.0	3420.7	
Avg	[illegible]	[illegible]	54.6%	[illegible]

Table 6.3 - Estimated Peyto Glacier melt 1967-74 (after Young, 1982) with average monthly proportions.

Estimate	June	July	August	September
Peyto Glacier	5.1 %	23.9%	46.1%	24.8%
UBC Model	19.5%	27.1%	30.3%	6.9%

Table 6.4 - Peyto Glacier monthly proportion of icemelt (estimated by Young,1982), and UBC Model monthly proportion calculated ice melt for Upper Bow Valley.

glaciers in the Upper Bow Valley. There were approximately 3 km^2 of glaciers in the Upper Bow Valley that were located below the terminus elevation of Peyto Glacier, and thus presumably will be snow-free and hydrologically active before Peyto. However, this alone cannot account for the disagreement in monthly proportions.

A more important source of calculated ice melt error may lie in the snowmelt routine algorithm (appendix 1). The model assumes an equal wedge snowmelt routine, and therefore no attention is directed to the variability of snowmelt over glacierized areas. Snow will persist longer on glaciers than the surrounding rock as the ice works to preserve the cold content of the pack. Thus in reality the glaciers will be hydrologically dormant in the spring much longer than the model estimates, which can explain the high modelled June icemelt estimation. Another key problem results from inaccurate snowmelt estimation: as the model assumes complete and total snowmelt in the basin, it can be assumed that an accelerated snowline retreat is inherently estimated. A summary of the snowline elevation on Peyto Glacier for 1969 is presented in table 6.5. The UBC Model estimates total snow ablation by August 5, when the snowline observed on Peyto Glacier was at approximately 2568 m. This results in errors between the monthly proportions of snowmelt; the ratio between July and August should be greater, as the snowline was lower in July by 461 m.

	June 1	July 1	Aug 1	Sept 1	Oct 1
Peyto Glacier S.L.E.	2143	2406	2568	2682	2766
UBC Estimate S.L.E. Bow Valley	2390	2867	3300	-	2435

Table 6.5 - Observed snowline elevations (S.L.E.) in meters above sea level for Peyto Glacier 1969 and UBC Model estimations.

6.1.2.3 Estimation of Groundwater

The upper and lower groundwater estimation are presented separately in figure 6.7. The upper groundwater flow rises sharply "in-sync" with spring melt and decreases steadily at fairly constant rate. The lower groundwater flow experiences very little increase in discharge throughout the summer. Lower groundwater flows display a lag of about 130 days before reacting to spring melt. This figure was derived solely from the optimization routine within the model. Quantifying the groundwater discharge in the Upper Bow Valley is very difficult due to the lack of data available.

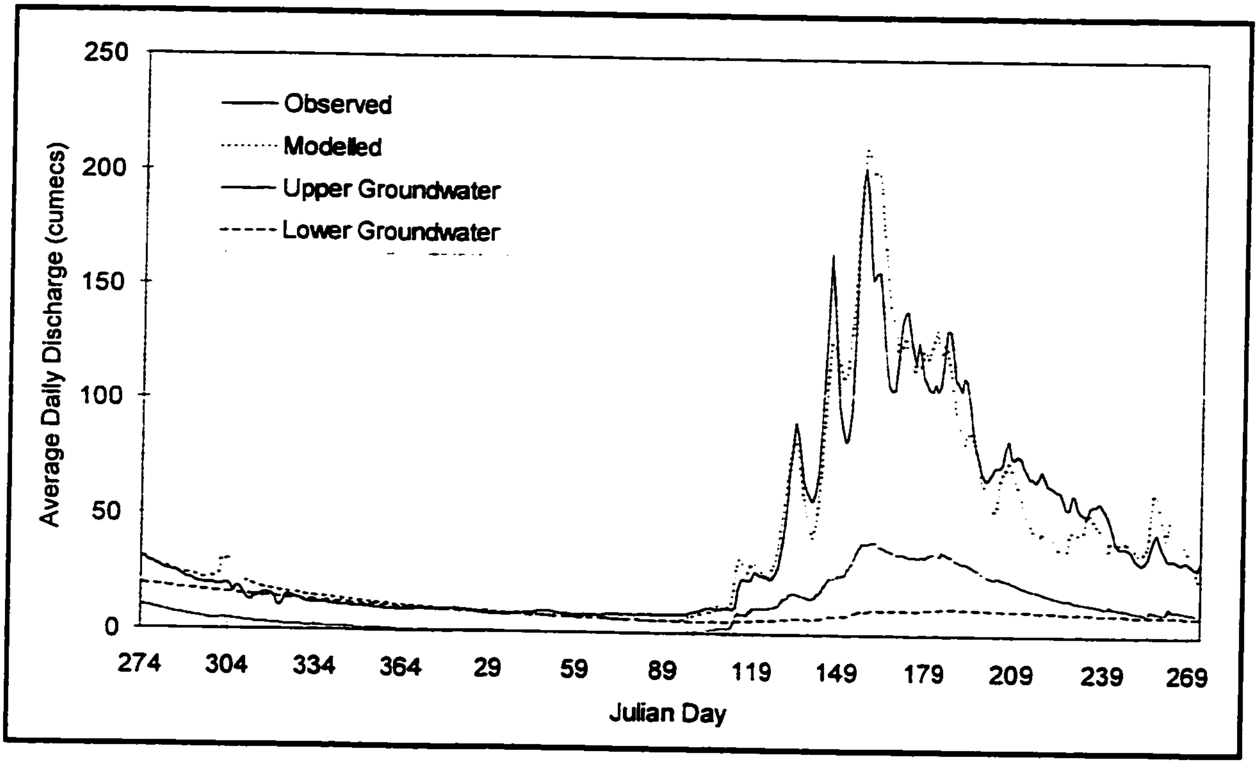


Figure 6.7 - Observed Bow River at Banff discharge and calculated groundwater flows for hydrologic year 1969.

6.2 Predictive Ability of the 1969 Calibration - Application to Other Years

As the UBC Model is largely empirical, it is not surprising that the application of 1969 calibration to other years without minor re-calibration produces relatively poor results. Statistical results of model runs for years 1950 to 1990 are presented in table 6.6. When extended to a 5 year period (1967-71), the results remain fairly strong at 81% efficiency ($r^2 = 0.85$). However, when the calibration is extended to years 1950-1991 the efficiency drops by between 10 to 85%. It is interesting to note that although the efficiency can drop to 6%, the coefficient of determination remains consistently high: the lowest value is 0.82. This suggests that the overall shape of the hydrograph is very good, however the volume of flow is miscalculated. Thus, the flow routing parameters of the model are assumed to be reasonably consistent and accurate. The greatest source of error is expected to be from the precipitation modelling routine because: 1) the extreme spatial variability of precipitation and; 2) the Lake Louise meteorological site was moved several times during the study period.

The model was run using just Banff precipitation data for comparison. For most decades, the removal of the Lake Louise meteorological data from the model training methodology results in better efficiencies; this is especially true for hydrologic years 1950-60. When Lake Louise precipitation data is used for elevation bands 3 to 9, the model grossly overestimates the total yield for all decades. The only period that does not display an overestimation of discharge is 1967 to 1971. Even when assuming Banff meteorological data for all elevation bands, discharge is still overestimated, except for hydrologic years 1960-70.

Model Run (Hydrologic Year)	Coef. Of Efficiency	Coef. Of Determination	cumecs: Observed avg. daily discharge	cumecs: Estimated avg. daily discharge	$m^3 \times 10^6$: Observed yield	$m^3 \times 10^6$: Estimated yield
1969 Lake Louise	0.93	0.93	39.8	37.4	1255.13	1179.45
1967-71 Lake Louise	0.81	0.85	36.5	36.9	1151.06	1163.68
1967-71 Banff	0.72	0.82	36.5	37.2	1151.06	1173.12
1950-60 Lake Louise	0.06	0.84	40.4	62.8	1274.05	1980.46
1950-60 Banff	0.75	0.87	40.4	45.8	1274.05	1444.35
1960-70 Lake Louise	0.62	0.87	41.5	49.9	1308.7	1573.65
1960-70 Banff	0.80	0.85	41.5	40.9	1308.7	1289.82
1970-80 Lake Louise	0.71	0.84	38.9	44.4	1226.75	1400.20
1970-80 Banff	0.73	0.84	38.9	44.6	1226.75	1406.51
1980-90 Lake Louise	0.57	0.84	38.0	47.9	1198.37	1510.57
1980-90 Banff	0.74	0.83	38.0	41.0	1198.37	1292.98

Table 6.6 - Statistical results of model runs from 1950-1990 using 1969 calibration ('Lake Louise' = bands 3-9 using Lake Louise met. station data; 'Banff' = bands 1-9 using Banff met. station data).

These results confirm initial apprehension about the quality of Lake Louise meteorological station data. The application of consecutive years of data when the station was not moved (ex. 1967-1971) produces acceptable results. However, model output during periods of station relocation are significantly compromised. This suggests that the precipitation modelling routine for the Lake Louise station from the original calibration is incompatible with years of station relocation. Essentially, caution must be exercised when using Lake Louise meteorological data for inter-decadal analysis.

The use of empirical models in hydrological forecasting often requires progressive re-calibration (Becker and Serban, 1990), especially for basins that display significant spatial meteorological variation. Alberta Environment regularly monitors the forecasts of the SSAAR model for the Bow River at Banff (in real time) and re-calibrate as necessary (Teng, pers. commun., 1997). Typically, re-calibration focuses on the meteorological routines of the model, which are tested against basin-wide observations of snowpack depth and rainfall. Slight seasonal, monthly, or even weekly anomalies in the spatial distribution of precipitation can give rise to large forecasting errors. When minor adjustments are made to the precipitation modelling routine of the UBC Model, significant improvements in output result. For example, model efficiency for hydrologic year 1990 is 78% when the 1969 calibration is applied. Slight adjustment to the precipitation modification parameters (reducing the positive precipitation adjustment) bring model efficiency up to 90%. It is likely that every year will display some anomalous meteorological behavior either at the monthly, weekly, or daily scale and as a result, the re-calibration of empirical models is uniformly required.

6.3 Discussion of the Calibration Methodology and Results

6.3.1 Confidence in the Hypsographic Curve Data

Confidence in the glacier cover data is not very high because of the problems associated with terrestrial mapping above the snow line. On aerial photographs it is very difficult to distinguish ice margins and surface relief when covered by a highly reflective, homogeneous snowpack. In addition, it is rare that the cartographer holds intimate knowledge of glacier systems. Thus, it is highly probable that the glacier boundaries represented on the NTS maps are really snowpack boundaries resulting in an overestimation of glacier area. In addition, glaciers are the only land cover in the basin that is assumed to be dynamic, and temporal glacier variations in the whole of the Bow Valley are not well documented.

Confidence in the forested area estimation is high as forests are easily distinguishable on air photography. In addition, forest cover is assumed stagnant over the basin for two reasons: 1) logging is prohibited in the Upper Bow Valley, and; 2) there have been no major fires within the last several decades. Minor variations in forest cover do exist north of Banff as a result of disease, however, these changes can be considered insignificant relative to the entire basin.

Areas of rock, ablation till, moraine (ground, terminal, lateral), and some erosional features are very difficult to differentiate on aerial photographs. As a result, all areas not classified as glacier, lake or forest are assumed as rock cover.

Therefore it is guaranteed that true rock cover is overestimated. This is especially problematic when estimating areas of impermeability as there are significant variations in infiltration potential within this highly lumped land cover classification.

A major point of concern in the hypsographic curve data is that there is no category assigned for alpine tundra or grasslands, which are known to exist within the study area. It is assumed that these areas have been lumped together with forests or rock cover. From a modellers perspective, this assumption could have significant repercussions when estimating snowmelt and evapotranspiration. Snowmelt under forest cover is controlled by the longwave radiation regime, where as in open areas it is controlled largely by the shortwave radiation budget (Quick and Pipes, 1994). In addition, rates of interception and evapotranspiration are extremely different between forested areas and grasslands. Ideally, areas of open meadow should be assigned a separate category.

6.3.2 Orientation Index

There are potential errors associated with the theory of the model algorithm (appendix 1). The model assumes all eastern, western and southern exposures as being 'southern' in relation to north facing slopes. In reality, snow and ice melt and evapotranspirative losses on western slopes are driven by both the shortwave and longwave radiation budget, as western slopes receive maximum sunlight later in the day when temperatures are generally higher. One the lee side, the hydrology of eastern slopes is driven primarily by the shortwave energy budget, as morning temperatures are cooler. Thus, western slopes should experience greater melt and evapotranspirative losses than eastern slopes.

In addition, the model does not assume a slope angle, which directly affects the energy available for melt and evaporation. Most macro-scale models designed for mountainous watersheds do not factor the inclusion of slope angles due to the complexity of the terrain. However, the use of remote sensing techniques can allow for a more detailed slope angle approach. Seidel *et al* (1997) have developed computer programs that incorporate SPOT-XS and Landsat-TM data into the Martinec Model to determine aspect, slope angle and snow depth for macro-scale basins in the Swiss Alps. Their works suggests the use of remote sensing data in macro-scale watershed modelling is extremely beneficial, however, it is also extremely costly, especially for SPOT-XS imagery. Similar techniques can be applied to the UBC Model for the Upper Bow Valley, allowing for a more detailed approach.

6.3.3 Meteorological Data Selection

Banff meteorological data is assumed to be accurate and of good quality as it is staffed and operated by Environment Canada. Confidence in the quality of data of the Lake Louise meteorological site is limited as it has been relocated three times during the record: 1974, 1981, and 1985. Caution is applied when using Lake Louise data; only consecutive years where the location was unchanged are used.

It is unfortunate that the altitudinal range between Banff (1396 masl) and Lake Louise (1534 masl) meteorological sites is only 127 m. Using meteorological data from stations displaying a greater altitudinal range would result in a more physical representation of the orographic meteorologic regime. Using the SSAR Model, Alberta Environment Protection uses Banff and Sunshine Village meteorological data for their flow forecasting of the Bow above Banff (Tom Teng, pers. comm., 1996). Sunshine Village meteorological station sits at approximately 2200m, and is therefore particularly useful in determining the frequency and magnitude of temperature inversions and precipitation patterns. Unfortunately, attempts at obtaining Sunshine meteorological data from the Banff National Park Warden Service were unsuccessful.

6.3.4 Rationale and Confidence - Temperature Lapse Rates

It is assumed that the model algorithms for temperature calculation are accurate as they were formulated on physically based theory and observation (Quick and Pipes, 1977). Under normal adiabatic conditions, confidence in the estimation of temperature lapse rates is fairly high. With the exception of local katabatic effects from glaciers (which only occur in approximately 3% of the basin), the overall basin trend in lapse rate estimation is assumed accurate. However, no confidence is placed in the estimation of temperature lapse rates under the influence of inversion conditions. Ideally, it would be best to calibrate the model lapse rates to observed meteorological conditions, unfortunately, the data available does not cover a significant altitudinal range. Temperature inversion conditions can be common in the Bow Valley under summer conditions of upslope weather, and can last for periods over a week (Gadd, 1995). In winter, it is common for cold, dense air to move south along the base of the Upper Bow Valley. Due to this influence, the temperature at Chateau Lake Louise (1740 masl) can be up to 15^{0}C warmer than Lake Louise town site (1534 masl).

Imprecision in estimating the temperature gradient will give rise to inaccuracies in precipitation modelling, which will affect the timing of calculated discharge. Inversion conditions resulting from upslope instabilities will result in liquid precipitation falling at higher elevation. The model assumptions will cause this precipitation scenario to be modelled as solid precipitation. As a consequence, the model will store this precipitation in the snowpack until conditions are suitable for melt. Ultimately, inversion conditions will result in the underestimation of discharge during precipitation events, and an overestimation of discharge when temperatures increase to allow "imaginary" snowpack ablation. Typically, late summer snowmelt is a common problem with the model predictions and is assumed to be a direct result of temperature lapse rate.

Another consequence of poor lapse rate estimation is inaccurate calculation of the ablation of snow and ice. The simplified energy budget method used in this model is entirely based on the longwave energy flux, and thus significant errors can occur if lapse rates are poorly represented.

6.3.5 Form of Precipitation

It is known that precipitation can fall as either snow or rain between temperatures of $0^{o}C$ and $4^{0}C$ (Barry, 1981), depending on the cold content of the snow crystals. However given the data requirements of the model, it is impossible to determine the physical state of precipitation within this temperature range. It can be assumed that most precipitation falling over $3^{0}C$ will be liquid, except on rare occasions where a strong vertical temperature gradient exists in the atmosphere. The assumptions made by the model do not consider these rare occasions. The model represents the average conditions of the expected physical state of precipitation, which is reasonable to assume. However, if calculated temperature lapse rates are misrepresented, then significant inaccuracies in calculated snowpack accumulation and runoff could occur.

6.3.6 Rainfall Calculation

Theoretically, the local convective nature of rainfall should make point source values more representative of regional conditions as compared to snowpack water equivalence (Quick and Pipes, 1994). However, this is not generally the case in the Upper Bow Valley. It is probable that great errors in rainfall estimation can occur based on the UBC Model assumptions due to the heterogeneity and inter-annual variation of the precipitation regime. It is assumed that errors in rainfall modelling will not translate to significant errors in annual yield estimation, as rainfall is not the dominant hydrological influence. Flow estimation errors from rainfall modelling inaccuracies will occur during the summer months, when flow is lowest. This was observed in the 1969 calibration.

6.3.7 Discussion of Ice Melt Alteration

Conceptually, an ice albedo of 0.3 is not representative of real-world glacier ice conditions. The lower parts of the glacier experience an upward movement of ice, which results in the deposition of supraglacial ablation till. In addition, surface debris from surrounding rock faces can also contribute to the collection of surface debris. This surface till reduces the albedo of the glacier and causes accelerated melting, which is significant considering the lower regions of the glacier are exposed for the longest duration and are the most hydrologically productive. As the melt season progresses, aeolian and organic debris will progressively collect on the ice surface, which further lowers the surface albedo. In addition, the albedo of ice-cored moraines is more closely related to the surrounding rock than glacier ice. It is accepted that the albedo of firn is significantly higher than glacier ice, however, these regions are typically not exposed for most of the year, except in anomalous years such as 1970. Table 6.7 summarizes glacier surface albedo measurements for Findelen and Z'Mutt glaciers recorded by Bezinge (1987).

Glacier	Surface type	Altitude (m)	Albedo
Findelen	glacier free of snow	2500	0.17
	glacier free of snow	2900	0.22
	limit of lower firn	3000	0.35
	limit of upper firn	3150	0.70
Z'Mutt	glacier free of snow	2400	0.18
	serac zone	2900	0.4

Table 6.7 - Variations of albedo of different types of glacier surface on the Findelen and Z'Mutt glaciers (from Bezinge, 1987).

Based on this logic, the ice albedo value in the model was lowered to a value of 0.23, which resulted in a 16% increase in water yield from glacier ice for hydrologic year 1969 (Table 6.8). Although overall efficiency for the entire year only increased by barely 1% after changing the ice albedo, June to August efficiency increased by 3%.

Albedo →	0.3	[redacted]	0.3	[redacted]	
Year	Avg. Daily Discharge (cumecs)	[redacted]	Total Yield ($m^3 x10^6$)	[redacted]	Residual ($m^3 x10^6$)
1969	4.289	[redacted]	52.68	[redacted]	8.72

Table 6.8 - Comparison of UBC model calculated icemelt daily discharge and total yield for the Upper Bow Valley assuming an ice albedo of 0.3 and 0.1 in the icemelt routine.

6.3.6 Confidence in the Snowmelt Routine

The model assumes a simplified version of the energy budget approach that was developed for use with only temperature data. This method has proven to be accurate in areas dominated by the longwave heat exchange, such as forests (Quick and Pipes, 1977 and 1994). However, open area melt is more a function of shortwave radiation, snowpack albedo, and convective heat transfer (Lang, 1986). Temperature alone is not an accurate indication of these variables as they are physically dependent on other factors, such as wind speed, cloud cover, and local topography. In addition, the influence of the convective and advective melt components increases at higher altitudes, where increased wind speeds and complex topography are dominant. Quick and Pipes (1994) estimate the energy budget on reasonable assumptions as described in appendix 1, however, the assumptions are based heavily on the estimation of wind speed and cloud cover, which will be discussed separately.

The snowmelt routine assumes a "wedge melt-out" over each elevation band, which represents the gradual recession of the snowline. In reality, determining the absolute snow line over complex terrain is often very difficult due to the strong influence of snow redistribution processes over complex terrain (de Scally, 1989). Problems with snowmelt estimation over glacierized areas have already been discussed. The effect of this snowmelt lag is not assumed to have a significant influence on the Bow River at Banff annual yield as the basin is only 3% glacierized. However, the insulating effect of the snow will delay ice melt. In addition to this, the model ignores processes of snow redistribution, which can result in significant prediction errors (more so in timing than in yield).

Another key problem with this model is that it assumes complete snow melt over the basin area: this is never the case. Even during the most extreme melt season of record in 1970 a small portion of the snowpack survived the hot temperatures to nourish glaciers the following year. It is difficult to assume a single cause for this problem, although it is probably a cumulative result from errors in calculating lapse rates, high altitude wind speed, cloud cover, snowpack accumulation and evaporation, in combination with the model's lumped slope parameter (which ignores meso- and micro topographic variability). As summer snowmelt is a minor contribution to river flow, this problem is not considered major, however, if the total snowpack is being ablated then it is highly likely that actual snow precipitation is being underestimated.

6.3.6.1 Wind Speed

An important component of the snow and icemelt routine is wind speed. Calculation of wind speed is based on the assumption that wind tends to produce a decrease in daily temperature range: essentially, cloudy conditions are assumed windy conditions. In reality, significant atmospheric pressure gradients can exist under open sky conditions. There is often a pressure gradient over the mountains in the southern Upper Bow Valley as a result of a band of high pressure resting west of the Rockies and a band of low pressure over the southern Alberta foothills (Gadd, 1995). Prevailing westerlies hit the western slopes of the Rockies, slow down and compress causing an increase in pressure. As they are forced over the barrier, they expand and speed up on the lee side of the Rockies. This process causes windy conditions throughout the year and can act independently of the daily temperature range. This wind regime is also independent of regional Chinook conditions, which the model fails to estimate. Chinook conditions in the Bow Valley can be associated with a high diurnal temperature range, however, wind conditions are anything but calm: a foehn wall will cause severe turbulent flow at the terrain surface.

In addition, the model simplifies the complexity of the mountain wind regime (which can be extremely variable diurnally) by assuming a constant increase with elevation. This assumption is typically true, especially for mountain peaks that stand alone but this relationship may exist for smaller peaks that are protected by larger ones (Egger, 1990). In addition, assuming a vertical increase in wind speed can be considered grossly elementary considering the diurnal, annual and spatial variability of mountain fluid dynamics. For example, the model does not assume katabatic influences, which are known to be significant in areas down slope from the glacierized regions of the basin. Overall, very little confidence is placed on the model's ability to estimate wind speed.

6.3.6.2 Cloud Cover

An important component influencing the energy budget is cloud cover. The UBC Model also assumes cloud cover as being related to the daily temperature range, such that the percentage of cloud cover increases as the daily temperature range decreases. It is known from experience that cloud cover in the Rockies is extremely diurnally variable, typically with clear skies in the morning and increasing convective cloud cover as the day progresses. A consistent trend observed in the Bow Valley area is a period of afternoon clearing sandwiched by overcast conditions (known as the 'idiots window'). In addition, cloud conditions are influenced by the effects of icefields and large glaciers, which cause increased cooling and condensation with elevation. From unfortunate experience, it has been noted that the Wapta Icefield typically experiences more cloud cover than regions south, probably a result of the forced adiabatic cooling from the ice. This is particularly consequential when estimating water production from glaciers, as cloud cover is the most important factor controlling the shortwave radiation budget.

6.3.7 Evapotranspiration Modelling

Confidence in evapotranspiration estimation is fairly low. First, the evapotranspiration demand only affects areas of the watershed that are permeable. In reality, impermeable areas can still experience evapotranspirative losses from surface pooling and fissure flow (both macro and micro). In addition, the transpiration ratio and the consumptive use can be quite variable depending on vegetation species. The model uses a standard evapotranspiration modifier for forested areas, which assumes an average value. The evapotranspiration modifier could be improved if it were adjusted to represent the vegetative signature of the basin.

Another deficiency of the model is that the evaporative loss from open water (lake and river) is not considered. Although this effect in the Upper Bow Valley is considered minimal given the small number of lakes and the cool average temperature of the water, the application of the model to areas containing large bodies of standing water could result in large errors. Overall, it is probable that the largest errors in evapotranspiration estimation result from the model's inability to calculate wind speed and cloud cover, as previously discussed.

6.3.9 Estimation of Groundwater

The values for P0PERC, P0DZSH, P0UGTK and P0DZTK were estimated by conducting a sensitivity analysis and by visual interpretation of the hydrograph. No physical data were directly employed to support these values. This is because: 1) the model assumptions for groundwater modelling are simplistic, and are therefore not intended to be calibrated with real data, and; 2) lack of hydrogeological data for the Upper Bow Valley. The model assumes that the groundwater aquifer is unconfined, and therefore will reflect fluctuations in precipitation, snowmelt and evaporation. This is reasonable as the geology of the basin is primarily composed of fractured carbonates and clastics.

The fast movement of groundwater in fractured limestone sub-strata can be significant (Bair, 1995), especially when combined with the high potential elevation energy inherent in a mountainous basin. The rate of water flow through the fractured sub-strata has been estimated at 0.02 m/s in the Bow Valley (Worthington, pers. commun, 1997). Given the terrain and heterogeneity of the geologic materials, determining the volumetric flow of groundwater through the estimation of equipotential lines is very difficult. The majority of springs nourishing the Bow River are located in the alluvium or river bed, and thus make volumetric estimations difficult to quantify (Ford, 1971). There are no computer codes available to simulate the groundwater regime of the Bow River above Banff (Worthington, pers. commun, 1997).

It can be assumed that the general groundwater flow trends calculated by the model are realistic, as seasonal fluctuations in unconfined aquifers reflect the variations in precipitation and evapotranspiration (Freeze and Cherry, 1979). Worthington and Ford (1995) have suggested that most of the spring recharge to the aquifer seeps out into the Bow River system throughout May to August. Field observations in the Peyto Glacier Basin generally support this relationship, however, it was noted that groundwater springs continued to flow generously throughout late summer despite extended periods of no precipitation. This may suggest that deep groundwater storage can augment surface flows in late summer. Based on this and the low estimated summer flows, the modelled recession flow of the upper groundwater component can be interpreted as being premature. However, without quantification from field data the only reasonable option for this project is to assume linear aquifer recharge and recession related to precipitation, evapotranspiration and snowpack ablation.

Theoretically, a percentage of groundwater recharge in the Upper Bow Valley seeps into deep, large aquifers (Worthington and Ford, 1995). Thus, it is likely that there is competition for flow with other low points in the region, such as Crowsnest Pass and the North Saskatchewan River. It is estimated that the groundwater catchment extends approximately halfway into each of these basins (Worthington, pers. commun, 1997), which would suggest that trans-basin sub-surface flow does occur. The model does not account for this and as these estimations are largely theoretical, the model cannot be trained to assume it.

6.3.9 Discussion of the Water Routing Assumptions

The routing parameters were chosen largely based on visual interpretation of the calculated hydrograph and through the sensitivity analysis option (M. Quick, pers. commun., 1997). It would have been ideal to determine the basin response time from historical event-runoff data. However, the Bow Valley data set is temporally too coarse for detailed hourly analysis. Correlation analysis was conducted using daily precipitation and temperature data from Lake Louise and Banff. Depending on the time of year, correlation coefficients were highest when a 2-3 day lag was assumed, which basically stands in agreement with the model estimations. In addition, stream flow velocity was estimated in the field as being approximately 0.5 m s^{-1} (Hopkinson 1997), and therefore Bow River flow times from all the sub-basins to the gauging site at Banff should be in the order of 1 to 3 days.

6.3.9.1 Fast Flow Routing

Passing the volume of fast flow discharge thorough two linear storage reservoirs produced the best results. The fast flow component determines the peaks on the hydrograph, which are loosely estimated in the 1969 calibration. However, errors in the fast flow routing alone cannot account for the underestimation of peak flows, for the problem is a vast combination of factors relating to surface and sub-surface flow.

Horton (1933, as cited in Bobba, *et al*, 1995) introduced the concept of overland flow to account for the rapid increase in stream discharge following a rainfall event. Hortonian flow is not assumed to be predominant in the lower elevations of the basin, as the vegetative cover and porous soil medium facilitate the rapid absorption of moisture, except in cases where the infiltration capacity of the soil is exceeded. However, as noted from field observation, the rock exposures and compacted tills common to the higher elevations of the basin exhibit a Hortonian flow regime, compounded by the extreme slope angles. From field observation, it was noted that during rainfall events, sheet flow over bedrock valley sides occurred. Significant overland flow also was observed in areas of compacted till and moraine, where surface crust formation from rain compaction was common. It is logical to assume that only those regions experiencing rapid overland flow contribute to peak discharge during precipitation events, where as rainfall falling in the lower valleys experience an interflow lag (Quick and Pipes, 1977). Thus, in terms of the fast flow component, it is most important to determine the absolute impervious area of the basin. Unfortunately, the GIS data used for this study provides only a rough estimate of exposed rock. Further quantification through remote sensing techniques would help to mitigate this problem. It is also important to note that parts of the impervious portions of the basin will drain into till, which will cause an interflow lag.

Routing times for fast runoff are likely to be seasonally dynamic. This is known to be true for glaciers as sub-glacial, en-glacial and supra-glacial channels mature over the course of the melt season resulting in quicker response times. In addition, the antecedent conditions of the upper soil layer are a big factor in determining rates of overland flow. Surface and sub-surface soil freezing can increase basin response time to hydrometeorologic forcings. The routing constants chosen are an annual compromise of the seasonal variations, and thus are subject to error.

The fast flow component is only considered a source of timing error during periods of active snowmelt and rainfall. At all other times of year, timing errors from the fast flow routing is minimal as relatively small volumes of water are treated as fast flow relative to subsurface flow. In terms of total yield, the fast flow component is not considered a large source of error at any time of the year. This is because the evaporative losses are usually minimal during periods of fast flow routing.

6.3.9.2 Interflow Time Constant for Snow

As a rule, the sub-surface flow component is the most significant constituent of water reaching the channel system (Finlayson and McMahon, 1995), and therefore, interflow routing has the potential for the greatest error in the Bow River hydrograph. The interflow time constant for snow was assigned a value of 4.8 - one day longer than for rain. This extra day accounts for the lags associated with snowpack flow routing. The routing time chosen for snow is meant to represent the average condition of the basin, which is assumed to be temporally and spatially variable. Analyses and *in situ* measurements of snowmelt infiltration into frozen soils are sparse (Male and Gray, 1981). The rate and amount of infiltration from snowmelt depends primarily on the moisture content and temperature of the frozen soil and the rate of snowmelt, which are ignored by the UBC Model. In addition, the type of soil freezing will affect infiltration rates; concrete frost will inhibit infiltration, whereas lattice or porous frost will allow some moisture flow.

As the snowpack becomes isothermal, meltwater slowly percolates down into the pack where it can be temporarily refrozen as part of the negative melt budget. Generally, the pore spaces between the snow grains can hold between 3 to 5% liquid water by weight (Male and Gray, 1981): the UBC Model assumes 5% liquid water by weight. As the snowpack ablates and becomes saturated, flow-through times are accelerated, and internal re-freezing becomes less dominant. However, by nature, snowpacks are rarely idealized systems with vertical uniform piston-type flow. Major internal discontinuities in snowpack density, such as depth hoar development and bottom and mid-layer ice formation, can significantly retard or accelerate in-snow flow rates. Preferential flow may occur by the formation of passageways in and under the snowpack. The development of such features are highly variable from year to year (especially rain-on-snow events), and will contribute to the limited predictive ability of the model's snowmelt routine.

6.3.9.3 Interflow Time Constant for Rain

An average isotropic value for P0IRTK (interflow time constant for rain) of 3.8 days was estimated, even though assuming an isotropic flow rate is limiting in itself. At first impression, an interflow constant of 3.8 days appears slightly fast for a basin that is over 2200 km^2 in area. However, given the hydraulic conditions typical of mountainous environments, and the drainage density of the basin (as outlined in figure 4.1), this value falls within the bounds of physical reality.

Although the soil types for the Upper Bow Valley are not accurately classified, it can be assumed that soil depths are generally shallow with a low clay content: conditions typical of mountainous areas (Luce, 1995). Soils of this type will inherently display a high hydraulic conductivity. Exceptions to this will exist in the valley bottoms, where processes of deposition can give rise to thick soil columns rich in silts.

It was noted from field observations of several alpine forests in the Upper Bow Valley that the soil-atmosphere interface is rarely free of organic protection (either living or detritus). Thus it is assumed that the presence of bottom layer vegetation, in addition to the forest biomass, creates a highly conductive soil in elevations below the tree line (especially when coupled with the typically extreme hydrologic gradients). To quantify interflow rates, lysimeters should be installed along vertical transects in each ecological community in the basin.

In reality, it is certain that an interflow rate for rain of 3.8 days is radically variable given the heterogeneous nature of the hydraulic gradients and the physical, chemical and biological nature of the soil medium in the Upper Bow Valley. Both the lateral and vertical non-uniformity of the aforementioned factors in the soil column will give rise to variances in Darcian-flow rates and hydraulic conductivity (Wierenga and Brusseau, 1995). Of particular importance is the preferential sub-surface flow of water through macro-pores and conduits (either of inorganic or organic influences). It is also assumed that the hydraulic conductivity is seasonally variable dependent on the degree of sub-surface freezing.

In addition, sub-surface flow rates are directly influenced by rates of infiltration (Ward and Dorsey, 1995). The rapid infiltration of rainfall causes convergent down slope movement of soil water, enlarging the saturated area at the base of the slope and increasing discharge to the stream (Bobba *et al*, 1995). The model does not consider rainfall intensity (except in extreme scenarios when rainfall exceeds the estimated infiltration capacity). Therefore, errors in interflow routing (and consequently, evapotranspiration) will result from assuming a constant rate of 3.8 days.

6.3.9.4 The Effect of Lakes on Flow Routing

The model does not directly estimate the effect of lakes on water routing. The effect of inflow impoundment in lakes is absorbed in the general routing parameters of the model. Although ideally it would be best to model the storage effect of lakes, it is reasonable to absorb the reservoir impoundment signature as part of the routing characteristics of the inflow parameters. There are approximately 15km^2 of lakes in the Upper Bow Valley, and most are located downstream from glacierized areas. As a result, the glacier runoff is likely to be moderated by lake impoundment.

The majority of the lakes in the Upper Bow Valley are generally long, deep and narrow. Thus it can be assumed that transverse flow is negligible and the current is guided primarily by the hydrographic slope, wind and the density gradient. In small alpine lakes the hydrographic slope can be a significant influence on flow rates and residence times. The hydrographic slope of Marion Lake in British Columbia is so great that it is described as being riverine in nature (Goldman and Horne, 1983), although it cannot be concluded that such lakes exist in the Bow Valley.

As river water enters an unstratified impoundment of neutral stability, velocity decreases exponentially, and turbulent mixing occurs. However the presence of a vertical density gradient (as a result of heat inputs or water chemistry) greatly facilitates the movement of water, such that a horizontal layer of less dense water can flow freely over the underlying thermocline or chemocline. As flow continues, the boundaries of these layers will experience some turbulent mixing of both momentum and heat, and the upper layer (epilimnion) can become thicker (allowing for greater temporary storage). Winds can act to increase the surface and subsurface eddy viscosity through Ekman currents, causing further turbulent mixing between the epilimnion and the hypolimnion (Hutchinson, 1957). Typically, high alpine lakes display a small thermal gradient (under 4^0C for most of the year) with a poorly developed, shallow thermocline that experiences frequent summer mixing due to wind (Yoshimura, 1936, as quoted in Hutchinson, 1957). The seasonal variation of density gradients in Bow Valley lakes are not known, and thus it is hard to speculate on the residence times of lake inputs.

Wind denivellation of lakes in the Upper Bow Valley is assumed to be very significant as katabatic and valley winds are strong and persistent. In addition, most lakes in the Upper Bow Valley can be considered valley lakes, and are orientated parallel to the direction of dominant wind flow. Winds can be especially significant in the nocturnal draining of lakes as inflows from glacierized areas recede and overnight katabatic winds become the dominant hydrologic forcing.

Chapter 7 - Methodology and Results of the Climatic Scenario Forcings

7.0 Introduction

This chapter will describe the methodology and present the results of the application of climatic scenarios to the 1969 calibration file of the UBC Model. In addition, UBC Model flow predictions using watershed files with adjusted glacier areas are presented.

7.1 Methodology

7.1.1 Areal Glacier Change

In order to estimate the effect of a changing climate on the hydrology of a watershed, the dynamic characteristics of all land covers must be estimated. It is assumed that rock and forest in the Upper Bow Valley will remain stagnant. To account for glacier melt, a linear rate of areal ice recession per elevation band as observed from 1951-1993 (based on photogrammetric measurements from the Hector Basin by Hopkinson {1997}) was assumed (figure 7.1). The observed trend was extended forward to estimate a 30% (modest glacier change) and a 62% (extreme glacier change) recession of the estimated 1993 areal glacier extent for the entire Bow Valley above Banff. These values were entered into the Bow Valley watershed description files of the UBC Model. In addition, a file was created assuming no glacier coverage.

