WATER
MANAGEMENT
CONSULTANTS
A Schlumberger Company

130-10691 SHELLBRIDGE WAY
RICHMOND, B.C. V6X 2W8,
CANADA

TELEPHONE: (604) 273 6299
TELEFAX: (604) 270 3644

March 31 2008

Nicola Watershed Community Round Table
Box 400
Merritt, BC
V1K 1B8

Attention: Elizabeth Salomon-de-Friedberg

Dear Elizabeth

Re: Surface and Groundwater Supply and Interaction Study- Phase 1 and 2
WUMP-2006-S02

We are pleased to enclose our Report on the Surface and Groundwater Supply and Interaction Study for the Nicola Watershed.

The report provides detailed information on water supply by sub basin and includes a conceptual understanding of groundwater/surface water interactions based on our analysis of the hydrogeology and topography of the Nicola Watershed. We have concluded that any groundwater abstraction in the Nicola Watershed will reduce downstream flows.

Thank you for this opportunity to work on this interesting study.

Yours truly,

CDN WATER MANAGEMENT CONSULTANTS INC.

C. David Sellars, P. Eng.
Project Manager

SURFACE AND GROUNDWATER SUPPLY AND INTERACTION STUDY – Phase 1 and 2

March 31 2008

7173

Prepared for:

Nicola Watershed Community Round Table
Box 400, Merritt, BC
V1K 1B8

Prepared by:

Water Management Consultants
130-10691 Shellbridge Way
Richmond, BC
V6X 2W8

CONTENTS

EXECUTIVE SUMMARY IX

1 INTRODUCTION 1

2 WATERSHED DESCRIPTION 3

2.1 Physiography and Drainage 3

2.2 Climate and Meteorology 4
- *2.2.1 Introduction 4*
- *2.2.2 Temperature 5*
- *2.2.3 Precipitation 5*
- *2.2.4 Snow Pack 6*
- *2.2.5 Precipitation Distribution 7*
- *2.2.6 Evaporation 8*

2.3 Bedrock Aquifers 8
- *2.3.1 General 8*
- *2.3.2 Nicola Group 8*
- *2.3.3 Triassic and Jurassic Intrusions 8*
- *2.3.4 Ashcroft Formation 8*
- *2.3.5 Spences Bridge Group 8*
- *2.3.6 Tertiary Rocks 9*
- *2.3.7 Bedrock Structures 9*

2.4 Surficial Geology 10
- *2.4.1 Pre Fraser Glaciation 10*
- *2.4.2 Fraser Glaciation 10*
- *2.4.3 Post Fraser Glaciation 11*

2.5 Surficial Aquifers 12
- *2.5.1 Spius Creek 12*
- *2.5.2 Coldwater River Valley 12*
- *2.5.3 Quilchena Creek Valley 12*
- *2.5.4 Stump Lake Creek 13*
- *2.5.5 Moore Creek 13*
- *2.5.6 Clapperton Creek 13*
- *2.5.7 Guichon Creek 13*
- *2.5.8 Witches Brook 14*
- *2.5.9 Upper Nicola Valley 15*
- *2.5.10 Middle Nicola Valley 15*
- *2.5.11 Merritt Aquifer 15*
- *2.5.12 Lower Nicola Valley 15*

3 GROUNDWATER 17

3.1 Groundwater Characterization 17
- *3.1.1 Introduction 17*
- *3.1.2 Groundwater Units 17*
- *3.1.3 Groundwater Recharge and Storage 18*
- *3.1.4 Groundwater Quality 18*

3.2 Mapped Aquifers 19
- *3.2.1 Mapped Aquifers in Guichon Creek Valley 19*
- *3.2.2 Mapped Aquifers in Nicola Valley near Merritt and Lower Nicola 21*
- *3.2.3 Mapped Aquifers near Nicola Lake 22*

3.3 Known Major Nicola Watershed Aquifers 22

3.4 Groundwater Use 23
- *3.4.1 Current Demand 23*
- *3.4.2 Future Demand 23*

4 GROUNDWATER/SURFACE WATER INTERACTION 25

4.1 Introduction 25

4.2 Elements of Interaction 26

4.3 Extraction from Surface Water 27

4.4 Extraction from Groundwater 28

4.5 Response of an Unconfined Aquifer to Pumping 29

4.6 Response of a Confined Aquifer to Pumping 29

4.7 Modelling a Typical Valley Aquifer System 30

4.8 Mitigation for Extraction 31
- *4.8.1 Demand Management 31*
- *4.8.2 Surface Water Storage 31*
- *4.8.3 Groundwater Storage 32*
- *4.8.4 Conjunctive Use 32*

4.9 Calculation Methodology 32
- *4.9.1 General 32*
- *4.9.2 Calculation Method Selection 32*

5 WATERSHED MODELLING 34

5.1 Methodology 34

5.2 Data for Watershed Modelling 35
- *5.2.1 Climate and Snowpack 35*
- *5.2.2 Hydrometric 35*

5.3 Sub-Catchment Description 36

5.3.1 Selection of Sub-Catchments *36*

5.3.2 Areas and Elevation Bands *36*

5.3.3 Climate Distribution *36*

5.3.4 Forest Cover *37*

5.3.5 Mountain Pine Beetle *38*

5.4 Sub-Catchment Calibration 39

5.5 Characterizing Non-Gauged Sub-catchments 40

6 WATER SUPPLY FORECASTING 41

6.1 Climate scenarios 41

6.2 Pine Beetle Scenarios 42

6.3 Results 43

6.4 Accuracy 46

7 NEXT STEPS 48

8 CONCLUSIONS AND RECOMMENDATIONS 50

8.1 Conclusions 50

8.2 Recommendations 52

REFERENCES 53

Tables

Table 2.1 Summary of Ten Sub-catchments
Table 2.2 Climate Stations within the Nicola Watershed
Table 2.3 Precipitation Ratios for Meteorological Stations in the Nicola Watershed
Table 2.4 Location of Snow Courses in and adjacent to Nicola Watershed
Table 2.5 Snow Water Equivalents and Ratios for the Average End of March
Table 3.1 Summary of Regional Aquifers
Table 3.2 Mapped Aquifers in the Nicola watershed
Table 5.1 Stream Gauge Locations used to calibrate the Watershed Model
Table 5.2 Average Yearly Precipitation and Temperature for each Sub Catchment
Table 5.3 Percent of MPB infestation by sub-catchment
Table 6.1 Changes in Temperature (°C) and Precipitation (mm) at Lornex (Highland Valley) for Different Climate Scenarios
Table 6.2 Scenarios Applied for Current and Future Water Supply
Table 6.3a Results of Drought Frequency Analysis for Scenario 1
Table 6.3b Results of Drought Frequency Analysis for Scenario 2
Table 6.3c Results of Drought Frequency Analysis for Scenario 3
Table 6.3d Results of Drought Frequency Analysis for Scenario 4
Table 6.3e Results of Drought Frequency Analysis for Scenario 5
Table 6.4 Drought Susceptibility Ratings for Nicola Sub Basins
Table 6.5 Model accuracy estimates expressed as plus/minus percentage

Figures

Figure 2.1 Nicola Watershed Site Location
Figure 2.2 Physiographic Map of Nicola Watershed
Figure 2.3 Nicola Watershed Site Plan
Figure 2.4 Location of Meteorologic, Snow Course and Hydrometric Stations
Figure 2.5 Comparison of Merritt and Lornex Temperatures, 1968 to 1972
Figure 2.6 Double Mass Precipitation Curves
Figure 2.7 Plot of Precipitation Multipliers and Curve Numbers
Figure 2.8 Geology of Nicola Watershed
Figure 2.9 Distribution of Glacial Lakes
Figure 2.10 Measured Witches Brook Flows
Figure 3.1 Mapped Groundwater Aquifers
Figure 3.2 Major Aquifers within the Nicola Watershed
Figure 4.1 Surface Water and Groundwater Interaction
Figure 4.2 Schematic of Groundwater Discharge to Base Flow
Figure 4.3 Streamflow Response to Pumping from an Unconfined Aquifer
Figure 4.4 Streamflow Response to Pumping from a Confined Aquifer
Figure 4.5 Downstream Baseflow History from Pumping a Confined and Unconfined Aquifer
Figure 5.1 Catchments in Watershed Model
Figure 5.2 MPB infestation in 2006
Figure 5.3 Beak Creek Calibration
Figure 5.4 Pennask Creek Calibration
Figure 5.5 Upper Coldwater River Calibration
Figure 5.6 Upper Spius Creek Calibration
Figure 5.7 Lower Spius Creek Calibration
Figure 5.8 Upper Guichon Creek Calibration
Figure 5.9 Cumulative Volume of Flows at Spences Bridge
Figure 5.10 Cumulative Volume of Flows Downstream of Nicola Lake
Figure 6.1 Estimated extent of MPB infestation in 2015
Figure 6.2 Scenario 1: Average annual natural flow in L/s/km^2
Figure 6.3 Scenario 2: Average annual natural flow in L/s/km^2
Figure 6.4 Scenario 3: Average annual natural flow in L/s/km^2
Figure 6.5 Scenario 4: Average annual natural flow in L/s/km^2
Figure 6.6 Scenario 5: Average annual natural flow in L/s/km^2
Figure 6.7 Scenario 1: Minimum annual weekly flow in L/s/km^2 for 1 in 15 year drought
Figure 6.8 Scenario 2: Minimum annual weekly flow in L/s/km^2 for 1 in 15 year drought
Figure 6.9 Scenario 3: Minimum annual weekly flow in L/s/km^2 for 1 in 15 year drought
Figure 6.10 Scenario 4: Minimum annual weekly flow in L/s/km^2 for 1 in 15 year drought
Figure 6.11 Scenario 5: Minimum annual weekly flow in L/s/km^2 for 1 in 15 year drought

Appendices

I Nicola Valley OCP
II Guide to Applying for a Certificate of Public Convenience and Necessity (CPCN)
III Description of Watershed Model
IV List of contacts
V Description of Data CD

GLOSSARY

Ablation till	Loose, permeable material deposited during the final down-wasting of glacial ice
Alluvium	Soil or sediments deposited by a river or other running water
Codepositional	Deposition of two or more sediment types at the same or at alternating times
Conductance	Fluid conductance is the rate at which a unit of material can transmit fluids.
Discontinuity	A surface between two layers of rock or sediment that represents either an interruption in the deposition of the layers or a displacement of one or both layers relative to each other
Esker	A serpentine ridge of sand and gravel, deposited by glacial meltwater
Exceedance	Instance of exceeding a limit or amount
Groundwater storage	Volume of water stored in aquifer
Hummocky	A low mound or ridge of earth
Ice marginal	Deposition adjacent to ice
Kame terrace	A terrace of glacial sand and gravel deposited between valley ice and valley sides
Kettle	A depression made by the melting of a detached mass of glacier ice that has been wholly or partly buried in the drift
$L/s/km^2$	Unit flow expressed as litres per second for each square kilometre in a sub basin
masl	Metres above sea level
Minimum annual monthly flow	The lowest monthly flow in a year
Minimum annual weekly flow	The lowest weekly flow in a year
NTS	National Topographic System
Pocked area	having an irregular surface
Sublimation	Snow that evaporates directly into the atmosphere without melting first.
Subsidence	Subsidence in the Earth's atmosphere is the movement of air towards the ground.

EXECUTIVE SUMMARY

The Surface and Groundwater Supply and Interaction Study - Phase 1 and 2 is intended to fill knowledge gaps as part of the planning process leading to a water use management plan for the Nicola Watershed. Phases 1 and 2 provide the foundation and direction for Phase 3, which was intended to focus on specific surface/groundwater interactions. The goal of the study is to determine the current and future water supply in the Nicola Watershed from surface and groundwater sources. This objective has been met.

We have completed the assessment of natural flows throughout the Nicola Watershed and have identified the distribution of available surface water and groundwater supply for current conditions and for future scenarios. We have also developed a conceptual understanding of groundwater/surface water interactions in the Nicola Watershed. We have concluded that any groundwater abstraction in the Nicola Watershed will reduce downstream flows.

Three major valley aquifers were identified within the Nicola Watershed, Guichon Valley Aquifer, Coldwater Valley Aquifer and the Nicola Valley Aquifer. These major (significant yield) aquifers are sand and gravel aquifers within the major valleys. In these valleys, streams and rivers in the current landscape, and more importantly, the much higher flowing glacial meltwater from glacial periods, deposited permeable sand and gravel. In these valleys, there are also larger areas which have the capability to recharge these sand and gravel aquifers.

Groundwater storage is an important element of the groundwater and surface water systems. Groundwater is stored within the developable aquifers and also within all of the geologic materials within the watershed. For example, groundwater is also stored within till-like materials and bedrock within the valley walls. Groundwater storage provides discharge to stream flows during the dry season as well as a resource for irrigation, industry and potable water year round.

Recent subdivision applications to the Thompson-Nicola Regional District have been required to include community water supply systems rather than developing individual wells for each lot. A community water supply system requires approval from the Province in the form of a Certificate of Public Convenience and Necessity (CPCN). An assessment of the impact of pumping of water wells on surface water and springs in areas where water licences are known to exist must be included in the groundwater report as part of the CPCN application.

The interaction of groundwater and surface water is of particular interest in semi-arid areas because of the importance of groundwater to maintaining stream baseflows. The contribution of groundwater to baseflow is affected by recharge to groundwater, storage in the aquifer and discharge from groundwater storage to the stream.

A conceptual understanding of groundwater/surface water interaction in the Nicola Watershed has been developed. The key factors are:

- Groundwater discharge to surface water is the primary source of stream base flow.
- Any groundwater extractions and consumptions in the Nicola Watershed will reduce downstream flows.
- Groundwater extraction from surficial aquifers will have a local effect on stream flows.
- Groundwater extraction from confined aquifers will have a more widespread effect on stream flows.

A key step in the study was calibration of the WMC Watershed Model using locations within the Nicola watershed where natural stream flows are measured. The watershed model simulates the natural hydrologic processes in a watershed including snowmelt, evapotranspiration, groundwater (recharge, storage and discharge), and surface runoff. The stream flow simulated by the model is the combination of surface runoff and groundwater discharge. Once the model was calibrated the model was extended across the Nicola Watershed to generate simulated natural flows for all sub basins for current conditions and for future water supply scenarios.

As expected the model indicated that the largest natural flows originate from the Coldwater, Spius and Upper Nicola sub basins with lower flows originating from the Guichon and Quilchena sub basins. The remaining sub basins have very low natural flows.

The drought frequency analysis showed that the Coldwater, Spius and Upper Nicola sub basins do not respond as significantly to extreme drought conditions as the other Nicola sub basins. This is because of the larger precipitation and snowpacks making these basins resilient to drought conditions. The other sub basins are very susceptible to extreme droughts and very low flows would occur in these basins with a 50-year drought. The most drought susceptible basins are Stump, Moore and Clapperton with low flows even in a moderate drought and flows of zero or close to zero in a 50-year drought.

The average annual natural flow out of the basin at Spences Bridge was calculated to be approximately 28,000 L/s (3.9 L/s/km^2). About 18,900 L/s of this flow originates in the Coldwater and Spius sub basins. These two sub basins represent 68% of the flow at Spences Bridge but only 23% of the total Nicola Watershed area. The Upper Nicola and Quilchena sub basins together contribute 6,800 L/s which is 24% of the flow at Spences Bridge. The remaining 2,300 L/s (8% of the flow at Spences Bridge) is contributed by the other sub basins.

For the year 2020 scenarios, flows generally increase because of the areas cleared as a result of the mountain pine beetle and some increase in precipitation. The drought susceptibility by sub basin is similar to current conditions.

For the year 2050 climate with regrowth of all mountain pine beetle areas, the estimated flows are generally similar to current conditions. The regrowth results in lower sub basin yields than in 2020 primarily because of interception and higher losses. The estimated flows are generally similar to current conditions with some higher flows due to greater winter precipitation.

We do not recommend that Phase 3 of this project be carried out as originally envisaged primarily because sufficient information is now available from this study and the water demand study for planning purposes. The recommended next steps for the Nicola Water Use Management Plan are as follows.

1. The water supply estimates in each sub basin should be compared with the water use and demand estimates developed by Summit (2007). The water use should include in-stream flows required by fisheries. This water budget analysis would provide an indication of which sub basins have a deficit and the degree of the water deficit in each sub basin.

2. Following the water budget study the water supply model should be modified to incorporate the demand and water use estimates and the model verified using regulated flow records on the Nicola River. This would provide a comprehensive model of the Nicola Watershed that can be used for water management planning.

3. The comprehensive model should be used to examine different water management scenarios. Scenarios would include different combinations of measures which could include:

    - Demand management
    - Additional surface water storage reservoirs
    - Groundwater recharge and storage systems
    - Mitigation of groundwater pumping by discharge in the dry season
    - Land use planning

1 INTRODUCTION

The Surface and Groundwater Supply and Interaction Study - Phase 1 and 2 is intended to fill knowledge gaps as part of the planning process leading to a water use management plan for the Nicola Watershed. The goal of this study is to determine the current and future water supply in the Nicola Watershed from surface and groundwater sources.

The objectives of the Study are:

1) To determine current water supply (surface and groundwater) and seasonal patterns of supply for the entire watershed.

2) To forecast future water supply and seasonal patterns stemming from climate change under a minimum of three scenarios.

3) To identify where and to what degree surface water and groundwater interact in order to understand more fully the implications of water extraction.

The Surface and Groundwater Supply and Interaction Study includes reviewing existing surface water and groundwater supply data and studies, forecasting water supply, summarizing existing groundwater and aquifer information by sub basin, identifying knowledge gaps, recommending a method by which water supply and surface and groundwater interaction can be presented or modeled and developing criteria for selecting areas for further study. In order to accomplish these objectives, information was collected from the active and/or historic climate and snow survey stations, the active and discontinued hydrometric stations within the Nicola Watershed and available groundwater data.

The hydrology of the Nicola Basin is complex with variations in precipitation, snowpack and surface cover throughout the basin. The seasonal variation in stream flows is significant as evapotranspiration and sublimation typically accounts for 80% to 90% of the precipitation and a large percentage of the runoff is generated from snowpack. There is also considerable stream flow variation from year to year. Compounding the spatial and temporal variation in stream flows is the interaction between surface water and groundwater which varies depending on the aquifer characteristics in each sub basin.

While the climate station and snow course coverage of the Nicola Basin is relatively good there are few hydrometric stations that record natural flows. Most hydrometric stations in the basin are on watercourses that have upstream water licences or are regulated by reservoirs. The complexity of the hydrology of the Nicola Basin and the limited data available present a significant challenge for developing an understanding of the basin hydrology. However, characterization of the natural flow hydrology of the basin is essential for water supply analysis and developing future water management plans.

Based on the limited natural flow data, defining surface water flows by extrapolating unit flows from the unregulated stream gauges would not take into account any known variations in groundwater/surface water interactions. Therefore, our approach to characterizing the hydrology of the Nicola Basin was to develop a preliminary watershed model for each sub basin. The WMC Watershed Model was calibrated using stream flow records on unregulated streams and was then extended to the entire basin. The model used a groundwater component and elevation bands for generating runoff and groundwater discharge.

