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Groundwater resources near Vanderhoof, British Columbia[1]

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Abstract: Water well records were used to interpret and assess groundwater resources near Vanderhoof, British Columbia. The variable quality and shortage of data in the well records complicated the assessment; however, a solid interpretation was developed. The geology of the study area is dominated by hydrogeologically significant glacial deposits of sand, gravel, till, and clay. A basalt flow southeast of Vanderhoof has yielded sufficient quantity and flow rates for domestic and agricultural use, and could prove to be of greater importance in the future.

Résumé : On a utilisé des registres de puits d'eau pour interpréter et évaluer les ressources en eau souterraine près de Vanderhoof (Colombie-Britannique). La qualité variable des données et le manque de données contenues dans les registres ont compliqué l'évaluation; cependant, l'interprétation présentée est bien étayée. La géologie de la région à l'étude est caractérisée par des dépôts glaciaires de sable, de gravier, de till et d'argile qui sont importants d'un point de vue hydrogéologique. Une coulée de basalte au sud-est de Vanderhoof a produit une quantité et un débit d'eau suffisants pour répondre aux besoins domestiques et agricoles et elle pourrait s'avérer d'une grande importance dans l'avenir.

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[1] Contribution to the Nechako NATMAP Project

INTRODUCTION

This research, a contribution to the Nechako NATMAP Project, tested the feasibility of using existing information from regional bedrock and surficial mapping, and local water well records to map aquifers and interpret potential groundwater resources in the Vanderhoof area of central British Columbia. It provides information necessary to make a reasonable interpretation of the continuity and hydrogeological characteristics of subsurface sediments and lava flows.

The only previous work in this area was that done by Halliwell et al. (1993). They identified unconfined aquifers open to the surface in this part of the Fraser River Basin based upon pre-existing surficial and bedrock geology maps and soil surveys.

SETTING

Vanderhoof is located in the geographic centre of British Columbia, 97 km west of Prince George (Fig. 1). The city lies in the Nechako River valley of the Fraser River Basin. Industry in this valley is primarily forestry and secondarily agriculture. The population of Vanderhoof is 4300 and serves a surrounding area of 18 400 people (Vanderhoof District Chamber of Commerce, 1997; Vanderhoof; www.hwy16.com). Water use is predominately domestic and partially industrial (Fig. 2).

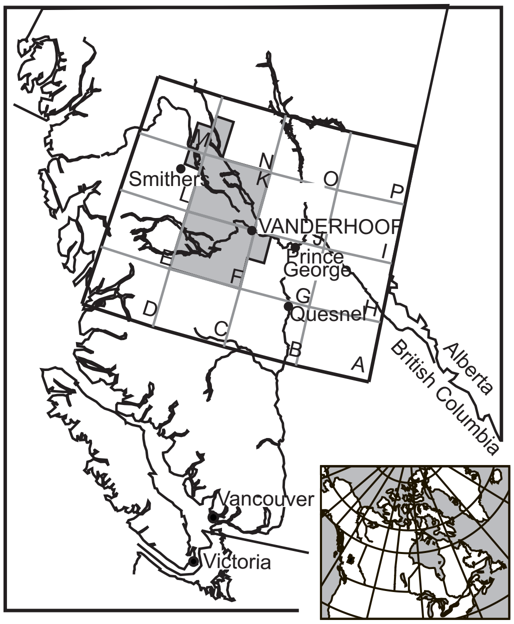

Figure 1. *Location of Vanderhoof in central British Columbia.*

METHODOLOGY

A general interpretation of the area's subsurface geology was developed from the bedrock and surficial geology maps of the area. Using well-log data and well location maps from the British Columbia Ministry of Environment, Lands and Parks, a computer database was created that included project well numbers, well depths, depths to water, depths to bedrock, well diameters, well yields, elevations, and lithologies (British Columbia Ministry of Environment, Land and Parks, 2000; www.elp.gov.bc.ca/wat/gws/gwsdata.html). This extensive database will be released as Open File 3891 (Mayberry, 2000).

Well location maps were digitized and the well log database was imported into the Geographic Information System (GIS) software ArcInfo^{TM} 7.0. An Arc Macro Language (AML) routine created by Andrew Makepeace (GSC Vancouver) was used to create stratigraphic cross-sections of selected wells. Sediment and rock units in these cross-sections were correlated to establish their 3-dimensional distribution. During compilation of well logs, it was found that lithological terms were frequently used inconsistently. For example, till was identified as "sand, gravel, and clay", or "sandy clay and rock". In order to make the unit correlations, inconsistent lithological terms were standardized. The distribution and flow of groundwater in the wells was used to interpret the aquifer potential of each of these 3-dimensional units.

Generalized 3-dimensional isopach maps of the sediment and rock units were generated using computer models. The models were created using Triangular Irregular Network (TIN) technology. Isopach surfaces were extrapolated between well control points using the ArcInfo^{TM} contouring program.

A contour map of the groundwater surface with 20 m contour intervals was created by plotting well water levels recorded at the time of drilling. This contour map was used as an approximation of the present groundwater potentiometric surface. A groundwater flow map was produced using this potentiometric surface, surface relief, and the 3-dimensional geological interpretation.

