Preliminary Groundwater Inventory of the City of Whitehorse

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Community Development Branch
Government of Yukon

prepared by:
Gartner Lee Limited

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March 28, 2003

Brian Ritchie, Manager Land Development
Community Development Branch
Government of Yukon
P.O. Box 2703
Whitehorse, Yukon Y1A 2C6

Dear Mr. Ritchie:

Re: 21913 – Preliminary Groundwater Inventory of the City of Whitehorse

Gartner Lee Limited is pleased to provide our report on the above noted project. This study provides a broad overview of groundwater resources within the City of Whitehorse and the environmental factors controlling the occurrence of groundwater. These factors, in turn, have significant impact on how the groundwater resources can be developed for human usage. The information compiled will help residents of the City, land developers and water managers utilize and protect this important resource to ensure a safe and sustainable water supply that will meet the community's future needs.

Accompanying this report are eight full-colour maps portraying a variety of groundwater related information. A water well database was compiled as part of the creation of these maps. This database has been incorporated into the Yukon wide water well database currently being prepared for the Energy Solutions Centre Inc.

We trust that this report meets your current needs. If you have any questions, or if we can be of further service, please feel free to contact me at (867) 633-6474 extension 23.

Yours very truly,
GARTNER LEE LIMITED

Forest Pearson, B.Sc., P.Eng.
Geological Engineer

FKP:fkp

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1. Introduction

1.1 Study Background

This study provides an overview of groundwater resources in the City of Whitehorse, Yukon. In 2001 the City of Whitehorse had a population of 19,058 (UMA Engineering Ltd. 2002), which represents approximately 62% of the total population of the Yukon Territory (Yukon Bureau of Statistics 2002). All residents of the City, are at least seasonally, dependant on groundwater for domestic water supply. Nationally there has recently been recognition of the sensitivity of surface water supplies, and to a lesser extent, groundwater resources. Developing, managing and protecting an abundant supply of good quality groundwater are key to the success of existing and future community development.

Historically, significant groundwater quality problems or competition for groundwater resources have not been major issues for the City. Groundwater resources have been relatively abundant and free of anthropogenic impacts. However, increased community growth can lead to the potential for conflicts over groundwater usage.

This study represents the Government of Yukon's Community Development Branch's contribution to the 2001/2002 Yukon Groundwater Initiative. Other partners in the Initiative include the:

- Department of Indian and Northern Development (DIAND), Water Resources
- City of Whitehorse, Engineering & Environmental Services; and
- Government of Yukon, Environmental Health Services

1.2 Purpose and Scope

This report documents a preliminary interpretation of available geological and hydrological information for the City of Whitehorse and provides an overview of existing groundwater uses and identifies potential areas for groundwater resource development. The purpose of this project is to compile baseline and background information related to groundwater in a concise format. This report will aid land use planners, developers, municipal engineers, health authorities and water managers with making decisions that may potentially interact with or utilize groundwater resources. This could be either the protection of existing groundwater uses, or the development of new groundwater resources.

This scope of study includes:

1. Identification of various groundwater regimes through maps of various aquifer media, including bedrock and overburden;
2. An updated and expanded water well database for the entire City of Whitehorse area;
3. An inventory of known groundwater users (quantity and location);

4. Generalized potentiometric surface maps (e.g. water table);
5. Major areas of groundwater recharge and discharge; and
6. Bedrock and overburden aquifer potential maps;

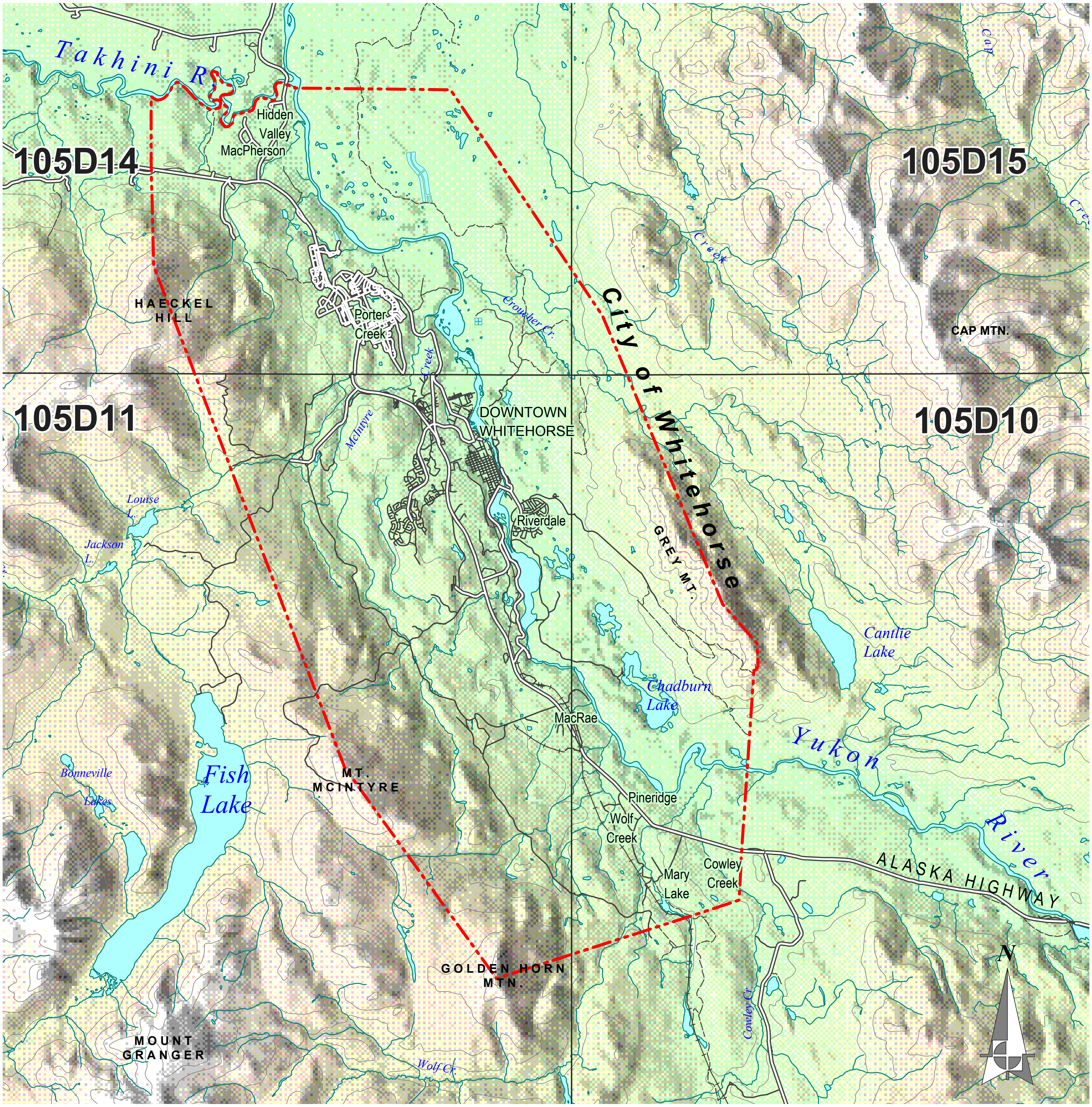
Note that the scope of this study includes a compilation of groundwater occurrence and utilization only. No significant review, compilation or assessment of groundwater quality was completed as part of this project.

This information can provide the basis for more detailed, site specific hydrogeological investigations. For example, the information contained in this report can form the regional framework for groundwater investigations conducted for rural residential subdivision development. Alternatively, the data presented here in spatial format (e.g. maps) can be used to complete aquifer sensitivity mapping using techniques such as DRASTIC (Aller et al. 1985) or Aquifer Vulnerability Index, AVI (Van Stempvoort et al. 1992).

This evaluation of groundwater resources is based primarily on readily available published and unpublished information. The geology of the area is presented as described in the geologic reports and maps of the area. The interpretation of hydrogeological regimes of the area is based on a review of a limited number of hydrogeological studies conducted across the City of Whitehorse. There is no complete or centralized water well database for the Yukon Territory nor for the City of Whitehorse. Water well locations were determined from tax roll information, background studies and site visits to a limited number of known groundwater users. The water well database developed for the Wolf Creek and Pineridge country residential subdivisions (Gartner Lee Limited 2001a) was expanded upon by incorporating water well records from previous reports and a limited number of borehole logs purchased from local water well drilling companies. Borehole logs purchased for this report are presented in Appendix A. No original field data were collected during this study other than site reconnaissance visits to major groundwater users in the City.

1.3 Location

The study area consists of the municipal boundary of the City of Whitehorse, which is located in south-central Yukon Territory, between longitudes 134° 50’ W and 135° 15’ W. At the north end the City is bounded by latitude 60° 50’ N and the south end by latitude 60° 35’ N. The City extends approximately 30 kilometres from north to south and 20 kilometres from east to west, encompassing an area of 416 km^2. Four 1:50,000 scale National Topographic Series (NTS) maps cover the study area, including 105D/10, 105D/11, 105D/14 and 105D/15. The study area is dominated by the northward flowing Yukon River that bisects the study area (Figure 1) into two sides of the Yukon valley.



Site Name: Whitehorse

File Name: 21913-F1.WOR

Gartner Lee

Scale: 1: 200,000

Community Development Branch
Government of Yukon

Preliminary Groundwater Inventory of the City of Whitehorse

Project Location Map

Project No: 21-913

Date Issued: MARCH 2003

Figure 1

2. Physical Setting

2.1 Physiography

The City of Whitehorse lies at the transition zone between the Yukon Plateau and the Coast Mountains physiographic regions (Wheeler 1961). The study area consists of a broad, north trending valley of the Yukon River, bounded to both the east and west by glacially rounded mountains. In addition, the study area falls within the South Yukon Lakes Ecoregion.

Local topographic relief ranges from 640 m along the Yukon River, to 1680 m at the peak of Golden Horn Mountain. The landscape settings of the Whitehorse area is shown on Map 1. The landforms of the Whitehorse area are attributable to numerous glacial episodes, the most recent being the McConnell glaciation between 35,000 and 10,000 years ago. The Whitehorse area has a complex sequence of glacial, glaciofluvial and glaciolacustrine deposits that are typical of deglaciation in mountainous terrain. These deglaciation features substantially affect and control hydrologic and hydrogeological regimes observed in the study area today.

The following landscape settings within the City of Whitehorse are presented as follows, and generally correspond to broad hydrogeological settings:

1. **Yukon River Plain** – these are low alluvial terraces shaped and moulded by the post glacial Yukon River. Downtown Whitehorse, and the Riverdale and Marwell areas all occupy portions of the Yukon River Plain. These areas are typically no more than 2 to 5 metres above river level and have flat, planer surfaces. Other areas identified as part of the Yukon River Plain landscape setting include:
   - Hidden Valley Subdivision (located on an abandoned meander of the Takhini River);
   - the terraces east of Schwatka Lake;
   - the abandoned meanders south of Chadburn Lake; and
   - the terraces at the mouth of Wolf and Cowley Creeks.

   The surface texture of these areas are typically composed of a thin layer (e.g 2 to 5 metres) of alluvial sand and gravel overlying glaciofluvial or glaciolacustrine deposits.

2. **Chadburn Lake/Long Lake Complex** – a long, linear area filling the Yukon River Valley with complex kame and kettle topography. Pitted outwash deposits with associated kettle lakes (sometimes referred to as an “esker complex”) were created by burial and subsequent melting of orphaned blocks of glacial ice during the last deglaciation. This landscape setting contains numerous “pothole” lakes which have no surface water in or outflows. However, the lakes of this area are hydraulically connected to the Yukon River and Schwatka Lake. This was demonstrated by the rise in water level observed in Hidden, Chadden and Chadburn Lakes after the completion of the

Whitehorse Rapids Hydroelectric project and the creation of Schwatka Lake. Surficial materials are composed of a complex sequence of sand, gravel and minor silt associated with a dynamic, ice contact margin.

3. **Glaciolacustrine Terraces** – a series of high terraces adjacent to the Yukon River. These terraces represent the lake bottom of a lake which filled the Whitehorse valley during deglaciation. The Whitehorse International Airport is located on the most significant of these terraces. Terrace elevations decrease towards the north (e.g. towards Lake Laberge). At the Whitehorse airport the terrace is at approximately 700 m above sea level (ASL). These glaciolacustrine terraces are comprised of a thick sequence of varved fine sand, silt, and clay, however are frequently capped by a two to five metre layer of glacial outwash sand. The broad lacustrine plain at the northwestern corner of the City has been included in this landscape setting, but is unique in that it includes a number of kettle lakes and areas partially overlain by eolian sand of the Whitehorse dune field.

4. **Upland Benches** –the area of rolling benches between the elevations of 700 and 800 m ASL. A mosaic of till, glacial outwash deposits and near surface bedrock characterizes these broad benches. The surfaces are frequently bisected by a series of northward trending glacial meltwater channels. Much of the rural residential and urban developments of the City of Whitehorse occupy the western upland benches. These urban areas include the major subdivisions of Granger, Hillcrest, McIntyre, Porter Creek and Crestview.

5. **Mountains and Alpine Area** – the mountains and piedmont areas forming the eastern and western boundaries of the City. For the purposes of this report, these areas are defined as those above 800 m elevation which rise to elevations greater than 1500 m ASL. Mountains in the study area include Haeckel Hill (which is a portion of Mt. Sumanik), Mt. McIntyre, Golden Horn Mountain and Grey Mountain (which is identified in the gazetteer as Canyon Mountain). These alpine areas are either exposed bedrock, or covered by a veneer of colluvial material and/or till.