2 WATERSHED DESCRIPTION

2.1 Physiography and Drainage

The Nicola Basin is located on the Thompson Plateau physiographic zone, which is a subzone of the Interior Plateau (Holland, 1976). The Interior Plateau is located between the Coast Mountains to the west and the Monashee and Selkirk Mountains to the east. The Thomson Plateau section ranges from the Coast Mountains to the Okanagan Valley. Much of the Thompson Plateau has gently rolling relief between 1200 and 1500 m. The elevation ranges from 600 m at Merritt (240 m at Spences Bridge) to over 2,000 m at some of the peaks on the west. Figure 2.1 illustrates the location of the Nicola Basin.

The Nicola River flows west through the basin and discharges to the Thompson River at Spences Bridge. Major tributaries include:

- Coldwater River
- Guichon Creek
- Quilchena Creek
- Clapperton Creek

A map illustrating the physiographic setting of the Nicola Basin is provided on Figure 2.2. The contours illustrated on Figure 2.2 were derived from a digital elevation model (DEM) provided by the BC Integrated Land Management Bureau. The DEM is a raster type layer with 25 metre resolution.

The study area includes all the rivers, creeks, streams and tributaries of the Nicola River from its headwaters to its confluence with the Thompson River at Spences Bridge. A series of ten sub-catchments for the Nicola Valley were defined by Urban Systems (Phase 1 Scoping Study, 2005). The sub-catchment boundaries were based on delineation of watersheds so that boundaries straddle the topographic highs between creeks and rivers. The boundaries of the ten sub-catchments are included on Figure 2.3. Table 2.1 summarizes the physical attributes of the ten areas.

Table 2.1: Summary of Ten Sub-catchments

	Area (km^2)	Elevation range (m)
Spius Creek	775	520 – 2260
Coldwater River	912	600 – 2100
Quilchena Creek	775	640 – 1860
Stump Lake Creek	313	640 – 1570
Moore Creek	205	640 – 1700
Clapperton Creek	256	640 – 1730
Guichon creek	1,226	585 – 1990
Upper Nicola	1,506	630 – 1950
Middle Nicola	263	600 – 1540
Lower Nicola	981	230 – 1940

2.2 Climate and Meteorology

2.2.1 Introduction

The weather in the Nicola Watershed is controlled to a great extent by the Coast Mountains. Sitting to the lee of these mountains, subsidence has reduced the precipitation so that much of the area is arid or semi-arid. Annual precipitation ranges between 264 and 770 millimetres per year with relatively low precipitation during late winter and early fall and relatively high precipitation during early summer and mid winter. Summer in this area is noted for the incursion of the Pacific High and the development of hot and dry weather. The weather tends to be dry and sunny with late afternoon or evening thunderstorms occurring mainly along the ridges. Eventually, the Pacific High does break down and, when this happens, it is common for widespread thunderstorms to develop as cooler, moist air begins to move into the area. Winters are a different story. Mountain valleys allow cold air to pool, creating inversions. Most of the valleys have rivers and lakes that seldom freeze up resulting in abundant moisture that the inversion can trap, supporting the development of low “valley cloud”. On the positive side, because of its location, only the strongest incursions of arctic air can force its way into this area. This being said, the temperatures in the area do tend to hover around freezing, and the cold surface layer can be difficult to remove, as the warm air moving in from the coast rides over the top of the cold air. The only real warming occurs with southerly winds, but this respite only lasts a few days as cold air is quick to re-establish itself in the valley bottoms.

Acquisition of information and data is an important component of Phase 1. Data collected are included on the Data CD which is described in Appendix V. According to the National Climate Data and Information Archive compiled by Environment Canada, there are thirteen active or inactive climate locations throughout the Nicola watershed (see Table 2.2).

Table 2.2: Climate Stations within the Nicola Watershed

Station	Station ID	Elevation (m)	Latitude		Longitude		Active dates	
			Degrees	Minutes	Degrees	Minutes	Start	End
Brookmere	1121090	972	49	49	120	52	1986	1994
Douglas Lake	1122541	808	50	9	120	12	1979	2006
Elkhart Lodge	112K653	1615	49	55	120	21	1992	1995
Highland Valley BCCL	1123468	1470	50	30	121	0	1966	1989
Highland Valley Lornex	1123469	1268	50	28	121	1	1967	2006
Lac Le Jeune	1124460	1305	50	28	120	31	1984	1988
Logan Lake	1124668	1101	50	30	120	49	1971	2004
Meadowgreen	1125060	1207	50	28	120	40	1980	1986
Craigmont	1125075	732	50	12	120	52	1962	1976
Merritt STP	1125079	609	50	6	120	48	1968	2006
Nicola Lake	1125586	633	50	15	120	27	1979	1985
Nicola Lake West End	1125590	642	50	10	120	37	1984	1992
Spences Bridge	1167637	235	50	25	121	19	1980	2002

Locations of meteorological stations in the Nicola Basin are provided on Figure 2.4.

2.2.2 Temperature

Figure 2.5 illustrates measured average monthly temperatures at Lornex and Merritt. There is a 759 m elevation difference between the two stations, so that the expected temperature difference would be about 4.9 ^{o}C assuming an altitude adjustment or environmental lapse rate of 6.5^{o} C per kilometre (Ritter, 2006). As illustrated on Figure 2.5, this expected temperature difference is reasonably consistent in the warm season, but the Merritt temperatures are closer to the Lornex temperatures in the winter, probably as a result of cool air being trapped in the valley.

2.2.3 Precipitation

Annual average precipitation has been measured from 264 mm at Spences Bridge to about 770 mm at Elkhart lodge. Precipitation varies both with position and with elevation. The position relates to the direction that weather approaches the region. Higher precipitation near high ground is a common occurrence. To allow comparison of measured precipitation over the basin from stations with a variety of monitoring periods, double mass curves were prepared. A mass curve is simply the cumulative precipitation over the period of record. Plotting the cumulative precipitation for one station against the cumulative precipitation for a second station, using the same time period creates a double mass curve. For this study all double mass comparisons were plotted against the Lornex station on the x axis. The slope of the double mass curve provides a ratio of the station precipitation to the Lornex precipitation. An example of two double mass curves, presented on Figure 2.6, illustrates the ratio for Merritt and Spences Bridge versus Lornex. Table 2.3 below tabulates the ratios calculated for each station.

Table 2.3: Precipitation Ratios for Meteorological Stations in the Nicola Watershed

Station	Elevation (m)	Period		Ratio[1]	Curve number[2]
Lornex	1268	Jan-67	Mar-01	1.00	1.5
Brookmere	972	Jul-86	Feb-94	1.43	2.4
HVC BCCL	1470	Jan-67	Jun-86	0.97	1.4
Lac le Jeune	1305	Oct-85	Nov-88	1.13	1.6
Meadowgreen	1207	Jun-80	Jun-86	1.10	1.6
Craigmont	732	Jan-67	Apr-76	0.81	1.5
Merritt STP	609	Aug-68	Mar-01	0.82	1.7
Nicola Lake W	633	Dec-84	Feb-92	0.77	1.5
Douglas Lake	808	May-79	Mar-01	0.84	1.5
Elkhart Lodge	1615	Aug-92	Jan-95	2.13	2.2
Logan Lake	1101	Jul-85	Mar-01	1.01	1.6
Nicola Lake	633	May-79	Jan-85	0.73	1.4
Spences Bridge	235	May-80	Mar-01	0.66	1.5

1. Ratio of precipitation at station to precipitation at Lornex
2. See Section 2.2.5

2.2.4 Snow Pack

Snowpack data is available from the Ministry of Environment Water Stewardship Division River Forecast Center. Station locations are presented in Table 2.4. Snow pack data also provides an indication of the precipitation distribution within the Nicola Basin. Several snow course stations within and adjacent to the basin were examined. The average end of March snow water equivalent (swe) for each station was compared to the Highland Valley snow course for the same time period and ratios calculated. The results are presented in Table 2.5.

Table 2.4: Location of Snow Courses in and adjacent to Nicola Watershed

Station Name	Station ID	Elevation (m)	Latitude		Longitude		Available Data	
			Degree	Second	Degree	Second	Start	End
Nicola Watershed								
Shovelnose Mountain	1C29	1450	49	52	120	52	1975	2005
Lac Le Jeune (Lower)	1C07	1370	50	28	120	30	1956	2005
Brookmere	1C01	980	49	49	120	52	1945	2005
Gnawed Mountain	1C19	1580	50	27	121	2	1967	2005
Highland Valley	1C09A	1510	50	30	120	59	1966	2005
Lac Le Jeune (Upper)	1C25	1460	50	27	120	30	1973	2005
Okanagan Boundary								
MacDonald Lake	2F23	1740	49	53	120	2	1977	2005
Islaht Lake	2F24	1480	49	59	119	48	1982	2005
Whiterocks Mountain	2F09	1830	50	1	119	45	1953	2005
Esperon Creek (Upper)	2F13	1650	50	5	119	45	1966	2005

The first two stations are in the Coldwater River drainage basin. Lac le Jeune, Gnawed Mountain and Highland Valley are within the Guichon Creek drainage basin. The last four stations are within the Okanagan Lake Basin, but are close to the drainage divide. The available data indicates that snow packs within the basin would be largest near the upper end of the Coldwater River.

Table 2.5: Snow Water Equivalents and Ratio for the Average End of March

Station Name	number	elev. (m)	swe (mm)	Ratio[1]	Curve number[2]
Shovelnose Mountain	1C29	1450	228	2.83	2.9
Brookmere	1C01	980	201	2.13	3.6
Lac Le Jeune (Lower)	1C07	1370	104	1.40	1.9
Lac Le Jeune (Upper)	1C25	1460	125	1.10	1.5
Gnawed Mountain	1C19	1580	121	1.28	1.6
Highland Valley	1C09A	1510	94	1.00	1.4
MacDonald Lake[3]	2F23	1740	418	5.15	3.4
Islaht Lake[3]	2F24	1480	225	2.73	2.8
Whiterocks Mountain[3]	2F09	1830	569	6.03	3.5
Esperon Creek (Upper)[3]	2F13	1650	408	4.33	3.3

1. Ratio of end of March snowpack at station compared to Highland Valley
2. See Section 2.2.5.
3. These four sites are outside the Watershed boundary

2.2.5 Precipitation Distribution

Based on the above precipitation and snowpack ratios, a methodology for describing the precipitation distribution was developed. First, the ratios were plotted against station elevation. A curve was then proposed to define the distribution of Lornex multiplier (Ratio in Tables 2.3 and 2.5) as a function of elevation, as it is generally accepted that precipitation increases with elevation according to a logarithmic relationship (Quick, 1995). A single parameter curve was selected as part of the coding for the WMC Watershed Model to simplify the use of the curves. The form of the curve was:

$$P = (0.6)(10^{(E*\log(a)/1000)})$$

Where P = average annual precipitation at multiplier of Lornex precipitation
E = elevation of the station (m)
a = curve number

The curve number represents the precipitation increase rate per 1,000 m of elevation, based on a constant Lornex precipitation multiplier of 0.6 at sea level. For the stations with the lowest precipitation, the curve number was 1.4. For the stations (snow courses) with the highest multipliers, the curve number was about 3.5 (see Figure 2.7). This information was used directly in the hydrologic modeling of the basin. The approximate curve number for each station is presented in Tables 2.3 and 2.5.

2.2.6 Evaporation

Evaporation has been calculated in this study using a methodology derived by Thornthwaite (1948). This methodology is discussed further in Appendix III.

2.3 Bedrock Aquifers

2.3.1 General

Characterizing the groundwater in the Nicola Watershed requires consideration of the geology. The BC Ministry of Energy, Mines and Petroleum Resources website provides maps created by the BC Geological Survey that outline the geology throughout BC. Bedrock geology in the basin has a considerable range of rock types as illustrated on Figure 2.8.

2.3.2 Nicola Group

The Nicola Group, of late Triassic and Early Jurassic age, is widespread in the basin, occupying a north-south band about 40 km wide. The western boundary of the band is near Merritt. The Nicola Group includes metavolcanic and metasedimentary rocks that are commonly moderately to highly fractured. Groundwater flow within these rock types is expected to be dominated by fractures with variable moderate to very low permeability.

2.3.3 Triassic and Jurassic Intrusions

Triassic intrusions includes the Mt Lytton complex and dioritic intrusions into the Nicola Group. Groundwater flow will be limited to faults and fractures within these intrusives.

There are several Jurassic intrusions, the larger of which are the Douglas Lake and Pennask granodiorites, the Eagle Plutonic Complex and the Guichon Batholith. Groundwater flow within these intrusives will be characterized by limited fracture flow.

2.3.4 Ashcroft Formation

The Ashcroft Formation of Jurassic age is exposed only in a small region about 10 km north of Merritt. The Ashcroft Formation includes argillite, siltstone, sandstone and conglomerate with minor carbonate. Groundwater flow within these sedimentary rocks is expected to be dominated by fractures with variable low to very low permeability. There is some potential for moderate to high permeability within the carbonate rock.

2.3.5 Spences Bridge Group

The Spences Bridge Group, of Cretaceous age, lies within a 20 km wide northwest trending band. The eastern boundary of the band is near Merritt. The Spences Bridge Group includes volcanic flows, pyroclastic rocks and intercalated sandstone, shale and conglomerate. Open fractures are expected although these rocks are old enough that many discontinuities may be healed. Permeabilities are therefore expected to generally be low.

2.3.6 Tertiary Rocks

Tertiary Volcanic and Sedimentary Rocks are mapped as Kamloops Group, Princeton Group and Allenby Formation. These rocks include volcanic flows and sedimentary rocks, including coal bearing units. The Tertiary volcanic rocks may have open fractures. Coal sequences also commonly have permeable strata. Groundwater movement within this rock mass therefore may be controlled by fractures, but may also be related to distinct rock types. The tertiary volcanic rock may locally form moderate to high permeability aquifers.

Tertiary intrusions include granodiorite of the Nicola Composite Pluton, directly north of Nicola Lake. Limited fracture flow is expected to be the primary mode of groundwater movement within this rock type.

2.3.7 Bedrock Structures

Groundwater flow in bedrock is most often along faults and fractures. The permeability of a fracture is generally believed to be proportional to the cube of the aperture width. As aperture may be at least somewhat closed under increased pressure, bedrock permeability, all other things equal, is expected to decrease with depth. This combined with the increased potential for ground movement near the ground surface results in a moderate to poor aquifer material near the top of rock. The open fractures possible within the Tertiary volcanics may provide local moderate to good aquifer material.

Structures have been mapped throughout the basin. These include:

- Spius Creek to Lornex Fault
- Eagle Shear Zone
- Coldwater Fault
- Guichon Creek Fault
- Deadman River Fault
- Clapperton Fault

Many other major faults are likely to exist in the area and smaller faults would number in the hundreds. Each of these faults is a potential groundwater pathway. Faults are the result of displacement of the rock along a discontinuity. As a result of the movement, fault gouge (a finely ground rock mass) often is present along the fault. The shearing also results in fracturing adjacent to the fault. The combination of the fracturing and the fault gouge often results in a planar feature with high permeability parallel to the fault and low permeability across the fault. Where surficial materials are not available for development of a groundwater resource, major fault structures, if they can be located, provide an alternative aquifer type.

2.4 Surficial Geology

Surficial geology has been mapped in the Nicola Basin area by Fulton (1975). Most of the surficial geology is the product of the last major glaciation, referred to by Fulton as the Fraser Glaciation. Although limited evidence of deposits predating Fraser Glaciation are evident, the Quaternary history of the area consists of several glacial and intra-glacial intervals. Some understanding of earlier glacial deposits removed or covered by the Fraser Glaciation may be available from the mapping of the Fraser Glaciation.

All geologic materials have some contribution to the groundwater regime. Even hard rocks allow some groundwater flow along fractures and faults, particularly near the ground surface. However, wells with sufficient yield to support more than a single family dwelling are most likely to require high permeability sands and gravels. Most if not all such deposits are within the major valleys. This is compounded by the tendency for developments to proceed first in valleys, where construction and utilities are easier to manage. For these reasons, the chronological description of the surficial geology is followed by a brief summary of the surficial aquifers in the major valleys.

2.4.1 Pre Fraser Glaciation

A laminated silt, considered to be from the glacial period predating Fraser Glaciation (Okanagan Centre Glaciation) is exposed at Merritt. An exposure of till that may be older than Okanagan Centre drift was mapped in Highland Valley. Oxidized sand, silt and gravel about 39 m thick near Merritt was believed to be deposited in the Olympia Interglaciation (between Fraser and Okanagan Centre Glaciation). Confined aquifers near Merritt may be pre-Fraser age.

2.4.2 Fraser Glaciation

The main deposit of the Fraser Glaciation is Kamloops Drift or till. Glacial till consists of a heterogeneous mixture of boulders through clay sizes. The till is widespread over the basin, occurring as a widespread discontinuous sheet over the uplands and slopes. Thicker sheets may be present in valleys or depressions protected from erosion.

Drumlinoid morainal deposits are widespread, but are particularly well developed at Tunkwa Lake and west of Quilchena Valley. These drumlins are often cored with some bedrock. Glacial till makes up most of the drumlins. In some cases, older sediments can be found within the drumlin, indicating that it is both an erosional and a depositional feature.

Glacial till may also underlie pocked areas, with many near circular enclosed depressions. These occur on benches in basins that were occupied by stagnant ice tonques.

Much of the area has been mapped as undifferentiated moraine, or ground moraine. This is often considered the most common type of till. However, drumlinoid moraine is more common in this basin. Most of these features contain fine grained materials unsuitable as aquifers. However, moraines may cover older permeable materials.

As glaciers wasted at the end of the Fraser Glaciation, there was considerable associated meltwater. The combination of stagnant ice and meltwater resulted in most of the Quaternary geology and geomorphology visible in the valleys today.

Hummocky sand and gravel was deposited as eskers, kame terraces, and knob and kettle topography. All three of these deposit types were the result of meltwater deposits in the vicinity of a wasting glacier. Where meltwater was confined to a single channel, an esker formed; where deposition was confined to a single area, a kame developed. Where gravel was spread through an area, filling hollows, crevasses and tunnels, the surface after the ice melted resembled a chaotic jumble of hummocks and ridges. All of these materials deposited with fast flowing water are good to very good aquifers.

Kettle terrace deposits are sand and gravel deposits that were deposited marginal to ice. These are present in lower Guichon Valley. Terraces containing kettle holes formed where meltwater deposited sand and gravel over stagnant ice blocks that left kettle holes upon melting. Kame terraces formed where meltwater deposited sand and gravel between an ice margin and the adjoining hill slope.

Terrace deposits were formed where a delta was deposited into a glacial lake as a result of meltwater inflows. These units may be composed of both fan deposits (subaerial) and delta deposits (lacustrine).

Glaciolacustrine deposits (silt and clay, some sand deposits) are widespread in the region. Fulton developed a layout for glacial lakes in the basin as the glaciers wasted. Figure 2.9 presents the estimated extent of the glacial lakes and the location of the spillways. The presence of the glacial lakes has some influence on the distribution of permeable material in the basin. Silt and clay deposited in lakes are unsuitable for groundwater development.

Lacustrine deposits are almost always codepositional with lake shore deposits, which may include deltas, small fans, beaches, and colluvium. These codepositional areas are mapped by Fulton as Lacustrine Complexes. Fans, deltas and beaches are often good aquifers, but may be of limited extent. Colluvium is usually a poor to moderate aquifer material.

