GROUNDWATER QUANTITY REPORT
FOR WRIA 1
PHASE II

November 30, 2001

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Glossary

http://www.deq.state.mi.us/erd/gwater/glossary.html#Transient%20Flow

http://www.epa.gov/seahome/groundwater/src/terms1.htm

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1.1 INTRODUCTION

Pursuant to the Phase II Technical Scope of Work adapted for the WRIA 1– Watershed Management Project, the Groundwater Quantity Study Group focused initially on describing the horizontal and vertical extent of aquifers in the study area. In addition, issues looked at included aquifer hydraulic properties, spatial distribution of water levels at selected wells within the basin and their temporal variations, as well as groundwater contribution to stream flow, i.e., baseflow characteristics of river/ groundwater interactions

The main activities carried out in order to achieve the above were: review of previous hydrogeologic and geologic studies, review of available databases containing parameters related to water quantity and balance, and review of relevant existing GIS layers.

The main purpose of this process was to attempt to prepare the background data for future modeling activities via developing a spatial, geometric model of the major aquifers within the study area, and compiling a hydraulic property database for them.

A main focus was on piecing together the horizontal delineation of the major aquifers as well as assessing the vertical extent of these aquifers. Since there is not a single report that covers the entire study area and contains all of the necessary information, a number of reports were used to compile the required information.

Generally speaking, our review of the literature presently available indicates that there is much information available about the USGS LENS study area. Unfortunately, the areas lying to the south and east of the LENS area are not well characterized. Thus, a potential success in developing and applying models for these areas will depend mostly on what sort of questions need to be addresses and at what level of resolution.

1.1.1. BACKGROUND

The Nooksack River-Sumas River area is located in the northwest corner of Washington State. Surface water sources originate in the northern cascades. Most surface water flows westerly via the Nooksack River to Bellingham Bay. A lesser amount flows northerly into British Columbia (Canada) via Sumas River, eventually emptying into the Fraser River. The north flowing Sumas River has cut into the Sumas Trough. British Columbia contributes surface water to the western part of the WRIA 1 through three south flowing tributaries, which cut through the Lynden Terrace. Baseflow of the Nooksack and Sumas Rivers is maintained by sizable flows of ground water from the glacial deposits of the area.

Major production of ground water is restricted to the glacial sands and gravels of the surficial aquifers of the study area, mostly along the plains of the lowlands and the valley floors of the rivers in the highlands. Wells produce from only a few gallons per minute to several hundred gpm in the more permeable outwash gravels.

The westernmost portion of Nooksack Basin is generally flat with low ground surface elevation. Surface elevations remain mostly below 200 feet above mean sea level (ft m.s.l) for about 20 miles inland. The changes in elevation toward the east then become sharp, numerous rugged mountains with high peaks relief, with Mt Baker (10,775 ft) and Mt Shuksan (9,127 ft) standing out prominently.

The major drainage within the Watershed Management Project study area is that of the Nooksack River. It has a total drainage area of 826 square miles (mi^2). A portion of the Nooksack River drainage area, approximately 49 mi^2, lies in Canada.

Near Deming (Figure 1.1.1a) the South Fork Nooksack River branches off to drain approximately. 183 mi^2 of a non-glacial area with peaks as high as 6,900 ft m.s.l. About 4 miles north-east (upstream) from Deming the rest of the Nooksack branches into the Middle Fork (which drains 102 mi^2 of the western and southwestern slopes of Mt. Baker), and the North Fork, which drains 281 mi^2 including the northern slopes of Mt Baker and Mt Shuksan.

In the central foothills an area of approximately 65 mi^2 along the border drains into Canada via the Sumas River system.

Coastal drainage systems, which flow independently to the coast, include the Dakota Creek (29 mi^2), the California Creek (22.9 mi^2), the Terrell Creek (12.5 mi^2).

The only current glacial activity of any consequence to be found in this watershed is located on Mt Baker and Mt Shuksan (Figure 1.1.1c), both having extensive snowfields as well as glacial activity. Glacial melt during the warmer spring and summer periods affects the flow rate of the Nooksack in the central plains.

The major chapters of this report are concerned with three hydrologic parts: central lowland/Nooksack River plains, coastal lands/western areas and Eastern Highlands. Figure 1.1.1b shows the locations of these areas. In the reminder of this chapter we discuss the general hydrogeologic features on the WRIA 1.

1.1.2 General Description of the Project Area Hydrogeology

The lowlands of the study area (i.e., the westernmost portion of the watershed management project area, including the coastal areas) have sand and gravel of glacial origin as their main groundwater reservoirs and are generally characterized as sedimentary aquifer systems. The major water bearing materials found within the WRIA 1 area are the river and glacier deposited silts, sands, and gravels of Quarternary age. In most of lowland areas of the Nooksack Basin characterized by recessional outwash and alluvial deposits, there is one water table and all wells drilled in these unconsolidated materials penetrate unconfined ground water. In the lowlands the principal areas of confined ground water are limited to an area near Ferndale, and to some coastal areas near Blaine.

Unconsolidated sediments, principally of glacial origin underlie the sands and gravels of the lowlands. These are relatively impermeable deposits, which retard deep percolation of groundwater and cause much of the groundwater to be intercepted by gaining streams. Abundant rainfall (typical of the region) over the area is the primary means of groundwater recharge.

The metamorphic rocks that comprise the bedrock of the eastern highlands and the southern half of Lummi Island do not contain openings other than small joint cracks and shear zones common to hard rocks, and consequently normally carry ground water only irregularly and in small quantities. The Tertiary sedimentary formations exposed in the foothills of the highlands carry small quantities of fresh ground water in few places where pore space permits.

The eastern portion of WRIA 1 is mountainous, heavily forested, and drained by many perennial streams. In the mountainous areas, igneous and metamorphic rocks largely underlie alluvial and sedimentary deposits along the major stream valleys. The groundwater occurrence is primarily restricted to the gravel deposits in the North, Middle, and South Fork valleys of the Nooksack River. Most of this area, though, is generally characterized as not having groundwater available in large quantities.

The principal surficial aquifers, (the uppermost, saturated zone, typically under unconfined water-table condition) are grouped into three aquifer units: the Sumas-Blaine Surficial Aquifer, Discontinuous Surficial Aquifers, and the Upper Valley Surficial Aquifers (Tooley and Erickson, 1996) (Figure 1.1.2)**.** The remainder of the project study area is characterized as having non-surficial aquifer types.

The Sumas-Blaine Surficial Aquifer

The principal aquifer in the Nooksack watershed is the Sumas-Blaine Aquifer (Figure 1.1.3). It underlies the flat glacial outwash plain between the towns of Sumas, Blaine, Ferndale, and the Nooksack River and occupies about 150 square miles. It consists of mostly sand and gravel glacial outwash deposits and alluvial gravel, sand, silt and clay deposits of the Nooksack and Sumas Rivers (Tooley and Erickson, 1996). The water table is typically less than 10 ft below ground surface (Morgan, 1999). The vertical extent of the Sumas-Blaine Aquifer ranges from less than 25 feet near Blaine (western edge) to more than 75 feet thick near Sumas (eastern edge) (Figure 1.2.3). At the northeastern edge the aquifer depth can be more than 200 feet thick (Cox and Kahle, 1999).

Discontinuous Surficial Aquifers

There are also many Discontinuous Surficial Aquifers spread throughout the WRIA 1. Many of these are located to the west and southwest of the Sumas-Blaine Aquifer, but there are also several of smaller sizes around Lake Whatcom and in the upper valleys. These are found in many geologic deposits such as beach, glacio-fluvial terrace deposits, modern alluvial and floodplain deposits, isolated outwash terraces, and marine terrace deposits (Tooley and Erickson, 1996).

The largest of these aquifers are located south of Ferndale, east of Blaine, across the bay southwest of Blaine, and east of Sumas. These aquifers are usually thin and not a major source of water. The definition of their lateral boundaries is based solely on surface soil properties, due to lack of sufficient well data (Morgan, 1999) (Figure 1.1.5).

The Upper Valley Aquifers

The Upper Valley Aquifers are associated with the north, middle, and south forks of the Nooksack River. These consist of interlayered mixtures of gravel, sand, silt and clay and occupy the river valley bottoms. They are limited in extent by the surrounding bedrock (Tooley and Erickson, 1996) (Figure 1.1.4).

Non-Surficial Aquifers

Large portions of WRIA 1 (Figure 1.1.2) are characterized (Tooley and Erickson, 1996) as “surficial aquifer not present”. These areas are located mainly in the southern portion (except small areas around Lake Whatcom), the eastern uplands (except along the river valleys of the North, Middle & South Fork Nooksack), and the western coastal areas (except for the Nooksack delta area and pockets of land around Blaine). The Sumas-Blaine Surficial Aquifer System of course, dominates the central and northern areas.

The generalized surficial geology of the study area describes the western/coastal and central lowlands as alluvial, terrace, glacial and other sedimentary deposits, and the mountainous eastern lands as sedimentary or meta-sedimentary rocks. Intrusive rocks of granitic and intermediate composition (WSU 1967) underlie the area around Mt Baker.

1.1.3 BASEFLOW

A variety of annual and monthly baseflow and stream flow statistics were calculated for each station, based on the available period of record, including monthly and annual mean flows, annual mean 7-day low flow, and total stream flow. On average, ground water discharge comprised roughly 70 % of total annual stream flow for the gages analyzed (Figure 1.1.7).

Since the contribution of baseflow to stream flow, as estimated by DOE, seems to be generally high, and since the procedure for estimating base flow is based on an empirical relationship not verified for the WRIA 1, we did the base flow estimates for the principal stream-gages in the study area (results are given within the corresponding sub-watersheds).

Base-flow was separated with the USGS public domain hydrograph separation software called HYSEP. The HYSEP program uses three methods to separate the base-flow and surface-runoff components of the stream flow hydrograph-fixed interval, sliding interval, and local minimum.

These methods can be described conceptually as three different algorithms to systematically draw connecting lines between the low points of the stream flow hydrograph. The sequence of these connecting lines defines the base-flow hydrograph. The techniques were developed by Pettyjohn and Henning (1979) and the software was implemented by Sloto and Crouse (1996). To use the method one needs to determine the number of days after which surface runoff ceases, N. This value is obtained from an empirical relation:

$$N = A^{0.2}$$

Where, A is the drainage area in square miles. The interval 2N used for hydrograph separation is the odd integer between 3 and 11 nearest to 2N.

The hydrograph separation begins one interval (2N days) prior to the start of the date selected for the start of the separation and ends one interval (2N days) after the end of the selected date to improve accuracy at the beginning and end of the separation.

In this study the local minimum method was used. This method checks each day to determine if it is the lowest discharge in one half interval minus one [0.5(2N-1)] days before and after the day being considered. If it is, then it is a local minimum and is connected by straight lines to adjacent local minimums. The base-flow values for each day between local minimums are estimated by linear interpolation. For example, a watershed, which has an N value of 2.4, its 2N values will be 5 days. Therefore, it is these five days, which will be considered as one interval. To select a given day as local minimum, one needs to compare that day's flow with 2 days [0.5(2N-1)] before and 2 days [0.5(2N-1)] after flow records in order to take the day as local minima. In this project a window of 11 days is used for the hydrograph separation.

1.1.4 Well Database

The well database covering the WRIA 1 was requested from the USGS, Washington State office, and a dump of all their well data on water quality and physical properties was received. The data was received in raw (unprocessed) format and it was manipulated using Microsoft (MS) Excel.

MS Access well database files were also received from the compilation prepared by DOE for the Aquifer Vulnerability Project (Laurie Morgan, 1996). These data are structured in tables (with parameter groups in fields rather than as individual field headings as in the database from the USGS) which makes it easier to query and plot in ArcView. A comparison with the USGS database showed that the two databases basically contain the same information, except that the well pumpage data was missing in the DOE database.

A Visual Basic for Applications (VBA) program was used to extract pumping discharge from the USGS database to incorporate into the DOE (Ecology) database.

The main databases of interest are (excluding those that focus on water quality):

1 Well log data from WCHHSD with 3200 records. It contains three tables which contain well log by parcel, including static water level, date and proposed use (tblWell); stratigraphy of the well log (tblWellMaterial) and results of well test (tblWellTest) Well-Data\well_log\Well logs WCHHSD. Out of these 2826 records are geographically referenced.

2 USGS Washington, MS Access USGS National Water Information System (NWIS)- Wells-Data\data\usgs97.mdb. Physical attributes of the well database include, water level (& measurement dates), well depth, pumping discharges, interval depths, lithologic unit code, altitude, X-Y coordinates

The physical attributes of the well database include water level (and its measurement dates), well depth, pumping discharges (only 1117 wells or 49.8 % of wells have pumping discharge data, out of the USGS96 data), screen interval depths, lithologic unit code and altitude. Using their X-Y coordinates all the wells were located on the basin GIS map via ArcView.

The Washington State Department of Ecology regulates the drilling of wells in the state and maintains drilling records for all wells within the state. The well database received does not, however, contain lithologic logs associated with wells.

The total number of wells recorded in the USGS download database, which is geographically referenced is 2243 (see the database Well-Data/Ecology/ka/shape/USGS96, Figure 1.1.8). From these wells, wells with lengthy records of water level measurements (12 months and more) were selected. There are forty such wells for the entire WRIA 1. Time series plots were prepared for these after computing their water elevations (in feet above sea level) from the well attributes for depth to water and altitude.

In addition, spatial water level plots were prepared using ArcView/GIS for the years with sufficient well water level data (1990 -375 wells (Figure. 1.1.15a), 1994-74 wells, 1991-61 wells (Figure. 1.1.15b), 1995 - 59 wells, 1972 – 57 wells, 1971 – 36 wells).

1.1.5 GIS LAYERS

A regional GIS topographic map was constructed using DEM (Digital Elevation Model) data obtained from the USGS GIS dataset web site. This map was used as a background reference to display other GIS layers.

GIS data (that can be read in ArcView) were obtained from various sources, but mostly from the Washington State Department of Ecology WWW sites and studies. Most of the

GIS layers were prepared using the USGS well information as part of the Aquifer Vulnerability Project (Morgan, 1996). See Appendix B for detail description.

Plots have been done for the following GIS data:

a) Soils lithologic codes / hydrologic groups (polygons from the Nooksack Surficial Aquifer GIS layer) (Washington State Department of Natural Resources, Figures 1.1.10, 1.1.11, and 1.1.12)
b) Critical Aquifer Recharge Areas as designated by Whatcom County. ArcInfo poly file with recharge potential calculated from local soil percolation rates, surficial geology, and well-log data (Figure 1.1.9). This figure also includes the wellhead protection area of Lummi Nation, which was delineated using a flow boundary criteria approach (LIBC, 1997). Further more, it is assumed that the flow boundaries approach essentially identifies critical aquifer recharge areas (Jeremy Freimund, 2001, written communication)
c) Potential Ground Water Contamination Sources, pulled from Facility/Site database, developed based on personal professional experience and judgment. (Facilities and Sites regulated by the DOE is a separate GIS work)(Fig 1.1.13).
d) Wellhead protection zones for Washington State (containing subclasses, one each for 6-month, 1-year, 5-year and 10-year time-of-travel zones-radii and developed "to prevent adverse impacts to groundwater) for both circular and noncircular (Fig 1.1.14). Most of the wellhead protection areas were calculated by analytical or numerical methods.

1.2 CENTRAL LOWLANDS / NOOKSACK BASIN PLAINS

This portion of the study area (Figure 1.2.1a and 1.2.1b) consists primarily of the lower drainage basin of the Nooksack River, and is composed mainly of floodplains and low hills. Surficial aquifers are a major source of water in this region and are recharged by infiltrated precipitation and irrigation (return flow). They readily interact with surface water and serve as important source of summer stream flows for the Nooksack (and its tributaries) (Figure 1.2.2).

In their report, Newcomb et al. (1949), divide western Whatcom County into two physiographic regions, the lowlands and the uplands (Figure 1.2.1e). The lowlands of western Whatcom County consist largely of the Nooksack River flood plain, the Custer Trough leading northwest to Drayton Harbor and Birch Bay, the Sumas River Trough leading northward to Canada and the Fraser River drainage, and the Lynden Terrace.

The uplands are composed of four low plateau areas (Figure 1.2.1e): (1) a small peninsular area southwest of Blaine called the Birch point upland, (2) the boundary upland which extends ten miles eastward from Blaine and across the Canadian border, (3) the Mountain View upland west of Ferndale, and (4) the King Mountain upland which extends northward from Bellingham to the Nooksack River Valley.

1.2.1 AQUIFERS AND GEOLOGY

A thick sequence of sandstones, shales, conglomerates of continental type and fresh-water deposits form the bedrock beneath the unconsolidated Pleistocene deposit throughout the lowlands of the Nooksack Basin. The streams flowing from melting ice front deposited recessional outwash consisting of sand, gravel and other finer material on the broad Nooksack River flood plain area (USGS, 1960).

Unconsolidated deposits of Pleistocene and recent age such as bedded sands, clays, gravel, and glacial till underlie most of the central (and coastal) lowland areas. These deposits were laid in the folded sandstones, shales, and Tertiary sedimentary rocks (Newcomb, 1949).

The geology of the area is further described according to the rock units in the area as Pre-Tertiary, Tertiary, and Quaternary. The Quaternary rock unit is subdivided into Pre-Vashon Pleistocene deposits, Vashon glaciation deposits, and recent alluvium.

The USGS LENS (Lynden-Everson-Nooksack-Sumas) study (Cox and Kahle, 1999) covers most of the Sumas Blaine aquifer (Figure 1.2.2), and includes the Nooksack basin lower plains (excluding the delta area at the mouth of the Nooksack) from just after the confluence of the upper valley forks of the Nooksack River to the upstream edge of the delta region.

Four principal hydrogeologic units are delineated in the LENS area (Figures 1.2.5a and 1.2.5b). These are, in order of increasing geologic age, the Sumas Aquifer, the Everson-Vashon semiconfining unit, the Vashon semiconfining unit, and the bedrock semiconfining unit (Cox and Kahle, 1999).

The Sumas unit is generally 40 to 80 feet thick but can be more than 200 feet thick in the northeastern part of the LENS study area (Cox and Kahle, 1999). The unit is the thinnest along the Nooksack River channel south of Lynden where it is about 15 feet thick. (Figures 1.2.3, 1.2.4, 1.2.6a and1.2.6b). The location of LENS area compared to WRIA 1 project area is shown in Figure 1.2.1d.

The Everson-Vashon unit is mostly composed of fine-grained material with scattered lenses of coarse-grained material (Cox and Kahle, 1999). The productive zone of this unit in the south-central part of the LENS study area (Figure 1.2.5a) is believed to be about a 30-foot interlayer of Deming Sand (Cox and Kahle, 1999). The thickness of the Everson-Vashon semiconfining unit is largely unknown because few wells penetrate it fully, but according to available drilling records, typical thickness is 100 to 200 feet (Cox and Kahle, 1999)

Thickness of the Vashon unit is unknown but probably does not exceed 200 feet (Cox and Kahle, 1999). The bedrock semiconfining unit consists of sandstone, mudstone, conglomerate and coal. Where the bedrock is exposed at or near land surface, the ground water is likely to occur under unconfined conditions; and where the bedrock is covered by a significant thickness of glaciomarine drift or till, the groundwater is likely to be confined (Attachment A). Figure 1.2.5b summarizes the lithologic, hydrologic, and water quality characteristics of the four geologic units.

The USGS report on the LENS study area contains detailed information characterizing the vertical extent of geologic formations. This information was used to prepare GIS layers to define the aquifer bottom elevation. Point values of the bottom of the aquifer were read off the map produced by Cox and Kahle (1999). These included 10 cross sectional maps shown on PLATE-2 (Attachment A) of Cox and Kahle (1999). A total of 198 depth points were read off the cross sectional map. Out of these 16 lie inside Canada. Those which are within the USGS well data were directly referenced using the USGS well file while the other points which lie inside Canada were digitized and transformed to the project coordinate system. The bottom aquifer level points were then interpolated using Arc/Info's TOPOGRIDTOOL to get a 50m by 50m resolution bottom layer grid. TOPOGRIDTOOL generally creates a hydrologically correct grid of elevation from point, line and polygon coverages. Controlling parameters in the algorithm include data types (which shows the primary type of the data input), drainage enforcement, and tolerance parameters which is used to adjust the calculation of the drainage enforcement process and control the degree of smoothing of output grid. Details of the algorithm can be found in Hutchinson (1989). Figure 1.2.7a shows the interpolated bottom aquifer for the whole LENS study area. The bottom layer obtained above does not cover completely the middle Nooksack watershed, and it leaves out some areas at the upper part as shown in Figure 1.2.7b.

One way of comparing the result of the interpolation is to look as the root mean square error between measured and calculated bottom level values and to estimate the slope of the plot. Figure 1.2.7c shows the comparison between measured and calculated bottom elevations. The regression line fitted to this plot has a slope of 1.0068 and R^2 of 0.9995.

Sumas River Valley – North Eastern plains

Groundwater in the Sumas River Valley is part of an integrated resource. Groundwater flow direction turns to the northeast in the Sumas Valley confined aquifer where it parallels the Sumas River (Associated Earth Science, 1995). The Sumas River drainage basin and the Sumas-Abbotsford Aquifer forms the northern / northeastern part of the study area (Figures 1.2.8 and 1.2.9).

1.2.2 HYDRAULIC PARAMETERS

The USGS LENS study area has most information available on aquifer hydraulic parameters. Cox and Kahle used specific capacity data to estimate horizontal hydraulic conductivities for each hydrogeologic unit. A summary of their results is presented in Table 1.2.1.

Table 1.2.1 Summary of horizontal hydraulic conductivity values calculated from specific-capacity data, by hydrogeologic unit

	HYDRAULIC CONDUCTIVITY (feet/day)					
Hydro-geologic unit	Number of wells	Minimum	25th percentile	Median	75th percentile	Maximum
Sumas Aquifer	170	6.8	74	270	610	7,800
Everson-Vashon Semiconfining Unit	32	3	19	81	160	570
Vashon Semiconfining Unit	4	2.4	7.2	52	950	1,800
Bedrock Semiconfining Unit	12	0.01	0.02	0.55	4.6	77

In some instances, closely spaced wells displayed vastly different calculated hydraulic conductivity values, but there was a trend of higher hydraulic conductivity values towards the northern parts and lower values toward the southwestern part of the LENS study area (Cox and Kahle, 1999). The median value of 81 feet per day for the Everson-Vashon semiconfining unit may be due to a bias in sampling resulting from wells that are screened in lenses of coarser material. Slug tests in the Everson-Vashon glaciomarine drift resulted in estimates of hydraulic conductivity of 0.0014 and 0.027 feet per day (Cox and Kahle, 1999). For estimates of porosity, Cox and Kahle cite Freeze and Cherry reporting that porosity values for sandy material range from 0.25 to 0.5 and 0.35 to 0.5 for silty material.

Water table contours of central Nooksack aquifers, generalized groundwater movement of the Nooksack basin and depth to water contours of central Nooksack aquifers are shown in Figures 1.2.2, 1.2.10, and 1.2.11 respectively.

Specific capacity data was used on 164 wells to calculate transmissivity within the Sumas-Blaine Aquifer. The geometric mean of the transmissivity data was 12,593 gpd/ft (1679.7 sq ft/day) and the range of one standard deviation above and below the geometric mean was 52,528 and 3,019gpd/ft, (6986 & 401 sq ft/day), respectively (Culhane, 1993) (Figure 1.2 .12). Transmissivity and storage coefficient values for wells within the LENS area are shown in Figures 1.2.13a and 1.2.13b (data from Cox and Kahle, 1999).
Hydraulic conductivity values for the Sumas area ranged from less than 10 ft/day to over 3,000 ft/day, based on specific capacity information from the drillers' log. Hydraulic conductivity estimates of 250 to 600 ft/day were obtained for a transition zone (Figures 1.2.14 and 1.2.15) based on pump test data (Associate Earth Sciences, Inc, 1996).

Several of other reviewed reports also covered areas within the LENS study area. Data from 14 wells within the Johnson Creek (Figures 1.2.16 and 1.2.17) (tributary of the Sumas) area were used to estimate hydraulic conductivity. Values generated ranged from 1.07 to 298 feet per day, with the geometric mean of 48.5 feet per day (Gibbons and

Culhane, 1994). Six of the fourteen wells were located in moraine and ice-contact deposits, while eight were completed within outwash sand and gravel. The geometric means of the hydraulic conductivities for the moraine and ice-contact deposits and outwash sand and gravel were about 13.6 and 126 feet per day, respectively (Gibbons and Culhane, 1994).

A separate study using 43 wells for a proposed gravel surface mine covering generally the same area (Johnson Creek Basin**)** (Figure 1.2.18) indicated that transmissivities ranged from 0.00015 to 0.716 m^2/s (138.2 to 665280 sq ft/day) (Golder Associates, 1992). Most values, however, fell in the range of 10^{-3} to 10^{-1} m^2/s, or 864 to 92952 sq ft/day (Golder Associates, 1992).

On average, the Sumas outwash deposits are characterized to have hydraulic conductivity ranging from 7 to 7,800 feet per day (Tooley and Erickson, 1996). Hydraulic conductivity values for LENS area wells are shown in Figure 1.2.13c (data from Cox and Kahle, 1999).

South of the Sumas City study area is the Strandell wellfield (Figures 1.2.19). This wellfield is used to satisfy the water needs of the City of Everson (Associated Earth Sciences, 1994). Pump tests of wells and the Strandell wellfield were performed to estimate transmissivity (T), the specific yield (S_y), and the horizontal hydraulic conductivity (K) of the aquifer. These results are summarized in Table 1.2.2 (Converse, 1994). Geologic logs and hydraulic testing indicate that the aquifer is stratified, has a minimum saturated thickness of approximately 140 feet, and exists under unconfined condition. The regional groundwater flow direction is from the uplands to the south toward the Nooksack River to the north. Groundwater flow at Strandell filed is locally to the north (Converse, 1993).

Within the LENS study area but to the west of the Strandell wellfield lies the East Pole Road wellfield (Figure 1.2.20). This wellfield serves 575 customers in north central Whatcom County, Washington (Water Resources Consulting LLC, 1997). The aquifer penetrated by the wellfield has the transmissivity of 21,400 gallons per day per foot (2858.48 sq ft/day) (Water Resources Consulting LLC, 1997). Aquifer thickness, according to the driller’s log is 45 feet, yielding a hydraulic conductivity of 0.04 ft/min or 63 ft/day (Water Resources Consulting LLC, 1997).

Table 1.2.2 Hydraulic properties of the Strandell wellfield

PARAMETER	AVERAGE VALUE
Hydraulic Conductivity	130 ft/day
Transmissivity	118,000 gpd/ft(15753 sq ft /day)
Specific Yield	0.20

Lake Whatcom Area

One isolated study on hydrogeology around Lake Whatcom is that of Y-Road I and II landfill investigation done by BEK Engineering & Environmental Inc. (BEK Engineering & Environmental, Inc, 2000). The area of the investigation is the Southern half of the Squalicum Lake Valley, located between Jenson Road to the north and Lake Whatcom to the south. The Y-Road landfills are located in a rural setting adjacent to Y-Road, approximately one mile north of Lake Whatcom in the South half of Section 19, Township 38 North, Range 4 East (BEK Engineering & Environmental Inc., 2000). The Squalicum Valley is underlain by undifferentiated glacial deposit, unconsolidated glacial sediment of the Sumas Outwash and Bellingham Drift, and by sedimentary bedrock of the Chucknut Formation.

The Squalicum Lake Valley aquifer is a confined aquifer that lies between the Chucknut Formation and overlying Bellingham Drift confining layer. Although it is generally assumed that the aquifer is directly underlain by the Chucknut Formation, driller's log typically do not penetrate the aquifer and therefore underlying units are not known well (BEK Engineering & Environmental Inc., 2000). Driller's log report that the water bearing formation penetrated by domestic wells consists of gravel and sand deposit. The aquifer thickness is estimated to be in the order of 5 feet to 20 feet thick. Hydrogeological investigation performed by BEK Engineering & Environmental on 10-inch public water supply well (Richalou Estates) completed in the Squalicum Valley aquifer revealed a 10 feet thick aquifer with an artesian flow of 322 gallons per minute at this location. A pump test conducted on this aquifer resulted in hydraulic conductivity of 181 feet/day (BEK Engineering & Environmental Inc., 2000).

1.2.3 Baseflow Characteristics, Aquifer Recharge and Water Level Time Series

In the lowlands the general configuration of the water table approximates the land surface. In terrace lands north of Lynden the water table lies near the surface and slopes towards streams. The lowest level of the regional water table is along the major streams, with water table beneath the Nooksack River flood plain being in general balance with the river into which the ground water escapes by effluent seepage. In the large trough followed northward by the Sumas River, the regional water table slopes northward toward the Fraser River in British Columbia, Canada. Groundwater occurrence within the lower Nooksack basin is shown in Figure 1.2.1f.

Shallow wells are the main source of water for farmsteads in the Mountain View upland (Figure 1.2.1e) and generally go dry in the summer and fall. Deeper wells have encountered "non-water-bearing clayey sections" before reaching bedrock (Newcomb et al., 1949).

According to Newcomb et al. (1949), it may be difficult to obtain groundwater in the highest part of the boundary upland but this may be due to the lack of exploratory drilling. Parts of the Mountain View upland, especially near the western side, parts of the boundary upland, and some places in the alluvial bottom lands in the Everson area lack adequate groundwater supply (Figure 1.2.1e) (Newcomb et al, 1949).

Nearly all aquifers are recharged through direct precipitation that is moderately heavy. In 1949, the rate of recharge was greater than the rate of use (Newcomb et al., 1949). Newcomb et al. felt the gravel aquifer beneath the fill at Ferndale could show overdraft if greater withdrawals were made (1949). Other areas of concern were aquifers with a till capping that intercepts and perches much of the precipitation and from which pumping was continuous and concentrated (Newcomb et al, 1949).

The LENS study area (Figure 1.2.1d) which covers most of the central Sumas –Blaine aquifer has recharge values in six classified ranges within the study area ranging from 11 in /year to 50 in/year (increasing roughly from south / south-west to east/ north-east) (Cox and Kahle, 1999) (Figure 1.2.21).

The Abbotsford Aquifer study area is located along the USA/Canada border within the LENS area (northern part). The aquifer covers an area of 200 km^2, and its recharge values range from 73 m^3/day to 160 m^3/day (Environment Canada, Sept 1999)**,** which, if spread over the area, gives extremely low values of .005 in/year to .012in/year**,** much less than the figure for the same area given in the LENS study.

The aquifers near the city of Sumas have annual ground water recharge ranging from 30 in/year in the Upland area and 6 in/year in the Sumas Valley (City of Sumas Wellhead Protection program/Plan Report).

Table 1.2.3 Estimated baseflow contribution, Lowland

STREAMFLOW GUAGE STATION	DRAINAGE AREA (sq miles)	MEAN ANNUAL Stream flow (cfs)	MEAN ANNUAL Baseflow (cfs)	MEAN ANNUAL Baseflow (in/yr)	MEAN ANNUAL Baseflow (cfs/mi^2)	MEAN BASEFLOW % of Stream flow
Fishtrap Cr. At Lynden, Wa.	22.3	38.00	29.00	18.00	1.30	76
Nooksack R. nr Lynden, Wa.	648.0	3813.00	2527.00	53.00	3.90	66

The average precipitation for the western areas/lowlands (Figure 1.2.1e) is estimated to be about 45 in/year and the average run-off about 18 in/year; the ground water recharge varies depending on the vegetation cover, evapotranspiration, etc.

Estimated baseflow contribution for two selected rivers (gage stations) in this area, Fishtrap Creek north of Lynden and Nooksack River in the central plains near Lynden, indicate 76 % and 66 % baseflow contributions respectively (baseflow/stream flow of 29 cfs / 38 cfs and 2927 cfs / 3813 cfs) (Figures 1.2.22, 1.2.23, 1.2.24 and 1.2.25).

The aquifers near the city of Everson and south of the city of Lynden have annual ground water recharge of 20 in/year and 18 in/year, respectively. (City of Everson Wellhead Protection Plan Report / Pole Road Water Association (PRWA) Report)

Lake Whatcom Area

Estimated baseflow contribution for two gage stations on the Whatcom Creek in the Lake Whatcom area (Figure 1.2.1c), Whatcom Creek near Bellingham and Whatcom Creek below Hatchery, indicate 53% and 39% baseflow contributions, respectively (baseflow/stream flow of 31cfs / 59 cfs and 33cfs / 85cfs)

Figures 1.2.26 – 1.2.49 show location of wells with lengthy (>12 months) recorded well water level data and their corresponding time series.

Table 1.2.4 Estimated baseflow contribution, Lake Whatcom area

STREAMFLOW GUAGE STATION	DRAINAGE AREA (sq miles)	MEAN ANNUAL Stream flow (cfs)	MEAN ANNUAL Baseflow (cfs)	MEAN ANNUAL Baseflow (in/yr)	MEAN ANNUAL Baseflow (cfs/mi^2)	MEAN BASEFLOW % of Stream flow
Whatcom Cr. nr Bellingham, Wa.	55.40	59.00	31.00	7.70	0.57	53
Whatcom Cr Blw Hatchery nr Bellingham, Wa.	56.10	85.00	33.00	8.10	0.59	39

1.3 COASTAL LANDS / WESTERN AREAS

These areas include the watersheds of rivers draining towards the Puget Sound, (excluding the Nooksack delta area), Birch Bay, Drayton Harbour, Georgia Strait, and the Lummi Bay (Figure 1.3.1).

The Lummi Indian Reservation is located about 7 miles west of the city of Bellingham. The reservation includes the peninsula separating Bellingham Bay from Lummi Bay, a strip of adjoining mainland to the north and a small island (known locally as Portage Island) just south of the Peninsula. The area is about 20 square miles. The maximum altitude of the peninsula is 220 feet (LIBC, 1997). The altitude of the delta lowland does not exceed 12 to 15 feet. The Peninsula extends southward between the marine waters of Bellingham Bay on the east and Lummi Bay and Hale Passage on the west.

1.3.1 AQUIFERS AND GEOLOGY

The coastal aquifers near the town of Blaine to the northwest, the Lummi Peninsula area, and the area southwest of Bellingham form part of the discontinuous surficial aquifers described earlier. The surficial geology of coastal lands is shown in Figure 1.2.4.

Northern Coastal

The California Creek and the South Dakota Creek drainage basin in the north-western part of the study area comprises the western part of this group (Didricksen, 1997).

The California Creek Drainage basin is west of and not contained within the USGS LENS study area. The terrace deposits in this area (Qt) are relatively thin, up to 15 feet, and generally unsaturated (Didricksen, 1997). Peat deposits (Qp) range from a few to about 35 feet thick. The thickness of the Sumas outwash unit (Qso) is unknown; regionally, it may exceed 50 feet (Didricksen, 1997) (Figure 1.3.2).
The Blaine city well (40/1E-4JI), which penetrates to 560 feet below sea level in Pleistocene materials, does not reach Tertiary rocks (USGS, 1960).

Near Blaine, a well has penetrated 746 feet of sediments without reaching bedrock, while west of Ferndale bedrock was encountered beneath 320 feet of Pleistocene sediments. North of Ferndale, a well reached bedrock beneath 615 feet (Easterbrook, 1973). At Cherry Point (between Blaine and Birch Bay along the coast) on the Strait of Georgia, wells have penetrated 300 feet of clay.

Along the Strait of Georgia sand and gravel deposits of various thickness overlay the Cherry Point silt. The sand and gravel thickness of about 45 feet has been measured (Easterbrook, 1973).

Southern Coastal

Vashon till has been deposited over much of the western portion of the WRIA 1 and consists of a single massive layer 10-30 feet thick which contains some lenses of bedded sand and gravel (Easterbrook, 1973). East of Ferndale and on the uplands west of Ferndale, Bellingham glaciomarine drift is mantled with a veneer of sand and gravel varying in thickness from 1-10 feet (Easterbrook, 1973).

Cross-sections along Bellingham Bay, Pangborn Bog, a peat bog near Wiser Lake, and a cross-section from Bellingham to the Canadian border (Easterbrook, 1973), indicate 15-25 feet of Bellingham glaciomarine drift top the sea cliffs at Cliffside, North Bellingham Bay as well as bluffs along the banks of the Nooksack.

Two miles south of Bellingham**,** 238 feet of Pleistocene sediments cover the bedrock. In the area north of Bellingham, the bedrock is below 100-300 feet of unconsolidated sediments (Easterbrook, 1973).

Lummi Peninsula

Pre-Tertiary metamorphic rocks are exposed in the mountainous southern half of Lummi Island. The buried surface of Tertiary rocks generally descends from the southern and eastern parts of the WRIA 1 area towards the northern coastal area. On Lummi Island the rock formations consist of cross-bedded and poorly consolidated arksoic sandstones and conglomerates which trend northwesterly, occupying the bottom of a distorted syncline in the northern half of the island (USGS, 1960)

The area of Washburn (1957) investigation consists of two uplands and one lowland, and it covers all the Lummi Indian reservation except Portage Island. The southern margin of the upland region northwest of the Lummi River is known as the Mountain View upland. The upland that forms the peninsula is called the Lummi Peninsula upland. The lowland is a delta that lies between the two uplands and separates the peninsula from similar uplands to the east. About two-thirds of the reservation consists of upland regions.

The geology of the reservation is varied and consists of unconsolidated sediments that overlie bedrock. Groundwater is obtained mostly from sand and gravel deposits in the unconsolidated sediment. The unconsolidated deposits consist of clay, silt, sand, gravel, and boulders, in various combinations. These deposits commonly change in composition laterally over a short distance (Cline, 1974).

Bedrock underlying the Lummi Indian Reservation consists mostly of sedimentary rocks, such as sandstone, shale, and conglomerate. The bedrock is buried deeply and only one well is known to have reached it, well 20 (Figures 1.3.26 and 1.3.27). It penetrates sandstone at a depth of 285 ft, or 92 ft below sea level (Cline, 1974).

1.3.2 HYDRAULIC PARAMETERS

The United States Department of the interior Geological Survey states that transmissivity values calculated for the study area in Lummi Indian Reservation range from 18,000 to 3,500 gallons per day per foot (2404.3 to 467.5 sq ft / day) (USGS, 1971) (Figure 1.3.3).

Horizontal hydraulic conductivity values in the glacial outwash deposits of the Puget Sound Lowland (Figure 1.3.4) range from about 15 to 100 ft/day (Didricksen, 1997). Hydraulic conductivity values of fine-grained interglacial deposits are estimated to range from 0.00001 to 1.0 ft/day (Didricksen, 1997). Based on well log data, transmissivity of the unconfined Sumas Outwash (Qso) (Figure 1.3.2) ranges from 700 to 23,400 ft^2/day and averages about 5,000 ft^2/day. Transmissivity in the confined Vashon Outwash (Qv) ranges from 40 to 13,500 ft2/day, and averages about 2,000 ft^2/day (Didricksen, 1997). Table 1.3.1 summarizes some of the hydraulic characteristics of the aquifers.

Table 1.3.1 Summary of hydraulic characteristics of aquifers, Coastal Lands

	QSO UNCONFINED AQUIFER	QV CONFINED OR SEMICONFINED AQUIFER
Specific Capacity		
Range	<1.0 – 90.9 gpm/ft drwdn	<1.0 – 40.0 gpm/ft drwdn
Average	10.0 gpm/ft drwdn	2.8 gpm/ft drwdn
Transmissivity		
Range	700 – 23,400 ft^2/d	40 – 13,500 ft^2/d
Average	5,000 ft^2/d	2,000 ft^2/d
Storativity (estimate)	0.1 – 0.3	10^{-3} – 10^{-5}

1.3.3 Baseflow Characteristics, Aquifer Recharge and Water Level Time Series

Estimated baseflow contribution on Nooksack River at Ferndale is 66%, (baseflow / stream flow of 2465cfs / 3734cfs) (Figures 1.3.5, 1.3.6 and 1.3.7).

Estimated baseflow contribution on Dakota Creek near Blaine is 54%, (baseflow / stream flow of 15 cfs/28cfs)

Table 1.3.2 Estimated baseflow contribution
(Nooksack River at Ferndale & Dakota Creek near Blaine)

Streamflow Gage Station	Drainage Area (sq miles)	Mean Annual Stream flow (cfs)	Mean Annual Baseflow (cfs)	Mean Annual Baseflow (in/yr)	Mean Annual Baseflow (cfs/mi^2)	Mean Baseflow % of Stream flow
Nooksack R. At Ferndale, Wa.	786.0	3734.00	2465.00	43.00	3.10	66
Dakota Cr. Nr Blaine, Wa.	18.4	28.00	15.00	11.00	0.81	54

As part of the USGS Regional Aquifer System Assessment in Puget Sound Lowlands, regression analysis was used to determine statistical relation between mean annual precipitation and groundwater recharge (Morgan and Jones, 1995). The following equation were derived for the areas where outwash or till are exposed at the land surface:

Outwash areas:

$$R = (0.8373P) – 9.77$$

Till areas:

$$R = (0.542P) – 6.06$$

Where R = mean annul recharge (in/year), and P = mean annual precipitation (in/year).

The aquifers of Dakota Creek Basin have annual ground water recharge of about 12 in/year (Sandal, 1990). The average precipitation for the western areas (which includes the coastal areas) is estimated to be about 45 in/year and the average run-off about 18 in/year**;** the ground water recharge varies depending on the vegetation cover, evapotranspiration, etc. (Eastbrook, 1973).

The shallow aquifers near the city of Blaine have annual ground water recharge ranging from 7 in/year – 20 in/year. (City of Blaine Wellhead Protection program / Plan Report)

At the Lummi Indian Reservation in 1972 about 38 million gallons (more than 90 percent of the total withdrawal) of groundwater was withdrawn for public supplies and less than 3 million gallons, was withdrawn by a number of wells for individual domestic use. No groundwater is withdrawn for industrial or irrigation use. This value is double the amount pumped in 1965 (Cline, 1974). The only well on Portage Island has not been used and there are no other water development projects on this uninhabited island (Cline, 1974).

The present USGS database shows that out of the 217 well which are within Lummi Peninsula, Lummi Island, part of the Nooksack delta, and Portage Island (as shown in Figure 1.3.29), only 91 have pumping rate data which totals to 1806 gal/min (949 million gallons per year). This area is 70.025 km^2. This translates to about 0.18 inches per year.

The shallow water-bearing sand beds underlying the Lummi Indian Reservation are recharged chiefly by direct percolation of rainfall. In addition, the aquifers underlying the northern part of the reservation receive some recharge by lateral movement of water from hydraulically continuous zones to the north, beyond the reservation boundary (Washburn, 1957).

Groundwater loss in the Lummi area occurs by evaporation and transpiration and discharge from springs and wells. As the semi-perched water table is close to the land surface, and there is a thick cover of vegetation over most of the reservation, considerable volume of ground water is transpired by plants, and/or evaporated from swampy areas. Many springs issue at the base of the sea cliffs and may be seen at low tide. Most of these springs flow but a few gallons a minute; however, it is believed that their aggregate discharge is large. There are relatively few wells in the area, and the individual yields from them are small (Washburn, 1957).

During the late summer and early fall, water levels in many of the shallow wells decline and yields are insufficient for domestic use. In March and April 1956, water levels were measured in shallow dug wells. Of 22 wells ranging in depth from 7 to 22 feet, the levels in 14 were within 5 feet of the land surface. In none of the 22 was the level more than 13 feet below the land surface. Many well owners reported an annual water-level fluctuation of 5 to 10 feet. From December 1955 to May 1956, periodic measurements of water level were made at well 338/2-7M1, located at the Lummi School. The highest water level in this well was 9.6 feet below the land surface, on December 30, 1955, and the lowest was 13.4 feet, on May 25, 1956 (Washburn, 1957).

USGS well measurements for selected wells on the Lummi Peninsula, which have a longer period of measurements, are shown in Figures 1.3.13 to 1.3.25. The well numbers and locations are shown in Figure 1.3.8. All the drilled wells and the deeper dug wells in the area yield enough water for domestic and stock purposes throughout the year. The water from a few of the deeper drilled wells is highly saline, which limits its usefulness.

The main water table beneath Lummi Peninsula rises only as high as about 20 ft above sea level in the northern part and about 11 ft in the southern part. North of the Peninsula the main water table has been observed to be as much as 35 ft above sea level. In some wells that tap the main water table near the shore, daily fluctuations of water levels are caused by the ocean tide. Wells, which are located on, perched water table show greater fluctuations and may even go dry in summer. The water table contours and direction of groundwater movement is shown in Figure 1.3.27 (Cline, 1974).

Figures 1.3.8 to 1.3.12 show locations of other coastal wells with lengthy (> 12 months) water level records and their corresponding water table time-series.

1.4 Eastern Highlands

The eastern uplands of the WRIA 1 form part of the northwestern edge of the Cascade Range. The major branches of the Nooksack River (North, Middle & South Fork) drain the large stratovolcanoes of the region, namely Mt Baker and Mt Shuksan. (Figures 1.4.1a, 1.4.1b, and 1.4.2a)

1.4.1 Aquifers and Geology

The predominant rocks in the eastern highland area include the Paleozoic sediments and volcanic flows, which were metamorphosed during mid-Mesozoic time. These dense, compact rocks are primarily impermeable to either retention or transmission of ground water except through occasional joint and fracture zones. They permit precipitation to be quickly drained off to surface streams. It is estimated that approximately 70% of total precipitation falling in the mountains will reach the gaging station at Deming (USGS, 1960). These pre-Tertiary metamorphic rocks are also exposed in a few places in the foothills, in particular in the Sumas area.

A few areas of Tertiary igneous rock occur in this region, although they are of little importance to the water resources of the Nooksack Basin. These areas include the Twin Sisters Mountain and Mount Shuksan at the headwaters of the North Fork Nooksack River.

The Glacier Creek Basin (Figures 1.4.2b and 1.4.3) is located roughly 15 miles east of the LENS study area in the upper valley of the project area. The Glacier Creek Area of the North Fork Nooksack Sub-Basin has been subdivided into lower, middle, and upper units (see Figure 1.4.3). The subsurface underlying the lower unit is between 2600 to 7500 feet thick and composed of fossiliferous, interbedded sandstone and argillite with Minor marl conglomerates. The middle unit is underlain by fossiliferous, thick-bedded sandstone and coarse sedimentary breccia with thinner beds of siltstone, about 4600 feet thick. The upper unit subsurface is composed of fossiliferous, interbedded sandstone and argillite, and is approximately 4300 feet thick (van Siclen, 1994).

1.4.2 Baseflow Characteristics and Aquifer Recharge

Estimated baseflow contributions for seven selected gage stations on rivers/streams in this area (Nooksack River North Fork, Middle Fork, South Fork and Skookum Creek) are shown in Table 1.4.1 (Figures 1.4.5, 1.4.6, 1.4.7 and 1.4.8).

Table 1.4.1 Estimated baseflow contribution, Eastern Highland

Streamflow Gage Station	Drainage Area (sq miles)	Mean Annual Streamflow (cfs)	Mean Annual Baseflow (cfs)	Mean Annual Baseflow (in/yr)	Mean Annual Baseflow (cfs/mi^2)	Mean Baseflow % of Streamflow
N.F. Nooksack R Blw Cascade Cr nr Glacier	105.00000	760.00	571.00	74.00	5.40	75
Nooksack (N. Fk.) R. nr Glacier, Wa.	195.00000	1073.00	815.00	57.00	4.20	76
N.F. Nooksack R. nr Deming, Wa.	282.00000	1663.00	1207.00	58.00	4.30	73
M.F. Nooksack R. nr Deming, Wa.	73.30000	458.00	298.00	55.00	4.10	65
S.F. Nooksack R. nr Wickersham, Wa.	103.00000	731.00	487.00	64.00	4.70	67
Skookum Cr. nr Wickersham, Wa.	23.10000	134.00	99.00	58.00	4.30	74
Nooksack R. At Deming, Wa.	584.00000	3183.00	2280.00	53.00	3.90	72

The critical recharge areas in the Upper Valleys are shown in Figure 1.4.4

1.5. Time-averaged, lumped-parameter groundwater balance model

Based on the spatial resolution a groundwater model can be classified as distributed and lumped model. For a lumped parameter hydrologic model, parts of the watershed are combined or lumped into individual hydrologic elements functioning as one unit. This approach gives a simplified computational unit as well as a regional view of the problem at hand, which is a basic level information for understanding the dominant processes in a given watershed. Certain hydrologic questions can be answered with enough detail without having detailed distributed data for the watershed. Results of such a model are a precursor for consequent detailed modeling effort

The components of the time-averaged, lumped groundwater balance model are discussed below. This model gives long-term steady – state average response of the catchment.

For a given watershed under consideration, the groundwater balance of the watershed can be expressed as

$$P + G_{in} - (Q_s + Q_p + ET + G_{out}) = 0$$

Where the terms in bracket are out flow from the watershed.

- P is precipitation
- G_{in} is groundwater inflow
- G_{out} is groundwater outflow
- ET is evapotranspiration
- Q_p is pumpage
- Q_s is stream outflow

The right hand side of the equation is the change in storage of the groundwater reservoir. Since we are interested is in long-term mass balance, the change in groundwater storage is assumed to be effectively zero.

For a given gaging station (or differences of gaging stations whenever the drainage area between two gaging stations is considered), once the direct runoff is separated from the stream flow data, the base flow will represent groundwater inflow or outflow over the stream reach. Therefore, the above expression can be simplified to

$$R - (Q_p + \Delta G) = 0$$

Where

ΔG is the base flow (or differences between two stations, whenever exists) and
R is groundwater recharge

The different parameters are estimated in each section for the respective drainages.

1.6 SUMMARY

This chapter summarizes the existing hydrologic and hydrogeologic data with the objective of using this information for future model formulation and population. The report is focused on the following primary issues:

a) spatial delineation of the WRIA 1 aquifer systems
b) aquifer hydrogeology
c) aquifer hydraulic properties, such as transmissivity, hydraulic conductivity, and storativity
d) dynamic aquifer behavior, as expressed by water table fluctuations
e) time averaged stream-aquifer interactions, expressed by baseflow/stream flow relationships

As we expected, the data coverage is distributed rather unevenly. The best set of data seems to exist for the Central Lowlands, whereas the data for the Coastal and eastern portions of WRIA 1 are quite sparse. Table 1.5.1 summarizes the hydraulic parameters. The table provides a regional picture of the hydraulic parameter variations over the study area.

The question whether the available information is sufficient to develop meaningful models can be answered only in the context of the decision-relevant information and its spatial resolution that such models will be expected to provide. There are a number of important water-balance type management questions that could be addressed using quite simple, spatially averaged dynamical models. There are other types of questions; more on the engineering design side that typically require more site-specific data than is currently available for some of the WRIA 1 areas. All these issues will be addressed in our future discussions concerned with scoping Phase III of the project.

Table 1.5.1 Hydraulic parameters summary, WRIA 1

Study Area	Parameters	Region	Range	Average	Source
LENS	Hydraulic conductivity (feet/day)	Sumas Aquifer	6.8 – 7,800	270 (median)	Cox and Kahle, 1999
		Everson-Vashon Semiconfining unit	3 - 160	81 (median)	
		Vashon Semiconfining unit	2.4 – 1,800	52 (median)	
		Bedrock Semiconfining unit	0.01 - 77	0.55 (median)	
Sumas Area	Hydraulic conductivity (feet/day)	Upland Sumas, Sumas outwash and Sumas river valley	10 – 3,000		Associated Earth Science, 1995
		May Road, Sumas and Fraser Valley trout hatchery well fields	250 - 600		
Johnson Creek	Hydraulic Conductivity (feet/day)		1.07 - 298	48.5 (geometric mean)	Gibbon and Culhane, 1994
	Transmissivity ($feet^2$/day)		138.2 - 66580		Golder Associates, 1992
Pole Road, near Lynden	Transmissivity ($feet^2$/day)			2860	Water Resources Consulting, LLC, 1997
	Hydraulic conductivity (feet/day)			63	
Strandell wellfield, Everson	Transmissivity ($feet^2$/day)	East Well		15,840	Converse, 1993
		West Well		10,080	
	Storage Coefficient	East Well		0.1	
		West Well		0.2	
Puget Sound Lowland	Transmissivity ($feet^2$/day)	Qso Unconfined Aquifer	700 – 23,400	5,000	Didricksen, 1997
		Qv Confined or Semiconfined	40 – 13,500	2,000	
	Storage Coefficient	Qso Unconfined Aquifer	0.1 – 0.3		
		Qv Confined or Semiconfined	0.001 – 0.00001		
Lummi Indian Reservation	Transmissivity ($feet^2$/day)		470 – 2,400		USGS, 1971
Dakota Watershed (Boundary Upland)	Transmissivity ($feet^2$/day)	Shallow semi-confined to confined	50 – 14,000		Golder Associates (1996)
		Deep Aquifer	3,000 – 5,000		

2.0 NORTHFORK NOOKSACK WATERSHED AND AQUIFER WATER BALANCE MODEL

2.1. The Watershed

The North Fork Nooksack watershed lies on the western slopes of the Cascade Mountains in northwest Washington State, approximately 30 miles northeast of the City of Bellingham and 5 miles south of the US/Canadian border. The watershed is one of the three major forks of the Nooksack River system, which flows west into Puget Sound (Bellingham Bay).

The North Fork Nooksack River flows through a valley, which was initially stream cut and later modified by glaciation. Steep side slopes rise over 7, 000 feet elevation. The distinguishing feature of the River is glacial run off for 6-8 months of the year, originating from glaciers on Mt. Shuksan and Mt. Baker.

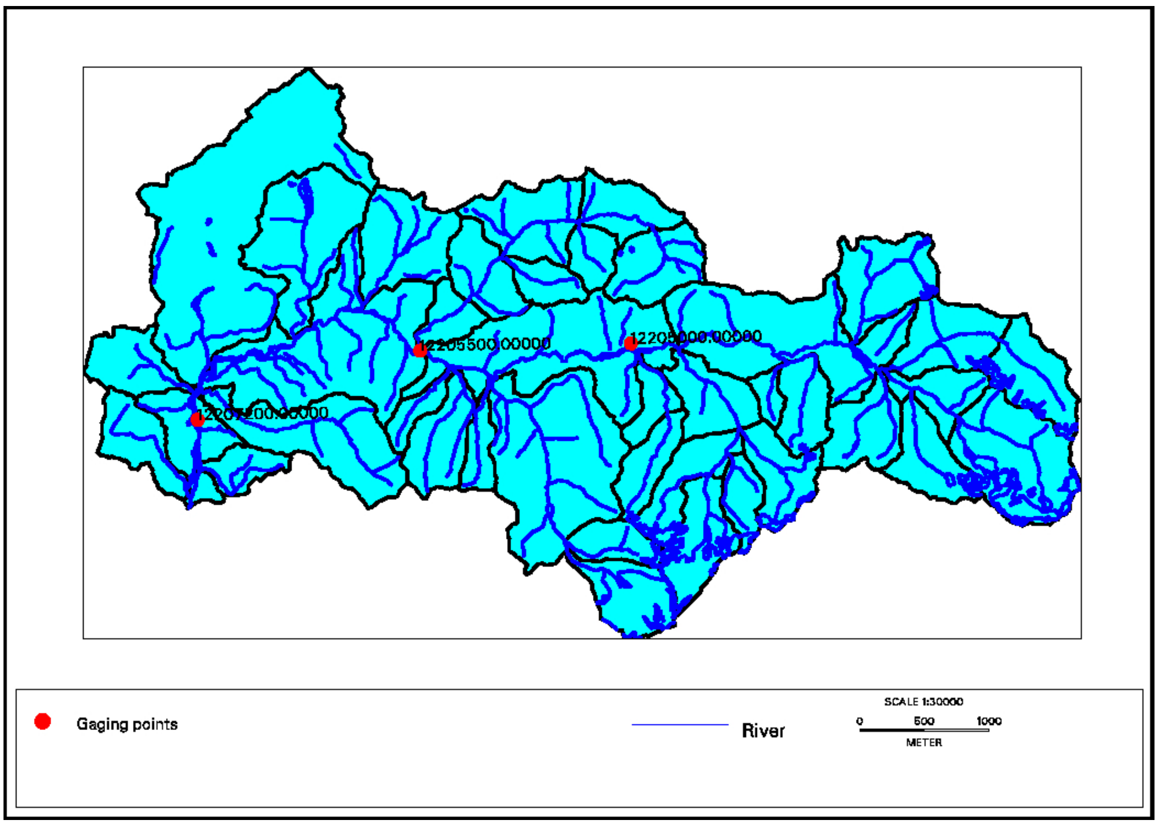

Figure 2.1.1 The North Fork Nooksack Watershed

2.2 Base flow

There are three baseflow measurement points: two places identified by station number 12205500 and 12205000 (site id of 330 and 331, shown in Figure 2.1.1) located inside the North Fork Nooksack watershed and another with station number 12207200(site id of

332). Station 12207200 is located near the outlet of the watershed. This station has a drainage area of 730km^2 while the total watershed area is 761km^2. The gage at 1220720 has 11 (1965-1975) years of annual average base flow information while the upper station of 12205000 (site id of 330) has 59 (1939-1997) years of data. The middle gage of 12205500 (site id 331) has only 4 (19935-1938) years of record. For comparison, the common years of the two stations (1965 –1975) are used.

2.3. GLACIER CREEK CONTRIBUTION

Glacier Creek, one of the major tributaries of the North Fork Nooksack River, is located 25 miles (40km) northeast of Bellingham. It originates as melt water from the Coleman and Roosevelt Glaciers at an elevation of 4,500 feet (1370m). The Creek is approximately 9 miles (14.5km) long. More description of the Creek and the basin can be found in Van Siclen (1994).

There are five years of stream flow data (1984-1988) for Glacier Creek. There are no common years between these data and station number 12207200, located at the outlet of North Fork Nooksack. But the data for these years are available for station # 12205000, located in the middle of North Fork Nooksack. All of the sub-basins within the upper North Fork Nooksack basin have similar physiographic, climatic, and ecologic characteristics (Van Siclen, 1994). Although differences in basin characteristics are reflected in the discharge area, good relationships exist between discharge data from Glacier Creek gage and gage # 12205000.

Correlation of short-term gage records with longer-term gage records is a common practice. Correlation analysis is the study of potential relationship between two variables. A scatter plot is a simple correlation method used to identify what type of relationship exists between the paired data sets. The scatter plot shown in Figure 2.3.1 demonstrates the correlation between flows of Glacier Creek and North Fork Nooksack River (gage # 12205000).

Mean monthly data from 1984-1988 of North Fork Nooksack and Glacier Creek have been correlated linearly. The correlation is restricted to monthly mean flows for the whole period of available data.

Assuming a linear correlation between the two river flows, mean monthly flow series are related as follows (Glacier Creek as dependent variable):

Regression slope	=0.195
Standard deviation of the slope	=0.0173
Coefficient of regression	=0.70

and the relation can be expressed through the following equation

$$\text{Glacier Creek} = 0.195 * \text{North Fork Nooksack} + 7.497$$

both river flows in ft^3/sec.

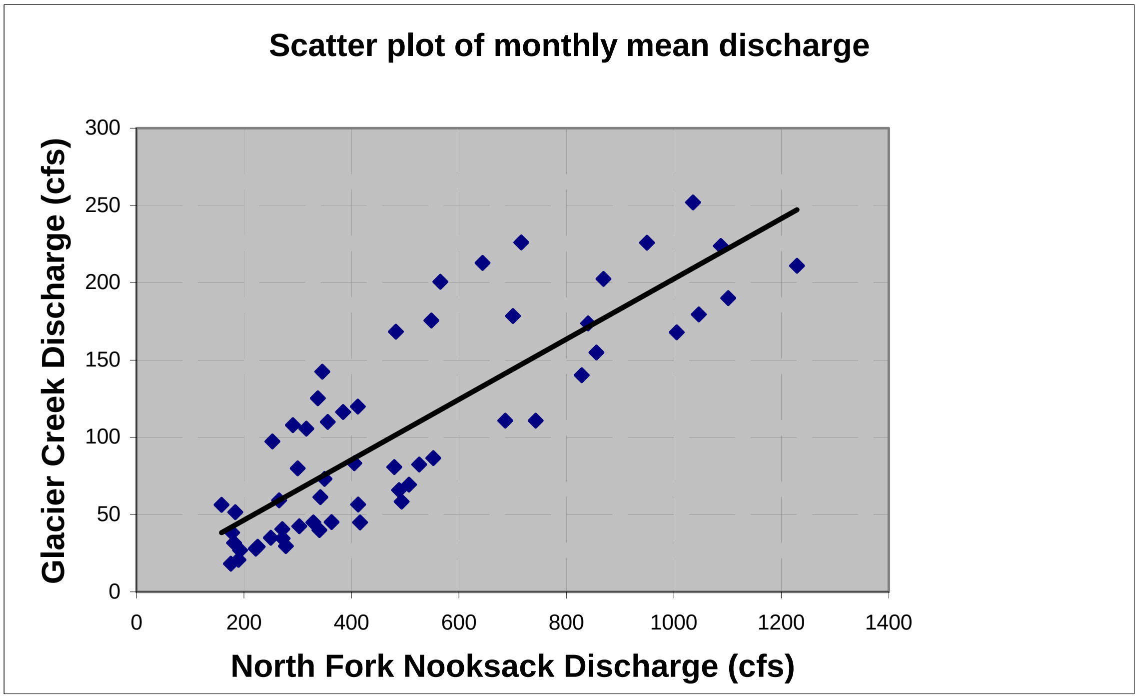

Figure 2.3.1 Scatter plot of North Fork Nooksack River and Glacier Creeks (1984-1988)

The relation shown by the above equation has a correlation coefficient of 0.84 and a regression coefficient of 0.7 suggesting a relatively strong relation between these two rivers flows, at least for the common years of measurements.

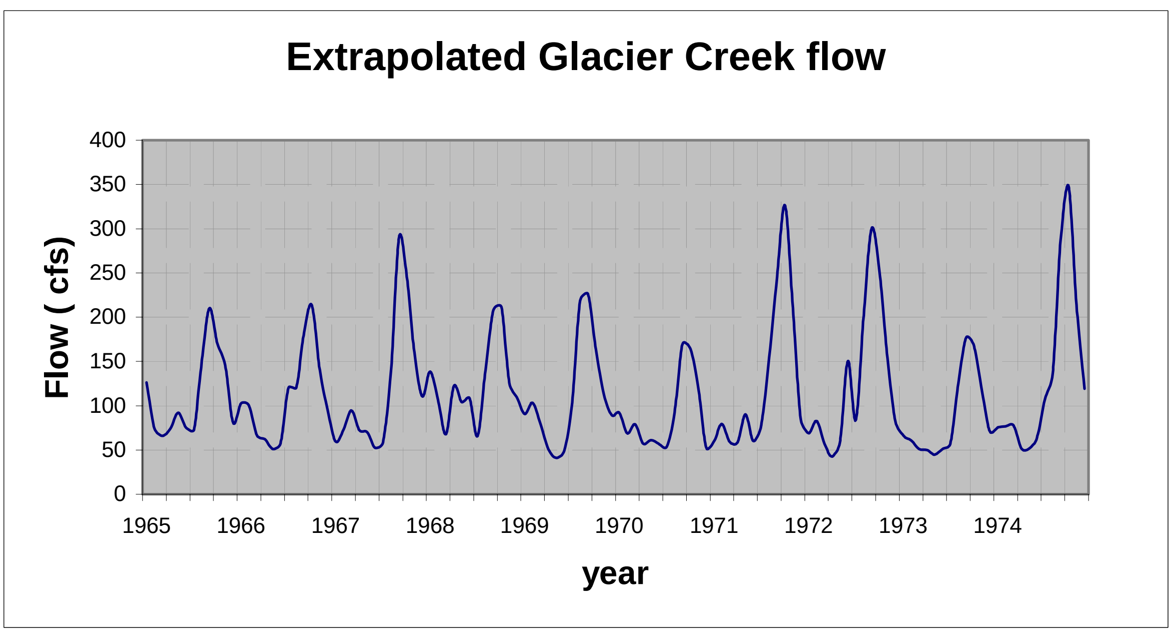

Figure 2.3.2 Extrapolated Glacier Creek flow

The correlation coefficient determines how the stream flows for two rivers are correlated, that is, if high flows of Glacier Creek are associated with high flows of North Fork Nooksack River and vice versa (positive correlation). Using the above equation the Glacier creek flows are calculated for years of 1965 – 1975. Figure 2.3.2 shows the extrapolated Glacier Creek flow.

The flow of Glacier Creek has been handled separately in the calculation of the mass balance (see below).

2.4 GROUNDWATER PUMPING

There are 20 pumping wells registered in Northfork Nooksack watershed. Out of these only 10 have data about the discharge amount (see Figure 2.4.1 for locations). There is only one value associated with each of the 10 pumping wells. The total pumping rate is 2943 g/min (7.73 million m^3 per year). This 0.5 inches per year over 177 sq. mile

2.5. RECHARGE

Recharge is the least well-defined value in the reports. Morgan and Jones (1995) used 27in average recharge value for around North Fork Nooksack region in their groundwater model to study the effect of groundwater withdrawal on discharge to streams and springs in small basins typical of the Puget Sound Lowland. In fact two values (27 and 18) cover the whole project area. Recharge values were based on studies of Woodward and others (1995) who used a Deep Percolation Model (DPM) to compute the infiltrating water to the ground. The DPM is a daily water budget model, which computes the groundwater recharge as a remaining term after evapotranspiration and surface runoff are deducted from the infiltration rate.

INVERSE RECHARGE ESTIMATION

Assuming the recharge to be the unknown in the mass balance equation, an inverse estimation for recharge can be performed using the other components of the water balance.

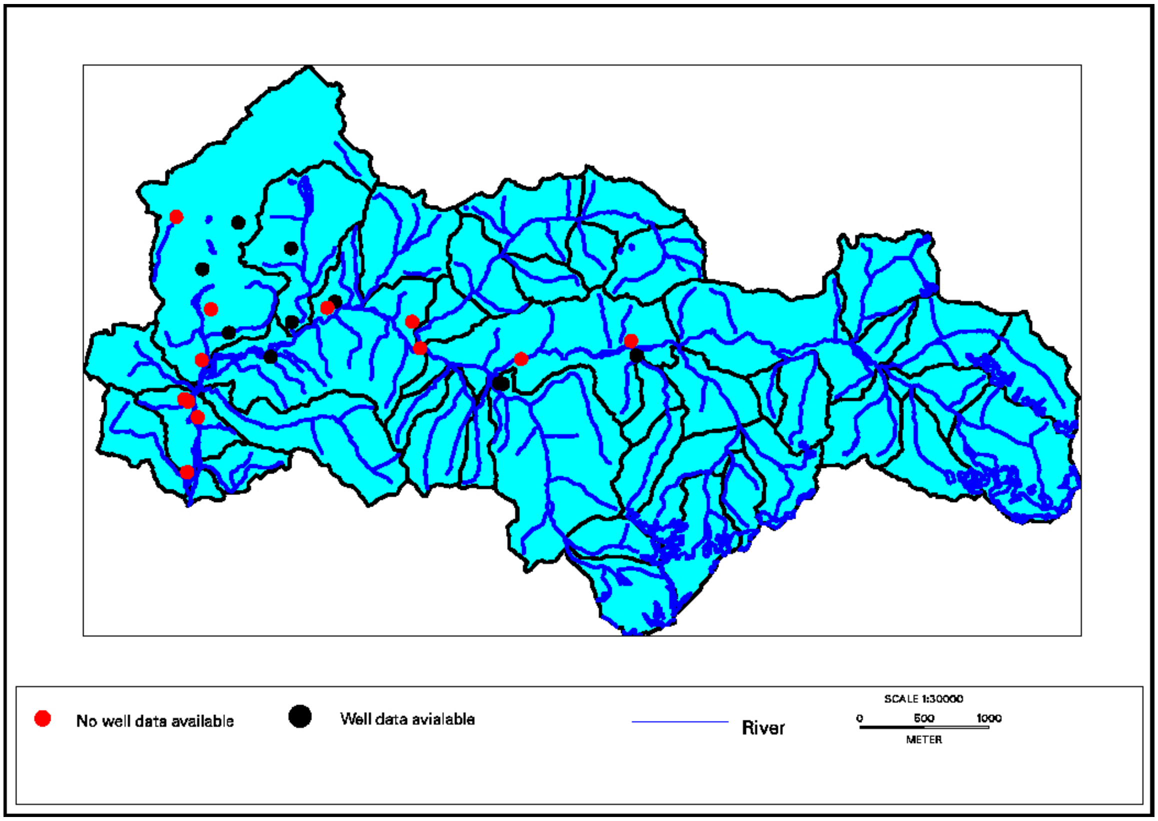

Figure 2.4.1 Areas with and without pumpage data

Case 1

Base flow for stations # 12205000 and 12207200 is shown in Figure 2.5.1. The base flow difference for these stations is shown in Figure 2.5.2. The cumulative base flow difference has been found and a linear regression line has been fitted to it. The line, which is forced to pass through the origin, has the following statistics:

Slope of regression line	=0.1124 in/day
Standard deviation of the slope	=0.0003 in/day
Coefficient of regression	=0.996

The daily cumulative base flow volume differences and the regression lines are shown on Figure 2.5.3.

Total annual base flow:

1. Using regression slope	=0.1124*365	= 41.03 in
2. Using slope - 2*Std	=(0.1124 – 2*0.0003)*325	= 40.81 in
3. Using slope + 2*Std	=(0.1124+2*0.0003)*325	= 41.25 in

Pumpage = 0.5 in/year

The uniform recharge value over the catchment will be the sum of the above base flows and the total pumpage.

Recharge1 = 41.53 in
Recharge2 = 41.31 in
Recharge3 = 41.75 in

Drainage area of station # 12205000 is 730.337km^2 and that of station # 12207200 is 271.934km^2. The difference between these two is the area contributing to the estimated pumpage and baseflow.

These are the recharge values between the two gaging stations necessary to maintain the pumpage and base flow.

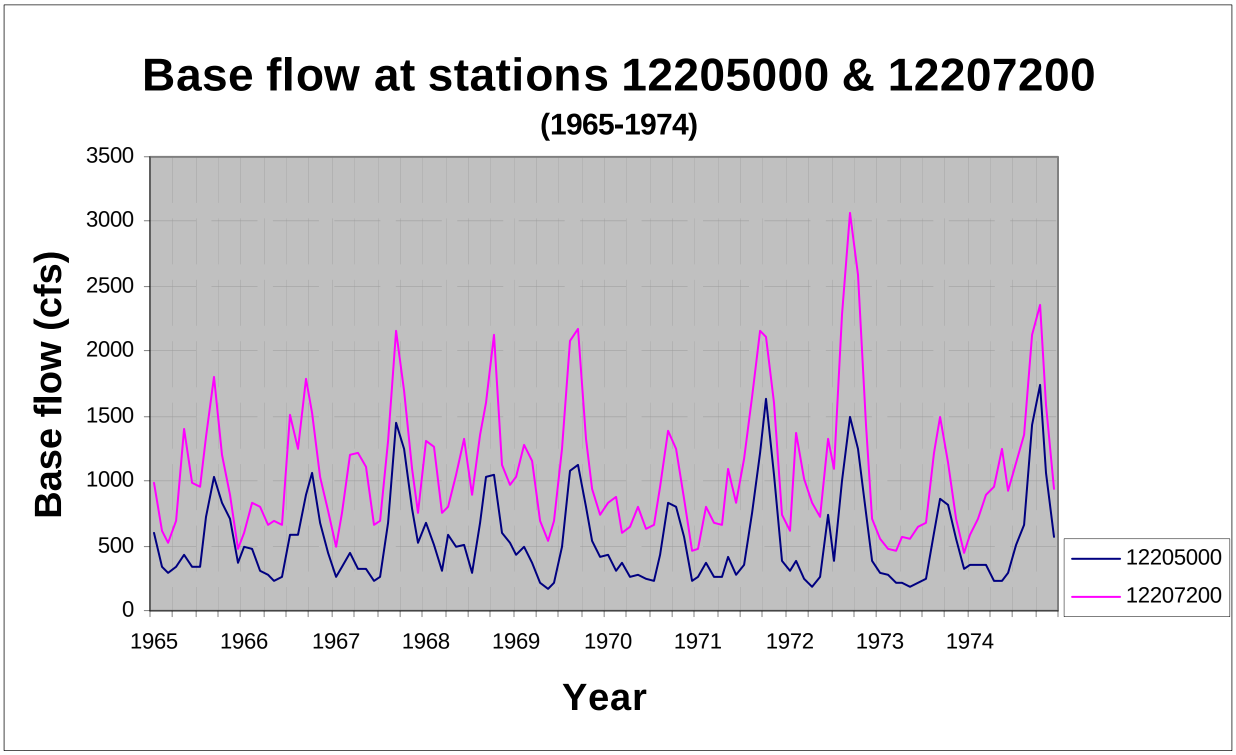

Figure 2.5.1 Base flow at stations # 1220500 (Middle Northfork Nooksack) and 12207200(outlet).

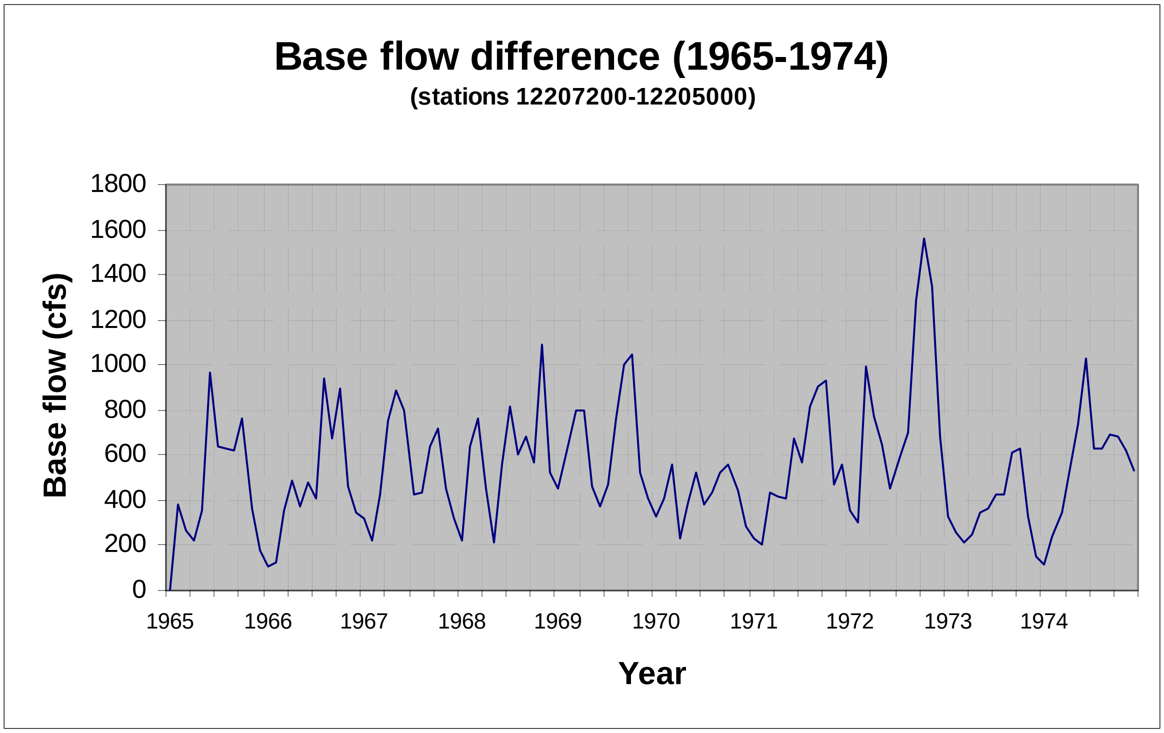

Figure 2.5.2 Base flow differences for station # 12207200 and 12205000.

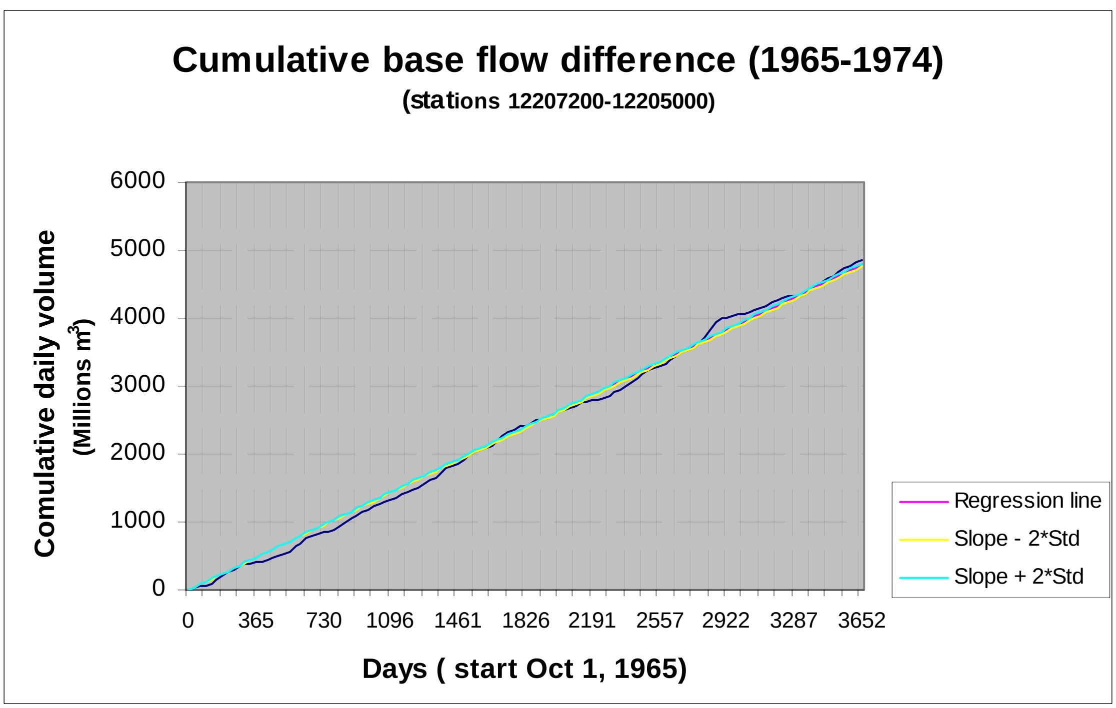

Figure 2.5.3 Cumulative base flow differences

Case 2

This case assumes that the Glacier Creek flow is to be subtracted from the observed base flow. This seems to be a fair assumption since the Glacier flow originates from glacier melt, and is imposed on the drainage area between these two gage measurement points as a boundary condition. Therefore, this flow is not produced by a recharge over the drainage area between the two measurement points.

Once the Glacier Creek flow is subtracted from the base flow differences a linear regression line is fitted to the data with the following statistics for the line.

Slope of regression line	=0.0889 in/day
Standard deviation of the slope	=0.0003 in/day
Coefficient of regression	=0.995

Total annual base flow:

1. Using regression slope	=0.0889*365	= 32.45 in
2. Using slope – 2*Std	=(0.0889-2*0.0003)*365	= 32.23 in
3. Using slope + 2*Std	=(0.0889+2*0.0003)*365	= 32.67 in

The uniform recharge value over the catchment will be the sum of the above base flows and the total pumpage.

Recharge1	= 32.95in
Recharge2	= 32.73in
Recharge3	= 33.27in

The above two cases of the recharge estimations indicate the range of recharge values that can be expected within the North Fork Nooksack Watershed. The second approach, which treated Glacier Creek as glacier melt boundary condition seems to be more appropriate.

2.6 Comparison of precipitation, stream flow and base flow

In the North Fork Nooksack catchment there are two precipitation measurement stations, which have relatively long periods of measurements: Glacier Ranger Station and Mount Baker Lodge. At the Mount Baker Lodge station none of the five (1948 – 1952) years has a complete measurement. Out of the 35 (1949 - 1983) years measured data at Glacier Ranger station only four water years have found to coincide with measurement of the stream flow. Other periods either do not have a complete measurement or do not coincide with stream flow measurements of stations 12205000 and 1207200, which are used for stream flow and base flow difference calculations. The common water years are 1967-1968 and 1970-1971. Consequently, these years are used for comparing precipitation data with the stream flow and base flow difference at the gaging stations. Figures 2.6.1 – 2.6.4

shows precipitation comparison with base flow gain, and Figures 2.6.5 – 2.6.8 shows precipitation comparison to stream flow gain.

Precipitation and base flow gain comparison

Water years 1967 – 1968

Slopes and ratios of slopes

Precipitation	0.2234 in/day
Stream flow	0.1929 in/day (with Glacier) 0.1684 in/day (without Glacier)
Base flow	0.1162 in/day (with Glacier) 0.0917 in/day (without Glacier)
Precipitation/stream flow	1.16 (with Glacier) 1.33 (without Glacier)
Precipitation/base flow	1.92 (with Glacier) 2.44 (without Glacier)

Water years 1970 -1971

Slopes and ratios of slopes

Precipitation	0.1713 in/day
Stream flow	0.1542 in/day (with Glacier) 0.1348 in/day (without Glacier)
Base flow	0.0946 in/day (with Glacier) 0.0753 in/day (without Glacier)
Precipitation/stream flow	1.11 (with Glacier) 1.27 (without Glacier)
Precipitation/base flow	1.8 (with Glacier) 2.28 (without Glacier)

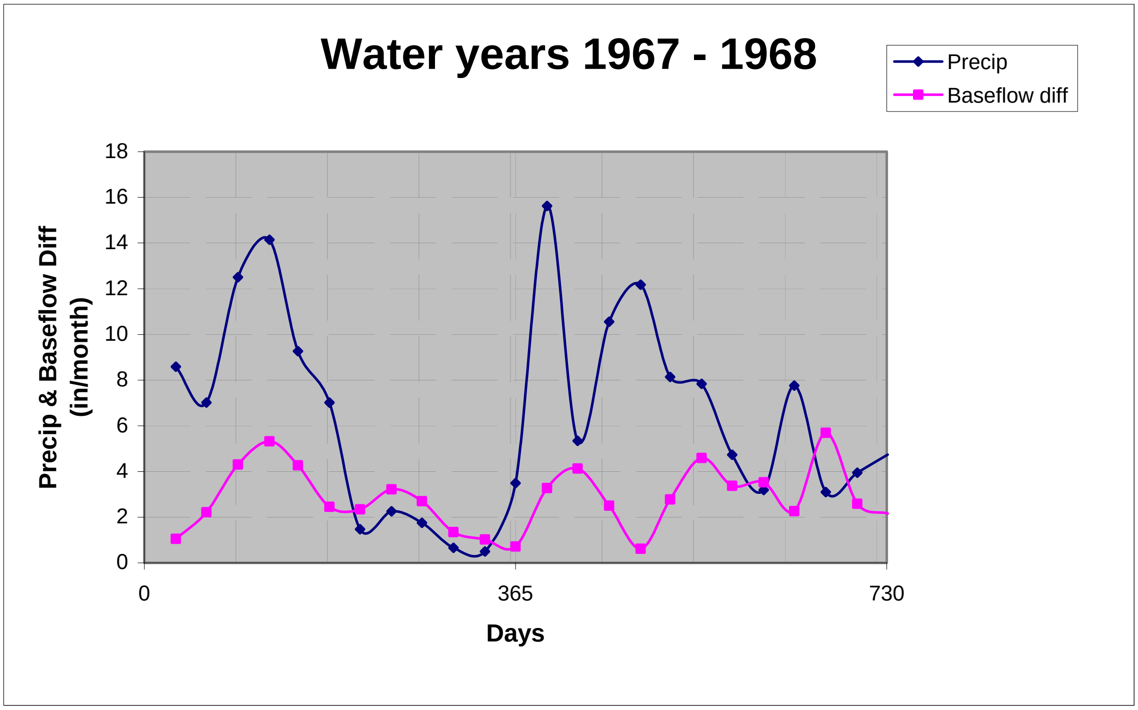

Figure 2.6.1 Precipitation and base flow differences, 1967 - 1968

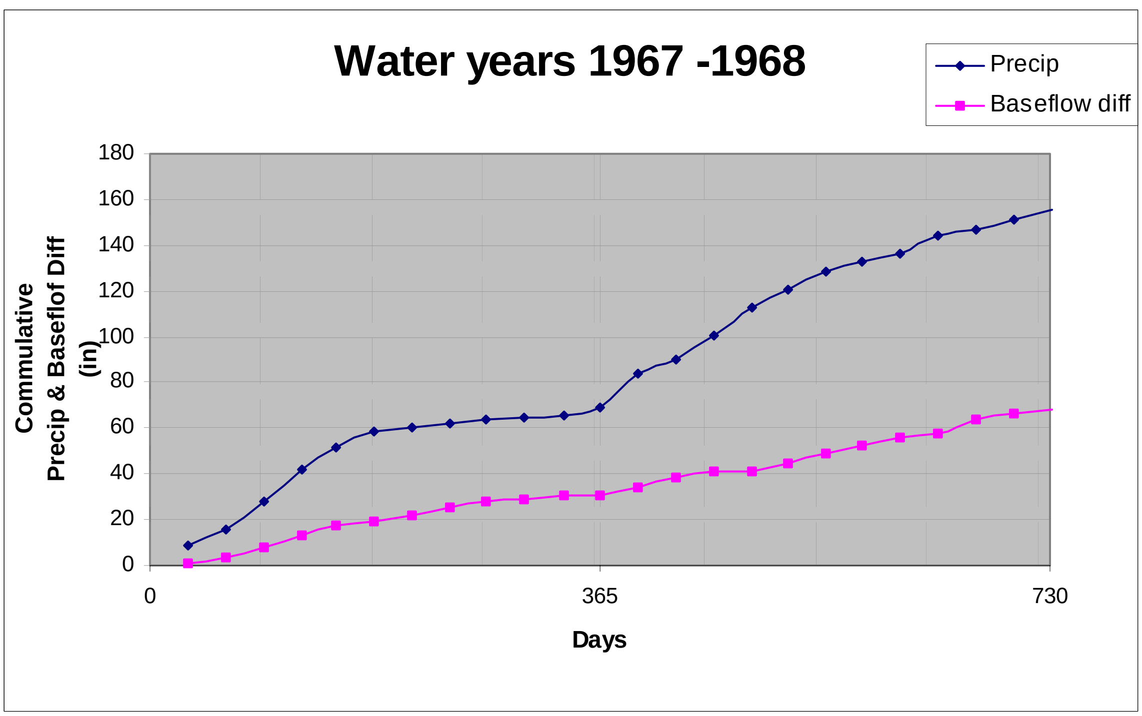

Figure 2.6.2 Cumulative precipitation and base flow differences, 1967 - 1968

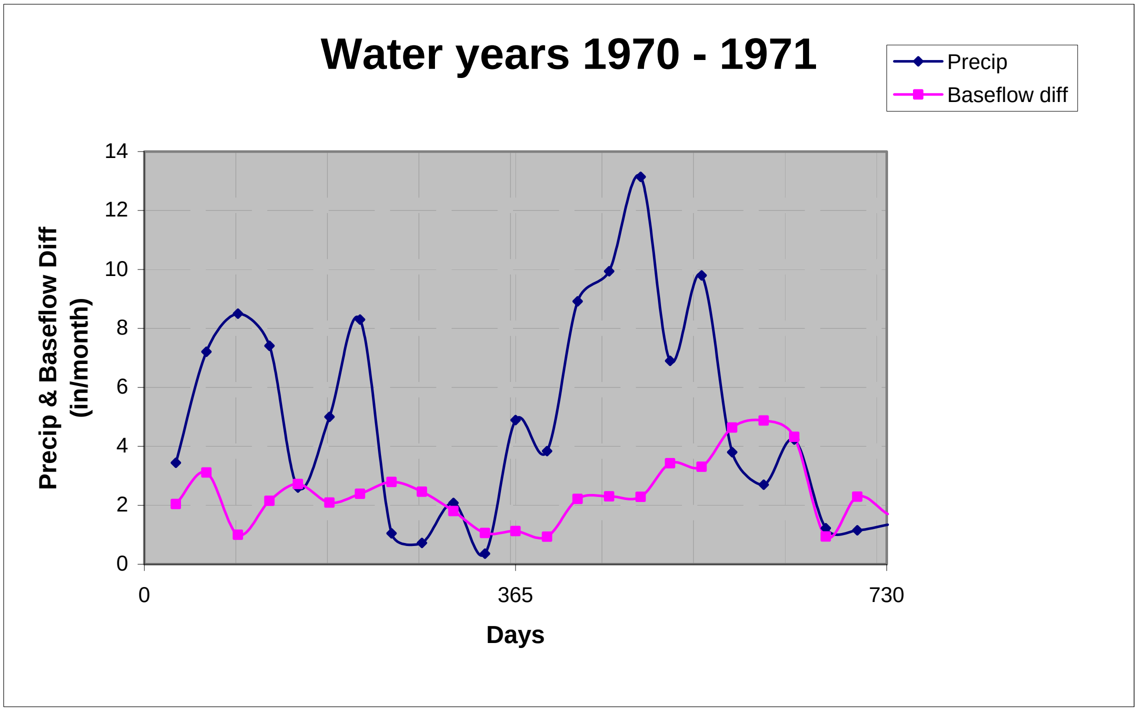

Figure 2.6.3 Precipitation and base flow differences, 1970 - 1971

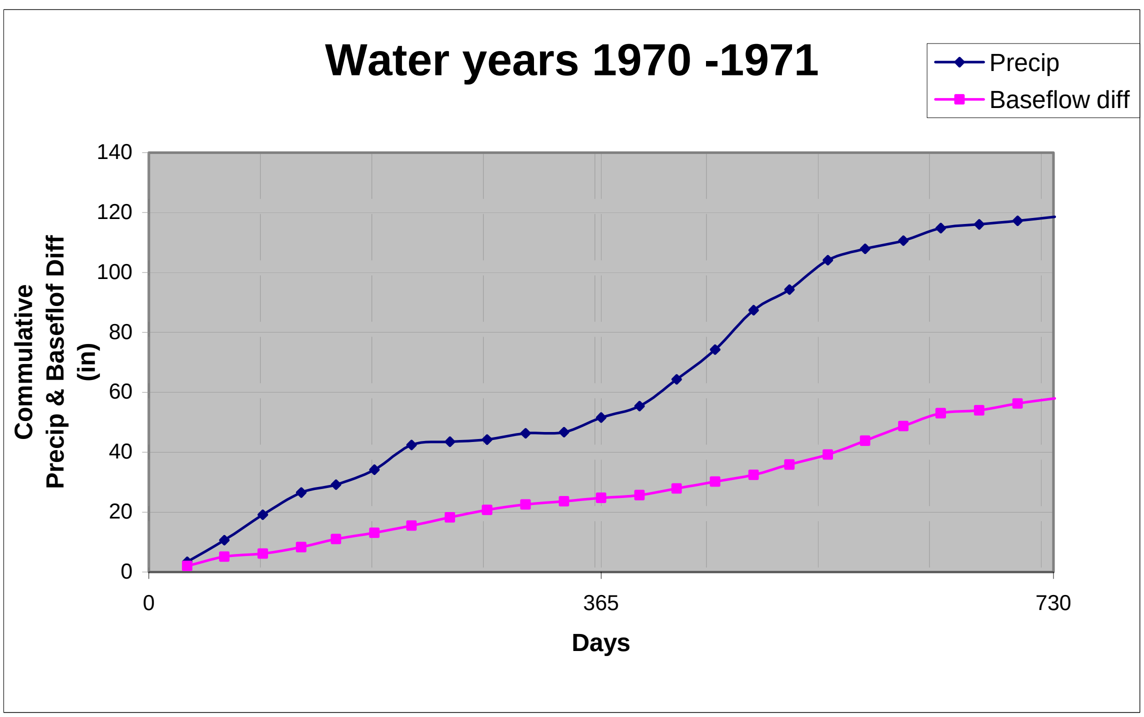

Figure 2.6.4 Cumulative precipitation and base flow differences, 1970 - 1971

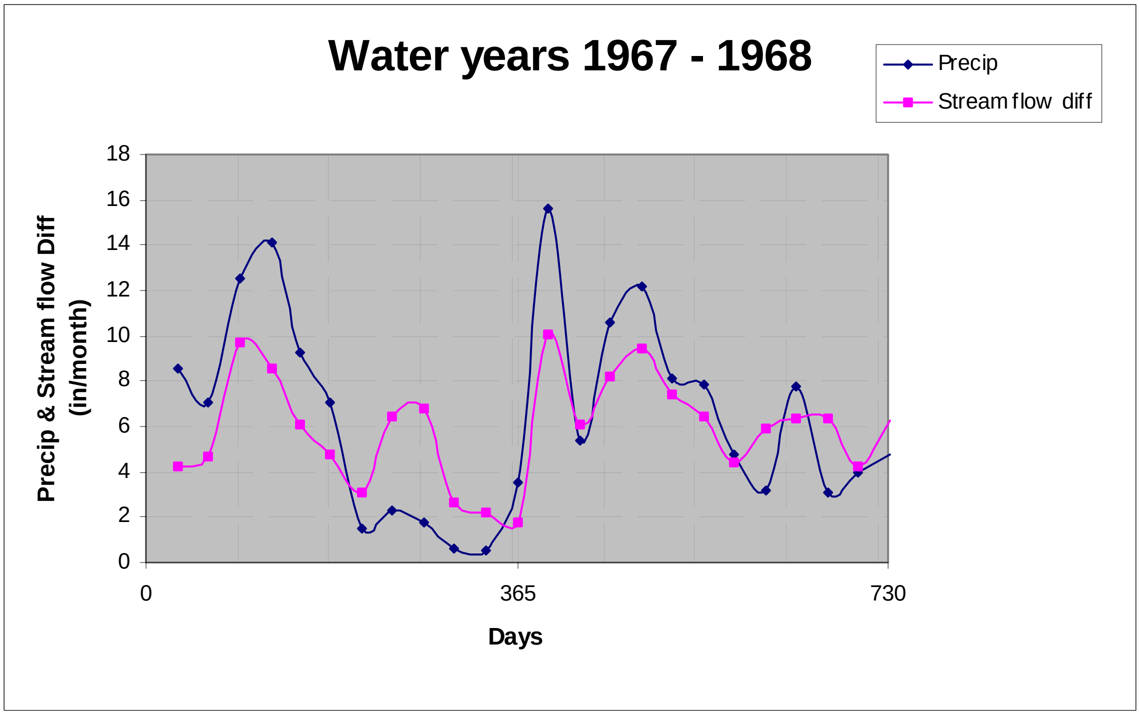

Figure 2.6.5 Precipitation and stream flow differences, 1967 - 1968

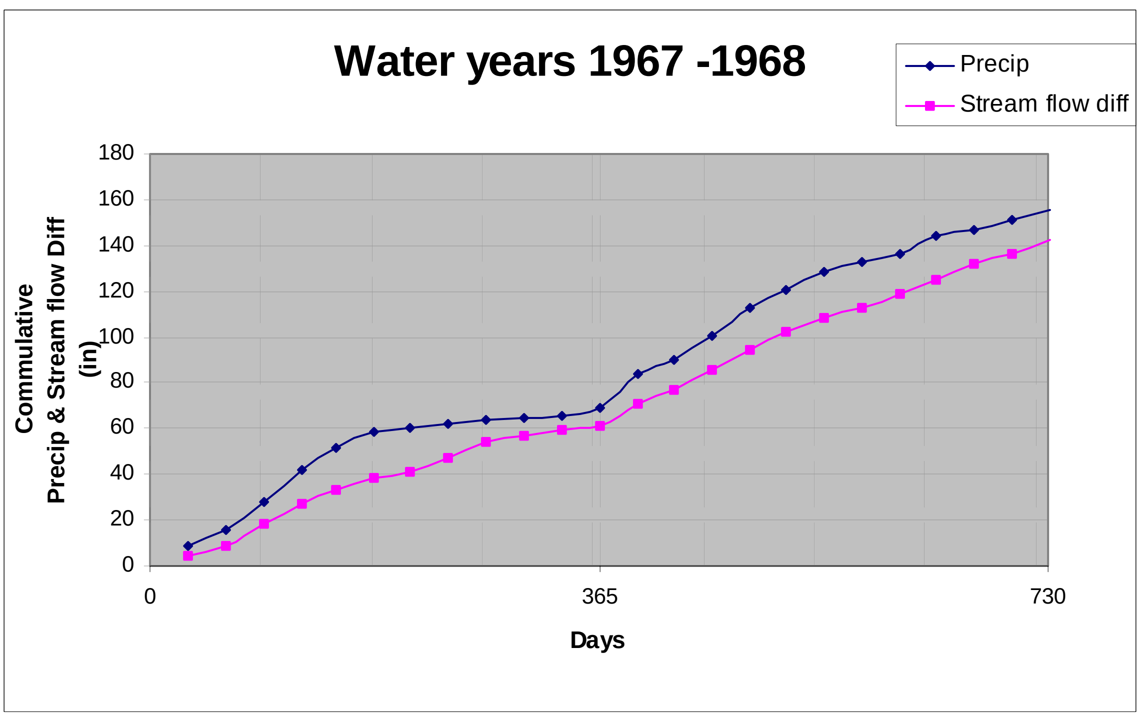

Figure 2.6.6 Cumulative precipitation and stream flow differences, 1967 - 1968

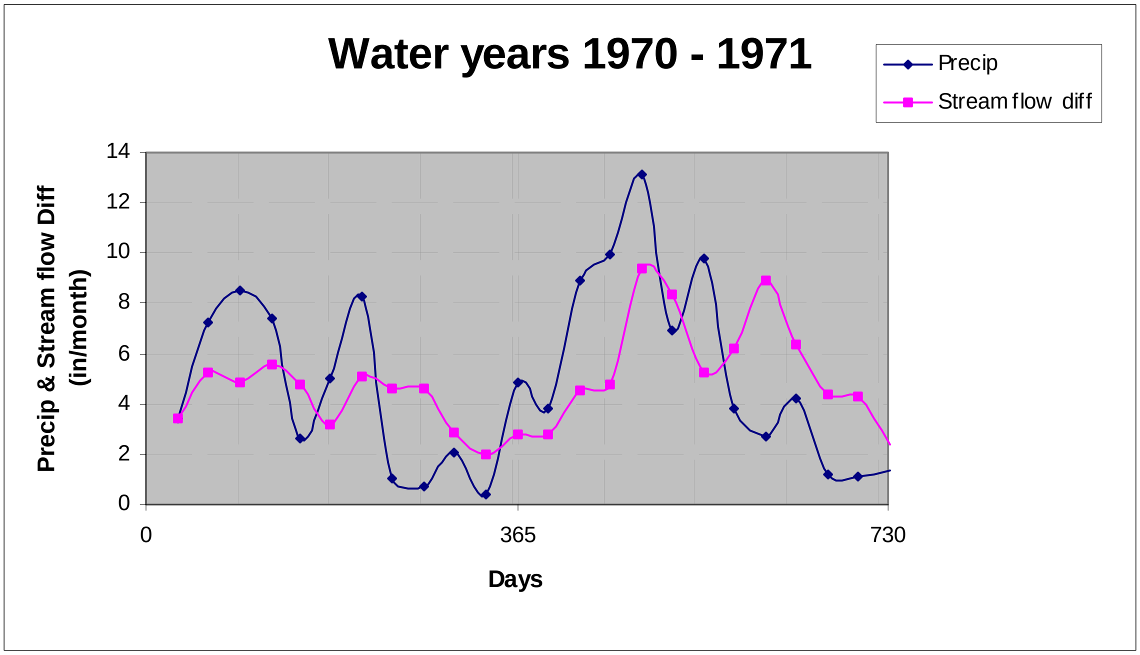

Figure 2.6.7 Precipitation and base flow differences, 1970 – 1971

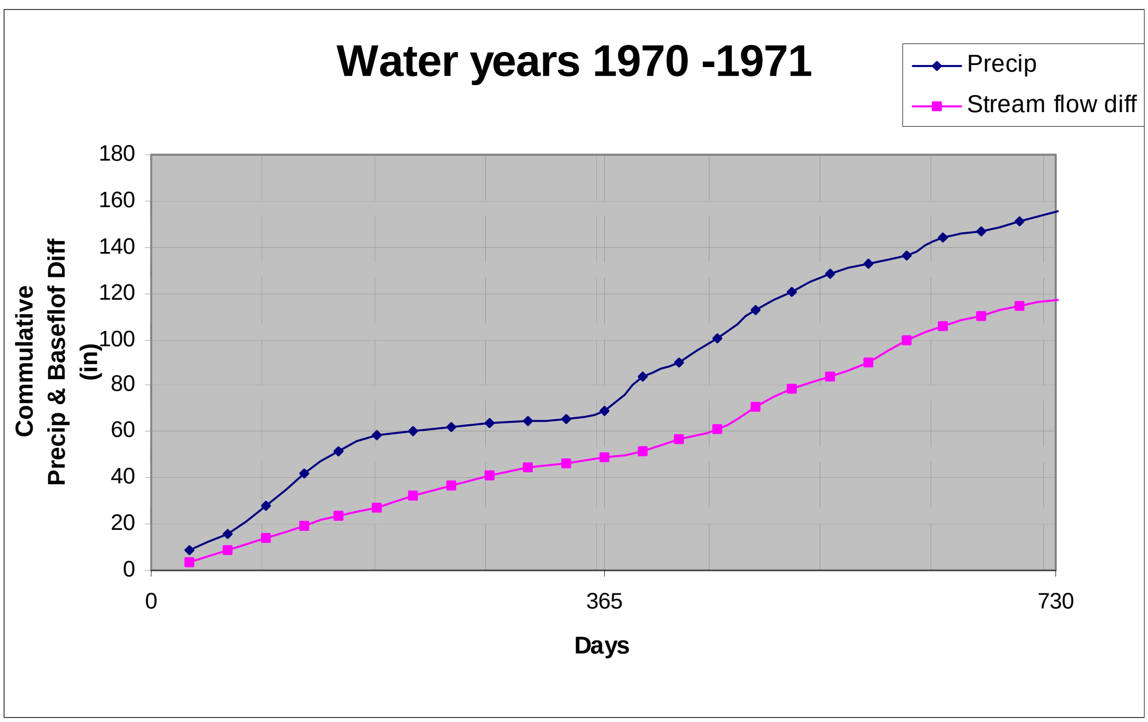

Figure 2.6.8 Cumulative precipitation and stream flow differences, 1970 - 1971

3.0 SOUTHFORK NOOKSACK WATERSHED AND AQUIFER WATER BALANCE MODEL

3.1 THE WATERSHED

The South Fork of the Nooksack River originates in the mountainous area southwest of Mount Baker (Beery, 1985). It descends to the valley below and eventually joins the main stem of the Nooksack River above the town of Deming (Washington State Division of Water Resources, 1960). Elevations range from 200 to 7,000 feet (Beery, 1995). While much of the surrounding terrain is rugged, the South Fork valley is broad and relatively flat, bordered by steep-sided foothills (Plake, 1992 and Beery, 1985). The average width of the South Fork floodplain is one and a half miles. Because of the flat nature of the valley, several of the basin areas encompass the entire width of the floodplain (Plake, 1992).

The river gradient averages 131 feet/mile. The South Fork basin receives around 100 inches of precipitation per year. The basin drains an area of 193 square miles. Drainage from the South Fork basin equals about 800,000 acre-feet per year making up about 30% of the Nooksack River's total annual discharge (Beery, 1985).