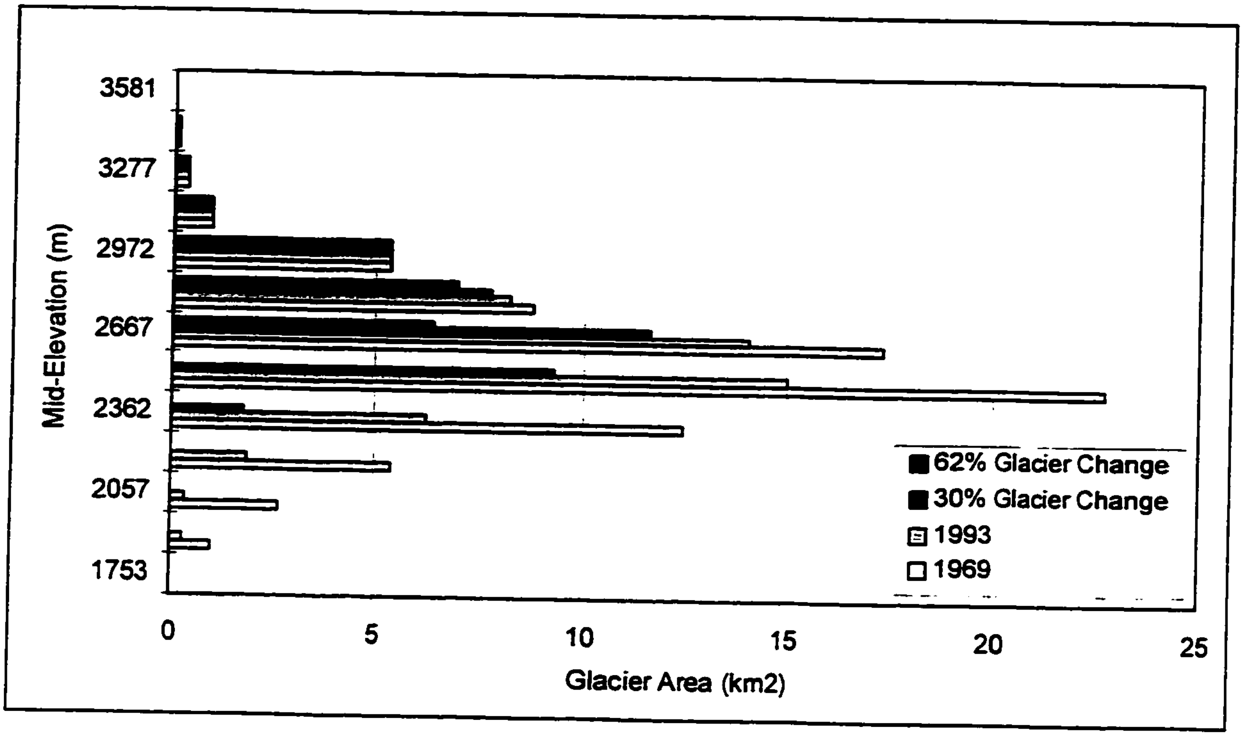


Figure 7.1 - Hypsographic curve of estimated future areal glacier extents based on the observed 1951-1993 linear trend. % change from 1993 estimated values.

7.1.2 Hypothetical Climatic Scenarios

Climatic scenarios were formulated based on $2xCO_2$ predictions from 8 General Circulation Models or GCM's (Canadian Centre for Climate {CCC}, Victoria; Commonwealth Scientific and Industrial Research Organization {CSIRO}, Melbourne; Geophysical Fluid Dynamics Laboratory {GFDL}, Princeton; Max Planck Institute for Meteorology {MPI}, Hamburg; Meteorological Research Institute {MRI}, Tsukuba, Japan; National Centre for Atmospheric Research {NCAR}, Boulder; and the United Kingdom Meteorological Office {UKMO}, Bracknell). With reference to the study area, there is agreement between most of these GCM's that winter temperatures will experience greater increases as compared to summer temperatures. In addition, all models suggest that minimum daily temperatures will be most sensitive to these increases resulting in a decrease of the diurnal temperature range. It is also estimated that winter precipitation will increase as a result of a pronounced maritime influence in western Canada. Summer precipitation is not expected to vary considerably. A summary of these model predictions is provided in the Intergovernmental Panel on Climate Change report (Gates, *et. al.*, 1996).

Although there is general agreement in predicted climatic trends for most models, absolute values display significant variability between GCM's. To represent the broad range of predictions of these models, several climatic scenarios were drafted (table 1). The minimum temperatures were given preferential weighting in all scenarios to simulate the estimated decrease in the diurnal temperature range. Winter precipitation is also preferentially weighted over summer precipitation; a 0.5 mm/day increase in winter precipitation is approximately equivalent to a 50% increase to the observed 1969 record and a 0.1 mm/day increase is about 10%. Winter months refer to October through April, and summer months are assumed as May to September (based on typical hydrometeorological conditions).

The meteorologic file for hydrologic year 1969 (from October 1 1968 to September 31 1969) of the UBC Model was adjusted to simulate each scenario. Model runs were performed on a Pentium 133 MHz PC using all 4 scenarios as the meteorologic forcing with the watershed description files of calculated 1969 and adjusted glacier extents (30% and 62% reduction and no glaciers).

Scenario	Temperature (°C)				Precipitation (mm/day)	
	Winter		Summer		Winter	Summer
	max	min	max	min		
1	1.5	3	1	2	0.5	0.2
2	0.5	1	0.3	0.6	0.1	0
3	1.5	3	1	2	0	0
4	0	0	0	0	0.5	0

Table 7.1 - Climatic scenarios (all values indicate increases in precipitation or temperature).

7.2 Results

Presenting the results of all four climatic scenarios vs. the 5 watershed files (original 1969, 1993, 30% and 62% reduction in glacier area and no glaciers) would be redundant as the results are overlapping in many cases. Adjusting the glacier area does not alter the UBC Model calculations for rainfall, snowmelt, evapotranspiration, and groundwater: only icemelt is affected. This is because the icemelt routine works independently of all other sub-models.

Thus, in the interest of clarity, results are presented in three parts. The first part presents the UBC Model estimations of Bow River at Banff discharge assuming various degrees of glacier recession. The second part strictly examines the icemelt component of the hydrograph when the model is forced by the climatic scenarios. And finally, the third section deals with the climatic sensitivity of the entire basin; results of the climate scenarios on the original 1969 calibration files are presented in full (meaning, all components of the hydrograph including evapotranspiration are examined).

7.2.1 Reduction of Glacier Area Using Observed Meteorological Conditions

UBC Model predictions for watershed files programmed to simulate a reduction in glacier area are presented graphically in figure 7.2 and in tabular form in table 7.2. The UBC Model translates reduction in glacier extents to significant reductions in annual discharge. Naturally, the majority of the discharge attenuation occurred during the summer months: July and August yield was reduced by 21.9% assuming no glaciers. Discharge is lowered most during the initial stages of melt, as glaciers retreat to higher elevations. The model does not calculate any significant variance in the timing between the discharge resulting from glacier area adjustment and the modelled 1969 discharge.

Glacier Area	Reduction in 1969 Annual Yield x 10^6 m^3	% Reduction in 1969 Annual Yield	Reduction in July-August Yield x 10^6 m3	% Reduction in July-August Yield
1993 extent	33.031	2.6%	21.939	6.5%
30% reduction	59.541	4.7%	39.605	13.1%
62% reduction	84.879	6.7%	58.483	17.2%
no glaciers	103.882	8.2%	74.298	21.9%

Table 7.2 - Reduction of Bow River at Banff discharge resulting from glacier area adjustment.

7.2.2 Reduction of Glacier Area Using Climatic Scenarios

The following results were generated by forcing the UBC Model with the climatic scenarios using watershed files that had been adjusted to account for glacier recession. Only the icemelt component is examined. The results are presented graphically in figures 7.3 to 7.6. Total yields are displayed in table 7.3.

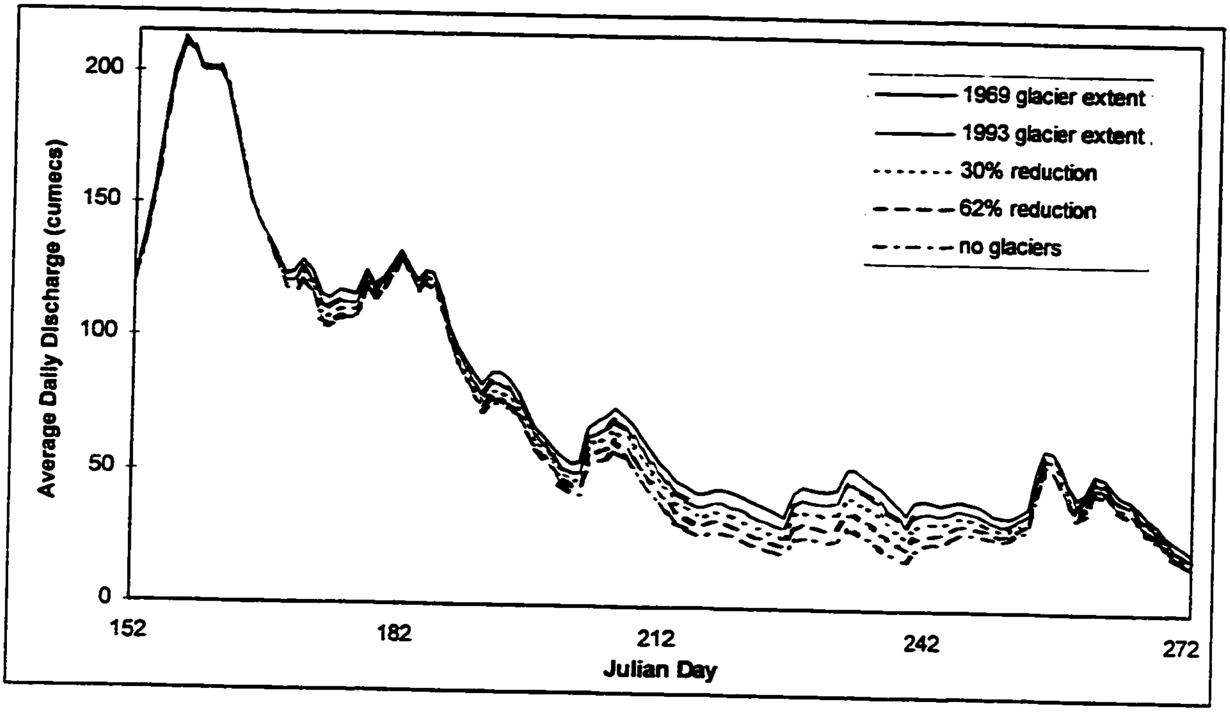


Figure 7.2 - Graph displaying the calculated average daily discharge at the Bow River at Banff resulting from the adjustment of glacier area. Percentages indicate the estimated reduction in glacier area from estimated 1993 values.

	Climate Scenario			
Watershed File	1	2	3	4
1969 calibration	87.685	69.885	98.657	51.245
30% glacier reduction	46.814	37.916	53.609	27.534
62% glacier reduction	22.656	18.524	26.874	12.867
1969 calibration file forced by observed meteorological file produced 61.755 $m^3 x10^6$ of icemelt				

Table 7.3 - Total yields of icemelt production in $m^3 \times 10^6$. Percentages of glacier reduction indicate recession from 1993 values.

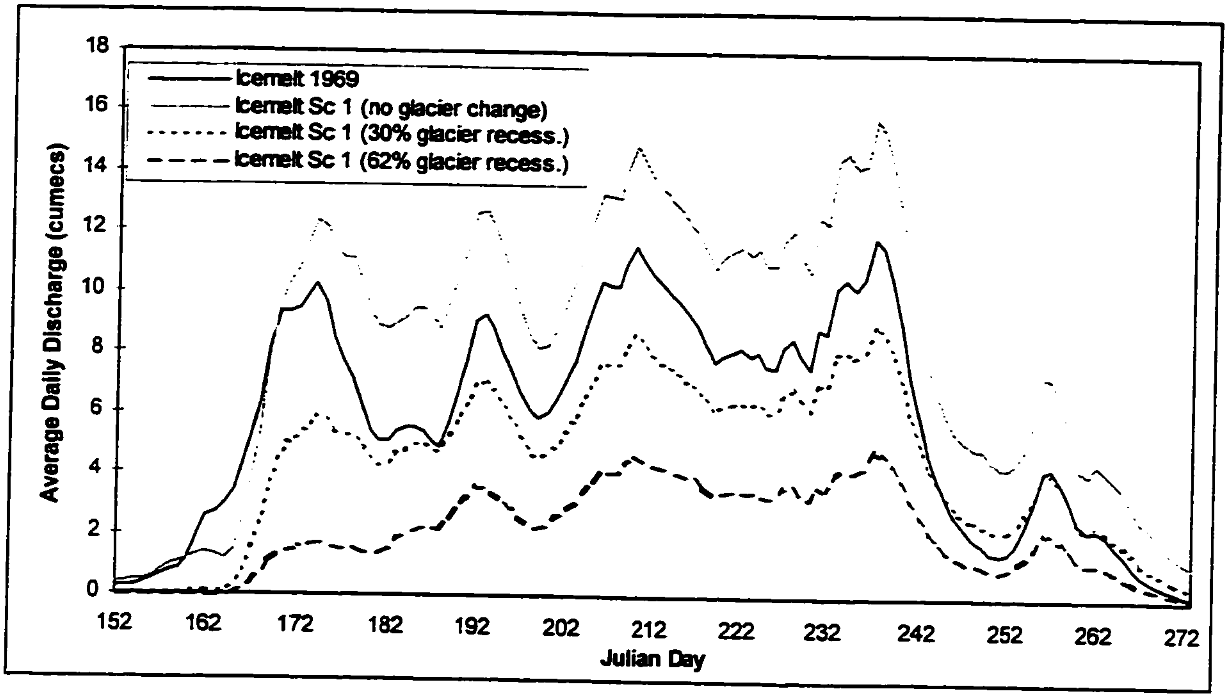


Figure 7.3 - Comparison of the UBC Model estimates of icemelt for various glacier extents using climate scenario 1.

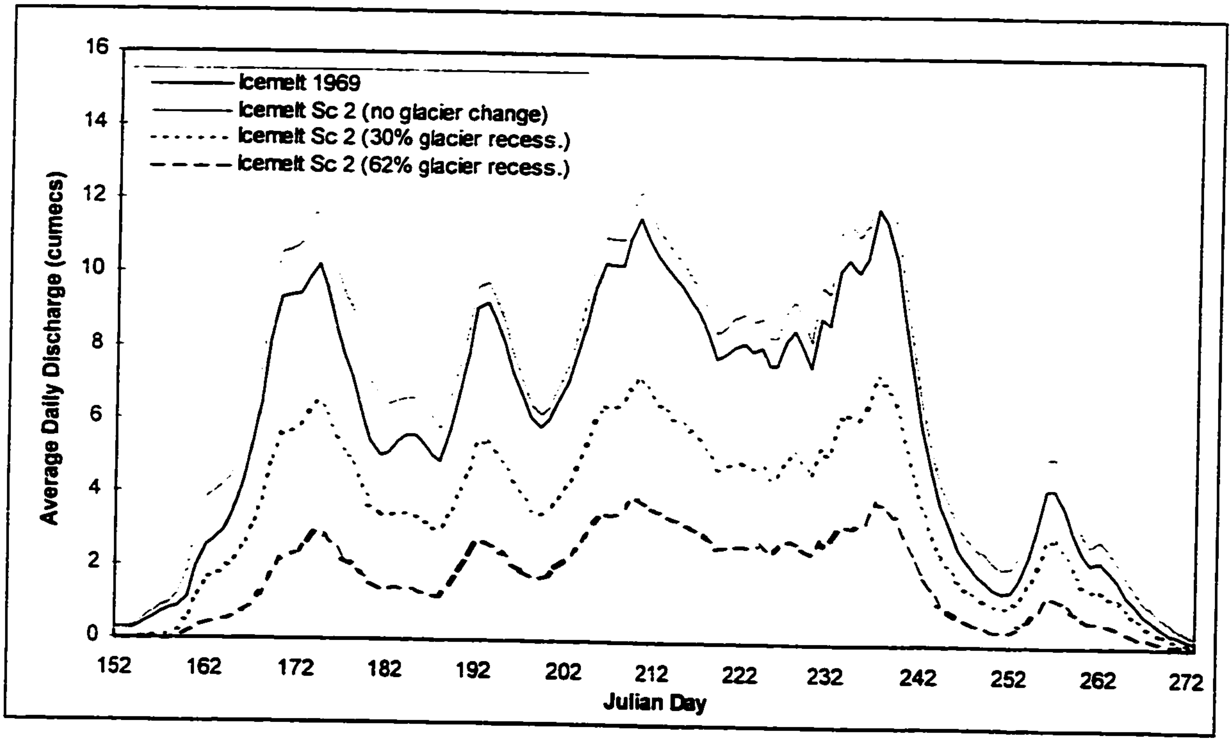


Figure 7.4 - Comparison of the UBC Model estimates of icemelt for various glacier extents using climate scenario 2.

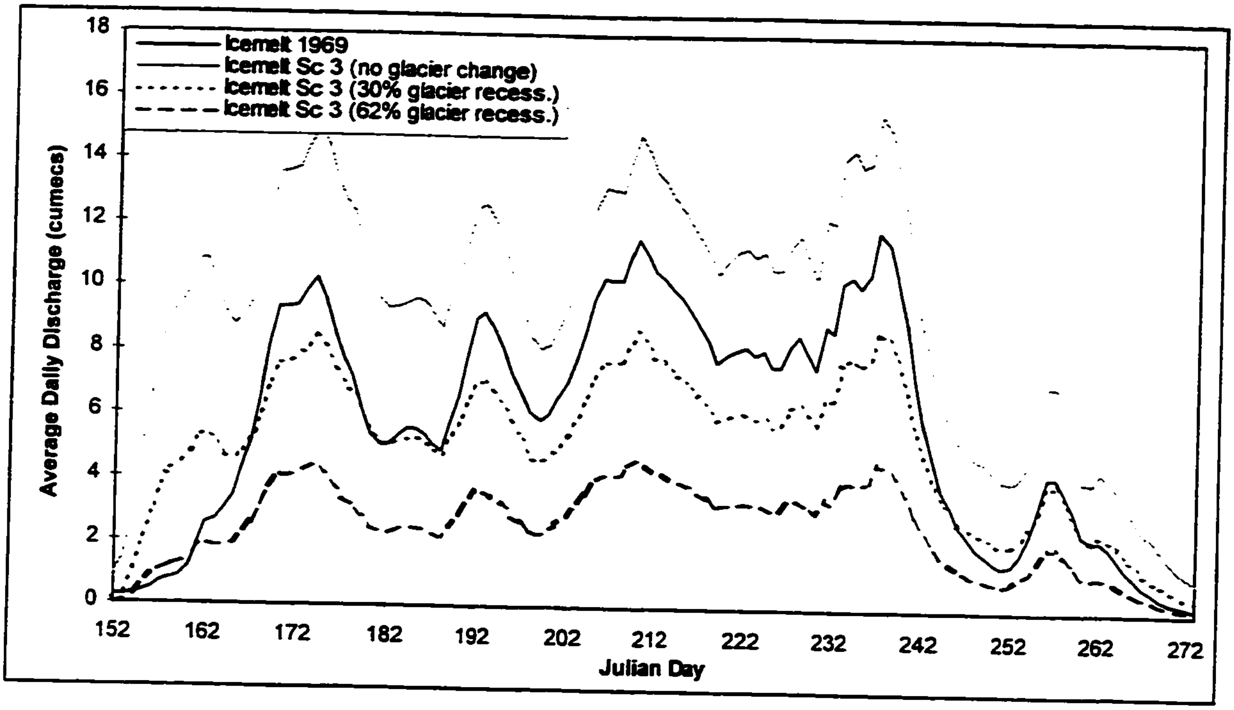


Figure 7.5 - Comparison of the UBC Model estimates of icemelt for various glacier extents using climate scenario 3.

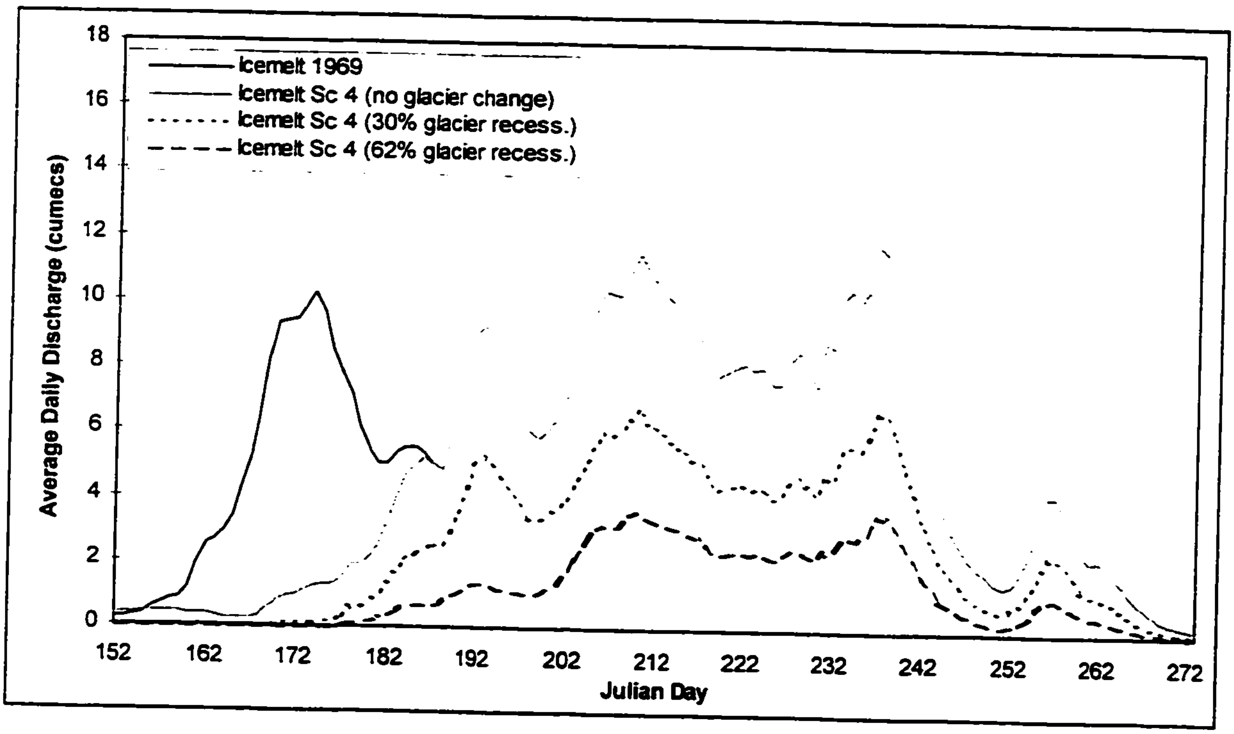


Figure 7.6 - Comparison of the UBC Model estimates of icemelt for various glacier extents using climate scenario 4.

A theme evident in all scenarios is that the model predicts glaciers to be less sensitive hydrologically to the heat budget as they decrease in size. Discharge peaks present in the 1969 calibration are progressively smoothed out as glacier area decreases. This is most likely the result of adiabatic temperature lapse rates causing cooler temperatures in the higher altitudes and thus dampening icemelt production.

A 50% increase in snowpack water equivalence delays icemelt; this trend is accentuated as glaciers ablate to higher elevations (figure 7.6). Using climate scenario 4, icemelt is delayed by about 2 weeks assuming no changes in glacier area, where as in the case of a 62% ice loss, melt is delayed by almost a month. Increased temperatures combat the effects of a heightened snow pack (figure 7.3), which results in an icemelt delay of about a week for each watershed file. Increased snowmelt will also contribute to groundwater recharge.

Increased temperatures accentuate and prolong icemelt. UBC Model discharge predictions for a 30% and 62% reduction in glacier size approach, and in some areas exceed, the original 1969 calibration flows (figure 7.5). When assuming a 30% ice loss, the model predicts that a significant increase in temperature alone, as in climate scenario 3, can generate high yields of icemelt; 53.609 $m^3 \times 10^6$ as compared to the original 1969 calibration file which produced 61.755 $m^3 \times 10^6$.

7.2.3 Application of Climatic Scenarios to the 1969 Upper Bow Valley Watershed File (no adjustment to glacier area)

A summary of the UBC Watershed Model estimates of icemelt, snowmelt, rainfall, groundwater and evapotranspiration for the 1969 watershed file when forced by all four climatic scenarios is presented in table 7.4. Each component of the hydrograph will be discussed in detail.

	1969	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Snowmelt ($m^3 \times 10^6$)	400.80	599.97 (49.7%)	413.11 (3.1%)	356.10 (-12.2%)	616.63 (53.9%)
Icemelt ($m^3 \times 10^6$)	61.78	87.72 (41.9%)	69.91 (13.1%)	98.72 (59.8%)	51.27 (-17.0%)
Rainfall ($m^3 \times 10^6$)	160.18	242.9 (51.7%)	173.80 (8.5%)	194.93 (21.7%)	169.27 (5.6%)
Groundwater ($m^3 \times 10^6$)	644.09	952.51 (47.9%)	678.52 (5.3%)	678.60 (5.3%)	883.97 (37.2%)
Evapotranspiration (mm)	654.56	719.48 (9.9%)	676.16 (3.3%)	719.36 (9.9%)	654.56 -
Total Discharge ($m^3 \times 10^6$)	1266.85	1883.21 (48.7%)	1335.32 (5.4%)	1328.35 (4.9%)	1721.14 (35.9%)

Table 7.4 - Summary of the effects of the climatic scenarios on rainfall, snowmelt, icemelt, groundwater, evapotranspiration and total discharge. Bracketed figures indicate % change from original 1969 calibration.

7.2.3.1 Snowmelt

The main hydrologic component of the Bow River above Banff is snowmelt. Figure 7.7 displays the effect of each scenario on snow accumulation and meltwater production. Climatic scenario 1 increased snowmelt discharge by 49.7%. The warmer temperatures result in the ablation period to commence about 7 days prior to the 1969 estimate, and total ablation of the snowpack occurs about 5 days later. The early melt period is much more intense when compared to the 1969 estimate. Peak spring discharge occurs on the same day as estimated in 1969, but is 33.6% greater.

The model does not calculate a drastic modification of the snowmelt hydrograph when forced with climate scenario 2. There was only an 3.1% increase in calculated snowmelt, even though winter precipitation was increased by about 10%. The warmer temperatures do not cause spring melt to occur significantly earlier (7 days), however, the early snow melt period (julian day 97 to 130) is much more intense (about 40% more per day).

Under the influence of climate scenario 3, estimated snowpack water equivalence for elevation band 4 decreased by 16.8%. Similar results were observed with other bands. The increase in temperature translated to a 12.2% decrease in estimated snowmelt discharge. This is largely the result of the warmer temperatures delaying the accumulation season by about two weeks. In addition, the increased temperatures transform early spring and late summer snowfall into rainfall. Without the periodic snowfalls in early spring, albedo decay continues uninterrupted, and thus increases the potential for snow melt. The model estimates snowmelt to begin 16 days prior to the 1969 calculation (figure 7.7). Essentially, snowmelt occurs more gradually over a longer period of time, and thus peak discharge, occurring on julian day 157, is reduced by 22.3% under the influence of scenario 3.

Scenario 4 (increasing snowfall by 55%) held the greatest influence on snowmelt discharge, increasing it by 53.9%. As temperature is not modified in this scenario, snowmelt commences on the same day as in the 1969 estimate, however, the snowpack does not completely ablate until roughly 20 days later. Peak melt is 19% greater, and occurs 13 days later than the 1969 estimate.

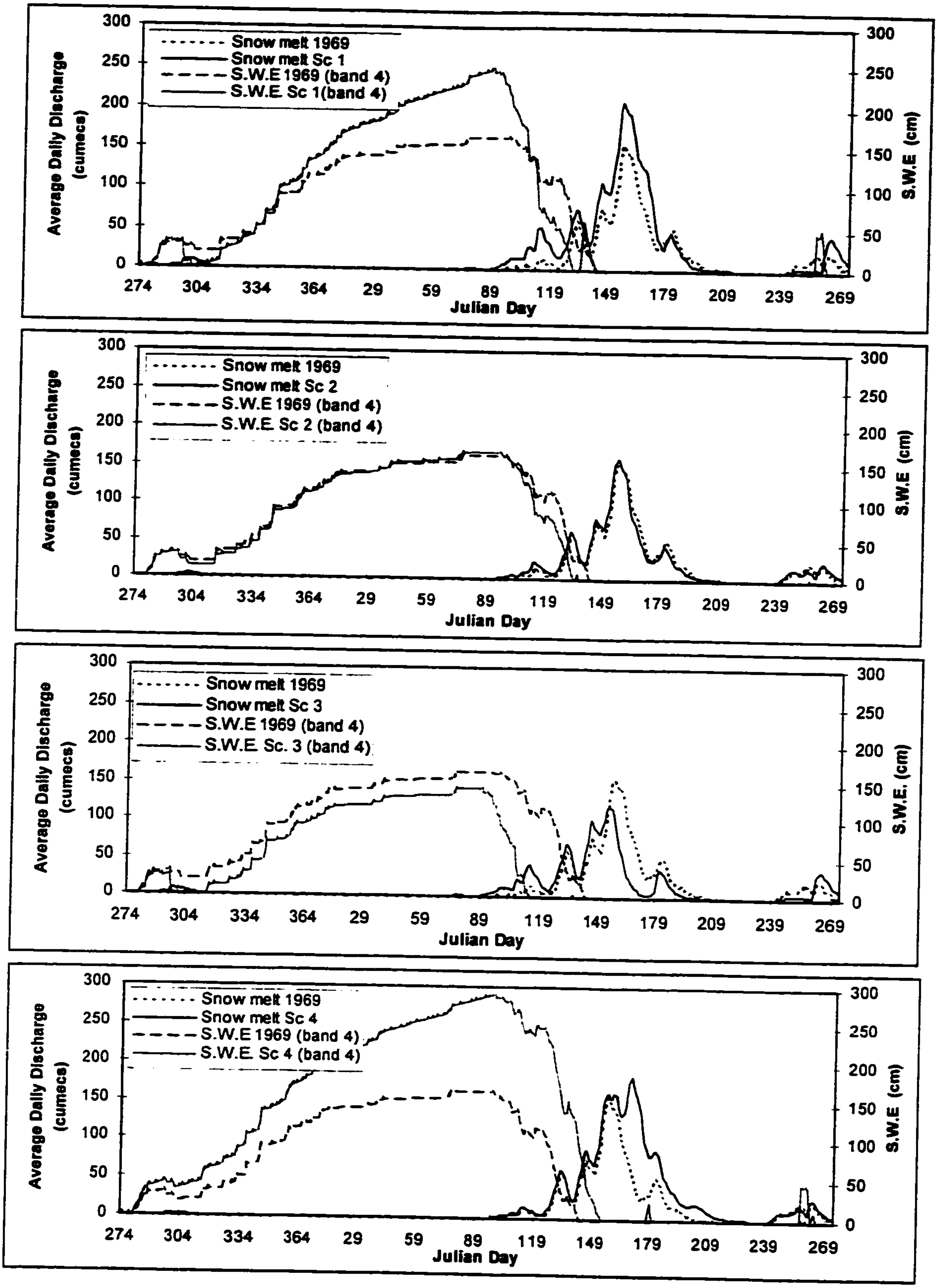


Figure 7.7 - Effect of climatic scenarios 1-4 on UBC Model estimated snow accumulation and snow meltwater in the Upper Bow Valley. Snowmelt is for entire basin and snow water equivalence (S.W.E.) is for elevation band 4 (2020-2247 m).

7.2.3.2 Icemelt

The results for the icemelt calculations are presented in figure 7.8. Climate scenario 1 delays glacier melt slightly as a result of a deeper snowpack, however, from julian day 170 onwards average daily melt is increased significantly: total yield is 41.9% greater than the 1969 estimate. Climate scenario 2 does not significantly influence the timing of icemelt but does increase total yield by 13.1%. The warmer temperatures of climate scenario 3 result in the glaciers being exposed earlier than the 1969 estimate, and thus icemelt begins roughly 8 days prior. The warmer temperatures also prolong the melt season into the next hydrologic year. Total yield from icemelt is magnified by 59.% under scenario 3. The heightened snowpack calculated by scenario 4 results in a significant delay of glacier melt; from julian days 130 to 187 icemelt is reduced by 71.2%. The model does not calculate any difference in icemelt for scenario 4 from julian day 187 onwards.

7.2.3.3 Rainfall

Results of the effect of the climatic scenarios on rainfall are presented graphically in figure 7.9. Increasing winter precipitation heightens rainfall by 5.6%, primarily the result of temperature lapse rates causing rain to occur in the lower elevation bands during snowfall events. Scenarios with increased temperatures (1-3) positively augment estimated discharge from rainfall during Spring and Autumn. This is because the increased temperatures force the model to transform snow into rain during periods of temperatures near 0^{o}C. Increasing both temperature and precipitation (scenario 1) results in a 51.7% increase in annual yield from rainfall, however June - September rainfall runoff was only increased by 26.8%.

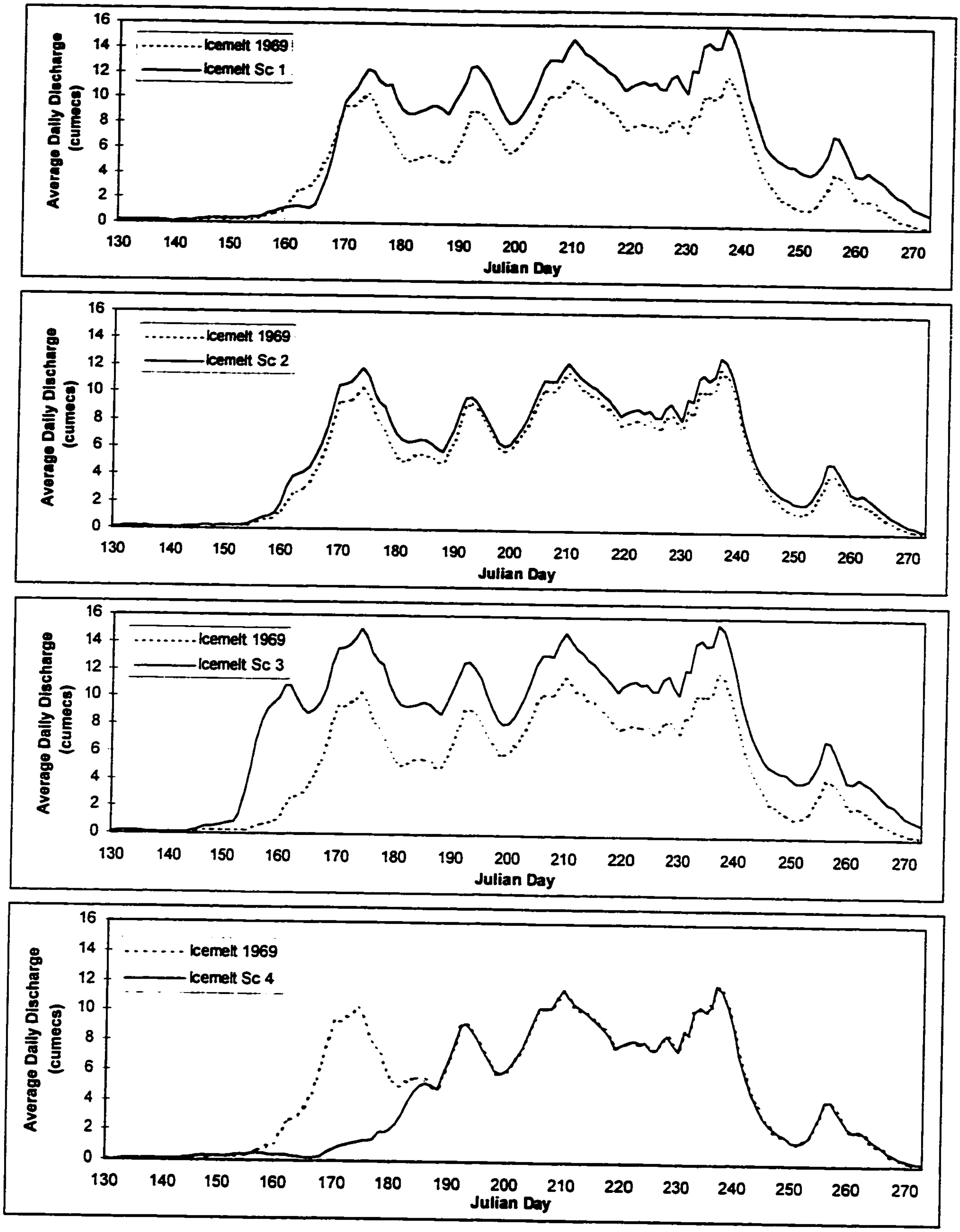


Figure 7.8 - The effect of climatic scenarios 1-4 on UBC Model calculated icemelt.

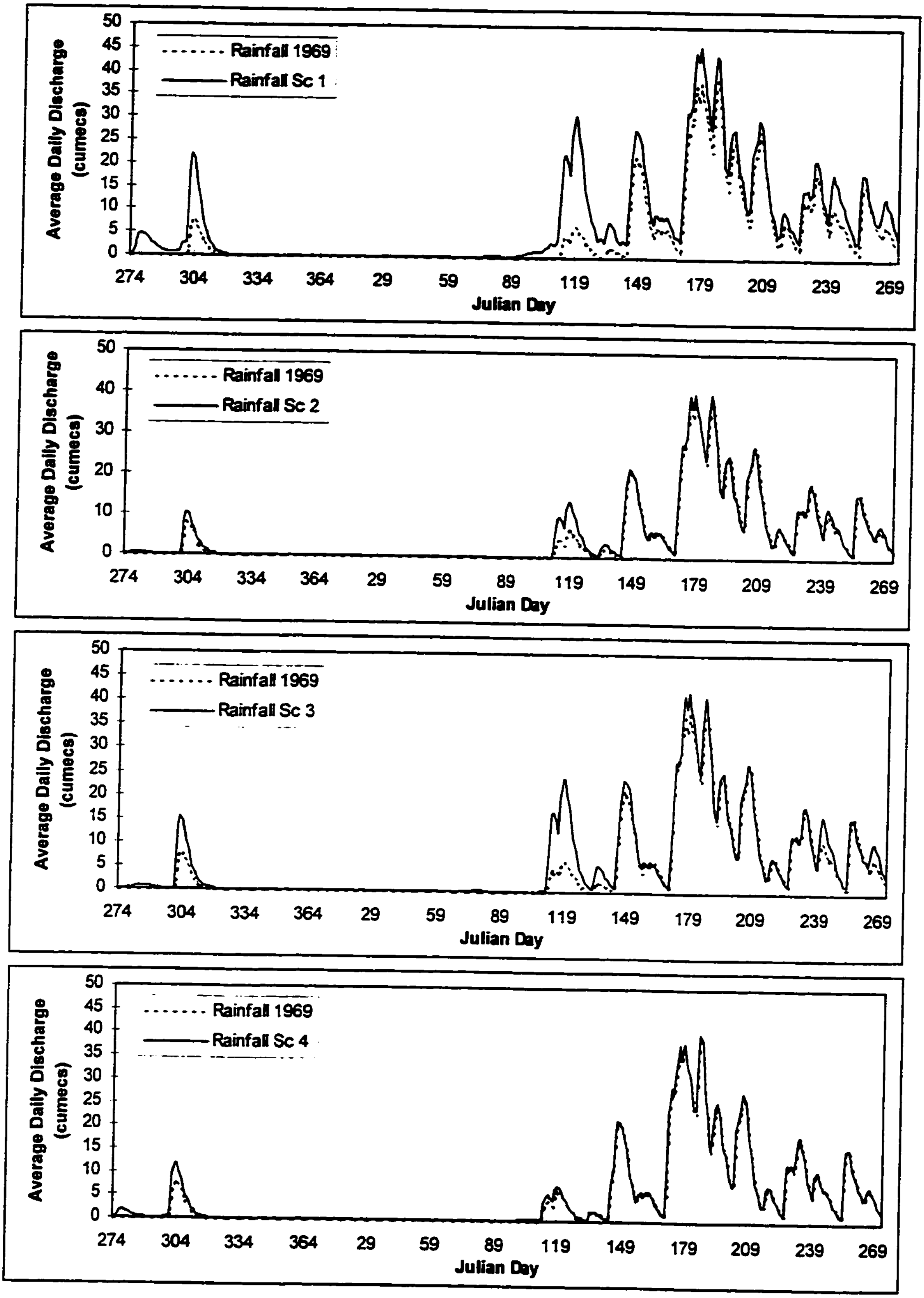


Figure 7.9 - Results of climate scenarios 1-4 on UBC Model estimates of discharge from rainfall.

