Groundwater Contribution to Columbia Lake in the Vicinity of Canal Flats

Columbia Lake Stewardship Society

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Executive Summary

A review of available scientific information indicated that no definitive work existed that established hydraulic gradient within the aquifer lying beneath Canal Flats or described the interaction between Kootenay River and Columbia Lake. The primary objective of this study is to establish the hydraulic gradient of the aquifer denoted as Aquifer 816 (BC Ministry of the Environment) and its contribution to Columbia Lake. The Ministry's water well review indicated a 9.1 m unconfined aquifer depth, depth to water of 4.6 m and aquifer thickness of 4.5 m. Using existing data and current measurements, Columbia Lake Stewardship Society's (CLSS) estimates that 8 to 13 million m^3 of groundwater is held in aquifer storage. Water Survey of Canada data from 1939 to 1985 were analyzed and indicated a consistent hydraulic head decline in the order of 6 to 7 m over a distance of 4000 m from Kootenay River to Columbia Lake.

Our conceptual model of groundwater flow in the Canal Flats area indicates a constant gradient towards Columbia Lake throughout the year. A groundwater flow divide within Aquifer 816 with flow south to Kootenay River does not exist, based on current data. Essentially, any precipitation/infiltration that percolates downward intersects the water table then flows towards Columbia Lake.

Darcy's Law flow equations were utilized to estimate groundwater flow into Columbia Lake with a range of hydraulic conductivity (K) values (<1.0, >0.1 m/s) representative of high energy fluvial environment of the Kootenay River floodplain but acknowledging the finer grained sediments of lake environments. Preliminary calculations based on K = 0.1 m/s indicates groundwater inflow of 42 million m^3 per year. Groundwater flow is estimated to be relatively consistent given constant aquifer characteristic: areal dimensions (length, width and water level), relatively constant hydraulic gradient and a constant hydraulic conductivity). We conclude that the Kootenay River is the predominant source of water to Columbia Lake via Aquifer 816.

CLSS hydrology work was employed to evaluate overall water inflow and outflow and to better define the contribution of groundwater to the lake. It is reasoned that during fall and spring (times with minimal evapotranspiration, minimal streamflow and Dutch Creek flowing directly into Columbia River) that WSC station volumes, net of Dutch Creek, represent groundwater flow and some streamflow. CLSS data indicated 4 cases based on average measured flows attributed to Dutch Creek sub-basin and Columbia Lake sub-basin with a net range of 1 to 4 cms (31.5 to 126 million m^3 of outflow). Recent CLSS late fall (2017) and early spring (2018) measurements indicated a 1 to 1.18 cms flow or 35 to 37 million m^3 per year; these flows are considered to represent minimum groundwater flow during these pre- and post-ice periods.

It is suggested that additional measurements during late fall and spring flows in Dutch Creek and WSC station and analysis of their differences might better define Columbia Lake sub-basin's flow and groundwater contribution. The two streams' flows located just upstream of WSC station (08NA045) need to be incorporated and their volume subtracted from the total flow at the WSC station to better estimate the lake's flow dynamics and the contribution of groundwater. Finally, we suggest a re-evaluation of Columbia Lake's flushing/retention rate that considers both input of groundwater and Dutch Creek's significant role to Columbia Lake.

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1.0 Introduction

Columbia Lake Stewardship Society (CLSS) has been involved in understanding the lake's ecosystem and in preserving it's near pristine water quality since 2014. CLSS's mission is to act as stewards in preserving the ecological health of Columbia Lake. By conducting water quality and quantity measurements, recording data, disseminating information and our reports, we will communicate with and encourage others to join in our mission to preserve Columbia Lake's water resources and natural environment.

CLSS measures surface water flows on Dutch Creek and Columbia River downstream of Columbia Lake. Springs located in the southwest corner of the lake's wetlands area are measured to provide an inflow volume. However, no specific study has been undertaken to determine the groundwater flow regime that exists between Kootenay River and Columbia Lake.

There is substantial water stored within the aquifer located beneath Canal Flats. However, the direction of groundwater flow and any seasonal variation needs to be determined to assess the contribution of groundwater to Columbia Lake. This study aims to establish the hydraulic gradient (and seasonal variations) and estimate the volume of groundwater flow into Columbia Lake to better understand the groundwater/surface water interaction with respect to Kootenay River and Columbia Lake.

This study reviewed historical hydraulic gradients between Kootenay River and Columbia Lake and answered the groundwater flow regime question. Attempting to quantify the lakes water balance is proving to be harder; utilizing CLSS's hydrology work on surface water flows in addition to this groundwater work is required as the two are explicitly linked. Gauged streamflow from the two sub-basins were utilized to estimate groundwater contribution to Columbia Lake. This study identifies that additional work is needed to understand the lake's dynamics.

1.1 Objectives

The objectives of this investigation are:

- determine the hydraulic gradient between Kootenay River and Columbia Lake
- provide an estimate of the groundwater volume entering Columbia Lake
- ground truth groundwater volume estimates in context with measured surface water sub-basin outflows; and
- suggest additional work to better define groundwater's role in Columbia Lake's water balance.