Another database was created using a small amount of water chemical analyses from the British Columbia Ministry of Environment, Lands and Parks. Included in the database were pH, turbidity, total alkalinity, total hardness, total fluoride, total calcium, total magnesium, total zinc, and total arsenic. The data was analyzed by use of graphs for hardness, arsenic, and fluoride.

GEOLOGY

The rocks and sediments underlying Vanderhoof consist mainly of basalt, sandstone, and siltstone bedrock overlain by thick glacial deposits. For this study, the area was divided into three regions, northwest of the Nechako River, southwest of the Nechako River, and southeast of Vanderhoof.

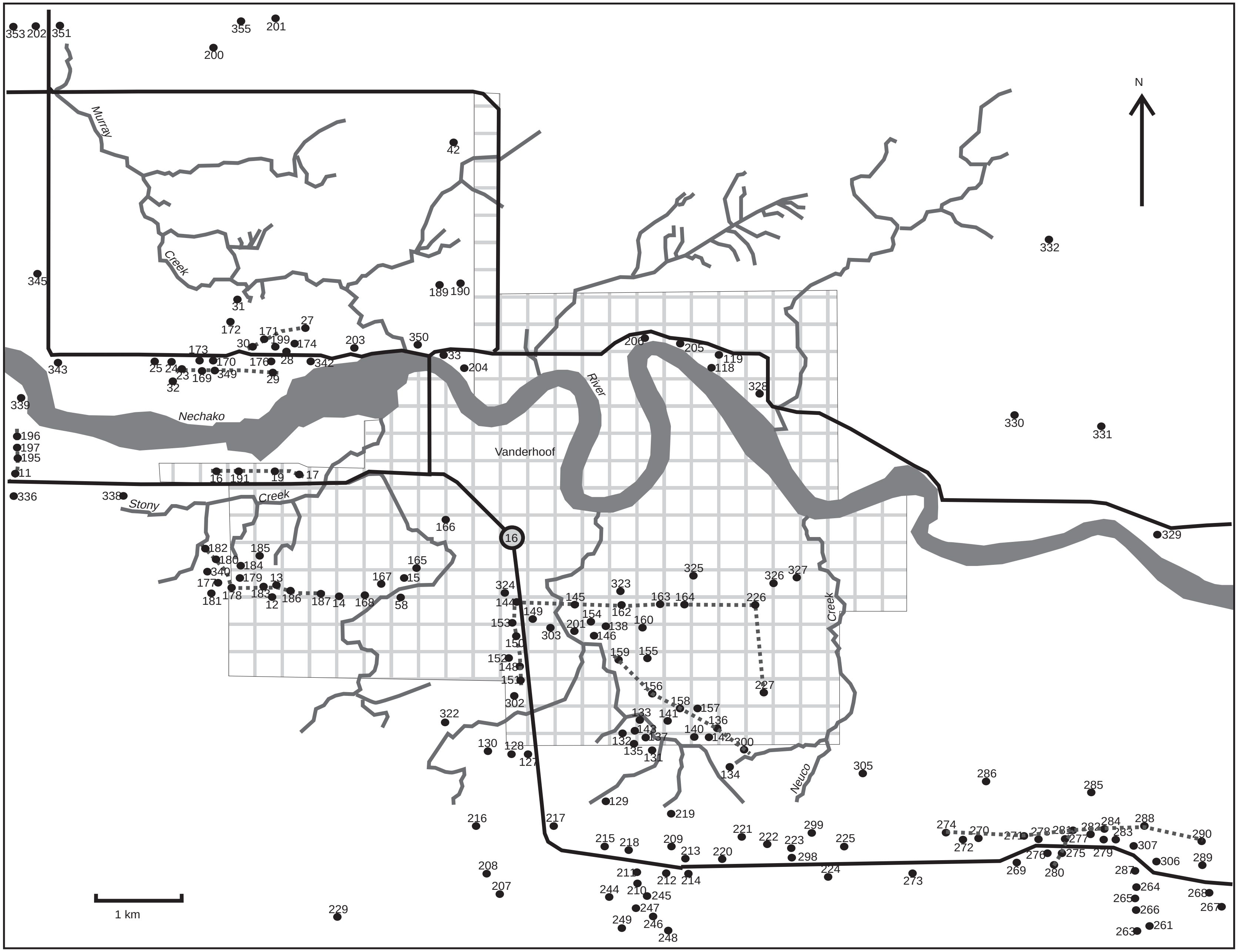

***Figure 2**. Well locations in Vanderhoof. Dotted lines joining well sites indicate locations of the cross-sections of Figures 4–11. Solid black lines are roads; grey grid pattern indicates full area of Vanderhoof municipality.*

Bedrock geology

The bedrock geology is quite consistent throughout the study area, Miocene sandstone and siltstone overlain by Miocene olivine-phyric basalt flows (Struik, 1998). The expanse of the sandstone appears to cover all regions of the study area (wells 23, 159, 165, 177, 263). It is the only bedrock seen in the northwest; however, mapping by Struik (1998) identified basalt bedrock in that region. Both black, vesicular basalt and sandstone bedrock are present beneath the surficial deposits in the southwest and southeast regions of the study area.