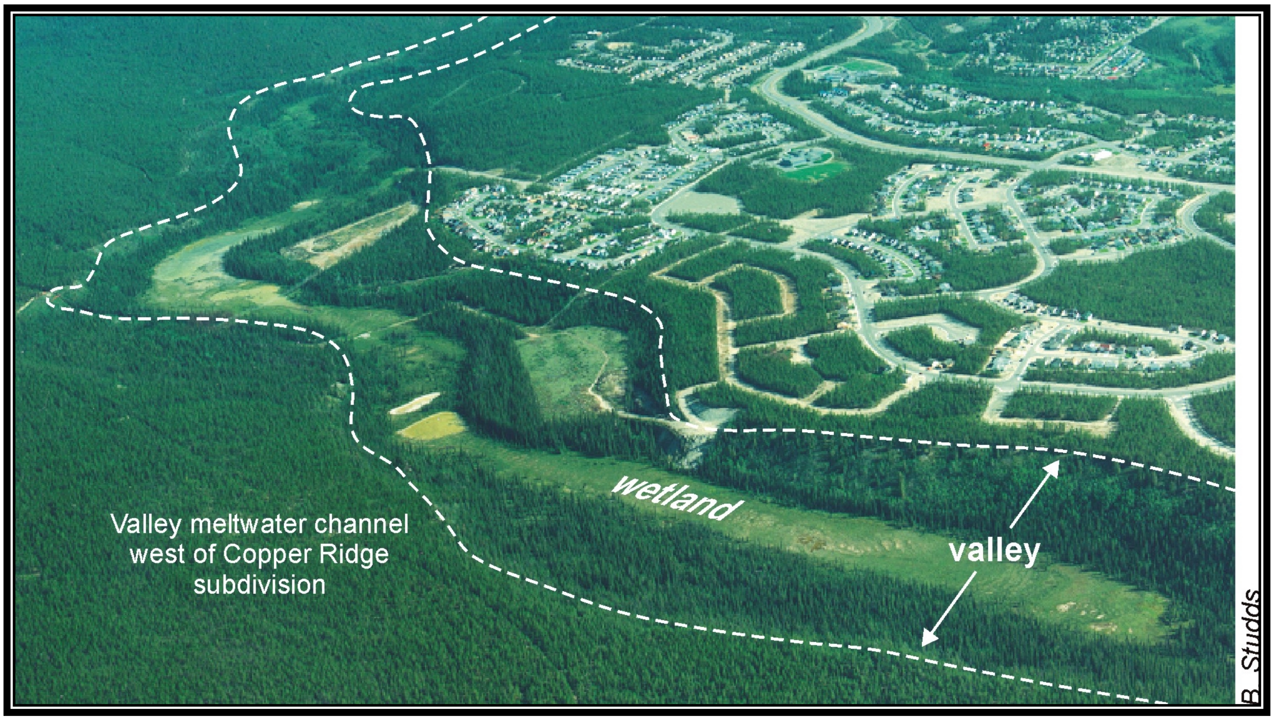
2.1.1 Meltwater Channels

A significant landform of the Whitehorse study area is glacial meltwater channels. These channels are also called *lateral overflow channels* by Wheeler in his 1961 report on the geology of the Whitehorse map area. Meltwater channels are products of deglaciation and have been cut diagonally across or parallel to the valley walls that flowed between the ice occupying the valley and the valley wall. These channels are cut into both bedrock and unconsolidated material. Locations of meltwater channels in the City of Whitehorse are illustrated on Map 1, and are classified into major and minor channels:

- Minor meltwater channels are common at and above the timberline. These channels are typically a few metres to ten metres deep and one to two hundred metres long. They frequently have cut notches across spurs on the valley walls.

- Major meltwater channels are found dissecting the Upland Benches west of the Yukon River. These larger, well developed meltwater channels are frequently incised into bedrock and support undersized streams or wetlands. They are frequently between five and ten metres deep and can extend for several kilometres. Examples of meltwater channels that support undersized streams include McIntyre Creek and Cowley Creek. The Hillcrest meltwater channel, immediatly west of the Granger and Copper Ridge residential subdivisions is an example of a channel without a stream, however, the bottom of the channel is occupied by a long, linear wetland. Figure 2 is an aerial view of the Hillcrest meltwater channel.

Figure 2. Hillcrest Meltwater Channel



Note: Figure courtesy of Yukon Geology Program and Geological Survey of Canada (Turner et al, 2003)

With respect to hydrogeology, the role and impact of these landforms on groundwater movement is not fully understood. However, it is speculated that the presence of the meltwater channels plays an important role the in study area's groundwater regime:

- Groundwater recharge – minor meltwater channels along the valley walls likely intercept overland and near surface flow. These channels could have the effect of increasing recharge and infiltration to the groundwater system by intercepting surface runoff from the valley walls.

- Drainage – the major meltwater channels may be acting as local drains, controlling water table elevations in the vicinity of the channel. Specifically, the major meltwater channels dissecting the Upland Benches are likely groundwater discharge sites.

- Kame deposits – sand and gravel kame terraces or kame deltas are found at the mouth of many of the major meltwater channels. These deposits were formed by meltwater deposition between the mouth of the channel and the glacier filling the valley. Examples of these include the Wolf Creek subdivision terrace, the McLean Lake gravel deposits, the Hillcrest and Upper Tank Farm gravel deposit; and the gravel underlying the Yukon College. Each of the kame terraces is associated with the end of a major meltwater channel. These sand and gravel deposits have potential to host overburden aquifers.

2.2 Drainage

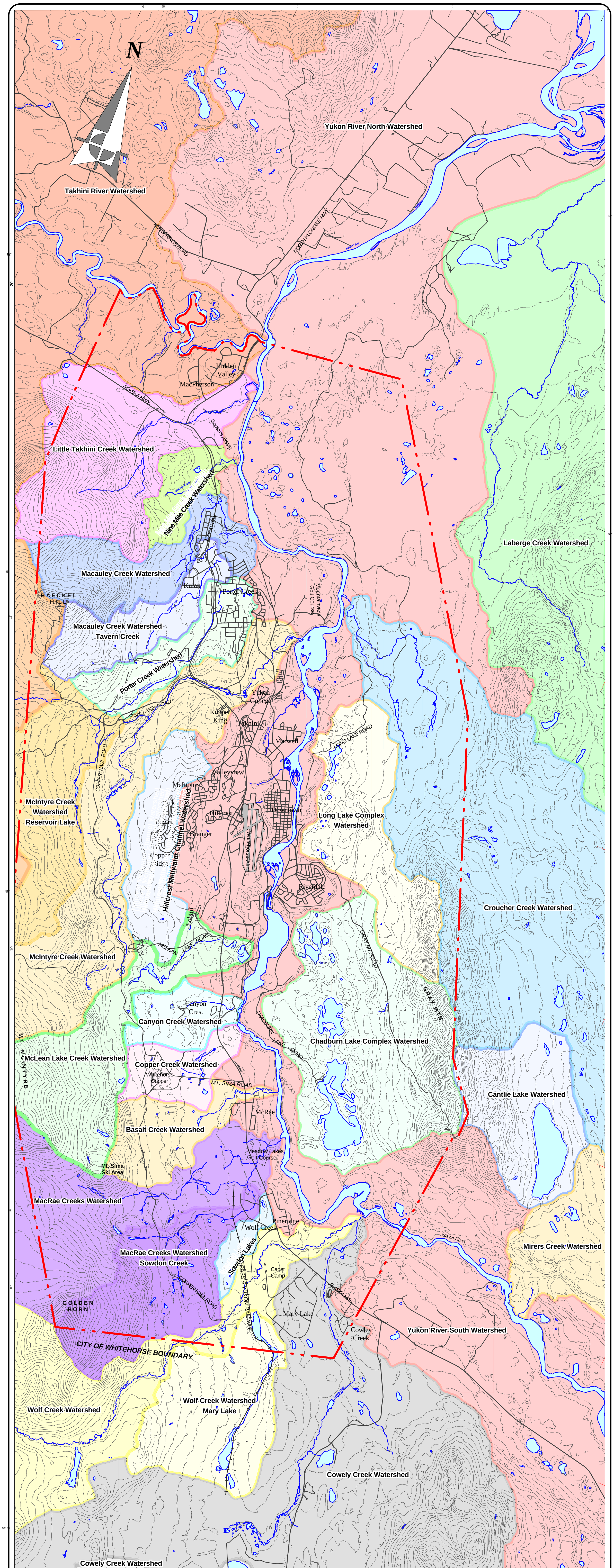
Drainage in the City of Whitehorse is dominated by the northward flowing Yukon River. All of the study area drains to the Yukon River. The northwestern City boundary is formed by the Takhini River that flows into the Yukon River. Within the City limits are a number of small creeks that drain the upland and surrounding areas, discharging to the Yukon River. The major, named creeks include (from south to north) Cowley Creek, Wolf Creek, MacRae Creek, Croucher Creek, McIntyre Creek and Little Takhini Creek. Additionally, there are two other significant creeks, McLean Lake Creek and Porter Creek, which discharge to small lakes with no surface water outlets. The location of these creeks and their corresponding watersheds are illustrated on Figure 3. A complete discussion of drainage in the Whitehorse area is presented in the "*Surface Water Inventory of the City of Whitehorse*" (Gartner Lee Limited 2001e)

Many of the major streams identified above have their headwaters east or west of the City limits. The gradient of streams through the study area ranges from less than 1% to up to 12% with stream gradients averaging 2.8%. The Yukon River through the City has a gradient of 0.07%.

The Whitehorse Rapids Hydroelectric Project consists of a dam and small reservoir on the Yukon River just upstream of downtown Whitehorse. The dam creates a small run-of-river reservoir called Schwatka Lake. This reservoir is approximately 150 ha in area and 2.8 km long. The construction and operation of the Whitehorse Rapids Hydroelectric impoundment has impacted the groundwater flow regime in the vicinity of the reservoir, including raising the water level in several of the surrounding pothole lakes and the Selkirk Aquifer.

Within the study area are several areas of closed, or internal drainage, which do not have any developed surface water drainage features other than pothole or kettle lakes. The most significant of these areas are the Chadburn Lake and Long Lake ice contact complexes. These areas are well drained, pitted and hummocky topography with numerous small lakes with no surface water interconnection (e.g. streams).

In summary, many of the watersheds not discharge into surface water systems, or are entirely "self contained" with no surface water outlet. This observation provides evidence of the complexity and high level of interaction between surface water and groundwater systems within the City.



City of Whitehorse and
Department of Indian and Northern Affairs

Figure 3: Watershed Overview Map

2 0 2 4

Kilometers

Scale: 1:125,000

TOPOGRAPHIC FEATURES

- City boundary
- Paved road
- Gravel road
- Railway
- Rivers/lakes
- Streams
- Contours (25m interval)

WATERSHEDS

- A Upper Yukon River - South
  - B Cowley Creek
    - B Cowley Lakes
  - C Mirers Creek
  - D Wolf Creek
    - D Mary Lake
  - E Cantlie Lake
  - F Sowdon Lake
  - G MacRae Creeks
    - G Sowdon Creek
  - H Basalt Creek
  - I Chadburn Lake Complex
  - J Copper Creek
  - K Canyon Creek
  - L Mclean Lake Creek
- M Upper Yukon River - North
  - N Hillcrest Meltwater Channel
  - O Long Lake Complex
  - P McIntyre Creek
    - P Reservoir Lake
  - Q Croucher Creek
  - R Porter Creek
  - S Laberge Creek
  - T Macauley Creek
    - T Tavern Creek
  - U Nine Mile Creek
  - V Little Takhini Creek
  - W Takhini River

NOTE: Watersheds with no surface water outlets are denoted by hatching.

Basemap:
Triathalon Mapping Corporation, 1996, 1:20,000 scale.
Based on 1994 aerial photography

Recommended Citation:
Gartner Lee Ltd., 2000:
Watershed Overview Map,
Whitehorse Surface Water Inventory.
Prepared for City of Whitehorse.
Digital cartography by D. Lu

GLL Project Number: 20-911	Last Modified: April 26, 2001
Gartner Lee Limited	Files Name: fig2e.wor

2.3 Climate and Water Balance

The climate of the Yukon is classified as sub-Arctic Continental due to large annual, daily, and day to day ranges in temperature, low relative humidity and irregular low precipitation. The wide range of mean temperatures and precipitation are the highest in Canada. Frequent intrusions of mild air from the Pacific Ocean results in a sub-Arctic rather than Arctic Climate (Wahl and Goos 1987).

One climate station located at the Whitehorse International Airport has been operated continuously since 1946. Other local climate stations include Riverdale (1959-1990) and the Wolf Creek forest site at the Boyle Barracks Cadet Camp (1993 to present). Table 1 provides a climate summary for the period of 1946 to 1990 for the Whitehorse Airport climate station. Figure 4 presents annual precipitation totals for Whitehorse between 1945 and 2001 with an annual average precipitation of 267 mm per year. The lowest recorded annual precipitation was 170 mm in 1947; maximum annual precipitation was 371 mm in 1991. Standard deviation of annual precipitation is 49 mm.

Due to the low total annual precipitation, annual groundwater recharge is in the Whitehorse area is relatively minimal, occurring primarily during spring thaw, which occurs in April and May. A water budget for Whitehorse completed by Environment Canada using climate norms from the period of 1943 to 1994 and is presented in the *"Wolf Creek and Pineridge Groundwater Usage Study"* which was prepared for the Engineering & Development Branch of the Government of Yukon (Gartner Lee Limited, 2001b). This water balance indicates that the annual average precipitation at Whitehorse is 266 mm. The water budget model also suggests that *potential* evapotranspiration exceeds the total annual precipitation. However, a modest surplus of 25 mm occurs during the months of March, April and the first week of May during freshet when evapotranspiration rates are relatively lower. Therefore, the Environment Canada model suggests that less than 10% of the precipitation is available for infiltration and recharge to groundwater on an annual average basis.

The City of Whitehorse is located in the zone of discontinuous permafrost. Some shallow, isolated pockets of permafrost are found in the City, however these deposits tend not to be laterally continuous. Permafrost is most often found in organic rich sediments associated with wetlands. From a hydrogeology and groundwater development perspective, permafrost does not seem to play a significant role in the City of Whitehorse.