1.2 Methodology

Previous reports were reviewed for information on water wells in the area. These include BC Ministry of Environment (MoE) Aquifer Vulnerability Mapping Project (Kohut, 2006), water well record updates to 2015 provided from a proprietary database (Waterline Resources Inc. Calgary). This review of available water wells concluded that there were limitations (within CLSS resources) to establishing a number of water wells that could be measured over the year to provide hydraulic gradients. Therefore, another approach was taken which involved a search of historic Water Survey of Canada records of Kootenay River and Columbia Lake. Although this method will not provide current water flow conditions, it did provide historical seasonal flows of Kootenay River and levels of Columbia Lake.

The Columbia Lake Management Strategy (USL) in 1997 was reviewed for pertinent facts on hydrology and reference to groundwater. BC MoE's Upper Columbia River Area, Columbia and Windermere Lakes Sub-Basins Water Quality Assessment and Objectives (Technical Appendix) was also reviewed.

2.0 Site Description

2.1 Physiography and Drainage

Other reports have described the physical setting of Columbia Lake and hence will not be described fully herein. In summary, Columbia Lake is bound by the Kootenay Ranges of the Rocky Mountains to the east, to the west by the Purcell Range of the Columbia - Omineca Mountains to the south by the Kootenay River and to the north by the alluvial fan of Dutch Creek. Pertinent facts of Columbia Lake are: lake volume of 74.87 million m^3, surface area of 25.74 km^2, average width of 1.75 km, length of 13.6 km and a mean depth of 2.9 m. The climate is dry as the Purcell Range isolate the area from moist Pacific air with spring and fall being noticeably drier than summer and winter.

2.2 Geology

Canal Flats and area lay within the western Cordillera physiographic region and is located on the margin of the American lithospheric plate. Deformities and other major structural events including strike-slip faults resulted in a strong northwest-southeast structural grain and are responsible for the present-day distribution of rocks, faults and other structures in the area (Clague, 1989). The Canal Flats area lies within the Rocky Mountain Syncline which is adjacent to several other prominent synclines, faults and overturned structures.

Reesor (1973) describes the geology of the Lardeau Map-Area East Half BC which includes the Dutch Creek and Canal Flats areas. A geological cross - sectional extending from Dutch Creek west indicates uppermost bedrock of the Dutch Creek Formation consisting of grey, green and black argillite and slate, dolomite and quartzite, and underlain by Kitchener-Siyeh Formation (dolomitic and calcareous argillite and quartzite). The Canal Flats area lies within the Rocky Mountain Trench which is covered predominately by unconsolidated sediments derived from bedrock and reworked by glacial and fluvial activities.

It is the uppermost unconsolidated sediments that is of particular interest as these sediments are responsible for the uppermost soil and subsurface materials that store and release groundwater. And it is approximately the last 10,000 years since the last glacial advance and retreat that resulted in our present-day land surface and surface water flows. Glacial-fluvial and/or fluvial processes are responsible for present day flow of the Kootenay River and of Columbia Lake.

3.0 Local Hydrogeology

3.1 Aquifer Vulnerability Mapping

Water well records were reviewed and analyzed as part of BC's MoE work on aquifer mapping. 44 well records were available in the Canal Flats area and consisted of mainly domestic wells, some industrial wells and one industrial observation well. Median well depth was 9.1 m and the depth to water was reported as 4.6 m. Therefore, the saturated thickness of the aquifer was 4.5 m.

Kohut (2006) mapped the Canal Flats aquifer (denoted as Aquifer 816) as a rectangular feature with an area of 7 km^2 (4 km x 1.75 km). It is noted generally as an unconfined aquifer in which the uppermost water surface fluctuates according to surface and atmospheric conditions. However, Kohut indicated both confined and unconfined aquifer conditions existed due to variations with the confining layer. Aquifer 816 was classified as moderate in demand and productivity, and high in terms of aquifer vulnerability due to a minimal to limited confining layer, high water table and porous aquifer characteristics.

The aquifer is a fluvial outwash feature created by the discharging Kootenay River and is comprised of gravel, cobbles and medium- to large-grained sand (well-washed and well-sorted). The aquifer is bound to the south by the Kootenay River and to the north by Columbia Lake and by bedrock to the east and west. Kohut commented that "groundwater flow likely moves north to Columbia Lake, westerly and southerly to Kootenay River and that the aquifer lies at a divide that is likely dependent upon the flow of the Kootenay River and water levels in Columbia Lake".

3.2 Updated Water Well Records

More recent water well records were obtained through a proprietary database that included additional water wells records to 2015 (Waterline Resources Inc., 2017). In total, 58 records were reported. Most were domestic water wells and of the same depth and general water level as found in Kohut's 2006 work.

CLSS decided that use of any domestic water wells, even for level measurement, may be contentious and therefore would not be pursued at this time with respect to defining flow gradients. Therefore, the list of available wells dwindled to a few industrial sources and an observation well. Also, a legal survey of well casing tops and ground elevations was a difficult exercise for CLSS with no set budget for such survey work.

Of note is a well owned by Tembec (well #103651). This well is located approximately 125 m from the north bank of the Kootenay River and allows for measurement of the height of the river.