7.2.3.4 Evapotranspiration

The effects of the climatic scenarios on UBC Model evapotranspiration estimates are graphically displayed in figure 7.10. As evapotranspiration is estimated from temperature alone, increases in precipitation do not cause evapotranspiration feedbacks. The extreme temperature modification of scenarios 1 and 3 cause an evapotranspiration increase of 9.9%. The same relationship is evident when the model is forced by the modest temperature increase of scenario 2: an evapotranspiration increase of 3.3% was generated by this scenario. The timing of the evapotranspiration increases are equable throughout the year.

7.2.3.5 Groundwater

As displayed in figure 7.11, increased snowmelt holds the greatest influence on estimated groundwater (upper and lower combined). A 55% increase in snowfall (scenario 4) translates to a 37.2% increase groundwater yield; when coupled with an extreme increase in temperature (scenario 1) this value is boosted to 47.9%. The model results suggest that increased snow precipitation will augment groundwater flows throughout the summer due to enhanced lower (deep) groundwater storage from spring melt, which is routed through the system much slower than upper groundwater. Warmer temperatures tend to expedite groundwater flows: climate scenario 3 caused spring groundwater augmentation to commence 22 days prior to the 1969 estimate, which results in a suppression of summer groundwater flow.

7.2.3.6 Bow River Discharge - Total Yields

Climate scenarios that significantly increase winter precipitation have the greatest influence on Bow River above Banff discharge (figure 7.12): peak flow is

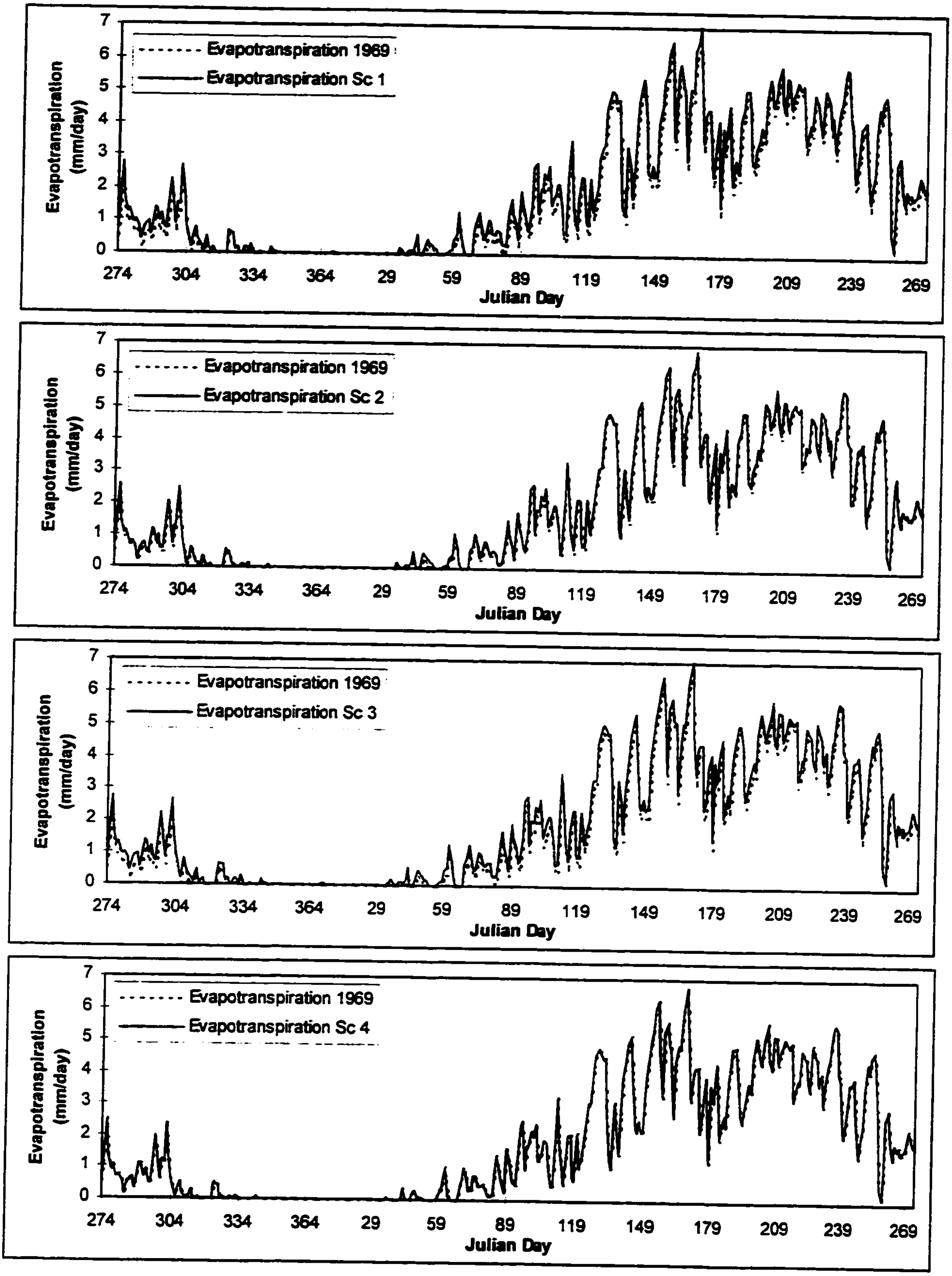


Figure 7.10 - Effect of climatic scenarios on UBC Model evapotranspiration estimates for the Upper Bow Valley.

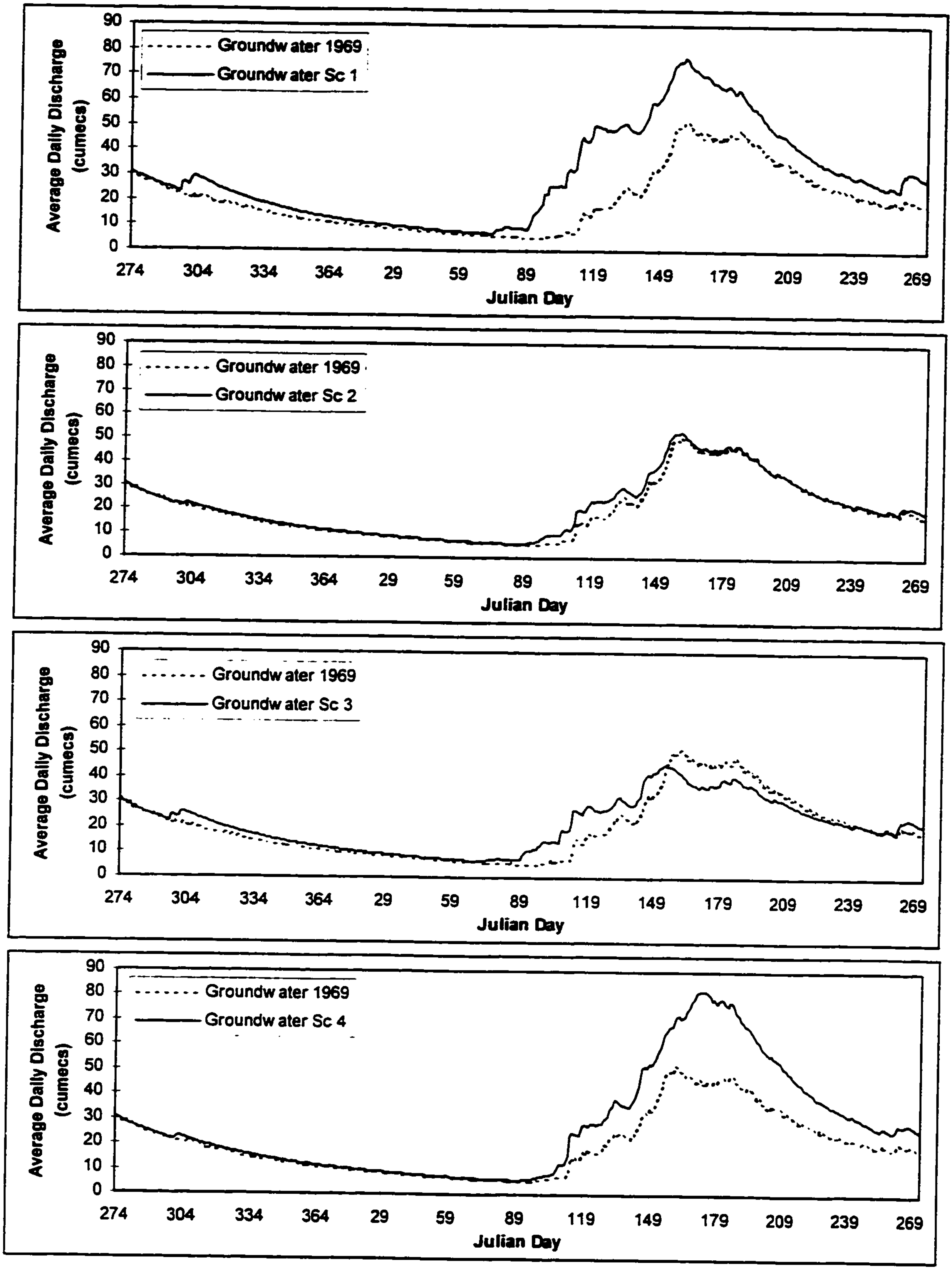


Figure 7.11 - Effect of climatic scenarios 1-4 on UBC Model estimates of groundwater discharge (upper and lower combined).

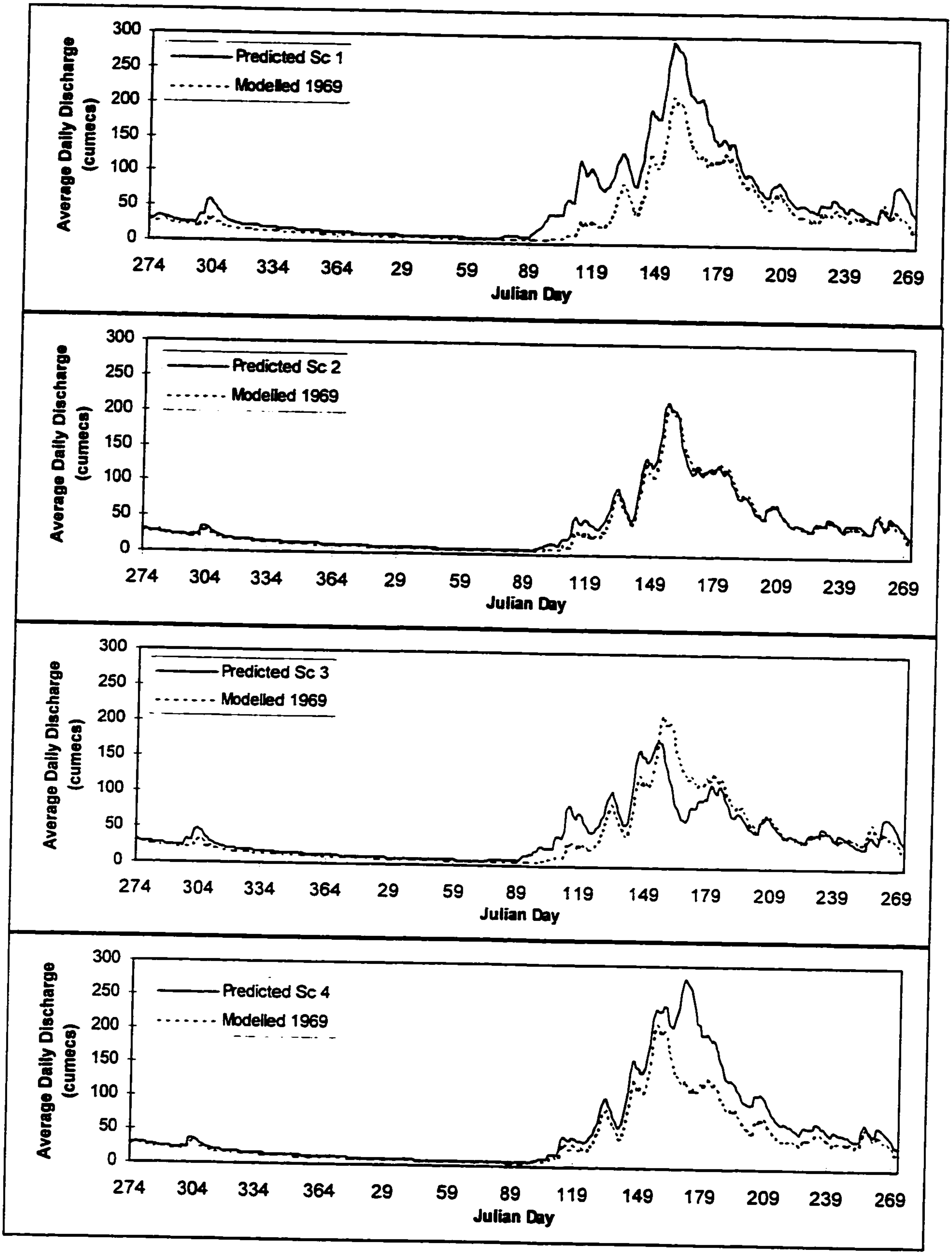


Figure 7.12 - Results of the climatic scenarios 1-4 on UBC Model estimates of total discharge.

accentuated and average daily discharge is augmented throughout the summer months by groundwater reserves. Extreme increases in temperature accelerate snowmelt and intensifies and prolongs glacier melt, which ultimately works towards moderating river flow over a longer period of time. Minor adjustments to both temperature and precipitation (scenario 2) do not lead to major variations in estimated total discharge.

7.3 Summary of Results

Results are verbally summarized in table 7.5. Shaded cells indicate important modifications to the hydrograph under the influence of climatic variation. A brief discussion of some of the important modifications to the hydrograph is given below.

A potential consequence of heightened snowfall in the Upper Bow Valley is the increased flood risk during spring runoff. In addition, a heightened snowpack increases the avalanche danger, which is a hazard to mountain travelers. Avalanches also have a pronounced effect on the hydrology of a basin (De Scally, 1989). The force of an avalanche transforms the snowpack into a much denser medium, which can persist long into the ablation season. In such a scenario, avalanche snow will augment the summer stream flows much like glaciers do, which will reduce the stress on the water resource.

UBC Model predictions for groundwater flows are basically a reflection of snowmelt patterns, thus increases in the snowpack will result in increases in groundwater flow. Although very little confidence is placed in the UBC Model estimations of groundwater flow, it is logical to assume that a major consequence of increased temperatures in the Upper Bow Valley is the alteration of the winter/summer groundwater ratio. The model predicts that snowmelt will occur earlier under a warmer climate, and thus as a result it can be expected that groundwater recharge will also occur earlier. As the model assumes a residence time of 30 days, earlier groundwater recharge will result in an equally earlier groundwater discharge, which will ultimately decrease late summer stream flow.

Increased temperatures will produce more icemelt during the summer, however as glaciers reduce in size, so does their potential to produce meltwater. This relationship can continue to the point where even an extreme increase in temperature cannot compensate for the loss of ice area (in terms of meltwater production). The effects of ice recession on water resources are expected to be most pronounced as the glaciers present in areas below 2800 masl ablate, as the ice in these lower elevations are the most hydrologicaly active during the summer season. Based on UBC Model predictions, it can be speculated that water shortages can occur within the next 25 to 50 years during the dry summer months if the observed trend of ice recession continues.

Process	Climate Scenario			
	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Snowmelt	[illegible]	• slightly earlier snowmelt • slight increase in yield • very little increase in peak melt	• much earlier snowmelt • decrease in snowmelt yield and peak melt	[illegible]
Icemelt	[illegible]	• small increase in daily icemelt • timing not significantly effected	[illegible]	• icemelt is delayed
Groundwater	[illegible]	• very little change in groundwater flows • recharge starts slightly earlier and is more intense during early spring, but returns to calibrated values during the summer	• slight increase in total yield • recharge begins earlier and is more intense during early spring • recession flow begins earlier, and peak groundwater flow is reduced	[illegible]
Evapotranspiration	• increase in annual evapotranspiration losses (10%) • no significant variance in timing	• slight increase in annual evapotranspiration losses (3.3%) • no significant variance in timing	• increase in annual evapotranspiration losses (10%) • no significant variance in timing	• no change
Total Discharge	• [illegible] • almost 50% increase	• small increase in total yield (5.4%)	• small increase in total yield (4.8%)	• large increase in total yield • 37% increase

Table 7.5 - Summary of conclusions of the effects of climate scenarios 1-4 on various components of Upper Bow. Those highlighted indicate important changes.

Chapter 8 - Discussion and Conclusions

8.1 Adjustment to Glacier Area

It is unlikely that the observed trend of glacier recession in the Hector Basin from 1951-1993 is representative of glacier dynamics in the rest of the Upper Bow Basin because of the extreme physiographic variability. Theoretically, it is acceptable to assume that the majority of glacier melt will occur in the lower elevation bands, as was assumed in this analysis. However, absolute values of areal recession are a coarse estimate at best. The decision to apply the photogrammetric work of Hopkinson (1997) to the entire Bow Valley above Banff to estimate a reduction in glacier size was greatly influenced by time and budget constraints. Ideally, detailed photogrammetric analysis should be conducted for all glacierized areas in the Upper Bow Valley to determine the rate and quantity of ice ablation from 1951 onwards. In addition, it would be most useful to use satellite imagery in determining ice melt over the last 2 decades. Establishing a digital database on glacier coverage in the Upper Bow Valley from the mid-70's onwards could be used to monitor change for future study.

8.2 - The Use of Climate Scenarios

General circulation models (GCM's) are based on the physical laws of conservation of energy and mass for a rotating globe exposed to an external energy source (Gates, 1987), and are used to simulate the behavior of the atmosphere.

The use of GCM data for watershed sensitivity analysis has been highly criticized. This is a result of several factors inherent with present-day GCM's which limit the confidence of the output results. First, unexpected large-scale and rapid global climate system changes are difficult to predict. According to Leggett (1994): "The complexity of the earth climate system disallows reliable prediction of the exact impact of the warming on weather patterns and the distribution of extreme events." The global climate system is a complex, non-linear collection of earth-ocean-atmosphere processes, and it is known that the rapid forcing of non-linear systems can result in unexpected behavior. Current GCM simulations are tested against known features of the observed climate system, and to a lesser degree, with more limited data from significantly different past climatic regimes. However, there has never been such a rapid increase in the concentration of atmospheric greenhouse gases as observed in the last 100 years (Sreenath, 1993). In addition, future emission scenarios (generated by the IPCC and used as the global standard in GCM simulations) are estimates at best, and do not consider the influx of volcanic aerosols, which have consequential negative radiative properties, or significant deviation from projected emission rates. Essentially, it is extremely difficult to calibrate a complex model with great confidence if there are no calibration data.

Another serious problem associated with GCM predictions is the coarse resolution of the data. Typically, most GCM's have a grid size of 4° x 5° (latitude x longitude), which equates to 445 km x 556 km (Sreenath, 1993), and confidence is higher in the hemispheric to continental scale predictions than in the individual grid points. Grid size resolution of GCM's are limited by computing power and the parameterization of climate physics (Giorgi and Mearns, 1991; Sreenath, 1993).

However, many impacts of global climate change function on a much smaller spatial scale, especially over complex, mountainous terrain. This is especially true for cloud formation, which is not well represented by GCM's and has an extreme influence on the net radiation budget. Thus, it is inherently limiting to use climate simulation data from several hundred kilometers away as there is no consideration of the local climatic interactions of the study site (which can be dominant over large scale forcings. To mitigate this problem, several methodologies have been developed to downscale GCM predictions to a finer scale by linking local surface variables with large scale circulation patterns (Giorgi and Mearns, 1991; Matyasovszky, *et al*, 1993; Matyasovszky and Bogardi, 1996), however, there has been limited success for applications over complex terrain.

Yet another serious deficiency with GCM data is that they do not generally account for the lateral transfer of water over land (Kite, *et al.*, 1994). GCM's typically estimate the vertical transfer of moisture at each grid point using precipitation, evapotranspiration and groundwater storages, however, excess water, or runoff, is repudiated by model algorithms. Thus, GCM's operate on an incomplete hydrological cycle. It is for this reason that Ripley and Cayan (1993) discovered months with negative runoff for some latitude zones when examining North American surface hydrology of a 20-year run of the Canadian Climate Centre's (CCC) first generation GCM. From a hydrological perspective, the absence of a complete hydrological cycle in a GCM can have serious negative impacts as the excess runoff from one grid point can quite possibly affect vertical moisture transport at another grid point. Work has been initiated by Kite *et al.* (1994) to mitigate this problem by meshing the SLURP model (National Hydrology Research Institute) with the CCC GCM. This methodology essentially acts as a quality control measure that verifies climate model output, but does not improve it. Thus, this work is the impetus for the development of a continental-scale hydrological model which eventually form a part of a comprehensive model of the global hydrological cycle. It is probable that such a model will take many years to develop and then refine to an acceptable level.

Therefore we are left with two options: one is to take a highly critical perspective of current GCM predictions and discredit their use in hydrological investigations on the basis of the above points (and others not mentioned here). Or, we can be aware of the errors and use GCM predictions as a tool in estimating the reaction of physical systems to global warming. The benefit of the later is that although the absolute results may be questionable, the general reaction trends will be evident, albeit on a coarse scale. In the least, these results can be used by policy makers as a guideline to prepare for future climatic variation. *A vague understanding of the potentially devastating outcomes of global warming is better than no understanding at all.*

8.3 Discussion of Results

8.3.1 Snow Accumulation and Ablation

The general trends for UBC Model estimates of snow accumulation and ablation are presented with confidence. It is logical to assume that an increase in winter precipitation will result in increased flood risk (with delayed peak spring melt), and a temporal shift of the snow depletion curve forward into late spring. In addition, warmer temperatures should act to reduce the snow accumulation period, and cause more precipitation to fall as rain. However, absolute values will contain errors resulting from the inability of the model to estimate complex snow redistribution processes, and from poor temperature lapse rate estimation. In addition, the UBC Model's deficiency in physically representing the moisture transport properties of the soil will contribute to inaccuracies in snowmelt runoff estimation.

Gan and Singh's (1997) study of the hydrologic sensitivity of the Athabasca River basin and the Sacremento and San Joaquin River basin using the Sacremento model and several GCM predictions produced both similar and contradictory snow accumulation and ablation results as this study. In both studies, increases in temperature produced more liquid winter precipitation, and thus increased winter runoff and decreased spring snowmelt runoff. However, a major contradiction is that the Sacremento Model predicted a large increase of the annual flood maxima under the influence of increased temperature, where as the UBC Model predicts a decrease in peak spring flow. Gan and Singh suggest that this increase is a result of rain-on-snow events. Logically, it is reasonable to assume that the annual flow maxima would be lowered by an decrease in snow storage, and not the opposite. However, it is difficult to compare the results of these studies in detail due to the spatial variability inherent - a direct comparison between the two models on the same basin is required before conclusions can be made.

Seidel *et al.* (1997) examined the effects of climate change on snowmelt runoff in the Alps using the Martinec Model and SPOT imagery. Under the influence of a warmer climate, Seidel *et al.* suggest that snowmelt will occur earlier, which therefore will cause the timing of summer discharge peaks to shift towards earlier months, although unlike in Gan and Singh's (1997) predictions, no increase in annual maxima is predicted. Despite the conflict in predicting peak melt, all three studies conclude that a warmer climate will result in earlier snow ablation and a shifting of the winter-to-summer ratio of runoff volumes.

8.3.2 Evapotranspiration

There is little confidence placed in the estimation of evapotranspiration under the influence of the climatic scenarios for two main reasons. First, the model operates on a soil moisture deficit, as opposed to defining the soil moisture content. This allows the model to save computational time and more importantly, avoids the need for the laborious collection of field data. This lumped approach is completely estimated by maximum and minimum temperature, and thus increases in precipitation have no effect in calculated evapotranspiration. It is logical to assume that actual evapotranspiration should increase with increases in precipitation, as more soil moisture is available.

Secondly, it is known from laboratory experiments (Idso, *et al.*, 1984) that an increase in atmospheric CO_2 concentrations results in an increase in the stomatic resistance of vegetation, leading to a decrease in evapotranspiration losses. Idso *et al.* (1984) suggested that a doubling of atmospheric CO_2 results in a stomatic resistance of aquatic hyacinth by a magnitude of 2.5 times. Kuchment (1989) assumed this relationship to be similar for wheat and various herbs, and estimated that a doubling of atmospheric CO_2 can suppress evapotranspiration by 20-30% under moist conditions and 10% in dry conditions in the Rostov Region of Russia. The model's evapotranspiration routine does not consider the stomatic resistance variability of vegetation with atmospheric CO_2. In future work, such significant changes in evapotranspiration should not be ignored: laboratory experiments should be conducted to determine the stomatal reaction of Upper Bow Valley vegetation to increases in atmospheric CO_2.

8.3.3 Groundwater

As already mentioned in chapter 6, the estimation of groundwater by the UBC Model is not substantiated by observed measurements. Thus, confidence in the absolute groundwater calculations is limited. However, it is highly likely that the groundwater discharge trends are realistic: basically a reflection of the snowmelt activity.

8.3.4 Icemelt

Icemelt results are presented with limited confidence. The model translates modest increases in temperature into a 13.1% increase in icemelt yields. The extreme increase in temperature augmented icemelt yield by 42%. It is likely that these figures are not accurate because of the model's quasi-physical nature, which can lead to an insensitivity to climatic variation. The model does not consider in detail the effects of aspect, slope angle, changes in glacier albedo, edge effect, ice-cored moraines or the formation of superimposed ice when estimating meltwater production from glacierized areas. In addition, cloud cover and wind speed are very loosely estimated; both factors extremely important to the energy budget. Naturally, the potential for significant errors to exist is high without the detailed inclusion of these factors in an icemelt model. Future work in estimating the climatic sensitivity of glaciers should include the use of a more physical icemelt model.

8.3.4.1 Glacier Response to a Changing Climate

If the observed linear trends in glacier recession from 1951-1993 were extended into the future, then we would expect a 30% decrease in glacier area (from 1993 estimated extents) to occur roughly around the year 2025, and a 62% decrease by the year 2055. If we were to extend the observed trends of glacier ablation displayed within the last 20 years, then these dates would be moved forward to roughly the years 2012 and 2030 respectively, as glacier melting has been progressively active in the Upper Bow Valley since the late 1970's. Based on these figures and GCM estimates of temperature increase, it is not impossible that glaciers in the Upper Bow Valley may indeed almost completely ablate by the turn of the next century. However, these conclusions are grossly cursory as the factors controlling glacier mass balance are not linear. The absolute ablation of glaciers in this region is unlikely to occur because many of the icefields perched high in the Upper Bow Basin are thicker and larger than the outlet glaciers that are subject to such rapid rates of ablation (particularly from edge-effect processes) . In addition, the elevation of these high altitude glacierized areas, such as the Wapta Icefield, may indeed be high enough to exceed the elevation of the average 0°C isotherm, which will work to preserve the glaciers into the future. To quantify these hypotheses, the application of a physical glacier model should be used in conjunction with predicted climatic scenarios.

Predicting glacier dynamics (areal cover) using GCM data is an extremely delicate problem which requires intense investigations of the non-linear relationships between climatological forcings and glacier feedback's. Oerlemans (1987) approached the problem of estimating the response of valley glaciers to climatic change using a simple dynamic glacier model. In order to estimate long-term glacier response to climate, Oerlemans concluded that ablation-meteorological relationships should be coupled with other important considerations, such as glacier surface and sub-surface geometry, flow rates, slope, aspect, elevation, response time, albedo, and shading from surrounding peaks. In addition, Oerlemans concluded that more work be conducted on this topic. Haeberli and Hoelzle (1995) developed another methodology using simple algorithms to estimate potential climate change effects on alpine glaciers. The parameterization scheme of this model is very simple, with glacier description data consisting of only total length, maximum and minimum altitude, and total surface area. Testing this procedure against observed glacier fluctuations proved promising, however, the authors admit that future projections are order-of-magnitude estimates only, this the result of significant uncertainties in estimating glacier characteristics (geometry) and the non-linear nature of the glacio-climatological regime. Many uncertainties exist with modelling glacier fluctuations, and an accurate, comprehensive, and widely-applicable glacier model eludes the scientific community.

8.4 Conclusions and Key Findings

This thesis presents a methodology to examine the climatic sensitivity of an alpine glacierized basin using minimal input data. As most mountainous basins do not have an extensive data record or a long history of scientific investigation, this methodology is widely applicable. However, the lack of data ultimately limits the confidence of the results as the hydrology of mountainous systems are complex and non-linear, and thus are not completely simulated by the linear nature of most hydrologic models. Nonetheless, this methodology has merit: it is likely that the trends simulated by the UBC Model calculations are correct although absolute calculations are probably not wholly accurate.

As snowmelt is the dominant hydrologic factor in the Upper Bow Valley, the UBC Model predicts that variations in winter precipitation regime will have the greatest effect on the hydrograph. GCMs estimate that winter precipitation will increase by as much as 50% in the Canadian Rockies as a result of an enhanced Pacific orographic effect. Although a 50% increase may appear drastic, the last two winters (1995-96 and 1996-97) have produced about 50%-60% more snow than usual in the Canadian Rocky Mountains. Although it is premature to suggest that these anomalies are a direct result of global warming, it is warranted to say that GCM predictions of snowfall are within the bounds of reality. If this predicted trend becomes reality, then glacier melt will be delayed into the spring and summer (depending on the temperature regime) as the snowpack aquifer will insulate the glacier surface. As the model erroneously estimates total ablation of the annual snowpack, no conclusions can be made concerning the effect of a heightened snowpack on the mass balance of glaciers.

The model suggests that the reduction of glacier area will lead to a decrease in the potential for glacier runoff. Increases in temperature will allow glaciers to produce more meltwater per unit area, however, even an extreme temperature increase cannot make up for significant glacier loss. In addition, the model suggests a non-linear relationship between glacier area and meltwater production: glaciers become less sensitive to meteorological forcings as they ablate to higher or more sheltered regions of the basin.

The model predicts that a significant consequence of a warmer climate is a shift in the winter/summer groundwater ratio. Warmer temperatures cause an earlier snowmelt, which in turn results in earlier groundwater recharge to the unconfined aquifer. This causes groundwater flow to be reduced during the summer, as snow meltwater is passed through the aquifer earlier. This feedback combined with a reduction in icemelt contribution can have potentially serious negative effects on summer discharge, when water is needed most.

The model also suggests that a warmer climate will increase evapotranspirative losses by as much as 10%, however, problems associated with the evapotranspiration routine limit the confidence of this conclusion. It is logical to assume that a warmer climate will indeed increase rates of evapotranspiration, therefore causing greater stress on the summer water budget. Research into the relationship between stomatal resistance of plants and increased CO_2 coupled with the application of a physical evapotranspiration model is needed to estimate the climatic sensitivity of evapotranspiration in the Upper Bow Valley.

8.5 Future Perspectives - The Impact of Global Warming on Water Resources on the South Saskatchewan River System

The results of this study suggest that significant changes in the hydrology of the Upper Bow Valley are plausible within the next 50 to 100 years given our current understanding of global climatic system. Downstream of Banff, it is predicted that global warming will further exacerbate existing water resources problems in the Prairie Provinces, particularly in the summer when water is needed most (Environment Canada, 1992). Reductions in the prairie water budget will increase the need for irrigation, thereby attributing more importance to water production in the mountainous headwaters, especially from snow and glacier aquifers.

The main question is how do we manage the resource to provide maximum sustainable yields? To answer this, water resource managers require methods of assessing the sensitivity of hydrologic systems to climate change to identify an adaptive approach. This study provides insight as to what might be expected from the Upper Bow Valley in years to come, and will be used as a tool by Alberta Environment to formulate adaptive policies and measures. However, a problem as large as global warming requires a broader, systems-orientated approach. Watershed management plans should be drafted on a continental scale, for it is impossible to effectively adapt to massive changes in the water budget by regional, or in some cases provincial, watershed planning; one has to acknowledge the dynamic hydrological processes both upstream and downstream. Essentially, the results from this study can be considered a drop in the bucket, however, when compiled with similar reports from other regions of the South Saskatchewan River Basin, insight in continental-scale watershed vulnerability can be achieved, and adaptive policies and actions can be made more effectively.

8.6 Suggestions for Improvement

In the late 1970's and early 80's, hydrologic model outputs were often considered indubitable. Experience has taught policy makers and modellers to take a critical stance when interpreting model estimations, (even despite the great advances made in modelling over the past decade). The following section is dedicated to critiquing the methodology used in this study and provides suggestions for improvement.

8.6.1 Application of a Physically-Based Model

The use of the UBC Model for such a study can be criticized on the basis that it is not a highly physical model. The predictive power of a quasi-physical model is inherently limited as a result of the calibration process and the coarse parameterization of hydrological and climatological processes. To a large extent, the model is history-based, and thus deviations from the observed calibration data transcend the model's predictive capability. It addition, the UBC Model does not consider many of the non-linear processes and feedbacks functioning within and between the hydrological and climatological parameters. The decision to use the UBC Model was greatly influenced by data and budget constraints; the UBC Model satisfied the limited data constraints and was available free of charge from the Department of Civil Engineering at the University of British Columbia. This is not to say that this analysis has no merit; it is highly likely that the UBC model estimates are an indication of the general trends to be expected from a warming climate, and thus the results successfully achieve the goal of a pilot study into this problem. However, confidence in the absolute values is limited because of the fairly coarse paramaterization and quasi-physical nature of the model. As with any study, there is room for improvement.

Ideally, a physically-based, data intensive model should be used for future analysis. By applying such a model, a better representation of the sensitivity of the physical processes functioning within the basin will be achieved. However, the collection of calibration data for a data-intensive model for a macro-scale (over 1500 km^2) basin is a tremendous task; several years of detailed reference data (hydrological, meteorological, pedological, and hydrogeological) would have to be collected over a large area. In addition, physical models are generally more suited towards smaller basins because of the intense parameterization involved (Singh, 1988), with the exception of the SLURP model (Kite and Kouwen, 1992). Thus it is suggested that smaller, representative basins be examined in finer detail.

Both a nival and glacierized basin should be studied, as the hydrological characteristics of both types of basins are distinct. Prime candidates could be the glacierized Hector basin and the nival Brewster Creek basin. Reducing the spatial scale would allow for a more detailed physical analysis of the hydrological and meteorological processes prevalent, and would reduce cost and effort. The results from such a study can be used as a surrogate for the entire basin by applying a landcover classification.

Several models can be used, however the SLURP model (Kite and Kouwen, 1992), is suggested as it is Canadian and under active development. The SLURP model was developed by the National Hydrology Research Institute and is a continuous simulation, highly distributed, physical hydrologic model that can account for changes in the spatial distribution and type of land cover over time. Thus, it is suitable for climatic change impact studies (Cattanach, *et al,* 1995), such as the one by Kite (1993) on the Kootenay Basin. The particular advantage of SLURP is that it will accept a physically-based glacier runoff model under development for BC Hydro by the National Hydrology Research Institute (Brugman, *et al.*,1995). This glacier model incorporates satellite imagery (SAR and Landsat TM) to estimate the surface dynamics of the glacier. This glacier model would be extremely valuable in estimating the water production from glaciers in the Upper Bow Valley.

8.6.2 Use of Satellite Imagery

As Brugman, *et al.* (1995) point out, it is highly recommended that satellite imagery be incorporated into the glacier melt modelling process to account for changes in ice extent. Satellite data for the Upper Bow Valley should be collected from as early as possible and be subject to a land cover classification to document the rate of glacier recession. This classification should then be combined with a Digital Elevation Model (DEM) of the entire basin which can be used for future monitoring. Franklin (1991) presents a simple yet effective methodology for combining remote sensing data with DEMs for mountainous terrain.

Satellite imagery can also be employed to estimate the net radiation budget of glaciers. Gratton *et al.* (1993) have developed a methodology that calculates the net radiation field of alpine glaciers using Landsat-5 Thematic Mapper images within 10% of the observed values. This analysis could be included into a highly physically-based ice melt model, such as the one developed by Brugman *et al.* (1995), to more accurately estimate runoff produced from glaciers in the Upper Bow Valley.

8.6.3 Establishment of a High Altitude Meteorological Station

Many of the problems experienced with this analysis could have been avoided if a high altitude meteorological station was operational in the Upper Bow Valley. Such a station would be invaluable for estimating the orographic enhancement of precipitation and the persistence of temperature inversions - two key elements of hydrologic modelling. B.C. Hydro has significantly improved its operational flow forecasting efficiency using the UBC Watershed Model by installing both valley and high altitude meteorological stations (Dan Nixon, pers. commun., 1997). The highest station in the Upper Bow Valley, which extends to over 3500 masl in some areas, is located at 2200 masl in Sunshine Village near Banff. This area receives unusually more winter precipitation than the rest of the basin, and is therefore probably not very representative. Ideally, a new high altitude station should be established much higher and in a more central location, preferably on the apex of several watershed boundaries so results can be directly applicable to more than one sub-basin. Data from this station would certainly improve model output.

8.6.4 Use of Isotopic Analysis to Verify Model Output

The results of isotopic analysis of river discharge can be used to separate the hydrograph to its fundamental components of snowmelt, icemelt, rainfall, and groundwater. Isotopic analysis of Bow River at Banff discharge, currently being conducted by Hopkinson and English of the Cold Regions Research Centre, should be employed to corroborate model output. Hydrograph separation using oxygen-18 and tritium can provide accurate insight of the contribution of ice melt to the Bow River, and thus can be used as a source of comparison with hydrological model predictions.

8.6.5 Maintenance of the Upper Bow Valley River Flow Gauges

The maintenance of the gauge network in the Upper Bow Valley is not a suggestion for improvement, but more an argument directed towards Environment Canada for sustaining the present system. Financial cutbacks have forced Inland

Waters to reduce the number of gauges in their flow monitoring program. Several gauges in the Upper Bow Valley have been deemed unimportant relative to the operating budget, including the Lake Louise gauge. *It is most important that these gauges remain operational to both preserve and extend the discharge record in the Upper Bow Valley, especially in light of the extreme glacier ablation and observed climatic variation prevalent in recent decades.* These gauges record the hydrological feedbacks of the basin to the changing climate, and thus are crucial to analyzing the system and preparing for the future. Economics cannot dictate the importance of this monitoring program.