Surficial geology

The glacial deposits comprise sand, silt, till, and gravel deposited as part of lakes, terraces, and floodplains (Plouffe, 1996). The area exhibits evidence of only the most recent glaciation — the Fraser Glaciation. Plouffe (1991) investigated the glacial history of the area. He found no pre-Fraser glaciation sediments. He determined the following sequence of events had occurred in the Vanderhoof area: at the onset of the Fraser Glaciation, piedmont glaciers that originated in the Skeena and Coast Mountains invaded central British Columbia from the northwest and west. These glaciers later coalesced with ice from the Cariboo Mountains, causing a shift in the ice-flow direction to a more east-northeasterly direction. During ice retreat, the Nechako River was blocked and its valley and all connected ground below 725–760 m were flooded, creating a glacial lake. In a later study, Plouffe (1997) concluded that this lake probably lasted 32 years, until the blocking dam was destroyed and the lake drained.

The glacial events recognized by Plouffe (1991) produced stratified and deformed sand and gravel deposits in the northwest corner of the study area which were later overlain by till (Plouffe, 1991). This till — Fraser Till — is the most abundant sediment resulting from the Fraser Glaciation. Its clayey texture resulted from the ice flowing over clayey, unconsolidated sediments (Plouffe, 1991). A blanket of clay and silt that was beneath the glacial lakes was deposited during ice retreat. These sediments are not thick enough to mask the underlying topography of the area; however, they reach thicknesses of up to 100 m in some wells. Fluvial gravel terraces along the river banks of the Nechako River were deposited as the glacial lake drained, as were the sand and outwash gravel deposits which were deposited along the east- northeast side (in front) of the retreating glacier (Fig. 3).

North of the Nechako River, the geology is dominated by till and clay with some fairly continuous deposits of sand with secondary gravel. In the southwest region, there are thick deposits of sand and thin, widespread gravel deposits that are possibly from a postglacial river. The southeastern region of the study area is dominated by discontinuous deposits of till, sand, gravel, and clay, scattered throughout the region.

STRATIGRAPHY

Throughout the three regions (*see* ‘Geology’), the predominate stratigraphic succession from oldest to youngest is basalt, till, and clay. The till and clay are locally interstratified by deposits of sand and gravel.

In the northwest region, the predominate till and clay succession ranges in thickness from 90 m to 150 m (Fig. 4, 5). Locally sand and gravel beds occur beneath the till (Fig. 4, well 29). With the well data available, the sand and gravel beds appear to be mainly thin sheets. An exception is the surface deposits of sand near the Nechako River (Fig. 4). The clay lake sediments form most of the sequence and are commonly bound at the top and bottom by sand and gravel beds, 2–20 m thick.

In the southwestern region, the till and overlying clay range in thickness from 40 to 140 m, and are underlain by basalt locally greater than 65 m thick (Fig. 6, 7, 8). A sandstone bed beneath the basalt of well 183 (Fig. 8) is probably of Miocene age (9–13 Ma). Rocks like this are exposed to the east of the study area along the Nechako River, east of Sinkut Creek and near and along Cluculz Creek (Struik and Wetherup, 1996). Closer to the Nechako River the sections are dominated by clay and sand. An exceptional 127 m of sand was intersected by well 17 just south of the Nechako River.

In the southeastern region, basalt and overlying clay dominate the stratigraphic succession (Fig. 9, 10). The clay ranges in thickness from 10 m to 25 m and is locally underlain and overlain by sheets of sand and secondary sheets of gravel. Wells in the southeastern region were drilled from surface elevations 50–70 m higher than near the Nechako River as is also the case in the southwestern region (*see* contour map of Fig. 3).

Several genetic relationships can be determined from interpreting the stratigraphy of the four regions as a whole. The Nechako River valley forms a broad low-lying area mostly north of the present river and is bound by steep banks of 50–60 m elevation. In the lowest areas adjacent to the Nechako River, abundant sands in the upper parts of the water wells are probably recent deposits of the river which were laid down as it cut channels through pre-existing glacial lake and till deposits. Elevations of basalt flows (Mathews and Rouse, 1984) in the valley and those in the southern bank differ by 150 m (Fig. 7, well 16; Fig. 8, well 182). These elevation differences may reflect topography that existed prior to the eruption of the basalt and therefore define a valley that existed prior to 9–13 Ma.