3.3 Estimation of Groundwater Storage

A substantial volume of groundwater is stored within the shallow aquifer in the Canal Flats vicinity. Based on aquifer areal distribution (4000 m length x 1750 m width and a saturated thickness of 4.5 m, 31.5 million m^3 of aquifer material exists. An assumed porosity of 25 to 40 % for clean sand and/or gravel (Freeze and Cherry 1979), indicates groundwater storage of 8 to 13 million m^3.

However, the direction of groundwater flow in unknown. Visual evidence from a large diameter bored well in the vicinity of Burns Avenue, indicated a strong flow to the north towards Columbia Lake in June 2016. Similar observations were noted in a pond on the property of Mr. Dave Belcher's sawmill operation (corner of Hwy 93/95 and Burns Avenue). No water well observations were available on lands closer to the Kootenay River and on the south side of Highway 93/95.

A literature review of the Baille-Grohman canal details indicated that locks were needed as the Kootenay River was reported to be 11 ft (3.35 m) higher than Columbia Lake. However, no date was provided related to these elevation differences or if seasonal water levels variations existed throughout the year.

3.4 Establishing Hydraulic Gradient

A rudimentary method to establish a net gradient between the two water bodies was conducted. It involved the use of Strava, a software program and GPS device mounted on a bicycle and several south to north transverses from the Kootenay River to Columbia Lake (and vice versa) to verify general ground surface elevations. As bicycle travel allowed going from "wheels in the water" to "wheels in the water", effectively this allowed a determination of hydraulic gradient.

Results indicated an initial elevation rise of 4 m in the immediate vicinity (300 m of Kootenay River) followed by overall decline of 11 m (over 3700 m to the shoreline of the Columbia Lake) along Highway 93/95. This net decline was 7 m (as measured on 17 April 2018). However, monthly or seasonal water levels were required to compare river to lake water levels in order to assess variations in gradient throughout the year.

CLSS determined that long-term WSC records were available for Kootenay River from 1939 to 1995 and for a station on Columbia Lake from 1967 to 1984. Kootenay River readings were daily flow volumes and height against a benchmark on the Canal Flats bridge. Columbia Lake readings were measured in feet above a specific datum related to a benchmark on the CPR line near the boat launch on Columbia Lake (southwest corner of lake). Scrutiny of the data indicated that once per month readings of lake levels could be compared to approximately similar daily water levels of the Kootenay River. Therefore, hydraulic gradients could be determined based on these historical records.

Water levels from random years from the overlapping period of 1967 to 1984 were reviewed and several years' data were analyzed. For example, 1982 data is presented below:

Table 1
Kootenay River and Columbia Lake Water Levels used to Determine Hydraulic Gradient

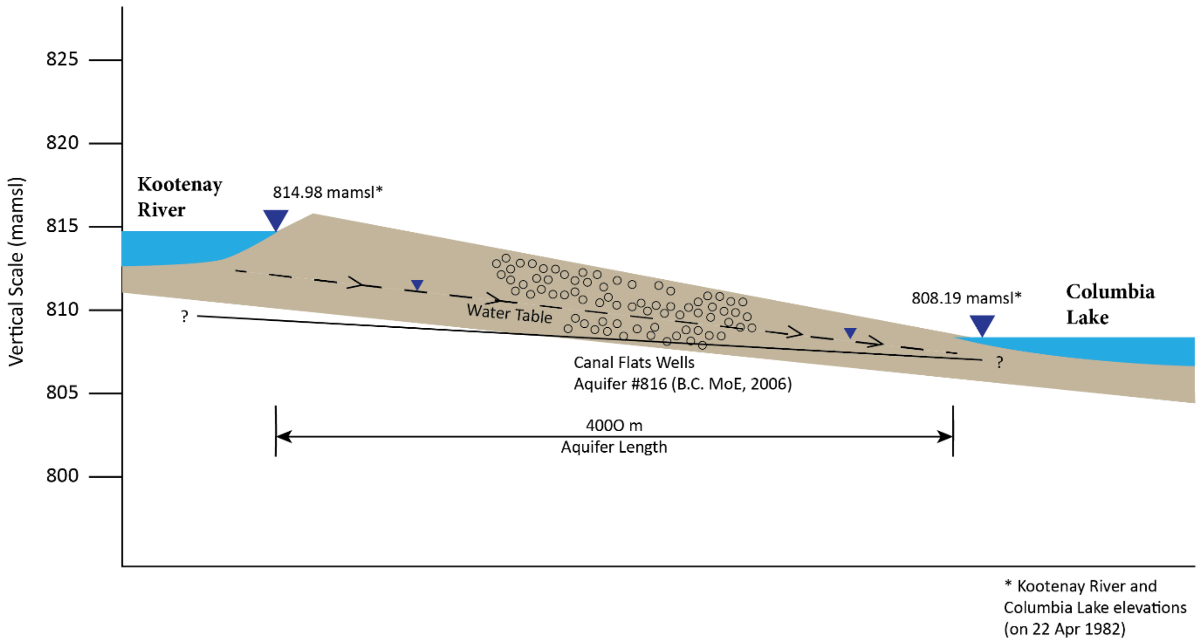
Date	Columbia (ft)	Lake (m)	Kootenay (m above datum)	River Elevation (m)	Water Level difference (m)	Gradient (WL /4000m)
Jan 15	2651.91	808.30	1.759	815.91	7.61	0.0019
Feb 12	2651.94	808.31	2.045	816.20	7.89	0.0020
Mar 17	2651.86	808.29	0.655	814.81	6.52	0.0016
Apr 22	2651.55	808.19	0.826	814.98	6.78	0.0017
May 12	2651.77	808.26	1.314	815.46	7.20	0.0018
Jun 8	2653.80	808.88	1.984	816.48	7.60	0.0019
Jun 23	2656.25	809.63	1.640	815.79	6.16	0.0015
Jul 16	2654.32	809.04	2.067	816.22	7.16	0.0018
Aug 11	2652.86	808.59	1.643	815.79	7.21	0.0018
Sep 14	2652.63	808.52	1.106	815.26	6.74	0.0017
Oct 5	2652.54	808.49	0.981	815.13	6.64	0.0017
Nov 4	2652.08	808.35	0.826	814.98	6.63	0.0017
Dec 1	2652.07	808.35	0.776	814.91	6.56	0.0016

