

NANAIMO RIVER BASIN
WATER MANAGEMENT PLAN
GROUNDWATER RESOURCE EVALUATION
AUGUST, 1991

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INTRODUCTION

The Nanaimo River Basin Water Management Planning study was initiated by the Nanaimo Regional office to assess the supply and demand of water in the Nanaimo River system for licensed water users and for instream fisheries needs. The purpose of this office evaluation is to provide Water Management Program with an overview of the hydrogeological conditions within the Nanaimo River basin including:

- locations of groundwater reservoirs (aquifers),
- extent of groundwater use and potential for further development,
- groundwater quality conditions and concerns,
- surface water / groundwater inter-relationship.

The following report is based on a review and analysis of available groundwater reports, water well record data, geologic reports and maps on file with the Groundwater Section and information provided by MacMillan Bloedel's Harmac Pulp Division.

GEOLOGY & PHYSIOGRAPHY

Figure 1 shows the distribution of surficial geologic materials within the basin area, which is predominantly within the East Coast Lowland of Vancouver Island. Bedrock is exposed over much of the Lowland area and according to Halstead (1961), consists mainly of Cretaceous Nanaimo Group shale, sandstone and conglomerate; whose weaker units have been eroded to form longitudinal valleys, with the more resistant units resulting in cuesta-like ridges. Several transverse valleys cut these longitudinal valleys; through the largest of these, the Nanaimo River flows eastward from the upland, then flows north to Nanaimo Harbour, in which it is building a large delta.

According to Halstead (1961 & 1967), the area has undergone glaciation. During the retreat and wastage of the last major ice advance, sea levels were considerably higher than at present.

Heavily loaded streams issuing from valley glaciers in Nanaimo River and Haslam Creek valleys deposited sand and gravel as deltas into a sea that was about 500 feet higher than present sea level. Marine and glacio-marine deposits were laid down in the seas that overlapped the Lowland and left a veneer of marine gravel, sand or silty clay with fossil shells.

During the period of lowering of sea level to the present, streams deposited gravel and sand and cut terraces in older deposits, and clays and silts were continually being deposited in the deeper waters. The deltaic sand and gravel deposits in the Nanaimo River valley are the source of the extensive aquifers in the basin.

WATER WELL DATA

Figure 1 shows the locations of approximately 1,500 water wells reported to have been constructed in the region which includes the Nanaimo River basin. However, this does not represent all wells constructed in the area, since there is no mandatory submission of well records in this province. Also, there are a number of well records collected from water well drillers but not yet processed into the groundwater data base system. The accompanying graph (Figure 1.1) has been prepared to show the cumulative number of wells constructed in the area over the past 40 years.

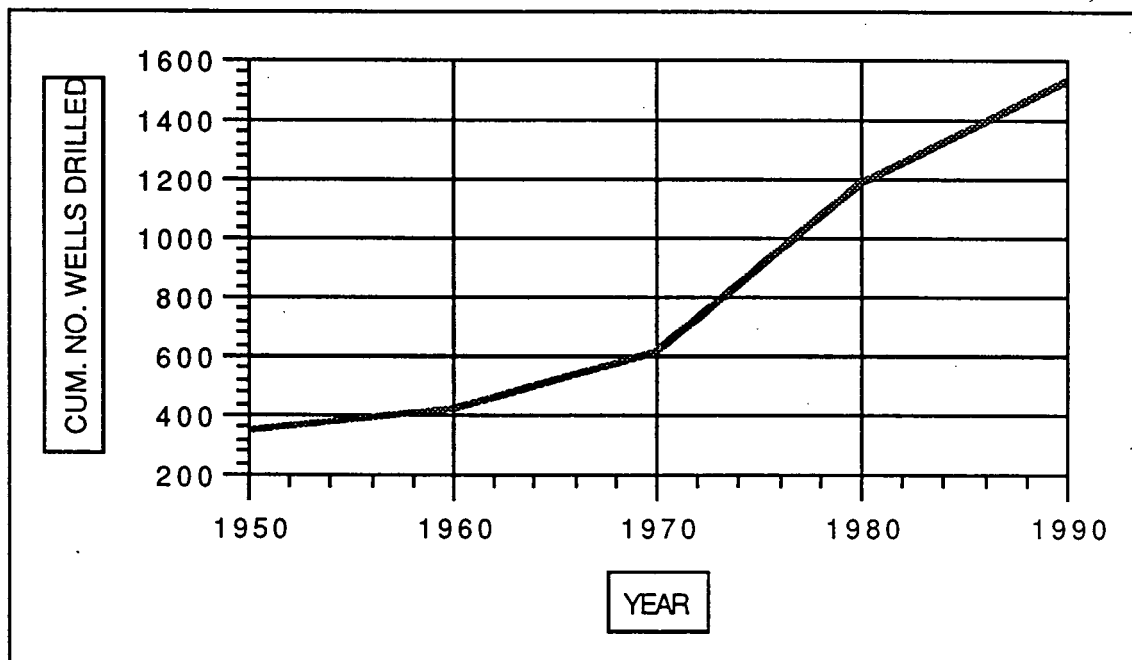


FIGURE 1.1 : Number of wells constructed, Cassidy Area

GROUNDWATER POTENTIAL - BEDROCK

Figure 1 shows the extent of bedrock exposure (bare and shallow surficial veneer over bedrock). This map also shows that the majority of water wells (approximately 75%) constructed in the area are in bedrock. Wells constructed in bedrock generally obtain groundwater from water-filled fractures in the rock. Because fractures can be erratic in their extent, positions and concentrations, and the open volume only occupies about 1% of the rock mass, the amount of groundwater that is available for extraction can be limited. Additional groundwater can also be recovered from porous bedrock, such as some sandstones.

Approximately 87% of the wells constructed in bedrock have reported yields less than 10 gpm (0.6 L/s), but generally sufficient for domestic needs. Approximately 12.5% of the bedrock wells (about 140 wells) have reported yields between 10 gpm and 49 gpm (3 L/s). There are only 0.5% of the bedrock wells (6 wells) that have reported yields between 50 and 100 gpm (6 L/s). These higher yields are not confirmed by long term pumping tests, but are based on drillers' short term tests. Longer term (up to 72 hours) constant rate pumping tests would be needed to assess the long term safe yields of these wells.

It is difficult to assess the potential for further development of water wells in bedrock, due to the lack of pumping test data and the uncertain nature of bedrock fractures. Additional wells in bedrock may be constructed, however, most yields are expected to be limited to meet only domestic needs. In areas where there are concentrations of wells, for example, South Wellington and east of Cassidy, construction of additional wells in bedrock may not be advisable due to potential pumping interference effects and the limited amount of groundwater in storage in the fractures of the bedrock to sustain additional groundwater withdrawals.

GROUNDWATER POTENTIAL - UNCONSOLIDATED DEPOSITS

Figure 2 shows the general extent of the major unconsolidated confined and unconfined groundwater aquifers in the area, generally referred to as the **Cassidy Aquifer**. In delineating the areal extent of the unconfined aquifer, the first consideration was the location of permeable sand and/or gravel deposits as outlined by Halstead (1961). The present extent of the Cassidy Aquifer, as shown in Figure 2 was subsequently modified by analyzing additional geological information from water well drillers' lithological logs as contained in numerous water well

records and from interpretation of hydrogeological cross-sections (Figures 3 - 9). Analysis of the hydrogeological cross-sections also identified the probable extent of a significant confined sand and gravel aquifer in the Cassidy area.

For the purpose of this assessment, the unconfined Cassidy Aquifer has been subdivided into 6 discrete areas, (A to F), as shown in Figure 2. The following is an evaluation of each of these aquifer areas. Table 1 summarizes some pertinent information regarding each of these areas.

AQUIFER AREA "A"

There is very limited groundwater information by way of water well records, etc. regarding this aquifer area. The area is underlain by permeable fluvial and glaciofluvial sand and gravel deposits. The limited well record data indicates that the thickness of the unconfined aquifer is about 20 feet (6 m).

Groundwater levels range from about 240 ft. (70 m) elevation in the northwest part of the aquifer to about 120 ft. (35 m) elevation in the southeast part of the aquifer. Figure 2 shows that the predominant direction of groundwater flow is in an eastern direction; from the Upland area towards the Nanaimo (Cassidy) airport area.

An evaluation of well record data and interpretation of cross-section (Figure 4), suggests that part of a confined (or semi-confined) aquifer underlies the southeastern section of Aquifer area "A".

As indicated in Table 1, the amount of groundwater in storage is estimated at about 3.8×10^9 gallons, of which about 3.3×10^9 gallons may be available for extraction. The unconfined and confined aquifers receive an estimated 1.3×10^9 gallons of recharge each year from precipitation. This is equivalent to continuous pumping at about 2,500 gpm. According to Nasmith (1952), Aquifer Area "A" receives significant additional recharge from influent seepage from the Nanaimo River and Haslam Creek.

Extraction of groundwater in excess of the annual recharge from precipitation may induce additional seepage of Nanaimo River and Haslam Creek flows into the aquifer, thereby reducing surface flows to some extent. The degree of surface water / groundwater inter-relationship and potential conflict with licensed use needs to be further evaluated.

As previously indicated, there are at present very few reported records of wells for this area. Extraction of groundwater is likely limited to meet domestic needs. There is potential for further groundwater development of this aquifer area.

AQUIFER AREA "B"

This aquifer area, although lying outside and adjacent to the Nanaimo River basin, is part of the main Cassidy Aquifer. According to Halstead (1961), this area is underlain by terraced fluvial and glacio-fluvial sand and gravel deposits.

The main source of recharge to this aquifer area is predominantly from precipitation. The annual amount of recharge is estimated at 0.4×10^9 gallons. The predominant direction of groundwater flow is towards the southeast, with eventual discharge into Ladysmith Harbour. Assessment of well record data indicates that flowing artesian conditions exist in the area, substantiating groundwater discharge into Ladysmith Harbour.

A review of 35 water well records indicates that most of the wells are constructed in unconsolidated sediments; are shallow, less than 60 feet (18 m) deep; have reported yields up to 20 gpm (1.3 L/s), and that the estimated average thickness of this aquifer is about 10 ft. (3 m). Further investigation by way of test drilling and geophysical testing would be needed to determine the aquifer thickness and depth of the unconsolidated deposits in this area. The estimated amount of groundwater use is less than 0.01×10^9 gallons per year, based on an assumed average domestic and gardening need of 1000 gallons per day. As noted in Table 1, the estimated amount of groundwater in storage is 0.55×10^9 gallons, of which about 0.48×10^9 gallons can be extracted. This suggests that there is further potential for groundwater development from this unconsolidated aquifer.

AQUIFER AREA "C"

There is very little groundwater information available for this aquifer area. This area was delineated as a potential aquifer based primarily on the distribution of terraced sand and gravel fluvial deposits as outlined by Halstead (1961). Of the three reported wells constructed within this area, one is a shallow flowing well beside Haslam Creek, of unknown yield. The other two wells are constructed in unconsolidated materials and are 32 ft. (10 m) and 48 ft. (14.5 m) deep, and have reported yields of 15 gpm (1 L/s) and 3 gpm (0.2 L/s), ie. sufficient for domestic needs.

Table 1 shows that the amount of recharge from precipitation is estimated at about 0.4×10^9 gallons per year. This is equivalent to continuous pumping at about 760 gpm (48 L/s). There is also good potential for additional recharge to this aquifer area from seepage from the Nanaimo River, which flows across this area. Stream flow measurements would be needed to quantify the

amount of recharge. Based on an estimated aquifer thickness of 10 ft. (3 m), the amount of groundwater in storage that can be effectively extracted is estimated at 0.5×10^9 gallons. Further hydrogeological site investigation, test drilling and possibly geophysical investigations would be needed to further define the groundwater potential of this under-developed aquifer.

AQUIFER AREA "D"

This aquifer area contains the most significant groundwater reservoirs in terms of aquifer potential and use. It is underlain by two major water-bearing sand and gravel deposits, arbitrarily designated as the Upper and Lower (Cassidy) Aquifers, as shown in Figures 4, 5, and 9. The extent of these aquifers has been defined on the basis of distribution of sand and gravel deposits and evaluation of water well record data.

