Elko Project Water Use Plan

Side Channel Sinkhole Monitoring Study

Implementation Year 1

Reference: ELKMON-3

Identifying the possible effects of Elko Dam headpond operations on groundwater levels in the Baynes Lake community.

Study Period: April 1, 2006 to December 31, 2008

January 19, 2017 note to file: This report was drafted in July 2009. Subsequently, BC Hydro representatives attended a meeting on September 22, 2009, with members of the Sinkhole Committee and the Comptroller of Water Rights to discuss the draft version of the report. It was then finalized November 2010. In error, the date of this report was not changed prior to finalizing. While this report is dated July 2009, it was actually finalized November 2010.

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Executive Summary

This investigation is a requirement of the Water Use Plan for the Elko Project and is part of a larger program designed to identify the possible effects of Elko Dam headpond operations on groundwater levels in the Baynes Lake community, which is located approximately 10 km southwest of Elko Dam.

The primary objectives of this monitoring program were to: 1) assess the feasibility and cost of reducing the range of the headpond operation from 30 cm to 15 cm during non-freshet periods, and 2) assess the relationship between headpond levels, corresponding water levels above the side channel sinkholes, and the potential benefits of higher headpond water levels on aquifer recharging. This report summarizes the preliminary results of a study designed to assist in determining whether headpond operations can be modified during the non-freshet period for increased aquifer recharging. Specifically, the hypotheses tested were H_1: It is operationally feasible to operate the Elko Dam headpond within a 15 cm range during the non-freshet period; H_2: Increased water depth over side channel sinkholes will increase the total volume of water infiltrating the side channel sinkholes and; H_3: It is more cost-effective to implement operational changes in the Elko Dam headpond than reconfigure the side channel containing the sinkholes to maintain the desired water depth over the sinkholes.

The key water use decisions impacted by this study are the operating limits of the Elko Dam headpond during non-freshet periods and the feasibility of undertaking physical works to improve surface flow over side channel sinkholes. This study was originally designed to provide key information needed to assess the feasibility of reducing the operating range of the headpond and to estimate the expected costs and benefits of this operational change (in terms of electrical power generation revenue, and likelihood of improving groundwater availability at Baynes Lake).

One of the fundamental questions with this study is the suggested link between headpond elevation and Baynes Lake aquifer recharge. It has been suggested that a higher headpond level results in increased water flow through the sinkholes thereby increasing available groundwater in local area resident's wells. Previous studies, reports, and existing anecdotal information about recharge response rates suggest a poor scientific link at best. The resources and time needed to confirm this relationship go far beyond the financial resources allocated for this study, although such a study may be useful. The study approach as proposed in the side channel sinkhole monitoring program Terms of Reference is a determination of annual sinkhole wetting and not an experimental monitoring study..

In addition to testing the primary hypotheses, this program provides information on sinkhole elevations in relation to natural river discharge. It has been suggested that the amount of water passing through the sinkholes and into the aquifer may be related to the number of days the sinkholes are wetted.The relationship between elevations and discharge will help to identify years when water infiltration may be of greater concern through reduced number of wetted days.

Recommendations focus primarily on maintaining current headpond operations during non-freshet periods and when possible, planning for operational flexibility to increase the amount of water in the headpond and side channel area.

Acknowledgements

Bill Sproule (Sproule Survey and Design) and Rob Simmerling (Kodiak Measurement Services Inc.) were contracted to collect all topographic and bathymetric survey data. Their expertise, precision, and attention to fine details were a great addition to the project.

Thanks also to the many community residents for providing critical historic information. In particular, Stan Doehle and Harley Greenwood from Baynes Lake, British Columbia were gracious in sharing their knowledge of the aquifer system, participating in field visits to identify sinkhole locations, and allowing access through their respective properties to assist in monitoring water level responses at Baynes Lake and local unnamed water bodies. Their knowledge and input also assisted with developing study design, equipment requirements, and implementation.

Marco Marrello of BC Hydro dedicated much of his time to monitoring water levels in the Baynes Lake community over the last two years and contributed to post-processing and analyses of the data.