The water level in Kootenay River is higher (6.16 to 7.89 m) than Columbia Lake as shown in Table 1. Monthly readings indicate that the hydraulic gradient (m/m) is quite consistent, ranging from 0.0015 to 0.0020 with a mean gradient of 0.0017. Other years WSC water level data was reviewed and showed similar results (that is, similar hydraulic gradient).

Within the 7 km^2 areal distribution of Aquifer 816, precipitation falling on the ground surface will infiltrate downward, intersect the water table and flow down slope towards Columbia Lake - the exception is the actual banks of the river where slope is to the south (this distance is approximately 300 m as measured on 17 April 2018). It is noted that the area south of Baille-Grohman Avenue and south of Highway 93/95 needs to be investigated with respect to water levels and flow.

The water table or piezometric level of an unconfined water table aquifers, such as Aquifer 816, is essentially a subdued reflection of the land surface. With a mean depth to water of only 4.6 m (as measured in Canal Flats water wells), the flow regime intersects both Kootenay River and Columbia Lake.

Figure 1
Conceptual Hydrogeology of Kootenay River to Columbia Lake (22 April 1982 water levels)



It is concluded that:

- A 6 to 7 m elevation difference between Kootenay River and Columbia Lake results in a mean hydraulic gradient of 0.0017 (1982 data). This indicates the Kootenay River provides is a head boundary with groundwater flow towards Columbia Lake.
- Aquifer 816, a cobble-gravel-coarse sand mixture is the medium that allows groundwater flow between the river and the lake.
- The Kootenay River is the predominant source of water to Columbia Lake in the vicinity of Canal Flats.
- Only a minor amount of precipitation via infiltration through the aquifer makes its way to the Kootenay River, that being precipitation that falls within the immediate banks of the Kootenay River.
- Based on current data, no significant groundwater flow divide within Aquifer 816 is believed to exist.

3.5 Aquifer Flow and Groundwater Volume

An estimation of groundwater flow and volume can be made based on known and estimated hydraulic parameters, specifically; aquifer length and width, saturated thickness and porosity or void space that is filled with groundwater. The historic hydraulic gradient between the two water bodies has been determined. The one remaining variable is hydraulic conductivity (K). It is a function of the medium and of the fluid that flows through it (in our case it's fresh water). Simply, K (m/s) has a high value for sands and gravel and low values for clays and most rocks.

From inspection of the unconsolidated deposits within Canal Flats and Kootenay River, a reasonable estimation of K can be assigned to the predominately gravel, cobbles and sand material. K is the most important parameter as it is the largest (in comparison to hydraulic gradient it is 2 orders of magnitude larger). K value has the largest variability and the greatest unknown in terms of defining a flow volume.

Photo 1 shows fluvial derived material associated with the Kootenay River at Canal Flats. The Kootenay River gravels are indicative of a high energy environment, with most of the finer-grained material washed away leaving predominately a clean, well washed, larger grained aquifer material. However, it is reasonable and still assumed that fine-grained sand and silt material are present and associated with Columbia Lake's shoreline. Choosing less that the maximum possible K value accommodates these finer grained sediments and allow for heterogeneous nature of subsurface aquifer materials

Freeze and Cherry (1979) indicate a range of 10^{-3} to 1 m/s for gravel and a range of 10^{-6} to 10^{-2} m/s for clean sand. Due to the high energy environment provided by flow from the Kootenay River and its repetitive spring freshet cycle, a well-washed clean gravel aquifer with minor sand content is assumed: K values for the aquifer could range from 1 m/s to 10^{-2} m/s.

Water well records completed in Canal Flats were reviewed to determine if pumping tests conducted might provide aquifer parameters such as transmissivity, storativity and specific yield. Four industrial and school wells were identified that had been pump tested at rates of 1635, 2180, 2725 and 3450 m^3 /d. However, no details were available that would allow one to determine if these were the results of acceptable pumping tests results (conducted under controlled conditions) or were derived aquifer yields.

Photo 1
Reworked Fluvial Gravels Located on Floodplain of Kootenay River, Canal Flats

3.5.1 Darcy Flow

The famous French hydraulics engineer Henry Darcy described a laboratory experiment in which he analyzed flow through a sand cylinder that was outfitted with inflow and outflow tubes. When water was allowed to fill the sand and then flow through one end and out the other, he determined the discharge with reference to the change in gradient of the cylinder. He found that the quantity (Q) was function of the gradient or height of the cylinder (from a horizontal position) and of the medium (sand).