Appendix 1 - Description of UBC Watershed Model Algorithms

The following UBC model description is adapted and condensed from Quick and Pipes (1994). For a more detailed description, the reader is directed to the original text.

A1.1 - Temperature Lapse Rates

The general form of the temperature lapse rate algorithms are given below:

<u>Maximum Temperature Lapse Rate (TXLAPS)</u>

TXLAPS = TZLAPS + (TLXM - TZLAPS) * TD/A0TERM (A1-1)

<u>Minimum Temperature Lapse Rate (TNLAPS)</u>

TNLAPS = TZLAPS - (TZLAPS - TLMN) * TD/A0TERM (A1-2)

where:

A0TERM = maximum temperature range under open sky conditions (selected from the data set TX-TN)
TD = daily temperature range (TX-TN)
TZLAPS = TZ - (PP/PPM) * (TZ - TZP)

and for the above:

PP = daily precipitation
TLXM = 10^0C/1000 m
TLMN = 0.5^0C/1000 m
TZ = 6.4^0C/1000 m (reference lapse rate for rain-free conditions)
TZP = 3.2^0C /1000 m (reference lapse rate when PP $\geq$ PPM)
PPM = 5 mm/day

A1.2 - Precipitation Enhancement

The equation includes a precipitation enhancement factor that produces a logarithmic increase in precipitation with elevation while also taking barrier height into consideration.

$$P_{IJL+1} = P_{IJL} * (1 + a)^{\Delta elev/100} \quad \text{(A1-3)}$$

where

P_{IJL} = he precipitation from meteorological station I for day J and elevation band L

a = precipitation gradient for elevation increase

Δelev = difference in elevation between the meteorological stations and the elevation band

Three precipitation gradients are possible:

P0GRADL = bands below E0LMID
P0GRADM = bands between E0LMID and E0LHI
P0GRADU = bands above E0LHI

A second algorithm describes the distribution of precipitation resulting from variations in temperature. The saturated adiabatic lapse rate (SALR) is temperature dependent such that when temperatures are high, SALR is low, and when temperatures are low, the SALR is high. The variation of temperature-dependent lapse rates is responsible for the sensitivity of snowfall to orographic effect and the relative immunity of warm, summer rainfall to orographic enhancement. This process is expressed as

$$P_{IJL+1} = P_{IJL} * (1 + (a - S * Tavg))^{\Delta elev/100} \qquad \text{(A1-4)}$$

where

Tavg = average temperature
S = precipitation modification gradient factor (imputed by user 0.1-1)

A1.3 - Form of Precipitation

The proportion of rain to snow (F0RMPP) falling in elevations displaying temperatures between 0^0C and A0FORM is calculated by

$$\text{F0RMPP} = \frac{T}{\text{A0FORM}} \qquad \text{(A1-5)}$$

Then rain, RN = PP * F0RMPP
and snow, SN = PP * (1-F0RMPP)

This equation is designed to calculate a greater proportion of precipitation as rain when temperatures approach A0FORM.

A1.4 - Precipitation Representation Factors

The modeled assumptions when applying PRF are:

if Tx < 0^0C then use P0SREP,
if Tx > A0FORM then use P0RREP,
if 0^oC < Tx < A0FORM then use linear interpolation between P0SREP and P0RREP.

A1.5 - Precipitation Adjustment Factor

The application of a PAF to the entire basin area assumes that a linear relationship exists between the observed conditions at the meteorological site and all other areas of the basin. In reality, this may not be the case. Thus, the model allows for a precipitation adjustment factor that can increase or decrease the precipitation calculated in a particular elevation band. This parameter is particularly useful for estimating snow redistribution and for "building glaciers".

A1.6 - Evapotranspiration

The UBC Model calculates evaporation through a three stage approach. The first stage estimates the daily potential evapotranspiration for the elevation band of the reference meteorological station. This algorithm includes a monthly factor that accounts for the seasonal variation of evaporation.

$$EVAP = A0EDDF * V0EMOF * TX \qquad (A1\text{-}6)$$

where

EVAP = potential evaporation rate for the reference meteorological station
A0EDDF = 0.133 (evaporation constant)
V0EMOF = seasonal evaporation variation factor

The second stage distributes the calculated daily potential evaporation rate for the reference meteorological station to the mid-elevation of the remaining elevation bands in the watershed using a standard lapse rate.

$$PE(x) = EVAP - A0PELA * \Delta\, elev/1000 \qquad (A1\text{-}7)$$

where

PE(x) = potential evaporation for elevation band x
A0PELA = 0.9 mm/km (lapse rate for evaporation constant A0EDDF)
Δ elev = elevation range between the EVAP elevation and the PET(x) elevation

The third stage estimates the actual evaporation rate per elevation band by processing the potential evaporation rate in conjunction with the calculated soil moisture deficit. This algorithm will be discussed in the soil moisture section.

As forest cover significantly influences the daily potential evapotranspiration rate (Strahler and Strahler, 1989), the model includes a forest cover modification algorithm.

$$PET(x) = PE(x) * (A0PEFO * C0TREE + 1.0 * (1 - C0TREE)) \quad (A1\text{-}8)$$

where

C0TREE = fraction of tree-covered area in the elevation band
A0PEFO = Evapotranspiration multiplier in forested areas

However, actual evapotranspiration rates are physically related to the density of vegetation cover (Strahler and Strahler, 1989), which decreases with increasing elevation. Thus, the model allows C0TREE to be modified by a canopy density factor, C0CANY, which is entered by the user and describes the density of tree cover per band.

A1.7 - Soil Moisture Model

A1.7.1 - First Priority - Impermeable Percentage (Fast Runoff)

The model allows the user to ascribe a certain percentage of each elevation band as being impermeable. Any input of water to these areas will be equivocally treated *as fast runoff,* representing surface runoff or quick percolation through coarse mediums. However, as the rates of the aforementioned processes are a function of the antecedent moisture conditions of the soil (Römkens, et. al, 1990), the model contains an algorithm that modifies the impermeable percentage of the watershed with changes in the soil moisture deficit.

$$IMP(x) = C0IMPA * 10^{(S0SOIL/P0AGEN)} \quad (A1\text{-}9)$$

where

IMP(x) = impermeable fraction in band x
C0IMPA = maximum impermeable fraction when the soil is fully saturated
S0SOIL = soil moisture deficit in band
P0AGEN = constant that regulates the sensitivity of the impermeable area to variations in soil moisture

A1.7.2 - Second Priority - Soil Moisture and Actual Evapotranspiration

The second priority satisfies the soil moisture deficit by allowing water inputs from icemelt, snowmelt and rainfall. After entering the soil layer budget, a portion of the soil water is routed out of the soil moisture model as a result of daily estimates of actual evapotranspiration.

$$AET = PET * 10(S0SOIL/P0EGEN) \quad (A1\text{-}10)$$

where

AET = actual evapotranspiration
PET = potential evapotranspiration
S0SOIL = current value of the band soil moisture deficit
P0EGEN = constant controlling the rate at which S0SOIL influences PET

Only permeable areas of the watershed are affected by the evapotranspiration demand.

The model calculates a new value of soil moisture deficit for every day.

$$S0SOILx = S0SOIL - PRN - BM + AET \quad (A1\text{-}11)$$

where

S0SOILx = new value of soil moisture deficit
PRN = rain input
BM = snow and glacier melt input

All water input flowing into the soil layer is stored until the soil moisture deficit reaches zero, at which point water will overflow into other priorities.

A1.7.3 - Third Priority - Groundwater Percolation

Discharge from the soil layer aquifer is allowed to flow into the groundwater storage until maxima is reached, when water is directed to the next priority. The groundwater percolation rate is a constant set by the user. The model processes water entering the groundwater component into two subdivisions: upper and lower groundwater. This separation simulates two rates of groundwater flow which can be adjusted independently to allow for a more accurate representation of watershed behavior. Within the model, the subdivision is controlled by the user-defined parameter P0DZSH, which describes the deep zone share.

$$UGR = (1 - P0DZSH) * P0PERC; \text{ and}$$

$$DGR = P0DZSH * P0PERC \quad (A1\text{-}12)$$

where

UGR = upper groundwater recharge
DGR = deep groundwater recharge
P0DZSH = deep zone share (user defined)
P0PERC = groundwater percolation limit (user defined)

A1.7.4 - Fourth Priority - Medium Runoff

Excess runoff from the groundwater component is directed into the medium runoff component, with the exception of glacier melt, which is re-routed to flow into the fast component of glacier meltwater production. Despite being categorized as the lowest priority, medium runoff is the most significant component of the soil moisture model during times of high volume snowmelt and rainfall.

A1.8 Watershed Routing

A1.8.1 - Fast Watershed Routing

The fast component of runoff passes through a series of reservoirs designed to mimic unit hydrograph convolution.

$$Q_{(t)} = \frac{1}{K^n} \bullet \frac{t^{n-1}}{(n-1)} \bullet e^{-t/k} \tag{A1-13}$$

where

K = linear storage constant for each of the reservoirs in the series (specified by user
n = the number of linear reservoirs in the cascade (specified by user)
t = time after input has occurred

A1.8.2 - Medium Runoff Routing

The medium runoff component is routed via a two stage algorithm. The first stage calculates daily discharge volumes from a linear storage reservoir based on a release constant entered by the user. The algorithm is programmed to apply an exponential decay to the release rate as a function of the total storage in the reservoir.

$$Q_t = Q_r + (1/(1+INTK)) * (W_i - Q_r) \tag{A1-14}$$

where

Q_t = daily discharge from medium runoff reservoir
Q_r = volume of water in reservoir
INTK = release rate constant (entered by user for snowmelt and rainfall)
W_i = discharge entering the medium component reservoir

The second stage involves applying a time distribution convolution to Q_t to represent an interflow unit hydrograph.

A1.8.3 - Slow Runoff Routing

The slow runoff component empirically describes both upper and lower groundwater flow using a single linear reservoir. The algorithm releases a fixed percentage of total groundwater storage for both upper and lower groundwater reservoirs. These release rates are entered by the user and are estimated from base flow conditions.

A1.9 - Snow and Ice Model

The UBC Model uses a simplified energy budget approach, which will be described in the following section.

A1.9.1 - Net Shortwave Energy Input

The model calculates the net shortwave energy budget as a function of estimated cloud cover, snow/ice albedo, and incident solar radiation.

$$\text{Melt} = I_s (1 - C_L)(1 - A_L) \text{ mm} \qquad \text{(A1-15)}$$

where

I_s = incident solar radiation
C_L = cloud cover (calculated in equation A1-27)
A_L = albedo of the snowpack (calculated in equations A1-30 and A1-31)

As incident radiation varies seasonally and with latitude, a separate calculation is used to estimate I_s:

$$I_s = 54 - 29 \cos 2\pi N/365 \text{ mm/day} \quad (\text{for } 35^0 \text{ North latitude})$$

A1.9.2 - Longwave Radiation - Clear Sky Conditions

The algorithm that estimates ice/snow melt from longwave radiation is based on a linearization of the Stefan-Boltzman law in the form of mm/day:

$$\begin{aligned} I_L &= \sigma(273 + T)^4 \text{ Langleys} \qquad \text{(a1-16)} \\ &= \sigma (273^4)(1 + 4T/273 + 6T^2/273^2 + \ldots) \\ &= 661(1 + 0.015T + 0.0001T^2 + \ldots) \text{ Langleys/day} \\ &= 82(6)(1 + 0.015T + \ldots) \text{ mm/day} \end{aligned}$$

where

σ = Stefan-Boltzman constant
t = temperature above freezing

Under clear sky conditions, the model estimates incoming gray body radiation is based on the equation:

$$I_{LA} = 0.757\sigma T^4 \qquad \text{(A1-17)}$$

where

I_{LA} = atmospheric longwave radiation
σ = Stefan-Boltzman constant

t = temperature above freezing

The factor of 0.757 is used to estimate the average vapor pressure influence on I_{LA}. Equation 3-17 is combined with equation 3-16 to yield:

$$I_{LA} = 661((0.757(1 + 0.015\ T_A) - (1 + 0.015T_S))\ \text{Langleys/day} \qquad \text{(A1-18)}$$

where

T_A = mean air temperature
T_S = snow/ice surface temperature

As the snow/ice surface temperature is always 0°C during melt, the equation now reads:

$$I_{LA} = 7.51T_A - 161 - 9.92\ T_s\ \text{Langleys/day} \qquad \text{(A1-19)}$$

or

$$I_{LA} = 0.94T_A - 20.1 - 1.24\ T_s\ \text{mm/day} \qquad \text{(A1-20)}$$

The value for I_{LA} does not become positive until T_A exceeds 21.4°C.

A1.9.3 - Net Longwave Radiation - Cloudy Conditions

Under 100% estimated cloud cover, the longwave adsorptive potential of clouds is expressed as:

$$I_{LNC} = 1.24\ (T_C\text{-}T_S)\ \text{mm/day} \qquad \text{(A1-21)}$$

where

I_{LNC} = net incoming longwave radiation
T_C = air temperature
T_S = snow/ice surface temperature

Finally, both clear and cloudy sky longwave radiation estimation equations are incorporated into the algorithm:

$$I_{LNT} = (-20 + 0.94\ T_A)(1 - C_L) + 1.24\ T_C * C_L\ \text{mm/day} \qquad \text{(A1-22)}$$

This algorithm is capable of estimating the net longwave radiation exchange for conditions ranging from clear skies to partial cloud cover.

A1.9.4 - Convective and Advective Heat Transfer

Quick and Pipes (1994) describe the melt produced from the convective heat transfer (under stable conditions) as:

$$Q_C = 0.18\ (p/101)\ T_A * V\ \text{mm/day} \qquad \text{(A1-23)}$$

and the melt produced from the advective heat transfer as:

$$Q_A = 0.35\ (p/101)\ T_d * V \text{ mm/day} \tag{A1-24}$$

where

p = atmospheric pressure
T_A= mean air temperature
T_d = dew point temperature (approximated by the minimum air temperature)
V = wind speed (km/h)

These equations are then subject to a reduction factor R_M which is a function of the bulk Richardson number R_I.

$$R_M = 1 - 7.7R_I \tag{A1-25}$$

where

$$R_I = (2g * T_z) / [T_A + 273)V^2_A] = 0.095T_A/V^2_A \tag{A1-26}$$

where

V = wind speed at reference height Z
T_z = mean temperature at reference height Z

The reduction factor R_m represents the decrease in convective and advective snowmelt potential caused by large scale surface roughness and slope affecting air mass stability. For positive air temperatures the R_M factor does not dip below zero, and for negative temperatures R_M increases quickly to about 1.8, and then gradually grows. However, as this reduction factor is based on idealized laboratory conditions, R_m may increase to as much as 2.5 times, depending on the degree of surface roughness and slope of the basin.

A1.9.5 - Rainmelt

The energy contained in liquid precipitation does not significantly contribute to the melting of snow and ice. Despite this, Quick and Pipes have included a simple equation to estimate snow and ice melt from rainfall:

$$\text{Rainmelt} = K * T_a * P_r \tag{A1-27}$$

where

K = constant representing the heat content of rain (mm/^{0}C rain)
P_r = rainfall
T_a = mean air temperature

The equation assumes that all rainfall is falling at the mean daily air temperature.

A1.9.6 - Cloud Cover Estimation

The UBC Model estimates the daily percentage cloud cover as a function daily temperature range:

$$(1-C_L) = (T_{MAX} - T_{MIN}) / D_R \qquad \text{(A1-27)}$$

where

C_L = cloud cover fraction
T_{MAX} = daily maximum temperature
T_{MIN} = daily minimum temperature
D_R = daily temperature range for open sky conditions

The equation assumes that percentage cloud cover varies inversely with diurnal temperature range, such that as percentage cloud cover increases, temperature range decreases.

A1.9.7 - Wind Estimate

Wind speed is estimated by two algorithms. The first algorithm assumes wind speed as a function of daily temperature range and estimates wind speed for elevation bands under 1000m.

$$V_b = P0VBMX - (P0VBMX - 1) * D_R/25 \qquad \text{(A1-28)}$$

where

V_b = wind speed (km/h)
P0VBMX = the maximum wind speed at elevations less than 1000 m in km/h (constant in model of 8km/h)
D_R = daily temperature range

The second algorithm estimates wind speed as a function of altitude for elevation bands higher than 1000m.

$$V_e = V_b \sqrt{\frac{C0ELEM}{1000}} \qquad \text{(A1-29)}$$

where

C0ELEM = band elevation
V_b = wind speed at 1000 m

The equation does not factor in large scale surface roughness or barrier effects.

A1.9.8 - Albedo of the Snow Surface

The shortwave reflectivity of the snow surface is modeled to simulate the variable decay rates of albedo through time. Fresh snow is assigned an albedo of 0.95 and is exposed to a rapid constant linear decay factor of 0.9 until it reaches a settled value of 0.65.

$$A_{LS(j+1)} = 0.9\ A_{LS(j)} \qquad \text{(A1-30)}$$

where

$A_{LS(j)}$ = albedo of snow (fresh snow = 0.95)
$A_{LS(j+1)}$ = albedo of snow exposed to linear decay

Once the settled value is reached, the albedo is subject to an exponential decay rate to simulate the ripening process of an aged snowpack.

$$A_{Lj} = A_{LS}^{(-RM/K)} \qquad \text{(A1-31)}$$

where

A_{Lj} = settled albedo value (0.65)
RM = cumulative seasonal melt (mm)
K = total seasonal melt (usually 3500 mm)

The model returns the albedo of the snowpack to 0.9 for new snow events over 15 mm, which are then subject to the aforementioned decay rates. The albedo for glacierized areas, including firn, ice, and glaciers with inorganic and organic debris covers, is given a blanket value of 0.3. There are no decay rates applied to this value as the melt season progresses. The model assumes this albedo value as soon as the glacier becomes free of snow.

A1.9.8 - Negative Melt Budget

To account for the cold content storage of snow and glaciers, a negative melt budget approach has been applied. The negative melt budget is calculated primarily from the mean air temperature and the latent heat contribution from the freezing of rain falling on the snowpack/glacier. A running sum of the antecedent cold content conditions of the snow/ice are stored and used to estimate the daily negative melt budget. The total is exposed to by a decay factor constant, which depends on temperatures of the previous 10 days.

$$CC = CC + (1/(1+P0CTK)) * (CCB - CC) \qquad \text{(A1-32)}$$

where

CC = cold content storage of ice/snow
P0CTK = antecedent negative melt time constant
CCB = TM + KCC*RN
KCC = latent heat contribution from the freezing of rain on ice/snow
TM = mean air temperature

RN = rainfall

The model does not consider the differences in thermal conductivity between ice and snow mediums.

Appendix 2 - Estimated Bow Valley Glacier Recession 1951-1993

Bow Valley Glacier Recession in km² 1951-93											
mid elev. (m)	1951	1958	1963	1969	1972	1977	1982	1987	1993	30% Less	62% Less
1753	0	0	0	0	0	0	0	0	0	0	0
1905	1.14	1.11	1.02	0.99	0.87	0.83	0.63	0.50	0.31	0	0
2057	3.40	3.12	2.73	2.62	2.32	2.25	1.54	1.05	0.37	0	0
2210	6.62	6.21	5.61	5.42	4.91	4.80	3.67	2.89	1.85	0	0
2362	14.39	13.74	12.74	12.42	11.53	11.32	9.41	8.09	6.25	1.72	0
2515	25.13	24.36	23.15	22.75	21.59	21.31	18.94	17.30	15.00	9.3	0
2667	18.43	18.11	17.59	17.41	16.88	16.75	15.72	15.00	14.01	11.6	6.41
2819	8.95	8.90	8.82	8.79	8.71	8.69	8.53	8.41	8.25	7.82	7.00
2972	5.39	5.39	5.39	5.39	5.39	5.39	5.39	5.39	5.39	5.39	5.39
3124	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94
3277	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
3429	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
3581	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

Based on observed recession trends in Hector Basin by Hopkinson (1997).

Appendix 3 - Correlation Analysis Between Banff and Lake Louise Meteorological Data and Bow River at Banff Discharge

Correlation Analysis Banff Meteorological Station and Bow at Banff Discharge (Three Day Lag)

1969

	Tmax5	Tmax6	Tmax7	Tmax8	P5	P6	P7	P8
D5	0.61				-0.31			
D6		0.61				-0.40		
D7			-0.42				0.53	
D8				0.18				0.18

1970

	Tmax5	Tmax6	Tmax7	Tmax8	P5	P6	P7	P8
D5	0.41				0.08			
D6		0.46				0.18		
D7			0.19				-0.21	
D8				0.19				0.19

Correlation Analysis Lake Louise Met. Station and Bow at Banff Discharge (Three Day Lag)

1969

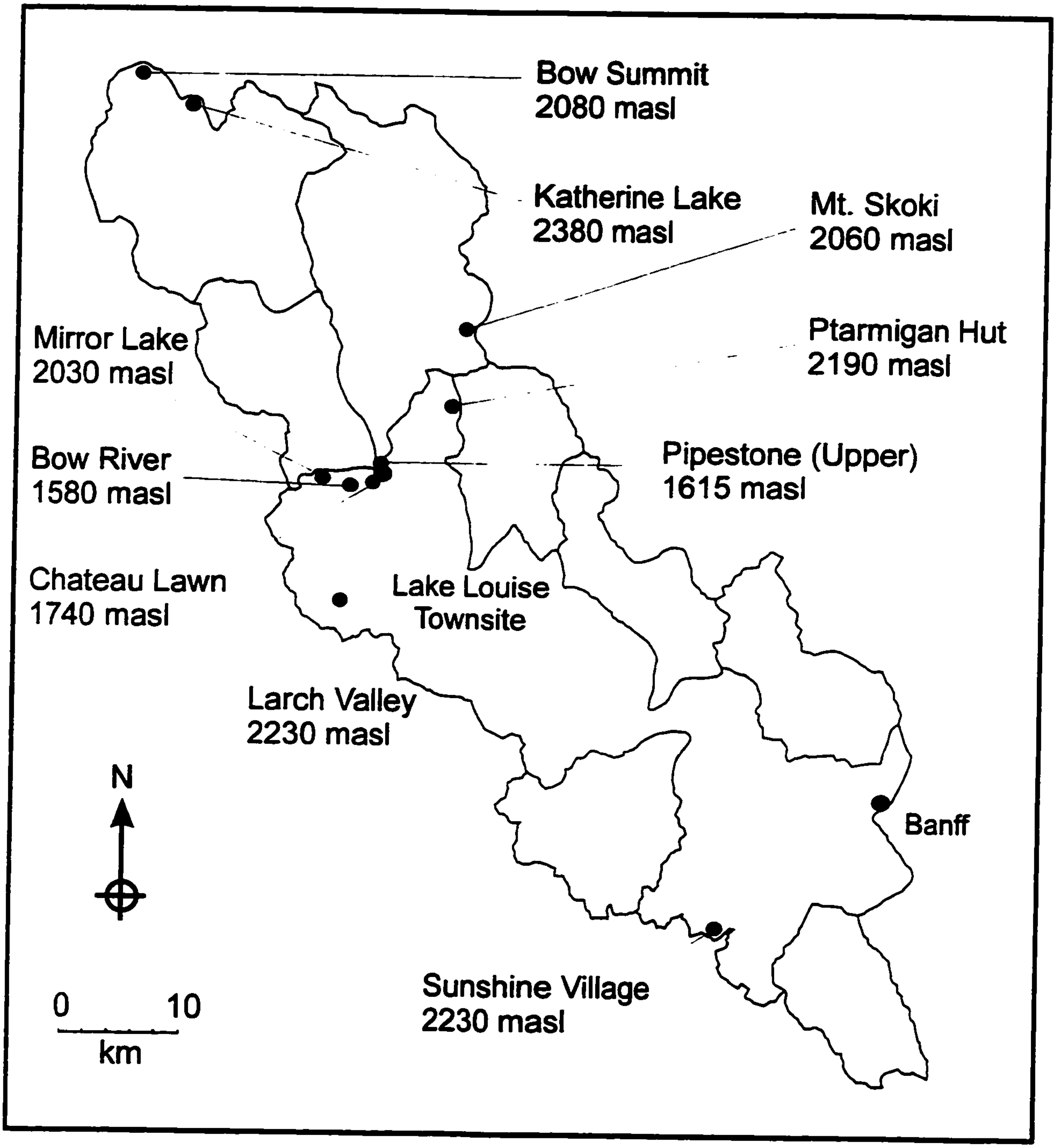
	Tmax5	Tmax6	Tmax7	Tmax8	P5	P6	P7	P8
D5	0.75				-0.13			
D6		0.55				-0.31		
D7			-0.37				0.18	
D8				0.40				-0.11

1970

	Tmax5	Tmax6	Tmax7	Tmax8	P5	P6	P7	P8
D5	0.31				0.47			
D6		0.65				0.08		
D7			0.26				-0.16	
D8				0.20				0.29

Numbers indicate month (ex. 5 = May).
Tmax indicates maximum temperature.
P indicates precipitation.

Appendix 4 - Location of Upper Bow Valley Snow Courses

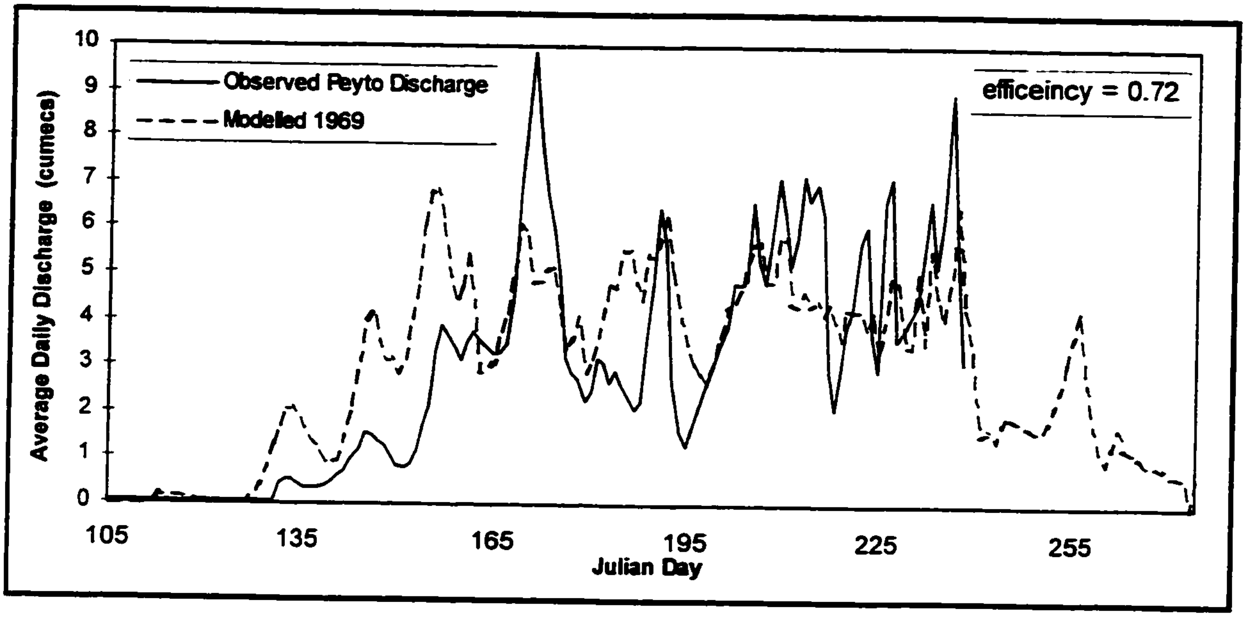


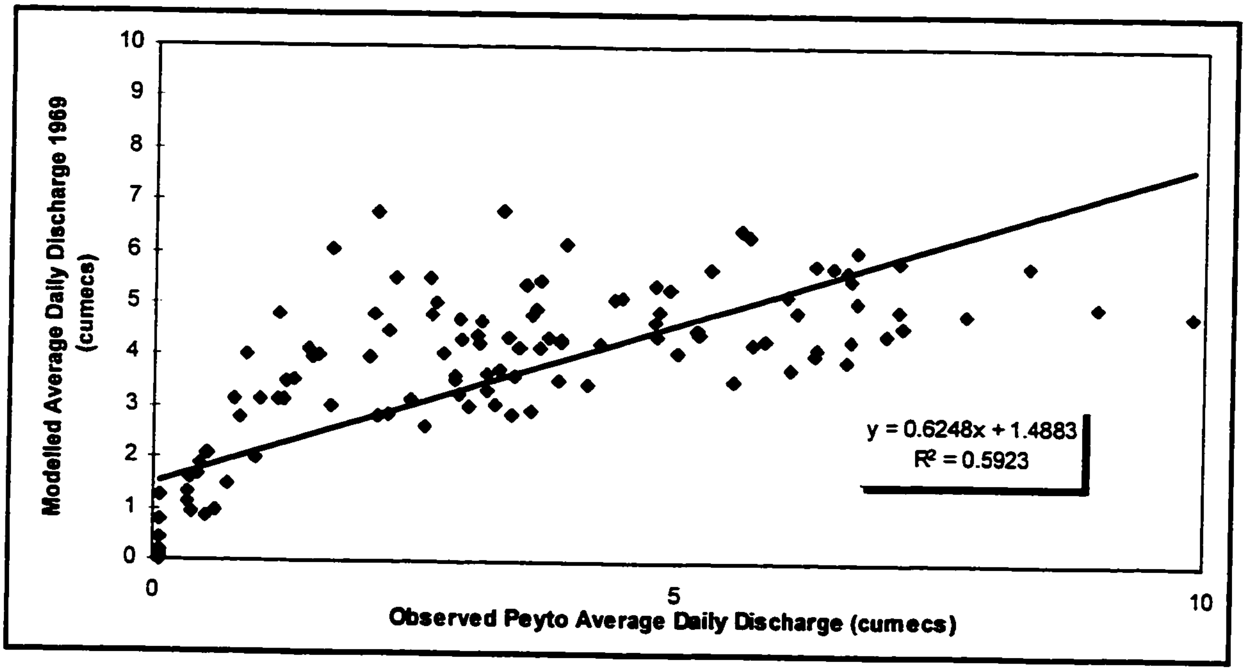
Appendix 5 - Peyto Glacier Winter Balance 1966-1995

Elevation Band m.a.s.l.	Winter Balance (mm water equivalence)									
	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
3100-3200	1970	3650	2920	2320	1690	1830	2370	3390	2890	2180
3000-3100	1800	3260	2600	2100	1540	1730	2210	2940	2540	1900
2900-3000	1730	3040	2460	2010	1470	1760	2160	2680	2360	1740
2800-2900	1580	2730	2200	1820	1350	1610	2000	2380	2130	1560
2700-2800	1410	2390	1920	1620	1210	1450	1820	2040	1870	1350
2600-2700	1270	2120	1690	1470	1090	1360	1720	1800	1690	1200
2500-2600	1110	1770	1390	1260	960	1180	1530	1420	1390	960
2400-2500	960	1480	1150	1080	840	1030	1380	1160	1190	800
2300-2400	760	1080	810	840	670	850	1180	770	880	550
2200-2300	650	880	640	730	590	750	1090	610	760	450
2100-2200	560	750	540	680	510	850	1180	590	780	440

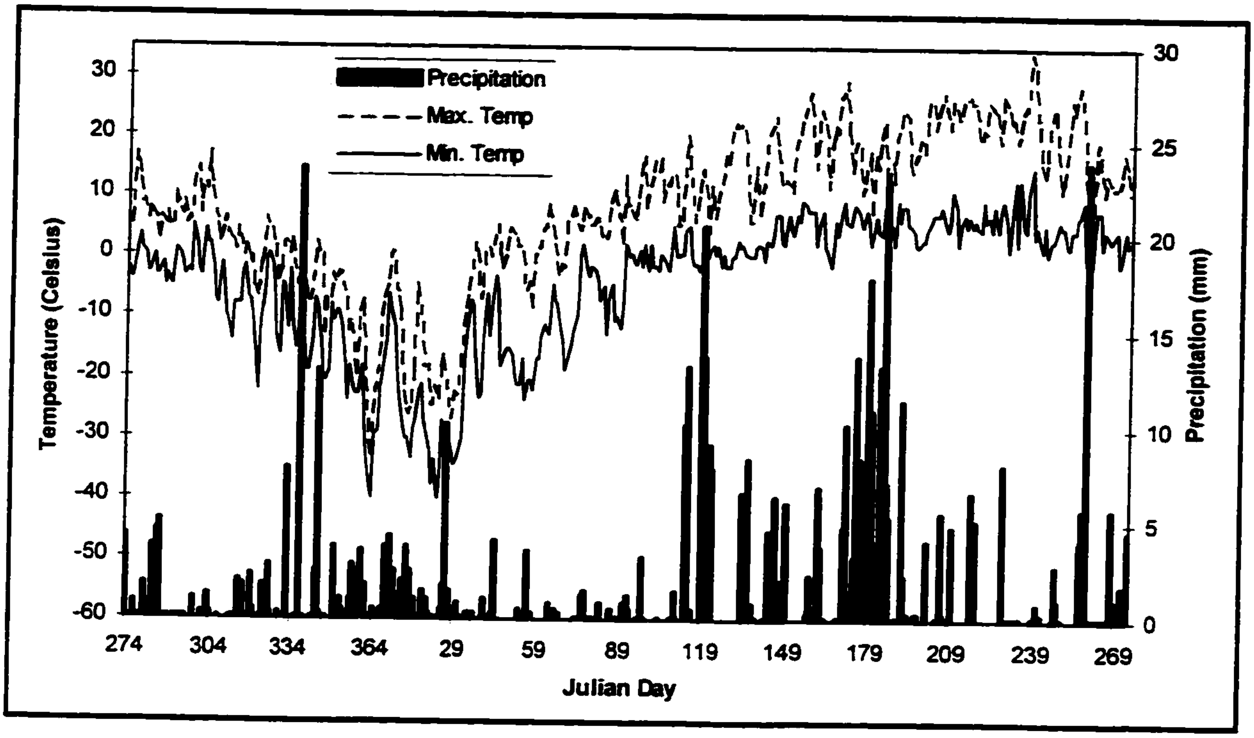
	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
3100-3200	2960	1460	2120	2130	1580	1830	2170	1730	2480	2500
3000-3100	2610	1320	1850	1890	1380	1590	1920	1490	2120	1760
2900-3000	2420	1230	1670	1730	1270	1380	1780	1292	1790	1760
2800-2900	2200	1130	1500	1590	1120	1270	1620	1160	1600	1670
2700-2800	1930	1010	1310	1420	960	1170	1430	1020	1420	1250
2600-2700	1720	900	1140	1280	820	1030	1270	870	1200	1250
2500-2600	1430	790	940	1090	650	980	1160	800	1100	930
2400-2500	1210	690	780	960	500	740	830	560	790	750
2300-2400	860	560	540	740	290	1190	1200	790	1150	560
2200-2300	720	480	440	660	200	430	410	260	380	250
2100-2200	660	380	300	590	140	210	250	80	100	290

	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
3100-3200	1810	1380	1620	1890	1770			1107	1492	1842
3000-3100	1700	1270	1480	1750	1650			1030	1386	1701
2900-3000	1590	1170	1360	1620	1540			953	1281	1560
2800-2900	1480	1060	1220	1470	1420			875	1175	1418
2700-2800	1370	950	1090	1330	1300			798	1070	1277
2600-2700	1250	840	950	1180	1180			739	944	1117
2500-2600	1130	730	810	1040	1060			662	894	1045
2400-2500	860	680	510	720	870			549	790	909
2300-2400	690	480	330	570	810			449	610	647
2200-2300	820	390	390	600	680			371	462	434
2100-2200	800	440	450	650	710			392	500	548

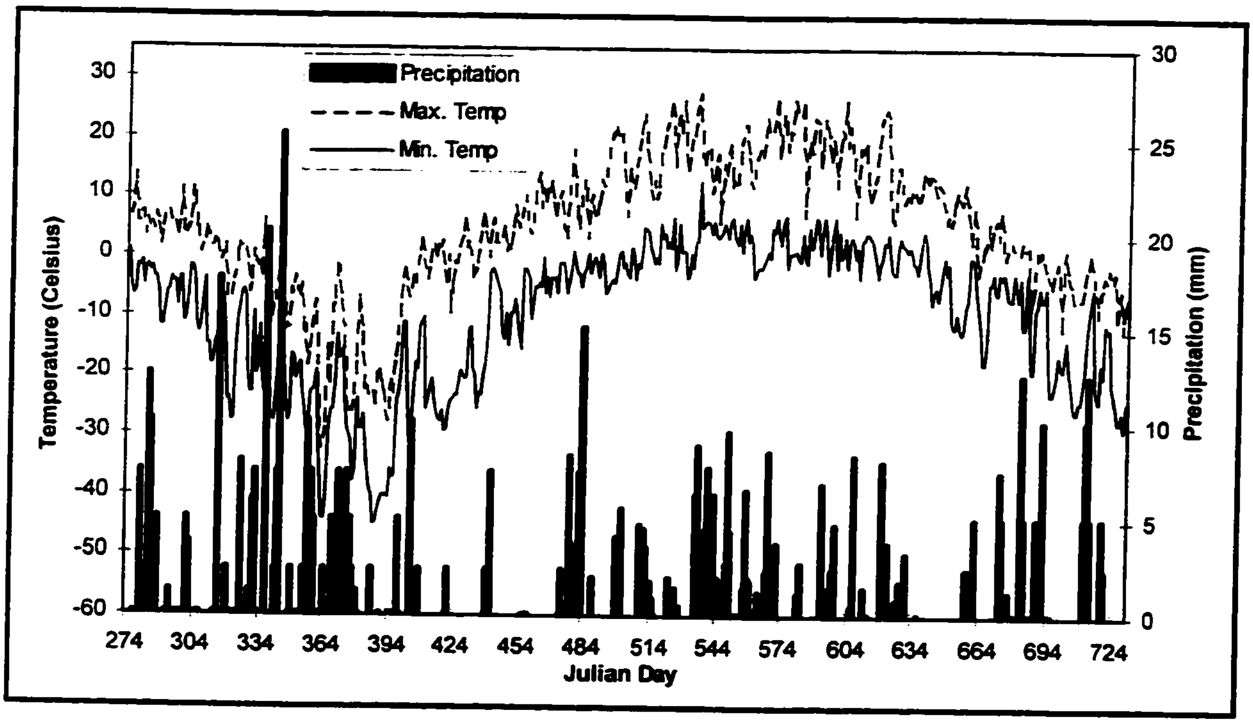

Observed Peyto Discharge
Modelled 1969
efficeincy = 0.72
Average Daily Discharge (cumecs)
Julian Day
0
1
2
3
4
5
6
7
8
9
10
105
135
165
195
225
255


y = 0.6248x + 1.4883
R² = 0.5923
Modelled Average Daily Discharge 1969 (cumecs)
Observed Peyto Average Daily Discharge (cumecs)
0
1
2
3
4
5
6
7
8
9
10
0
5
10