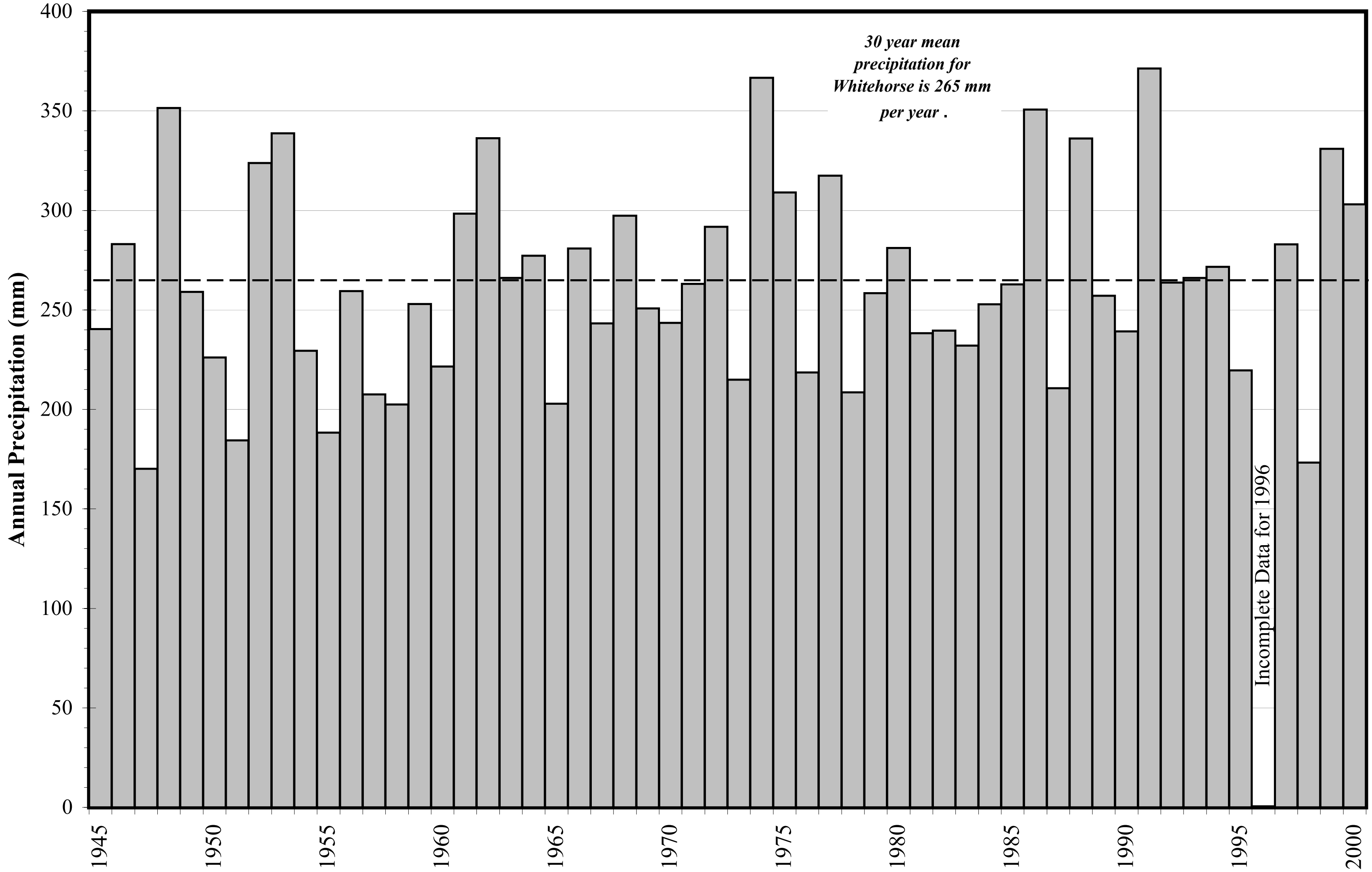
Table 1. Normal Monthly Precipitation and Temperature Data for Whitehorse Airport, 1971 -2000

	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation (mm)													
Mean Rain	163.1	0.2	0.1	0.0	1.3	13	29.7	41.4	38.5	29.3	8.8	0.7	0.3
Mean Snow *	104.3	16.5	11.3	10.4	5.7	2.2	6.3	0.0	0.9	4.8	15	18.5	18.2
Mean Total	267.4	16.7	11.4	10.4	7.0	15.2	30.3	41.4	39.4	34.1	23.8	19.2	18.5
Temperature (^oC)													
Mean Daily	-0.7	-17.7	-13.7	-6.6	0.9	6.9	11.8	14.1	12.5	7.1	0.6	-9.4	-14.9
Mean Daily Max.	4.5	-13.3	-8.6	-0.8	6.4	13.1	18.5	20.5	18.5	12.2	4.3	-5.8	-10.6
Mean Daily Min.	-5.9	-22	-18.7	-12.3	-4.6	0.7	5.1	7.7	6.3	2.0	-3.1	-13.0	-19.1

Notes: ** water equivalent*

Source: Environment Canada, Atmospheric Environment Services, 2002

Figure 4. Whitehorse Annual Precipitation



Data Provided By: Dept. of Indian and Northern Affairs Canada, Water Resources Section

(whse hist temp & precip.xls / 4/9/2003 / 21913 / FKP)

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3. Geological Setting

A thorough appreciation of the geological units that comprise the bedrock and surficial deposits of the City of Whitehorse and their geological history is fundamental in gaining an understanding of groundwater resources and their significance to the City of Whitehorse. The following discussions of bedrock and overburden geology are based on a review and compilation of existing reports and maps. Some of the mapping has been either simplified or modified for the purposes of this study and the scale of maps used.

3.1 Bedrock Geology

The bedrock geology of the Whitehorse area has been mapped in a piecemeal fashion over the last twenty five years. The most recent bedrock mapping was completed by Hart in 1997 at 1:50,000 scale and covers 105D/14 portion of the City. Other geological mapping includes Hart and Radloff, (1990) covering 105D/11 and the Whitehorse Copper Belt area compilation by Watson in 1984 at 1:20,000 scale. For this project, the Yukon Digital Geology compilation by the Geological Survey of Canada (1999) was used. This compilation includes all of the above noted mapping.

Generally, the City of Whitehorse is underlain by sedimentary and metasedimentary rocks of the Whitehorse Trough Supergroup. These rocks formed in a marine environment some 200 million years ago and include both clastic sediments such as sandstones and shales as well as carbonate sediments such as limestone. Subsequently, these sediments were extensively folded and faulted. Between 110 and 60 million years ago, magmatic rocks intruded the Whitehorse Trough rocks, cooling to form the granitic rocks of the Whitehorse Batholith and Mt. McIntyre Pluton. These rocks were subsequently uplifted, eroded and in some places deeply weathered. Less than nine million years ago, lava rose to the surface near the southwestern portion of Whitehorse. These lavas flowed down into the proto-Yukon River valley, and now form the dramatic cliffs of the Miles Canyon and Whitehorse Rapids. The various formations and units are listed in Table 2 and the major units are described briefly in the following sections.

Simplified bedrock geology of the City of Whitehorse is shown on Map 2 in the back pocket of this report. Bedrock topopgrahy is interpreted from bedrock surface exposure and bedrock contacts reported in water well logs. Map 2 shows the locations and reported elevations of bedrock contacts in the water well records. It should be noted that this is little to no depth-to-bedrock information in the northeast portion of the City in the area of the sewage lagoons. Bedrock depths in this area are purely speculative based on extrapolation of trends seen elsewhere in the valley.

Table 2. Summary of Bedrock Units Underlying the City of Whitehorse

Age	Formation		Member	Description
Miocene	Miles Canyon Basalt			Dark red to brown weathering, columnar jointed olivine basalt flows, commonly amygdoloidal and vesicular.
Tertiary	Nisling Range Plutonic Suite		Haeckel Hill Pluton	Medium to coarse-grained hornblende-biotite granite and granodiorite
Mid-Cretaceous	Whitehorse Plutonic Suite		Mt. McIntyre Pluton	Biotite quartz-monzonite and biotite granite
			Whitehorse Batholith	Grey weathering medium-granied hornblende and biotite-hornblend granodiorite
Jurassic	Whitehorse Trough Super Group	Laberge Group	Undifferentiated	Sandstone, greywacke, argillite, siltstone, arkose.
Triassic		Aksala Formation	Mandana Member	Undifferentiated maroon and green sandstone, mudstone, shale and tuff.
			Hancock Member	Resistant, light grey weathering, massive to sparsely bioclastic limestone to densely fossiliferous.
			Casca Member	Brown shale, black and minor red siltstone, greenish, calcareous greywacke and interbedded bioclastic, argillaceous limestone.

Major bedrock units present within the City of Whitehorse are described in further detail as below:

3.1.1 Miles Canyon Basalt

The Miles Canyon Basalt is the youngest bedrock formation found in the City. Columnar-jointed, variably vesicular and amygdaloidal flows and scoria dominate the Miles Canyon Basalt. Individual flows are up to 20m thick, but may occur as this thin as one metre. Additionally, many flow surfaces are marked by highly vesicular flow tops and bottoms or scoria. The basalt is found to underlie portions of the Wolf Creek and Mary Lake rural residential subdivisions in the south, and extend northward through the valley centre, terminating somewhere near the south end of downtown Whitehorse. The unit is well exposed in the walls of Miles Canyon and at the Whitehorse Rapids hydroelectric site. The thickest sequence of basalt to be recorded was almost 110 metres in test hole TH 1-79 south of the Riverdale subdivision (Stanley Associates Engineering Ltd. 1980).

Most exposures of Miles Canyon Basalt unconformably overlie weathered and oxidized granodioritic bedrock of the Whitehorse Batholith. However, some basalts overlie variably consolidated gravel of probable Neogene in age.

3.1.2 Whitehorse Batholith

Underlying the unconsolidated sediments or Miles Canyon Basalt flows are granodiorites of the Whitehorse Batholith. Hart and Radloff (1990) describe the Whitehorse Batholith as follows:

> "The Whitehorse Batholith extends over 600km^2 including much of the area in and around Whitehorse. It consists of a variably zoned Cretaceous intrusive body ranging from diorite to granite, but dominated by granodiorite that intrudes folded sedimentary and volcanic rocks of the Triassic Whitehorse Trough (Hart and Radloff, 1990). Although variably jointed, the granodiorite lacks a continuous, systematic joint set in three planes. The rocks are brittle and variably fractured and most fractures are steeply inclined or nearly vertical. Although fracture analysis has not been undertaken, regional structures typically trend northwesterly, with a more closely spaced series of smaller east-northeasterly trending faults and fractures (Hart and Radloff,1990)."

The batholith underlies most of the western half of the City. The units appears in outcrop in many locations west of the Alaska Highway. The intrusive rocks of the Whitehose Batholith and McIntyre Pluton are shown in pink on Map 2. The rocks of the Whitehorse Batholith intrude the variably folded and faulted Triassic aged rocks of the Aksala Formation.

3.1.3 Aksala Formation

Hart (1997) identified three members of the Aksala Formation: 1) Mandanna Member, 2) Hancock Member, and 3) the Casca Member. These units are described as follows:

Mandanna Member
The Mandanna Member (shown in purple on Map 2) is described by Hart (1997) as being composed of well-bedded or massive, green and maroon to brick-red siltstone, greywacke, sandstone and tuff with local occurrences of conglomerate. Mandanna member rocks overly and interfinger with Hancock Member limestone. The Mandanna member is conformably overlain by the Lebarge Group.

These rocks are found primarily in the western and northern portion of the City. The Mandanna and the other two members of the Aksala Formation have been intruded by the Whitehorse, Mt. McIntyre and Haeckel Hill Plutons. These rocks have subsequently been faulted and offset by a series of west-northwest trending faults.

Hancock Member
The Hancock Member (shown in light blue on Map 2) in the study area is described by Hart (1997) as being dominated by limestone and limey siltstone. The unit is fossiliferous and grades upward to the overlying Mandanna Member. Hancock Member rocks are found extensively along the western portion

of the City. Pendants and embayments of this unit into the Whitehorse Batholith localize the copper-gold-silver skarn deposits of the Whitehore Copper Belt. The Copper Belt is a 50 km long track of rocks which produced a total of 10,130,000 tonnes of copper ore from 1900 to 1982. Production came from a series of six open pits with the bulk of the production from the underground operation at the Little Chief deposit. Grey Mountain and surrounding area that forms the eastern boundary of the City is underlain by Hancock Member rocks

Casca Member
The Casca Member (shown in dark blue/purple on Map 2) in the study area is described by Hart as the lowest member of the Aksala formation. It is lithologically diverse and lacks diagnostic lithlogical association that defines the other member. The Casca Member contains a wide range of fine to medium-grained clastic rocks (mainly sandstone, greywacke and argillite) which are locally pyritic or calcareous. Casca Member rocks have been identified in the Haeckel Hill area and at the southern end of the City. Future bedrock research may potentially reclassify some areas as being underlain by Casca Member rocks.

3.2 Surficial Geology

The landforms of the Whitehorse area can be largely attributable to the last ice age (McConnell), estimated to have existed between 35,000 and 10,000 years ago. The Whitehorse valley has a complex sequence of glacial, glaciofluvial and glaciolacustrine deposits that are typical of the deglaciation process in mountainous terrain. The overburden deposits of the City of Whitehorse have been mapped at 1:20,000 scale by Mougeot GeoAnalysis and Agriculture and Agri-Foods Canada (1996). One of the most prominent landscape features of the City of Whitehorse is the Chadburn Lake and Long Lake ice contact complexes. This is a broad band of dramatic hummocky terrain filling the east side of the Yukon River valley north and south of downtown Whitehorse. These areas represent stagnation points during the ice retreat of the last glaciation. In these areas significant heterogeneous deposits of sand and gravel have filled the paleo-Yukon River valley. Burial of orphaned ice blocks, which subsequently melted resulted in a hummocky landscape dominated by kettles and pothole lakes.

The textural characteristics of surficial deposits as well as their distribution and stratigraphic relationships are important to the occurrence and movement of groundwater. Groundwater movement is potentially rapid in granular materials and very slow in fine textured materials. Surface deposits with a similar origin or genesis will have similar textural properties. These deposits have therefore been grouped according to their material genesis and textural characteristics. Their distribution over the City of Whitehorse are shown in Map 3 (in pocket).

Surface materials are summarized in Table 3 and are listed from youngest at the top, to oldest at the bottom. With the exception of organic materials, most deposits less than 1 metre thick are typically not shown on Map 3. Therefore, in many areas covered with a veneer of till or colluvium, the veneer is not shown.

Table 3. Summary of Surficial Deposits

Surficial Material	Texture	Landform(s)	Description
Organic	silt and organic material, ranging from fibric to humic.	wetland deposits	Typically thinner than 0.5 m, saturated and frequently permafrost rich. Includes marl deposits.
Fluvial	sand, silt and gravel	river plains, stream valley bottoms	Typically found along Yukon River, includes downtown Whitehorse and Riverdale areas at surface.
Eolian	fine sand and some silt	undulating and ridges (dunes)	Most significant area is Whitehorse Dune Field, located north of the City sewage lagoons. Dunes are vegetated.
Glaciolacustrine	fine sand, silt and clay	plains and terraces	Forms escarpments around downtown Whitehorse and underlies most of the northeastern corner of the City.
Glaciofluvial	well graded sand and gravel	plains, terraces, ridges or occasionally hummocky	Glacial outwash sand and gravel. Sand overlies glaciolacustrine deposits. Frequently found at mouth of meltwater channels.
Ice Contact Deposits	heterogeneous deposits of sand, and gravel with some localize silt	hummocky, pitted, kame and kettle topography	Areas of significant kame & kettle topography. Typically significant deposits of sand and gravel. Forms Chadburn Lake and Long Lake complexes.
Morainal (Till)	pebbly to bouldery gravel with sitly, sandy matrix	rolling plains, blankets and veneers over bedrock	Found commonly above 700 m elevation. Frequently very coarse grained and difficult to distinguish from other sand and gravel deposits.
Bedrock	rock	mountains, ridges, cliffs and escarpments	Found at or near surface above 850 m elevation. Typically covered with a veneer of colluvium or till.