2.4.3 Post Fraser Glaciation

These include deposits since the disappearance of the Fraser Glaciation ice about 10,000 years ago.

Complexes of sand, gravel, silt and peat have been deposited in stream floodplains, deltas, and along shorelines. These modern deposits are not very visible, as they are typically below the level of present day deposition. In general, floodplains include coarse sand and gravel lining present and abandoned channels, silt and sand deposited on the floodplain, and peat and silt in the backwater deposits formed on floodplains.

Fan deposits consist of poorly sorted gravel, sand, silt and clay. They are widespread and are volumetrically the most important post-glacial unit. Fans are formed where there is an abrupt change in gradient. The rapid change in gradient accounts for the rapid deposition and the poorly sorted deposit. Typically, the volume of these materials is insufficient to result in a good aquifer. However, the transition from late glacial to post glacial may have resulted in sand and gravel infilling of glacial meltwater channels that may result in a significant aquifer.

2.5 Surficial Aquifers

2.5.1 Spius Creek

There are terrace deposits in the middle reaches of Spius Creek, which may indicate the presence of good aquifers. There are few reported wells in this area. Most of the reported groundwater wells are near the confluence of Spius Creek with the Nicola River. Most of these wells indicate about 40 m of low permeability material overlying sand and gravel, indicating the presence of a confined aquifer (Piteau and Associates, 1984). At least some of the confining material is the result of silt deposition in a glacial lake. A few wells have been constructed in bedrock at Spius Creek.

2.5.2 Coldwater River Valley

The Coldwater River headwaters are in steep mountain terrain south of Merritt. The valley has been infilled with glacial and alluvial sand and gravel. The lower portion of the valley was flooded during the late glacial period by a succession of glacial lakes (Lake Quilchena, Lake Hamilton, and Lake Merritt, Figure 2.9). The result was a thick succession of glacial lake deposits. The lake deposits are bounded by fans and other near-shore deposits that may result in some local moderate aquifers. Fulton has identified older similar deposits near Merritt. After the glacial lakes drained, a channel was eroded into the lake sediments subparallel to the current course of Coldwater River and the channel backfilled with coarse sand and gravel. The sand and gravel deposit has since spread over areas not eroded, resulting in a widespread aquifer near the confluence with the Nicola River (see Section 2.5.11, Merritt Aquifer). This deposit is continuous with shallow sand and gravels along the Coldwater River floodplain.

Deeper confined aquifers of significant extent may be located along the valley. A deep well (Active Mountain Well, Carriou, 2006) has intercepted a confined aquifer along the Coldwater River.

In the upper reaches of the Coldwater River, glaciers remained as a source of meltwater to the glacial lakes and meltwater channels. These areas are expected to include ice contact deposits, some glacial lake deposits and outwash deposits. The ice contact deposits and outwash will provide local moderate to good aquifers.

2.5.3 Quilchena Creek Valley

As the ice sheet thinned at the end of the last glacial period, a lake formed around the ice margins in the Nicola Watershed (see Figure 2.9). The land surface was first bared on the south side of the basin, with a glacial lake adjacent to the ice, filling Quilchena Creek Valley. The meltwater spilled to the south out of the basin from the Quilchena Creek Valley.

As the ice sheet thinned further, lower spillways were occupied, including Salmon River and Campbell Creek. During this extensive period, glacio-lacustrine sediments were deposited in the Quilchena Creek Valley. Fans and deltas peripheral to the valley are expected from this lake phase. In addition, the lake deposits as always may overlie earlier sand and gravel aquifers. Post glacial alluvial deposits are present in the lower reaches of the valley, near Nicola Lake. Wells have been drilled in sand and gravel aquifers near the lake.

2.5.4 Stump Lake Creek

Stump Lake Creek valley did serve as a spillway for some time during the glacial lake stage of the Nicola Basin. Although there would have been considerable flow of water from the lake, the sand and gravel suited for aquifer material is more likely to be located upstream of glacial lakes rather than downstream. Several well logs from this valley confirm that large aquifers have not been located. Near Nicola Lake, reported wells intersected a confined aquifer, with reasonable yield.

2.5.5 Moore Creek

Moore Creek and Stump Lake Creek are the two major drainages reporting to the upstream end of Nicola Lake. The majority of the valley is relatively narrow, limiting the capacity of potential valley aquifers. However, Fulton has mapped this valley with hummocky gravels, and sand and gravel terrace deposits. These valley fill materials may be thick enough for a poor to moderate unconfined aquifer. There is no evidence to suggest the presence of a deeper aquifer.

2.5.6 Clapperton Creek

Clapperton Creek flows into the Nicola River immediately downstream of Nicola Lake. Most of the wells in the Clapperton Creek valley are drilled at the downstream end towards the confluence with the Nicola Valley. Upstream, the Clapperton Creek valley is mapped as fan deposits, possibly suitable as a moderate unconfined aquifer. No water wells are mapped in the upper part of the Clapperton Creek valley.

2.5.7 Guichon Creek

Guichon Creek valley is expected to include post and pre Fraser Glaciation aquifers similar to Witches Brook (Section 2.5.8). Wells in the valley are relatively shallow (50 m), indicating that deeper aquifers probably are present. Fulton (1975) has mapped surficial deposits in the valley as:

- Kettle Terrace deposits
- Hummocky gravels
- Fan deposits
- Stream terrace

The depositional environment for these surficial deposits was late glacial. Fulton interpreted the setting as:

- Southward movement of the glaciers during much of the last glacial period. Much of the earlier deposits may have been removed from the valley during this period, although sand and gravel and lake deposits may have been deposited in front of the advancing ice.
- As the glacier elevation decreased, ice stopped entering the valley from the north, leaving a stagnant tongue of ice in the valley bottom. During this period, meltwater from north of the valley flowed south along and over the stagnant ice, depositing sand and gravel on and adjacent to the ice.
- With time the stagnant ice elevation lowered and the north end of the valley was ice free. Surface water and sediment still flowed from the north at this time.
- With time the ice elevation reduced enough that meltwater from the north was diverted along the Thompson River Valley. The stagnant ice melted with no further source of outside water.
- When ice remained only in Nicola River Valley, a glacial lake was formed near the confluence with Nicola River. As a result some glacio-lacustrine deposits are present at the south end of the valley.
- Since the glacial period, alluvium has been deposited as Guichon Creek has eroded material and redeposited sands and sand and gravel along the channel alignment.

The environment during the last glacial period provided a significant source of sand and gravel as aquifer material. The source of the material and the depositional environment is conducive to deposition of sand and gravel over most if not all of the valley. Furthermore, this activity may have occurred several times previously, as glacial advance and decline was probably similar in previous glacial periods. Fan and colluvial deposits along the valley margins are probably also present, similar to Witches Brook.

In summary, both confined and unconfined moderate to very good aquifers of expected continuously over the Guichon Creek Valley, primarily because the valley was a major meltwater channel during the late glacial period. The lower 10 km of the creek is mapped as fan material that has been eroded from the valley and redeposited in this reach of the creek. There are several shallow wells in this area into a shallow unconfined aquifer.

2.5.8 Witches Brook

Due to mining activity, subsurface quaternary geology is better understood in Highland Valley than other locations in the Nicola Watershed. The east half of Highland Valley is drained by Witches Brook, which flows into Guichon Creek at Logan Lake. Under Witches Brook an ancient bedrock valley has been infilled with over 300m of glacial, lacustrine, colluvial and alluvial materials. The result is distinct aquifers with significant extent along the valley:

- The basal aquifer which is present near the top of rock over the western half of Witches Brook.
- Alluvial fan aquifers codepositional with lacustrine deposits that overlie the basal aquifer. The alluvial fans and other lacustrine bounding deposits provide communication between the other aquifers. This was particularly evident during long term pumping required to dewater for the Valley Open Pit.
- The main aquifer is continuous over all of the Highland Valley section of Witches Brook. This aquifer covers the underlying lacustrine deposits, probably deposited during the advance of Fraser Glaciation.

- The surficial aquifer, representing discontinuous sand and gravel units in the near surface late glacial deposits.

In summary Highland Valley contains Fraser Glaciation and earlier overburden deposits which have resulted in three significant aquifers. At the valley borders, these aquifers communicate with border deposits, particularly alluvial fans. During mine dewatering, the diversion of surface water and dewatering of the valley aquifers resulted in a flow reduction in Witches Brook (see Figure 2.10).

2.5.9 Upper Nicola Valley

Upper Nicola Valley (upstream of Nicola Lake) was also inundated by glacial lakes (similar to Quilchena Creek and Coldwater River). The geologic mapping by Fulton does not indicate as much lacustrine deposits. However, some lacustrine deposits persist, although much of the lake bed is dominated by drumlinoid moraine. The valley fill is mapped as fan deposits, except near Nicola Lake where they are mapped as alluvium. Wells drilled near Nicola Lake are in a confined sand and gravel aquifer.

Upstream of Douglas Lake, an unconfined sand and gravel aquifer has been drilled. Downstream of Douglas Lake, no good quality aquifers have been identified in the valley.

2.5.10 Middle Nicola Valley

Middle Nicola includes from the inlet to Nicola Lake down to and including Merritt. A surficial aquifer is present at most locations along the Nicola River. Several wells have been drilled deeper and have encountered a deeper confined aquifer. This deeper aquifer is likely continuous from Nicola Lake through to Lower Nicola. The deep aquifer is under consideration for supplementing the Merritt water supply.

2.5.11 Merritt Aquifer

The Merritt aquifer is an unconfined aquifer in Merritt between the Coldwater and Nicola Rivers. A previous channel was eroded adjacent to the Coldwater River and infilled with permeable sand and gravel. Additional gravel deposited over the adjoining areas is also part of the Merritt Aquifer. The buried channel is about 0.5 km wide, centred on Coldwater Avenue and extends from Orme Street to Main Street. It is likely that the deeper section extends further northwest of Main Street. Studies reported by Carriou (2006) indicate that the Merritt Aquifer is an unconfined aquifer. This report further notes that a high degree of surface water/groundwater interaction may be contributing to depletion of the nearby rivers from pumping of the City wells.

2.5.12 Lower Nicola Valley

Lower Nicola Valley (downstream of Merritt) was ice filled during most of the glacial lake era. However, near the end of the glacial lake era, this area became ice free and was inundated with water while the lake spilled through Stump Lake valley. Glacial lake deposits and peripheral fans are mapped through the area. Modern alluvium dominates the valley floor. Channels of some depth are expected but not defined similar to buried Coldwater River channel gravels in Merritt. Many wells have been developed in this area, and the province has mapped aquifers in this area. Both the unconfined and confined aquifers present near Merritt probably extend into the Lower Nicola. Near the confluence with Guichon Creek, groundwater production is from both a confined aquifer and an unconfined aquifer. Presumably, if adequate water was available in the shallow unconfined aquifer, the well was stopped as a shallow well. Where, shallow production was not adequate, the well was extended to the deeper confined aquifer. It is quite likely that the confined aquifer near Merritt, the confined aquifer near the confluence with Guichon Creek and the confined aquifer near the confluence with Spius Creek are continuous.

3 GROUNDWATER

3.1 Groundwater Characterization

3.1.1 Introduction

Characterization of groundwater was evaluated using the information collected during the literature review and using online information resources. The BC Ministry of Environment Water Resources Atlas displays information related to the water resources for the Province of British Columbia, such as watersheds, water quantity and quality monitoring sites, aquifers, water wells and flood protection works. In areas where aquifers were unmapped, water well logs and geologic maps were used to approximate the extent of aquifers and potentially determine if the aquifers were currently being used for groundwater extraction. There were approximately four hundred water wells found via the Water Resource Atlas within the Nicola Watershed. The vast majority of these water wells were along valley bottoms and were completed within the Quaternary sediments.

3.1.2 Groundwater Units

Sand and Gravel Aquifers. Most of the major production of groundwater is from sand and gravel aquifers located along major valleys. These sands and gravels were deposited as alluvium or as glacially related water washed deposits. These units will always be the source of groundwater supply in the Nicola Watershed. The sands and gravel aquifers may be confined below less permeable units or they may be unconfined (exposed on the ground surface). All but one of the mapped aquifers are sand and gravel aquifers.

Bedrock Aquifers. Fractured bedrock can provide a resource for groundwater extraction. Typically, yields from bedrock are suitable for single family dwellings rather than communities, agricultural or industrial needs. However, there will be some locations in the watershed where fractured rock will provide a reasonable yield.

Overburden Aquitards. Overburden materials may include a sufficient portion of silt or clay to act as aquitards or materials that retard the flow of groundwater to or from an aquifer. An aquitard may help to protect an aquifer from surface contamination. An aquitard may also impede the rate at which an aquifer can be recharged and/or spread the area that provides recharge to an aquifer over a larger area.

3.1.3 Groundwater Recharge and Storage

Aquifers are recharged in a number of ways. These include:

1. By direct precipitation or snowmelt on the surface overlying the aquifer.
2. By losses of streamflow through stream beds if the groundwater level is below the stream level.
3. By groundwater flow from adjacent materials. For example, groundwater recharge occurs into poor quality aquifers on mountain slopes and slowly migrates towards a nearby valley. This groundwater, although it may not be a developable resource contributes recharge to the valley aquifer.
4. By water returns, including over-irrigation and waste water disposal to land.

Groundwater recharge is a function of the quantity and temporal distribution of rainfall and snowmelt, the local soil and vegetation, slope angles and slope aspect. Precipitation varies significantly across the watershed, as does topography and soils. Generally, water available for runoff or infiltration is expected to be low in the central part of the basin, with most water available in the Spius and Coldwater sub-catchments. Within those higher precipitation watersheds, recharge will be high on flat gravely valley floors and moderate to low on adjoining slopes.

For Upper Spius Creek, the average annual excess water calculated was 610 mm and the average infiltration was 132 mm. The expectation is that the infiltration would be near 610 mm on the valley floor and would be less than 132 mm on the adjoining slopes.

For Upper Guichon Creek, the average annual average excess water calculated was 53 mm, and the average infiltrated was 24 mm. The expectation is that the infiltration would be near 53 mm on the valley floor and would be less than 24 mm on the adjoining slopes. For comparison, the calculated recharge for Lower Guichon is only 2 mm, because the area is so dry.

Groundwater storage is an important element of the groundwater system. Groundwater is stored within the developable aquifers and also within all of the geologic materials within the watershed. For example, groundwater is stored within till-like materials and bedrock within the valley walls. Storage provides discharge to stream flows during the dry season as well as a resource for irrigation, industry and potable water year round.

3.1.4 Groundwater Quality

A review of the available geochemical data was undertaken to assess if there are any limitations to the availability of groundwater for use. Such limitations could include the common occurrence of iron and manganese in groundwater and potential implications due to land use (i.e. mining activities, agricultural impacts of fertilizer use, etc.). Clare Audet, public health inspector with Interior Health noted that water quality of the community water supplies of the Nicola Watershed are generally good, with the exception of some samples that exceed the drinking water standard for arsenic in wells installed in bedrock and for some seasonal concentrations that exceed some drinking water standards for water at Kingsvale.

Naturally elevated concentrations to above drinking water standards of iron (0.3 mg/L) and manganese (0.05 mg/L) are common in groundwater which is in a reduced state. A reduced state is most common in confined aquifers or where groundwater is discharging from a confined state. As the drinking water standards for iron and manganese are aesthetic objectives, these exceedances are not usually a major concern. Oxidation and filtration are required to reduce these concentrations.

The interim maximum drinking water standard for arsenic is 0.025 mg/L and the proposed maximum is 0.005 mg/l. Arsenic concentrations exceeding these recommendations are not uncommon in water supply wells constructed in bedrock, particularly where there is some arsenic mineralization (e.g. arsenopyrite).

There have been no recorded large scale industrial or agricultural sources of contaminants that have impacted potable water supplies in the Nicola Watershed. There have been reports of contamination of residential water supplies by gas station tank leakage and there is a trace of nutrient contamination, not of concern with respect to health. Increases in sulphate and molybdenum concentration have been recorded adjacent to the mine in Highland Valley. These increases do not impact other water users.

A water sample collected from a River Ranch well in 1994 and reported by BC Groundwater (2006) had a sulphate concentration of 118 mg/L. The drinking water aesthetic objective is 500 mg/L and the guideline for fresh water aquatic life is 100 mg/L. Concentration of iron and manganese slightly exceeded the drinking water standard in this sample. This well is installed in a relatively deep confined aquifer.

3.2 Mapped Aquifers

3.2.1 Mapped Aquifers in Guichon Creek Valley

The province of British Columbia has 19 aquifers mapped in the Nicola Basin (see Table 3.1 and Figure 3.1). In the BC Aquifer Classification system, aquifers are rated from I for heavily developed aquifers to III for lightly developed aquifers. Aquifers are also rated from A, for a vulnerable aquifer, (perhaps because it is unconfined with overlying gravel) to C, (perhaps because the aquifer has an extensive confining layer with no windows). Mapped aquifers in the regime are classified over the full range, from IA to IIIC. Following is a brief discussion regarding each of the aquifer areas.

Highland Valley (Aquifers 819, 820 and 824). Aquifers 819 and 820 are downstream of the HVC copper mine within Witches Brook valley. Aquifer 819 is a little larger but has the same classification rating as 820. Witches Brook valley includes a basal aquifer, the Main Aquifer and the Surficial Aquifer. Both the Main Aquifer and the Surficial Aquifer are believed to extend over the length of the valley. The basal aquifer may be present over about half the valley. Aquifer 824 appears to represent the open pit area, which also includes three separate permeable fan deposits (Trojan, West and Bethsaida). The aquifers underlying Witches Brook in Highland Valley were very productive aquifers. They have been largely dewatered to allow mining to progress.

Upper Guichon Creek (Aquifers 822, 826 and 827). These mapped aquifers are located at Logan Lake (822), south of Mamit Lake (827) and about 5 km south of Mamit Lake (826).

Kala (2003) reported that the Guichon Aquifer adjacent to Logan Lake (822) covers a significant area of the valley floor based on nearby drilling. Based on the depositional environment described by Fulton, sand and gravel deposits are expected along most of the valley, both from the latest as well as earlier glacial advances. Kala's estimate of aquifer area upstream of Logan Lake was 20 km^2, compared to the 0.6 km^2 in Table 3.1. The smaller area reflects the requirement of the provincial government for subsurface information to confirm the continuity of an aquifer. Kala describes the local valley fill material as an extremely thick and complex sequence of glacial tills, glacio-fluvial sands and gravels, and lacustrine silts and clays. All three of the Logan Lake water supply wells intercepted till-like materials both above and below the developed aquifer. Surficial mapping by Fulton identifies kettled terrace deposits and modern alluvium on the valley floor. Kala interpreted the three Logan Lake wells to depths of about 50 m which were installed in glacio-fluvial meltwater sediments associated with Kamloops drift of the Fraser Glaciation period. They further interpreted that the overlying aquitards are typically composed of layers of dense ablation till and reworked finer grained deposits. This aquifer is listed with a classification of IC, indicating that the demand on the aquifer productivity is high (I) and that there is significant protection from potential surface contamination (C).