Appendix 7 - Banff and Lake Louise Meteorological Data for Hydrologic Year 1969



Banff Meteorological Data



Lake Louise Meteorological Data

Appendix 8 - Raw Data: UBC Model Estimations for Bow Valley

Original 1969 Calibration								
Julian Day	Observed (cumecs)	Modelled (cumecs)	Residual (cumecs)	Snowmelt (cumecs)	Icemelt (cumecs)	Rainfall (cumecs)	Groundwater (cumecs)	evapo-transpiration (mm/day x 10)
274	31.4	30.6	-0.8	0	0	0	30.6	5.228
275	31.4	30.13	-1.27	0.015	0	0	30.11	10.97
276	30	29.69	-0.31	0.056	0	0.001	29.64	24.89
277	29.4	29.25	-0.15	0.068	0	0.012	29.17	13.6
278	28.9	28.85	-0.05	0.096	0.001	0.029	28.72	9.413
279	27.8	28.42	0.616	0.098	0.001	0.035	28.28	10.54
280	27.3	27.98	0.676	0.088	0.001	0.035	27.85	6.985
281	26.6	27.56	0.96	0.085	0.001	0.041	27.43	7.108
282	26.1	27.14	1.043	0.077	0.001	0.042	27.02	7.256
283	25.6	26.74	1.137	0.068	0.001	0.045	26.62	5.181
284	25.4	26.33	0.932	0.056	0.001	0.041	26.23	1.561
285	24.9	25.93	1.033	0.044	0.001	0.035	25.85	5.181
286	25.1	25.65	0.55	0.035	0	0.039	25.58	5.989
287	24.7	25.27	0.574	0.027	0	0.036	25.21	6.621
288	23.6	24.9	1.305	0.02	0	0.031	24.85	3.555
289	22.9	24.55	1.645	0.015	0	0.025	24.5	4.546
290	22.2	24.22	2.023	0.039	0	0.02	24.16	11.14
291	22	23.98	1.976	0.129	0	0.017	23.83	10.54
292	21.1	23.71	2.609	0.19	0	0.014	23.5	6.621
293	20.7	23.42	2.721	0.222	0	0.012	23.19	9.017
294	20.5	23.1	2.598	0.212	0	0.01	22.88	4.83
295	20.1	22.76	2.664	0.184	0	0.008	22.57	4.951
296	19.7	22.43	2.732	0.151	0	0.006	22.27	9.413
297	19.7	22.9	3.203	0.908	0.001	0.009	21.98	19.73
298	19.9	23.27	3.369	1.54	0.001	0.027	21.7	15.54
299	20.1	23.11	3.005	1.65	0.001	0.032	21.42	6.346
300	19.4	22.73	3.329	1.547	0.001	0.031	21.15	12.29
301	19.4	24.23	4.833	1.695	0.001	1.406	21.13	11.81
302	19.5	29.59	10.09	1.962	0.001	6.07	21.56	23.92
303	19.7	30.79	11.09	2.013	0.001	7.504	21.28	14.74
304	19.7	30.12	10.42	1.813	0.001	7.308	21	5.771
305	18.7	28.66	9.961	1.523	0.001	6.409	20.73	3.785
306	16.5	26.99	10.49	1.225	0	5.298	20.46	0.637
307	18.2	25.38	7.176	0.956	0	4.215	20.2	2.794
308	18.3	23.95	5.647	0.73	0	3.265	19.95	5.181
309	16.5	22.73	6.232	0.549	0	2.48	19.7	2.16
310	15.1	21.72	6.623	0.407	0	1.856	19.46	1.047
311	13.3	20.89	7.593	0.299	0	1.372	19.22	0.637
312	12.9	20.21	7.311	0.218	0	1.005	18.99	0.146
313	14.4	19.65	5.247	0.157	0	0.73	18.76	2.794
314	14.7	19.18	4.475	0.113	0	0.527	18.54	0.637
315	14.9	18.78	3.875	0.081	0	0.378	18.32	0.014
316	15.7	18.43	2.729	0.058	0	0.27	18.1	0.637
317	16.3	18.12	1.823	0.041	0	0.192	17.89	0
318	15.3	17.85	2.549	0.029	0	0.136	17.68	0
319	15.6	17.6	1.998	0.02	0	0.096	17.48	0
320	14	17.37	3.365	0.014	0	0.067	17.28	0
321	10.6	17.15	6.546	0.01	0	0.047	17.09	0
322	10.2	16.94	6.738	0.007	0	0.033	16.9	0
323	12.4	16.74	4.339	0.005	0	0.023	16.71	4.951

324	15.3	16.55	1.249	0.003	0	0.019	16.53	4.317
325	15	16.37	1.375	0.002	0	0.026	16.35	4.317
326	14.6	16.2	1.597	0.002	0	0.027	16.17	0.637
327	14.2	16.02	1.82	0.001	0	0.024	16	0.637
328	13.8	15.85	2.045	0.001	0	0.02	15.82	0
329	13.3	15.67	2.373	0.001	0	0.016	15.66	0
330	12.9	15.5	2.605	0	0	0.012	15.49	0.637
331	12.5	15.34	2.84	0	0	0.009	15.33	0.637
332	12.1	15.18	3.079	0	0	0.007	15.17	0.086
333	12	15.02	3.02	0	0	0.005	15.02	1.047
334	11.9	14.87	2.965	0	0	0.004	14.86	0
335	11.8	14.71	2.913	0	0	0.003	14.71	0
336	11.8	14.56	2.764	0	0	0.002	14.56	0
337	11.7	14.42	2.718	0	0	0.001	14.42	0.014
338	11.6	14.27	2.674	0	0	0.001	14.27	0
339	11.4	14.13	2.732	0	0	0.001	14.13	0
340	11.3	13.99	2.693	0	0	0.001	13.99	0
341	11.2	13.86	2.656	0	0	0	13.86	0
342	11	13.72	2.722	0	0	0	13.72	0.637
343	11	13.59	2.589	0	0	0	13.59	0.086
344	10.9	13.46	2.559	0	0	0	13.46	0.086
345	10.8	13.33	2.531	0	0	0	13.33	0
346	10.7	13.2	2.504	0	0	0	13.2	0
347	10.6	13.08	2.48	0	0	0	13.08	0
348	10.6	12.96	2.357	0	0	0	12.96	0
349	10.5	12.84	2.337	0	0	0	12.84	0
350	10.4	12.72	2.318	0	0	0	12.72	0
351	10.4	12.6	2.201	0	0	0	12.6	0
352	10.3	12.49	2.185	0	0	0	12.49	0
353	10.3	12.37	2.071	0	0	0	12.37	0
354	10.1	12.26	2.159	0	0	0	12.26	0
355	10	12.15	2.149	0	0	0	12.15	0
356	9.88	12.04	2.159	0	0	0	12.04	0
357	9.77	11.93	2.162	0	0	0	11.93	0
358	9.66	11.83	2.166	0	0	0	11.83	0
359	9.6	11.72	2.121	0	0	0	11.72	0
360	9.54	11.62	2.078	0	0	0	11.62	0
361	9.49	11.52	2.026	0	0	0	11.52	0
362	9.43	11.42	1.986	0	0	0	11.42	0
363	9.37	11.32	1.947	0	0	0	11.32	0
364	9.32	11.22	1.899	0	0	0	11.22	0
365	9.34	11.12	1.782	0	0	0	11.12	0
1	9.4	11.03	1.627	0	0	0	11.03	0
2	9.54	10.93	1.393	0	0	0	10.93	0
3	9.63	10.84	1.21	0	0	0	10.84	0
4	9.77	10.75	0.978	0	0	0	10.75	0.014
5	9.77	10.66	0.887	0	0	0	10.66	0.086
6	9.77	10.57	0.798	0	0	0	10.57	0
7	9.68	10.48	0.799	0	0	0	10.48	0
8	9.54	10.39	0.852	0	0	0	10.39	0
9	9.43	10.31	0.875	0	0	0	10.31	0
10	9.43	10.22	0.79	0	0	0	10.22	0
11	9.43	10.14	0.706	0	0	0	10.14	0
12	9.49	10.05	0.562	0	0	0	10.05	0
13	9.63	9.97	0.34	0	0	0	9.97	0
14	9.85	9.888	0.038	0	0	0	9.888	0
15	10	9.808	-0.19	0	0	0	9.808	0
16	9.91	9.728	-0.18	0	0	0	9.728	0
17	9.85	9.649	-0.2	0	0	0	9.649	0
18	9.63	9.571	-0.06	0	0	0	9.571	0

19	9.57	9.494	-0.08	0	0	0	9.494	0
20	9.49	9.418	-0.07	0	0	0	9.418	0
21	9.26	9.343	0.083	0	0	0	9.343	0
22	9.06	9.268	0.208	0	0	0	9.268	0
23	8.92	9.195	0.275	0	0	0	9.195	0
24	8.69	9.122	0.432	0	0	0	9.122	0
25	8.5	9.049	0.549	0	0	0	9.049	0
26	8.27	8.978	0.708	0	0	0	8.978	0
27	8.07	8.907	0.837	0	0	0	8.907	0
28	7.82	8.837	1.017	0	0	0	8.837	0
29	7.62	8.768	1.148	0	0	0	8.768	0
30	7.59	8.7	1.11	0	0	0	8.7	0
31	7.5	8.632	1.132	0	0	0	8.632	0
32	7.5	8.564	1.064	0	0	0	8.564	0
33	7.56	8.498	0.938	0	0	0	8.498	0
34	7.59	8.432	0.842	0	0	0	8.432	0
35	7.65	8.367	0.717	0	0	0	8.367	0.637
36	7.7	8.302	0.602	0	0	0	8.302	0.146
37	7.73	8.238	0.508	0	0	0	8.238	0
38	7.84	8.175	0.335	0	0	0	8.175	0
39	7.93	8.112	0.182	0	0	0	8.112	0.146
40	8.13	8.05	-0.08	0	0	0	8.05	0.146
41	8.27	7.989	-0.28	0	0	0	7.989	0.014
42	8.41	7.928	-0.48	0	0	0	7.928	0.637
43	8.52	7.867	-0.65	0	0	0	7.867	3.555
44	8.69	7.808	-0.88	0	0	0	7.808	0.086
45	8.72	7.748	-0.97	0	0	0	7.748	0
46	8.81	7.69	-1.12	0	0	0	7.69	0.086
47	8.83	7.631	-1.2	0	0	0	7.631	1.405
48	8.86	7.574	-1.29	0	0	0	7.574	2.794
49	8.92	7.517	-1.4	0	0	0	7.517	1.405
50	8.86	7.46	-1.4	0	0	0	7.46	1.047
51	8.75	7.404	-1.35	0	0	0	7.404	0.637
52	8.58	7.348	-1.23	0	0	0	7.348	0.387
53	8.44	7.293	-1.15	0	0	0	7.293	0
54	8.24	7.239	-1	0	0	0	7.239	0
55	8.04	7.184	-0.86	0	0	0	7.184	0
56	7.93	7.131	-0.8	0	0	0	7.131	0
57	7.73	7.077	-0.65	0	0	0	7.077	0.014
58	7.67	7.025	-0.65	0	0	0	7.025	0.146
59	7.65	6.972	-0.68	0	0	0	6.972	0.387
60	7.62	6.921	-0.7	0	0	0	6.921	2.794
61	7.65	6.869	-0.78	0	0	0	6.869	3.555
62	7.65	6.818	-0.83	0	0	0	6.818	10.18
63	7.67	6.768	-0.9	0	0	0	6.768	5.712
64	7.7	6.718	-0.98	0	0	0	6.718	1.047
65	7.73	6.668	-1.06	0	0	0	6.668	0.086
66	7.76	6.619	-1.14	0	0	0	6.619	0
67	7.76	6.57	-1.19	0	0	0	6.57	0
68	7.79	6.522	-1.27	0	0	0	6.522	0
69	7.82	6.474	-1.35	0	0	0	6.473	4.951
70	7.84	6.426	-1.41	0	0	0	6.426	6.226
71	7.87	6.379	-1.49	0	0	0	6.379	10.18
72	7.9	6.332	-1.57	0	0	0	6.332	6.576
73	7.9	6.285	-1.61	0	0	0	6.285	2.794
74	7.93	6.239	-1.69	0	0	0	6.239	3.555
75	7.9	6.199	-1.7	0.006	0	0	6.194	7.621
76	7.87	6.17	-1.7	0.018	0	0.003	6.148	6.951
77	7.84	6.129	-1.71	0.022	0	0.004	6.103	4.317
78	7.82	6.084	-1.74	0.021	0	0.004	6.059	4.317
79	7.79	6.04	-1.75	0.022	0	0.004	6.014	4.951
80	7.82	5.993	-1.83	0.02	0	0.003	5.97	4.069
81	7.84	5.946	-1.89	0.017	0	0.003	5.927	1.405

82	7.84	5.899	-1.94	0.013	0	0.002	5.884	1.047
83	7.87	5.853	-2.02	0.01	0	0.002	5.841	2.16
84	7.9	5.808	-2.09	0.008	0	0.001	5.798	9.017
85	7.9	5.763	-2.14	0.006	0	0.001	5.756	14.13
86	8.21	5.719	-2.49	0.004	0	0.001	5.714	9.413
87	8.13	5.677	-2.45	0.003	0	0	5.673	6.226
88	8.04	5.634	-2.41	0.002	0	0	5.632	2.309
89	7.99	5.593	-2.4	0.002	0	0	5.591	16.56
90	7.99	5.604	-2.39	0.05	0	0.005	5.55	12.58
91	8.21	5.613	-2.6	0.096	0	0.007	5.51	8.78
92	8.27	5.642	-2.63	0.136	0	0.015	5.492	5.942
93	8.21	5.626	-2.58	0.155	0	0.019	5.452	5.01
94	8.1	5.662	-2.44	0.187	0	0.018	5.457	11.93
95	7.99	5.95	-2.04	0.386	0	0.016	5.548	23.77
96	8.13	6.278	-1.85	0.686	0	0.014	5.577	25.33
97	8.72	7.033	-1.69	0.972	0	0.051	6.01	9.944
98	9.15	7.224	-1.93	1.145	0	0.063	6.015	17.57
99	9.34	7.985	-1.36	1.688	0	0.062	6.235	17.36
100	9.68	8.435	-1.24	2.144	0	0.054	6.237	21.89
101	10.1	8.74	-1.36	2.456	0	0.045	6.239	20.37
102	10.4	9.142	-1.26	2.815	0	0.036	6.291	24.53
103	10.7	9.429	-1.27	2.926	0	0.029	6.473	12.41
104	10.8	9.545	-1.25	2.952	0	0.023	6.57	14.09
105	10.7	9.607	-1.09	2.942	0	0.018	6.647	15.97
106	10.6	9.662	-0.94	2.97	0	0.013	6.678	18.93
107	10.6	12.01	1.414	4.548	0.002	0.01	7.454	18.6
108	10.9	12.85	1.95	5.327	0.003	0.019	7.501	11.17
109	10.9	12.58	1.679	5.112	0.004	0.034	7.429	4.317
110	11	11.87	0.871	4.51	0.004	0.038	7.319	4.951
111	10.8	11.77	0.965	4.346	0.004	0.042	7.373	20
112	10.6	16.18	5.579	7.169	0.007	0.039	8.965	32.37
113	11.9	28.87	16.97	12.01	0.014	2.837	14.01	19.58
114	19.3	31.96	12.66	12.99	0.016	4.12	14.83	10.81
115	23.5	30.74	7.241	11.99	0.015	4.235	14.5	5.181
116	23.4	28.37	4.973	10.36	0.013	3.816	14.18	14.74
117	23.1	26.57	3.466	9.48	0.011	3.206	13.87	20.97
118	23.2	29.5	6.297	8.7	0.011	5.454	15.33	20.8
119	25.9	30.92	5.024	7.468	0.009	6.378	17.07	7.742
120	26.8	29.58	2.783	6.126	0.008	6.126	17.32	6.435
121	25.8	27.73	1.926	5.197	0.007	5.335	17.19	21.23
122	25.2	26.5	1.305	4.503	0.008	4.538	17.46	10.91
123	25.4	25.35	-0.05	3.941	0.008	3.886	17.51	13.89
124	24.9	24.72	-0.18	4.084	0.011	3.164	17.46	18.53
125	23.8	25.24	1.441	5.437	0.012	2.492	17.3	27.18
126	24.3	28.95	4.647	9.107	0.017	1.916	17.91	31.01
127	26.7	32.19	5.486	12.61	0.021	1.448	18.11	31.28
128	29.2	38.3	9.104	18.32	0.028	1.078	18.87	42.59
129	34.8	47.52	12.72	26.52	0.04	0.794	20.16	46.37
130	44.7	57.76	13.06	35.57	0.055	0.58	21.56	48.14
131	57.2	68.33	11.13	44.92	0.078	0.42	22.92	47.15
132	70.5	76.78	6.28	52.55	0.1	0.303	23.83	44.9
133	81	84.42	3.424	59.18	0.121	0.217	24.91	45.43
134	92.3	83.38	-8.92	56.53	0.127	1.545	25.18	28.43
135	86.7	75.78	-10.9	49.14	0.116	1.981	24.54	13.03
136	75.6	66.54	-9.06	40.51	0.099	2.009	23.93	9.974
137	66.3	58.39	-7.91	32.96	0.091	1.799	23.54	30.88
138	62.3	51.44	-10.9	26.67	0.087	1.512	23.17	24.53
139	59.7	45.2	-14.5	21.26	0.081	1.218	22.64	14.96
140	57.5	42.26	-15.2	18.87	0.08	0.952	22.35	27.05
141	60.9	47.31	-13.6	23.35	0.086	0.728	23.15	39
142	69.4	58.37	-11	33.29	0.106	0.548	24.42	44.65

143	83.5	70.41	-13.1	44.49	0.131	0.407	25.38	49.58
144	109	92.37	-16.6	57.17	0.163	7.009	28.03	51.84
145	140	111.9	-28.1	69.82	0.206	11.67	30.25	39.99
146	166	126.3	-39.7	75.53	0.247	18.25	32.3	23.54
147	145	126	-19	71.67	0.252	21.46	32.59	22.01
148	119	118.4	-0.59	65.17	0.239	20.59	32.41	25.47
149	100	117.2	17.18	62.98	0.249	20.15	33.81	22.01
150	90.3	111.5	21.18	58.83	0.251	18.54	33.86	22.27
151	83.8	112.1	28.25	60.99	0.25	15.9	34.92	38.55
152	85.5	121.7	36.24	71.46	0.262	12.96	37.06	43.5
153	95.7	135.3	39.55	85.57	0.273	10.21	39.2	51.2
154	133	156.9	23.86	106.4	0.292	7.855	42.31	54.04
155	168	179.9	11.94	128.3	0.387	5.936	45.29	60.22
156	197	199.7	2.733	146.8	0.528	4.423	47.97	63.12
157	203	212.3	9.277	155.8	0.674	5.951	49.89	48.16
158	191	209.2	18.16	152.4	0.788	5.981	50.02	33.24
159	165	202.4	37.36	146.1	0.849	5.33	50.09	53.27
160	154	201.5	47.49	142.8	1.156	6.46	51.11	56.46
161	157	201.6	44.6	141.9	1.946	6.281	51.51	49.75
162	158	194.3	36.26	134.7	2.541	6.17	50.87	48.55
163	147	177.8	30.78	119.9	2.696	5.435	49.76	26.71
164	127	164.1	37.13	107.6	2.981	4.505	49.07	43.97
165	114	151.4	37.37	96.07	3.441	3.591	48.27	48.93
166	108	142.7	34.75	87.98	4.255	2.786	47.72	47.94
167	106	137	31.03	82.53	5.192	2.118	47.19	60.69
168	107	130.9	23.92	76.42	6.425	1.587	46.48	63.12
169	117	123.9	6.94	68.85	8.123	1.174	45.79	67.76
170	135	124.6	-10.4	60.21	9.337	9.215	45.82	44.74
171	140	129	-11	50.1	9.359	22.96	46.59	32.26
172	141	124.2	-16.8	41.26	9.428	27.85	45.67	40.72
173	131	116.3	-14.7	34.58	9.83	27.08	44.86	42.17
174	123	114.6	-8.37	29.64	10.26	29.86	44.86	42.17
175	118	117.5	-0.48	27.64	9.629	34.73	45.52	21.8
176	127	116.9	-10.1	25.86	8.474	37.24	45.3	24.98
177	123	116	-7.01	29.26	7.699	34.23	44.8	34.7
178	112	125	13	34.53	7.142	37.68	45.65	39.34
179	109	120	11.03	33.84	6.116	35.2	44.88	12.5
180	107	122.5	15.55	38.37	5.383	32.86	45.93	36.85
181	106	127.6	21.61	44.85	5.034	30.65	47.08	31.64
182	109	132.4	23.42	51.66	5.058	28.67	47.04	38.51
183	106	127.5	21.45	51.31	5.374	24.64	46.12	43.99
184	108	121.5	13.54	46.56	5.551	23.47	45.95	19.93
185	120	125.6	5.618	39.54	5.548	32.76	47.77	24.41
186	133	124.5	-8.53	32.23	5.358	39.26	47.61	27.29
187	132	115.1	-16.9	25.67	5.03	37.86	46.54	23.67
188	120	104.4	-15.6	20.91	4.848	33.15	45.51	39.45
189	111	96.99	-14	18.98	5.692	27.51	44.82	42.88
190	109	91.06	-17.9	18.44	6.605	21.94	44.08	48.72
191	106	86.43	-19.6	18.21	7.786	17.03	43.4	48.72
192	112	83.29	-28.7	16.63	9.048	14.97	42.64	42.44
193	110	87.52	-22.5	14.09	9.23	21.14	43.06	27.8
194	100	87.3	-12.7	12.05	8.784	24.07	42.4	25.52
195	90.3	85.27	-5.03	10.43	8.105	25.07	41.66	30.77
196	81.8	80.04	-1.76	9.221	7.347	22.74	40.73	33.75
197	75.6	73.46	-2.14	7.798	6.681	19.17	39.81	37.63
198	71.4	67.23	-4.17	6.395	6.092	15.82	38.92	34.77
199	68.2	63.37	-4.83	5.247	5.835	14.16	38.12	45.74
200	67.1	59.64	-7.46	4.362	6.028	11.85	37.39	52.16
201	69.1	56.49	-12.6	3.714	6.517	9.54	36.72	49.55
202	71.9	53.78	-18.1	3.209	7.052	7.452	36.06	43.81
203	73.1	54.56	-18.5	2.859	7.74	8.482	35.48	47.05

204	72.8	67.34	-5.46	2.645	8.698	19.55	36.45	51.73
205	74.5	70.27	-4.23	2.473	9.668	22.3	35.83	56.15
206	80.7	71.98	-8.72	2.188	10.36	24.11	35.33	45.36
207	85.2	74.6	-10.6	1.863	10.28	27.29	35.17	41.95
208	77.6	72.04	-5.56	1.574	10.27	25.67	34.53	52.66
209	76.7	68.51	-8.19	1.36	11.02	22.1	34.03	52.16
210	78.4	64.28	-14.1	1.151	11.56	18.09	33.48	43.79
211	77	59.13	-17.9	0.942	11.09	14.29	32.8	47.05
212	73.9	54.61	-19.3	0.757	10.61	11.02	32.23	49.55
213	70.8	51.02	-19.8	0.605	10.36	8.34	31.72	51.71
214	68.2	47.88	-20.3	0.482	9.998	6.223	31.18	49.95
215	68.5	45.4	-23.1	0.387	9.728	4.591	30.69	49.12
216	66.8	43.19	-23.6	0.313	9.332	3.355	30.18	50.48
217	69.1	42.72	-26.4	0.255	8.983	3.77	29.71	31.94
218	71.9	44.78	-27.1	0.204	8.392	6.909	29.28	34.52
219	68.2	44.17	-24	0.167	7.747	7.536	28.72	38.62
220	65.4	43.4	-22	0.14	7.943	6.977	28.34	37.35
221	64.8	42.05	-22.8	0.122	8.084	5.954	27.89	47.95
222	63.1	40.6	-22.5	0.102	8.206	4.838	27.46	46.72
223	62.9	38.86	-24	0.084	7.98	3.804	26.99	45.42
224	62.3	37.72	-24.6	0.069	8.094	2.922	26.63	38.99
225	58.3	36	-22.3	0.055	7.601	2.205	26.13	35.39
226	55.2	35.07	-20.1	0.046	7.579	1.642	25.8	49.47
227	55.5	43.96	-11.5	0.04	8.288	9.677	25.96	47.77
228	61.4	46.36	-15	0.034	8.57	12.21	25.55	44.97
229	60.3	45.07	-15.2	0.029	8.034	11.97	25.04	37.51
230	55.5	44.5	-11	0.024	7.525	12.31	24.64	40.97
231	53.2	44.55	-8.65	0.022	8.877	11.21	24.44	30.53
232	53	45.41	-7.59	0.081	8.718	12.53	24.09	36.22
233	52.1	52.53	0.433	0.123	10.25	17.94	24.22	43.85
234	56.1	52.79	-3.31	0.131	10.48	18.35	23.83	44.97
235	56.6	50.25	-6.35	0.126	10.17	16.49	23.46	53.23
236	56.9	47.78	-9.12	0.115	10.56	13.83	23.27	55.92
237	58	46.26	-11.7	0.099	11.92	11.12	23.13	55.11
238	57.2	43	-14.2	0.082	11.53	8.672	22.71	40.79
239	54.9	39.57	-15.3	0.065	10.55	6.623	22.33	38.82
240	51.8	36.54	-15.3	0.142	9.006	5.491	21.9	20.89
241	49	40.42	-8.58	0.339	7.32	10	22.76	22.93
242	44.5	41.63	-2.87	2.361	5.941	10.89	22.43	31.66
243	40.8	40.69	-0.11	3.906	4.722	10.08	21.98	37.54
244	38.8	40.15	1.355	6.07	3.828	8.6	21.66	38.1
245	38.5	40.42	1.916	8.841	3.218	6.986	21.37	39.59
246	38.8	41.26	2.462	10.18	2.665	7.285	21.13	27.51
247	38.5	40.68	2.179	10.86	2.277	6.698	20.84	14.57
248	37.1	39.66	2.56	11.32	1.998	5.797	20.55	18.77
249	35.4	38.19	2.79	11.43	1.784	4.752	20.22	24.13
250	33.1	36.27	3.173	11.15	1.543	3.76	19.82	35.97
251	32	35.13	3.129	11.32	1.434	2.901	19.48	43.77
252	31.4	35.4	3.999	12.47	1.498	2.197	19.24	41.34
253	32	37.11	5.112	14.58	1.805	1.64	19.09	45.97
254	34	39.27	5.273	16.66	2.444	1.21	18.96	47.73
255	37.4	52.56	15.16	18.26	3.154	11.11	20.03	44.57
256	42.2	61.47	19.27	21.39	4.233	15.56	20.29	25.31
257	45	60.33	15.33	20.42	4.242	15.81	19.86	5.228
258	42.5	55.1	12.6	17.72	3.775	14.17	19.44	1.385
259	38.5	48.6	10.1	14.55	3.148	11.86	19.04	10.38
260	35.7	42.76	7.064	11.7	2.52	9.892	18.65	26.77
261	33.7	45.28	11.58	14.36	2.238	8.963	19.72	28.93
262	33.1	52.02	18.92	21.11	2.302	7.555	21.05	20.54
263	33.7	50.73	17.03	21.77	2.075	6.272	20.6	14.3
264	33.1	47.06	13.96	20.02	1.757	5.005	20.28	18.93

265	32.3	44.02	11.72	17.19	1.426	5.226	20.17	17.09
266	31.7	42.59	10.89	14.11	1.121	7.071	20.29	17.97
267	32.8	39.23	6.43	11.37	0.868	7.128	19.87	16.14
268	32.6	36.4	3.798	9.712	0.685	6.363	19.64	17.21
269	31.7	32.98	1.278	7.907	0.527	5.319	19.22	17.36
270	30.6	29.75	-0.85	6.263	0.399	4.265	18.82	23.11
271	29.7	26.97	-2.73	4.9	0.299	3.329	18.44	21.93
272	29.4	24.61	-4.79	3.76	0.222	2.562	18.06	18.23
273	32.6	22.71	-9.89	2.895	0.164	1.955	17.7	17.79

1969 calibration forced by climate scenario 1								
Julian Day	Observed (cumecs)	Modelled (cumecs)	Residual (cumecs)	Snowmelt (cumecs)	Icemelt (cumecs)	Rainfall (cumecs)	Groundwater (cumecs)	evapo-transpiration (mm/day x 10)
274	31.4	30.9	-0.5	0.018	0	0.081	30.8	8.222
275	31.4	30.49	-0.91	0.029	0	0.157	30.31	13.97
276	30	31.33	1.333	0.133	0	1.359	29.84	27.89
277	29.4	32.85	3.451	0.294	0.01	3.01	29.54	16.56
278	28.9	34.92	6.022	0.951	0.073	4.325	29.57	12.37
279	27.8	35.35	7.547	1.224	0.112	4.803	29.21	13.54
280	27.3	34.69	7.385	1.263	0.119	4.548	28.75	9.983
281	26.6	33.88	7.277	1.188	0.109	4.269	28.31	9.392
282	26.1	32.83	6.732	1.062	0.092	3.801	27.88	10.21
283	25.6	31.88	6.285	0.956	0.075	3.398	27.46	7.961
284	25.4	30.76	5.357	0.808	0.06	2.848	27.04	4.194
285	24.9	29.83	4.927	0.699	0.046	2.445	26.64	7.961
286	25.1	29.27	4.172	0.65	0.035	2.135	26.45	8.983
287	24.7	28.41	3.714	0.56	0.026	1.767	26.06	9.577
288	23.6	27.57	3.971	0.46	0.019	1.412	25.68	5.458
289	22.9	26.79	3.89	0.368	0.014	1.102	25.31	7.327
290	22.2	26.24	4.036	0.41	0.01	0.873	24.94	14.13
291	22	26.91	4.908	1.107	0.008	0.755	25.04	13.54
292	21.1	26.95	5.852	1.499	0.008	0.709	24.74	9.577
293	20.7	26.78	6.079	1.661	0.008	0.727	24.38	11.93
294	20.5	26.27	5.775	1.562	0.007	0.668	24.04	7.747
295	20.1	25.67	5.566	1.372	0.005	0.588	23.7	7.236
296	19.7	25.1	5.397	1.172	0.004	0.55	23.37	12.37
297	19.7	33.64	13.94	6.203	0.05	0.864	26.52	22.73
298	19.9	37.98	18.08	8.862	0.076	2.159	26.88	18.16
299	20.1	38.16	18.06	9.091	0.079	2.538	26.45	8.631
300	19.4	37.06	17.66	8.2	0.071	2.708	26.08	15.07
301	19.4	48.26	28.86	9.183	0.095	10.1	28.87	14.72
302	19.5	57.42	37.92	8.826	0.104	18.98	29.52	26.92
303	19.7	60.02	40.32	8.447	0.123	21.97	29.47	17.74
304	19.7	57.32	37.62	7.35	0.118	20.89	28.96	8.393
305	18.7	52.69	33.99	6.046	0.103	18.09	28.46	6.565
306	16.5	47.68	31.18	4.794	0.084	14.83	27.97	1.906
307	18.2	43.03	24.83	3.721	0.067	11.75	27.49	4.697
308	18.3	39	20.7	2.832	0.052	9.085	27.03	7.961
309	16.5	35.63	19.13	2.123	0.039	6.89	26.57	4.444
310	15.1	32.88	17.78	1.572	0.029	5.149	26.13	2.667
311	13.3	30.68	17.38	1.152	0.022	3.803	25.7	1.906
312	12.9	28.92	16.02	0.837	0.016	2.782	25.29	0.904
313	14.4	27.51	13.11	0.605	0.011	2.02	24.88	4.893
314	14.7	26.38	11.68	0.434	0.008	1.456	24.48	1.906
315	14.9	25.45	10.55	0.31	0.006	1.044	24.09	1.906
316	15.7	24.69	8.99	0.22	0.004	0.749	23.72	0.287
317	16.3	24.04	7.742	0.156	0.003	0.535	23.35	1.906
318	15.3	23.48	8.181	0.11	0.002	0.381	22.99	0.062
319	15.6	22.99	7.386	0.077	0.001	0.27	22.64	0.122
320	14	22.54	8.541	0.054	0.001	0.19	22.29	0
321	10.6	22.13	11.53	0.038	0.001	0.134	21.96	0
322	10.2	21.76	11.56	0.027	0.001	0.094	21.64	0
323	12.4	21.4	9.002	0.019	0	0.066	21.32	0.062
324	15.3	21.18	5.875	0.029	0	0.072	21.07	6.854
325	15	21.18	6.177	0.29	0	0.114	20.77	6.22
326	14.6	21.12	6.519	0.419	0	0.146	20.55	6.22
327	14.2	20.84	6.64	0.43	0	0.143	20.27	1.906
328	13.8	20.49	6.693	0.387	0	0.126	19.98	1.906
329	13.3	20.13	6.83	0.325	0	0.105	19.7	0

330	12.9	19.77	6.871	0.261	0	0.084	19.43	1.906
331	12.5	19.43	6.928	0.204	0	0.065	19.16	1.906
332	12.1	19.1	7.003	0.156	0	0.049	18.9	0.587
333	12	19.19	7.19	0.117	0	0.076	19	2.667
334	11.9	18.9	7.003	0.087	0	0.079	18.74	0.062
335	11.8	18.62	6.819	0.064	0	0.072	18.48	0
336	11.8	18.34	6.542	0.046	0	0.061	18.23	0
337	11.7	18.07	6.374	0.034	0	0.049	17.99	0.287
338	11.6	17.82	6.216	0.024	0	0.038	17.75	0
339	11.4	17.57	6.168	0.017	0	0.029	17.52	0
340	11.3	17.33	6.028	0.012	0	0.022	17.29	0
341	11.2	17.1	5.897	0.009	0	0.016	17.07	0
342	11	16.87	5.872	0.006	0	0.012	16.85	1.906
343	11	16.65	5.654	0.004	0	0.009	16.64	0.587
344	10.9	16.44	5.542	0.003	0	0.006	16.43	0.587
345	10.8	16.24	5.436	0.002	0	0.005	16.23	0
346	10.7	16.03	5.334	0.001	0	0.003	16.03	0
347	10.6	15.84	5.237	0.001	0	0.002	15.83	0
348	10.6	15.64	5.044	0.001	0	0.002	15.64	0
349	10.5	15.46	4.956	0	0	0.001	15.45	0
350	10.4	15.27	4.872	0	0	0.001	15.27	0
351	10.4	15.09	4.691	0	0	0.001	15.09	0
352	10.3	14.91	4.614	0	0	0	14.91	0
353	10.3	14.74	4.441	0	0	0	14.74	0
354	10.1	14.57	4.471	0	0	0	14.57	0
355	10	14.41	4.405	0	0	0	14.4	0
356	9.88	14.24	4.362	0	0	0	14.24	0
357	9.77	14.08	4.312	0	0	0	14.08	0
358	9.66	13.92	4.265	0	0	0	13.92	0
359	9.6	13.77	4.171	0	0	0	13.77	0
360	9.54	13.62	4.08	0	0	0	13.62	0
361	9.49	13.47	3.981	0	0	0	13.47	0
362	9.43	13.33	3.896	0	0	0	13.33	0
363	9.37	13.18	3.813	0	0	0	13.18	0
364	9.32	13.04	3.722	0	0	0	13.04	0
365	9.34	12.9	3.564	0	0	0	12.9	0
1	9.4	12.77	3.369	0	0	0	12.77	0
2	9.54	12.64	3.096	0	0	0	12.64	0
3	9.63	12.51	2.875	0	0	0	12.51	0
4	9.77	12.38	2.607	0	0	0	12.38	0.287
5	9.77	12.25	2.48	0	0	0	12.25	0.587
6	9.77	12.13	2.356	0	0	0	12.13	0
7	9.68	12	2.324	0	0	0	12	0
8	9.54	11.88	2.344	0	0	0	11.88	0
9	9.43	11.77	2.336	0	0	0	11.77	0
10	9.43	11.65	2.22	0	0	0	11.65	0
11	9.43	11.54	2.106	0	0	0	11.54	0
12	9.49	11.42	1.933	0	0	0	11.42	0
13	9.63	11.31	1.682	0	0	0	11.31	0
14	9.85	11.2	1.354	0	0	0	11.2	0
15	10	11.1	1.096	0	0	0	11.1	0
16	9.91	10.99	1.081	0	0	0	10.99	0
17	9.85	10.89	1.037	0	0	0	10.89	0
18	9.63	10.78	1.155	0	0	0	10.78	0
19	9.57	10.68	1.114	0	0	0	10.68	0
20	9.49	10.58	1.094	0	0	0	10.58	0
21	9.26	10.49	1.226	0	0	0	10.49	0
22	9.06	10.39	1.33	0	0	0	10.39	0
23	8.92	10.3	1.375	0	0	0	10.3	0
24	8.69	10.2	1.511	0	0	0	10.2	0
25	8.5	10.11	1.609	0	0	0	10.11	0