According to Kohut (1979), the Upper Aquifer, occurs under water table conditions, ranges in thickness from 20 ft. (6 m) to 85 ft. (26 m), and is comprised mainly of terraced fluvial sand and gravel (Halstead, 1961). Based on an evaluation of well record data and cross-sectional views, the Upper Aquifer overlies a massive deposit of blue clay (possibly glacial till) which ranges from 20 ft. (6 m) to 100 ft. (30 m) in thickness. This clay unit overlies the Lower Aquifer which occurs under confined conditions and is comprised mainly of compacted sand interbedded with cemented gravel and/or yellow clay.

Kohut (1979) analyzed groundwater level data from well records and determined that shallow groundwater in the Upper Aquifer generally moves from west to east through the main area of the aquifer. A local groundwater mound (divide) occurs north of the airport, as shown in Figure 2. This divide coincides closely to the south boundary of the Nanaimo River basin area. From this area, groundwater moves northward towards Haslam Creek and Nanaimo River, and southward towards Ladysmith Harbour.

Recharge to the Upper Aquifer comes from precipitation and influent seepage from Haslam Creek and Nanaimo River in the upper reaches of these water courses. The amount of precipitation recharging the Upper Aquifer is estimated at 0.9×10^9 gallons per year. This is equivalent to about 1700 gpm (107 L/s) of continuous pumping. As indicated in Table 1, the amount of groundwater in storage in the Upper Aquifer is estimated at 5.1×10^9 gallons, assuming an average aquifer thickness of 25 ft. (7.6 m). Assuming a specific yield of 0.88, the estimated amount of extractable groundwater is 4.5×10^9 gallons.

The Upper Aquifer is an important source of water supply for domestic, irrigation, community and industrial use. There are approximately 100 known domestic wells in the area. Based on an

average conservative withdrawal rate of 3 gpm (0.2 L/s), the total amount of groundwater use from these wells is about 300 gpm (19 L/s). Well record data indicates that there are about 9 water wells completed in the Upper Aquifer that have potential well yields of between 50 gpm (3.2 L/s) and 100 gpm (6.3 L/s). These wells are utilized for airport, irrigation, community and development (trailer parks, etc) use and are located in the south part of the aquifer area. Total withdrawals from these wells is estimated at about 500 gpm (32 L/s).

The most significant (major) groundwater wells in terms of use, are located in the northern part of the aquifer area, adjacent to the Nanaimo River and Haslam Creek. These major users, capable of extracting more than 1000 gpm (63 L/s) include:

- Harmac Pulp Mill Production Well "A" : 3200 gpm (202 L/s)
- Harmac Pulp Mill Production Well "C" : 1600 gpm (101 L/s)
- Harmac Pulp Mill Production Well "D" : 3400 gpm (215 L/s)
- Harmac Pulp Mill Production Well "E" : 1200 gpm (76 L/s)
- Harmac Pulp Mill Production Well "F" : 1200 gpm (76 L/s)
- Fisheries Canada Hatchery Well
(formerly Harmac Prod. Well "B") : 1000 gpm (63 L/s)
- Boat Harbour Development Prod. Well : 1200 gpm (76 L/s)

The above figures represent the actual production capacities of each well, with the exception of the Boat Harbour Development well, which has not yet been put in production.

Based on limited pumping test data, it appears that the transmissivity of the Upper Aquifer is about $7 \times 10^{-2} \text{ m}^2/\text{s}$ (Foweraker, et al, 1985). To obtain more information regarding the hydraulic properties of the Upper Aquifer it is recommended that pumping test of selected production wells be performed.

A provincial observation well (No. 228), completed to a depth of 218 ft. (66.5 m) is located in the south part of Aquifer area D (see Figure 2), in the vicinity of the majority of domestic, irrigation and development wells. Historic hydrograph data for this observation well since 1978 is shown in Figure 10, and indicates that this well reflects seasonal fluctuations of water levels with an annual cycle in response to precipitation. Based on the trend of the seasonal low water levels for the period of record, it is evident that there is a natural equilibrium between aquifer withdrawals and recharge. This implies that the aquifer in the vicinity of this observation well is not being depleted and that there is potential for further development.

There are no observation wells at present in the area of the

major production wells in the north part of the aquifer area. Based on information from Harmac Pulp Mill, Fisheries Canada and E. Livingston (for Boat Harbour Development), the total amount of withdrawal from these major wells is estimated at about 11,600 gpm (732 L/s), or 6.1×10^9 gallons per year. At this time there are no reported indications that this amount of withdrawal has caused any significant local "mining" or depletion of the aquifer.

Personal communications with Harmac Pulp Mill technical staff indicate that the well performance in their production wells has decreased. Further investigation is required to assess the apparent decrease in well performance to determine whether it is a well hydraulic problem (ie. encrustation or bridging of screens, etc.) or an aquifer depletion concern. An observation well in the vicinity of the major production wells is recommended to evaluate water level trends in response to major groundwater withdrawals.

Assuming that the storage capacity of the Upper Aquifer has not been diminished, the amount of precipitation recharging the aquifer (estimated at 0.9×10^9 gallons) is not sufficient to maintain withdrawal rates from the major production wells. Additional recharge to the highly permeable unconfined sand and gravel Upper Aquifer, of at least 5.8×10^9 gallons per year, is most likely being provided from naturally influent and induced streamflow seepages from Haslam Creek and Nanaimo River to maintain the above major withdrawals. This amount of recharge is equivalent to a flow of about 25 cfs. Historical streamflow data to 1986 for the Nanaimo River at Cassidy (upstream of the major production wells) indicates that in Sept., 1973, a minimum daily discharge of $1.22 \text{ m}^3/\text{s}$ or about 43 cfs, was reported.

It is evident from the above analysis that groundwater extraction from the major wells along the Nanaimo River and Haslam Creek, near its confluence with the Nanaimo River, may have a significant influence on low flow conditions of the Nanaimo River, downstream of the major wells. Further evaluation by way of streamflow measurements is needed to assess the actual amount of streamflow loss to the aquifer and production wells. It is uncertain at this time how much additional groundwater development and extraction may occur in this area before existing production wells are significantly affected.

In order to mitigate the above concerns, it is recommended that an evaluation be considered of the potential for artificially recharging the aquifer in the vicinity of the major production wells, as well as the potential for recycling industrial water.

An outline of the probable extent of the Lower Aquifer is shown in Figure 2. The Lower Aquifer is comprised mainly of interbedded sand with cemented gravel and/or yellow clay, and directly overlies the bedrock. The maximum known thickness of the

unconsolidated deposits overlying bedrock in the Cassidy area is 218 ft. (66 m), occurring in Observation Well 228, located southwest of the airport. Based on depth to bedrock contours (after Kohut, 1979), and cross-sectional views (Figure 3, 4, and 5) there is evidence of a major bedrock trough trending north to south along the western side of the airport. It is within this bedrock low that the Lower Aquifer occurs.

Assuming an average aquifer thickness of 40 ft. (12 m), the amount of groundwater in storage in the Lower Aquifer is estimated at 3.5×10^6 gallons. The source(s) of recharge to this confined aquifer is not known but may in part come from leakage from the overlying aquifer and in part from the surrounding bedrock. The Lower Aquifer has not been developed to date; consequently, its yield potential is not definitely known. According to Kohut (1979), it should be capable of providing several hundred gallons per minute (up to 20 L/s) to individual wells.

AQUIFER AREA "E"

Aquifer area "E" occupies an area of approximately 21×10^6 sq. ft. or about 483 acres. There are approximately 21 wells constructed in the shallow sand and/or gravel deposits to depths of less than 50 ft. (13 m).

Based on limited lithological and water level data from well records, it appears that the unconfined aquifer may have an average thickness of 25 ft. (7.6 m). Assuming a porosity of 0.25 for sands and gravels, and a specific yield of 0.88, the amount of extractable groundwater from storage is estimated at 1×10^9 gallons. Recharge to the unconfined aquifer is predominantly from rainfall and is estimated at 0.3×10^9 gallons per year.

Water level data from well records indicates that the unconfined aquifer has a relatively shallow groundwater table, and groundwater flow is from the airport area towards Ladysmith Harbour. At least two significant springs (one recorded flowing at 10 gpm (0.6 L/s) to 20 gpm (1.2 L/s) in August 1976), indicative of groundwater discharge from the unconfined aquifer occur at the head of Ladysmith Harbour. Kohut (1979) indicated that additional groundwater discharge may also occur below sea level within Ladysmith Harbour.

The amount of groundwater flow into Ladysmith Harbour was estimated by Kohut (1979) to be in the range of 16 gpm (1 L/s) to 160 gpm (10 L/s), assuming an aquifer permeability of 10^{-2} cm/sec to 10^{-3} cm/sec, an hydraulic gradient of 0.015, and an estimated saturated aquifer thickness of 25 ft. (7.6 m), and an aquifer width of 3500 ft. (1067 m).

Estimated potential well yields range from 2 gpm (0.1 L/s) to

as high as 75 gpm (4.7 L/s). Well use appears to be predominantly domestic and minor irrigation/development. There is good potential for additional well development for domestic and minor irrigation/development purposes.

Kohut (1979) suggests that although there is very little stratigraphic data for the region between the airport and Ladysmith Harbour, it is probable that the bedrock low, mentioned previously, may also extend to Ladysmith Harbour. Within this bedrock low, there is a possibility that the Lower Aquifer of aquifer area "D" may extend towards Ladysmith harbour.

There is no data available on the hydraulic gradient and direction of flow in the Lower Aquifer, although it would be expected to be from the airport area towards Ladysmith Harbour. North of Ladysmith Harbour significant artesian flows may be expected from wells drilled into the Lower Aquifer. Further groundwater exploration by way of test drilling and geophysical testing would be needed to investigate these possibilities.

AQUIFER AREA "F"

Aquifer area "F", occupying an area of approximately 44×10^6 sq. ft. or about 1012 acres, has been delineated as the area from the confluence of the Nanaimo River and Haslam Creek to the Nanaimo delta. This narrow elongated floodplain aquifer, bounded on each side by predominantly shale and sandstone bedrock, is underlain mainly by fluvial sand and gravel with some minor silt and clay (Halstead, 1961). The actual thickness of the unconsolidated sediments is not known from available well record data; however, cross-sections 6 and 7 (Figure 8) indicate that the average thickness may be in the order of 50 ft. (15 m). Further evaluation by way of geophysical testing and/or test drilling within the floodplain and deltaic deposits will be needed to confirm this.

Based on available well record data and an assumed average aquifer thickness of 20 ft. (6 m), the volume of groundwater in storage that can be extracted is estimated at about 1.4×10^9 gallons. Recharge to this aquifer from precipitation is estimated at 0.6×10^9 gallons per year. The amount of additional recharge from the Nanaimo River is not known but may be more significant than precipitation. Further evaluation of streamflow data is needed to assess the amount of influent seepage.

There are about 19 shallow wells constructed in this aquifer area. Well depths are typically less than 40 ft. (12 m) deep. The yields from the majority of the wells are generally sufficient for domestic use and one well in the delta was reportedly rated at 100 gpm (6.3 L/s). There are five major production wells constructed for the North Cedar Water Works District, whose potential yields

vary between 200 gpm (12.6 L/s) and 510 gpm (32.2 L/s). According to G. U. Proctor (1989), the present production from three of its five wells is just over 480 gpm (30 L/s). The other two production wells were taken out of service due to iron bacteria problems.

Based on the volume of extractable groundwater in this area and the amount of recharge, this aquifer has a significant capacity for additional development of higher capacity production wells. To determine the quantitative capacity of this aquifer more detailed hydrogeological investigations and assessments are needed including, test drilling, pumping tests, geophysical surveys and streamflow measurements.