Thick sequences of glacial outwash and Glacial Marine Drift were deposited in the valleys during the periods of glaciation. Since the retreat of the last glaciation, the rivers and streams have been filling the valley with alluvial material (W.D. Purnell and Associates, 1988).

There are three river gage points with relatively long periods (20 years or more) of measurements, two of them are on South Fork Nooksack, one at Deming at the confluence where South Fork Nooksack joins the other Forks and the other more or less in the middle of the watershed with a drainage area of 103 mi^2. The third station is on Skookum Creek, with relatively smaller drainage area, 23.1 mi^2.

The following analysis considers only the upper part of South Fork Nooksack just upstream of gage station 12209000 as shown in the following Figure 3.1.1. The upper South Fork Nooksack watershed is shown in red.

3.2 BASE FLOW

The available flow at gaging station 12209000 has been separated into base flow and surface flow for the whole record. There is a continuous 40 (1936 – 1975) years of data and another 2 (1997 – 1998) years of data. While comparing with precipitation data, only those overlapping years with the precipitation data are considered. Figures 3.2.1 and 3.2.2 show the base flow plots for 1936 - 1975. For ease of visualization the continuous data has been split into two parts as shown below

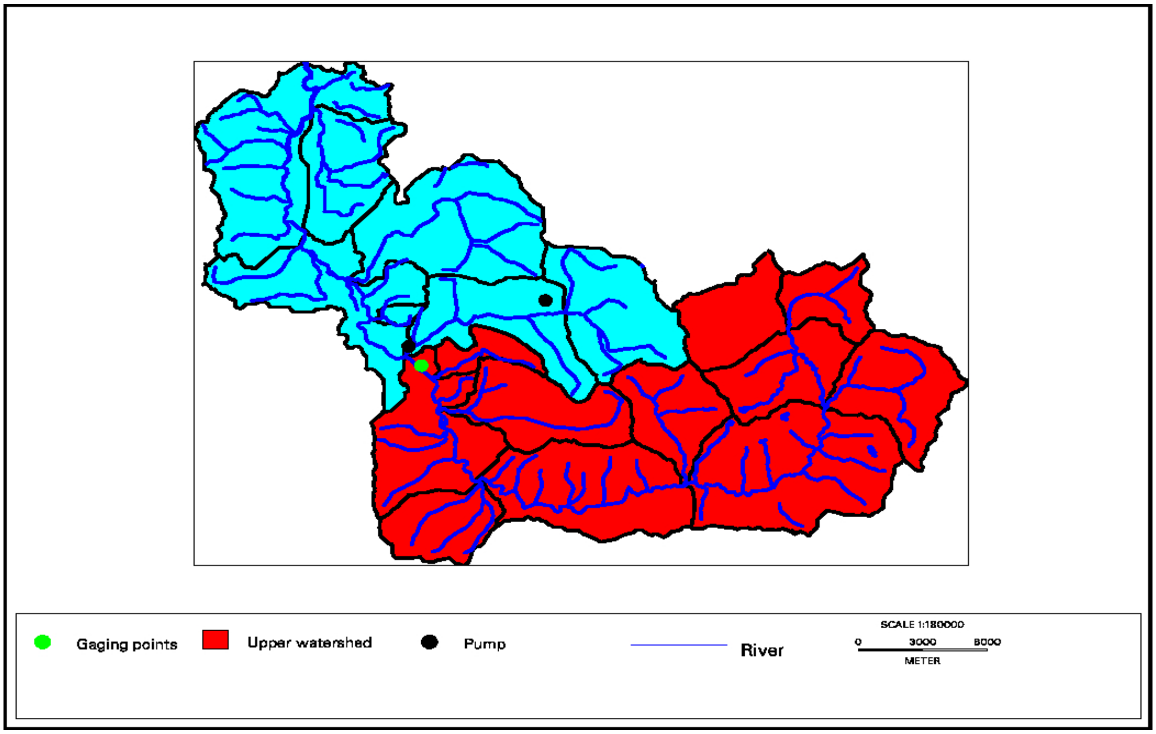

Figure 3.1.1 Watershed of South Fork Nooksack.

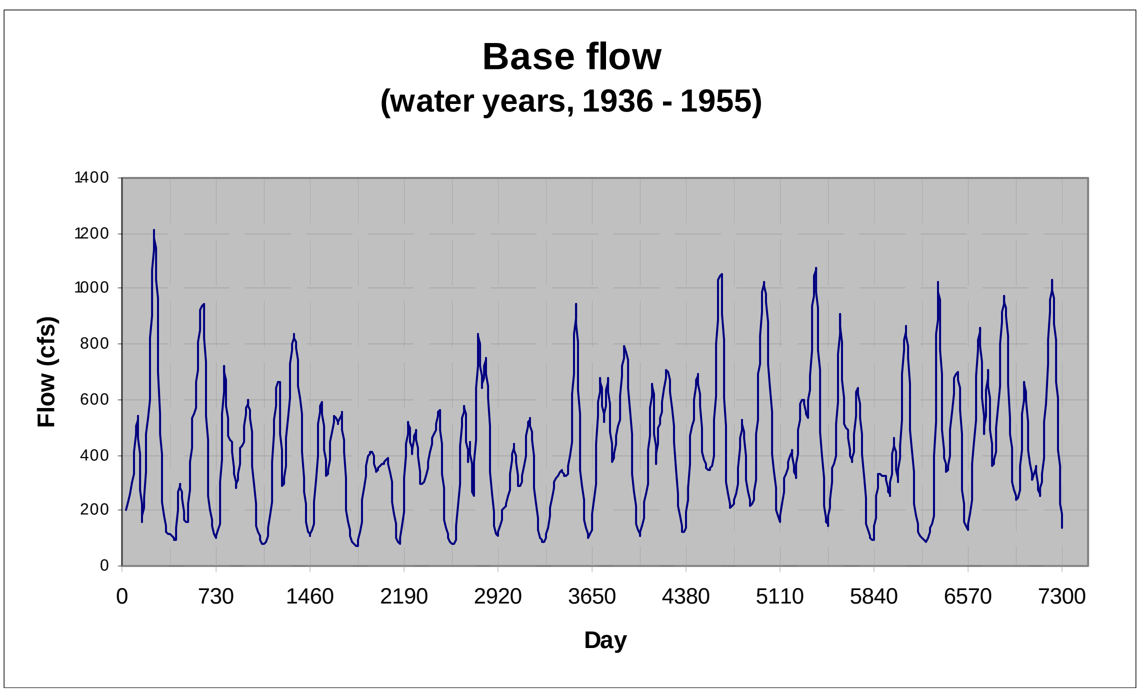

Figure 3.2.1 Base flow at gaging station 12209000, 1936 – 1955.

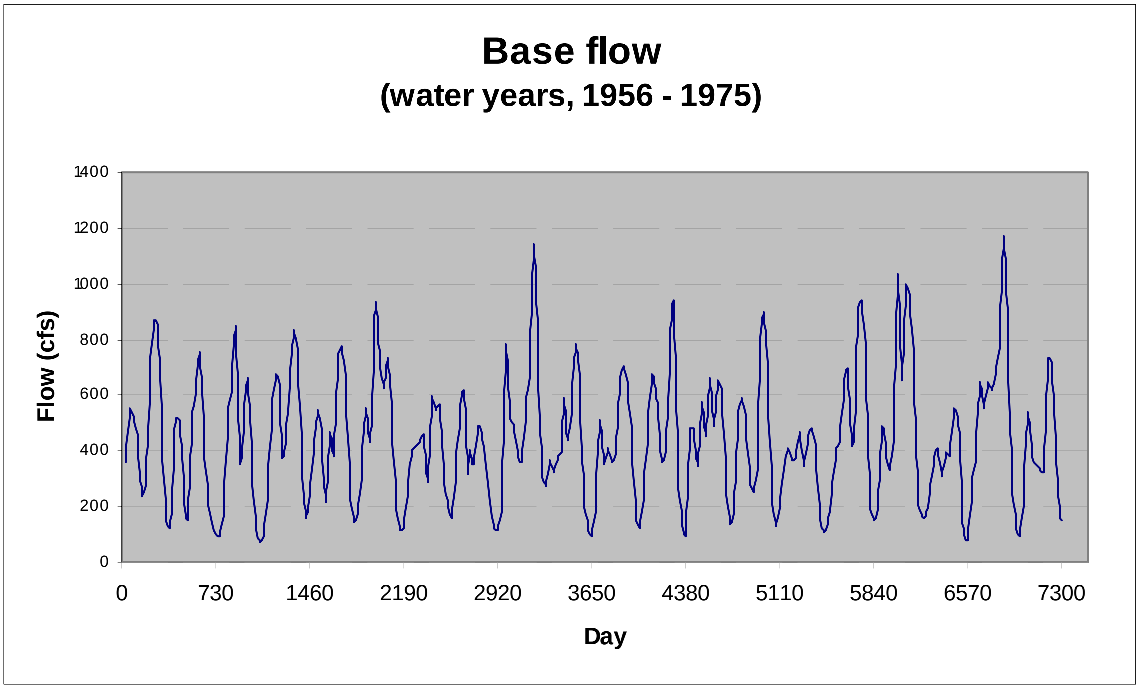

Figure 3.2.2 Base flow at gaging station 12209000, 1956 – 1975.

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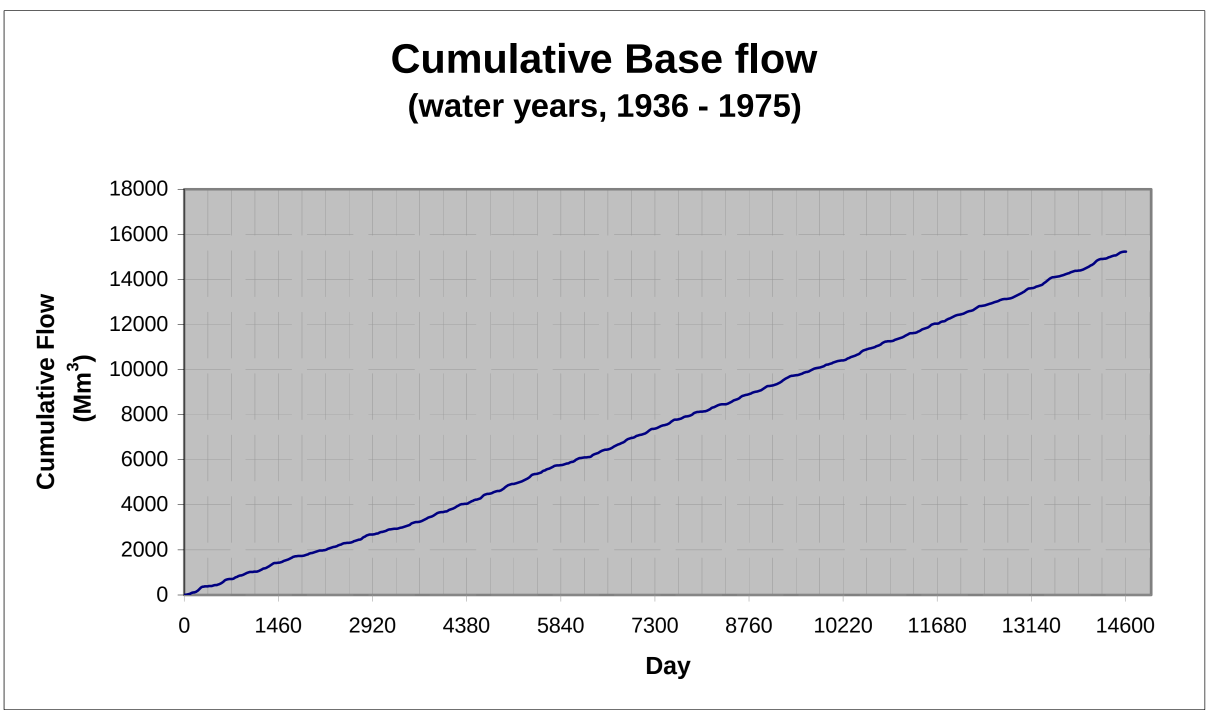

Figure 3.2.3 Cumulative base flow at gaging station 12209000

Cumulative base flow

Figure 3.2.3 shows the cumulative base flow, which is basically a straight line with constant slope. A linear regression line has been fitted whose slop is 1023423.5 m^3/day with a regression coefficient of 0.998

3.3 GROUNDWATER PUMPING

The USGS data shows that there are no pumping wells inside the upper South Fork Nooksack. Just at the mouth of the watershed there is one 500gpm pump and another 100 gpm. This leaves the pumpage in the vicinity to be 600gpm (See Figure 3.1.1).

3.4 RECHARGE

Recharge for aquifers in the shallow fluvial soils comes from the South Fork Nooksack River and percolation of surface water through the sandy soils while recharge for aquifers in glacial soils come from the south (W.D. Purnell and Associates, 1988). This parameter is the least well defined in the project area. Morgan and Jones (1995) used a value of 18in and 27in for the area of Puget Sound lowland in their groundwater model to study the effect of groundwater withdrawal on discharge to streams and springs in small basins typical of the Puget Sound Lowland.

Inverse recharge estimation

Using the recharge as an unknown in the mass balance equation, an inverse estimation for recharge can be performed using other components of the water balance. Since there are no wells that exactly fall inside the Upper South Fork Nooksack watershed, the recharge falling over the area will be directly associated with the base flow observed and this equals to an annual value of about 55 in. The precipitation slope (see below) results in an average annual value of 107 in. Therefore, the recharge in this region is about half the precipitation.

3.5 COMPARISON OF PRECIPITATION, STRREAM FLOW AND BASE FLOW

There are two precipitation stations within the vicinity of the South Fork Nooksack watershed: Elbow Lake and Upper Baker Dam. The station at Elbow Lake has insufficient data. The Upper Baker Dam station has 36 (1965 – 2000) years of data with some missing values. Comparing with stream flow records at gage station 12209000 there are two continuous periods that mach.: 9(1967 – 1975) years of data and a two year data between 1997 – 1998. Though located just outside of the South Fork Nooksack watershed, the Upper Baker Dam station can represent the precipitation at the upper part of the watershed, and is used in the following analysis.

Slopes and ratio of slopes

Water years 1967 – 1975

Precipitation	0.2939 in/day
Stream flow	0.2854 in/day
Base flow	0.1628 in/day
Precipitation/Stream flow	1.03
Precipitation/Base flow	1.81

Water years 1997 – 1998

Precipitation	0.8986 in/day
Stream flow	0.3346 in/day
Base flow	0.1903 in/day
Precipitation/Stream flow	2.69
Precipitation/Base flow	4.72

The ratios obtained for the short period of time (1997 – 1998) are significantly higher than those for the long term. Figures 3.5.1 – 3.5.8 shows plots of precipitation comparison to stream flow and base flows for the two measurement periods. We believe that the results obtained for the long period (1967 – 1975) are more representative of the average steady – state behavior of the watershed system.

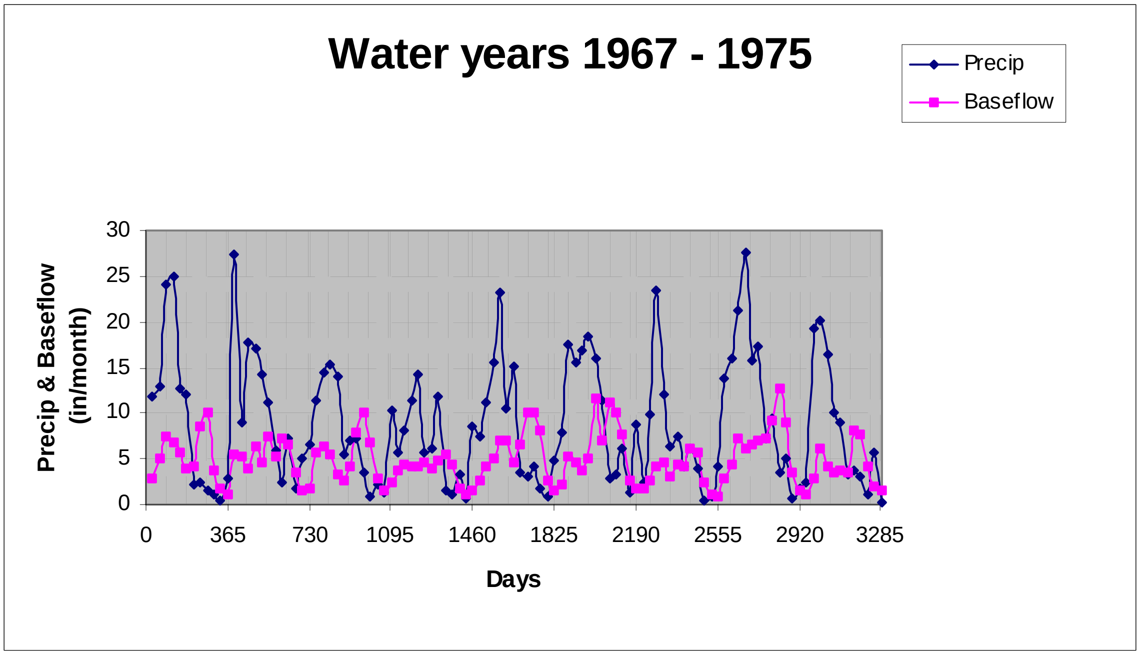

Figure 3.5.1 Precipitation/Base flow comparison, 1967 – 1975

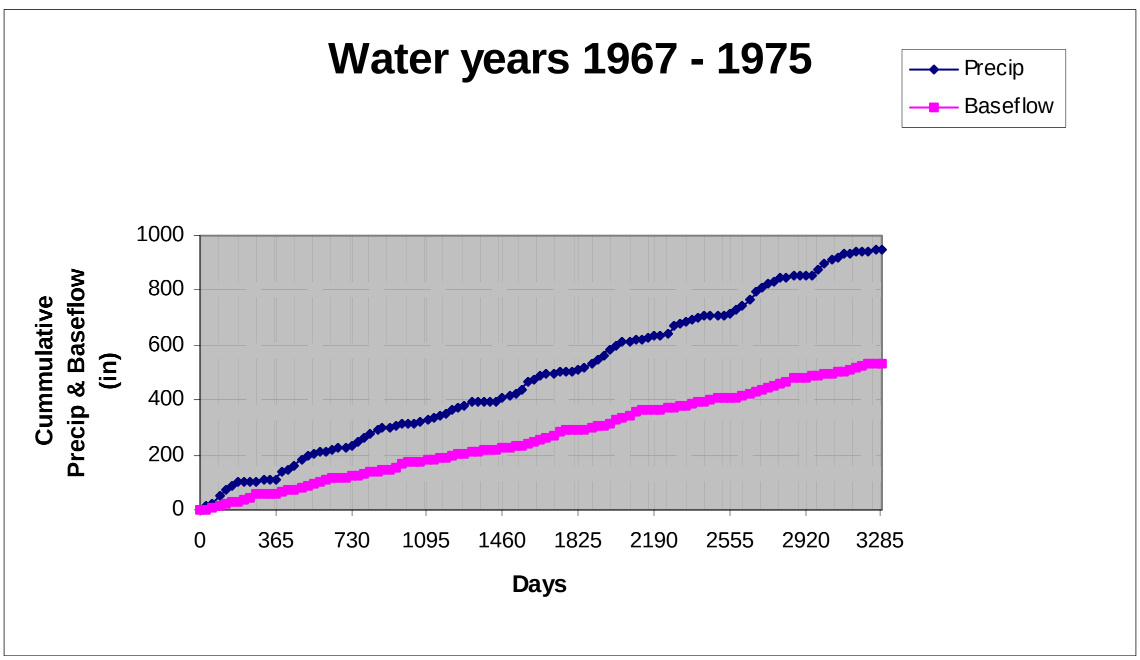

Figure 3.5.2 Precipitation/Cumulative base flow comparison, 1967 – 1975

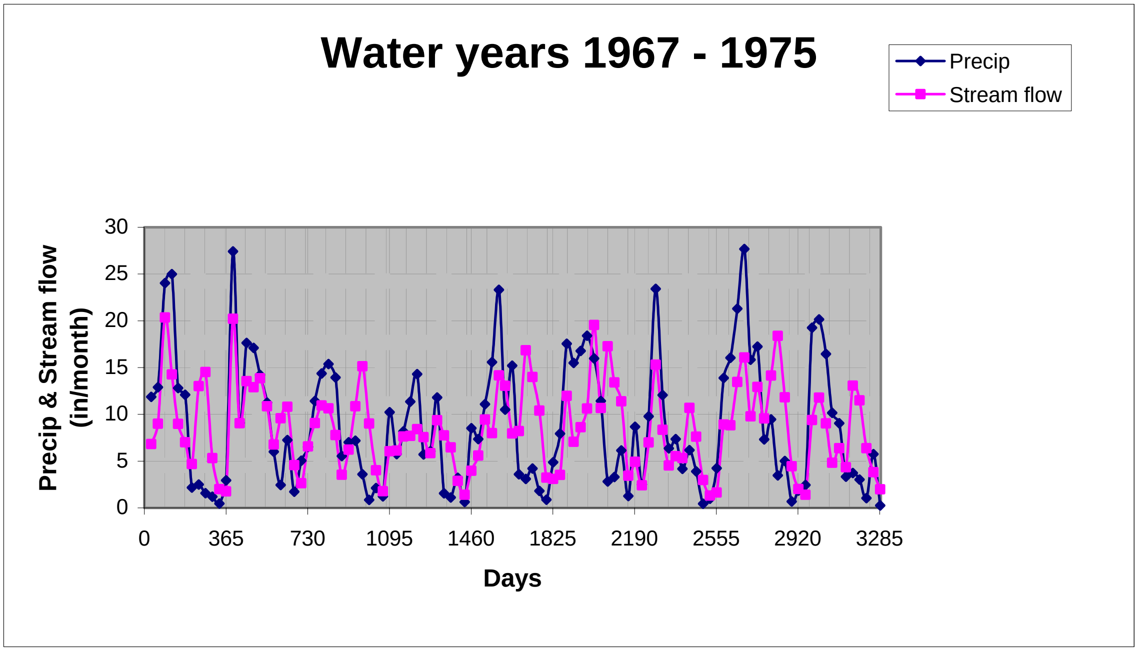

Figure 3.5.3 Precipitation/Stream flow comparison, 1967 – 1975

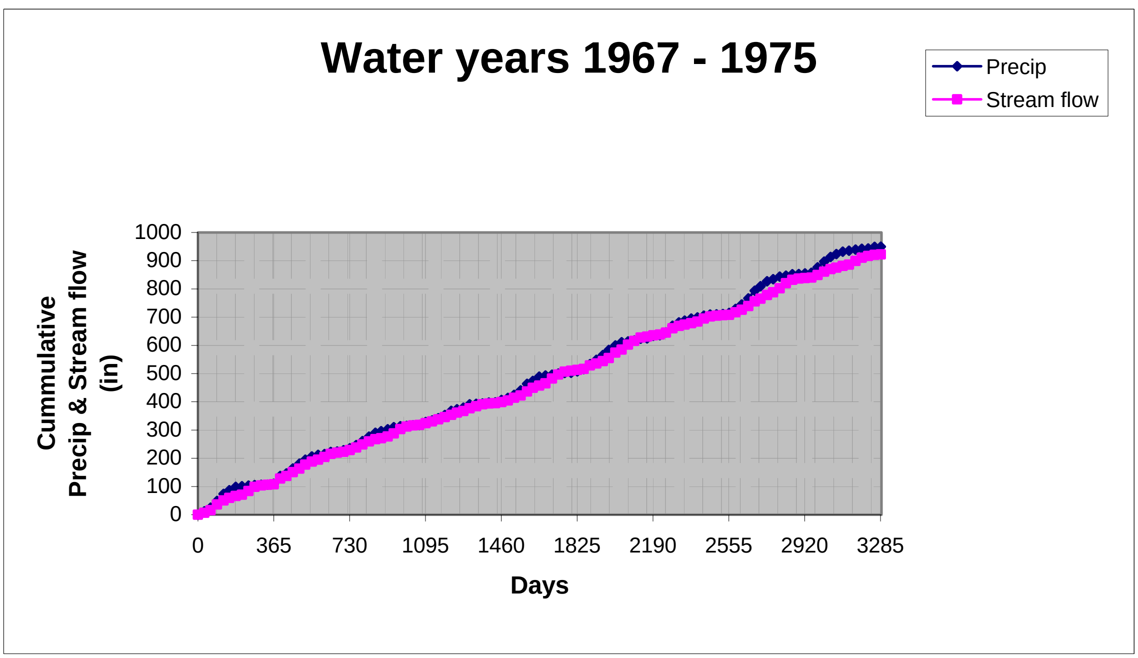

Figure 3.5.4 Precipitation/Cumulative stream flow comparison, 1967 – 1975

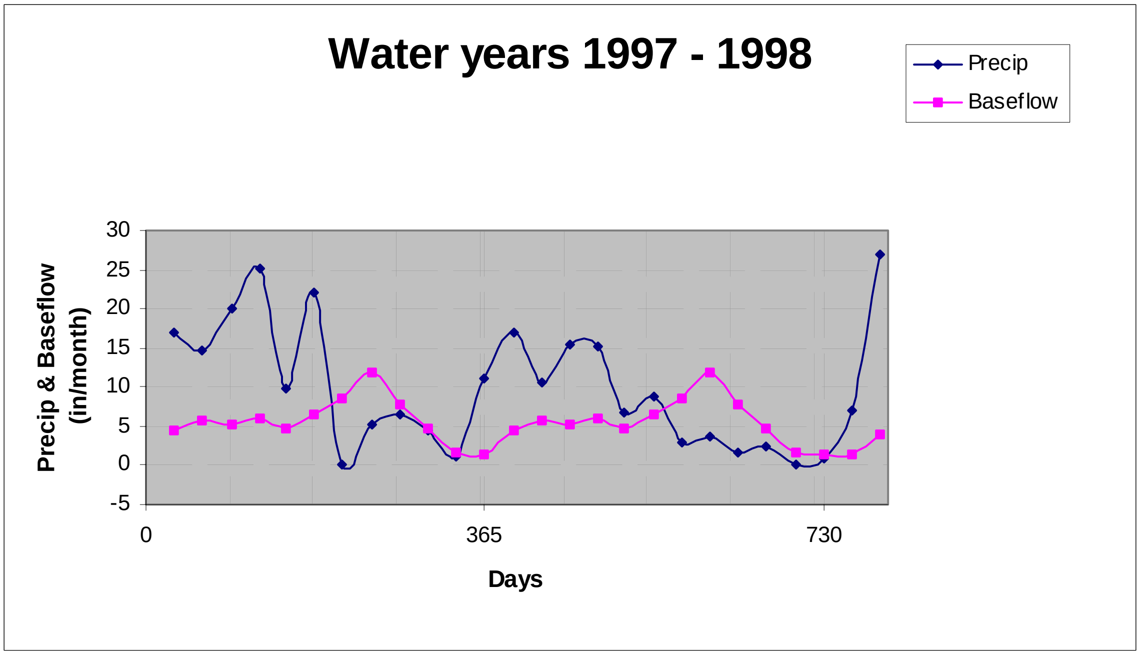

Figure 3.5.5 Precipitation/Base flow comparison, 1997 – 1998

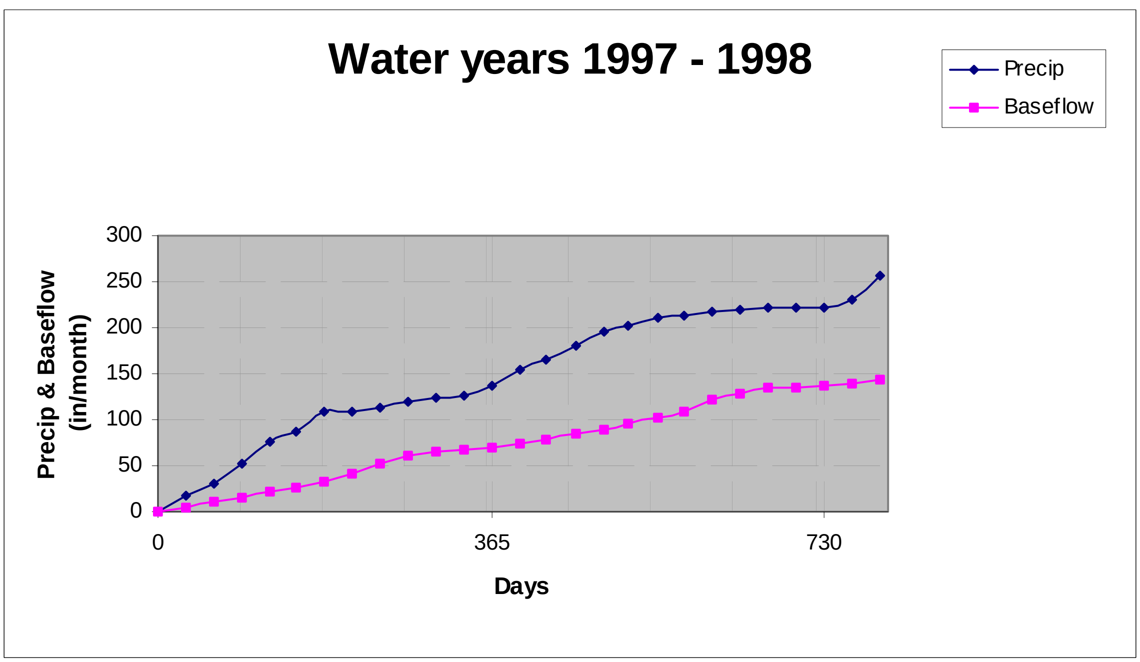

Figure 3.5.6 Precipitation/Cumulative base flow comparison, 1997 – 1998

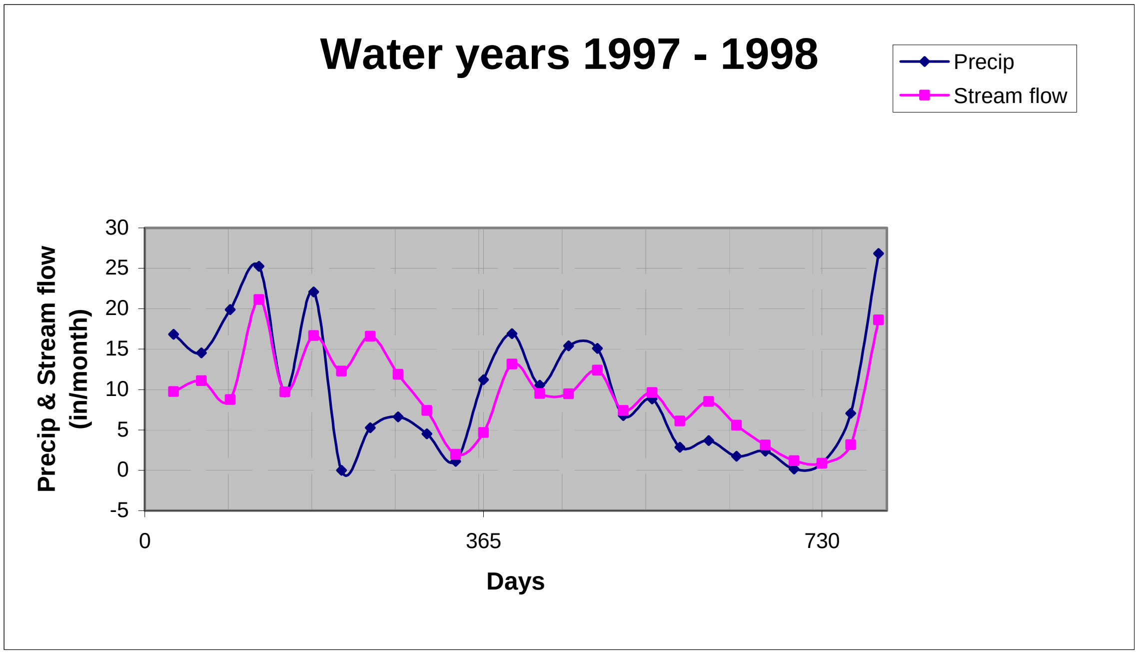

Figure 3.5.7 Precipitation/Stream flow comparison, 1997 – 1998

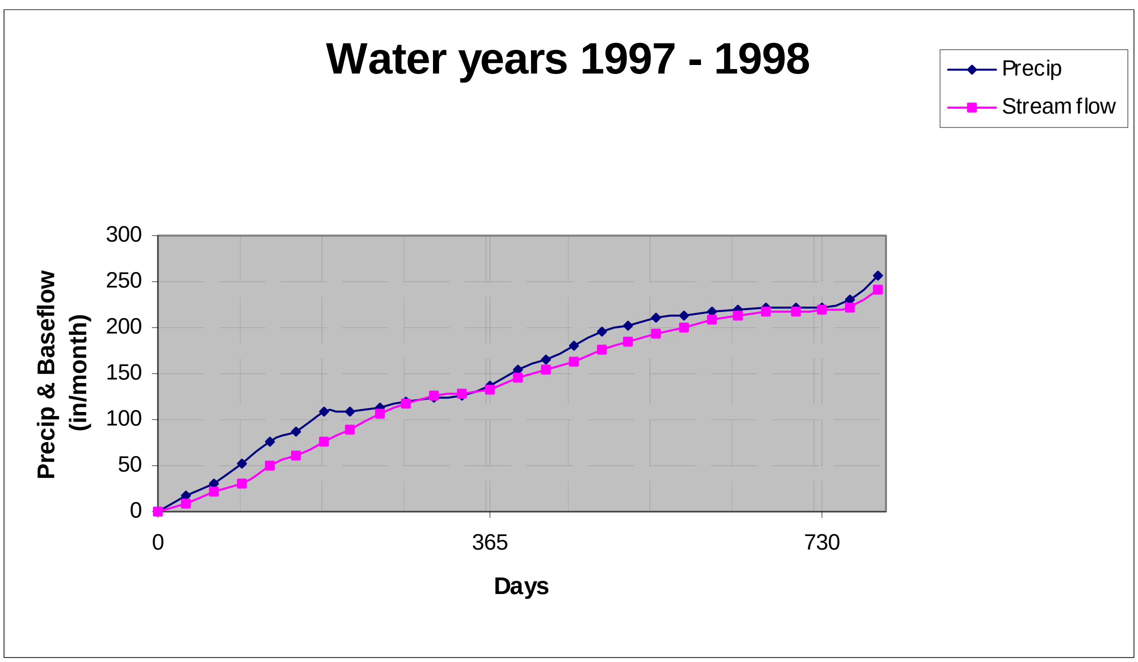

Figure 3.5.8 Precipitation/Cumulative stream flow comparison, 1997 – 1998

In looking Figures 3.5.4 and 3.5.8 one has to keep in mind two things: 1) the precipitation station is just outside of the South Fork watershed and may not be 100% representative of the precipitation that would be received by the upper South Fork watershed; 2) precipitation value at Upper Baker Dam station is a point value while the stream flow is an integrated catchment response; and 3) in areas like South Fork where there a big difference in topography within relatively short distance one might expect a higher variation on amount of precipitation received within a watershed.

3.6 SEEPAGE RUNS

The seepage runs on South Fork Nooksack River is done by USGS. There are four days in which measurements are taken. These are 8/25/98, 8/26/98, 9/29/98 and 9/30/98. The measurements along the river are done with a day difference at selected locations. Here, the analysis is done on two ways: aggregating the two days measurements and single day analysis. Note that on some days (8/25/98 and 9/30/98) the data do not cover the whole South Fork Nooksack River.

Case 1 *Aggregating the one-day different measurement.*

This case ignores the variation on the daily flow measurements because of a day difference. Figure 3.6.1 and 3.6.2 shows the seepage runs for aggregated seepage run. The triangular dot plots on these Figures show the locations of tributaries joining the river. These tributaries were obtained from the hydrography GIS layer and may not necessarily be having flows during the measurement time.

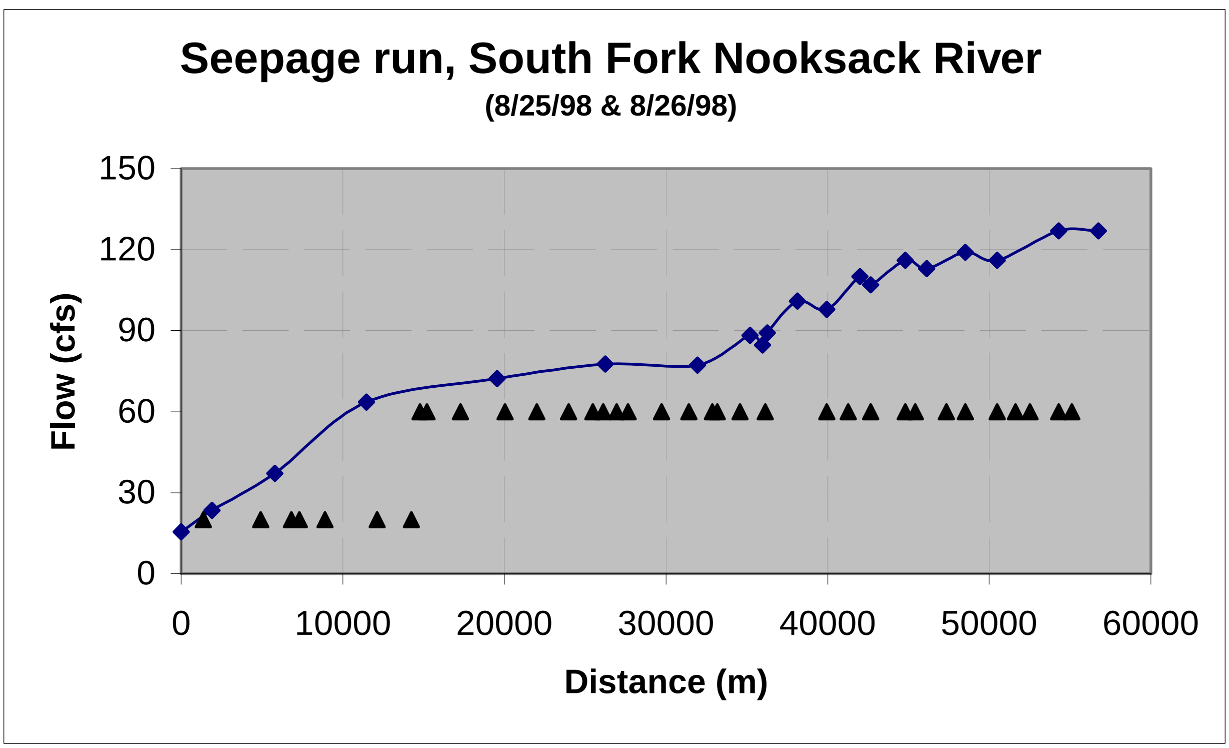

Figure 3.6.1 Seepage run for South Fork Nooksack River, 8/25/98 and 8/26/98.

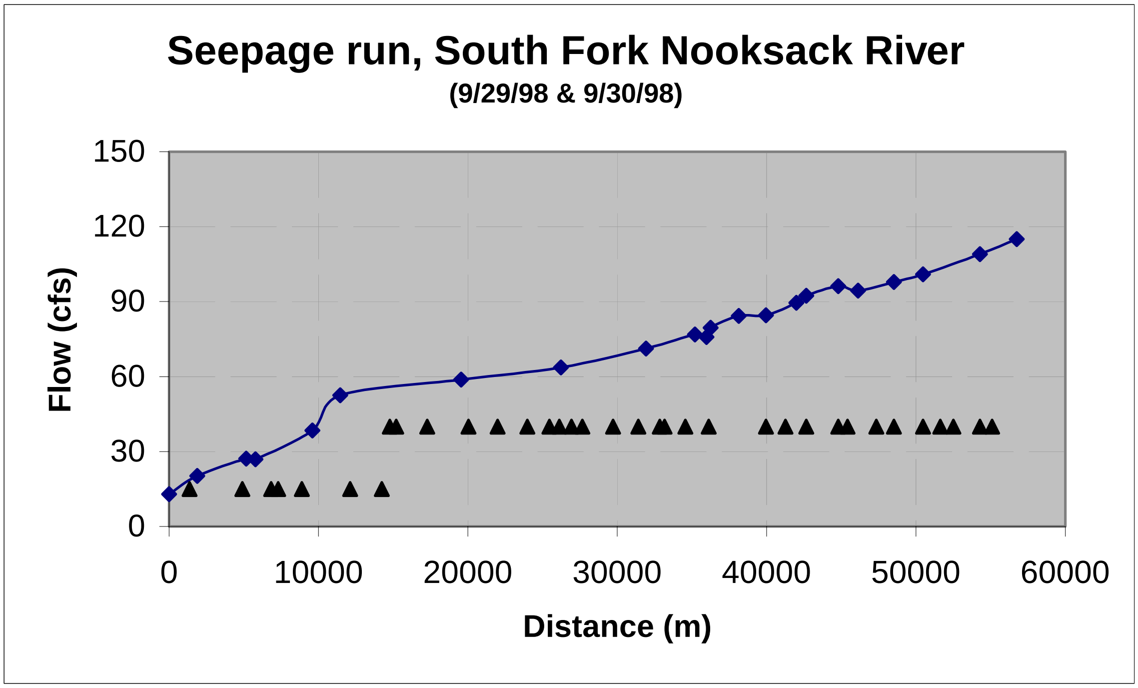

Figure 3.6.2 Seepage run for South Fork Nooksack River, 9/29/98 and 9/30/98.

Assuming a linear stream flow production along the river, the stream flow per unit mile is found to be 3.0571 cfs/mi (cubic feet per second per mile) for 8/25/98 and 8/26/98; and 2.57 cfs/mi for 9/29/98 and 9/30/98. The average is 2.81 cfs/mi. In general, the rive shows as a gaining stream even though there are local losing reaches as shown in the above figures.

Case 2 *Individual day measurements*

Here, each day measurements have been considered independently. Figure 3.6.3 - 3.6.6 shows the seepage run plots for this case.

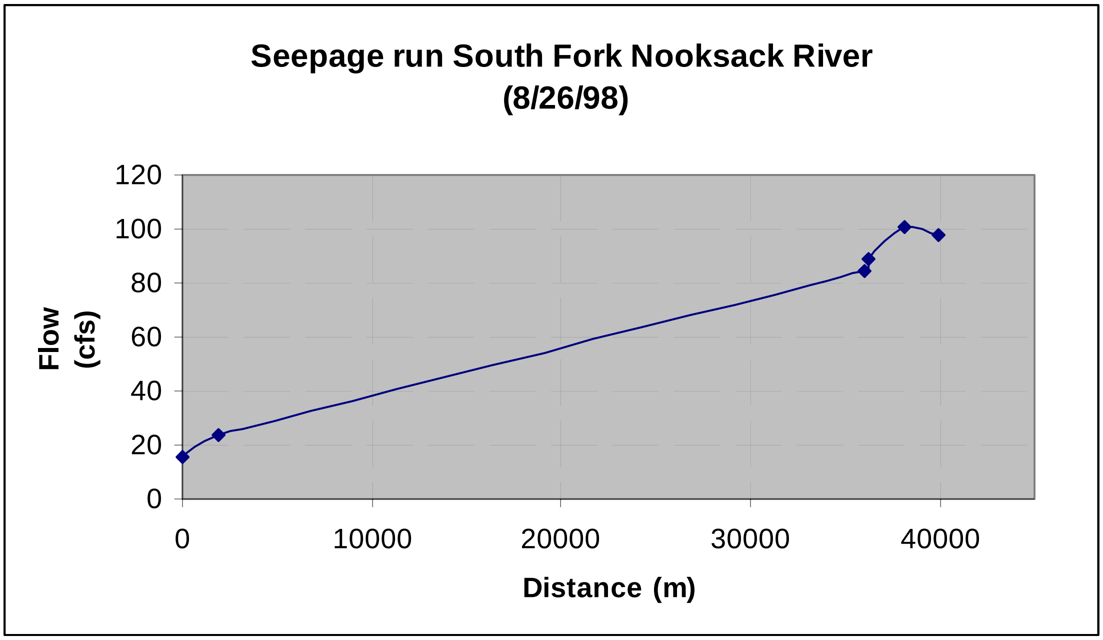

Figure 3.6.3 Seepage run for South Fork Nooksack River, 8/29/98.

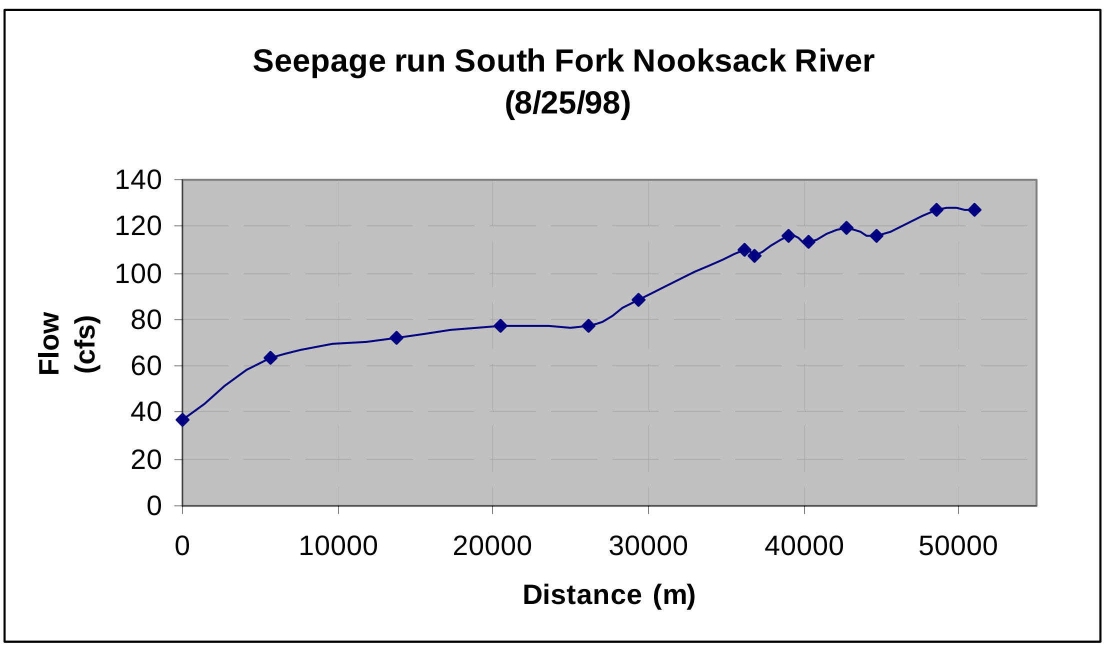

Figure 3.6.4 Seepage run for South Fork Nooksack River, 8/25/98.

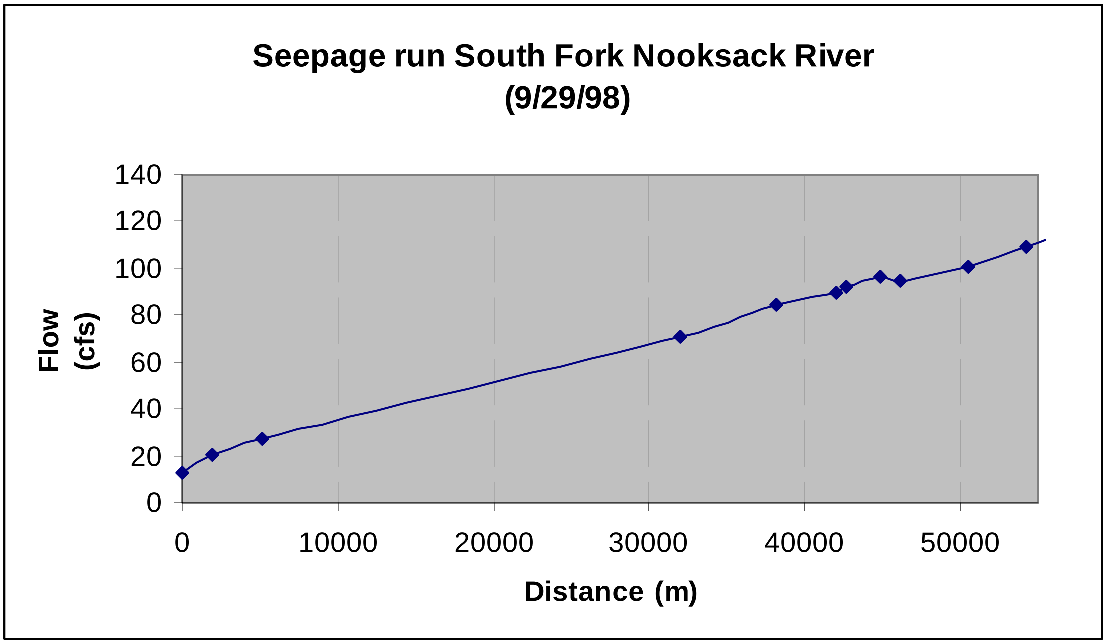

Figure 3.6.5 Seepage run for South Fork Nooksack River, 9/29/98.

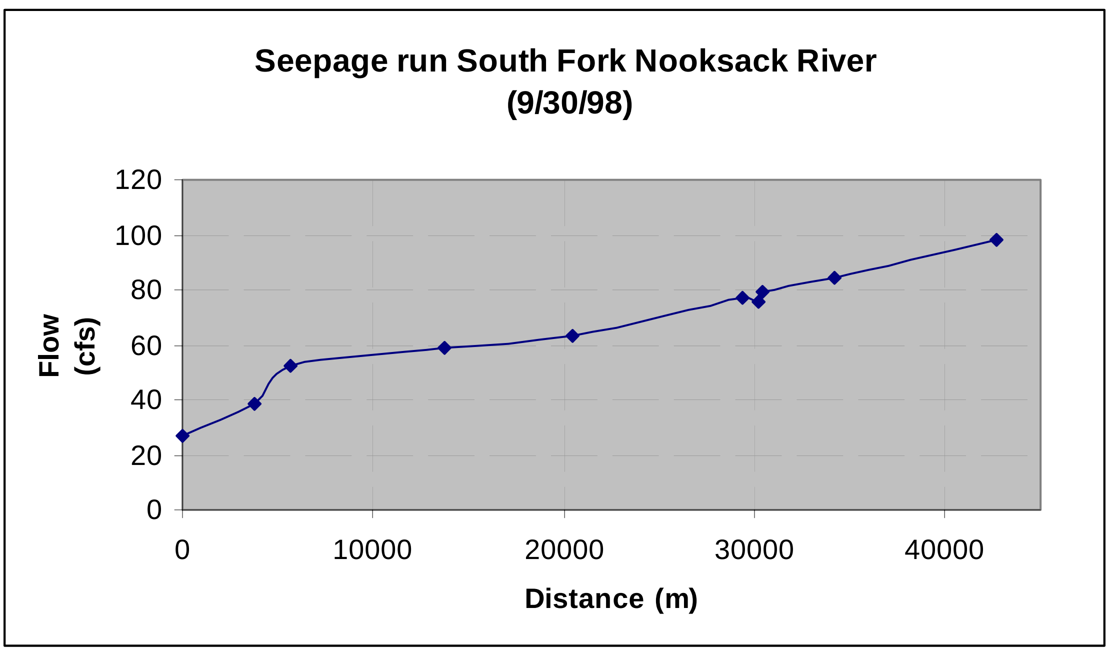

Figure 3.6.6 Seepage run for South Fork Nooksack River, 9/30/98.

The stream flows per unit length are found to be 2.735 cfs/mi, 3.218 cfs/mi, 2.735 cfs/mi, 2.414 cfs/mi for 8/25/98, 8/26/98, 9/29/98 and 9/30/98 respectively. The average is 2.78 cfs/mi.

4.0 THE MIDDLE NOOKSACK WATERSHED AND AQUIFER WATER BALANCE MODEL

4.1. THE WATERSHED

This area includes the watershed that belongs to the stretch of Nooksack river which starts near Deming where the North, Middle and South Fork Nooksack rivers meet, and ends near Lynden as shown in Figure 4.1.1. The two sections gages are selected because they have relatively longer period of measurements. The following map shows the area. It has a drainage area of 183.533km^2.

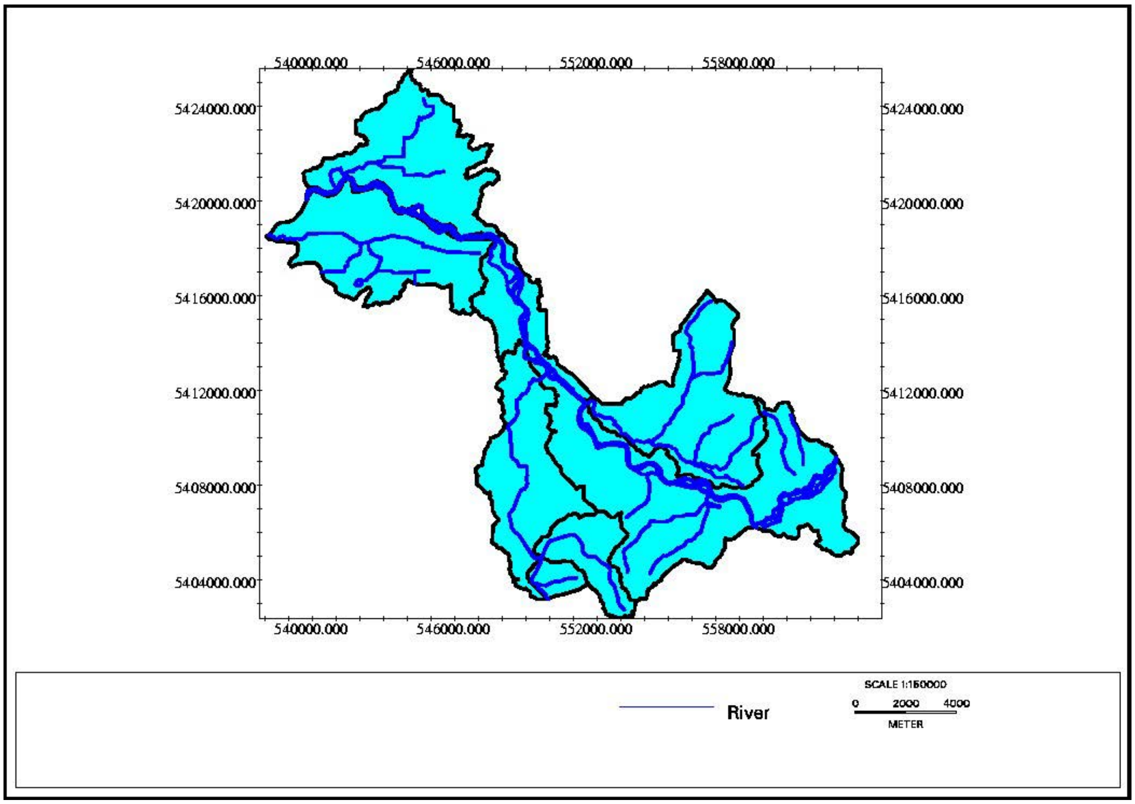

Figure 4.1.1 The middle stretch watershed.

4.2. BASE FLOW

For the middle stretch two gaging stations have been used with relatively long periods of measurements. One is located below the confluence at Deming. This station (Station # 12210500) has record for 1935 – 1957 and 1964-present, with a drainage area of 584mi^2 (1511.9km^2). The other station is at Lynden (Station # 12211500), with drainage area of 648mi^2(1677.6km^2). It has a record for 1945-1967.

The calculated contributing area between these two points of measurement is 165.688km^2. This is different from the area estimated using the digital elevation model.

Base flow analysis has been divided into two parts: 1946 – 1957 and 1964 – 1967 water years for which common years of data are available for the above stations.

Water years 1946 – 1957

This is the longer period of the two. Base flow plots are shown below. Figure 4.2.1 shows the base flows at Lynden and Deming. Figure 4.2.2 and Figure 4.2.3, respectively, show the base flow differences and cumulative differences between these two stations. Multiplying the monthly flow differences by the respective number of days and adding them find the cumulative differences.

A linear regression line has been fitted to the data whose statistics is shown below. The line is forced to pass through the origin.

Slope	=333618.3 m^3/day
Standard deviation of the slope	=11037.5 m^3/day
Coefficient of regression	=0.49

The regression lines with a slope shifted by twice the standard deviation on both sides are also shown on Figure 4.3.3.

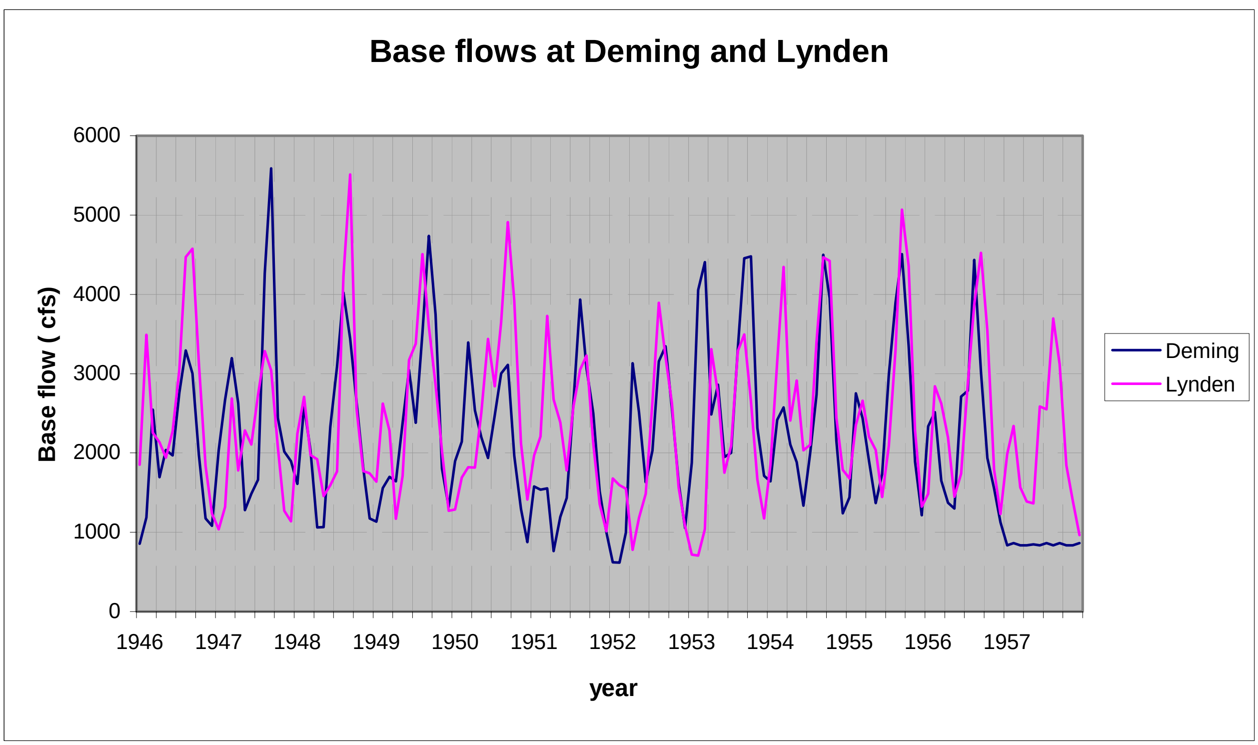

Figure 4.2.1 Base flow at Lynden and Deming.

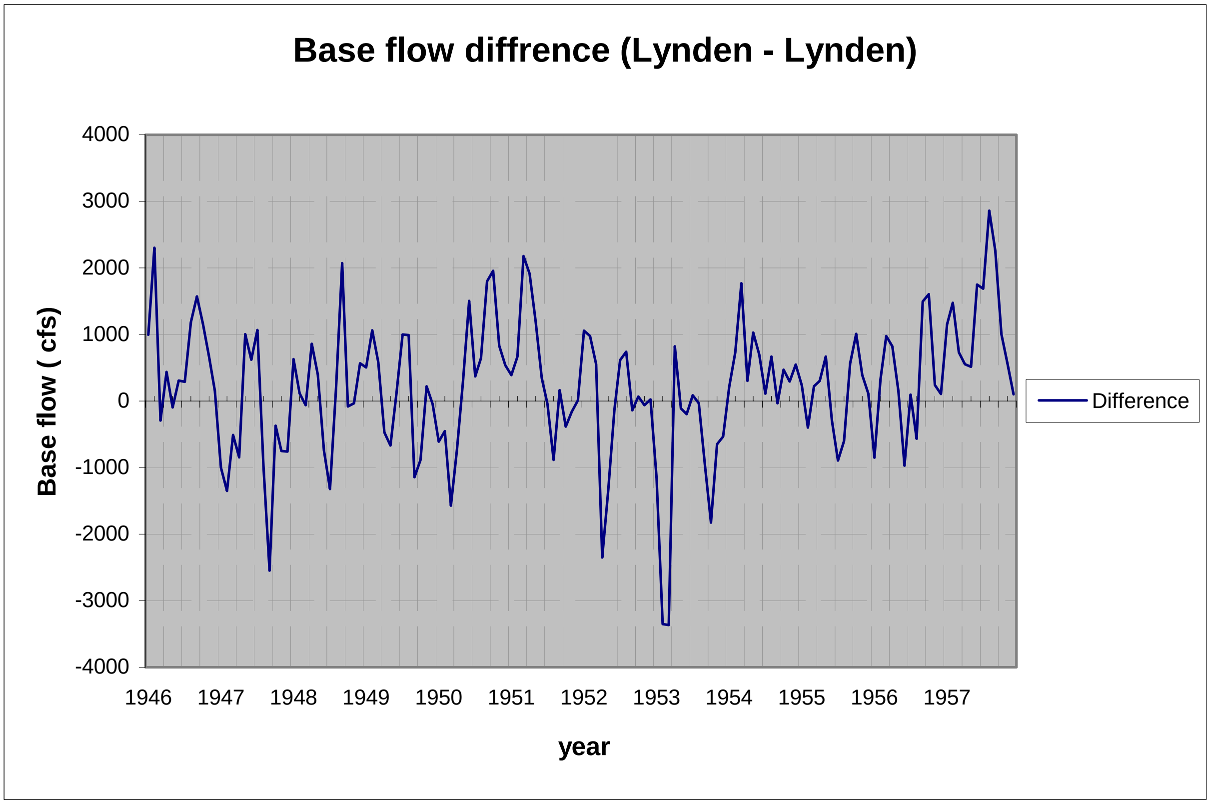

Figure 4.2.2 Base flow difference between Lynden and Deming.

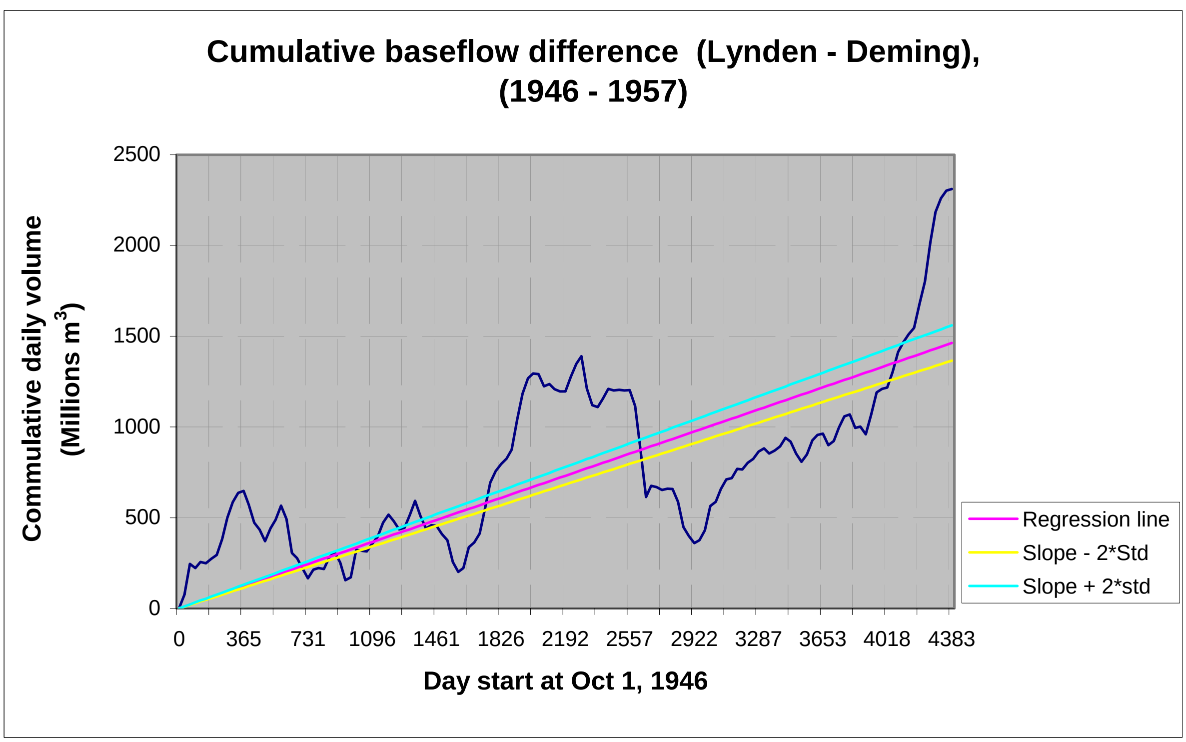

Figure 4.2.3 Cumulative base flow difference

Water years 1964 – 1967

The short period of flow observed in this segment of recorded data have shown greater fluctuations making the regression line fitting difficult. The cumulative base flow differences have shown a steeper slope in the first part of the record and then it becomes approximately constant (which implies zero base flow). Figure 4.2.4 shows base flow observation at Lynden and Deming for this period. Figure 4.2.5 shows the base flow differences between these two stations in cubic feet per second.

Two cases are analyzed for this part of observation.

Case 1

The period 1964 – 1967 is taken as one continuous event. A regression line is fitted for the cumulative daily flow, which is depicted on Figure 4.2.6 also shown are the slope±2*Std lines. The statistics of the slope is as follows:

Slope	=750240.7 m^3/day
Standard deviation of the slope	=55921.3 m^3/day
Coefficient of regression	=0.57

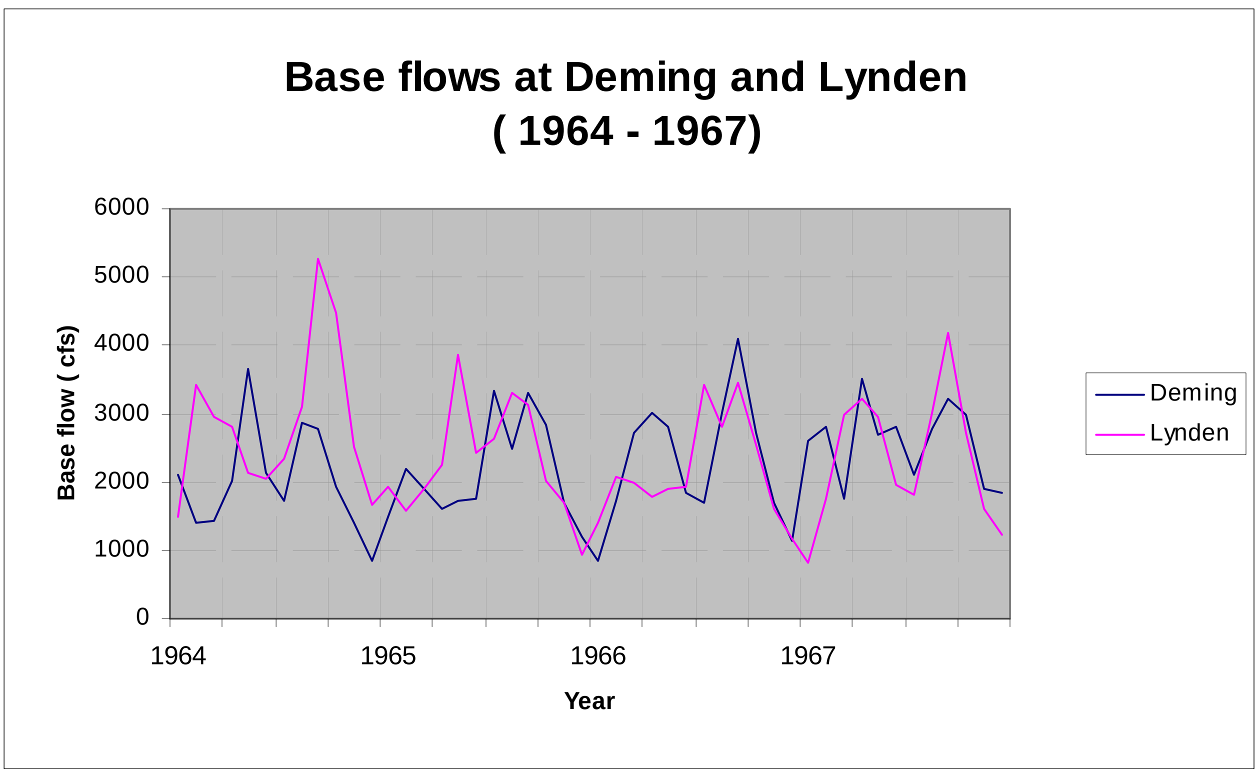

Figure 4.2.4 Base flow observation at Deming and Lynden stations

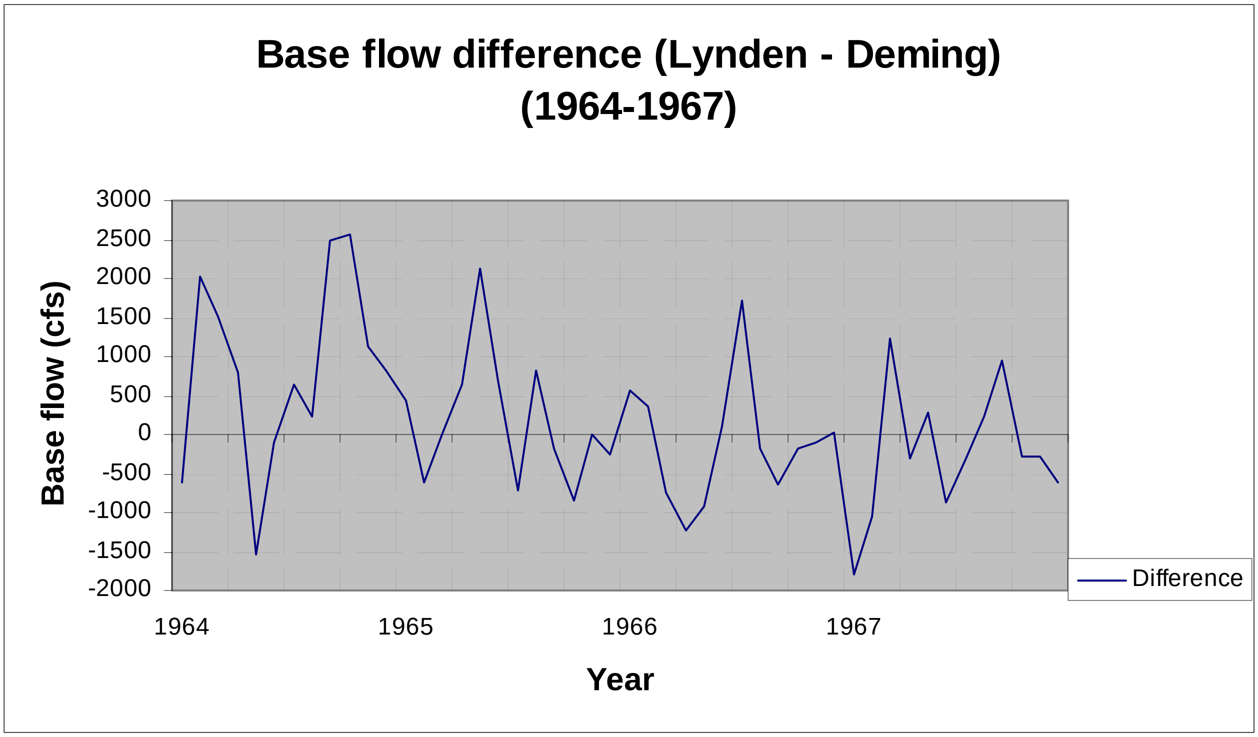

Figure 4.2.5 Base flow differences between Lynden and Deming

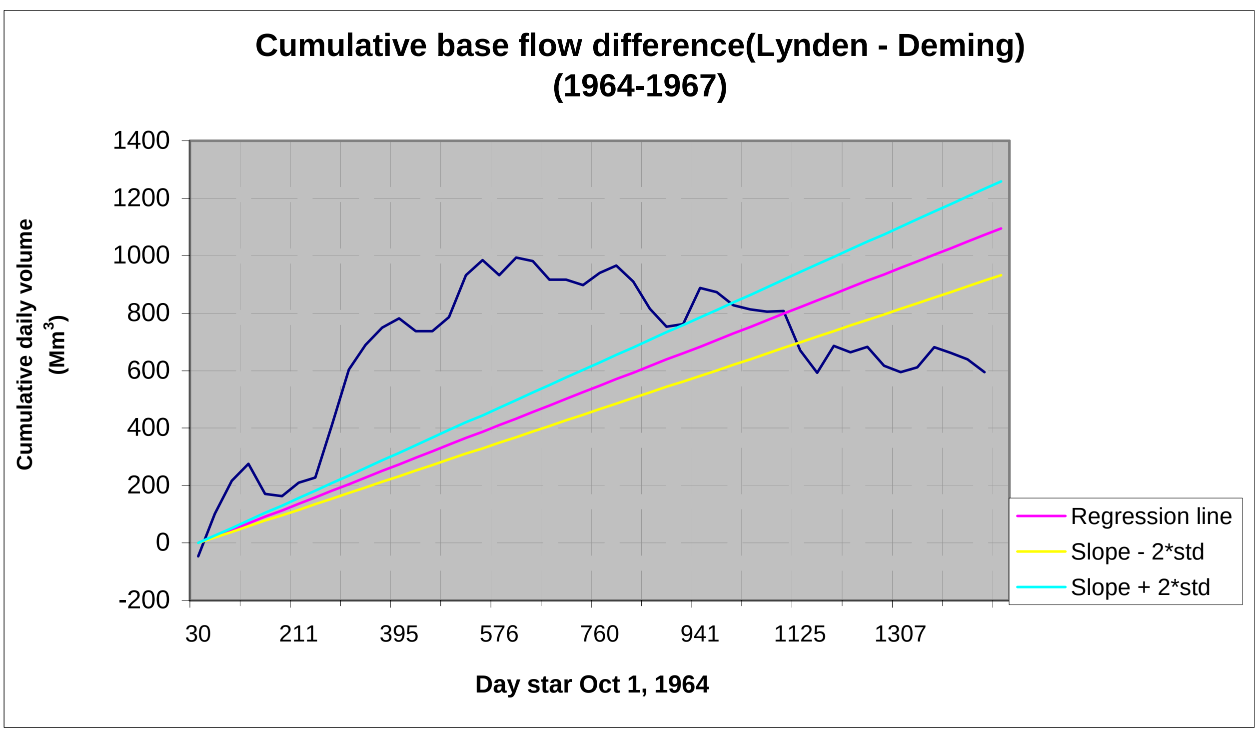

Figure 4.2.6 Regression line fitted on cumulative base flow difference

The slope obtained here is more than twice that of the water years 1946 – 1957. This shows a relatively higher variation on this piece of record.

Case 2

In this case the observed water years are split into two parts following the break in the slope of the cumulative base flow difference between Lynden and Deming. This results in two water years each containing two years. These are 1964, 1965 and 1966, 1967. A regression line is fitted for both segments and is shown, respectively, in Figures 4.2.7 and 4.2.8. The slopes statistics are as follows.

Water year 1964, 1965

Slope	=1560455.11 m^3/day
Standard deviation of the slope	=56494.04 m^3/day
Coefficient of regression	=0.88

Water year 1966, 1967

Slope	= - 476044.54 m^3/day
Standard deviation of the slope	=57428.07m^3/day
Coefficient of regression	=0.76

The slope of the water years 1964, 1965 is about five times that of the years 1946-1957. The slope of the water years 1966 and 1967 is almost the same as that of the 1946-1957, but with the negative sign.

As will be shown later the inverse recharge estimation used the slope derived for water years 1946 -1957 as it is the one with the longer data record.

4.3. GROUNDWATER PUMPING

There are 202 water withdrawal wells. Out of these only 86 have data about the withdrawal, 116 of them do not.

The total withdrawal rate for these wells is 15,025 gal/min
(= 15,025*0.003787*60*24*365 = 29.906Mm^3)

There are wells just outside the surface watershed boundary. These wells are not included in the above calculation.

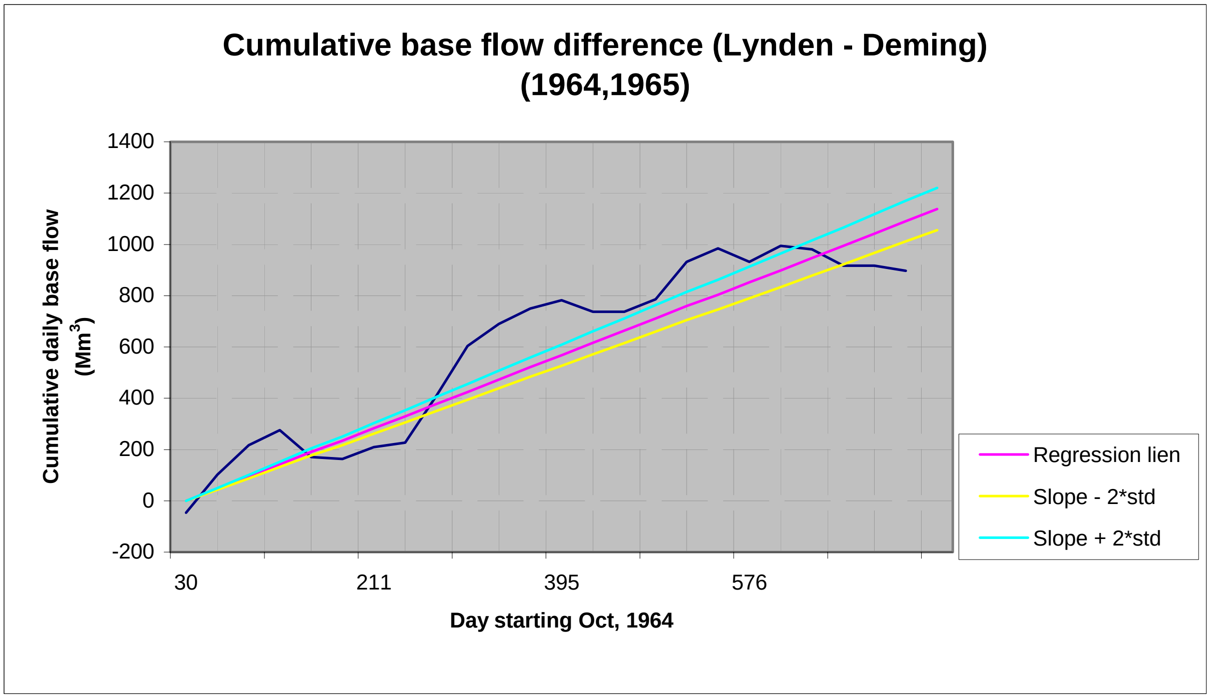

Figure 4.2.7 Regression line fitted to base flow differences at Lynden and Deming (1964,1965)

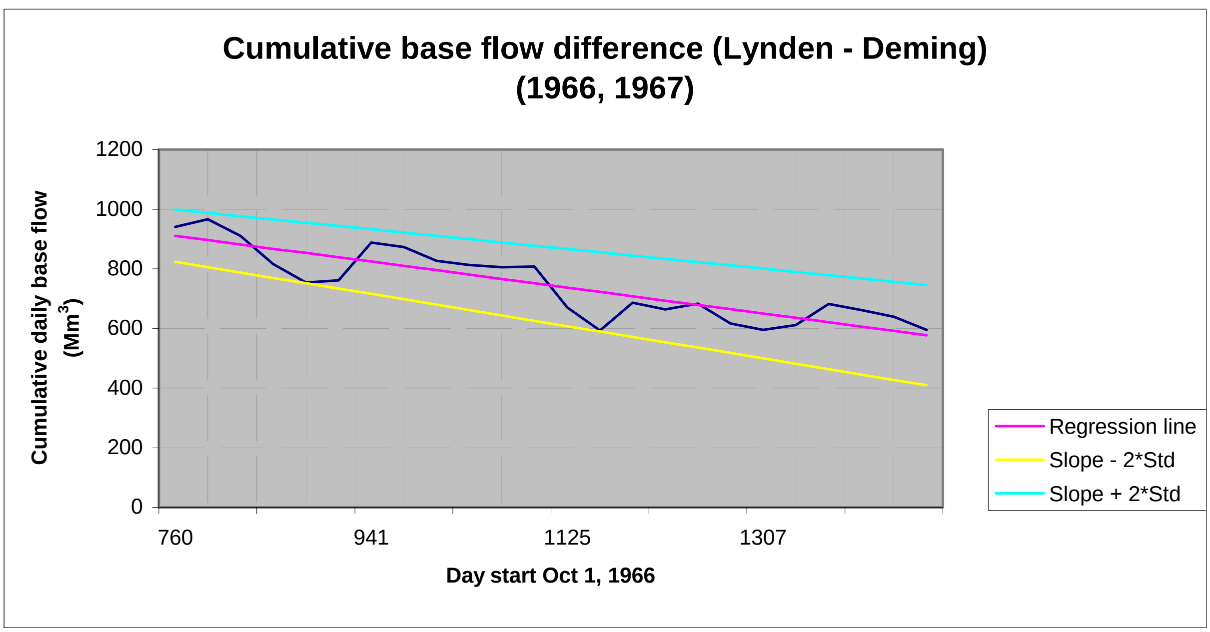

Figure 4.2.8 Regression line fitted to base flow differences at Lynden and Deming (1966,1967)

4.4. RECHARGE

The lower part of the middle stretch is included in the LENS study report (Cox and Kahle, 1999). Hence recharge values are taken from the report. These values also extended to the upper part of the middle stretch.

Based on the recharge map provided in the LENS study area the following recharge map is produced for the middle stretch.

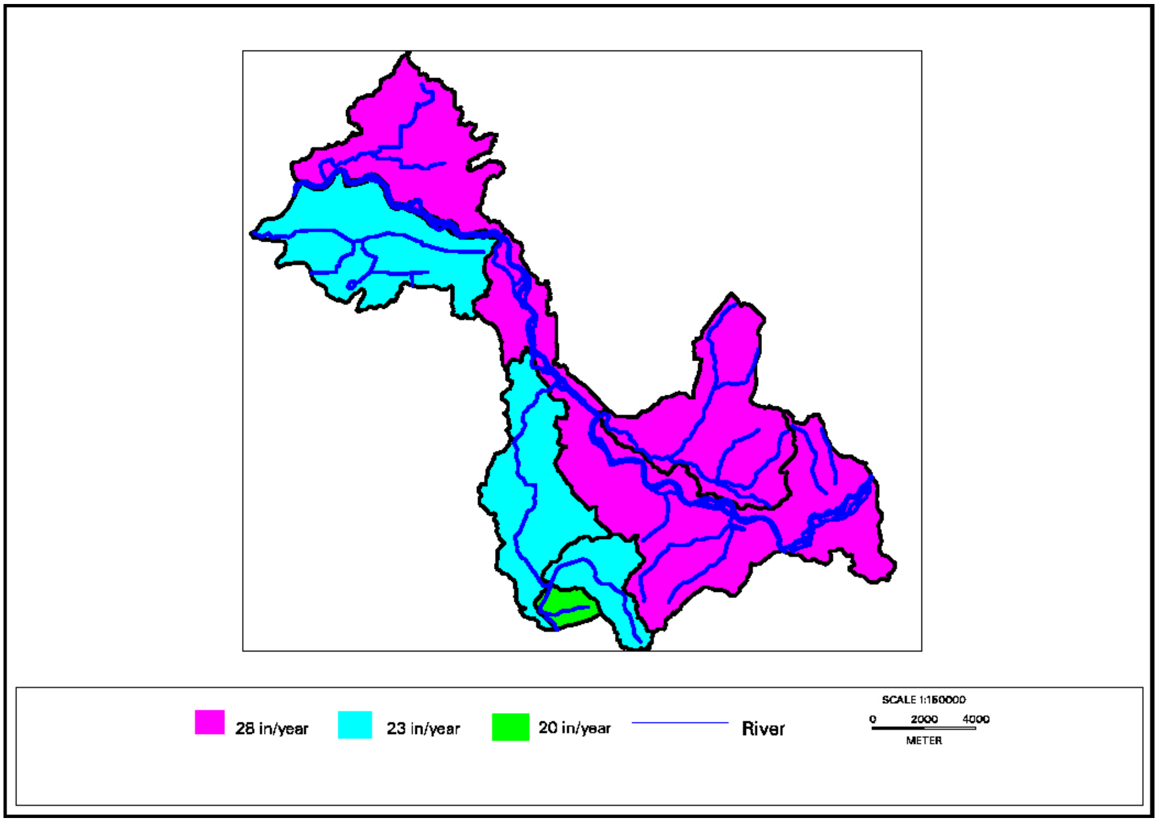

Figure 4.4.1 Recharge map of middle Nooksack watershed.

In the following paragraphs, we describe the recharge estimation techniques used in the LENS study area.

The map (Figure4.4.1) with the rates of ground-water recharge in the LENS study area was generated by Vaccaro (sited by Cox and Kahle, 1999, but not given in the reference list), USGS, with four point estimates of recharge (A,B,C,&D) by Kohut. Kohut used the water balance method of analysis by Thornthwaite and Mather and an analysis of long-term water-level records in two wells (Cox and Kahle, 1999). Using 30 years of meteorlogical data from the Abbotsford Airport weather station and a soil-moisture capacity of 100 milliliters per meter, the water balance analysis generated a recharge estimate of 37.5 inches per year (Cox and Kahle, 1999). The estimates are based on ten years of water level records at well 092G.009.2.1.3-47. Using specific storage values of

0.1, 0.2, and 0.3 resulted in recharge estimates of 10.7, 22, and 32 inches per year (Cox and Kahle, 1999). Well 092G.009.2.1.3-47 is reported to only penetrate sand and gravel that is expected to have a specific storage value around 0.1 to 0.3. This would result in a recharge estimate for this area ranging from 32 to 48 inches per year (Cox and Kahle, 1999). Well 092G.009.1.2.3-10 is located near ice-contact deposits and is reported to have encountered silty material in addition to sand and gravel. The recharge estimate for this well, based on water level analysis and specific storage values of 0.1 and 0.2, ranges from 11 to 32 inches per year (Cox and Kahle, 1999). Similar duration and specific storage values were used for water levels from this well, which resulted in recharge estimates of 16, 32, and 48 inches. The specific storage for gravelly sand deposits typically is between 0.2 and 0.3; deposits with more intermixed fines would generally be 0.2 or less (Cox and Kahle, 1999).

In general, according to the analysis by Vaccaro, recharge in areas underlain by fine-grained deposits constitutes about 36% of annual precipitation while recharge in areas underlain by coarse-grained material constitutes about 63% of annual precipitation (Cox and Kahle, 1999). The regional estimates of Vaccaro, based primarily on precipitation amount and underlying geology, compare well with Kohut's estimates based on site-specific data. Data used by Kohut are shown in Table 4.4.1.

Table 4.4.1. Precipitation and estimated recharge at two stations within the LENS study area

	Clearbrook Weather Station, Whatcom County			Abbotsford Weather Station, Abbotsford Airport, British Columbia		
Month	Average precipitation (inches)	Potential evapotranspiration (inches)[1]	Average ground-water recharge (inches)[1]	Average precipitation (inches)	Potential evapotranspiration (inches)[2]	Average ground-water recharge (inches)[2]
January	5.6	0.2	5.4	8.2	0.2	8.0
February	4.6	0.5	4.1	6.3	0.6	5.6
March	4.1	1.2	3.9	5.5	1.1	4.4
April	3.2	2.1	1	4.0	1.9	2.1
May	2.6	3.2	0	3.1	3.0	0.1
June	2.6	3.6	0	2.5	3.8	0
July	1.5	4.5	0	1.6	4.5	0
August	1.7	4.1	0	2.2	4.1	0
September	2.8	2.9	0	3.5	3.0	0.5
October	5.2	1.7	3.5	6.0	1.7	4.3
November	5.6	0.9	4.7	7.6	0.8	6.8
December	6.6	.04	6.2	9.0	0.4	8.6
Total annual	46.1	25.4	27.8	59.5	25.2	40.4

[1] Estimated by the Washington Department of Natural Resources, 1960.
[2] Estimated by Kohut, 1987.

Inverse recharge estimation for 1946-1957

Using the water balance equation, one can calculate the probable recharge that might occur in the watershed based on base flow and pumpage estimates. As shown above the regression statistic gives three values for the daily baseflow difference slope, which correspondingly result in three values of uniform recharge amount over the middle stretch watershed.

Total annual base flow:

1. Using regression slope	$= 333618.262m^3/day * 365 = 121.77Mm^3$
2. Using slope – 2*std	$= (333618.262 - 2*11037.7154) = 113.71Mm^3$
3. Using slope + 2*std	$= (333618.262 + 2*11037.7154) = 129.82Mm^3$

The uniform recharge value over the catchment will be the sum of the above base flow and the total pumpage.

Recharge 1	$= (121.77Mm^3 + 29.906Mm^3)/ 165.688*10^6*m^2$	= 36in
Recharge 2	$= (113.71Mm^3 + 29.906Mm^3)/ 165.688*10^6*m^2$	= 34in
Recharge 3	$= (129.82Mm^3 + 29.906Mm^3)/ 165.688*10^6*m^2$	= 38in

4.5 COMPARISON OF PRECIPITATION, STRREAM FLOW AND BASE FLOW

Out of the four precipitation stations within and in the vicinity of the middle Nooksack watershed only the one at Clearbrook has a relatively longer period of measurement. The other three have fewer years of measured data. The years, which are in common with stream flow measurements at Deming and Lynden are 1946 – 1950, 1951 – 1957 and 1964 – 1967.

Figures 4.6.1 – 4.6.6 shows precipitation comparison with base flow and Figures 4.5.7 – 4.5.12 shows precipitation comparison with stream flow for the three segments of record period. The cumulative precipitation slopes are:

1945 – 1950	=0.1336 in/day
1951 – 1957	=0.1337 in/day
1964 – 1967	=0.1471 in/day

Analyzing the plots reveals low record period time at the following months.

1946 – 1950:	Dec, Nov, June, April, Feb, June, Dec.
1951 – 1957:	May, Jan, Nov, Dec, July, (the others are not so small)
1964 – 1967:	Feb, Nov, April, July, Jan, June, Oct, March.

Stream flow:

This seems to show a higher fluctuation than base flow.