26	8.27	10.02	1.748	0	0	0	10.02	0
27	8.07	9.928	1.858	0	0	0	9.928	0
28	7.82	9.84	2.02	0	0	0	9.84	0
29	7.62	9.752	2.132	0	0	0	9.752	0
30	7.59	9.666	2.076	0	0	0	9.666	0
31	7.5	9.581	2.081	0	0	0	9.581	0
32	7.5	9.497	1.997	0	0	0	9.497	0
33	7.56	9.415	1.855	0	0	0	9.415	0
34	7.59	9.333	1.743	0	0	0	9.333	0
35	7.65	9.252	1.602	0	0	0	9.252	1.906
36	7.7	9.173	1.473	0	0	0	9.173	0.904
37	7.73	9.094	1.364	0	0	0	9.094	0
38	7.84	9.017	1.177	0	0	0	9.017	0
39	7.93	8.94	1.01	0	0	0	8.94	0.904
40	8.13	8.864	0.734	0	0	0	8.864	0.904
41	8.27	8.79	0.52	0	0	0	8.79	0.287
42	8.41	8.716	0.306	0	0	0	8.716	1.906
43	8.52	8.643	0.123	0	0	0	8.643	5.84
44	8.69	8.571	-0.12	0	0	0	8.571	0.587
45	8.72	8.5	-0.22	0	0	0	8.5	0
46	8.81	8.43	-0.38	0	0	0	8.43	0.587
47	8.83	8.36	-0.47	0	0	0	8.36	3.302
48	8.86	8.291	-0.57	0	0	0	8.291	4.697
49	8.92	8.223	-0.7	0	0	0	8.223	3.302
50	8.86	8.156	-0.7	0	0	0	8.156	2.667
51	8.75	8.09	-0.66	0	0	0	8.09	1.906
52	8.58	8.024	-0.56	0	0	0	8.024	1.334
53	8.44	7.959	-0.48	0	0	0	7.959	0
54	8.24	7.895	-0.34	0	0	0	7.895	0
55	8.04	7.832	-0.21	0	0	0	7.832	0
56	7.93	7.769	-0.16	0	0	0	7.769	0
57	7.73	7.707	-0.02	0	0	0	7.707	0.287
58	7.67	7.645	-0.02	0	0	0	7.645	0.904
59	7.65	7.585	-0.07	0	0	0	7.585	1.334
60	7.62	7.525	-0.1	0	0	0	7.525	4.697
61	7.65	7.465	-0.18	0	0	0	7.465	5.84
62	7.65	7.406	-0.24	0	0	0	7.406	13.17
63	7.67	7.348	-0.32	0	0	0	7.348	7.615
64	7.7	7.29	-0.41	0	0	0	7.29	2.667
65	7.73	7.233	-0.5	0	0	0	7.233	0.587
66	7.76	7.177	-0.58	0	0	0	7.177	0
67	7.76	7.121	-0.64	0	0	0	7.121	0
68	7.79	7.065	-0.72	0	0	0	7.065	0
69	7.82	7.01	-0.81	0	0	0	7.01	6.854
70	7.84	6.956	-0.88	0	0	0	6.956	9.142
71	7.87	6.902	-0.97	0	0	0	6.902	13.17
72	7.9	6.849	-1.05	0	0	0	6.849	9.357
73	7.9	6.796	-1.1	0	0	0	6.796	4.697
74	7.93	6.766	-1.16	0.02	0	0.002	6.744	5.458
75	7.9	8.986	1.086	0.645	0	0.051	8.29	10.54
76	7.87	9.784	1.914	1.022	0	0.235	8.527	9.94
77	7.84	10.06	2.218	1.135	0	0.326	8.597	6.415
78	7.82	10.64	2.823	1.198	0	0.358	9.086	6.22
79	7.79	11.05	3.263	1.229	0	0.36	9.464	7.236
80	7.82	10.95	3.132	1.138	0	0.33	9.484	6.986
81	7.84	10.6	2.757	0.971	0	0.28	9.346	3.302
82	7.84	10.28	2.439	0.789	0	0.227	9.263	2.667
83	7.87	9.929	2.059	0.62	0	0.178	9.13	4.063
84	7.9	9.621	1.721	0.476	0	0.145	9	11.93
85	7.9	9.588	1.688	0.468	0	0.146	8.974	17.13
86	8.21	9.394	1.184	0.412	0	0.13	8.852	12.37

87	8.13	9.178	1.048	0.342	0	0.109	8.728	9.142
88	8.04	8.966	0.926	0.272	0	0.087	8.606	4.67
89	7.99	8.807	0.817	0.225	0	0.095	8.488	19.56
90	7.99	12.38	4.389	1.287	0	0.157	10.93	15.58
91	8.21	15.09	6.882	2.392	0	0.238	12.46	11.77
92	8.27	18.38	10.11	3.528	0	0.333	14.52	8.722
93	8.21	20.07	11.86	4.091	0	0.396	15.58	7.631
94	8.1	21.43	13.33	4.575	0	0.468	16.38	14.93
95	7.99	24.98	16.99	6.417	0.001	0.58	17.98	26.77
96	8.13	26.62	18.49	7.55	0.001	0.705	18.36	28.33
97	8.72	33.53	24.81	9.866	0.001	0.889	22.77	12.94
98	9.15	34.56	25.41	10.52	0.002	1.029	23.02	20.57
99	9.34	40.68	31.34	13.47	0.003	1.141	26.07	20.36
100	9.68	41.62	31.94	14.48	0.003	1.233	25.9	24.89
101	10.1	41.44	31.34	14.42	0.003	1.304	25.71	23.37
102	10.4	41.07	30.67	14.13	0.003	1.359	25.58	27.53
103	10.7	41.51	30.81	14.07	0.007	1.398	26.03	15.41
104	10.8	41.39	30.59	13.85	0.01	1.43	26.1	17.09
105	10.7	41.2	30.5	13.47	0.012	1.681	26.03	18.97
106	10.6	41.37	30.77	13.4	0.013	2.068	25.88	21.93
107	10.6	56.58	45.98	22.75	0.038	2.485	31.3	21.6
108	10.9	63.94	53.04	28.12	0.058	2.916	32.84	14.09
109	10.9	63.21	52.31	27.78	0.065	2.992	32.38	6.601
110	11	60.14	49.14	25.23	0.066	2.799	32.05	7.236
111	10.8	59.91	49.11	24.08	0.07	3.038	32.72	23
112	10.6	76.48	65.88	35.34	0.094	4.038	37	35.37
113	11.9	111.6	99.7	50.58	0.137	16.52	44.36	22.58
114	19.3	120.7	101.4	53.06	0.151	22.08	45.43	13.8
115	23.5	115.3	91.82	48.61	0.145	22.19	44.38	7.961
116	23.4	106.7	83.31	42.48	0.134	20.17	43.93	17.74
117	23.1	98.81	75.71	36.96	0.123	17.92	43.8	23.97
118	23.2	106.1	82.86	33.71	0.116	25.93	46.3	23.8
119	25.9	110.2	84.28	29.34	0.111	30.65	50.08	10.03
120	26.8	104.4	77.62	24.48	0.101	29.61	50.23	9.435
121	25.8	96.92	71.12	20.86	0.098	26.32	49.64	23.69
122	25.2	89.93	64.73	18.16	0.098	22.09	49.58	13.37
123	25.4	83.83	58.43	16.03	0.096	18.29	49.41	16.35
124	24.9	79.2	54.3	15.58	0.1	14.58	48.95	20.99
125	23.8	77.39	53.59	17.76	0.099	11.31	48.22	29.64
126	24.3	81.74	57.44	23.12	0.105	9.922	48.6	33.47
127	26.7	84.27	57.57	27.84	0.107	8.206	48.12	33.74
128	29.2	89.33	60.13	34.52	0.115	6.533	48.17	45.05
129	34.8	96.83	62.03	42.98	0.13	5.065	48.66	48.83
130	44.7	104.5	59.77	51.51	0.149	3.851	48.96	50.6
131	57.2	116.7	59.51	62.14	0.179	4.275	50.12	49.61
132	70.5	124.7	54.21	70.04	0.202	3.989	50.48	47.36
133	81	131.2	50.24	76.59	0.22	3.419	51.01	47.89
134	92.3	132.1	39.84	74.02	0.216	6.864	51.04	30.89
135	86.7	123.2	36.52	65.61	0.197	7.656	49.75	15.49
136	75.6	110.8	35.15	54.81	0.17	7.317	48.45	12.43
137	66.3	99.94	33.64	45.42	0.15	6.354	48.01	33.34
138	62.3	91.75	29.45	38.46	0.143	5.227	47.93	26.99
139	59.7	84.39	24.69	32.75	0.136	4.146	47.36	17.42
140	57.5	82.99	25.49	31.95	0.137	3.205	47.7	29.51
141	60.9	91.4	30.5	38.44	0.143	3.812	49.01	41.46
142	69.4	105.2	35.83	51.18	0.168	3.659	50.22	47.11
143	83.5	120.3	36.79	65.6	0.2	3.184	51.31	52.04
144	109	145.9	36.95	82.22	0.241	9.493	53.99	54.3
145	140	169.3	29.26	98.76	0.297	13.77	56.44	42.45
146	166	190.5	24.46	108.9	0.36	22.04	59.2	26
147	145	194	49.04	106.4	0.377	27.72	59.53	24.47

148	119	185.9	66.88	99.19	0.368	27.3	59.02	27.93
149	100	186.3	86.28	98.49	0.388	26.56	60.84	24.47
150	90.3	181.4	91.14	95.26	0.396	24.57	61.21	24.73
151	83.8	181.9	98.12	98.01	0.394	21.1	62.42	41.01
152	85.5	193.6	108.1	109.7	0.404	18.62	64.91	46.08
153	95.7	208.8	113.1	125.7	0.408	15.45	67.24	53.78
154	133	232.2	99.16	149.8	0.456	12.32	69.54	56.62
155	168	258.1	90.09	176.3	0.473	9.567	71.75	62.8
156	197	280.5	83.46	198.6	0.571	7.28	73.99	65.7
157	203	293.9	90.86	208.2	0.788	9.624	75.26	50.74
158	191	291.3	100.3	205.2	0.965	9.624	75.51	35.82
159	165	283	118	197.9	1.064	8.565	75.51	55.85
160	154	280.8	126.8	194	1.162	9.201	76.41	59.04
161	157	281.3	124.3	194.1	1.328	8.507	77.33	52.33
162	158	271.8	113.8	184.8	1.372	9.284	76.3	51.13
163	147	249.5	102.5	165	1.288	8.604	74.61	29.29
164	127	231.6	104.6	149.5	1.198	7.35	73.57	46.55
165	114	219.8	105.8	139.6	1.447	5.98	72.78	51.51
166	108	216.5	108.5	137.1	2.362	4.709	72.33	50.52
167	106	211.9	105.9	131.8	3.66	4.892	71.5	63.27
168	107	208.2	101.2	127.6	5.512	4.432	70.72	65.7
169	117	207.2	90.16	125.6	7.823	3.736	70.02	70.34
170	135	211	75.97	119.5	9.664	11.67	70.15	47.32
171	140	211.4	71.41	104.9	10.32	25.75	70.46	34.84
172	141	201.3	60.32	89.38	10.86	31.84	69.24	43.3
173	131	186.2	55.18	75.5	11.61	31.15	67.93	44.75
174	123	177.1	54.09	63.77	12.34	33.61	67.37	44.75
175	118	172.2	54.2	51.99	12.16	40.56	67.49	24.38
176	127	164.1	37.13	41.44	11.39	44.56	66.73	27.56
177	123	153	30.02	33.8	11.08	42.75	65.39	37.28
178	112	150.6	38.57	28.31	11.11	45.87	65.28	41.92
179	109	144	34.95	26.7	10.06	42.56	64.63	15.08
180	107	149.7	42.74	35.44	9.23	39.08	65.98	39.43
181	106	154	48.01	43.74	8.853	35.71	65.7	34.22
182	109	152.9	43.88	45.26	8.789	34.04	64.79	40.83
183	106	145.8	39.83	43.77	8.969	29.55	63.54	46.31
184	108	139.6	31.57	39.36	9.192	27.99	63.02	22.25
185	120	145.7	25.68	34.1	9.445	37.61	64.53	26.73
186	133	146.2	13.19	28.81	9.429	43.88	64.08	29.61
187	132	139.2	7.176	24.02	9.19	43.19	62.78	25.99
188	120	128.3	8.304	19.9	8.814	38.22	61.37	41.77
189	111	118.8	7.757	16.89	9.745	31.89	60.23	45.2
190	109	109.1	0.103	14.02	10.54	25.54	59	51.04
191	106	100.8	-5.15	11.57	11.52	19.88	57.87	51.04
192	112	97.57	-14.4	9.556	12.6	18.54	56.88	44.76
193	110	102.1	-7.86	7.698	12.66	24.76	57.03	30.12
194	100	101.7	1.748	6.091	12.17	27.44	56.05	27.84
195	90.3	99.25	8.948	4.838	11.42	28	54.99	33.09
196	81.8	93.18	11.38	3.911	10.37	25.14	53.76	36.07
197	75.6	87.61	12.01	3.26	9.373	22.38	52.6	39.95
198	71.4	81.81	10.41	2.784	8.513	19.04	51.47	37.09
199	68.2	78.18	9.978	2.501	8.137	17.1	50.44	48.06
200	67.1	74.52	7.417	2.399	8.299	14.34	49.48	54.48
201	69.1	71.39	2.289	2.421	8.837	11.55	48.58	51.87
202	71.9	70.02	-1.88	2.451	9.57	10.26	47.74	46.13
203	73.1	71.39	-1.71	2.521	10.43	11.46	46.98	49.37
204	72.8	84.22	11.42	2.619	11.55	22.37	47.69	54.05
205	74.5	86.9	12.4	2.723	12.56	24.73	46.88	58.47
206	80.7	88.33	7.626	2.769	13.27	26.11	46.17	47.68
207	85.2	92.06	6.863	2.565	13.21	30.23	46.06	44.27
208	77.6	89.37	11.77	2.278	13.15	28.71	45.23	54.98

209	76.7	85.56	8.864	2.014	14.18	24.84	44.53	54.48
210	78.4	80.87	2.474	1.76	14.9	20.39	43.82	46.11
211	77	75.01	-1.99	1.511	14.38	16.15	42.97	49.37
212	73.9	69.75	-4.15	1.256	13.8	12.47	42.23	51.87
213	70.8	66.75	-4.05	1.027	13.52	10.63	41.57	53.89
214	68.2	63.43	-4.77	0.83	13.1	8.632	40.86	52.13
215	68.5	60.48	-8.02	0.67	12.81	6.785	40.22	51.3
216	66.8	57.66	-9.14	0.543	12.36	5.211	39.55	52.66
217	69.1	56.76	-12.3	0.442	12.02	5.36	38.94	34.12
218	71.9	59.91	-12	0.359	11.48	9.579	38.5	36.7
219	68.2	59.34	-8.86	0.294	10.84	10.39	37.81	40.8
220	65.4	58.4	-7	0.247	11.25	9.595	37.3	39.53
221	64.8	56.55	-8.25	0.216	11.44	8.176	36.72	50.13
222	63.1	54.56	-8.54	0.196	11.56	6.637	36.16	48.9
223	62.9	53.43	-9.47	0.178	11.3	6.372	35.58	47.6
224	62.3	52.29	-10	0.166	11.48	5.547	35.1	41.17
225	58.3	50.2	-8.1	0.151	10.99	4.563	34.49	37.57
226	55.2	48.78	-6.42	0.145	10.98	3.619	34.03	51.65
227	55.5	57.53	2.032	0.146	11.83	11.51	34.05	49.95
228	61.4	60.82	-0.58	0.142	12.12	15.01	33.55	47.15
229	60.3	59.28	-1.02	0.126	11.33	14.9	32.92	39.69
230	55.5	58.26	2.756	0.107	10.68	15.05	32.42	43.15
231	53.2	58.28	5.078	0.091	12.54	13.57	32.08	32.71
232	53	58.61	5.605	0.081	12.38	14.53	31.61	38.4
233	52.1	67.85	15.75	0.073	14.42	21.16	32.19	46.03
234	56.1	68.21	12.11	0.064	14.71	21.75	31.69	47.15
235	56.6	65.08	8.483	0.056	14.21	19.59	31.22	55.41
236	56.9	61.73	4.83	0.051	14.31	16.46	30.91	58.1
237	58	59.71	1.707	0.05	15.8	13.24	30.62	57.29
238	57.2	57.07	-0.13	0.045	15.35	11.56	30.12	42.97
239	54.9	53.49	-1.41	0.039	14.26	9.532	29.65	41
240	51.8	49.87	-1.93	0.07	12.49	8.176	29.14	23.07
241	49	57.32	8.316	0.115	10.35	16.54	30.3	25.11
242	44.5	58.01	13.51	0.744	8.976	18.42	29.87	33.84
243	40.8	55.25	14.45	1.2	7.537	17.21	29.31	39.72
244	38.8	53.3	14.5	1.879	6.564	15.98	28.88	40.1
245	38.5	50.67	12.17	2.643	5.918	13.66	28.45	41.59
246	38.8	49.47	10.67	3.059	5.385	12.98	28.04	29.51
247	38.5	47.26	8.76	3.151	5.112	11.36	27.64	16.57
248	37.1	44.73	7.634	3.103	4.91	9.5	27.22	20.77
249	35.4	43.75	8.348	3.13	4.861	8.886	26.87	26.13
250	33.1	41.58	8.484	3.042	4.518	7.626	26.4	37.97
251	32	39.67	7.671	3.165	4.291	6.219	26	45.77
252	31.4	38.4	6.998	3.568	4.271	4.903	25.66	43.34
253	32	37.4	5.399	3.816	4.473	3.773	25.34	47.97
254	34	37.94	3.938	3.869	5.024	3.945	25.1	49.73
255	37.4	50.01	12.61	3.824	5.824	14.14	26.22	46.57
256	42.2	55.84	13.64	3.937	7.381	18.43	26.09	27.31
257	45	54.71	9.708	3.574	7.253	18.31	25.57	7.222
258	42.5	50.69	8.193	3.016	6.39	16.22	25.06	2.549
259	38.5	45.82	7.316	2.449	5.297	13.5	24.57	12.38
260	35.7	43.97	8.267	4.086	4.248	11.19	24.44	28.77
261	33.7	63.21	29.51	20.21	4.102	10.01	28.88	30.93
262	33.1	82.15	49.05	38.23	4.464	8.377	31.08	22.54
263	33.7	85.33	51.63	42.49	4.153	7.856	30.82	16.3
264	33.1	87.72	54.62	44.21	3.861	8.089	31.56	20.93
265	32.3	86.52	54.22	41.85	3.45	9.543	31.68	19.09
266	31.7	85.05	53.35	37.02	2.98	13.2	31.86	19.97
267	32.8	79.57	46.77	32.2	2.583	13.38	31.41	18.14
268	32.6	73.85	41.25	28.54	2.393	11.98	30.94	19.21
269	31.7	66.94	35.24	23.74	2.042	10.82	30.34	19.36

270	30.6	59.42	28.82	18.98	1.66	9.1	29.69	25.11
271	29.7	53.62	23.92	15.69	1.454	7.333	29.15	23.93
272	29.4	48.35	18.95	12.73	1.255	5.813	28.55	20.23
273	32.6	44.06	11.46	10.46	1.109	4.511	27.99	19.79

1969 calibration forced by climatic scenario 2

Julian Day	Observed (cumecs)	Modelled (cumecs)	Residual (cumecs)	Snowmelt (cumecs)	Icemelt (cumecs)	Rainfall (cumecs)	Groundwater (cumecs)	evapo-transpiration (mm/day x 10)
274	31.4	30.64	-0.76	0.012	0	0.014	30.61	53.78
275	31.4	30.2	-1.2	0.048	0	0.022	30.13	148.7
276	30	29.83	-0.17	0.062	0	0.112	29.65	203.4
277	29.4	29.48	0.075	0.063	0	0.223	29.19	91.78
278	28.9	29.13	0.225	0.068	0.008	0.302	28.75	48.01
279	27.8	28.7	0.903	0.066	0.014	0.315	28.31	46.61
280	27.3	28.24	0.941	0.059	0.015	0.289	27.88	45.24
281	26.6	27.81	1.21	0.06	0.014	0.279	27.46	83.4
282	26.1	27.37	1.275	0.062	0.012	0.253	27.05	58.99
283	25.6	26.98	1.379	0.079	0.009	0.242	26.65	41.26
284	25.4	26.55	1.154	0.079	0.007	0.21	26.26	39.98
285	24.9	26.14	1.244	0.071	0.006	0.191	25.88	45.36
286	25.1	25.88	0.784	0.09	0.004	0.207	25.58	37.48
287	24.7	25.5	0.8	0.089	0.003	0.191	25.22	86.01
288	23.6	25.1	1.503	0.078	0.002	0.163	24.86	35.08
289	22.9	24.71	1.809	0.065	0.002	0.132	24.51	64.44
290	22.2	24.39	2.187	0.111	0.001	0.105	24.17	77.72
291	22	24.13	2.127	0.204	0.001	0.085	23.84	31.66
292	21.1	23.85	2.747	0.266	0.001	0.069	23.51	30.56
293	20.7	23.57	2.867	0.315	0	0.058	23.19	48.45
294	20.5	23.23	2.733	0.304	0	0.047	22.88	33.33
295	20.1	22.88	2.782	0.266	0	0.038	22.58	27.43
296	19.7	22.54	2.84	0.228	0	0.032	22.28	62.69
297	19.7	24.48	4.777	1.882	0.009	0.047	22.54	29.83
298	19.9	25.06	5.163	2.726	0.012	0.086	22.24	68.66
299	20.1	24.85	4.753	2.802	0.012	0.095	21.94	32.7
300	19.4	24.3	4.899	2.537	0.011	0.095	21.66	85.95
301	19.4	27.95	8.552	3.064	0.013	2.785	22.09	21.83
302	19.5	34.53	15.03	3.31	0.013	8.648	22.56	79.44
303	19.7	35.77	16.07	3.123	0.012	10.38	22.25	20.16
304	19.7	34.65	14.95	2.693	0.011	10	21.95	22.68
305	18.7	32.58	13.88	2.203	0.009	8.72	21.65	48.07
306	16.5	30.29	13.79	1.741	0.007	7.182	21.36	29.31
307	18.2	28.12	9.92	1.342	0.005	5.701	21.07	17.11
308	18.3	26.22	7.922	1.015	0.004	4.409	20.79	30.47
309	16.5	24.63	8.126	0.757	0.003	3.345	20.52	48.09
310	15.1	23.32	8.215	0.559	0.002	2.501	20.25	53.83
311	13.3	22.25	8.95	0.408	0.002	1.847	19.99	57.75
312	12.9	21.39	8.487	0.296	0.001	1.352	19.74	16.2
313	14.4	20.68	6.283	0.213	0.001	0.981	19.49	34.23
314	14.7	20.1	5.404	0.153	0.001	0.708	19.24	20.82
315	14.9	19.62	4.721	0.109	0	0.507	19	12.13
316	15.7	19.21	3.509	0.077	0	0.362	18.77	11.6
317	16.3	18.85	2.552	0.055	0	0.257	18.54	11.1
318	15.3	18.54	3.236	0.039	0	0.182	18.32	10.61
319	15.6	18.25	2.651	0.027	0	0.128	18.1	10.15
320	14	17.99	3.989	0.019	0	0.09	17.88	15.95
321	10.6	17.74	7.145	0.013	0	0.063	17.67	37.13
322	10.2	17.51	7.315	0.009	0	0.044	17.46	14.59
323	12.4	17.3	4.895	0.006	0	0.031	17.26	21.96
324	15.3	17.09	1.794	0.004	0	0.031	17.06	8.123
325	15	16.92	1.92	0.011	0	0.045	16.86	7.772
326	14.6	16.73	2.132	0.013	0	0.046	16.67	7.438
327	14.2	16.54	2.339	0.013	0	0.041	16.48	7.121
328	13.8	16.35	2.546	0.011	0	0.035	16.3	7.989
329	13.3	16.16	2.857	0.009	0	0.028	16.12	21.66

330	12.9	15.97	3.072	0.007	0	0.022	15.94	6.265
331	12.5	15.79	3.291	0.005	0	0.017	15.77	6.01
332	12.1	15.61	3.515	0.004	0	0.013	15.6	15.17
333	12	15.44	3.443	0.003	0	0.009	15.43	5.544
334	11.9	15.28	3.375	0.002	0	0.007	15.27	7.617
335	11.8	15.11	3.311	0.002	0	0.005	15.1	9.752
336	11.8	14.95	3.15	0.001	0	0.004	14.95	8.127
337	11.7	14.79	3.093	0.001	0	0.003	14.79	4.773
338	11.6	14.64	3.039	0.001	0	0.002	14.64	7.576
339	11.4	14.49	3.087	0	0	0.001	14.49	9.434
340	11.3	14.34	3.039	0	0	0.001	14.34	10.25
341	11.2	14.19	2.993	0	0	0.001	14.19	7.975
342	11	14.05	3.049	0	0	0	14.05	4.781
343	11	13.91	2.909	0	0	0	13.91	4.657
344	10.9	13.77	2.87	0	0	0	13.77	13.86
345	10.8	13.63	2.834	0	0	0	13.63	3.795
346	10.7	13.5	2.8	0	0	0	13.5	12.33
347	10.6	13.37	2.768	0	0	0	13.37	8.665
348	10.6	13.24	2.638	0	0	0	13.24	3.597
349	10.5	13.11	2.611	0	0	0	13.11	3.55
350	10.4	12.99	2.585	0	0	0	12.98	3.512
351	10.4	12.86	2.461	0	0	0	12.86	3.483
352	10.3	12.74	2.439	0	0	0	12.74	3.464
353	10.3	12.62	2.32	0	0	0	12.62	7.299
354	10.1	12.5	2.401	0	0	0	12.5	8.182
355	10	12.39	2.385	0	0	0	12.39	3.457
356	9.88	12.27	2.39	0	0	0	12.27	3.472
357	9.77	12.16	2.387	0	0	0	12.16	3.497
358	9.66	12.05	2.386	0	0	0	12.05	10.94
359	9.6	11.94	2.336	0	0	0	11.94	7.554
360	9.54	11.83	2.288	0	0	0	11.83	3.624
361	9.49	11.72	2.231	0	0	0	11.72	3.686
362	9.43	11.62	2.186	0	0	0	11.62	3.756
363	9.37	11.51	2.143	0	0	0	11.51	9.098
364	9.32	11.41	2.09	0	0	0	11.41	3.927
365	9.34	11.31	1.969	0	0	0	11.31	6.616
1	9.4	11.21	1.81	0	0	0	11.21	4.027
2	9.54	11.11	1.572	0	0	0	11.11	11.59
3	9.63	11.01	1.385	0	0	0	11.01	4.989
4	9.77	10.92	1.149	0	0	0	10.92	4.392
5	9.77	10.82	1.055	0	0	0	10.82	6.479
6	9.77	10.73	0.962	0	0	0	10.73	4.691
7	9.68	10.64	0.96	0	0	0	10.64	13.81
8	9.54	10.55	1.009	0	0	0	10.55	17.78
9	9.43	10.46	1.029	0	0	0	10.46	5.231
10	9.43	10.37	0.941	0	0	0	10.37	5.436
11	9.43	10.28	0.853	0	0	0	10.28	5.655
12	9.49	10.2	0.707	0	0	0	10.2	6.898
13	9.63	10.11	0.481	0	0	0	10.11	10.08
14	9.85	10.03	0.177	0	0	0	10.03	25.59
15	10	9.944	-0.06	0	0	0	9.944	20.41
16	9.91	9.861	-0.05	0	0	0	9.861	11.45
17	9.85	9.78	-0.07	0	0	0	9.78	10.08
18	9.63	9.7	0.07	0	0	0	9.7	19.98
19	9.57	9.62	0.05	0	0	0	9.62	7.945
20	9.49	9.541	0.051	0	0	0	9.541	25.75
21	9.26	9.464	0.204	0	0	0	9.464	22.45
22	9.06	9.387	0.327	0	0	0	9.387	36.31
23	8.92	9.311	0.391	0	0	0	9.311	37.97
24	8.69	9.236	0.546	0	0	0	9.236	20.99
25	8.5	9.162	0.662	0	0	0	9.161	17.05

26	8.27	9.088	0.818	0	0	0	9.088	10.85
27	8.07	9.015	0.945	0	0	0	9.015	11.35
28	7.82	8.943	1.123	0	0	0	8.943	27.62
29	7.62	8.872	1.252	0	0	0	8.872	26.21
30	7.59	8.802	1.212	0	0	0	8.802	30.71
31	7.5	8.732	1.232	0	0	0	8.732	54.12
32	7.5	8.663	1.163	0	0	0	8.663	25.03
33	7.56	8.595	1.035	0	0	0	8.595	19.18
34	7.59	8.528	0.938	0	0	0	8.528	15.4
35	7.65	8.461	0.811	0	0	0	8.461	43.61
36	7.7	8.395	0.695	0	0	0	8.395	67.03
37	7.73	8.329	0.599	0	0	0	8.329	69.89
38	7.84	8.264	0.424	0	0	0	8.264	72.84
39	7.93	8.2	0.27	0	0	0	8.2	75.89
40	8.13	8.137	0.007	0	0	0	8.137	25.69
41	8.27	8.074	-0.2	0	0	0	8.074	80.52
42	8.41	8.011	-0.4	0	0	0	8.011	63.6
43	8.52	7.95	-0.57	0	0	0	7.95	39.44
44	8.69	7.889	-0.8	0	0	0	7.889	25.13
45	8.72	7.828	-0.89	0	0	0	7.828	96.23
46	8.81	7.768	-1.04	0	0	0	7.768	99.96
47	8.83	7.709	-1.12	0	0	0	7.709	103.8
48	8.86	7.65	-1.21	0	0	0	7.65	107.7
49	8.92	7.592	-1.33	0	0	0	7.592	111.7
50	8.86	7.534	-1.33	0	0	0	7.534	115.9
51	8.75	7.477	-1.27	0	0	0	7.477	120.1
52	8.58	7.42	-1.16	0	0	0	7.42	124.4
53	8.44	7.364	-1.08	0	0	0	7.364	119.2
54	8.24	7.308	-0.93	0	0	0	7.308	133.4
55	8.04	7.253	-0.79	0	0	0	7.253	138
56	7.93	7.199	-0.73	0	0	0	7.199	115.2
57	7.73	7.145	-0.59	0	0	0	7.145	147.5
58	7.67	7.091	-0.58	0	0	0	7.091	152.4
59	7.65	7.038	-0.61	0	0	0	7.038	157.4
60	7.62	6.985	-0.63	0	0	0	6.985	162.5
61	7.65	6.933	-0.72	0	0	0	6.933	167.6
62	7.65	6.881	-0.77	0	0	0	6.881	172.9
63	7.67	6.83	-0.84	0	0	0	6.83	178.3
64	7.7	6.779	-0.92	0	0	0	6.779	45.93
65	7.73	6.728	-1	0	0	0	6.728	47.31
66	7.76	6.678	-1.08	0	0	0	6.678	48.71
67	7.76	6.629	-1.13	0	0	0	6.629	82.36
68	7.79	6.58	-1.21	0	0	0	6.58	133.4
69	7.82	6.531	-1.29	0	0	0	6.531	212.1
70	7.84	6.482	-1.36	0	0	0	6.482	218.1
71	7.87	6.435	-1.44	0	0	0	6.435	224.1
72	7.9	6.387	-1.51	0	0	0	6.387	230.2
73	7.9	6.34	-1.56	0	0	0	6.34	193.3
74	7.93	6.293	-1.64	0	0	0	6.293	60.63
75	7.9	6.299	-1.6	0.051	0	0.001	6.247	62.2
76	7.87	6.299	-1.57	0.09	0	0.008	6.201	63.78
77	7.84	6.266	-1.57	0.1	0	0.011	6.155	76.6
78	7.82	6.229	-1.59	0.108	0	0.012	6.11	67
79	7.79	6.19	-1.6	0.114	0	0.011	6.065	68.63
80	7.82	6.134	-1.69	0.104	0	0.01	6.021	82.33
81	7.84	6.072	-1.77	0.088	0	0.008	5.977	133.6
82	7.84	6.01	-1.83	0.071	0	0.006	5.933	73.61
83	7.87	5.95	-1.92	0.056	0	0.005	5.89	301.2
84	7.9	5.893	-2.01	0.043	0	0.004	5.847	307.9
85	7.9	5.846	-2.05	0.039	0	0.003	5.804	314.7
86	8.21	5.797	-2.41	0.033	0	0.003	5.761	321.6

87	8.13	5.748	-2.38	0.026	0	0.002	5.719	328.5
88	8.04	5.7	-2.34	0.021	0	0.002	5.678	277.9
89	7.99	5.654	-2.34	0.016	0	0.002	5.636	342.4
90	7.99	6.133	-1.86	0.163	0	0.01	5.961	87.34
91	8.21	6.473	-1.74	0.309	0	0.015	6.149	89.09
92	8.27	6.933	-1.34	0.463	0	0.03	6.439	89.09
93	8.21	7.133	-1.08	0.54	0	0.039	6.553	90.85
94	8.1	7.274	-0.83	0.645	0	0.039	6.553	92.61
95	7.99	7.742	-0.25	1.004	0	0.036	6.59	199.5
96	8.13	8.281	0.151	1.536	0	0.036	6.702	364
97	8.72	10.79	2.069	2.27	0.001	0.036	6.709	391.7
98	9.15	11.26	2.109	2.617	0.001	0.089	8.43	99.69
99	9.34	13.33	3.988	3.618	0.001	0.109	8.533	358
100	9.68	14.02	4.336	4.264	0.001	0.11	9.599	218.3
101	10.1	14.42	4.325	4.618	0.001	0.104	9.647	420.1
102	10.4	14.6	4.197	4.867	0.001	0.095	9.71	427.2
103	10.7	14.5	3.803	4.867	0.001	0.086	9.643	434.3
104	10.8	14.26	3.456	4.831	0.001	0.079	9.592	124.5
105	10.7	13.97	3.268	4.666	0.002	0.073	9.515	294.7
106	10.6	13.9	3.302	4.465	0.002	0.068	9.433	348.1
107	10.6	19.84	9.235	4.489	0.001	0.065	9.346	462.5
108	10.9	22.38	11.48	8.157	0.006	0.069	11.6	117.4
109	10.9	22.05	11.15	10.19	0.01	0.094	12.08	139.5
110	11	20.89	9.889	10.04	0.011	0.129	11.87	120.9
111	10.8	21.06	10.26	9.079	0.011	0.133	11.67	122.6
112	10.6	28.94	18.34	8.999	0.011	0.15	11.9	406.7
113	11.9	48.83	36.93	14.41	0.018	0.163	14.35	504.1
114	19.3	53.66	34.36	22.06	0.033	6.907	19.82	127.7
115	23.5	51.35	27.85	23.35	0.038	9.684	20.59	179.4
116	23.4	46.87	23.47	21.37	0.036	9.848	20.09	131.1
117	23.1	43.17	20.07	18.39	0.032	8.835	19.61	314.9
118	23.2	48.59	25.39	16.34	0.028	7.418	19.39	537.7
119	25.9	50.1	24.2	14.99	0.027	11.97	21.6	544.3
120	26.8	47.66	20.86	12.86	0.025	13.72	23.5	137.7
121	25.8	44	18.2	10.55	0.021	13.1	23.99	139.3
122	25.2	41.26	16.06	9.02	0.02	11.37	23.59	279.8
123	25.4	38.67	13.27	7.828	0.022	9.488	23.92	142.5
124	24.9	36.73	11.83	6.816	0.024	7.86	23.97	144.1
125	23.8	36.9	13.1	6.625	0.028	6.262	23.81	183
126	24.3	41.62	17.32	8.424	0.031	4.857	23.59	588.5
127	26.7	44.65	17.95	13.49	0.04	3.692	24.4	594.5
128	29.2	50.19	20.99	17.64	0.048	2.764	24.2	600.5
129	34.8	57.81	23.01	23.59	0.061	2.045	24.49	606.3
130	44.7	66.08	21.38	31.14	0.078	1.498	25.09	612.1
131	57.2	77.3	20.1	39.13	0.096	1.088	25.77	617.8
132	70.5	86.31	15.81	49.03	0.123	0.785	27.36	623.4
133	81	94.02	13.02	57.19	0.146	0.564	28.42	628.9
134	92.3	93.73	1.43	64.04	0.169	0.402	29.41	634.3
135	86.7	85.76	-0.94	61.24	0.172	2.551	29.77	427.2
136	75.6	75.75	0.146	53.35	0.158	3.243	29.01	161.2
137	66.3	66.69	0.389	44.06	0.136	3.275	28.27	162.5
138	62.3	58.2	-4.1	35.84	0.124	2.925	27.8	633.9
139	59.7	50.95	-8.75	28.52	0.117	2.452	27.11	320.5
140	57.5	47.63	-9.87	22.43	0.109	1.97	26.44	166.2
141	60.9	51.61	-9.29	19.87	0.104	1.537	26.12	325.1
142	69.4	61.79	-7.61	23.74	0.106	1.174	26.6	673.8
143	83.5	73.97	-9.53	33.11	0.119	0.883	27.68	678.3
144	109	97.11	-11.9	44.43	0.134	0.655	28.75	682.6
145	140	118.5	-21.5	58.34	0.156	7.067	31.55	686.8
146	166	135.2	-30.8	72.8	0.188	11.59	33.96	380
147	145	136.9	-8.06	80.58	0.221	18.18	36.25	173.7
				78.03	0.225	22	36.69	257

148	119	130.4	11.42	72.33	0.213	21.35	36.53	348.6
149	100	130.6	30.63	71.29	0.223	20.96	38.16	176.5
150	90.3	125.8	35.48	67.76	0.226	19.42	38.38	177.3
151	83.8	126.7	42.94	70.25	0.227	16.71	39.55	643.8
152	85.5	136.7	51.22	81.02	0.239	13.65	41.82	523.9
153	95.7	150.8	55.06	95.62	0.248	10.77	44.12	718.6
154	133	173.3	40.33	117.5	0.337	8.299	47.16	659.7
155	168	195.2	27.18	138.6	0.498	6.277	49.76	724.2
156	197	209.4	12.41	153.1	0.678	4.68	50.98	726.8
157	203	218.9	15.86	159.5	0.842	6.138	52.38	533.9
158	191	215.7	24.75	156	0.962	6.117	52.67	182.9
159	165	209.6	44.56	150.1	1.22	5.428	52.83	733.6
160	154	206.8	52.84	145.4	1.909	6.53	52.98	735.6
161	157	205.5	48.52	143.1	3.074	6.33	52.97	666.3
162	158	193.8	35.8	131.7	3.846	6.197	52.01	739.1
163	147	174.2	27.2	114	3.983	5.45	50.75	367.7
164	127	157.4	30.36	98.81	4.187	4.513	49.85	742
165	114	144.5	30.51	87.3	4.541	3.594	49.08	743.2
166	108	137.2	29.22	80.55	5.309	2.787	48.57	720.4
167	106	129.3	23.26	73.19	6.215	2.118	47.74	745.2
168	107	121.3	14.31	65.2	7.508	1.586	47.01	745.9
169	117	115	-2.01	58.23	9.261	1.174	46.32	746.5
170	135	117.3	-17.7	51.21	10.56	9.188	46.31	723
171	140	124.1	-15.9	43.14	10.62	23.23	47.16	226.8
172	141	121.8	-19.2	36.51	10.79	28.22	46.3	411
173	131	115.2	-15.8	30.94	11.3	27.45	45.47	322.9
174	123	113.3	-9.74	25.86	11.83	30.18	45.4	410.9
175	118	119.3	1.304	25.5	11.24	36.26	46.31	186.7
176	127	121.4	-5.57	25.34	10.04	39.84	46.21	186.6
177	123	121.7	-1.32	29.56	9.366	37.02	45.75	186.4
178	112	124.2	12.24	29.04	8.977	40.22	46	457.5
179	109	118	8.981	27.41	7.857	37.37	45.34	185.9
180	107	121.6	14.62	33.33	7.019	34.64	46.63	496
181	106	127.9	21.94	41.55	6.574	32.06	47.76	185.3
182	109	129.1	20.09	45.65	6.426	29.75	47.26	739.9
183	106	122.5	16.51	44.2	6.515	25.45	46.33	738.3
184	108	115.8	7.834	39.04	6.584	24.17	46.05	184.1
185	120	120.8	0.825	32.77	6.562	33.66	47.83	183.7
186	133	121.2	-11.8	26.87	6.367	40.21	47.72	363.7
187	132	113.1	-18.9	21.7	6.024	38.73	46.69	182.6
188	120	103.6	-16.4	18.27	5.768	33.89	45.71	728
189	111	96.72	-14.3	17	6.6	28.1	45.02	492.3
190	109	90.41	-18.6	16.31	7.451	22.4	44.24	722.9
191	106	83.86	-22.1	14.51	8.533	17.39	43.44	720.1
192	112	79.95	-32.1	12.37	9.659	15.24	42.68	694.1
193	110	84.3	-25.7	10.06	9.768	21.35	43.12	308.6
194	100	84.56	-15.4	8.475	9.318	24.3	42.47	215.8
195	90.3	83.18	-7.12	7.489	8.647	25.29	41.75	480.1
196	81.8	77.83	-3.97	6.267	7.845	22.93	40.8	696.5
197	75.6	71.45	-4.15	5.122	7.11	19.33	39.89	700.4
198	71.4	65.59	-5.81	4.18	6.449	15.94	39.02	674.3
199	68.2	62.13	-6.07	3.484	6.165	14.25	38.24	692.8
200	67.1	58.82	-8.28	3.012	6.369	11.91	37.53	688.8
201	69.1	56.05	-13.1	2.693	6.902	9.578	36.87	684.7
202	71.9	53.67	-18.2	2.44	7.505	7.477	36.25	622.1
203	73.1	54.72	-18.4	2.278	8.266	8.497	35.68	676
204	72.8	67.55	-5.25	2.039	9.31	19.55	36.65	671.6
205	74.5	70.45	-4.05	1.79	10.33	22.29	36.04	666.9
206	80.7	72.24	-8.46	1.551	11.05	24.1	35.54	662.2
207	85.2	74.97	-10.2	1.319	10.99	27.27	35.39	657.4
208	77.6	72.47	-5.13	1.094	10.97	25.65	34.76	652.4