The useful form of Darcy's Law that describes flow from Kootenay River towards Columbia Lake is:

> $Q = KiA$,
> where Q is quantity (m^3/s)
> K is hydraulic conductivity (m/s)
> i is gradient (m/m)
> A is the area (m^2) of the saturated aquifer.

Case 1@ K=1 m/s, the volume of groundwater flowing annually to Columbia Lake is approximately 422 million m^3.

Case 2 @K=0.1m/s, annual flow is 42 million m^3

Case 3 @K=0.01m/s, annual flow is 4 million m^3

Case 1 has simply too much flow attributed to groundwater and at times is more than the total outflow measured at the lake outlet at WSC station 08NA045. And we see no geologic reason to accept a hydrogeologic model with significant deep groundwater discharge. Columbia Lake is the local groundwater flow divide (lowest elevation) with surrounding groundwater discharging into Columbia Lake.

Case 3 represents a K value associated with clean sand but not the high energy environment aquifer evident on the Kootenay River floodplain/Aquifer 816.

Based on professional opinion, Case 2 reflects a more reasonable K value consistent with the aquifer's gravel-cobble-sand composition. It also sets a preliminary K value consistent with local pumping test results and well test comments. In comparison to the springs at the southeast corner of the lake, their yearly flow is 0.03 cms (945,000 m^3/yr). Case 2 suggests that the total groundwater inflow flow entering the lake is 44 times as large as the springs' contribution, or approximately a half order of magnitude larger than the springs discharge.

Given the wide range of possible flows based on different K values, a method to ground truth our estimated groundwater flow is warranted. One method involves back calculation from CLSS hydrology measurements from the Columbia Lake and Dutch Creek sub-basins.

4.0 Hydrological Analysis

4.1 Background

BC Ministry of Environment assessed and reported on BC Hydro's Application for Kootenay River Diversion (McKean and Nordin, 1985). The report described both Lake Windermere and Columbia Lake basins. Their focus was on water quality rather than quantity, but the report did provide basic hydrologic parameters of the two sub-basins. Their data was provided from WSC station 08NA045 located on Columbia River south of Fairmont Hot Springs. The two water basins were measured as 890 km^2 and mean annual runoff was 351,850 dams (1 dam = 1000 m^3). Both lakes are similar: high altitude, large shallow lakes with a north-south orientation.

The 1985 report multiplied the watershed ratio x area basin to get an annual inflow to Columbia Lake of 73,100 dams (and 523,000 dams to Lake Windermere). Accordingly, McKean and Nordin estimated that Columbia Lake's water volume was flushed once per year based on these annual average inflow rates and their estimate of the lake's volume.

McLean and Nordin's estimates were based solely on surface water flow with no contribution from groundwater. They also indicated that since Dutch Creek entered Columbia Lake at its outlet, it had minor influence on the lake; however, their focus was water quality and not quantity.

Table 2
Hydrology Estimates for Columbia and Windermere Lakes (after McKean and Nordin, 1985)

Basin	Water Shed Ratio	Size (ha)	Inflow (dams)	Flush Rate (yrs)	Water Retention (yrs)
Columbia Lake	3.95	18,500	73,100	1.0	1.0
Windermere Lake	3.95	132,500	523,000	8.1	0.13

The Regional District of East Kootenay's Columbia Lake Water Management Strategy (USL,1997) was reviewed for any information related to hydrology or groundwater.

USL noted that Columbia Lake basin upstream of the outlet is 881 km^2, of which 696 km^2 is from Dutch Creek and the remaining 185 km^2 from other local drainages and the lake itself. Columbia Lake outflow data at WSC 08NA045 was reported as 323.5 million m^3.

With respect to groundwater, USL stated: "it is known that a considerable amount of water is contributed via groundwater from the Kootenay River and simplified calculations suggest groundwater contributions exceed 100 million m^3/yr". However, the study set the total local inflow to Columbia Lake at 40 million m^3.