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1.0 Introduction

The Elko project is located within the Regional District of East Kootenay on the Elk River in southeastern British Columbia, approximately 70 km southeast of Cranbrook. The 185-km long river flows south from Elk Lakes in the Continental Ranges of the Rocky Mountains into the Kootenay River near Lake Koocanusa Reservoir. The Elko project is a run-of-the-river diversion consisting of the Elko Dam, concrete pipeline, surge tank and steel penstocks leading to a 12 MW capacity generating station located about 1.2 km downstream of the dam (Figure 1.0). Water from the generating station is then discharged back into the Elk River. To gain an additional 2.8 m of hydraulic head for power generation, flashboards are annually installed on top of the spillway in July at the tail end of the freshet. The flashboards are generally removed in April prior to the start of freshet. The Elko Dam headpond operation is divided into two time periods: spring and summer freshet, and fall and winter non-freshet. During non-freshet conditions, inflows to the headpond are less than plant capacity and the plant is operated to match generation to available inflows. Historically, management of the headpond levels required manual changes and there were highly variable levels observed in the headpond. Currently, the headpond is operated to maintain an average water elevation of 20 cm below the flashboards (30 cm range) and managed by an automated headpond controller which continuously alters power generation diversion to match headpond inflow rate to maintain constant elevation in the headpond.

Beginning in the 1970's, area residents expressed concerns that many groundwater wells were being negatively affected by operation of the Elko Dam headpond during non-freshet periods (Johanson 1976). The speculated cause of this was a number of plugged sinkholes (filled in by East Kootenay Power in the 1960s) located in a side channel at the top end of the headpond. The headpond only became wetted outside of the freshet when at its highest operating level and when the flashboards were installed, creating backwatering in the channel. Observations of the sinkholes during the high water level period have confirmed that there is approximately 30 cm of water above the tops of the plugged sinkholes.

The upstream end of the side channel, which contains the sinkholes, has become overgrown with alders and grass, and remains dry throughout the year. Members of the Sinkhole Committee believed that maintaining water above the sinkholes would provide groundwater benefits, as this water would pass down through the sinkholes and help recharge the aquifer. It was assumed that water passing through the plugged sinkholes lead directly to, and supplied, the main aquifer (groundwater) around the community of Baynes Lake (Figure 1.1). It was hypothesized that lower headpond levels could isolate sinkholes, reduce surface water supply to the aquifer, and ultimately negatively impact groundwater wells used by Baynes Lake community members.

In 1986, BC Hydro modified the operations of the headpond to increase water levels by approximately one m to benefit aquifer recharging. Local residents reported that the change improved groundwater deficiency problems but that these were still present, though not as pronounced and mostly occurring during 'dry years' (Boyer 1992).

A direct link between sinkhole inflow and groundwater level in the Baynes Lake area is difficult to establish (Johanson 1976; Boyer 1992) because the sinkholes are deposits of highly permeable gravel and silt situated amongst bedrock outcropping that control directional flow and storage of groundwater (Clague 1973). However, many of the Baynes Lake residents believe that increased headpond operating levels during the non-freshet period would improve inflow into the sinkholes in two ways:

- increasing the number of sinkholes that are wetted, and
- increasing the hydrostatic head over the sinkholes thereby increasing the volume of water passing through the sinkholes into the groundwater table.

During the Water Use Planning (WUP) process the Consultative Committee (CC) recognized that several factors confounded an assessment of the effect of headpond operation on groundwater resources for Baynes Lake, and that these factors create uncertainty about the most appropriate management action to resolve the issue.

The CC investigated several management actions to help resolve this issue with the Baynes Lake residents and the following two were proposed as major components to the monitoring study and for future consideration:

- operate the headpond at a narrower range to maximize sinkhole inundation; or,
- physically reconfigure the river channel bed to ensure sinkhole inundation under normal headpond operations.

The Consultative Committee agreed that given the uncertainty about the connection between headpond levels and groundwater levels, a stepwise approach was required to address this issue.

The fundamental management questions addressed by this monitoring study are associated with potential impacts of Elko Dam headpond operations on groundwater availability (for human consumptive purposes) for the community of Baynes Lake. The two management questions being addressed by this study are:

1) Will increased water levels over side channel sinkholes increase surface water infiltration into the local aquifer, and is the contribution sufficient to improve groundwater availability at Baynes Lake?

2) If increased water levels over side channel sinkholes provide significant benefits, is the most cost-effective way to achieve increased water levels through operational changes of headpond operation during non-freshet periods, or through physical reconfiguration of the side channel that contains the sinkholes?