GROUNDWATER QUALITY ASSESSMENT

A review of well record data indicates that there is laboratory chemical analysis data for groundwater from only four water wells. Figure 2 shows the locations of the water quality test sites and Table 3 provides a summary of the groundwater quality data. A review of Water Quality Check Program chemistry analyses reports indicates that there are analyses of groundwater quality for an additional 46 wells. Table 4 provides a summary of this data. The locations of the well (chemistry) sites are not provided since they have not been correlated with existing well record data. Further investigation and evaluation of this data is needed to match the location information provided on the analysis reports with well record data from Groundwater Section's database files.

An analysis of the groundwater quality from the above-mentioned four wells indicates that the samples were obtained from relatively shallow depths (less than 200 ft. {61 m}), within unconsolidated deposits and within a relatively shallow groundwater flow system. The significance of a shallow groundwater flow system is that most natural waters will be low in Total Dissolved Solids (TDS), low in Specific Conductance and relatively soft to moderately soft in Hardness. This appears to be the case for groundwaters within the Nanaimo River basin area.

For the parameters tested, most of the groundwaters have chemical concentrations within acceptable water quality limits. A high iron content (11.1 mg/L Dissolved) was noted in sample site number 3. This well (Observation Well 228) has not been used for production purposes for at least 40 years and the source of iron content in the water may be from corrosion of the well casing.

Further analysis of the Water Quality Check Program reports is needed to evaluate and correlate sampling depths, aquifer types (ie. bedrock or unconsolidated), sampling date, etc.

AQUIFER CONTAMINATION POTENTIAL

At present there are no known groundwater contaminated sites within the basin area. However, the entire Cassidy Aquifer is potentially susceptible to contamination due to the fact that the aquifer occurs under shallow water table conditions (generally less than 25 ft. (7.6 m) below ground), and is comprised of highly permeable sediments that are susceptible to rapid infiltration of potential contaminants into the groundwater system.

According to Kohut (1979), apart from individual domestic and low density septic disposal systems, any large scale septic disposal schemes or sanitary landfill operations whereby large quantities of untreated effluent or waste is disposed in a small area, should not be permitted or approved without an adequate hydrogeological investigation and monitoring to assess the effects of any proposals on the groundwater regime. Particular precautions should be considered in the siting of any petroleum storage facilities or highway salt storage areas, etc., in areas close to communities utilizing the Cassidy Aquifer for water supply.

It is further recommended that the Cassidy Aquifer be established as a Groundwater Management Area to restrict activities which could lead to aquifer degradation and to maintain the aquifer for water supply purposes.

GROUNDWATER/SURFACE WATER INTER-RELATIONSHIP

Early investigations of the groundwater resources in the Cassidy area by Odynsky (1952) and Nasmith (1952), revealed that there is an inter-relationship between the permeable unconfined sand and gravel (Cassidy) aquifer and Nanaimo River and Haslam Creek. These surface waters along their courses, naturally draw from and lose water to the groundwater system due to the hydraulic continuity between these water courses and the Cassidy Aquifer.

Since the construction of a number of major production wells along the Nanaimo River and Haslam Creek during the past 40 years, the relationship between groundwater withdrawals and surface water flows and the potential for surface water/groundwater conflicts has not been assessed.

An assessment of the effects of major groundwater withdrawals and potential for additional withdrawals on stream flows would require among other considerations, a review and analysis of licensed surface water use, groundwater inventory and extraction data, groundwater level measurements, streamflow measurements, water quality sampling (surface and groundwater), pumping tests and possibly test drilling and monitor well construction.

CONCLUSIONS AND RECOMMENDATIONS

The above office study of the groundwater resource in the Nanaimo River basin has included a review and evaluation of available geologic and hydrogeologic data from water well records, groundwater reports and various geologic maps. The Nanaimo River basin contains a significant and highly permeable sand and gravel aquifer, termed the Cassidy Aquifer, which provides groundwater for domestic, irrigation, community, fish hatchery and industrial uses. The extent of the Cassidy Aquifer has been identified and a quantitative assessment of the groundwater use and potential for further development has been addressed.

Limited groundwater quality data has also been identified and water quality appears to be generally within drinking water quality guidelines. There are no apparent significant groundwater quality or contamination concerns. There appears to be a significant groundwater/surface water inter-relationship and potential for conflict.

Recommendations have also been addressed in the report and include:

- 1) the establishment of an observation well in the area of the major production wells along the Nanaimo River and Haslam Creek,
 - estimated cost for drilling and completing a 100 ft. (30 m), six inch diameter well and monitor equipment is \$6,000.; estimated time: 1 week (from contract to recorder installation),
- 2) additional hydrogeological investigation and pumping tests to assess hydraulic aquifer properties (ie. Transmissivity, Storage coefficient, well yields, etc.),
 - estimated cost may be in the order of \$10,000., and take up to 2 weeks to complete,
- 3) additional groundwater quality testing and evaluation,
 - estimated cost may be in the order of \$10,000. for sampling, laboratory analyses, and data evaluation,
- 4) test drilling and geophysical surveys to assess aquifer thickness, extent and potential,
 - estimated costs may be in the order of \$25,000. and take up to 4 weeks to complete,
- 5) streamflow measurements and evaluation to assess the surface water/groundwater inter-relationship,
 - Estimated costs for field and office assessment is \$2,000.,

and may take up to 1 week to complete,

6) investigation and evaluation of land-use practices to identify and analyze the potential for groundwater contamination by man-made activities.

- estimated cost is \$2,000., and take up to 2 weeks to complete.

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TABLE 1: SUMMARY OF AQUIFER AREAS

Unconf.	Area	Area	Estimated Average Aquifer		Assume Porosity, n = 0.25		Assuming specific	Estimated Recharge	
Aquifer	sq. ft.	acres	Thickness	Volume	Vol. GW in Storage		yield factor= 0.88	From Precipitation *	
Area	x 10^6		ft.	CU.FT.X10^6	CU. FT.X10^6	GAL.X10^6	Am't Extractable GW	CU.FT.X10^6	GAL.X10^6
							GAL.X10^6		
A	101	2323	20	2020	505	3777	3324	174	1299
B	29	667	10	290	73	546	480	50	373
C	29	667	10	290	73	546	480	50	373
D	68	1564	40	2720	680	5086	4476	117	875
E	21	483	25	525	131	980	862	36	270
F	44	1012	20	880	220	1646	1448	76	566
Total	325	7475	-	7055	1764	13194	11610	560	4081

Confined Aquifer

Area	47	1079	40	1880	470	3516	3094		
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NOTE: * Average annual precipitation (Nanaimo Airport) = 1104 mm. = 42.8 in.

- Based on a conservative Thornwaite water budget analysis, (Table 2)
amount of moisture available for runoff + ground infiltration = 580mm. = 22.8 in.
- Based on generally coarse nature of surficial materials, and assuming 90% infiltration (according to B. Turner),
Estimated Amount of Annual Recharge = 522 mm. = 20.6 in.

TABLE 2: THORNWAITE WATER BUDGET (After, Turner, 1991)

STATION: NANAIMO A

Water Budget (mm)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
PE	6	14	24	44	76	98	117	106	73	42	18	10	628
P	178	117	108	58	38	40	23	33	45	101	161	202	1104
P-PE	172	103	84	14	-38	-58	-94	-73	-28	59	143	192	476
Accum PWL					-38	-96	-190	-264	-291				
St	300	300	300	300	264	217	158	124	113	172	300	300	
StCh	0	0	0	0	-36	-47	-59	-34	-11	59	128	0	
AE	6	14	24	44	74	87	82	67	56	42	18	10	524
Def	0	0	0	0	2	11	35	39	17	-0	0	0	104
N	172	103	84	14	0	0	0	0	0	0	15	192	580

PE = potential evapotranspiration

P = precipitation

P-PE = precipitation minus potential evapotranspiration

Acum PWL = accumulated potential water loss

St = soil moisture storage; maximum value assumed to be 300 mm

StCh = water added to (+) or withdrawn from (-) soil moisture storage

AE = actual evapotranspiration

Def = moisture deficit, (PE-AE)

N = moisture surplus, (P-AE)-StCh

AK016.20

TABLE 3: GROUNDWATER SAMPLING SITES

Sample Site No.	1	2	3	4
BCGS Well No.(092G)	.001.2.3.2#25	.001.2.3.2#30	.001.2.3.4#16	.001.4.1.4#23
Type / Depth	UNC / 20'	UNC / 19'	UNC / 218'	UNC / 79'
Sample Date	76/07/22	76/08/16	84/09/26	90/11/21
pH	6.8	6.7	6.7	7.3
Temp. °C	-	13	-	-
Spec. Cond. $\mu\text{mho/cm}$	136	289	123	63.6
Alk. (phnl)	< 0.5	< 0.5	< 0.5	-
Alk. (tot.)	29.9	106.0	55.6	17.5
Chloride (diss.)	20.7	19.4	5.5	3.8
Nitrogen($\text{NO}_2 + \text{NO}_3$)	0.22	0.37	< 0.02	< 0.005
Nitrogen (KJel)	< 0.01	0.23	0.37	-
Phosph. (diss.)	0.003	0.031	0.003	-
Calcium (diss.)	14.0	29.8	14.5	-
Iron (Tot.)	0.1	1.1	168	< 0.03
Iron (diss.)	< 0.1	0.6	11.1	< 0.03
Magnesium (diss.)	3.3	7.9	4.34	1.26
Manganese (Tot.)	< 0.02	0.2	0.43	0.01
Manganese (diss.)	< 0.02	0.19	0.26	< 0.005
Sodium (diss.)	5.5	14.3	4.3	3.18
T.D.S.	110	194	84	40
Hardness (CaCO_3)	48.5	107	54.3	22.3
Sulphate (diss.)	< 5.0	11.9	1.3	4.1
Lead (diss.)	0.001	< 0.001	< 0.1	< 0.001
Pot. (diss.)	0.5	2.2	0.4	0.13