4.2 CLSS Annual Water Quantity (Hydrology) Assessment

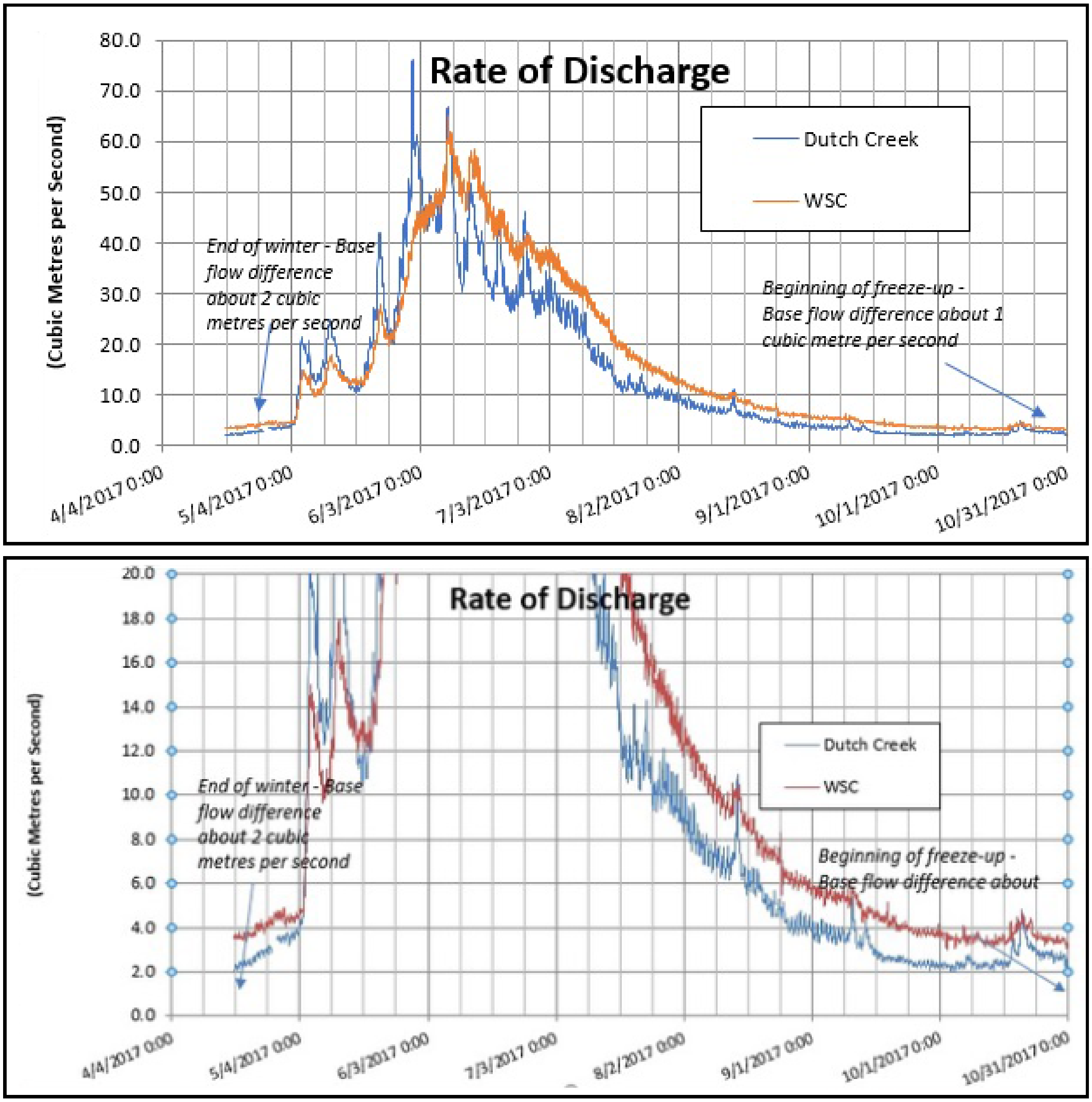
CLSS measures streamflow in Columbia River throughout the year and in Dutch Creek for a portion of the year. Readers are directed to the CLSS website for a full review of the yearly monitoring. The Columbia River monitoring station (former Water Survey of Canada station 08NA045) measures the combined flow of the Columbia Lake sub-basin, Columbia Lake, Columbia River from its start to the monitoring station and Dutch Creek. Subtraction of the flows of Dutch Creek essentially leaves the contribution of Columbia Lake sub-basin, plus two small streams located between Columbia Lake's outlet and the WSC monitoring station.

In particular, if flow measurements from the periods of time when evaporation and transpiration are minimal, then a better approximation of baseflow could be determined. Baseflow is defined as total subsurface groundwater flow and involves both saturated and unsaturated zones. The conceptual groundwater model herein indicates a steady inflow of groundwater due to a relatively consistent hydraulic gradient throughout the year, a defined aquifer length, constant water table and a constant head boundary provided by the Kootenay River.

Figure 2 (Figure 14 of the CLSS 2017 Water Quantity Monitoring Report) compares flows measured on Dutch Creek and at WSC station 08NA045. WSC station shows that water flows at this station are always greater than measurements recorded at Dutch Creek station (late fall and early spring only). This trend is maintained until late fall where readings become unreliable due to two factors - ice build-up on Dutch Creek that distorts measurements, and minimum water flows that cannot be measured on Columbia River as the actual measuring points are not located on the base of the river but approximately 3 to 4 cm higher than river bottom.

Based on a series of fall 2017 and spring 2018 measurements, the average readings at WSC station are estimated to range from 4 to 6 cms, and the average readings for same time period on Dutch Creek are 2 to 3 cms (personal communication B. Thompson, April 2018).

Figure 2
Rate of Discharge



Source: Figure 14 of the CLSS 2017 Water Quantity Monitoring Report

Taking into account the measurements available to work with: Average Dutch Creek sub-basin contributions and average Columbia Lake sub-basin outflows at WSC station, four cases may apply: maximum and minimum for Dutch Creek's flows and maximum and minimum of Columbia Lake's flows at WSC station.