GROUNDWATER LEVELS

It was not possible to produce a potentiometric surface map for this project because static levels of well water have not been measured, and because there are numerous discontinuous aquifers in the study area; however, depths to water at the

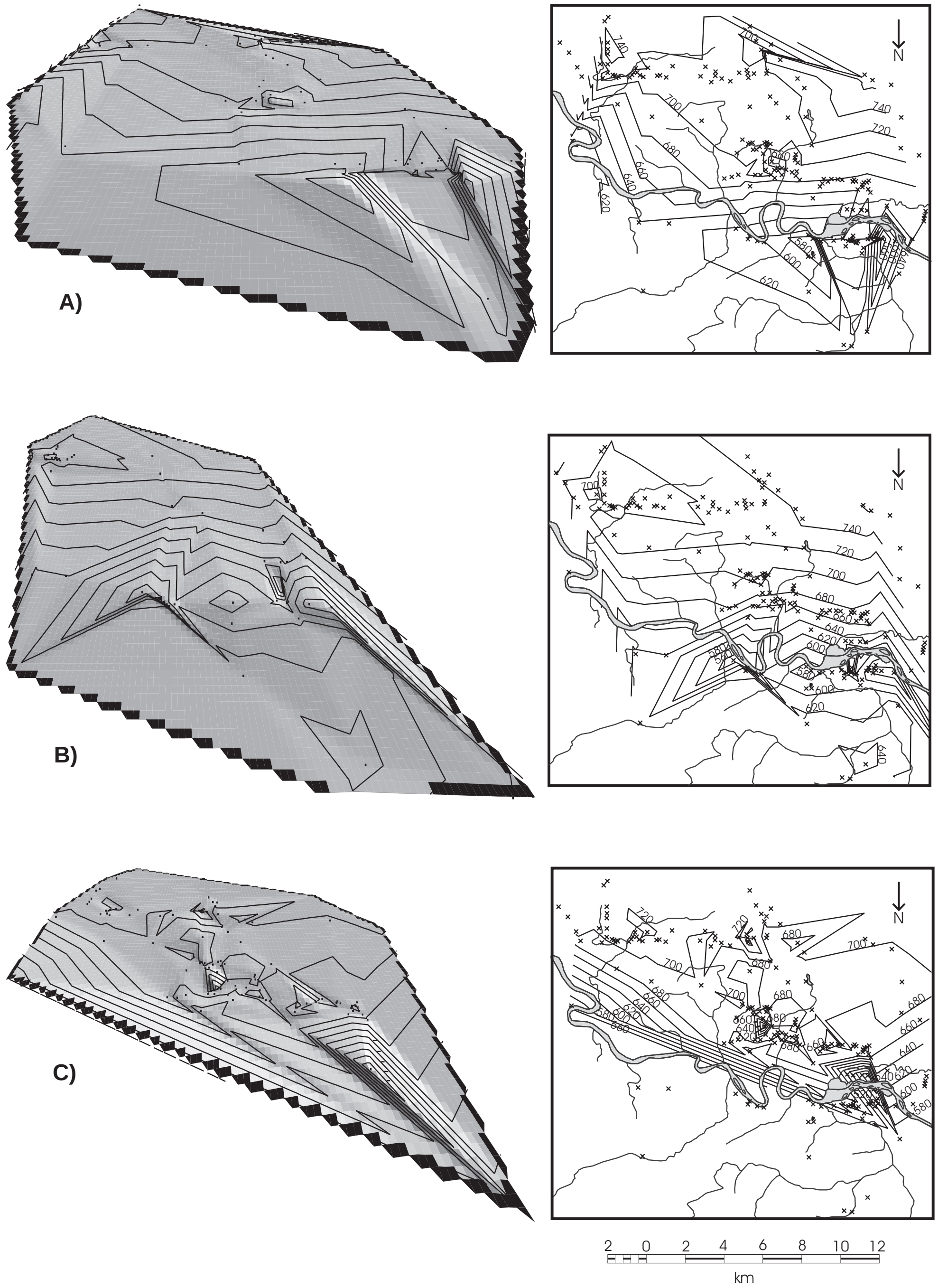

Figure 3. *Three-dimensional models of the surface to units of* ***A)*** *sand,* ***B)*** *gravel, and* ***C)*** *basalt bedrock and corresponding contour maps. Elevations are in metres above sea level. Three-dimensional models have a vertical exaggeration of five times. See Figure 2 for geographic names. Maps and images are with south to top of page because the 3-D features are more easily seen in that direction.*

time of drilling were recorded and these have been used to create a generalized contour map of water levels in wells (Fig. 11). Groundwater levels were recorded over a period of approximately three decades. Numerous changes to the water levels could have occurred during that time, caused by such factors as seasonal fluctuations, precipitation changes, withdrawal fluctuations, and usage drawdown. Because numerous discontinuous unconfined aquifers occur in the area, the water-level map does not necessarily reflect the level of one aquifer, but rather, several.

GROUNDWATER FLOW

The topographic highs flanking the Nechako River are the area's groundwater recharge areas. The river valley is the main groundwater discharge area. The Nechako River may serve as a groundwater source in the western part of the study area as the north and south banks of the river are in part lower than the river. Recharge of groundwater resources in the Vanderhoof area occurs predominantly in the spring season when the snowfall from the previous winter melts, and when the area is not subjected to much evapotranspiration.