Table 3.1 Mapped Aquifers in the Nicola Watershed

Aquifer Number	Descriptive Location	Productivity Rating	Classification	Size (Km ^{2})	NTS No.
74	Merritt	High	IA	5	092I/02
75	Joeyaska	Moderate	IIC	1.5	092I/02
76	Stumbles Creek	Moderate	IIIA	7	092I/02
77	Lower Nicola	Moderate	IIC	3	092I/02
78	West End of Nicola Lake	Moderate	IIIA	2	092I/02
79	Lower Clapperton Creek	Moderate	IIIA	4.5	092I/02
80	Nicola	Moderate	IIIC	2.5	092I/02
713	Quilchena Cr; S shore of Nicola Lake	Low	IIA	4	92I/02 and 92I/01
714	Nicola Lake Indian Reserve	Low	IIA	2.5	92I/01
715	mouths of Moore and Stumplake Creeks	High	IIIC	4	92I/01 and 92I/08
724	Nicola R fldpln between Canford & Coyle	Moderate	IIIA	11	92I/03 and 92I/02
725	South of Nicola R & Spius Cr con; W of Canford (bedrock)	Low	IIIB	11	92I/03 and 92I/02
726	Nicola R & Spius Cr con; w of Canford	Moderate	IIIC	3.5	92I/03
819	Highland Valley – W. of Logan Lake	High	IC	6.1	092I/06, 092I/07
820	Highland Valley – W of Logan Lake	High	IC	6	092I/06
822	Logan Lake / SW of Kamloops	High	IC	0.6	092I/07
824	Highland Valley near Award Creek	High	IIC	0.8	092I/06
826	Guichon Creek –S of Kamloops	Moderate	IIA	0.7	092I/07
827	South of Mamit Lake	Moderate	IIIC	2	092I/07

Source: http://www.env.gov.bc.ca/wsd/plan_protect_sustain/groundwater/wells.html

There is little information available for either aquifer 826 or 827. Both lie in the Guichon Creek Valley. Surficial geologic mapping by Fulton indicates hummocky gravels and modern alluvium on the valley floor. Aquifer 826, about 5 km south of Mamit Lake is listed with a classification of IIA, indicting an aquifer with demand at a moderate portion of its productivity (II) and probably with little surface protection (A). The aquifer immediately south of Mamit Lake is listed with a classification of IIIC, indicating an aquifer with little demand on its productivity and with significant overlying protection. The implication is that these aquifers are within quite different settings. This is consistent with the presence of both shallow and deep aquifers in the Guichon Creek Valley.

Two aquifers (76 and 77) are mapped in Guichon Creek Valley immediately above the confluence with Nicola River. Aquifer 77 is the deeper confined aquifer (the letter C infers that the aquifer has significant overlying protection). The presence of both shallow and deep wells in this area, with drill logs describing fine grained material overlying the deeper aquifer, supports these characterizations.

3.2.2 Mapped Aquifers in Nicola Valley near Merritt and Lower Nicola

Two aquifers (74 and 75) are mapped in the immediate vicinity of Merritt. According to Ministry of Environment online mapping, the most highly produced aquifer in the area is the Merritt aquifer (74). In 1970 Ed Livingston described the depositional history of the Merritt aquifer to be:

> At the time of melting of the last glaciers in the Merritt area the Nicola Valley was dammed, probably by ice both east and northwest of Merritt, forming a lake at least 250 feet deep at Merritt. Dirty meltwater from the Coldwater Valley brought sand, silt and clay into this lake. These sediments were deposited on the lake bottom as prominently banded clays (lake beds) seen in road and river cuts in the Merritt area. As the dams forming the lake were destroyed, the lake level decreased and it finally disappeared in the Merritt area. Once the lake had gone, the Coldwater River, which was probably choked with gravel above the former lake level, cut into the soft lake beds to a level perhaps as much as 100 feet below its present level. As the size of the river decreased due to depletion of ice in the mountains to the southwest, the river channel became filled with clean gravel forming the gravel fan on which most of the town is built. This gravel is the aquifer supplying the town wells.

The understanding of the aquifer was recently reviewed by BC Groundwater (2006). The thickness of the Merritt aquifer ranges from 5 to 50 m; however, about 80 percent of the aquifer is interpreted to be less than 10 m thick. The area that is less than 10 m thick occurs mostly on the floodplain between the Coldwater and Nicola Rivers. The deepest part of the aquifer occurs along a trough that runs sub-parallel to the Coldwater River. Most of the five city production wells access this deep trough for the city water supply. An averaged estimate of 100 litres per second of groundwater is extracted from five City of Merritt production wells. The groundwater that is accessed by the wells is pumped from the unconfined surficial aquifer. The BC Ministry of Environment, Water Stewardship Division classified the Merritt aquifer as one of nine type “IA” aquifers in the province of BC. A type “IA” is considered to be a heavily developed, high vulnerability aquifer.

The study by BC Groundwater found that the entire surficial aquifer system (Coldwater Valley and Nicola Valley aquifers) that includes the aquifer developed for the community water supply should be considered unconfined. They further note that available data suggests that river flows are currently being depleted by the production wells.

Currently, the City of Merritt is investigating the potential development of a new groundwater supply well that will operate independently from the existing production wells. The siting of a possible production well is within a deeper aquifer system. The deep aquifer system is thought to be confined by the overlying glaciolacustrine silt; however, the hydraulic connectivity of the deep aquifer with the surficial aquifer and/or the surface hydrology has not been determined.

Three aquifers (724, 725 and 726) are mapped in the Nicola River Valley downstream of the confluence with Guichon Creek. Aquifer 724 is near surface, 725 is a bedrock aquifer near the confluence with Spius Creek and 726 is a confined, deeper aquifer. There are both shallow and deep wells in the area. Presumably, the presence of shallow wells primarily confirms the presence of the unconfined aquifer, with deeper wells only present either where the unconfined aquifer was not present or where it provided insufficient yield.

3.2.3 Mapped Aquifers near Nicola Lake

Three aquifers, 78, 79 and 80 are mapped near the west end of Nicola Lake. Aquifer 78 extends along the lake shore, in sand and gravel of a mapped fan material. Aquifer 79 is a surficial aquifer near the outlet of Nicola Lake, within fan materials. Aquifer 80 is a less vulnerable aquifer underlying Aquifer 79, indicating that both a confined and an unconfined aquifer are present in this area.

Three aquifers, 713, 714 and 715 are mapped on the south shore and near the head of Nicola Lake. Aquifer 713 is within Quilchena Creek fan and delta materials near the shore of Nicola Lake. Aquifer 714 is within the Nicola River fan and delta materials. Aquifer 715 is within the fan and delta materials of Stump Lake Creek on the shore of Nicola Lake.

3.3 Known Major Nicola Watershed Aquifers

The major (significant yield) aquifers are sand and gravel aquifers within the major valleys. In these valleys, current streams and rivers, and more importantly, the much higher flowing glacial meltwater deposited permeable sand and gravel. In these valleys, there are also larger areas which have the capability to recharge these sand and gravel aquifers. These regional aquifers are illustrated on Figure 3.2. These aquifer distributions are based on an interpretation of the available drill hole logs supplemented by an understanding of the geologic history. These aquifers are:

- Guichon Valley Aquifer: The provincial government has mapped several aquifers in the Guichon Valley based on the presence of wells. The presence of the producing areas and the depositional environment leads to the interpretation of the presence of both unconfined and confined aquifers over most of the valley. The aquifers are expected to have some continuity with Nicola Valley Aquifers.

- Coldwater Valley Aquifer: Both unconfined and confined aquifers have been identified in the Coldwater Valley. The surficial aquifer merges with the Nicola Valley unconfined aquifer at Merritt, where the Merritt Aquifer has been mapped.
- Nicola Valley Aquifer: Both unconfined and confined aquifers have been identified along the Nicola River from Nicola Lake to the confluence with Spius Creek. Downstream of Spius Creek, the valley narrows, probably reducing the aquifer yield. At Merritt, the unconfined aquifer has a high yield, because of the coarse sand and gravel and the presence of two rivers to recharge the aquifer. Where tested, the deeper aquifers have good yield, but safe yields have not yet been defined.

3.4 Groundwater Use

3.4.1 Current Demand

The current groundwater use in the Nicola Watershed was estimated by Summit Environmental Consultants (2007). In that report, water demand was defined as the water supply required to satisfy the needs of the user and water use was defined as the water actually used or the estimated actual use. The estimated annual demand of water in the Nicola Watershed is 53,288,000 m^3. Of the water demand in the watershed, approximately 31 percent is sourced from groundwater. The sub-basins most reliant on groundwater are the Clapperton basin (71 percent), Coldwater basin (56 percent), Guichon basin (39 percent) and Lower Nicola basin (39 percent).

Within the Nicola Watershed there are several groundwater users including agricultural, industrial, business and commercial, domestic, institutions and recreation and resorts. The largest water demand comes from the agricultural sector. Agriculture accounts for approximately 76 percent of the total water demand in the Nicola Watershed, however only 19 percent of that is sourced from groundwater. Despite the relatively low percentage of agricultural water sourced from groundwater, agriculture accounts for over 50 percent of the total water demand from the groundwater resource in the Nicola Watershed. Other significant users of groundwater include domestic and industrial accounting for approximately 20 percent and 17 percent of the total groundwater demand, respectively.

The City of Merritt provides the water supply for the residents and industry in and around Merritt. According to BC Groundwater Consulting Services (2006), the average withdrawal from five production wells installed in the Merritt aquifer is approximately 100 L/s, although the maximum daily demand is approximately 225 L/s. The Merritt aquifer is the only aquifer in the Nicola Watershed that is classified as an IA aquifer indicating that it is highly vulnerable and highly produced.

3.4.2 Future Demand

Summit (2007) estimated that the population of the Nicola basin may increase from approximately 15,000 residents in 2006 to approximately 18,000 by 2020 under a low growth projection to approximately 36,000 residents by 2020 under a high growth projection. The majority of the population growth is expected to occur in Merritt. Since the residents in Merritt are nearly entirely dependent on groundwater for their water supply, this population growth will place an additional strain on the groundwater supply that is currently classified as highly produced. The City of Merritt is currently investigating the potential for a new groundwater supply well. According to two reports by Kala dated April and October, 2004, the desired well yield from the new groundwater supply would be in the order of 100 L/s.

An Official Community Plan (OCP) (attached in Appendix I) has been prepared by the Thompson-Nicola Regional District (TNRD) for the Nicola Valley to guide future development in the area. Section 10 of the OCP addresses water resources and states that use of surface water sources is prohibited unless the development is serviced by a community water system. In paragraph 10.3 the plan states that development utilizing groundwater may be required to provide a hydrogeological report stating that use of such groundwater will not interfere with, intercept, or otherwise detrimentally affect surface water resources.

Recent subdivision applications to the TNRD have been required to install community water supply systems rather than developing individual wells for each lot. A community water supply system requires approval from the Province in the form of a Certificate of Public Convenience and Necessity (CPCN). CPCN application guidelines are attached in Appendix II. A CPCN application is reviewed by several provincial agencies including the Regional Heath Board and the Utility Regulation Section of BC Environment. For systems using groundwater, the application is also reviewed by the Groundwater Section of the Water Stewardship Division of BC Environment. Appendix 9 of the CPCN Guidelines describes the requirements for groundwater reports to support a CPCN application. An assessment of the impact of pumping of the water well on surface water and springs in areas where water licences are known to exist must be included in the groundwater report.

There are a number of recent and on-going development applications within the Nicola Watershed. A summary of some of the more significant applications is provided below.

Marshall Springs Resort, Brookmere. The proposed development is for 178 recreational/commercial strata lots. Water will be supplied from groundwater and a well with a capacity of 39 L/s has been investigated.

Coquihalla Pass All Season Resort. About 3000 units are being considered for this development. The current thinking is that the majority of the water supply will come from East Anderson Creek in the Fraser River drainage. A groundwater source may also be considered in the headwaters of the Coldwater River.

Nicola Lakeshore Estates. This development is on Monck Park Road on the west side of Nicola Lake and includes 260 dwelling units. The Nicola Lakeshore Utility Company obtained a CPCN in 2005 and is supplying water from groundwater sources.

Quilchena on the Lake. This development has been recently constructed on the south side of Nicola Lake and includes a 40 lot subdivision.

Sagebrush Golf and Country Club. This proposed development is on the south side of Nicola Lake and was approved by the TNRD in 2001 and by the Agricultural Land Commission (ALC) in 2000. It will include a 31 lot strata subdivision around a golf course.

Chutter Ranch subdivision. This 87 lot subdivision, located just east of Merritt, is zoned agricultural in the Nicola Valley OCP and has received approval from the TNRD and the ALC.

4 GROUNDWATER/SURFACE WATER INTERACTION

4.1 Introduction

The Nicola Watershed has a surface cover primarily composed of forest or range lands. At the ground surface, the main components of the hydrologic cycle governing water availability in the Nicola Watershed are precipitation as snow or rain, losses by sublimation, evaporation and transpiration. The excess water moves through the basin as groundwater and surface water. The interaction between groundwater and surface water is complex and can take many different forms as explained in this section.

In general a stream can be a gaining stream, a losing stream and occasionally a disconnected stream. A gaining stream occurs when the groundwater level in the aquifer surrounding the stream is higher than the stream level. Consequently the stream is gaining since groundwater is flowing into the stream. A losing stream occurs where the groundwater level is lower than the stream level. As a result the stream loses water to recharge the groundwater system. In some cases the groundwater level can become disconnected to the stream. In the case where the stream is disconnected from the groundwater system, the rate of loss from the stream is limited by the conductance of the streambed and the aquifer below. Water loss from a disconnected stream to the groundwater system can be great. Figure 4.1 provides schematics of a gaining, losing and disconnected stream.

During periods of snowmelt and heavy rain, water runs off the land to streams or infiltrates to join the groundwater system. Downstream, water may infiltrate into the ground from stream beds or groundwater may discharge, becoming part of the surface flow in the stream. In the Nicola Watershed, all of the surface water and groundwater is expected to report in the Nicola River or in the sands and gravels underlying the Nicola River immediately upstream of the confluence with the Thompson River at Spences Bridge. Simply, all water in the Nicola Watershed originates as rain or snow within the watershed. There is no other source of water. All of the water is either lost as sublimation and evapotranspiration or discharges into the Thompson River Valley with Nicola River as surface flow or through sands and gravels underlying the river.

In between arriving in and leaving the Nicola Watershed, the water may flow as groundwater or surface water. Some water may migrate between surface water and groundwater several times before leaving the watershed. For example, snowmelt on the upper slopes may infiltrate into the ground and migrate some distance down slope before discharging into a small stream channel. After flowing to the base of the slope, the same water may infiltrate back into the groundwater system as it passes over an alluvial fan. After leaving the alluvial fan and passing into the valley aquifer, the water may discharge into the main stream channel. Further downstream, due to a change in groundwater hydraulics, the water could again infiltrate from the stream bed back into the valley aquifer. Further downstream, this water probably discharges into the stream channel. Some of the snow that melted at the same time as this water probably passed over the groundwater system and migrated all the way to the Thompson River without entering the groundwater system.

As noted above, all water available within the Nicola Watershed arrives as rainfall or snowfall within the Nicola Watershed. No other source of water is available. Any consumptive use within the Nicola Watershed, either from groundwater or surface water, will reduce downstream flows unless the consumptive use can be offset by reduced evapotranspiration.

Groundwater/surface water interaction is a characteristic of all natural stream channels. The interaction is most obvious during long dry spells when surface water flows are solely the result of groundwater discharge into streams. Interaction is also obvious along some stream reaches during dry periods where streams will dry up as a result of losses to the groundwater system and re-emerge further downstream.

Groundwater/surface water interaction can be altered as a result of removal of either groundwater or surface water from the natural flow system. In either case, if water is consumed, it is removed from the flow system, and will not report downstream.

The interaction of groundwater and surface water is influenced by groundwater storage. As described in Section 2, aquifers with sufficient permeability to allow pumping of considerable flow rates are present in most of the major valleys within the watershed. As groundwater is present in these aquifers, there is a considerable volume of water stored within the basin that interacts with the major streams. It is this storage that provides flow to the streams throughout the drier portions of the year. Extraction of groundwater therefore is primarily from storage when pumping begins. As water is extracted, the water table lowers, so that a drawdown cone develops around the well. The drawdown cone continues to grow until the cone intercepts the same volume of groundwater recharge as is being pumped from the well. It is only when the drawdown cone is fully developed (maximum extent) that the full impact of pumping groundwater is felt by the surface water regime.

4.2 Elements of Interaction

The interaction of groundwater and surface water is of particular interest in semi-arid areas because of the importance of groundwater to maintaining stream baseflows. The contribution of groundwater to baseflow is affected by recharge to groundwater, storage in the aquifer and discharge from groundwater storage to the stream.

Natural groundwater recharge sources include:

- Infiltration of rainfall and snowmelt into slopes. This groundwater moves downslope. Some of that water discharges into stream beds contributing to stream flow. The remainder of this groundwater enters the valley aquifer (aquifer underlying the bottom of the valley).

- Portions of the tributary stream flow that includes groundwater discharge may infiltrate into alluvial fans at the base of the slope so that groundwater is re-infiltrated, contributing to the valley aquifer.
- On the valley floor snowmelt and rainfall can recharge the valley aquifer.
- If the stream stage is above the local groundwater level, water from the stream will recharge the aquifer.

Natural groundwater discharges from the aquifer as follows:

- As springs on or at the base of slopes, contributing to stream flow, or to growth of vegetation.
- Where the elevation is low, the valley gradient flattens or the properties or dimensions of the aquifer change, groundwater may discharge from the aquifer and contribute to streamflow.

The groundwater process is one of storing and releasing water to the surface water environment. Groundwater recharge predominates when there is a wet period or snowmelt so that recharge is occurring globally and additional recharge is occurring into streams with a higher stage (water level) and a greater width. The overall system is one of long term balance with water entering the system equal to water leaving the system. Short term imbalance is carried by changes in groundwater storage.

As groundwater recharge occurs every wet period, the net condition is for the groundwater system to contribute to the baseflow of streams. In this way, groundwater provides streamflow in between periods of rain and or snowmelt.

There are circumstances where not all groundwater is discharged as surface flows within a watershed. One example would be where there is significant regional groundwater flow out of a watershed. In the case of the Nicola Watershed, the geology and topography of the basin is such that regional groundwater flow systems out of the watershed are not significant. Essentially under natural conditions all groundwater recharge in the Nicola Watershed is eventually discharged as stream flow in the Nicola River or in the sands and gravels underlying the river at this location.

Water extraction from the surface water or groundwater systems will change the interaction. Removal of water from a stream may reduce the stream stage and thereby increase groundwater discharge to the stream. Removal of groundwater from valley aquifers beneath the stream will reduce groundwater discharge to the stream. The primary influence of these activities is on stream baseflow. Therefore stream baseflow will be the primary concern in the following discussion.

4.3 Extraction from Surface Water

The natural groundwater/surface water extraction rate is dependent on material properties and the hydraulic relationship between the two systems. Specifically, the rate of interaction is dependent on the following surface water conditions assuming groundwater conditions remain unchanged:

- Loss from stream flow will increase with an increase in the stream width that accompanies increased surface flows. Similarly, the rate of groundwater recharge from the streambed will decrease with decreased stream width accompanying reduced stream flows.
- Loss from stream flow will increase with an increase in the stream stage that accompanies increased surface flows. Similarly, the rate of groundwater recharge from the streambed will decrease with decreased stream stage accompanying reduced stream flows.
- Gain to surface water flow will decrease with an increase in stream stage that accompanies increased surface flow.