The following descriptions of the surficial materials of Whitehorse are adapted from the *Soil, Terrain and Wetland Survey of the City of Whitehorse* (Mougeot GeoAnalysis and Agriculture and Agri-Foods Canada 1996)

3.2.1 Organic Deposits

Organic deposits are formed of decomposed vegetation and are often referred to as peat or muck deposits. These deposits are frequently found in former glacial meltwater channels. Along the Yukon River, the only significant organic deposits occur in the Marwell area, just north of downtown Whitehorse. The most extensive areas of wetlands occur along the northern and eastern boundaries of the City. Organic deposits are shown in purple on Map 3.

Organic deposits are usually associated with landforms such as depressions or channels where abundant moisture is present, the result of either poor drainage or perennial high groundwater tables. In many cases they mark the outline of former lake basins that have dried up or drained away. In these cases the organic deposit may be composed of marl, a mixture of snail shells, lime surfaces and clay. Organic deposits usually cover small surfaces with nearly flat or gently sloping surface topography. There are few deposits thicker than 1.0 metre in the City. In many areas the organic material is frozen until late in the summer or are permanently frozen. The underlying material can range from silt to bouldery gravel.

All organic deposits in the City of Whitehorse are associated with wetlands, and therefore are typically interpreted to represent areas of groundwater discharge.

3.2.2 Fluvial Deposits

Fluvial or alluvial deposits range from fine sand and silt sized sediments to gravelly deposits of variable depth and extent. They are the result of modern or Holocene streams and rivers. Fuvial deposits in the City of Whitehorse include finer-grained sediments associated with the Yukon and Takhini Rivers and the coarser deposits which form broad gravel bars and islands close to the downtown area. Small, narrow fluvial deposits are also associated with many of the tributary streams within the City. It is common to find a silt blanket overlying gravelly and sandy fluvial deposits. Topography for these materials tends to be gently undulating with low terraces and ridges that are probably related to successive down cutting of the watercourses. A cap of organic material is commonly found overlying fluvial sediments. Fluvial deposits are shown in light yellow on Map 3.

3.2.3 Colluvial Deposits

Colluvial deposits are formed by the downslope movement of materials by the action of slope erosion, bedrock weathering and frost shattering. Colluvium is generally an unsorted mixture of silt to gravel size sediment with a high content of bedrock clasts. This material typically forms a veneer over bedrock in the alpine areas of the City. Colluvium frequently blankets the slopes of meltwater channels. There are some areas within the City that have thicker or more significant accumulations of colluvium, however, the extent of these deposits is typically quite small and therefore is below the mapping scale used for the project—subsequently this material is not shown on the project maps.

3.2.4 Eolian Deposits

Eolian materials are transported and deposited by wind. They generally consist of medium to fine sand and silt that is well sorted and non-compacted. The most significant occurrence of these deposits is at the northeastern portion of the City in the Whitehorse Dune Field. These ancient dunes have overtime become vegetated and stabilized. Wheeler (1961) states that the dunes are parabolic dunes formed by southerly winds. Such winds, although not strong today, were probably more powerful when glacial ice lay further south in the Yukon River valley. At that time, down-flow or katabatic winds probably blew off the ice in a northerly direction and formed dunes on a non-vegetated outwash plain or dried up lake beds north of the ice front. Eolian material north of the City likely overlies glaciolacustrine deposits. Eolian deposits are shown in dark yellow on Map 3.

3.2.5 Glaciolacustrine Deposits

Glaciolacustrine deposits are important stratigraphic units as they are frequently found near surface, and these deposits act as a major aquitard. They are often capped by glaciofluvial sand and gravel such as the sand layer forming the surface of the Whitehorse airport. Exposures of the glaciolacustrine sediments form the familiar escarpments along the Yukon River and around the downtown area. Sediment thickness ranges from 20 to over 150 m as seen in test hole TH 1-80 in Riverdale (Stanley Associates Enginering Ltd. 1981).

Glaciolacustrine deposits are dominantly composed of well-sorted, well-stratified laminae of clay, silt and very fine sand of various proportions. Textural analysis of the sediments indicate a silt content of between 54% to 58% and clay content of 41% to 45% at a depth of 3 to 4 metres. (Mougeot GeoAnalysis and Agriculture and Agri-Foods Canada 1996). In general sand content increases closer to the source of sediments in this case, the ice front or incoming streams into the lake. The clay content usually increases towards the deeper portion of the lake basin. Inclusions of sand and gravel may be found at depth in several areas, particularly close to the Porter Creek subdivision on both sides of the river.

Significant glaciolacustrine deposits are shown in blue on Map 3. Note that many of the deposits shown on this map are capped by a glaciofluvial sand which is not shown.

3.2.6 Glaciofluvial Deposits

Glaciofluvial deposits include both ice contact and outwash deposits, however, ice contact deposits have been identified separately and are described in the following section. Glaciofluvial outwash has a variable thickness and a high clast size variability. They are commonly composed of cobble to pebble sized gravel with sandy beds and a silt cap. These deposits are frequently found in association with meltwater channels, either as terraces or as deposits at the mouth of the channel. Examples include sand and gravel deposits along the Copper Haul Road and the Fish Lake Road. Sandy outwash blankets cap the glaciolacustrine deposits over most of the lower Porter Creek bench, the Whitehorse Airport and many flat surfaces and terraces in the southern portion of the City. Glaciofluvial deposits are show in light orange on Map 3.

3.2.7 Ice Contact Deposits

Ice contact deposits are a type glaciofluvial deposit that are created either in direct contact with or in proximity to glacial ice. Bouldery and cobbly gravel are very common in these deposits, as well as pockets of silty and sandy gravel. The material is extremely heterogeneous and significant changes in texture can occur over short distances. The ice contact deposits are characterized by a pitted and hummocky topography, which represents the locations of buried ice blocks which have subsequently thawed and collapsed. Individual deposits can be limited in their surface extent, but their thickness can exceed 20 metres. In the Hidden Lake area, south of Riverdale, these deposits have been documented to be over 90 metres thick.

These materials are typically found:

1. to represent a standstill point during the retreat of the glaciers, such as the Chadburn Lake and Long Lake complexes;
2. as sinuous pitted ridges representing standstill points such as those found along the Alaska Highway west of the MacPherson subdivision area (e.g. the Stevenson area); or
3. as high level terraces with depressions associated with meltwater channels. Examples include the McLean Lake deposit and the lower portion of McIntyre Creek.

Ice contact deposits are shown in dark orange on Map 3.

3.2.8 Morainal Deposits (Till)

Moraine deposits are dominantly composed of till, which usually is a mixture of gravel, sand, silt and clay size particles sometimes referred to as a boulder-clay. In the Whitehorse area, morainal deposits typically have a low clay content and a high content of pebbles, cobbles and boulders (more than 70%). A silt veneer or loess commonly caps these deposits. Lenses or pockets of coarse sand and gravel are common. The thickness of moraine deposits can exceed 10 metres. In the study area, till is generally exposed at elevations higher than 730 m on the valley side, but can be associated with bedrock outcrops. Morainal deposits are shown in green on Map 3.

A discontinuous veneer (e.g. less than 1 metre thick) is found on the valley walls at elevations above 900 m ASL. In many cases at these elevations, the morainal material may include colluviated till and colluviated rubbly and weathered bedrock. As these till veneers are very thin and do not typically control or host significant groundwater occurrences, they are not shown on the accompanying maps.

The morainal deposits located west of the Copper Haul Road and in the Wolf Creek and Mary Lake areas appear to be coarser and much gravellier than those located at slightly lower elevations. Mougeot (1996) suggests that meltwater channels become poorly defined at lower elevation and that running water may have winnowed fine particles away from the till, without depositing any significant volumes of gravel.

3.2.9 Bedrock

Bedrock geology is described in Section 3.1. It should be noted however that grus, a friable, even loose weathered granite is found in many areas west of the Alaska Highway. Areas of bedrock at or very near surface are shown in pink on Map 3.

4. Hydrogeological Setting

4.1 Groundwater Occurrence

Groundwater is part of the hydrologic cycle, which has resulted from the infiltration of water at the earth's surface, through the "unsaturated zone" into the "saturated zone". The water stored in the saturated zone is called groundwater. Under the influence of gravity and hydraulic head, groundwater moves to a point of natural discharge such as a stream, lake or pumping well. Natural recharge to these systems occur either directly from precipitation infiltrating into the ground or indirectly from snowmelt, standing bodies of water or surface streams.

An aquifer is defined as a water bearing geologic unit such as a sand or gravel which has a potential for yielding water of usable quantity and quality. An aquitard is a water-bearing geologic unit that does not yield or transmit water readily. Clay and till are typically considered to be aquitards. An aquifer in the context of this report is one that will supply water for at least domestic use. Within the City of Whitehorse, aquifers are hosted within both overburden sediments and in bedrock.

Groundwater is stored and moves through pore spaces between soil grains. The capacity of any material to absorb, yield or hold water is dependant on the porosity and permeability of the material (i.e. the volume of interstices or voids and the interconnection of these interstices, respectively). Porosity is dependant on soil particle geometry and arrangement. Thus, a high porosity material such as a shale or clay will not yield large quantities of water due to the absorption phenomena resulting from the molecular size and poor interconnection of the pore spaces.

Within the overburden, the most productive materials are the granular deposits of sand and gravel. In the Whitehorse area, these materials are typically found within the glaciofluvial, ice contact and to a lesser extent, the fluvial deposits. The extent of these materials is shown on Map 3. The tills in the Whitehorse area tend to be relatively granular, and therefore coarse grained zones within the tills are occasionally developed as low-yield aquifers. Examples of these are found in the Pineridge subdivision and likely some of the deeper wells in the Hidden Valley subdivision area.

The ability of bedrock in the study area to provide abundand quantities of groundwater is based on the type of bedrock. The Miles Canyon Basalt bedrock in the study area is the most widely developed unit for groundwater. Well developed vertical and horizontal fractures within the basalt readily transmit groundwater.

The most widely exposed bedrock in the City is composed of the granitic rocks of the Whitehorse Batholith. Numerous residential wells, especially in the Cowley Creek subdivision, are completed in this unit, however many are reported to be relatively deep and/or of low yield. Furthermore, there are several instances of wells drilled into Whitehorse Batholith rocks that did not provide sufficient yield for domestic usage. Development of groundwater supplies in this unit is contingent on the well intersecting a fracture, or series of fractures capable of transmitting flow. These fractures are referred to as "active fractures". Otherwise, the granitic rocks are crystalline, massive and do not produce any significant quantities of groundwater.

No previous studies have examined the groundwater yield or potential of rocks of the Aksala Formation. However, there are some wells completed in the northern portion of the City completed in Aksala Formation rocks. Groundwater occurrence in these units is speculated based on their physical properties.

4.1.1 Hydraulic Properties

The major hydraulic properties used to characterize an aquifer include:

- transmissivity (T);
- storativity (S);
- saturated aquifer thickness (b); and
- hydraulic conductivity (K).

The T, S, and K properties are generally established from pumping tests and geological logging.

The transmissivity of an aquifer is the measure of its productivity or how easily groundwater flows through an aquifer. Transmissivity is defined as hydraulic conductivity divided by aquifer thickness, and is presented in terms of square metres per day (m^2/day).

Storativity, also referred to as "coefficient of storage", is defined as the volume of water released from, or taken into storage, per unit surface area of the aquifer per unit change in head. This property is dimensionless and is usually between 0.01 and 0.35 for unconfined aquifers and 0.00001 to 0.001 for confined aquifers (Freeze and Cherry 1979).

Aquifer thickness is the measured saturated thickness of an aquifer in metres (m). In the case of unconfined aquifers, the saturated thickness will vary with fluctuations in the water table.

Hydraulic conductivity of an aquifer is commonly determined by dividing the transmissivity by the aquifer thickness and is frequently expressed as m/s. This property is a measure of groundwater movement through a unit of the aquifer.

A summary of bedrock and overburden aquifer parameters determined from test drilling and pump testing conducted in the City are presented in sections 4.3 and 4.4 respectively.

4.2 Groundwater Movement

Groundwater movement generally follows the regional topographic trends although locally flow may be complex. Where the stratigraphy involves several geological units with differing hydraulic conductivity, groundwater flows mostly in the unit(s) with the highest conductivity. On the other hand, where stratigraphy is dominated by a single geological unit or a few units with similar hydraulic conductivity, movement can be relatively simple and governed strictly by local hydraulic gradients.

In crystalline bedrock (e.g. granitic rocks), groundwater movement is strictly limited through fractures in the rocks. The location, orientation, fracture aperture, extent of fracturing and the interconnectivity of the fractures are extremely difficult if not impossible to determine. If a water well does not intersect a fracture, inflow to the well will be negligible. If a water well does successfully intersect a fracture, inflow to the well can be significant, however aquifer storage is frequently limited to the fracture, and consequently can be easily depleted. Therefore groundwater flow in crystalline rocks is extremely complex and almost impossible to predict with any certainty.

In volcanic rocks (e.g. basalt) groundwater moves mainly through interconnected vesicles, joints, and bedding (e.g. flow surfaces). Permeability through the basalt is relatively consistent as discontinuities in the rock are pervasive in three dimensions. For this reason, it is commonly assumed that the basalt behaves similar to other uniform porous media such as sand and gravel.

Groundwater flow in overburden materials is primarily through interconnected granular pore spaces. Sands and gravels have porosities of between 15-30% with a high degree of interconnection of the pore spaces. Groundwater movement is potentially rapid in these materials. Fine grained materials such as silt and clay typically have porosities of between 30-50% with a considerably lower degree of interconnected pore spaces. Groundwater flow through fine grained materials is relatively low.

4.2.1 Potentiomentric Surface

Groundwater movement is from areas of high pieziometric head (e.g. static groundwater level) as reported in wells toward areas of lower pieziometric head. A contour map of the water level elevations is referred to as a potentiometric surface map. Regionally, the groundwater flow is away from the mountains and towards the Yukon River. In the granular deposits along the Yukon River, such as the Chadburn Lake and Long Lake ice contact complexes, groundwater flow is interpreted to be parallel with the Yukon River, which flows northward. The regional groundwater flow pattern is shown on Map 4. No data related to vertical gradients is available anywhere within the City of Whitehorse.

The potentiometric surface elevation was compiled from static water levels reported in water well records. The static water levels are generally measured immediately after completion of the well by the driller and may not represent the true static water levels due to incomplete recovery of water levels. The static water levels can, however, be used to approximate the potentiometric surface in the area.

However, many portions of the City do not have any water wells, and in those areas water levels shown on Map 4 are interpolated from surface water features.