In the northwest region, the discontinuous, near-surface deposits of sand and the continuous, deeper deposits of sand and gravel receive groundwater from intermediate and local groundwater flow systems. Hydraulic conductivities were not measured in Vanderhoof; however, standard values (Table 1) are high for such deposits. It is therefore assumed that the sand and gravel deposits in the northwest region provide a large supply of groundwater to wells in the region.

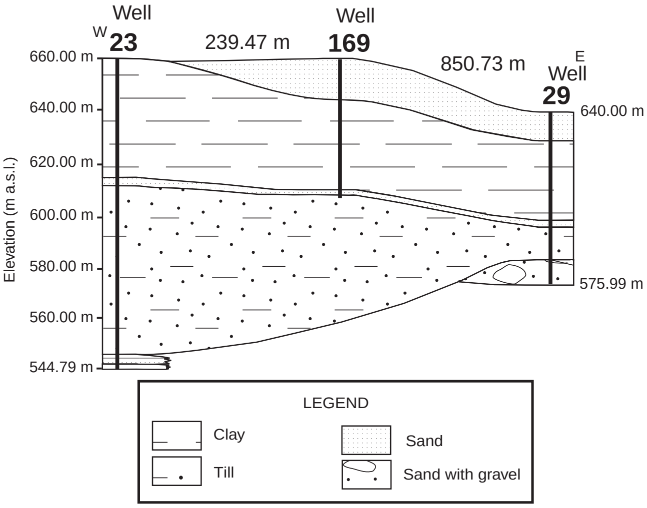

Figure 4. Stratigraphic cross-section of wells in the northwest region with legend. Well locations shown in Figure 2. Horizontal distance between wells is labelled, but not to scale.

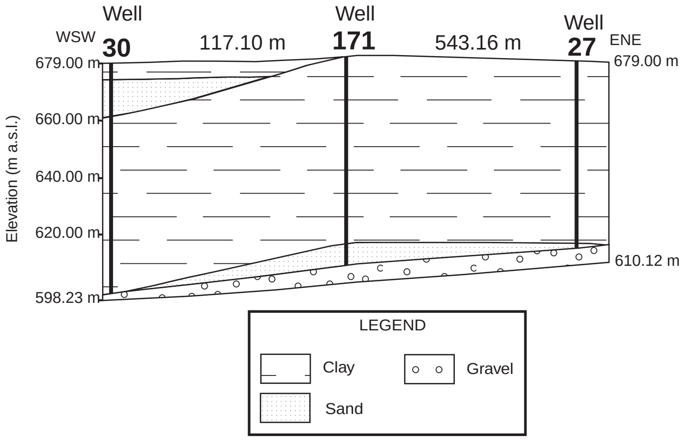

Figure 5. Stratigraphic cross-section of wells in the northwest region. Well locations shown in Figure 2. Horizontal distance between wells is labelled, but not to scale.

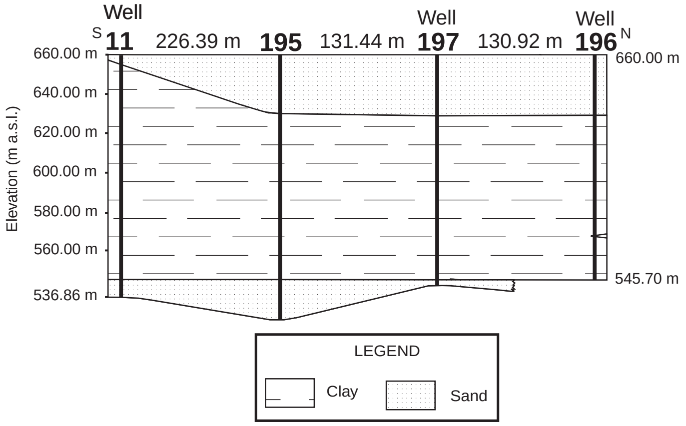

Figure 6. Stratigraphic cross-section of wells in the southwest region. Well locations shown in Figure 2. Horizontal distance between wells is labelled, but not to scale.

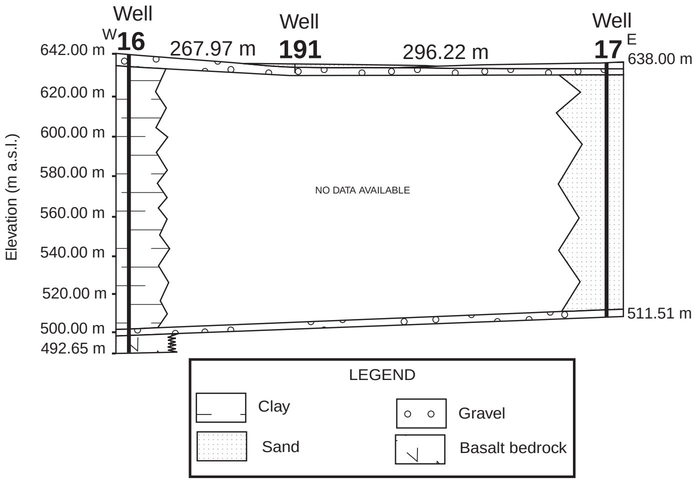

Figure 7. Stratigraphic cross-section of wells in the southwest region. Well locations shown in Figure 2. Horizontal distance between wells is labelled, but not to scale.