Table 4: Water Quality Check Program Chemistry Analyses

	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1	NTS A	NTS B	NTS C	Last Name	First Name	Phone No.	Address #1	Address #2	City	Postal Code	Description of Sampling Site	Location of Sampling Site	Corner	Size	Sector	T.P.	R	LD	Lot
2																			
3	92	G	4	Raffle	Robert	754-4189	2045 Pecos Rd. St SW RR#4		Nanaimo	V8R-5X8	Lot 2 Sec 12 Range 5 Plan 32838 Cranberry Dist	Well tap at head			12		5	19	2
4	92	G	4	Stead	Doug		RR#4 Nanaimo B.C.		Nanaimo	V8R-5X8	South Wellington, 100 ft. drilled well								
5	92	G	4	Baun	Judy	753-5954	620 Chestnut St.		Nanaimo	V8S-2L2	River Terrace Rd., Lot 20 Plan 26345 Sec 5&6 Range 5, Cranberry	Lot 20 River Terrace Rd., untreated Tap water			5&6		5	19	20
6	92	G	4	Tonn	Walter K.	754-5802	1261 Scotchtown Rd. Site 2 RR#4 Nanaimo		Nanaimo	V9R-5X9	Lot 1 Sec 11 Range 6 Plan 1700 Cranberry Dist	Tap water from Tonn's well			11		6	19	1
7	92	G	4	Pittman	David		Site V2 RR#4 Nanaimo B.C.		Nanaimo	V8R-5X9	200 ft well Cranberry Bright Van. Isl.								
8	92	G	4	Couchman	Angela	753-0757	Site SW RR#4 Nanaimo B.C.		Nanaimo	V8R-5X9	End of Minto Rd. South Wellington								
9	92	G	4	Thatcher	F.	754-9527	Site R RR #4 Thatcher Rd. Nanaimo		Nanaimo	V8R-5X3	Cedar Bank Farms, Tap from residential house well	Sec 9 Range 7 Cranberry Dist			9		7	19	
10	92	G	4	Thatcher	F.	754-9527	Site R RR#4 Nanaimo B.C.		Nanaimo	V8R-5X9	Cedar Bank Farms Sec 9 Range 7, Cranberry Dist					9		7	19
11	92	G	4	Stupich	Stan		P.O. Box 105 Cassidy B.C.		Cassidy	V0R-1H0	Dug well cement casing, gravel pit								
12	92	G	4	Lapi	Christy		P.O. Box 29 Cassidy B.C.		Cassidy	V0R-1H0	Lapi House Cassidy								
13	92	G	4	Leed	Larry W.		P.O. Box 1886 Ladysmith B.C.		Ladysmith	V0R-2E0	Leed Tap water Cassidy 24 ft. well								
14	92	G	4	Paton	Steve	245-8111	Box 74 Cassidy B.C.		Cassidy	V0R-1H0	Nanaimo Airport								
15	92	G	4	Gardner	Mary		RR#1 Hinn Rd. Ladysmith		Ladysmith	V0R-2E0	Gardner, dug well Cassidy area								
16	92	G	4	Greene	Sharon		Box 47 Cassidy B.C.		Cassidy	V0R-1H0	Home Cassidy well								
17	92	G	4	Sundstrom	V.A.		P.O. BOX 1737 Ladysmith B.C.		Ladysmith	V0R-2E0	Drilled well Cassidy area								
18	92	G	4	Rudd	Murray	883-9224	P.O. Box 94 Garden Bay B.C.	Springhill Rd. Parksville	Garden Bay	V0N-1S0	Judge's Farm Cassidy B.C. (Springhill Rd. Parksville ?)	Judge's Farm Cassidy B.C. (Springhill Rd. Parksville ?)							
19	92	G	4	Scurlfield		722-2520	P.O. Box 1162		Nanaimo	V8R-6E7	Remainder of Fract. sec.5 Range 6 Cedar Ld.				5		6	7	
20	92	G	4	Askin	Susan	754-7987	724 O'Brien Place Drive Nanaimo		Nanaimo	V8R-6B1	Lot 16 Plan 9877 Sec 7 Range 6 LD 7	2596 Pyllades Drive Cedar B.C.			7		6	7	16
21	92	G	4	Sanford	W.J.	722-2283	Box 128 Cedar P.O. Cedar B.C.		Cedar	V0R-1J0	Tap water from Sanford, well, Cedar B.C.								
22	92	G	4	Bertram	Cindy	722-2747	Box 333, 1751 Akenhead Rd.		Cedar	V0R-1J0	Lot 2 Plan 2189 Sec 3 LD 32	Well is downhill from septic field			3			33	2
23	92	G	4	Luffman	Richard	722-2118	1940 Harmac Rd. Box 300 Cedar B.C.		Cedar	V0R-1J0	Lot 1 Sec 17 Range 8 Plan 40229 Cranberry Dist	Tap Water from Luffman well			17		8	19	1
24	92	G	4	Wilson	Linda	722-2898	1339 Ivor Rd. C-12 Site 1 RR#2		Nanaimo	V8R-5K2	Lot 2 Sec 19 Range 4 Plan 35760 Cedar Dist	Cedar Dist			19		4	7	2
25	92	G	4	Clemens	Brian	641-1420	2948 Nelson Rd. RR#2 Site J2 C.5		Nanaimo	V8R-5K2	Lot A Section 17 Range 4 Plan 37964 Cedar Dist	Well on our property			17		4	7	A
26	92	G	4	Brachat	Daryl		5714 Caddell Dr. S. Delta B.C.	Brachat Cabin	Cedar	V4E-1B5	Tap Water	Brachat Cabin							
27	92	G	4	Butler	Ron		P.O. BOX 39		Cedar	V0R-1J0	Water Domestic	Cedar B.C.			9		1	7	
28	92	G	4	Reynolds	Peter J.		RR#3 Decourcy		Ladysmith	V0R-2E0	Reynolds 150 ft. Well Cedar Dist.	Lot C							C
29	92	G	4	Swain	Douglas		Site K2 RR#2		Nanaimo	V8R-5K2	Swain Tap water Cedar								
30	92	G	4	Cameron	Colin		Box 15 Cedar B.C.		Cedar	V0R-1J0	Domestic Well	Cedar			0				
31	92	G	4	Wilson	Linda	722-2898	1339 Ivor rd. C-12 Site 1 RR#2		Nanaimo	V8R-5K2	Lot 2 Sec 19 RGE 4 PLAN 35760 CEDAR DIST	Cedar Dist			19		4	7	2
32	92	G	4	Voysey	Omer W.	722-3669	RB 50 RR#4		Nanaimo	V8R-5X9	South 10 chains & west 10 chains of Sec 10 RGE 2 Cedar L.D.	Dug well			10		2	7	
33	92	G	4	Morgan	Owen	722-2791	P.O. Box 238 Cedar B.C.		Cedar	V0R-1J0	Lot 1 Plan 18561 Sec.1 Range 7 Cedar land Dist				1		7	7	1
34	92	G	4	Morgan	Christine G.	722-2681	P.O. Box 274		Cedar	V0R-1J0	Tap water from Morgan's well, Cedar	E1/2 Lot 2 Sec. 8 Rge.2 Cedar Dist. Plan 8303	E1/2		8		2	7	2
35	92	G	4	Cliffe	Robert G.	722-2625	Site G C-18 RR#2		Nanaimo	V8R-5K2	Tap water from well at 1813 Rugg Rd. Cedar B.C.	Sec.2 Range 14 except parcel B and west 60 chains			2		14		
36	92	G	4	Klimes	Greg	722-2627	RR#2 Site G		Nanaimo	V8R5K2	Lot 1 Shasta Rd. Sec.13&14 Range 4 Plan 29676 Cedar Dist	Tap Well Water taken during low flow conition Quite gassy, no smell			13		4	7	1
37	92	G	4	Kasse	Ted	722-2033	RR#2 Site 1 Aquatan Place		Nanaimo	V8R-5K2	Lot 3 sect.17 Range 4 Cedar dist. Plan 33123				17		4	7	3
38	92	G	4	Woodward	V.H.		Tiesu Rd. RR #3		Ladysmith	V0R-2E0		Ladysmith							
39	92	G	4	Giovando	Larry B.		RR#4 Site Q2		Nanaimo	V8R-5X9	120 ft. well 300 ft. from lake with peat bottom	Cedar area							
40	92	G	4	MacNaughton	Donna	753-0497	General Delivery Cedar P.O.		Nanaimo	V0R-1J0	MacNaughton Domestic Well	#5 Morden Rd. Water doesn't meet Can. Drinking Water Standards. See coliform amount.							
41	92	G	4	Littleton	David	753-2852	RR#1 Site X-3		Nanaimo	V8R-5K1	Spring on property	Nanaimo River Rd.							
42	92	G	4	Tudor	Vera		Site L Shasta Rd. RR#2		Nanaimo	V8R-5K2	Cedar	Well in Cedar							
43	92	G	4	Beaudry	Victor		Site H2 RR#2		Nanaimo	V8R-5K2	Well uncertain depth Cedar Nanaimo area								
44	92	G	4	Preston	Mark		Box 96 Cedar P.O. Cedar B.C.		Cedar, South	V0R-1J0									
45	92	G	4	McGregor	Robin	754-1291	Site J2 RR#2		Nanaimo	V8R-5K2	Lot A Sec.17 Plan 37964 Cedar	Water is chlorinated after the holding tank by a carbon filter.			17		4		
46	92	G	4	McGregor	Robin	754-1291	Site J2 RR#2		Nanaimo	V8R-2K5	Tap water from McGregor well in Cedar B.C.	Cedar B.C.							
47	92	G	4	Lewis	Ted	245-2641	RR#4 Quennell R.D. RB64		Nanaimo	V8R-5X9	Tap water Lewis's well-Cedar B.C.								
48	92	G	4	Klimes	Gregory J.	722-2627	Site G C-37 RR#2		Nanaimo	V8R-5K2	Lot #1 Ravenhill Rd. Sections 13 & 14 Range #4 Plan # 29676 Cedar Land District								