In the Nicola Watershed extraction from surface water will reduce the stream flow through the extraction period. The maximum demand and therefore the maximum extraction is usually during hot dry periods when stream flow is lowest. The surface water extraction will result in a decreased width and a lower stage so that in zones where stream losses have been experienced, the stream losses will decrease, and in areas where stream gains have been experienced, gains will increase as the stream stage lowers. This contribution to stream flow as a result of lowering the stream stage is generally known as a stream bank storage contribution. Bank storage is a contribution to stream flow from groundwater storage. As a result, extraction from surface water may partially be naturally mitigated by contribution from groundwater storage. However, this is not water from outside the Nicola Watershed. It is a temporal redistribution of water from within the watershed. The water naturally mitigating the extraction is water that will not be available in the system in the future.

4.4 Extraction from Groundwater

Extraction from groundwater removes water from storage and results in a lowering of the groundwater level (unconfined aquifer) or piezometric level (confined aquifer). The amount of drawdown and the width of the drawdown cone (area of influence of the well) are dependent on aquifer and aquifer cover material properties, the available recharge and the pumping rate.

The lowering of the piezometric level will result in a reduction of groundwater discharge to the surface water environment. This will be an important loss to the downstream environment in the dry summer months. The loss to stream flow is illustrated schematically in Figure 4.2. Prior to development, groundwater discharge supplied baseflow to the stream flow. Following development, pumping reduced the volume of water in storage, thereby lowering the groundwater table. The groundwater gradient was therefore reduced along with the groundwater discharge to the stream baseflow.

For a surficial aquifer (unconfined) that directly underlies the stream bed the losses to stream flow are manifested locally. For a confined aquifer with a low permeability cover material, recharge to the aquifer from the ground surface is impeded. For a confined aquifer, therefore, the drawdown extends further before enough recharge is available to balance the quantity of water extracted. The effect of extraction from a confined aquifer is therefore spread over a much larger area. Stream flow changes are therefore not limited to near the pumping wells. However, over time, a balance must be established between the volume of water recharging the groundwater system, with the water leaving the system. Therefore groundwater extraction from any aquifer will reduce stream flows.

Water has been pumped from Highland Valley for an extended period to lower the water table in the valley and allow mining to proceed. As a result, flows have decreased in Witches Brook, a tributary to Guichon Creek. The loss of Witches Brook flow as a result of surface water interception and pumping from the aquifers is illustrated on Figure 2.10.

4.5 Response of an Unconfined Aquifer to Pumping

Pumping from an unconfined valley aquifer will result initially in removal of water from storage. Most of the water is from the pore spaces in the sand and gravel. As the pumping continues, a drawdown cone develops (greater drawdown near the well). The drawdown cone will continue to grow until the average recharge within the cone of influence (inside the drawdown cone) is equal to the average pumping rate. This assumes that such a balance will be met before the drawdown at the well is sufficient to result in a dry well. As there is more potential recharge from a streambed than from a natural ground surface, it is not uncommon for the drawdown cone to capture some stream flow.

For some environments, there is not a one to one correlation between volume pumped and volume lost to baseflow. When the water table is reduced, there may be potential for greater groundwater recharge. In addition, a deeper water table may result in reduced evapotranspiration. Both of these reduce losses to the stream.

4.6 Response of a Confined Aquifer to Pumping

Pumping from a confined valley aquifer will result in a different response than an unconfined aquifer. Groundwater will initially be removed from storage within the confined aquifer. As pumping continues, the drawdown cone will continue to extend outwards from the pumping well. The confining layer limits the amount of recharge to the confined aquifer and the drawdown cone extends until the recharge into the confined aquifer equals the pumping rate, assuming that such a balance will be met before the drawdown at the well is sufficient to result in a dry well. The reasons the response in a confined aquifer is different than an unconfined aquifer is that:

- A lower permeability material overlies the confined aquifer, so that the rate of recharge from the surface is constrained by the overlying aquitard (material impeding groundwater flow).
- The confined aquifer is often deeper and often has a greater available drawdown than an unconfined aquifer
- Drawdown of the water table in an unconfined aquifer results in a reduction of the aquifer thickness and therefore a reduction of the ability of the aquifer to transmit water. The water level in a well constructed in a confined aquifer can be lowered all the way to the top of the aquifer before any impediment to aquifer flow will be noticed.

4.7 Modelling a Typical Valley Aquifer System

To illustrate the difference between the response to pumping from an unconfined and a confined aquifer a simple MODFLOW model was prepared. MODFLOW is a three dimension groundwater flow modelling software that can be used to simulate the groundwater flow within and between aquifers. The model was prepared with assumed parameters typical of unconfined and confined aquifer systems.

The model consisted of a simple valley system with a gently sloping stream situated between two hills. The base of the valley was represented as a 500 metre wide sequence of layered sediments which were defined in the model with a 15 metre thick surficial sand and gravel aquifer overlying a 10 metre thick silty aquitard overlying and confining a 10 metre thick deep sand and gravel aquifer. The hills were modelled as relatively low permeability bedrock. A bedrock unit was also used to simulate the material surrounding the aquifers and aquitards. Recharge was applied to the hills and to the surficial aquifer. The recharge value was adjusted so that the stream was modelled as a typical gaining stream and consequently, under a natural scenario with no groundwater pumping, streamflow increased with distance downstream. The model was used to simulate a scenario where no pumping occurs.

A second scenario was used to simulate the response to pumping from an unconfined aquifer. The same model was used as for the natural scenario; however, a simulated pumping well was input into the surficial aquifer of the model. The total pumping rate for the well was arbitrarily selected at 0.035 m^3/s. The well was situated approximately 50 meters from the stream. The well was screened from approximately 5 metres below ground surface (mbgs) to 10 mbgs. The well was placed in the model so that any upstream and/or downstream boundary effects would be negligible.

A third scenario was used to simulate the response to pumping from a confined aquifer. The same model was used as for the natural scenario; however, one pumping well was input into the confined aquifer. The pumping rate for the well was selected at 0.035 m^3/s. The well was situated directly below the stream and screened from approximately 30 mbgs to 35 mbgs. The well was placed in the model so that any upstream and/or downstream boundary effects would be negligible.

Results of modelling the unconfined aquifer are plotted on Figure 4.3. Figure 4.3 plots the streamflow with distance downstream and includes the response to pumping for the unconfined scenario. For time zero, or pre-pumping, the streamflow is gradually increasing with distance downstream since it was modelled as a gaining stream. Plots of the streamflow at several times since pumping was initiated are also plotted on Figure 4.3. The location of the pumping well is at the zero value on the x axis. As shown on the plot, the streamflow drops abruptly within the immediate vicinity of the well. At approximately 250 meters downstream of the well, the stream is beyond the drawdown cone of the well. Within the drawdown cone of the well, the stream is interpreted as a losing stream since the volume of streamflow is not constantly increasing. At the downstream limit of the drawdown cone, the streamflow is reduced by the pumping rate of the well (0.035 m^3/s).

Figure 4.4 plots the streamflow with distance downstream and includes the response to pumping for the confined scenario. As shown on the plot, the streamflow begins to drop below the natural streamflow approximately 1000 metres upstream and continues to perhaps more than 1500 metres downstream. The drawdown cone for the confined case is on the order of 2500 metres length along the valley basin as opposed to approximately 500 metres for the unconfined case. The stream only becomes a slightly losing stream at late times, with a much less pronounced effect on stream loss than the confined case. Nevertheless, at the downstream limit of the drawdown cone, the streamflow is reduced by the pumping rate in the well (0.035 m^3/s).

Figure 4.5 provides a plot intended to illustrate the timing difference associated with pumping from a confined and unconfined aquifers. As illustrated on the plot, as the unconfined aquifer is pumped the streamflow decreases slowly as water in storage is removed. After approximately 40 days the storage in the surficial aquifer is used up and the water pumped from the well is replaced mostly by the stream. Once the storage is used up in the unconfined aquifer, the streamflow quickly drops to a level approximately 0.035 m^3/s less than the initial streamflow value. Pumping from the confined aquifer results in little to no streamflow loss for the first 40 days. Once the storage in the confined aquifer is consumed, the streamflow decreases relatively gradually until a steady state is reached at a level approximately 0.035 m^3/s less than the initial streamflow value.

The time for full impact of groundwater pumping on stream flows is influenced by site specific details. It is clear from Figures 4.4 through 4.6 that groundwater pumping from confined aquifers requires a longer time to equilibrate than unconfined aquifers. Furthermore, pumping from a confined aquifer affects a much greater area than pumping from an unconfined aquifer. Consequently, there is not as great an effect in the immediate vicinity of the pumping well. Given the natural variability of stream flow, the impacts are much more difficult to detect.

4.8 Mitigation for Extraction

An important aspect in defining the need for data and selecting calculation methodologies for groundwater/surface water interactions is recognizing the range of mitigative methods available for extraction. Following are some common methodologies.

4.8.1 Demand Management

Demand Management is a common method for mitigating low flows. This requires enforced and or voluntary reduction of water use during periods of low flow to maintain sufficient flow for downstream needs. This strategy is often used together with surface water storage.

4.8.2 Surface Water Storage

The common surface water mitigation for reduced base flow is to construct a reservoir to store water during high flow periods and discharge the stored water during low flow periods to meet downstream water needs. This type of mitigation was applied by Highland Valley Copper to mitigate for any water losses to downstream users as a result of their water use from Witches Brook. This was accomplished by water storage and release from Mamit Lake. This method is effective, but requires the construction and operation of a reservoir. In addition, storage of water in a reservoir creates a large water surface open to evaporation resulting in additional water losses.

4.8.3 Groundwater Storage

Storage in the groundwater system could be used as mitigation for reduction of stream low flows as a result of groundwater extraction. Compensation flows could be provided from groundwater so that there would be no reduction of the critical summer low flows. This can be accomplished by utilizing the storage capacity within the aquifer. In months when low flows are a concern, additional water can be pumped from the aquifer to provide the necessary low flows. This will reduce the reliable yield available to well operators, but provides a method where water can be extracted while still meeting downstream environmental requirements.

4.8.4 Conjunctive Use

Conjunctive use includes storage of surface water in the groundwater system during high flows with enhanced recharge methods, with tools such as spreading basins and injection wells. During dry periods, water is pumped from the groundwater system using standard groundwater wells. This method is a conceptually simple technique to replace relatively costly and environmental damaging surface water reservoirs.

4.9 Calculation Methodology

4.9.1 General

Water resource evaluations often involve an integrated analysis of groundwater and stream conditions (Blum et al, 2002). These studies are often required for:

- Defining the effect of groundwater extraction on existing water uses on a stream system.
- Defining the effect of a changed hydrograph on the groundwater elevations in the riparian zone.
- Defining the effect of channel restoration activities on stream gains/losses resulting from shallow groundwater conditions.
- Defining the effect of schedule of groundwater use under a drought management plan on baseflows in a stream at present and into future years, as lagged impact.
- Defining the basin yield, accounting for both surface flows and groundwater flows.
- Evaluating mitigation schemes considered for potential stream base flow reductions.

4.9.2 Calculation Method Selection

To represent the complete hydrologic cycle, all watershed models include integrated groundwater and surface water components. The method selected for a given task is driven by the needs of the problem of interest, the available data and the benefits of added complexity. Methodologies include:

- Lumped parameter watershed modeling programs, such as the UBC watershed model and HBV-EC;
- Distributed watershed modelling programs such as WATFLOOD and SLURP;
- Fully integrated surface water/groundwater models such as MIKE SHE;

- Separate groundwater and surface water routines which can be integrated manually.

Each of the methods requires a different level of available data and is capable of delivering more or less detail.

A surface water program that will provide daily or less flow rates requires consideration of stream channel storage along with detailed climatic inputs and calibration data. Channel sections are required at many locations. If weekly or monthly flows are required, this level of channel detail is not required, allowing concentration on climatic information to calibrate to measured flows. The Nicola Watershed study requires weekly and monthly flows, so programs that include channel geometry are more complex than required.

Most groundwater programs require identification and geometry of aquifers and aquitards. Material properties are required that input to groundwater flow rates, directions and velocities. This level of information must be gathered with subsurface investigation combined with geophysical techniques to assist with interpolation and extrapolation of drillhole data. This calculation method can be implemented in regions where aquifers are laterally extensive with extensive drillhole and geophysical information. This is possible with such aquifers as the Ogallala Aquifer which underlies the high plains of the United States from western Texas to South Dakota. It is more difficult to provide the required level of groundwater information for the Nicola Watershed, which includes mountainous terrains and disconnected aquifers, with minimal definition of hydrogeological parameters.

Watershed models typically include, in some fashion, all aspects of the hydrologic cycle. In several watershed models, the groundwater system is modeled as a linear aquifer. Discharge from the aquifer to stream is calibrated by direct comparison to stream baseflow measurements. Estimates of groundwater flow are then only required under the stream gauge site. This can be modeled using a simple Darcy formula. This procedure provides flows from the basin, including contributions from surface water and groundwater. As the required output is weekly or monthly, detailed channel descriptions are not required. As the project requires naturalized flow and does not need to define safe yield for individual well fields, detailed hydrogeologic parameters are also not required. Based on this assessment, a lumped parameter watershed model was selected. As Water Management Consultants have developed a routine for watershed modelling that has been applied in Highland Valley, at Summerland and at Hedley, the WMC Watershed Model was selected for modelling the Nicola Watershed and sub basins.

5 WATERSHED MODELLING

5.1 Methodology

The WMC Watershed Model was used to develop a model for the Nicola River and all its tributary streams to the confluence with Thompson River. The model considers both surface water and groundwater components of streamflow, which were estimated primarily according to the characteristics of stream base flow, the stream flow response to precipitation and snowmelt and the expected groundwater recharge and discharge. The basic inputs to the groundwater recharge/discharge simulation were temperature and precipitation according to the climate distribution formulated in Section 2.2. The model incorporates evapotranspiration, sublimation, infiltration, discharge and surface detention factors, which were adjusted during the calibration process to provide a reasonable match between measured and simulated surface flows. The model produced a weekly record of surface water and groundwater flows from each sub-catchment specified on Figure 2.3. A detailed methodology for the WMC Watershed Model is included in Appendix III.

Accumulation of snowpack and subsequent spring snowmelt are important processes for hydrologic characterization of the Nicola Basin. The watershed model calibration includes comparison of calculated snowpack to measured snowpack at several points within the basin. Although snowfall is typically difficult to measure and local conditions often result in significant variation in sublimation throughout the winter, snowpack conditions are critical for evaluating water supply. Ten snow course measurement stations were used to compare to calculated snowpack. This snowpack data was distributed throughout the basin by applying the climate variability assessed from the climate data as described in Section 2.2.

The WMC Watershed Model was calibrated with flow measurements from six unregulated streams using concurrent climate and snowpack data. Once the calibration for the six sub-catchments was complete, the model was extended to all the sub-catchments in the Nicola Basin by developing hypsometric curves (area-elevation relationships) for all sub-catchments and generating flows for each sub-catchment for the period from 1967 to 2006. This provided a preliminary estimate of weekly natural flows throughout the Nicola Basin for a 39 year period.

5.2 Data for Watershed Modelling

5.2.1 Climate and Snowpack

The National Climate Data and Information Archive compiled by Environment Canada was used to collect climate data within the Nicola Watershed. Table 2.2 lists the thirteen climate stations that temperature and precipitation data was collected from. The locations of the climate stations are illustrated on Figure 2.4.

Snowpack data was collected from the Ministry of Environment Water Stewardship Division River Forecast Center. In total, data from six snow course stations within the Nicola basin were considered and four additional stations were considered from the Okanagan Watershed. Table 2.4 presents the snow course locations. The locations of the snow course stations are illustrated on Figure 2.4.

Climate data was input to the watershed model based on the factors presented on Tables 2.3 and 2.5. These were refined through the calibration process.

The basic input to the model was derived from daily temperature and precipitation records for Lornex. Precipitation and average temperature for quarter monthly periods were calculated from the daily records. For each of the simulated sub catchments, a first estimate of the precipitation curve number was assigned (see Section 2.2.5) based on proximity to meteorological and snow course stations. The curve numbers were modified slightly over the calibration process to best meet known hydrologic conditions. Temperature was estimated in all areas of the model using the environmental lapse rate applied to the Lornex record.

5.2.2 Hydrometric

Hydrometric stations are required for calibration of a watershed model. Hydrometric data was collected through the Water Survey of Canada hydrometric database. There are forty-nine inactive and twelve active hydrometric stations within the Nicola watershed. However, of the forty-nine inactive hydrometric stations, twenty-six recorded natural stream flows. Furthermore, only two of these stations were active during the period of record. Of the twelve active hydrometric stations, four stations have a period of record similar or equal to the snowpack data and record natural stream flow. The six hydrometric stations that have sufficient record to calibrate the watershed model are presented in Table 5.1. The locations of the hydrometric stations are illustrated on Figure 2.4.

Table 5.1 Stream Gauge Locations used to calibrate the Watershed Model

Station Code	Stream Name	Drainage Area (km^2)	Sub-Basin	Latitude		Longitude		Active Dates	
				Degree	Second	Degree	Second	Start	End
08LG064	Beak Creek	85	Upper Nicola	50	7	119	59	1981	2001
08LG048	Coldwater River	316	Coldwater	49	51	120	54	1965	2005
08LG016	Pennask Creek	87	Upper Nicola	49	58	120	8	1920	2005
08LG008	Spius Creek	780	Spius	50	8	121	2	1970	2005
08LG056	Guichon Creek	78.2	Guichon	50	37	120	55	1967	2005
08LG068	Spius Creek	178.6	Spius	49	57	121	5	2000	2005

5.3 Sub-Catchment Description

5.3.1 Selection of Sub-Catchments

The study area includes all the rivers, creeks, streams and tributaries of the Nicola River from its headwaters to its confluence with the Thompson River at Spences Bridge. A series of ten sub-catchments for the Nicola Valley have been defined by Urban Systems (Phase 1 Scoping Study, 2005). The sub-catchment boundaries were based on delineation of watersheds so that boundaries straddle the topographic highs between creeks and rivers. The boundaries of the ten sub-catchments are included on Figure 2.3.

As described above, natural stream flow has been measured at six locations within the Nicola basin. Not all of these hydrometric stations are located at the outflow from the ten sub-catchments. For the purpose of the watershed model, additional catchments were delineated from the point of streamflow measurement. The sub-catchments were further subdivided by delineating a boundary from the outflow of five lakes: Pennask Lake, Douglas Lake, Nicola Lake, Stump Lake and Mamit Lake.

It was assumed that aquifers are located in association with Quaternary deposits as discussed in Section 2.5. Therefore, further subdivisions were delineated along Guichon, Coldwater and Nicola valleys where Quaternary material has been deposited. By delineating catchment boundaries to accommodate the Quaternary deposits, characteristics of groundwater supply in the Nicola Watershed could be more realistically simulated. In total, forty sub-catchments were used to simulate natural surface water and groundwater flows within the Nicola basin. The boundaries of the forty sub-catchments are included in Figure 5.1.