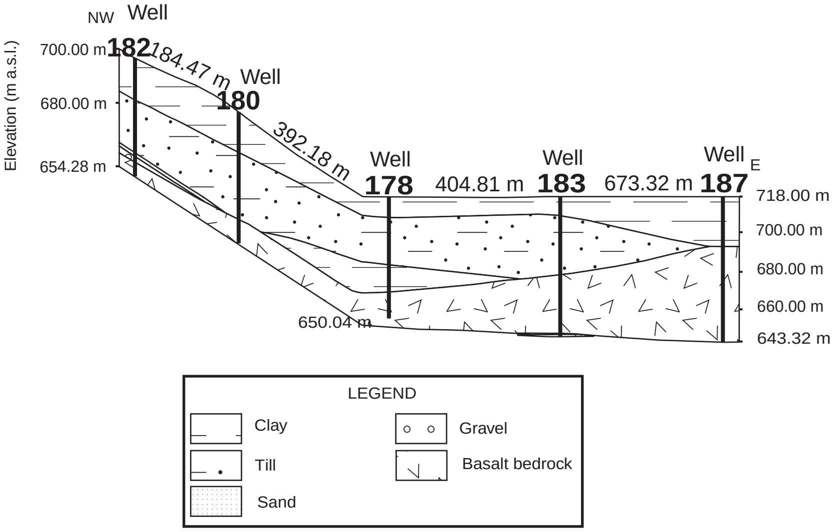

Figure 8. *Stratigraphic cross-section of wells in the southeast region. Well locations shown in Figure 2. Horizontal distance between wells is labelled, but not to scale. At the bottom of well 183, there is a thin layer of volcanic sand (0.8 m) underlain by 0.9 m of gravel which are difficult to see due to the scale of the diagram.*

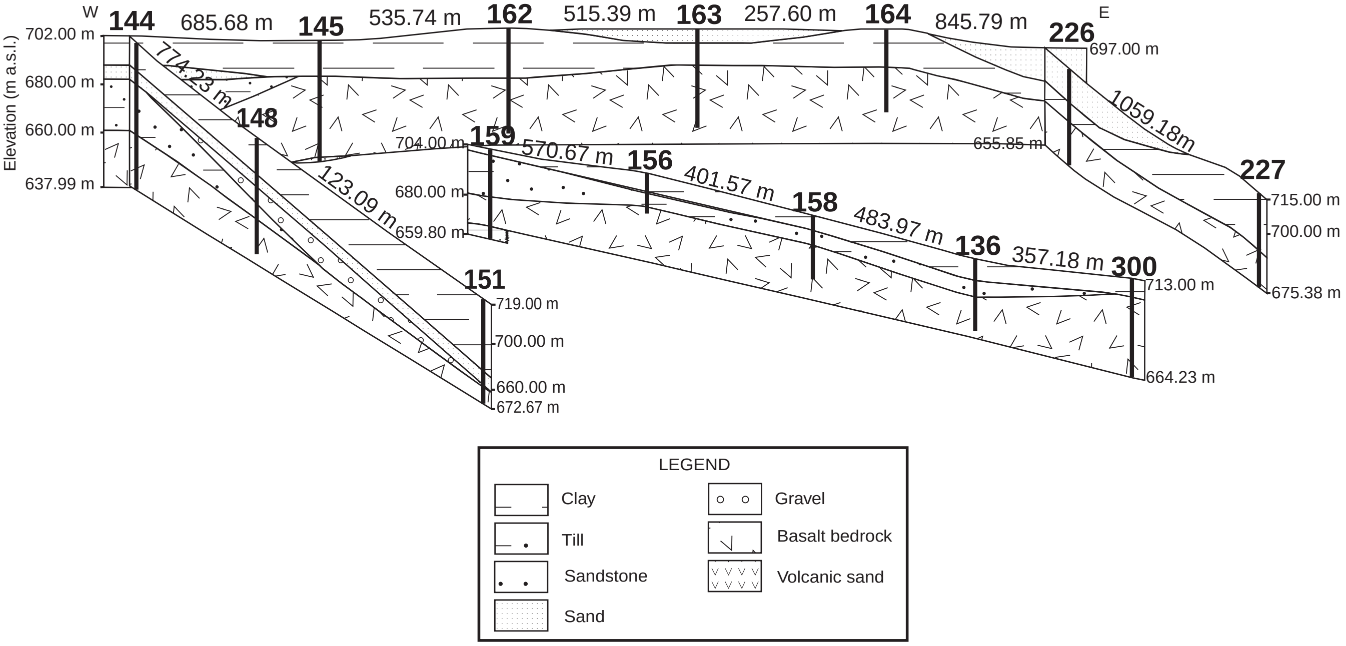

Figure 9. *Stratigraphic cross-section of wells (numbers in bold) in the southeast region. Well locations shown in Figure 2. Horizontal distance between wells is labelled, but not to scale. Note the thin deposit of volcanic sand at the bottom of well 145. Well 156 has a 0.9 m deposit of sand between the clay and till which is too small to see on a diagram of this scale.*