1946 – 1950:	Dec, Feb, Oct, June, Dec, May, Oct, Feb

1951 – 1957:	Jan and Dec, which can be clearly seen as an appreciable lower points
1964 –1967:	Feb, Nov, Dec, Feb, June, Oct

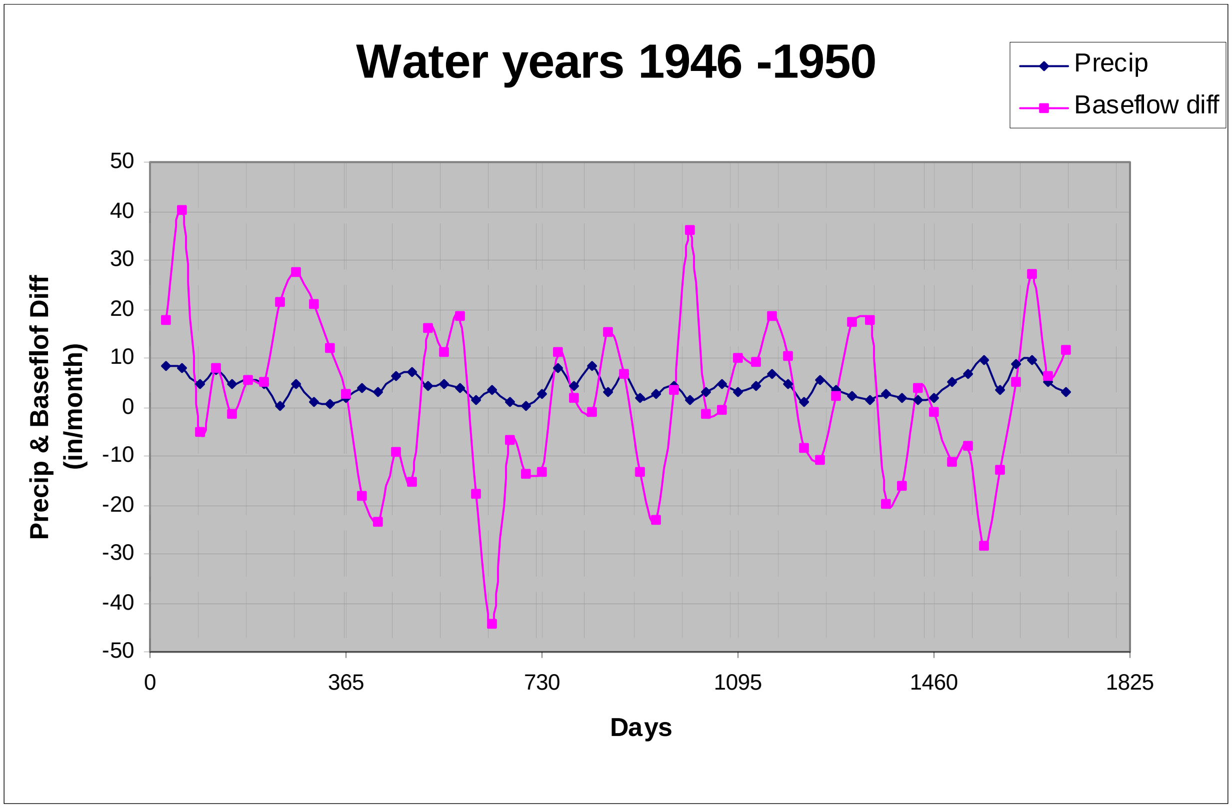

Figure 4.5.1 Precipitation and base flow difference, 1946 – 1950

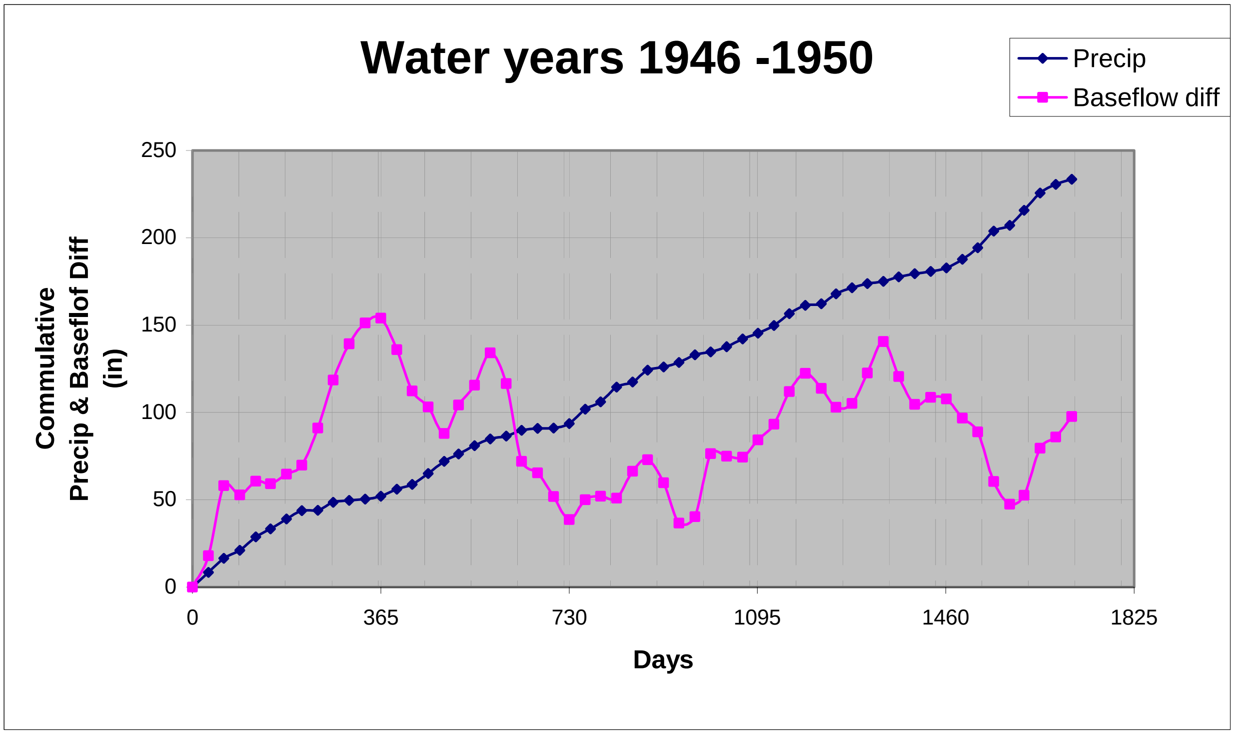

Figure 4.5.2 Cumulative precipitation and base flow differences, 1946 - 1950

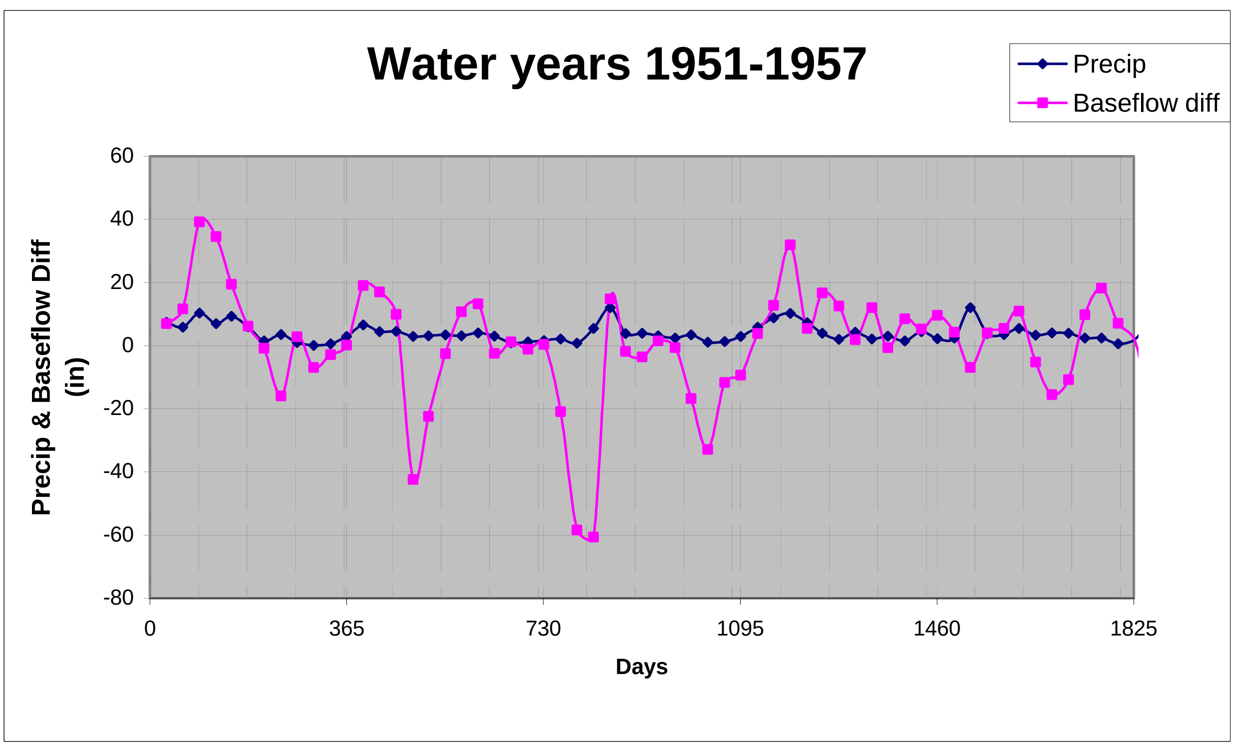

Figure 4.5.3 Precipitation and base flow difference, 1951 – 1957

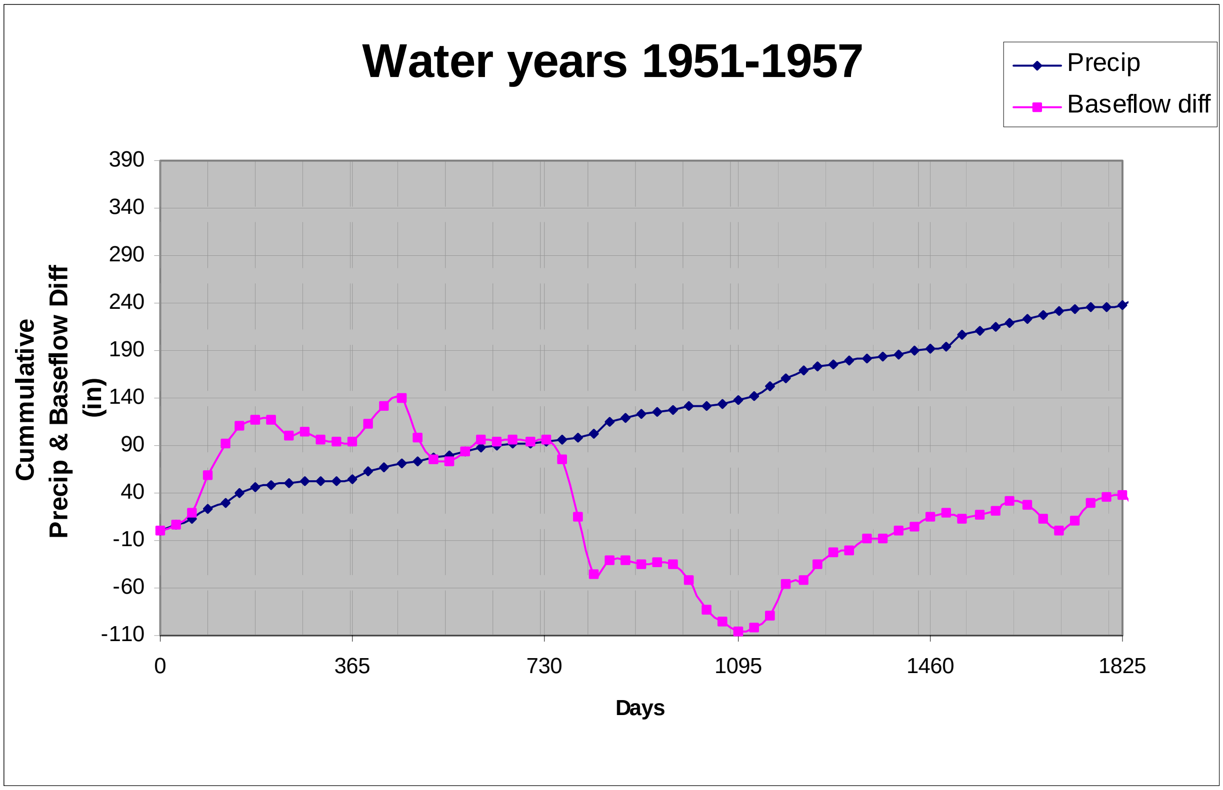

Figure 4.5.4 Cumulative precipitation and base flow difference, 1950 - 1957

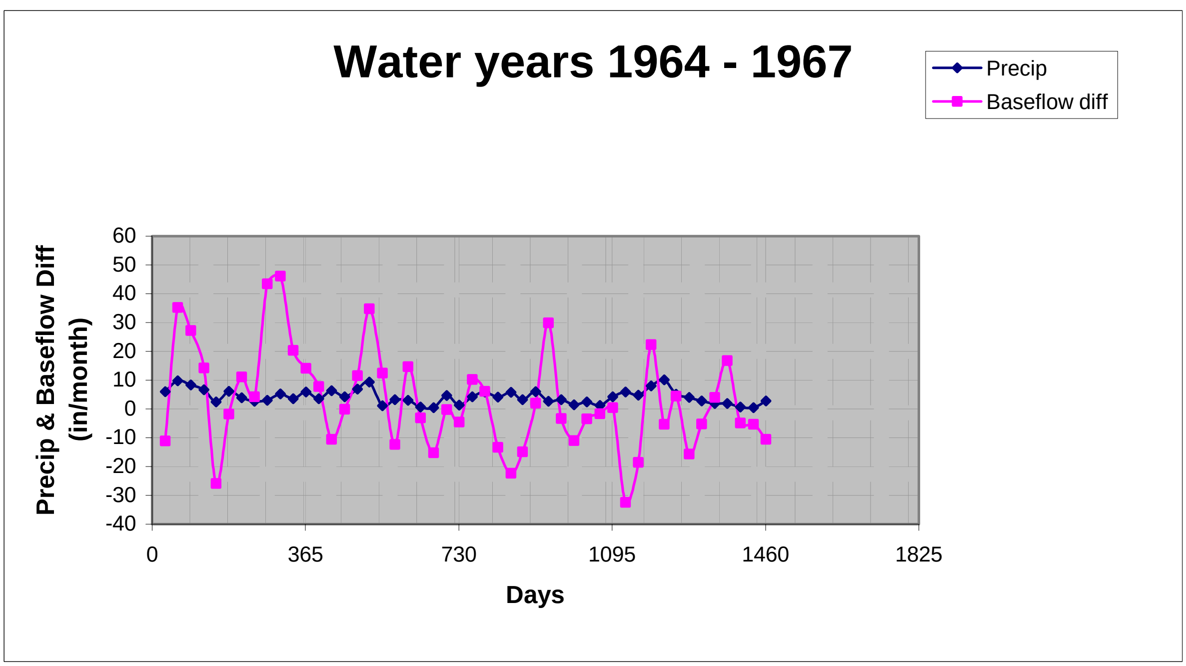

Figure 4.5.5 Precipitation and base flow difference, 1964 – 1967

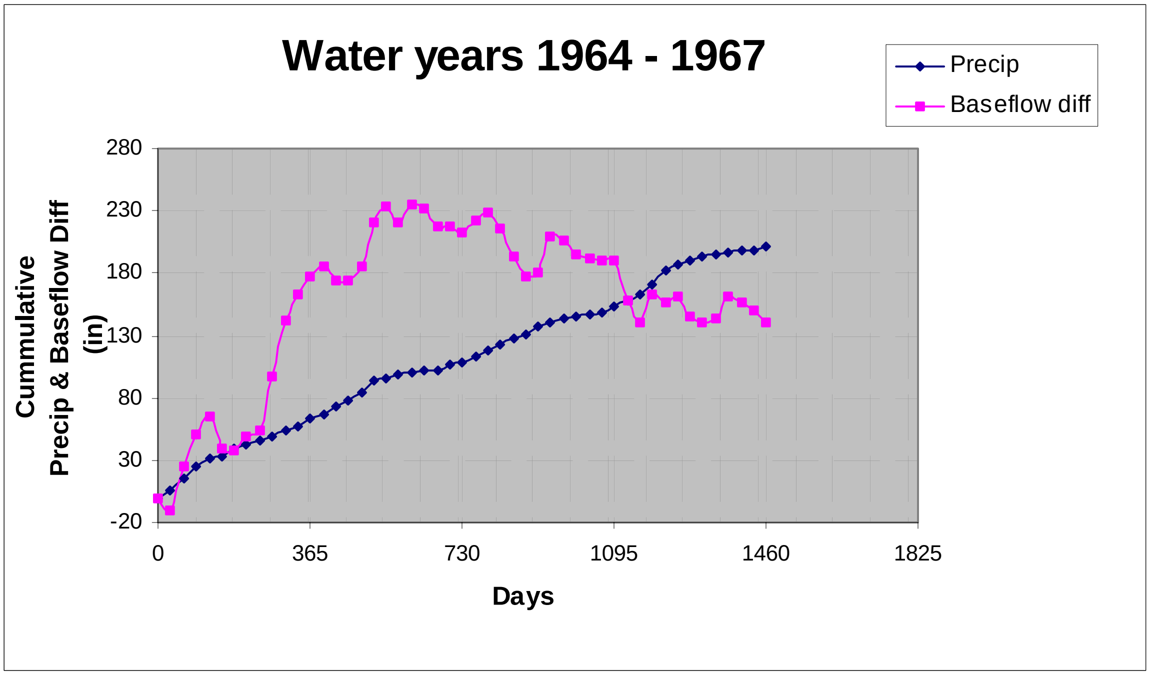

Figure 4.5.6 Cumulative precipitation and base flow difference, 1964 - 1967

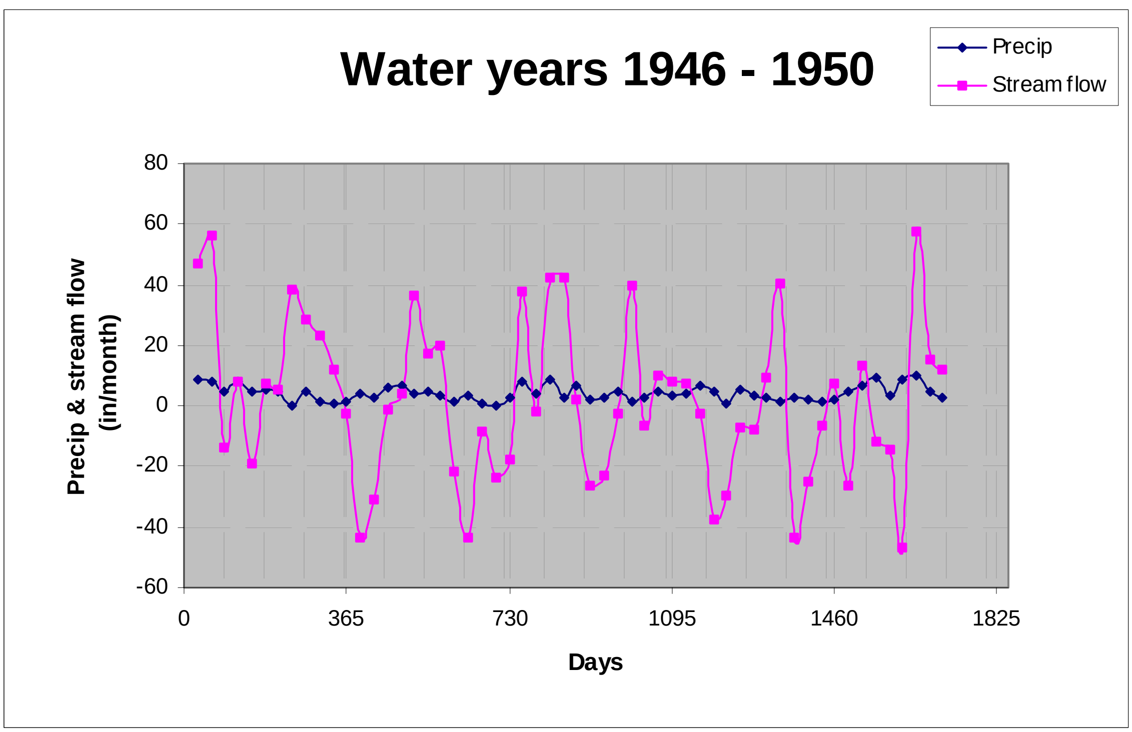

Figure 4.5.7 Precipitation and stream flow difference, 1946 – 1950

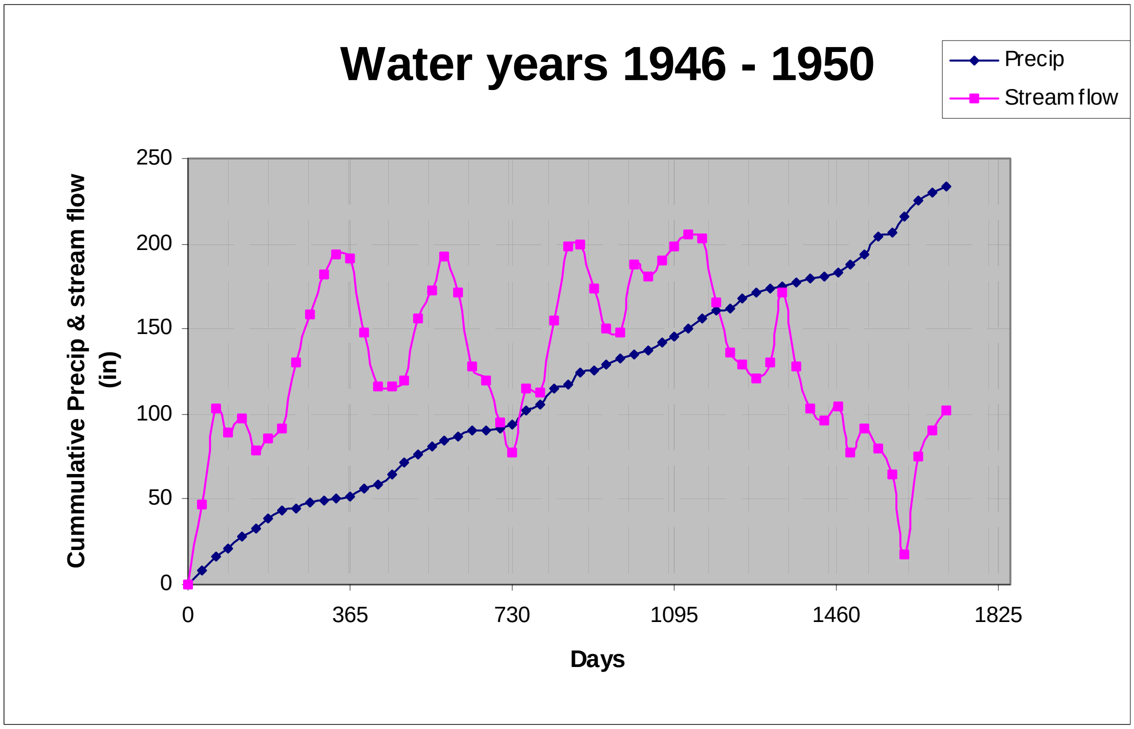

Figure 4.5.8 Cumulative precipitation and stream flow difference, 1946 – 1950

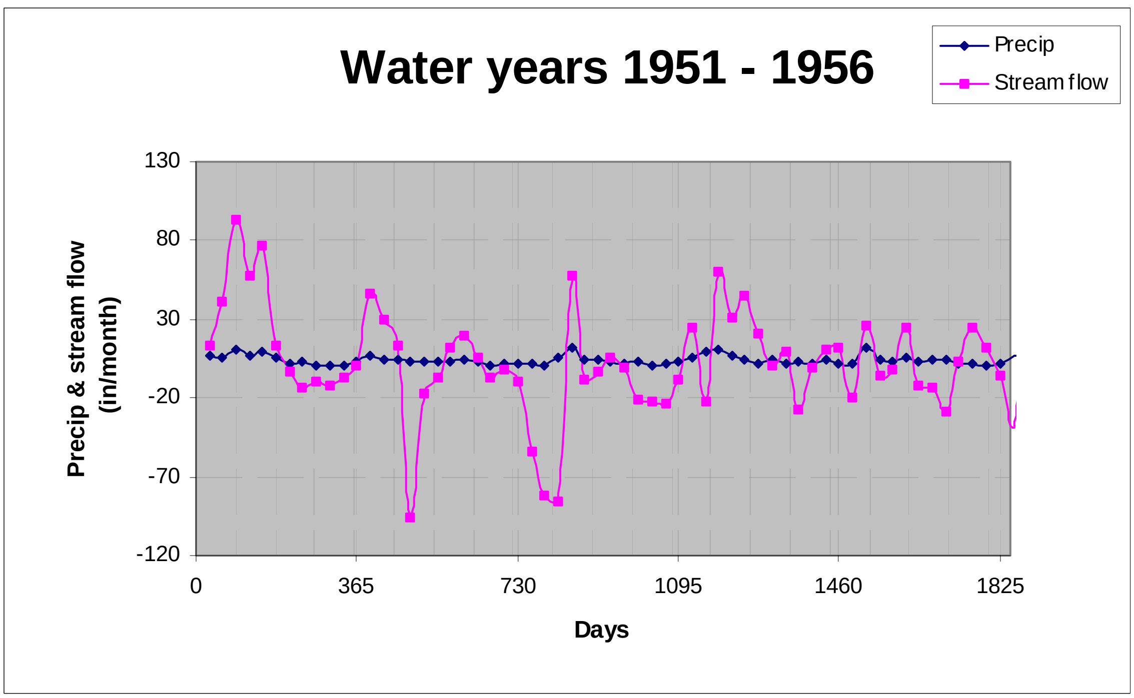

Figure 4.5.9 Precipitation and stream flow difference, 1951 – 1956

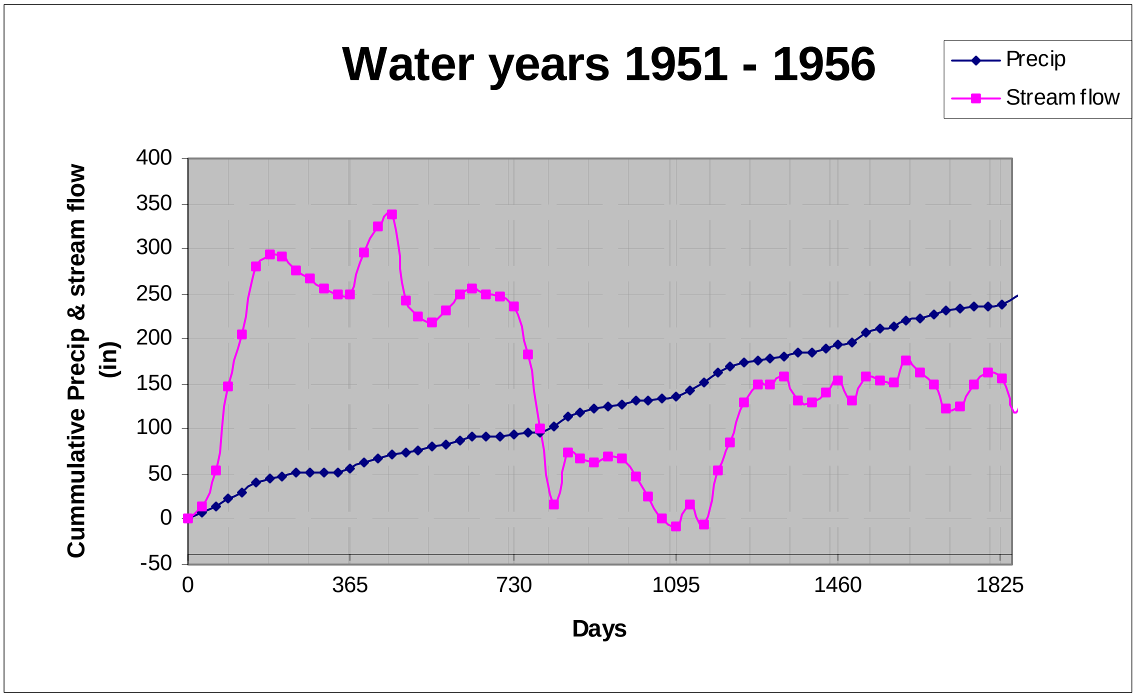

Figure 4.5.10 Cumulative precipitation and stream flow difference, 1951 - 1956

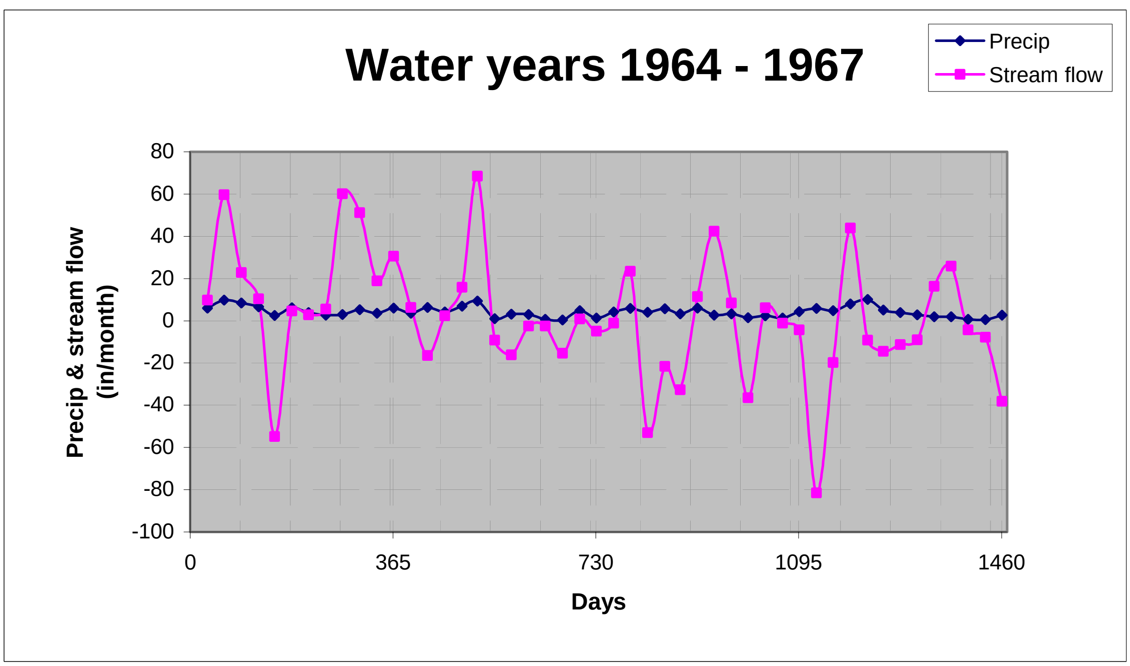

Figure 4.5.11 Precipitation and stream flow difference, 1964 – 1967

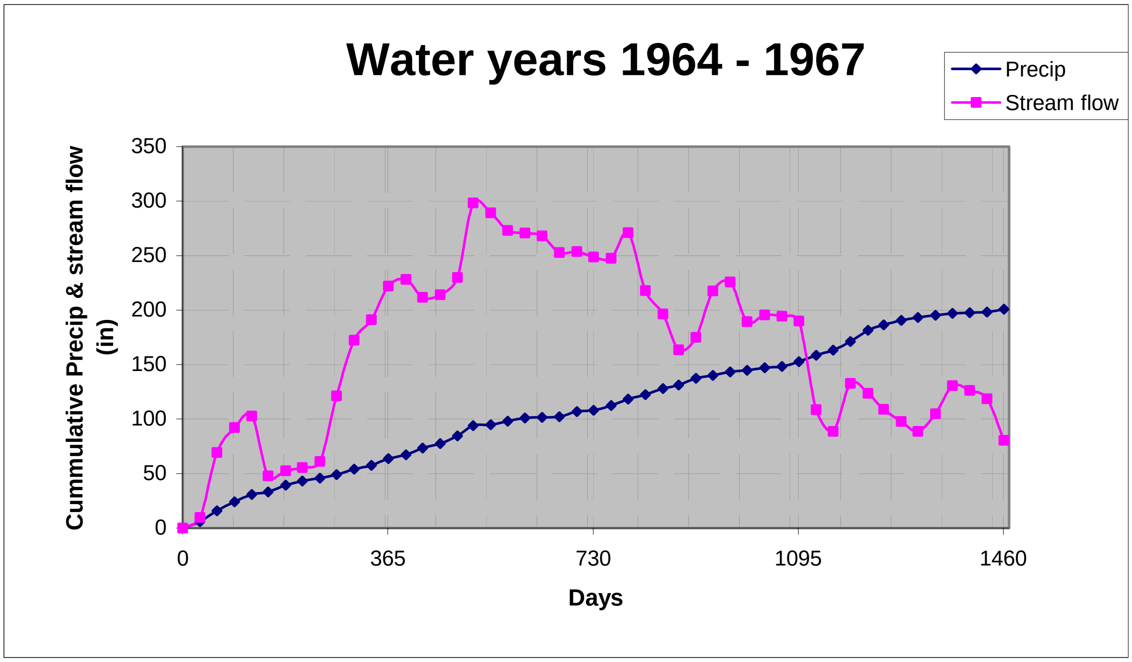

Figure 4.5.12 Cumulative precipitation and stream flow difference, 1964 – 1967

Typical of the plots is that except for the cumulative base flow plot of 1964 – 1967 (Figure 4.5.6), the cumulative plots of base flow and stream flow start with an ascending limb exceeding the precipitation for approximately two years then fall below the cumulative precipitation plot.

This indicates that during the analyzed intervals the system was not in steady state, and suggests that subsequent water balance analysis for this period will have to take into account the groundwater storage fluctuations.

Analysis of the cumulative base flow for this stream stretch shows that quite frequently during the analyzed periods the stream is losing water, and that the cumulative base flow is on average quite flat, contrary to the behavior we observe in North and South Forks of Nooksack.

The cumulative base flow for this river stretch shows quite irregular behavior. At some times, the stream is gaining, and others it is losing. Furthermore, the comparison with the precipitation data shows that at times the base flows is significantly larger than the available from precipitation water.

Based on our conversations with the USGS personnel, we believe that all these irregularities are due to malfunctioning of the Deming gage. Apparently the river channel has changed significantly over time, but the gage has not been properly recalibrated. We recommend, therefore, that a new gage be installed downstream from Deming, where the river channel is more stable.

4.6 SEEPAGE RUNS

The seepage data available for Mainstem Nooksack River Watershed are from two sources: WRCD/CES (Whatcom County Conservation District and Cascade Environmental Service) and a more recent data from USU field crew. Each of these data sources is discussed below.

WRCD/DES DATA

There are four seepage-run points along Mainstem Nooksack River (see Figure 3.6.1). Following the identification name given by the data sources:
M -135, near Deming
M -133, above Lynden near Sickney Island Road
M – 142, near Lynden at state highway 539
M – 134, at Ferndale

Only three of the above points, at most, have flow data on the same day. There are four days with three of the seepage data points and three days with only two data points. Table 4.6.1 shows the seepage results for the above stations.

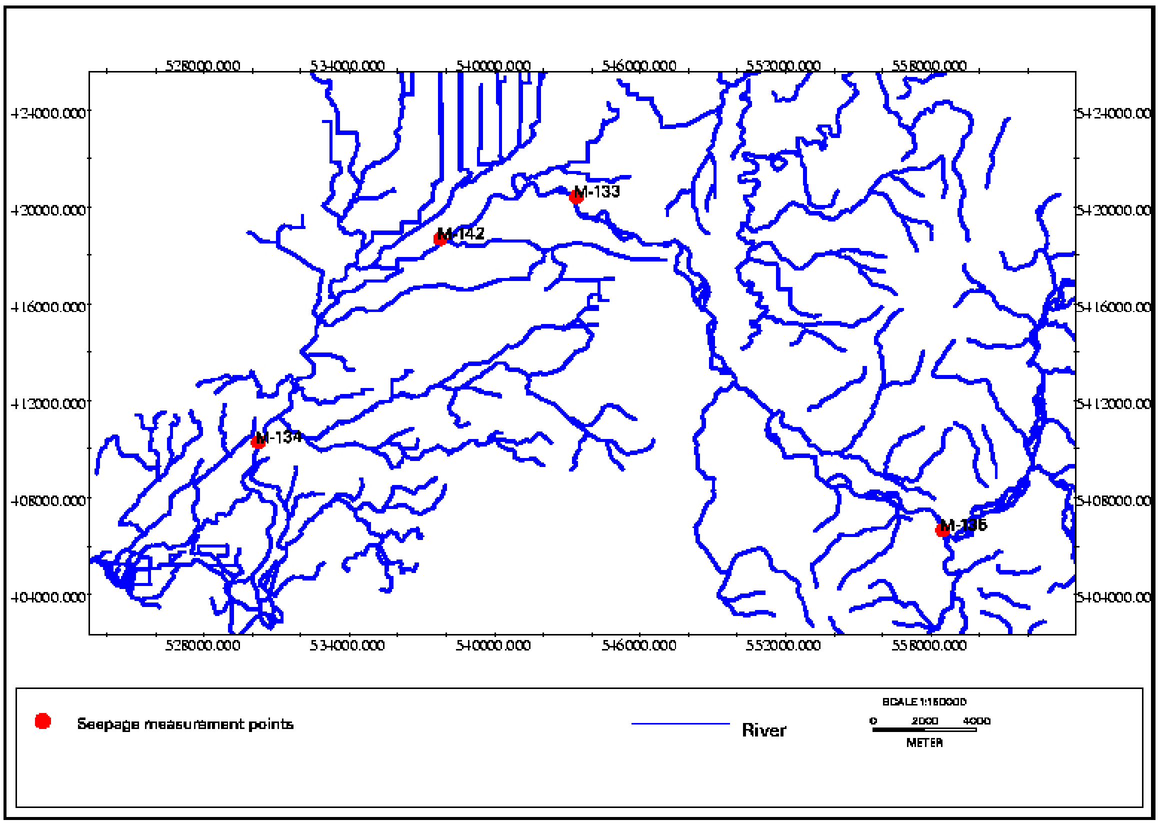

Figure 4.6.1 Mainstem Nooksack seepage measurement points of WRCD/DES DATA.

Table 4.6.1 Seepage results, WRCD/DES data, Mainstem Nooksack.

Date	Distance from station M-135 (m)	River recharge (cfs)	Remark
8/2/95	0	1690	
	47782.796	1870	
8/3/95	0	1715	Average*
	33043.501	1640	
	47782.796	1780	
8/24/95	0	1070	
	33043.501	1320	
	47782.796	1410	
9/18/95	0	988	
	33043.501	1040	
	47782.796	1070	
9/19/95	0	942.5	Average*
	25782.75	1010	
	47782.796	1070	
9/21/95	0	830	
	47782.796	932	

* Average indicate there are two values given on the same day.

Dates with data on three seepage sites are plotted as shown in Figures 4.6.2 – 4.6.5.

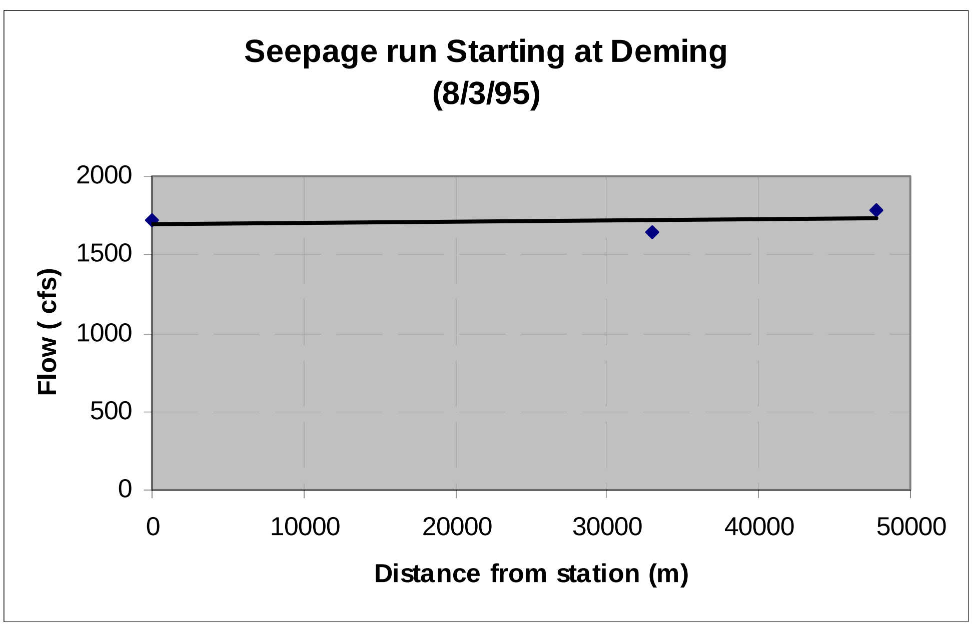

Figure 4.6.2 Mainstem Nooksack seepage run result, 8/3/95

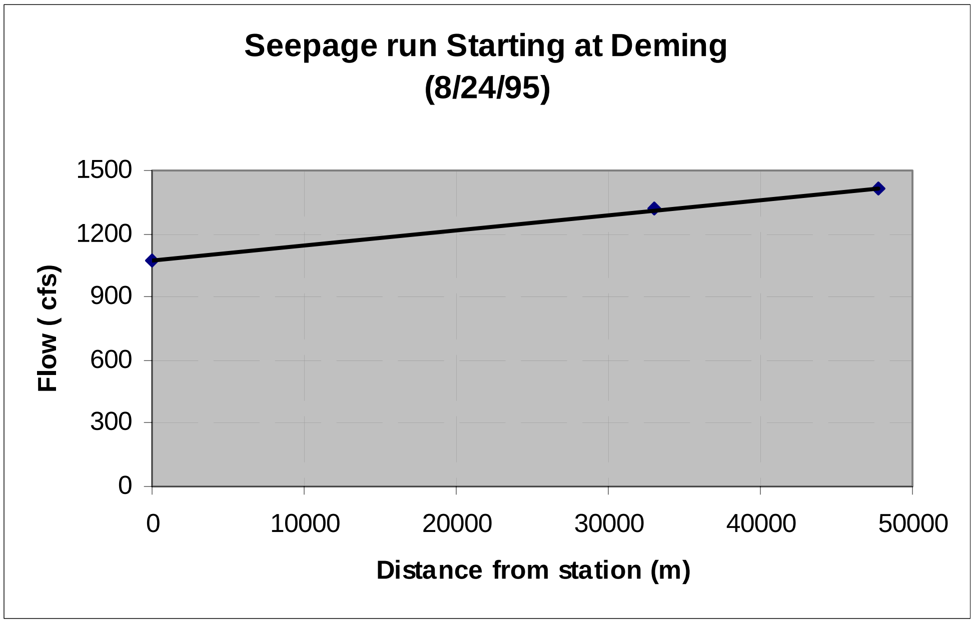

Figure 4.6.3 Mainstem Nooksack seepage run result, 8/24/95

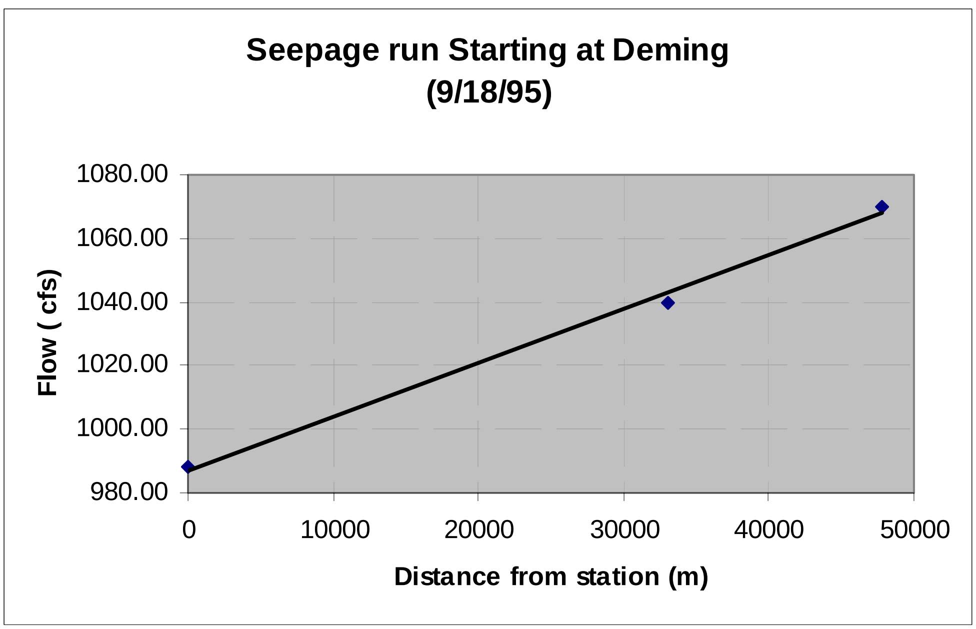

Figure 4.6.4 Mainstem Nooksack seepage run result, 9/18/95

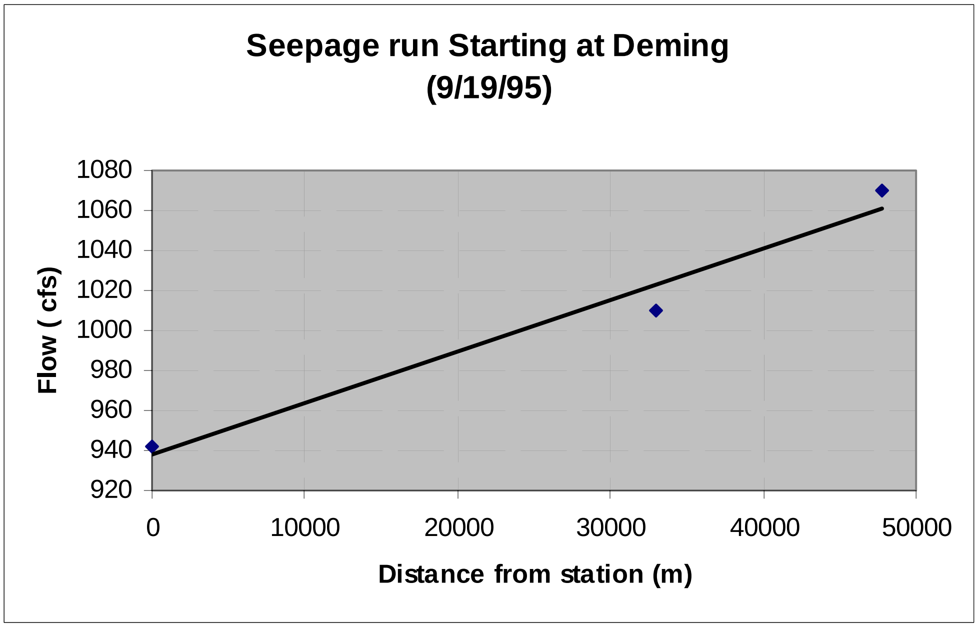

Figure 4.6.5 Mainstem Nooksack seepage run result, 9/19/95

Seepage results can be used as an indicator for the river flow per unit length. Therefore, the above data is used to estimate Mainstem Nooksack River flow per unit length. The following table shows the average stream flow per mile river length

Table 4.6.2 Average stream flow gain on Mainstem Nooksack River.

Date	Average stream recharge (cfs/mile)
8/3/95	1.1263
8/24/95	11.5848
9/18/95	2.7353
9/19/95	4.1834
Average	**4.907**

USU FIELD CREW DATA

Duke Engineering Cartography out of Bellingham located seepage points used by USU on Mainstem Nooksack River. The following table gives information regarding the measurement points (see Figure 4.6.6 below). It was also reported that additional measurement location was located between #9 and #12 but not sampled because of equipment failure.

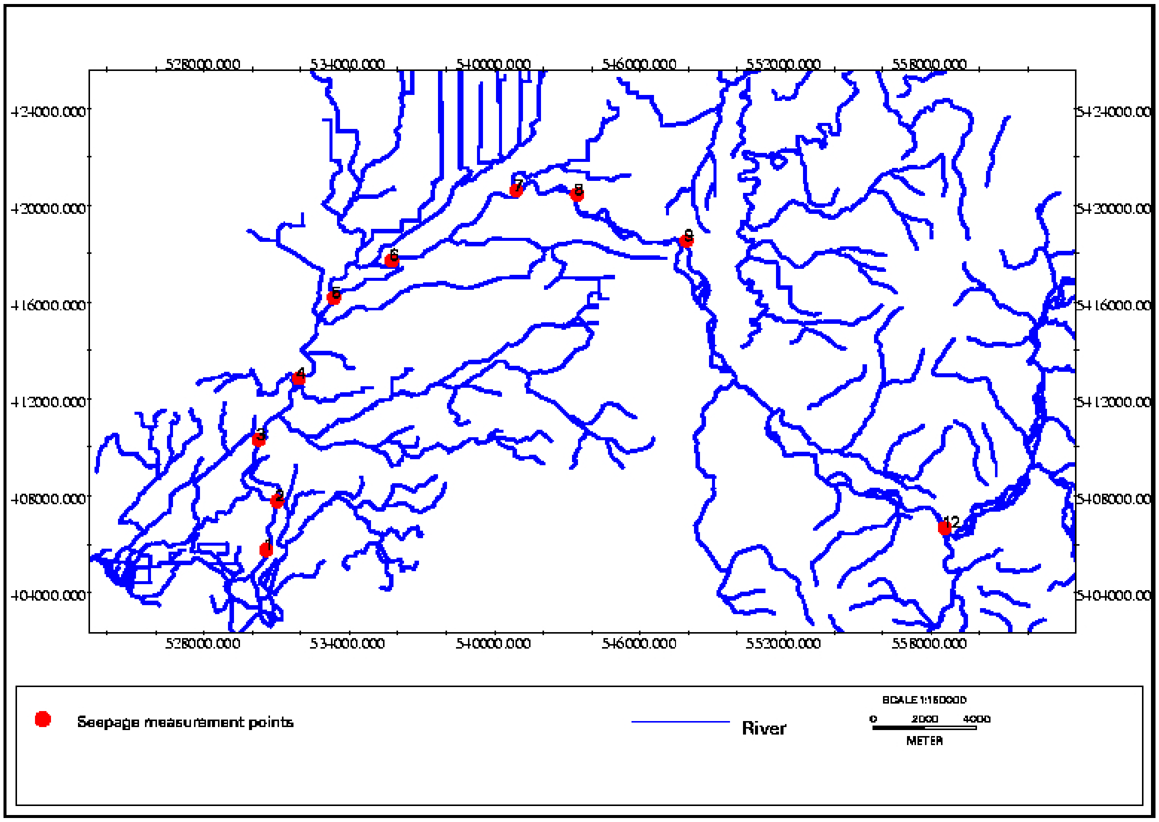

Figure 4.6.6 Mainstem Nooksack USU seepage measurement points.

Table 4.6.3 Seepage Site Route (From the Confluence to the Mouth), Mainstem Nooksack

Path Id	From Seepage Site #	To Seepage Site #	From	To	Distance (m)
1	12	9	0	19775.484	19775.48
2	9	8	19775.484	25350.551	5575.067
3	8	7	25350.551	28609.805	3259.254
4	7	6	28609.805	35364.781	6754.976
5	6	5	35364.781	39524.961	4160.18
6	5	4	39524.961	44119.43	4594.469
7	4	3	44119.43	47572.215	3452.785
8	3	2	47572.215	51185.703	3613.488
9	2	1	51185.703	53382.234	2196.531

There are a number of streams that feeds Mainstem Nooksack River between these measurement points. Table 4.6.4 shows the locations of different stream joining the River.

Table 4.6.4 Locations of streams feeding Mainstem Nooksack

Seepage Station	Distance (m)	Stream recharge (cfs)	Until	Remark
12	0	1739.275		
	11118.5		Smith Creek	
	13209.5		Anderson Creek	Loss (-61 cfs)
9	19775.484	1678.333		
8	25350.551	1771.7		Gain(+93.4)
	28078.484		Unamed	
7	28609.805	1683.575		Loss(-88.1)
	32602.805		Unamed	
6	35364.781			
	35968.781		Fish trap	
	36890.781		Bertrand Creek	
5	39524.961	1754.275		Gain(+70.7)
	40745.961		Unamed	
4	44119.43	1816.85		Gain(+62.6)
	45775.43		Tenmile Creek	
3	47572.215	1857.925		Gain(+41)
2	51185.703	1801.9		Loss(-56)
1	53382.234	1852.825		Gain(+51)

Arrows on Figure 4.7.7, in the order given in Table 4.7.4, indicate the locations of these feeding streams.

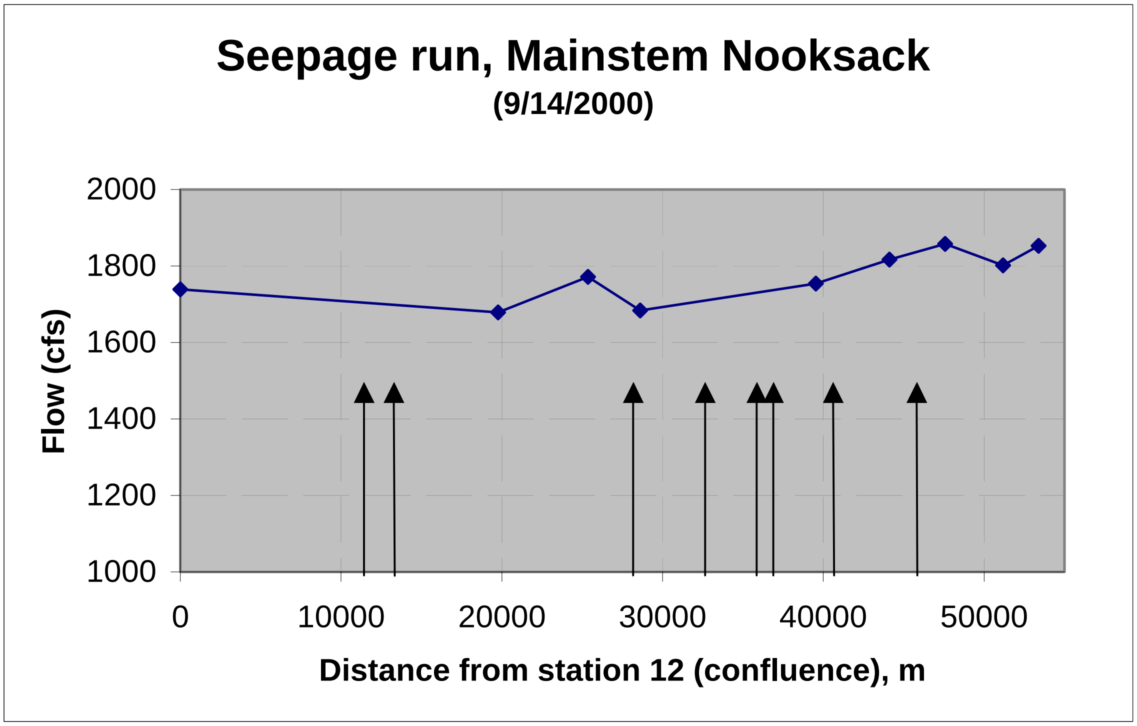

Figure 4.6.7 Mainstem Nooksack seepage run by USU, 9/14/2000.

The average flow gain per unit mile estimated using the field measurements is 4.344 cfs/mile (cubic feet per second per mile). This value is comparable with the long-term average given above by WRCD/DES data. This value reflects the combined effects of stream flow loss/gain. It is interesting to see (as shown in the last column of Table 4.6.4) though not all the reaches are gaining. The column shows the total loss or gain within the reach between seepage run sites. In order to better visualize these gain and losses along the Mainstem Nooksack one has to look at the gain or losses per unit mile. Figure 4.6.8 shows these changes in flows per unit mile within each reach.

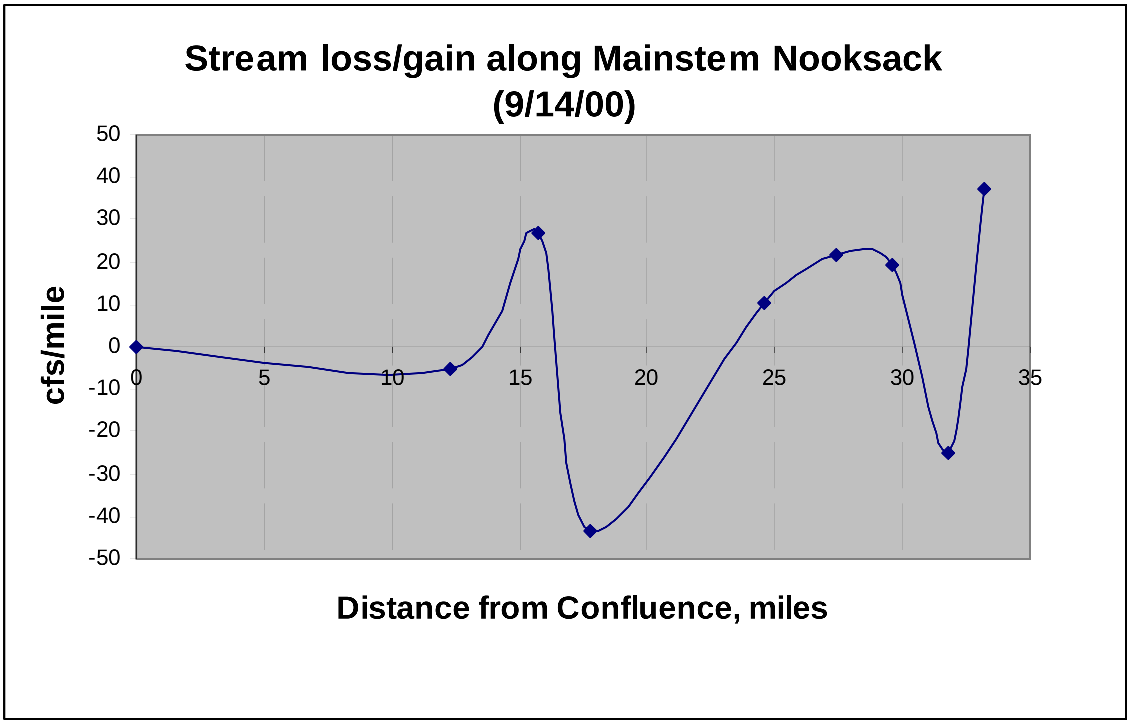

Figure 4.6.8 Changes in stream flow gain/loss on Mainstem Nooksack, 9/14/2000

On the same day of USU seepage runs measurements were conducted, the USGS also took measurements on different tributaries. This includes inflow/outflows to Mainstem Nooksack, Tenmile, Fishtrap, Bertrand, Kamm, Smith and Anderson Creeks. Figure 4.6.9 shows the locations of all the seepage runs taken on 9/14/00 by USU and the USGS. The labels indicate the flow in cubic feet per second (cfs). A zero value indicated the creek was dry on that day.

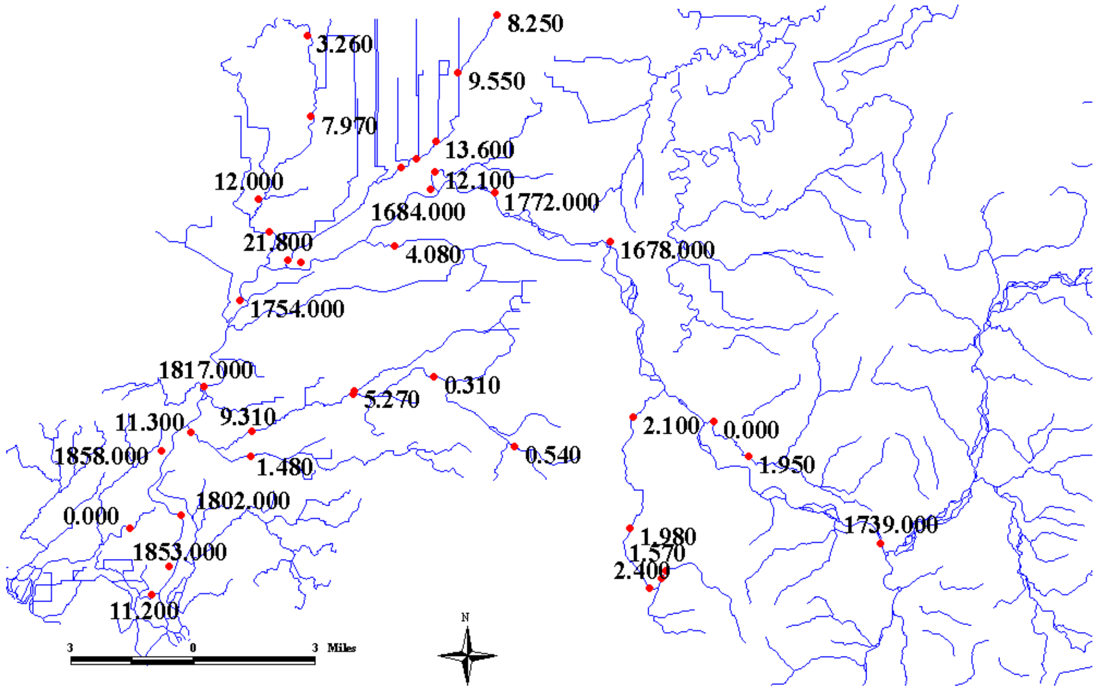

Figure 4.6.9 WRIA 1 Seepage runs by USU and the USGS, 9/14/00.

NOTE

The current Middle Stretch Nooksack water balance analysis does not include the lower Nooksack River portion between station #12212100 (below Lynden) and station #12213500 (below Ferndale) due to the fact that there are no common years of flow data between these two stations.

5.0 THE WRIA 1 COASTAL WATERSHEDS AND THEIR AQUIFER WATER BALANCE MODEL

5.1 THE WATERSHED

The coastal watersheds include Dakota, California, Terrell, Unnamed and Lummi watersheds. The current analysis focuses on the Dakota Creek watershed. The others, because of unavailability of data, have not been analyzed.

The Dakota Creek watershed encompasses two physiographic regions: the Boundary Upland and the Custer Trough (Sandal, 1990). The Boundary Upland comprises the northern half of the Fraser Lowland and ranges in elevation from sea level to around 540 feet (Sandal, 1990 and Whatcom County Conservation District, 1987)(see Figure 5.5.1).

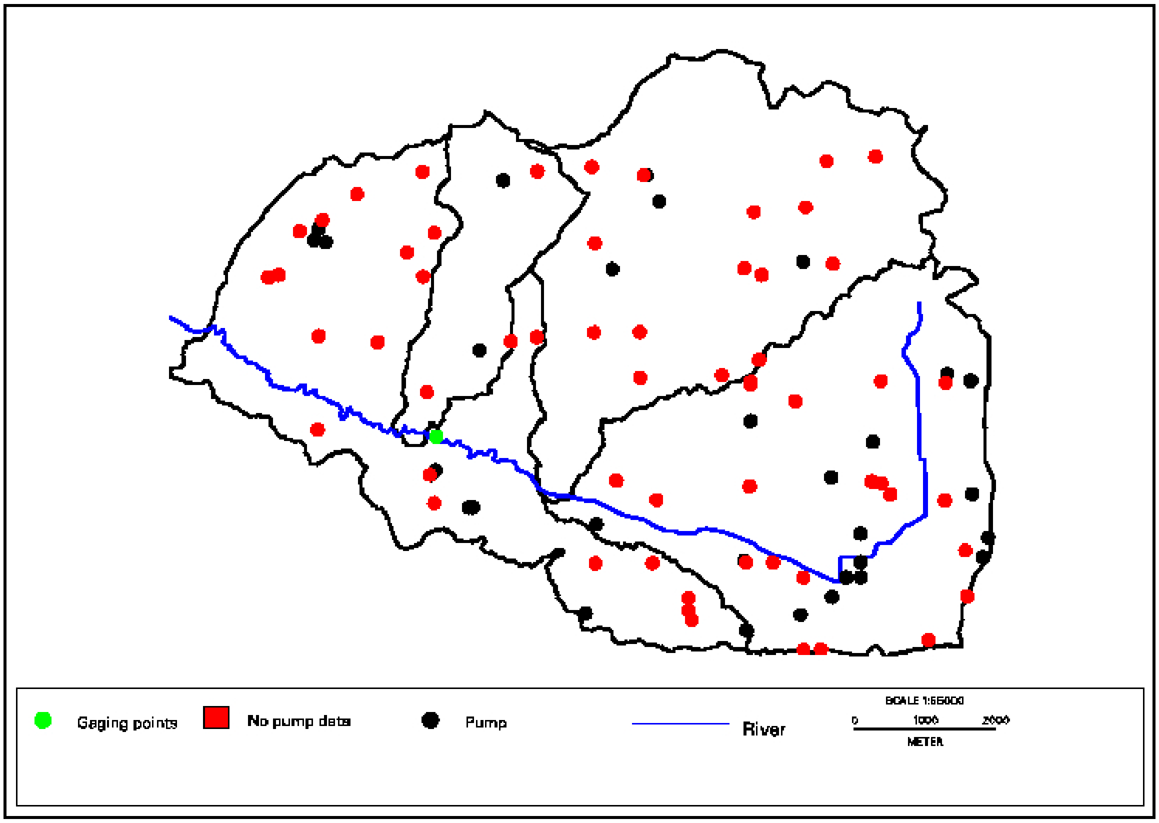

Figure 5.5.1. The Dakota Watershed.

The Boundary Uplands are located immediately east of Blaine and consist of low lying hills and rolling topography that parallels the Canadian border in northwestern Whatcom County (Whatcom County Conservation District, 1987). The Custer Trough is a broad valley to the south of the Boundary Upland. It is generally flat with elevations below 100 feet (Whatcom County Conservation District, 1987). The Custer Trough and the Boundary Upland are separated by an abrupt change in slope (Sandal, 1990).

The North Fork of Dakota Creek originates about a half mile north of the Canadian border near the summit of the Boundary Uplands and flows southwesterly to the Custer Trough where it joins the South Fork (Whatcom County Conservation District, 1987). The South Fork originates near Bertrand Creek at the eastern end of the Custer Trough (Whatcom County Conservation District, 1987). It flows northwesterly to the North Fork confluence (Whatcom County Conservation District, 1987). The Dakota Creek continues northwesterly until it reaches Drayton Harbor (Whatcom County Conservation District, 1987).

Average annual rainfall values in the Boundary Upland and the Custer Trough are 62 and 40 inches, respectively. The watershed area is approximately 31.7 square miles and has mean annual runoff averages of 13.5 inches or 22,900 acre-feet (Whatcom County

Conservation District, 1987). This results in an average annual flow of 31.6 cfs (Whatcom County Conservation District, 1987).

A shallow aquifer system occurs at depths between 100 and 300 feet bgs in the central portions of the Boundary Upland and at depths between 60 and 160 feet bgs along the southern and western flank of the Boundary Upland (Golder Associates, 1996). This aquifer system is semi-confined to confined in the Boundary Upland area (Golder Associates, 1996). Estimated transmissivities for the area average between 1,000 and 3,000 ft^2/day but vary from 50 to 14,000 ft^2/day (Golder Associates, 1996).

A deep aquifer system consists of two to three layers of sand and gravel and occurs at depths between 600 and 750 feet bgs (Golder Associates, 1996). Pumping tests indicate that the aquifer system has a transmissivity of about 3,000 to 5,000 ft^2/day but may be as low as 700 ft^2/day (Golder Associates, 1996).

5.2. BASE FLOW

There was one gaging station (number 12214000), which the USGS operated between 1949 and 1954, but there is a discontinuity between 09/30/53 – 05/13/54. Therefore, only four years (1949-1952) have been used as one continuous unit. As will be explained later, these data had to be split into two parts because of precipitation data gap at Blaine station.

Further more the plots are done starting January and ending in December rather than following a water year like other Nooksack Watershed reports because of the small record of data available. Figure 5.2.2 and 5.2.3 shows the stream flow and base flows in inches per month and the cumulative values in inches for the complete record

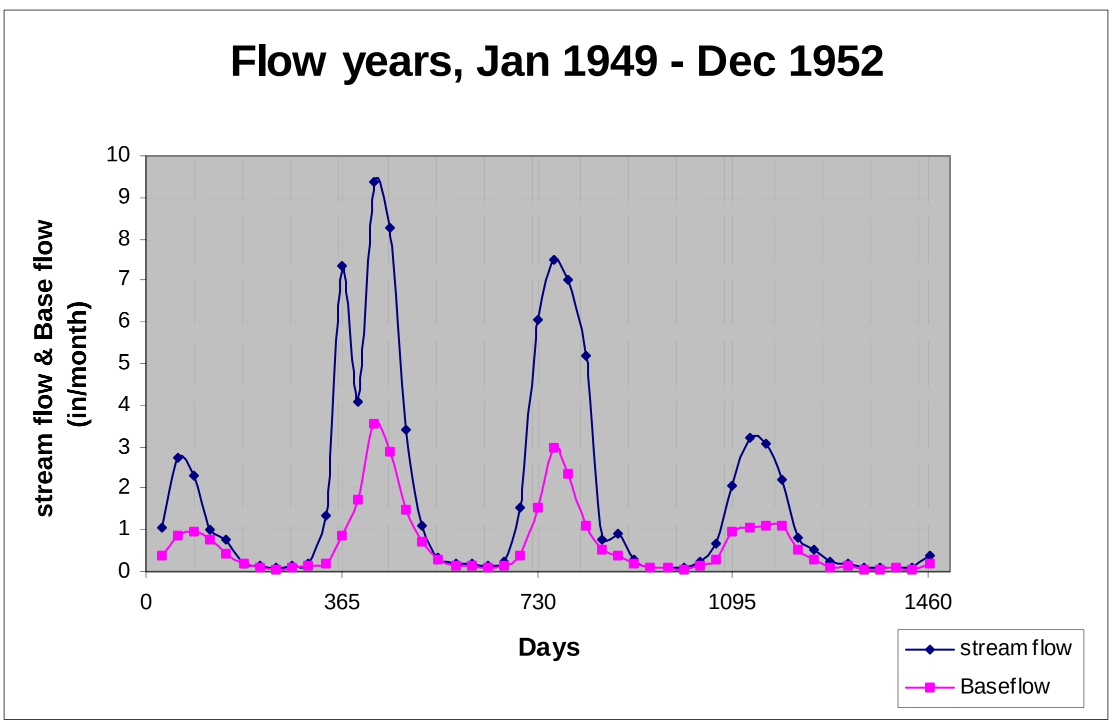

Figure 5.2.2 Dakota Creek stream flow and base flow measurements comparison.

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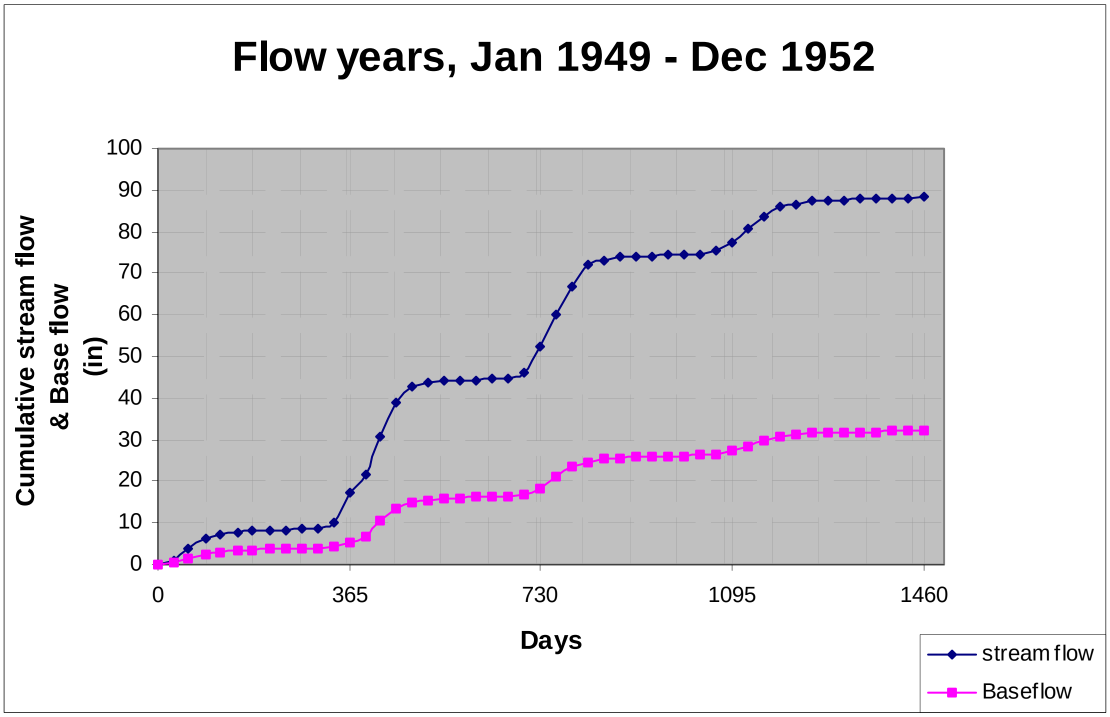

Figure 5.2.3 Dakota Creek cumulative stream flow and stream flow.

5.3 GROUNDWATER PUMPING

There are 92 pumping wells in the USGS database located in the whole Dakota Watershed. Out of these, only 32 have data about pumping rates. The total pumping rate is 6309 gpm. Sixty-six are located up stream of the gaging point. From these 23 have pumping rate data, with the total of 4088 gpm. It is this value that is used for inverse recharge estimation for the area upstream of the gaging point.

5.4. RECHARGE

Sandal (1990) used a water balance method and estimated groundwater recharge to be 30% (12 in) of the total precipitation for the upper Dakota Creek catchment between May 1989 and June 1990. His approach involved the use of published characteristics of soil and vegetation to provide estimate of surface runoff and evapotranspiration. The estimated recharge was the residual of the total evapotranspiration and runoff, which was taken as the equivalent groundwater runoff.

Golder Associates (1995) used a subjective optimization procedure to estimate the recharge occurring within the Upper Dakota Creek catchment. The procedure is based on hydrologic water balance method. To estimate recharge they adjusted a number of coefficients associated with surface runoff, infiltration and groundwater runoff (base flow to the Creek) until the calculated total daily runoff matches the measured daily runoff of

Dakota Creek. This analysis resulted in groundwater recharge between 10 to 20% (5 to 9in). Golder Associates (1995), comparing the calculated values with that of Sandal (1990) estimated the recharge in the Upper Dakota Creek to be between 15 and 25% of the total precipitation.

Recharge to the shallow aquifer has been estimated at between 7 and 20 inches per year (Golder Associates, 1996).

For the Boundary Upland, Golder Associates (1995) used two methods of estimating recharge:

> Soil-moisture budgeting method, which estimate groundwater recharge as a residual of input (precipitation) and the outputs (evapotranspiration, runoff, and change in soil moisture). This method assumes that the potential evapotranspiration (based on temperature data collected from Blaine station) and soil-moisture deficit must be satisfied before groundwater recharge occur.
>
> Water level fluctuation method, this gives groundwater recharge as a sum of pumpage, volume of water stored in the aquifer between water levels of two time periods and groundwater runoff.

The first method estimates 20 to 26 in of groundwater recharge between June 1989 and May 1990), which is equivalent to 38 to 58 % of the total precipitation occurring within the Boundary Upland during this time. The second method resulted recharge estimate between 7 and 10 in (less than half the first method).

The amount of recharge to the deep aquifer has not been determined.

Inverse recharge estimation

Assuming the recharge to be the unknown in the mass balance equation, an inverse estimation for recharge can be performed using the other components of the water balance.

A linear regression line has been fitted to the cumulative base flow with the following statistics:

Slope of regression line	=0.025108 in/day
Standard deviation of the slope	=0.000375 in/day
Coefficient of regression	=0.96

Hence, total annual base flow is

1. Using regression slope	=0.025108*365	= 9.2in
2. Using slope – 2*Std	=(0.025108-2*0.000375)*365	= 8.9in
3. Using slope + 2*Std	=(0.025108+2*0.000375)*365	= 9.4in

Pumpage	=(4088 gpm)	= 6.72in

The uniform recharge value over the catchment will be the sum of the above base flows and the total pumpage.

Recharge1	= (9.2 + 6.72)	= 15.92in
Recharge2	= (8.9 + 6.72)	= 15.62in
Recharge3	= (9.4 + 6.72)	= 16.12in

Therefore, the recharge up stream of the gage station is about 16 inches per year. Based on estimated average precipitation of 43 in (see precipitation part), this will be about 38%.

5.5 Comparison of Precipitation, Stream flow and Base flow

The nearby precipitation station with sufficiently long data is the one at Blaine. It has about hundred years of data with some gaps in between. One of the gaps has fallen within the USGS stream flow data record period and makes the flow data to be split into two. The longest segment being between January 1949 to June 1951 and the other between August 1951 and December 1952. Figures 5.5.1 – 5.5.4 shows the precipitation, stream flow, and base flow for the two segments of record periods and Figures 5.5.5 – 5.5.8 show the cumulative plots for the same periods.

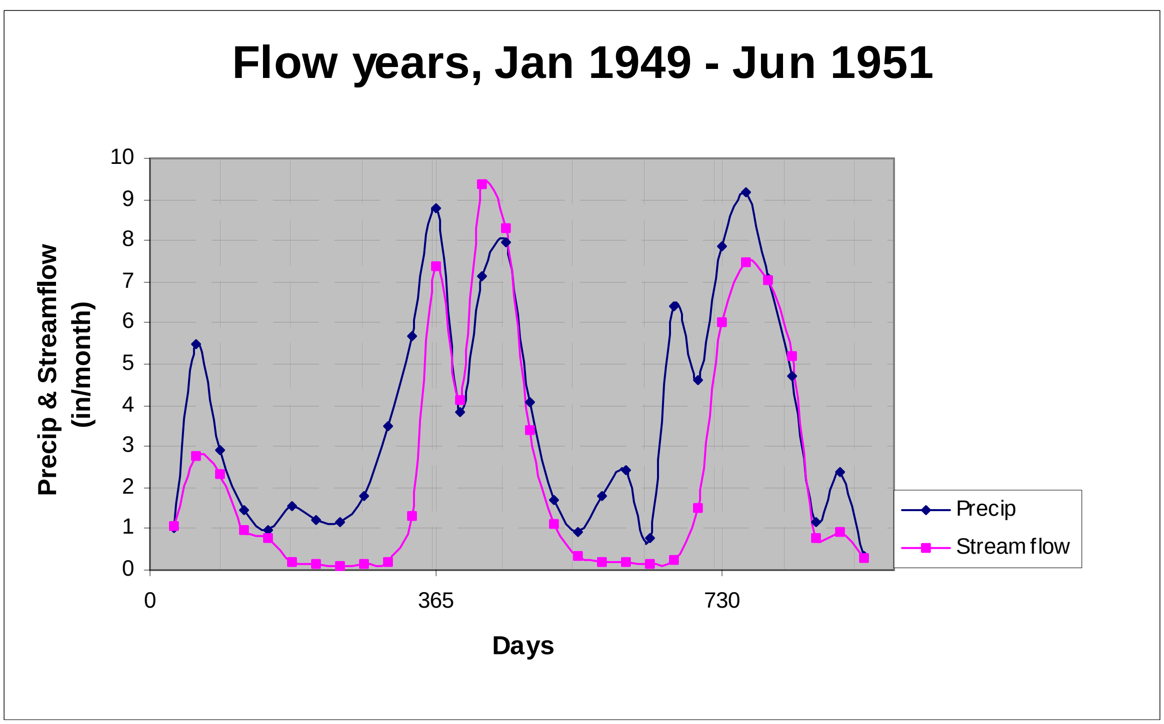

Figure 5.5.1 Dakota Creek precipitation and stream flow comparison, 1949 – 1951.

The slope of the cumulative precipitation gives about 43 in per year for January 1949 to June 1951which is more or less consistent with the long-term average. Even if at some points the precipitation seems lower than the stream flow, the cumulative precipitation is consistently higher than the cumulative stream flow (see Figure 5.5.5 below)

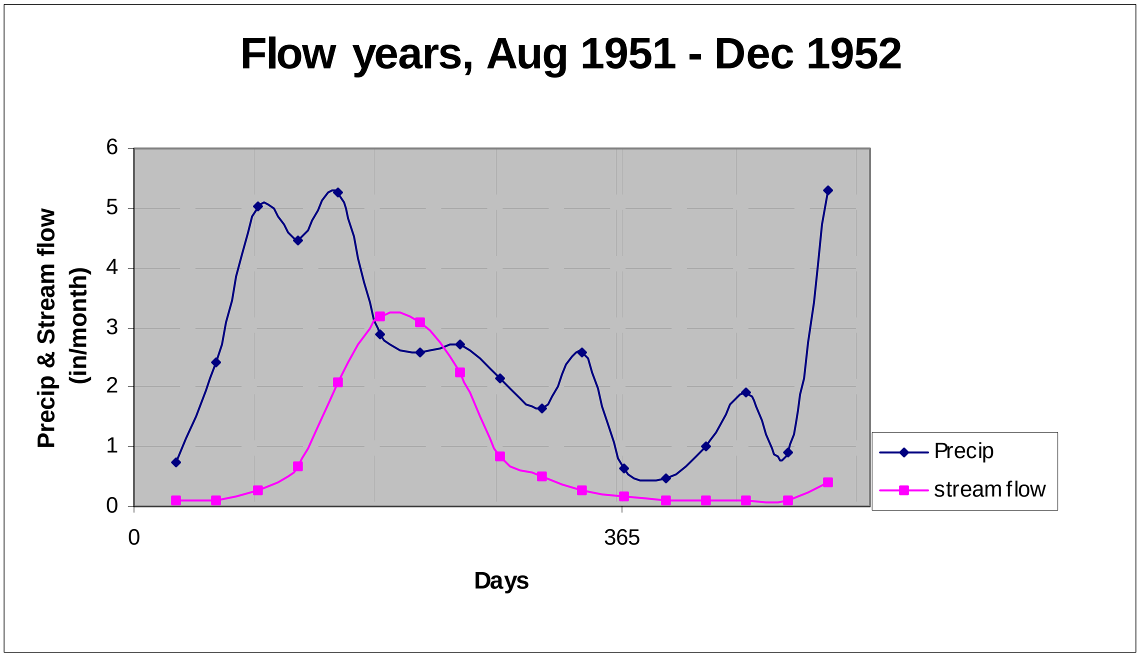

Figure 5.5.2 Dakota Creek precipitation and stream flow comparison, 1951 – 1952.

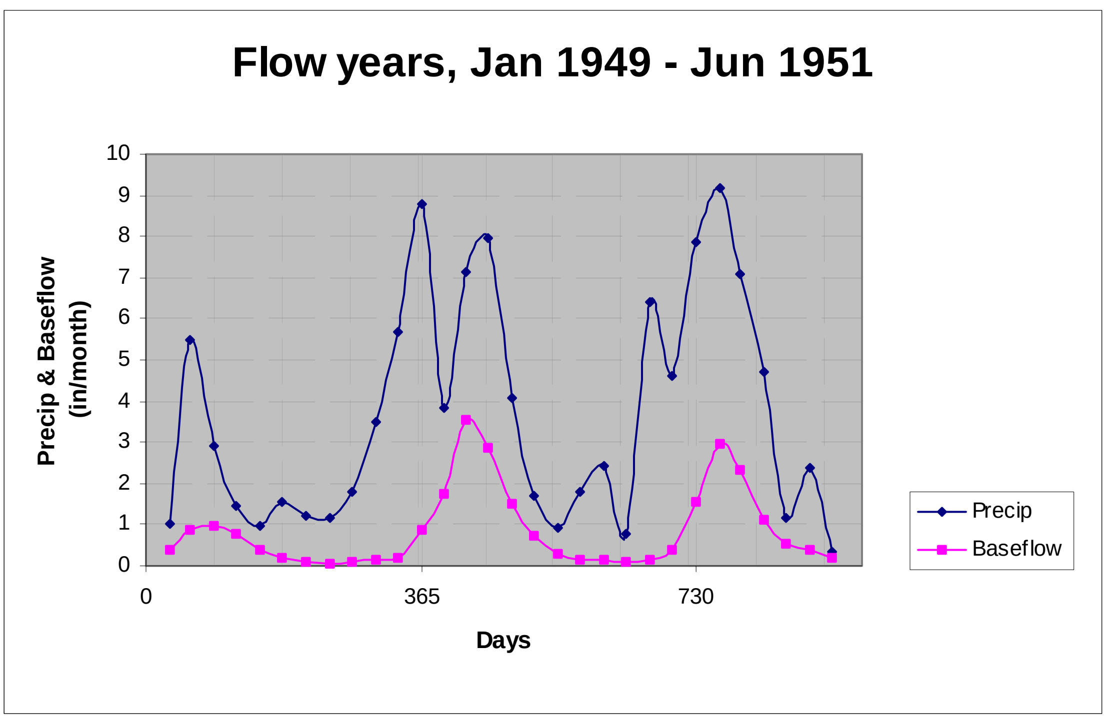

Figure 5.5.3 Dakota Creek precipitation and base flow comparison, 1949 – 1951.

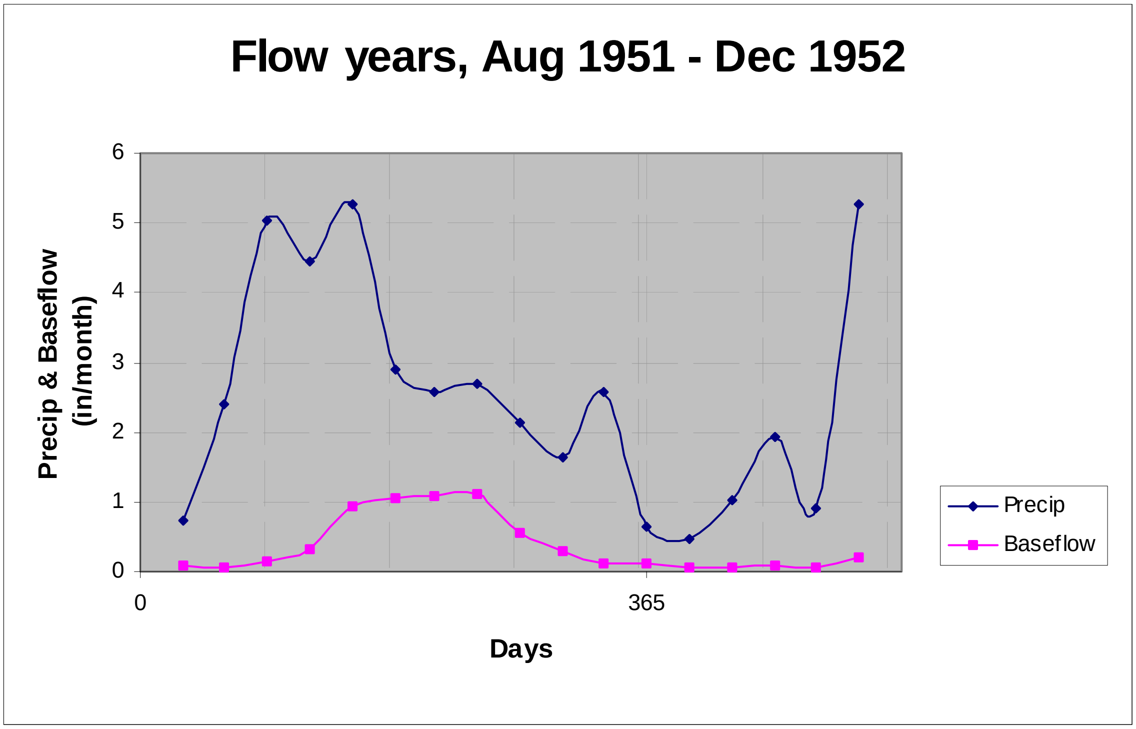

Figure 5.5.4 Dakota Creek precipitation and base flow comparison, 1951 – 1952.

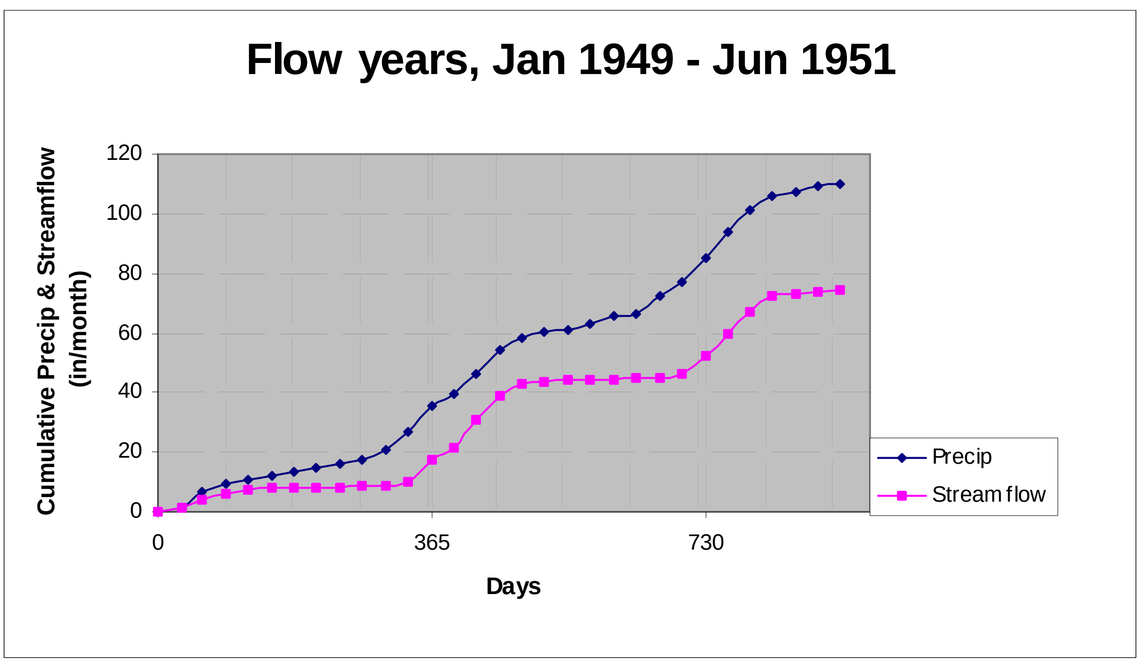

Figure 5.5.5 Dakota Creek cumulative precipitation and stream flow comparison, 1949 – 1951.

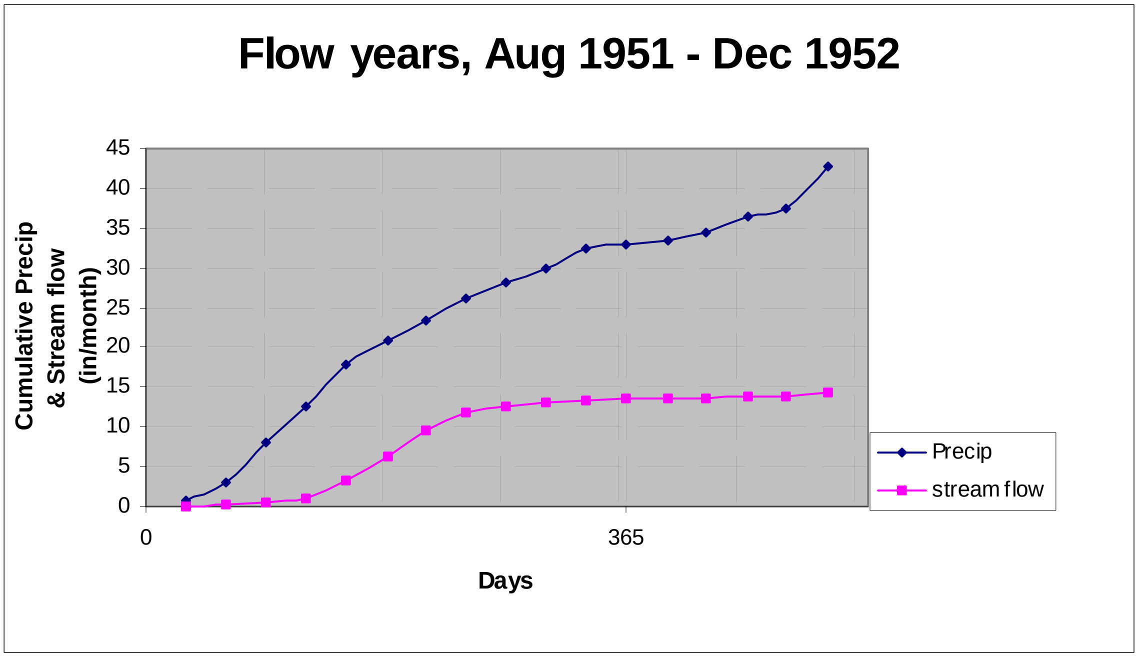

Figure 5.5.6 Dakota Creek cumulative precipitation and stream flow comparison, 1951 – 1952.

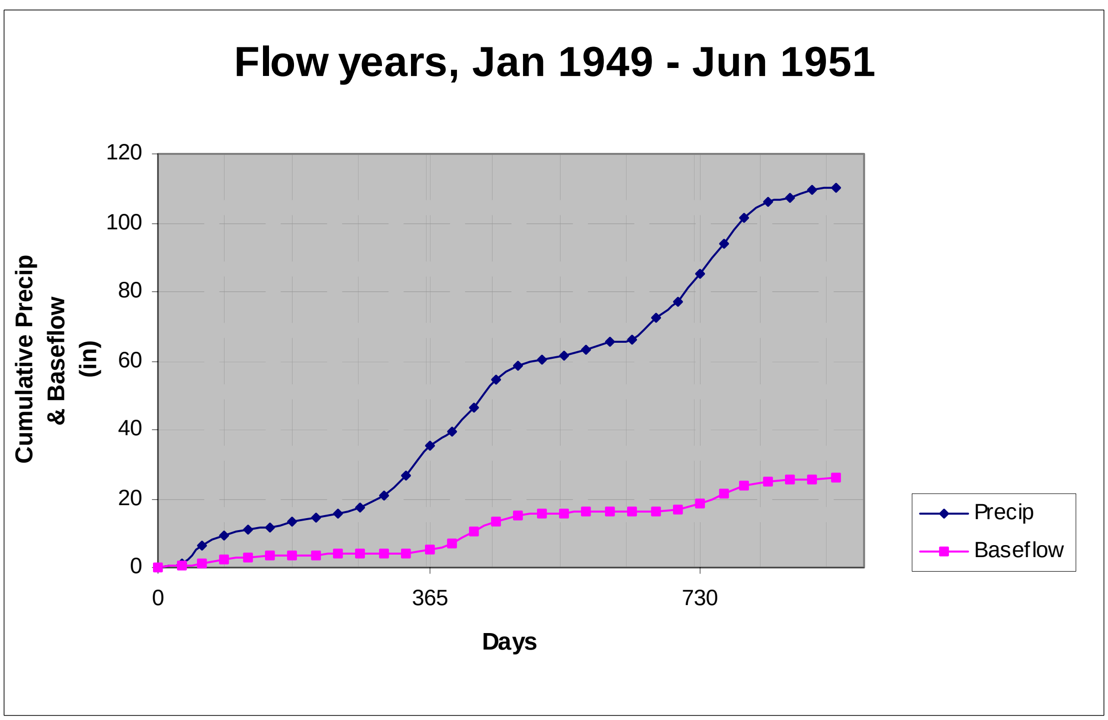

Figure 5.5.7 Dakota Creek cumulative precipitation and base flow comparison, 1949 – 1951.

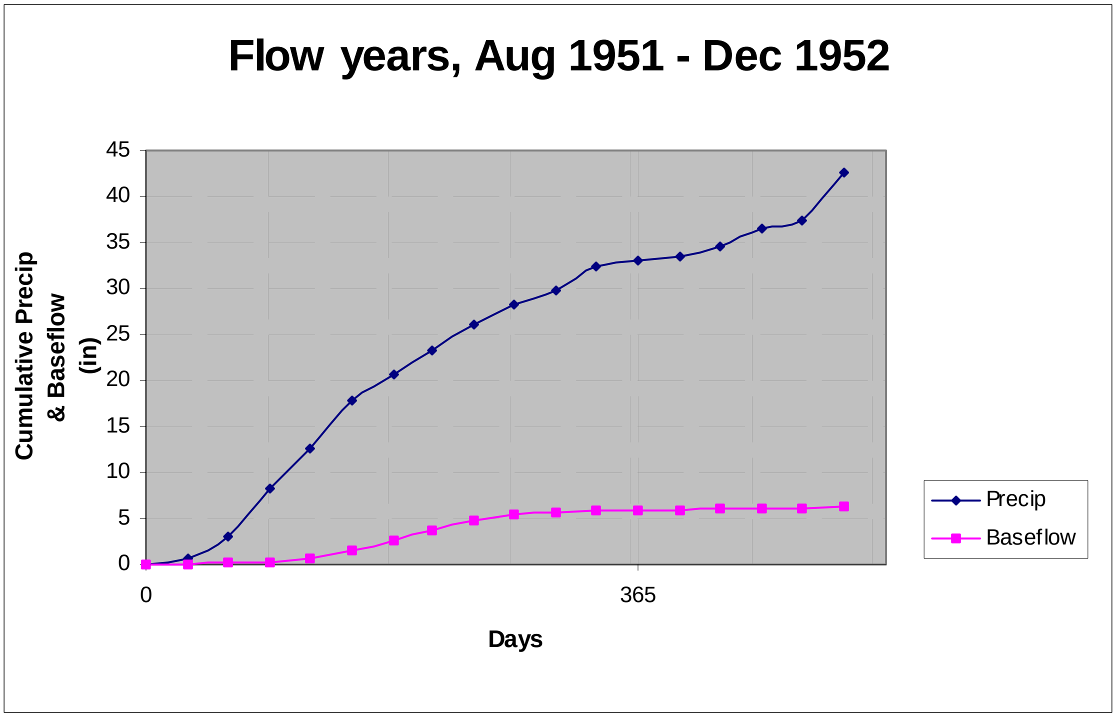

Figure 5.5.8 Dakota Creek cumulative precipitation and base flow comparison, 1951 – 1952.

Slopes and ratios of slopes

Flow periods Jan 1949 – June 1951

Precipitation	0.1156 in/day
Stream flow	0.0702 in/day
Base flow	0.0251 in/day
Precipitation/stream flow	1.65
Precipitation/base flow	4.61

Flow periods Aug 1951 – 1952

Precipitation	0.0874 in/day
Stream flow	0.0702 in/day
Base flow	0.0251 in/day
Precipitation/stream flow	1.25
Precipitation/base flow	3.48

Note that while calculating the slope ratios, stream flow and base flow slopes of the continuous data (1949 – 1952) have been used. Since the precipitation data have gaps the respective slopes have been used for each period.

6.0 THE WRIA 1 SUMAS-ABBOTSFORD SUB-WATERSHED AND AQUIFER WATER BALANCE MODEL

6.1 THE WATERSHED

This watershed is within the Sumas-Abbotsford low land. The Sumas-Abbotsford Lowland area lies within the trans-border region of the United State and Canada and encompasses about 1000 mi^2 (square mile). The Sumas-Abbotsford sub-watershed considered here is only 77.235 mi^2 (see Figure 6.1.1) and consists of the Sumas, Johnson and Saar watersheds. The upper part of Saar watershed contains an unnamed part. Out of these the Sumas watershed is the largest. In the Sumas-Abbotsford sub-watershed there are three major streams: Sumas, Johnson and Saar. The Sumas River is the biggest. This analysis does not include Chilliwack because of data unavailability.

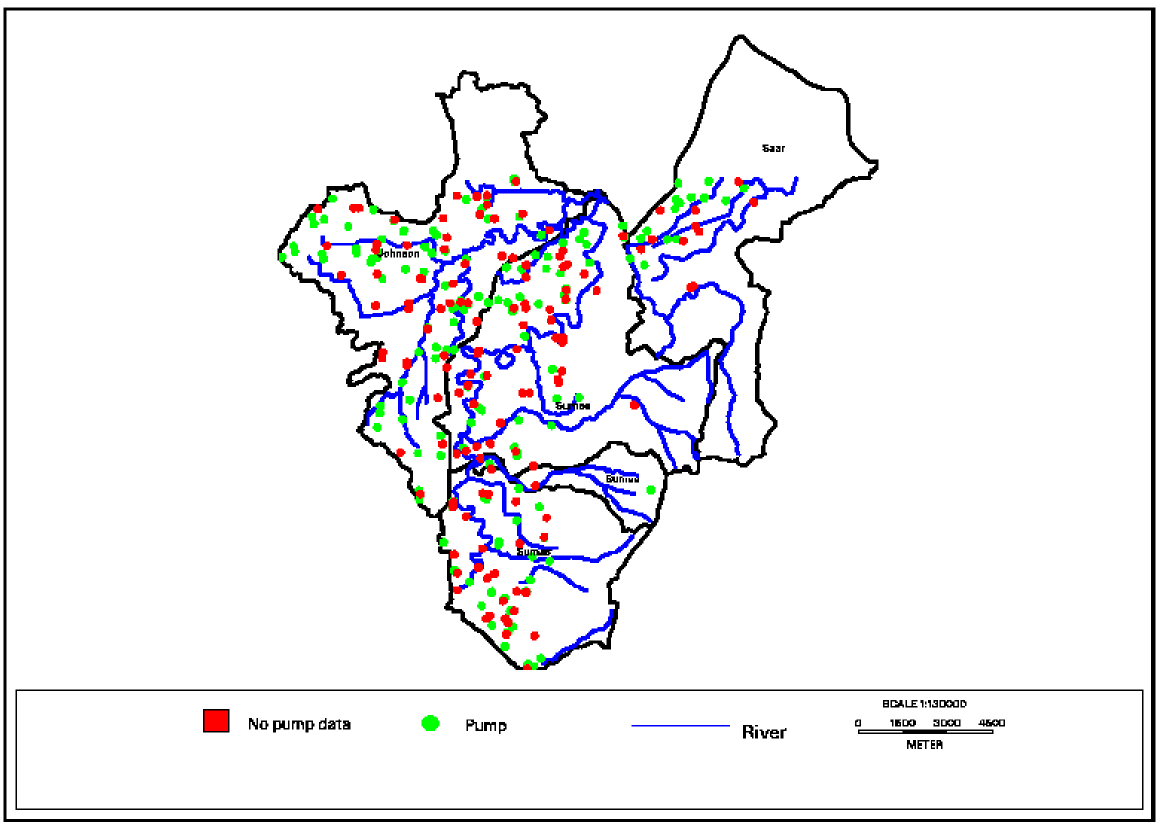

Figure 6.1.1 Sumas-Abbotsford sub-watershed.

The Sumas River Basin is located in the middle part of the Sumas-Abbotsford sub-watershed (see Figure 6.1.1). With the exception of Johnson Creek, all major tributaries of the Sumas River originate near the summit of Sumas Mountain (Washington State Division of Water Resources, 1960). The main stem starts on the southwest side of the mountain and flows in a northerly direction along the base of the mountain. Johnson Creek joins the river just east of Sumas City and from there, the Sumas River flows northeasterly, draining the middle northern part of the WRIA 1 study area and the adjacent Cascade Range foothills and discharging to the Fraser River 10 miles northeast of Abbotsford crossing the Canadian border (Washington State Division of Water Resources, 1960, Cox and Kahle, 1999).

Elevations in the watershed range from 3,300 feet on the top of Sumas Mountain to 30 feet at the lower end of the Sumas trough (Washington State Division of Water Resources, 1960). Clearbrook, a town in the middle of Sumas-Abbotsford sub-watershed, receives an average precipitation of 46 inches per year.

One of the comprehensive studies in Sumas-Abbotsford area is that of the LENS study report (Cox and Kahle, 1999). The LENS study area covers 225 mi^2 in the southern part of Sumas-Abbotsford Lowland.

Although groundwater in most of the Sumas aquifer is unconfined it becomes confined in places in Sumas River Valley where it overlain by recent lacustrine silt and clay and along the margin of the Sumas Valley where it is overlain by fine-grained ice-contact deposits (Cox and Kahle, 1999).

The drainage area based on DTM (that is the area shown in Figure 6.1.1) is 77.235 mi^2 (square mile) while the one obtained from the gaging station information at Sumas River near Huntingdon, B.C., is 57.6 mi^2. For the sake of consistency with other parts of WRIA 1 watershed, here also the area as given by the USGS have been used.

6.2 BASE FLOW

Gaging station # 12215100, Sumas River near Huntingdon, B.C., is situated north of Sumas city after Johnson Creek and Saar Creek joined and just after US-Canada international boundary. Therefore, the analysis made here include these three sub-watersheds: Sumas, Johnson and Saar. This gaging station is the only one around this region, which has a relatively long period of measurements. There are three pieces of measurement periods: water years 1961 – 1963, 1965 – 1968 and 1974 – 1978. These records are from USGS measurement. Figures 6.2.1 – 6.2.3 shows the stream flow baseflow comparison for the respective periods and Figures 6.3.4 – 6.3.6 shows stream flow and baseflow cumulative plots. Measurements between 1952 – 59 and 1978 – present are recorded by Environment Canada and are not available for this analysis (Tarboton et al, 2000).

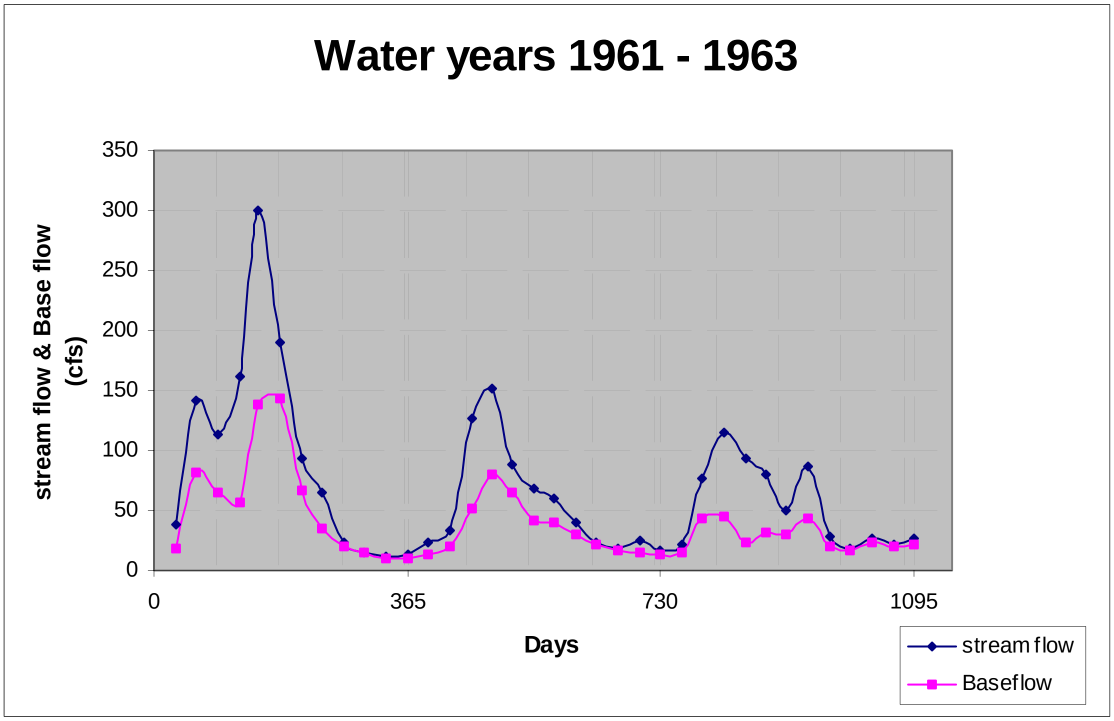

Figure 6.2.1 Sumas River stream flow and baseflow measurement comparison, 1961 - 1963.

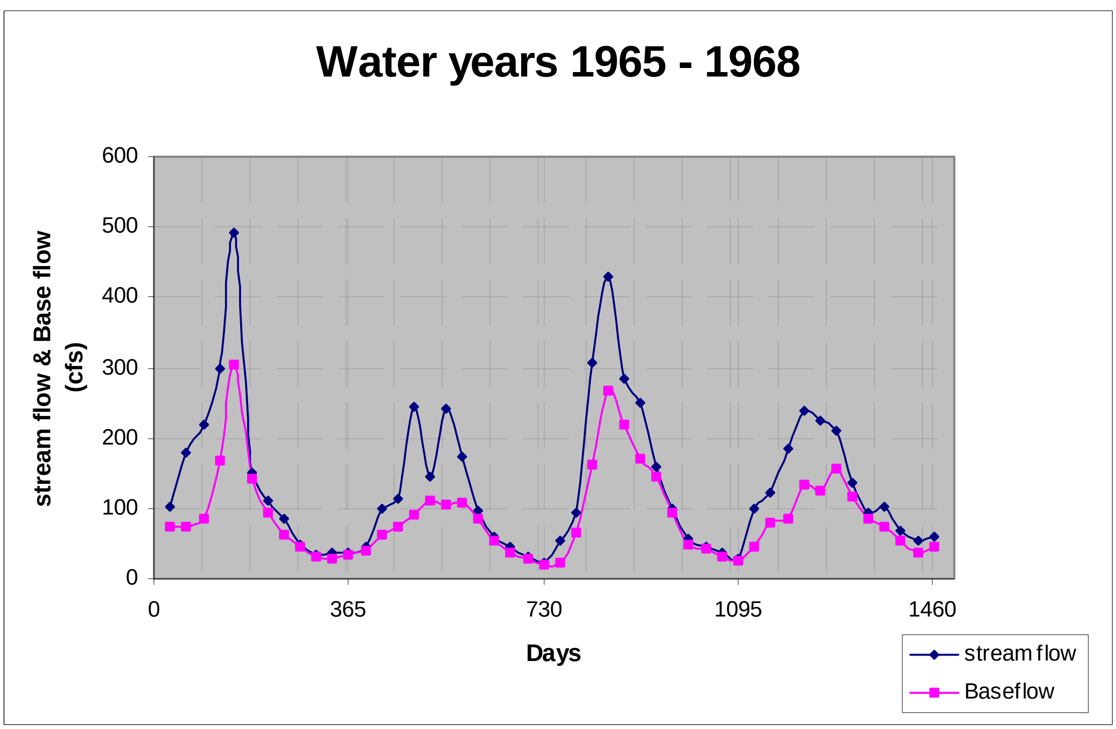

Figure 6.2.2 Sumas River stream flow and baseflow measurement comparison, 1965 – 1968

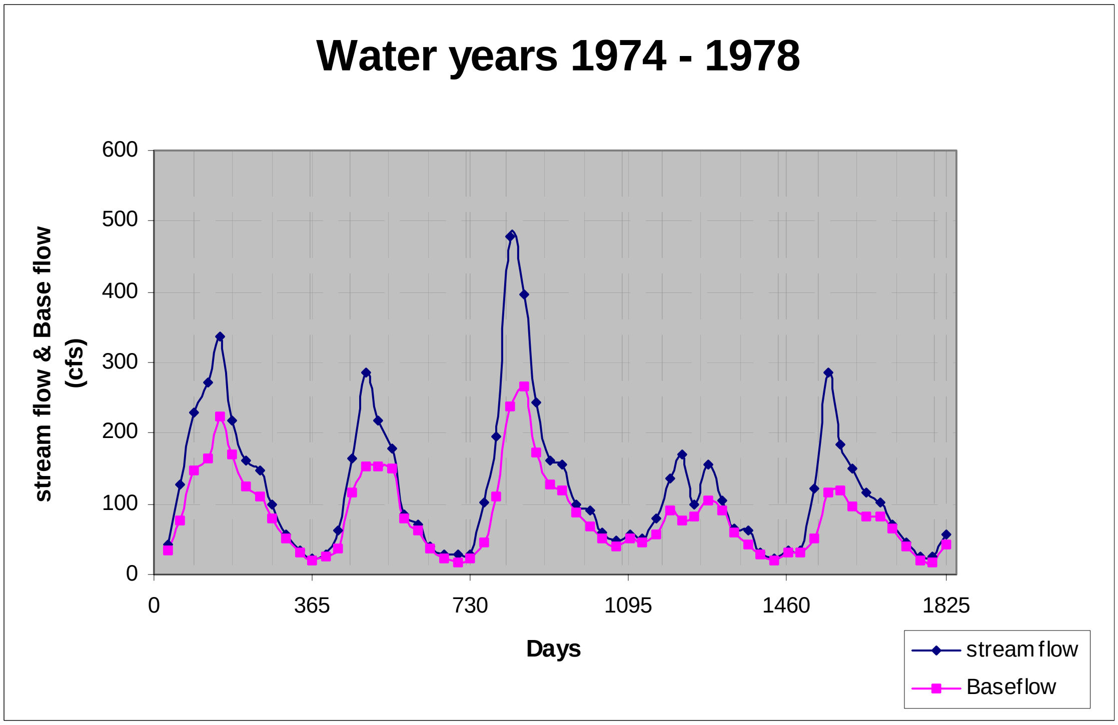

Figure 6.2.3 Sumas River stream flow and baseflow measurement comparison, 1974 – 1978

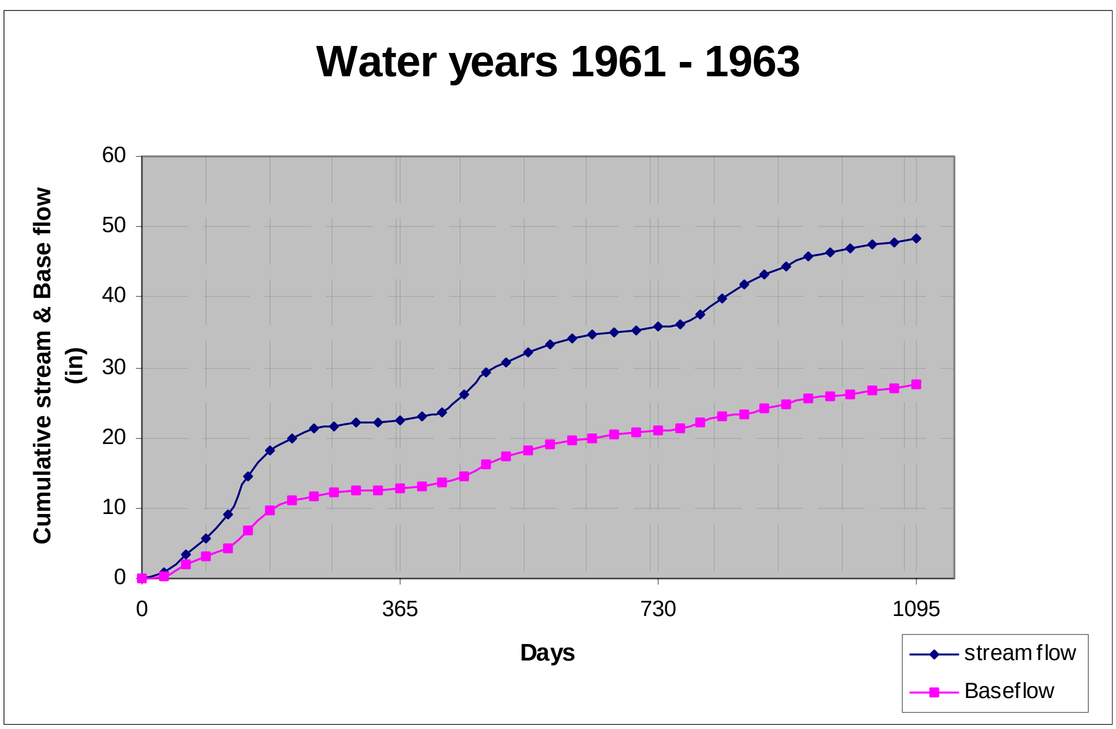

Figure 6.2.4 Sumas River cumulative Stream flow and baseflow comparison, 1961 – 1963

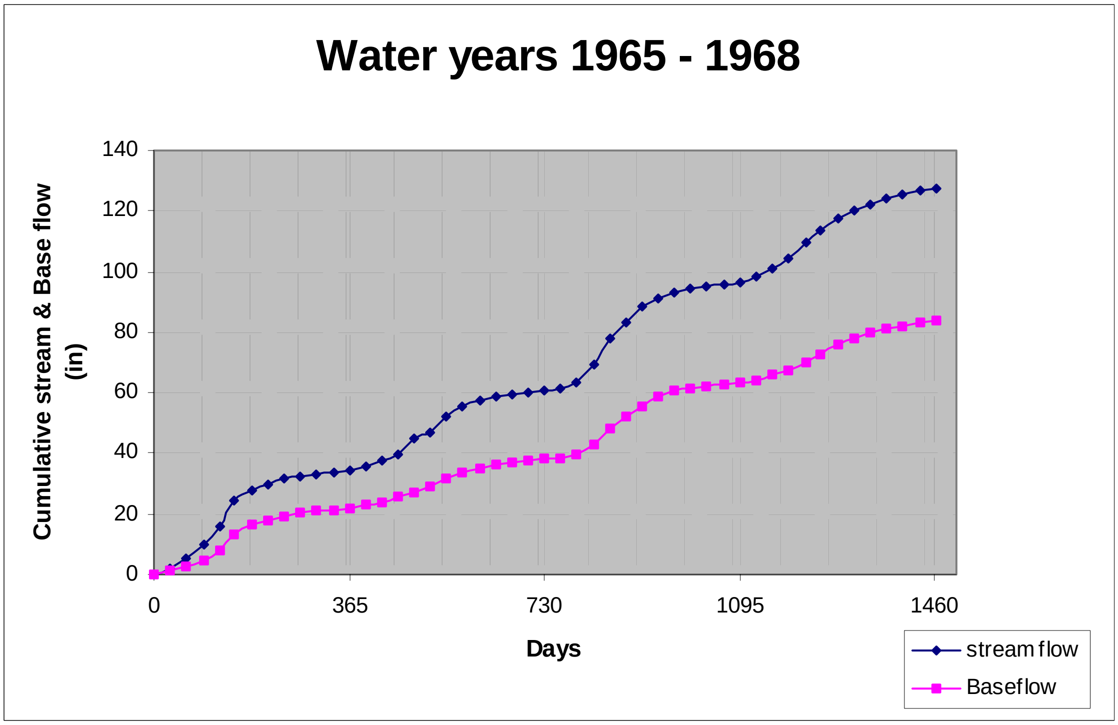

Figure 6.2.5 Sumas River cumulative Stream flow and baseflow comparison, 1965 – 1968

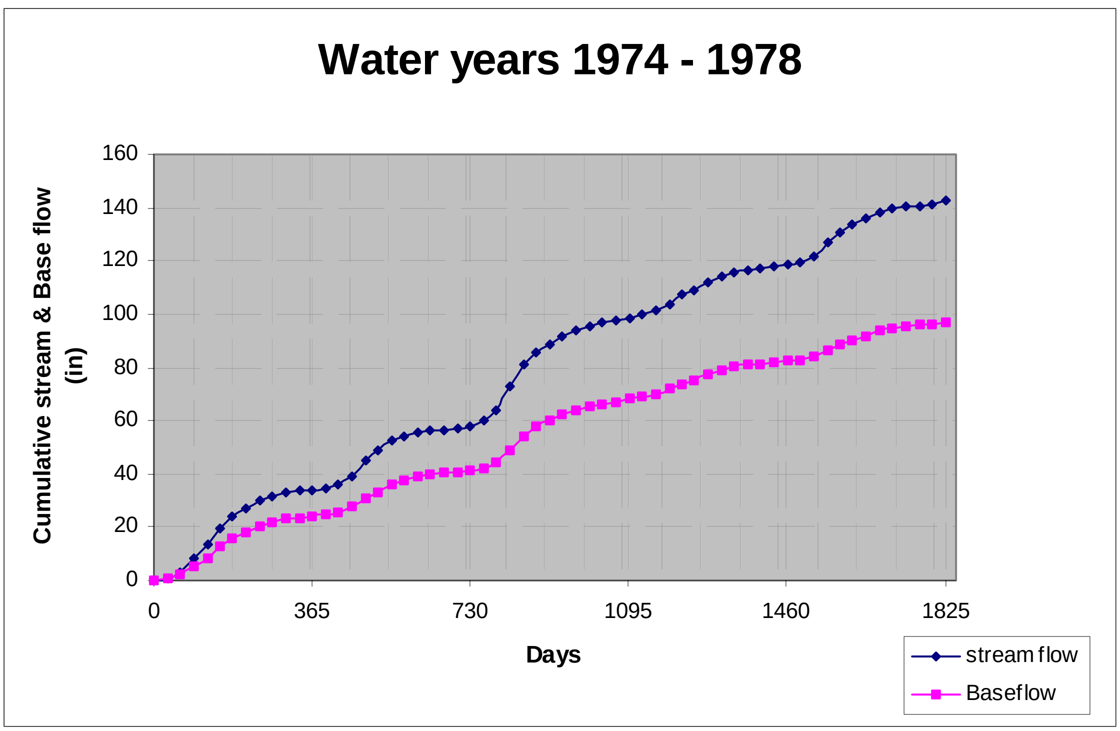

Figure 6.2.6 Sumas River cumulative Stream flow and baseflow comparison, 1974 – 1978

6.3 GROUNDWATER PUMPING

The Upland region of Sumas-Abbotsford sub-watershed is known as the Abbotsford-Sumas aquifer, and the aquifer is used as a drinking water supply both north and south of the Canadian border. The greatest use of the aquifer is within Abbotsford, B.C., where as many as 90,000 people use the groundwater for drinking at certain times of the year (Associated Earth Science, 1995). Sumas's water system is the largest system tapping the aquifer within the United States (Associated Earth Science, 1995).