5.3.2 Areas and Elevation Bands

The elevation within the Nicola basin ranges from approximately 240 metres above sea level (masl) near Spences Bridge to approximately 2260 masl (metres above sea level) near the headwaters of Spius Creek. Since temperature and precipitation vary with elevation, each of the sub-catchments was divided by a series of elevation bands. Eight elevation bands were selected at 200 m contour intervals. Representative climate conditions (temperature and precipitation) were calculated for the centre elevation of each elevation band and applied to each sub-catchment in the watershed model. Figure 5.1 illustrates the forty sub-catchments and highlights the elevation bands used to describe elevation dependent climate conditions.

5.3.3 Climate Distribution

Based on the description of climate in Section 2.2, and incorporating the elevation bands into each sub-catchment, the average yearly precipitation was calculated for all the sub-catchments (Table 5.2). As indicated by the values presented in Table 5.2, the areas with the highest precipitation and lowest temperatures are towards the south west side of the Nicola basin within Coldwater and Spius sub-catchments. The areas with the lowest precipitation and highest temperatures include areas within the lower and middle Nicola Valley and to the north east near Stump Lake.

Table 5.2: Average Yearly Precipitation and Temperature for each Sub Catchment

Sub-Catchment	Area (km^2)	Precipitation (mm/yr)	Temperature (°C)
Upper Nicola	1,506	402	4.3
Stump	313	309	6.0
Moore	205	340	3.9
Quilchena	775	419	4.1
Middle Nicola	263	301	6.5
Clapperton	256	346	3.5
Coldwater	912	629	4.9
Guichon	1,226	348	4.0
Spius	775	877	3.3
Lower Nicola	981	308	6.1

5.3.4 Forest Cover

The extent of vegetative cover is important to understand when estimating the amount of water that is available for surface runoff and infiltration. Forested areas will intercept more precipitation than non-forested areas and result in higher rates of evaporation and sublimation. Furthermore, higher rates of transpiration would be expected where the rooting system of forested areas are able to access deeper water in the soil. Higher rates of evapotranspiration and sublimation in forested areas result in less water available for surface runoff and infiltration into groundwater. Lower rates of evapotranspiration and sublimation in a non-forested area or a de-forested area can result in higher infiltration and runoff, and can lead to a higher peak discharge from a watershed and potentially slope instability.

To integrate vegetative cover into the watershed model, a current estimate of the extent of vegetation cover was downloaded from the BC Integrated Land Management Bureau and imported into ArcMap GIS software. The vegetation resource inventory (VRI) was designed to identify where forest resources are located and show how much of a given vegetation resource (for example, timber or coarse woody debris) is within an inventory unit. The VRI has been created from the analysis of vegetation polygons from existing aerial photography information and ground sampling to determine how much of a given characteristic is within the inventory area. Vegetation polygons from the VRI are irregular in shape and are typically less than 1 square kilometre area. Any forest cover polygon that has greater than 5 percent crown closure was considered to be vegetated. The downloaded data was prepared as a series of shapefiles identifying forested and non-forested areas throughout the basin. The areas were then classified according to elevations bands within each sub-catchment.

Estimates of the difference in annual water yield from a forested versus a non-forested grassland were postulated by a pair of studies relating to afforestation (von Stackelberg et al., 2007 and Farley et al, 2005). The studies concluded that as a grassland land type was changed to a forested land type, the surface runoff yield decreased between approximately 15 and 35 percent. Aside from large areas in the Quilchena, Upper Nicola, Middle Nicola and Stump catchments the majority of non-forested areas in the Nicola basin are relatively isolated, being surrounded by large areas of forested land type. As such, the non-forested areas are mostly small areas within a largely forested catchment. Furthermore, the areas defined as forested are likely to have some component of grassland within them. Based on the method of determining the forested versus non-forested areas, it is reasonable to assume that the percent difference in surface runoff yield between the areas is likely at the low end of the range provided in the afforestation studies. An increase in surface runoff yield of 15 percent was expected for the Nicola Watershed for a non-forested area. Changes would most likely be observed during high flows.

5.3.5 Mountain Pine Beetle

A publication by the Canadian Forest Service by Heilie et al. (2005) introduces the life cycle of the Mountain Pine Beetle (MPB) and summarizes the research conducted regarding MPB infestation in semi-arid watersheds. The MPB is a bark beetle that is native to North America and attacks lodgepole, ponderosa, sugar and western white pines. The life cycle of the MPB is approximately one year, however can be significantly disrupted by cold early fall or mid-spring temperatures or very cold winter temperatures. The MPB digs through the base of pines to lay eggs and introduces a fungus that stains the pine tree blue. The fungus develops and spreads through the sapwood and interrupts the flow of water to the crown of the tree. Once the eggs hatch, the MPB larvae feed on the nutrient flow in the tree, which eventually results in the death of the tree. After being infested for about a year, the needles of the tree change from green to yellow, to red and finally to grey.

Pine trees killed by MPB die standing mostly intact; however, over time their canopy cover decreases as needles and branches are lost (Huggard and Lewis, 2007). Crown cover of a forest provides a large surface area where rainfall and snowfall is intercepted and available for evaporation and sublimation. Furthermore, as the tree dies, its consumption of water for transpiration is diminished and eventually stops. Consequently, as the canopy cover deteriorates and the tree dies, the rate of evapotranspiration and sublimation is expected to decrease and more precipitation will fall, unconsumed by vegetation, to the ground surface and result in greater availability of water for surface runoff or infiltration into groundwater.

Heilie et al. (2005) tabulated a summary of the results of studies conducted to assess the hydrological impact of MPB infestation. Heilie et al (2005) reported that the increase in annual water yield from infested basins ranged from 10 to 15 percent. Huggard and Lewis (2007) prepared a study relating to the effects of salvaging or not salvaging pine stands killed by MPB. They found that the forest canopy could recover more quickly from MPB infestation if the infested trees were removed and replanted with seedlings. At this point it is unknown to what extent a MPB infested area will be cleared and replanted; however it can be assumed that at least some of the area will be cleared. Because clearing of the forest canopy would result in higher initial increases in water yield than a slow diminishing canopy as a result of MPB kill, for the purpose of the watershed model an MPB infested area was assumed to have a conservative increase of 15 percent annual water yield as compared to a non-infested area.

Since 1999, the B.C. Ministry of Forests has surveyed the majority of the forested land in the province using the classic sketch mapping technique known as the overview survey method. The purpose of the survey is to record and report the general trends in disturbance patterns across the provincial forested land base (including provincial parks, private land, and Tree Farm Licences but not federal parks). The survey has been a key source of data documenting the development of the current mountain pine beetle outbreak in the interior of B.C. The areas of MPB infestation for 2006 were estimated by Ministry of Forests and Range and were downloaded from the BC Integrated Land Management Bureau and imported into ArcMap GIS software. The forested areas, described above, were further subdivided into areas that are currently infested with Mountain Pine Beetle (MPB). The MPB coverage includes a percentage of pine stand infested for each forested area. Based on two publications (Huggard and Lewis, 2007 and Heilie et al., 2005) and conversation with Doug Lewis of the Ministry of Environment, areas with greater than 50 percent of the pine stand infected with MPB were selected as MPB infested areas. Figure 5.2 illustrates the extent of MPB infestation in 2006. Table 5.3 provides the percentage of MPB infestation for year 2006 in each of the ten sub-catchments. Also provided in Table 5.3 is the percentage of MPB infested area within the total area of the Nicola Basin and the percentage of the forested area that is infested with MPB within the Nicola Basin.

Table 5.3: Percent of MPB infestation by sub-catchment

Sub-catchment	Percentage
Upper Nicola	5
Stump	12
Moore	11
Quilchena	4
Middle Nicola	5
Clapperton	8
Coldwater	3
Guichon	20
Spius	2
Lower Nicola	5
% of Total Area	8
% of Forested Area	10

For the model simulation of current conditions, the MPB infested areas are included in the model. It is understood that the current MPB outbreak started in 1994 (Heilie et al., 2005) and the current MPB infested areas are not relevant to the entire modelled period (1967 to 2006). However, the current MPB infested area takes up a relatively small fraction of the total area (approximately 8 percent) and likely have little effect on the overall hydrology of the Nicola basin. Although the MPB has little effect in 2006, it was included in the simulation for comparison with simulations of future conditions.

5.4 Sub-Catchment Calibration

A total of six sub-catchments were calibrated to stream gauges that have measurements of natural stream flow. Basic inputs included temperature and precipitation. The watershed model calculates snowpack generated during winter and as part of the calibration process, the calculated snowpack was compared to measured snowpack at nearby snow course locations. With appropriate inputs, several factors can be adjusted to provide a reasonable fit to streamflow measurements. Sublimation and evapotranspiration factors can be adjusted to increase or decrease the calculated streamflow. Low stream flows during the late winter (prior to freshet) and late summer will be controlled primarily by groundwater discharge.

Factors controlling infiltration and discharge rates of groundwater can be adjusted to fit to low streamflow conditions.

Figures 5.3 through 5.8 present the comparison of calculated and measured streamflow at the six calibrated sub-catchments. Each plot provides the monthly calculated and measured streamflow and the cumulative streamflow.

5.5 Characterizing Non-Gauged Sub-catchments

Six sub-catchments in the Nicola basin were calibrated based on measured natural streamflow. The factors governing streamflow and groundwater recharge/discharge from the remaining thirty-four sub-catchments required rationalized estimates. Inputs for climate were selected for each sub-catchment based on the description in Section 2.2.5 and Section 5.3.3.

Fortunately, the six calibrated sub-catchments represent relatively diverse geographical and geological locations. Because the calibration catchments are representative of a large area, comparison could be made between several of the non-gauged sub-catchments and the calibrated sub-catchments so that the hydrologic and hydrogeologic factors could be reasonably estimated.

Estimates of factors related to groundwater recharge and discharge were derived from comparisons to the calibrated catchments and information regarding surficial geology. The description of surficial geology prepared in Section 2.4 was used to estimate the capacity of the surficial materials to allow infiltration of surface water, the rate at which groundwater would be discharged from aquifers within each sub-catchment and the rate of groundwater flow between sub-catchments.

Once estimates of the model parameters were input into the model, the surface water flow from several catchments was compared to measurements from stream gauges recording streamflow from regulated watersheds. It was assumed that the modelled natural flow would be higher than the measured flow because of the water demand in the basin. Measured and calculated streamflow was compared at six locations, Nicola River above Nicola Lake, Quilchena Creek near Nicola Lake, at the outflow of Nicola Lake, Coldwater River near Merritt, Guichon Creek near Nicola River and Nicola River at Spences Bridge. Figures 5.9 and 5.10 plots measured and calculated cumulative streamflow at Nicola River near Spences Bridge and downstream of Nicola Lake, respectively. Summit (2007) provided estimates of the water demand, water use and licensed quantities of water in the Nicola Basin. Figures 5.9 and 5.10 provide curves relating to the modeled flow minus the demand use and licensed quantity. As illustrated on the plot, when including the estimated demand, use and licensed quantity from the Nicola basin, the cumulative calculated natural surface water flow out of the Nicola basin compares well to the cumulative measured flow from the basin.

6 WATER SUPPLY FORECASTING

This section of the report presents estimates of natural flows for each of the 10 sub basins in the Nicola Watershed for different climate and pine beetle scenarios. The flow estimates were derived from the output of the watershed model described in Section 5.

6.1 Climate scenarios

The Climate BC Model was used to estimate future temperatures and precipitation with results from CGCM, the Canadian Global Coupled Model. The Climate BC Model was developed by Wang et al (2006) and Hamann and Wang (2005). Climate BC calculates seasonal and annual climate variables for the reference period (1961-1990), for specific locations based on latitude, longitude and elevation. Future climate projections for the years 2020 and 2050 were available from the Climate BC Model from the CGCM for two scenarios:

- A2: Assumes regional resiliency and adaptation
- B2: Assumes local resiliency and adaptation

Compared with B2, Scenario A2 has higher CO_2 concentrations, a larger human population, greater energy consumption and more change in land use.

The Climate BC model was used to generate monthly climate normals for the Highland Valley climate station location (Lornex) and then used to estimate future changes to temperature and precipitation at this location. The results are shown in Table 6.1.

In Table 6.1, the numeric increases in temperature for each month are shown compared with the 1961-1990 climate normals and the increases in precipitation are shown as a factor of the 1961-1990 climate normals. In the watershed model, for each month, the temperature increases were applied to all daily temperatures and the precipitation factors were applied to all daily precipitation values.

Table 6.1: Changes in Temperature (^{o}C) and Precipitation (mm) at Lornex (Highland Valley) for Different Climate Scenarios

Normals 1961-1990			**2020:A2**				**2020:B2**			
Month	Temp	Precip	Temp	Precip	**Temp inc**	**P factor**	Temp	Precip	**Temp inc**	**P factor**
January	-6.7	42	-5.6	42	**1.1**	**1.00**	-5.6	43	**1.1**	**1.02**
February	-3.8	27	-2.1	29	**1.7**	**1.07**	-2	30	**1.8**	**1.11**
March	-1.3	22	0.3	24	**1.6**	**1.09**	0.1	22	**1.4**	**1.00**
April	2.6	24	4.1	27	**1.5**	**1.13**	3.9	24	**1.3**	**1.00**
May	7.1	37	8.1	34	**1**	**0.92**	8.1	37	**1**	**1.00**
June	11.4	38	12.3	39	**0.9**	**1.03**	12.5	39	**1.1**	**1.03**
July	14.1	36	15.2	34	**1.1**	**0.94**	15.2	32	**1.1**	**0.89**
August	14	34	15.3	37	**1.3**	**1.09**	15.2	32	**1.2**	**0.94**
September	9.6	30	10.6	31	**1**	**1.03**	10.4	31	**0.8**	**1.03**
October	4.4	28	5.4	25	**1**	**0.89**	5.2	27	**0.8**	**0.96**
November	-2.4	39	-1.6	42	**0.8**	**1.08**	-1.6	41	**0.8**	**1.05**
December	-6.4	42	-5.6	44	**0.8**	**1.05**	-5.4	46	**1**	**1.10**
Normals 1961-1990			**2050:A2**				**2050:B2**			
Month	Temp	Precip	Temp	Precip	**Temp inc**	**P factor**	Temp	Precip	**Temp inc**	**P factor**
January	-6.7	42	-4.3	44	**2.4**	**1.05**	-4.7	44	**2**	**1.05**
February	-3.8	27	-0.8	28	**3**	**1.04**	-1	30	**2.8**	**1.11**
March	-1.3	22	1.5	22	**2.8**	**1.00**	1.2	22	**2.5**	**1.00**
April	2.6	24	5.5	23	**2.9**	**0.96**	5.1	25	**2.5**	**1.04**
May	7.1	37	9.3	31	**2.2**	**0.84**	8.9	32	**1.8**	**0.86**
June	11.4	38	13.4	35	**2**	**0.92**	13.1	35	**1.7**	**0.92**
July	14.1	36	16.3	33	**2.2**	**0.92**	16	32	**1.9**	**0.89**
August	14	34	16.1	35	**2.1**	**1.03**	15.8	35	**1.8**	**1.03**
September	9.6	30	11.6	32	**2**	**1.07**	11.3	31	**1.7**	**1.03**
October	4.4	28	6	28	**1.6**	**1.00**	5.8	27	**1.4**	**0.96**
November	-2.4	39	-0.7	46	**1.7**	**1.18**	-1.1	44	**1.3**	**1.13**
December	-6.4	42	-4.8	45	**1.6**	**1.07**	-5	46	**1.4**	**1.10**

P factor is the ratio precipitation is multiplied by for the scenario

6.2 Pine Beetle Scenarios

Section 5.3.5 provides an outline of the lifecycle of the Mountain Pine Beetle (MPB) and its effect on pine stands, and describes the current extent of MPB infestation in the Nicola Watershed. The watershed model described in Section 5 was used to estimate the future water supply in the Nicola basin with the estimated change due to MPB infestation. The scenarios for the MPB infestation include:

- MPB infestation for current conditions (2006)
- MPB infestation for 2015
- MPB infestation for 2050

The current MPB infestation was included in the watershed model described in Section 5.3.5.

The Ministry of Forests and Range has estimated the potential extent of MPB infestation for the year 2015. The MPB infested areas were downloaded from the BC Integrated Land Management Bureau and imported into ArcMap GIS software. As with the current conditions, they assumed that areas with greater than 50 percent of the pine stand infected with MPB were selected as MPB infested areas. Based on this assumption, they estimated that approximately 40 percent of the total area in the Nicola basin will be infested by MPB by 2015. Figure 6.1 illustrates the estimated extent of MPB infestation in 2015.

The condition of the forested areas in the Nicola basin in 2050 is difficult to predict. It will depend on several factors including climate and decisions regarding de-foresting and re-foresting. Several scenarios are possible; however, for the purpose of this report, a conservative scenario with respect to water supply is used. For the 2050 scenario it was assumed that MPB infestation has been removed from the Nicola Watershed and the forested areas have had time to regenerate. Huggard and Lewis (2007) compared the MPB kill area to an equivalent clearcut area (ECA) where an ECA value of 100 percent equates to a fully cleared area. They estimated that if seedlings are planted after MPB kill, the predicted ECA value approaches zero after 20 to 35 years, while natural forest regeneration would require an additional 15 to 20 years. Based on Huggard and Lewis (2007) it is reasonable to assume that the forest would be given enough time to regenerate by 2050. For the MPB infestation for 2050, areas corresponding to the current vegetated and non-vegetated areas were included in the watershed model with no inclusion of MPB infested areas.

6.3 Results

The five scenarios shown in Table 6.2 were applied for developing the estimates of current and future water supply in each sub basin.

Table 6.2: Scenarios Applied for Current and Future Water Supply

Scenario	Climate	Pine beetle condition
1	Current climate	Current conditions
2	CGCM 2020: A2	Year 2015 projection
3	CGCM 2020: B2	Year 2015 projection
4	CGCM 2050: A2	Regrowth conditions
5	CGCM 2050: B2	Regrowth conditions

The following statistical analyses were carried out on the data for minimum annual weekly, minimum annual monthly and annual natural flows. The term “minimum annual monthly flow” means the minimum monthly flow in each year. Similarly the minimum annual weekly flow is the minimum weekly flow in each year.

- Mean
- 1 in 5 year drought frequency
- 1 in 10 year drought frequency
- 1 in 15 year drought frequency
- 1 in 50 year drought frequency

The estimated drought frequency flows in each sub basin for the five scenarios are provided in Tables 6.3a, 6.3b, 6.3c, 6.3d and 6.3e. The natural flows in each sub basin are the flows only from that sub basin and do not include any stream flows from upstream sub basins.