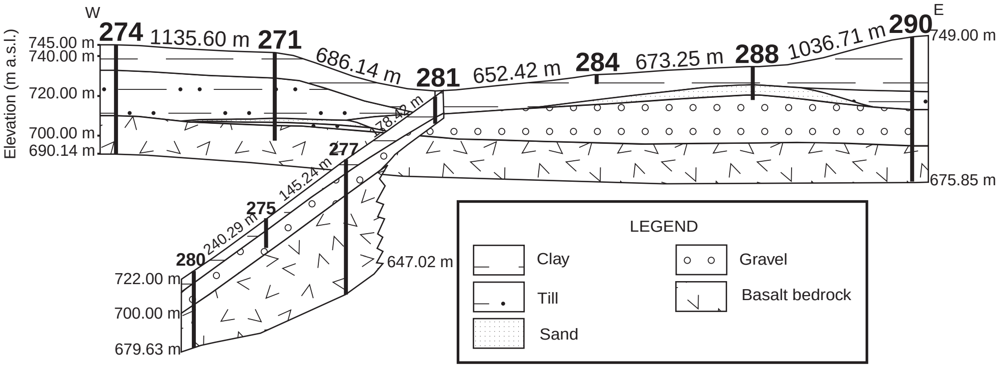

***Figure 10**. Stratigraphic cross-section of wells (numbers in bold) in the southeast region. Well locations shown in Figure 2. Horizontal distance between wells is labelled, but not to scale.*

In the southwest region, there are thick and fairly continuous deposits of outwash sand, and thin, continuous deposits of gravel (presumably related to meltwater channels) that supply large volumes of groundwater, particularly to the lumber mill on the north side of Highway 16, L & M Lumber. Due to the low elevation of the southwest region and presumably high water consumption, it is possible that drawdown of the water table near the lumber mill (Fig. 7, wells 16, 191, 17) has or may result in a withdrawal of water from the Nechako River rather than the gravel aquifers found at approximately 642 m and 510 m above sea level in these wells.

Groundwater flow in the southeast region moves regionally through the vesicular basalt and locally through the layers of sand and gravel found within the clay and till above the bedrock.

The fairly high hydraulic conductivity of basalt (Table 1) is due to the number and spacing of fractures which are very important in controlling both hydraulic conductivity and porosity (Wood and Fernandez, 1988). The porosity of the basalt in Vanderhoof is unknown, but vesicular basalt has an average porosity of 25%. Permeability is controlled by joints and faults that developed during cooling and/or subsequent tectonic activity (Wood and Fernandez, 1988). Cooling joints are concentrated along the top and bottom of the basalt flows. As such, the centre of the lava flow has the greatest density and the lowest hydraulic conductivity. The wells in the southeast region of Vanderhoof that tap the basalt do so shallowly (3–25 m). The upper part of the flow provides sufficient volumes of groundwater for domestic and agricultural usage. The hydrogeological significance of the lower part of the basalt flow in unknown. The deeper basalt aquifers apparently carry regional groundwater flow, whereas flow in overlying sands and gravels is local.

Till and silt ranging in thickness from 4 m to 109 m blanket the Vanderhoof area. Despite the low hydraulic conductivity of glacial materials such as till and silt, they possess hydrogeological continuity. Even where till is considered an

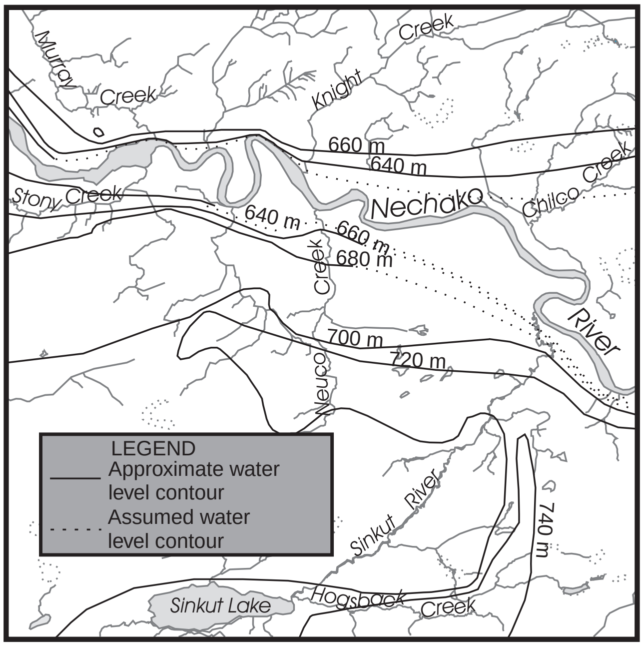

***Figure 11.** Contour map of groundwater level. Elevations in metres above sea level.*

Table 1. Range of typical values of hydraulic conductivity (Freeze and Cherry, 1979).