Case 1 maximum contribution of Columbia Lake (6 cms) and minimum contribution of Dutch Creek (2 cms); net 4 cms

Case 2 minimum of Columbia Lake (4) and maximum DC (3); net 1.0 cms

Case 3 maximum of DC (3) and Max of CL (6), net 3 cms

Case 4 minimum of CL (4) and minimum of DC (2); net 2 cms

Therefore, the overall flow of Columbia Lake sub-basin is 1.0 to 4 cms or 31.5 to 126 million m^3.

Table 3
Range of Columbia Lake Sub-basin Baseflow to Total Outflow WSC 08NA045

	Net Columbia Lake Sub-basin Baseflow (million m^3)	Baseflow as % of annual lake outflow
Case 1-net 4 cms	126	39
Case 2- net 1.0 cms	31.5	10
Case 3- net 3 cms	94.5	29
Case 4- net 2 cms	63	19.5

using 323.5 million m^3 outflow of USL 1997 report

It is reasoned that Case 1 where Dutch Creek has minimum flow and Columbia Lake maximum value is unlikely as Dutch Creek watershed is considerably larger and therefore Dutch Creek will have more impact on outflow.

Case 3 where both Columbia Lake and Dutch Creek have maximum flows (net flow of 3 cms) is possible but could represent precipitation events occurring in both sub-basins.

Case 2 where effects are caused by maximum flows on Dutch Creek and minimum flow on Columbia Lake basins (accounts for larger Dutch creek sub-basin).

Case 4 represents minimum flows in each sub-basin.

These four possible cases indicate the significance of the Columbia Lake sub-basin contribution during the year when Dutch Creek station (DC) flows are minimal.

4.2.1 In-situ Measurements

CLSS flow measurements in early spring (2018) indicated 4.4 kms (WSC) and 3.5 cms at DC (net 1.1) and late autumn (2017) of 3.45 cms (WSC) and 2.27 cms (DC), net 1.18 cms. These are the most recent, late in season reliable readings from DC and represent minimal average flows that can be read accurately. Accordingly, in autumn and spring, when less evaporation and transpiration takes place, a net flow of

1 to 1.18 kms equates to 35 to 37 million m^3 per annum, and represents minimum groundwater flow into Columbia Lake.

There are six streams and creeks that inflow directly into Columbia Lake; by mid-summer most are minor contributors (except Dutch Creek) and by autumn are considered to be minimal contributors to the lake. If baseflow calculations are performed when these creeks are at a minimum, then base flow is predominately groundwater flow. CLSS or others have not attempted to monitor these (Marion, Hardie and Sun on the west side of the lake, and Landsdowne and Warspite Creeks on the east side).

4.3 Columbia Lake's Water Residence Time

In terms of water residence/turnover time, past calculations were based solely on surface water runoff estimates. McKean and Nordin estimated a flushing rate of once per year and an annual volume of approximately 73 million m^3 into Columbia Lake.

Given the fact that streamflow into Columbia Lake is minor to intermittent, particularly in the late summer and autumn months, groundwater might play a more significant role in counteracting lake evaporation and stabilization of lake level. The hydraulic gradients determined from this study and the hydrogeologic characteristics of Aquifer 816 indicates that at least 42 million m^3 of groundwater is contributed to Columbia Lake annually, based on a conservative hydraulic conductivity value. This volume has not been included in prior flushing calculations. Similarly, the role of Dutch Creek's influence on lake level and therefore the hydraulic gradients seen at the south end of Columbia Lake need to be investigated. Hence, a review of the Columbia's Lake's flushing rate is warranted.

CLSS's report and Figure 2 (Figure 14 of the CLSS 2017 Water Quantity Monitoring Report) shows declining discharge of Dutch Creek basin water over time as it drains directly into Columbia River. Stated another way, the Columbia River sub-basin and lake become more influential to the overall flow measured at WSC station, and groundwater is a significant portion of this flow.

4.4 Groundwater Temperature

Groundwater and spring's water temperature of 7 degrees C was measured near the bridge (as it flows into the south end of Columbia Lake along the boardwalk trail) on 15 July 2018. Meanwhile, the ambient air temperature was 29 degrees C on a warm summer evening at 7:15 pm. Nearby Kootenay River water temperature was recorded at 13 degrees C at 7:30 pm (15 July 2018). Using a conservative hydraulic conductivity value of 0.1 m/s), 42 million m^3 enter the lake and have a cooling effect on the lake. This may reduce algae bloom, increase oxygen in the lake and be beneficial to both fish, plant and other aquatic life.

5.0 Discussion

The Kootenay River is the predominant water source of water into Columbia Lake in the vicinity of Canal Flats. Groundwater recharge to Columbia Lake is consistent (year-round) due to a relatively constant hydraulic gradient. It is noted that no assessment has been made of groundwater baseflow occurring along lake's 13.6 km length.

We also note that the two streams entering between Columbia Lake outlet and upstream of WSW station 08NA045 need an assessment of their streamflow and be included in the WSC station data.

More streamflow measurements during late fall and early spring on Dutch Creek and the WSC station on Columbia River might provide a more accurate picture of groundwater contribution to the Columbia Lake sub-basin.

6.0 References

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Appendix A

BC Ministry of Environment
Aquifer Classification - Canal Flats, BC

AQUIFER CLASSIFICATION WORK SHEET

DATE: March 23, 2006

AQUIFER MAPPER: A.P. Kohut

AQUIFER LOCATION: Canal Flats.