Table 4: Water Quality Check Program Chemistry Analyses

	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW
1	Plan	Date of Sample	Water Sample Source	Depth Metres	Depth Feet	Water Treated?	Treatment Type	pH	Res. Filterable-0.45u mg/L	Turbidity NTU	Alkaline Total 4.5 mg/L	Hardness Total mg/L	Specific Conductance us/cm	Coliform LD/100	Coliform MPN	Total MPN	Fluoride LD/100	Fluoride mg/L	Fluoride Dissolved mg/L	Boron LD/100	Boron mg/L	Boron LD/100	Boron mg/L	Barium LD/100	Barium mg/L	Calcium LD/100	Chromium LD/100	Chromium mg/L	
2	32838	87-07-27	Tap well	101	330	Y	Bleach	8.3		76.0	268.0	30.8	585	< 2.20	0.0				0.44		0.31			0.05	8.07	< 0.03	0.02		
3		81-03-09	Tap water	30	100			7.4	278	30.0	208.0	7.4	490	< 2.20	0.0		< 0.10	0.05	0.00		0.00			0.00	42.50	< 0.01	0.00		
4	26345	86-05-26	Tap water	4	12	N		6.9	142	6.3	70.1	74.5	231	< 2.20	0.0		< 0.10	0.05	0.00		0.01	< 0.01	0.01	0.01	25.40	< 0.01	0.01		
5	1700	85-08-28	Tap water	6	20	N		6.9	142	0.5	101.0	85.9	225	> 16.00	0.0		< 0.10	0.05	0.02	< 0.01	0.01	0.01	0.01	23.30	< 0.01	0.01			
6		85-02-26	Tap well	61	200			8.3	682	1.0	240.0	14.6	1210	< 2.20	0.0			1.28	0.88	< 0.01	0.01	0.01	0.01	5.35	< 0.01	0.01			
7		86-02-16	Tap Well	26	86	Y	Softener	7.4	982	2.8	366.0	61.5	1510	< 2.00	0.0			0.10	0.30	< 0.01	0.01	0.01	0.01	17.50	< 0.01	0.01			
8		85-07-16	House well	37	122	N		8.0	666	0.2	179.0	44.4	1210	< 2.20	0.0			0.16	0.24	< 0.01	0.01	0.01	0.01	0.39	14.30	< 0.01	0.01		
9		85-07-16	Dug well	4	12			6.8	140	4.7	81.4	73.7	226	< 2.20	2.2		< 0.10	0.05	< 0.01	0.01			0.02	21.70	< 0.01	0.01			
10		88-10-11	Dug well	0	0			6.4		0.1	28.3	55.8	203		55.0		< 0.10	0.05	< 0.01	0.01	< 0.01	0.01	0.01	15.70	< 0.01	0.01			
11		82-08-03	Tap water	0	0			6.6	88	0.2	46.5	43.4	116	< 2.20	0.0		< 0.10	0.05	< 0.01	0.01	< 0.01	0.01	0.01	13.90	< 0.01	0.01			
12		84-02-13	Tap water	7	24			6.5	53	0.6	26.2	25.5	77	< 2.20	0.0		< 0.10	0.05	< 0.01	0.01	< 0.01	0.01	0.01	7.87	< 0.01	0.01			
13		87-09-09	Well	8	25	N		6.5		15.0	39.7	42.3	129	< 2.20	0.0		< 0.10	0.05	< 0.01	0.01	< 0.01	0.01	0.01	12.40	< 0.01	0.01			
14		82-08-23	Well	5	18			6.9	116	0.3	72.0	60.8	187	< 2.20	0.0		< 0.10	0.05	0.03	< 0.01	0.01	0.01	0.01	18.40	< 0.01	0.01			
15		82-06-22	Tap water	0	0			6.5	80	0.2	34.0	33.6	112	< 2.20	0.0		< 0.10	0.05	< 0.01	0.01	< 0.01	0.01	0.01	10.10	< 0.01	0.01			
16		81-06-11	Tap water	10	33			8.0	678	38.0	359.0	138.0	1200	< 2.20	0.0			0.23	0.00	< 0.01	0.01	< 0.01	0.01	42.90	< 0.01	0.00			
17		86-12-30	Well	24	80	N		7.9	114	1.9	84.2	71.6	176	< 2.00	0.0		< 0.10	0.05	< 0.01	0.01	< 0.01	0.01	0.01	15.60	< 0.01	0.01			
18		89-01-23	Tap water	0	0	N		8.5		1.0	220.0	10.8	580	< 2.00	0.0			0.80	0.25	< 0.01	0.01	< 0.01	0.01	2.88	< 0.01	0.01			
19		88-08-29	Well	35	115	N		9.0		3.5	220.0	5.3	640	< 2.00	0.0			1.89	0.55	< 0.01	0.01	< 0.01	0.01	1.61	< 0.01	0.01			
20		88-09-13	Tap water	21	70	N		8.0		0.1	196.0	218.0	1060	< 2.00	0.0			0.46	0.80	< 0.01	0.01	< 0.01	0.01	63.80	< 0.01	0.01			
21		88-10-03	Well	0	0	N		6.9		1.3	35.0	39.3	134			6.0	< 0.10	0.05	< 0.01	0.01		0.01	0.01	11.80	< 0.01	0.01			
22	40229	88-06-13	Well	3	10	Y	Household Bleach	8.0		4.8	204.0	35.7	610			30.0		0.54	0.85	0.02	0.02	0.02	0.02	11.00	< 0.01	0.01			
23	35760	88-04-11	Tap	73	240	N		6.9		3.0	132.0	32.6	410			2.0		0.27	0.48	0.15	0.15	0.15	0.15	10.50	< 0.01	0.01			
24	37964	88-05-15	Tap Water	64	210	Y	Charcoal filter	9.1		0.7	188.0	1.5	620	< 2.00	0.0			3.15	0.96	< 0.01	0.01	< 0.01	0.01	0.51	< 0.01	0.01			
25		82-01-03	Tap Water	0	0			7.0	562	3.6	124.0	60.6	1060	< 2.20	0.0			0.53	**	0.00	0.00	0.00	0.00	19.50	< 0.01	0.00			
26		83-04-30	Well	0	0			7.7	178	100.0	120.0	56.2	276	> 16.00	0.0			0.17	0.07	0.07	0.07	0.07	0.07	15.20	< 0.01	0.01			
27		84-07-19	Well	46	150			8.1	1940	3.5	181.0	140.0	3680	< 2.20	0.0			4.30	0.73	0.03	0.03	0.03	0.03	46.00	< 0.01	0.04			
28		85-01-14	Tap Well	0	0			8.7	194	3.4	140.0	8.8	340	< 2.20	0.0			1.26	0.23	0.01	0.01	0.01	0.01	3.92	< 0.01	0.01			
29		83-03-01	Well	0	7			8.8	136	3.5	98.0	6.3	209	< 2.20	0.0			0.32	0.10	0.01	0.01	0.01	0.01	1.93	< 0.01	0.01			
30	35760	87-12-23	Tap Well	73	240	UNK		7.2		2.0	252.0	23.3	630	> 16.00	0.0			0.76	1.01	0.12	0.12	0.12	0.12	8.30	< 0.01	0.01			
31		87-10-19	Dug well	6	20	No		6.8		0.4	43.8	67.7	220	< 2.20	0.0			0.10	0.18	0.12	0.12	0.12	0.12	17.90	< 0.01	0.01			
32	18561	87-03-10	Well	34	112	No		8.2	400	0.5	222.0	11.7	702	< 2.00	0.0			0.44	0.21	< 0.01	0.01	< 0.01	0.01	3.75	< 0.01	0.01			
33	8303	87-03-30	Tap Well	17	55	UNK		7.4	264	0.1	186.0	42.8	450	> 16.00	0.0			0.19	0.17	0.07	0.07	0.07	0.07	13.20	< 0.01	0.01			
34		86-08-05	Tap water	122	400	No		7.7	4090	0.6	81.9	185.0	7180	< 2.00	0.0			0.96	1.06	0.38	0.38	0.38	0.38	64.70	< 0.01	0.01			
35	28676	86-08-11	Tap Well	91	300	No		6.4	1490	2.0	82.7	227.0	2340	< 2.00	0.0			1.74	0.90	0.18	0.18	0.18	0.18	80.10	< 0.01	0.01			
36	33123	87-02-23	Well	37	122	No		7.5	246	0.4	170.0	92.6	420	< 2.00	0.0			0.29	0.10	0.20	0.20	0.20	0.20	29.20	< 0.01	0.01			
37		83-03-22	Tap Well	51	166			7.7	280	18.0	185.0	13.5	450	< 2.20	0.0			1.12	0.34	0.01	0.01	0.01	0.01	4.03	< 0.01	0.01			
38		82-12-06	Well	37	120			7.8	164	8.5	103.0	5.7	250	< 2.20	2.2			0.22	0.10	< 0.01	0.01	< 0.01	0.01	1.60	< 0.01	0.01			
39		82-10-08	Domestic Well	49	160			6.9	248	0.7	158.0	126.0	403	> 16.00	0.0			0.10	0.07	0.05	0.05	0.05	0.05	41.70	< 0.01	0.01			
40		87-05-16	Spring	0	0	No		6.5	58	0.2	19.8	21.9	70	< 2.00	0.0		< 0.10	0.05	0.02	< 0.01	0.01	< 0.01	0.01	6.65	< 0.03	0.02			
41		82-03-15	Well	29	95			7.3	302	0.4	170.0	99.1	503	< 2.00	0.0			0.55	0.22	< 0.01	0.01	< 0.01	0.01	29.30	< 0.01	0.01			
42		82-02-26	Well	0	7			5.7	166	0.5	24.5	73.4	250	< 2.20	0.0		< 0.10	0.05	< 0.01	0.01			0.06	18.80	< 0.01	0.01			
43		82-01-25	Well	49	160			8.3	1130	2.9	335.0	76.2	1680	< 2.20	0.0			1.48	0.00	< 0.01	0.00			0.00	28.20	< 0.01	0.00		
44	37964	86-04-21	Well	64	210	Yes	Chlorinated	9.3	372	1.1	205.0	3.2	668	< 2.00	0.0			3.50	1.12	0.03	0.03	0.03	0.03	1.19	< 0.01	0.01			
45		86-11-17	Tap Well	64	210	Yes	Resin Filter	7.3	324	1.0	41.9	< 0.1	612	< 2.00	0.0		< 0.10	0.05	0.66	< 0.01	0.01	< 0.01	0.01	< 0.01	< 0.01	0.01			
46		86-01-28	Tap-Well	20	67	Yes	Filter (not charco	7.1	228	0.5	172.0	< 0.1	394	< 2.00	0.0		< 0.10	0.05	0.06	< 0.01	0.01	< 0.01	0.01	28.40	< 0.01	0.01			
47		85-12-10	Well	91	300	No		6.0	170	1.0	49.7	56.1	260	> 16.00	16.0		< 0.10	0.05	0.02	0.03	0.03	0.03	0.03	16.60	< 0.01	0.01			

Table 4: Water Quality Check Program Chemistry Analyses

	AX	AY	AZ	BA	BB	BC	BD	BE	BF	BG	BH	BI	BJ	BK	BL	BM	BN	BO	BP	BQ	BR	BS	BT	BU
	Cu	Copper	Copper	Iron	Iron	Iron	Magnesium	Mar	Mange	Manganese	Zinc	zinc	zinc	Nitr	Nitrog	Nitrogen NO3+NO2 Dis	Nitr	Nitrog	Nitrogen NO3 Diss(N)	Nitr	Nitrog	Nitrogen NO2 Diss (N)	W	Lab Form Number
	LD	DV	mg/L	LD	DV	mg/L	mg/L	LD	DV	mg/L	LD	DV	mg/L	LD	DV	mg/L	LD	DV	mg/L	LD	DV	mg/L		
1			0.03			4.44	2.59			0.09			0.02	< 0.02		0.01		< 0.02				0.003		1003370
2			0.00			1.30	5.90			0.00			0.00			0.00		< 0.02			0.01	< 0.005	0.003	103554W
3			0.01			0.50	2.69			0.14			0.02			0.83		< 0.005			0.83	< 0.005	0.003	1002203
4			0.04			0.08	6.74			0.03			0.19			0.26		< 0.005			0.25	< 0.005	0.007	1001256
5			0.01			0.06	0.29			0.01	< 0.01	0.01	< 0.02			0.01		< 0.02			0.01	< 0.005	0.003	1000658
6			0.02			0.09	4.33			0.01	< 0.01	0.01	< 0.02			0.01		< 0.02			0.01	< 0.005	0.003	1001763
7			0.01			0.02	2.12			0.02	< 0.01	0.01	< 0.02			0.01		< 0.02			0.01	< 0.005	0.003	1001272
8			0.01			1.36	4.74			0.07			0.01	< 0.02		0.01		< 0.02			0.01	< 0.005	0.003	1001271
9			0.05	< 0.01		0.01	4.02	< 0.01		0.01			0.03			8.60		< 0.005			8.60	< 0.005	0.003	1001134
10			0.05			0.03	2.11	< 0.01		0.01			0.01			0.00		< 0.005			1.05	< 0.005	0.003	209856W
11			0.13			0.10	1.41	< 0.01		0.01			0.01			0.00		< 0.005			0.04	< 0.005	0.003	316184W
12			0.02			3.50	2.76			0.14			0.41			0.61		< 0.005			0.61	< 0.005	0.003	87010546
13			0.23			0.06	3.62			0.02			0.02			0.00		< 0.005			1.47	< 0.005	0.003	210647W
14			0.06			0.10	2.03	< 0.01		0.01			0.01			0.00		< 0.005			0.52	< 0.005	0.003	207356W
15			0.00			4.50	7.50			0.00			0.00			0.00		< 0.02			0.01	< 0.005	0.003	108587W
16			0.03			1.19	7.93			0.04			0.01			0.24		< 0.005			0.24	< 0.005	0.003	86014673
17			0.04			0.04	0.87	< 0.01		0.01	< 0.02	0.01	< 0.02			0.01		< 0.02			0.01	< 0.005	0.003	88015573
18			0.01			0.26	0.31	< 0.01		0.01			0.01	< 0.01		0.01		< 0.02			0.01	< 0.005	0.003	88008297
19			0.05	< 0.01		0.01	14.30			0.05			0.06			0.06		< 0.005			0.05	< 0.005	0.015	88009259
20			0.12			0.18	2.38			0.02			0.13			0.10		< 0.005			0.10	< 0.005	0.003	88009811
21			0.02			0.74	2.00			0.31	< 0.01	0.01	< 0.02			0.01		< 0.02			0.01	< 0.005	0.003	88003668
22			0.17			0.43	1.56			0.07			0.02	< 0.02		0.01		< 0.02			0.01	< 0.005	0.003	88000404
23			0.02			0.05	0.05	< 0.01		0.01	< 0.01	0.01	< 0.02			0.01		< 0.02			0.01	< 0.005	0.003	88002667
24			0.00			0.50	2.90			0.00			0.00			0.00		< 0.02			0.01	< 0.005	0.003	200019W
25			0.01			16.20	4.43			0.62	< 0.01	0.01	< 0.02			0.00		< 0.02			0.01	< 0.005	0.003	304258W
26			0.09			0.41	6.16			0.09			0.32			0.00		< 0.02			0.01	< 0.005	0.003	405171W
27			0.01			0.22	0.30			0.01	< 0.01	0.01				0.00		< 0.02			0.01	< 0.005	0.003	413659W
28			0.11			0.54	0.37	< 0.01		0.01	< 0.01	0.01				0.00		< 0.02			0.01	< 0.005	0.003	302150W
29			0.39			0.21	0.62			0.02			0.03			1.28		< 0.005			1.28	< 0.005	0.003	300143
30			0.19			0.06	5.58	< 0.01		0.01			0.04	**		1.24		< 0.005			1.24	< 0.005	0.003	300140
31			0.01			0.05	0.57			0.02	< 0.01	0.01	< 0.02			0.01		< 0.02			0.01	< 0.005	0.003	1002901
32			0.01			0.04	2.39			0.26			0.05			0.11		< 0.005			0.11	< 0.005	0.003	1002923
33			0.02			0.12	5.73			2.18			1.95	< 0.02		0.01		< 0.02			0.01	< 0.005	0.003	1002486
34			0.03			0.31	6.67			0.15			0.14			0.53		< 0.005			0.49	< 0.005	0.043	1002511
35			0.12			0.08	4.78			0.05			0.03			0.10		< 0.005			0.10	< 0.005	0.003	1002894
36			0.01			0.98	0.83			0.03			0.02			0.00		< 0.005			0.02	< 0.005	0.003	302796W
37			0.16			0.50	0.41			0.01			0.05			0.00		< 0.005			0.20	< 0.005	0.003	216810W
38			0.02			0.27	5.43			0.07			0.01			0.00		< 0.005			0.05	< 0.005	0.005	213767W
39			0.07	< 0.03		0.02	1.28	< 0.01		0.01			0.06			0.78		< 0.005			0.78	< 0.005	0.003	1003368
40			0.05			0.07	6.29			0.02			0.05			0.00		< 0.005			1.20	< 0.005	0.024	2022584W
41			0.57			0.21	6.42			0.01			0.04			0.00		< 0.005			1.96	< 0.005	0.003	201784W
42			0.00			0.50	1.40			0.00			0.00			0.00		< 0.020			0.00	< 0.020	0.010	200771W
43			0.01			0.09	0.06	< 0.01		0.01	< 0.01	0.01	< 0.02			0.01		< 0.02			0.01	< 0.005	0.003	1002206
44			0.01			0.08	0.01	< 0.01		0.01	< 0.01	0.01	< 0.02			0.01		< 0.02			0.01	< 0.005	0.003	1003703
45			0.09			0.12	5.89			0.53	< 0.01	0.01				0.03		< 0.005			0.03	< 0.005	0.003	1001721
46			0.02			0.27	3.56			0.14	< 0.01	0.13				4.85		< 0.005			4.24	< 0.005	0.614	1001746