Due to the frequently thin nature of the overburden deposits, it is assumed that there is a significant degree of connectivity between groundwater flow in bedrock and groundwater flow in overburden. Therefore, it is assumed that the water levels shown on Map 4 are generally representative of both overburden and bedrock groundwater systems.

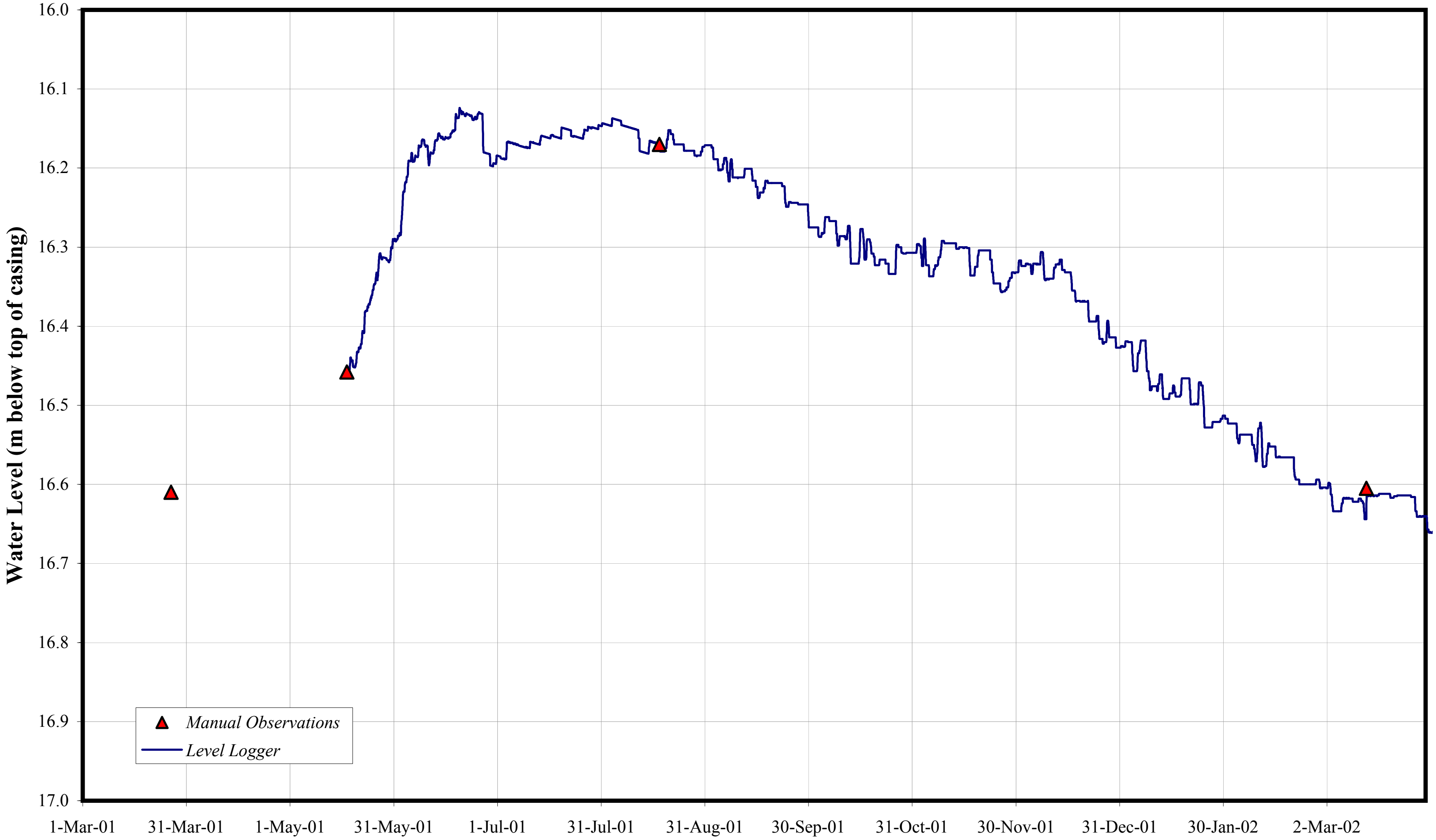
4.2.2 Water Level Data

The change in storage of a groundwater resource can be identified by the measurement of rising and declining static (non-pumping) water levels in wells or boreholes. During periods of high precipitation, storage in the groundwater zone is increased as infiltrating water percolates downwards into the saturated zone under the influence of gravity. Conversely, storage is decreased under conditions where the infiltrating water is intercepted before reaching the saturated zone or when excessive discharge from that zone continues. These conditions can occur during periods of low precipitation and or high use of groundwater by human activity or uptake by vegetation.

To date, only one single long-term groundwater level monitoring well has been completed in the Yukon. The well is located in the Wolf Creek subdivision (see Map 4) and has provided the City of Whitehorse with its first full year of continuous groundwater elevation levels (Figure 5). The well has been fitted with an automated water-level measurement device and has been collecting data since March 2001. This monitoring well is considered representative of site specific conditions and water level flucations appear to correlate with the predicted water budget calculation completed Environment Canada (Gartner Lee Limited 2001b).

The water budget prepared by Environment Canada includes long term monthly means for precipitation data collected weekly over the period of 1943 to 1994. The annual mean evapotranspiration was calculated to be 241 mm or 91% of the mean annual precipitation of 266 mm. This leaves a water surplus of about 25 mm available for runoff or infiltration and recharge to groundwater systems. Surplus occurs during about 11 weeks of the year during February, March and April, with the majority of the surplus occurring in April (68%). If the weekly water surplus values predicted in the Environment Canada water balance (Gartner Lee Limited 2001b) are compared with the water elevation values observed in the monitoring well at Wolf Creek, it is evident that such a surplus plays and important role for recharging groundwater systems. During non-surplus periods a steady decline in the groundwater elevation occurs, however during the months of April through May when a surplus of water is present, a steady rise in the groundwater table can be observed. As might be expected there is a lag time between these two events, which is expected given the transient nature of the recharge water moving through the unsaturated zone.

Figure 5. Wolf Creek Observation Well Hydrograph
(March 2001 - April 2002)



Data Source: DIAND Water Resources, 2002

(wolfwell 2001_02 - fig5.xls / 4/9/2003 / 21-913 / FKP)

Therefore, the groundwater level data presented suggests that groundwater recharge during months of surplus precipitation plays an important role in the hydrogeological system. Additionally the response at the observation site suggests that the recharge process is of relatively short duration.

4.2.3 Groundwater Recharge & Discharge

Major areas of groundwater recharge and discharge have been identified using surficial deposits mapping, bedrock mapping, wetland mapping and topography. These areas are shown in Map 5 (in back pocket).

Major Areas of Recharge

Groundwater recharge areas within the City of Whitehorse (ie. areas where the direction of groundwater flow is downward) are generally coincident with topographically elevated areas. The recharge areas are the initial source of groundwater and are an essential part of the groundwater flow system. The rate of groundwater recharge is dependant to a large extent upon the hydraulic conductivity of the surface materials and the terrain characteristics. Coarse texture soils are generally considered to have high potential for groundwater recharge. These consist of sand and gravel deposits such as glaciofluvial deposits, or thicker sequences of till in upland areas. Areas of recharge in overburden materials are shown in light orange on Map 5.

Areas where significant recharge occurrs in bedrock were interpreted to exist where permeable bedrock is at or near surface. These generally consisted of sedimentary bedrock of the Aksala Formation. Most upland areas of Miles Canyon Basalt are blanketed by granular deposits, and therefore are shown as overburden recharge sites. Areas of major bedrock recharge are shown in pink on Map 5. Areas underlain by granitic rocks of the Whitehorse Batholith are not considered major bedrock recharge sites. This is due to the relatively low permeability in these crystalline rocks. However, recharge will occur to fracture and fault systems in these units, but recharge in these areas will be minimal relative to other units.

Map 5 also shows locations of disappearing streams. These are streams that flow into a lake or small pond that have no surface water outlet. It is interpreted that these streams infiltrate to the ground at these sites, acting as major groundwater recharge locations. Examples of known disappearing streams include:

- the Mary Lake subwatershed;
- ephemeral streams to Sowdon Lakes in the Wolf Creek subdivision;
- Lower Crater Lake;
- "Canyon Creek" at the west side Miles Canyon;
- McLean Creek at Hobo Lake;
- Hidden Lake in Porter Creek subdivision;

- Tavern Creek (pond south of MacDonald Rd.); and
- Macauley Creek (pond east of Crestview subdivision).

The lower reaches of Wolf Creek and Sowdon Creek (which runs through the Wolf Creek subdivision) are both thought to be influent creeks. An influent creek is one where the water level in the creek is above the groundwater table, and consequently, the creek looses water to the groundwater system. In Wolf Creek this was observed in monitoring wells at the Boyle Barracks Cadet Camp (Gartner Lee Ltd. 2001f). Sowdon Creek flows through the western portion of Wolf Creek subdivision, but frequently disappears completely by the time it reaches Boss Road. Both of these creeks likely contribute significantly to groundwater recharge the in the Wolf Creek subdivision area.

Major Areas of Discharge

Groundwater discharge areas (i.e. areas where groundwater movement is toward the surface) are usually topographically low areas such as immediately adjacent to streams and the Yukon River. The groundwater table is generally at or very near the surface in these areas. Many of the areas underlain by wetlands as shown on the Surficial Geology map (Map 3 in pocket) are expected to be groundwater discharge sites. Major groundwater discharge sites and known springs are shown in blue of Map 5. Areas mapped as fens in the City of Whitehorse Wetland Map (Mougeot GeoAnalysis and Agriculture and Agri-Foods Canada 1996) are shown as groundwater discharge sites. This is due to the morphology of fens being defined by groundwater discharge and the associated vegetation communities.

Most of the Yukon River is considered a major discharge site as the river is interpreted to act a regional drain for the entire study area. However, due to the presence of the dam at Whitehorse Rapids Hydroelectric project, the river recharges the basalt and granular overburden groundwater system in the Riverdale area. This is demonstrated by water elevations in a series of pothole lakes, known as Hidden Lakes, east of the Yukon River relative to the Schwatka Lake reservoir. These water levels in the lakes decrease with distance from the reservoir.

4.3 Groundwater in Bedrock

Rock type controls groundwater availability in bedrock. As discussed in Section 3.1, the City is underlain by three primary packages of rocks; 1) Sedimentary and meta-sedimentary rocks of the Whitehorse Trough Super Group; 2) Crystaline rocks of the Whitehorse Basolith; and 3) volcanic rocks comprising the Miles Canyon Basalt.

4.3.1 Sedimentary Rocks

Very few well documented water wells are completed in the sedimentary rocks of the Whitehorse Trough Super Group within the City of Whitehorse. There may be one or two domestic wells at the north end of the City (near the Cousins Airstrip) completed in Mandanna Member rocks, the fine grained member of the Aksala Formation. Northwest of the City along the Alaska highway, a number of water wells are completed in Mandanna Member rocks. These bedrock wells can range in depth from 20 to over 100 metres and are typically low yield (Hydrogeological Consultants Ltd. 1994). This would be consistent with the fine grained nature of the sediments comprising the Mandanna Formation rocks.

The limestones of the Hancock Formation are found along the western side of the Whitehorse valley, and also comprise much of Grey Mountain. This unit has not been studied with respect to groundwater occurrence, but has potential for groundwater development. This is due to the anticipated brittle fracturing in the limestone, and potential for solution channels and areas of high porosity such as reefal or fossiliferous phases of the bedrock.

The Upper Porter Creek Springs and the Stinky Lake Spring are the only known springs originating from bedrock. The Upper Porter Creek spring is interpreted to be groundwater originating along the Porter Creek fault.

4.3.2 Igneous Rocks

Much of the City of Whitehorse is underlain by the granodiorite and diorite of the Whitehorse Batholith. Due to the crystalline nature of these rocks, successful development of a well is contingent on the borehole intersecting a fracture within the rock mass. The distribution of fractures is unknown and has a pronounced influence on well yields, and can result in moderate and low capacity wells within close proximity to one another.

Numerous domestic wells are completed in the rocks of the Whitehorse Batholith at the south end of the City. Likely all the wells in the Cowely Creek subdivisions are completed in these rocks, as well as some of the water wells in the western portions of the Mary Lake and Wolf Creek Subdivisions (the interpreted distribution of this rock type is illustrated on Map 2). It is estimated that at least 70 domestic wells at the south end of the City are completed in this rock type.

As stated earlier, the success of completing a well with adequate yield is contingent on the borehole intersecting a fracture or fracture zone in the rock mass. This has resulted in some very deep well or wells with little to no yield. For example, a 213 m deep well was drilled at the Boyle Barracks Cadet Camp near Wolf Creek, but the hole was abandoned because it produced almost no water. There are numerous other anecdotal accounts of unsuccessful wells (due to low yield) in this rock type within the City of Whitehorse. However, there have been many successful domestic wells completed in these rocks, but many are quite deep and low yield.

Table 4. Summary of Granodiorite Bedrock Hydraulic Properties

Well Name	Location	Transmissivity (m^2/day)*	Aquifer Thickness (m)**	Reference
BH 77-1	Wolf Creek Subdivision – near north end of Harbottle Rd.	0.26 – 0.56	30	Golder Brawner & Associates Ltd. 1977
BH 77-6	West of Wolf Creek Subdivision	0.1	53	Golder Brawner & Associates Ltd. 1977
BH 77-7	South end of Mary Lake Subdivision	0.1 – 0.9	49	Golder Brawner & Associates Ltd. 1977
BH 84-1	South end of Mary Lake Subdivision	30-90	4	Thompson Geotechnical Consultants Ltd. 1984
BH 84-2	East side of Mary Lake Subdivisions (Near Bluebell Pl. & Fireweed Dr.)	0.085	25	Thompson Geotechnical Consultants Ltd. 1984
WTH 1-95	Cowley Creek II Subdivision	0.6 – 2.2	52	Hydrogeological Consultants Ltd. 1995

*Notes: *If multiple tests or test analysis, the range of values is presented.*

***This is the penetrated aquifer thickness, actual aquifer thickness may be greater.*

A series of seven deep wells are completed in weathered granodiorite at the Lobird Trailer Court. These wells supply most of the trailer park's water supply, but are low yield and the operator of the site frequently needs to rely on trucked water delivery to supplement the development's needs (see Section 5.1.2) These wells range in depth from 50 to 200 metres. As they are completed in decomposed granitic rocks, they require frequent redevelopment to remove material from the borehole that has sloughed off the borehole walls.