209	76.7	69.01	-7.69	0.893	11.76	22.08	34.28	626.6
210	78.4	64.87	-13.5	0.72	12.34	18.07	33.74	580.3
211	77	59.77	-17.2	0.574	11.84	14.28	33.07	637
212	73.9	55.31	-18.6	0.457	11.33	11	32.51	631.6
213	70.8	51.78	-19	0.37	11.06	8.328	32.01	626.2
214	68.2	48.68	-19.5	0.303	10.68	6.213	31.49	620.6
215	68.5	46.24	-22.3	0.253	10.4	4.583	31.01	615
216	66.8	44.06	-22.7	0.214	9.985	3.349	30.52	609.2
217	69.1	43.65	-25.4	0.183	9.64	3.773	30.06	603.4
218	71.9	45.81	-26.1	0.155	9.068	6.943	29.64	539.9
219	68.2	45.25	-23	0.133	8.436	7.58	29.1	591.5
220	65.4	44.56	-20.8	0.113	8.697	7.021	28.73	359.6
221	64.8	43.24	-21.6	0.094	8.865	5.992	28.29	579.3
222	63.1	41.81	-21.3	0.078	9	4.869	27.87	573.1
223	62.9	40.06	-22.8	0.063	8.764	3.829	27.41	566.8
224	62.3	38.94	-23.4	0.053	8.885	2.942	27.06	560.5
225	58.3	37.21	-21.1	0.043	8.377	2.22	26.57	536.2
226	55.2	36.28	-18.9	0.037	8.348	1.653	26.25	547.6
227	55.5	45.23	-10.3	0.033	9.096	9.702	26.4	541
228	61.4	47.64	-13.8	0.03	9.384	12.23	25.99	534.4
229	60.3	46.29	-14	0.026	8.775	12	25.49	527.8
230	55.5	45.68	-9.82	0.023	8.234	12.33	25.09	521.1
231	53.2	45.9	-7.3	0.021	9.748	11.23	24.89	128.6
232	53	46.69	-6.31	0.023	9.586	12.55	24.53	507.5
233	52.1	53.92	1.825	0.033	11.26	17.97	24.66	275.4
234	56.1	54.2	-1.9	0.037	11.51	18.38	24.27	493.8
235	56.6	51.63	-4.97	0.037	11.16	16.52	23.92	486.9
236	56.9	49.09	-7.81	0.034	11.48	13.86	23.72	480
237	58	47.62	-10.4	0.029	12.87	11.14	23.58	473
238	57.2	44.34	-12.9	0.024	12.46	8.689	23.16	466
239	54.9	40.9	-14	0.019	11.44	6.636	22.8	459
240	51.8	37.86	-13.9	0.143	9.816	5.523	22.38	306.7
241	49	43.27	-5.73	0.438	8.005	11.47	23.36	325.7
242	44.5	45.91	1.409	3.357	6.599	12.83	23.12	240.8
243	40.8	45.27	4.474	5.279	5.319	12.02	22.66	430.7
244	38.8	45.16	6.362	8.055	4.404	10.32	22.39	423.6
245	38.5	45.83	7.332	11.44	3.813	8.416	22.16	416.5
246	38.8	46.87	8.068	13.2	3.283	8.428	21.96	409.4
247	38.5	46.69	8.192	14.42	2.932	7.603	21.74	100.6
248	37.1	45.65	8.549	15.01	2.666	6.504	21.46	98.81
249	35.4	44.51	9.106	15.5	2.511	5.293	21.2	213.5
250	33.1	41.38	8.276	14.17	2.246	4.167	20.79	381
251	32	38.23	6.231	12.48	2.114	3.203	20.43	374
252	31.4	36.08	4.684	11.39	2.164	2.419	20.12	366.9
253	32	35.59	3.594	11.47	2.463	1.802	19.86	359.9
254	34	37.52	3.52	13.3	3.129	1.327	19.76	352.9
255	37.4	51.51	14.11	15.56	3.899	11.2	20.86	345.9
256	42.2	58.09	15.89	16.46	5.132	15.62	20.87	106.5
257	45	56.45	11.45	15.04	5.109	15.86	20.44	82.99
258	42.5	51.49	8.991	12.74	4.532	14.21	20.01	81.26
259	38.5	45.57	7.068	10.3	3.772	11.89	19.6	100
260	35.7	40.46	4.759	8.317	3.016	9.916	19.21	244.6
261	33.7	46.21	12.51	13.73	2.767	8.982	20.72	167.5
262	33.1	56.12	23.02	23.28	2.912	7.57	22.36	74.45
263	33.7	55.97	22.27	24.96	2.654	6.42	21.93	91.48
264	33.1	53.47	20.37	24.13	2.286	5.197	21.86	107.7
265	32.3	51.11	18.81	21.64	1.891	5.731	21.85	105.2
266	31.7	50.06	18.36	18.31	1.511	8.221	22.02	117.2
267	32.8	46.67	13.87	15.37	1.189	8.436	21.67	69.03
268	32.6	44	11.4	13.8	0.998	7.596	21.6	64.58
269	31.7	39.9	8.204	11.59	0.803	6.382	21.13	227.7

270	30.6	35.8	5.198	9.355	0.627	5.133	20.68	245.6
271	29.7	32.41	2.706	7.647	0.485	4.015	20.26	118.8
272	29.4	29.42	0.024	6.114	0.37	3.1	19.84	73.3
273	32.6	27.03	-5.57	4.932	0.287	2.368	19.44	56.78

1969 calibration forced by climate scenario 3								
Julian Day	Observed (cumecs)	Modelled (cumecs)	Residual (cumecs)	Snowmelt (cumecs)	Icemelt (cumecs)	Rainfall (cumecs)	Groundwater (cumecs)	evapo-transpiration (mm/day x 10)
274	31.4	30.82	-0.58	0.002	0	0.067	30.75	53.78
275	31.4	30.36	-1.04	0.003	0	0.091	30.26	126.3
276	30	29.88	-0.12	0.003	0	0.092	29.78	203.4
277	29.4	29.44	0.04	0.003	0.015	0.093	29.33	70.6
278	28.9	29.22	0.32	0.032	0.1	0.162	28.93	48.01
279	27.8	28.86	1.062	0.042	0.147	0.176	28.5	46.61
280	27.3	28.43	1.125	0.041	0.155	0.164	28.07	45.24
281	26.6	28.27	1.673	0.078	0.141	0.412	27.64	64.59
282	26.1	28.02	1.925	0.119	0.119	0.56	27.23	42.57
283	25.6	27.82	2.217	0.188	0.097	0.709	26.82	41.26
284	25.4	27.41	2.009	0.203	0.076	0.702	26.43	39.98
285	24.9	27.08	2.179	0.226	0.059	0.752	26.04	38.72
286	25.1	26.79	1.688	0.279	0.044	0.799	25.67	37.48
287	24.7	26.34	1.637	0.275	0.033	0.732	25.3	70.47
288	23.6	25.83	2.226	0.243	0.024	0.621	24.94	35.08
289	22.9	25.31	2.41	0.203	0.018	0.504	24.59	49.9
290	22.2	24.92	2.721	0.27	0.013	0.395	24.24	63.67
291	22	25.37	3.367	0.846	0.01	0.305	24.21	31.66
292	21.1	25.28	4.184	1.169	0.01	0.235	23.87	30.56
293	20.7	25.04	4.343	1.313	0.009	0.179	23.54	35.81
294	20.5	24.61	4.112	1.244	0.007	0.139	23.22	28.45
295	20.1	24.1	4.001	1.08	0.006	0.107	22.91	27.43
296	19.7	23.61	3.909	0.922	0.004	0.081	22.6	51.36
297	19.7	30.44	10.74	5.344	0.088	0.093	24.91	25.47
298	19.9	32.36	12.46	7.435	0.127	0.141	24.66	58.15
299	20.1	32.11	12.01	7.542	0.131	0.15	24.29	23.6
300	19.4	30.95	11.55	6.757	0.118	0.137	23.93	76.22
301	19.4	39.36	19.96	7.115	0.142	6.344	25.76	21.83
302	19.5	46.75	27.25	6.707	0.146	13.69	26.21	70.45
303	19.7	48.35	28.65	6.549	0.163	15.55	26.09	20.16
304	19.7	46.22	26.52	5.751	0.152	14.65	25.67	19.36
305	18.7	42.77	24.07	4.758	0.13	12.62	25.26	40.1
306	16.5	39.08	22.58	3.788	0.106	10.32	24.87	21.66
307	18.2	35.65	17.45	2.935	0.084	8.15	24.48	17.11
308	18.3	32.68	14.38	2.231	0.064	6.28	24.1	23.44
309	16.5	30.2	13.7	1.67	0.049	4.751	23.73	41.34
310	15.1	28.19	13.09	1.235	0.036	3.544	23.37	47.37
311	13.3	26.57	13.27	0.904	0.027	2.614	23.02	55.28
312	12.9	25.27	12.37	0.657	0.019	1.91	22.68	13.83
313	14.4	24.22	9.821	0.474	0.014	1.385	22.35	28.56
314	14.7	23.37	8.669	0.34	0.01	0.998	22.02	15.39
315	14.9	22.67	7.768	0.243	0.007	0.715	21.7	12.13
316	15.7	22.09	6.388	0.176	0.005	0.514	21.39	11.6
317	16.3	21.59	5.288	0.127	0.004	0.368	21.09	11.1
318	15.3	21.15	5.848	0.091	0.003	0.262	20.79	10.61
319	15.6	20.76	5.156	0.065	0.002	0.186	20.5	10.15
320	14	20.4	6.399	0.046	0.001	0.131	20.22	11.79
321	10.6	20.07	9.47	0.033	0.001	0.093	19.94	37.13
322	10.2	19.76	9.562	0.023	0.001	0.065	19.67	10.78
323	12.4	19.47	7.072	0.016	0	0.046	19.41	18.32
324	15.3	19.22	3.923	0.025	0	0.046	19.15	8.123
325	15	19.07	4.073	0.116	0	0.058	18.9	7.772
326	14.6	18.88	4.277	0.156	0	0.07	18.65	7.438
327	14.2	18.63	4.434	0.156	0	0.068	18.41	7.121
328	13.8	18.37	4.571	0.139	0	0.059	18.17	6.82

329	13.3	18.11	4.807	0.116	0	0.049	17.94	18.86
330	12.9	17.85	4.947	0.093	0	0.039	17.72	6.265
331	12.5	17.6	5.096	0.072	0	0.03	17.49	6.01
332	12.1	17.36	5.255	0.055	0	0.023	17.28	12.69
333	12	17.15	5.15	0.041	0	0.044	17.07	5.544
334	11.9	16.94	5.036	0.031	0	0.048	16.86	5.332
335	11.8	16.72	4.921	0.022	0	0.045	16.65	7.552
336	11.8	16.51	4.709	0.016	0	0.038	16.45	6.007
337	11.7	16.3	4.602	0.012	0	0.031	16.26	4.773
338	11.6	16.1	4.5	0.008	0	0.025	16.07	5.6
339	11.4	15.9	4.504	0.006	0	0.019	15.88	7.522
340	11.3	15.71	4.414	0.004	0	0.014	15.7	8.401
341	11.2	15.53	4.329	0.003	0	0.011	15.52	6.176
342	11	15.35	4.348	0.002	0	0.008	15.34	4.081
343	11	15.17	4.172	0.002	0	0.006	15.16	3.975
344	10.9	15	4.1	0.001	0	0.004	14.99	12.19
345	10.8	14.83	4.031	0.001	0	0.003	14.83	3.795
346	10.7	14.67	3.966	0.001	0	0.002	14.66	10.73
347	10.6	14.5	3.905	0	0	0.002	14.5	7.099
348	10.6	14.35	3.747	0	0	0.001	14.35	3.597
349	10.5	14.19	3.691	0	0	0.001	14.19	3.55
350	10.4	14.04	3.639	0	0	0.001	14.04	3.512
351	10.4	13.89	3.489	0	0	0	13.89	3.483
352	10.3	13.74	3.443	0	0	0	13.74	3.464
353	10.3	13.6	3.298	0	0	0	13.6	5.82
354	10.1	13.46	3.357	0	0	0	13.46	6.703
355	10	13.32	3.318	0	0	0	13.32	3.457
356	9.88	13.18	3.301	0	0	0	13.18	3.472
357	9.77	13.05	3.277	0	0	0	13.05	3.497
358	9.66	12.91	3.254	0	0	0	12.91	9.431
359	9.6	12.78	3.185	0	0	0	12.78	6.023
360	9.54	12.66	3.117	0	0	0	12.66	3.624
361	9.49	12.53	3.041	0	0	0	12.53	3.686
362	9.43	12.41	2.978	0	0	0	12.41	3.756
363	9.37	12.29	2.916	0	0	0	12.29	7.454
364	9.32	12.17	2.846	0	0	0	12.17	3.927
365	9.34	12.05	2.709	0	0	0	12.05	4.89
1	9.4	11.93	2.533	0	0	0	11.93	4.027
2	9.54	11.82	2.279	0	0	0	11.82	9.812
3	9.63	11.71	2.076	0	0	0	11.71	4.259
4	9.77	11.6	1.826	0	0	0	11.6	4.392
5	9.77	11.49	1.717	0	0	0	11.49	4.535
6	9.77	11.38	1.61	0	0	0	11.38	4.691
7	9.68	11.27	1.594	0	0	0	11.27	11.73
8	9.54	11.17	1.63	0	0	0	11.17	15.62
9	9.43	11.07	1.637	0	0	0	11.07	5.231
10	9.43	10.97	1.536	0	0	0	10.97	5.436
11	9.43	10.87	1.436	0	0	0	10.87	5.655
12	9.49	10.77	1.278	0	0	0	10.77	5.888
13	9.63	10.67	1.041	0	0	0	10.67	7.45
14	9.85	10.58	0.725	0	0	0	10.58	25.59
15	10	10.48	0.481	0	0	0	10.48	17.55
16	9.91	10.39	0.478	0	0	0	10.39	8.461
17	9.85	10.3	0.447	0	0	0	10.3	7.277
18	9.63	10.21	0.576	0	0	0	10.21	16.73
19	9.57	10.12	0.547	0	0	0	10.12	7.945
20	9.49	10.03	0.539	0	0	0	10.03	22.19
21	9.26	9.942	0.682	0	0	0	9.942	18.73
22	9.06	9.856	0.796	0	0	0	9.856	34.76
23	8.92	9.771	0.851	0	0	0	9.771	37.97
24	8.69	9.688	0.998	0	0	0	9.688	16.73

25	8.5	9.605	1.105	0	0	0	9.605	12.6
26	8.27	9.524	1.254	0	0	0	9.524	10.85
27	8.07	9.443	1.373	0	0	0	9.443	11.35
28	7.82	9.364	1.544	0	0	0	9.364	22.53
29	7.62	9.285	1.665	0	0	0	9.285	20.89
30	7.59	9.207	1.617	0	0	0	9.207	25.16
31	7.5	9.131	1.631	0	0	0	9.131	48.9
32	7.5	9.055	1.555	0	0	0	9.055	14.13
33	7.56	8.98	1.42	0	0	0	8.98	14.75
34	7.59	8.906	1.316	0	0	0	8.906	15.4
35	7.65	8.833	1.183	0	0	0	8.833	22.95
36	7.7	8.761	1.061	0	0	0	8.761	64.16
37	7.73	8.689	0.959	0	0	0	8.689	69.89
38	7.84	8.619	0.779	0	0	0	8.619	72.84
39	7.93	8.549	0.619	0	0	0	8.549	63.69
40	8.13	8.48	0.35	0	0	0	8.48	19.76
41	8.27	8.411	0.141	0	0	0	8.411	54.07
42	8.41	8.344	-0.07	0	0	0	8.344	36.08
43	8.52	8.277	-0.24	0	0	0	8.277	22.26
44	8.69	8.211	-0.48	0	0	0	8.211	23.15
45	8.72	8.145	-0.57	0	0	0	8.145	92.1
46	8.81	8.08	-0.73	0	0	0	8.08	99.96
47	8.83	8.016	-0.81	0	0	0	8.016	103.8
48	8.86	7.953	-0.91	0	0	0	7.953	107.7
49	8.92	7.89	-1.03	0	0	0	7.89	111.7
50	8.86	7.828	-1.03	0	0	0	7.828	115.9
51	8.75	7.767	-0.98	0	0	0	7.767	120.1
52	8.58	7.706	-0.87	0	0	0	7.706	124.4
53	8.44	7.646	-0.79	0	0	0	7.646	77.77
54	8.24	7.586	-0.65	0	0	0	7.586	133.4
55	8.04	7.527	-0.51	0	0	0	7.527	133.5
56	7.93	7.469	-0.46	0	0	0	7.469	69.31
57	7.73	7.411	-0.32	0	0	0	7.411	147.5
58	7.67	7.354	-0.32	0	0	0	7.354	152.4
59	7.65	7.297	-0.35	0	0	0	7.297	157.4
60	7.62	7.241	-0.38	0	0	0	7.241	162.5
61	7.65	7.185	-0.46	0	0	0	7.185	158.7
62	7.65	7.13	-0.52	0	0	0	7.13	172.9
63	7.67	7.076	-0.59	0	0	0	7.076	178.3
64	7.7	7.022	-0.68	0	0	0	7.022	45.93
65	7.73	6.968	-0.76	0	0	0	6.968	47.31
66	7.76	6.915	-0.84	0	0	0	6.915	48.71
67	7.76	6.863	-0.9	0	0	0	6.863	60.87
68	7.79	6.811	-0.98	0	0	0	6.811	111.3
69	7.82	6.759	-1.06	0	0	0	6.759	212.1
70	7.84	6.708	-1.13	0	0	0	6.708	218.1
71	7.87	6.657	-1.21	0	0	0	6.657	224.1
72	7.9	6.607	-1.29	0	0	0	6.607	230.2
73	7.9	6.557	-1.34	0	0	0	6.557	167.9
74	7.93	6.546	-1.38	0.038	0	0	6.508	60.63
75	7.9	7.666	-0.23	0.646	0	0.031	6.988	62.2
76	7.87	8.434	0.564	1.007	0.001	0.198	7.228	63.78
77	7.84	8.672	0.832	1.104	0.001	0.266	7.3	65.39
78	7.82	8.904	1.084	1.143	0.001	0.268	7.492	67
79	7.79	9.006	1.216	1.15	0.001	0.239	7.617	68.63
80	7.82	8.859	1.039	1.051	0.001	0.2	7.607	70.28
81	7.84	8.572	0.732	0.891	0	0.161	7.52	102.8
82	7.84	8.313	0.473	0.721	0	0.125	7.466	73.61
83	7.87	8.043	0.173	0.565	0	0.096	7.382	301.2
84	7.9	7.804	-0.1	0.433	0	0.072	7.299	294.7
85	7.9	7.76	-0.14	0.42	0	0.053	7.286	281

86	8.21	7.611	-0.6	0.367	0	0.039	7.204	321.6
87	8.13	7.456	-0.67	0.303	0	0.029	7.124	328.5
88	8.04	7.307	-0.73	0.241	0	0.021	7.045	242
89	7.99	7.181	-0.81	0.199	0	0.015	6.968	342.4
90	7.99	10.48	2.491	1.327	0	0.024	9.131	87.34
91	8.21	12.55	4.345	2.432	0.001	0.031	10.09	89.09
92	8.27	14.67	6.397	3.454	0.003	0.056	11.15	90.85
93	8.21	15.04	6.834	3.826	0.004	0.073	11.14	92.61
94	8.1	15.2	7.1	4.044	0.004	0.072	11.08	159.1
95	7.99	16.91	8.916	5.445	0.006	0.063	11.39	322.8
96	8.13	17.68	9.552	6.279	0.007	0.054	11.34	391.7
97	8.72	21.05	12.33	8.122	0.013	0.089	12.83	99.69
98	9.15	21.44	12.29	8.652	0.014	0.096	12.68	314.6
99	9.34	25.85	16.51	11.28	0.022	0.089	14.46	174
100	9.68	26.54	16.86	12.1	0.025	0.076	14.34	420.1
101	10.1	26.24	16.14	11.95	0.024	0.061	14.2	408.9
102	10.4	25.78	15.38	11.6	0.023	0.048	14.11	434.3
103	10.7	25.74	15.04	11.35	0.027	0.038	14.32	110.3
104	10.8	25.36	14.56	10.97	0.029	0.029	14.34	246.6
105	10.7	24.99	14.29	10.65	0.031	0.022	14.28	299.3
106	10.6	24.7	14.1	10.49	0.03	0.017	14.17	442.7
107	10.6	36.65	26.05	18.35	0.06	0.012	18.23	117.4
108	10.9	42.1	31.2	22.77	0.087	0.055	19.19	119.1
109	10.9	41.61	30.71	22.43	0.095	0.194	18.89	120.9
110	11	39.24	28.24	20.24	0.096	0.242	18.66	122.6
111	10.8	39.35	28.55	19.84	0.102	0.281	19.13	353.4
112	10.6	50.85	40.25	28.67	0.135	0.268	21.77	455.5
113	11.9	79.19	67.29	40.68	0.189	11.37	26.95	127.7
114	19.3	85.92	66.62	42.16	0.204	16.43	27.13	129.4
115	23.5	81.72	58.22	38.21	0.193	16.86	26.46	131.1
116	23.4	73.95	50.55	32.68	0.175	15.17	25.93	258
117	23.1	67.19	44.09	28.72	0.155	12.74	25.58	514.7
118	23.2	73.52	50.32	26.29	0.141	19.76	27.33	486
119	25.9	75.87	49.97	22.33	0.131	24.32	29.09	137.7
120	26.8	70.86	44.06	18.09	0.118	23.83	28.82	139.3
121	25.8	63.54	37.74	14.35	0.112	20.96	28.11	237.5
122	25.2	56.85	31.65	11.53	0.11	17.49	27.72	142.5
123	25.4	51.36	25.96	9.369	0.106	14.51	27.37	144.1
124	24.9	47.34	22.44	8.622	0.108	11.57	27.04	145.6
125	23.8	47.09	23.29	11.14	0.106	8.98	26.86	563.3
126	24.3	50.39	26.09	16.32	0.109	6.83	27.12	594.5
127	26.7	53.27	26.57	20.97	0.109	5.116	27.08	600.5
128	29.2	58.59	29.39	27.28	0.111	3.786	27.41	606.3
129	34.8	65.81	31.01	34.98	0.118	2.774	27.94	612.1
130	44.7	73.62	28.92	42.95	0.125	2.016	28.53	617.8
131	57.2	84.79	27.59	53.37	0.138	1.455	29.83	623.4
132	70.5	93.96	23.46	62.01	0.147	1.044	30.76	628.9
133	81	102.5	21.52	69.79	0.153	0.745	31.83	634.3
134	92.3	105.5	13.19	68.51	0.148	4.441	32.39	379.2
135	86.7	98.16	11.46	60.8	0.133	5.611	31.62	161.2
136	75.6	87.41	11.81	50.84	0.116	5.633	30.82	162.5
137	66.3	76.16	9.861	40.98	0.105	5.018	30.06	584.8
138	62.3	67.12	4.823	33.25	0.101	4.193	29.58	271
139	59.7	59.86	0.164	27.37	0.095	3.362	29.04	166.2
140	57.5	57.76	0.256	26.07	0.094	2.619	28.98	274.9
141	60.9	63.29	2.395	31.48	0.094	1.997	29.72	673.8
142	69.4	76.53	7.133	43.6	0.104	1.5	31.33	678.3
143	83.5	91.79	8.291	57.69	0.115	1.112	32.87	682.6
144	109	118.4	9.371	74.75	0.173	7.404	36.05	686.8
145	140	143.4	3.38	92.29	0.305	11.81	38.97	328.1
146	166	162.1	-3.86	101.8	0.46	18.58	41.29	173.7

147	145	164.8	19.77	98.86	0.531	23.75	41.63	204.6
148	119	156.4	37.4	91.2	0.554	23.54	41.11	296
149	100	154.8	54.79	88.62	0.643	23.22	42.31	176.5
150	90.3	148.8	58.51	83.94	0.705	21.73	42.43	177.3
151	83.8	147.1	63.27	84.52	0.776	18.79	42.99	590.4
152	85.5	153.2	67.7	92.58	0.904	15.39	44.33	470.3
153	95.7	161.4	65.67	102.9	1.438	12.17	44.88	718.6
154	133	173.4	40.37	115.8	2.968	9.389	45.18	605.5
155	168	177.4	9.439	120.4	4.924	7.109	45.04	724.2
156	197	176.8	-20.2	119.9	6.731	5.305	44.86	726.8
157	203	174.9	-28.1	115.4	8.243	6.516	44.74	479.2
158	191	165.8	-25.2	106.1	9.18	6.342	44.19	182.9
159	165	150.8	-14.2	92.34	9.476	5.56	43.38	733.6
160	154	137.9	-16.1	78.77	9.949	6.488	42.74	735.6
161	157	126	-31	66.85	10.81	6.215	42.17	611
162	158	114	-44	55.8	10.81	6.005	41.38	739.1
163	147	100.8	-46.2	45.23	9.911	5.245	40.42	312.1
164	127	90.22	-36.8	37.06	9.164	4.324	39.66	742
165	114	81.12	-32.9	30	8.774	3.435	38.91	743.2
166	108	74.41	-33.6	24.4	9.05	2.658	38.31	664.5
167	106	69.47	-36.5	20.15	9.576	2.017	37.73	745.2
168	107	66.06	-40.9	16.69	10.66	1.509	37.2	745.9
169	117	63.82	-53.2	13.71	12.31	1.115	36.69	746.5
170	135	69.88	-65.1	11.11	13.57	8.706	36.49	666.9
171	140	82.81	-57.2	8.764	13.64	22.83	37.57	186.8
172	141	85.46	-55.5	6.855	13.78	27.89	36.94	355
173	131	83.3	-47.7	5.411	14.36	27.18	36.35	266.9
174	123	85.68	-37.3	4.309	15	29.97	36.41	354.9
175	118	93.16	-24.8	3.974	14.49	37.37	37.32	186.7
176	127	96.23	-30.8	3.735	13.3	41.87	37.33	186.6
177	123	93.22	-29.8	4.532	12.7	39.23	36.76	186.4
178	112	97.89	-14.1	5.858	12.4	42.28	37.35	401.6
179	109	96.36	-12.6	8.833	11.03	39.29	37.2	185.9
180	107	106.9	-0.11	21.33	10	36.29	39.27	440.3
181	106	115.8	9.803	33.12	9.519	33.4	39.76	185.3
182	109	115.6	6.647	36.31	9.344	30.8	39.19	708.2
183	106	108.9	2.865	34.73	9.396	26.25	38.49	738.3
184	108	104	-4.01	31.03	9.514	24.98	38.47	184.1
185	120	111.8	-8.2	26.72	9.66	34.86	40.55	183.7
186	133	114	-19	22.31	9.521	41.47	40.69	308.7
187	132	106.8	-25.2	17.89	9.173	39.86	39.88	182.6
188	120	96.63	-23.4	14	8.748	34.84	39.04	728
189	111	87.88	-23.1	10.92	9.666	28.87	38.41	437.9
190	109	79.83	-29.2	8.601	10.47	23.01	37.75	722.9
191	106	73.41	-32.6	6.914	11.48	17.85	37.17	720.1
192	112	70.35	-41.6	5.608	12.55	15.58	36.62	640.3
193	110	76	-34	4.476	12.62	21.64	37.27	255
194	100	77.01	-23	3.513	12.14	24.57	36.79	177.7
195	90.3	75.91	-14.4	2.767	11.4	25.54	36.2	427
196	81.8	71.15	-10.7	2.212	10.36	23.14	35.44	643.7
197	75.6	65.37	-10.2	1.812	9.352	19.5	34.71	700.4
198	71.4	60.03	-11.4	1.471	8.467	16.08	34.01	622
199	68.2	56.99	-11.2	1.169	8.069	14.36	33.4	692.8
200	67.1	53.98	-13.1	0.921	8.216	12	32.85	688.8
201	69.1	51.46	-17.6	0.727	8.745	9.646	32.34	684.7
202	71.9	49.39	-22.5	0.573	9.409	7.528	31.87	571.1
203	73.1	50.74	-22.4	0.458	10.25	8.577	31.45	676
204	72.8	63.98	-8.82	0.375	11.43	19.65	32.52	671.6
205	74.5	67.27	-7.23	0.317	12.49	22.39	32.06	666.9
206	80.7	69.37	-11.3	0.273	13.23	24.18	31.68	662.2
207	85.2	72.39	-12.8	0.234	13.17	27.33	31.66	657.4

208	77.6	70.16	-7.44	0.195	13.11	25.69	31.16	652.4
209	76.7	67.18	-9.52	0.162	14.14	22.11	30.78	578
210	78.4	63.45	-14.9	0.133	14.86	18.09	30.38	532.1
211	77	58.55	-18.5	0.108	14.32	14.29	29.83	637
212	73.9	54.22	-19.7	0.089	13.73	11.01	29.39	631.6
213	70.8	50.79	-20	0.07	13.39	8.334	29	626.2
214	68.2	47.76	-20.4	0.054	12.9	6.217	28.58	620.6
215	68.5	45.39	-23.1	0.041	12.55	4.585	28.21	615
216	66.8	43.27	-23.5	0.031	12.06	3.351	27.82	609.2
217	69.1	43	-26.1	0.023	11.7	3.811	27.46	603.4
218	71.9	45.38	-26.5	0.017	11.16	7.023	27.18	495.1
219	68.2	44.97	-23.2	0.012	10.55	7.67	26.74	591.5
220	65.4	44.57	-20.8	0.009	10.98	7.105	26.47	315.7
221	64.8	43.39	-21.4	0.007	11.21	6.065	26.11	579.3
222	63.1	42.06	-21	0.005	11.35	4.929	25.78	573.1
223	62.9	40.34	-22.6	0.003	11.06	3.876	25.4	566.8
224	62.3	39.31	-23	0.002	11.19	2.978	25.14	536.4
225	58.3	37.67	-20.6	0.002	10.67	2.247	24.75	494.7
226	55.2	36.8	-18.4	0.001	10.64	1.673	24.49	547.6
227	55.5	45.95	-9.55	0.001	11.49	9.767	24.69	541
228	61.4	48.45	-13	0.001	11.78	12.31	24.36	534.4
229	60.3	46.99	-13.3	0	11	12.07	23.92	527.8
230	55.5	46.38	-9.12	0	10.36	12.42	23.6	521.1
231	53.2	47	-6.2	0	12.25	11.31	23.43	128.6
232	53	47.88	-5.12	0.005	12.12	12.62	23.13	507.5
233	52.1	55.53	3.428	0.012	14.14	18.07	23.31	237.8
234	56.1	55.91	-0.19	0.013	14.43	18.49	22.98	493.8
235	56.6	53.25	-3.35	0.012	13.94	16.62	22.68	486.9
236	56.9	50.54	-6.36	0.011	14.05	13.94	22.54	480
237	58	49.17	-8.83	0.009	15.55	11.2	22.41	473
238	57.2	45.89	-11.3	0.007	15.08	8.74	22.06	466
239	54.9	42.41	-12.5	0.005	13.97	6.675	21.76	459
240	51.8	39.19	-12.6	0.015	12.2	5.587	21.39	272.8
241	49	47.08	-1.92	0.056	10.1	14.3	22.63	292.4
242	44.5	48.34	3.837	0.657	8.762	16.58	22.33	208
243	40.8	46.14	5.339	1.11	7.362	15.76	21.91	430.7
244	38.8	43.43	4.627	1.794	6.401	13.64	21.59	423.6
245	38.5	40.8	2.304	2.568	5.757	11.18	21.3	416.5
246	38.8	39.87	1.072	2.996	5.225	10.64	21.01	387.5
247	38.5	38.12	-0.38	3.101	4.945	9.33	20.74	100.6
248	37.1	36.08	-1.02	3.063	4.738	7.829	20.45	98.81
249	35.4	34.24	-1.16	3.099	4.663	6.292	20.19	184.4
250	33.1	32.08	-1.02	3.019	4.317	4.91	19.83	381
251	32	30.53	-1.47	3.147	4.087	3.75	19.55	374
252	31.4	29.75	-1.65	3.553	4.06	2.818	19.32	366.9
253	32	29.26	-2.74	3.8	4.252	2.091	19.12	359.9
254	34	29.1	-4.9	3.853	4.748	1.535	18.97	352.9
255	37.4	40.62	3.22	3.809	5.542	11.37	19.9	345.9
256	42.2	46.68	4.476	3.924	7.109	15.76	19.88	84.72
257	45	46.03	1.031	3.562	7.015	15.99	19.47	82.99
258	42.5	42.57	0.071	3.006	6.194	14.31	19.06	81.26
259	38.5	38.22	-0.28	2.438	5.141	11.98	18.66	79.54
260	35.7	35.78	0.082	3.205	4.125	10.04	18.41	221.3
261	33.7	49.49	15.79	15.41	4.03	9.114	20.94	144.7
262	33.1	66.65	33.55	31.22	4.435	7.689	23.31	74.45
263	33.7	69.85	36.15	35.28	4.142	7.223	23.21	72.77
264	33.1	71.1	38	37.36	3.849	6.213	23.69	86.34
265	32.3	70.18	37.88	35.69	3.43	7.198	23.86	84.34
266	31.7	69.46	37.76	31.69	2.95	10.7	24.11	96.88
267	32.8	64.61	31.81	27.31	2.541	11.09	23.67	66.19
268	32.6	60.08	27.48	24.34	2.339	10.04	23.36	64.58

269	31.7	53.6	21.9	20.32	1.989	8.454	22.84	208.8
270	30.6	47.03	16.43	16.28	1.612	6.811	22.33	245.6
271	29.7	42.19	12.49	13.54	1.398	5.331	21.92	100.9
272	29.4	37.88	8.479	11.06	1.197	4.154	21.47	58.3
273	32.6	34.45	1.848	9.171	1.051	3.187	21.04	56.78

1969 calibration forced by climate scenario 4								
Julian Day	Observed (cumecs)	Modelled (cumecs)	Residual (cumecs)	Snowmelt (cumecs)	Icemelt (cumecs)	Rainfall (cumecs)	Groundwater (cumecs)	evapo-transpiration (mm/day x 10)
274	31.4	30.63	-0.77	0	0	0	30.63	53.78
275	31.4	30.16	-1.24	0.015	0	0.006	30.14	159.9
276	30	30.49	0.495	0.186	0	0.637	29.67	203.4
277	29.4	30.79	1.385	0.262	0	1.242	29.28	102.4
278	28.9	30.68	1.778	0.313	0.001	1.535	28.83	48.01
279	27.8	30.28	2.479	0.331	0.001	1.561	28.39	46.61
280	27.3	29.67	2.371	0.307	0.001	1.41	27.95	45.24
281	26.6	29.02	2.416	0.281	0.001	1.203	27.53	92.8
282	26.1	28.35	2.254	0.248	0.001	0.987	27.12	68.11
283	25.6	27.73	2.129	0.212	0.001	0.799	26.72	41.26
284	25.4	27.12	1.724	0.173	0	0.627	26.32	39.98
285	24.9	26.73	1.825	0.136	0	0.48	26.11	53.65
286	25.1	26.44	1.345	0.105	0	0.376	25.96	37.48
287	24.7	25.95	1.254	0.08	0	0.288	25.59	93.78
288	23.6	25.49	1.894	0.06	0	0.217	25.22	39.59
289	22.9	25.06	2.163	0.044	0	0.161	24.86	71.71
290	22.2	24.7	2.5	0.062	0	0.131	24.51	84.74
291	22	24.45	2.454	0.164	0	0.126	24.16	31.66
292	21.1	24.19	3.093	0.241	0	0.123	23.83	30.56
293	20.7	23.96	3.262	0.33	0	0.131	23.5	54.78
294	20.5	23.63	3.134	0.333	0	0.12	23.18	39.42
295	20.1	23.27	3.168	0.297	0	0.102	22.87	30.96
296	19.7	22.94	3.238	0.281	0	0.094	22.56	68.35
297	19.7	23.73	4.034	1.105	0.001	0.148	22.48	35.29
298	19.9	24.22	4.324	1.779	0.001	0.263	22.18	73.91
299	20.1	24.07	3.968	1.887	0.001	0.29	21.89	37.76
300	19.4	23.66	4.263	1.76	0.001	0.298	21.6	90.81
301	19.4	27.66	8.256	2.221	0.001	2.83	22.6	21.83
302	19.5	35.43	15.93	2.604	0.001	9.564	23.26	83.94
303	19.7	37.36	17.66	2.65	0.001	11.78	22.93	23.62
304	19.7	36.45	16.75	2.385	0.001	11.46	22.61	26.83
305	18.7	34.34	15.64	2.003	0.001	10.05	22.29	52.05
306	16.5	31.89	15.39	1.61	0	8.3	21.98	33.13
307	18.2	29.53	11.33	1.257	0	6.602	21.68	17.11
308	18.3	27.45	9.153	0.96	0	5.114	21.38	33.99
309	16.5	25.7	9.195	0.722	0	3.884	21.09	51.46
310	15.1	24.25	9.148	0.535	0	2.906	20.81	57.06
311	13.3	23.07	9.771	0.393	0	2.149	20.53	57.75
312	12.9	22.12	9.218	0.286	0	1.573	20.26	19.16
313	14.4	21.34	6.944	0.207	0	1.143	19.99	37.07
314	14.7	20.71	6.008	0.149	0	0.824	19.74	23.53
315	14.9	20.18	5.28	0.106	0	0.591	19.48	12.13
316	15.7	19.73	4.032	0.076	0	0.422	19.23	11.6
317	16.3	19.35	3.045	0.054	0	0.3	18.99	11.1
318	15.3	19	3.704	0.038	0	0.212	18.75	10.61
319	15.6	18.7	3.098	0.027	0	0.15	18.52	10.15
320	14	18.42	4.419	0.019	0	0.105	18.29	18.03
321	10.6	18.16	7.559	0.013	0	0.074	18.07	37.13
322	10.2	17.91	7.714	0.009	0	0.052	17.85	16.49
323	12.4	17.68	5.282	0.006	0	0.036	17.64	23.78
324	15.3	17.46	2.16	0.004	0	0.025	17.43	8.123
325	15	17.26	2.265	0.003	0	0.037	17.23	7.772
326	14.6	17.06	2.464	0.002	0	0.038	17.02	7.438
327	14.2	16.86	2.662	0.001	0	0.034	16.83	7.121
328	13.8	16.66	2.863	0.001	0	0.028	16.63	9.45
329	13.3	16.47	3.167	0.001	0	0.023	16.44	23.06