There are 290 registered wells in this watershed. Out of these 158 of them has pumping data which totals to 33946 gpm (see Figure 6.7.1).

6.4 RECHARGE

Cox and Kahle (1999) report an average annual groundwater recharge estimate of 28 inches per year near the Clearbrook Weather Station based on the works of Vaccaro and others. The reported Cox and Kahle (1999) recharge estimate varies between 11 to 50 inches per year for the rest of the Sumas-Abbotsford sub-watershed. This estimate is based on a monthly soil water budget using precipitation data and estimates of potential evapotranspiration.

Associated Earth Science (1995), estimates a recharge of 6 inches and 30 inches for the Upland out wash area and the Sumas Valley region, respectively. These values were based on water balance calculation of published values of evapotranspiration and run off coefficients and subsequent groundwater model calibration.

Inverse recharge estimation

Assuming the recharge to be the unknown in the mass balance equation, an inverse estimation for recharge can be performed using the other components of the water balance.

A linear regression line has been fitted to the cumulative base flow with the following statistics:

Water year 1961 –1963

Slope of regression line	=0.0285 in/day
Standard deviation of the slope	=0.000633 in/day
Coefficient of regression	=0.91

Hence, total annual base flow is

1. Using regression slope	=0.0285*365	= 10.4in
2. Using slope – 2*Std	=(0.0285-2*0.000633)*365	= 9.94in
3. Using slope + 2*Std	=(0.0285+2*0.000633)*365	= 10.86in

Annual pumpage =(33946 gpm in 77.235 mi^2) = 13.2in

The uniform recharge value over the catchment will be the sum of the above base flows and the total pumpage.

Recharge1 = (10.4 + 13.2) = 23.6in
Recharge2 = (9.94 + 13.2) = 23.14in
Recharge3 = (10.86 + 13.2) = 24.06in

Water year 1965 –1968

Slope of regression line =0.0583 in/day
Standard deviation of the slope =0.000457 in/day
Coefficient of regression =0.99

Hence, total annual base flow is

1. Using regression slope =0.0583*365 = 21.3in
2. Using slope – 2*Std =(0.0583-2*0.000457)*365 = 20.9in
3. Using slope + 2*Std =(0.0583+2*0.000457)*365 = 21.6in

Annual pumpage =(33946 gpm in 77.235 mi^2) = 13.2in

The uniform recharge value over the catchment will be the sum of the above base flows and the total pumpage.

Recharge1 = (21.3 + 13.2) = 34.5in
Recharge2 = (20.9 + 13.2) = 34.1in
Recharge3 = (21.6 + 13.2) = 34.8in

Water year 1974 –1978

Slope of regression line =0.0581 in/day
Standard deviation of the slope =0.00051 in/day
Coefficient of regression =0.98

Hence, total annual base flow is

1. Using regression slope =0.0581*365 = 21.2in
2. Using slope – 2*Std =(0.0581-2*0.00051)*365 = 20.8in
3. Using slope + 2*Std =(0.0581+2*0.00051)*365 = 21.6in

Annual pumpage =(33946 gpm in 77.235 mi^2) = 13.2in

The uniform recharge value over the catchment will be the sum of the above base flows and the total pumpage.

Recharge1 = (21.2 + 13.2) = 34.4in

Recharge2	= (20.8 + 13.2)	= 34in
Recharge3	= (21.6 + 13.2)	= 34.8in

Recharge estimated from water years 1961 – 1963 give about 23 inches per year while the estimate from water years 1965 – 1968 and 1974 – 1978 both give about 34 inches per year. The yearly average rainfall based on Clearbrook's weather station observation is 48.7, 48.3 and 46.9 inches per year for the three time periods, respectively. This is in concert with the long-term average of 46.14 inches per year for the station. These differences in recharge come partly because of difference in stream flow observed at the gaging station. The averages stream flows for the three periods are 69, 137 and 121 cfs, respectively.

6.5 Comparison of Precipitation, Stream flow and Base flow

The nearby climate station with sufficiently long record is that of Clearbrook. This station has about 85 years of precipitation record. Here, only those measurement years, which coincide with measured stream flow, are taken for the analysis. Figures 6.5.1 – 6.5.6 shows precipitation comparison with base flow and stream flow and Figures 6.5.7 – 6.5.12 shows the cumulative comparison plot. The slope comparison is shown below.

Slopes and ratios of slopes

Water year 1961 – 1963

Precipitation	0.1333 in/day
Stream flow	0.0502 in/day
Base flow	0.0285 in/day
Precipitation/stream flow	2.66
Precipitation/base flow	4.68

Water years 1965 – 1968

Precipitation	0.1324 in/day
Stream flow	0.0905 in/day
Base flow	0.0583 in/day
Precipitation/stream flow	1.46
Precipitation/base flow	2.27

Water years 1974 – 1978

Precipitation	0.1285 in/day
Stream flow	0.0847 in/day
Base flow	0.0581 in/day
Precipitation/stream flow	1.52
Precipitation/base flow	2.21

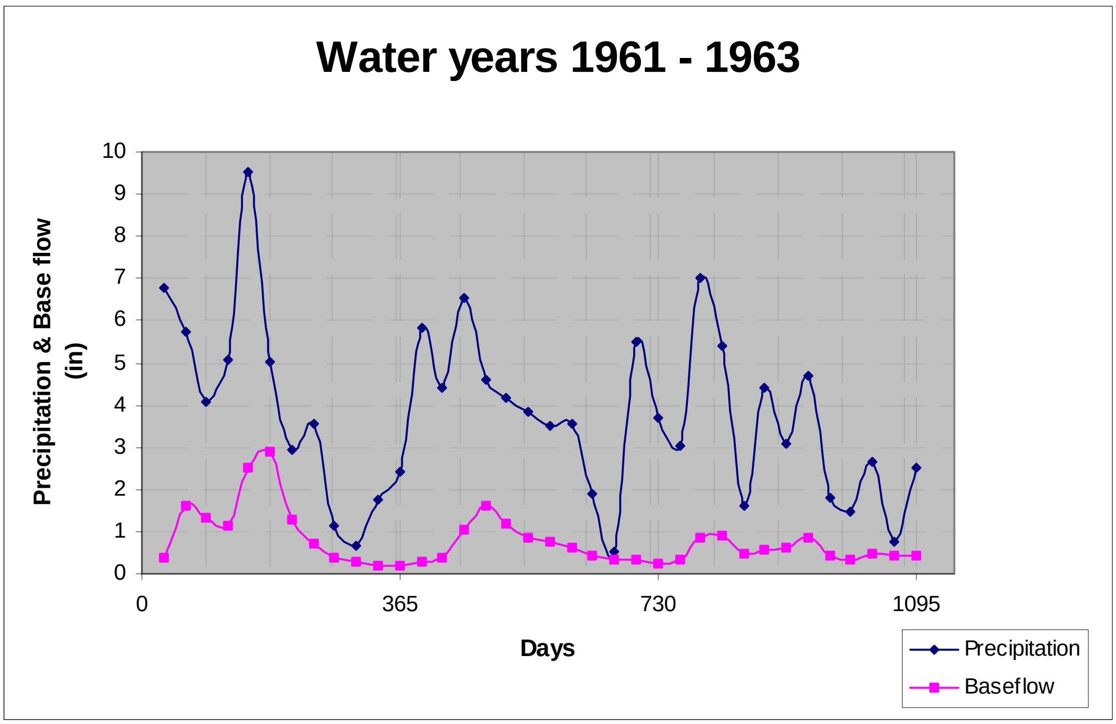

Figure 6.5.1 Precipitation/Baseflow comparison, 1961 – 1963, Sumas River

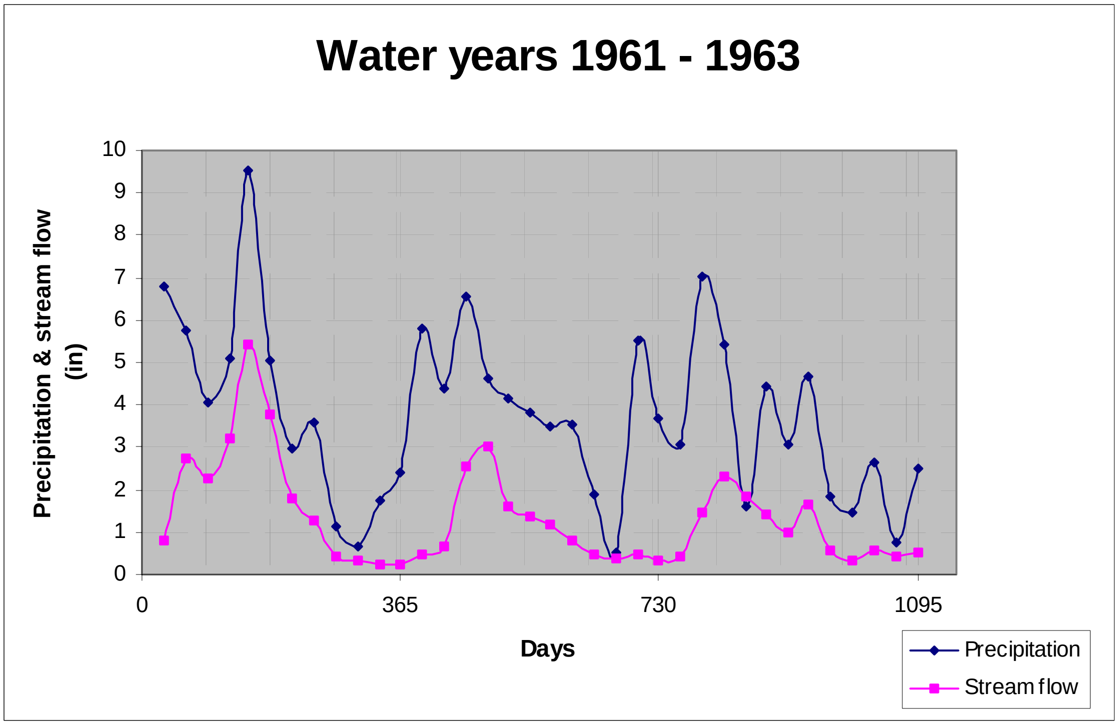

Figure 6.5.2 Precipitation/Stream flow comparison, 1961 – 1963, Sumas River

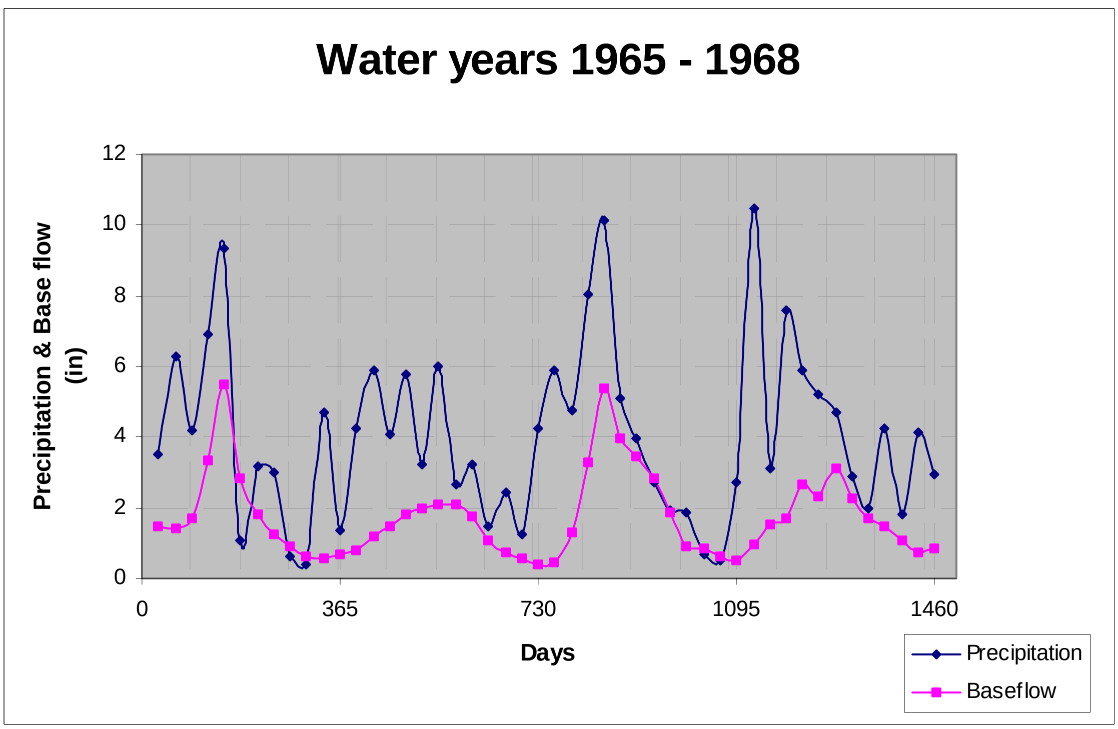

Figure 6.5.3 Precipitation/Baseflow comparison, 1965 – 1968, Sumas River

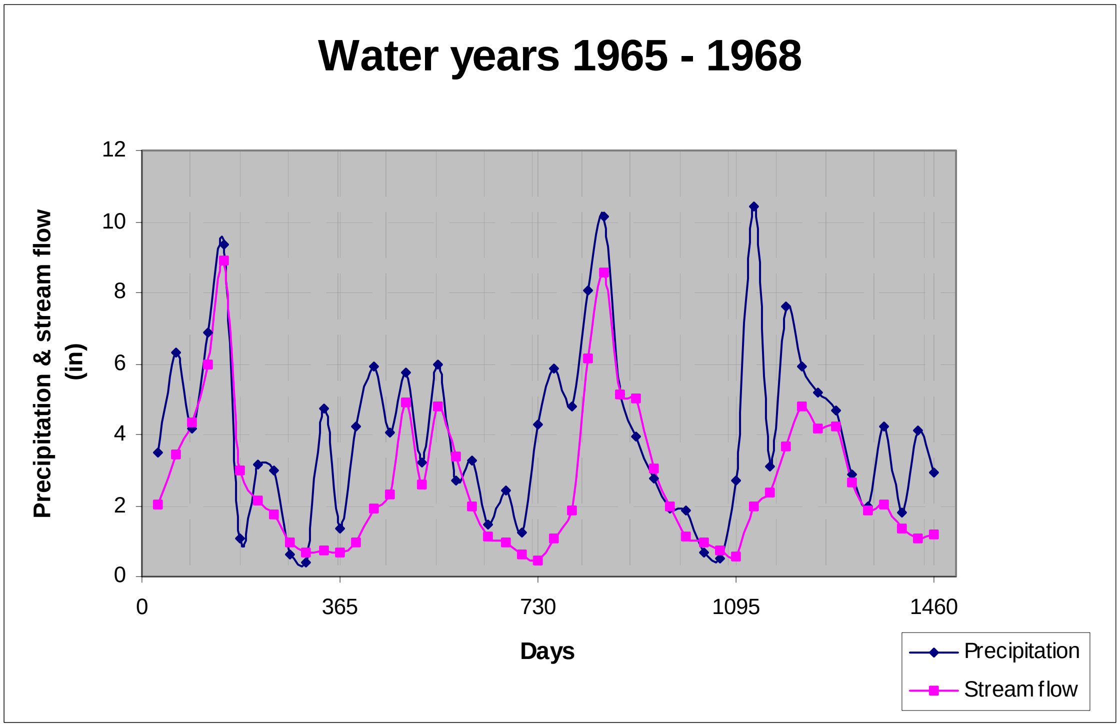

Figure 6.5.4 Precipitation/Stream flow comparison, 1965 – 1968, Sumas River

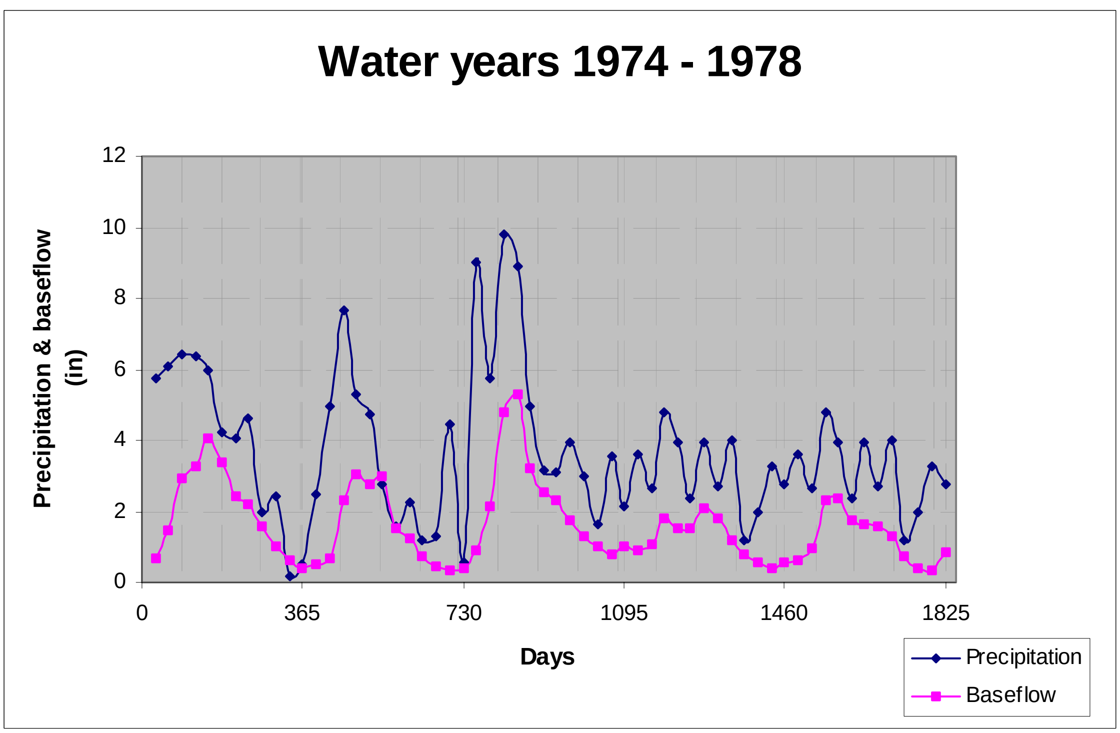

Figure 6.5.5 Precipitation/Base flow comparison, 1974 – 1978, Sumas River

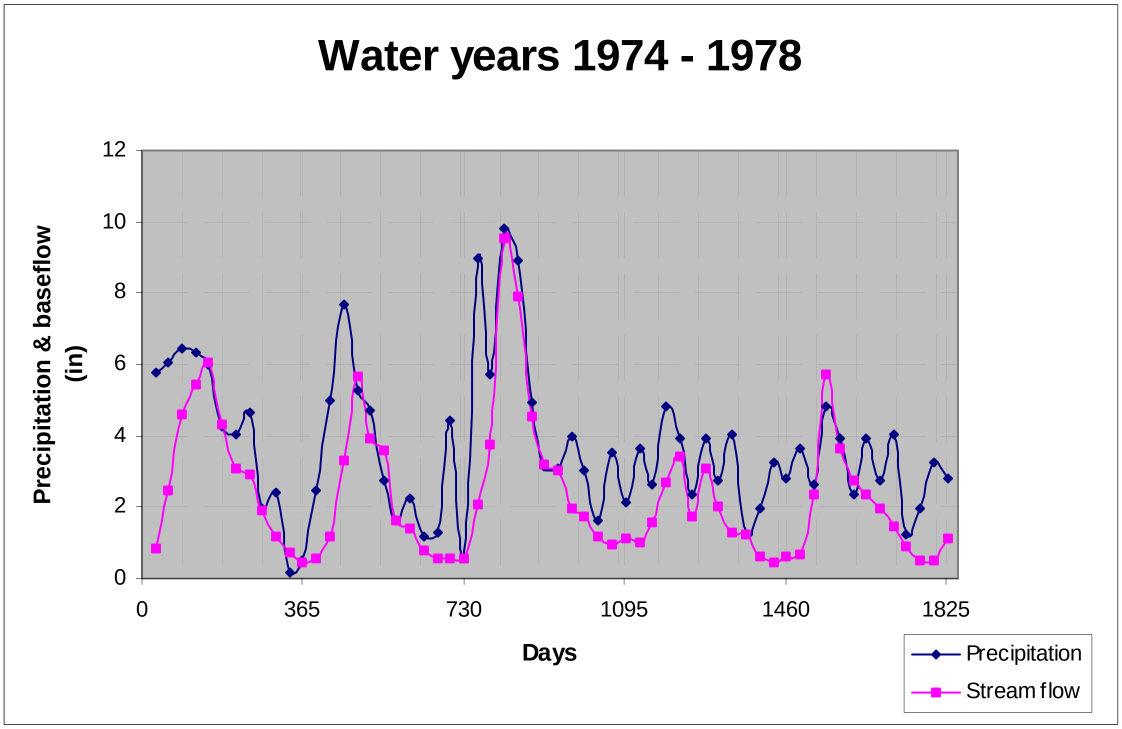

Figure 6.5.6 Precipitation/Stream flow comparison, 1974 – 1978, Sumas River

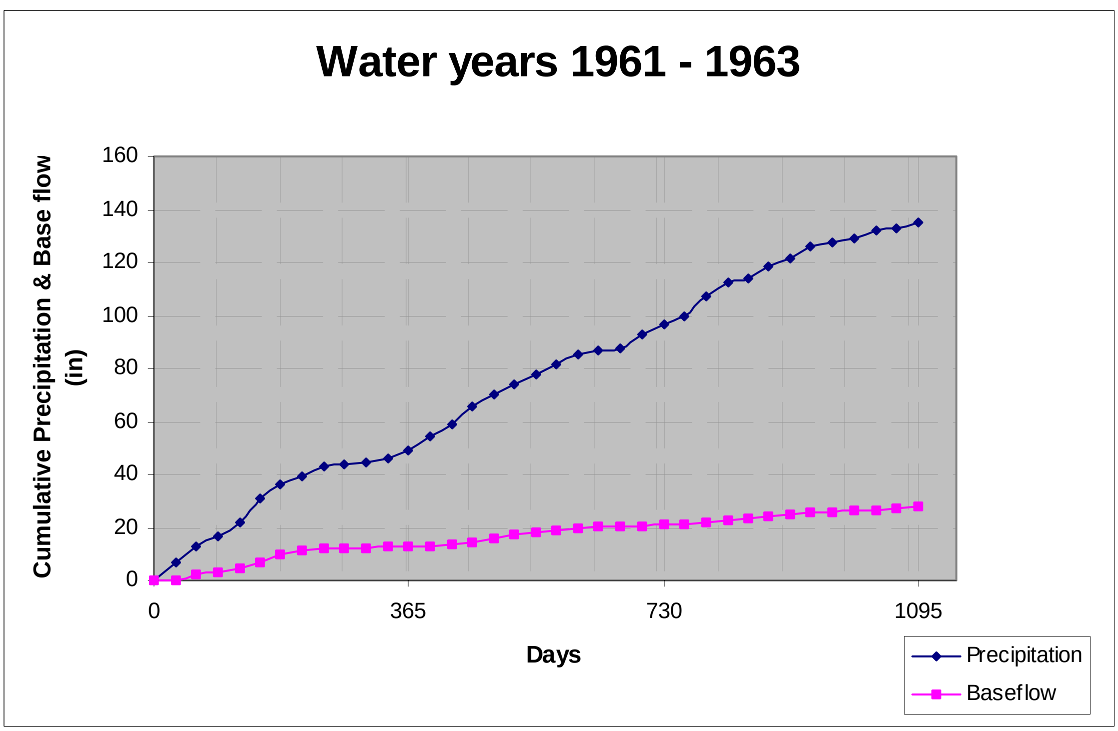

Figure 6.5.7 Cumulative precipitation/Baseflow comparison, 1961 – 1963, Sumas River

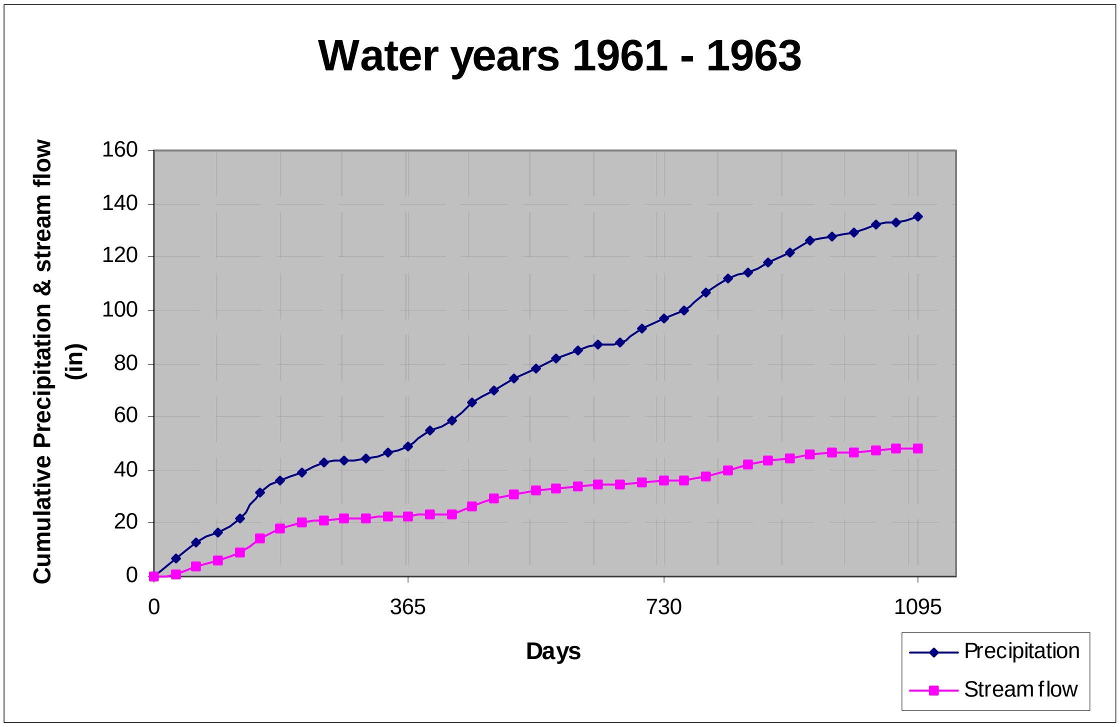

Figure 6.5.8 Cumulative precipitation/Stream flow comparison, 1961 – 1963, Sumas River

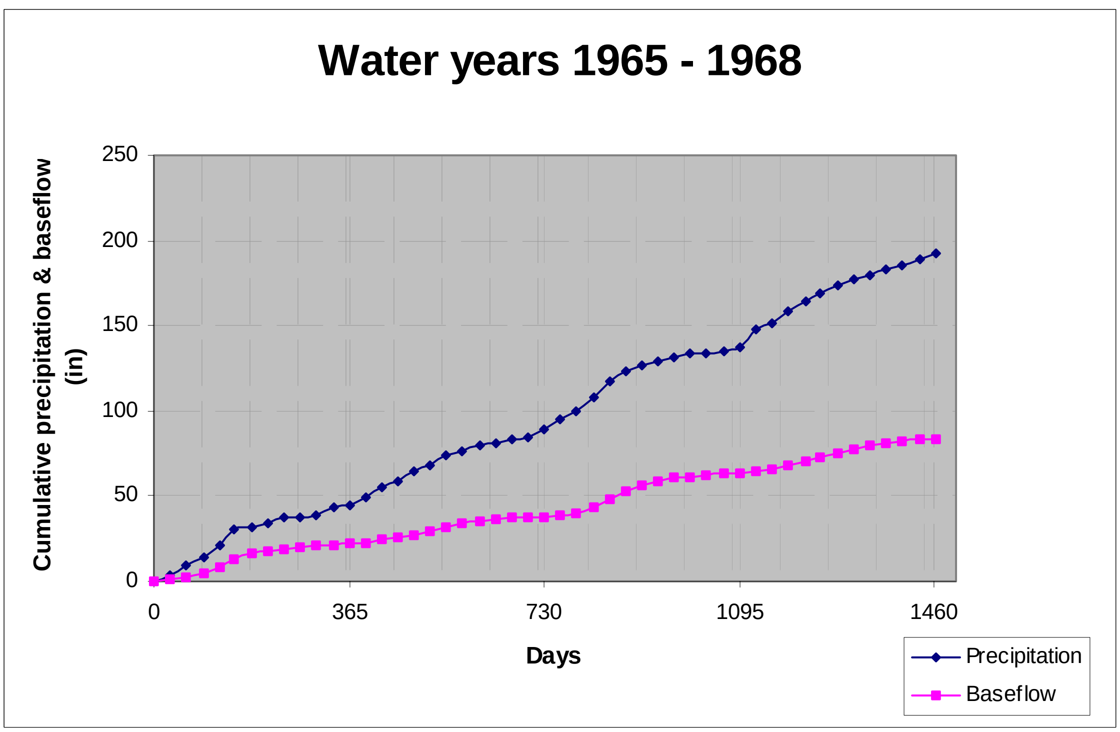

Figure 6.5.9 Cumulative precipitation/Baseflow comparison, 1965 – 1968, Sumas River

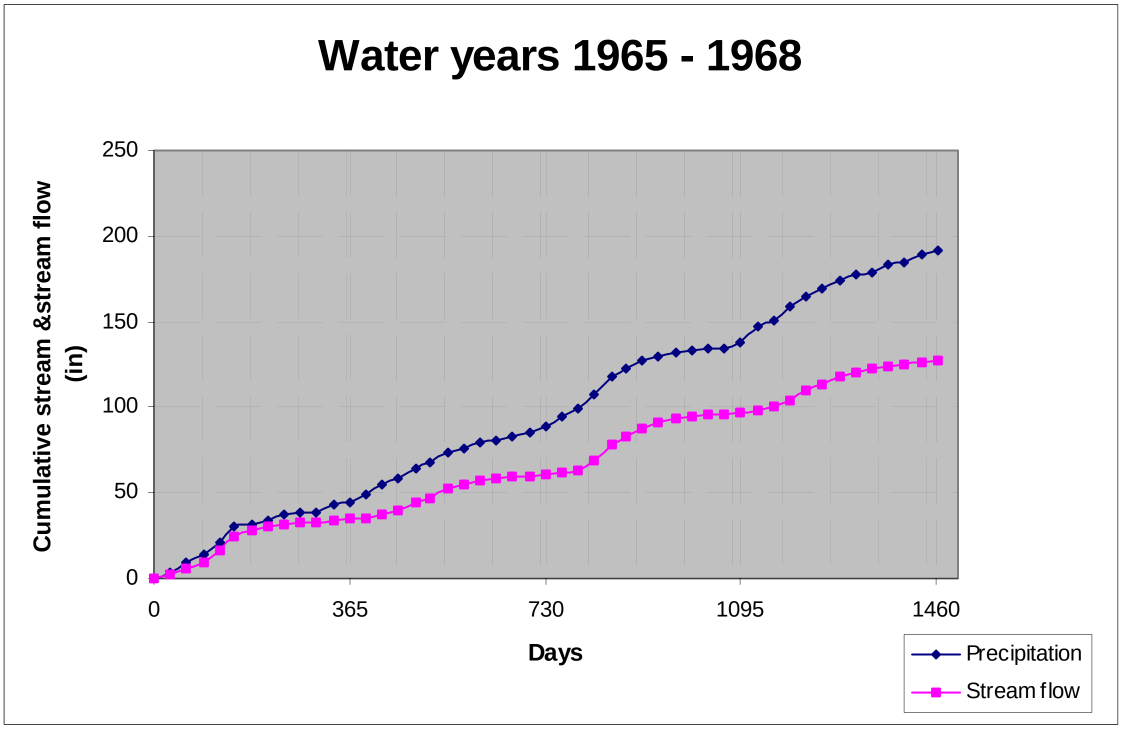

Figure 6.5.10 Cumulative precipitation/Stream flow comparison, 1965 – 1968, Sumas River

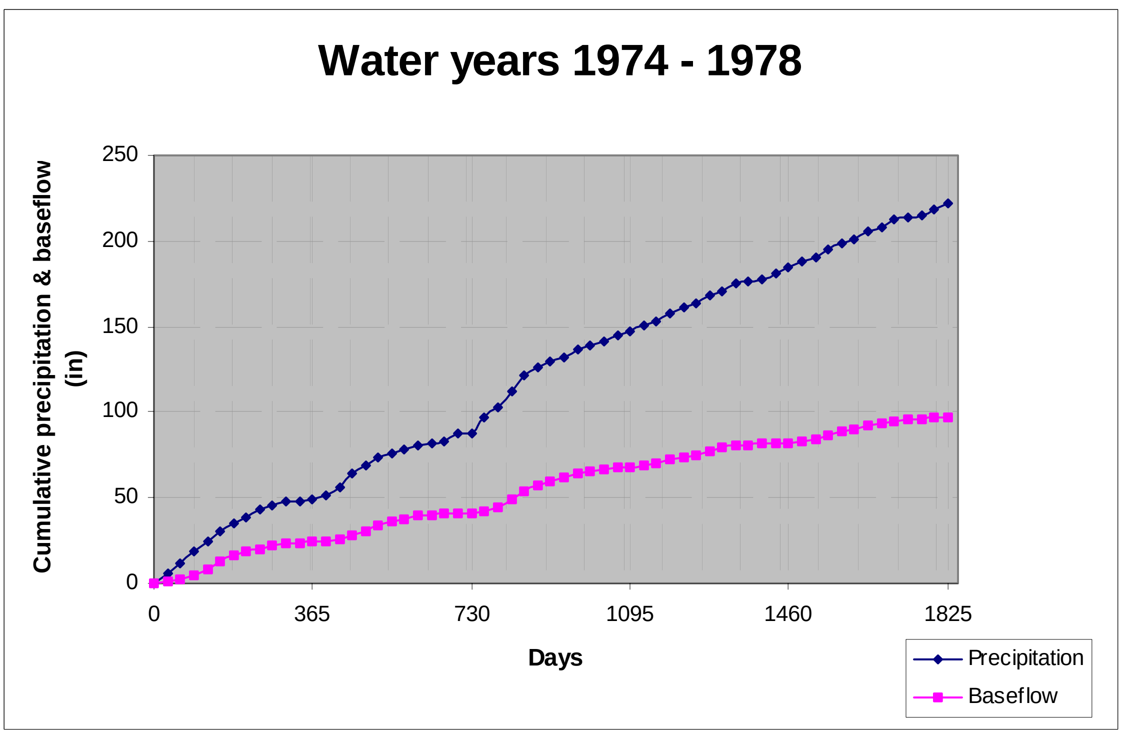

Figure 6.5.11 Cumulative precipitation/Baseflow comparison, 1974 – 1978, Sumas River

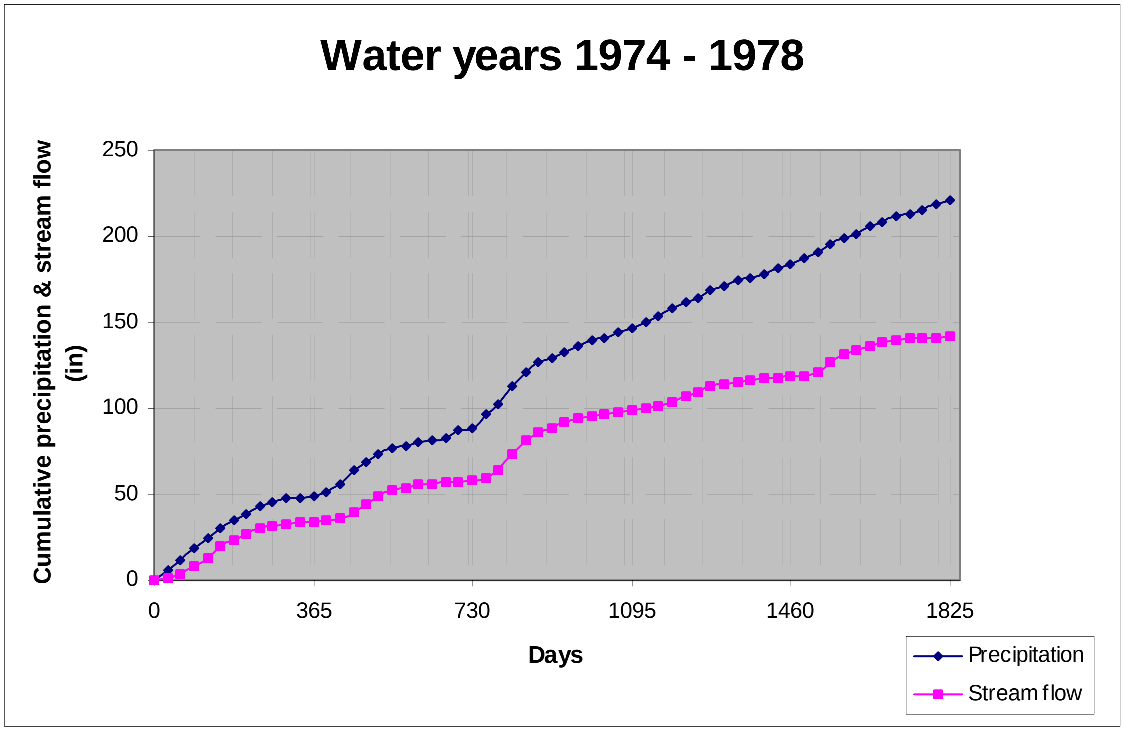

Figure 6.5.12 Cumulative precipitation/Stream flow comparison, 1974 – 1978, Sumas River

6.6 SEEPAGE RUNS

The only creek on this watershed with limited seepage run data is Johnson Creek. There are three seepage-run sites on Johnson Creek. Out of the four measurement days three of them are done on all the three sites. In addition, unlike other seepage run in the WRIA 1 project areas, these runs are given as an average of two days measurement. Table 6.6.1 shows the seepage run results including the flow contributed by tributaries. Seepage results for this creek came from WDOE, Gibbons and Culhane.

Table 6.6.1 Seepage runs on Johnson Creek.

Date	Distance	Flow (cfs)	Remark	Tributary supply (cfs)
Aug 2-3, 1993	0	3.44		
	2832		Tributary	0.44
	3119		Tributary	2.04
	8009		Tributary	
	8635	6.93	Not accurate	
	8828		Tributary	4.18
	9260	19.55		
Jun 17-18, 1993	0	14.04		
	2832		Tributary	0.89

	3119		Tributary	2.45
	8009		Tributary	
	8635	34.07		
	8828		Tributary	5.39
	9260	40.65		
Sept 20-21, 1993	0	3.09		
	2832		Tributary	0.4
	3119		Tributary	2.42
	8009		Tributary	
	8635	3.85	Not accurate	
	8828		Tributary	4.88
	9260	15.52		

Figures 6.6.1 – 6.6.3 shows plots of the seepage run. The arrows show the tributary entry points.

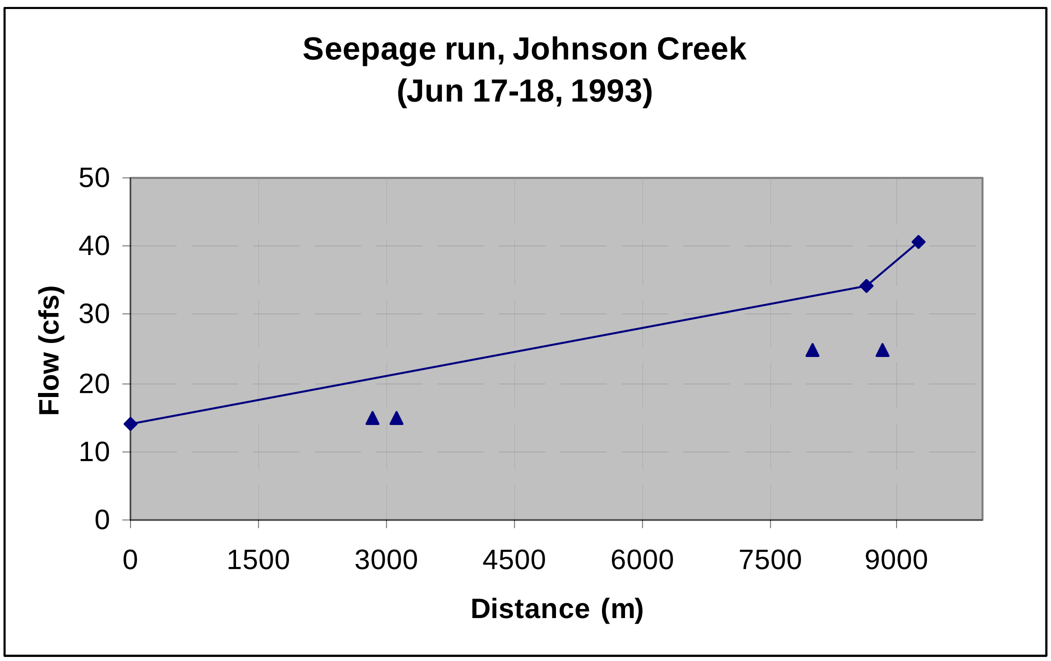

Figure 6.6.1 Seepage run for Johnson Creek, Jun 17 – 18, 1993.

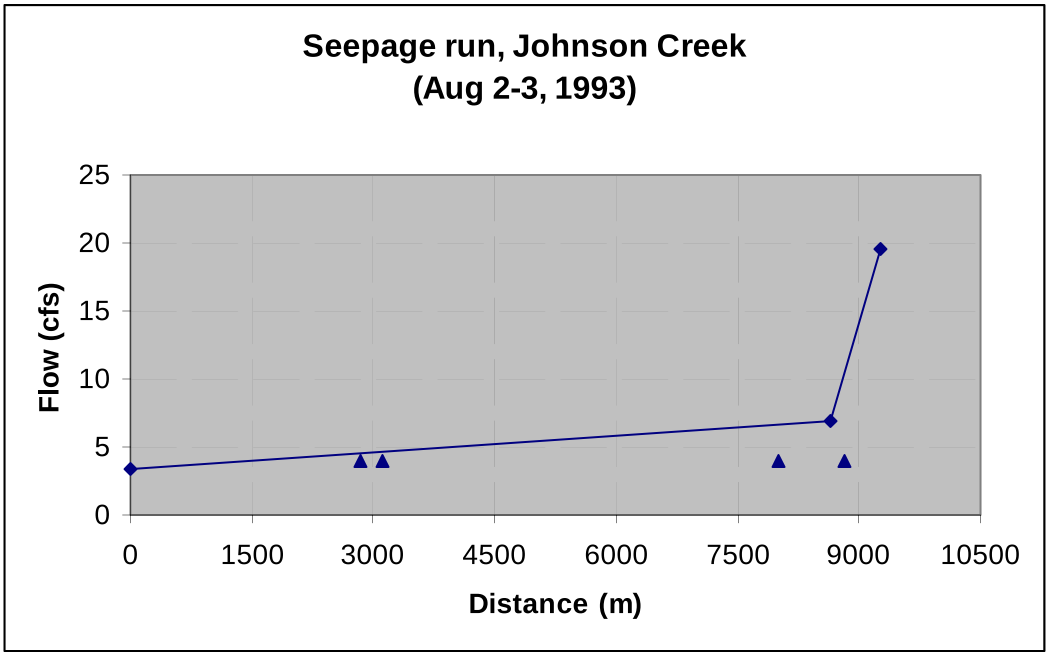

Figure 6.6.2 Seepage run for Johnson Creek, Aug 2 - 3, 1993.

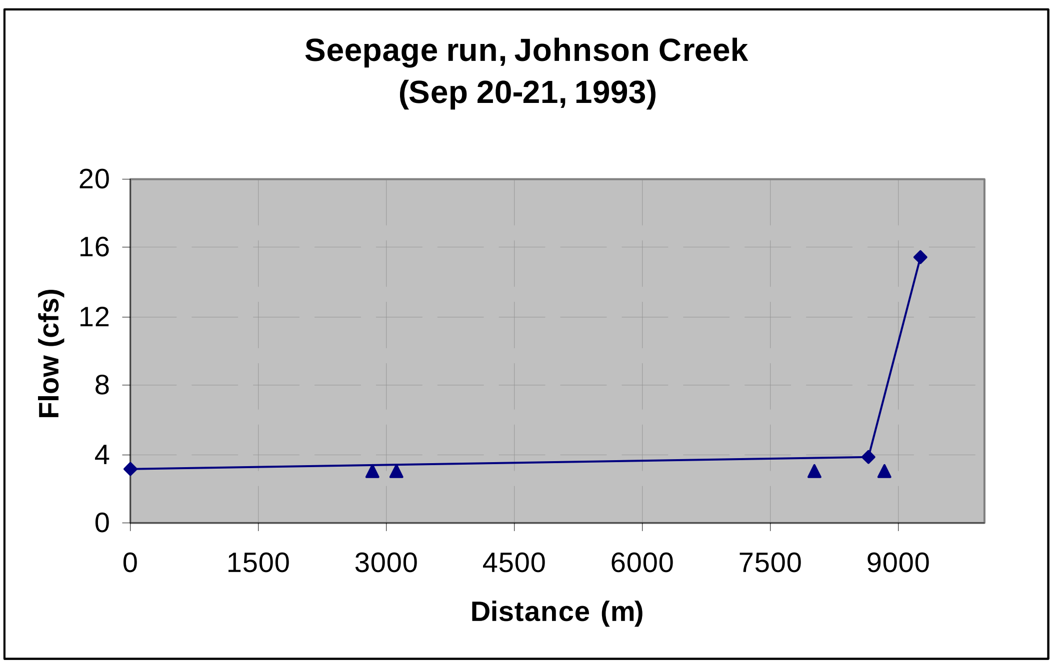

Figure 6.6.3 Seepage run for Johnson Creek, Sep 20 - 21, 1993.

The stream flow production per unit length is found by assuming a uniform production along the creek and is 4.18 cfs/mi, 1.93 cfs/mi and 1.29 cfs/mi, respectively for the months of June, August and September. One has to be careful in interpreting these results, as there are abrupt changes in the slops because of differences on the flows of the tributaries. The fact that the measurements are few (only three point) makes it difficult to perform a more complicated curve fitting.

NOTE

While finding the length of seepage run points along the rivers, the hydrography coverage and seepage coverage have been used. Sometime the seepage points do not exactly fall on the hydrography coverage and are, therefore, approximated to the nearest point on the river coverage.

6.7 CONCLUSION AND RECOMMENDATION

The inverse recharge estimation done for the water years 1961 – 1963, 1965 – 1968 and 1974 – 1978 shows a reasonable agreement with that of earlier reports. However, there are certain data constraints, which need to be addressed. Comparison of the information given for the station and the one derived from DTM for the contributing area associated with stream gage station #12215100, Sumas River near Huntingdon, B.C., shows a difference of about 20 mi^2 (square mile). More over, this station is the only one in the region with longer period of record.

Like other parts of WRIA 1 study area, the pump data for this region is incomplete and has only one average value. Time series values would help greatly future works.

The seepage runs are too few to make meaningful interpretations.

7.0 FISHTRAP WATERSHED AND AQUIFER WATER BALANCE MODEL

7.1 THE WATERSHED

Fishtrap Creek watershed is located in northwest Whatcom County and drains into the Nooksack River. Fishtrap drains 30.6 square miles, of which slightly more than half is in Canada (Erickson 1995). The majority of the Fishtrap Creek basin lies within the Lynden Terrace, a flat lowland with elevations ranging from 150 feet near the Canadian border to about 50 feet where it meets the Nooksack lowlands. The northwestern quarter of the basin (entirely in Canada) is the Fishtrap Uplands-B.C., a hilly area with elevations ranging from about 500 feet to 150 feet. The southern edge of the basin, downstream from Lynden, lies within the Nooksack lowlands, less than 50 feet in elevation.

Precipitation in the basin ranges from over 60 inches per year in the northern uplands to about 40 inches per year in the lowlands. Seventy percent of the precipitation falls between October and March; June, July and August receive 12 percent of the yearly average.

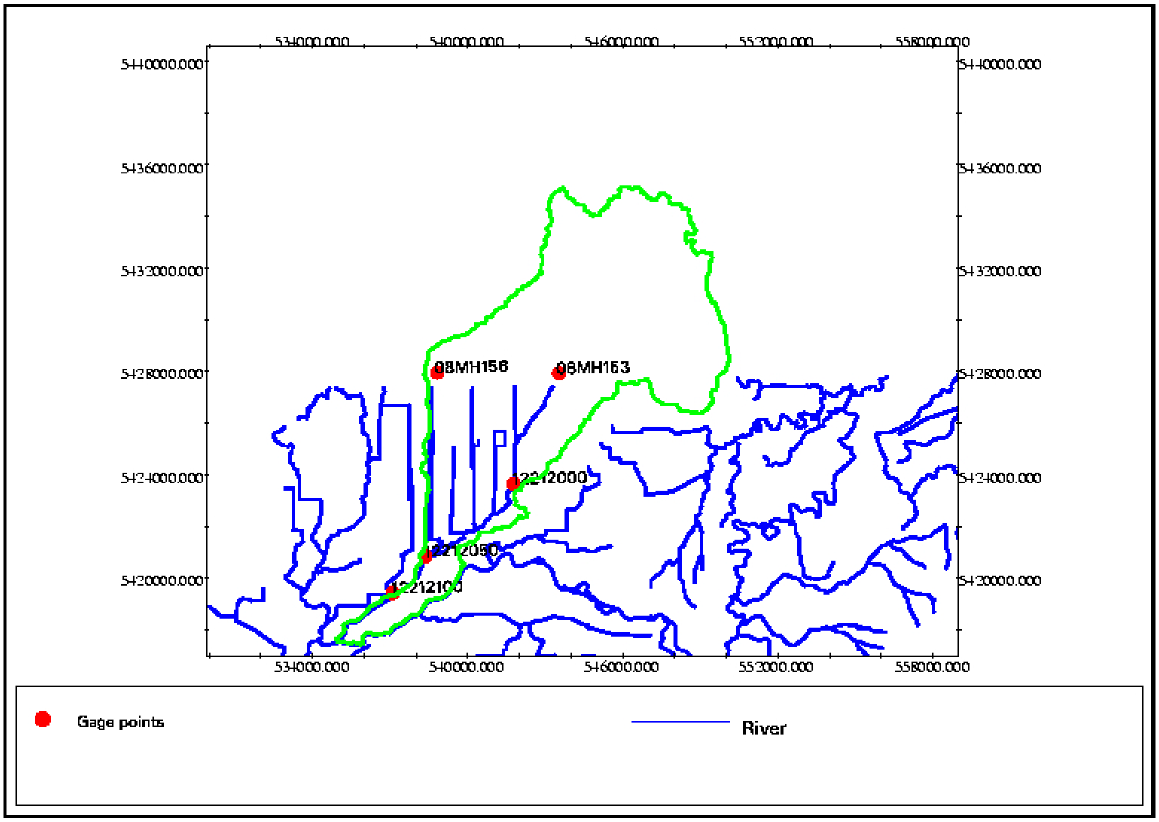

Figure 7.1.1 The Fishtrap Watershed.

In Canada most the tributaries to Fishtrap Creek flow in natural channels, but in the U.S. the drainage network has been highly modified to form a system of north/south ditches at half-mile interval adjacent to the roads (see Figure 7.1.1).

Fishtrap Creek lies within that part of the Sumas aquifer, which is predominantly outwash sand and gravel, generally unconfined and is overlain by the Everson-Vashon semiconfining unit (Cox and Kahle, 1999).

7.2 BASE FLOW

There are five stream gage points in Fishtrap Watershed. Three stations are in a close range and are within the United States. From up stream to the mouth: station #1221200 (above Lynden) with 23 (1948 – 1971) water years of data. This station has 22.3 sq. mi (square mile) of contributing area. Station #12212050 with one year of data (1999 water year) with contributing area of 37.8 sq. mi. Station #12212100 with recent (1996 –1999) 2 years of data and contributing area of 38.1 sq. mi. The analysis considered the two stations with 23 and 2 years of data (USGS on-line data). Gage station #08MH156 and 08MH153 are within Canada. The digital elevation model gives an area of 20 sq. mi for station #12212000 and 35.416 sq. mi for #12212050.

For ease of visualization the base flow and stream flow plots for station #12212000 has been broken into three. Figure 7.2.2 – 7.2.4 shows these plots.

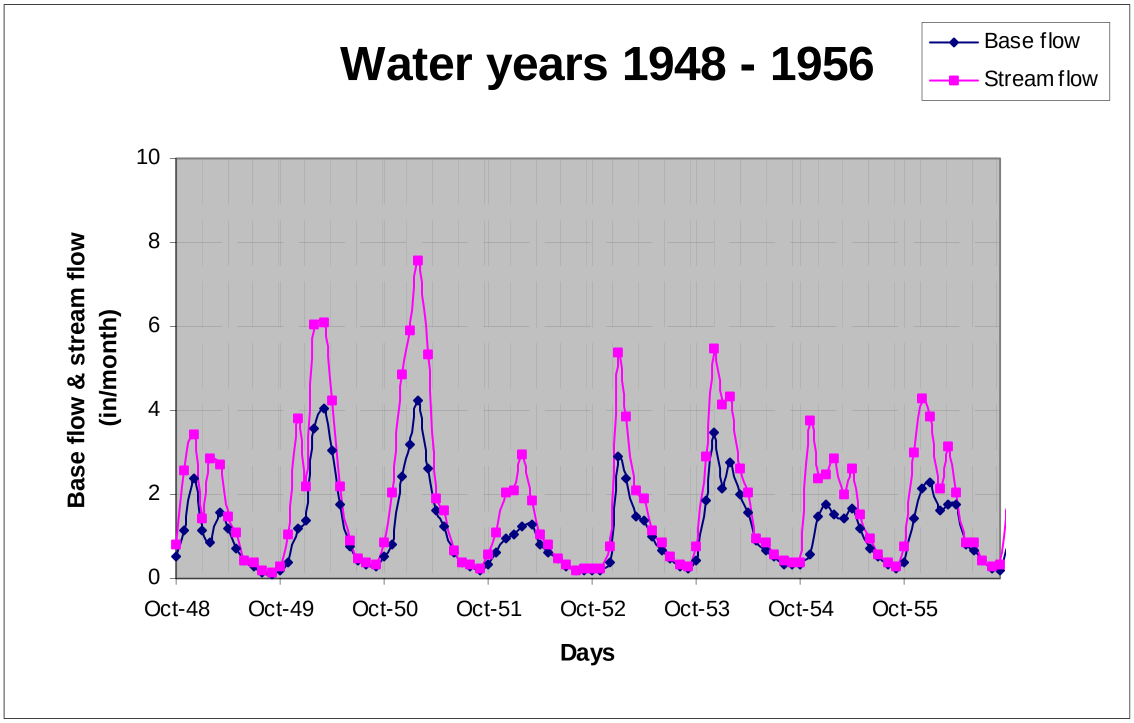

Figure 7.2.2 Base flow and stream flow for Fishtrap Creek, 1948 –1956.

Figure 7.2.5 shows the cumulative plots of base flow and stream flow for the whole record period.

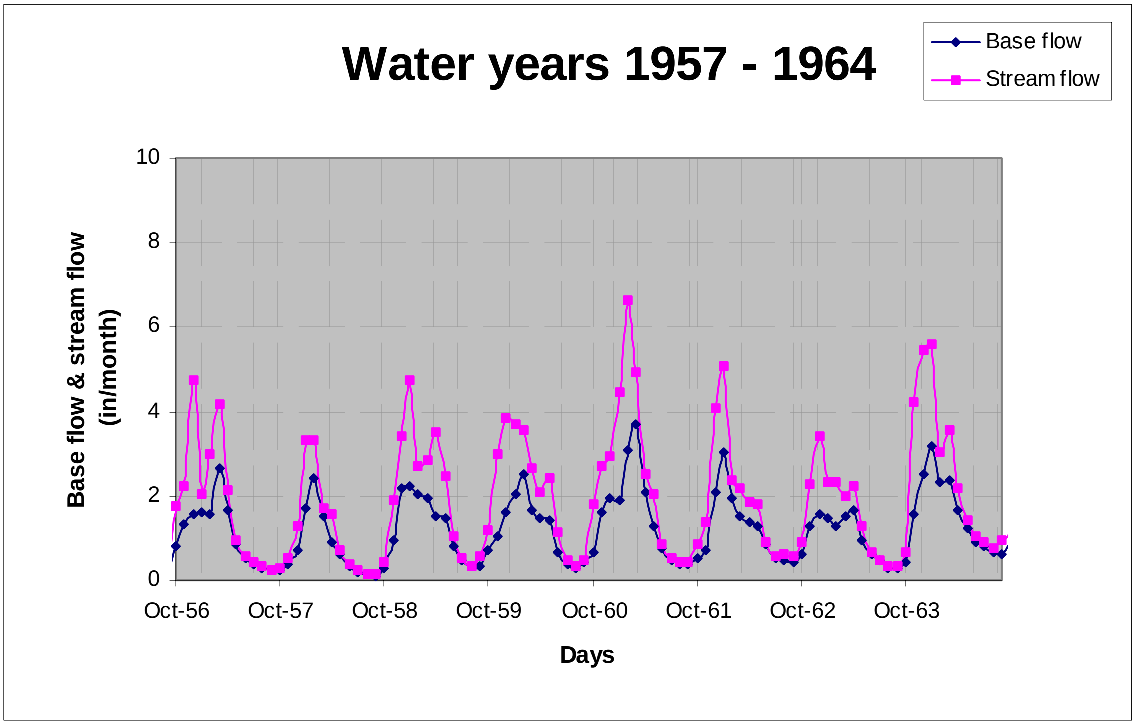

Figure 7.2.3 Base flow and stream flow for Fishtrap Creek, 1957 –1964

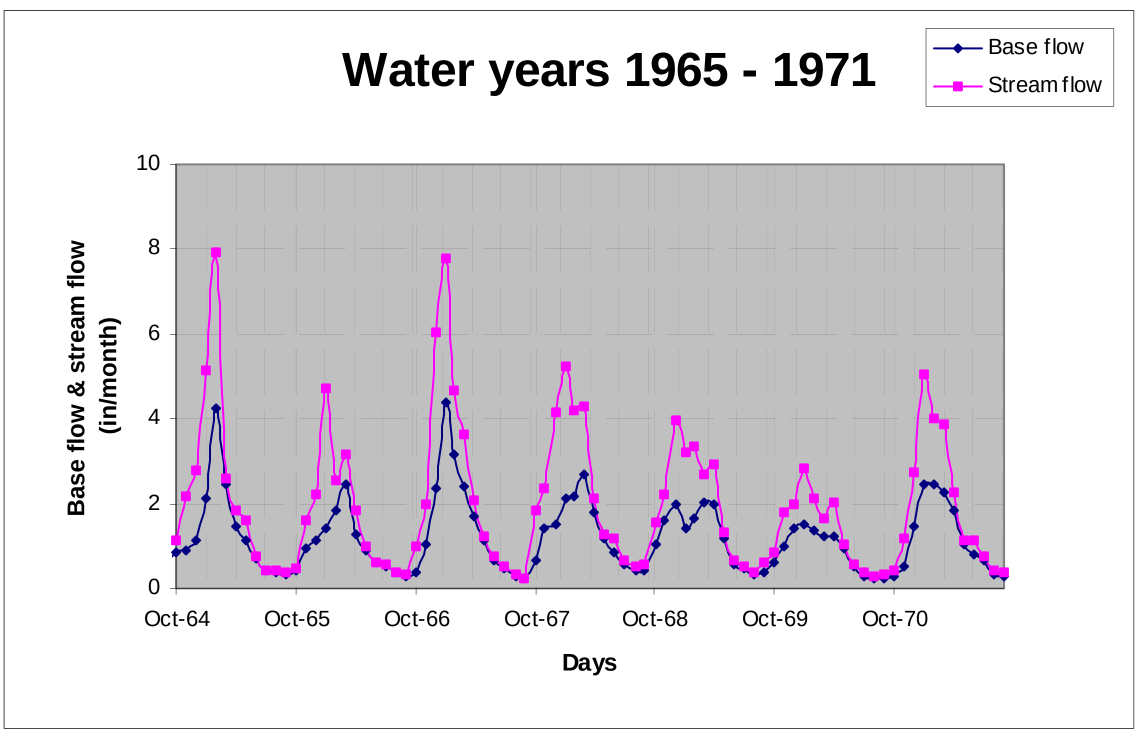

Figure 7.2.4 Base flow and stream flow for Fishtrap Creek, 1965 –1971

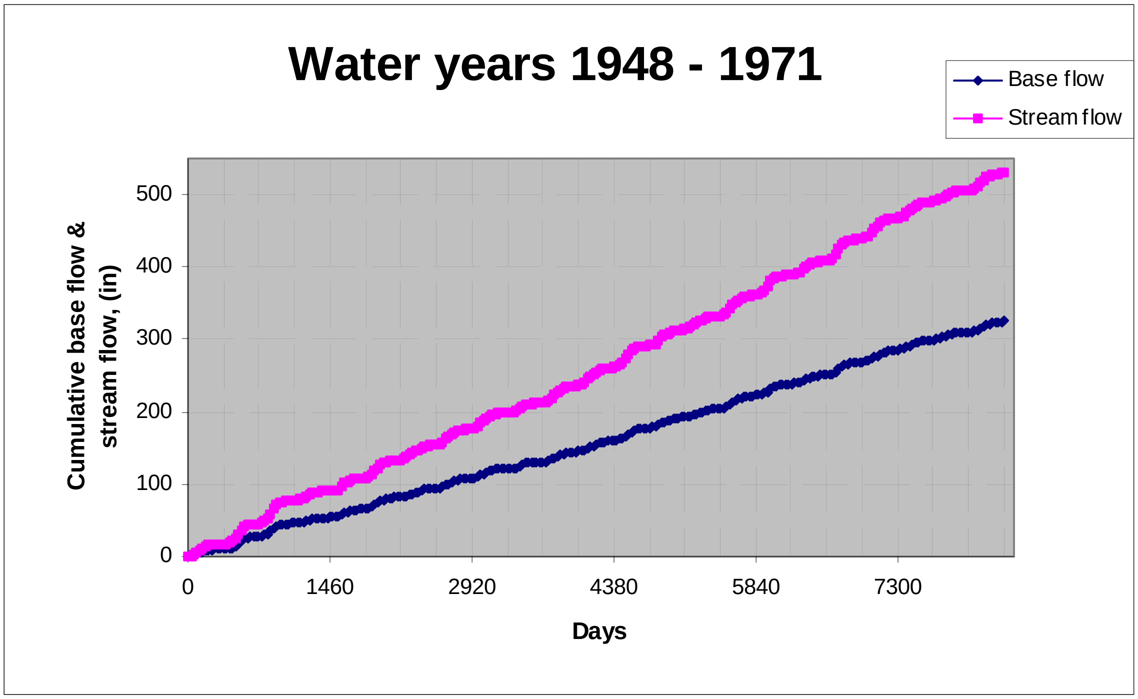

Figure 7.2.5 Cumulative base flow and stream flow for Fishtrap Creek, 1948 –1971

The two years plot of station #12212100 is shown in Figure 7.2.6 and 7.2.7.

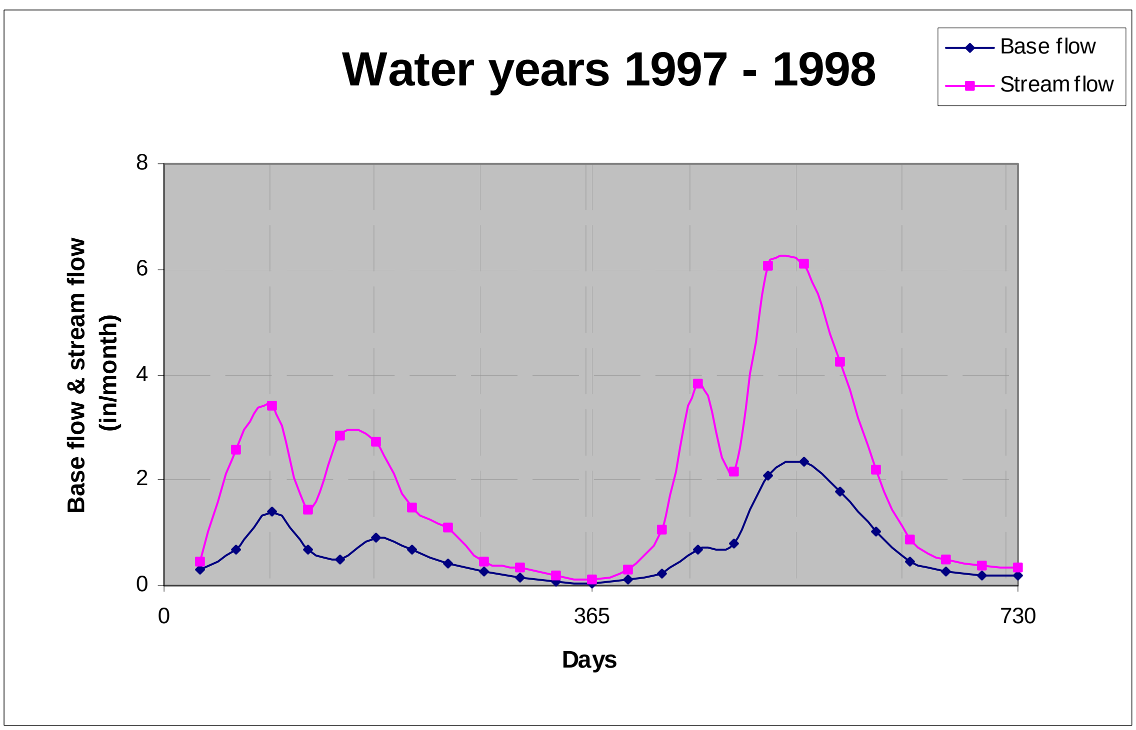

Figure 7.2.6 Base flow and Stream for station #12212100, 1997 –1998, Fishtrap Creek

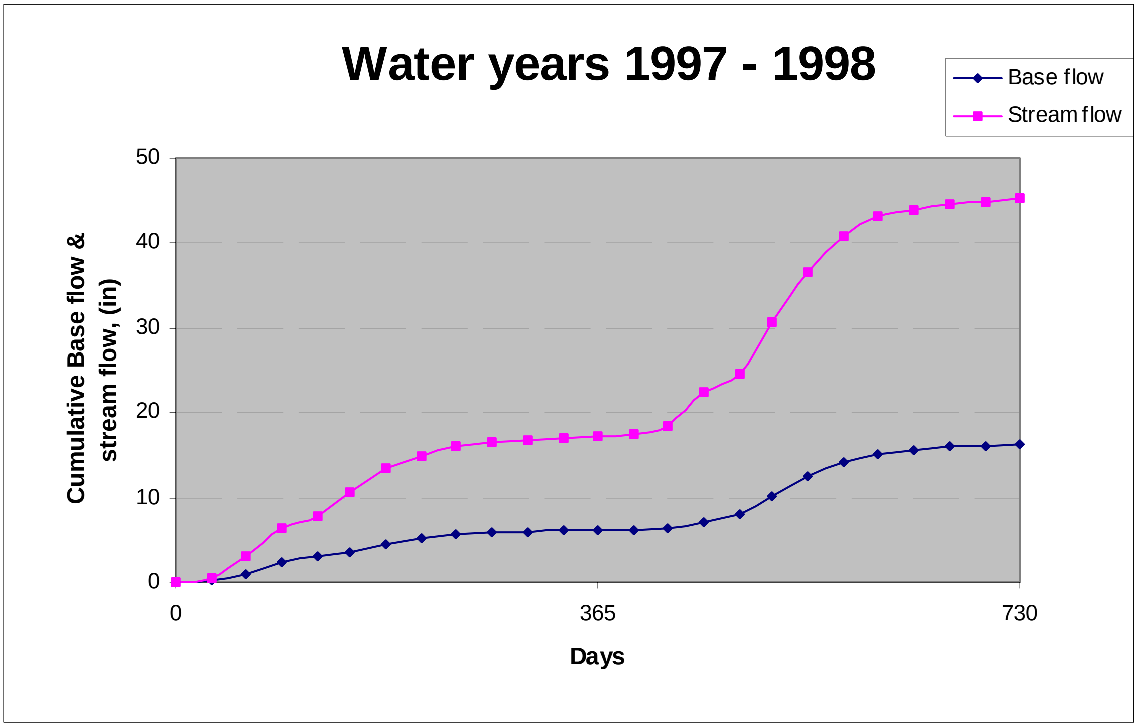

Figure 7.2.7 Cumulative base flow and stream flow for Fishtrap Creek, 1997 –1998

7.3 GROUNDWATER PUMPING

Two sets of pump data has been analyzed corresponding to watersheds of gaging station 12212000 and 12212150. Within the first watershed there are 35 pumps with 23 of them having pumping rate data totaling 4429 gpm (gallons per minute). Within the second watershed, there are 105 pumps of which 60 have pumping rate data totaling 10,007 gpm.

7.4 RECHARGE

According to Cox and Kahle (1999), (estimates are based on Vaccaro et al., 1996, and Kohut, 1989), most of the Fishtrap watershed has a recharge of 26 – 30 inches per year. A point estimate at Abbotsford Airport, just outside of Fishtrap water shed has 38 inches per year.

Inverse recharge estimation

Assuming the recharge to be the unknown in the mass balance equation, an inverse estimation for recharge can be performed using the other components of the water balance.

A linear regression line has been fitted to the cumulative base flow with the following statistics:

Station 12212000, water year 1951 – 1971

Slope of regression line	= 0.0384in/day
Standard deviation of the slope	= 0.00054in/day
Coefficient of regression	=0.998

Hence, total annual base flow is

1. Using regression slope	=0.0384*365	= 14.02in
2. Using slope – 2*Std	=(0.0384-2*0.00054)*365	= 13.23in
3. Using slope + 2*Std	=(0.0384+2*0.00054)*365	= 14.80in
Annual pumpage	=(4429 gpm in 20 mi^2)	= 7in

The uniform recharge value over the catchment will be the sum of the above base flows and the total pumpage.

Recharge1	= (14.02 + 7)	= 21.02in
Recharge2	= (13.23 + 7)	= 20.23.1in
Recharge3	= (14.80 + 7)	= 21.80in

Water year 1997 –1998

Slope of regression line	=0.0216 in/day
Standard deviation of the slope	=0.000671 in/day
Coefficient of regression	=0.926

Hence, total annual base flow is

1. Using regression slope	=0.0216*365	= 7.88in
2. Using slope – 2*Std	=(0.0216-2*0.000671)*365	= 7.69in
3. Using slope + 2*Std	=(0.0216+2*0.000671)*365	= 8.08in
Annual pumpage	=(10,007 gpm in 35.416 mi^2)	= 8.55in

The uniform recharge value over the catchment will be the sum of the above base flows and the total pumpage.

Recharge1	= (7.88 + 8.55)	= 16.43in
Recharge2	= (7.69 + 8.55)	= 16.24in
Recharge3	= (8.08 + 8.55)	= 16.63in

Recharge estimated from water years 1948 – 1971 give about 20 inches per year while the estimate from water years 1997 – 1998 both give about 16 inches per year. The yearly average rainfall based on Clearbrook’s weather station observation for 1951 – 1971 is 47.6 inches per year.

For 1948 –1971 the stream flow and base flow slopes are 0.0628 in/day and 0.0384 in/day, while for the water years 1997 –1998 these slops are 0.0616 in/day and 0.0216 in/day, respectively. Comparing these two periods the base flow decreased 43% while the stream flow decrease by 2%. Some of the reasons attributing to this discrepancy could the extremely few year measurement for the second period, as well as the conditions assumed for the base flow separation. The long-term slope, which shows the integrated catchment response, should be more representative for the watershed.

7.5 Comparison of Precipitation, Stream Flow and Base Flow

The nearest precipitation station with relatively longer period of record is that of Clearbrook. The Clearbrook station data has a common year with station #12212000 but it does not have any common years of data with station #12212100. Like the plots of base flow and stream flow, the precipitation plot is also broken into three parts for ease of visualization. Hence, Figure 7.5.8 – 7.5.11 shows these plots.

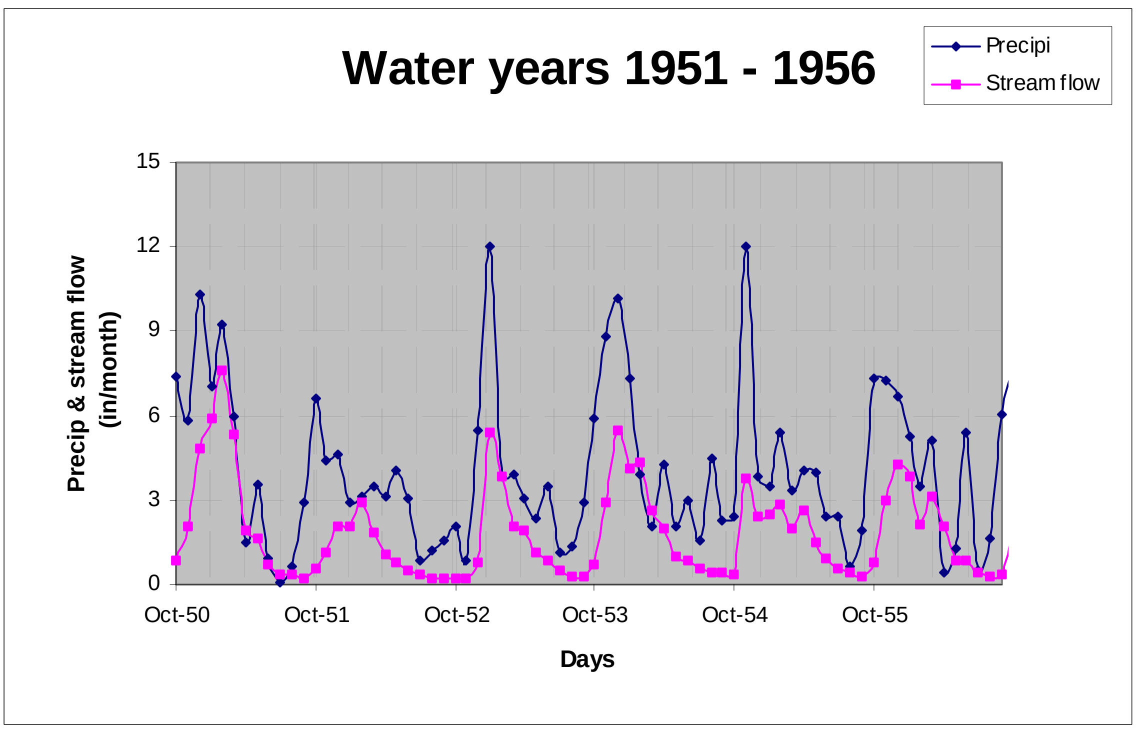

Figure 7.5.8 Precipitation and stream flow for Fishtrap Creek, 1951 –1956

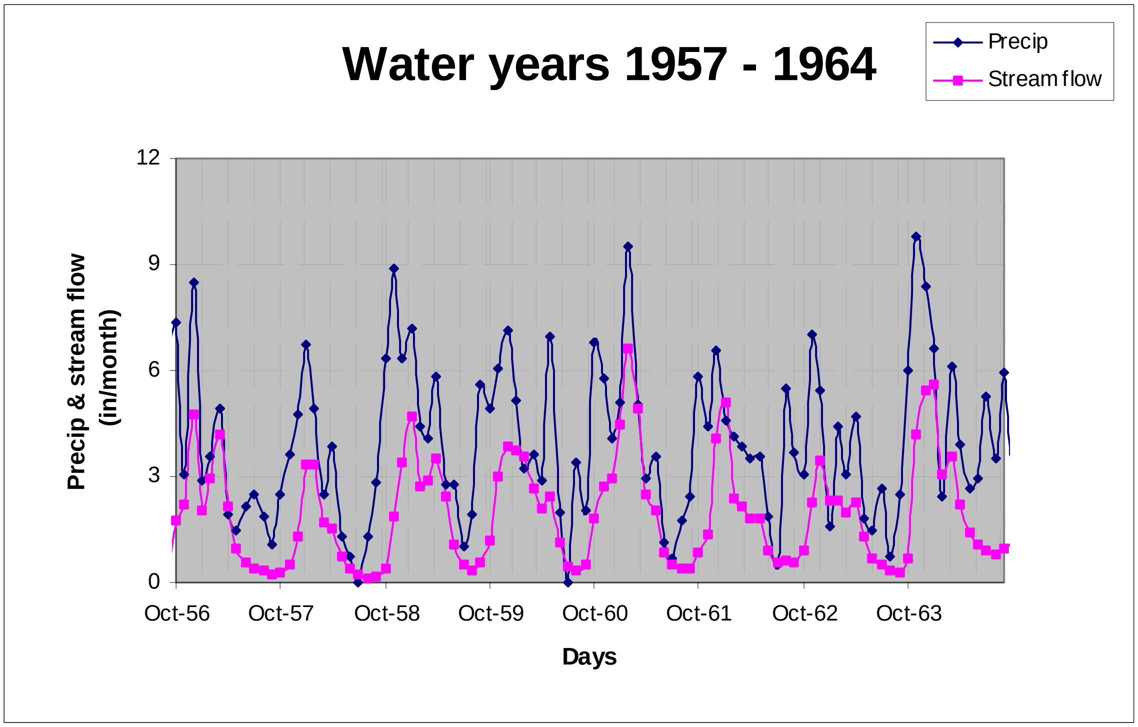

Figure 7.5.9 Precipitation and stream flow for Fishtrap Creek, 1957 –1964

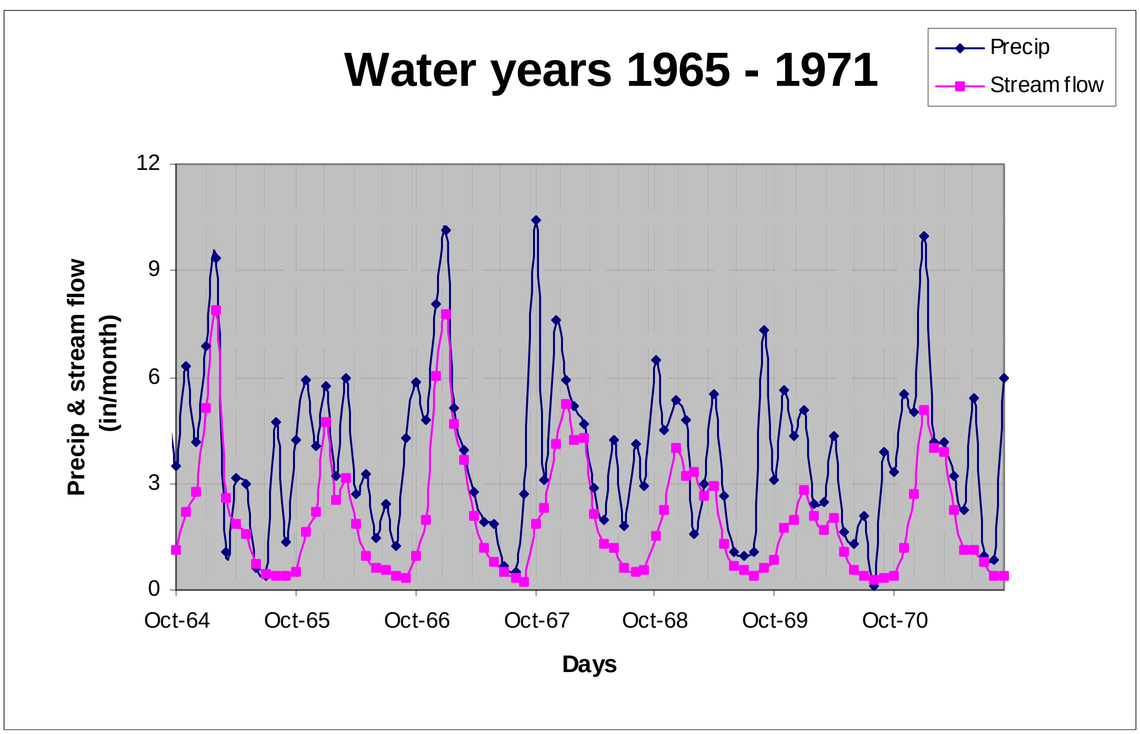

Figure 7.5.10 Precipitation and stream flow for Fishtrap Creek, 1965 –1971

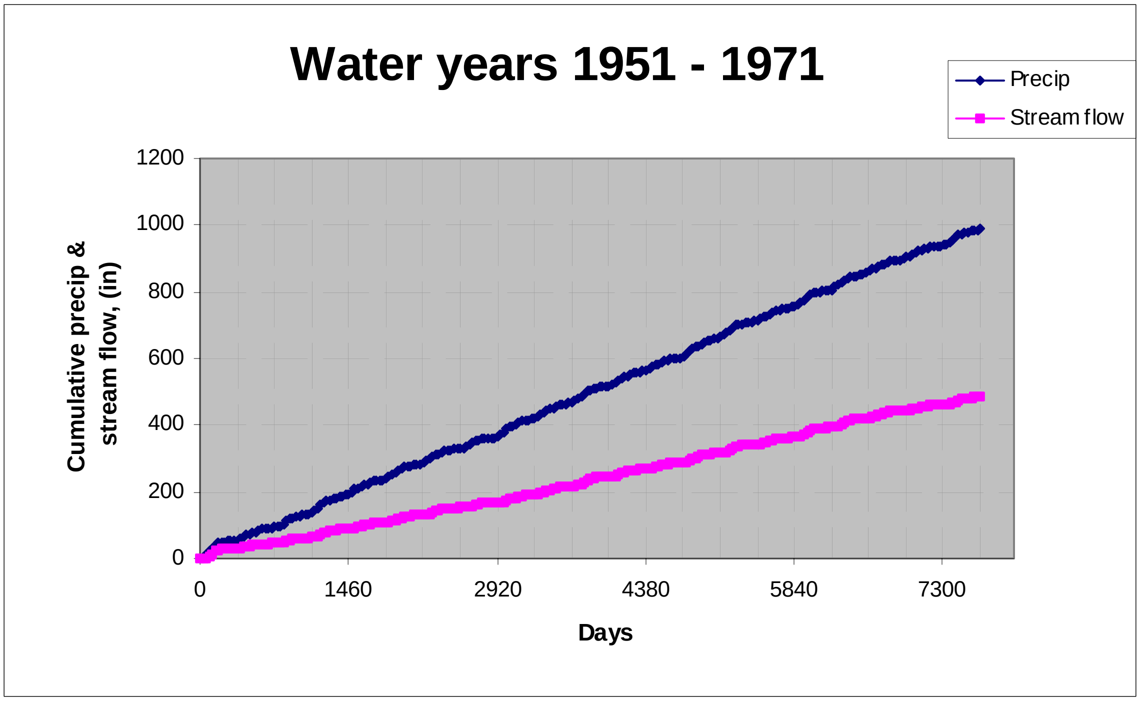

Figure 7.5.11 Cumulative precipitation and stream flow for Fishtrap Creek, 1951 –1971.

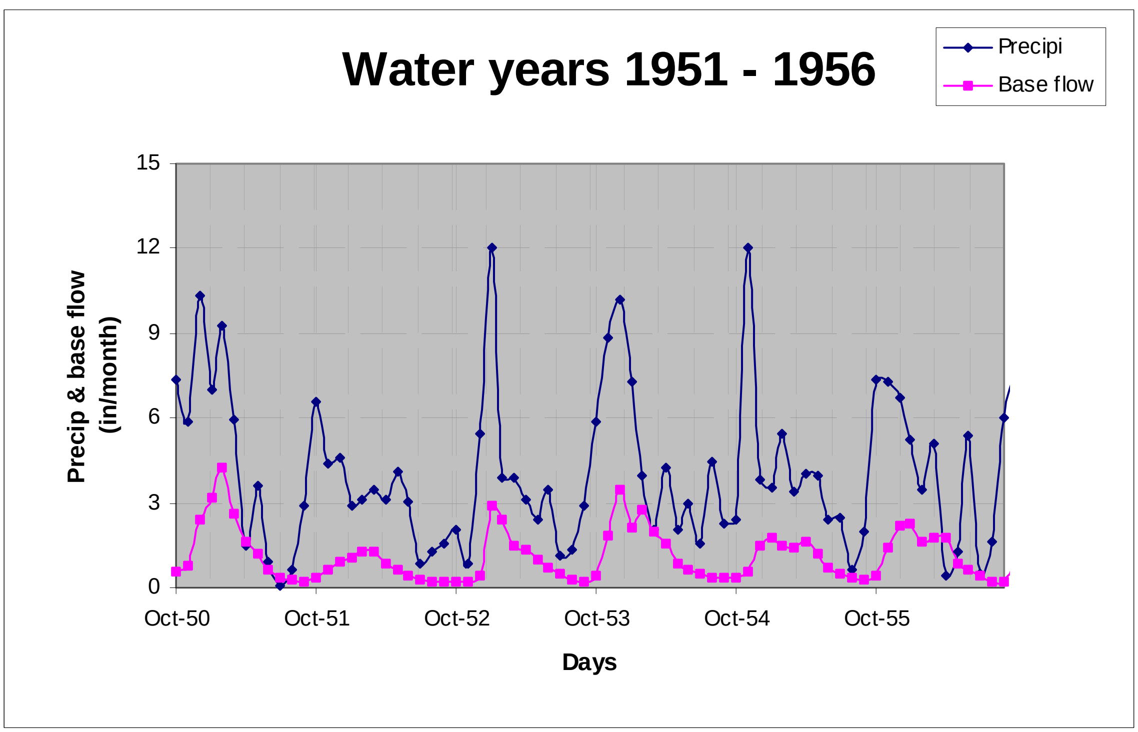

Figure 7.5.12 Precipitation and base flow for Fishtrap Creek, 1951 –1956

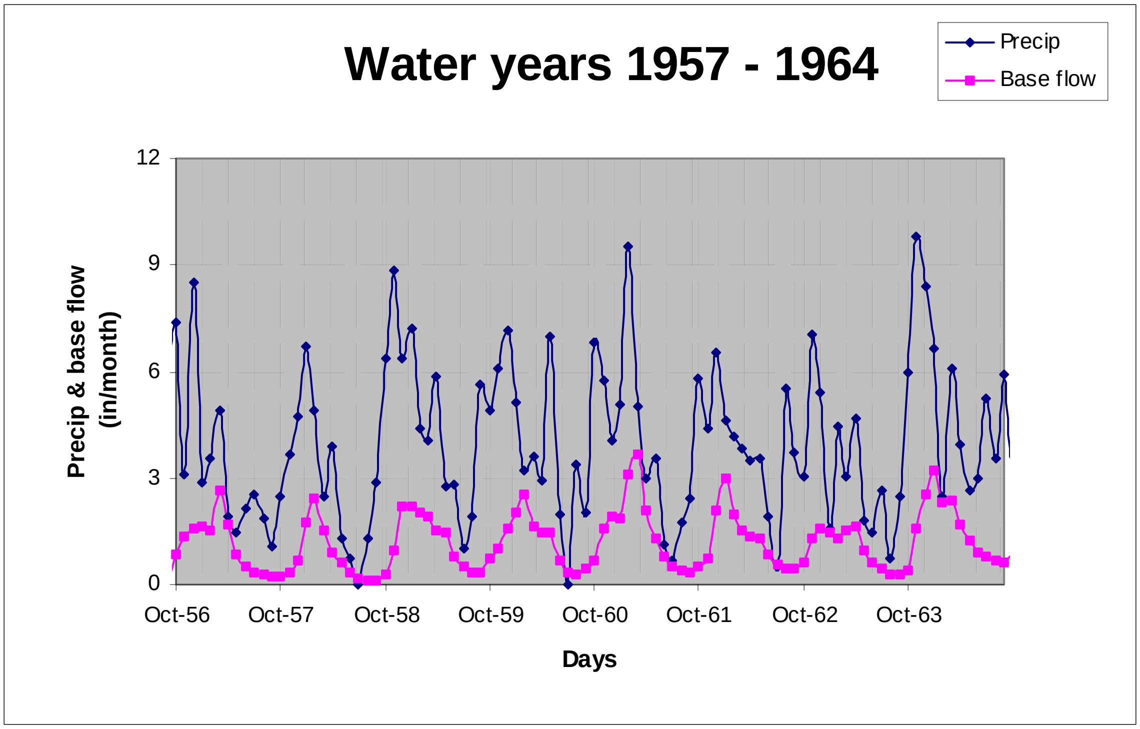

Figure 7.5.13 Precipitation and base flow for Fishtrap Creek, 1957 –1964

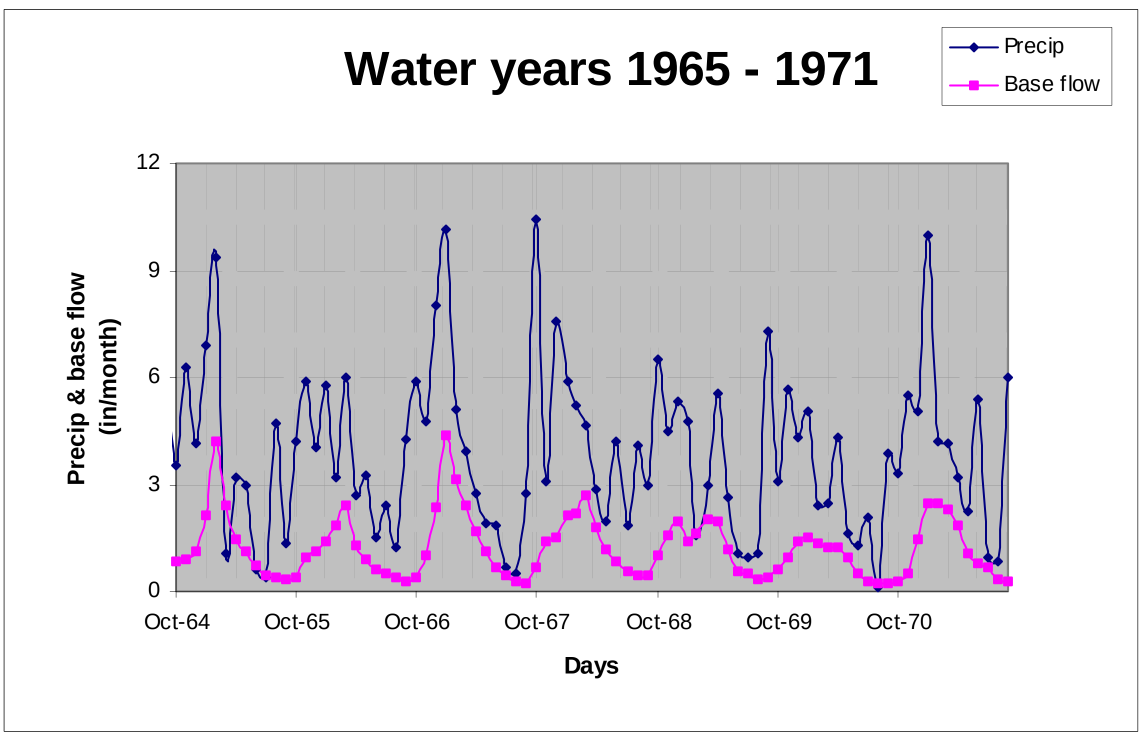

Figure 7.5.14 Precipitation base flow for Fishtrap Creek, 1965 –1971

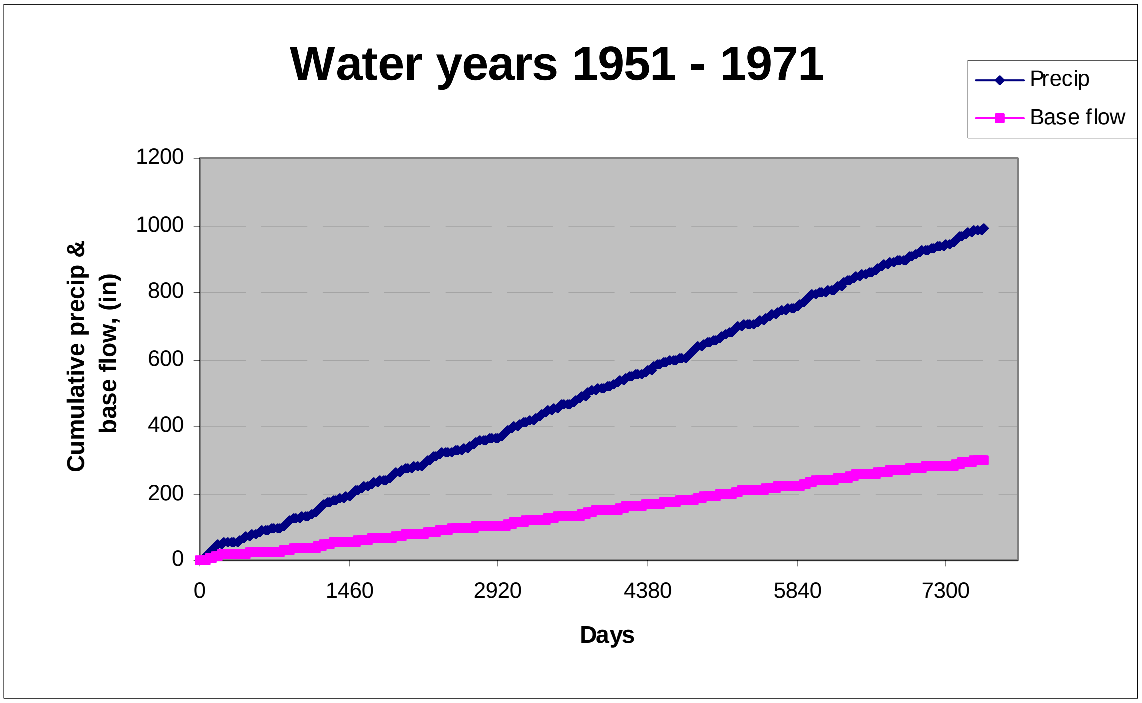

Figure 7.5.15 Cumulative precipitation and base flow for Fishtrap Creek, 1951 –1971.

7.6 SEEPAGE RUNS

There are three seepage measurement sites on Fishtrap Creek. The data were collected by Washington Department of Ecology (WDOE), Whatcom County Conservation District, Cascade Environmental Service (WRCD/CES), and Water Survey of Canada. The measurement stations are denoted by M-60, M-303 and M-62, from North to South (see Figure 7.6.1).

There are five tributaries on these sections. Four of them are unnamed channels and the fifth one is called Pepin Creek. The data for six measurement dates are shown in Table 7.6.1.

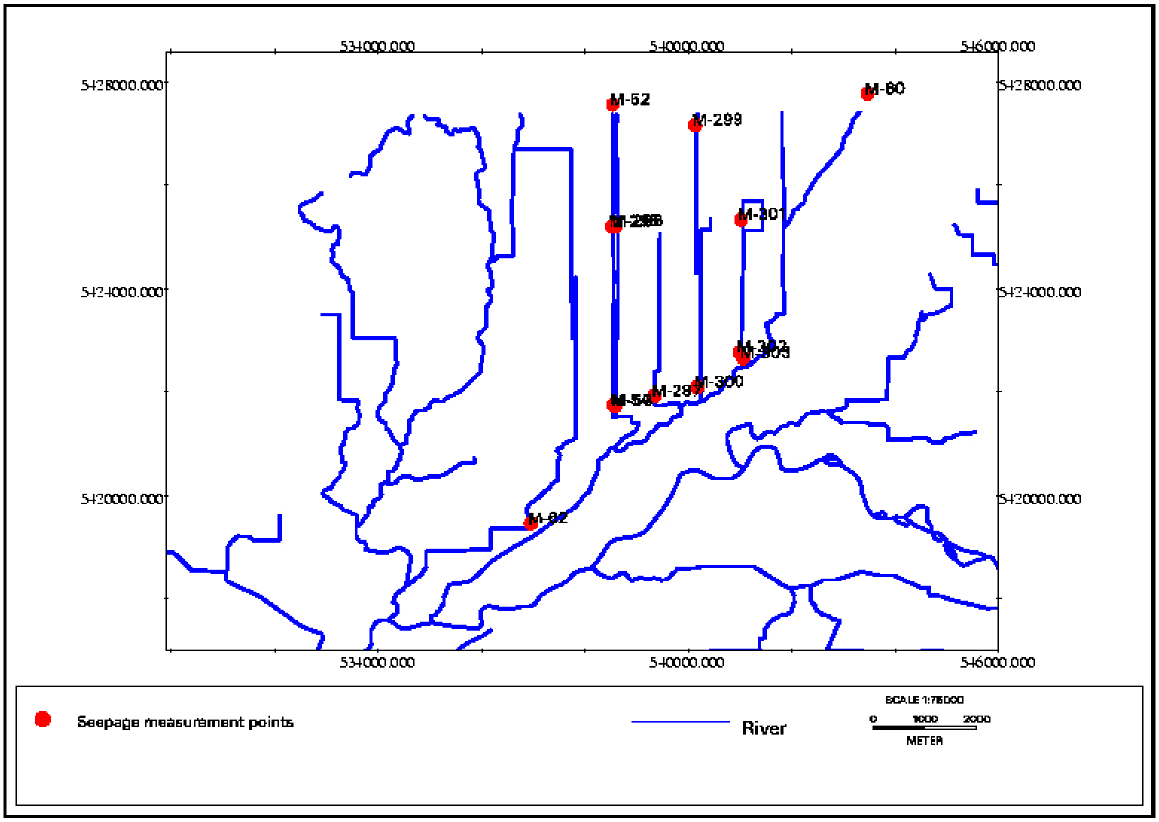

Figure 7.6.1 Seepage measurement points on Fishtrap Creek, 1993 & 1994.

The first column in Table 7.6.1 is measurement day, the second column is the station name and the third column shows the distance from the starting seepage station and/or tributary feeding Fishtrap Creek. The remark column shows actual data for the given station. For station M-62 the last three measurements have a day difference. Therefore, the plots for these days should be taken only as visualizing the flow condition. The last column shows the inflow coming from the tributaries on the same day. The locations of these tributaries are shown with arrows on the plots. Figure 7.6.2 – 7.6.6 shows the plots of the above table.