Material	Hydraulic conductivity (m/s)
Vesicular basalt	10^{-7}–10^{-2}
Till	10^{-12}–10^{-2}
Silt	10^{-9}–10^{-5}
Silty sand	10^{-7}–10^{-3}
Clean sand	10^{-6}–10^{-2}
Gravel	10^{-3}–1

aquitard, considerable recharge can occur through time to underlying aquifers by vertical movement (Stephenson et al., 1988). A well connected fracture network can considerably elevate the hydraulic conductivities of otherwise low-permeability materials. Fractures are considered to influence the movement of groundwater in fine-grained till and glacial lake sediments. The ability of till and clay to conduct groundwater would allow for greater recharge of the underlying basalt bedrock and the deposits of sand and gravel underlying or within beds of till and silt. It would also promote groundwater flow in the basalt aquifer throughout the southwest and southeast regions.

Most glacial sequences contain irregularly shaped bodies of sand and gravel which tend to be relatively thin (<10 m) and irregular in geometry (Lloyd, 1983). The laterally extensive deposits of sand and gravel in the southwest and southeast regions are capable of transmitting significant quantities of water (Foxworthy et al., 1988). More commonly, however, the sand and gravel deposits are discontinuous bodies like those exhibited in the southeast region that act as local zones of high hydraulic conductivity amidst materials of lower hydraulic conductivity (Stephenson et al., 1988), such as till and silt.

Wells with extremely high yields (>4.42 L/s, and as great as 31.55 L/s) are found in gravel deposits of several aquifers scattered throughout the study area. The gravel sediments formed as glaciofluvial outwash.

WATER QUALITY

Few groundwater analyses are available in the Vanderhoof area and are limited to the northwest region of the study area. Exact well locations and numbers are unknown. The available data shows the groundwater to be generally hard (60–150 mg/L Ca^{2+} and Mg^{2+}) or very hard (>150 mg/L Ca^{2+} and Mg^{2+}), and to have a pH range from neutral to mildly basic (7–9), a conductivity range from 105 S to 1890 S, a small number of the wells treated with chlorine, a few wells with above average concentrations of arsenic (Fig. 12), and low levels of NO_3^-.

Vanderhoof area groundwater can be classed as Type II of Freeze and Cherry (1979); hard water of the Ca-Mg-HCO_3^- type, slightly alkaline, fresh waters with less than 1000 mg/L of total dissolved solids (TDS). Type II waters are primarily the result of carbonate mineral dissolution and are modified by cation exchange processes. The general absence of gypsum, anhydrite, and halite can explain extremely low (<100 mg/L) concentrations of Cl^- and SO_4^{2-} (Freeze and Cherry, 1979).

The Guidelines for Canadian Drinking Water Quality cite a maximum concentration of 0.05 mg/L for arsenic (Howard, 1997), and several wells in the study area approach or exceed that level. Because the location of these wells is unknown, the source of the As is not known. Basalt has a typical As concentration of 2 mg/kg (ppm) (Drever, 1982). Arsenic is also associated with sulphide deposits of minerals such as Cu, Zn, Mo, Ag, Hg, and Pb. These sulphide minerals weather rapidly and thus, could give rise to high concentrations of dissolved As (Drever, 1982).

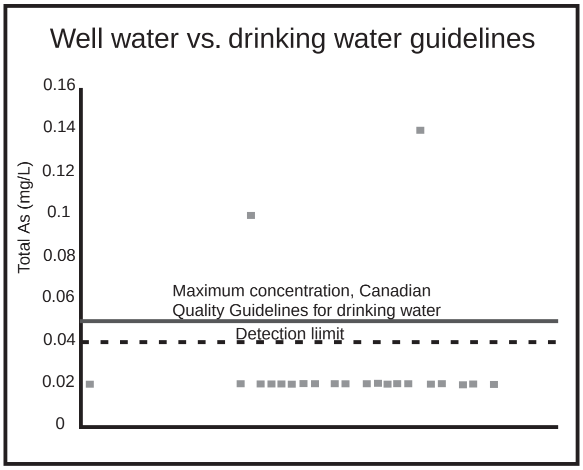

Figure 12. *Scatter plot of arsenic concentrations in well waters.*

DISCUSSION

Considering the limited data available and implemented in this study, the project was successful in identifying and understanding the hydrogeological systems at work in the study area in general terms. Clearly, a larger number of wells would have allowed for a more detailed study and a better understanding.

Despite the lack of, or inconsistencies in the existing water well records, enough information was available to allow for the production of a sound hydrogeological interpretation of the Vanderhoof area and assessment of its groundwater resources. Subsurface mapping is crucial in this process and has illustrated the numerous deposits of hydrogeologically significant materials throughout the study area. Use of subsurface data has also indicated the presence of a large, phyric basalt aquifer in the southeast region of the study area that was previously unrecognized. Where wells in the southeast region are dependent on irregular, discontinuous sand and/or gravel aquifers (Fig. 10), it is possible that the basalt beneath these glacial deposits could prove significant as a future source of groundwater. This is said without knowledge of recharge rates or transit time of the groundwater as data of these characteristics is unavailable.

ACKNOWLEDGMENTS

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