AQUIFER NUMBER: 816

NTS MAP SHEETS: 82J/4

BCGS TRIM Maps (1:20,000): 082J011, 012

CLASSIFICATION: IIA **RANKING: 13**

Aquifer Size:
Area of aquifer is approximately 7.0 km^2.

Aquifer Boundaries:
The aquifer boundary has been delineated using spatially limited water well record information, topography and geology mapping (Leech, 1959).

Geologic Formation (overlying): Pleistocene and Holocene deposits including sandy clay, silt, sand, gravel and glacial till.

Geologic Formation (aquifer): Fluvial and glaciofluvial deposits comprised of sand, sand and gravel and boulders in the floodplain the Kootenay River and Columbia Lake Valley.

Confined/Partially Confined/Unconfined: Unconfined and confined locally.

Vulnerability:
High. The geometric mean (geomean) depth to static water level is 4.59 metres (15.05 feet). The geometric mean thickness of the confining layer where present is 2.36 metres (7.7 feet). The range of thickness of the confining layer is from 0.30 to 15.54 metres (1 to 51 feet).

Productivity:
High. Well yields reported in the well records range up to 31.54 L/s (500 USgpm). The geometric mean of 15 reported well yields is 2.16 L/s (34.2 USgpm) and the median well yield is 1.89 L/s (30.0 USgpm). Calculated specific capacity values for 3 wells, where tested, ranged from 5.3 to 160 Usgpm/ft of drawdown.

Depth to Water Table:
The geometric mean static water level is 4.59 m (15.05 ft) and the median static water level is 4.57 metres (15.0 feet) based on 29 well records.

Direction of Groundwater Flow:
Groundwater likely moves northerly towards Columbia Lake, westerly and southerly down the Kootenay River Valley. The aquifer lies at divide that is likely dependent upon flow of the Kootenay River and water levels in Columbia Lake.

Recharge:
Precipitation over the aquifer and infiltration from the Kootenay River.

Domestic Well Density:
Moderate over aquifer area, 5 wells/km^2.

Type of Water Use:
Domestic (private and community), commercial and other uses (e.g. observation well).

Reliance on Source:
Important source for various uses.

Conflicts Between Users:
None documented.

Quantity Concerns (type, source, level of concern):
None documented.

Quality Concerns (type, source, level of concern):
None documented of health concern. A field survey conducted in 1967 showed hardness ranging from 204 to 238 mg/L, pH of 7.5 and total iron = nil for two wells.

Comments:
The geometric mean depth of water wells in this aquifer is 9.11 metres (29.9 feet). The median depth of wells is 7.62 metres (25.0 feet) and the range of well depths is from 4.27 to 48.77 metres (14 to 160 feet).

The statistics quoted for this aquifer are based on 14 to 35 water well records.

References:

Berardinucci, J. and K. Ronneseth. 2002. *Guide to Using the BC Aquifer Classification Maps for the Protection and Management of Groundwater*. Water, Air and Climate Change Branch. BC Ministry of Water, Land and Air Protection. Victoria, B.C. 54 pp.

Leech, G.B. 1959. *Canal Flats, Kootenay District, British Columbia.* Geological Survey of Canada, Preliminary Map 24-1958.

AQUIFER CLASSIFICATION AND RANKING

AQUIFER LOCATION: Canal Flats.

AQUIFER NUMBER: 816

CLASSIFICATION: **IIA** **RANKING VALUE:** **13**

Classification Component:

Level of development: **Moderate** – ***Moderate*** level of demand in relationship to ***high*** level of aquifer productivity and water availability.

Level of Vulnerability: **High:** ***High*** level of vulnerability to surface contamination.

Ranking Component:

	Ranking Value
Productivity:	3
Vulnerability:	3
Size:	2
Demand*:	2
Type of Use:	3
Quality Concerns:	0
Quantity Concerns:	0
Total:	**13**

- Demand has been assessed subjectively. Demand is based on domestic well density, number and type of wells, and general knowledge of well use and land use in the area. Demand assumes that the reported well capacity is the amount of water used, which can be misleading. The reported well capacity can be higher than actual use.

Number of water wells available for aquifer delineation = 35
Statistical Summary of Well Record Data for Aquifer # 816

	Well Depth		***Depth to Water***		***Depth to Bedrock***		***Reported Well Yield ****		***Estimated Thickness of Confining Materials *****	
Number of Wells	35	35	29	29			15	15	14	14
	m	ft	m	ft	m	ft	L/s	gpm	m	ft
Maximum	48.77	160	6.86	22.5			31.54	500	15.54	51
Minimum	4.27	14	2.44	8			0.32	5	0.30	1

Average	11.24	36.9	4.78	15.7			4.73	74.9	4.63	15.2
Median	7.62	25.0	4.57	15.0			1.89	30.0	2.13	7.0
Geometric Mean	9.11	29.9	4.59	15.05			2.16	34.3	2.36	7.7

* - USgpm

** aquifer appears to be confined locally in a channel feature

Appendix B

2015 Water Well Database

Posted on CLSS Website

Appendix C

WSC Station Data

- Kootenay River 08NF002
- Columbia Lake SW Boat Launch 08NA064

Posted on CLSS website