4.3.3 Volcanic Rocks

The most widely developed and explored bedrock unit is the volcanic rocks of the Miles Canyon Basalt. The interpreted distribution of these rocks are shown on Map 2. This unit extends from the southern end of the City down the valley centre almost to downtown Whitehorse. This rock type supplies domestic water to many private wells in the Wolf Creek, Pineridge, Mary Lake and MacRae Subdivisions. Although groundwater yields from wells completed in the basalt are only moderate, their yield is consistent throughout the unit and volumes of water suitable for individual domestic needs can be readily produced from this formation.

In the Riverdale area, three exploration wells have been drilled through the basalt into underlying materials. The thickness of the basalt in this area ranges from 37.8 m (TH 1-78, Stanley Associates

Engineering Ltd. 1978) to 110 m (TH 1-79, Stanley Associates Engineering Ltd. 1980). The thickness of this unit underlying the rural residential subdivisions at the south end of the City is unknown.

A number of water wells are located at Paddlewheel Village, which is along the Alaska Highway, just south of downtown Whitehorse. Several of these wells are used to supply a trucked water delivery business. Although little information is available on the nature of the groundwater resource in this area, several water well records were obtained (Appendix A). All of these logs show wells being completed in bedrock, with total depth ranging from 78 to 130 m below ground surface. The logs do not specify bedrock type, but most of the wells are drilled only a short distance into the bedrock. This information, along with driller reported yields ranging from 8 to 60 gallons per minute, suggest the bedrock type is likely basalt as opposed to granodiorite.

Basalt also occurs as dykes and/or sills in the granitic host rocks. Although the frequency and distribution of such dykes/sills is unknown and not well documented, at least two water wells are known to be completed in such features. The Wolf Creek North subdivision test well is the only fully documented occurrence. This test well encountered volcanic materials after drilling through approximately 10 metres of weathered granite (grus) (Gartner Lee Limited 2001c).

Table 5. Summary of Basalt Bedrock Hydraulic Properties

Well Name	Location	Transmissivity (m^2/day)*	Aquifer Thickness (m) **	Reference
BH 77-3	Wolf Creek Subdivision – Dawson Rd. near Alaska Highway	1.7 – 9.1	12	Golder Brawner & Associates Ltd. 1977
BH 77-4	West of Wolf Creek Subdivision	2.7 – 3.4	21	Golder Brawner & Associates Ltd. 1977
BH 77-8	North end of Mary Lake Subdivision – Near Alaska Highway	0.4 – 1.9	3	Golder Brawner & Associates Ltd. 1977
BH 84-3	Mary Lake Subdivision – End of Lupin Pl.	0.9	28.5	Thompson Geotechnical Consultants Ltd. 1984
TH 00-1	Wolf Creek North Subdivision	0.46	4	Gartner Lee Ltd. 2001c
TH 02-01	Vanier School, Riverdale	18	82.7	Gartner Lee Ltd. 2003a
LTMW No. 1	Wolf Creek Subdivision – Dawson and Cronkhite Roads	0.37	5.2	Gartner Lee Ltd. 2003b

Notes: **If multiple tests or test analysis, the range of values is presented.*

***This is the penetrated aquifer thickness*

4.3.4 Bedrock Aquifers and Bedrock Aquifer Potential

Map 6 illustrates the extent of major bedrock aquifers and interpreted bedrock aquifer potential. The extent and continuity of the various "aquifers" is based on the distribution of the host rock, but the hydrogeological continuity within the aquifer is unknown. Areas on this map have been identified as follows:

Proven Aquifers – there are bedrock aquifers with proven yields that are capable of meeting domestic water supply demands. The Miles Canyon Basalt is the only one proven aquifer that has been identified in the study area. Although there are numerous other water wells completed in other rock types within the City, based on the low yield and inconsistent nature of these host rocks (e.g. granodiorite), these areas have not been classified as major proven aquifers.

Indicated Aquifers – these are areas with either similar rock types to Proven Aquifers, or have some limited groundwater development and/or potential. The most extensive area of indicated aquifers is located at the northwest portion of the City. This is an area underlain by sedimentary rocks with a few isolated domestic wells and bedrock springs. This area has potential for groundwater development in bedrock, however, very little is known about the groundwater resource potential.

Inferred Aquifers – these are areas with rock types usually associated with water supply potential, however no known development or testing of the groundwater resource potential has been completed. In the Whitehorse area, areas of Hancock Member limestone has been identified as an inferred aquifer. This is based on the known groundwater potential offered by limestone rocks elsewhere in Canada, however, this unit has not been tested in the Whitehorse area.

4.4 Groundwater in Overburden

Development of groundwater resources is more extensive and has been more successful in overburden within the City of Whitehorse. Due to the complex glacial and de-glaciation related landscape of Whitehorse, there are areas of significant sand and gravel deposits that host, or potentially host, good high yield overburden aquifers. The most significant groundwater user, the City of Whitehorse, obtains a portion of their municipal supply from a sand and gravel, unconfined aquifer, called the Selkirk Aquifer, underlying the Riverdale subdivision. There are several other smaller volume groundwater users obtaining water from unconsolidated deposits elsewhere in the City. Furthermore, numerous domestic water wells in the City's rural residential subdivisions are completed in overburden deposits.

All of the significant sand and gravel deposits are glaciofluvial in origin and were deposited by meltwater emanating from retreating glaciers. Generally, these deposits are found as one of two types:

1. Ice contact or stagnant ice valley-fill deposits: stagnation of retreating glaciers in the Whitehorse valley deposited vast quantities of sand and gravel. These deposits form the kame and kettle topography of the Chadburn Lake and Long Lake complexes. The City's water supply aquifer, the Selkirk Aquifer, is interpreted to be part of such deposits.

2. Kame deltas – these are sand and gravel deposits associated with the terminus or mouth of meltwater channels along the valley walls. Examples include the Hillcrest area, the McIntyre Creek aquifer, possibly the Porter Creek subdivision area, and the gravel deposits at the head of Little Takhini Creek.

A secondary common hydrogeological setting for overburden groundwater development is within gravelly zones within tills. Some of the tills in the Whitehorse area are occasionally quite coarse grained with limited fine grained content. Occasionally, low-yield domestic water wells are successful if such a zone is intersected. Furthermore, there are occasionally coarser grained materials overlying bedrock (occasionally referred to as a boulder lag), and some domestic wells in the Wolf Creek subdivision are likely developed in such a setting.

4.4.1 Overburden Aquifers

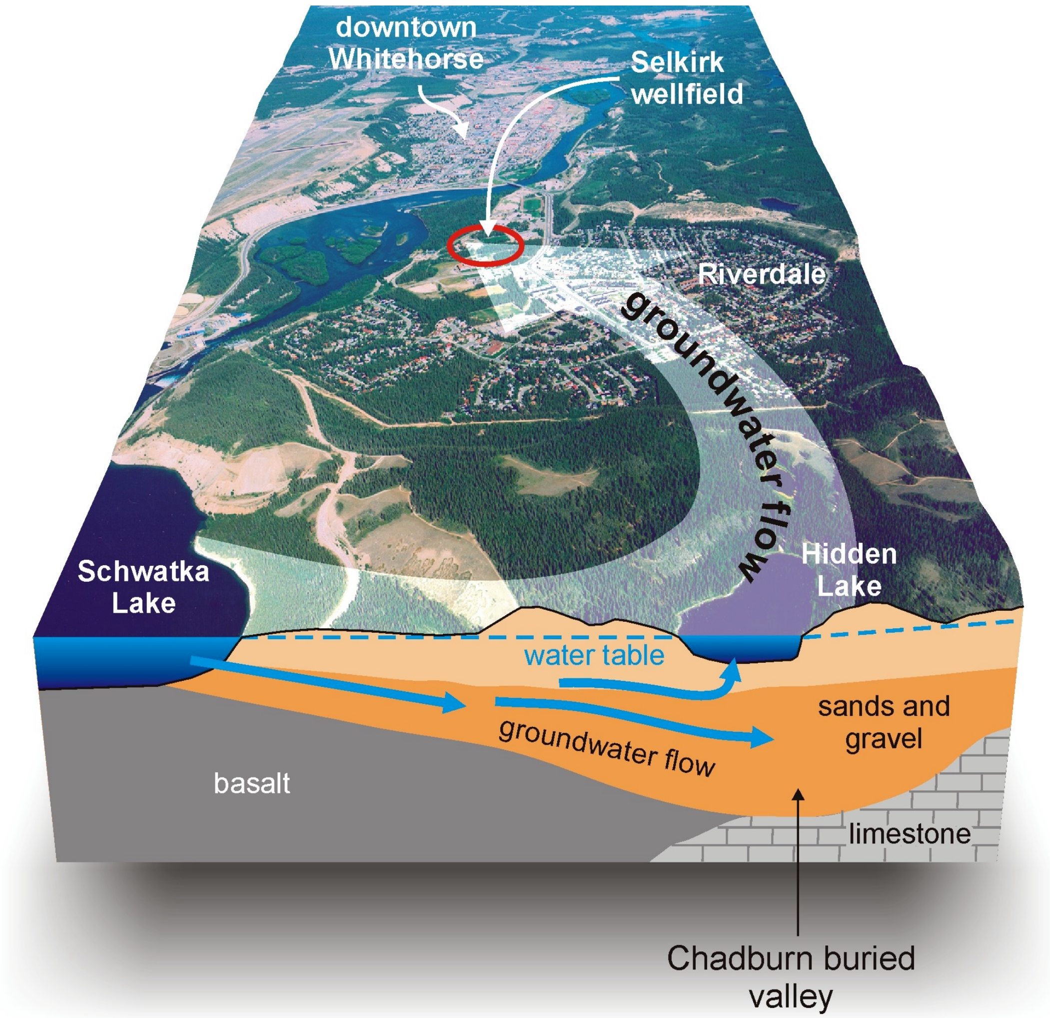
Map 7 illustrates the extent of major overburden aquifers. This section provides a brief overview of these known overburden aquifers:

Selkirk Aquifer – the Selkirk Aquifer is likely the most significant unconsolidated aquifer in the City. This aquifer supplies the City of Whitehorse's groundwater for the municipal water supply. The aquifer underlies the Riverdale subdivision, located on the east side of the Yukon River. The aquifer in the vicinity of the Selkirk Well Field has a saturated thickness of 50 to 65 metres.

The Selkirk Aquifer system is characterized by groundwater flow originating from the Schwatka Lake Reservoir and the Hidden Lakes area south of Riverdale subdivision. The groundwater flows northward, discharging to the Yukon River. Water levels and flow in the aquifer are substantially affected and controlled by the Whitehorse Rapid Hydroelectric dam on the Yukon River. This flow system is shown schematically in Figure 6.

The Selkirk Aquifer has been explored and utilized since the 1956. Numerous test wells have been completed in the area. The results of some of the aquifer parameters are presented in Table 6.

Figure 6. Conceptual Flow Model of Selkirk Aquifer



Note: Figure courtesy of Yukon Geology Program and Geological Survey of Canada (Turner et al, 2003)

The City mixes this relatively warm groundwater (typically produced at 4°C) with cold surface water during the winter to help prevent freezing of the water mains. In spring, the groundwater is also mixed with the turbid surface water to reduce turbidity to acceptable levels in the water distribution system. In 2001 the City extracted 1,597,961 m^3 of groundwater from the Selkirk Aquifer. The Whitehorse Rapids Fish Hatchery also draws groundwater from this aquifer to supply its operation. In 2001 the hatchery withdrew 1,040,520 m^3 of groundwater from the Selkirk Aquifer. These groundwater users are discussed further in Sections 5.1.1 and 5.3.4 respectively.

Table 6. Summary of Selkirk Aquifer Hydraulic Properties

Well Name	Location	Transmissivity (m^2/day)*	Aquifer Thickness (m) **	Reference
WW-1	City Production Well – Selkirk Well Field	2448	57 est. (3)	Gartner Lee Ltd. 2000
WW-2	Abandoned City Production Well – North end of Selkirk Well Field	995	>10 (3.1)	Stanley Associates Engineering Ltd. 1980b
WW-3	Abandoned City Production Well – North end of Selkirk Well Field	220	>12.3 (3.1)	Stanley Associates Engineering Ltd. 1980b
WW-4	City Production Well – Selkirk Well Field	2131	50 est. (4.5)	Gartner Lee Ltd. 2000
WW-5	City Production Well – Selkirk Well Field	440	50 est. (4.6)	Stanley Associates Engineering Ltd. 1980
WW-6	City Production Well – Selkirk Well Field	5820	50 est. (6.4)	Gartner Lee Ltd. 2001d
TH 1-78	Test Well – South end of Selkirk Well Field	447	10.7 (?) (3.4)	Stanley Associates Engineering Ltd. 1978
FW-2	Fish Hatchery Well – South end of Selkirk Well Field	268	6.7 (4.57)	Kala Groundwater Consultants Ltd. 1986
TH 1-97	Test Well – East end of Selkirk Well Field	420	50 (2.44)	Gartner Lee Ltd. 1999
TH 02-01 (Overburden)	Vanier School Test Well (Overburden Test)	83	5.5 (1.07)	Gartner Lee Ltd. 2003a
TH 79-1	Test Well - South side of Riverdale	2088	43 (2.1)	Stanley Associates Engineering Ltd. 1980a
TH 79-2	Test Well – North of Hidden Lake	2984	>85 (2.7)	Stanley Associates Engineering Ltd. 1980a

Notes: **If multiple tests or test analysis, the range of values is presented.*

***Number in brackets indicates length of screen*

Wolf Creek/Pineridge Overburden Aquifer – It is estimated that approximately 50 % of the 168 domestic water wells in the Wolf Creek and Pineridge rural residential subdivisions are completed as overburden wells (Gartner Lee Limited 2001a). Although very little is known as to the nature of the deposits hosting these wells, it is assumed that most are completed in gravelly zones or boulder lags lying on the bedrock surface. The overburden in this area is typically 25 to 40 metres thick. Only one test well completed in the overburden is documented for this area. This well is located on Dawson Road and was completed in a coarse sand overlying bedrock at a depth of 35 metres below ground. Pumping tests report a transmissivity on the order of 29 to 121 m^2/day (Golder Brawner & Associates 1977).

Spruce Hill Aquifer – The Spruce Hill rural residential subdivision, developed in 1999, is a small development of approximately 30 lots at the south end of the City of Whitehorse. Two test wells were completed as part of the subdivision. These wells intersected a confined sand and gravel aquifer at a depth of 50 to 60 metres below ground. Aquifer transmissivity was estimated to be between 5 and 20 m^2/day. The aquifer is interpreted to be a glacial outwash or glaciofluvial ice-contact gravel confined by a sequence of glaciolacustrine silt and clay.