Table 7.6.1 Seepage run for Fishtrap Creek

Date		Distance	Flow (cfs)	Remark	Joining Creek	Creek Input (cfs)
9/13/93	M-60	0	2.9			
		2725			un named	
	M-303	6075	5.3		un named	0
		7206			un named	0
		7641			un named	0
		9415			Pepin Creek	2.35
	M-62	11869	10.4			
9/20/93	M-60	0	5.5			
		2725			un named	
	M-303	6075	6.7		un named	0
		7206			un named	0.1
		7641			un named	0
		9415			Pepin Creek	3.3
	M-62	11869	14.6	Average		
11/8/93	M-60	0	3.5			
		2725			un named	
	M-303	6075	5.7		un named	0
		7206			un named	0.2
		7641			un named	0
		9415			Pepin Creek	3.4
	M-62	11869	13			
12/14/93	M-60	0	54.1			
		2725			un named	
	M-303	6075	70.5		un named	10.6
		7206			un named	7
		7641			un named	4.9
		9415			Pepin Creek	14
	M-62	11869	168	12/13/93		
1/12/94	M-60	0	51.9	1/12/84		
		2725			un named	
	M-303	6075	74.8		un named	8.1
		7206			un named	10.5
		7641			un named	6.8
		9415			Pepin Creek	20.4
	M-62	11869	182	1/11/94		
1/25/94	M-60	0	17.3			
		2725			un named	
	M-303	6075	27.1		un named	3
		7206			un named	2.8
		7641			un named	1.6
		9415			Pepin Creek	7.6
	M-62	11869	63.1	1/24/94		

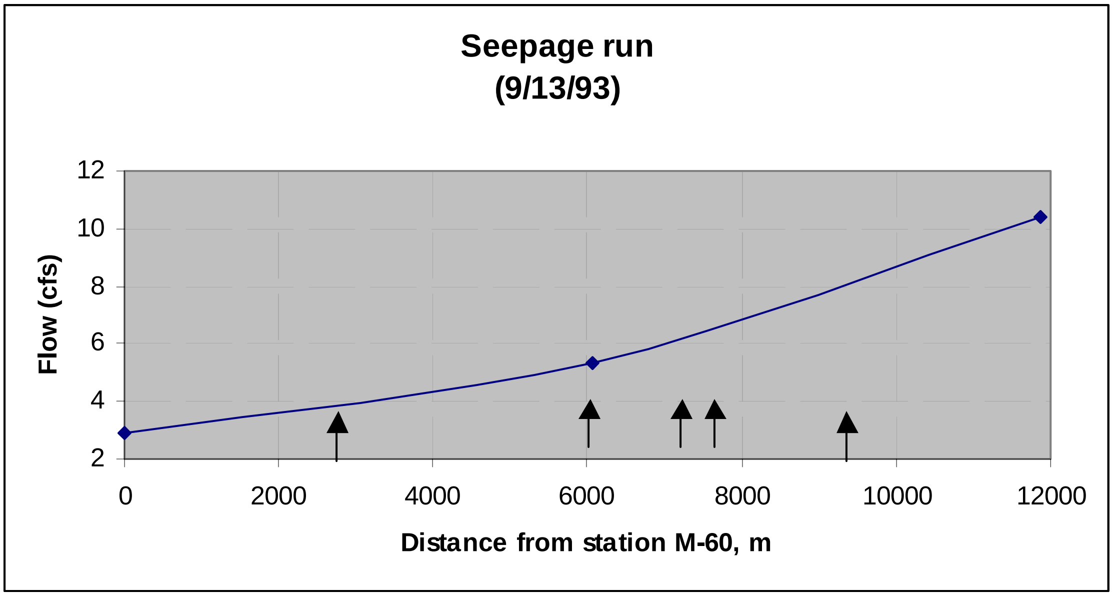

Figure 7.6.2 Seepage run of Fishtrap Creek, 9/13/93

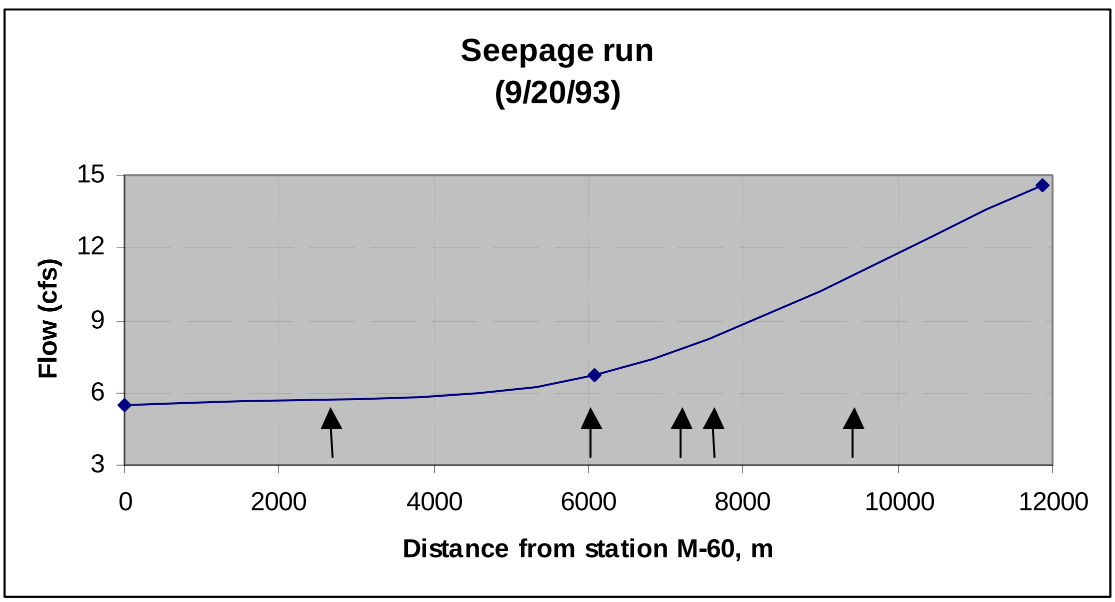

Figure 7.6.3 Seepage run of Fishtrap Creek, 9/20/93

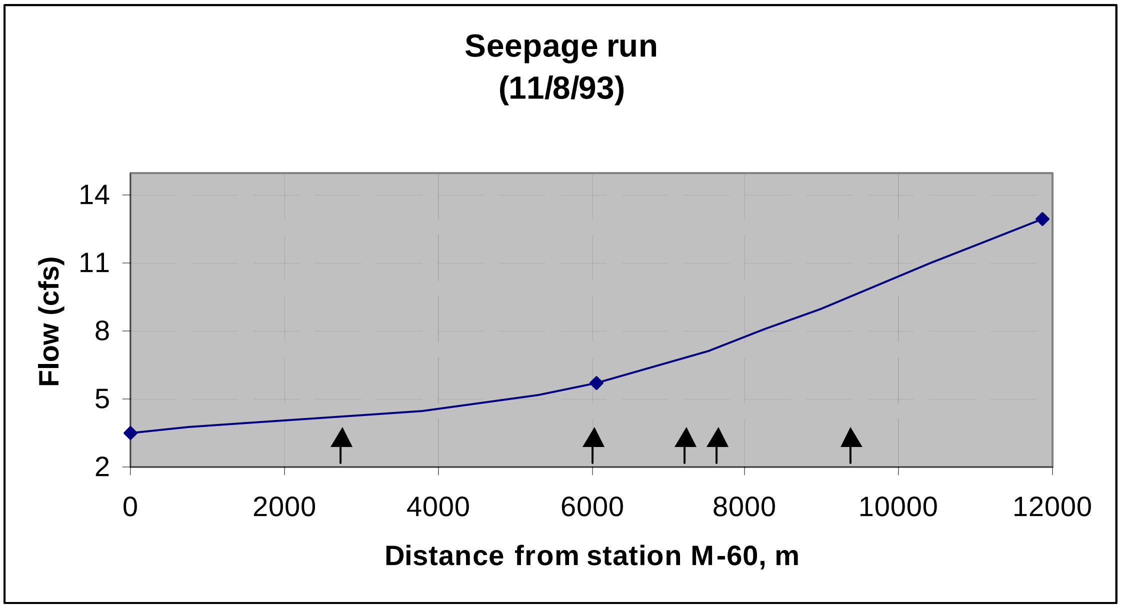

Figure 7.6.4 Seepage run of Fishtrap Creek, 11/8/93

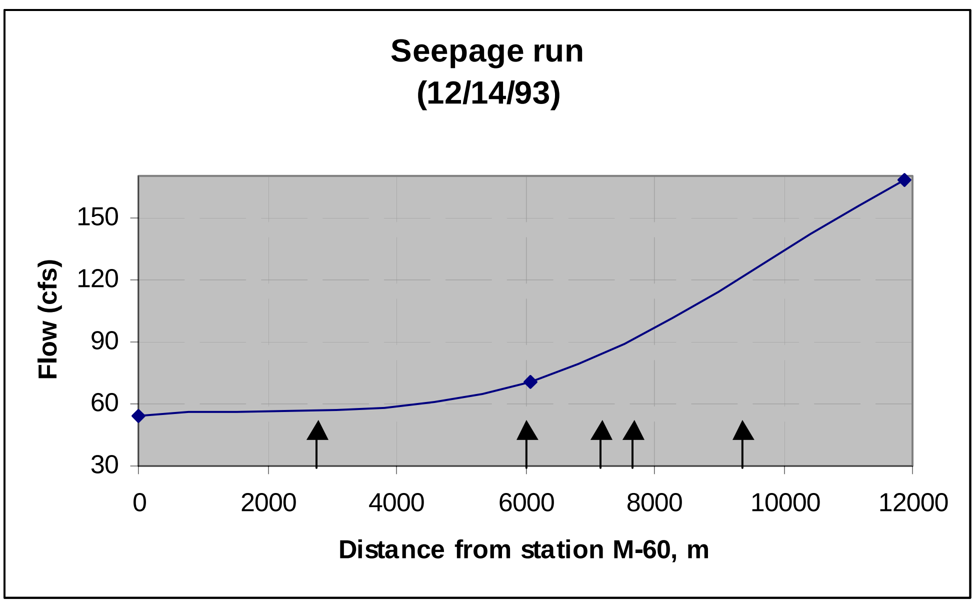

Figure 7.6.5 Seepage run of Fishtrap Creek, 12/14/93

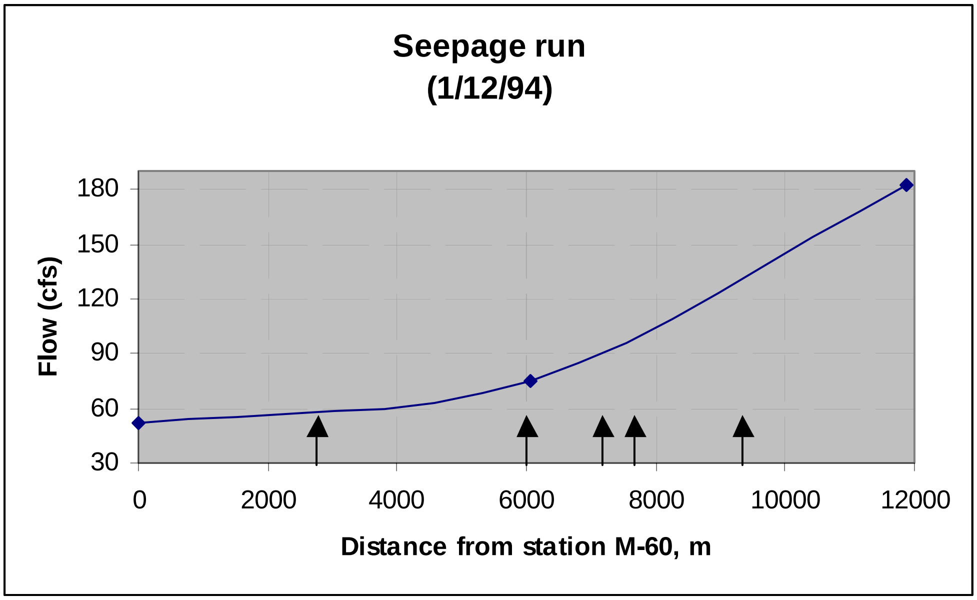

Figure 7.6.6 Seepage run of Fishtrap Creek, 1/12/94

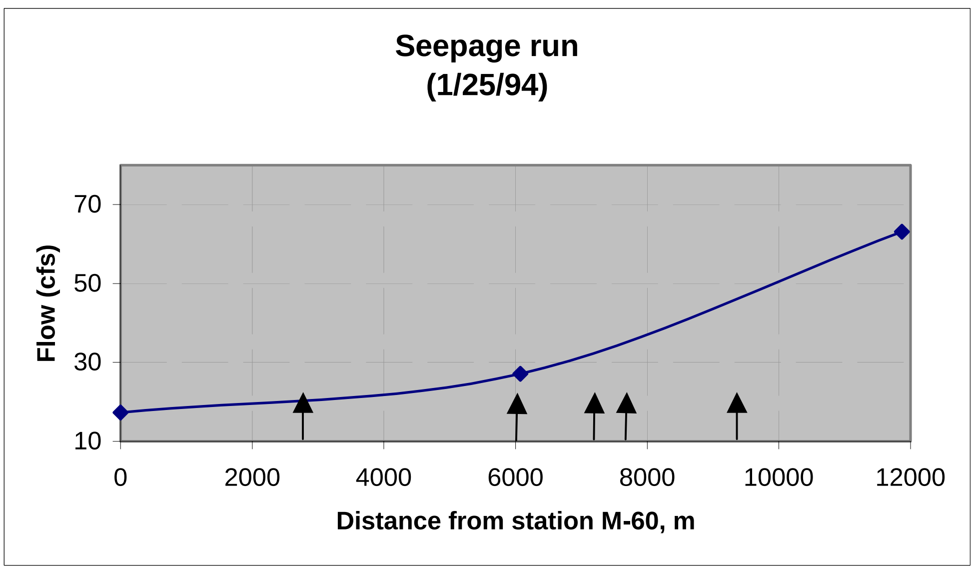

Figure 7.6.7 Seepage run of Fishtrap Creek, 1/25/94

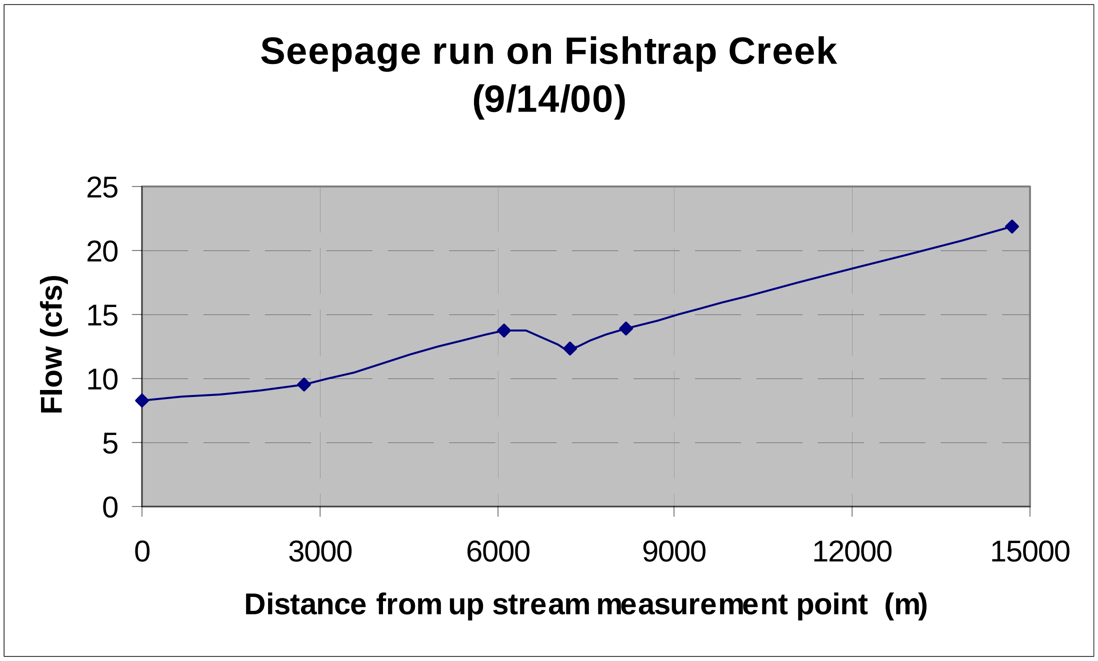

Figure 7.6.8 Seepage run of Fishtrap Creek, 9/14/00

A more recent seepage run result is shown on Figure 7.6.8. The locations of these seepage points are shown on Figure 7.6.9. These runs were made by USGS on different tributaries while USU was taking on Mainstem Nooksack.

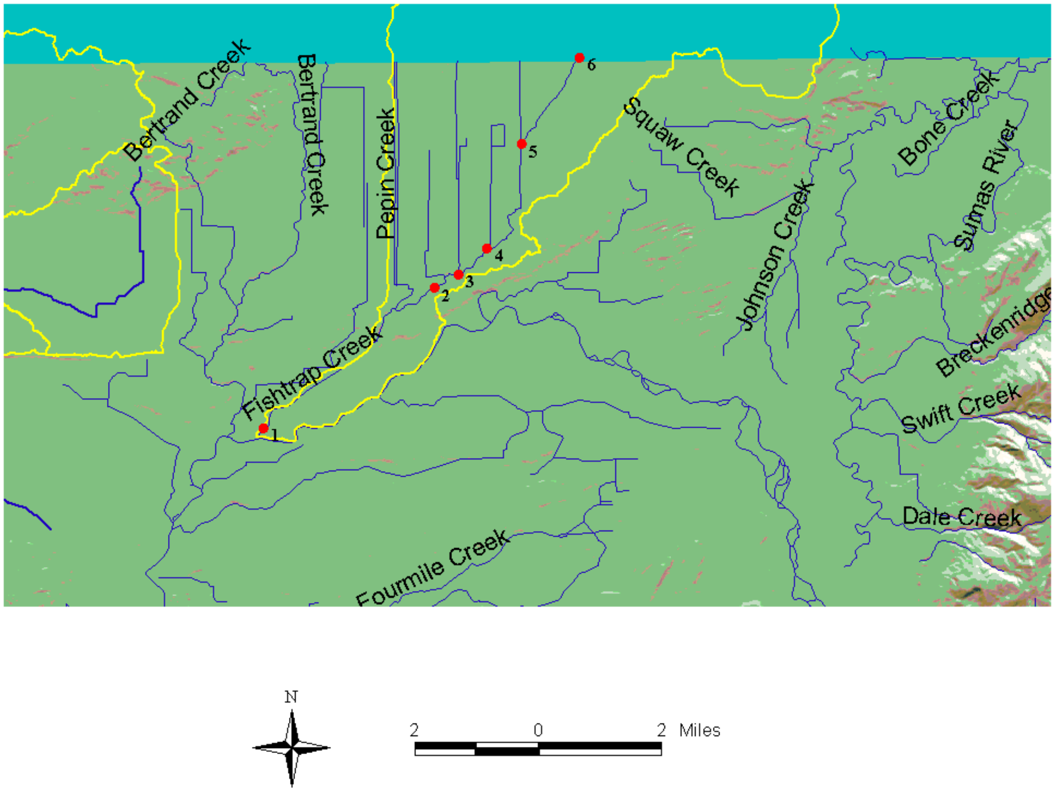

Figure 7.6.9 Seepage run location of Fishtrap Creek, 9/14/00

The flow per unit length of for the river has been found by assuming a linear stream flow production and is shown in Table 7.6.2. The average stream flow gain for 9/14/00 measurement is 1.448 cfs/mile. This is comparable with 0.97 cfs/mile on 9/13/93 and 1.29 cfs/mile on 9/20/93

Table 7.6.2 Flow per unit mile, Fishtrap Creek.

Date	Stream recharge (cfs/mile)
9/13/93	0.97
9/20/93	1.29
11/8/93	1.29
12/14/93	15.29
1/12/94	17.54
1/25/94	6.11
Average	7.08

As shown in the table the flow per unit mile increase during the wintertime. This is also partly because the tributaries delivered higher flows during these times (see table 7.6.1). Figure 7.6.8 shows the variation of flow per unit mile for the above six months.

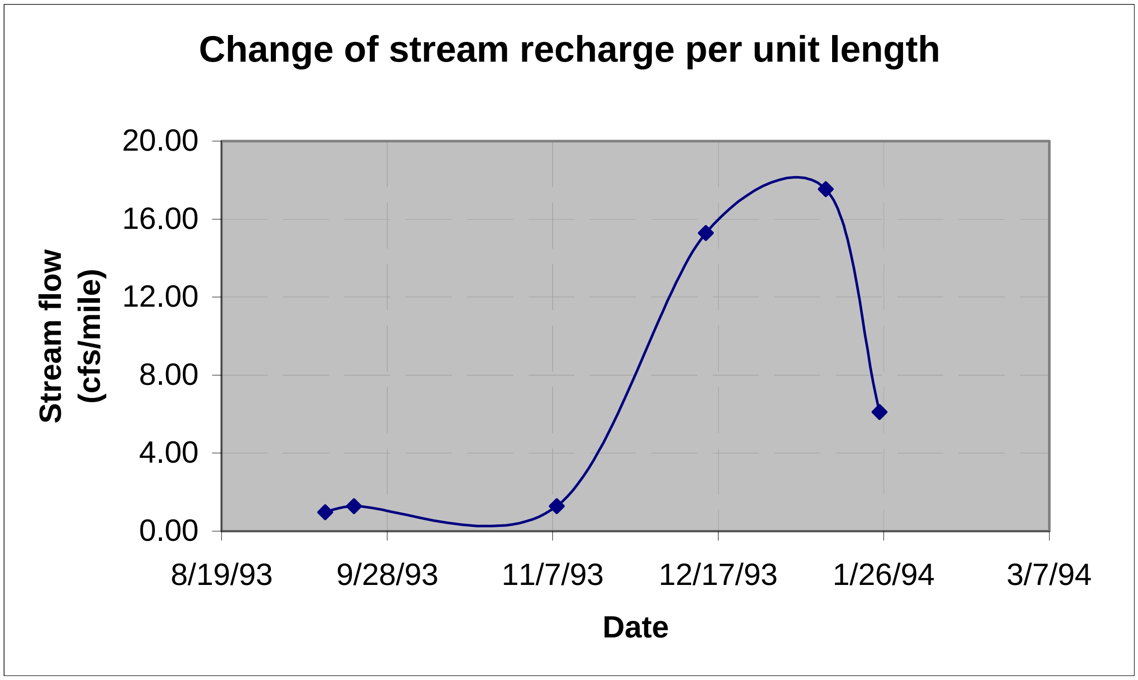

Figure 7.6.8 Variation stream flow production per unit mile, Fishtrap Creek.

8.0 TENMILE SUB-WATERSHED AND AQUIFER WATER BALANCE MODEL

8.1 The Watershed

Tenmile Creek is a tributary of the lower Nooksack River, entering the Nooksack at rivermile 6.9 near the town of Ferndale. Tenmile and its two tributaries, Fourmile and Deer Creek, drain a major portion of the Whatcom Basin lying south of the Nooksack River between the settlements of Strendell and Goshen to the east and Ferndale to the west. The watershed comprises 35 square miles. Elevations range between 10 and 370 feet above mean see level. The watershed consists of predominantly flat terrain with rolling hills along Deer Creek and upper Tenmile Creek. Stream gradients are very low, less than 0.5 percent, except for the headwater areas of the Deer and Tenmile (WCCD, 1986) (see Figure 8.1.1).

Precipitation in the watershed ranges between 35 inches in the western end to 45 inches in the eastern part of the area. Seventy percent of the precipitation falls as rain between the months of October and March. April and September are the transition months between the wet and dry seasons. June, July and August receive about 12 percent of the yearly average (WCCD, 1986).

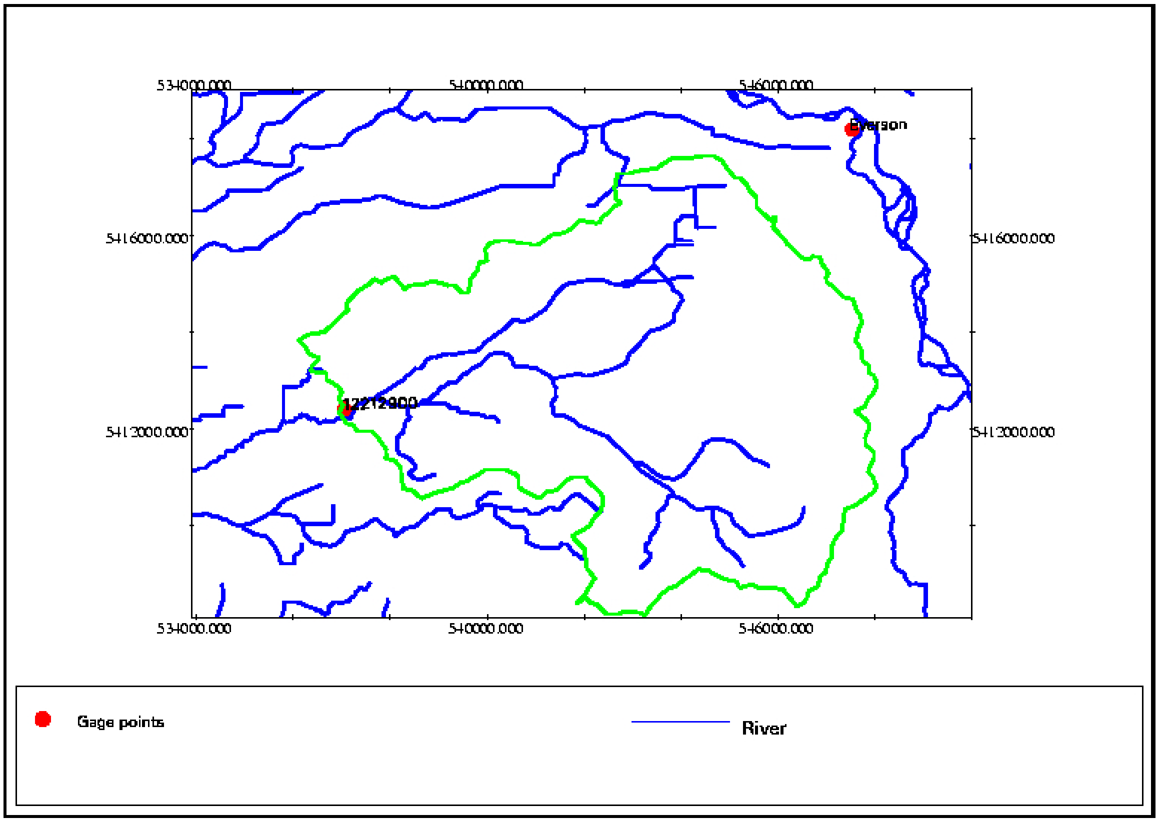

Figure 8.1.1 Upper Tenmile watershed

Transmissivity of Deer Creek Aquifer, tributary to Tenmile Watershed, is estimated to be about 45,000 gallons per day per foot (gpd/ft), based on specific capacity data from well logs. Hydraulic conductivity was estimated to be on the order of about 900 gpd/ft^2 (Pacific Groundwater Group, 1995).

8.2 Base Flow

There are two USGS gaging station on Tenmile Creek. Station #12212900, Tenmile Creek at Laurel and #12213000 further down stream, Tenmile Creek near Ferndale. The station at near Ferndale does not have enough data (< 1 year hard copy, Tarboton(2000)), while the one at Laurel has 4 (1969 – 1972) water years of data. Hence the analysis used the data from this station.

Figures 8.2.1 and 8.2.2 show the stream flow and base flow plots.

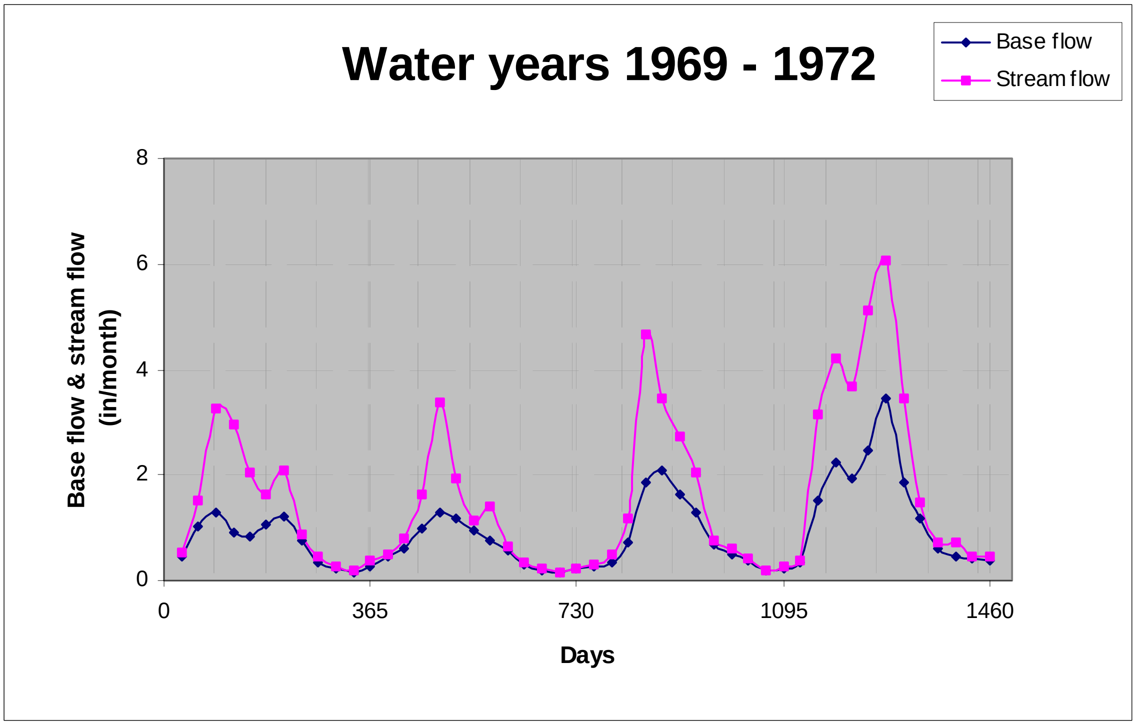

Figure 8.2.1 Tenmile Creek stream flow and base flow, water year 1969 - 1972

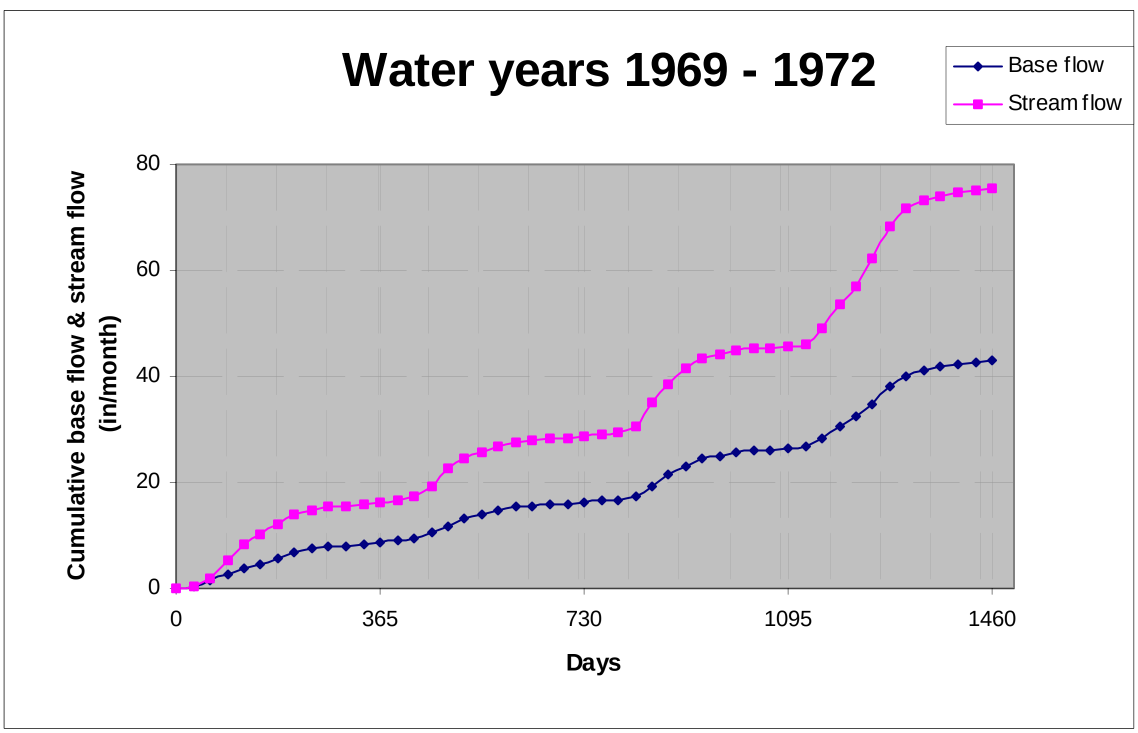

Figure 8.2.2 Tenmile Creek stream flow and base flow, water year 1969 - 1972

8.3 Groundwater Water Pumping

Out of the 237 registered wells 142 of them have pumpage data totaling 11,228 gpm (gallons per minute). This well point file has been CLIPped using ARC/Info’s function to select those wells, which lie completely within the watershed associated with gaging station #12212900.

8.4 Recharge

Part of the Tenmile Creek which belongs to the Unconfined Sumas Aquifer have a recharge estimate between 16 to 20 inches per year, while a smaller lower part which belongs to Everson-Vashon and Vashon semiconfining unit has a recharge estimate of 11 to 15 inches per year (Cox and Kahle, 1999).

Pacific Groundwater Group (1995) estimates recharge for Deer Creek using a water balance model of Blaney-Criddle. Recharge is assumed to be that amount precipitation in excess of evapotranspiration and soil moisture storage. The method used published values of soil moisture holding capacity and runoff percentage values. This approach resulted in recharge estimate between 8 to 13.4 inches per year. The two rates were generated using different crop factor to reflect the variation in the land use in the project area.

Inverse recharge estimation

Assuming the recharge to be the unknown in the mass balance equation, an inverse estimation for recharge can be performed using the other components of the water balance.

A linear regression line has been fitted to the cumulative base flow with the following statistics:

Water year 1969 –1972

Slope of regression line	=0.0268 in/day
Standard deviation of the slope	=0.000436 in/day
Coefficient of regression	=0.96

Hence, total annual base flow is

1. Using regression slope	=0.0268*365	= 9.78in
2. Using slope – 2*Std	=(0.0268-2*0.000436)*365	= 9.46in
3. Using slope + 2*Std	=(0.0268+2*0.000436)*365	= 10.10in
Annual pumpage	=(11228 gpm in 52.514 mi^2)	= 6.47in

The uniform recharge value over the catchment will be the sum of the above base flows and the total pumpage.

Recharge1 = (9.78 + 6.47) = 16.25in
Recharge2 = (9.46 + 6.47) = 15.93in
Recharge3 = (10.10 + 6.47) = 16.57in

Hence, based on base flow slop analysis and pumpage the recharge within the upper part of Tenmile creek is about 16 inches per year.

8.5 Comparison of Precipitation, Stream flow and Base flow

The nearby climate stations with sufficiently long record are that of Bellingham 2N and Bellingham FCWOS, AP. Those measurement years, which coincide with measured stream flows, are taken for the analysis. These two stations have very comparable measurements and hence the average reading of the two stations are used for comparing with stream flow and base flows. For the periods considered the difference between these two station is very small (see Figures 8.5.1), justifying a simple arithmetic mean between the two sets of data can be used without areal interpolations using, for example, Thiessen Polygon method (Chow et. al, 1987).

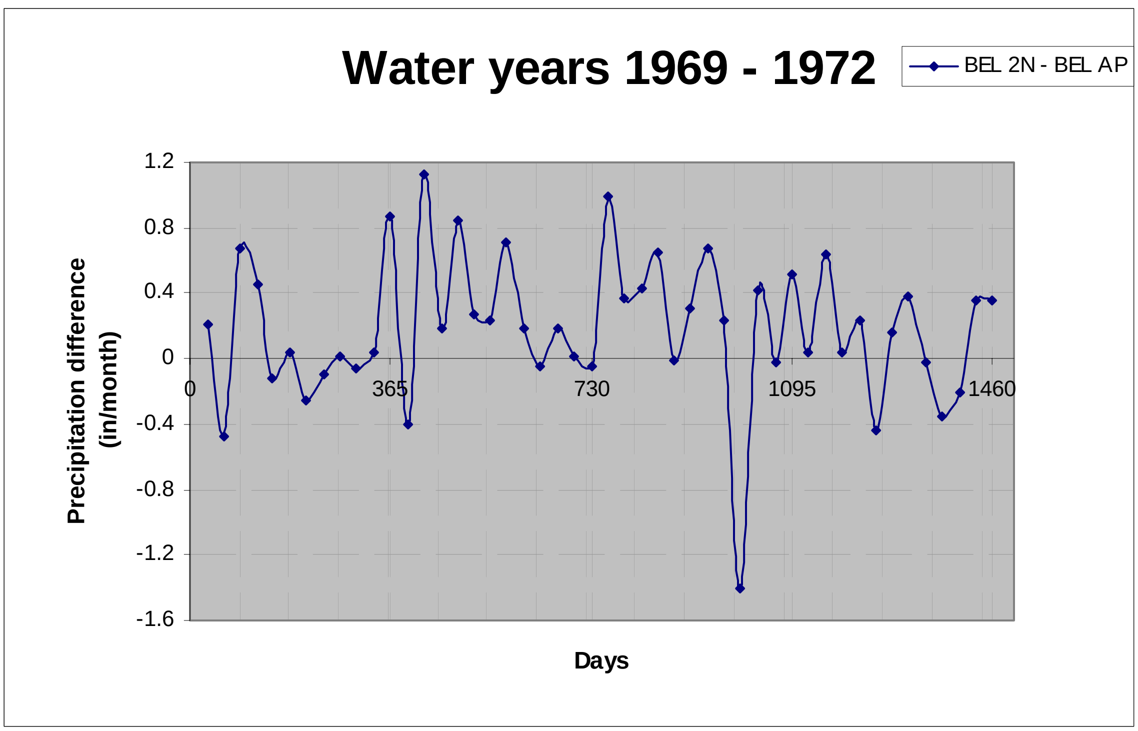

Figure 8.5.1 Precipitation measurement difference, 1969 – 1972, Bellingham stations

Figures 8.5.2 and 8.5.3 shows average precipitation comparison with base flow and stream flow and Figures 8.5.4 and 8.5.5 shows the cumulative comparison plot.

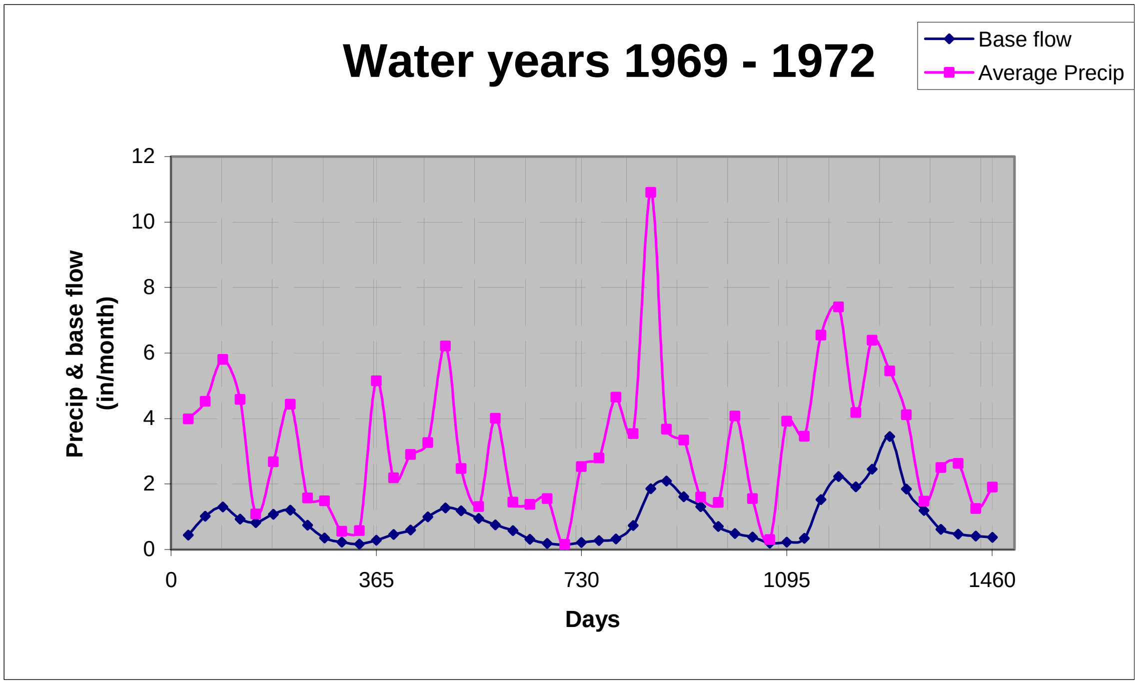

Figure 8.5.2 Average precipitation and base flow comparison, 1969 – 1972, Tenmile Creek

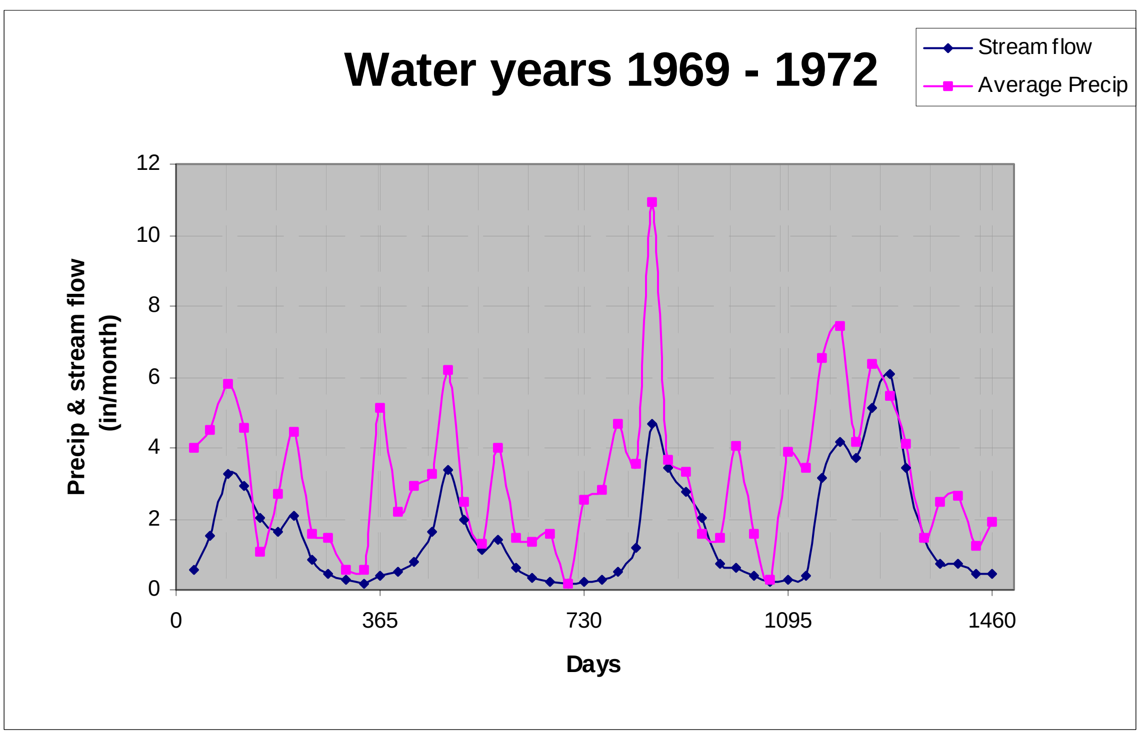

Figure 8.5.3 Average precipitation and stream flow comparison, 1969 – 1972, Tenmile Creek

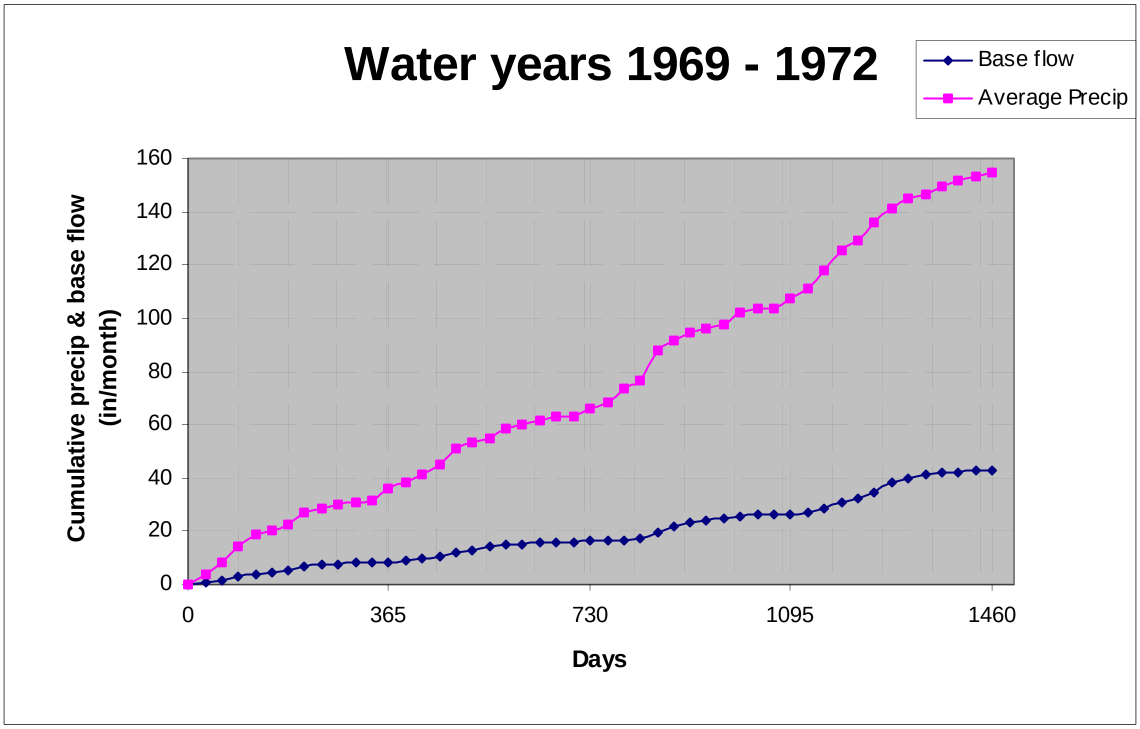

Figure 8.5.4 Cumulative average precipitation and stream flow comparison, 1969 – 1972, Tenmile Creek

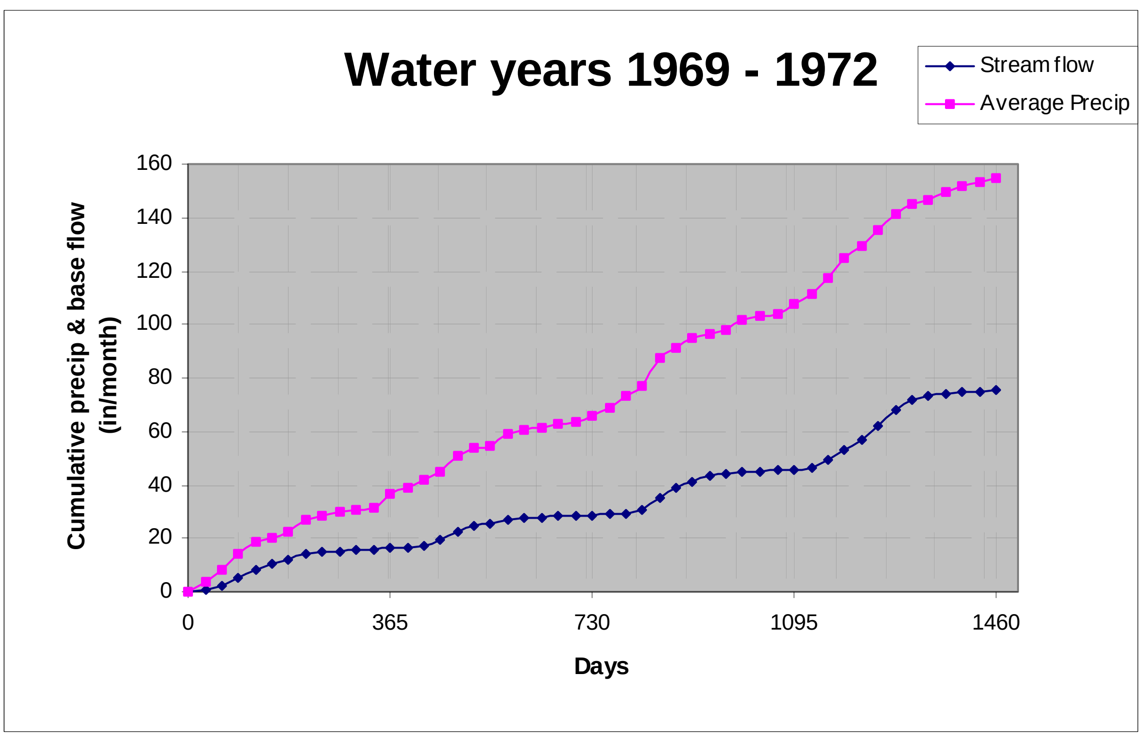

Figure 8.5.5 Cumulative average precipitation and base flow comparison, 1969 – 1972, Tenmile Creek

The respective slops comparisons are shown below

Slopes and ratios of slopes

Water year 1969 – 1972

Average precipitation	0.1037 in/day
Stream flow	0.0475 in/day
Base flow	0.0268 in/day
Precipitation/stream flow	2.18
Precipitation/base flow	3.86

Hence, based on the flow years considered (1969 – 1972 water years) about half of the precipitation goes to stream flow while less than one-third goes to base flow.

8.6 SEEPAGE RUNS

Seepage runs results on 9/14/00 were done by the USGS. Figures 8.6.1 and 8.6.2 shows measured values and locations. An assumed linear stream flow gain results in 1.26 cfs/mile on average, even though the first segment of the river does seem a losing reach.

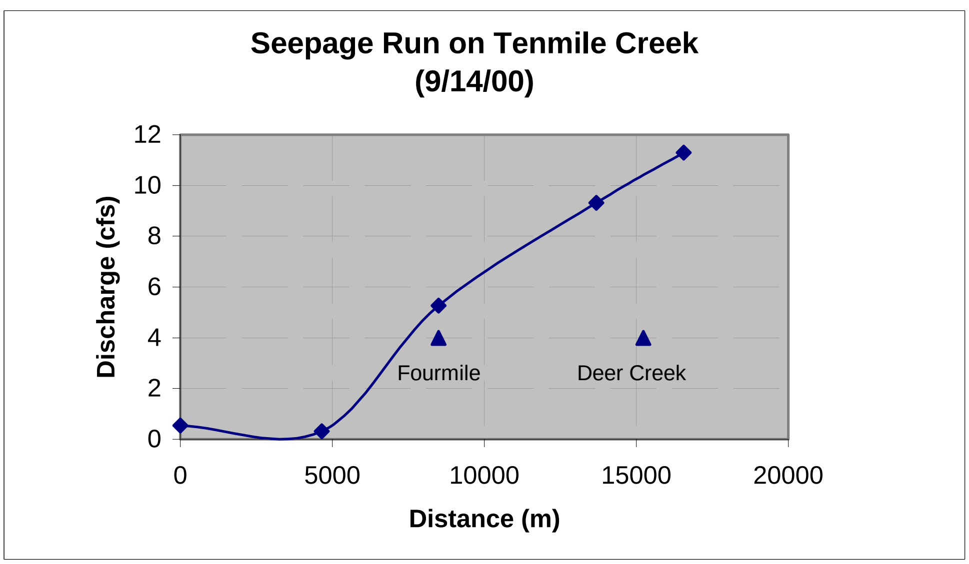

Figure 8.6.1 Tenmile Creek seepage run results, 9/14/00

Table 8.6.1. Tenmile seepage run results, 9/14/00

Measurement Location	Latitude	Longitude	Date	Q (cfs)
Ten mile Creek at Barrett Road	48 51 12	122 34 24	9/14/00	11.3
Ten mile Creek at Northwest Drive	48 51 14	122 32 26	9/14/00	9.31
Deer Creek (tributary) at Northwest Drive	48 50 42	122 32 29	9/14/00	1.48
Ten mile Creek at Meridian Road	48 52 00	122 29 09	9/14/00	3.46
Four mile Creek at Meridian Road	48 52 04	122 29 08	9/14/00	5.27
Ten mile Creek At Hannegan Road	48 52 21	122 26 33	9/14/00	0.31
Ten mile Creek at Noon Road	48 50 51	122 23 59	9/14/00	0.54

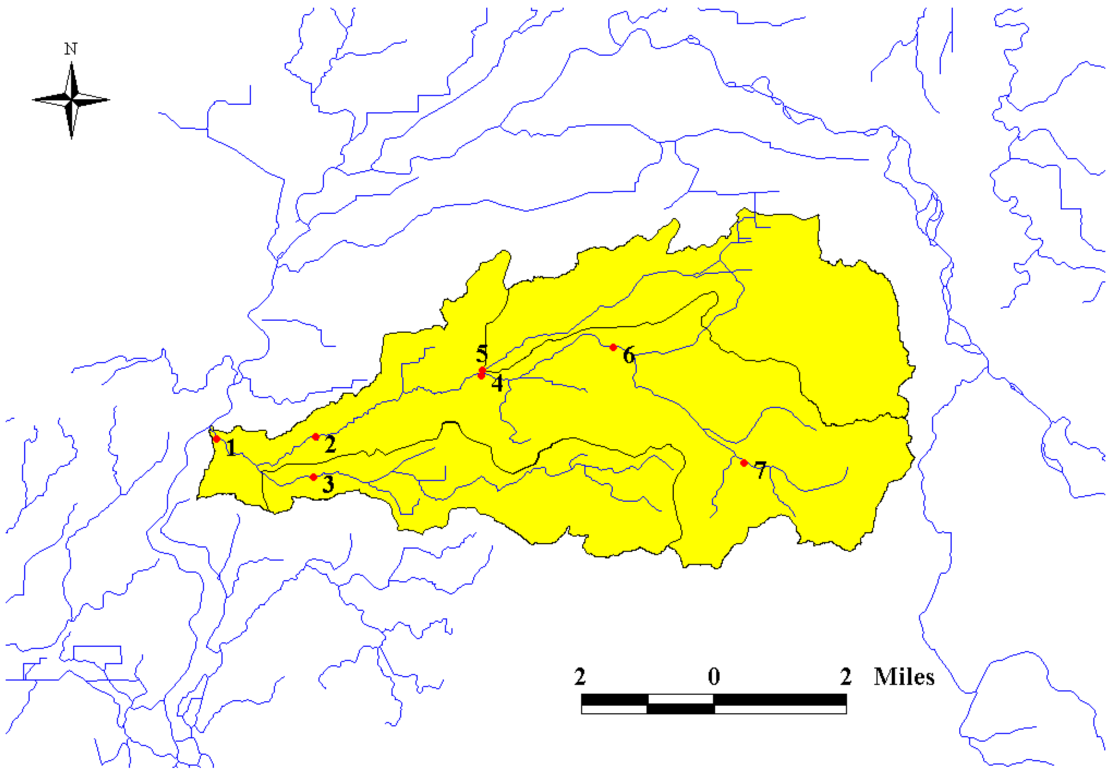

Figure 8.6.2 Tenmile Creek seepage run locations, 9/14/00

8.7 Conclusion and Recommendation

The inverse recharge estimation results in about 16 inches per year for the upper part of Tenmile Creek watershed. This estimate compares well with those of Cox and Kahle (1999), 11 – 20 inches per year, and Pacific Groundwater Group (1995), 8 to 13.4 inches per year. Average precipitation slopes shows about half the precipitation goes to stream flow and less than one-third goes to base flow.

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Appendix A

Figures

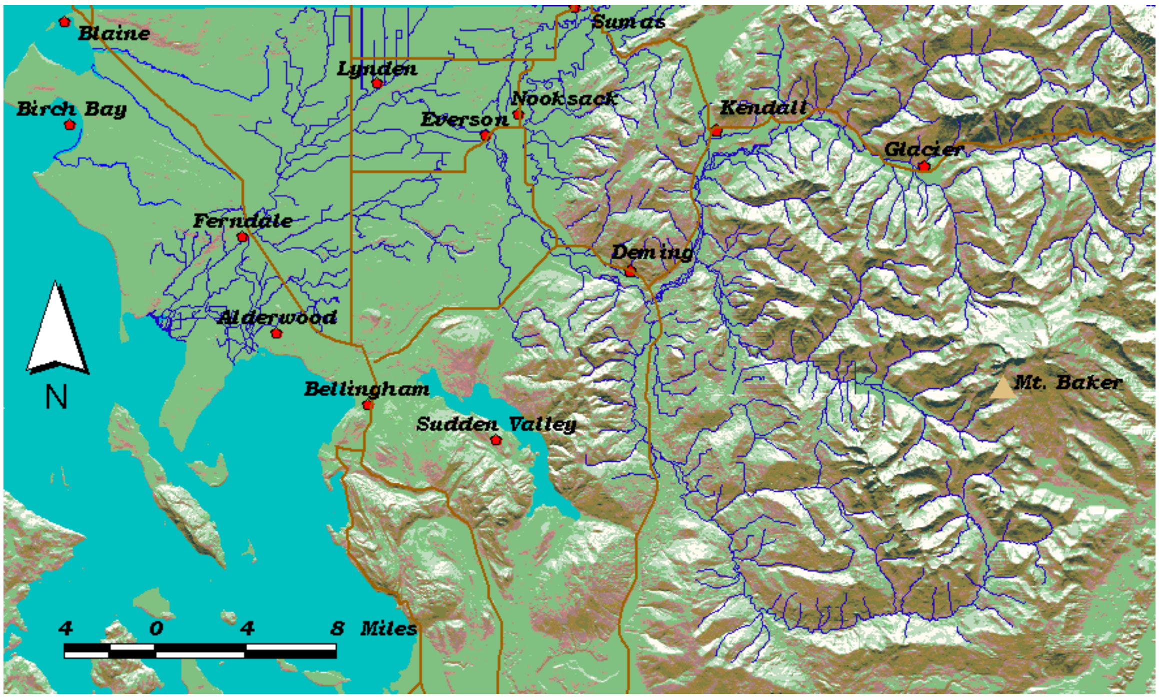

Figure 1.1.1a Major towns in the WRIA 1 study area

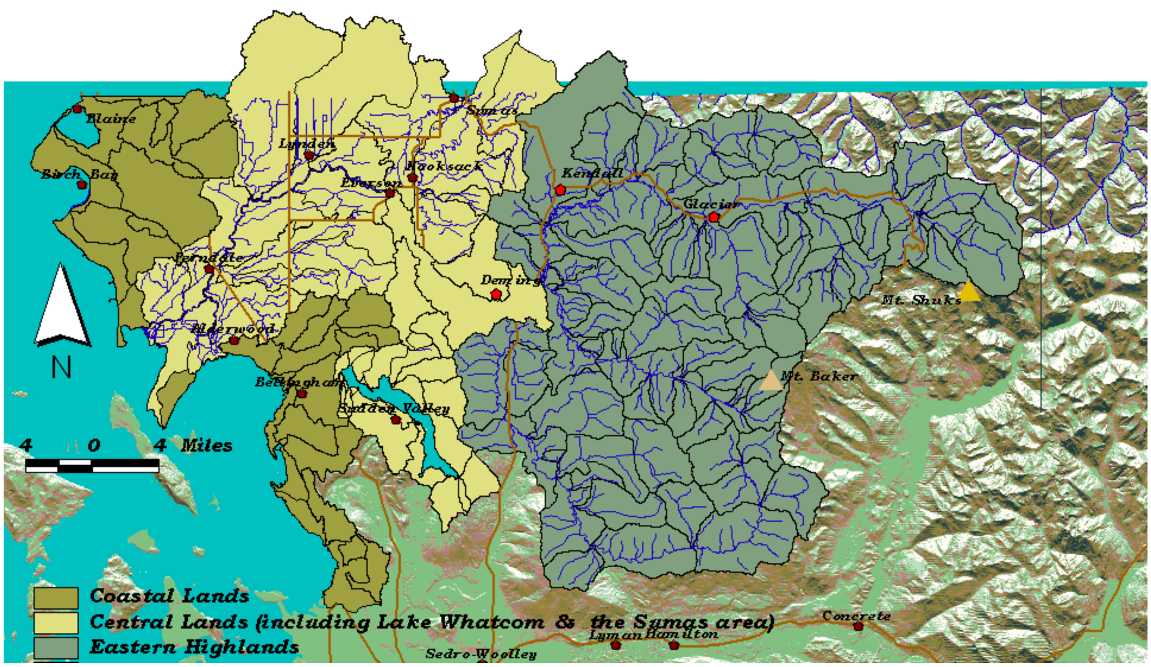

Figure 1.1.1b Location of coastal lands, central lands and eastern highlands of the WRIA 1

Figure 1.1.1c Location of NorthFork, MiddleFork & SouthFork Nooksack Rivers (source:USGS)

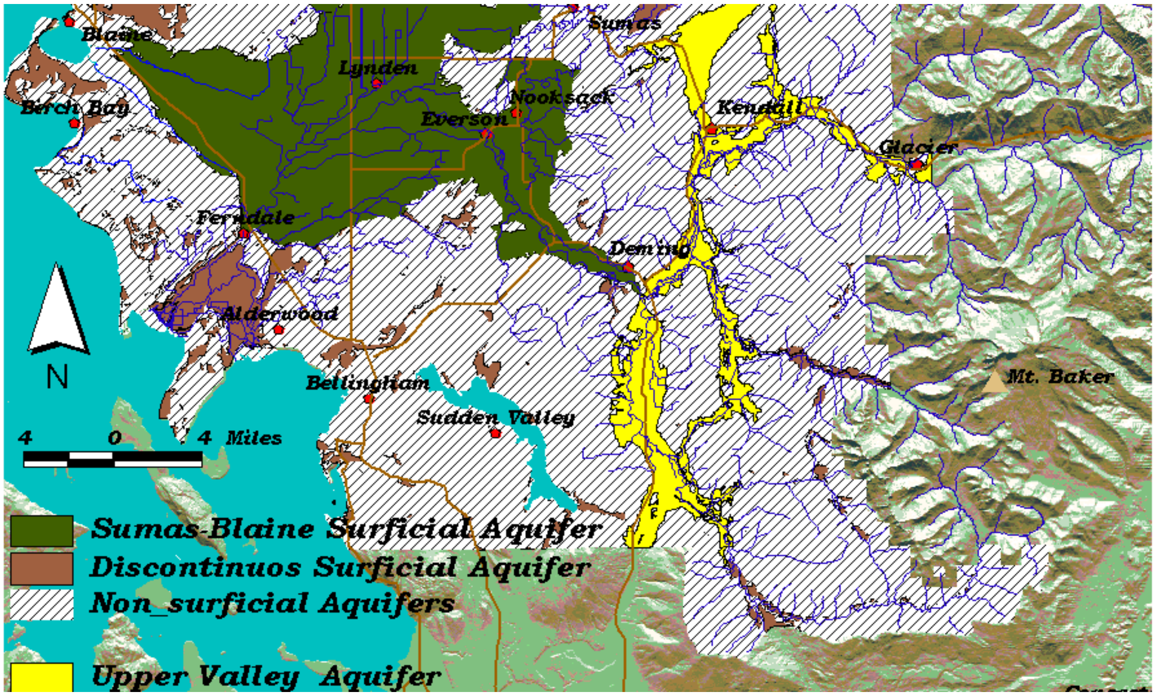

Figure 1.1.2 Location of surficial aquifers

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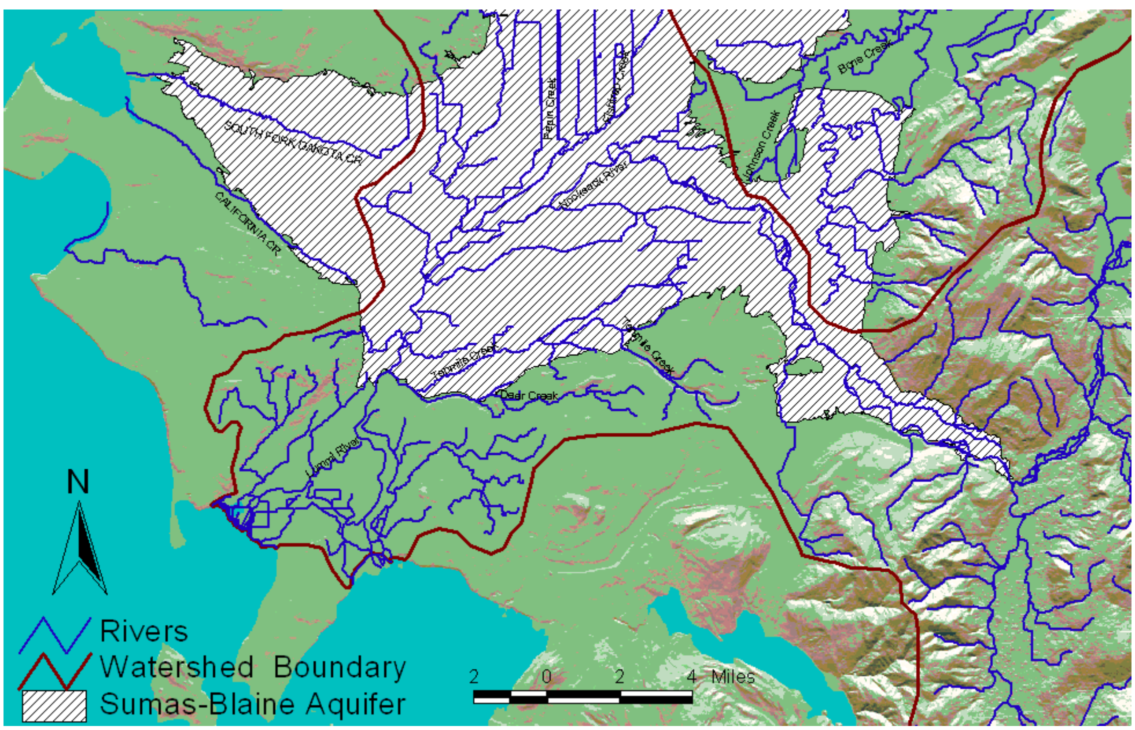


Figure 1.1.3 Sumas-Blaine Surficial Aquifer

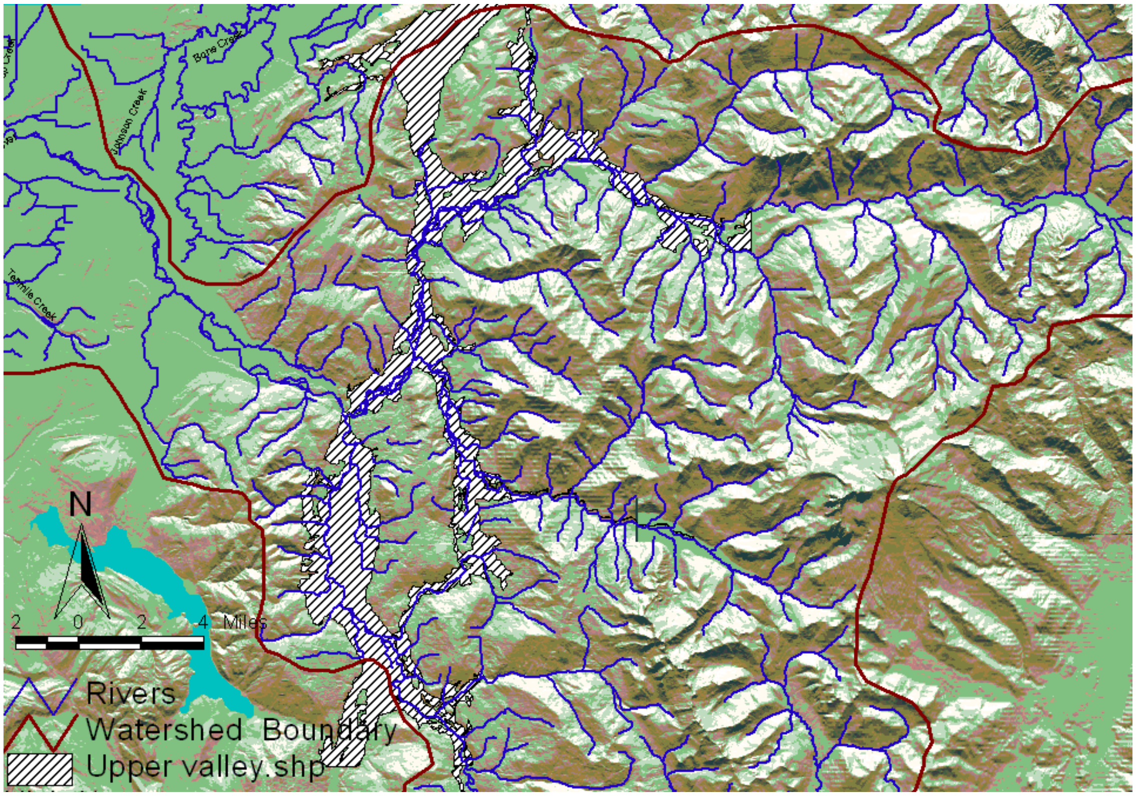


Figure 1.1.4 Upper Valley Surficial Aquifer

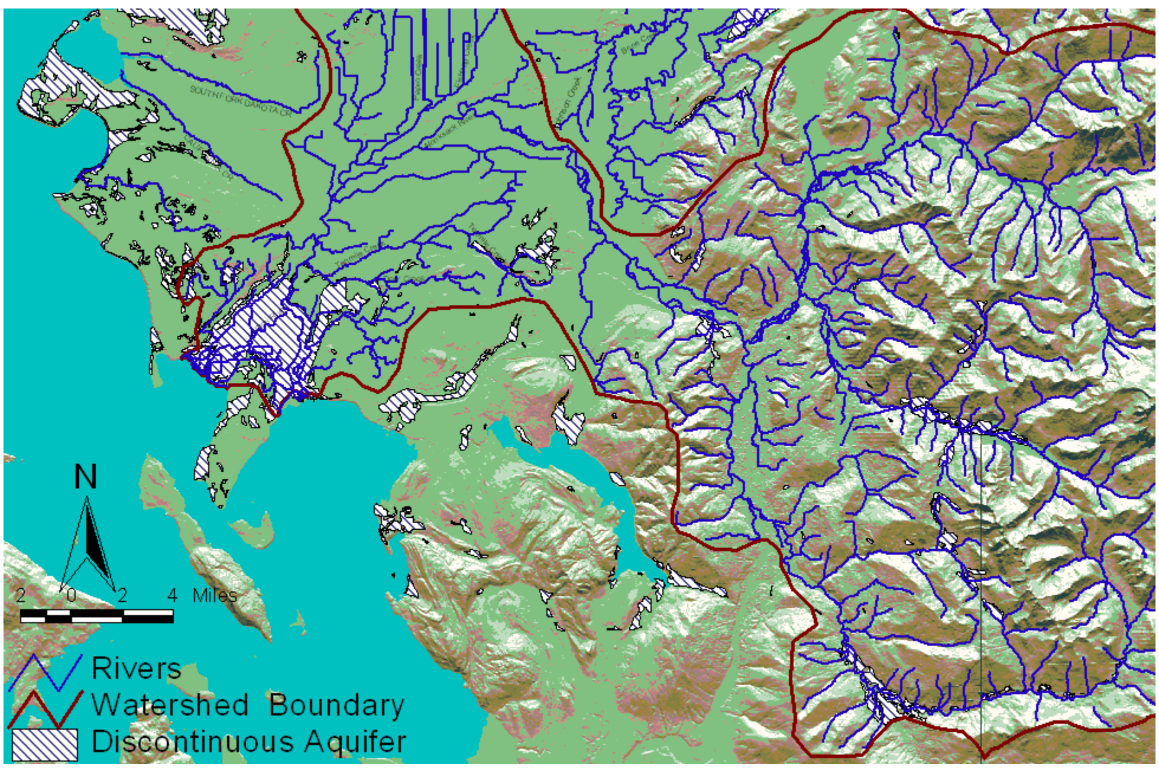


Figure 1.1.5 Discontinuous Surficial Aquifers

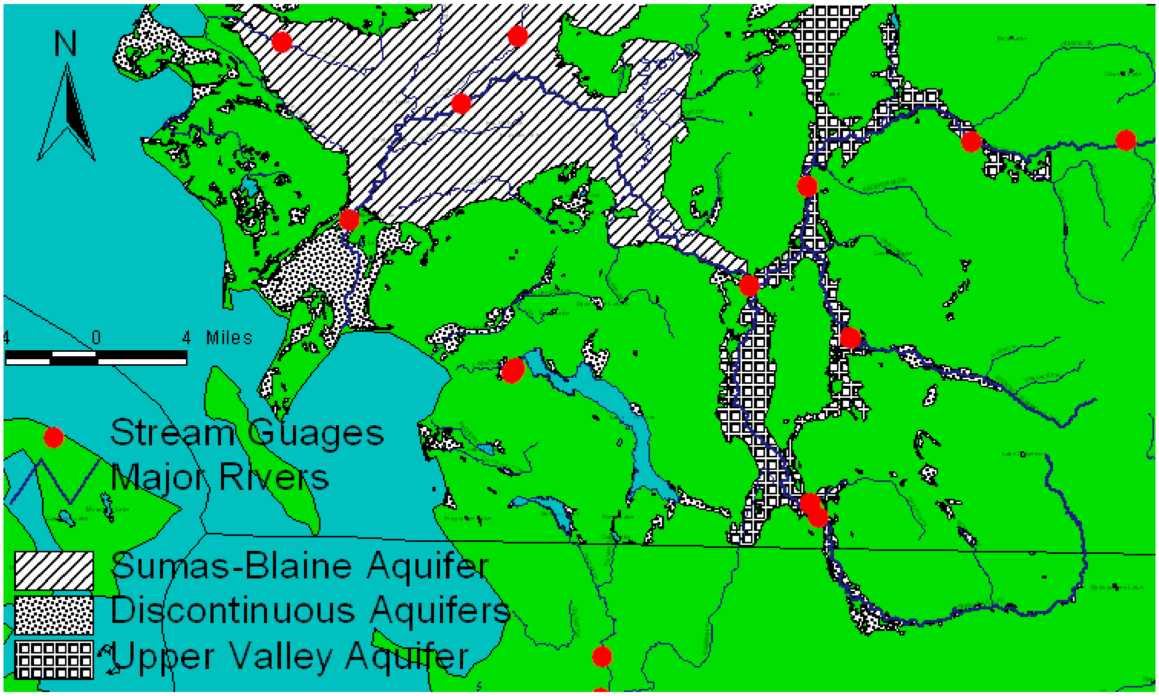


Figure 1.1.6 Stream gauges with estimated baseflow

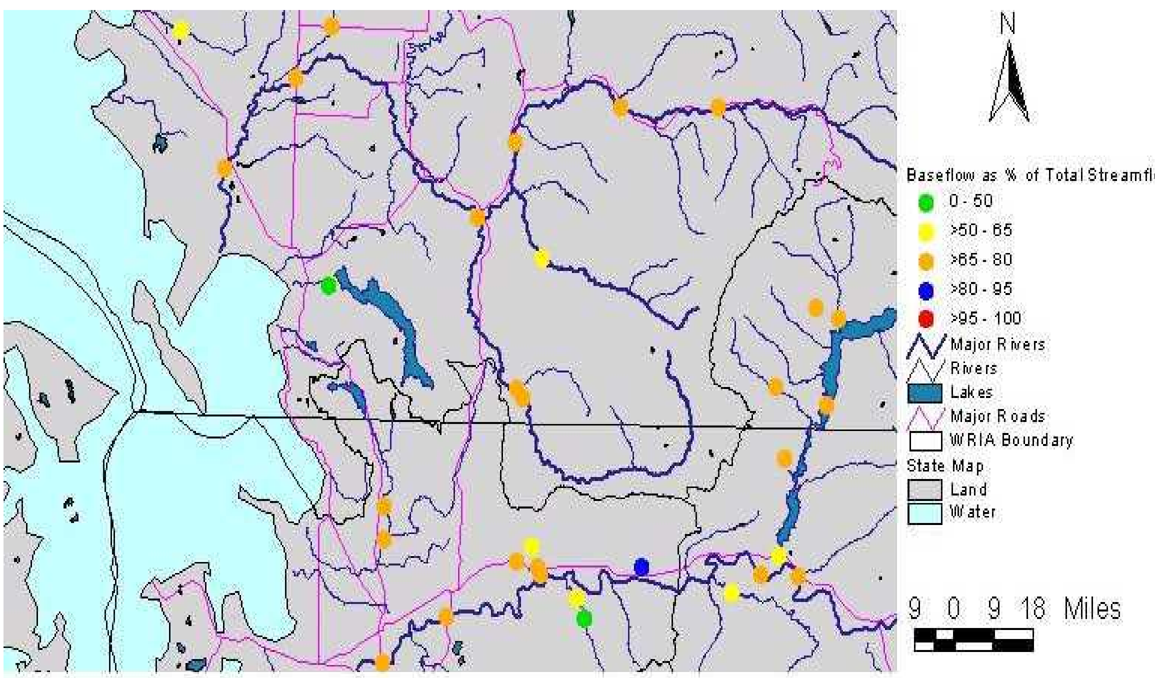


Figure 1.1.7 Estimated Baseflow Contribution (percentage) (Source: Sinclaire and Pitz, 1999)

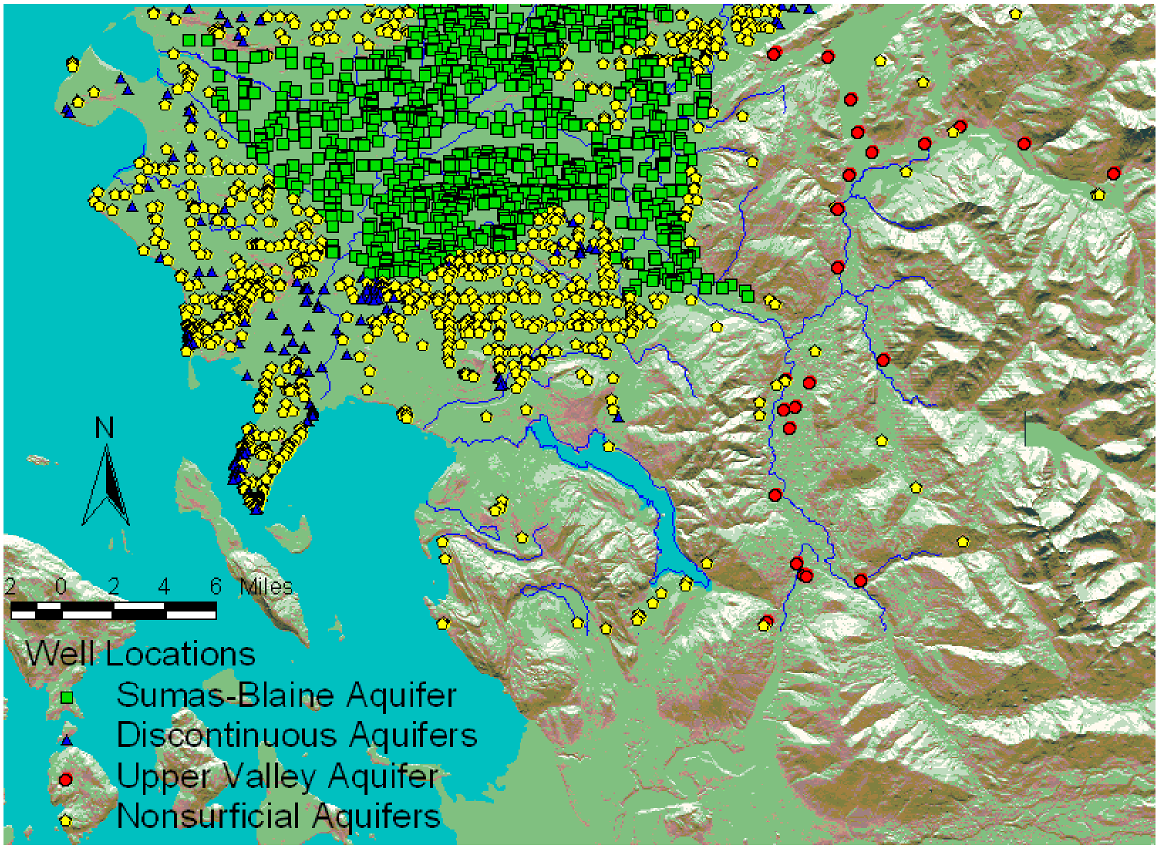


Figure 1.1.8 Locations of wells and their aquifer type

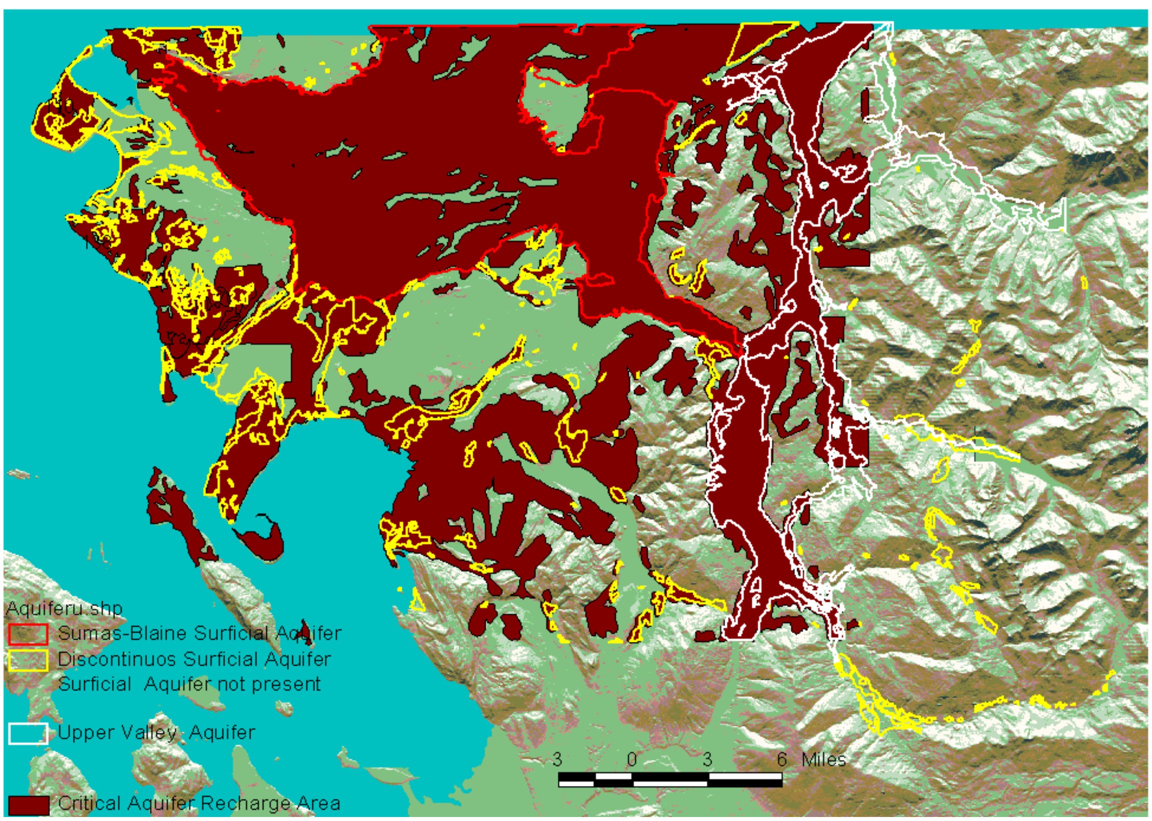


Figure 1.1.9 Critical Aquifer Recharge Areas

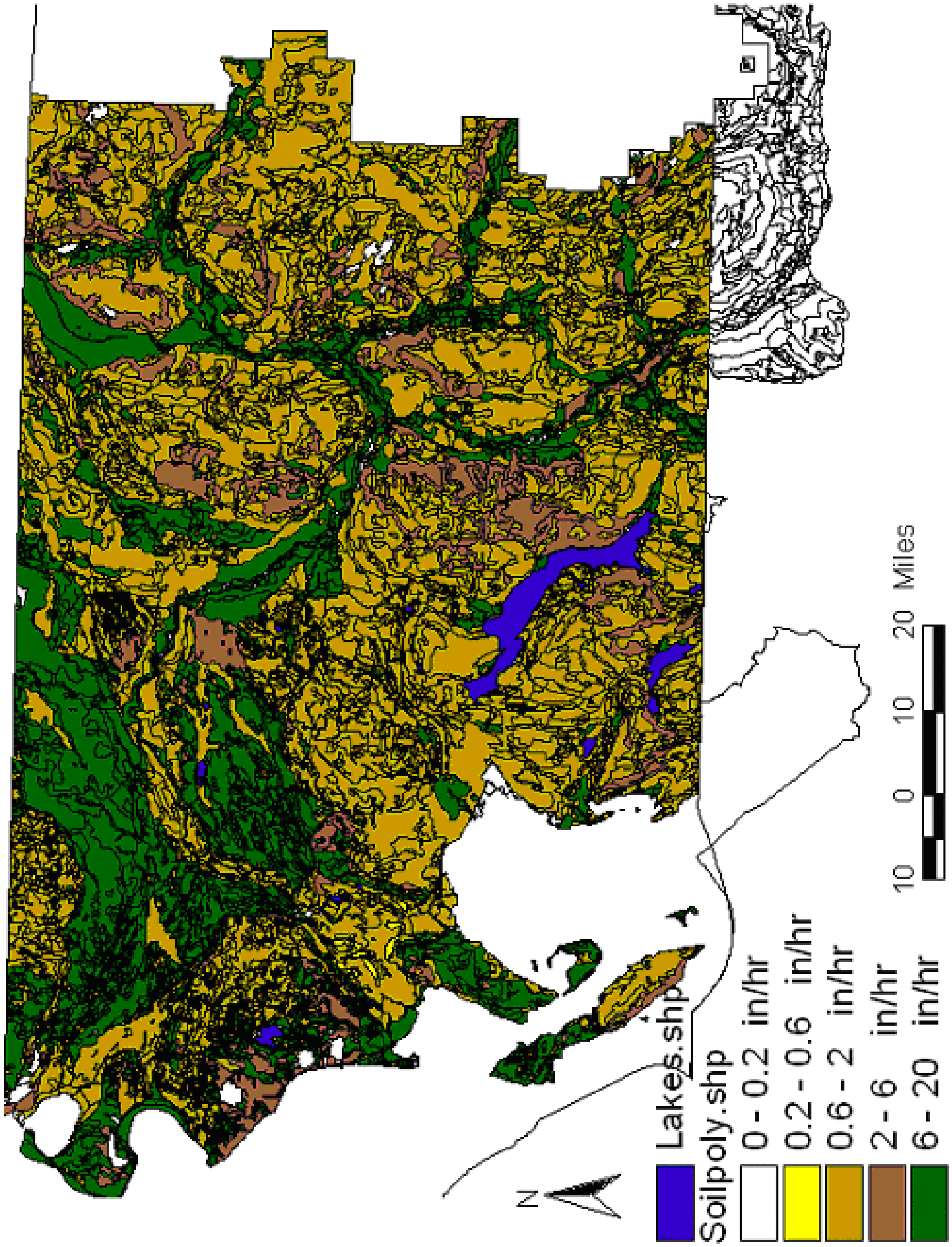


Figure 1.1.10 Maximum soil permeability

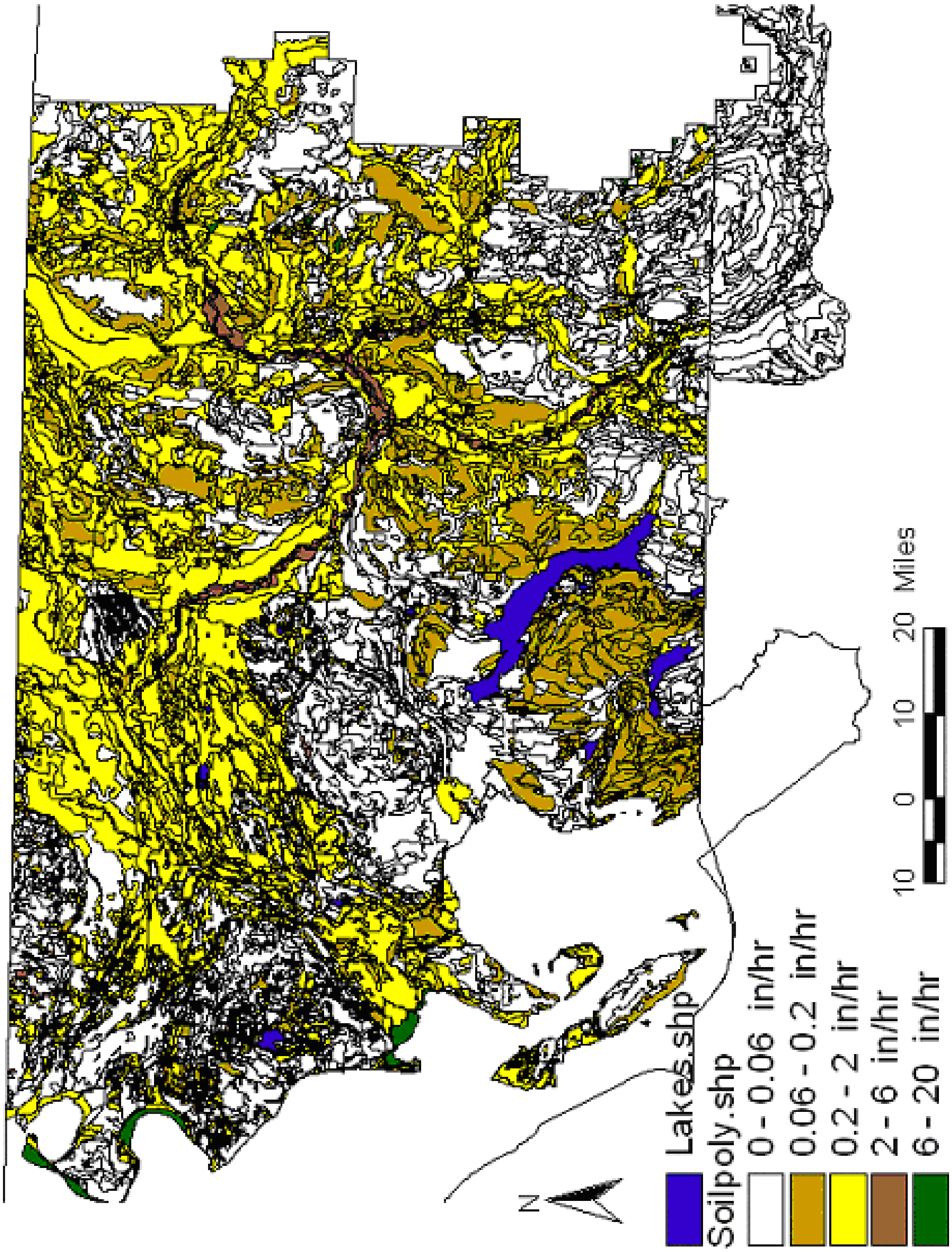


Figure 1.1.11 Minimum soil permeability

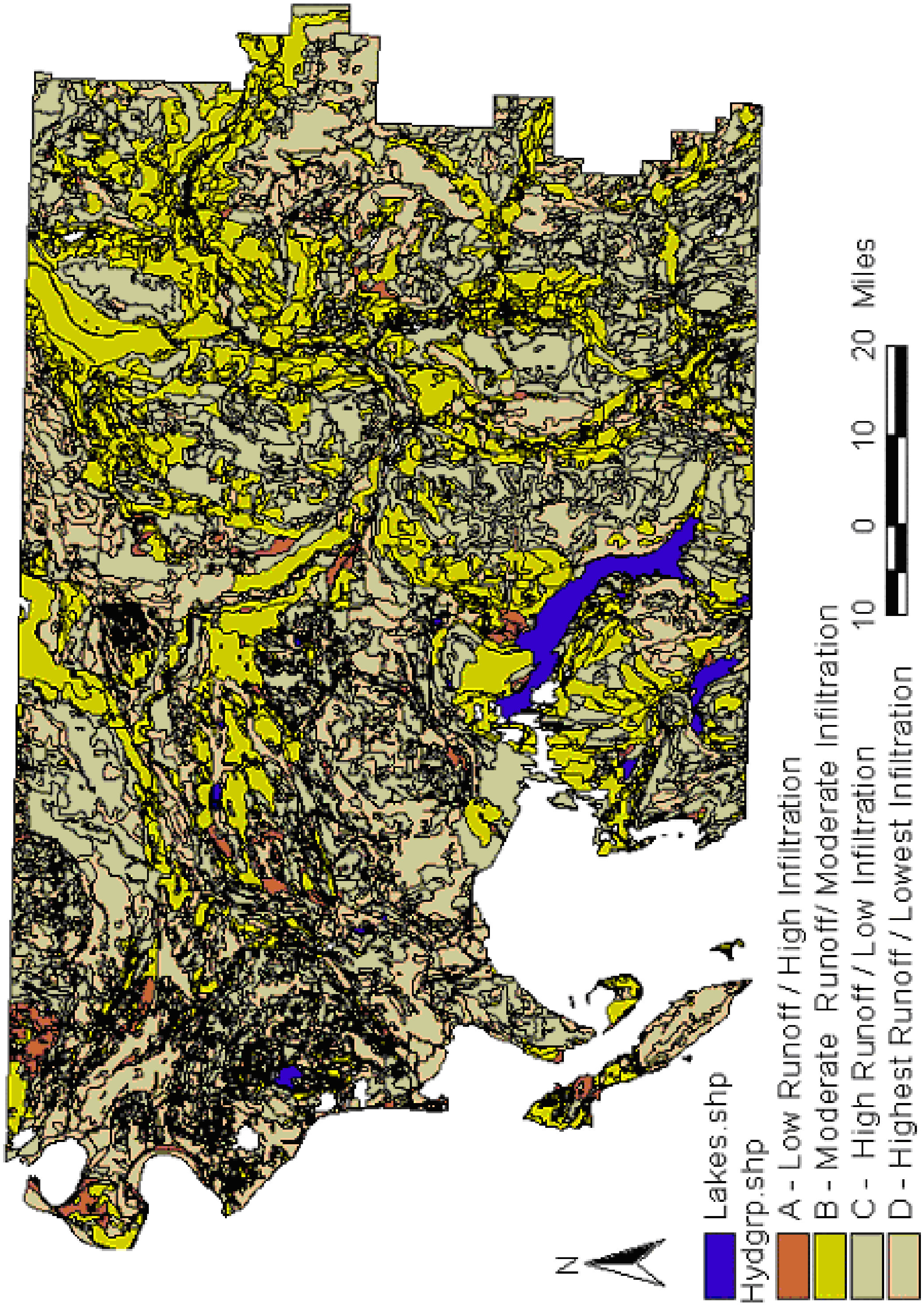


Figure 1.1.12 Soil Hydrologic Groups

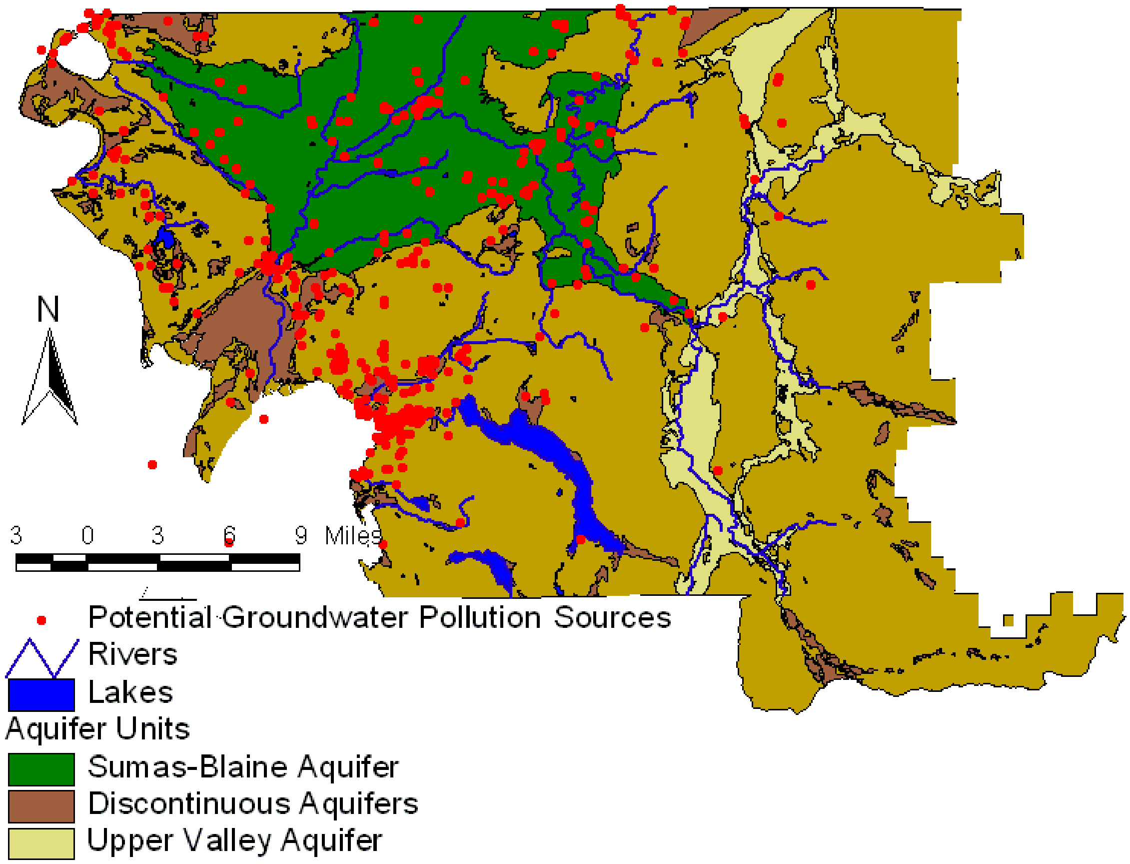


Figure 1.1.13 Layout showing potential groundwater pollution sources

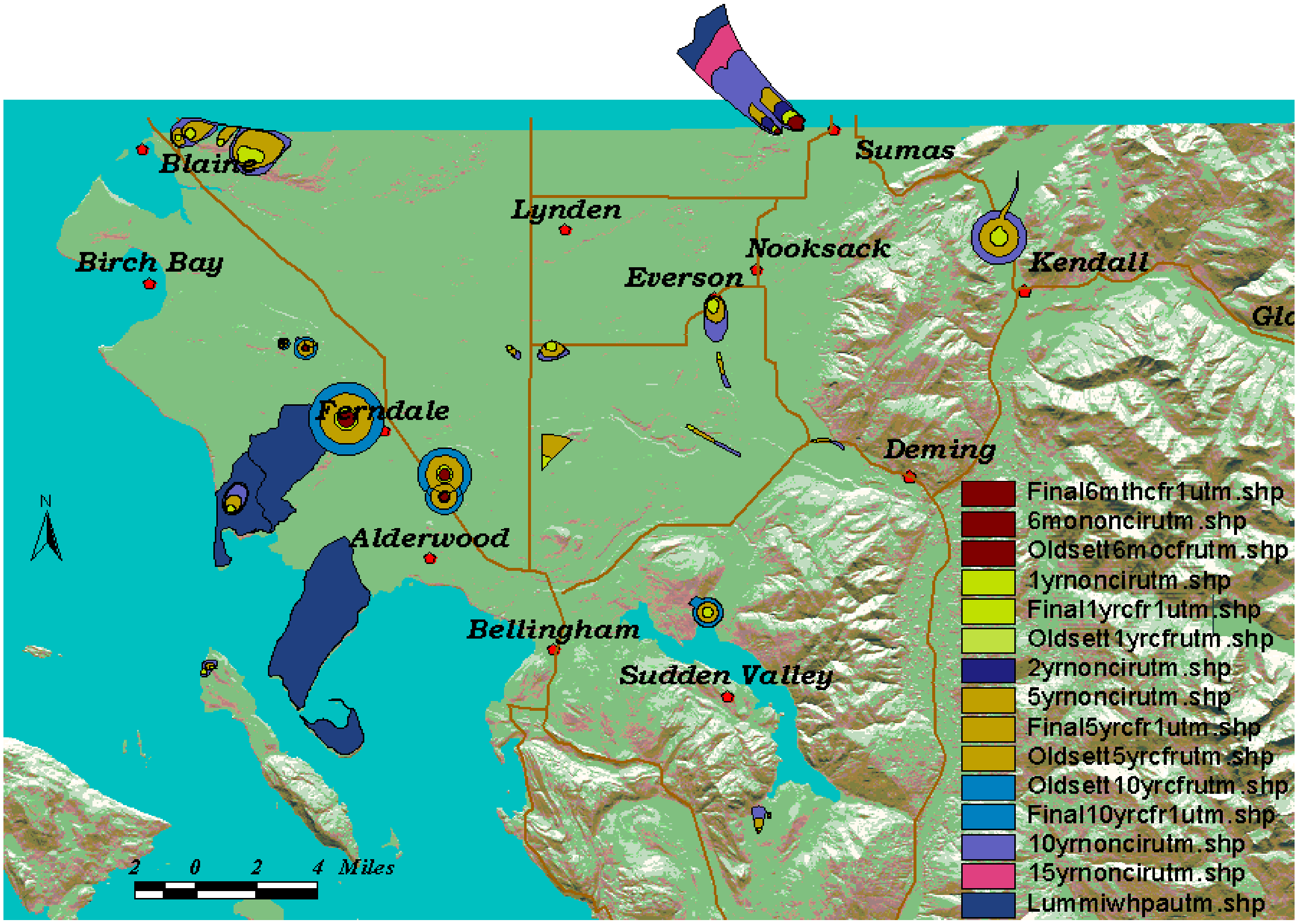


Figure 1.1.14 Wellhead protection zones, recent data (both circular and noncircular).