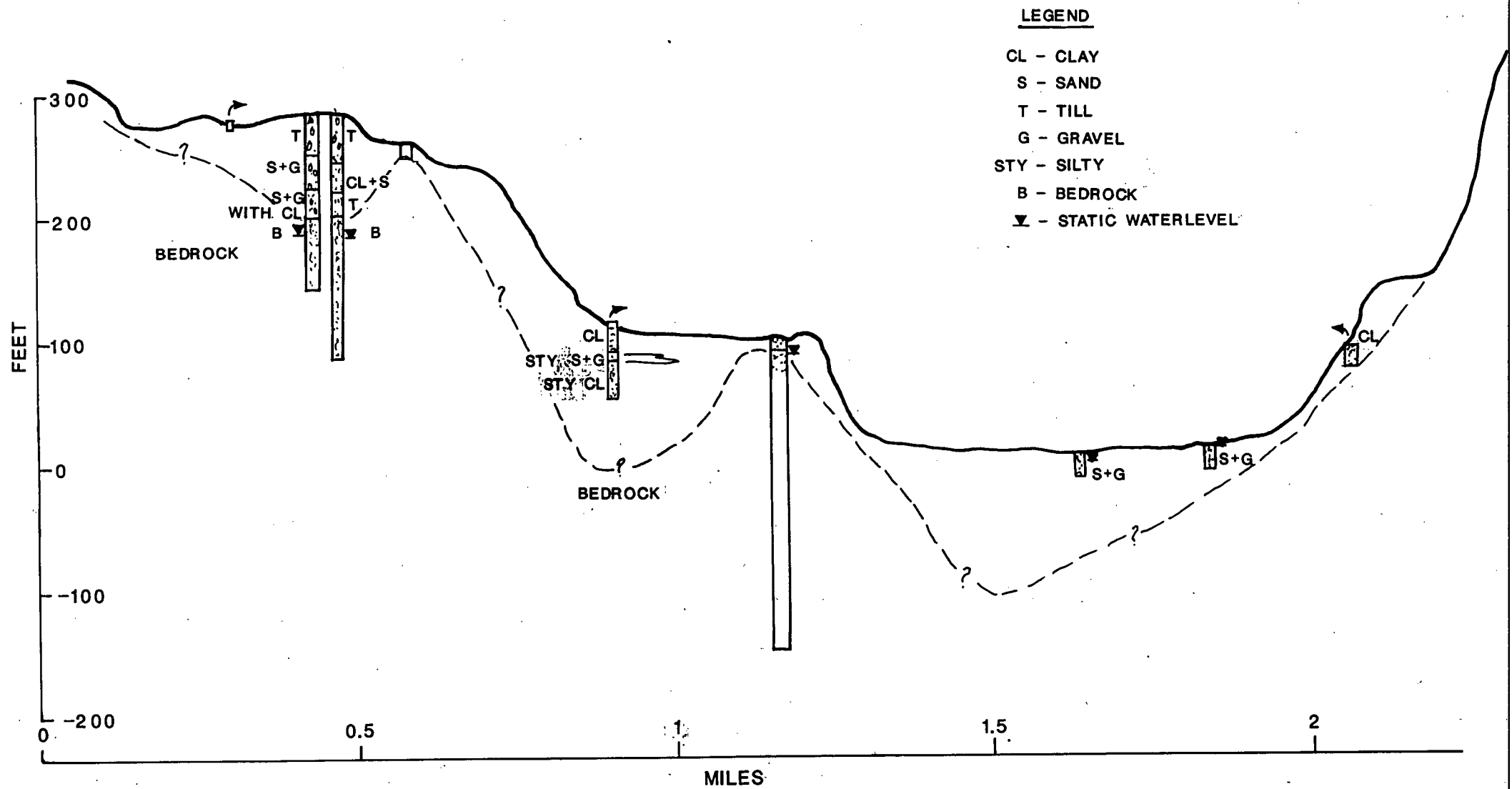


FIGURE 3 CROSS SECTION 1-1
 - NANAIMO RIVER BASIN
 GROUNDWATER RESOURCE EVALUATION (AUG. 1991)

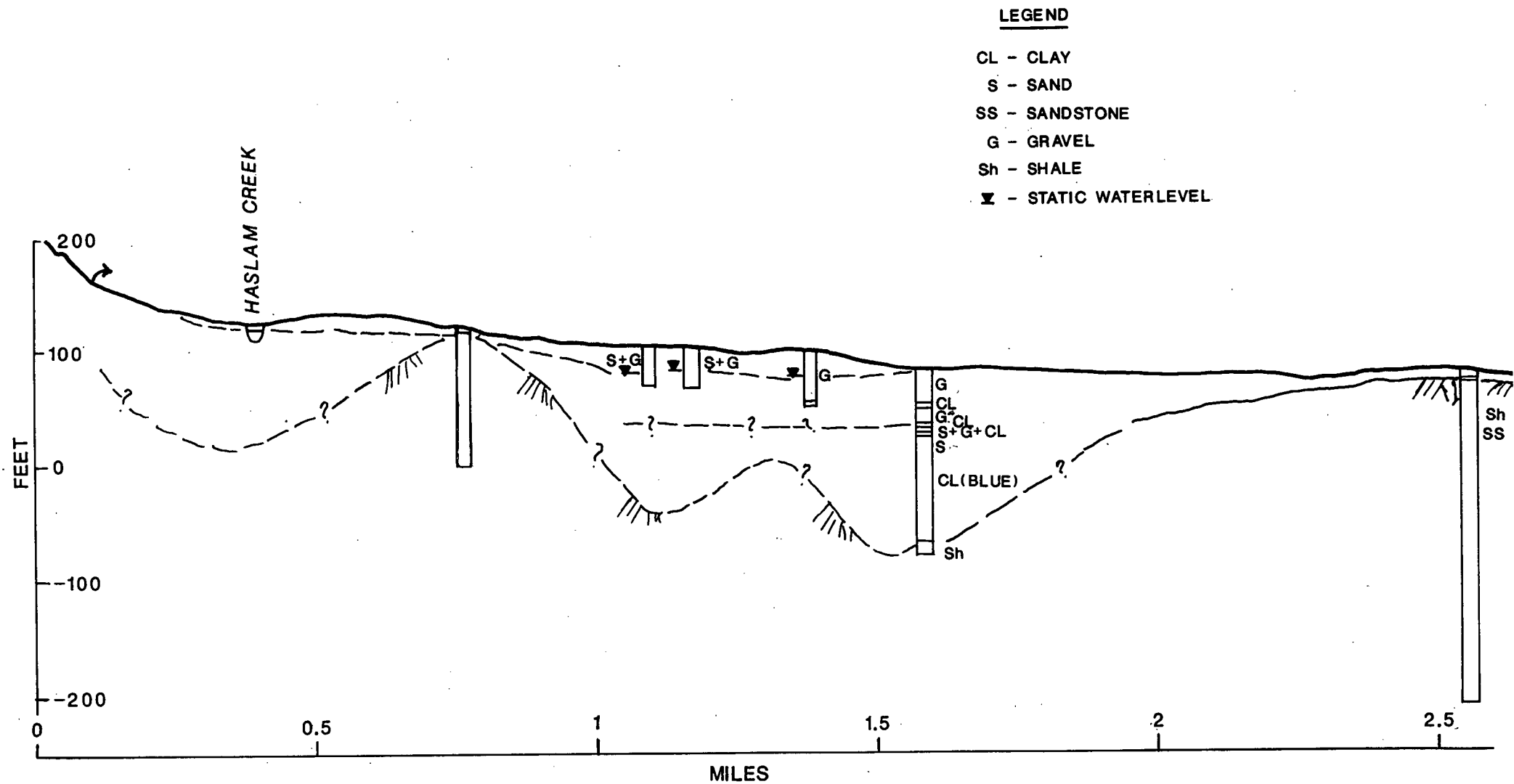


FIGURE 5 CROSS SECTION 3-3
 NANAIMO RIVER BASIN
 GROUNDWATER RESOURCE EVALUATION (AUG. 1991)