MacPherson/Hidden Valley Aquifers – The rural residential subdivisions of MacPherson and Hidden Valley are located at the northern end of the City of Whitehorse. There are at least 75 private water wells in the subdivisions, which constitutes just over 50 % of the homes in the subdivisions. Based on limited water well records for the area, it appears that wells are completed generally at two depths:

1. approximately 50 to 55 m below surface; and
2. between 80 and 120 m below surface.

The upper interval likely represents a discontinuous outwash gravel below glaciolacustrine silt and clay. The lower aquifer is likely a coarse grained zone in till at, or just above bedrock. The groundwater resources of the MacPherson area were initially assessed by Hydrogeological Consultants Ltd. in 1976 as part of the subdivisions development. Four test wells were drilled and three pumping tests conducted. Transmissivities ranging from 2.2 to 82 m^2/day were reported.

4.4.2 Overburden Aquifer Potential

Map 7 also illustrates the interpreted extent of overburden aquifer potential. These are areas with promising host geology, but no significant groundwater development or exploration. Areas on this map have been identified as follows:

Indicated Aquifers – these are areas with similar geological conditions to Proven Aquifers. These areas are defined primarily by surficial geology mapping. Some of the indicated aquifers include (from south to north):

- Pitted outwash (ice-contact) terrain north of Cowley Creek subdivision – potential for continuation of Spruce Hill Aquifer type setting.
- Wolf Creek Valley Aquifer – granular sediments associated with Wolf Creek, currently hosts the Boyle Barracks Cadet Camp water supply well, and the manual wells at the Wolf Creek campground.
- Canyon Cresent area – granular kame delta and ice contact deposits. At least eight domestic water wells are completed in this area.
- Chadburn Lake area (ice-contact) – likely continuation of Selkirk Aquifer type geology.
- Ear Lake area (ice-contact) – similar pitted outwash/kame and kettle terrain as Chadburn Lake area.

- Long Lake area (ice-contact) – similar to Chadburn Lake area. One test well drilled in 1980 east of the hospital (Stanley Associates Engineering Ltd. 1981)
- Hillcrest area – sand and gravel kame delta. Numerous environmental monitoring wells drilled as part of Upper Tank Farm environmental site assessment and remediation work. Three test water wells were drilled by Stanley Assocaites Engineering Ltd. in 1978 at the mouth of the Hillcrest meltwater channel.
- McIntyre Creek Aquifer – The sand and gravel deposits located along McIntyre Creek just north of the Takhini subdivision have been previously identified as McIntyre Creek Aquifer. However, there is no known extensive use of this resource. Hydrogeological assessment of the area is limited to a couple of poorly documented test holes completed in 1973. The exact location of these wells is unknown, but two of the wells were subject to extended pumping test (>10 hours) at approximately 10 L/s (130 igpm) (Interra Environmental Consultants Ltd. 1975).
- Porter Creek – kame delta and limited pitted outwash deposits. Two municipal supply wells at the south end of the subdivision were drilled in 1963 and supplied a small water supply system until the City extended water mains to the Porter Creek area (presumably in the early 1970's). Two "disappearing streams" and associated springs are found at the north end of the Porter Creek subdivision. At least five water wells are located in the MacDonald Road industrial area at the north end of Porter Creek subdivision. At least one of these wells is completed in overburden.
- Crestview – sand and gravel deposits north of the Crestview subdivision area, however no information about groundwater resource potential.
- MacPherson West – kame delta deposits and pitted outwash. Potentially continuation and surface expression of MacPherson subdivion aquifer.
- Stevenson area – sand and gravel deposit, possibly terminal moraine. Single test well drilled in 1990 by Klohn Leonoff Yukon Ltd.

Inferred Aquifers – these are areas with potential for overburden hosted groundwater resources, however no known development or testing of the groundwater resource potential has been completed. In the Whitehorse area, these are primarily shallow groundwater potential associated with glacial meltwater channels. The Arctic Ova fish farm is believed to be drawing their water from such a hydrogeological setting.

5. Groundwater Use and Development

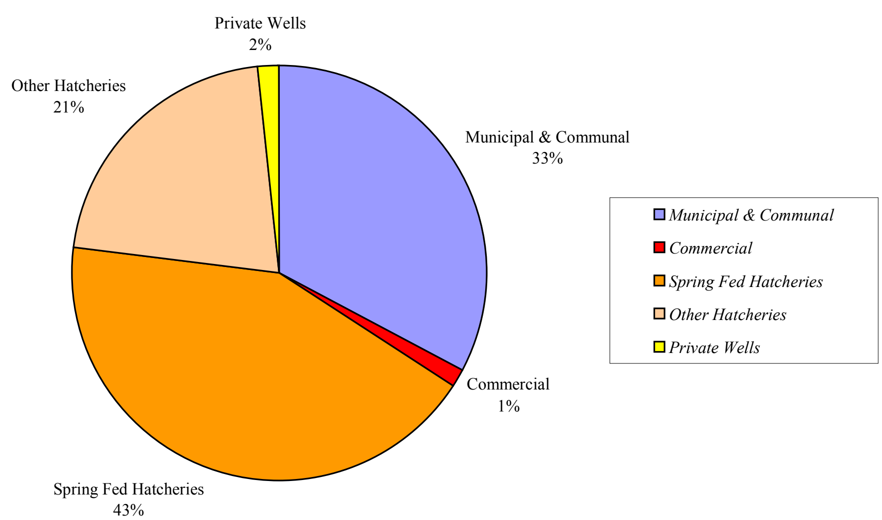
An appreciation of existing water use in the area is fundamental to the development of the area's water resources. The various groundwater uses within the City of Whitehorse are described in this section. For the purposes of this report, water usage has been organized into four broad types of groundwater users found in the City :

1. Municipal and Communal Water Supply
2. Commercial Water Supplies
3. Fish Hatcheries
4. Rural Residential Water Usage

Groundwater usage for agriculture and/or industry (e.g. manufacturing, mining, etc.) is not known to exist within the City.

Total groundwater usage within the City for 2001 was estimated to be approximately 4,900,000 m^3. Figure 7 provides a summary of estimated groundwater usage for 2001. Details of the various groundwater users are provided in the following sections. Wells and major groundwater user locations are shown on Map 8.

Figure 7. Estimated Distribution Groundwater Usage in the City of Whitehorse for 2001



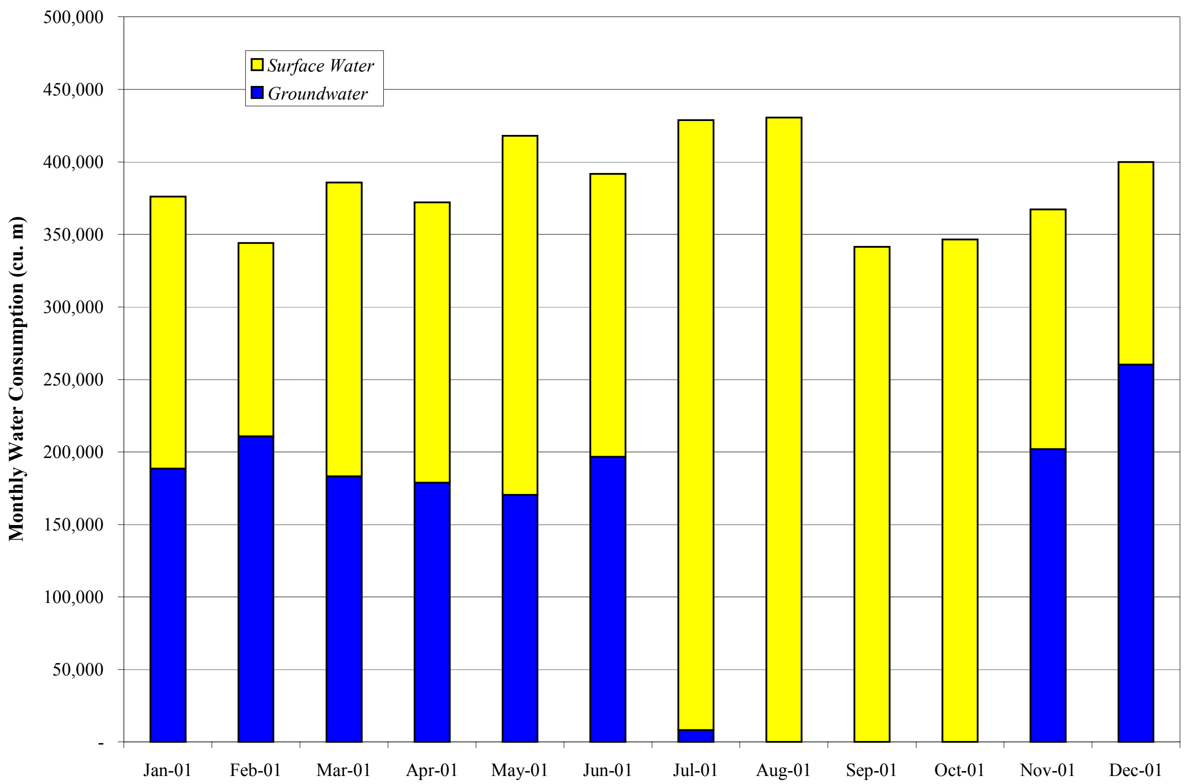
5.1 Municipal and Communal Water Supply

5.1.1 City of Whitehorse

The City of Whitehorse relies heavily on groundwater as part of its municipal water supply. A visit to the Selkirk Pumping Station located in the Riverdale subdivision in April 2002 by GLL personnel provided insight into the recent trends in pumping and system operations. Based on total monthly water volume statistics for 2001, provided by the City of Whitehorse, significant groundwater use occurs throughout the winter and spring months. The entire monthly groundwater use for 2001 is provided in Figure 8.

The City of Whitehorse currently holds a water license with the Yukon Territory Water Board (MN93-001) which permits the removal of 20,000 m^3 of groundwater per day. Based on the 2001 water usage data (Figure 8), the highest daily groundwater extraction rate is estimated to have occurred during the month of February with an average daily production of 7,525 m^3/day. In 2001 the City of Whitehorse used approximately 4,601,848 m^3 of water, 35% or 1,597,961 m^3 of which was groundwater.

Figure 8. 2001 City of Whitehorse Water Usage



The City well field consists of four production wells, known as Warm Water Wells (WW) Nos. 1, 4 5, and 6. All of the wells are completed in the shallow, unconfined sand and gravel Selkirk Aquifer at depths ranging from 12 to 27 m below ground surface. Summaries of the well field are provided in the *Selkirk Management Study* (Stanley Associates Engineering Ltd. 1979) and more recently in the *1997 Warm Water Well Development Program* (Gartner Lee Ltd. 1999).

The most productive well is WW 6. In 2001, WW 6 was used to supply most of the groundwater and was pumped intermittently at a constant rate of approximately 130 L/s (L. Shipman, pers. comm., 2003). Unless exceptionally high flow demands occur, (i.e. the number 2 booster pump in the Selkirk Pump house is used), wells WW 1, WW 4 and WW 5 are not pumped.

In recent years, maintaining low turbidity levels has become an operational issue for the City. Blending the more turbid surface water with groundwater has provided the City with an effective means of reducing turbidity levels in the distribution water. It is likely that the City will therefore increasing rely on groundwater in the future.

5.1.2 Lobird Trailer Court

The Lobird Trailer Court is located on the flank of a broad bedrock-cored hill approximately 4km south/southwest of downtown Whitehorse. The operation currently holds a water license with the Yukon Territory Water Board (MS94-021).

A site visit by GLL personnel in April 2002 provided a good overview of the groundwater system that services a portion of the Lobird area water needs. Blake Battersby maintains and operates the a network of eight wells and the water distribution system at Lobird. Three of these wells however are abandoned, one is frozen and the remaining four are capable of providing only a portion of the subdivision's total water supply. Currently there are approximately 75 homes and 15 apartments within the subdivision with a water demand of approximately $35m^3$/day. However, the maximum yield from the well field is approximately $25m^3$/day (B. Battersby, pers. comm., 2002). During dry periods or during periods with low recharge such as fall and winter, the well field provides significantly less water (i.e. approximately $15m^3$/day). Water is deliver by truck on an as needed basis to meet the additional demand.

All of the operational wells are completed in weathered granitic bedrock, known as gruss. Based on well logs provided by Mr. Battersby (Appendix A), the overburden material consists of a sandy till which typically extends to a depth of approximately 2 to 6 metres below ground surface. The wells are typically completed through the overburden material until competent bedrock was encountered and then an open (uncased) hole drilled into bedrock. The bedrock appears relatively massive with few active water bearing fractures as demonstrated by the need to complete the wells at significant depth (e.g. greater than 200 m deep). The wells have relatively low yields (i.e. < 0.5 L/s). None of the wells when pumped reach a steady state condition (i.e. drawdown stabilizes) and consequently they require intermittent pumping to maintain adequate water levels. The pumping schedule for each well is set by the site operator using timers. The schedule is modified to account for seasonal fluctuations in the water table.

5.1.3 Boyle Barracks Cadet Camp

The Boyle Barracks Cadet Camp is located approximately 15 km southeast of the Whitehorse City center. The facility is currently leased to the Department of National Defense (DND) and is operated as a Cadet Training Camp. There are five full time employees, and the most intense site use occurs during a 7-week period throughout the summer when approximately 300 to 350 people live at the camp. It is estimated that during this high occupancy period, approximately 75 - 115 m^3/day of groundwater is used (J. Nystad, pers. comm., 2001). The facility currently has a water license for operation of on-site septic systems, however this license does not cover the use of groundwater.

The facility is supplied with drinking water from two wells that are completed adjacent to Wolf Creek. The wells are screened across a depth of approximately 8 to 9 metres below ground surface, and are believed to be drawing water from an aquifer consisting of basal gravels on top of bedrock or from the weathered (i.e. highly fractured) bedrock itself. The site operators noted that historically the wells have produced adequate water and have not gone dry or had any seasonal or long-term deterioration in water quality.

5.2 Commercial Water Supply

5.2.1 Glacier Water Services

Glacier Water Services is located at 91305 Alaska Highway (Paddlewheel Village), approximately 4 km south of downtown Whitehorse. No water licence issued under the Yukon Waters Act could be located for the operation. The facility operates both a truck and bottled water service which relies on three moderately deep wells (100 m, 98 m and 96 m), each with a reported capacity of 1.5, 3, and 4.5 L/s (M. Nikon, pers comm., 2002). Borehole logs for these wells report completion in the bedrock (Appendix A).

The facility operator was not available to provide the project personnel with a site tour, consequently groundwater usage for the operation is estimated. The operation currently has two 3500 gallon full-time water delivery trucks and is reportedly seeking to purchase a third. Based on this scale of business, it is reasonable to assume that each truck delivers approximately five loads per day, five days a week, accounting for a groundwater use of approximately 125 - 150m^3/day. The approximate volume of groundwater used for the bottled water operation could not be obtained, however it is expected to be relatively insignificant compared to trucked water volumes. Additionally it is understood that during summer months the facility provides water to the High Country Campground via a private water line. Based on the size of the campground facility, it is estimated that this facility, during summer months would use no more than 20 m^3 of groundwater each day.