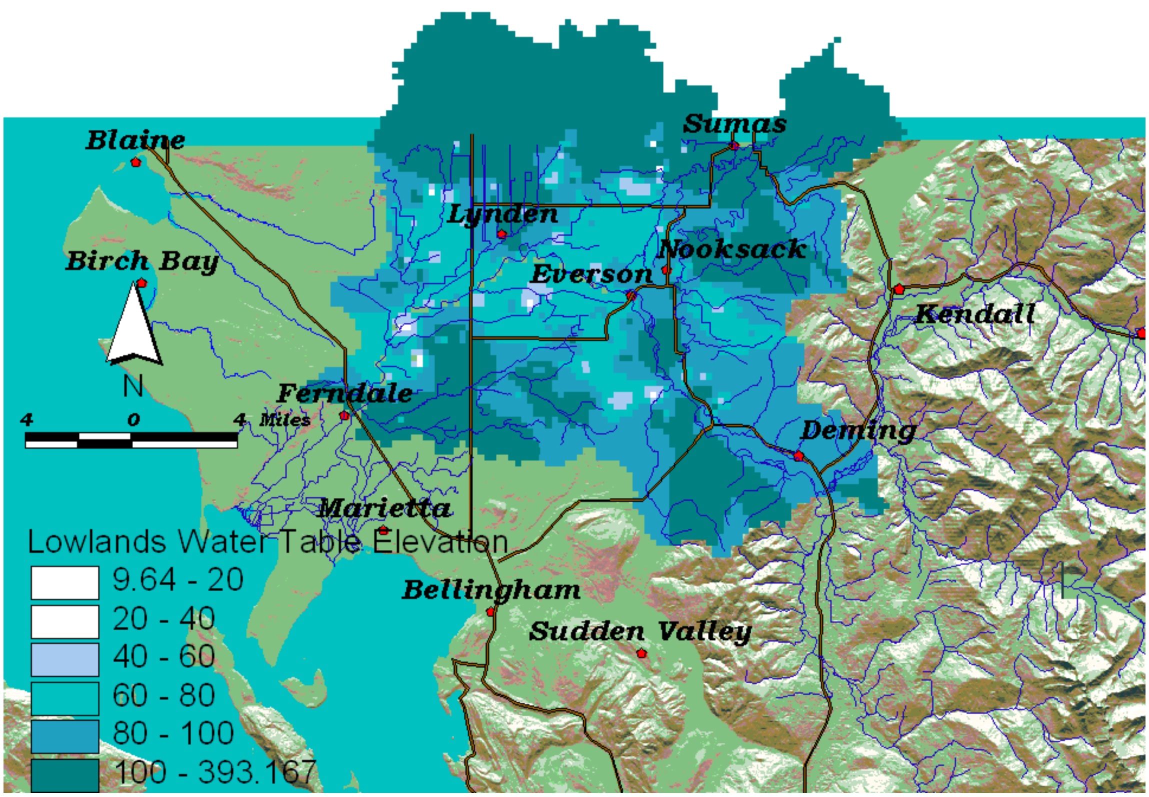


Figure 1.1.15a. Water table elevation in feet above msl, 1990

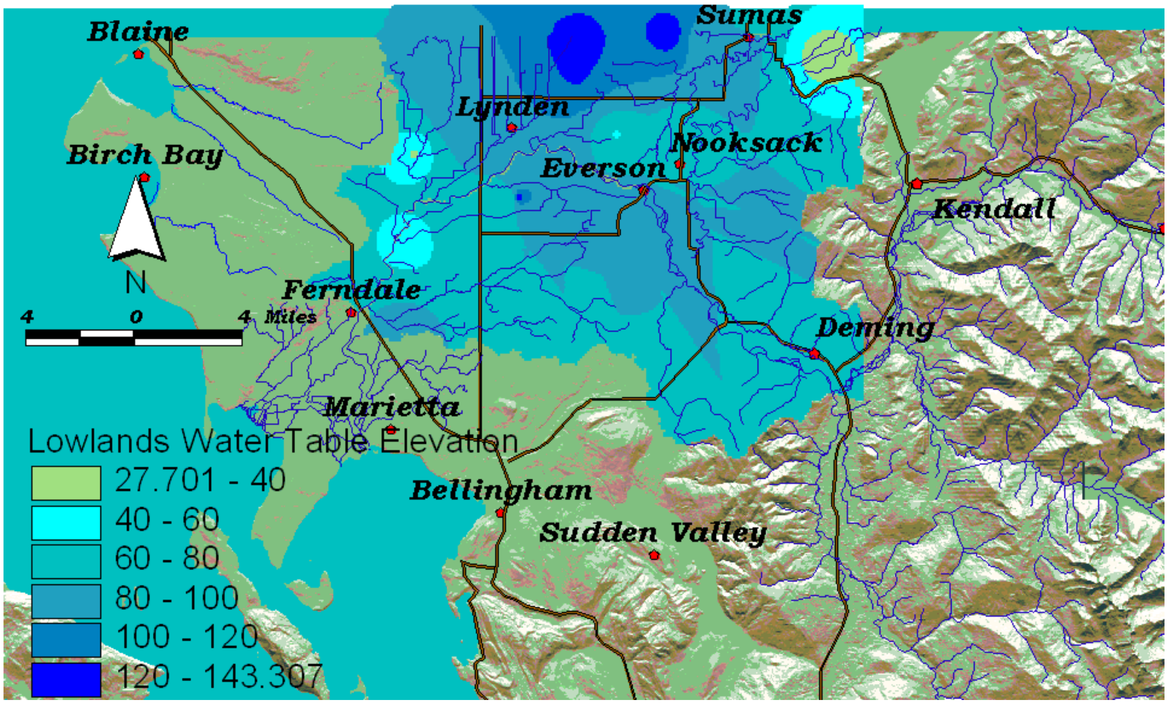


Figure 1.1.15b Water table elevation in feet above msl, 1991

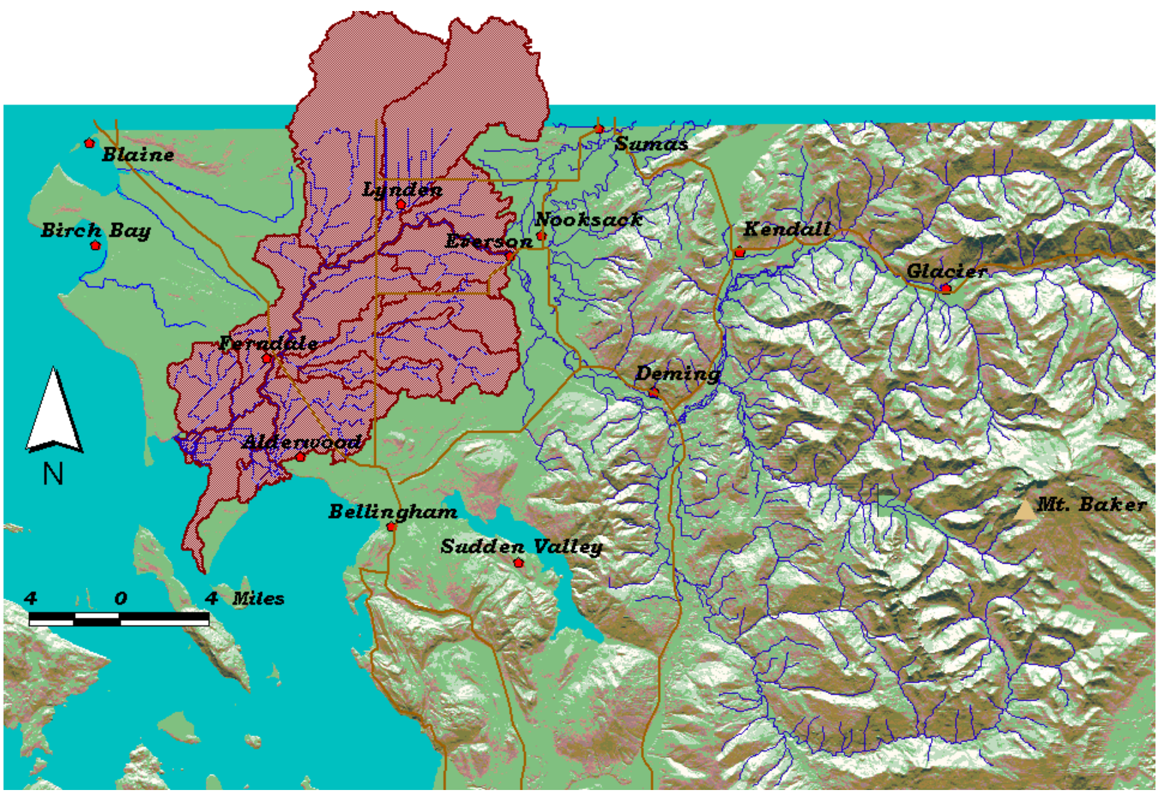


Figure 1.2.1aThe watershed of the lower lowlands of the Nooksack

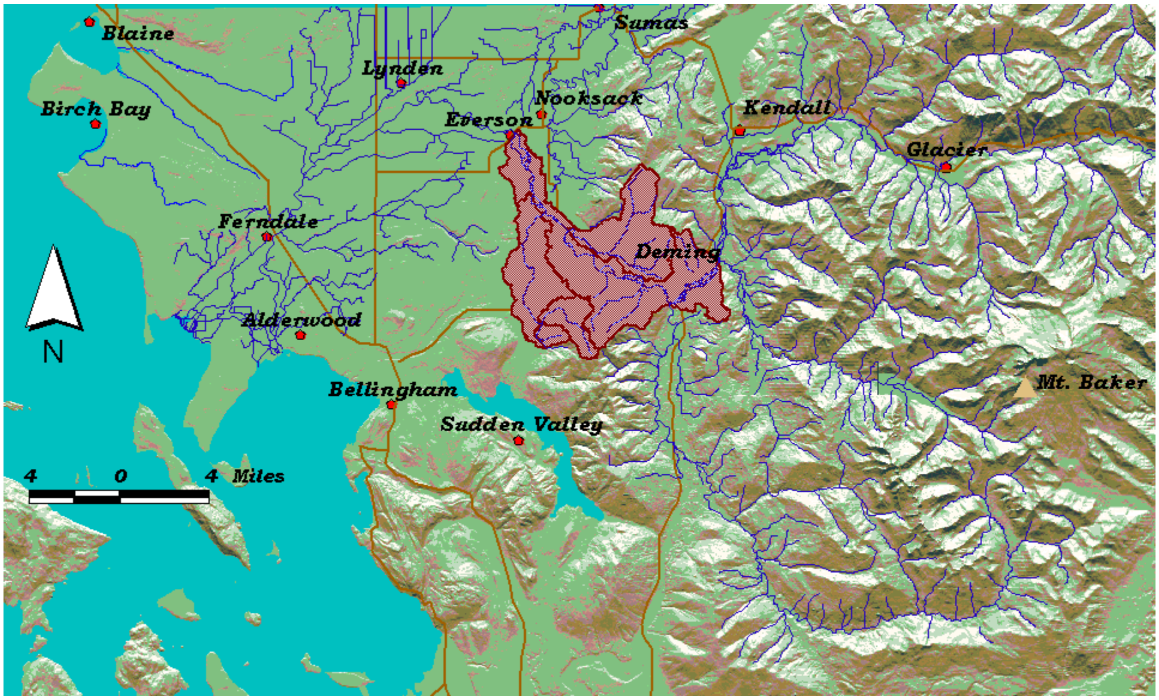


Figure 1.2.1b. The watershed of the upper lowlands of the Nooksack

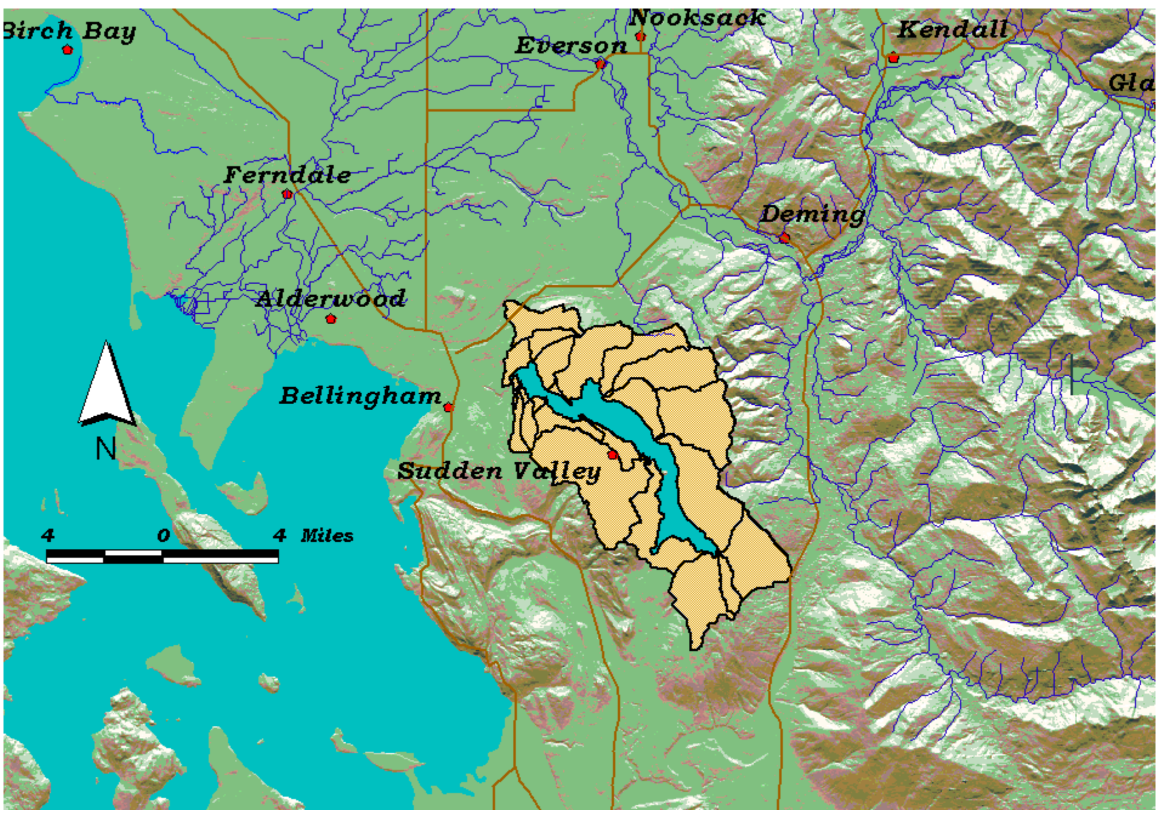


Figure 1.2.1c Lake Whatcom sub-watersheds

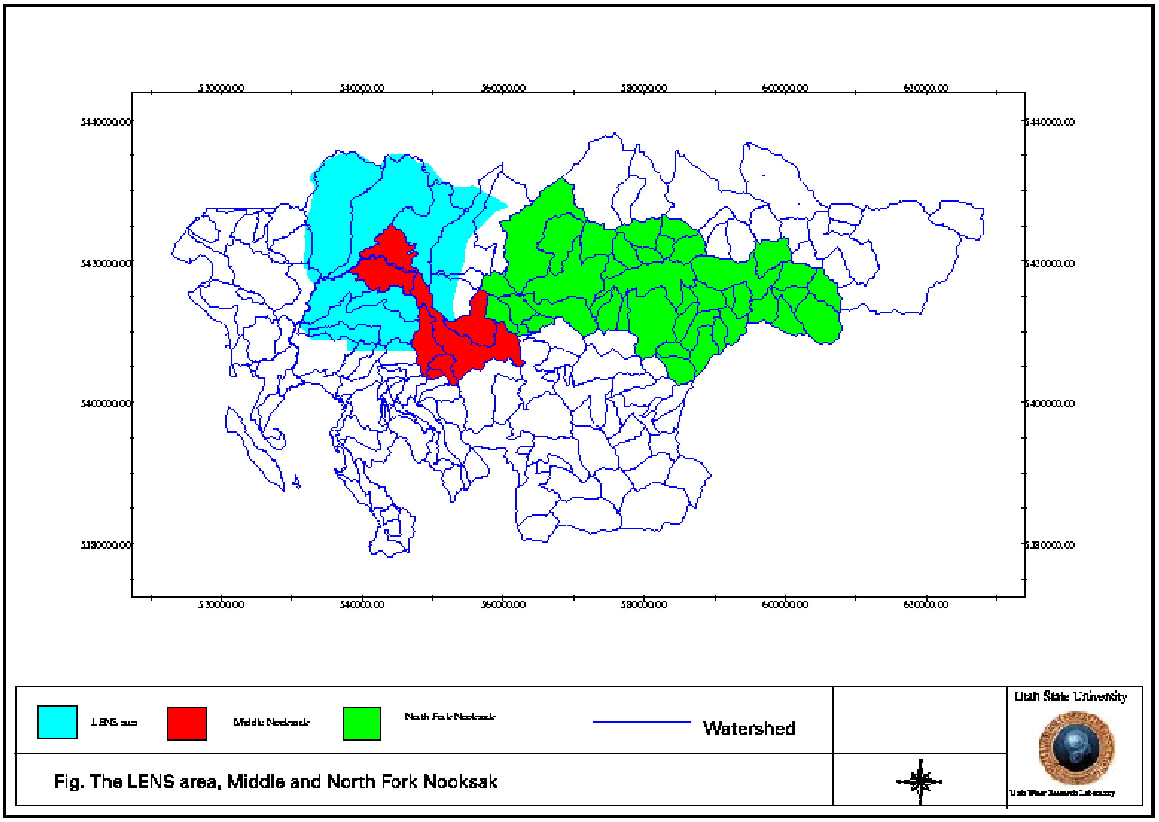


Figure 1.2.1d The location of the LENS area (light blue)

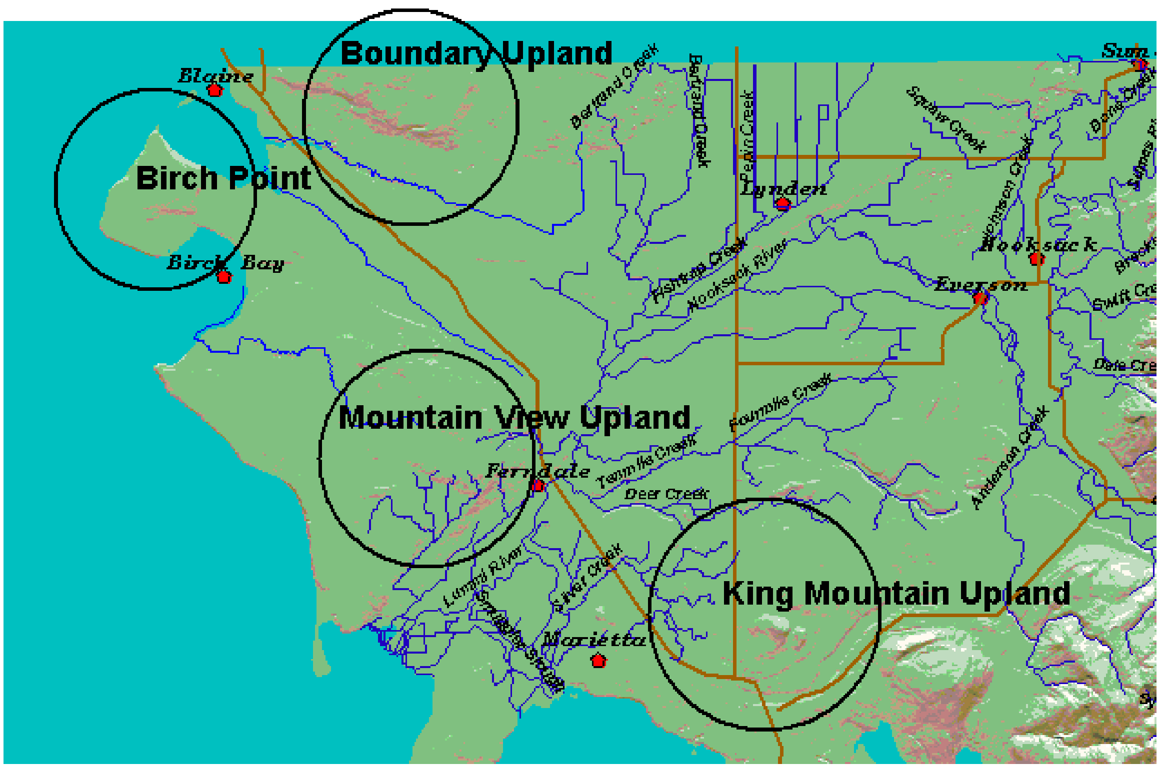


Figure 1.2.1e The lowlands and uplands of central and coastal lands

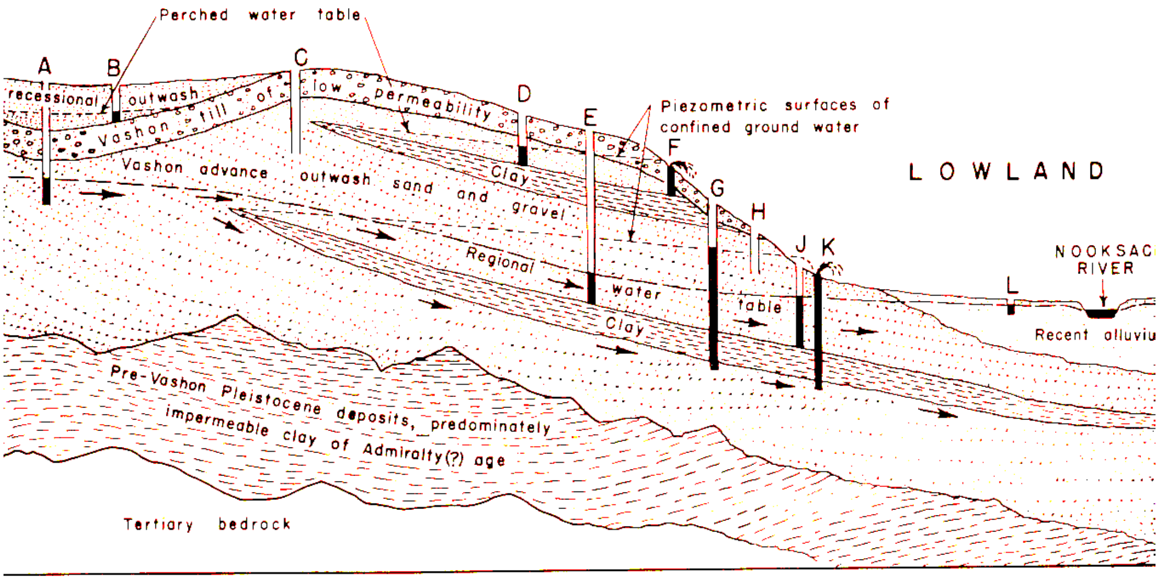


Figure 1.2.1f Groundwater occurrence within the lower Nooksack River basin (vertical scale exaggerated) (USGS,1960)

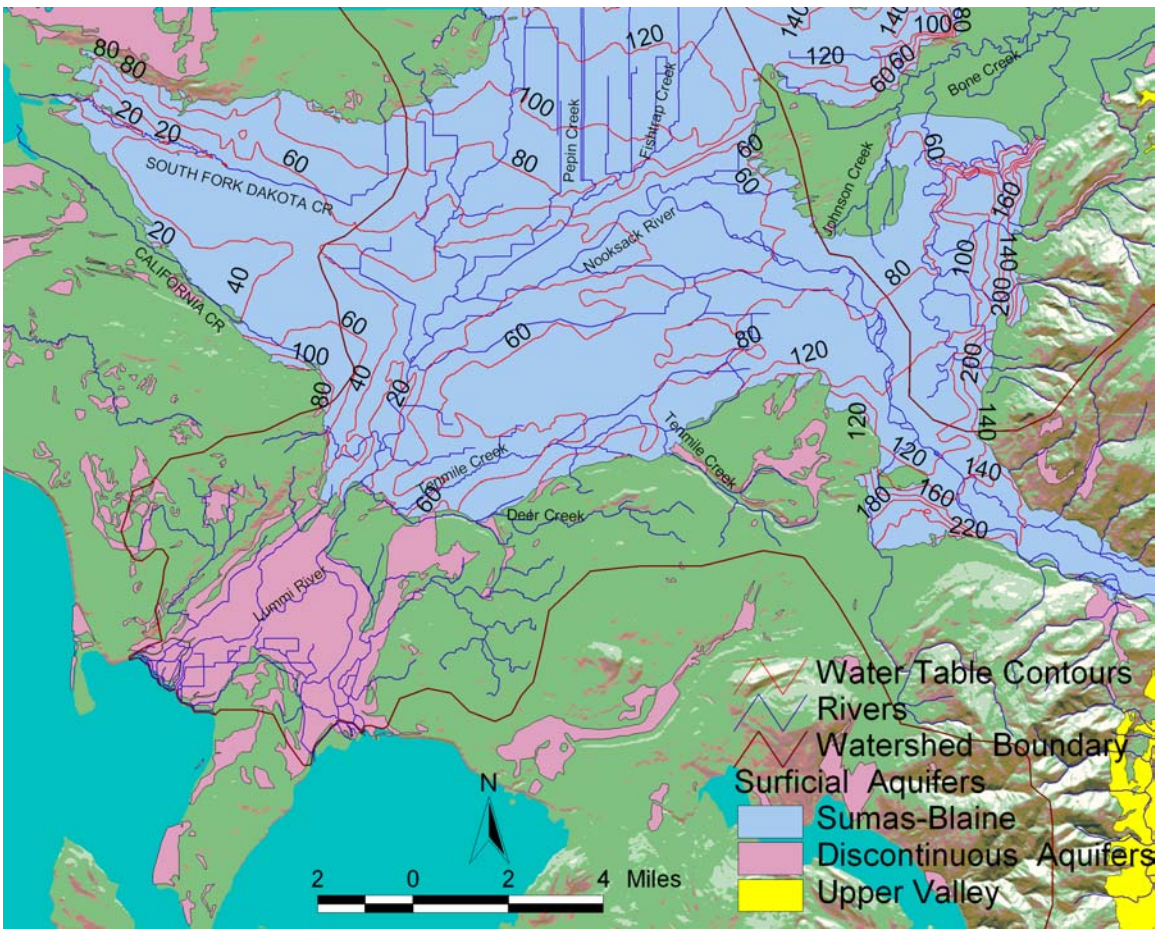


Figure 1.2.2 The aquifers and water table contours of the lowlands of the Nooksack

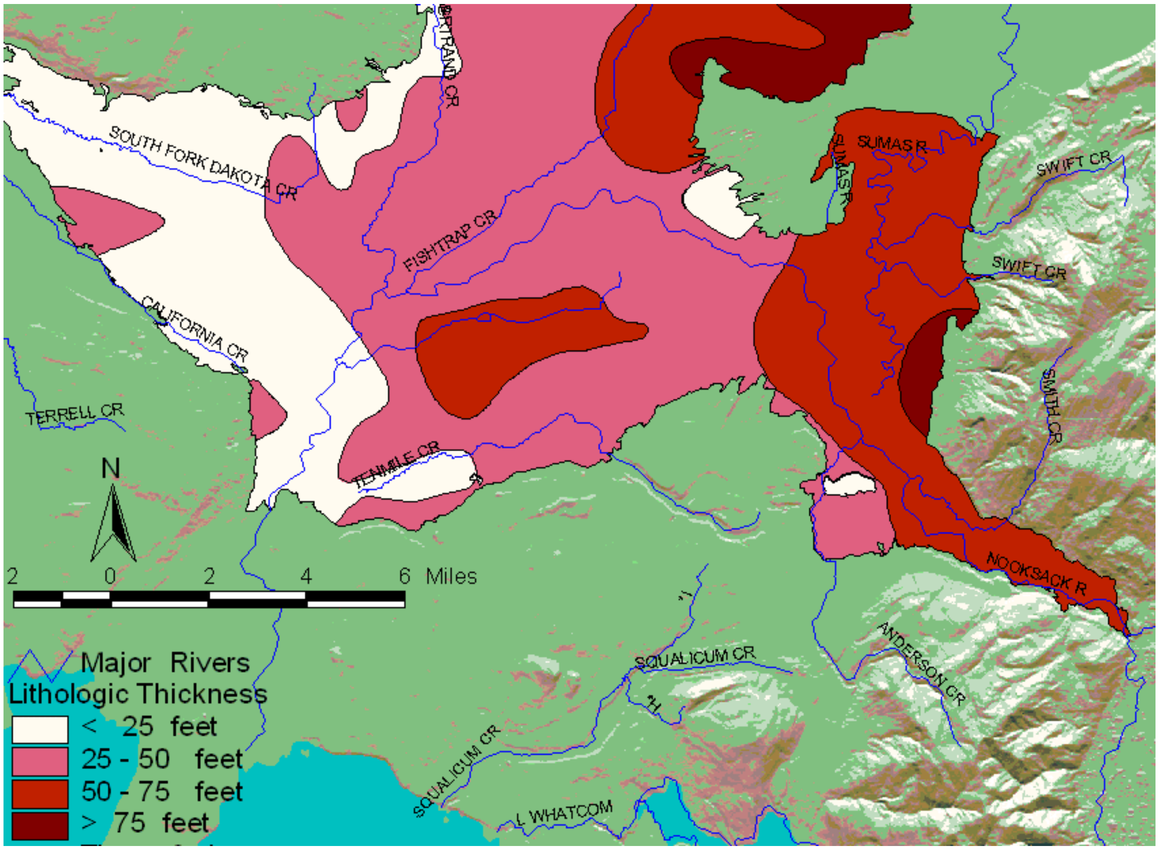


Figure 1.2.3 Aquifer thickness of central/ lowlands of the Nooksack

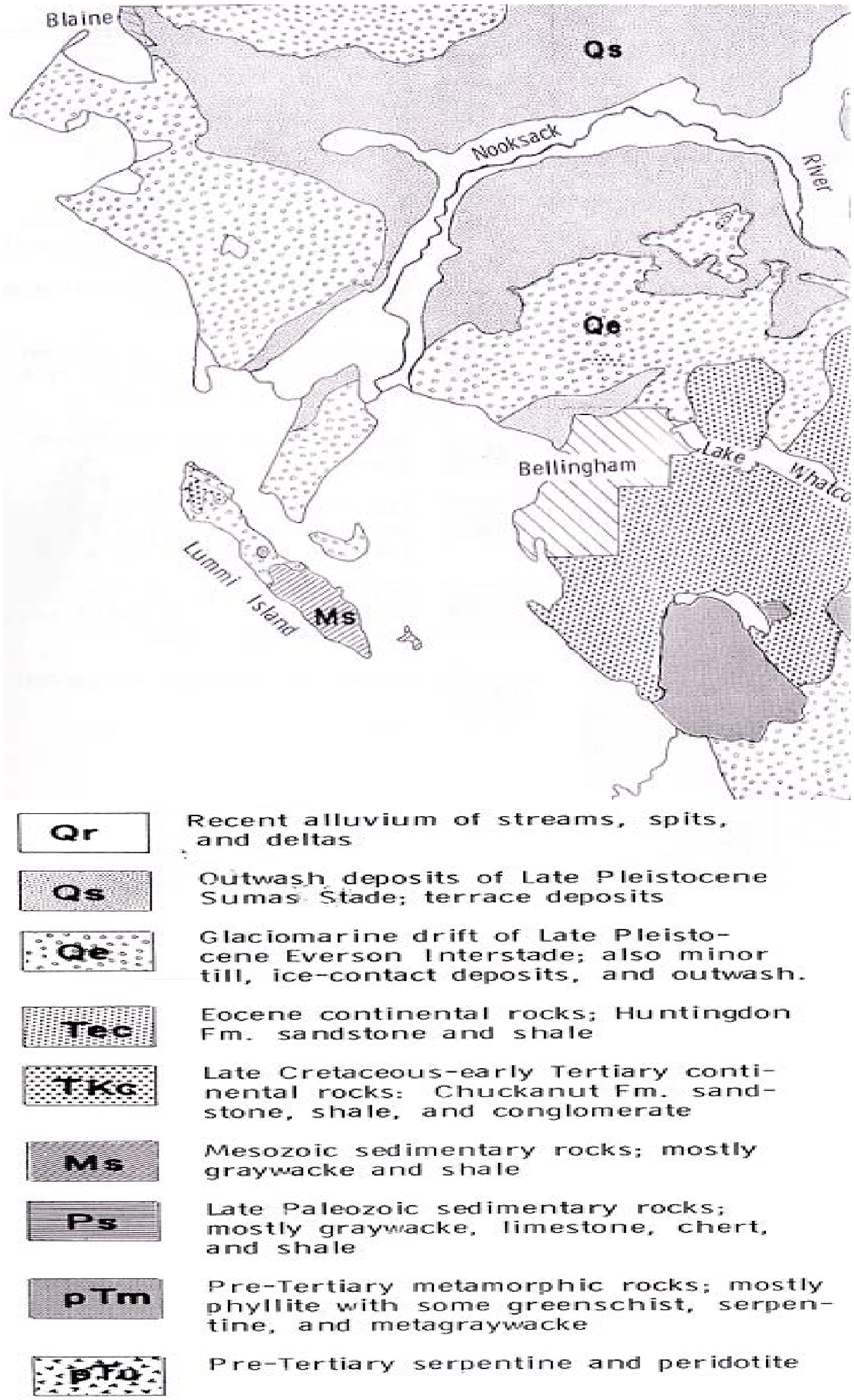


Figure 1.2.4 Surficial geology of central and coastal areas (Source: Easterbrook, 1971)

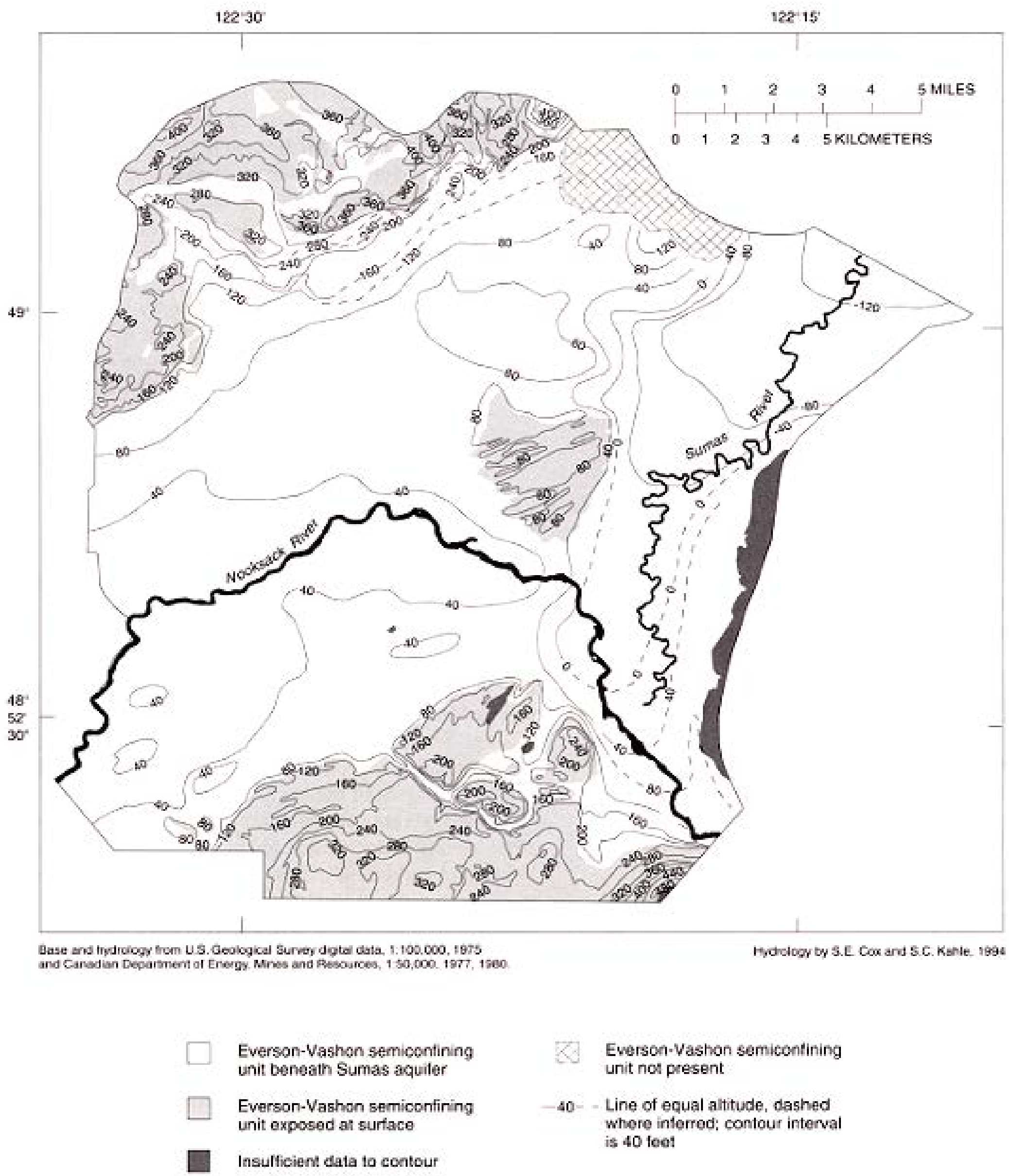


Figure 1.2.5a Geology of the LENS area (Lynden-Everson-Nooksack-Sumas) (Source: Cox and Kahl, 1999).

Period	Epoch	Geologic unit	Hydrogeologic unit	Typical thickness, in feet		Characteristics: Lithologic	Characteristics: Hydrologic	Characteristics: Water quality
Quaternary	Holocene	Qsp Peat	Sumas aquifer Qs	0 - 15	40 - 80	Stratified sand and gravel outwash with minor clay lenses. Outwash grades from pebble-cobble alluvium near Abbotsford to sand with fine-grained lenses southwest of Lynden. Unit includes Nooksack and Sumas River alluvium, till and ice-contact deposits, lacustrine and flood-plain silt and clay, and peat	Highly productive unconfined aquifer. Unit shows a weak trend in hydraulic conductivity because of a lateral decrease in grain size. Lenses of clay, till, or peat cause locally confined or perched ground-water conditions. The unit is confined in much of the Sumas Valley by overlying lacustrine silt and clay and underlying clay presumed to be glaciomarine drift	Ground waters are typically of a calcium- or magnesium-bicarbonate type, with dissolved solids concentrations between 110 and 190 milligrams per liter. These ground waters are generally dilute, slightly acidic with low alkalinity, and typically well oxygenated. Elevated concentrations of dissolved nitrates are common in many areas; in other areas high concentrations of dissolved iron and manganese restrict the use of some ground waters
		Qsf Fine-grained alluvium		0 - 15				
	Holocene / Pleistocene	Qsc Coarse-grained alluvium		0 - 20				
	Pleistocene	Qso, Qsi Sumas ice-contact deposits, Sumas Outwash		20 - 200 (Qsi: 20 - 60)				
		Qed Everson glaciomarine drift	Everson-Vashon semiconfining unit Qev	100 - 200		Glaciomarine drift consisting of unsorted pebbly clay and sandy silt with occasional coarse-grained lenses as thick as 30 feet. Unit may include Vashon till and Esperance sand at its base	Generally a confining bed but coarse-grained lenses yield usable amounts of water to numerous wells. Salty water is present in most of the deepest wells within the unit	Concentrations of major ions are highly variable without a consistent water type. Dissolved solids typically range from 170 to 1,300 milligrams per liter of dissolved oxygen, and nitrate typically ranges from 0.1 to 1.5 milligrams per liter. Large concentrations of iron, manganese and chloride are common in many locations
		Qvd Vashon Drift	Vashon semiconfined unit Qv	- -		Primarily till and gravel	Limited aerial extent; yields are variable	Ground waters are not extensive and can be either a calcium-magnesium-bicarbonate or a sodium-chloride type with dissolved solids concentrations typically near 126 milligrams per liter
Tertiary	Paleocene-miocene	Tbr Huntingdon and Chuckanut Formations	Bedrock semiconfining unit Tbr	- -		Sandstone, mudstone, and conglomerate, with some coal-bearing strata	Water yield is controlled primarily by secondary fracture permeability. Water yield is low where the rocks are unfractured	Ground waters are typically of a sodium-bicarbonate or sodium-chloride type with dissolved solids concentrations between 300 to 1,800 milligrams per liter. Concentrations of dissolved oxygen and nitrate are typically less than 0.1 milligrams per liter

Figure 1.2.5b Geology of the LENS area (Lynden-Everson-Nooksack-Sumas) (Source: Cox and Kahle, 1999).

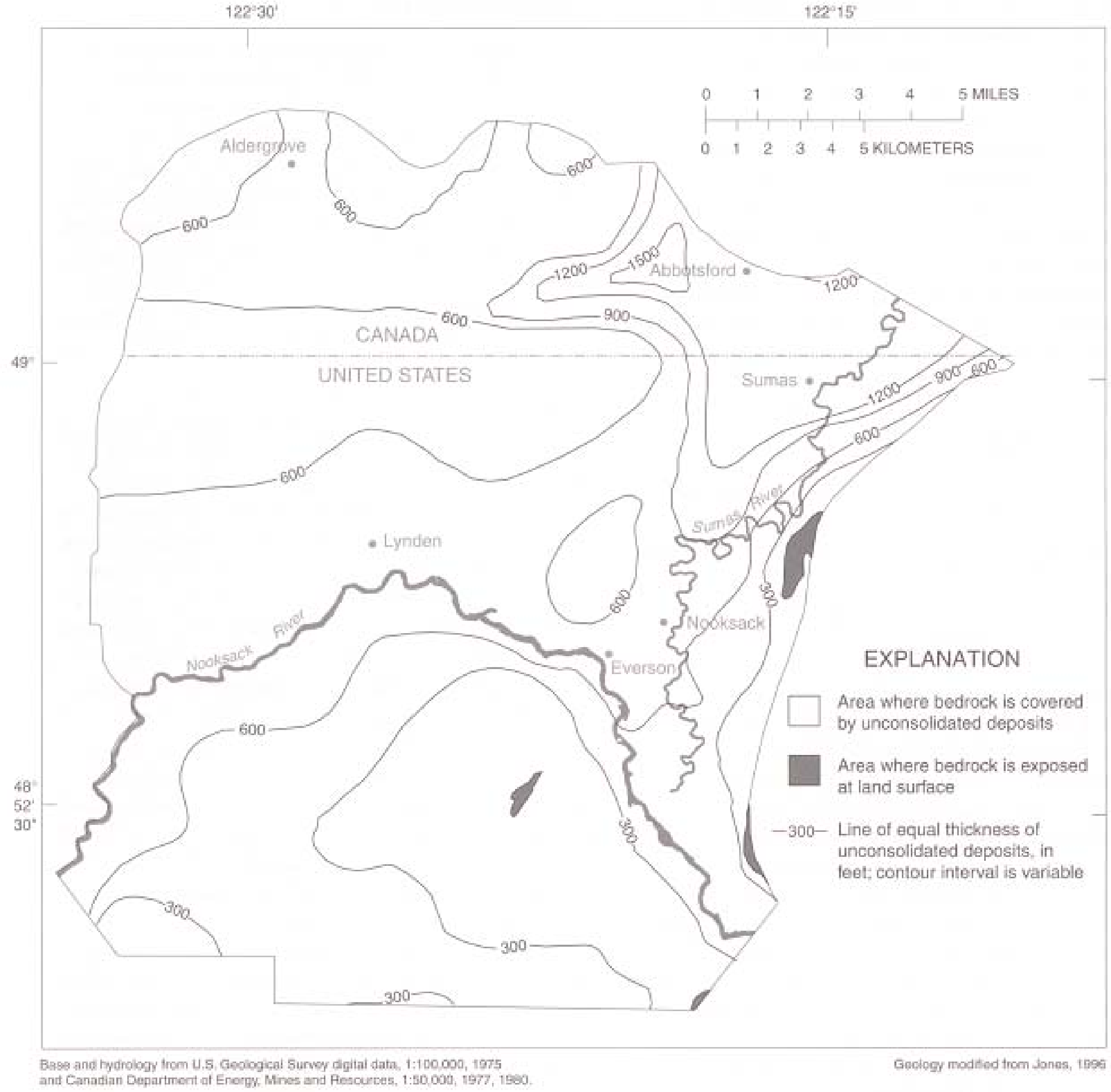


Figure 1.2.6a Bedrock elevation contours of the LENS area (Lynden-Everson-Nooksack-Sumas) (Source: Cox and Kahle, 1999).

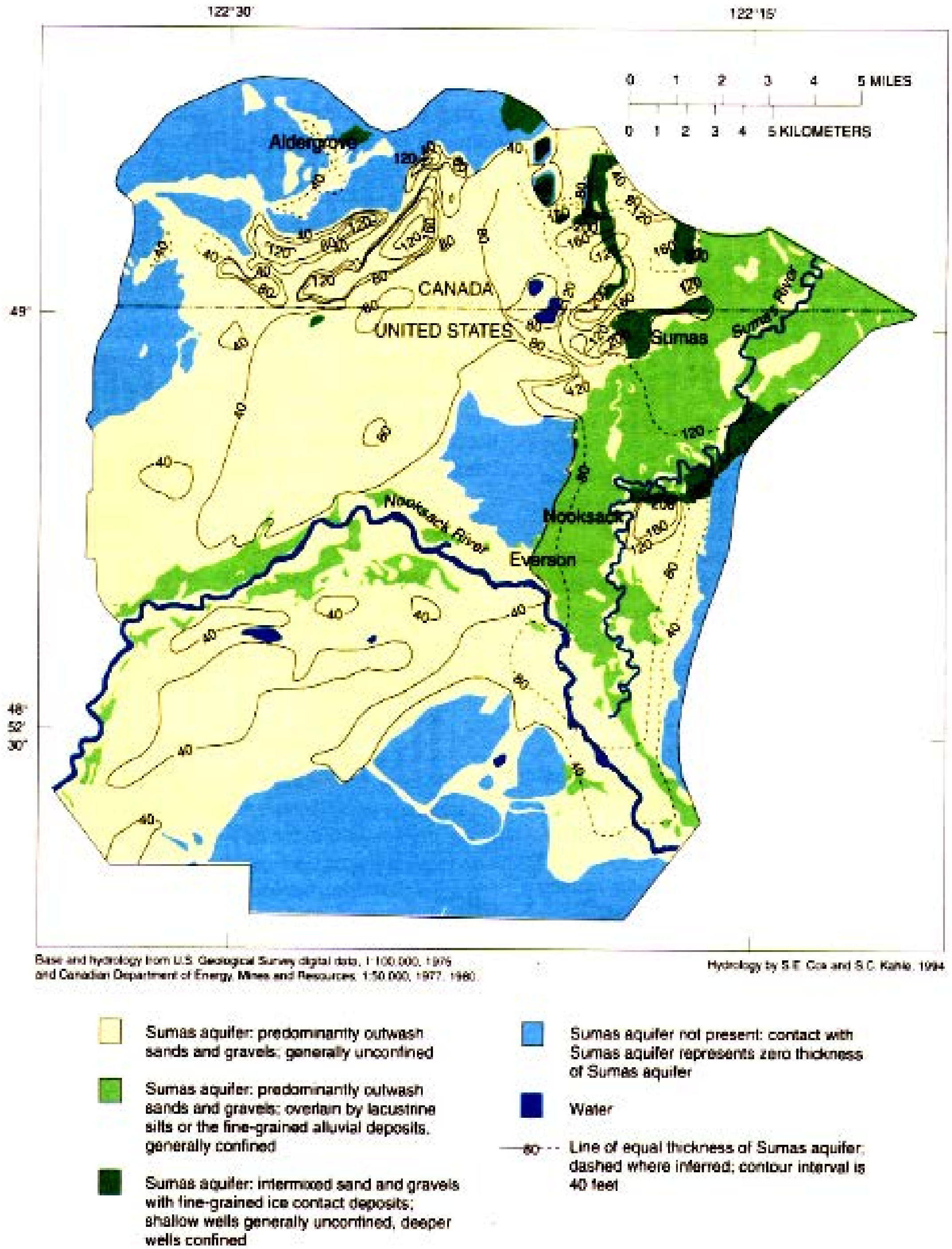


Figure 1.2.6b LENS area aquifer extent and thickness contours (Source: Cox and Kahle, 1999).

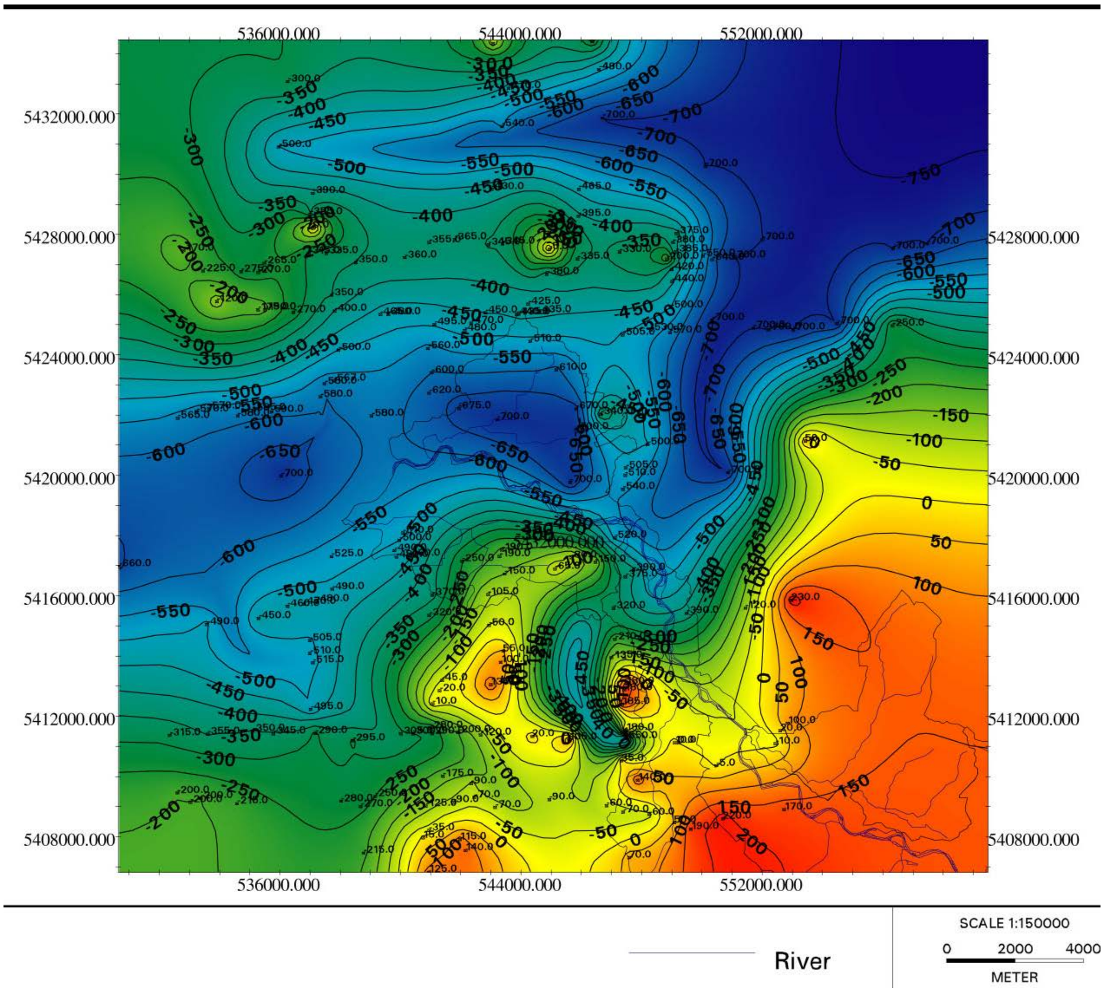


Figure 1.2.7a Contour map of the aquifer bottom elevation - LENS area

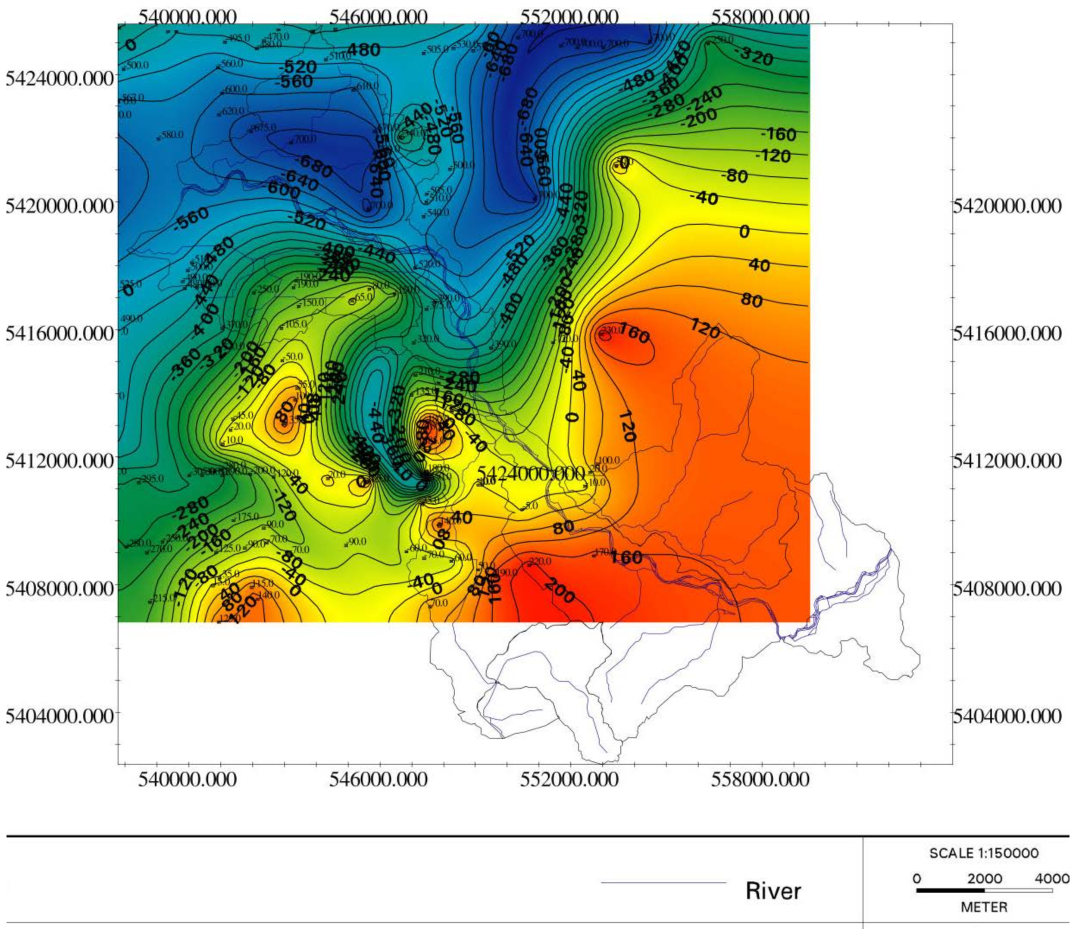


Figure 1.2.7b Location of LENS area in the central Nooksack watershed

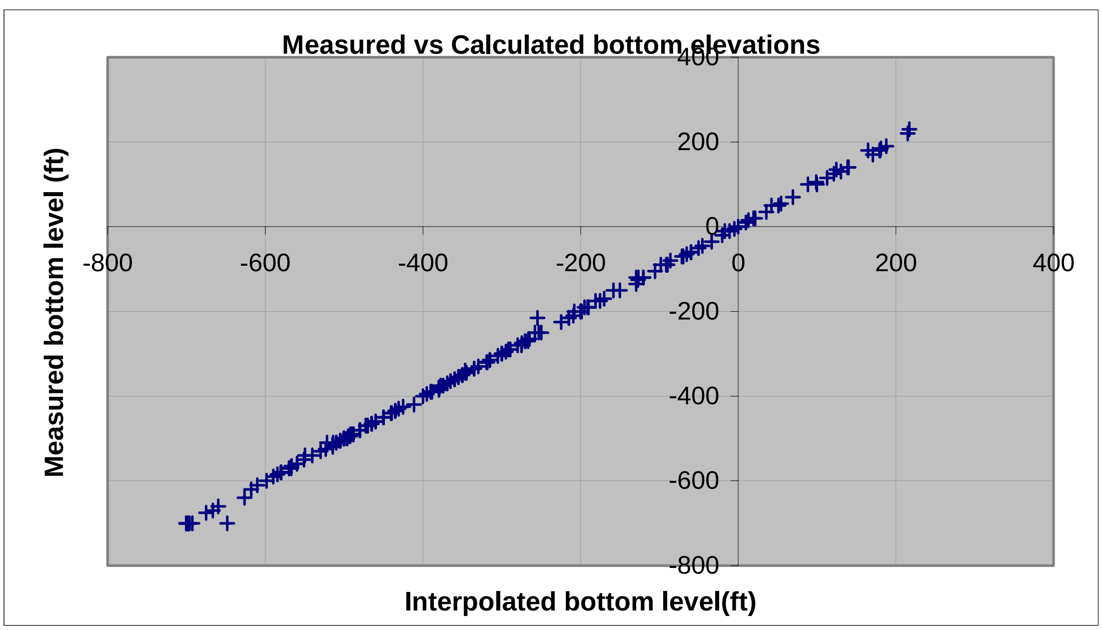


Figure 1.2.7c LENS area plot of measured vs. calculated bottom elevations

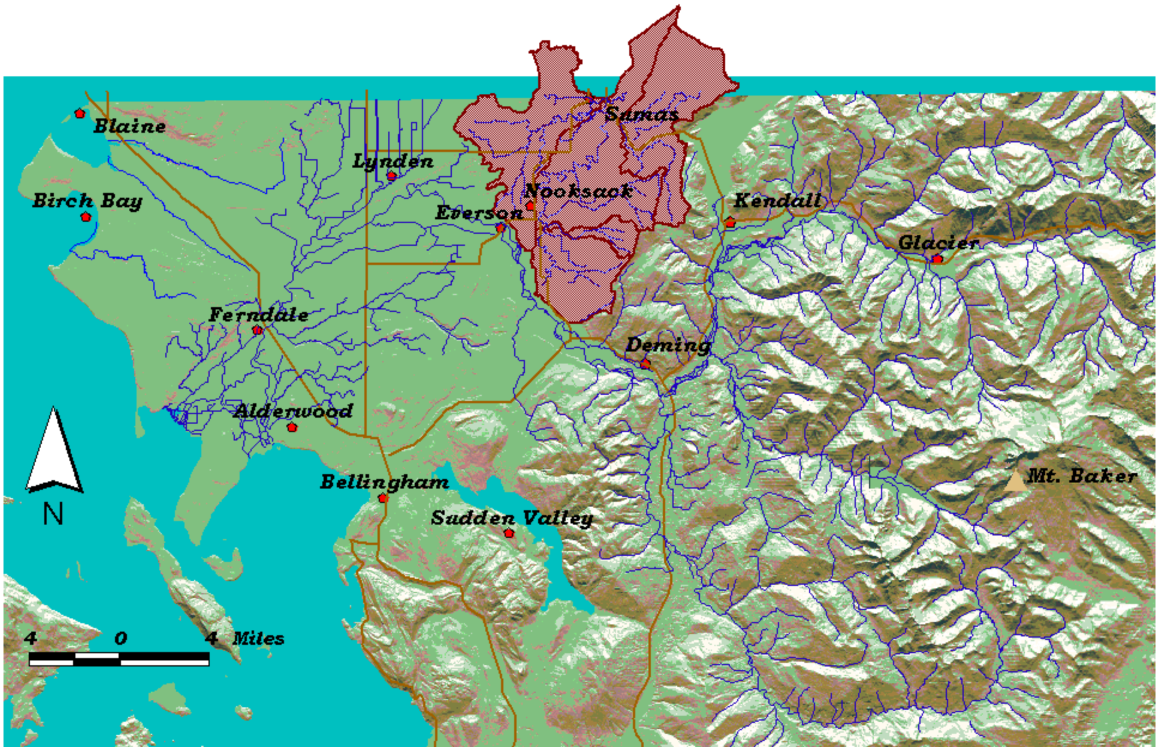


Figure 1.2.8 Sumas River watershed

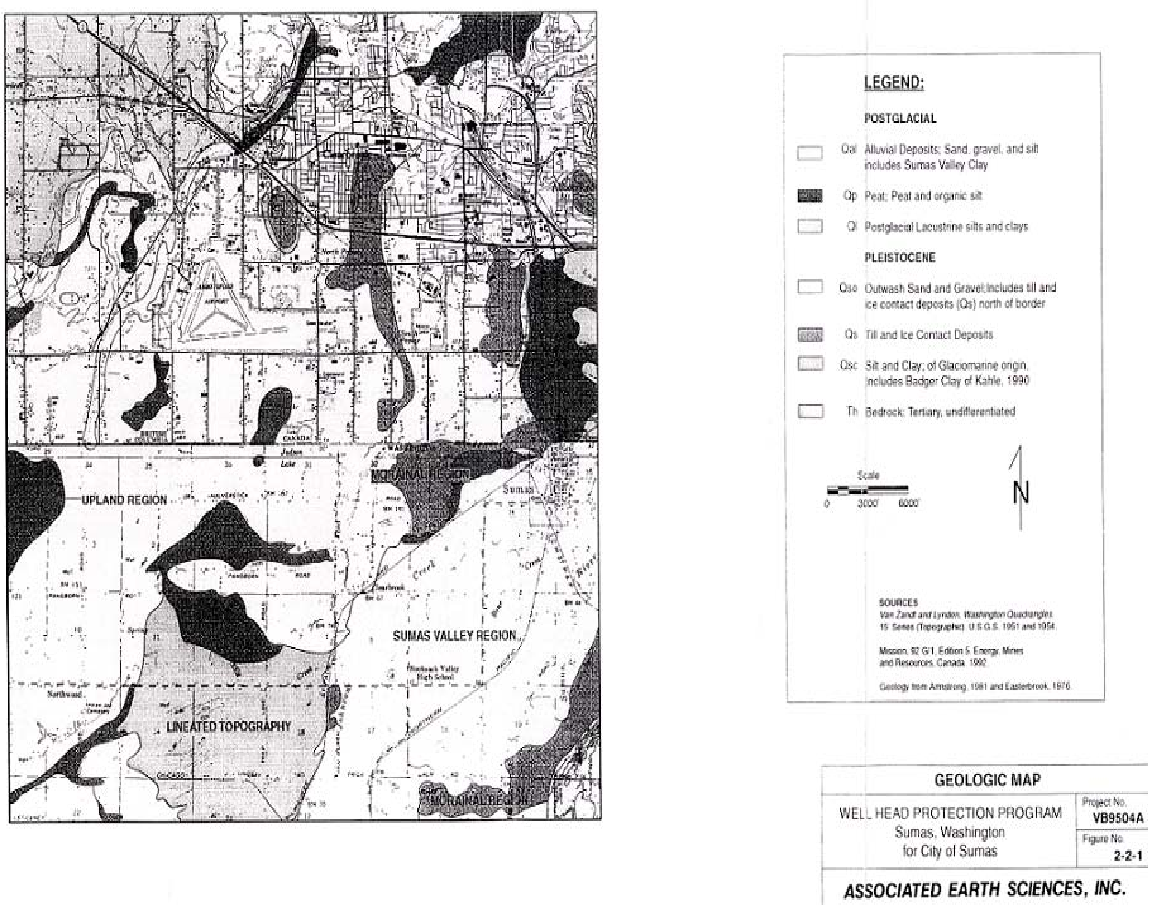


Figure 1.2.9 Geology of the Sumas Valley region (Source: Associated Earth Science, 1995).

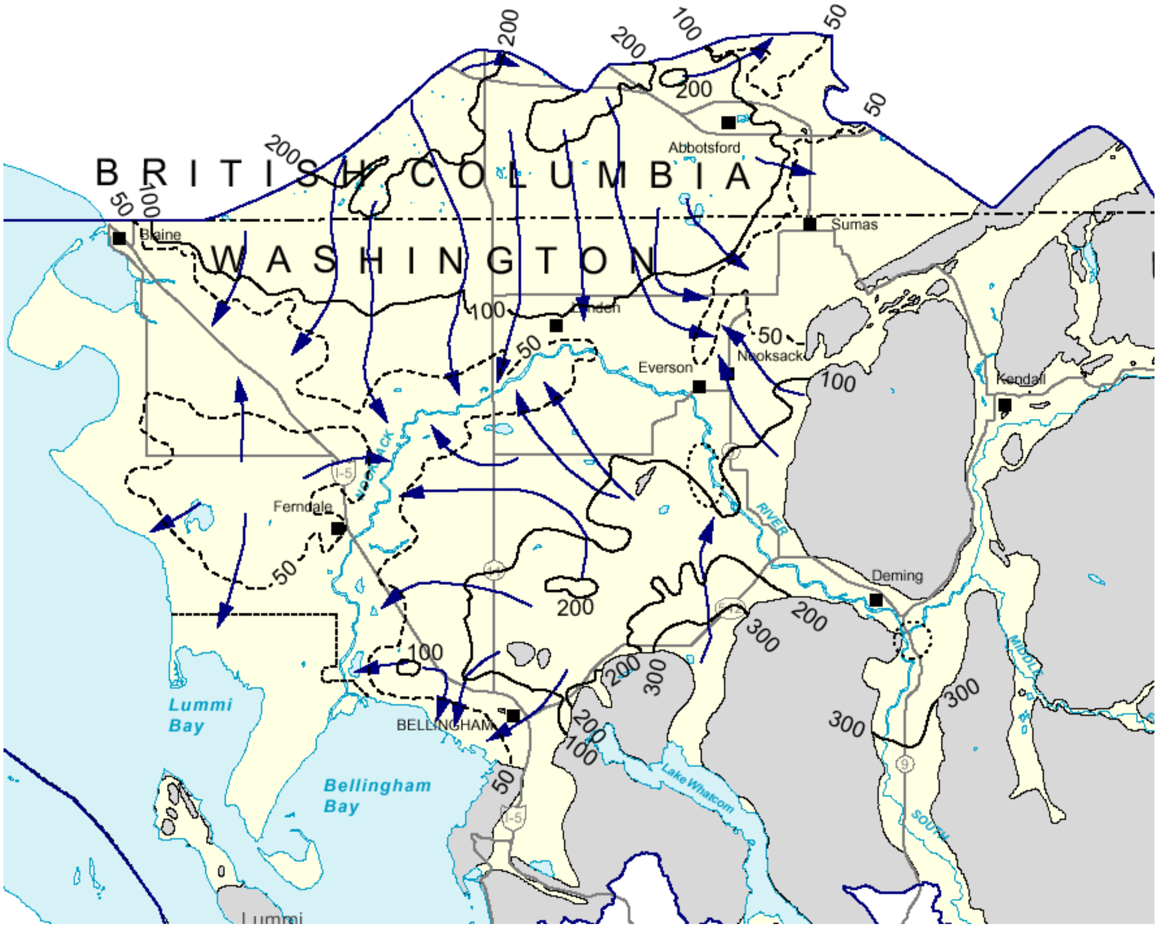


Figure 1.2.10 Generalized groundwater movement of the Nooksack basin (Source: USGS)

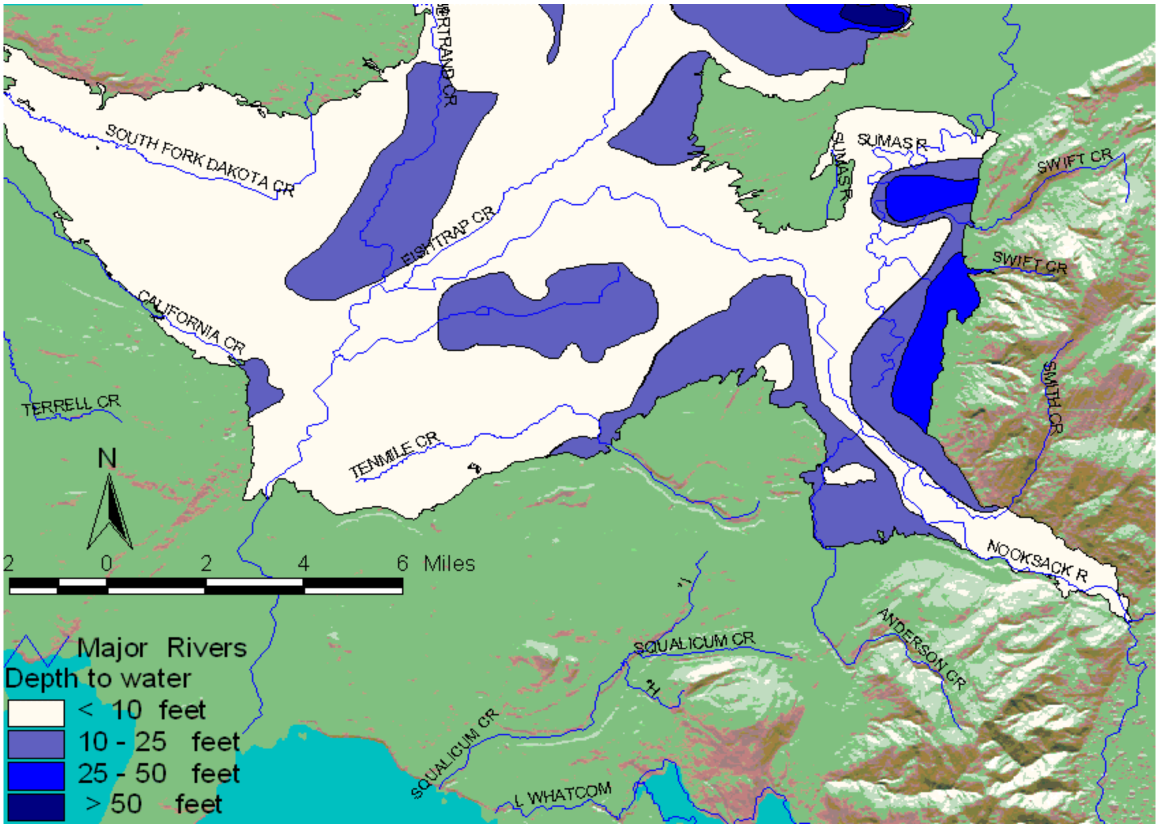


Figure 1.2.11 Depth to water for central Nooksack aquifers

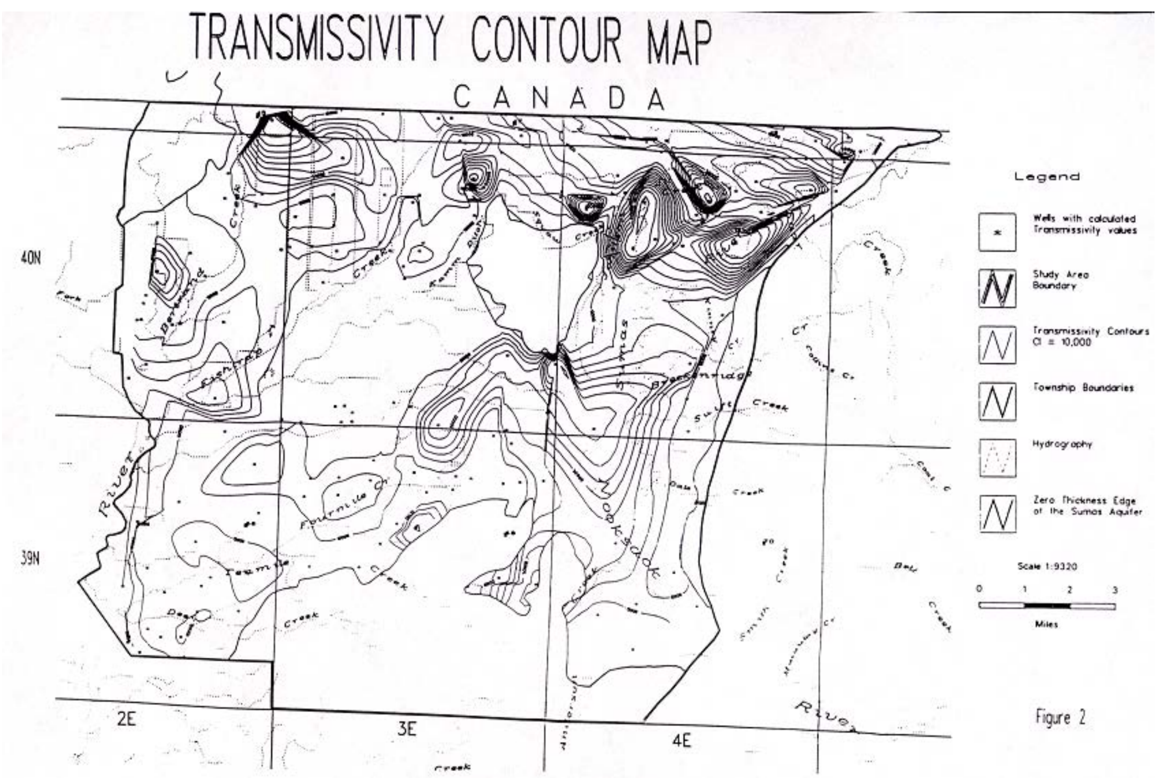


Figure 1.2.12 Transmissivity contours of central Nooksack/Sumas aquifers (Source: Culhane, 1993)

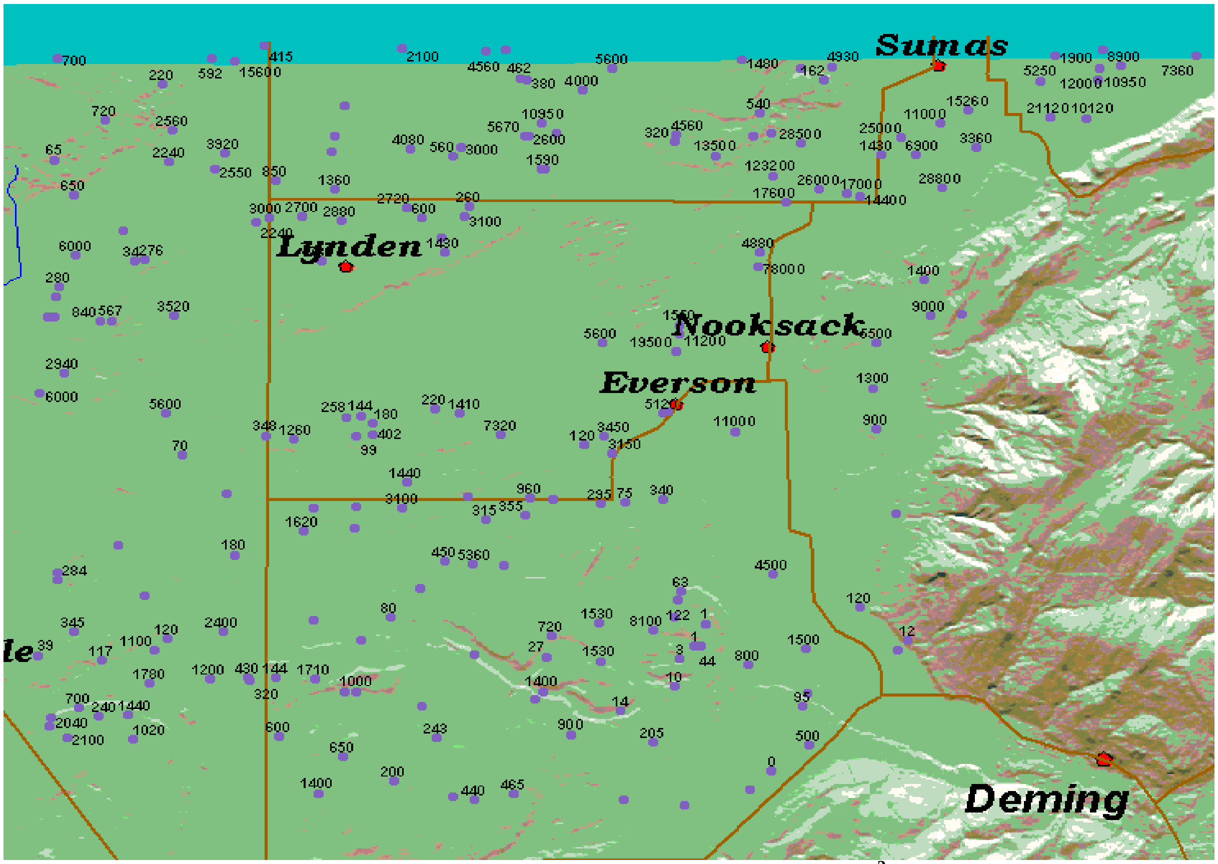


Figure 1.2.13a Transmissivity -LENS area (ft^2/day)

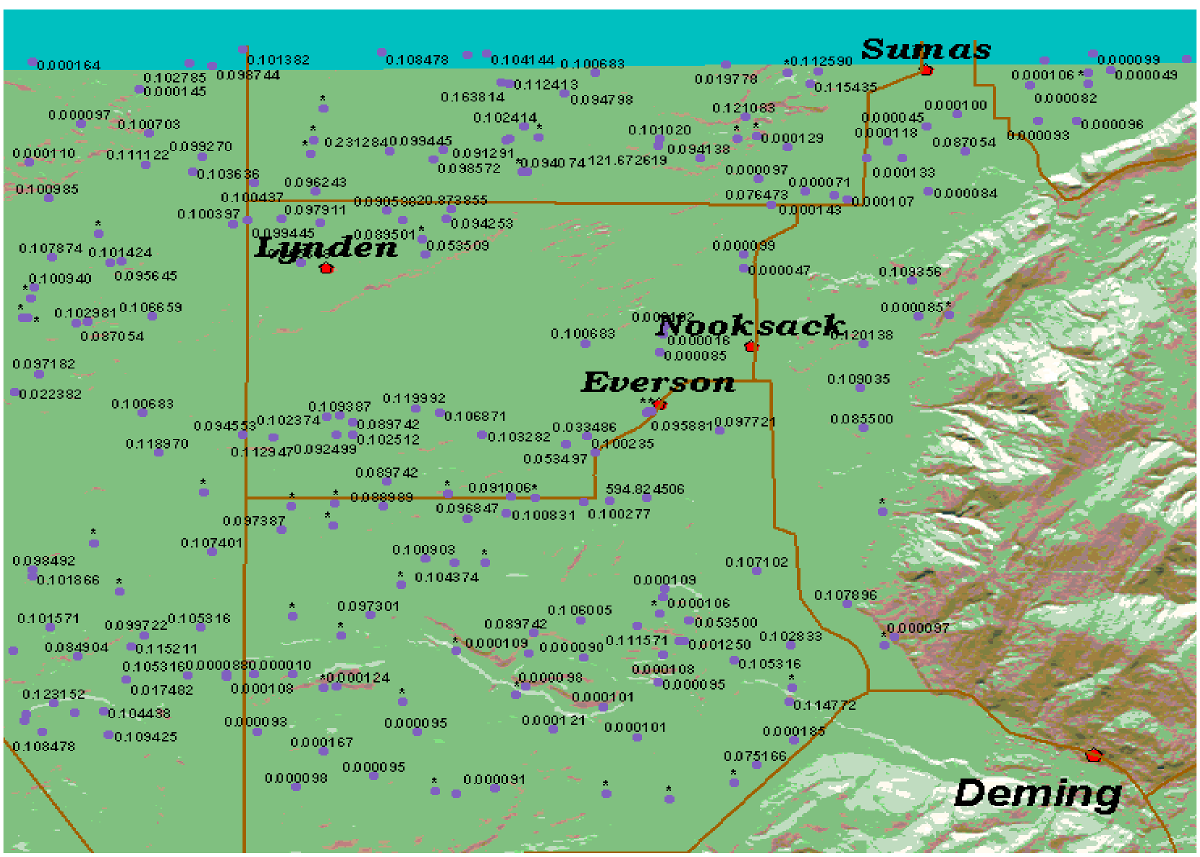


Figure 2.2.13b Storage coefficient - LENS area

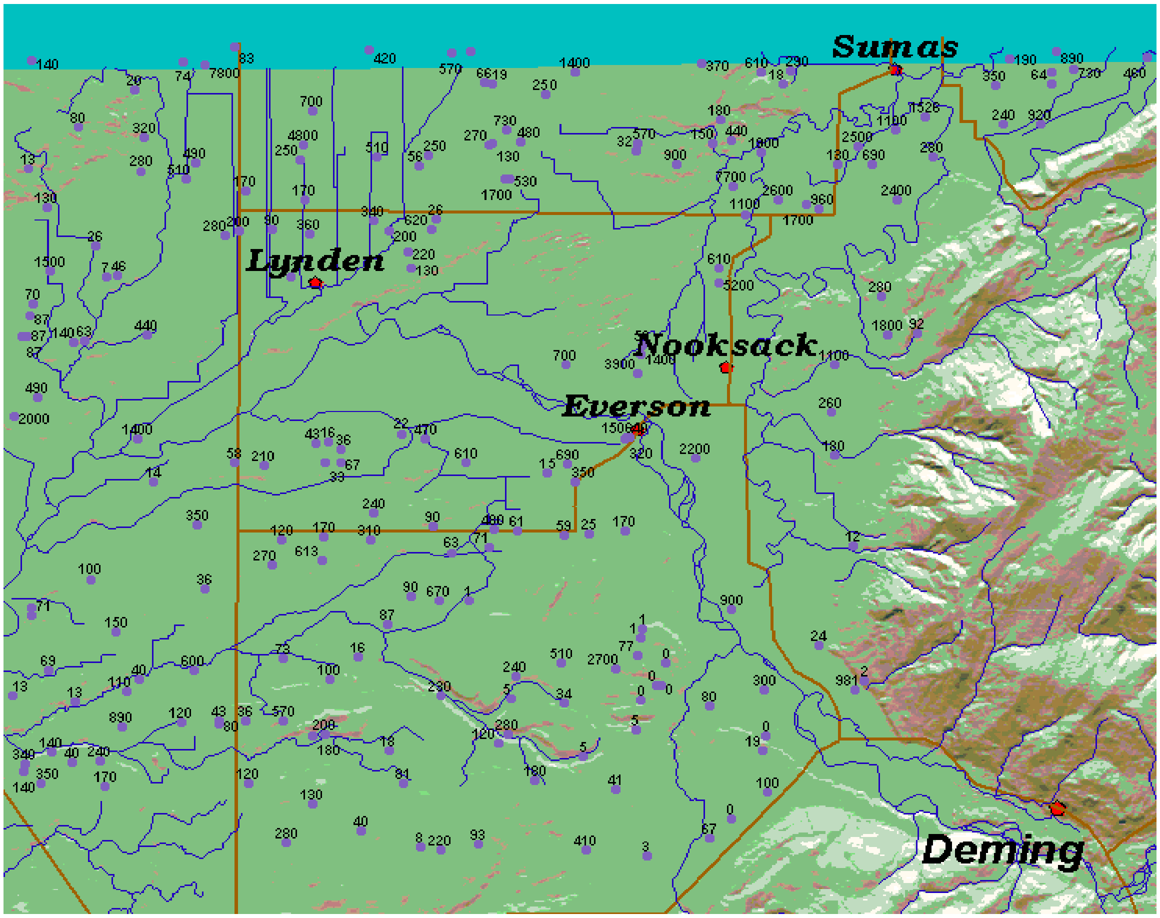


Figure 2.2.13c Hydraulic Conductivity - LENS area (ft/day)

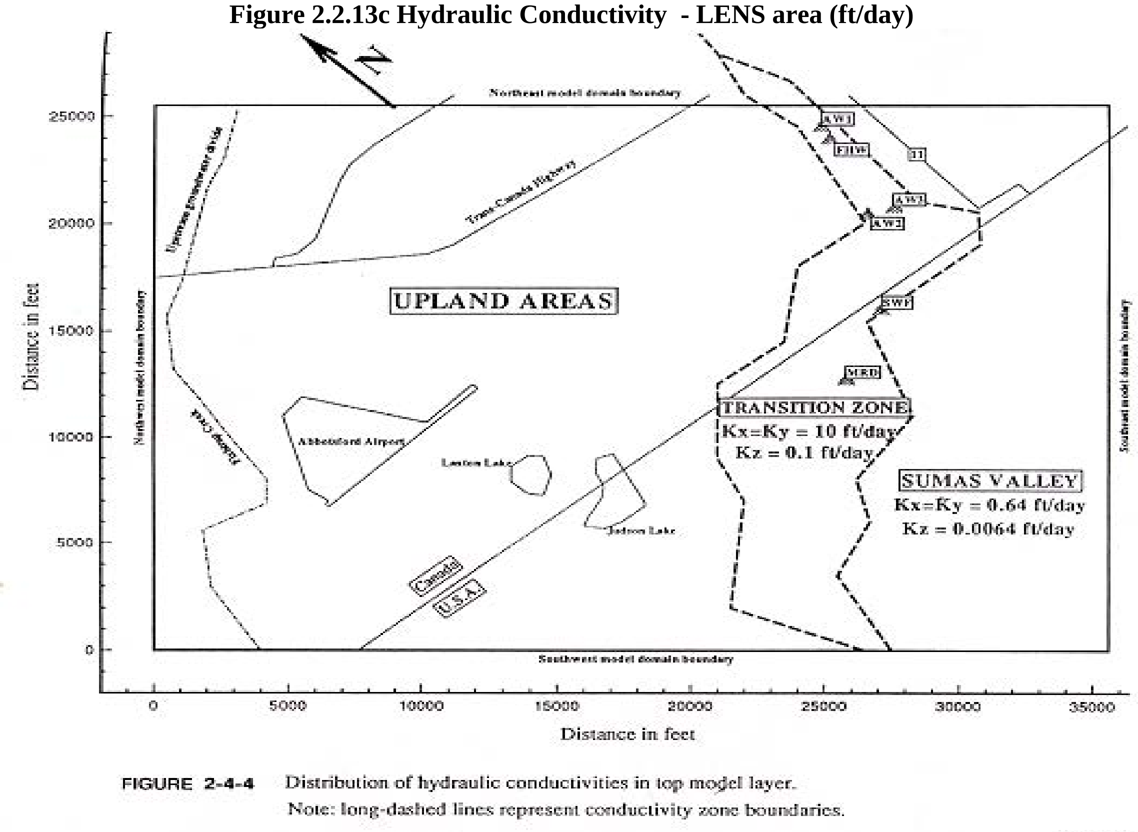


Figure 2.2.14 Sumas area: hydraulic conductivity distribution (top model layer)

(Source: Associated Earth Science, 1995)

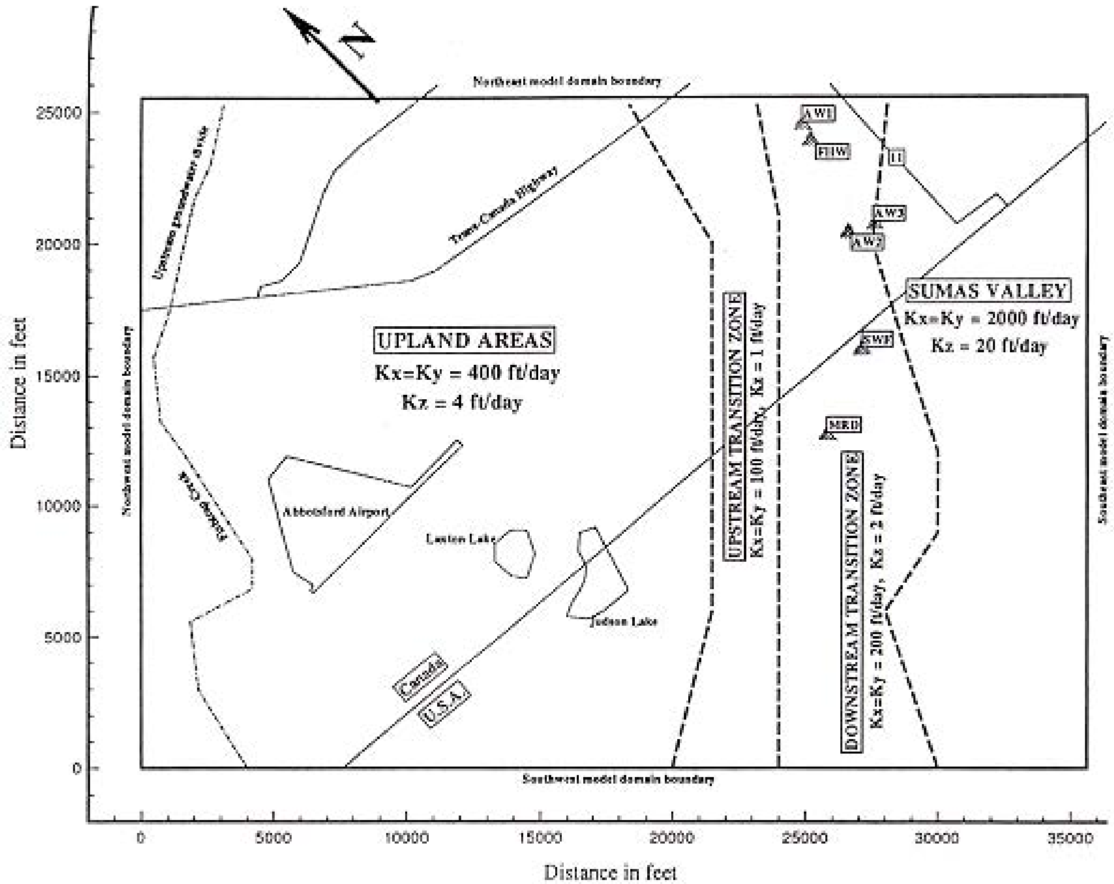


FIGURE 2-4-5 Distribution of hydraulic conductivities in bottom model layer.
Note: long-dashed lines represent conductivity zone boundaries.

Figure 1.2.15 Sumas area: hydraulic conductivity distribution (bottom model layer)
(Source: Associated Earth Science, 1995)

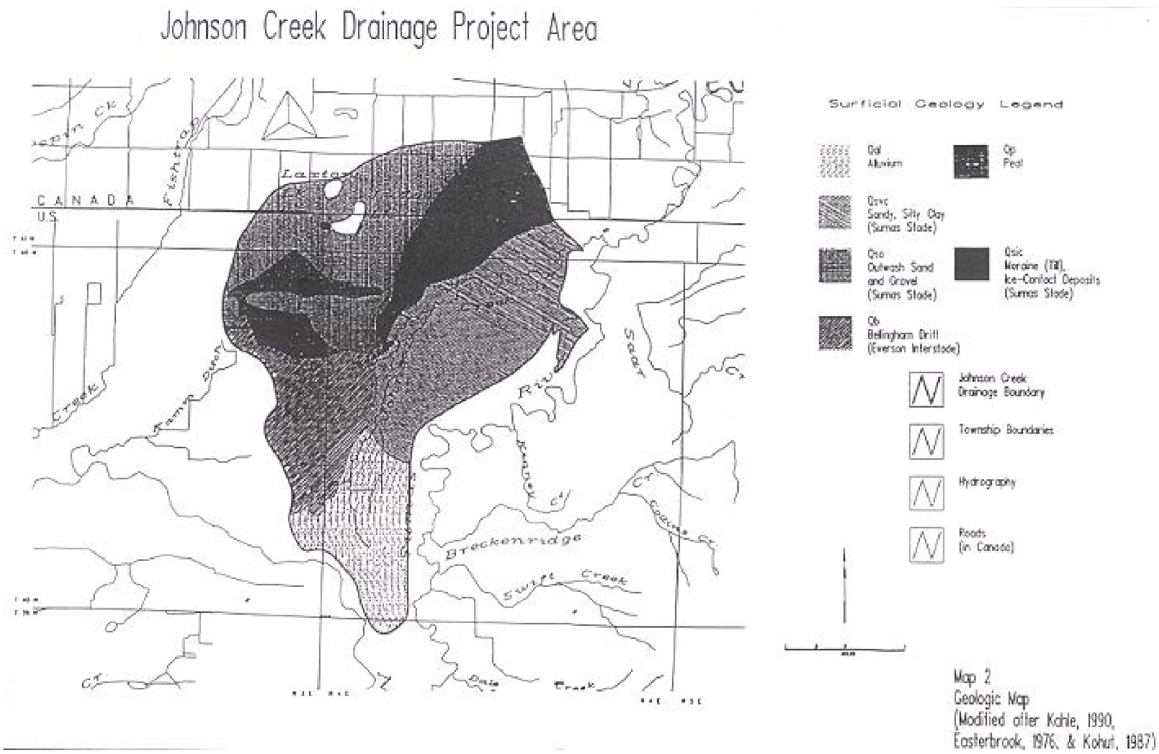


Figure 1.2.16 Johnson Creek (Sumas River tributary) drainage & geologic map (Source: Culhane, 1993)

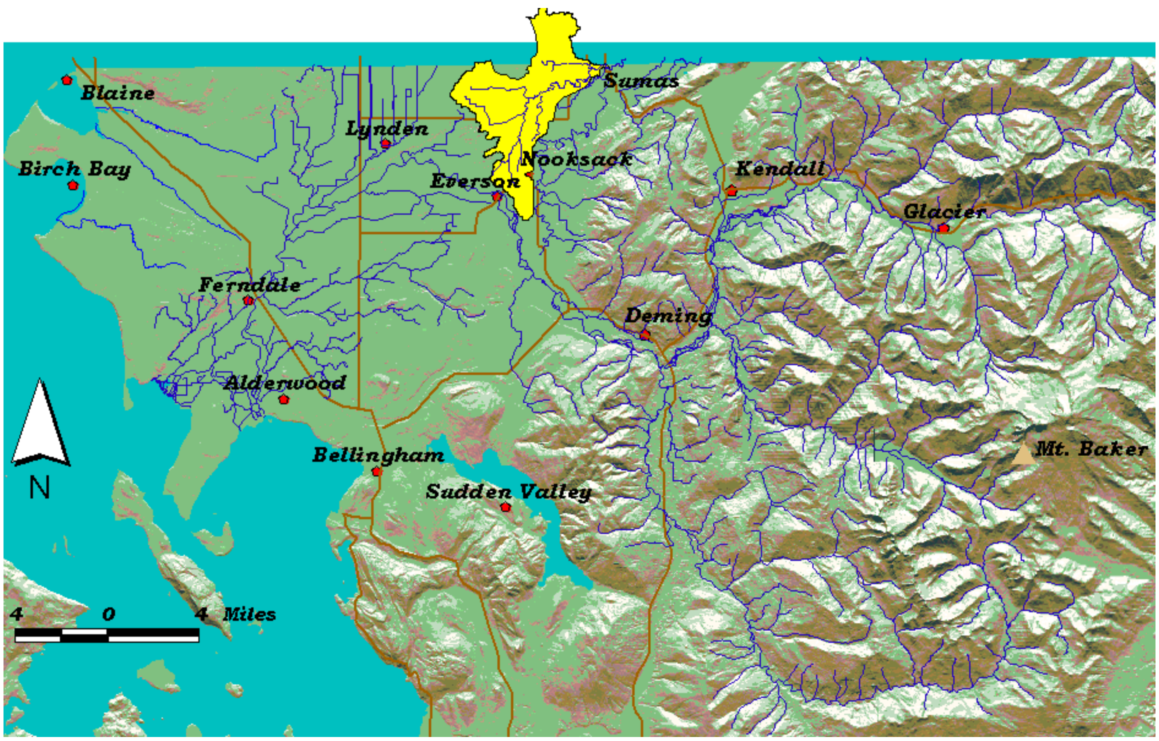


Figure 1.2.17 Location of Johnson Creek & drainage basin

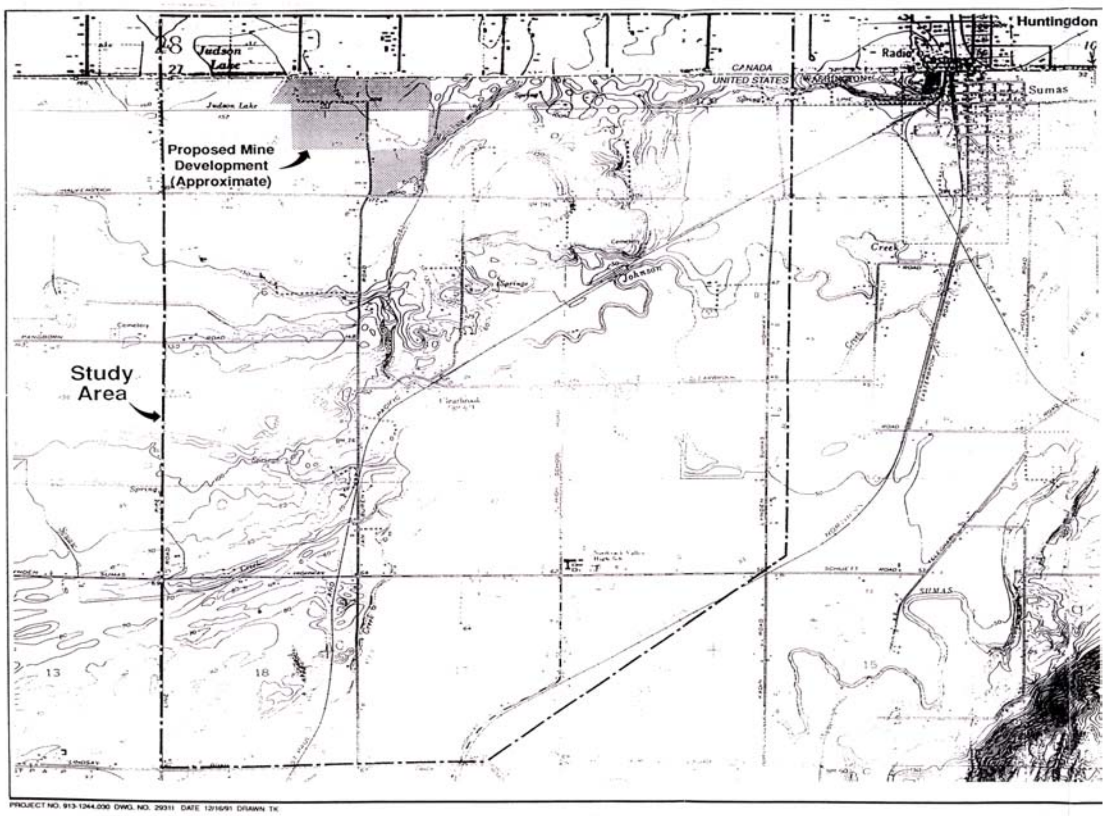


Figure 1.2.18 Johnson Creek study area (Golder Associates, 1992)

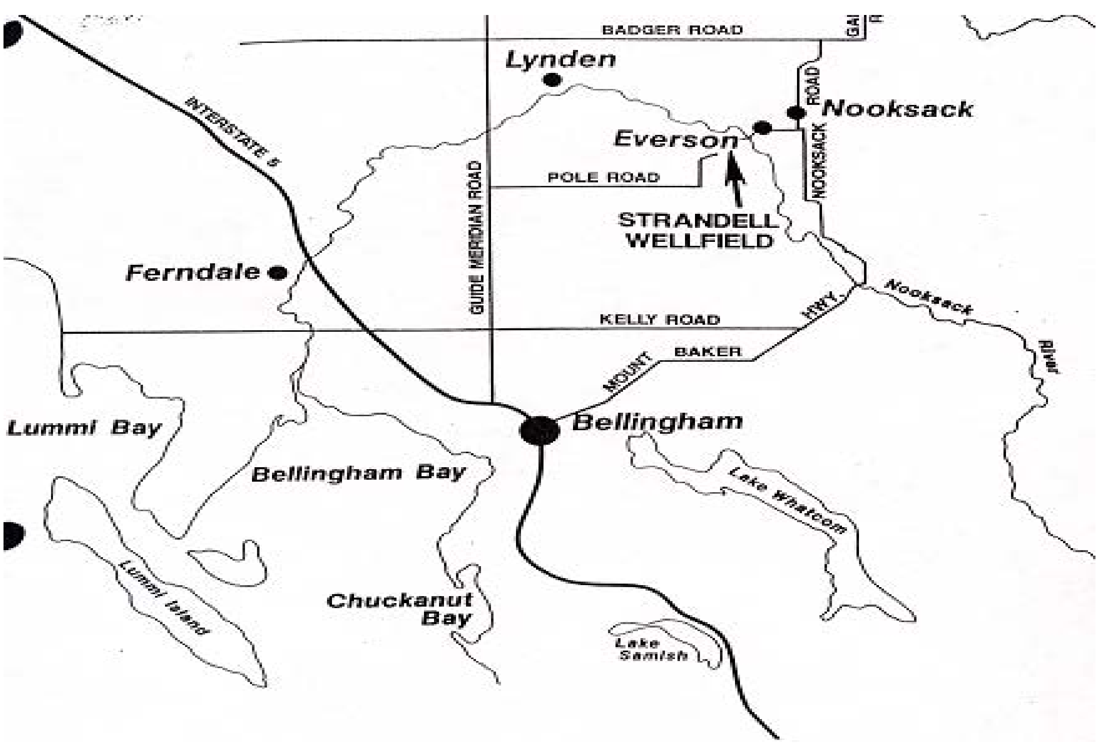


Figure 1.2.19 Location of Strandell Wellfield (near Everson, central Nooksack)

(Source: Associated Earth Sciences, 1994)

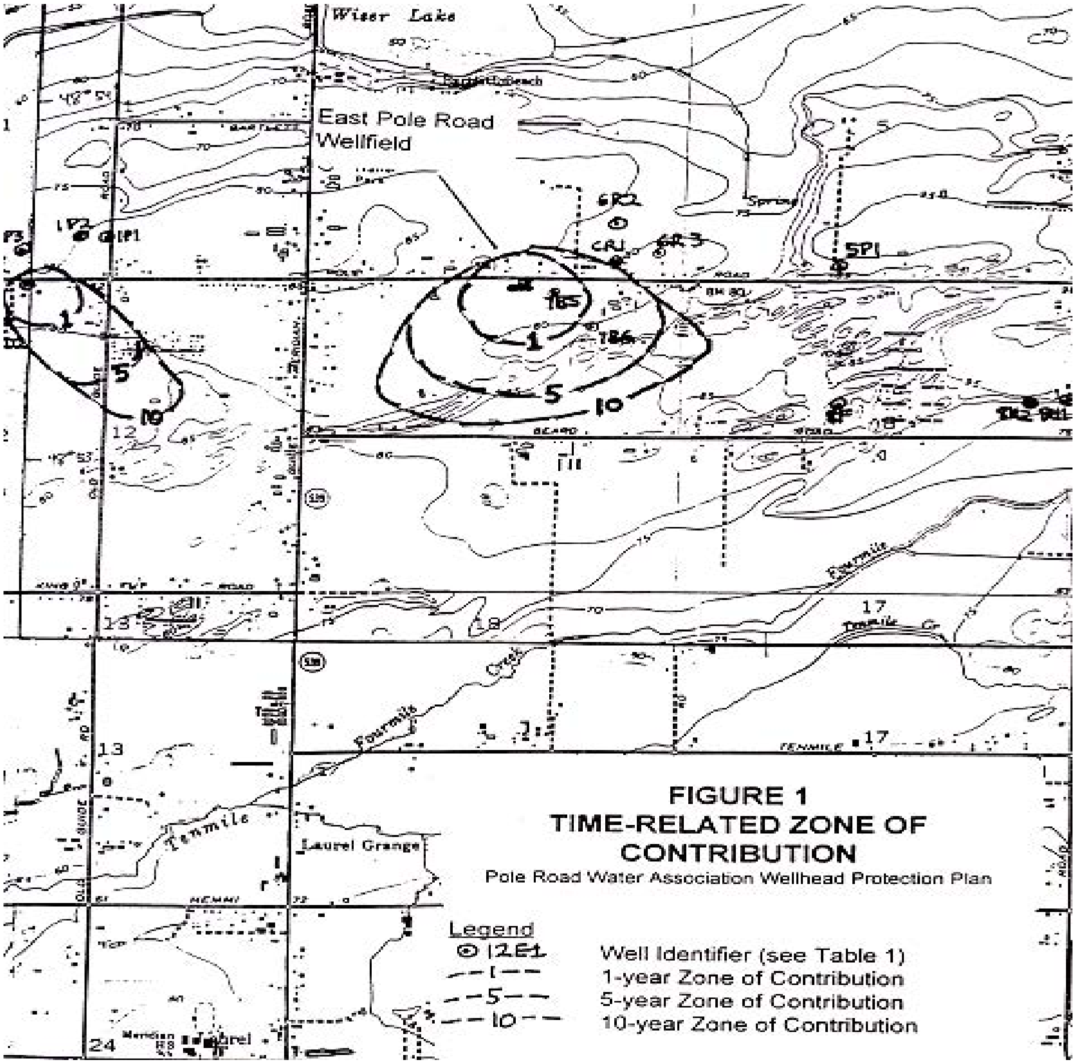


Figure 1.2.20 Location of East Pole Road Wellfield (near Lynden, central Nooksack)

(Source: Water Resources Consulting LLC, 1997)

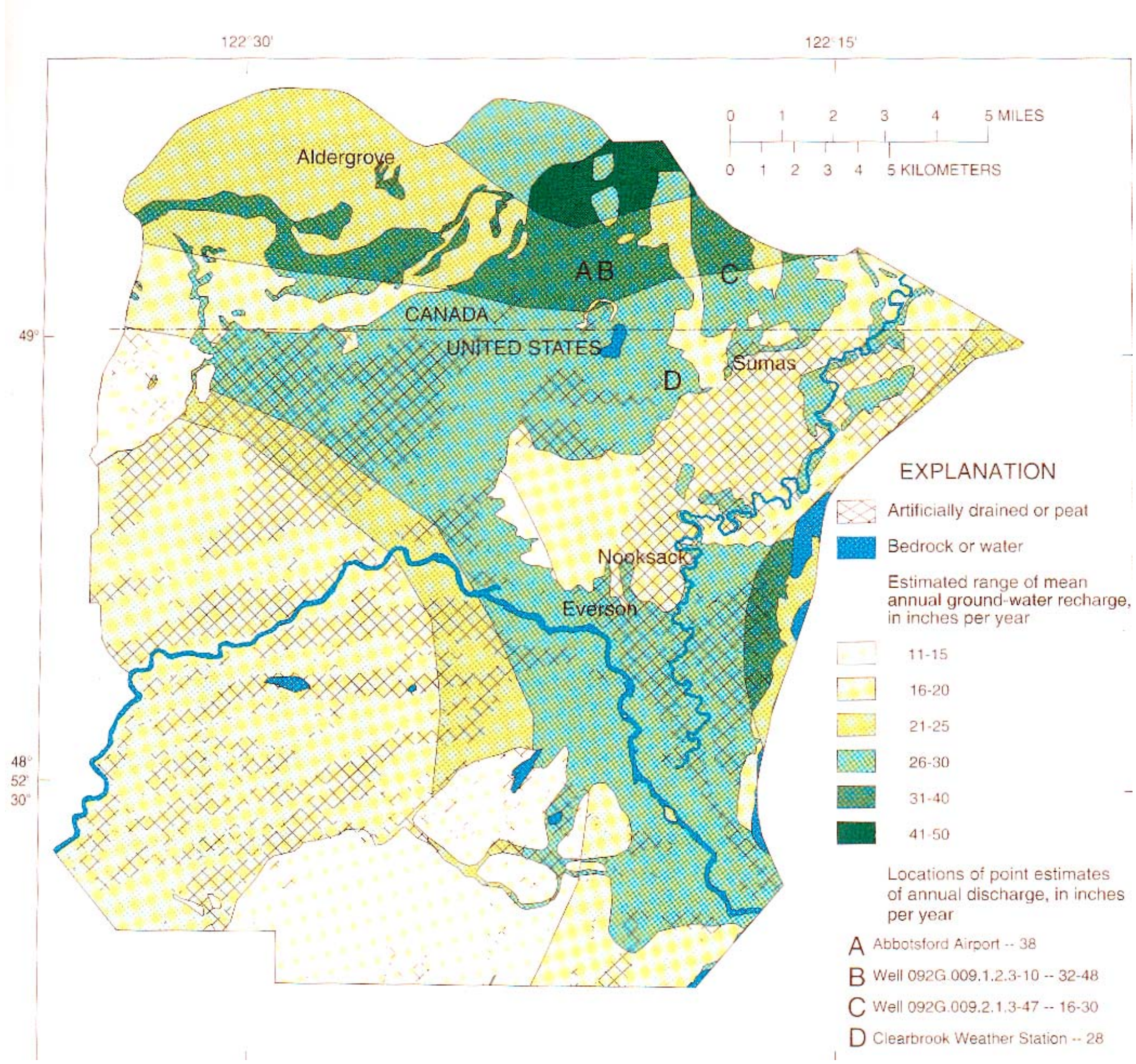


Figure 1.2.21 Annual groundwater recharge of the LENS area (Source: Cox and Kahle, 1999).