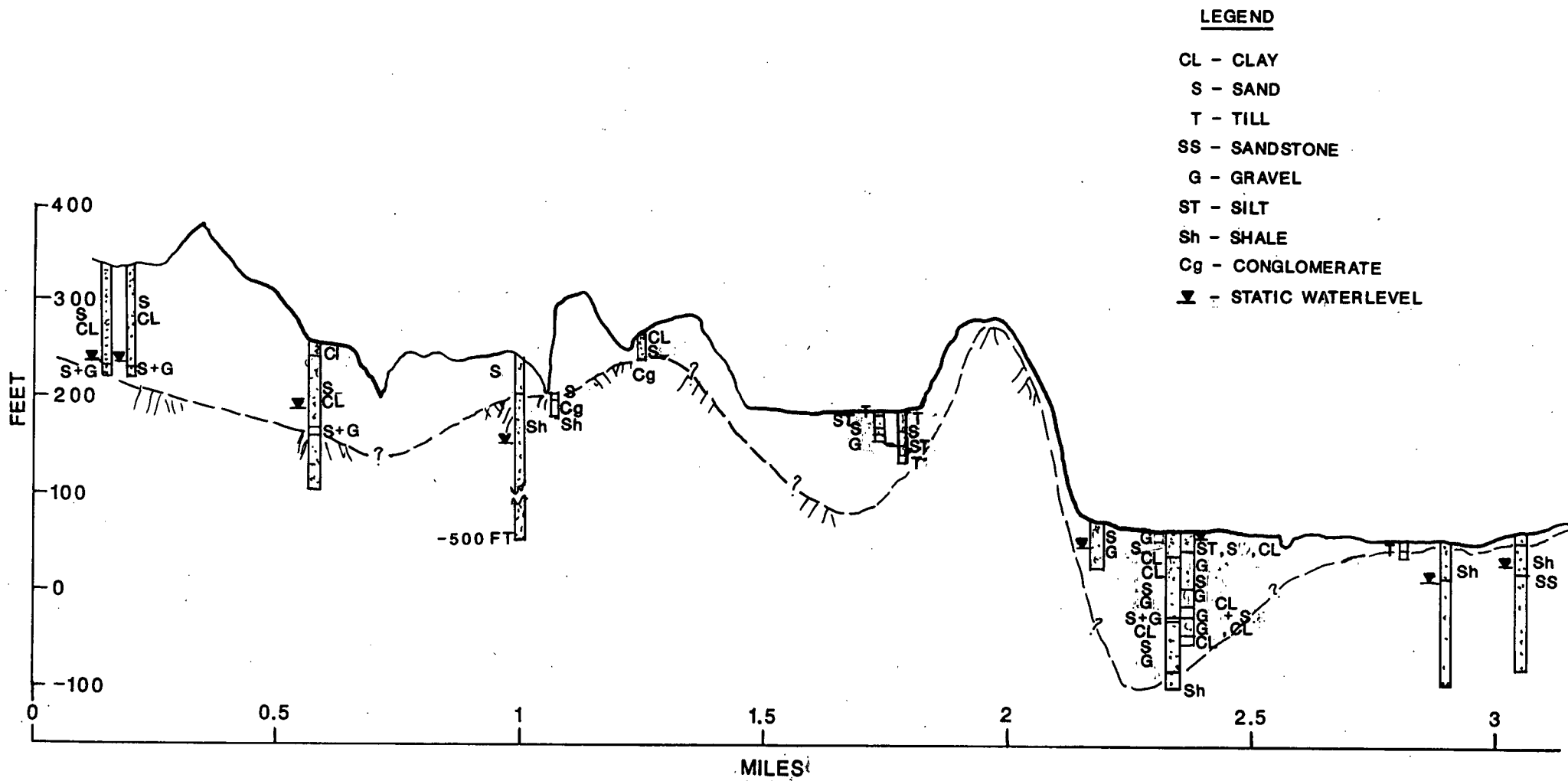


FIGURE 6 CROSS SECTION 4-4
 NANAIMO RIVER BASIN
 GROUNDWATER RESOURCE EVALUATION (AUG. 1991)

LEGEND

CL - CLAY

SS - SANDSTONE

Sh - SHALE

Cg - CONGLOMERATE

▼ - STATIC WATERLEVEL

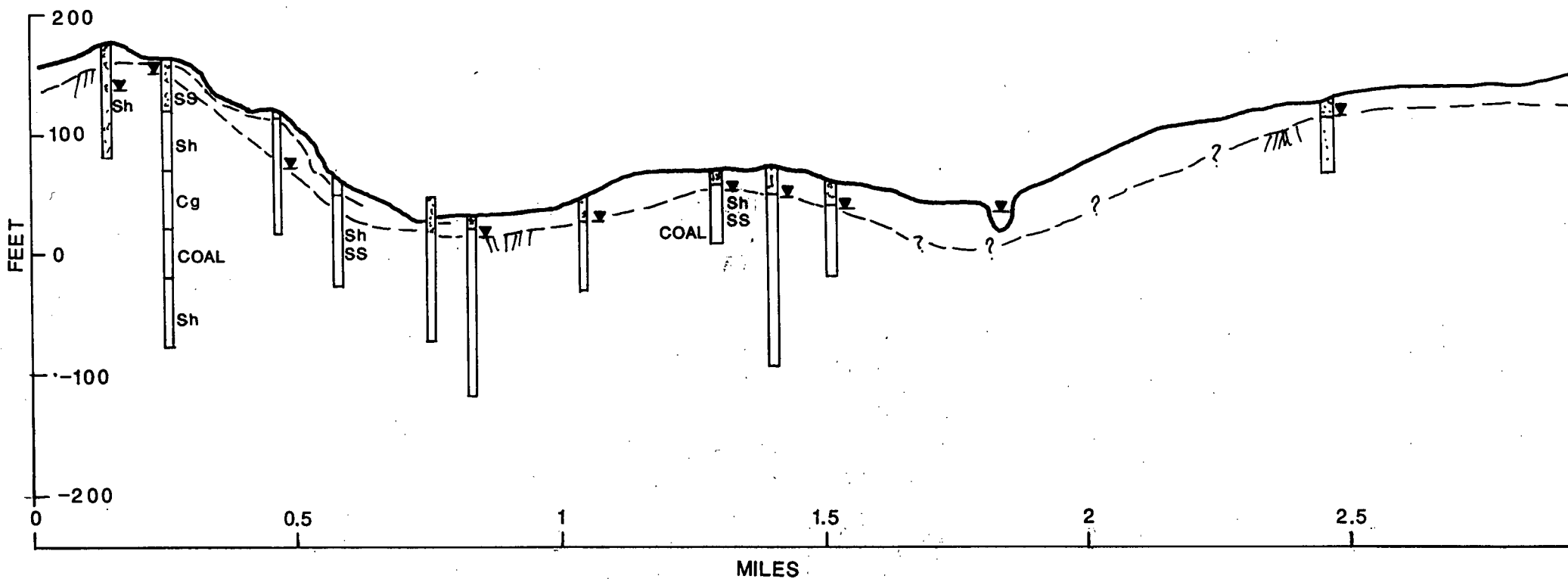


FIGURE 7 CROSS SECTION 5-5

NANAIMO RIVER BASIN

GROUNDWATER RESOURCE EVALUATION (AUG. 1991)

LEGEND

▼ - STATIC WATERLEVEL

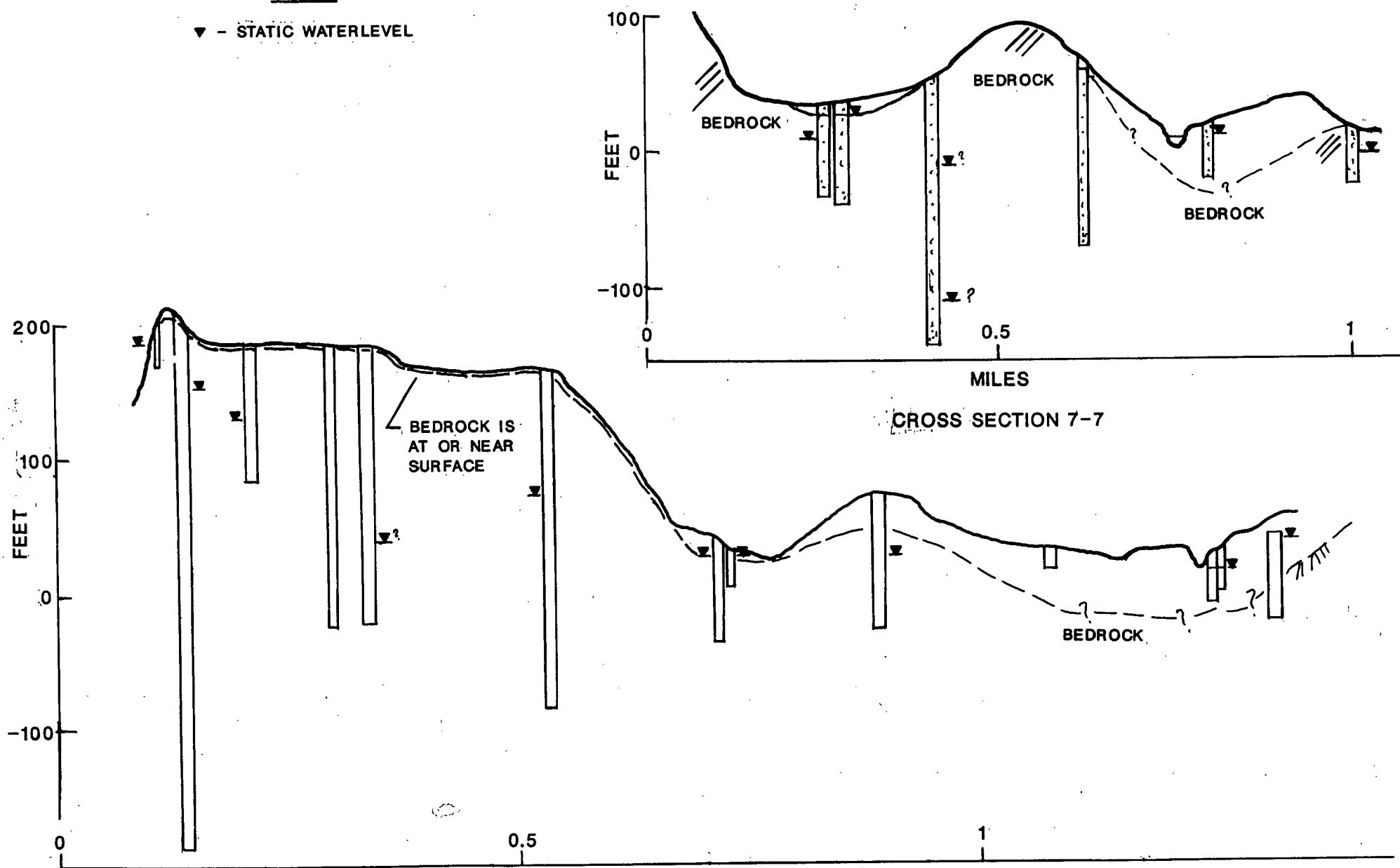


FIGURE 8 CROSS SECTION 6-6
NANAIMO RIVER BASIN
GROUNDWATER RESOURCE EVALUATION (AUG. 1991)