The drought frequency analyses were carried out using the computer program FFAME developed by the Province of British Columbia. The minimum annual weekly and minimum annual monthly low flows were for the period July to October because winter low flows are of

Table 6.3a: Results of Drought Frequency Analysis for Scenario 1

	SCENARIO 1									
	Average Monthly Flows l/s									
Month	**Upper Nicola**	**Stump**	**Moore**	**Quilchena**	**Clapperton**	**Middle Nicola**	**Coldwater**	**Guichon**	**Spius**	**Lower Nicola**
January	1757.95	34.69	41.51	443.64	48.67	9.97	2403.23	608.63	2343.56	264.50
February	1720.60	26.04	34.80	434.17	39.76	13.49	3009.41	559.50	3306.21	247.59
March	1896.23	22.79	30.85	822.07	33.48	20.19	4636.68	519.55	6249.14	257.84
April	5887.59	29.77	31.31	4675.61	32.86	39.63	15593.87	579.23	21327.94	278.83
May	16505.47	210.20	205.77	8307.10	281.63	114.30	30179.61	2727.04	37351.72	690.28
June	11682.04	156.95	250.64	4275.66	347.86	87.25	23641.71	4128.44	25219.69	931.78
July	5175.04	95.79	181.75	2914.13	241.58	60.90	10058.74	2329.85	8091.18	725.68
August	2619.29	50.76	110.25	1778.89	136.99	39.40	4718.08	1060.19	3431.29	480.11
September	2193.74	35.77	89.35	1235.04	108.76	27.23	2507.77	854.82	2103.97	415.35
October	2008.14	32.90	73.22	866.07	88.55	18.89	3814.97	778.94	3409.20	363.73
November	1996.75	41.64	59.64	639.67	71.48	13.32	4348.58	721.37	4393.72	318.53
December	1784.40	41.35	48.57	471.93	57.59	9.58	2392.42	650.06	2207.21	279.93
Average	4602.27	64.89	96.47	2238.66	124.10	37.85	8942.09	1293.13	9952.90	437.85

	SCENARIO 1									
	DROUGHT FREQUENCY - Minimum Annual Weekly l/s									
	Upper Nicola	**Stump**	**Moore**	**Quilchena**	**Clapperton**	**Middle Nicola**	**Coldwater**	**Guichon**	**Spius**	**Lower Nicola**
Mean	1690.00	4.06	37.50	701.00	38.60	10.00	1720.00	604.00	1150.00	248.00
1 in 5	1290.00	0.35	11.60	434.00	9.59	4.15	1410.00	264.00	955.00	105.00
1 in 10	1100.00	0.10	5.35	319.00	3.71	2.61	1270.00	135.00	872.00	59.00
1 in 15	1014.01	0.06	3.47	269.28	2.11	2.12	1205.65	84.34	836.90	42.68
1 in 50	798.00	0.01	0.00	150.00	0.00	1.16	1050.00	0.00	752.00	7.67

	SCENARIO 1									
	DROUGHT FREQUENCY - Minimum Annual Monthly l/s									
	Upper Nicola	**Stump**	**Moore**	**Quilchena**	**Clapperton**	**Middle Nicola**	**Coldwater**	**Guichon**	**Spius**	**Lower Nicola**
Mean	1800.00	5.55	42.20	796.00	45.20	11.10	1930.00	633.00	1290.00	262.00
1 in 5	1380.00	0.53	13.40	495.00	12.00	4.40	1520.00	283.00	1050.00	111.00
1 in 10	1180.00	0.16	6.19	367.00	4.71	2.71	1360.00	150.00	957.00	62.50
1 in 15	1092.26	0.10	3.98	313.18	2.65	2.18	1295.65	97.18	922.49	45.13
1 in 50	868.00	0.02	0.00	183.00	0.00	1.15	1150.00	0.00	843.00	7.76

	SCENARIO 1									
	DROUGHT FREQUENCY - Annual l/s									
	Upper Nicola	**Stump**	**Moore**	**Quilchena**	**Clapperton**	**Middle Nicola**	**Coldwater**	**Guichon**	**Spius**	**Lower Nicola**
Mean	4240.00	23.60	55.10	2070.00	62.10	19.20	8690.00	923.00	9630.00	308.00
1 in 5	2870.00	5.23	17.80	1210.00	17.30	6.51	6600.00	399.00	7180.00	130.00
1 in 10	2300.00	2.23	8.64	833.00	7.62	3.70	5620.00	237.00	6050.00	75.80
1 in 15	2066.01	1.51	5.83	670.97	4.89	2.89	5187.13	180.84	5552.78	56.73
1 in 50	1510.00	0.29	0.34	275.00	0.00	1.37	4100.00	61.00	4300.00	16.30

Table 6.3b: Results of Drought Frequency Analysis for Scenario 2

	SCENARIO 2									
	Average Monthly Flows l/s									
Month	Upper Nicola	Stump	Moore	Quilchena	Clapperton	Middle Nicola	Coldwater	Guichon	Spius	Lower Nicola
January	2545.48	56.36	52.78	656.87	61.57	17.16	3568.31	752.77	3803.61	382.20
February	2920.96	50.56	49.49	1169.60	54.50	32.73	5512.91	708.21	6883.29	399.95
March	4074.16	81.85	52.84	2241.59	53.58	77.14	8543.30	732.99	11275.12	497.75
April	12083.70	151.33	91.67	6864.47	103.17	117.74	21291.06	1211.31	27299.51	554.56
May	18471.62	253.40	262.70	6761.60	356.64	145.30	27969.44	3470.64	32503.72	988.84
June	10872.83	162.62	258.04	3662.80	351.23	102.34	21870.18	3663.00	22160.94	1057.41
July	5479.21	97.92	194.94	2628.32	251.50	68.00	8382.59	2125.74	6594.95	859.50
August	3524.89	62.94	139.59	1826.53	172.73	47.04	4250.13	1229.01	3489.90	661.49
September	2957.29	45.84	109.90	1236.67	132.94	32.48	2662.46	1011.84	2074.91	559.08
October	2641.07	42.57	90.18	865.38	108.49	22.42	3944.87	913.16	3633.77	488.88
November	2680.35	54.67	73.47	675.94	87.70	15.68	5957.59	851.92	6203.17	427.99
December	2419.79	54.53	59.85	497.84	70.76	11.15	3227.27	777.58	3116.43	375.88
Average	5889.28	92.88	119.62	2423.97	150.40	57.43	9765.01	1454.01	10753.28	604.46

	SCENARIO 2									
	DROUGHT FREQUENCY - Minimum Annual Weekly l/s									
	Upper Nicola	Stump	Moore	Quilchena	Clapperton	Middle Nicola	Coldwater	Guichon	Spius	Lower Nicola
Mean	2360.00	5.48	55.80	700.00	62.10	12.20	1820.00	737.00	1150.00	370.00
1 in 5	1850.00	0.38	20.00	445.00	20.40	5.10	1500.00	347.00	971.00	175.00
1 in 10	1600.00	0.09	9.56	335.00	9.13	3.36	1360.00	198.00	896.00	106.00
1 in 15	1483.01	0.06	6.04	287.62	5.51	2.83	1295.65	137.92	864.41	79.50
1 in 50	1180.00	0.01	0.00	173.00	0.00	1.79	1140.00	0.00	788.00	20.00

	SCENARIO 2									
	DROUGHT FREQUENCY - Minimum Annual Monthly l/s									
	Upper Nicola	Stump	Moore	Quilchena	Clapperton	Middle Nicola	Coldwater	Guichon	Spius	Lower Nicola
Mean	2460.00	6.81	60.70	791.00	68.40	14.10	1990.00	757.00	1280.00	389.00
1 in 5	1940.00	0.47	21.90	505.00	22.80	5.70	1580.00	361.00	1060.00	184.00
1 in 10	1680.00	0.12	10.60	384.00	10.40	3.57	1430.00	211.00	989.00	110.00
1 in 15	1563.01	0.07	6.76	333.11	6.33	2.91	1371.50	151.33	961.51	82.27
1 in 50	1260.00	0.01	0.00	209.00	0.00	1.61	1240.00	14.00	900.00	19.70

	SCENARIO 2									
	DROUGHT FREQUENCY - Annual l/s									
	Upper Nicola	Stump	Moore	Quilchena	Clapperton	Middle Nicola	Coldwater	Guichon	Spius	Lower Nicola
Mean	5470.00	50.90	77.90	2270.00	97.10	32.90	9450.00	1120.00	10400.00	487.00
1 in 5	3770.00	15.50	30.00	1370.00	34.30	11.40	7200.00	512.00	7840.00	236.00
1 in 10	3070.00	7.02	15.70	972.00	17.00	6.08	6180.00	310.00	6700.00	146.00
1 in 15	2771.67	4.46	10.79	798.27	11.27	4.48	5723.73	235.71	6196.93	112.07
1 in 50	2070.00	0.00	0.48	372.00	0.00	1.35	4590.00	73.40	4960.00	35.40

Table 6.3c: Results of Drought Frequency Analysis for Scenario 3

	SCENARIO 3									
	Average Monthly Flows l/s									
Month	Upper Nicola	Stump	Moore	Quilchena	Clapperton	Middle Nicola	Coldwater	Guichon	Spius	Lower Nicola
January	2521.57	53.65	50.90	683.29	59.01	18.34	3625.12	728.49	3857.52	377.35
February	3013.10	53.77	49.24	1274.97	53.54	37.47	5847.84	696.18	7288.78	421.13
March	3747.96	77.99	51.42	2023.97	52.56	78.12	7608.89	706.28	10089.36	480.49
April	10827.91	114.86	69.77	6310.63	73.08	102.56	19427.20	967.13	25277.27	495.59
May	19530.16	275.60	281.37	7384.62	383.93	151.03	30140.26	3537.93	35189.57	1020.63
June	11618.44	172.36	273.08	3798.03	373.18	105.40	22627.49	4004.23	22935.71	1116.08
July	5270.29	93.39	188.17	2554.27	242.05	67.20	8273.65	2075.51	6372.94	835.48
August	3102.17	61.50	130.47	1677.12	158.10	46.13	3943.80	1078.17	3005.09	628.09
September	2809.92	44.37	106.81	1212.27	128.89	31.59	2586.42	954.65	1975.14	546.65
October	2623.26	40.86	87.18	850.26	104.56	21.79	4207.43	885.08	3973.02	477.55
November	2658.52	52.02	71.02	655.30	84.48	15.26	5864.79	827.32	6114.32	418.06
December	2398.58	51.87	57.85	494.07	68.12	10.87	3527.25	755.77	3472.32	367.16
Average	5843.49	91.02	118.11	2409.90	148.46	57.15	9806.68	1434.73	10795.92	598.69

	SCENARIO 3									
	DROUGHT FREQUENCY - Minimum Annual Weekly l/s									
	Upper Nicola	Stump	Moore	Quilchena	Clapperton	Middle Nicola	Coldwater	Guichon	Spius	Lower Nicola
Mean	2330.00	5.54	56.30	697.00	63.60	12.00	1820.00	729.00	1150.00	364.00
1 in 5	1820.00	0.41	20.80	442.00	21.70	5.09	1500.00	351.00	962.00	174.00
1 in 10	1570.00	0.10	9.93	330.00	9.62	3.36	1350.00	202.00	884.00	105.00
1 in 15	1453.01	0.06	6.12	282.03	5.56	2.82	1285.65	141.69	850.66	78.44
1 in 50	1160.00	0.01	0.00	165.00	0.00	1.76	1120.00	0.71	771.00	18.70

	SCENARIO 3									
	DROUGHT FREQUENCY - Minimum Annual Monthly l/s									
	Upper Nicola	Stump	Moore	Quilchena	Clapperton	Middle Nicola	Coldwater	Guichon	Spius	Lower Nicola
Mean	2430.00	6.72	61.00	791.00	69.40	13.90	1990.00	750.00	1290.00	383.00
1 in 5	1900.00	0.48	22.60	502.00	23.90	5.66	1580.00	366.00	1050.00	183.00
1 in 10	1650.00	0.12	10.80	377.00	10.70	3.55	1430.00	217.00	967.00	111.00
1 in 15	1533.01	0.07	6.67	322.60	6.26	2.89	1365.65	157.33	933.07	83.86
1 in 50	1230.00	0.01	0.00	191.00	0.00	1.58	1230.00	18.20	855.00	22.50

	SCENARIO 3									
	DROUGHT FREQUENCY - Annual l/s									
	Upper Nicola	Stump	Moore	Quilchena	Clapperton	Middle Nicola	Coldwater	Guichon	Spius	Lower Nicola
Mean	5410.00	47.70	82.30	2250.00	89.10	31.40	9470.00	1090.00	10400.00	476.00
1 in 5	3690.00	14.10	31.80	1340.00	31.70	10.60	7210.00	504.00	7840.00	229.00
1 in 10	2990.00	6.29	16.50	939.00	15.80	5.73	6180.00	311.00	6700.00	142.00
1 in 15	2691.67	4.00	11.19	762.34	10.55	4.30	5729.58	240.22	6202.78	109.24
1 in 50	1980.00	0.00	0.02	329.00	0.00	1.55	4610.00	87.30	4990.00	35.80

Table 6.3d: Results of Drought Frequency Analysis for Scenario 4

	SCENARIO 4									
	Average Monthly Flows l/s									
Month	**Upper Nicola**	**Stump**	**Moore**	**Quilchena**	**Clapperton**	**Middle Nicola**	**Coldwater**	**Guichon**	**Spius**	**Lower Nicola**
January	2623.67	109.05	72.89	1268.32	79.40	44.57	5571.36	919.13	6440.31	528.06
February	3726.05	140.37	73.89	2412.26	75.29	86.95	7951.26	902.65	10216.65	625.93
March	5448.71	212.21	94.83	3509.17	93.54	159.57	10239.65	1074.27	13414.06	702.89
April	11588.50	228.30	143.45	6398.63	172.47	148.73	19852.29	1827.37	25062.45	702.94
May	11384.93	224.81	230.64	4742.62	299.95	139.06	22531.19	2898.44	24608.67	891.52
June	5550.95	130.33	191.35	2545.97	238.48	96.31	15575.57	2146.65	14388.77	816.12
July	3310.53	81.99	160.64	1906.46	197.19	64.78	5737.49	1429.16	4372.23	720.47
August	2451.05	54.17	128.33	1413.87	153.35	43.99	3282.36	1080.58	2512.44	614.34
September	2239.88	38.27	105.49	1001.30	125.61	30.15	2172.66	1006.98	1810.12	537.21
October	2126.74	36.87	86.29	695.35	102.15	20.82	4016.89	936.69	3723.25	470.47
November	2456.47	51.91	70.68	724.31	83.03	14.95	7559.20	891.74	7963.39	413.32
December	2042.02	56.31	58.44	549.37	68.03	11.81	4103.26	805.68	4217.11	366.78
Average	4579.13	113.72	118.08	2263.97	140.71	71.81	9049.43	1326.61	9894.12	615.84

	SCENARIO 4									
	DROUGHT FREQUENCY - Minimum Annual Weekly l/s									
	Upper Nicola	**Stump**	**Moore**	**Quilchena**	**Clapperton**	**Middle Nicola**	**Coldwater**	**Guichon**	**Spius**	**Lower Nicola**
Mean	1760.00	5.47	62.30	556.00	69.30	13.40	1610.00	773.00	1090.00	368.00
1 in 5	1330.00	0.43	24.40	332.00	24.80	5.98	1320.00	377.00	912.00	176.00
1 in 10	1130.00	0.11	11.00	237.00	10.10	3.65	1190.00	216.00	838.00	104.00
1 in 15	1034.07	0.07	5.95	196.64	4.73	2.83	1131.50	148.73	806.41	76.16
1 in 50	796.00	0.01	0.00	98.60	0.00	1.06	995.00	0.00	730.00	12.10

	SCENARIO 4									
	DROUGHT FREQUENCY - Minimum Annual Monthly l/s									
	Upper Nicola	**Stump**	**Moore**	**Quilchena**	**Clapperton**	**Middle Nicola**	**Coldwater**	**Guichon**	**Spius**	**Lower Nicola**
Mean	1850.00	7.08	61.00	630.00	75.60	15.40	1750.00	809.00	1200.00	386.00
1 in 5	1420.00	0.59	23.10	378.00	27.20	6.65	1410.00	402.00	993.00	185.00
1 in 10	1210.00	0.16	10.60	272.00	11.10	3.89	1280.00	237.00	912.00	111.00
1 in 15	1116.41	0.10	6.13	227.54	5.28	2.91	1227.35	167.97	880.41	81.58
1 in 50	878.00	0.02	0.00	120.00	0.00	0.82	1090.00	5.54	806.00	14.70

	SCENARIO 4									
	DROUGHT FREQUENCY - Annual l/s									
	Upper Nicola	**Stump**	**Moore**	**Quilchena**	**Clapperton**	**Middle Nicola**	**Coldwater**	**Guichon**	**Spius**	**Lower Nicola**
Mean	4260.00	53.90	93.70	2130.00	107.00	40.30	8700.00	1130.00	9440.00	504.00
1 in 5	2890.00	15.10	39.40	1250.00	42.10	13.20	6550.00	573.00	7030.00	245.00
1 in 10	2320.00	6.71	20.00	852.00	20.00	6.80	5600.00	361.00	5980.00	150.00
1 in 15	2074.32	4.35	12.64	677.10	11.77	4.88	5184.68	276.77	5529.58	113.26
1 in 50	1490.00	0.00	0.00	245.00	0.00	1.17	4160.00	81.50	4430.00	29.60

Table 6.3e: Results of Drought Frequency Analysis for Scenario 5

	SCENARIO 5									
	Average Monthly Flows l/s									
Month	**Upper Nicola**	**Stump**	**Moore**	**Quilchena**	**Clapperton**	**Middle Nicola**	**Coldwater**	**Guichon**	**Spius**	**Lower Nicola**
January	2347.99	91.50	60.76	984.53	65.60	35.19	4829.42	789.64	5521.41	461.35
February	3391.47	103.38	64.14	2137.18	67.02	68.45	7770.27	801.62	10006.93	550.81
March	4804.21	162.97	74.46	3155.86	70.38	135.61	9638.93	917.08	12701.32	621.09
April	11418.74	215.48	127.37	6632.17	151.12	146.53	20559.64	1632.79	26181.15	647.88
May	12629.19	233.67	235.61	5371.10	311.57	140.99	23970.51	3092.49	26698.29	894.08
June	6223.14	133.00	184.11	2763.96	231.93	97.30	16834.00	2278.15	15976.08	812.22
July	3398.61	83.66	162.14	1989.90	199.90	65.43	6320.71	1481.85	4682.48	717.29
August	2465.88	55.61	126.17	1483.82	149.32	44.48	3475.02	1036.59	2644.62	600.40
September	2228.59	39.49	103.72	1043.27	122.31	30.47	2299.16	955.11	1797.83	524.60
October	2091.04	37.18	84.80	725.95	99.38	21.04	3803.24	886.01	3430.08	459.02
November	2256.58	50.60	69.10	639.47	80.29	14.78	6518.38	835.00	6778.97	402.25
December	1952.74	52.06	56.33	467.55	64.77	10.65	3819.68	751.64	3931.63	353.77
Average	4600.68	104.89	112.39	2282.90	134.46	67.58	9153.25	1288.16	10029.23	587.06

	SCENARIO 5									
	DROUGHT FREQUENCY - Minimum Annual Weekly l/s									
	Upper Nicola	**Stump**	**Moore**	**Quilchena**	**Clapperton**	**Middle Nicola**	**Coldwater**	**Guichon**	**Spius**	**Lower Nicola**
Mean	1760.00	5.93	57.50	582.00	61.20	13.30	1640.00	711.00	1100.00	354.00
1 in 5	1340.00	0.50	21.60	357.00	20.50	5.98	1350.00	332.00	923.00	167.00
1 in 10	1140.00	0.14	9.94	262.00	8.56	3.72	1210.00	184.00	849.00	98.30
1 in 15	1049.92	0.08	5.72	221.05	4.49	2.93	1157.35	123.63	818.00	71.74
1 in 50	821.00	0.01	0.00	124.00	0.00	1.26	1020.00	0.00	744.00	11.30

	SCENARIO 5									
	DROUGHT FREQUENCY - Minimum Annual Monthly l/s									
	Upper Nicola	**Stump**	**Moore**	**Quilchena**	**Clapperton**	**Middle Nicola**	**Coldwater**	**Guichon**	**Spius**	**Lower Nicola**
Mean	1850.00	7.13	62.20	659.00	66.90	15.30	1780.00	745.00	1220.00	373.00
1 in 5	1430.00	0.56	23.50	407.00	22.60	6.66	1430.00	355.00	1000.00	175.00
1 in 10	1220.00	0.15	10.80	302.00	9.52	3.97	1300.00	201.00	920.00	102.00
1 in 15	1132.26	0.09	6.22	258.13	5.06	3.03	1247.35	138.64	888.41	74.04
1 in 50	903.00	0.01	0.00	154.00	0.00	1.03	1130.00	0.00	815.00	10.20

	SCENARIO 5									
	DROUGHT FREQUENCY - Annual l/s									
	Upper Nicola	**Stump**	**Moore**	**Quilchena**	**Clapperton**	**Middle Nicola**	**Coldwater**	**Guichon**	**Spius**	**Lower Nicola**
Mean	4280.00	58.20	87.00	2140.00	97.60	37.50	8800.00	1070.00	9590.00	482.00
1 in 5	2910.00	17.90	35.80	1260.00	36.80	12.50	6640.00	524.00	7150.00	233.00
1 in 10	2330.00	8.26	18.10	868.00	17.30	6.69	5670.00	320.00	6080.00	141.00
1 in 15	2090.17	5.38	11.47	693.68	10.35	4.99	5248.83	240.45	5612.03	105.55
1 in 50	1510.00	0.00	0.00	263.00	0.00	1.75	4210.00	57.50	4480.00	24.50

less interest. The Three Parameter Lognormal distribution was found to provide the best fit to the data.