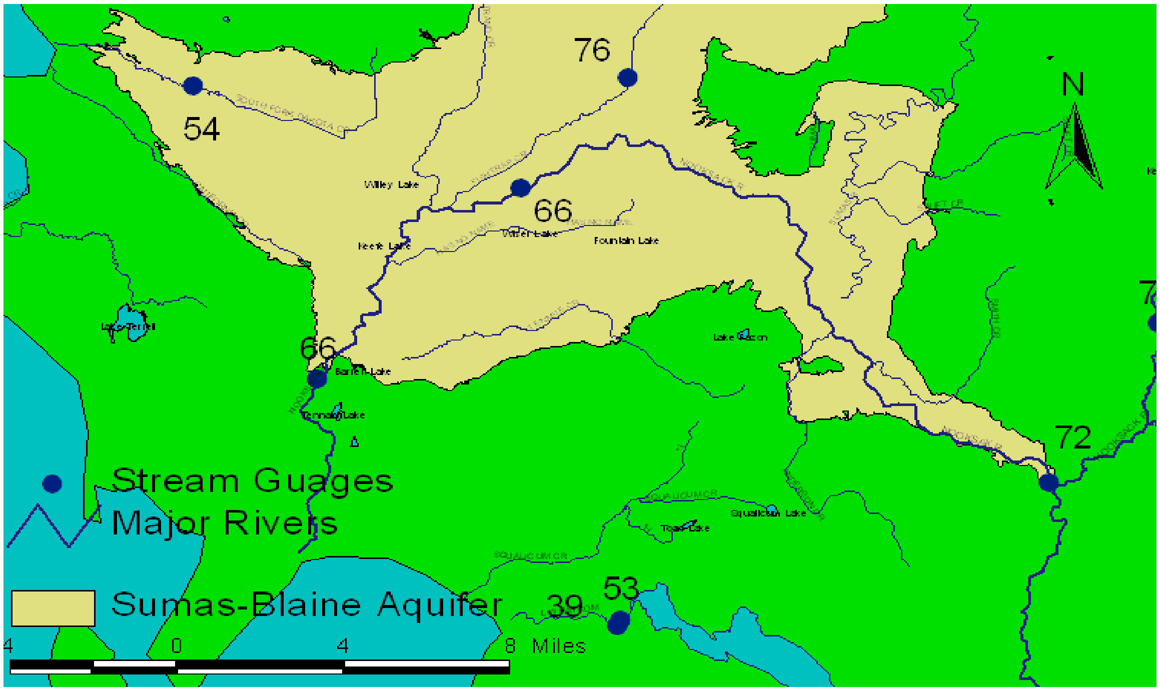


Figure 1.2.22 Baseflow contribution - mean annual (percentage), Sumas-Blaine Aquifer

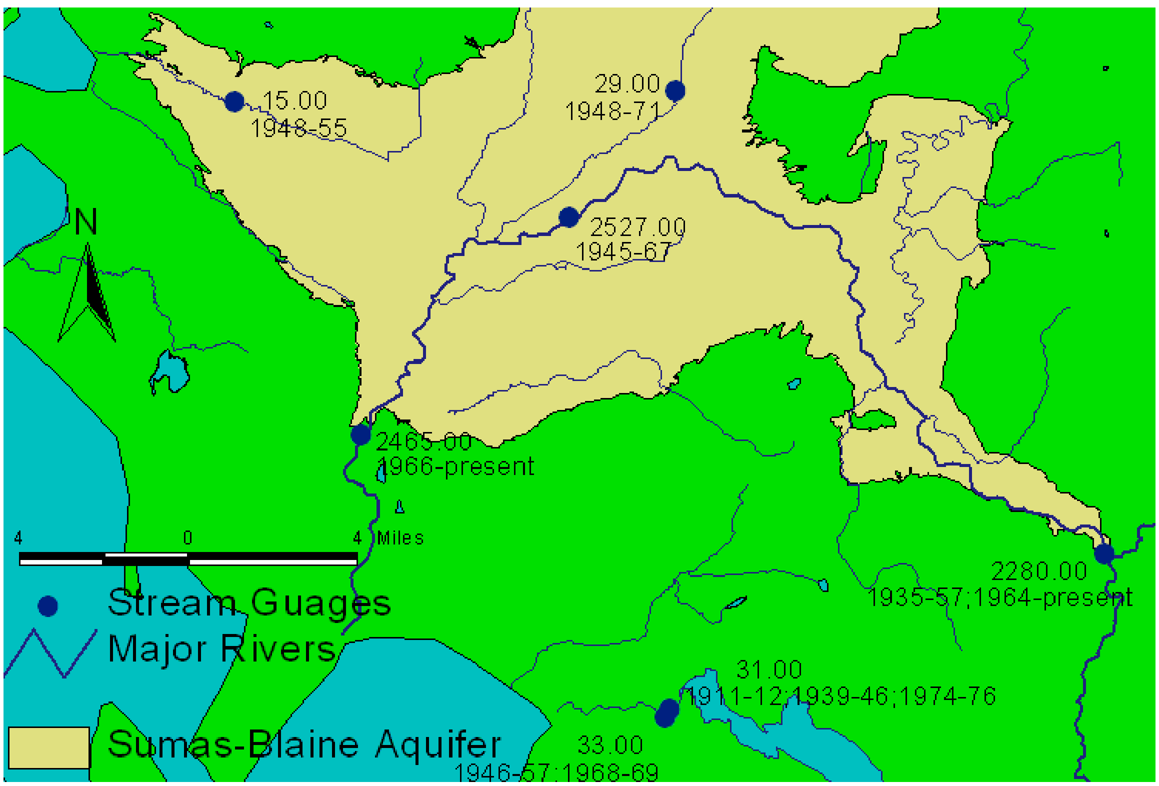


Figure 1.2.23 Baseflow contribution - mean annual (cfs), Sumas-Blaine Aquifer

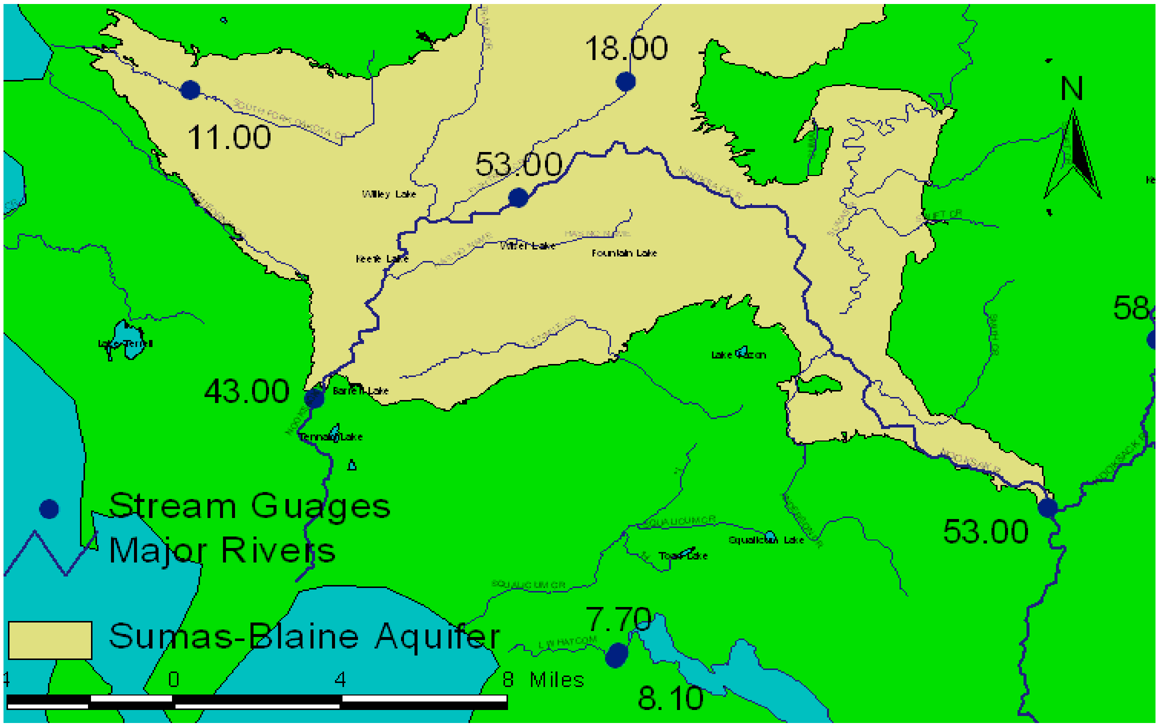


Figure 1.2.24 Baseflow contribution - mean annual (in/year), Sumas-Blaine Aquifer

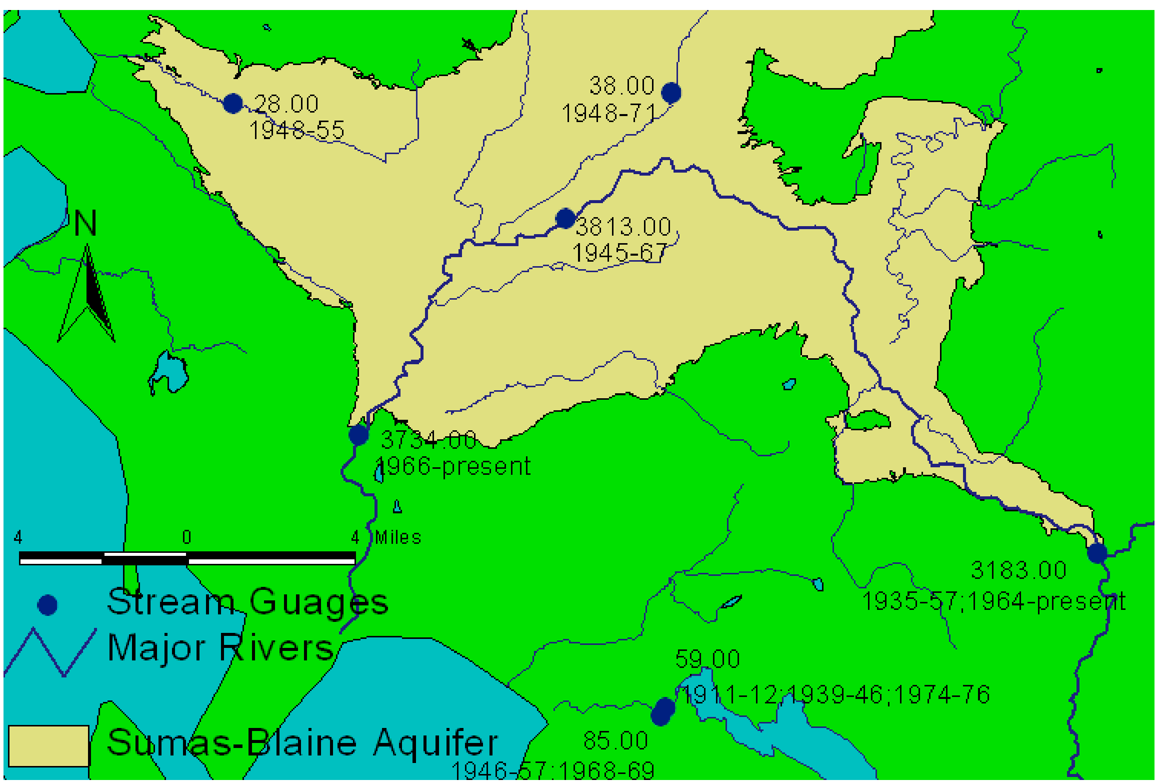


Figure 1.2.25 Mean annual streamflow (cfs), Sumas-Blaine Aquifer

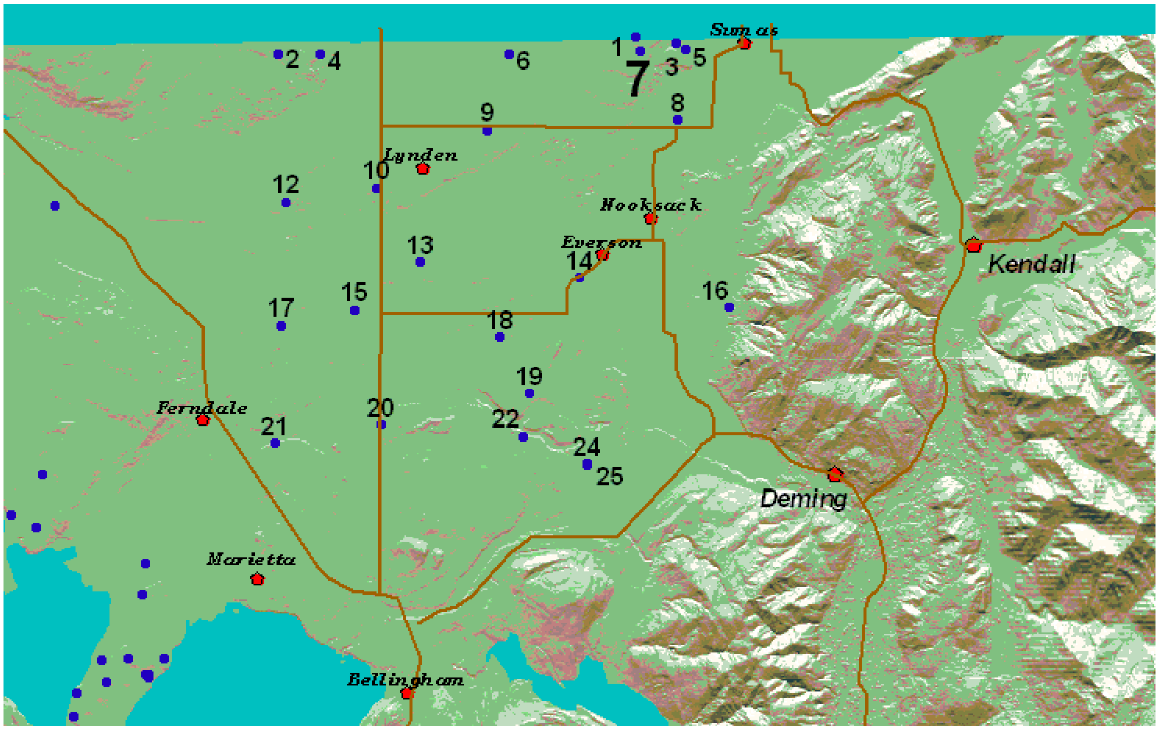


Figure 1.2.26 Location of wells in the central lands with lengthy (>12 months) recorded well water level data

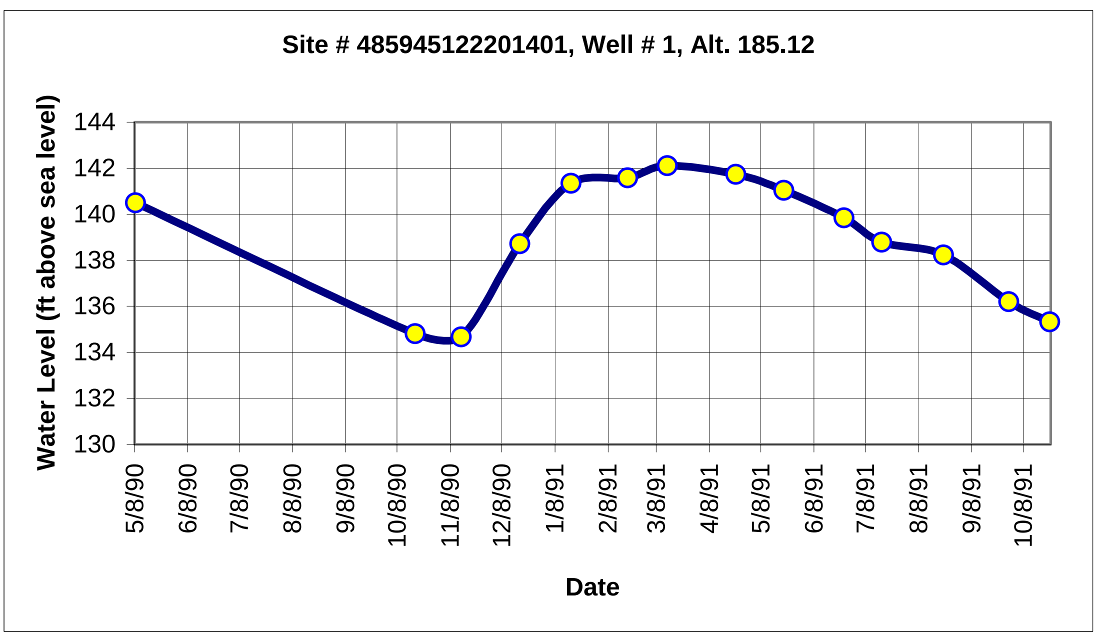


Figure 1.2.27 Time series for Site # 485945122201401, Well # 1, Alt. 185.12

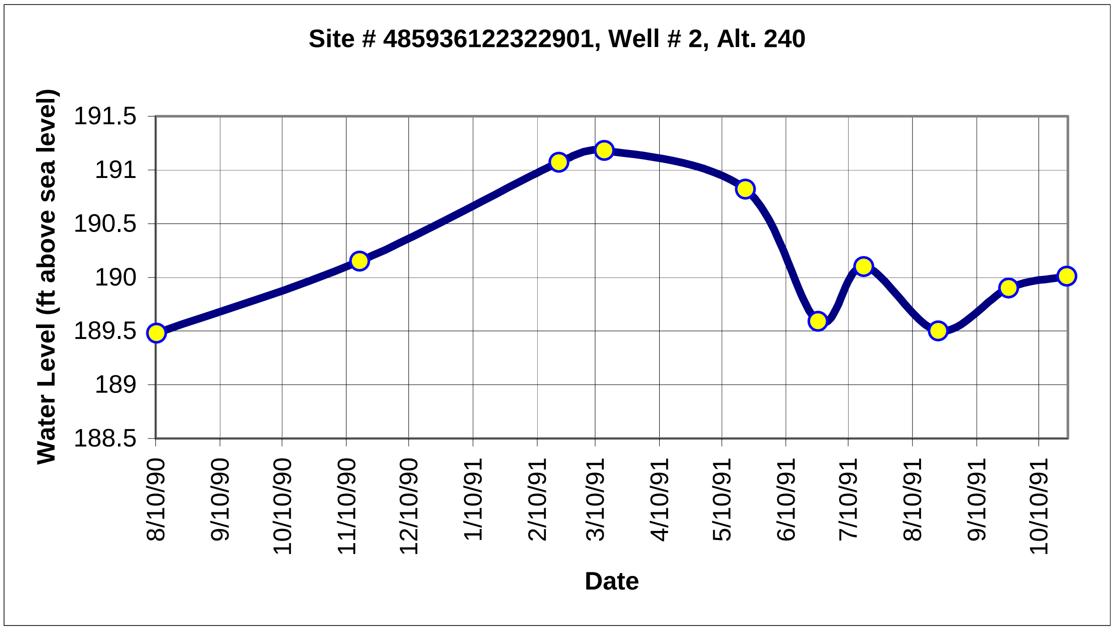


Figure 1.2.28 Time series for Site # 485936122322901, Well # 2, Alt. 240

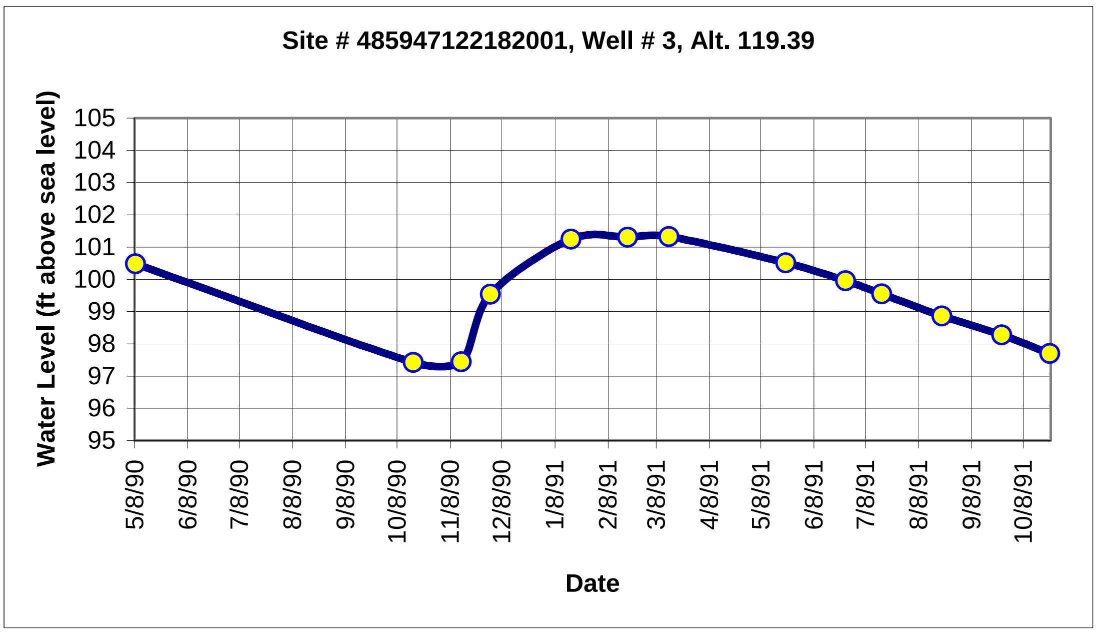


Figure 1.2.29 Time series for Site # 485947122182001, Well # 3, Alt. 119.39

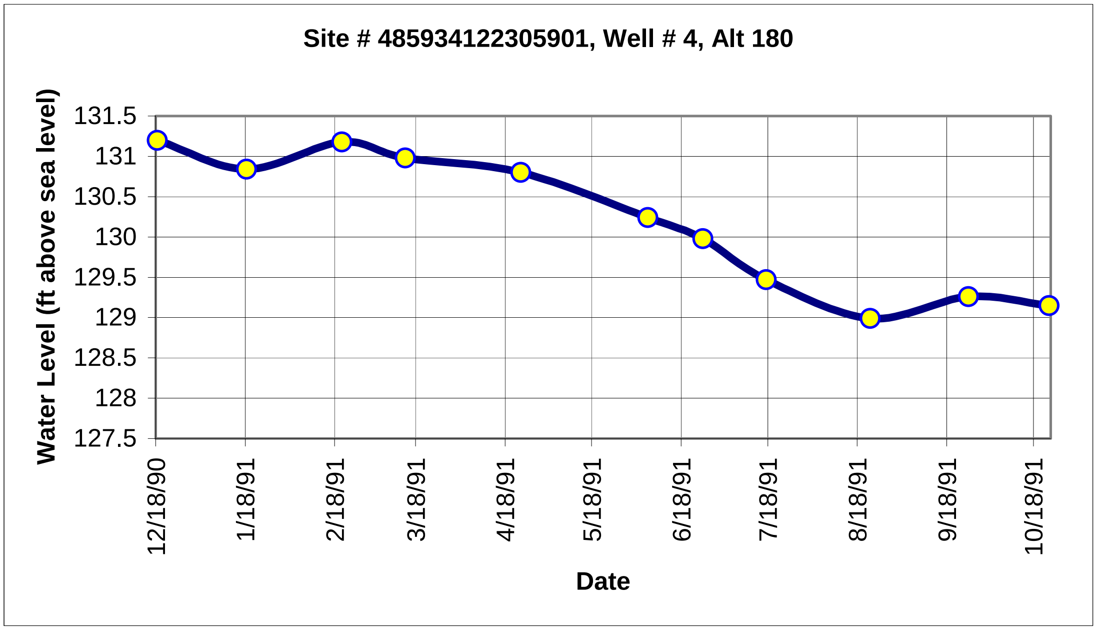


Figure 1.2.30 Time series for Site # 485934122305901, Well # 4, Alt 180

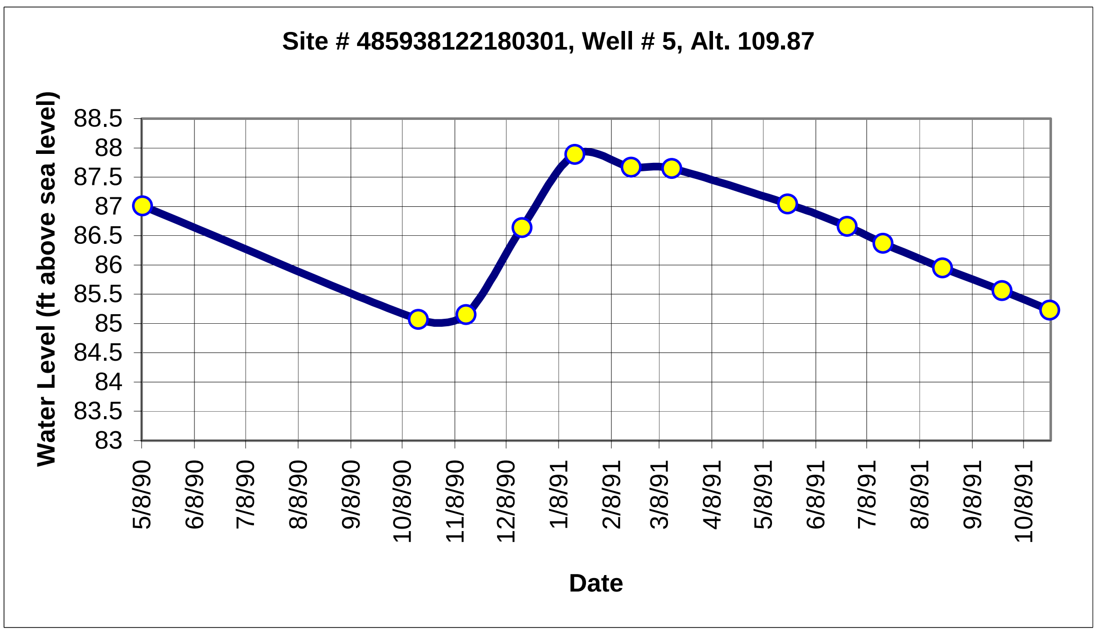


Figure 1.2.31 Time series for Site # 485938122180301, Well # 5, Alt. 109.87

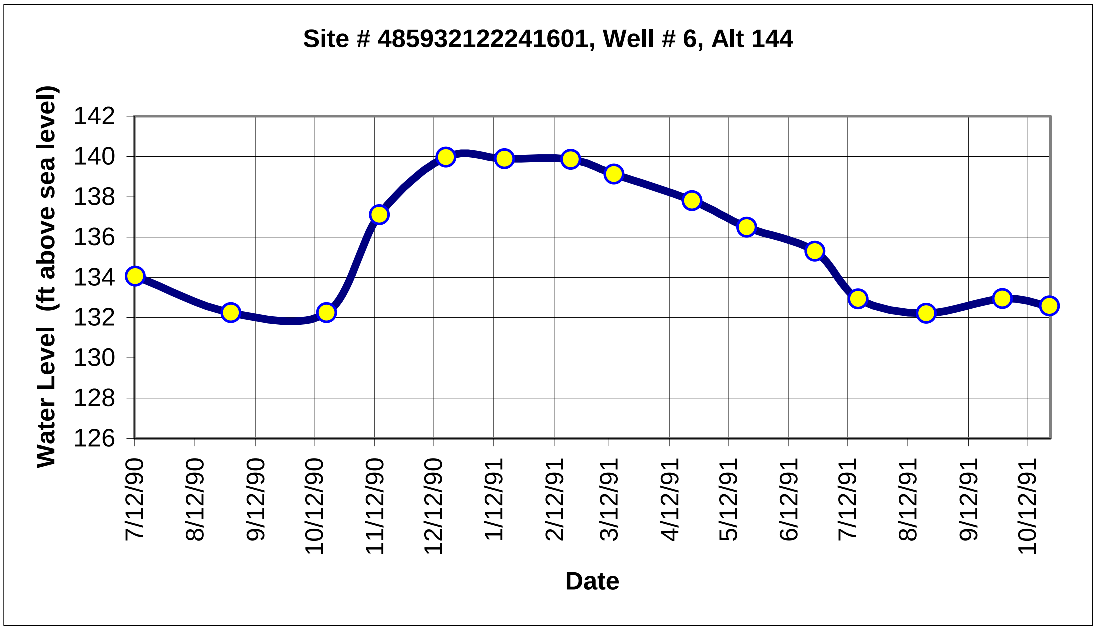


Figure 1.2.32 Time series for Site # 485932122241601, Well # 6, Alt 144

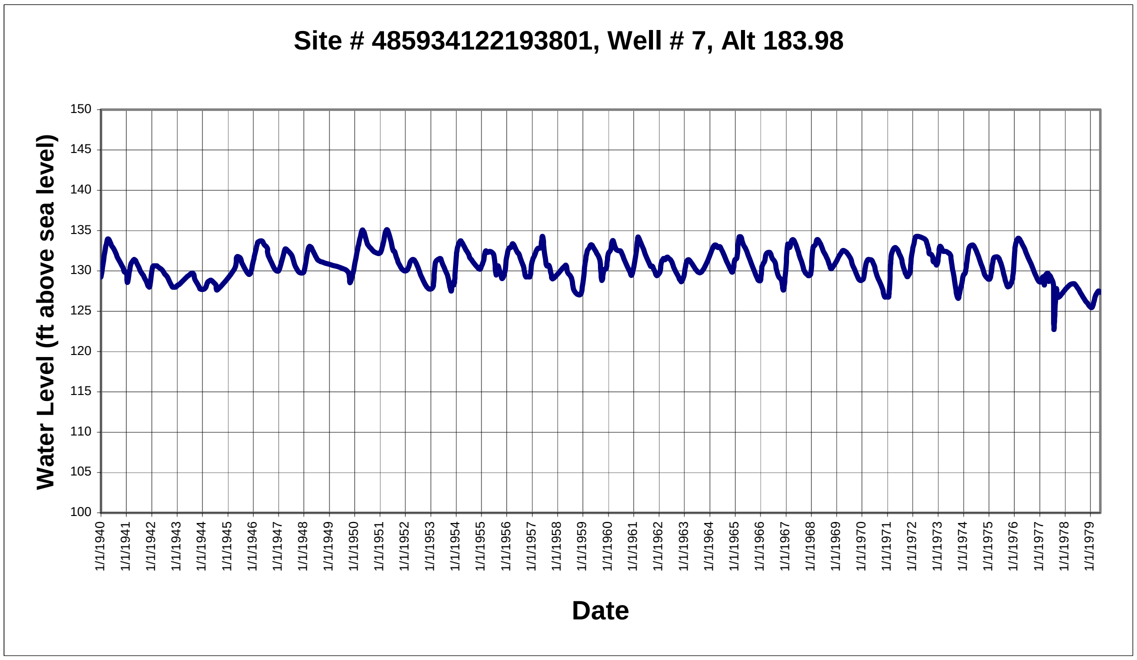


Figure 1.2.33 Time series for Site # 485934122193801, Well # 7, Alt 183.98

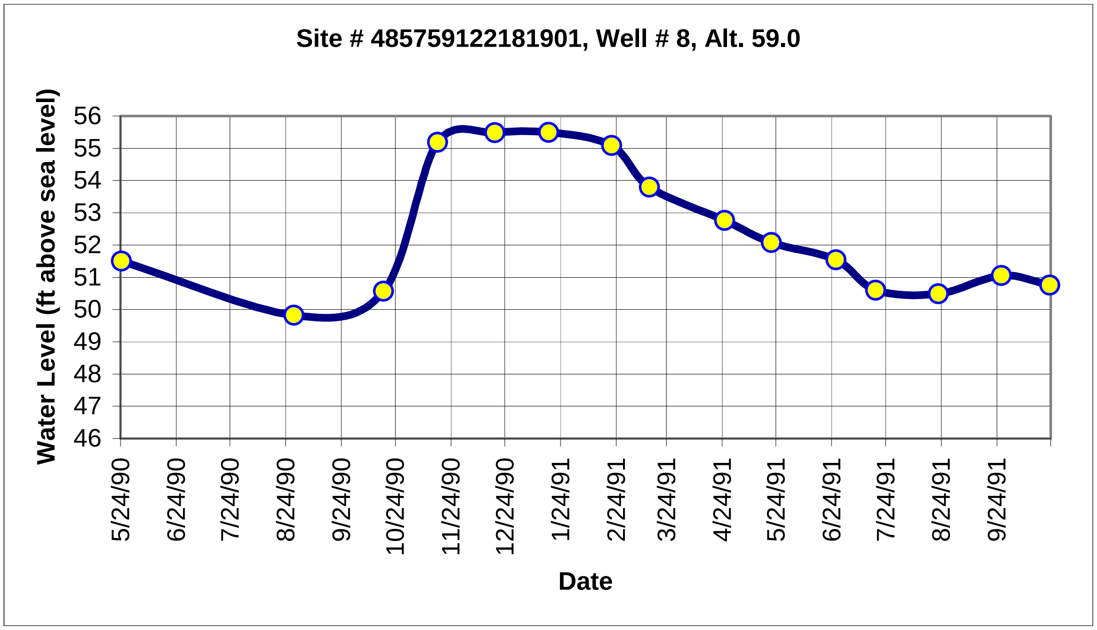


Figure 1.2.34 Time series for Site # 485759122181901, Well # 8, Alt. 59.0

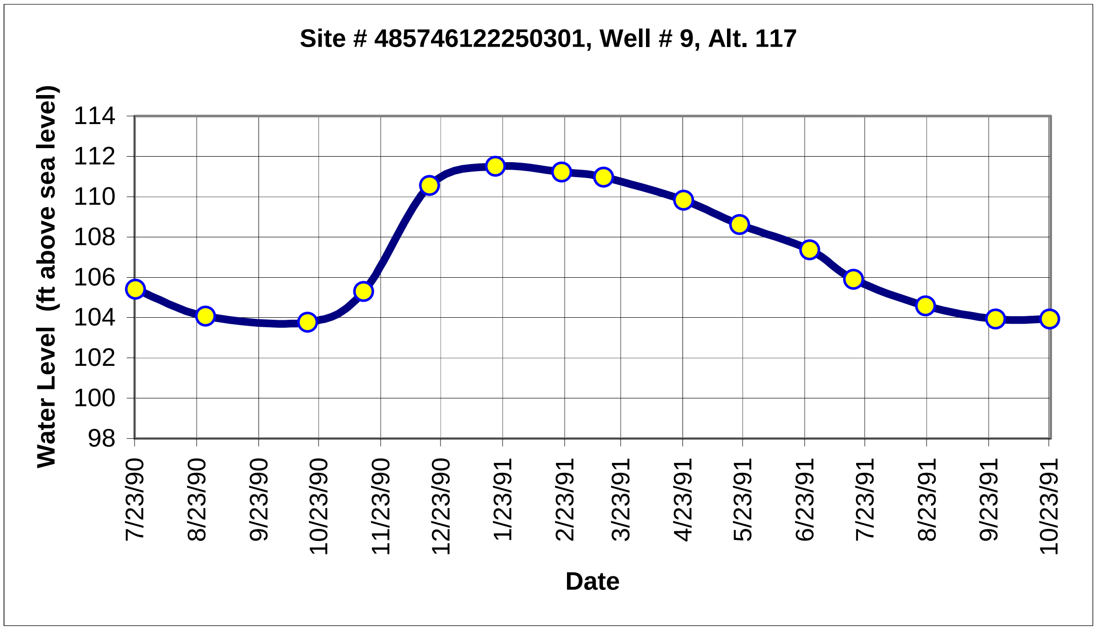


Figure 1.2.35 Time series for Site # 485746122250301, Well # 9, Alt. 117

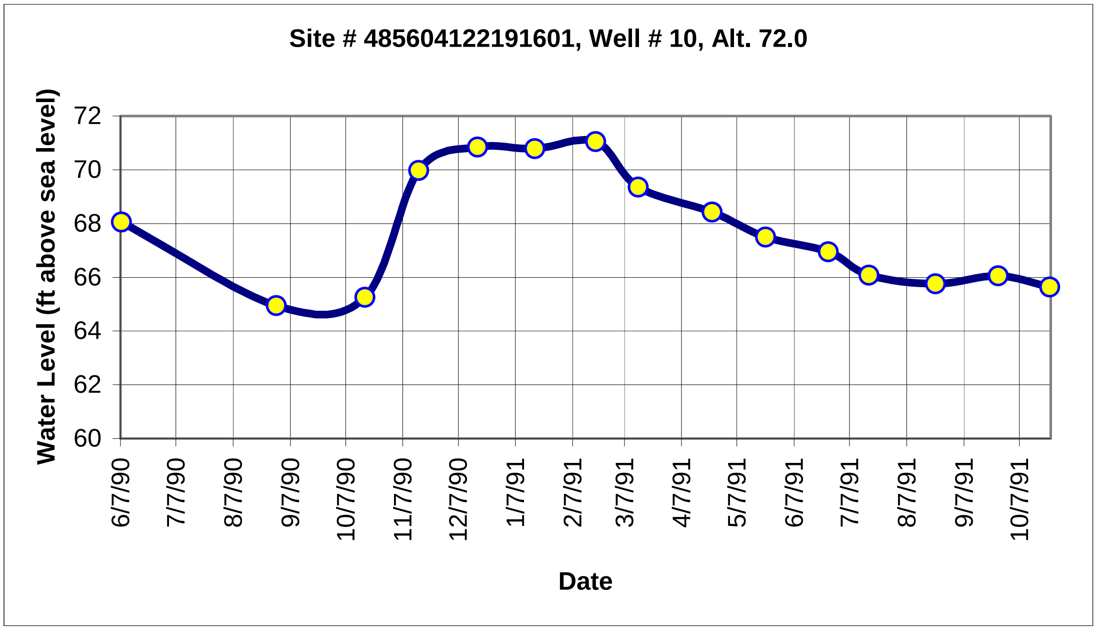


Figure 1.2.36 Time series for Site # 485604122191601, Well # 10, Alt. 72.0

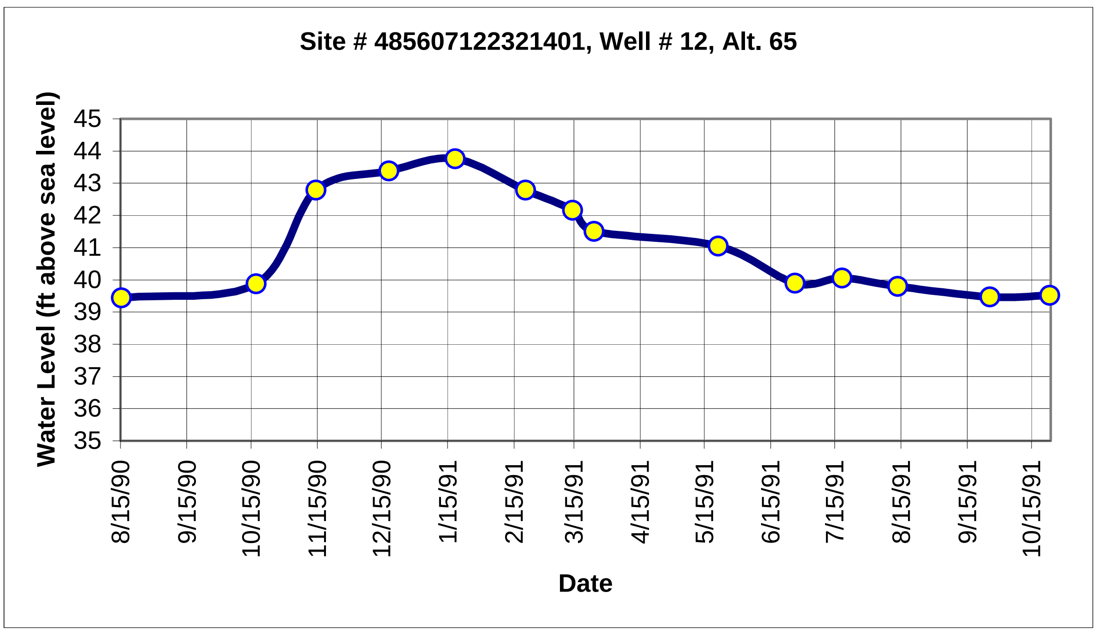


Figure 1.2.37 Time series for Site # 485607122321401, Well # 12, Alt. 65

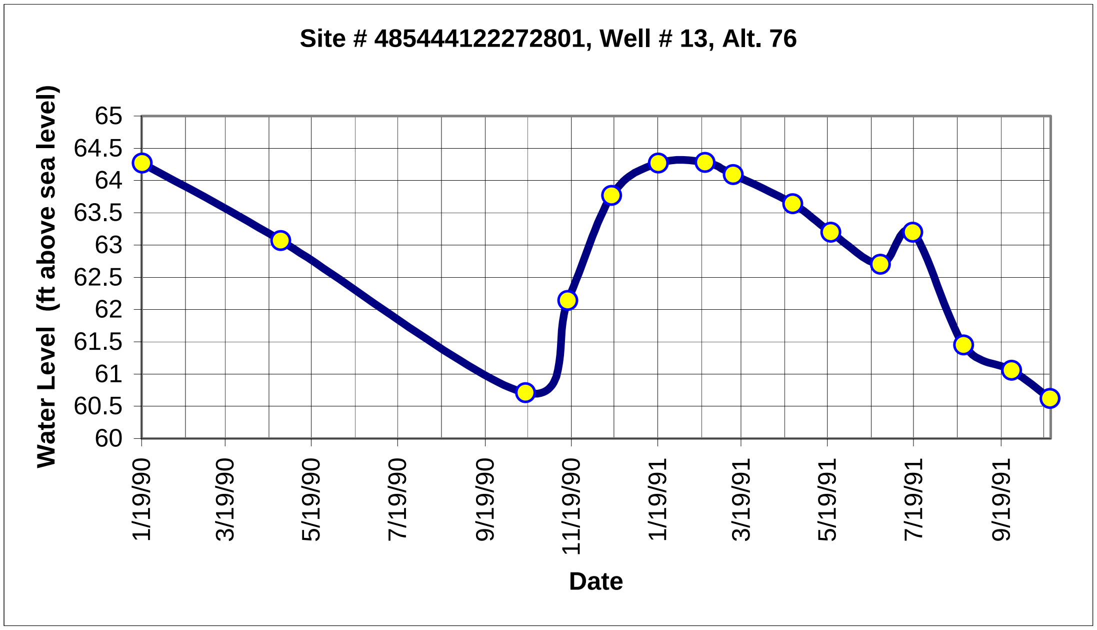


Figure 1.2.38 Time series for Site # 485444122272801, Well # 13, Alt. 76

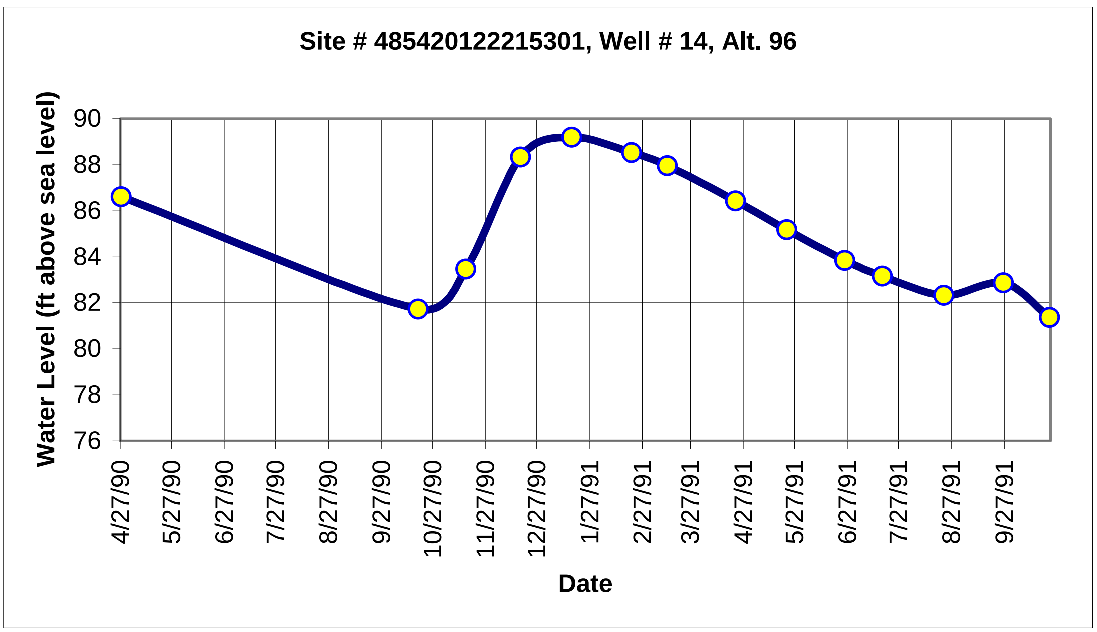


Figure 1.2.39 Time series for Site # 485420122215301, Well # 14, Alt. 96

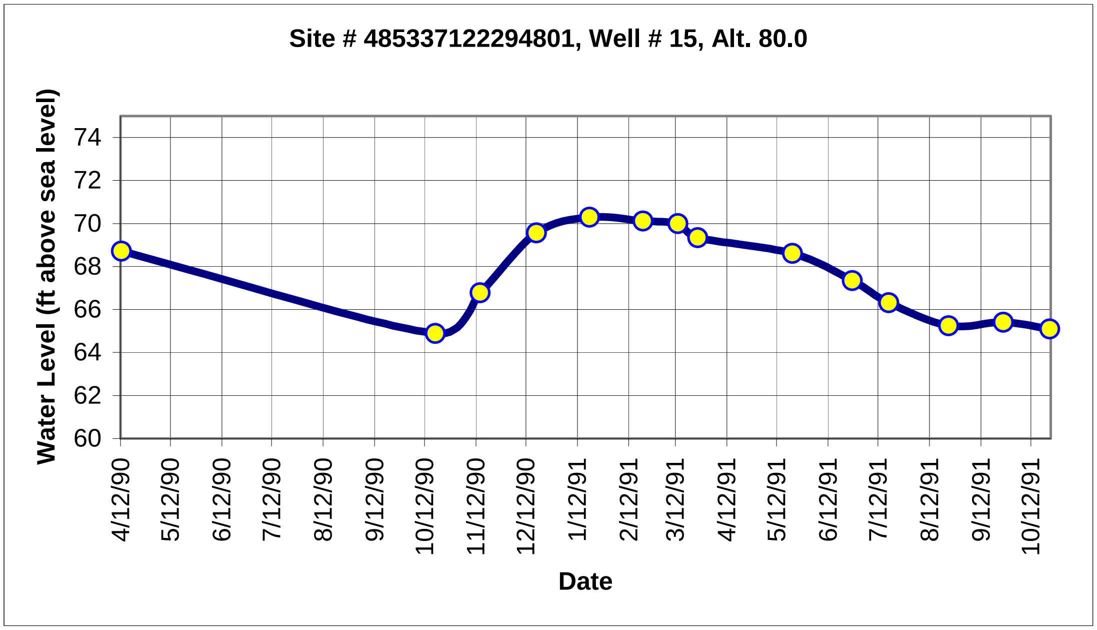


Figure 1.2.40 Time series for Site # 485337122294801, Well # 15, Alt. 80.0

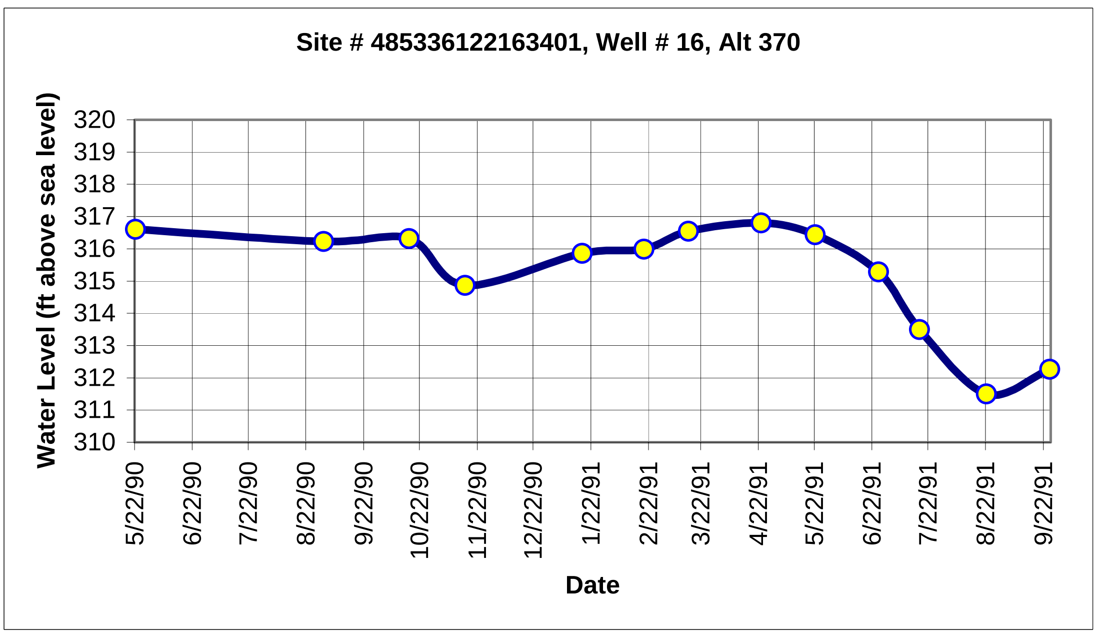


Figure 1.2.41 Time series for Site # 485336122163401, Well # 16, Alt 370

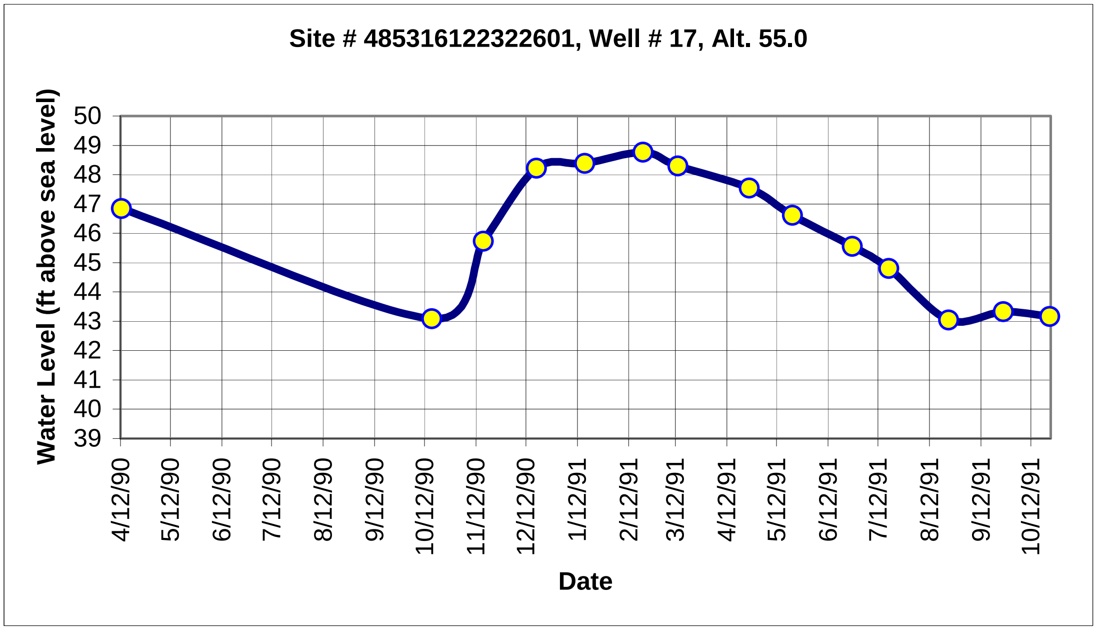


Figure 1.2.42 Time series for Site # 485316122322601, Well # 17, Alt. 55.0

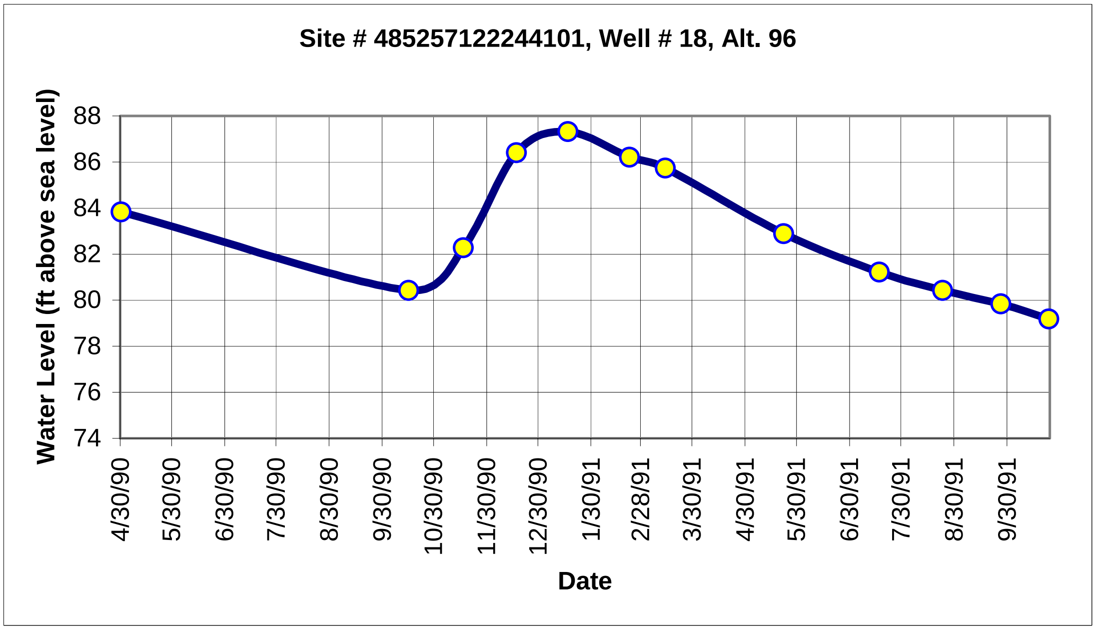


Figure 1.2.43 Time series for Site # 485257122244101, Well # 18, Alt. 96

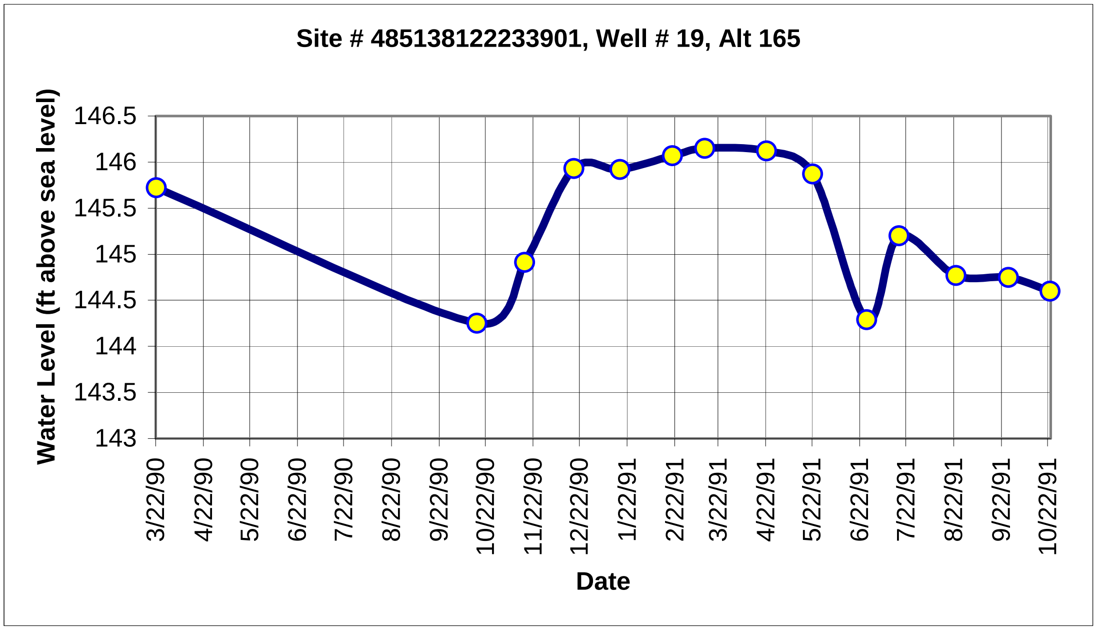


Figure 1.2.44 Time series for Site # 485138122233901, Well # 19, Alt 165

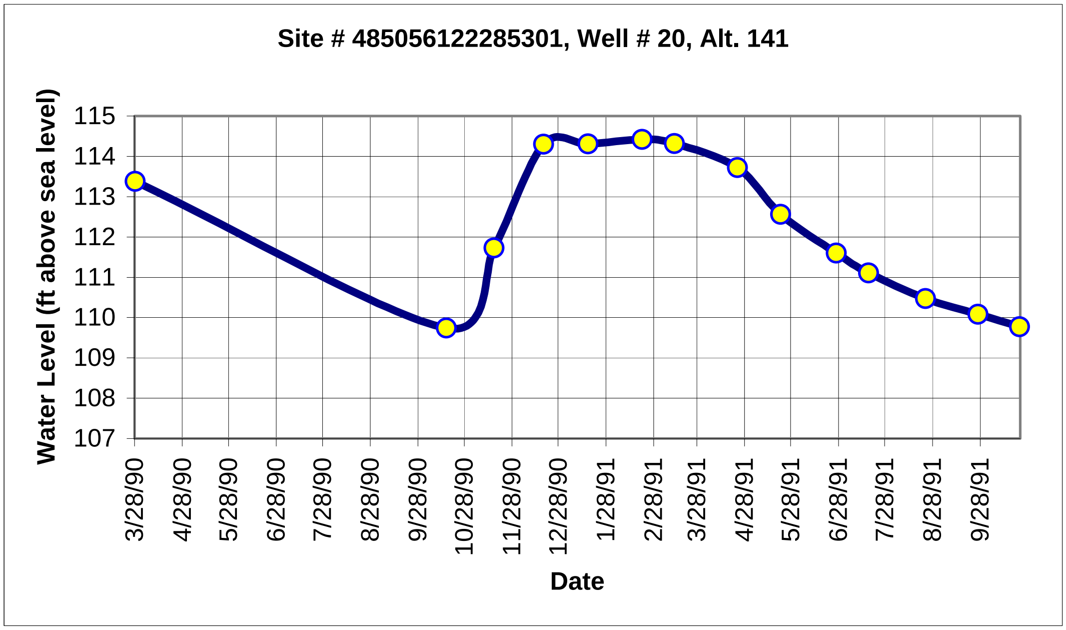


Figure 1.2.45 Time series for Site # 485056122285301, Well # 20, Alt. 141

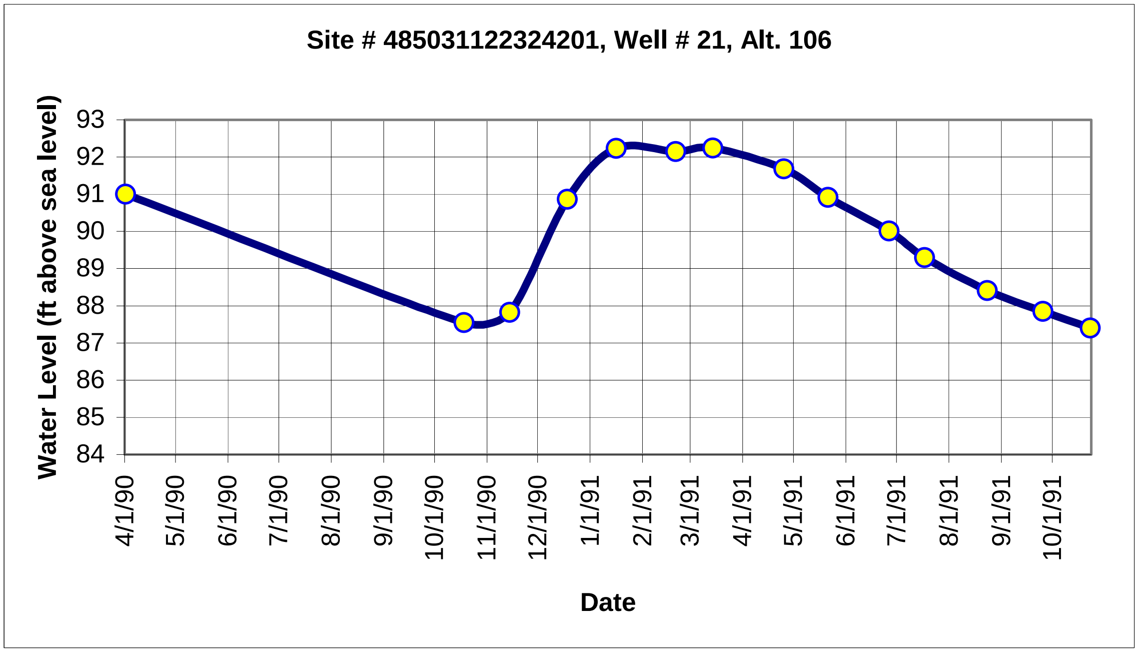


Figure 1.2.46 Time series for Site # 485031122324201, Well # 21, Alt. 106

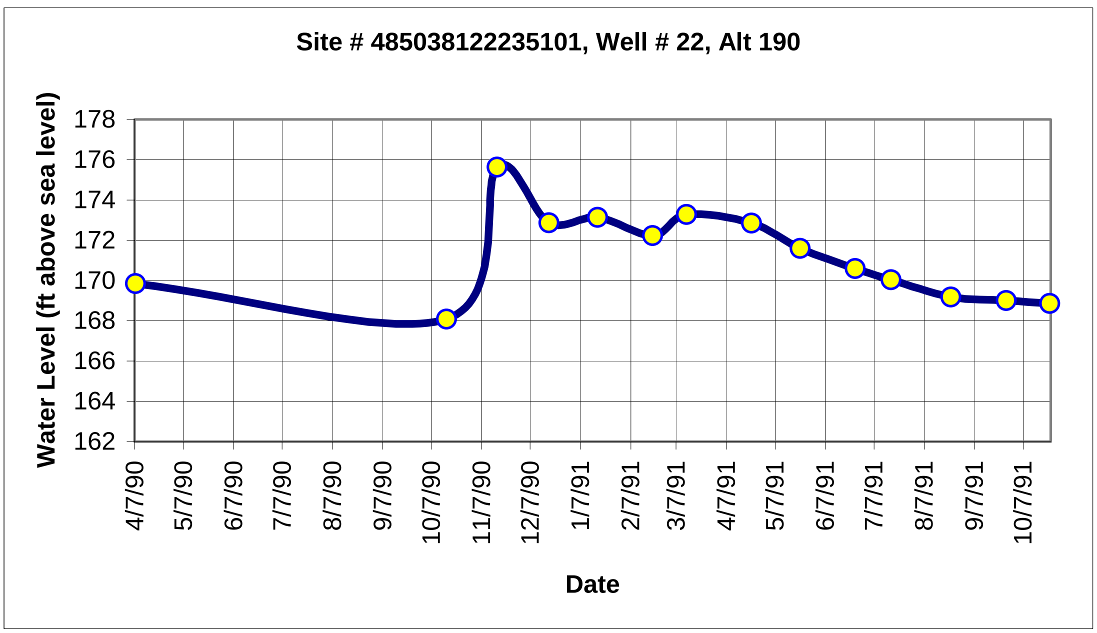


Figure 1.2.47 Time series for Site # 485038122235101, Well # 22, Alt 190

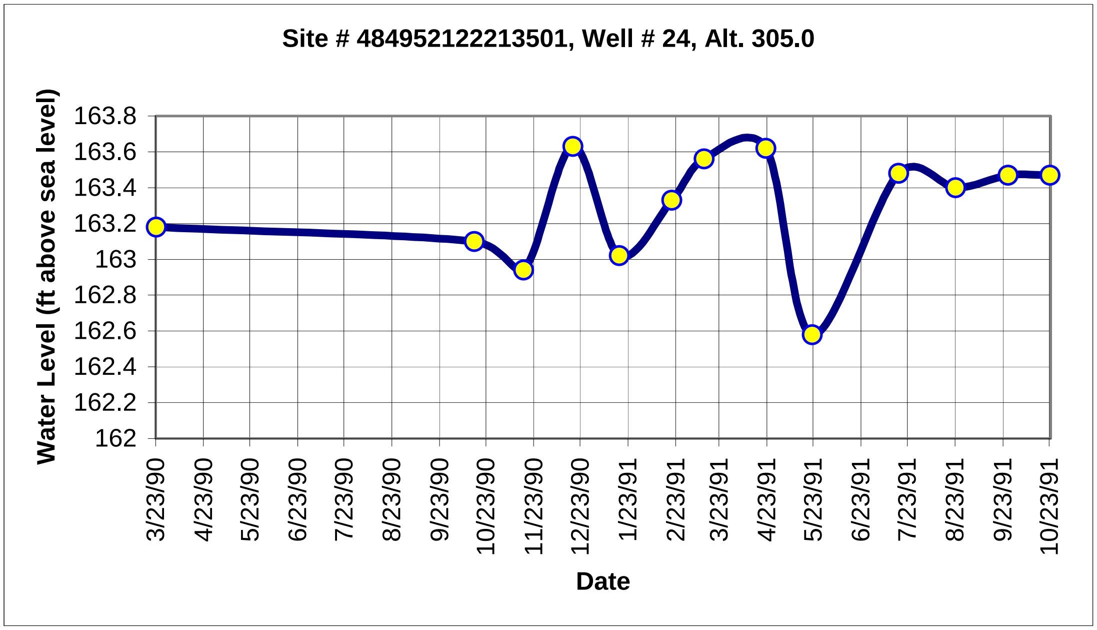


Figure 1.2.48 Time series for Site # 484952122213501, Well # 24, Alt. 305.0

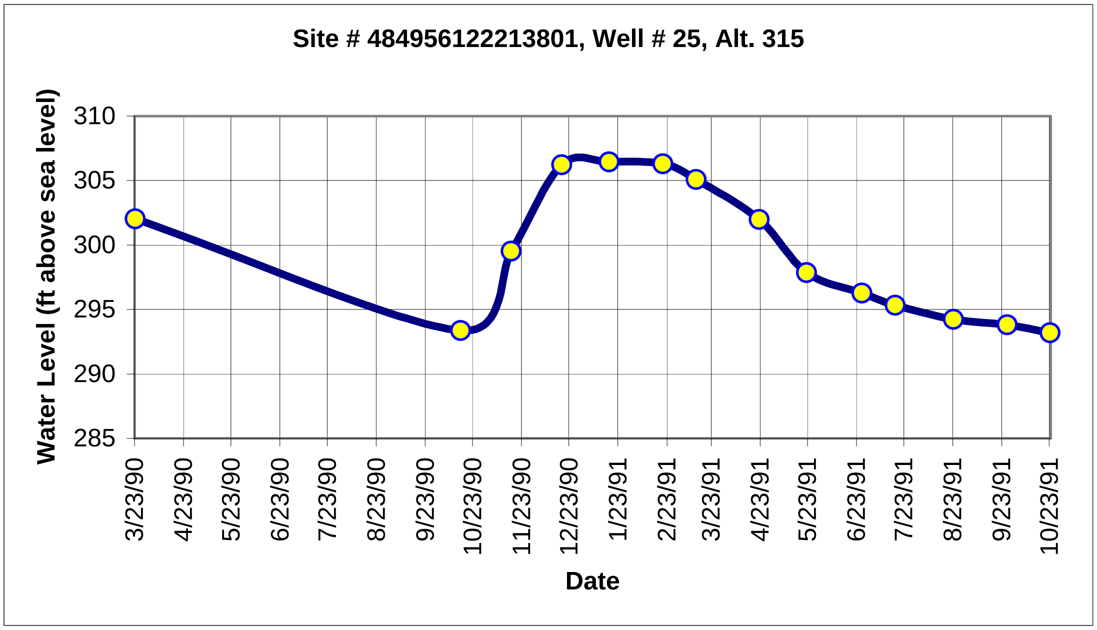


Figure 1.2.49 Time series for Site # 484956122213801, Well # 25, Alt. 315

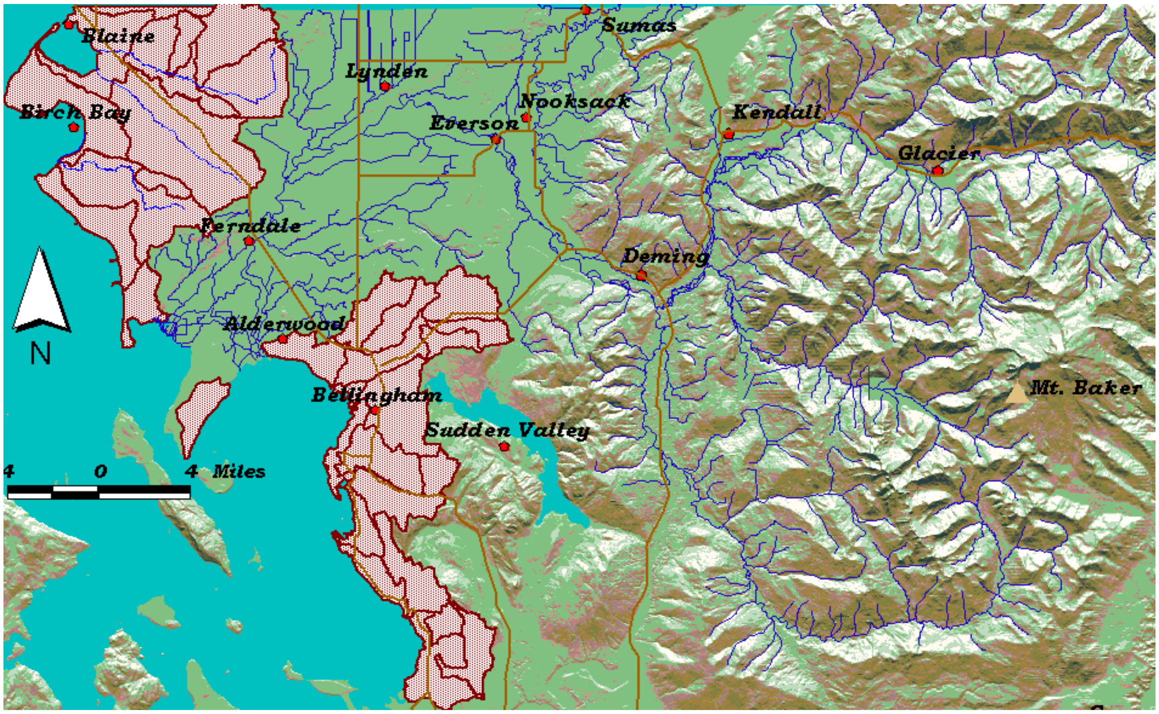


Figure 1.3.1. Coastal watersheds

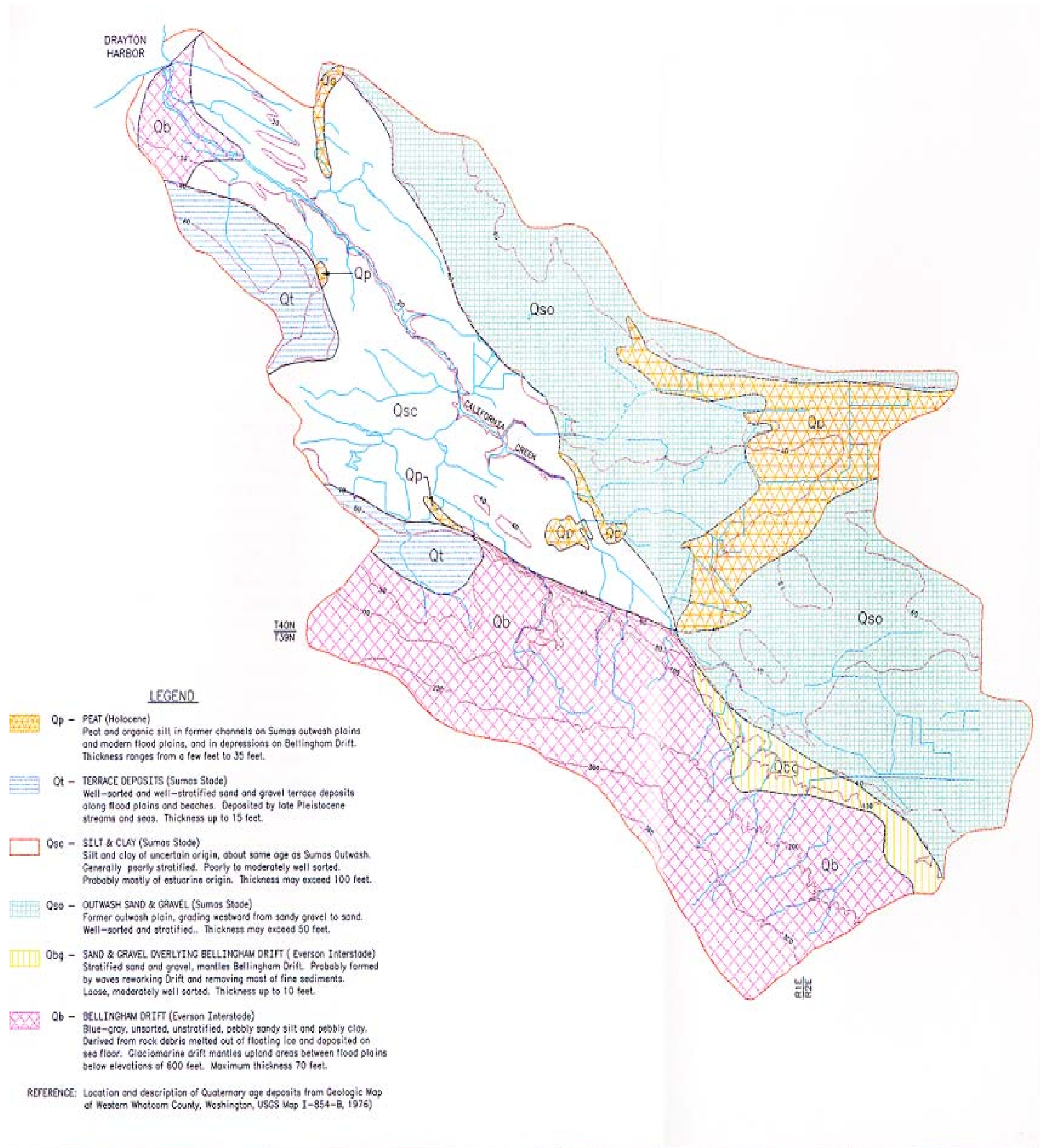


Figure 1.3.2 California Creek drainage basin - surficial geology (Source: Didrickson, 1997)

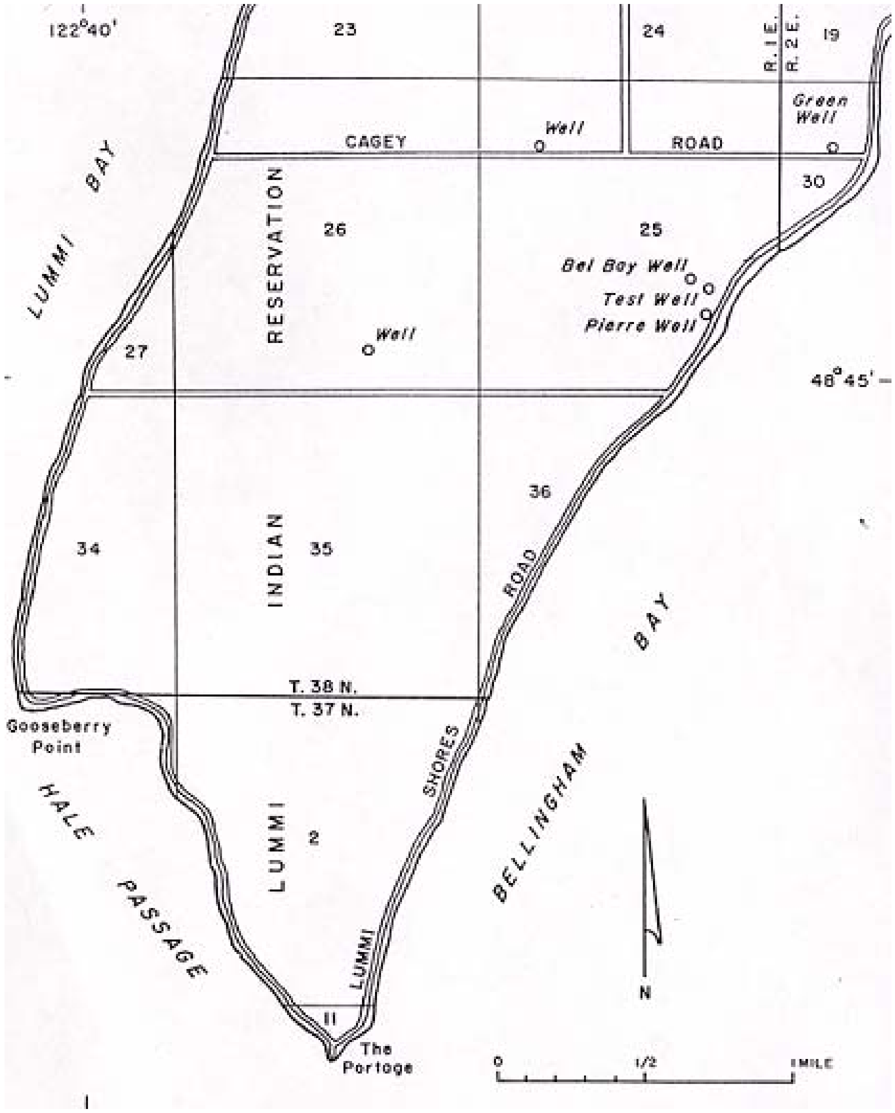


Figure 1.3.3 Wells within the Lummi Indian Reservation (Source; USGS, 1974)

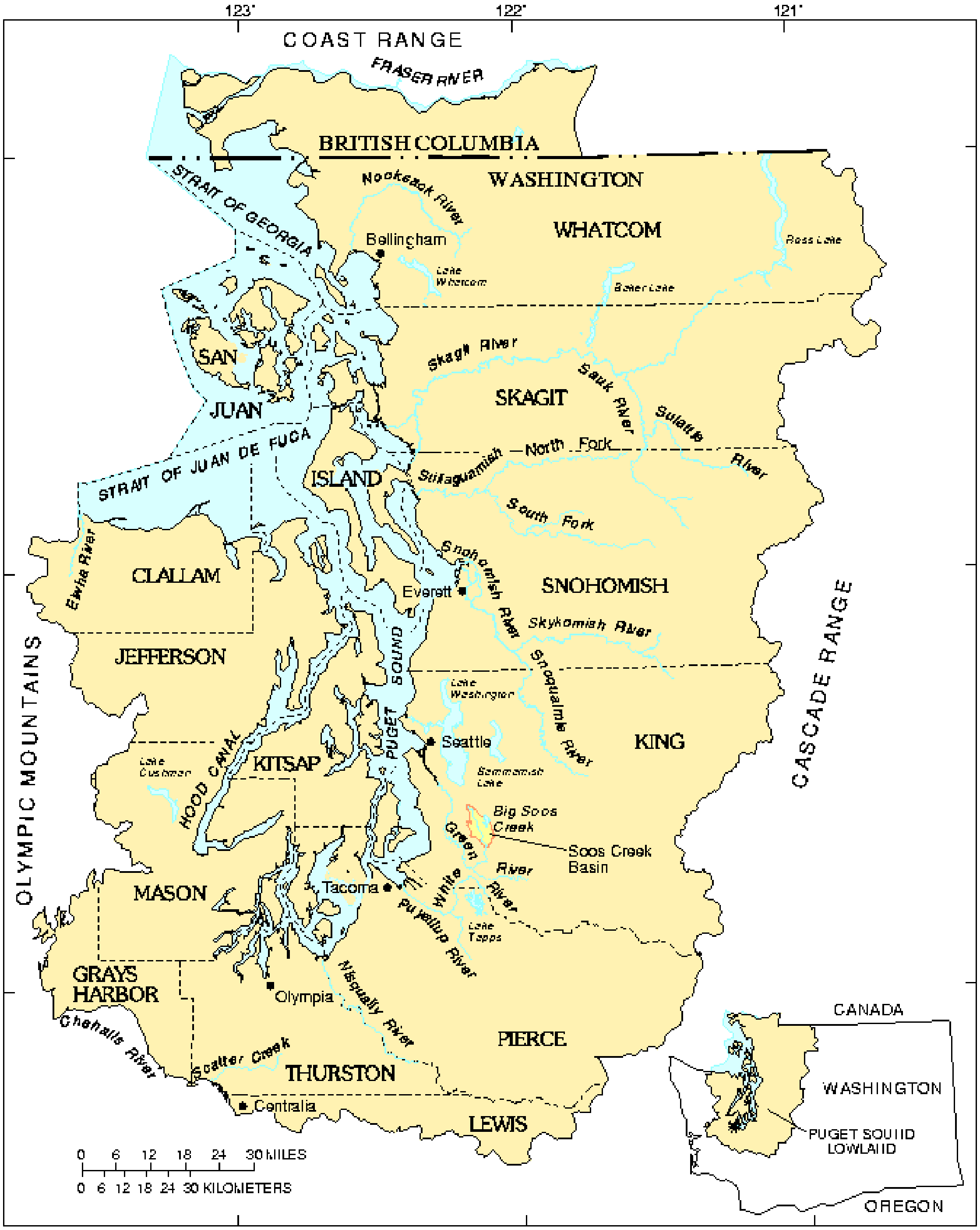


Figure 1.--Location and features of the Puget Sound Lowland, Washington.

Figure 1.3.4 Location and features of the Puget Sound lowland (Source: Morgan and Jones, 1995)

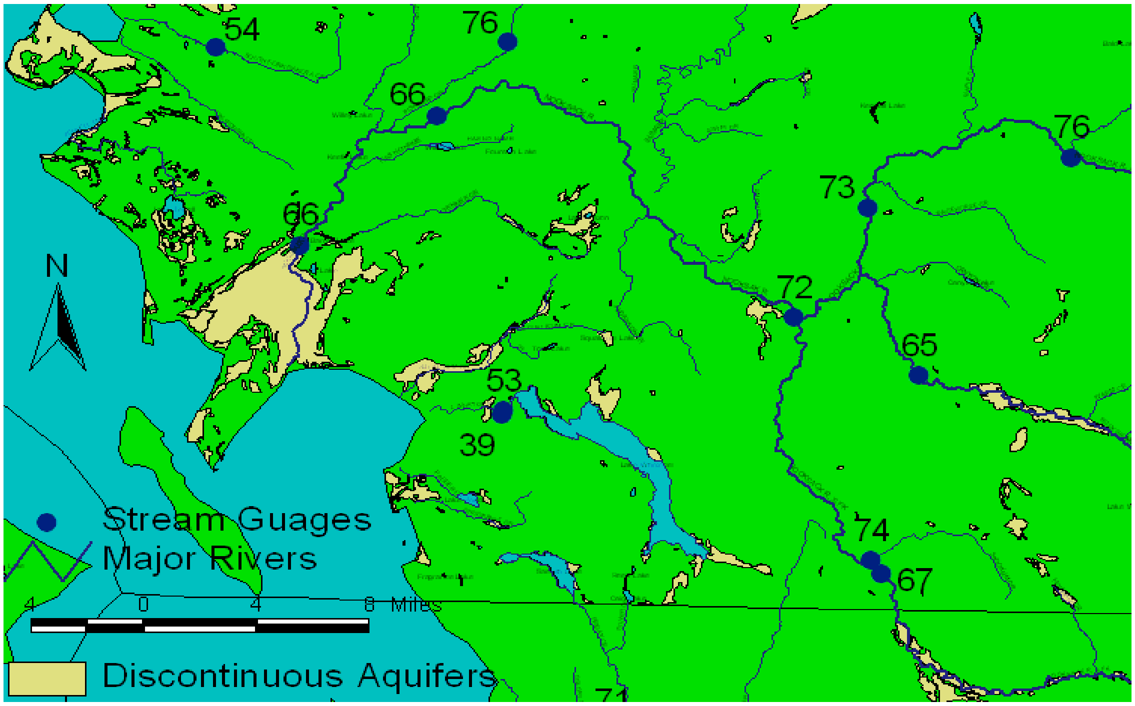


Figure 1.3.5 Baseflow contribution -mean annual (percentage), Discontinuous Aquifers

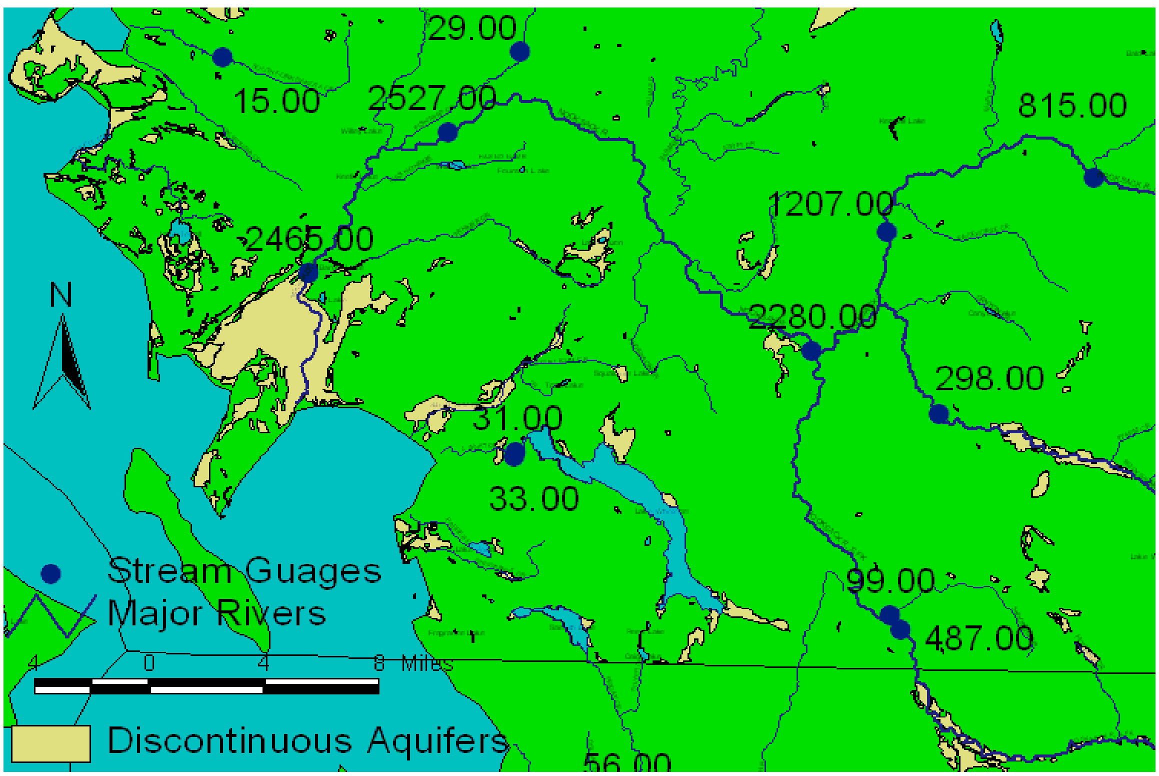


Figure 1.3.6 Baseflow contribution-mean annual (cfs), Discontinuous Aquifers

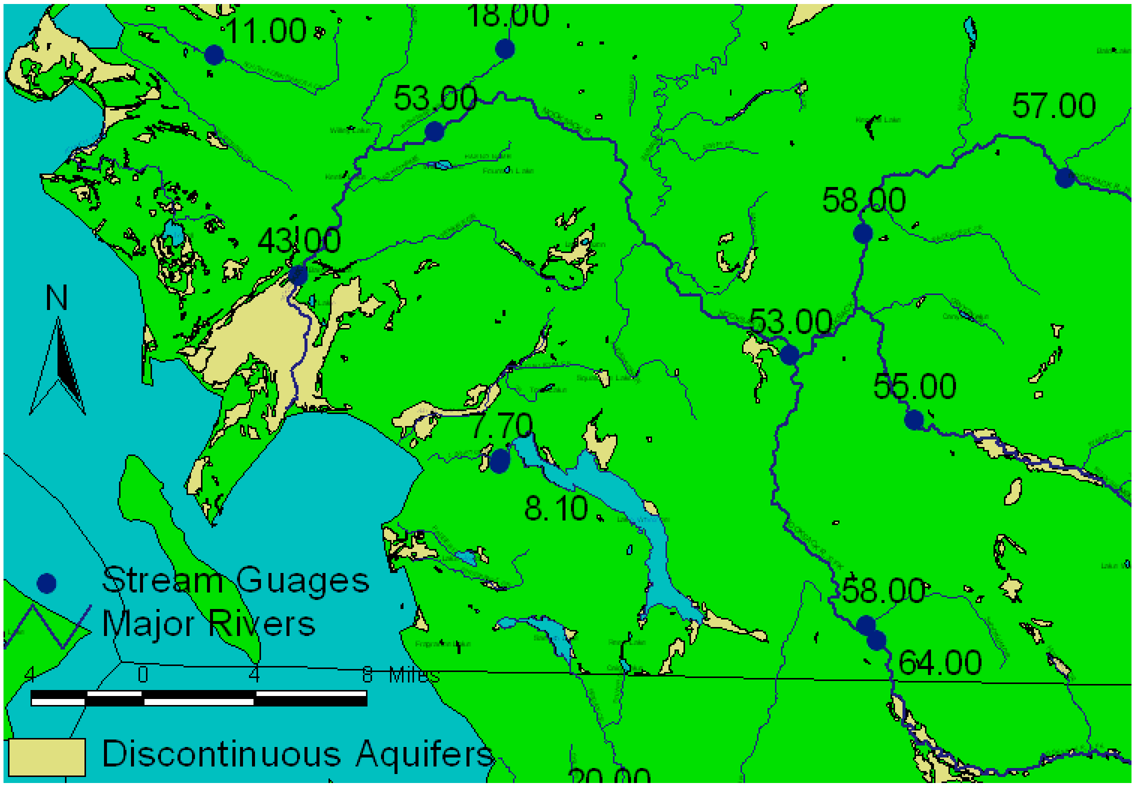
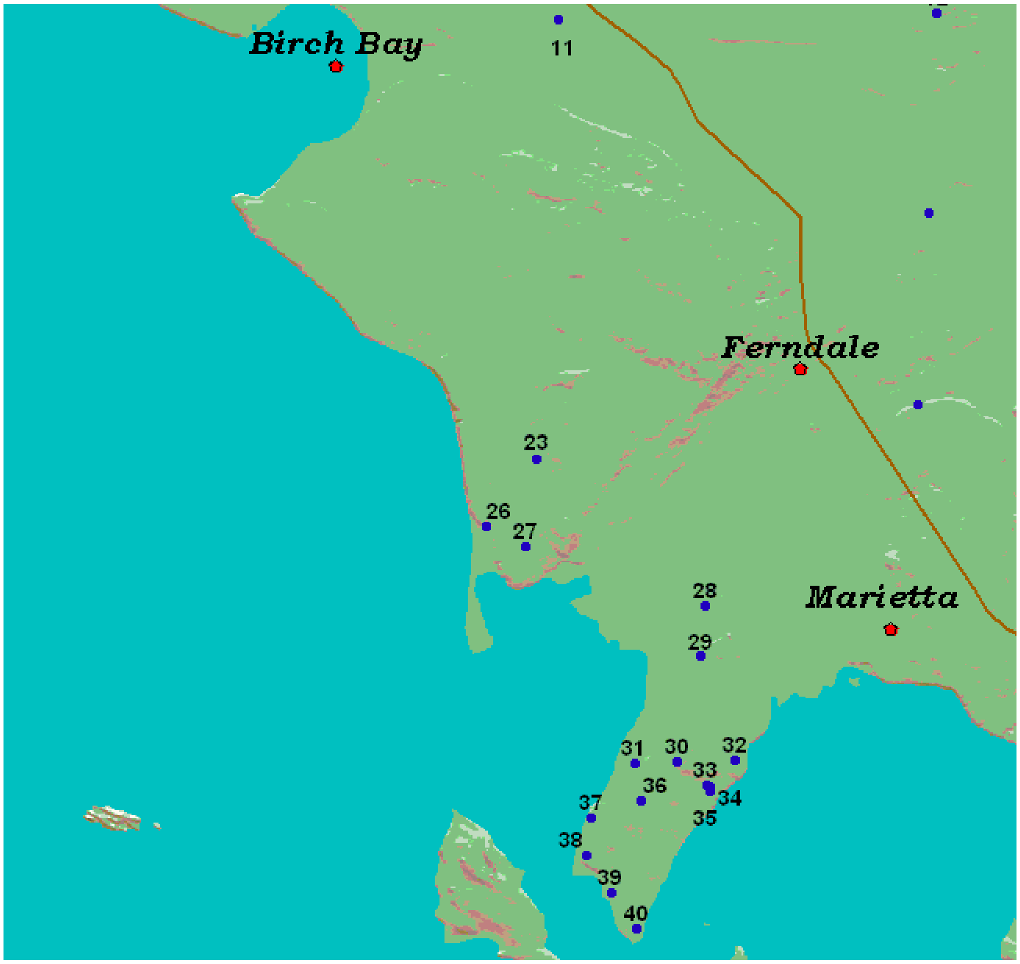


Figure 1.3.7 Baseflow Contribution - mean annual (inches/year), Discontinuous Aquifers



Figures 1.3.8 Location of coastal wells with lengthy (> 12 months) water level records