LEGEND

CL - CLAY

S - SAND

G - GRAVEL

Sh - SHALE

BLDS - BOULDERS

▼ - STATIC WATERLEVEL

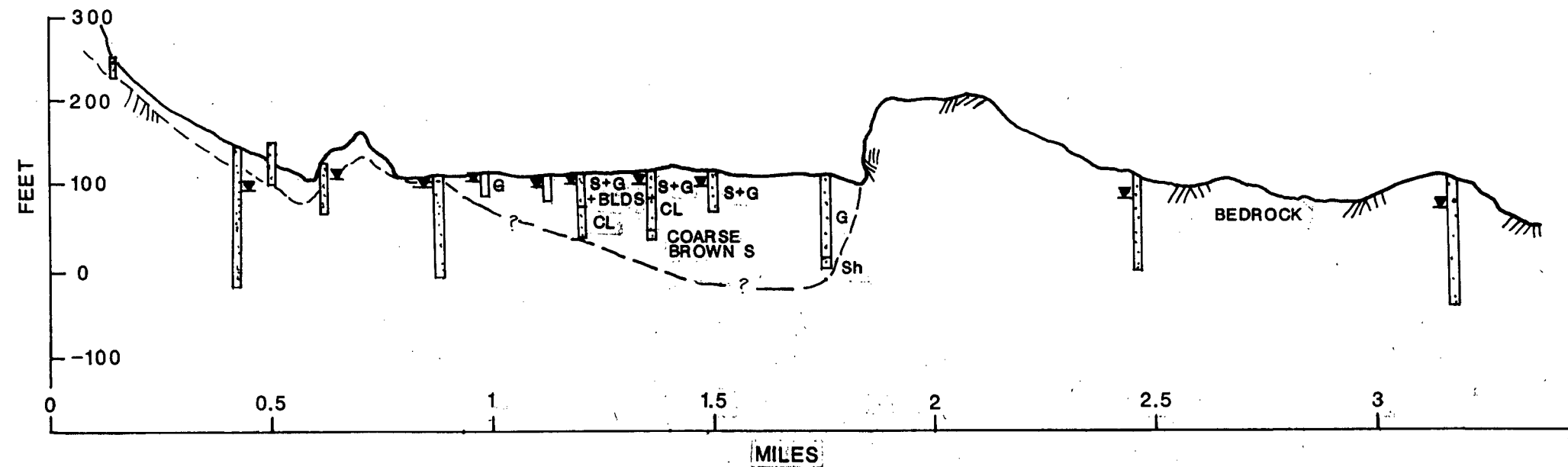
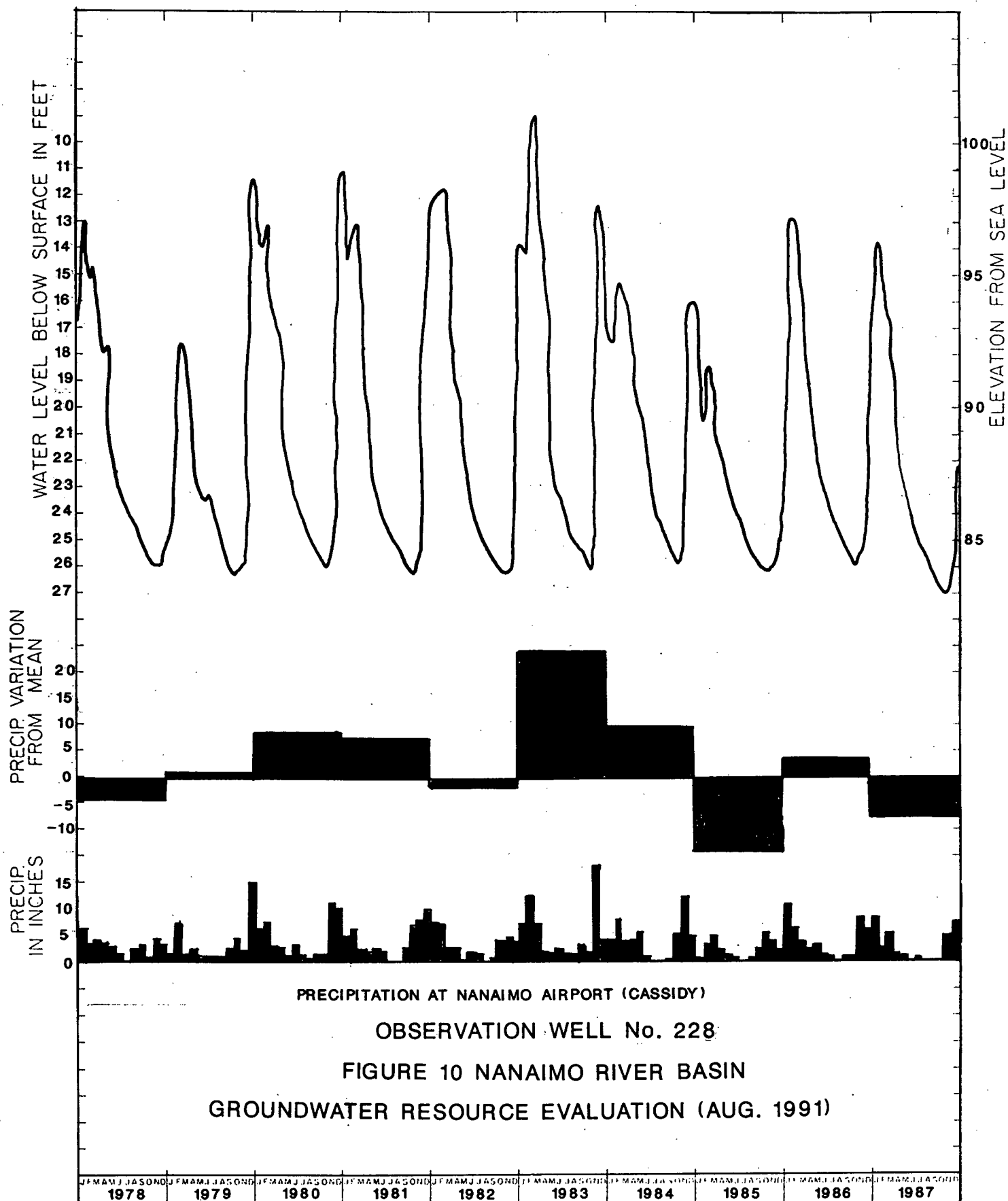


FIGURE 9 CROSS SECTION 8-8

NANAIMO RIVER BASIN

GROUNDWATER RESOURCE EVALUATION (AUG. 1991)

HYDROGRAPHS SHOWING WATER LEVEL FLUCTUATIONS



HYDROGRAPHS SHOWING WATER LEVEL FLUCTUATIONS

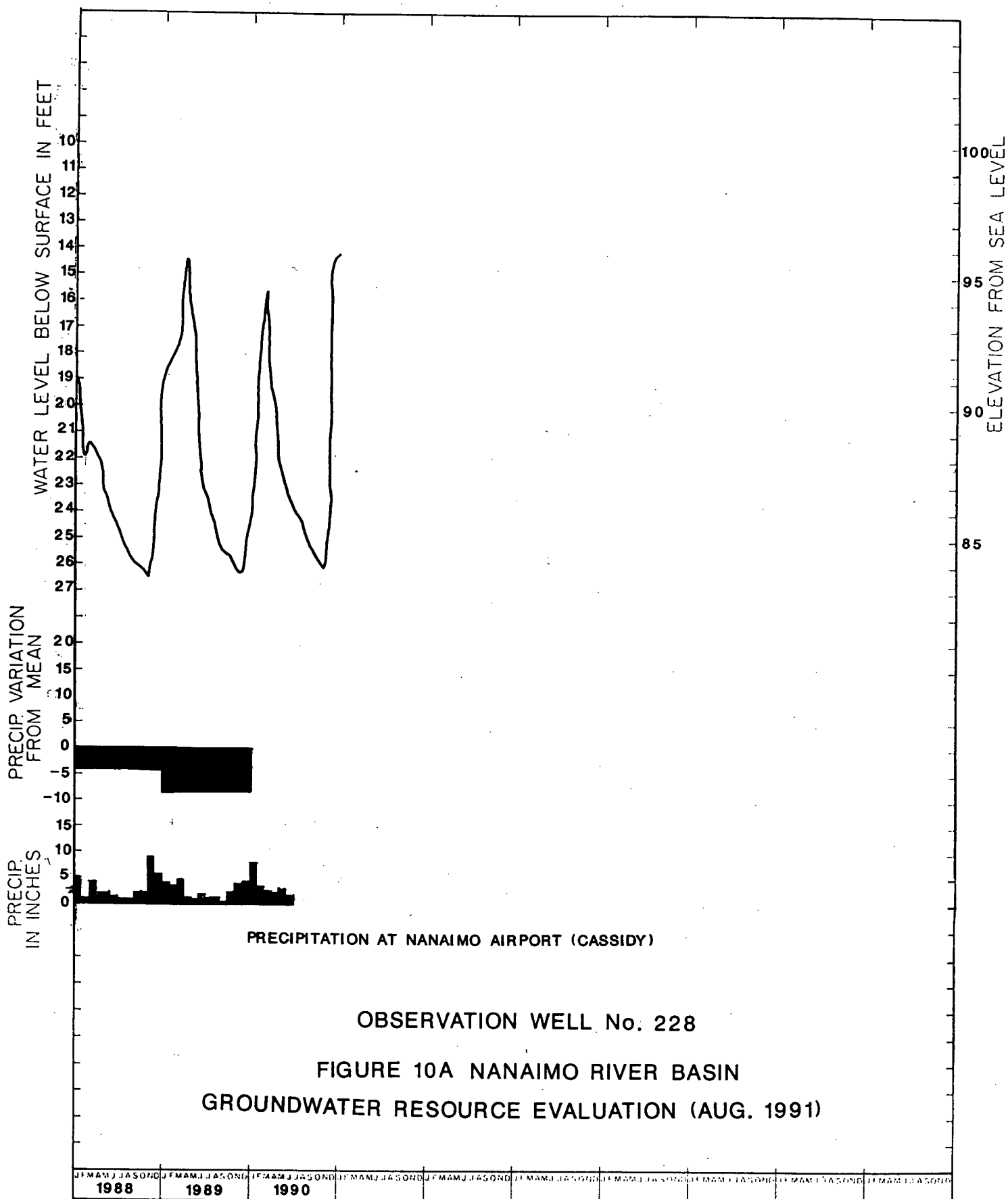


FIGURE 1 NANAIMO RIVER BASIN

WATER MANAGEMENT PLAN

GROUNDWATER RESOURCE EVALUATION (AUG. 1991)

SURFICIAL GEOLOGY AFTER HALSTEAD, 1961.

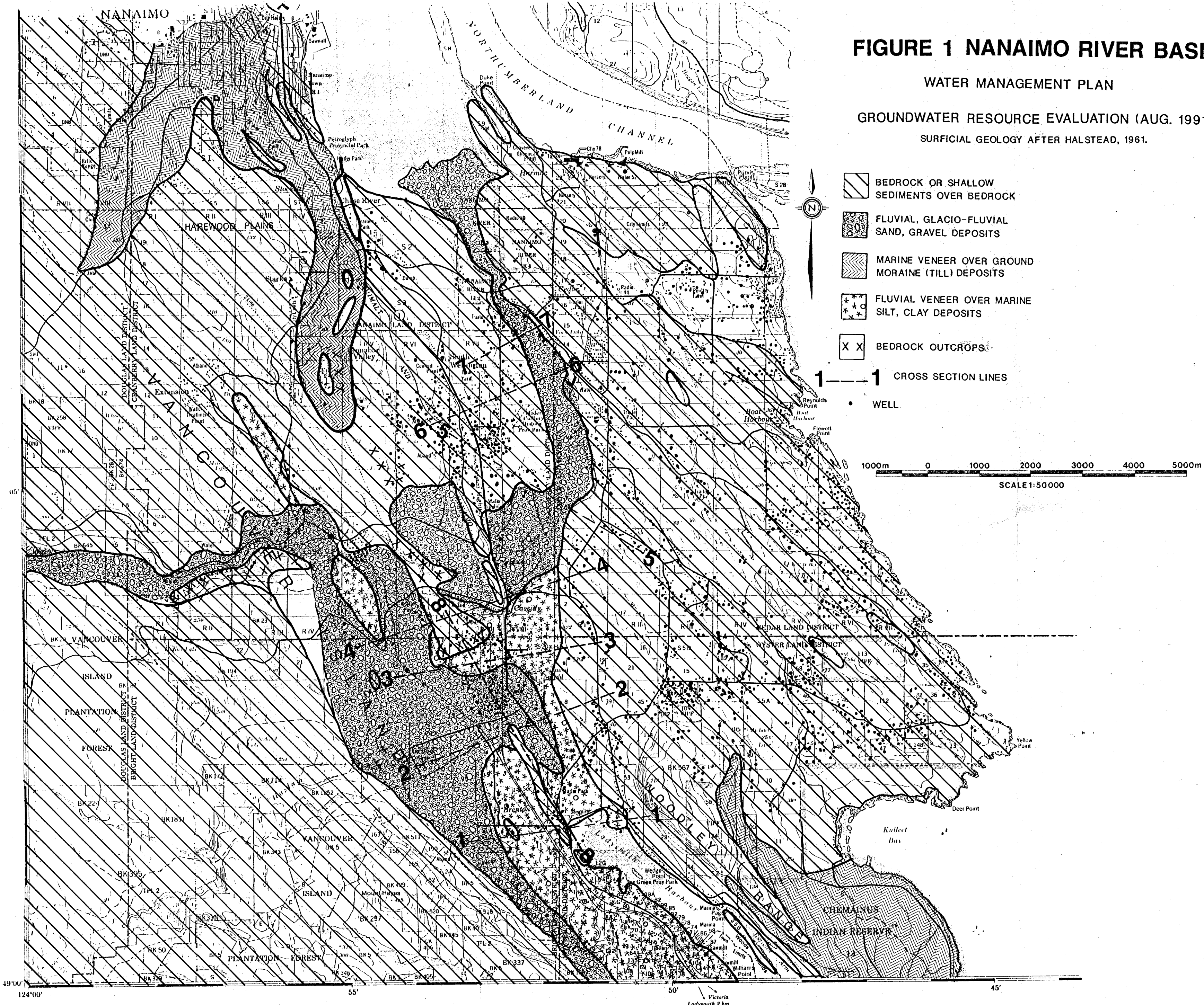


FIGURE 2 NANAIMO RIVER BASIN

WATER MANAGEMENT PLAN

GROUNDWATER RESOURCE EVALUATION (AUG. 1991)