5.2.2 MacRae Area

Although this area has many service industrial facilities, (i.e. light woodworking, autobody shops, storage, lumber yard, etc.) none are considered to be significant consumers of water, with the exception of the McCrae [sic] Restaurant/Motel and Service Station. This facility complex utilizes a single deep bedrock well located at the rear of the hotel/restaurant building. Several individual buildings are serviced by this well.

The manager of the Petro-Canada Service Station provided details regarding the history of the well and estimates on the approximate volume of groundwater used each day. Water usage varies considerably depending on the time of year, however based on an estimate taken when the facility was using trucked water due to a pump failure and the construction of a new well, approximately 6 m^3/day were required for operation. Surrounding lots require minimal water use, and have historically used shallow wells, which have had problems associated with low yield (J. Murphy, pers. comm., 2002).

5.2.3 Yukon Springs

Yukon Springs is located at 92281 Alaska Highway (east of the Crestview subdivision) and is currently owned and operated by Paul Sheridan as a bottled water facility. The operation currently holds a water license with the Yukon Territorial Water Board (IN94-001).

The site is located on a terrace above Macauley Creek and the Yukon River. A small groundwater spring originally discharged at the toe of the terrace. The site operator installed a perforated pipe at a depth of approximately 2.5 m as a collector. This pipe intercepts a portion of the spring, and drains the water into a concrete reservoir, equipped with a pump that provides water to the bottling facility as needed (P. Sheridan, pers. comm., 2002). An overflow drain within the reservoir maintains a constant water level, and excess water is discharged to the toe of the terrace slope, the same location where the spring discharges naturally. These waters merges with Macauley Creek which in turn discharges to the Yukon River less than a kilometre downstream.

The flow rate from the perforated pipe into the reservoir is relatively constant year round and is estimated to be 115 m^3/day (per com Sheridan, 2002). Approximately five percent (5.75m^3/day) of this flow is used by the facility. The nature of the hydrogeological regime comprising the spring is not known at this time.

5.3 Fish Hatcheries

There are currently four fish hatcheries or fish rearing operations within the City of Whitehorse, all of which are dependent, at least in part, on groundwater. Three of the facilities rely on the natural discharge of groundwater to surface (i.e. springs). The groundwater is collected using ponds and channeled through either a pipe or surface flow into the facility. Only the Whitehorse Rapids Hatchery in Riverdale, actively pumps groundwater using standard water wells. The primary advantage of using groundwater over surface water in a fish hatchery is that its temperature is not as variable as that of surface water. This "warm" water provides a source of naturally flowing water for incubating fish eggs during winter months when air temperatures commonly drop well below freezing for extend periods of time. Furthermore, surface water can carry pathogens that may negatively effect the hatchery operations.

A brief summary of each hatchery is provided as well as estimates regarding the volume of groundwater used on a daily basis. Note that in most cases the term "used" refers to a rate which the water passes through the operation rather than to groundwater removed and consumed by the process.

5.3.1 Arctic Ova

Arctic Ova is located on the southern side of the Kluan Industrial Park and, at the time of the site visit, was operating as a fish hatchery for arctic char. The facility is owned and operated by Gavin Johnston of Salt Spring Island, British Columbia. The facility employee, Ms. Jennifer Peterson provided a site tour, in April 2002. The facility also holds a water license with the Yukon Territorial Water Board (IN90-008).

The facility is located in the Tavern Creek meltwater channel. The source of the operation's water is located within a low-lying area, up-gradient of the property (i.e. a wetland area), where water appears to be discharging to surface (ie. groundwater springs). This area appears to be perennially saturated and capable of providing the facility with "warm" flowing water throughout the year (i.e. usually above 1.0^{o}C). The amount of water collected by the system varies seasonally from approximately 432 to 864 m^3/day (Evanachan Holding Inc. Annual Report Water Use License IN90-008).

A small excavated depression within the discharge area acts as a pond and provides the first in a step-like series of three fish rearing ponds, all of which are linked consecutively by short surface water channels. A standpipe located in the uppermost pond has a small diameter pipe connected below the water surface which feeds directly into the fish hatchery building approximately 150 m downstream. This pipe provides a relatively constant flow of "warm" water throughout the year from the uppermost pond.

5.3.2 McIntyre Creek Fish Hatchery

The McIntyre Creek Fish Hatchery is located on the western side of Mountain View Dr. between Yukon College and Porter Creek Subdivision. The hatchery is officially operated by the Department of

Fisheries and Oceans (DFO), and is under the direction of Ms. Trix Tanner. The facility also holds a water license with the Yukon Territorial Water Board (MS98-098).

Similar to the utilization of ground/surface water at the Arctic Ova fish hatchery, the McIntyre Creek Fish Hatchery also relies on a groundwater discharge zone (i.e. springs). This spring has been identified in the past by Hydrogeological Consultants Ltd. (1976), as the McIntyre Creek Springs. Located to the east side of McIntyre Creek, these groundwater springs converge into a small creek and provide the hatchery with seasonal flows of approximately 432 to 720 m^3/day (T. Tanner, pers. comm., 2002). Detailed records of flow throughout the year are not kept. The temperature of the inflow at the hatchery ranges between 2 and 6^oC. The water is reported to be quite hard at approximately 200 mg/L $CaCO_3$, however this does not seem to affect the operation of the hatchery. Additionally, dissolved oxygen concentrations range from 10 to 12 mg/L suggesting that the groundwater is significantly oxygenated by contact with the atmosphere prior to entering the hatchery.

5.3.3 Icy Waters Fish Hatchery

Icy Waters Fish Hatchery is located at km 4.2 along the Fish Lake Rd. The facility lies at the historical Pueblo Mine Site and at the time of the site visit was operated by Jonathan Lucas of Whitehorse. GLL personnel conducted a site visit in April 2002 and observed a groundwater and surface water utilization method similar to the Arctic Ova and McIntyre Creek fish hatcheries. The facility currently holds a water license with the Yukon Territorial Water Board (IN87-007).

There are two primary sources of water used by the facility. The majority of the water is taken from the pentstocks that feed the Fish Lake Hydroelectric Project. This water is returned to the hydroelectric projects diversion(s), which eventually flows into McIntyre Creek.

The second source of water used by the facility is a series of groundwater springs that discharge to surface along a slope between the hydroelectric plant and the hatchery. This spring provides the headwaters to Porter Creek, and is referred to as the Upper Porter Creek Springs. A constructed pond located at the base of the slope provides a capture reservoir. A 250 mm diameter pipe conveys the water to the hatchery and rearing facilities located approximately 310 m to the southeast. This system provides between 4320 and 4752 m^3/day of water to the facility. This water source is particularly important, as its temperature is relatively constant, usually ranging between 3 to 5.5^oC throughout the year. This temperature is reported to be ideal for incubating fish eggs (J. Lucas, pers. comm., 2002). Additionally, this water contains saturated levels of dissolved oxygen (i.e. approx. 10 and 13ppm), and has background nitrate concentrations ranging from 0.14 to 0.22mg/L. Ammonia concentrations in the spring water are also reported to range between 0.02 and 0.1mg/L.

5.3.4 Whitehorse Rapids Fish Hatchery

The Whitehorse Rapids Fish Hatchery is located in the Riverdale subdivision adjacent to City's Selkirk Pump House. The facility is owned by the Yukon Energy Corporation and operated R & D Environmental Management Inc. The hatchery primarily produces Chinook Salmon, however some freshwater species are also raised. The facility currently holds a water license with the Yukon Territorial Water Board (MS94-005).

Ms. Sandra Beitz, an employee at the facility, provided GLL staff with a tour of the facility in April, 2002. Unlike the other fish hatcheries located in Whitehorse, this facility relies completely on actively pumped groundwater. A well (68.3 m deep) located approximately 260 m southeast of the property, provides the source for the facility's water. A secondary back-up well is located on the property however this well is not normally used and has a significantly lower yield than the main production well. The wells are completed in the Selkirk Aquifer.

Regardless of season, the groundwater at the inflow to the facility is reported to have a constant temperature of 5.8^{o}C. This water has a relatively low dissolved oxygen (DO) concentration and therefore an aerator tower is used to boost the DO to a concentration that is more desirable for rearing fish (i.e. 12 mg/L).

Unlike other fish hatcheries located in Whitehorse, the production well pumping system is capable of producing a variable flow rate that allows water to be drawn on an "as needed" basis. Consequently, shortly after the fish eggs hatch and begin to grow (February through May) significantly higher volumes of groundwater are used (1,247m^3/day based on 2001/2002 data). During the remaining eight months of the year, groundwater usage is reported to drop to approximately 464 m^3/day.

5.4 Rural Residential Groundwater Usage

Approximately 9% of the population of Whitehorse area lives in rural residential settings (UMA Engineering Ltd. 2001). These are subdivisions with no municipal supplied water or sewer. Homeowners provide their on water supply and on-site septic. Many opt for private, on-site water wells, however truck water delivery is considered a viable alternative and utilized by many homeowners.

Water usage by the average household is assumed to be:

Residential Demand **= Personal Usage + Lawn and Garden Watering**
= (271 m^3/year) + (68 m^3/year)
= 339 m^3/year/household

Where:

Personal Usage = (0.275 m^3/person/day) x (2.7 people/household) x (365 days/year)
= 301 m^3/year/household.

Lawn and Garden Watering = (225 m^2) x (0.025 m/week) x (12 weeks)
= 68 m^3/year/household

Estimated average personal water demand is based on information appearing in *Ontario Rural Residential Design Manual* (1995). The Yukon average number of people per household is 2.7 (Yukon Bureau of Statistics 1997). In estimating water consumption for lawn and garden watering, it is assumed that each household irrigates a lawn and garden that has an average area of 225 m^2 (e.g. 15 x 15 m). Average irrigation rates are assumed to be 0.025 m/week (1-inch week) over the period of June to August.

It should be noted that the groundwater used by private water wells is not completely removed from the groundwater flow system. Water used in the home is typically discharged back to ground via the on-site septic system. Therefore the bulk of rural residential groundwater water usage does not represent a major groundwater depletion.

As there are no requirements for well registry in the Yukon, the exact number and location of private water wells is unknown. However, tax roll information does indicate whether a well is present on the property. Tax roll data were reviewed to identify lots with water wells. Map 8 shows the known distribution of water wells in the City of Whitehorse. Tax roll data quality is limited to the last time the property was assessed, and whether or not the assessor noted a water well on site. Table 7 provides a summary of the estimated number of domestic water wells in the City of Whitehorse, and the associated groundwater usage.

Table 7. Estimated Number of Private Water Wells and Associated Groundwater Usage

Subdivision	Estimated No. of Water Wells	Total Groundwater Usage (m^3/year)
Cowley Creek	32	8,678
Mary Lake & Spruce Hill	57	15,458
Wolf Creek	116	31,457
Pineridge	55	14,916
MacRae, Canyon Cres., & McLean Lake	12	3,254
MacRae Industrial *	17	12,410
MacPherson	49	13,289
Hidden Valley & Mayo Road	33	8,950
Other	12	3,254
Total	334	98,380

*Notes: * Assume industrial/commercial wells utilize 2 m^3/day.*

6. Conclusions

This study provides a broad overview of groundwater resources within the City of Whitehorse and the environmental factors controlling the occurrence of groundwater. These factors, in turn, have significant impact on how the groundwater resources can be developed for human usage. The information compiled will help residents of the City, City planners and water managers utilize and protect this important resource to ensure a safe and sustainable water supply that will meet the City's future needs. Specific conclusions derived from this study include:

1. Groundwater is an important resource to the residents of the City of Whitehorse. All residents are, at least seasonally, dependent on groundwater as a source of clean, reliable potable water. Reliance on groundwater will increase overtime as the population expands.

2. The landscape and geology of the Yukon River valley is quite complex and varies considerably across the Whitehorse City limits. Many different hydrogeological regimes have been identified within the City. Five landscape settings, which correspond to broad hydrogeological settings have been defined as follows:
    - Yukon River Plain
    - Chadburn Lake & Long Lake Complex
    - Glaciolaustrine Terraces
    - Upland Benches
    - Mountain and Alpine Area

    Each of these landscape settings provide different opportunities and challenges with respect to development of groundwater resources.

3. The City is underlain by three primary bedrock types:
    - Triassic to Jurassic aged sedimentary and meta-sedimentary rocks of the Whitehorse Trough Supergroup. Very little groundwater assessment or development of these rocks has been completed within the City of Whitehorse.
    - Cretaceous granitic rocks of the Whitehorse Batholith. Development of abundant groundwater supplies from these rocks is challenging due to the crystalline and massive nature of the rock. At least 70 domestic water wells have been completed in this rock type, however many are deep and/or of low yield.
    - Micoene aged volcanic rocks known as the Miles Canyon Basalt. Many domestic water wells are completed in this rock type. This rock has very consistent hydraulic properties with an average hydraulic conductivity of 2×10^{-6} m/s. (Pearson et al., 2000)

4. Groundwater development from overburden deposits is common within the City. The two most promising hydrogeological settings for potential high yield groundwater development are:
   - Ice-contact sand and gravel deposits found along the Yukon River north and south of downtown Whitehorse. The Selkirk Aquifer it the most significant overburden aquifer and currently supplies approximately one third of the City's municipal water supply.
   - Kame deltas or kame terraces which are sand and gravel deposits found at the mouth of glacial meltwater channels. Currently there is very little groundwater development of this hydrogeological setting.

   A third common hydrogeological setting for overburden groundwater development are coarse grained zones, or boulder lags, found on the bedrock surface and overlain by glacial tills. This setting is typically of lower yield, but adequate to support domestic water wells.

5. It is estimated that in 2001 4,900,000 m^3 of groundwater was utilized within the City of Whitehorse. Approximately 43% of this was water derived from springs and used in fish hatcheries. Based on data provided by the City of Whitehorse, municipal demand accounted for approximately 33% (or about 1,600,000 m^3 in 2001) of the total groundwater utilization within the City. Private domestic water wells constituted less than 2% of the total groundwater consumption in the study area.

6. There are no legal requirements for registration of water in the Yukon, and therefore the location and number of water wells within the City is unknown. However, based on the gathered information, it is estimated that there are at least 330 private water wells within the City of Whitehorse supplying groundwater to about 1,000 of the City's residents.

As this report constitutes primarily inventory and compilation study, no major recommendations are presented at this time.

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Appendices

Appendix A

Water Well Logs

(Hardcopy Only)

List of Maps