330	12.9	16.28	3.376	0	0	0.018	16.26	6.265
331	12.5	16.09	3.59	0	0	0.014	16.08	6.01
332	12.1	15.91	3.807	0	0	0.01	15.9	16.4
333	12	15.73	3.729	0	0	0.008	15.72	5.544
334	11.9	15.55	3.655	0	0	0.006	15.55	8.759
335	11.8	15.38	3.584	0	0	0.004	15.38	10.85
336	11.8	15.22	3.417	0	0	0.003	15.21	9.187
337	11.7	15.05	3.353	0	0	0.002	15.05	4.773
338	11.6	14.89	3.292	0	0	0.002	14.89	8.565
339	11.4	14.73	3.335	0	0	0.001	14.73	10.39
340	11.3	14.58	3.28	0	0	0.001	14.58	11.18
341	11.2	14.43	3.228	0	0	0.001	14.43	8.874
342	11	14.28	3.279	0	0	0	14.28	5.655
343	11	14.13	3.132	0	0	0	14.13	5.509
344	10.9	13.99	3.088	0	0	0	13.99	14.69
345	10.8	13.85	3.047	0	0	0	13.85	3.795
346	10.7	13.71	3.007	0	0	0	13.71	13.12
347	10.6	13.57	2.97	0	0	0	13.57	9.448
348	10.6	13.44	2.836	0	0	0	13.44	3.597
349	10.5	13.3	2.803	0	0	0	13.3	3.55
350	10.4	13.17	2.773	0	0	0	13.17	3.512
351	10.4	13.04	2.645	0	0	0	13.04	3.483
352	10.3	12.92	2.619	0	0	0	12.92	3.464
353	10.3	12.79	2.494	0	0	0	12.79	8.039
354	10.1	12.67	2.572	0	0	0	12.67	8.921
355	10	12.55	2.552	0	0	0	12.55	3.457
356	9.88	12.43	2.553	0	0	0	12.43	3.472
357	9.77	12.32	2.546	0	0	0	12.32	3.497
358	9.66	12.2	2.541	0	0	0	12.2	11.7
359	9.6	12.09	2.488	0	0	0	12.09	8.319
360	9.54	11.98	2.436	0	0	0	11.98	4.246
361	9.49	11.87	2.376	0	0	0	11.87	4.159
362	9.43	11.76	2.328	0	0	0	11.76	3.756
363	9.37	11.65	2.281	0	0	0	11.65	9.92
364	9.32	11.55	2.226	0	0	0	11.55	3.927
365	9.34	11.44	2.102	0	0	0	11.44	7.479
1	9.4	11.34	1.939	0	0	0	11.34	4.717
2	9.54	11.24	1.698	0	0	0	11.24	12.47
3	9.63	11.14	1.509	0	0	0	11.14	5.902
4	9.77	11.04	1.271	0	0	0	11.04	4.392
5	9.77	10.94	1.174	0	0	0	10.94	7.451
6	9.77	10.85	1.078	0	0	0	10.85	4.691
7	9.68	10.75	1.073	0	0	0	10.75	14.85
8	9.54	10.66	1.12	0	0	0	10.66	18.86
9	9.43	10.57	1.138	0	0	0	10.57	5.231
10	9.43	10.48	1.048	0	0	0	10.48	5.436
11	9.43	10.39	0.958	0	0	0	10.39	5.655
12	9.49	10.3	0.809	0	0	0	10.3	8.16
13	9.63	10.21	0.582	0	0	0	10.21	11.39
14	9.85	10.13	0.276	0	0	0	10.13	25.59
15	10	10.04	0.04	0	0	0	10.04	21.84
16	9.91	9.956	0.046	0	0	0	9.956	12.94
17	9.85	9.873	0.023	0	0	0	9.873	11.64
18	9.63	9.791	0.161	0	0	0	9.791	21.61
19	9.57	9.71	0.14	0	0	0	9.71	7.945
20	9.49	9.629	0.139	0	0	0	9.629	27.53
21	9.26	9.55	0.29	0	0	0	9.55	24.31
22	9.06	9.472	0.412	0	0	0	9.471	36.31
23	8.92	9.394	0.474	0	0	0	9.394	37.97
24	8.69	9.317	0.627	0	0	0	9.317	23.12
25	8.5	9.242	0.742	0	0	0	9.242	19.28

26	8.27	9.167	0.897	0	0	0	9.167	10.85
27	8.07	9.093	1.023	0	0	0	9.093	11.35
28	7.82	9.019	1.199	0	0	0	9.019	30.16
29	7.62	8.947	1.327	0	0	0	8.947	28.86
30	7.59	8.875	1.285	0	0	0	8.875	33.49
31	7.5	8.804	1.304	0	0	0	8.804	54.12
32	7.5	8.734	1.234	0	0	0	8.734	15.95
33	7.56	8.665	1.105	0	0	0	8.665	14.75
34	7.59	8.596	1.006	0	0	0	8.596	15.4
35	7.65	8.528	0.878	0	0	0	8.528	33.28
36	7.7	8.461	0.761	0	0	0	8.461	67.03
37	7.73	8.394	0.664	0	0	0	8.394	69.89
38	7.84	8.328	0.488	0	0	0	8.328	72.84
39	7.93	8.263	0.333	0	0	0	8.263	75.89
40	8.13	8.199	0.069	0	0	0	8.199	19.76
41	8.27	8.135	-0.14	0	0	0	8.135	67.29
42	8.41	8.072	-0.34	0	0	0	8.072	49.84
43	8.52	8.009	-0.51	0	0	0	8.009	25.13
44	8.69	7.947	-0.74	0	0	0	7.947	23.15
45	8.72	7.886	-0.83	0	0	0	7.886	96.23
46	8.81	7.825	-0.99	0	0	0	7.825	99.96
47	8.83	7.765	-1.07	0	0	0	7.765	103.8
48	8.86	7.705	-1.15	0	0	0	7.705	107.7
49	8.92	7.646	-1.27	0	0	0	7.646	111.7
50	8.86	7.587	-1.27	0	0	0	7.587	115.9
51	8.75	7.53	-1.22	0	0	0	7.53	120.1
52	8.58	7.472	-1.11	0	0	0	7.472	124.4
53	8.44	7.415	-1.02	0	0	0	7.415	98.48
54	8.24	7.359	-0.88	0	0	0	7.359	133.4
55	8.04	7.303	-0.74	0	0	0	7.303	138
56	7.93	7.248	-0.68	0	0	0	7.248	92.24
57	7.73	7.193	-0.54	0	0	0	7.193	147.5
58	7.67	7.139	-0.53	0	0	0	7.139	152.4
59	7.65	7.085	-0.57	0	0	0	7.085	157.4
60	7.62	7.032	-0.59	0	0	0	7.032	162.5
61	7.65	6.979	-0.67	0	0	0	6.979	167.6
62	7.65	6.926	-0.72	0	0	0	6.926	172.9
63	7.67	6.874	-0.8	0	0	0	6.874	178.3
64	7.7	6.823	-0.88	0	0	0	6.823	45.93
65	7.73	6.772	-0.96	0	0	0	6.772	47.31
66	7.76	6.721	-1.04	0	0	0	6.721	48.71
67	7.76	6.671	-1.09	0	0	0	6.671	93.1
68	7.79	6.622	-1.17	0	0	0	6.622	144.4
69	7.82	6.572	-1.25	0	0	0	6.572	212.1
70	7.84	6.524	-1.32	0	0	0	6.524	218.1
71	7.87	6.475	-1.39	0	0	0	6.475	224.1
72	7.9	6.427	-1.47	0	0	0	6.427	230.2
73	7.9	6.38	-1.52	0	0	0	6.38	205.9
74	7.93	6.332	-1.6	0	0	0	6.332	60.63
75	7.9	6.286	-1.61	0	0	0	6.286	62.2
76	7.87	6.239	-1.63	0	0	0	6.239	74.72
77	7.84	6.193	-1.65	0	0	0	6.193	90.61
78	7.82	6.148	-1.67	0	0	0	6.148	67
79	7.79	6.104	-1.69	0.001	0	0	6.102	77.46
80	7.82	6.06	-1.76	0.002	0	0	6.057	97.39
81	7.84	6.015	-1.82	0.002	0	0	6.013	149
82	7.84	5.971	-1.87	0.002	0	0	5.969	73.61
83	7.87	5.927	-1.94	0.001	0	0	5.925	301.2
84	7.9	5.883	-2.02	0.001	0	0	5.882	307.9
85	7.9	5.843	-2.06	0.001	0	0.004	5.839	314.7
86	8.21	5.802	-2.41	0.001	0	0.005	5.796	321.6

87	8.13	5.759	-2.37	0	0	0.005	5.753	328.5
88	8.04	5.716	-2.32	0	0	0.005	5.711	295.9
89	7.99	5.676	-2.31	0	0	0.006	5.67	342.4
90	7.99	5.836	-2.15	0.057	0	0.018	5.761	87.34
91	8.21	5.909	-2.3	0.111	0	0.022	5.776	89.09
92	8.27	6.147	-2.12	0.158	0	0.031	5.959	90.85
93	8.21	6.221	-1.99	0.18	0	0.033	6.008	92.61
94	8.1	6.276	-1.82	0.216	0	0.03	6.029	219.8
95	7.99	6.537	-1.45	0.4	0	0.032	6.105	384.6
96	8.13	6.805	-1.32	0.646	0	0.04	6.119	391.7
97	8.72	7.539	-1.18	0.908	0	0.094	6.537	99.69
98	9.15	7.728	-1.42	1.074	0	0.126	6.528	379.8
99	9.34	9.043	-0.3	1.622	0	0.165	7.256	240.4
100	9.68	9.714	0.034	2.117	0	0.203	7.394	420.1
101	10.1	10.22	0.125	2.473	0	0.238	7.514	427.2
102	10.4	10.79	0.394	2.878	0	0.268	7.648	434.3
103	10.7	11.26	0.556	3.01	0	0.276	7.969	148.2
104	10.8	11.52	0.721	3.109	0	0.283	8.129	318.7
105	10.7	11.67	0.97	3.127	0	0.289	8.253	372.5
106	10.6	11.9	1.298	3.276	0	0.303	8.319	462.5
107	10.6	17.1	6.496	5.535	0.001	0.365	11.2	132.5
108	10.9	19.2	8.298	6.703	0.001	0.473	12.02	165.1
109	10.9	19.12	8.218	6.534	0.001	0.482	12.1	120.9
110	11	18.54	7.54	5.843	0.001	0.435	12.26	122.6
111	10.8	18.95	8.149	5.71	0.001	0.491	12.75	433.3
112	10.6	25.57	14.97	9.003	0.002	0.612	15.95	504.1
113	11.9	42.02	30.12	14.2	0.003	4.098	23.73	127.7
114	19.3	45.73	26.43	15.21	0.004	5.583	24.93	207.1
115	23.5	44.06	20.56	14	0.003	5.626	24.43	131.1
116	23.4	41.37	17.97	12.17	0.003	5.059	24.14	343.3
117	23.1	39.06	15.96	10.71	0.003	4.369	23.97	537.7
118	23.2	42.55	19.35	9.893	0.003	6.648	26	544.3
119	25.9	43.97	18.07	8.595	0.002	7.466	27.91	155.4
120	26.8	42.01	15.21	7.101	0.002	7.047	27.86	139.3
121	25.8	39.76	13.96	6.073	0.002	6.079	27.6	297.9
122	25.2	39.06	13.86	5.474	0.002	5.12	28.46	142.5
123	25.4	38	12.6	5.019	0.003	4.332	28.65	162.6
124	24.9	37.24	12.34	5.303	0.003	3.5	28.44	201.8
125	23.8	38.12	14.32	7.164	0.003	2.742	28.21	588.5
126	24.3	41.93	17.63	11.03	0.004	2.1	28.79	594.5
127	26.7	44.87	18.17	14.43	0.005	1.581	28.85	600.5
128	29.2	50.56	21.36	19.81	0.006	1.175	29.57	606.3
129	34.8	58.83	24.03	27.36	0.007	0.864	30.59	612.1
130	44.7	68.48	23.78	35.98	0.009	0.63	31.87	617.8
131	57.2	81	23.8	46.38	0.02	0.456	34.15	623.4
132	70.5	91.42	20.92	55.3	0.032	0.328	35.76	628.9
133	81	101.2	20.17	63.29	0.05	0.234	37.6	634.3
134	92.3	101.3	9.007	61.51	0.06	1.606	38.14	447.7
135	86.7	93.43	6.733	54.13	0.059	2.056	37.19	161.2
136	75.6	83.25	7.653	44.9	0.052	2.089	36.22	162.5
137	66.3	75.44	9.143	37.39	0.051	1.872	36.13	654.9
138	62.3	68.8	6.504	31.31	0.053	1.575	35.87	341.7
139	59.7	62.43	2.729	25.84	0.053	1.269	35.27	166.2
140	57.5	59.79	2.292	23.62	0.056	0.992	35.12	346.6
141	60.9	65.64	4.742	28.48	0.067	0.759	36.34	673.8
142	69.4	78.47	9.067	39.36	0.091	0.572	38.45	678.3
143	83.5	91.85	8.346	51.53	0.119	0.425	39.77	682.6
144	109	116.7	7.741	65.95	0.155	7.056	43.58	686.8
145	140	140.5	0.461	81.16	0.202	11.75	47.35	402.2
146	166	158.8	-7.16	89.14	0.247	18.42	51.04	173.7
147	145	159	14.02	85.56	0.255	21.7	51.5	279.4

148	119	150.3	31.32	78.27	0.247	20.84	50.97	371.2
149	100	148.6	48.63	75.34	0.264	20.41	52.61	176.5
150	90.3	141.5	51.25	70.06	0.271	18.8	52.42	177.3
151	83.8	140.6	56.83	71.16	0.281	16.13	53.06	666.7
152	85.5	149.9	64.43	81.31	0.311	13.16	55.15	547
153	95.7	163	67.26	95.24	0.345	10.37	57	718.6
154	133	183.4	50.41	115.4	0.393	7.98	59.64	682.8
155	168	204.6	36.64	136	0.43	6.031	62.16	724.2
156	197	222.4	25.44	153.1	0.451	4.495	64.39	726.8
157	203	236	33	162.9	0.458	6.083	66.58	557.3
158	191	235.1	44.12	161.3	0.452	6.127	67.22	182.9
159	165	231.2	66.15	157.4	0.426	5.465	67.89	733.6
160	154	233.8	79.85	157.1	0.401	6.605	69.76	735.6
161	157	240.6	83.6	161.9	0.384	6.416	71.9	690
162	158	238.4	80.36	159.5	0.352	6.308	72.22	739.1
163	147	223.1	76.11	146.1	0.307	5.56	71.16	391.5
164	127	213.6	86.63	137.2	0.268	4.609	71.57	742
165	114	209.7	95.67	133.4	0.239	3.675	72.33	743.2
166	108	214.5	106.5	137.3	0.227	2.851	74.13	744.3
167	106	223	117	144.8	0.221	2.168	75.83	745.2
168	107	239.6	132.6	159.7	0.332	1.624	77.95	745.9
169	117	258.8	141.8	177.2	0.578	1.202	79.76	746.5
170	135	277	142	185.1	0.818	9.811	81.3	747
171	140	282.5	142.5	175.5	0.923	23.89	82.22	250.9
172	141	278.2	137.2	166.1	1.014	28.88	82.29	435.1
173	131	270.7	139.7	159.4	1.123	28.06	82.12	347
174	123	266.5	143.5	152.5	1.242	30.88	81.87	434.9
175	118	253.8	135.8	135.4	1.305	35.75	81.4	186.7
176	127	235	108	115.3	1.304	38.21	80.2	186.6
177	123	216.7	93.7	101.4	1.475	35.1	78.74	186.4
178	112	213.4	101.4	94.1	1.917	38.59	78.79	481.4
179	109	197.6	88.6	82.4	1.921	36.06	77.22	185.9
180	107	196.6	89.62	82.05	2.162	33.72	78.68	519.8
181	106	196.6	90.62	83.54	2.528	31.52	79.03	209.2
182	109	199.2	90.19	88.06	3.203	29.56	78.37	739.9
183	106	195.5	89.47	88.86	4.095	25.44	77.08	738.3
184	108	188.2	80.21	82.98	4.687	24.26	76.28	184.1
185	120	190.6	70.62	73.96	5.018	33.9	77.74	183.7
186	133	187.9	54.87	64.97	5.201	40.62	77.08	387.2
187	132	175.6	43.58	55.96	5.03	39.17	75.32	182.6
188	120	163.4	43.41	49.99	4.848	34.31	73.73	728
189	111	152	41.02	44.83	5.692	28.47	72.28	515.6
190	109	141.5	32.54	40.49	6.605	22.72	70.83	722.9
191	106	133.5	27.45	37.62	7.786	17.64	69.49	720.1
192	112	129.3	17.32	35.7	9.048	15.54	68.2	717.2
193	110	131.9	21.88	32.06	9.23	21.79	68.08	331.5
194	100	128.6	28.61	27.7	8.784	24.72	66.8	238.7
195	90.3	124.2	33.86	24.15	8.105	25.7	65.53	502.9
196	81.8	117.3	35.51	21.69	7.347	23.28	64.1	704
197	75.6	110.3	34.72	20.14	6.681	19.62	62.72	700.4
198	71.4	104.1	32.73	19.04	6.092	16.2	61.39	696.7
199	68.2	100.8	32.64	18.64	5.835	14.58	60.19	692.8
200	67.1	98.16	31.06	19.01	6.028	12.24	59.07	688.8
201	69.1	96.38	27.28	19.93	6.517	9.868	58.03	684.7
202	71.9	94.77	22.87	20.67	7.052	7.719	57	644
203	73.1	96.24	23.14	20.88	7.74	8.871	56.09	676
204	72.8	108.3	35.52	19.79	8.698	20.11	56.67	671.6
205	74.5	109.8	35.29	18.31	9.668	22.87	55.62	666.9
206	80.7	110.1	29.41	16.67	10.36	24.67	54.89	662.2
207	85.2	110.9	25.75	14.82	10.28	27.82	54.37	657.4
208	77.6	106.4	28.83	12.97	10.27	26.13	53.29	652.4

209	76.7	101.2	24.46	11.31	11.02	22.48	52.34	647.4
210	78.4	95.22	16.82	9.763	11.56	18.38	51.37	600.9
211	77	88.36	11.36	8.252	11.09	14.52	50.29	637
212	73.9	82.4	8.497	7.015	10.61	11.19	49.32	631.6
213	70.8	77.65	6.853	6.092	10.36	8.469	48.43	626.2
214	68.2	73.44	5.24	5.274	9.998	6.318	47.53	620.6
215	68.5	69.99	1.495	4.583	9.728	4.66	46.68	615
216	66.8	66.9	0.102	3.993	9.332	3.406	45.82	609.2
217	69.1	65.88	-3.22	3.49	8.983	3.967	45.06	603.4
218	71.9	67.34	-4.56	3.02	8.392	7.285	44.33	559.1
219	68.2	66.02	-2.18	2.633	7.747	7.951	43.46	591.5
220	65.4	64.46	-0.94	2.368	7.943	7.364	42.74	378.5
221	64.8	62.52	-2.28	2.2	8.084	6.284	41.99	579.3
222	63.1	60.62	-2.48	2.095	8.206	5.106	41.27	573.1
223	62.9	58.43	-4.47	1.98	7.98	4.016	40.52	566.8
224	62.3	56.9	-5.4	1.861	8.094	3.085	39.87	560.5
225	58.3	54.65	-3.65	1.636	7.601	2.328	39.1	554
226	55.2	53.27	-1.93	1.436	7.579	1.733	38.49	547.6
227	55.5	61.95	6.453	1.283	8.288	9.913	38.36	541
228	61.4	63.97	2.567	1.135	8.57	12.48	37.7	534.4
229	60.3	62.2	1.898	0.974	8.034	12.23	36.96	527.8
230	55.5	61.2	5.696	0.838	7.525	12.59	36.33	521.1
231	53.2	60.57	7.366	0.779	8.877	11.48	35.87	128.6
232	53	60.93	7.926	0.738	8.718	12.79	35.3	507.5
233	52.1	67.79	15.69	0.747	10.25	18.25	35.33	291.5
234	56.1	67.72	11.62	0.715	10.48	18.66	34.72	493.8
235	56.6	64.89	8.295	0.674	10.17	16.76	34.15	486.9
236	56.9	62.23	5.331	0.668	10.56	14.06	33.75	480
237	58	60.71	2.707	0.681	11.92	11.29	33.37	473
238	57.2	57.25	0.046	0.618	11.53	8.81	32.76	466
239	54.9	53.53	-1.37	0.528	10.55	6.728	32.2	459
240	51.8	50.42	-1.38	0.841	9.006	5.608	31.61	321.2
241	49	54.9	5.895	2.004	7.32	10.17	32.44	340
242	44.5	56	11.5	4.56	5.941	11.07	31.94	254.9
243	40.8	54.35	13.55	6.104	4.722	10.24	31.28	430.7
244	38.8	52.94	14.14	8.032	3.828	8.735	30.77	423.6
245	38.5	52.33	13.83	10.49	3.218	7.094	30.31	416.5
246	38.8	52.38	13.58	11.52	2.665	7.382	29.89	409.4
247	38.5	51.09	12.59	11.91	2.277	6.779	29.42	100.6
248	37.1	49.4	12.3	12.07	1.998	5.863	28.95	98.81
249	35.4	47.41	12.01	11.97	1.784	4.804	28.46	225.9
250	33.1	45.08	11.98	11.54	1.543	3.8	27.9	381
251	32	43.6	11.6	11.61	1.434	2.931	27.4	374
252	31.4	43.6	12.2	12.7	1.498	2.22	27.01	366.9
253	32	43.99	11.99	13.77	1.805	1.657	26.62	359.9
254	34	45.61	11.61	15.47	2.444	1.222	26.35	352.9
255	37.4	58.79	21.39	17.05	3.154	11.17	27.33	345.9
256	42.2	67.7	25.5	20.31	4.233	15.63	27.45	117.4
257	45	66.59	21.59	19.51	4.242	15.88	26.89	82.99
258	42.5	61.39	18.89	16.98	3.775	14.23	26.35	81.26
259	38.5	54.9	16.4	13.98	3.148	11.92	25.82	110.2
260	35.7	49.17	13.47	11.37	2.52	9.937	25.31	254.6
261	33.7	53.32	19.62	15.79	2.238	9.018	26.25	177.3
262	33.1	63.85	30.75	25.52	2.302	7.608	28.38	74.45
263	33.7	63.56	29.86	27.18	2.075	6.404	27.85	100.8
264	33.1	61.16	28.06	26.32	1.757	5.158	27.87	116.8
265	32.3	58.25	25.95	23.27	1.426	5.492	28.01	114.1
266	31.7	56.46	24.76	19.41	1.121	7.578	28.31	125.9
267	32.8	52.74	19.94	15.82	0.868	7.686	28.32	77.54
268	32.6	49.19	16.59	13.3	0.685	6.881	28.28	64.58
269	31.7	44.73	13.03	10.71	0.527	5.762	27.69	235.8

270	30.6	40.58	9.977	8.404	0.399	4.625	27.11	245.6
271	29.7	37.01	7.311	6.509	0.299	3.613	26.56	126.5
272	29.4	34.01	4.606	4.955	0.222	2.786	26.02	80.79
273	32.6	31.58	-1.02	3.772	0.164	2.127	25.49	64.08

Appendix 9 - UBC Model Estimates of Icemelt for 30% and 62% Glacier Recession with Climatic Scenario Forcings

30% glacier recess. from 1993 estimates					
Julian Day	Icemelt obs. met.	Icemelt Sc 1	Icemelt Sc 2	Icemelt Sc 3	Icemelt Sc 4
140	0	0	0	0	0
141	0	0	0	0	0
142	0	0	0	0	0
143	0	0	0	0	0
144	0	0	0	0.006	0
145	0	0	0	0.022	0
146	0	0	0	0.041	0
147	0	0	0	0.051	0
148	0	0	0	0.055	0
149	0	0	0	0.066	0
150	0	0	0	0.075	0
151	0	0	0	0.085	0
152	0	0	0	0.103	0
153	0	0	0	0.34	0
154	0	0	0.011	1.053	0
155	0.012	0	0.033	2.021	0
156	0.032	0.015	0.06	2.956	0
157	0.054	0.048	0.084	3.74	0
158	0.072	0.076	0.103	4.246	0
159	0.084	0.095	0.225	4.433	0
160	0.227	0.115	0.581	4.745	0
161	0.622	0.144	1.188	5.279	0
162	0.949	0.156	1.62	5.374	0
163	1.07	0.15	1.74	4.976	0
164	1.261	0.142	1.894	4.676	0
165	1.538	0.307	2.119	4.569	0
166	1.987	0.808	2.545	4.814	0
167	2.496	1.511	3.038	5.192	0
168	3.153	2.482	3.758	5.876	0.016
169	4.1	3.657	4.746	6.844	0.051
170	4.817	4.581	5.527	7.572	0.086
171	4.858	4.916	5.61	7.605	0.103
172	4.919	5.193	5.764	7.721	0.117
173	5.161	5.519	6.115	8.052	0.132
174	5.451	5.843	6.474	8.409	0.15
175	5.107	5.746	6.158	8.074	0.181
176	4.467	5.375	5.468	7.349	0.208
177	4.012	5.237	5.051	6.944	0.309
178	3.672	5.285	4.789	6.74	0.547
179	3.115	4.799	4.159	5.963	0.595
180	2.716	4.428	3.689	5.388	0.758
181	2.524	4.29	3.43	5.126	0.966
182	2.569	4.365	3.352	5.068	1.336
183	2.797	4.608	3.422	5.165	1.825
184	2.895	4.804	3.442	5.238	2.136
185	2.869	4.967	3.398	5.283	2.307
186	2.74	5.006	3.273	5.189	2.41
187	2.544	4.903	3.078	4.974	2.386
188	2.452	4.734	2.962	4.746	2.544
189	2.939	5.264	3.457	5.256	3.08
190	3.506	5.748	3.987	5.745	3.601

62% glacier recess. from 1993 estimates					
Julian Day	Icemelt obs. met.	Icemelt Sc 1	Icemelt Sc 2	Icemelt Sc 3	Icemelt Sc 4
140	0	0	0	0	0
141	0	0	0	0	0
142	0	0	0	0	0
143	0	0	0	0	0
144	0	0	0	0	0
145	0	0	0	0	0
146	0	0	0	0	0
147	0	0	0	0	0
148	0	0	0	0	0
149	0	0	0	0	0
150	0	0	0	0	0
151	0	0	0	0	0
152	0	0	0	0	0
153	0	0	0	0.066	0
154	0	0	0	0.274	0
155	0	0	0	0.56	0
156	0	0	0	0.842	0
157	0	0	0	1.078	0
158	0	0	0	1.233	0
159	0	0	0.034	1.291	0
160	0.04	0	0.14	1.46	0
161	0.155	0	0.321	1.785	0
162	0.254	0	0.454	1.949	0
163	0.294	0	0.494	1.877	0
164	0.354	0	0.544	1.868	0
165	0.441	0.052	0.616	1.955	0
166	0.579	0.205	0.747	2.217	0
167	0.734	0.42	0.899	2.544	0
168	0.934	0.713	1.199	3.038	0
169	1.352	1.065	1.694	3.677	0
170	1.724	1.34	2.136	4.093	0
171	1.789	1.439	2.241	4.079	0
172	1.849	1.522	2.385	4.101	0
173	2.004	1.61	2.637	4.239	0
174	2.208	1.702	2.895	4.392	0
175	2.091	1.678	2.783	4.141	0.009
176	1.829	1.571	2.464	3.684	0.02
177	1.622	1.531	2.233	3.382	0.052
178	1.456	1.582	2.063	3.204	0.124
179	1.221	1.452	1.763	2.787	0.143
180	1.05	1.376	1.542	2.486	0.197
181	0.968	1.389	1.412	2.346	0.262
182	1.02	1.538	1.377	2.335	0.377
183	1.175	1.807	1.428	2.436	0.527
184	1.222	1.988	1.423	2.476	0.622
185	1.188	2.124	1.378	2.48	0.675
186	1.104	2.209	1.309	2.423	0.707
187	1.002	2.203	1.223	2.303	0.701
188	0.965	2.165	1.198	2.206	0.751
189	1.223	2.492	1.485	2.519	0.906
190	1.572	2.804	1.817	2.841	1.05

191	4.254	6.333	4.655	6.354	4.162
192	5.04	6.978	5.32	6.978	4.738
193	5.19	7.027	5.396	7.028	4.784
194	4.955	6.749	5.143	6.756	4.522
195	4.57	6.325	4.768	6.342	4.237
196	4.142	5.739	4.33	5.767	4.002
197	3.771	5.195	3.936	5.217	3.82
198	3.441	4.718	3.578	4.729	3.664
199	3.3	4.521	3.432	4.527	3.625
200	3.417	4.634	3.569	4.646	3.841
201	3.702	4.962	3.898	4.988	4.229
202	4.002	5.373	4.25	5.383	4.694
203	4.381	5.864	4.685	5.852	5.336
204	4.953	6.534	5.32	6.554	6.258
205	5.558	7.175	5.964	7.223	7.122
206	6.009	7.659	6.44	7.712	7.791
207	5.984	7.667	6.43	7.708	7.956
208	5.996	7.683	6.444	7.707	8.115
209	6.453	8.253	6.913	8.26	8.77
210	6.763	8.641	7.238	8.633	9.17
211	6.478	8.31	6.928	8.285	8.933
212	6.181	7.959	6.611	7.917	8.661
213	6.021	7.788	6.438	7.704	8.507
214	5.789	7.53	6.192	7.408	8.27
215	5.615	7.35	6.012	7.197	8.082
216	5.365	7.076	5.755	6.904	7.813
217	5.137	6.844	5.527	6.657	7.564
218	4.753	6.504	5.146	6.292	7.162
219	4.342	6.123	4.735	5.89	6.745
220	4.4	6.304	4.819	6.037	6.722
221	4.45	6.403	4.881	6.113	6.751
222	4.502	6.472	4.938	6.169	6.812
223	4.364	6.323	4.795	6	6.685
224	4.415	6.407	4.853	6.054	6.761
225	4.127	6.101	4.552	5.743	6.471
226	4.114	6.086	4.537	5.718	6.47
227	4.55	6.639	5.003	6.265	7.029
228	4.735	6.9	5.202	6.498	7.284
229	4.45	6.501	4.883	6.101	7.008
230	4.167	6.176	4.586	5.773	6.723
231	4.811	7.128	5.307	6.695	7.249
232	4.686	6.99	5.176	6.578	7.055
233	5.558	8.06	6.113	7.674	7.821
234	5.732	8.226	6.3	7.883	7.938
235	5.613	7.981	6.164	7.683	7.785
236	5.935	8.118	6.451	7.859	8.098
237	6.81	9.004	7.342	8.777	9.078
238	6.623	8.751	7.137	8.536	8.901
239	6.06	8.122	6.556	7.91	8.304
240	5.164	7.078	5.611	6.88	7.271
241	4.192	5.846	4.567	5.676	6.034
242	3.371	5.018	3.724	4.878	4.906
243	2.654	4.178	2.971	4.067	3.884
244	2.12	3.611	2.422	3.512	3.081
245	1.754	3.238	2.071	3.145	2.492
246	1.428	2.921	1.758	2.833	1.987
247	1.189	2.724	1.538	2.636	1.608
248	1.018	2.569	1.373	2.482	1.331
249	0.887	2.51	1.274	2.409	1.12
250	0.755	2.313	1.128	2.21	0.928
251	0.701	2.203	1.062	2.097	0.831
252	0.744	2.223	1.102	2.112	0.846

191	2.058	3.171	2.244	3.24	1.198
192	2.572	3.53	2.653	3.626	1.344
193	2.708	3.549	2.714	3.659	1.353
194	2.605	3.382	2.58	3.489	1.281
195	2.396	3.141	2.381	3.244	1.206
196	2.159	2.838	2.156	2.936	1.146
197	1.956	2.567	1.959	2.653	1.099
198	1.775	2.329	1.781	2.402	1.056
199	1.699	2.243	1.712	2.314	1.042
200	1.762	2.329	1.801	2.409	1.168
201	1.922	2.538	2.004	2.636	1.396
202	2.087	2.775	2.214	2.885	1.7
203	2.296	3.039	2.47	3.161	2.114
204	2.607	3.397	2.83	3.552	2.607
205	2.951	3.766	3.206	3.935	2.951
206	3.201	4.048	3.475	4.204	3.201
207	3.181	4.063	3.465	4.188	3.181
208	3.191	4.098	3.477	4.189	3.191
209	3.459	4.434	3.751	4.492	3.459
210	3.64	4.666	3.937	4.697	3.64
211	3.495	4.498	3.772	4.502	3.495
212	3.344	4.329	3.608	4.309	3.344
213	3.276	4.269	3.533	4.216	3.276
214	3.162	4.156	3.412	4.073	3.162
215	3.084	4.089	3.332	3.984	3.084
216	2.957	3.965	3.203	3.843	2.957
217	2.836	3.845	3.083	3.714	2.836
218	2.609	3.622	2.852	3.486	2.609
219	2.363	3.373	2.601	3.233	2.363
220	2.377	3.428	2.629	3.285	2.377
221	2.404	3.466	2.663	3.322	2.404
222	2.439	3.506	2.704	3.361	2.439
223	2.366	3.429	2.632	3.277	2.366
224	2.403	3.479	2.675	3.32	2.403
225	2.242	3.3	2.502	3.141	2.242
226	2.25	3.305	2.508	3.145	2.25
227	2.474	3.581	2.746	3.414	2.474
228	2.558	3.687	2.834	3.51	2.558
229	2.39	3.447	2.646	3.27	2.39
230	2.218	3.242	2.465	3.063	2.218
231	2.508	3.652	2.783	3.47	2.508
232	2.414	3.534	2.68	3.357	2.414
233	2.85	4.104	3.15	3.91	2.85
234	2.931	4.222	3.24	4.02	2.931
235	2.869	4.134	3.172	3.929	2.869
236	3.07	4.284	3.361	4.069	3.07
237	3.593	4.85	3.896	4.624	3.593
238	3.514	4.749	3.806	4.522	3.514
239	3.213	4.421	3.496	4.195	3.213
240	2.729	3.842	2.98	3.633	2.729
241	2.211	3.163	2.42	2.985	2.211
242	1.754	2.655	1.939	2.509	1.754
243	1.361	2.169	1.521	2.053	1.361
244	1.058	1.831	1.2	1.737	1.058
245	0.847	1.607	0.991	1.529	0.847
246	0.668	1.414	0.811	1.349	0.668
247	0.533	1.268	0.68	1.212	0.533
248	0.438	1.151	0.585	1.103	0.438
249	0.365	1.09	0.521	1.043	0.365
250	0.299	0.985	0.448	0.942	0.299
251	0.273	0.943	0.416	0.902	0.273
252	0.29	0.983	0.437	0.942	0.29

253	0.932	2.38	1.286	2.262	1.013
254	1.319	2.743	1.698	2.596	1.385
255	1.745	3.267	2.17	3.122	1.798
256	2.364	4.178	2.893	4.045	2.409
257	2.377	4.119	2.893	4.006	2.413
258	2.119	3.635	2.572	3.544	2.147
259	1.768	3.016	2.143	2.944	1.79
260	1.416	2.408	1.714	2.353	1.432
261	1.232	2.29	1.548	2.276	1.244
262	1.233	2.442	1.594	2.475	1.243
263	1.097	2.241	1.438	2.292	1.104
264	0.916	2.034	1.219	2.093	0.921
265	0.734	1.772	0.993	1.829	0.738
266	0.572	1.492	0.783	1.543	0.574
267	0.437	1.255	0.604	1.3	0.439
268	0.334	1.127	0.491	1.167	0.336
269	0.251	0.945	0.386	0.978	0.253
270	0.187	0.759	0.297	0.786	0.188
271	0.137	0.648	0.225	0.667	0.138
272	0.1	0.545	0.168	0.559	0.1
273	0.072	0.468	0.125	0.481	0.073

253	0.378	1.107	0.532	1.066	0.378
254	0.569	1.351	0.74	1.303	0.569
255	0.784	1.668	0.986	1.608	0.784
256	1.085	2.158	1.35	2.077	1.085
257	1.098	2.136	1.362	2.055	1.098
258	0.982	1.889	1.216	1.817	0.982
259	0.821	1.569	1.016	1.509	0.821
260	0.658	1.253	0.814	1.205	0.658
261	0.554	1.163	0.719	1.139	0.554
262	0.531	1.201	0.718	1.203	0.531
263	0.462	1.085	0.638	1.098	0.462
264	0.38	0.953	0.534	0.972	0.38
265	0.301	0.804	0.43	0.824	0.301
266	0.233	0.658	0.336	0.676	0.233
267	0.176	0.535	0.257	0.551	0.176
268	0.133	0.458	0.202	0.473	0.133
269	0.099	0.374	0.156	0.386	0.099
270	0.073	0.294	0.118	0.305	0.073
271	0.053	0.242	0.088	0.249	0.053
272	0.038	0.197	0.065	0.202	0.038
273	0.028	0.163	0.047	0.168	0.028

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IMAGE EVALUATION TEST TARGET (QA-3)

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6"

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