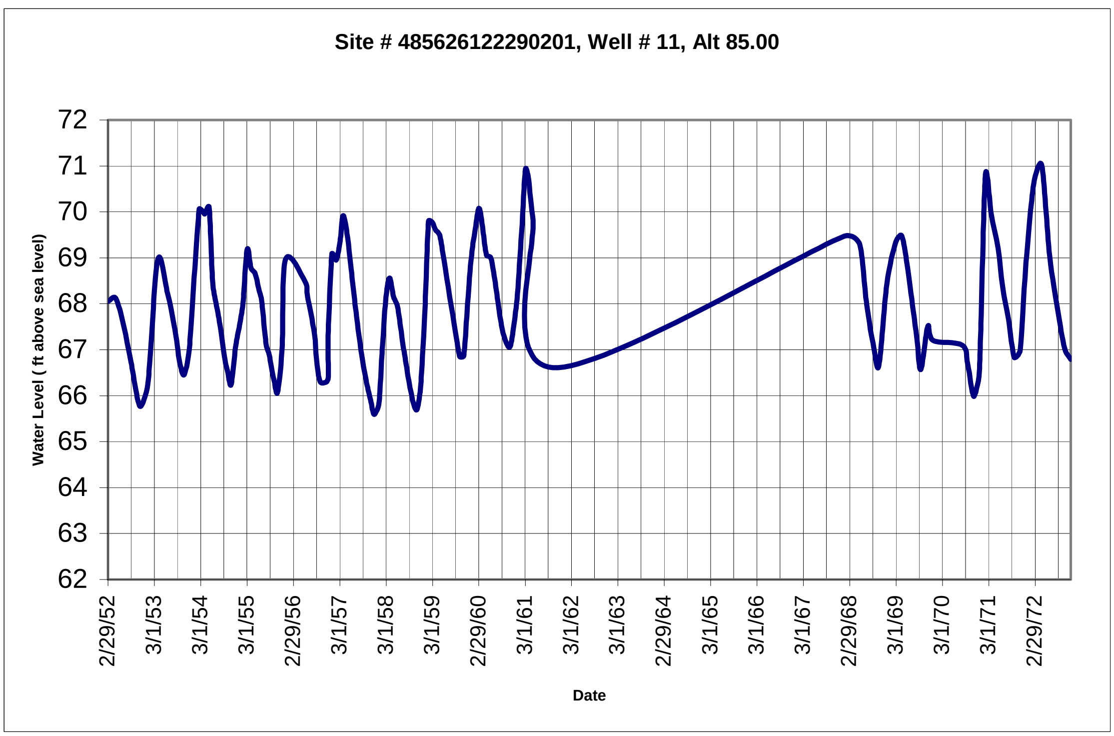


Figure 1.3.9 Time series for Site # 485626122290201, Well # 11, Alt 85.00

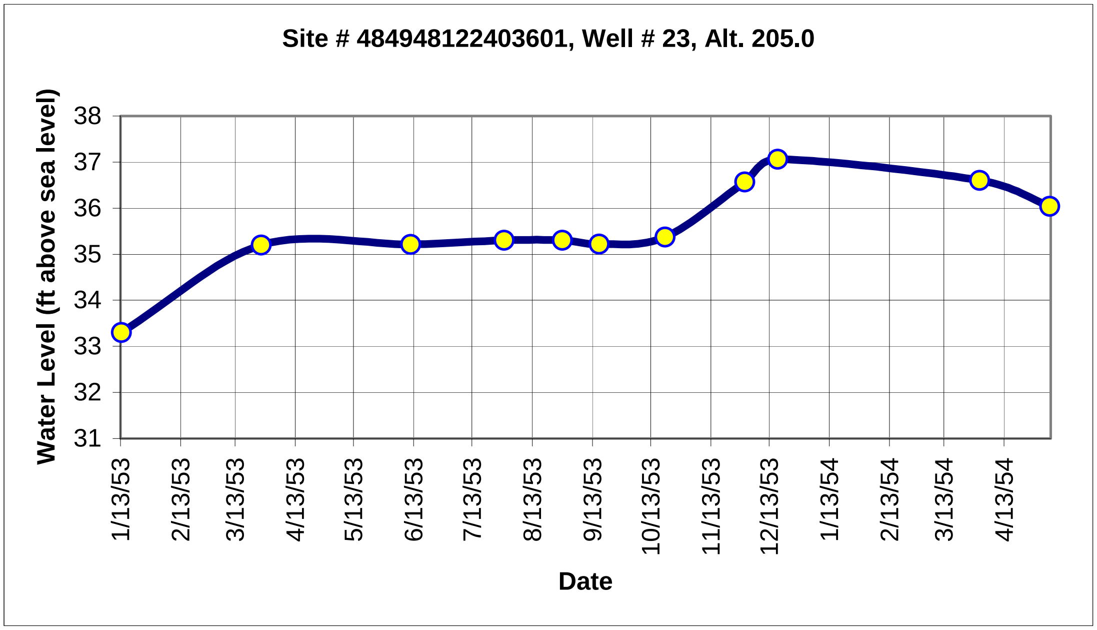


Figure 1.3.10 Time series for Site # 484948122403601, Well # 23, Alt. 205.0

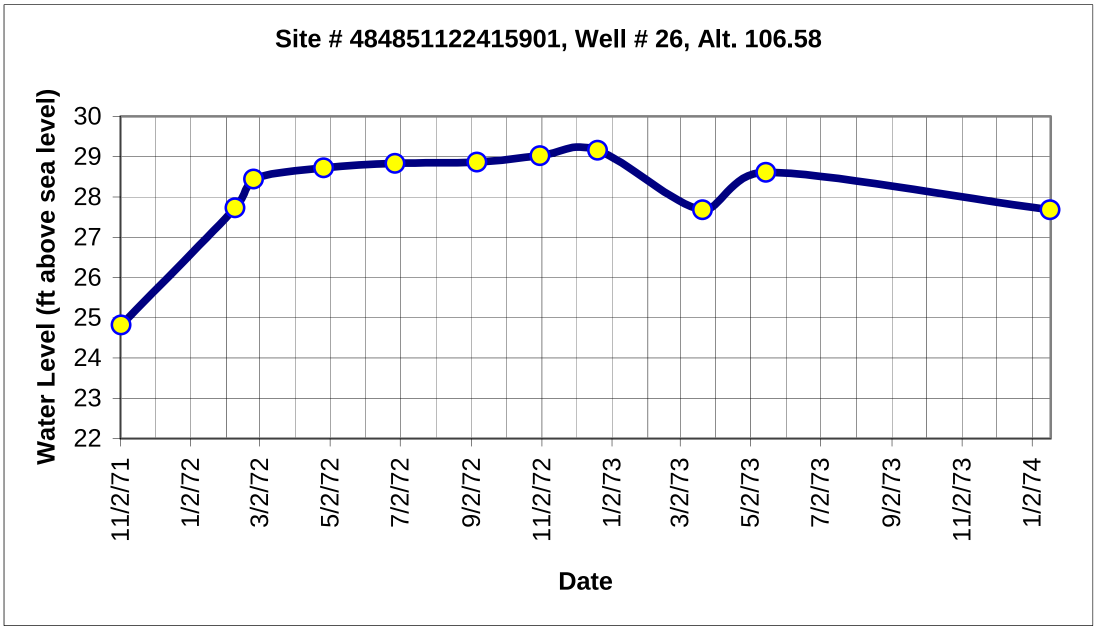


Figure 1.3.11 Time series for Site # 484851122415901, Well # 26, Alt. 106.58

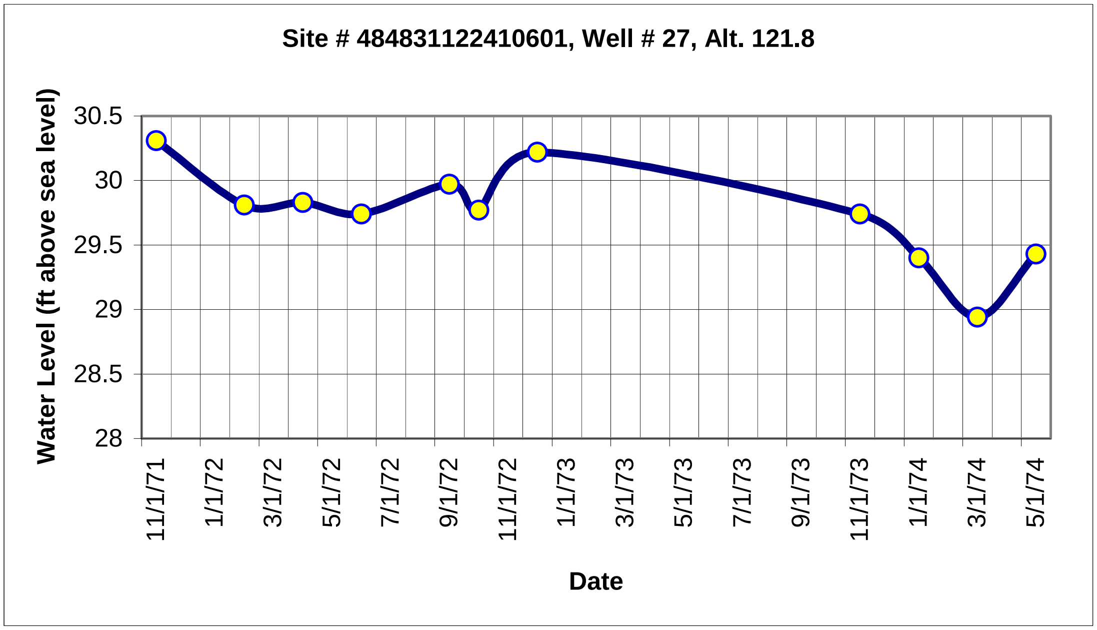


Figure 1.3.12 Time series for Site # 484831122410601, Well # 27, Alt. 121.8

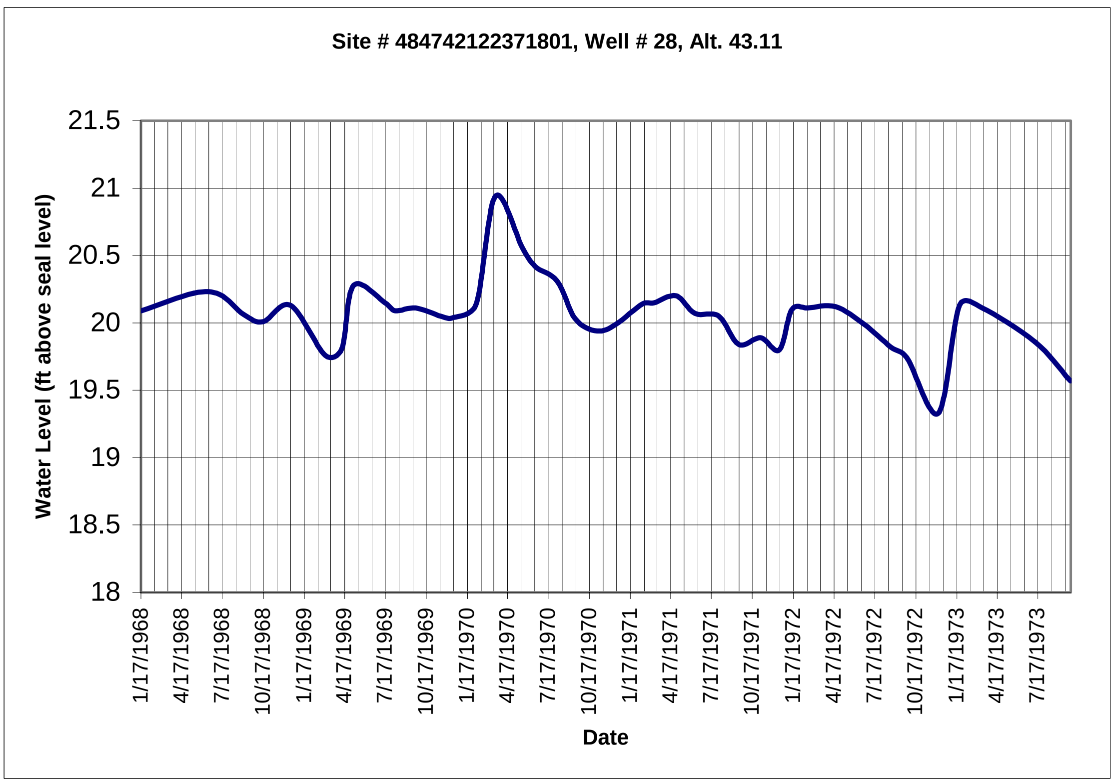


Figure 1.3.13 Time series for Site # 484742122371801, Well # 28, Alt. 43.11

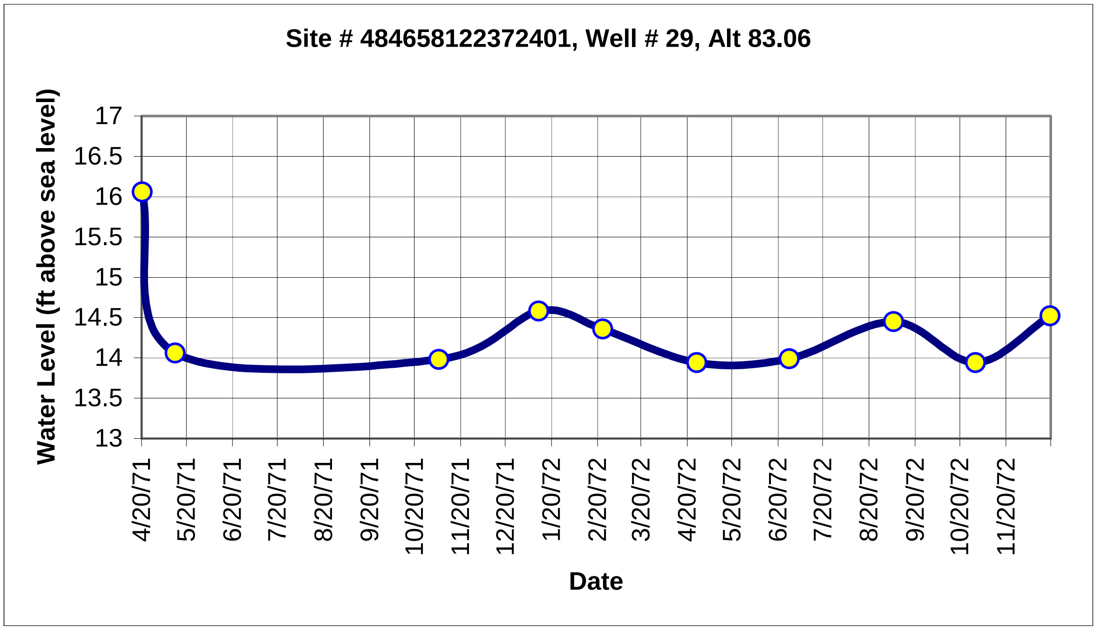


Figure 13.14. Time series for Site # 484658122372401, Well # 29, Alt 83.06

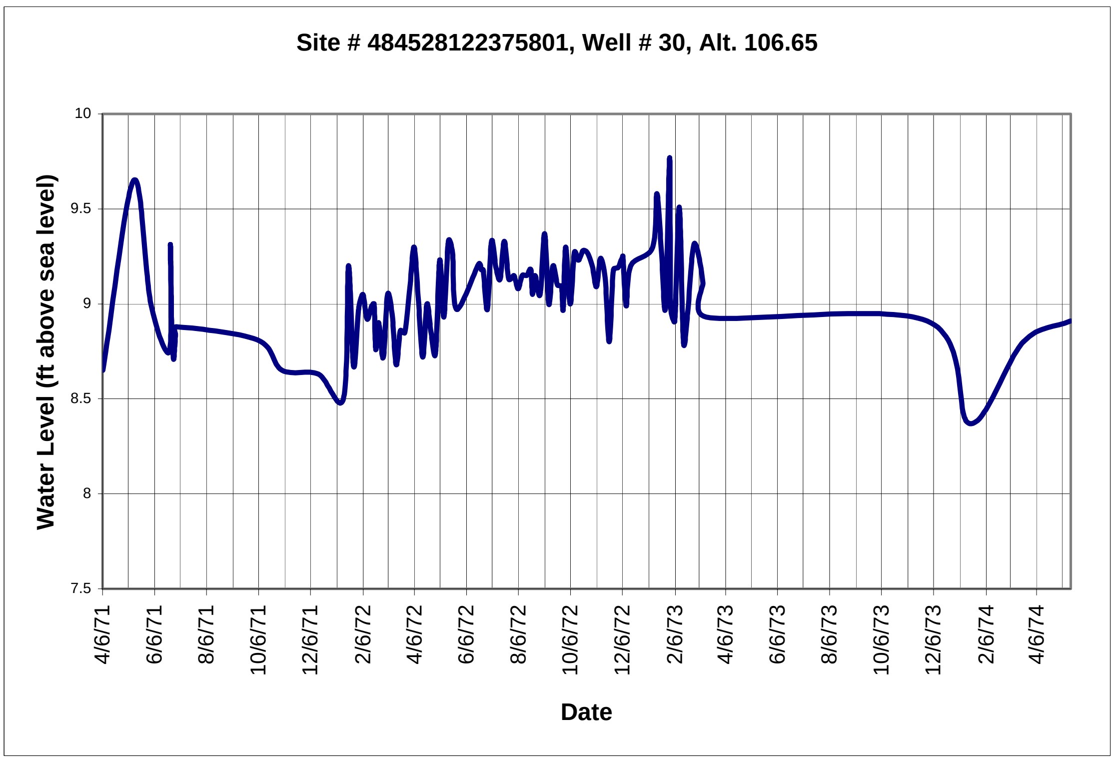


Figure 1.3.15. Time series for Site # 484528122375801, Well # 30, Alt. 106.65

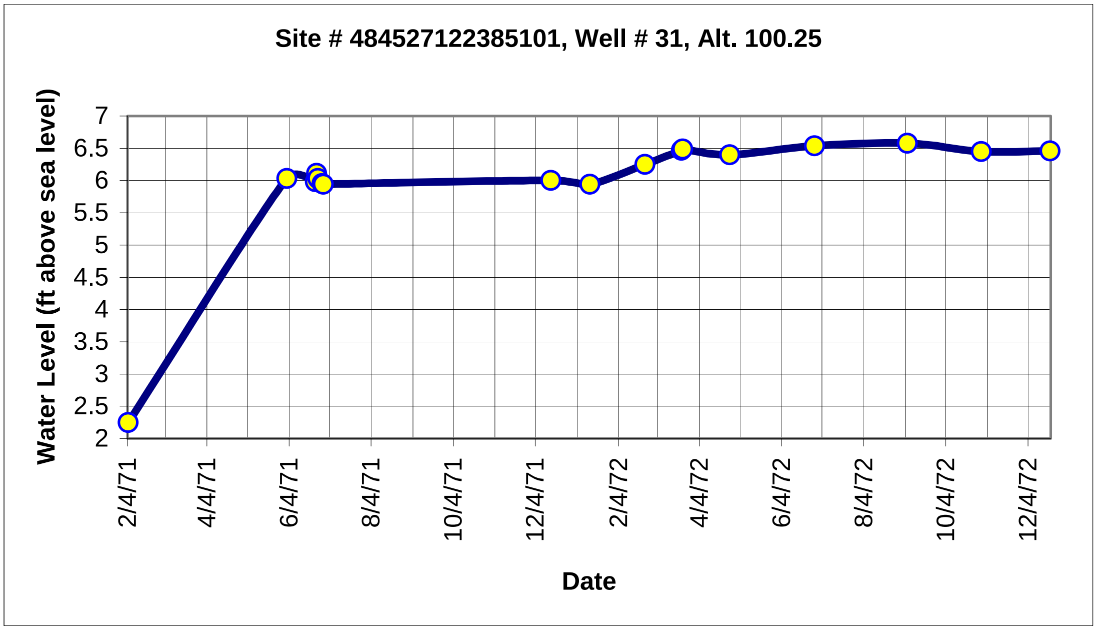


Figure 1.3.16 Time series for Site # 484527122385101, Well # 31, Alt. 100.25

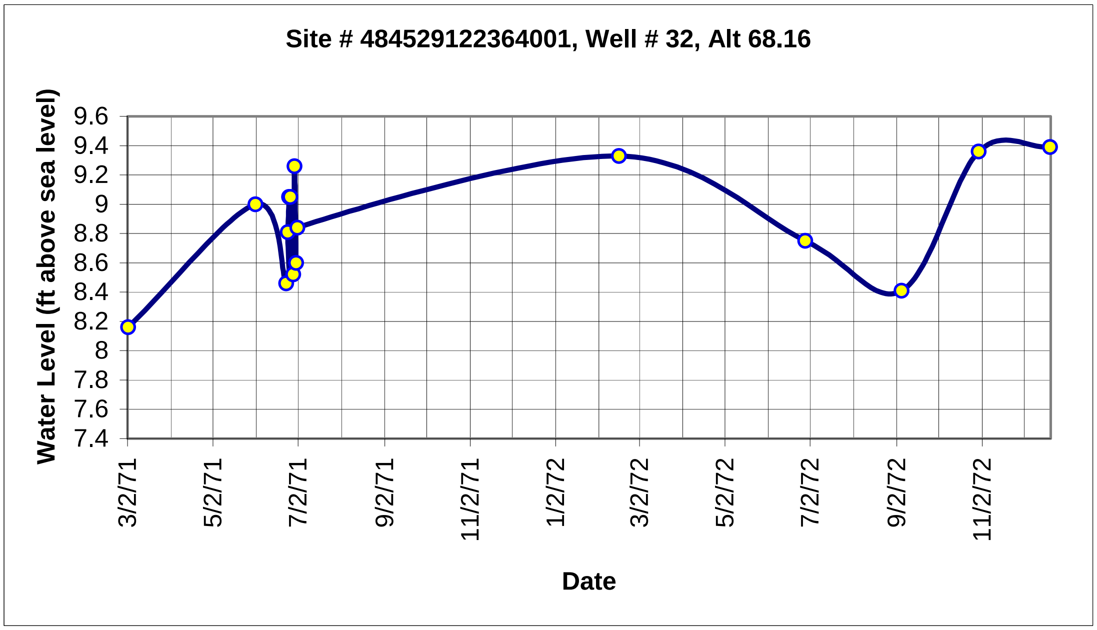


Figure 1.3.17 Time series for Site # 484529122364001, Well # 32, Alt 68.16

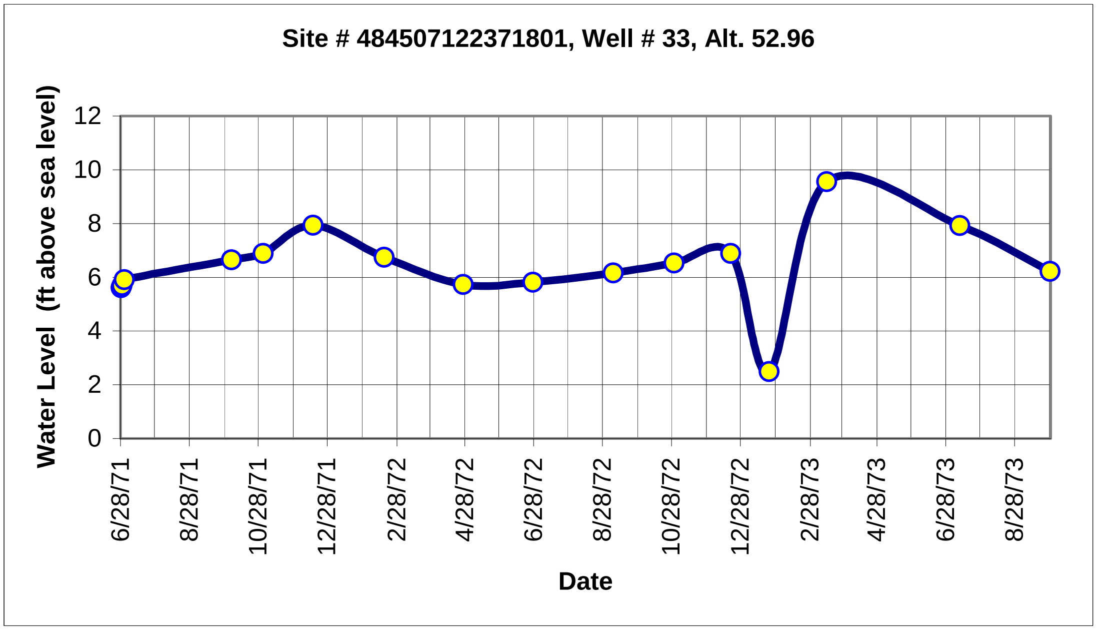


Figure 1.3.18 Time series for Site # 484507122371801, Well # 33, Alt. 52.96

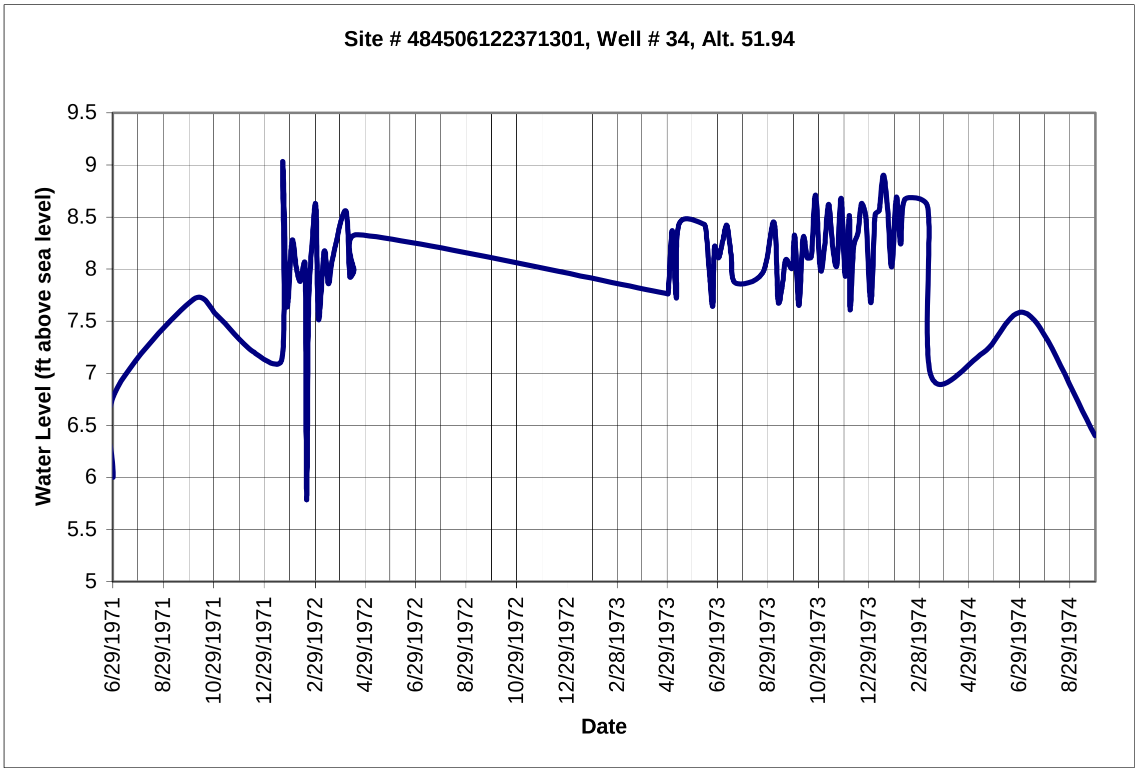


Figure 1.3.19 Time series for Site # 484506122371301, Well # 34, Alt. 51.94

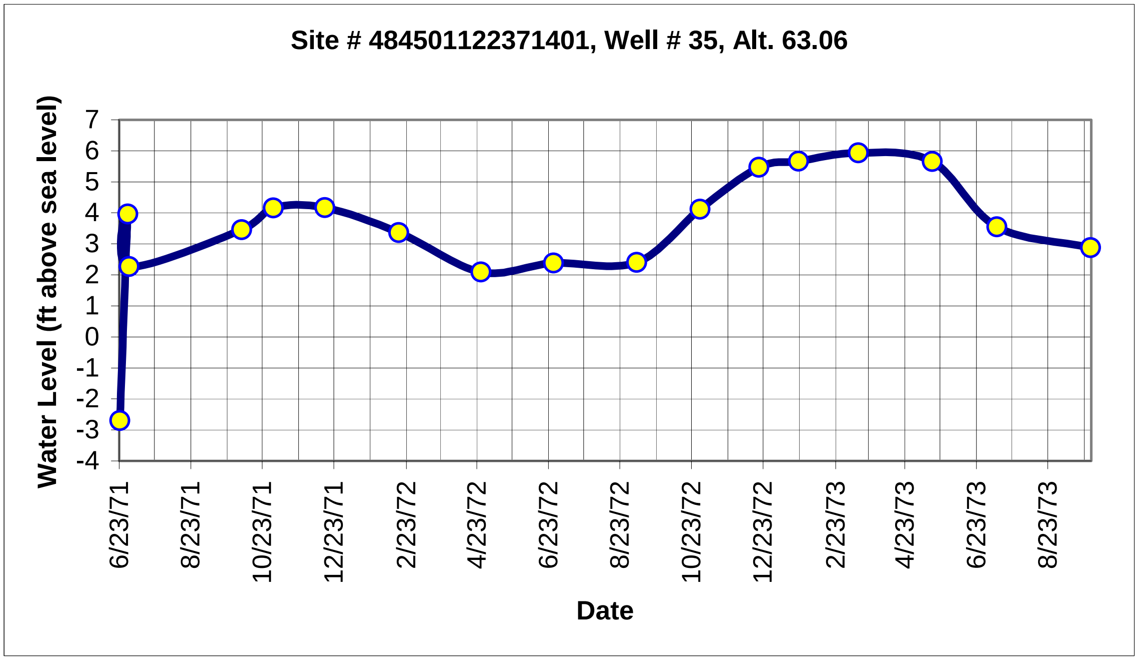


Figure 1.3.20 Time series for Site # 484501122371401, Well # 35, Alt. 63.06

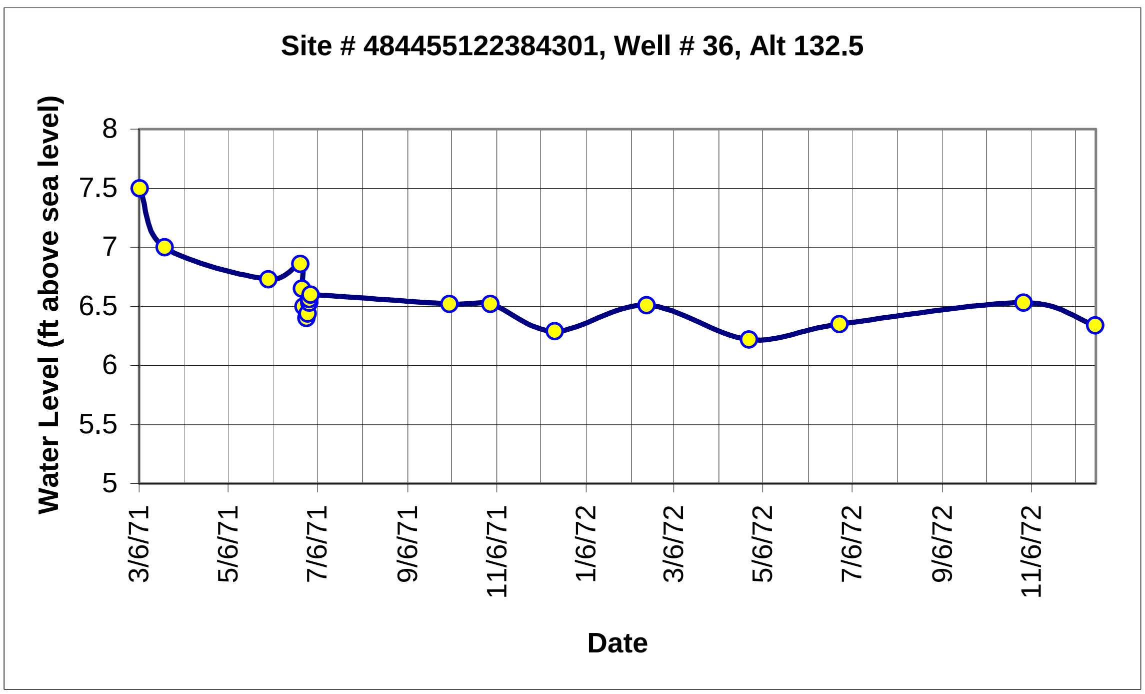


Figure 1.3.21 Time series for Site # 484455122384301, Well # 36, Alt 132.5

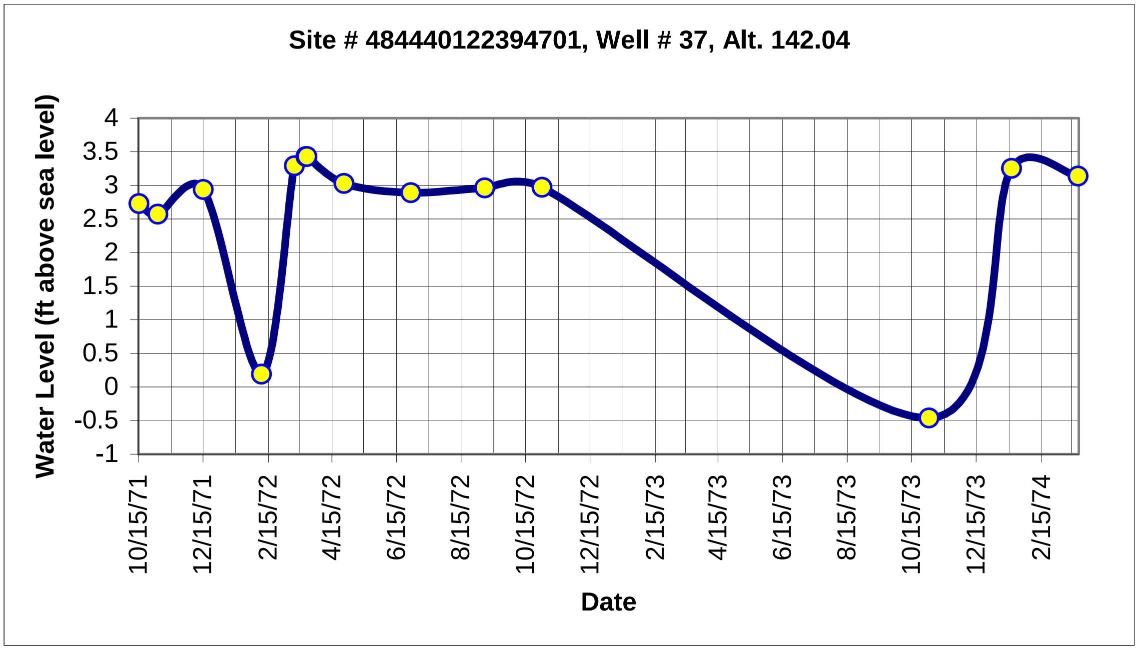


Figure 1.3.22 Time series for Site # 484440122394701, Well # 37, Alt. 142.04

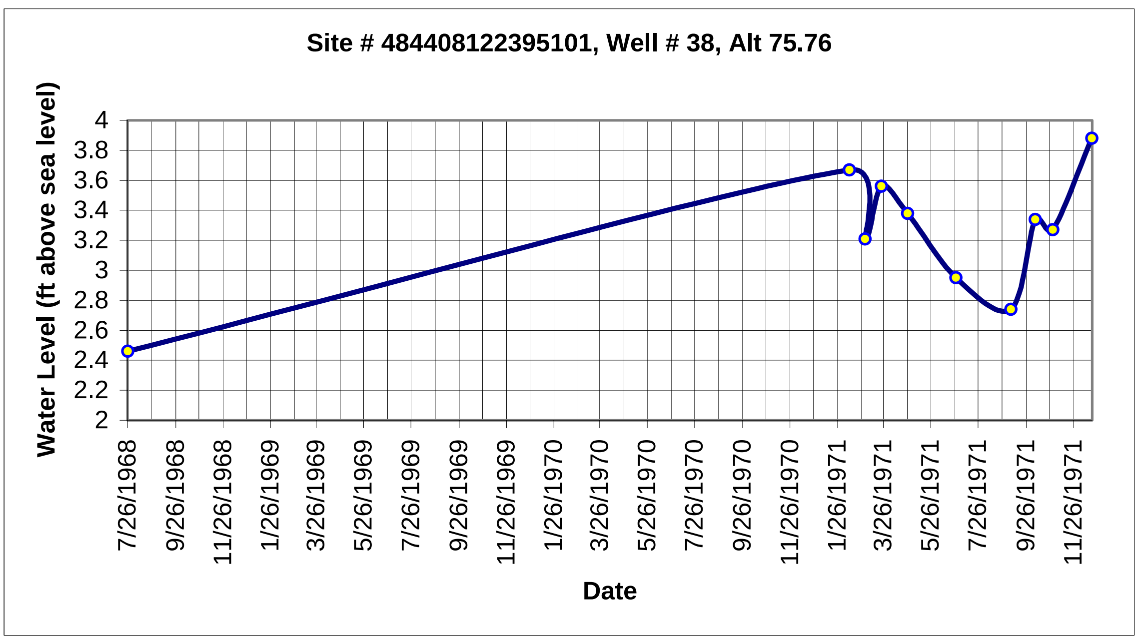


Figure 1.3.23 Time series for Site # 484408122395101, Well # 38, Alt 75.76

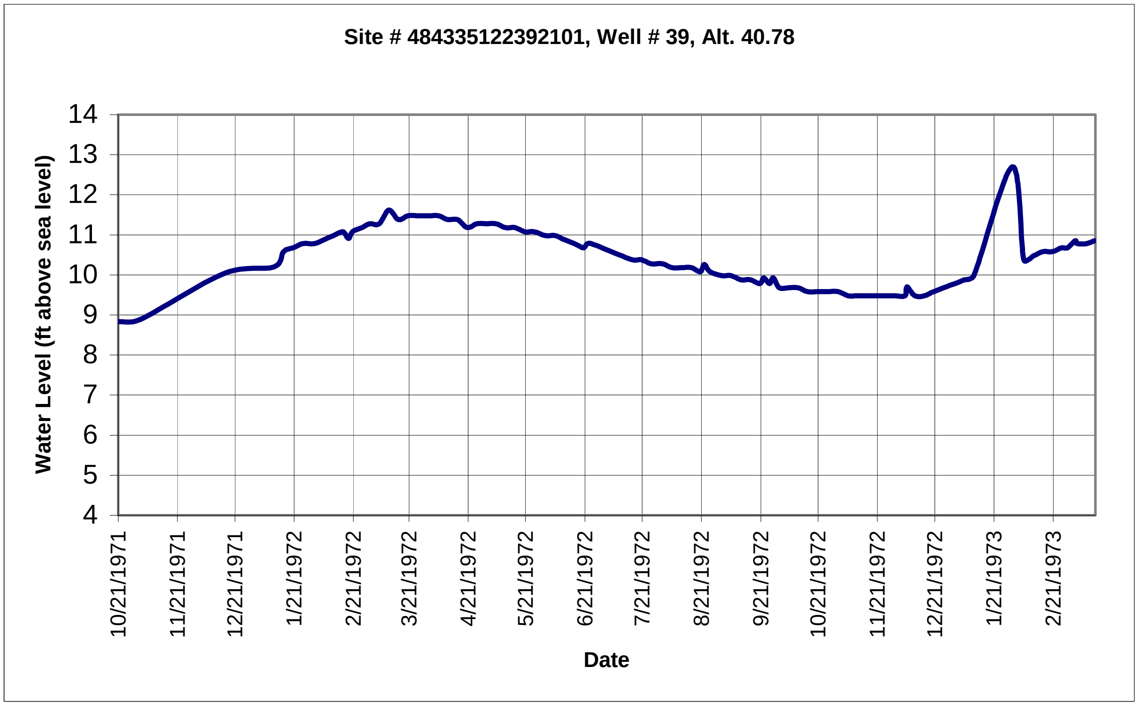


Figure 1.3.24 Time series for Site # 484335122392101, Well # 39, Alt. 40.78

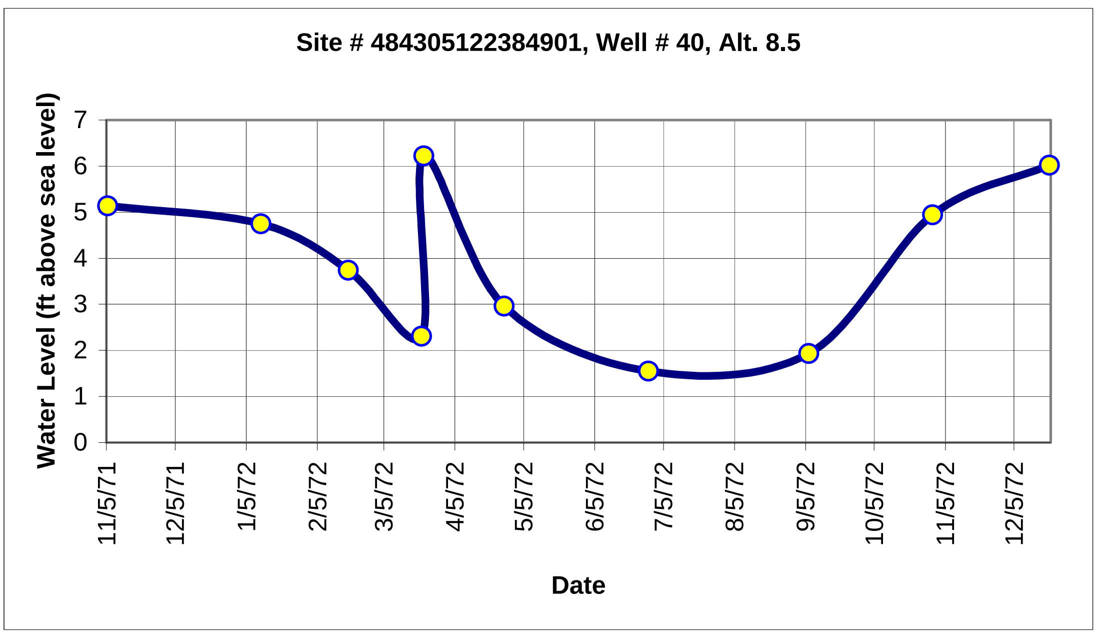


Figure 1.3.25 Time series for Site # 484305122384901, Well # 40, Alt. 8.5

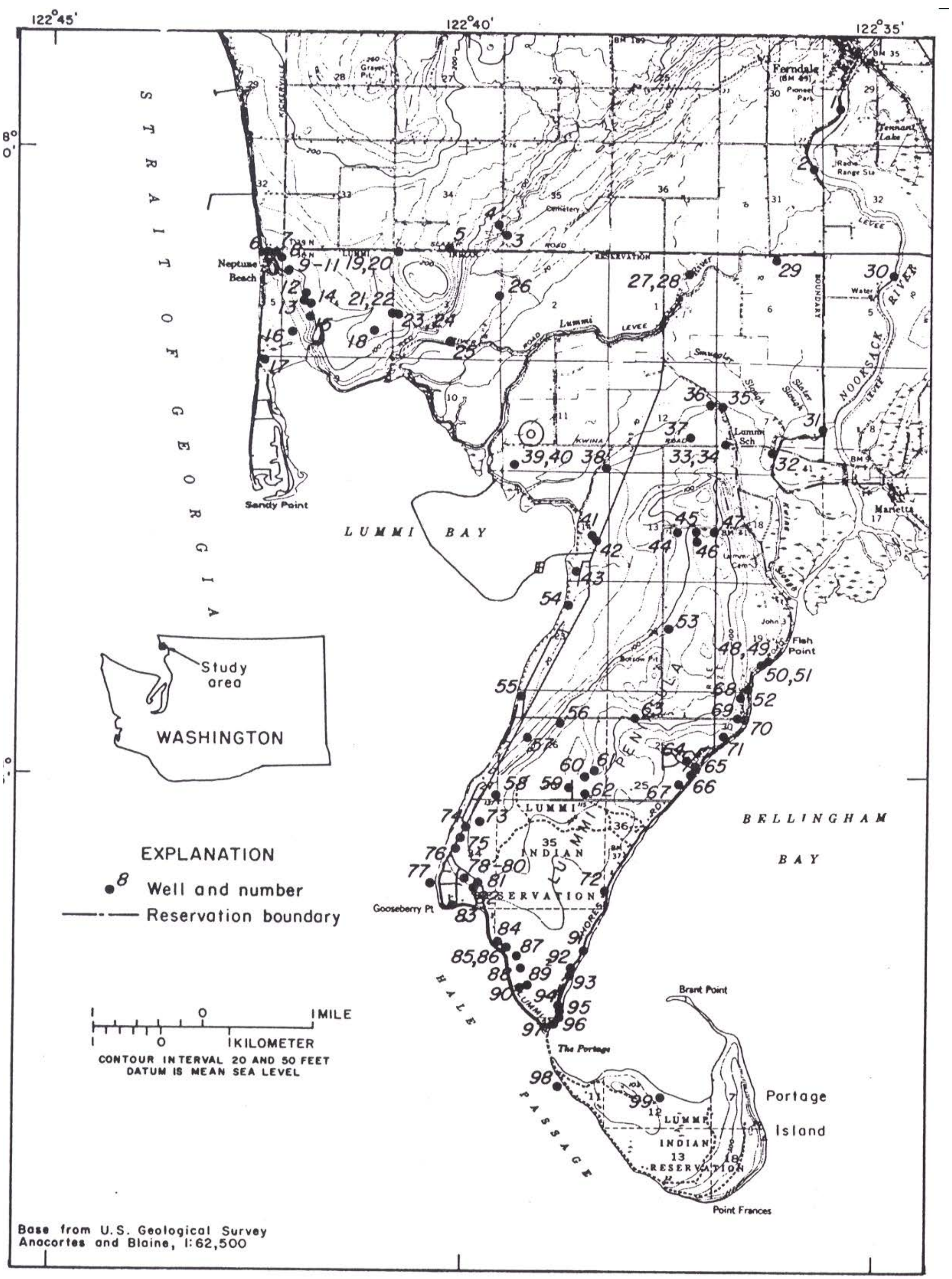


Figure 1.3.26 Area of investigation in Cline (1974) and well locations.

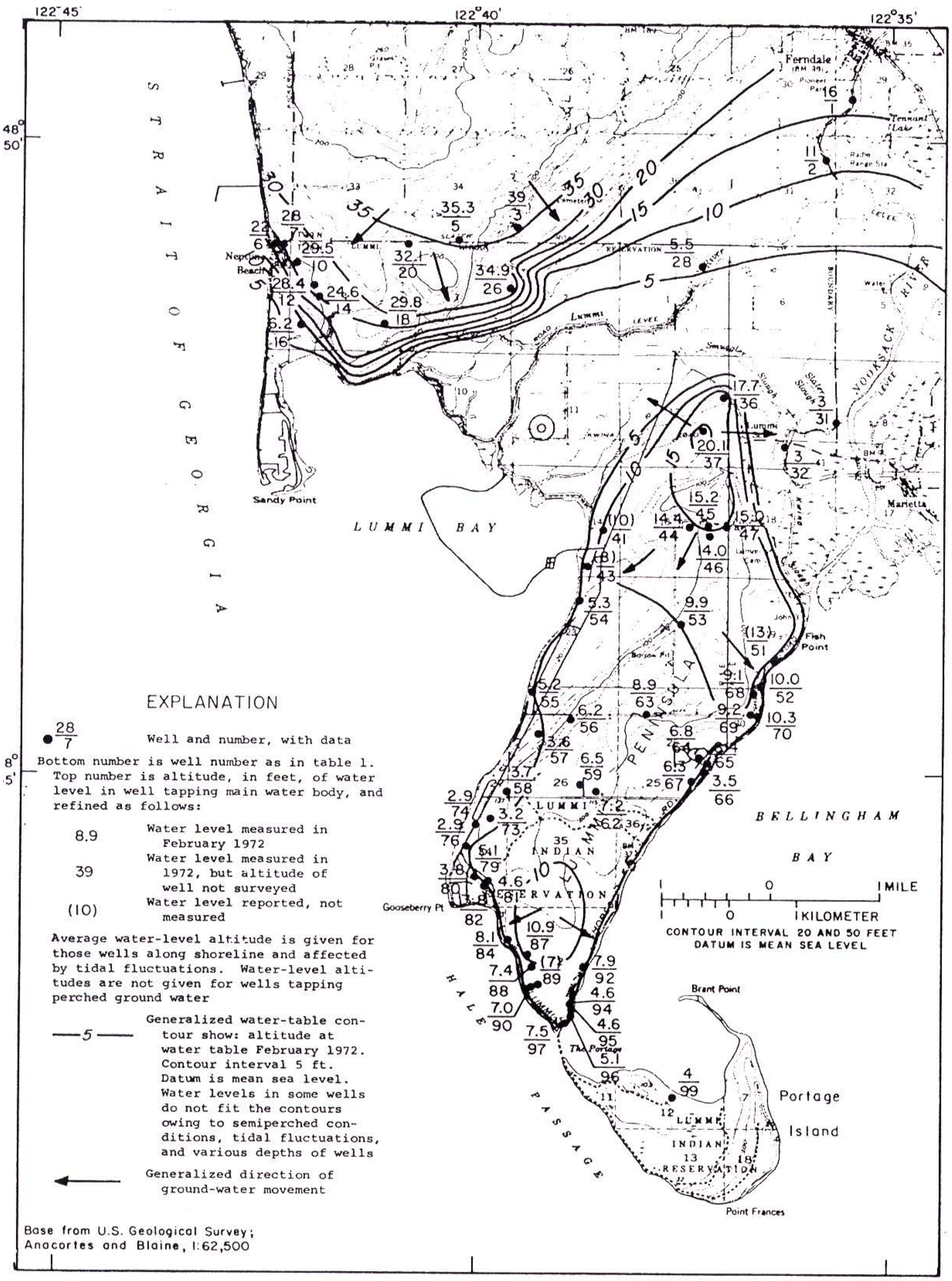


Figure 1.3.27 Water table contours and direction of groundwater movement in the main groundwater body, Lummi Indian Reservation (Source; Cline, 1974).

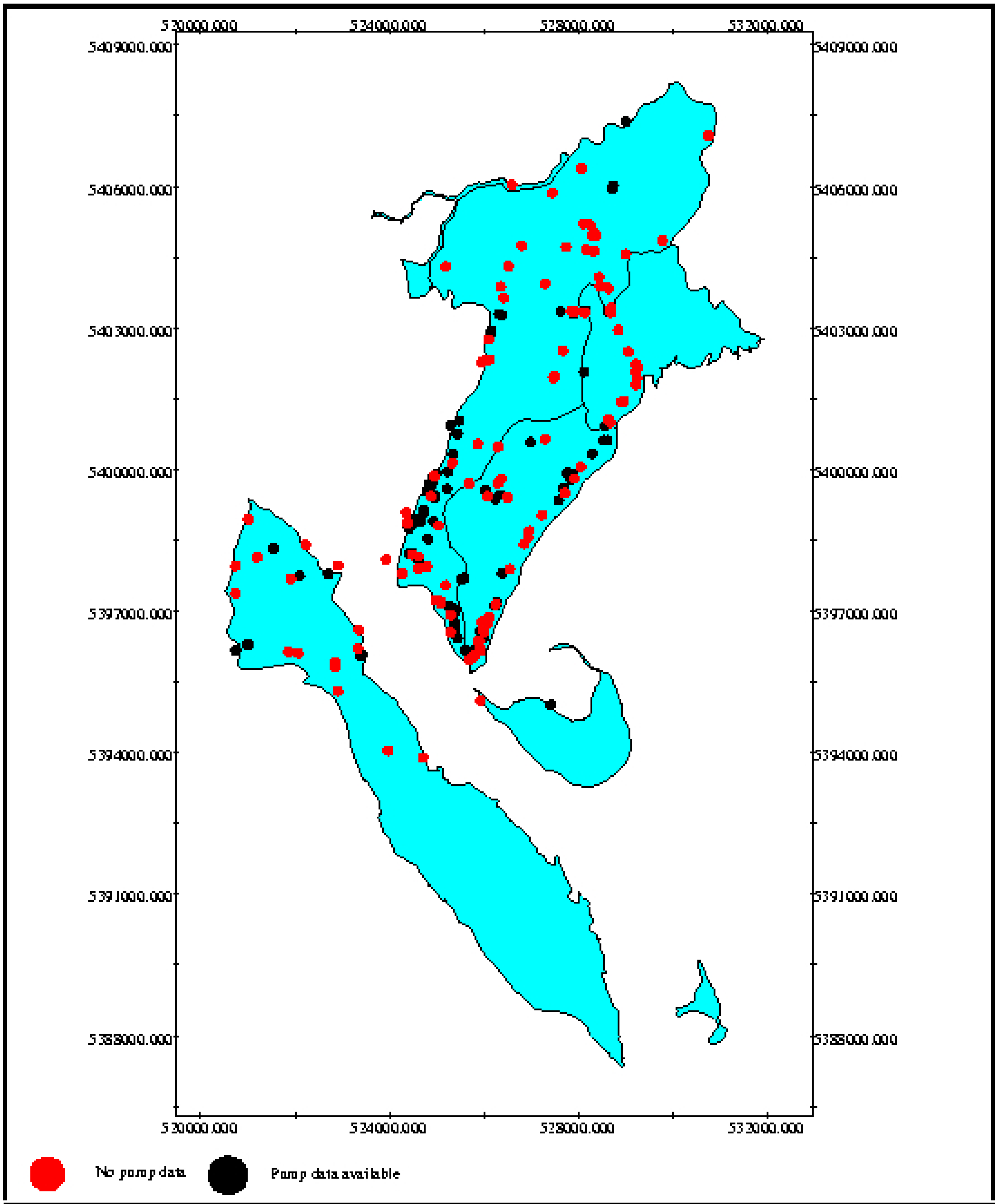


Figure 1.3.28 Areas with and without pump data in Lummi Peninsula, Lummi Island, Nooksack delta and Portage Island.

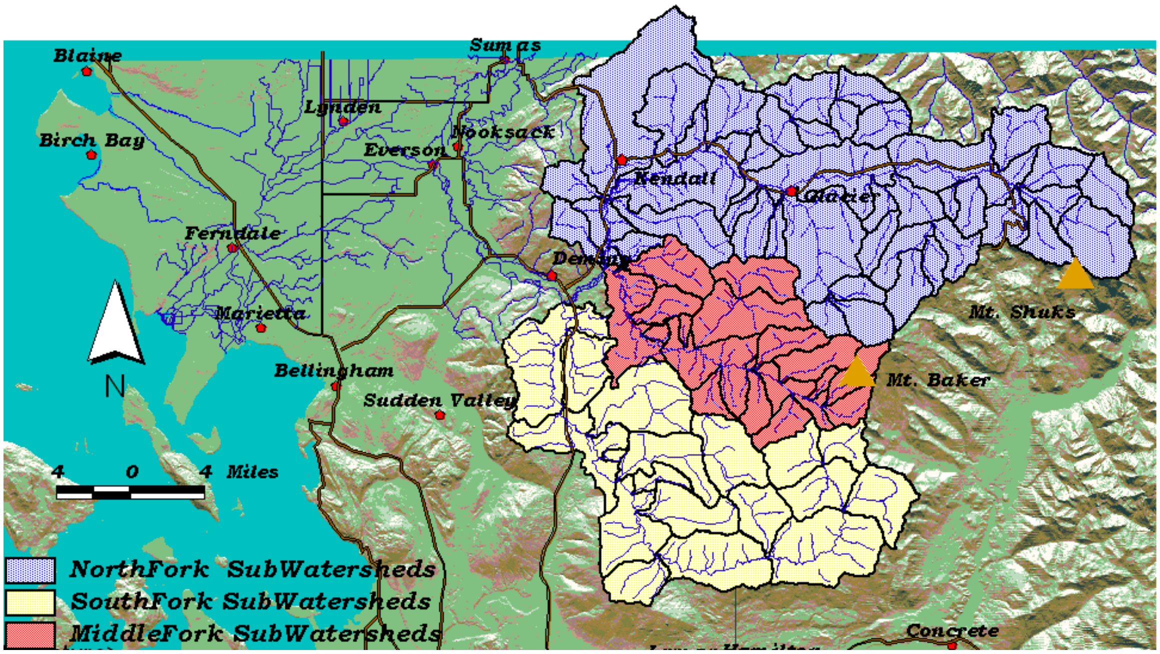


Figure 1.4.1a Watersheds of highlands of the Nooksack basin

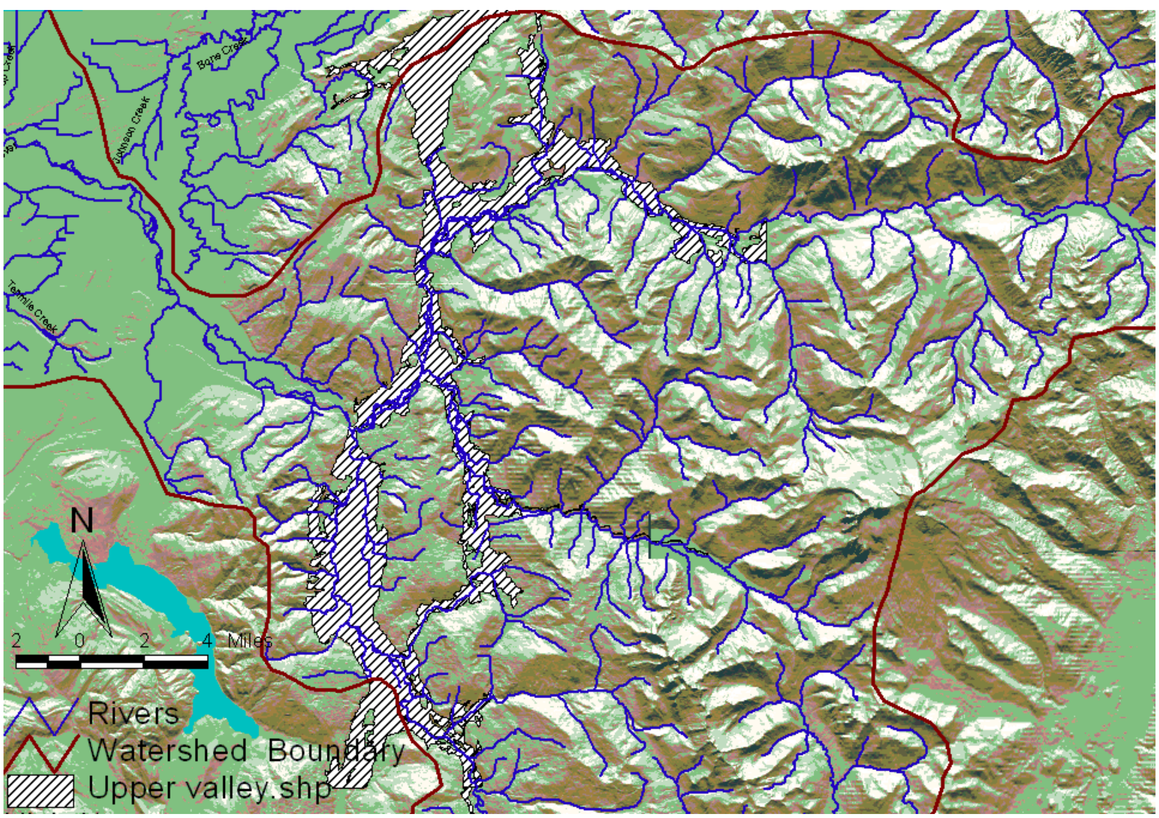


Figure 1.4.2a Upper Valley Aquifers & watershed boundary

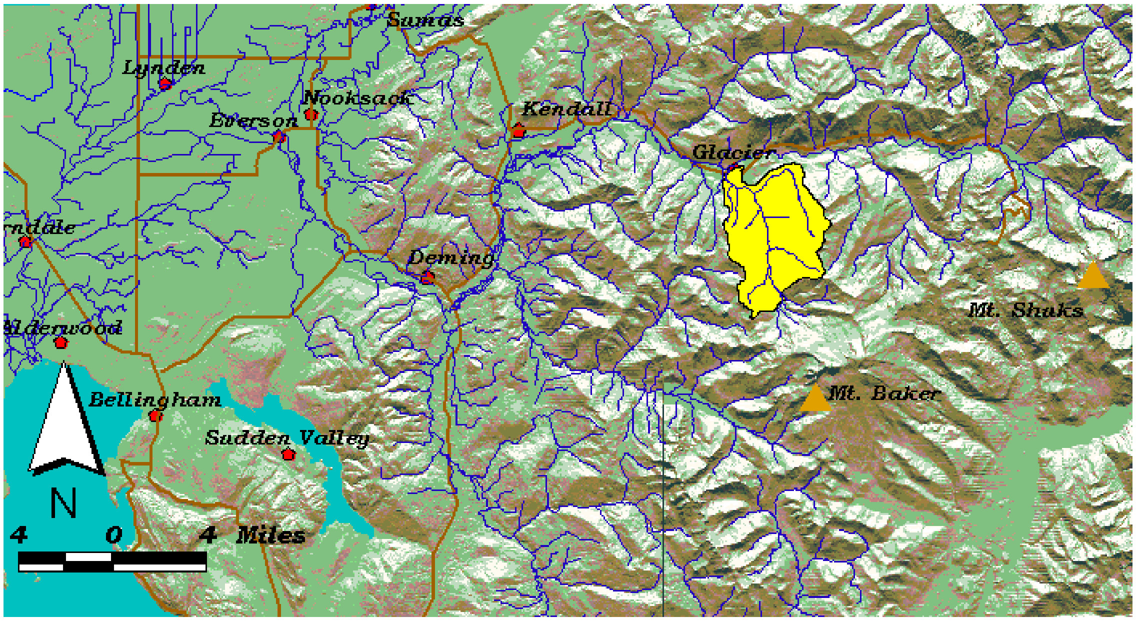


Figure 1.4.2b Location of Glacier Creek & drainage basin

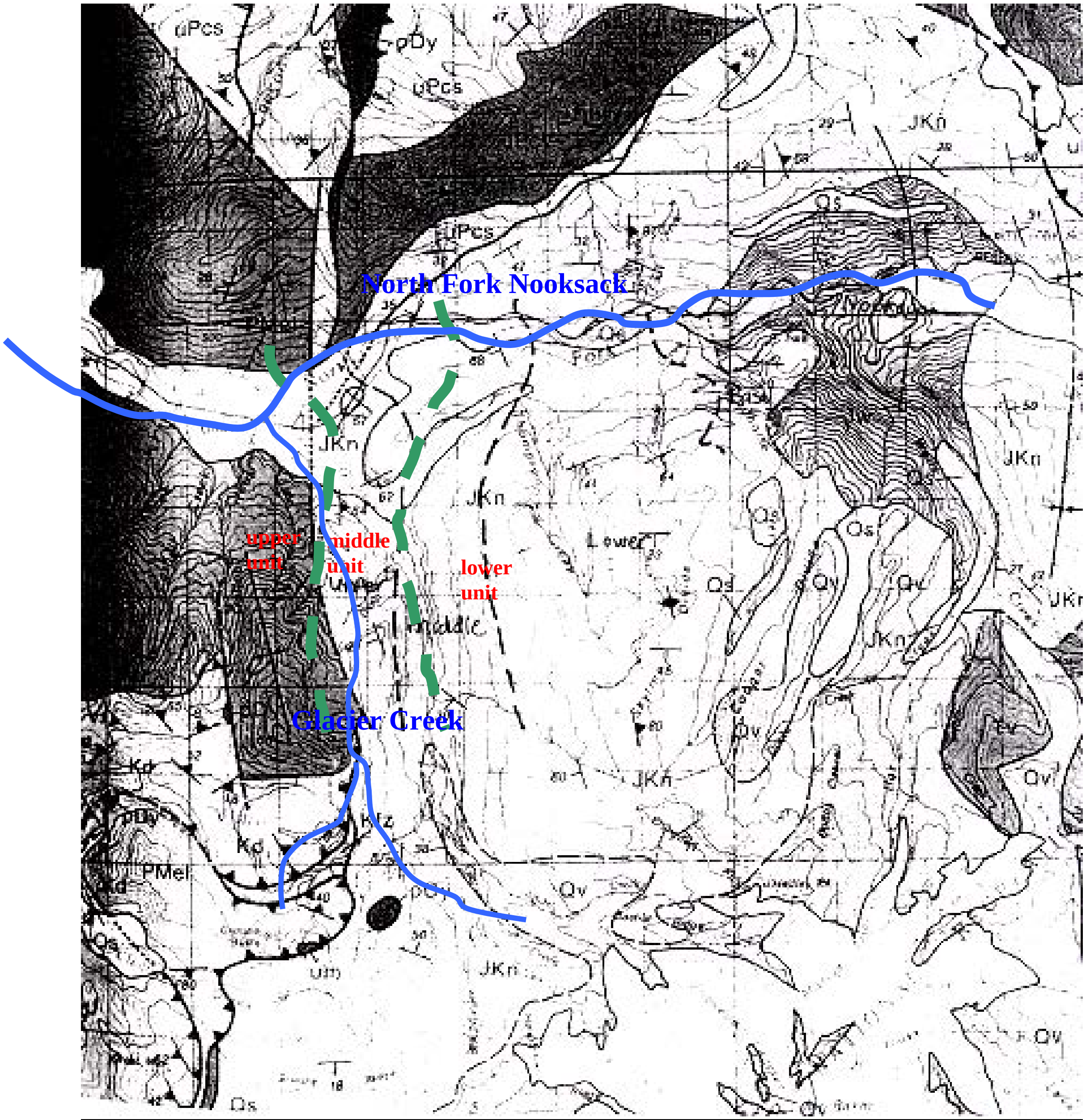
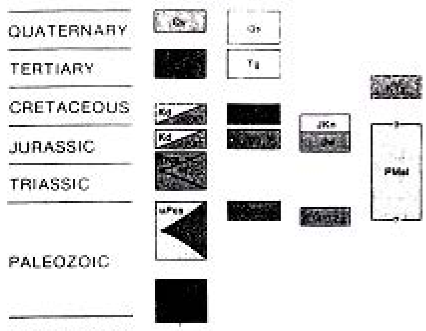


Figure 1.4.3 Geologic Map of Glacier Creek Area part of the Nooksack NorthFork (Source: van Siclen, 1994).

MAP UNITS

- **Qs** — SEDIMENTARY DEPOSITS: unconsolidated surficial materials
- **Qv** — VOLCANIC ROCKS: andesitic deposits related to Mt Baker
- VOLCANIC ROCKS: predominantly andesitic to dacitic pyroclastic deposits
- **Tg** — GRANITIC ROCKS: chiefly granodiorite and quartz diorite
- SEDIMENTARY ROCKS: sandstone, siltstone and shale, mainly Chuckanut Fm
- FAULT ZONE: sheared argillaceous material and serpentinite with blocks of metamorphic rock
- SKAGIT METAMORPHIC SUITE: phyllite, schist, gneiss, meta-granitic rock
- SHUKSAN METAMORPHIC SUITE:
  - **Kd** — DARRINGTON PHYLLITE: chiefly quartzose, carbonaceous phyllite
  - SHUKSAN GREENSCHIST: metabasaltic greenschist and blueschist
  - BARROISITE SCHIST
- BAKER LAKE BLUESCHIST: metabasaltic greenschist and blueschist
- **JKn** — NOOKSACK GROUP: volcanic sandstone, siltstone and argillite
- **Jw** — WELLS CREEK VOLCANICS: slightly metamorphosed andesites and dacites
- **PMel** — ELBOW LAKE FORMATION: metamorphosed ribbon chert, basalt and volcanic sandstone
- CULTUS FORMATION:
  - SEDIMENTARY ROCKS: volcanic sandstone and siltstone
  - KERATOPHYRE
- VEDDER COMPLEX: amphibolite, blueschist, muscovite schist
- DEER PEAK METAVOLCANICS: metamorphosed andesitic to dacitic pyroclastic deposits
- CHILLIWACK GROUP:
  - **uPcs** — SEDIMENTARY ROCKS: slightly metamorphosed volcanic sandstone, siltstone, shale, minor limestone and chert
  - VOLCANIC ROCKS: slightly metamorphosed andesitic pyroclastic rocks
- YELLOW ASTER COMPLEX: gneiss, gabbro, diorite and greenstone
- ULTRAMAFIC ROCKS: dunite, harzburgite, serpentinite

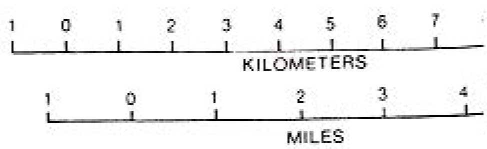
AGE AND CORRELATION OF MAP UNITS



- BEDDING
- OVERTURNED BEDDING
- FOLIATION
- LINEATION: STRETCHED CLASTS
- ANTICLINE
- SYNCLINE
- OVERTURNED ANTICLINE
- OVERTURNED SYNCLINE
- CONTACT

Base from USGS
1:100,000 Baker River (1979),
Sauk (1978), Port Townsend (1973),
and Bellingham (1975).

SCALE 1:100,000



CONTOUR INTERVAL 50 METERS

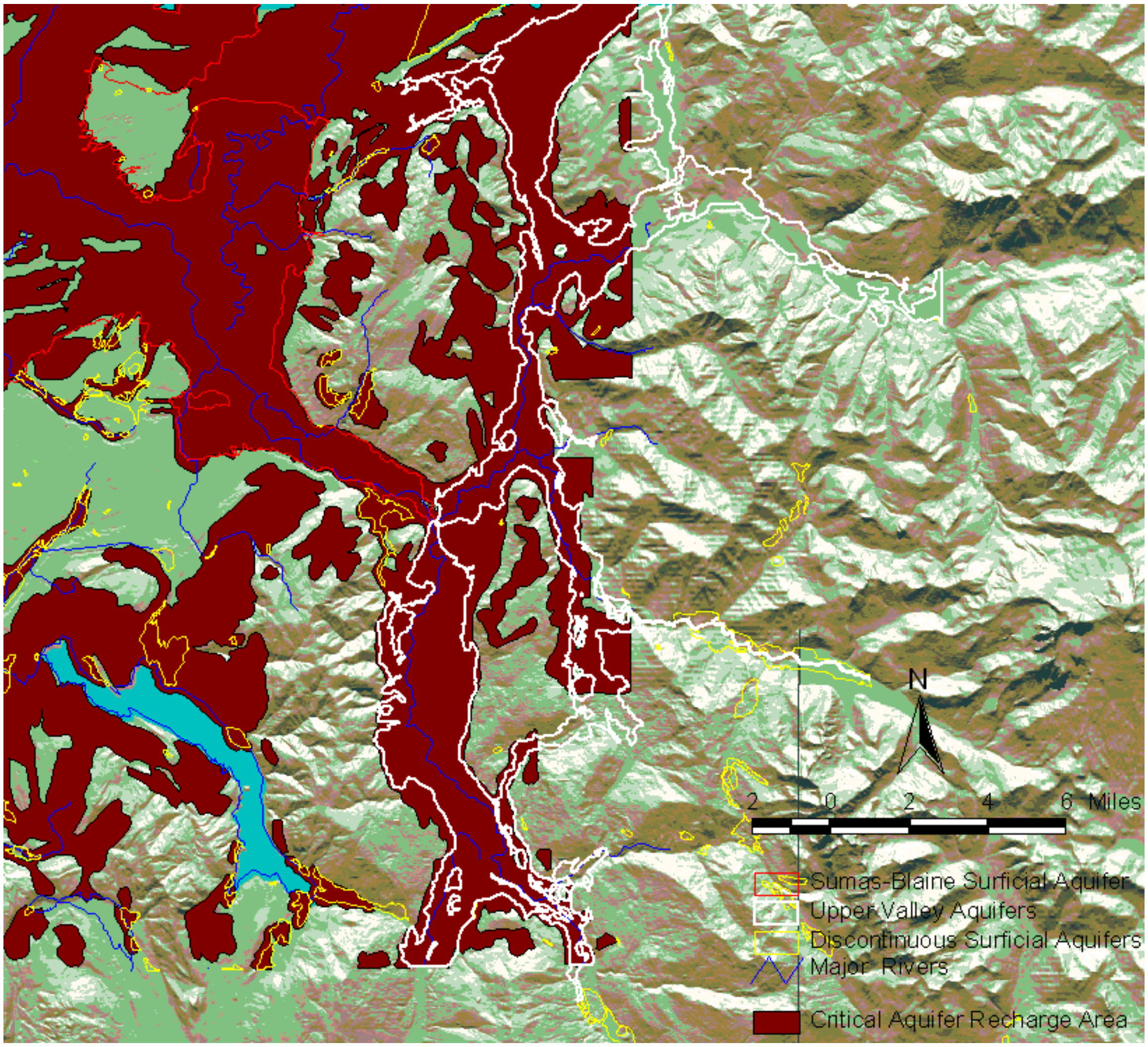


Figure 1.4.4 Upper Valley Critical Recharge Areas & Surficial Aquifer

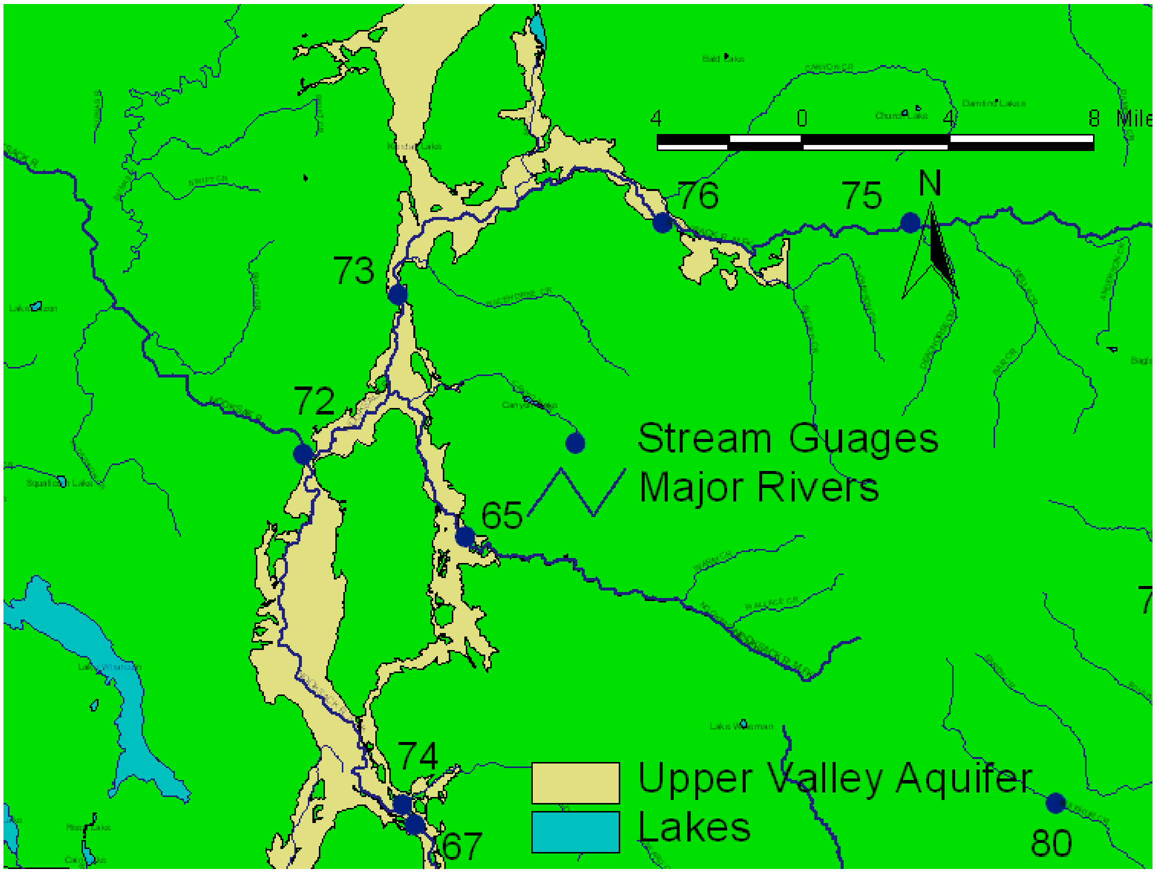


Figure 1.4.5 Baseflow contribution - mean annual (percentage), Upper Valley Aquifer

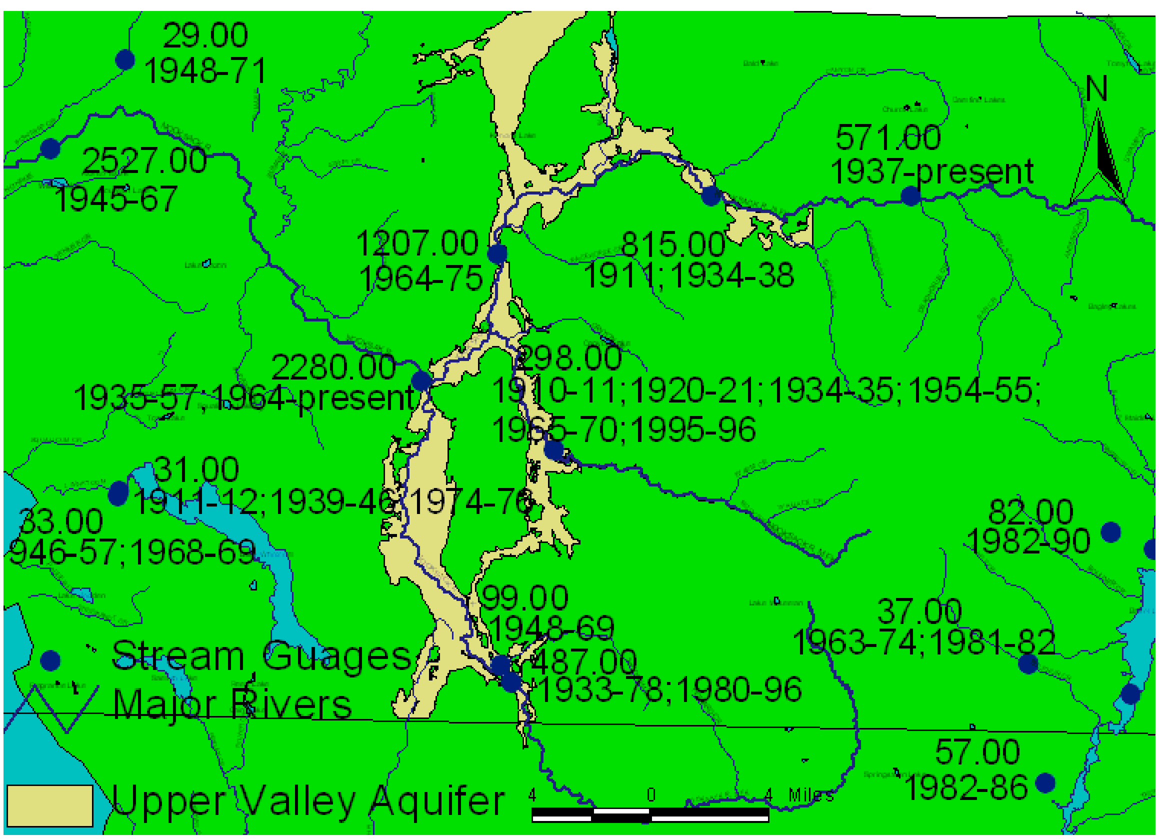


Figure 1.4.6 Baseflow contribution -mean annual (cfs), Upper Valley Aquifer

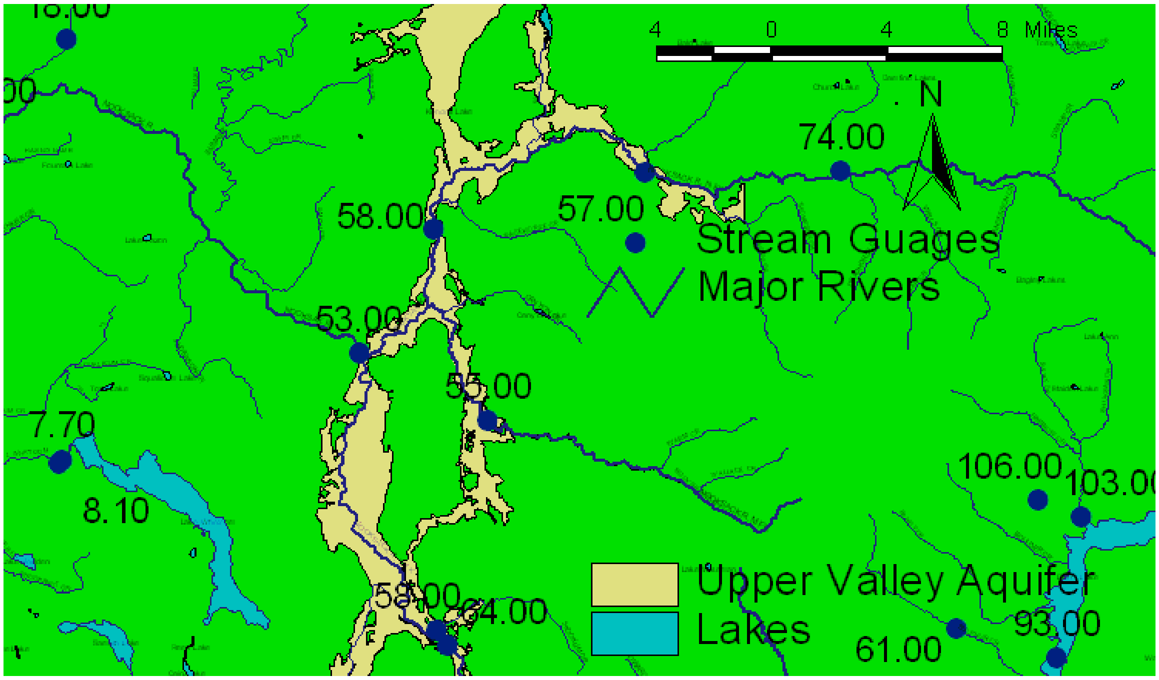


Figure 1.4.7 Baseflow Contribution -mean annual (inches/year), Upper Valley Aquifer

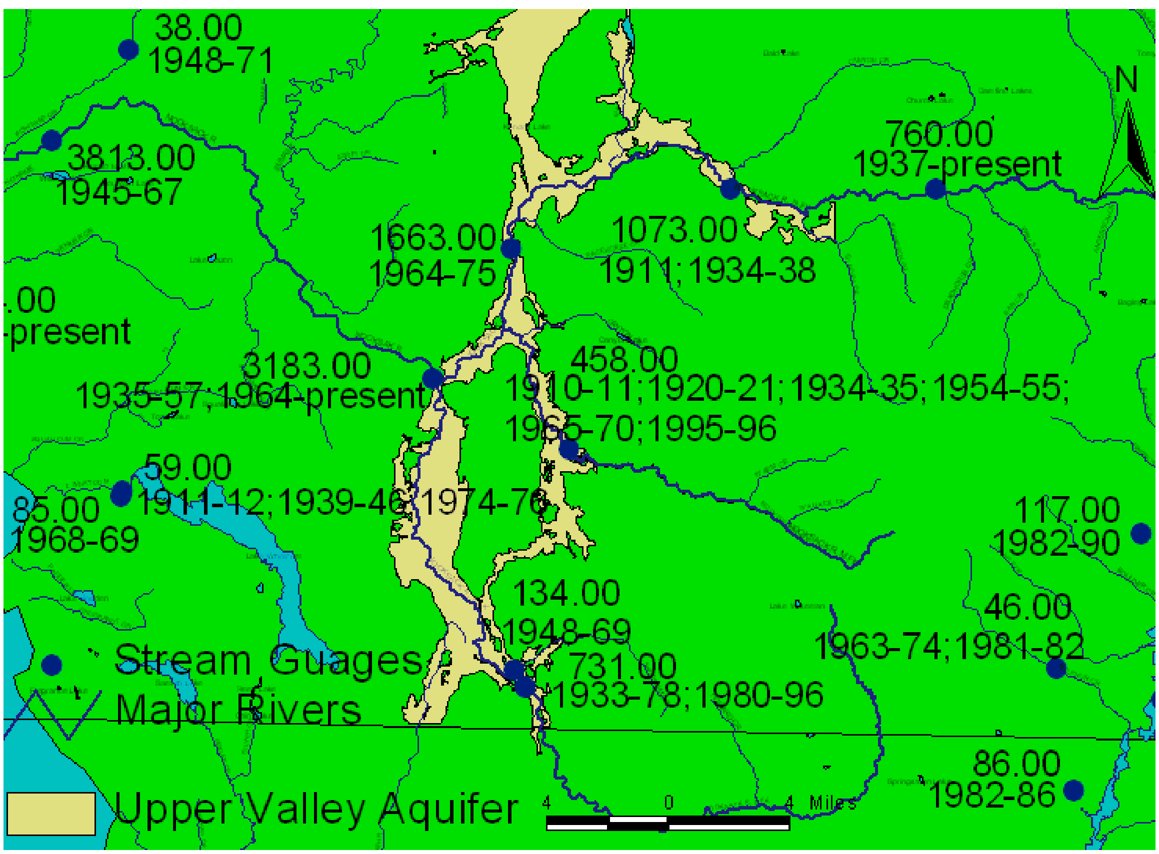


Figure 1.4.8 Mean annual streamflow (cfs), Upper Valley Aquifer

Appendix B

Metadata

Nooksack Groundwater Quantity
Database Description
March 2001

The database placed under the main folder "Nook-Database" can be accessed at the ftp site named ftp://nooksack.cee.usu.edu/Private/Nook-Database/, and located on the USU Nooksack FTP server. If the address changes, please contact rtpack@cc.usu.edu. The folder contains currently available data and is structured to accommodate forthcoming data/information.

The folder contains 10 sub-folders set-up as follows:

1. **Basic stream flow data (**Folder name: *Base flow-data***)**

This contains the Washington Department of Ecology (DOE) compilation of base flow estimation data for 582 stream gauging stations in Washington State (13 stations in the WRIA 1 area) in "dbf" file. The attributes of the file include (in addition to period of records/years of data, station names/station numbers and drainage area in square miles):

Annual data: **Baseflow-data/Annstats.dbf**

a) mean annual baseflow estimates in cfs
b) minimum annual baseflow estimates in cfs
c) maximum annual baseflow estimates in cfs
d) mean annual baseflow estimates in inches (over the associated drainage area)
e) minimum annual baseflow estimates in inches
f) maximum annual baseflow estimates in inches
g) mean annual baseflow estimates in percentages of streamflow
h) minimum annual baseflow estimates in percentages of streamflow
i) maximum annual baseflow estimates in percentages of streamflow
j) mean annual baseflow estimates in cfs per square mile of drainage area
k) minimum annual baseflow estimates in cfs per square mile
l) maximum annual baseflow estimates in cfs per square mile
m) mean annual baseflow estimates in percentages of streamflow
n) minimum annual baseflow estimates in percentages of streamflow
o) maximum annual baseflow estimates in percentages of streamflow
p) mean annual streamflow estimates in cfs
q) minimum annual streamflow estimates in cfs
r) maximum annual streamflow estimates in cfs

Monthly data: **Baseflow-data/seamstr.dbf**

a) mean monthly baseflow estimates in cfs
b) minimum monthly baseflow estimates in cfs
c) maximum monthly baseflow estimates in cfs
d) mean monthly baseflow estimates in inches
e) minimum monthly baseflow estimates in inches
f) maximum monthly baseflow estimates in inches

g) mean monthly baseflow estimates in percentages of streamflow
h) monthly baseflow estimates in percentages of streamflow
i) maximum monthly baseflow estimates in percentages of streamflow
j) mean monthly baseflow estimates in cfs per square mile
k) minimum monthly baseflow estimates in cfs per square mile
l) maximum monthly baseflow estimates in cfs per square mile
m) mean monthly baseflow estimates in percentages of streamflow
n) minimum monthly baseflow estimates in percentages of streamflow
o) maximum monthly baseflow estimates in percentages of streamflow
p) mean monthly streamflow in cfs
q) minimum monthly streamflow in cfs
r) maximum monthly streamflow in cfs
s) mean monthly streamflow in inches
t) minimum monthly streamflow in inches
u) maximum monthly streamflow in inches
v) mean monthly surface run-off in cfs
w) minimum monthly surface run-off in cfs
x) maximum monthly surface run-off in cfs
y) mean monthly surface run-off in inches
z) minimum monthly surface run-off in inches
aa) maximum monthly surface run-off in inches

Seven-day Average: **Baseflow-data/Annstats.dbf**

a) mean 7-day streamflow estimates in cfs
b) minimum 7-day streamflow estimates in cfs
c) maximum 7-day streamflow estimates in cfs

The monthly and annual data for the whole stations are give in files annstats.dbf and seasmstr.dbf while those stations which are within WRIA 1 are give in AsciData sub directory in text format. Station location file is also given.

Annual and seasonal gif files for flows are also given in their respective folders as anngifs and seasgifs.

Table 1 Steamgauges used for baseflow estimation

No	Station No.	**Stream Gauging Station Name**	Period of Record
1	12203000	**Whatcom Cr. nr Bellingham, Wa.**	1911-12;1939-46;1974-76
2	12203500	**Whatcom Cr Blw Hatchery nr Bellingham**	1946-57;1968-69
3	12205000	**N.F. Nooksack R Blw Cascade Cr nr Glacier**	1937-present
4	12205500	**Nooksack (N. Fk.) R. nr Glacier, Wa.**	1911;1934-38
5	12207200	**N.F. Nooksack R. nr Deming, Wa.**	1964-75
6	12208000	**M.F. Nooksack R. nr Deming, Wa.**	1910-11;1920-21;1934-35; 1954-55;1965-70;1995-96
7	12209000	**S.F. Nooksack R. nr Wickersham, Wa.**	1933-78;1980-96
8	12209500	**Skookum Cr. nr Wickersham, Wa.**	1948-69
9	12210500	**Nooksack R. At Deming, Wa.**	1935-57;1964-present
10	12211500	**Nooksack R. nr Lynden, Wa.**	1945-67
11	12212000	**Fishtrap Cr. At Lynden, Wa.**	1948-71
12	12213100	**Nooksack R. At Ferndale, Wa.**	1966-present
13	12214000	**Dakota Cr. nr Blaine, Wa.**	1948-55

2. GIS Layers

GIS data (that can be read in ArcView) were obtained from various sources, primary of the being the Washington State Department of Ecology's (DOE) sites and studies. Most of the GIS layers were prepared from USGS well information as part of the Aquifer Vulnerability Project (Morgan 1996). These data reflect extensive analyses conducted as part of basin groundwater studies with attribute tables showing tabular representation of the GIS information. Contained within this folder are the following sets of GIS layers placed in separate folders

Aquifers

These are DOE layers prepared as part of the aquifer characterization project and include most of the GIS data referred to in the preliminary data review report. The major aquifer GIS layers are:

a) Surficial Aquifer of the Nooksack Watershed, developed from SCS soil survey, hydrogeology, and well information (showing the delineation of three major surficial aquifer zones as well as the non-surficial aquifer zone.) **GIS_Layers/Aquifers/Surficial_Aquifers**
b) Soils lithologic codes/ hydrologic groups (polygons from the Nooksack Surficial Aquifer GIS layer) (Washington State Department of Natural Resources) (Figures. 10,11,12) **GIS_Layers/Aquifers/Litho_code_and_hydrologic**

c) Public Water Supply Wells (Washington Department of Health) (attribute table includes well depth, water treatment type, well capacity, and resident population) **GIS_Layers/Aquifers/Public_wells_doh**

d) Surficial Aquifer depth to water contours based on well information. (Sumas – Blaine /Central Whatcom County) (described as professional interpretation of well water levels to determine the lower limit of depth to water) **GIS_Layers/Aquifers/Depth_to GW**

e) Water Table Contours based on selected wells and surface water elevations (Sumas - Blaine Surficial Aquifer /Central Whatcom County, Washington) (flow direction identifiable- generated from surface analysis of Triangular Irregular Network(TIN) on ArcInfo.) Data source described as : Hydrography from 1:100000 streams intersersected with 7.5' DEM and wells from USGS GWSI and Water Quality Management Areas. **GIS_Layers/Aquifers/Water_table_contour**

f) USGS Wells from Ground Water Site Information (GWSI) Database Statewide information (attribute table information is similar to the USGS GWDATA groundwater/well database) Compiled by the Dept of Ecology (April 1996) **GIS_Layers/Aquifers/USGS96_wells**

g) Surficial Aquifer thickness based on well information (Sumas – Blaine) (prepared by the DOE - data source described as professional interpretation based on well logs), **GIS_Layers/Aquifers/Aq_thickness**.

h) Land Use/Land Cover (LULC) polygon coverage. Created from the USGS GIRAS files by the Dept of Ecology. (uses LULC codes to delineate land use as agricultural, water body, urban areas etc) **GIS_Layers/Aquifers/Land_use**

i) Washington state major shorelines and state boundary. Includes Columbia River and Vancouver Island. **GIS_Layers/Aquifers/Shoreline_washington_boundary**

j) Critical Aquifer Recharge Areas as designated by Whatcom County. ArcInfo poly file rated with recharge potential calculated from local soil percolation rates, surficial geology, and well-log data **GIS_Layers/Aquifers/Recharge_areas**

k) Potential Ground Water Contamination Sources (pulled from Facility/Site database, based on personal professional experience and judgement) (Facilities and Sites regulated by the Dept of Ecology is a separate GIS work) **GIS_Layers/Aquifers/Potential_gw_cont_sources**

l) Wellhead protection zones for Washington state (containing subclasses, one each for 6-month, 1-year, 5-year and 10-year time-of-travel zones/ radii - purpose described as “to prevent adverse impacts to groundwater”). **GIS_Layers/Aquifers/Wellhead_protection_zone**

m) WA DNR 1:24 K scale hydrography **GIS_Layers/Hydrography/**

n) Pointfile showing locations and dates of miscellaneous streamflow measurements done by USGS, WWU, DOE, WCCD, etc. Seepage=1 means seepage measurement exists, 0=no seepage measurement **GIS_Layers/MiscMeasurements/**

o) NRCS soil GIS vector files, (1:20K scale – 1992) **GIS_Layers/soil/soilUTM83**

p) Public Water System well locations. Points were located with GPS device by WCHHSD **GIS_Layers/PWS well locations/pwsutm1983**

q) In addition, layers on Rivers, Sub-Watersheds Roads, Cities, County boundaries, Lakes.. are compiled, **GIS_Layers/Aquifers/Cities**, **County_whatcom**, **Lakes**, **Rivers**, **Roads1**, **roads2**,

r) Whatcom County Health and Humans Services Department (WCHHSD) miscellaneous database with information on topo maps, water rights and water use. **GIS_Layers/well logs WCHHSD/ wriadb2000.mdb**

s) USU seepage measurements **GIS_Layers/seepage/**

t) Recent well head protection zones including both circular and non-circular from WCHHSD. **GIS_Layers/well_head/Data**. Also included in this directory is an excel file (WHPA's) indicating the type of modeling used to delineate the capture zone.

Base flow

GIS layers from the DOE Estimation of Base flow characteristics study are included here.

a) Precipitation. Precipitation contour coverages from the DOE **GIS_Layers/Baseflow/Precip/**
b) Rivers. Rivers GIS coverage from the USGS – HUC (Hydrologic Unit Code) and EPA – River Reach Files **GIS_Layers/Baseflow/Rivers, Mjrrvrs**
c) Sub watersheds. WRIA 1 sub watersheds GIS coverages obtained from Dr Bob Pack. **GIS_Layers/subwatersheds/**

The following GIS layers were prepared within the study group:

a) Well Locations. Well-location layers were prepared from well data/attributes for well-location by aquifer type (2243 wells), wells with time series (> 12 months) (40 wells) **GIS_Layers/WellTimeSeries/wells40**, wells with pumping discharge. (Well-Data\TimeSeries)
b) Water Level. Water elevation layers were interpolated for years of records with the most wells (1971, 1972, 1990, 1991, 1994, 1995) using these point themes. **GIS_Layers/WaterLevels/**
c) Hydraulic conductivity (LENS area). Surficial and non-surficial hydraulic conductivity layers were interpolated for the LENS area **GIS_Layers/HydrCond/**
d) DEM. Those are digital elevation model "quad" layers downloaded from the USGS web site and merged on ArcView to produce the topographic maps of the project area. (They do not include the parts of the project in Canada – as they were not available with the USGS)
e) Depth of impermeable layer interpolated for the LENS study area. These values are obtain from cross-sectional plots of Cox and Kahle, 1999 and interpolated using Arc/Info's TOPOGRID tool. **GIS_Layers/Aquifer/bottom.e00**

3. Maps

USGS pdf maps on project area ground water system & surface water system downloaded from the USGS site.

a) Surficial Hydrogeologic Units of the Puget Sound Aquifer System in the WRIA 1 Study Area **Maps-pdf/mapGW1**
b) Generalized Pattern of Ground-Water Movement for the Puget Sound Aquifer System in the WRIA 1 Study Area **Maps-pdf/mapGW2**
c) Water-Level Contours in the Uppermost Aquifer of the Lynden-Everson-Nooksack-Sumas (LENS) Study Area **Maps-pdf/mapGW3**
d) Locations of Selected Wells in the WRIA 1 Study Area by Primary Water Use **Maps-pdf/mapGW4**
e) Approximate Locations of Aquifer Tests in the WRIA 1 Study Area **Maps-pdf/mapGW5**
f) Locations of Selected Wells in the WRIA 1 Study Area with Sufficient Information to Compute Hydraulic Conductivities **Maps-pdf/mapGW6**
g) Locations of Selected Wells in the WRIA 1 Study Area with Five or More Historical Water Levels **Maps-pdf/mapGW7**
h) Distribution of Soil Map Units in the WRIA 1 Study Area **Maps-pdf/mapGW8**
i) Soil Permeability in Parts of the WRIA 1 Study Area **Maps-pdf/mapGW9**
j) Locations of Sites with Miscellaneous Streamflow Measurements in the WRIA 1 Study Area **Maps-pdf/mapSW1**
k) Locations of Gages with Continuous Streamflow Measurements in and near the WRIA 1 Study Area **Maps-pdf/mapSW2**
l) Locations and Names of 1:24,000-Scale USGS Topographic Maps **Maps-pdf/mapWB1**
m) Watershed Boundaries Delineated from Digital Elevation Models **Maps-pdf/mapWB3**
n) Locations of Climate and Snow-Accumulation Stations in and near the WRIA 1 Study Area **Maps-pdf/mapCET1**
o) Mean Annual Precipitation in the WRIA 1 Study Area (1961-90) **Maps-pdf/mapCET2**
p) Provisional Mean Annual Temperature in the WRIA 1 Study Area (1961-90) **Maps-pdf/mapCET3**
q) Extent of Snow cover in the Pacific Northwest on October 1, 1999 (jpg) **Maps-pdf/mapCE4**
r) Extent of Snow cover in the Pacific Northwest on December 23, 1999 (jpg) **Maps-pdf/mapCE5**
s) Forest Cover in the WRIA 1 Study Area in 1898 **Maps-pdf/mapLU1**
t) Land Use and Land Cover in the WRIA 1 Study Area in 1936 **Maps-pdf/mapLU3**
u) Land Use and Land Cover in the WRIA 1 Study Area from 1973 through 1976 **Maps-pdf/mapLU6**
v) Land Use and Land Cover in Parts of the WRIA 1 Study Area in 1991 **Maps-pdf/mapLU7**
w) Land Use and Land Cover in the Lynden-Everson-Nooksack-Sumas (LENS) Study Area in 1992 **Maps-pdf/mapLU8**
x) Evergreen and Deciduous Forest Cover in the WRIA 1 Study Area in 1992 **Maps-pdf/mapLU9**
y) Forest Density in the WRIA 1 Study Area in 1992 **Maps-pdf/mapLU10**

z) Projected Future Land Use in Whatcom County **Maps-pdf/mapLU11**

4. Well Data

This folder has the well database received from the following sources:

a) USGS Washington. MS Access USGS National Water Information System (NWIS)- **Wells-Data\data\usgs97.mdb** The physical attributes of the well database include, water level (& measurement dates), well depth, pumping discharges, interval depths, lithologic unit code , altitude, X-Y coordinates
b) USGS Well-log database (unprocessed) with the physical attributes shown on Table 2. **Well-Data\USGS\USGS GW Quantity data-originalformat** (zip file)
c) Washington Department of Ecology (DOE). MS Access well database files from Aquifer Vulnerability Project (Laurie Morgan 1996) – (similar physical attributes to USGS database). MS Access database Environmental Investigations and Laboratory Section database - **Wells-Data\data\eils97.mdb** - (similar physical attributes to USGS database)
d) Washington Department of Health (DOH). MS Access database from DOE Drinking Water Section, Public Drinking Water Supply Database – DWAIN **Wells-Data\data\doh97.mdb** (similar physical attributes to USGS database)
e) Whatcom Water Division. MS Excel database. (less physical attributes than the USGS database) **Well-Data\WhatcomWaterDivision\Wells-waterDivision.**
See the GIS part for the well data geographically referenced.
f) Well log data from WCHHSD with 3200 records. It contains three tables which contain well log by parcel, including static water level, date and proposed use (tblWell); stratigraphy of the well log(tblWellMaterial) and results of well test (tblWellTest) **Well-Data\well_log\Well logs WCHHSD**

Also within this folder are sub- folders on:
a) Well time series. MS Excel tables and graphics. Wells with lengthy records of water levels (depth to water) (12 months and more) were identified to be 40 wells in number. Time series plots were prepared for those after computing their water elevations (in feet above sea level) from the well attributes for depth to water and altitude. **Wells-Data/TimeSeries/**
b) Well water levels. MS Excel tables. Prepared for those years with water level data from most wells (1995 -375 wells, 1994-74 wells , 1991- 61 wells, 1990 - 59 wells, 1972 – 57 wells, 1971 – 36 wells) **Wells-Data/WaterLevel**\/

Table 2 Well-log physical attributes (USGS)

	USGS WATER RESOURCES DIVISION	4	CONSTRUCTION HOLE DATA	11	MISCELLANEOUS OTHER DATA
			Record Type		Record Type
	GROUND WATER SITE SCHEDULE		Record Sequence No		Record Sequence No
			Sequence No of Parent Record		Other Data Type
1	GENERAL SITE DATA		Depth to top of Interval		Other Data Location
	Agency Code		Depth to bottom of Interval		Data Format
	Site ID		Diameter of Interval	12	MISCELLANEOUS VISIT DATA
	Project No.	5	CONSTRUCTION CASING DATA		Record Type
	Station Name		Record Type		Record Sequence No
	Latitude		Record Sequence No		Date of Visit
	Longtitude		Sequence No of Parent Record		Name of Person
	Lat-Long Accuracy		Depth to top of Casing	13	MISCELLANEOUS QW DATA
	District		Depth to bottom of Casing		Record Type
	State		Diameter of Casing		Record Sequence No
	County / Town		Casing Material		Date of QW Measurement
	County Code		Casing Thickness		Aquifer Sampled
	Land Net	6	CONSTRUCTION OPENING DATA		Parameter Code
	Location		Record Type		Value
	Map Scale		Record Sequence No	14	MISCELLANEOUS LOGS DATA
	Altitude		Sequence No of Parent Record		Record Type
	Method of Measurement		Depth to top of Interval		Record Sequence No
	Accuracy		Depth to bottom of Interval		Type of Log
	Hydrologic Unit Code (HUC)		Diameter of Interval		Beginning Depth
	Drainage Basin Code		Material Type		Ending Depth
	Topographic Setting		Type of Opening		Source of Data
	Agency Use		Length of Opening	15	MISCELLANEOUS NETWORK DATA
	Date Inventoried		Width of Opening		Record Type
	Station Type	7	CONSTRUCTION MEASURE POINT DATA		Record Sequence No
	Data Type		Record Type		Type of Network
	Instruments		Record Sequence No		Beginning Year
	Remarks		Beginning Date		Ending Year
2	GROUND-WATER SITE DATA		Ending Date		Type of Analyses
	Data Reliability		MP Height		Source Agency
	Site Type	8	CONSTRUCTION LIFT DATA		Frequency of Collection
	Date of Construction		Record Type		Method of Collection
	Use of Site		Record Sequence No		Analyzing Agency
	Use of Water		Type of Lift		Primary Network Site
	Aquifer Type		Date Recorded		Secondary Network Site
	Primary Aquifer		Pump Intake Depth	16	DISCHARGE DATA
	Hole Depth		Type of Power		Record Sequence No
	Well Depth		Horse Power Rating		Date Discharge Measured
	Source of Depth		Manufacturer		Type of Discharge
	Water Level		Serial No.		Discharge (gpm)
	Date Water Level Measured		Power Company		Source of Data
	Method of Water Level Meas.		Power Company Account No.		Method of Discharge Meas.
	Site Status for Water Level		Power Meter No.		Production Water Level
	Source of Water Level Data		Pump Rating		Static Water Level
3	CONSTRUCTION DATA		Additional Lift		Method of Water Level Meas.
	Record Type		Person/Company Maintaining Pump		Pumping Period
	Record Sequence No		Rated Pump Capacity		Specific Capacity
	Date of Construction		Standby Power		Drawdown
	Name of Contractor		Horse Power of Standby Power Source	17	GEOHYDROLOGIC DATA
	Source of Data	9	MISCELLANEOUS OWNER DATA		Record Type
	Method of Construction		Record Type		Record Sequence No
	Type of Finish		Record Sequence No		Depth to Top of Unit
	Type of Seal		Date of Ownership		Depth to Bottom of Unit
	Bottom of Seal		Name		Unit Identifier
	Method of Development	10	MISCELLANEOUS OTHER ID DATA		Lithology
	Hours of Development		Record Type		Contributing Unit
	Special Treatment		Record Sequence No		Lithologic Modifier
			Other ID	18	GEOHYDROLOGIC AQUIFER DATA
			Assigner		Record Type
					Record Sequence No
					Sequence No of Parent Record
					Date
					Static Water Level
					Contribution

5. Surface Water

Data on project area stream flow statistics from the following gauging stations. These include annual and monthly average streamflow, timeseries tables/graphs, locations (lat-long), annual & monthly exceedence relationships. These files are located in **SurfaceWater\NookStream\spreadsheets** The files start with sproul. The Transformed period of records.xls gives the file names corresponding to station numbers.

Table 3. Streamgauging stations in study area

No	Station	Station Name	Records
1	12211500	Nooksack River near Lynden	Daily flow, 1945-1967
2	12208500	Canyon Creek at Kulshan	Daily flow, 1949-1953
3	12210500	Nooksack River at Deming	Daily flow, 1936-2000 (23
4	12209500	Skookum Creek near Wickersham	DF, 1948-1969
5	12214500	Sumas River near Sumas	DF, 1948-1954
6	12214000	Dakota Creek near Blaine	DF, 1948-1955
7	12213100	Nooksack River at Ferndale	DF, 1967-2000 (31 is
8	12212900	Tenmile Creek at Laurel	DF, 1968-1972
9	12212000	Fishtrap Creek at Lynden	DF, 1948-1971
10	12210000	South Fork Nooksack River at Saxon Bridge	DF, 1921-1934
11	12209000	South Fork Nooksack River near Wickersham	DF, 1935-2000 (18 is
12	12208000	Middle Fork Nooksack River near Deming	DF, 1910-2000 (15 is
13	12207200	North Fork Nooksack River near Deming	DF, 1964-1975
14	12206000	Kendall Creek at Kendall	DF, 1948-1950
15	12205500	North Fork Nooksack River near Glacier	DF, 1911-1938
16	12205000	North Fork Nooksack River below Cascade Creek	DF, 1938-2000 (7 is 2000)
17	12203000	Whatcom Creek near Bellingham	DF, 1911-1976
18	12202300	Olsen Creek	DF, 1968-1969
19	12202050	Smith Creek	DF, 1968-1969
20	12202000	Austin Creek	DF, 1949-1970
21	12201950	Anderson Creek near Bellingham	DF, 1969-1972
22	12203500	Whatcom Cr Blw Hatchery Nr Bellingham, Wash.	DF, 1946-1969
23	12206900	Racehorse Cr At North Fork Road Nr Kendall, Wa	DF, 2000
24	12210900	Anderson Creek At Smith Road Near Goshen, Wa	DF, 2000
25	12212050	Fishtrap Creek At Front Road At Lynden, Wa	DF, 2000
26	12212100	Fishtrap Creek At Flynn Road At Lynden, Wa	DF, 1997-1998
27	12207750	Warm Creek Near Welcome, Wa	DF, 1999
28	12207850	Clearwater Creek Near Welcome, Wa	DF, 1999
29	12209490	Skookum Cr Above Diversion Nr Wickersham, Wa	DF, 1999

6. Publications

This has two sub-folders, one on the list of relevant publications from Whatcom county water division library and another on the list of publications available with the USU groundwater quantity study group.

7. Reports

This folder is meant to contain reports produced within the study group and has the preliminary –data review report within it.

8 Preliminary data review report

This report has a separate folder from the above containing the text and the images used in the report.

9 Images

Included within this folder are images (jpg, bmp) used in report preparations

10 Miscellaneous

Nothing at the moment but could contain project miscellany such as correspondences

Nooksack Database structure