Drought frequency is determined by statistical analysis of the data. For example, to estimate the drought frequency of annual low monthly flows, the steps are as follows:

- For each of the 39 years of data generated by the model, select the lowest annual monthly flow. This provides a set of 39 low flows.
- Rank the low flows from lowest to highest. The lowest flow has a return period frequency of approximately once in 39 years. The second lowest flow has a return period of being equal or lower of twice in 39 years (about 1 in 19.5 years).
- The FFAME computer program interpolates the data set and provides estimates of drought for any return period.
- The FFAME computer program also extrapolates the data to longer return periods including the 1 in 50 year drought.

Table 6.3a shows the estimated natural flows for the current conditions. As expected the largest flows originate from the Coldwater, Spius and Upper Nicola sub basins with lower flows originating from the Guichon and Quilchena sub basins. The remaining sub basins have very low natural flows.

The drought frequency analysis shows that the Coldwater, Spius and Upper Nicola sub basins do not respond as significantly to extreme drought conditions as the other Nicola sub basins. This is because of the larger precipitation and snowpacks making these two basins resilient to drought conditions. In the Coldwater sub basin the 1 in 50-year drought for the minimum annual weekly flow is 87% of the 15-year drought. Similarly in the Spius sub basin the 1 in 50-year drought weekly flow is 90% of the 1 in 15-year drought.

In the Stump, Moore and Clapperton sub basins the 1 in 50-year drought weekly flow is zero or close to zero even though under average conditions, the minimum annual weekly flows in Moore and Clapperton are close to 40 L/s. Even in an average year there is very little flow from the Stump sub basin. Guichon Creek, Middle Nicola and Lower Nicola sub basins also have very low 1 in 50-year minimum annual weekly flows.

This assessment leads to a potential classification of the Nicola sub basins in terms of drought susceptibility as shown in Table 6.4

Table 6.4: Drought Susceptibility Ratings for Nicola Sub Basins

Sub basin	**Drought susceptibility rating**
Coldwater	Resilient to extreme drought[1]
Spius	Resilient to extreme drought
Upper Nicola	Resilient to extreme drought
Middle Nicola	Very susceptible to extreme drought[2]
Lower Nicola	Very susceptible to extreme drought
Quilchena	Very susceptible to extreme drought
Guichon	Very susceptible to extreme drought
Stump	Very susceptible to all droughts[3]
Moore	Very susceptible to all droughts
Clapperton	Very susceptible to all droughts

Notes:
1. Annual low flows in extreme drought years are high compared to other sub basins.
2. In a 1 in 50 year drought year, annual low flows are less than 25% of average annual low flows.
3. Annual low flows in all drought years are significantly less than in average years.

The Upper Nicola, Middle Nicola, Quilchena and Guichon sub basins are very susceptible to extreme droughts and very low flows would occur in these basins with a 50-year drought. The most drought susceptible basins are Stump, Moore and Clapperton with low flows even in a moderate drought and flows of zero or close to zero in a 50-year drought.

These drought susceptibility ratings are applicable to stream flows at the sub basin scale. For areas such as the Coldwater and Spius sub basins, the lower parts of the sub basins are more drought susceptible than the upper parts because the streams are flowing from high runoff areas towards lower runoff areas.

For Scenario 2 and Scenario 3, flows generally increase because of the cleared areas as a result of the MPB and some increase in precipitation. The drought susceptibility by sub basin is similar to Scenario 1. The estimated sub basin flows for Scenario 2 with the 2020 A2 condition, are similar to the flows for Scenario 3 with the 2020 B2 condition. Even though the average temperatures are higher in the A2 condition, the higher winter precipitation in the B2 condition compensates. In the Nicola watershed higher precipitation in the winter is more effective for water supply than higher precipitation in the summer because of the lower winter evapotranspiration rates.

For Scenario 4, and Scenario 5, with 2050 climate and regrowth of all MPB areas, the estimated flows are less than 2020 conditions. The regrowth results in lower sub basin yields than in 2020 primarily because of interception and higher losses. The 2050 flows are generally similar to current conditions with some higher flows due to greater winter precipitation.

Maps of estimated mean annual sub basin flows for all 5 scenarios are provided in Figure 6.2 to 6.6. Maps of minimum annual weekly flows for the 1 in 15 year drought condition are shown in Figures 6.7 to 6.11.

The average annual natural flow out of the basin at Spences Bridge was calculated to be approximately 28,000 L/s (3.9 L/s/km^2). About 18,900 L/s of this flow originates in the Coldwater and Spius sub basins. These two sub basins represent 68% of the flow at Spences Bridge but only 23% of the total Nicola Watershed area. The Upper Nicola and Quilchena sub basins together contribute 6,800 L/s which is 24% of the flow at Spences Bridge. The remaining 2,300 L/s (8% of the flow at Spences Bridge) is contributed by the other sub basins.

6.4 Accuracy

The water supply forecasts are based on calibration of the model with natural flows in six catchments within the Nicola Watershed. The most accurate forecasts in Section 6.3 will be for annual average natural flows for current conditions in sub basins with similar characteristics to the catchments used for calibration. Thus the annual average flow forecasts for Upper Nicola, Coldwater, Spius and Guichon sub basins are expected to be accurate. Less accuracy is expected for the sub basins without natural flow records such as Clapperton, Middle Nicola, Lower Nicola, Stump and Moore sub basins.

The estimates of minimum annual monthly and minimum annual weekly flows are less accurate than the estimates of average annual flows as they are dependent on more accurate modelling of groundwater discharges. However, the accuracy is expected to be higher in Upper Nicola, Coldwater, Spius and Guichon sub basins for the same reasons outlined above and less accurate in the other sub basins.

There are considerable uncertainties in the generation of the future scenario forecasts because the model inputs are very approximate. The generation of climate in 2020 and 2050 from the Canadian Global Coupled Model is very uncertain for the following reasons:

- Assumptions have to be made of the magnitude of future greenhouse gas releases to the atmosphere which are dependent on predictions of political, social and economic factors throughout the world.

- Global atmospheric models do not simulate all the factors affecting the Earth's climate and produce generalized results with coarse geographic resolution.

- Downscaling of the results at a coarse geographic resolution to a specific location where localized affects are important introduces more uncertainty.

- Climatic variations on a day-to-day basis will not necessarily follow the patterns of past climate.

The future MPB conditions are also very uncertain because so many assumptions have to be made to develop the projections.

The following table characterizes our opinion of the accuracy of the different flow estimates

Table 6.5: Model accuracy estimates expressed as plus/minus percentage

Sub basin	Average flow	Low flows	Future conditions
Coldwater	10	20	30
Spius	10	20	30
Middle Nicola	20	30	40
Lower Nicola	20	30	40
Quilchena	20	30	40
Guichon	10	20	30
Upper Nicola	10	20	30
Stump	20	30	40
Moore	20	30	40
Clapperton	20	30	40

7 NEXT STEPS

A conceptual understanding of groundwater/surface water interaction in the Nicola Watershed has been presented in Section 4. The key factors are:

- Groundwater/surface water interaction is a characteristic of all natural stream flows. Groundwater discharge provides stream flow during dry periods.
- Any groundwater extractions in the Nicola Watershed will reduce downstream flows.
- Groundwater extraction from surficial aquifers will have a local effect on stream flows.
- Groundwater extraction from confined aquifers will have a more widespread effect on stream flows.

The Terms of Reference for this study includes a requirement for recommendations for a Phase 3 which would include data collection and detailed modelling of groundwater/surface water interactions at selected locations. However we do not recommend that Phase 3 be conducted as originally envisaged for the following reasons:

1. The modelling carried out for this study included groundwater/surface water interactions to a level consistent with the available data for each basin. The water supply estimates in this report for each sub basin include both groundwater and surface water contributions.

2. Development of a more detailed surface/groundwater model such as MIKE SHE would require considerable data collection and effort and would not, in our view significantly improve the estimates of available water supply in each sub basin. The most important data are the long-term streamflow records on unregulated basins and these data were rigorously used as part of the modelling already carried out.

3. Given the uncertainties in the climate spatial distribution and other factors, collecting groundwater data will not significantly improve the sub basin water supply estimates.

4. Investigating groundwater/surface water interactions at specific sites would be of great interest but would not significantly add to the overall understanding of basin–wide water supply. These types of investigations would be best carried out by

proponents of new groundwater development as part of a permit application process. We believe that such detailed studies are not the best use of public funds.

The next step in the Nicola Water Use Management Plan should compare the water supply estimates in each sub basin with the water use and demand estimates developed by Summit (2007). The water use should include in-stream flows required by fisheries. This water budget analysis would provide an indication of which sub basins have a deficit and the degree of the water deficit in each sub basin.

Following the water budget study the water supply model should be modified to incorporate the demand and water use estimates and the model verified using regulated flow records on the Nicola River. This would provide a comprehensive model of the Nicola Watershed that can be used for water management planning.

The comprehensive model can then be used to examine different water management scenarios. Scenarios would include different combinations of measures which could include:

- Demand management
- Additional surface water storage reservoirs
- Groundwater recharge and storage systems
- Mitigation of groundwater pumping by discharge in the dry season
- Land use planning

8 CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

1. Most of the major production of groundwater in the Nicola Watershed is from sand and gravel aquifers located along major valleys. These sands and gravels were deposited as alluvium or as glacially related water washed deposits. These units will always be the source of groundwater supply in the Nicola Basin.

2. Fractured bedrock can provide a resource for groundwater extraction. Typically, yields from bedrock are suitable for single family dwellings rather than communities, agricultural or industrial needs. However, there will be some locations in the basin where fractured rock will provide a reasonable yield.

3. Groundwater storage is an important element of the groundwater system. Groundwater is stored within the developable aquifers and also within all of the geologic materials within the basin. Storage provides discharge to stream flows during the dry season as well as a resource for irrigation, industry and potable water year round.

4. Three major valley aquifers were identified within the Nicola Watershed:

    - Guichon Valley Aquifer
    - Coldwater Valley Aquifer
    - Nicola Valley Aquifer

5. Recent subdivision applications to the Thompson-Nicola Regional District have been required to install community water supply systems rather than developing individual wells for each lot. A community water supply system requires approval from the Province in the form of a Certificate of Public Convenience and Necessity (CPCN). An assessment of the impact of pumping of the water well on surface water and springs in areas where water licences are known to exist must be included in the groundwater report.

6. A conceptual understanding of groundwater/surface water interaction in the Nicola Watershed has been developed. The key factors are:

    - Groundwater/surface water interactions are a characteristic of natural stream flow.

    - Any groundwater extractions in the Nicola Watershed will reduce downstream flows.

    - Groundwater extraction from surficial aquifers will have a local effect on stream flows.

    - Groundwater extraction from confined aquifers will have a more widespread effect on stream flows.

7. Six catchments in the Nicola basin were calibrated using the WMC Watershed Model using measured natural stream flow for the calibration process. The six calibrated sub-catchments represent relatively diverse geographical and geological locations.

8. Estimates of factors related to groundwater recharge and discharge were derived from comparisons to the calibrated catchments and information regarding surficial geology.

9. Natural flows, including both groundwater and surface water for current watershed conditions were estimated using the output from the WMC Watershed Model. As expected, the largest flows originate from the Coldwater, Spius and Upper Nicola sub basins with lower flows originating from the Guichon and Quilchena sub basins. The remaining sub basins have very low natural flows.

10. The drought frequency analysis showed that the Coldwater, Spius and Upper Nicola sub basins do not respond as significantly to extreme drought conditions as the other Nicola sub basins. This is because of the larger precipitation and snowpacks making these basins resilient to drought conditions.

11. The other sub basins are very susceptible to extreme droughts and very low flows would occur in these basins with a 50-year drought. The most drought susceptible basins are Stump, Moore and Clapperton with low flows even in a moderate drought and flows of zero or close to zero in a 50-year drought.

12. The average annual natural flow out of the basin at Spences Bridge was calculated to be approximately 28,000 L/s (3.9 L/s/km2). About 18,900 L/s of this flow originates in the Coldwater and Spius sub basins. These two sub basins represent 68% of the flow at Spences Bridge but only 23% of the total Nicola Watershed area. The Upper Nicola and Quilchena sub basins together contribute 6,800 L/s which is 24% of the flow at Spences Bridge. The remaining 2,300 L/s (8% of the flow at Spences Bridge) is contributed by the other sub basins.

13. For the year 2020 scenarios, flows generally increase because of the cleared areas as a result of the mountain pine beetle impacts and some increase in precipitation. The drought susceptibility by sub basin is similar to current conditions.

14. For Scenario 4, and Scenario 5, with 2050 climate and regrowth of all MPB areas, the estimated flows are less than 2020 conditions. The regrowth results in lower sub basin yields than in 2020 primarily because of interception and higher losses. The 2050 flows are generally similar to current conditions with some higher flows due to greater winter precipitation.

8.2 Recommendations

We do not recommend that Phase 3 of this project be carried out as originally envisaged primarily because sufficient information is now available from this study and the water demand study for planning purposes. The recommended next steps for the Nicola Water Use Management Plan are as follows.

1. The water supply estimates in each sub basin should be compared with the water use and demand estimates developed by Summit (2007). The water use should include in-stream flows required by fisheries. This water budget analysis would provide an indication of which sub basins have a deficit and the degree of the water deficit in each sub basin.

2. Following the water budget study, the water supply model should be modified to incorporate the demand and water use estimates and the model verified using regulated flow records on the Nicola River. This would provide a comprehensive model of the Nicola Watershed that can be used for water management planning.

3. The comprehensive model should be used to examine different water management scenarios. Scenarios would include different combinations of measures which could include:

    - Demand management
    - Additional surface water storage reservoirs
    - Groundwater recharge and storage systems
    - Mitigation of groundwater pumping by discharge in the dry season
    - Land use planning

REFERENCES

BC Groundwater (2006) Surface Water/Groundwater Interaction Study, Stage I. A Report prepared for the City of Merritt.

Berardinucci J. and K Ronneseth (2002). Guide to Using the BC Aquifer Classification Map for the Protection and Management of Groundwater. Ministry of Water Land and Air Protection.

Blum Varda S., Deborah L. Hathaway and Kaylea M. White (2002). Modeling Flow at the Stream-Aquifer Interface. A Review of this Feature in Tools of the Trade. American Water Resource Association Conference on Surface Water-Groundwater Interactions.

Fulton Robert J. (1975) Quaternary Geology and Geomorphology, Nicola-Vernon Area, British Columbia. Geological Survey of Canada Memoir 380.

Hamann, A. and Wang, T. 2005. Models of climatic normals for genecology and climate change studies in British Columbia. Agricultural and Forest Meteorology 128: 211-221.

Huggad, D. and Lewis, D. 2007. Summary of: ECA Effects of Options for Mountain Pine Beetle Salvage – Stand and Watershed Level Reports.

Heilie, J.F., Peters, D.L., Tattrie, K.R., Gibson, J.J. 2005. Review and Synthesis of Potential Hydrologic Impacts of Mountain Pine Beetle and Related Harvesting Activities in British Columbia. Natural Resources Canada, Canadian Forest Service.

Kala Groundwater Consulting (2003). Report of findings: District of Logan Lake Groundwater Supply Investigation Wellheads Management Program Logan Lake, British Columbia.

Kala Groundwater Consulting (2004). The Corporation of the City of Merritt Groundwater Supply Investigation Testwell Siting. Prepared for the City of Merritt.

Kala Groundwater Consulting (2004). Groundwater Potential Evaluation and Test Well Siting Study City of Merritt, British Columbia. Prepared for the City of Merritt.

Quick, M. 1995 The UBC Watershed Model. Chapter in Computer Models of Watershed Hydrology. Water Resources Publications.

Ritter, Michael E. (2006) The Physical Environment: an Introduction to Physical Geography. http://www.uwsp.edu/geo/faculty/ritter/geog101/textbook/title_page.html

Summit Environmental Consultants Ltd. (2007). Nicola River Watershed Present and Future Water Demand Study. Prepared for Nicola Watershed Community Round Table

Thornthwaite C.W., (1948). An approach to a Rational Classification of Climate. American Geophysiocal Review Volume 38.

Urban Systems Ltd., (2005). Nicola River Basin Management Strategy Phase 1: Scoping Study Towards Sustainable Water Stewardship in the Nicola Valley. Prepared for the Nicola Stock Breeders Association.

Wang, T., Hamann, A., Spittlehouse, D., and Aitken, S. N. 2006. Development of scale-free climate data for western Canada for use in resource management. International Journal of Climatology, 26(3):383-397.

von Stackelberg, N.O., Chescheir, G.M., Skaggs, R.W., Amatya, D.M. 2007. Simulation of the Hydrologic Effects of Afforestation in the Tacuatemboi River Basin, Uruguay. American Society of Agricultural and Biological Engineers, 50(2): 455-468

Farley, K.A., Jobbagy, E.G., Jackson, R.B. 2005. Effects if afforestation on water yield: a global synthesis with implications for policy. Global Change Biology, 11: 1565-1576

Figures