The water use decisions impacted by this study are the operating limits of the Elko Dam headpond during non-freshet periods and the feasibility and necessity for undertaking physical works to improve surface flow over side channel sinkholes. The study will provide key information needed to assess whether it is operationally feasible to reduce operating range of the headpond, as well produce an estimate of the expected costs and benefits (in terms of electrical power generation revenue, and likelihood of improving groundwater availability at Baynes Lake).

Figure 1.0. Map showing the geographic location of Elko Generating Station.

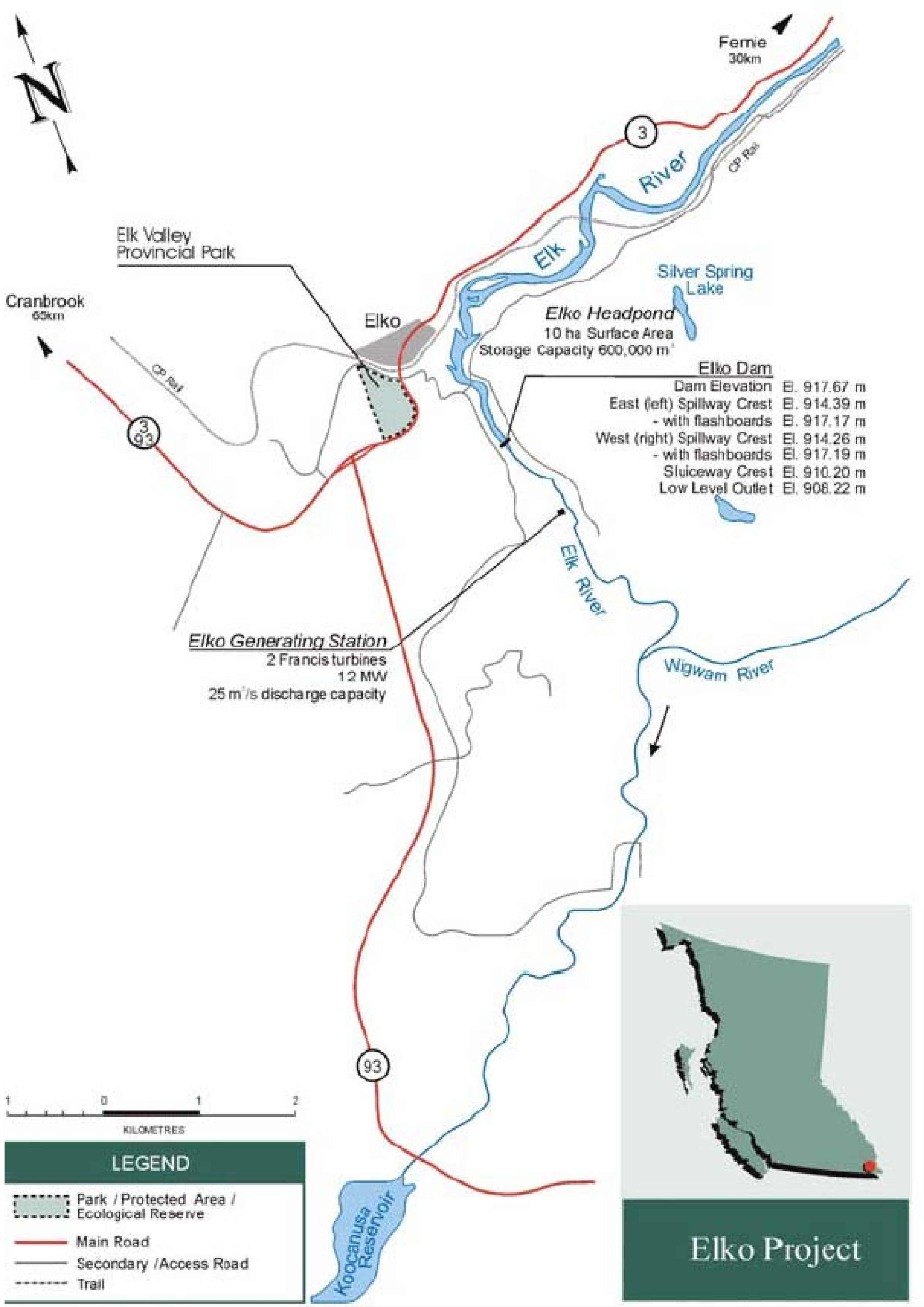
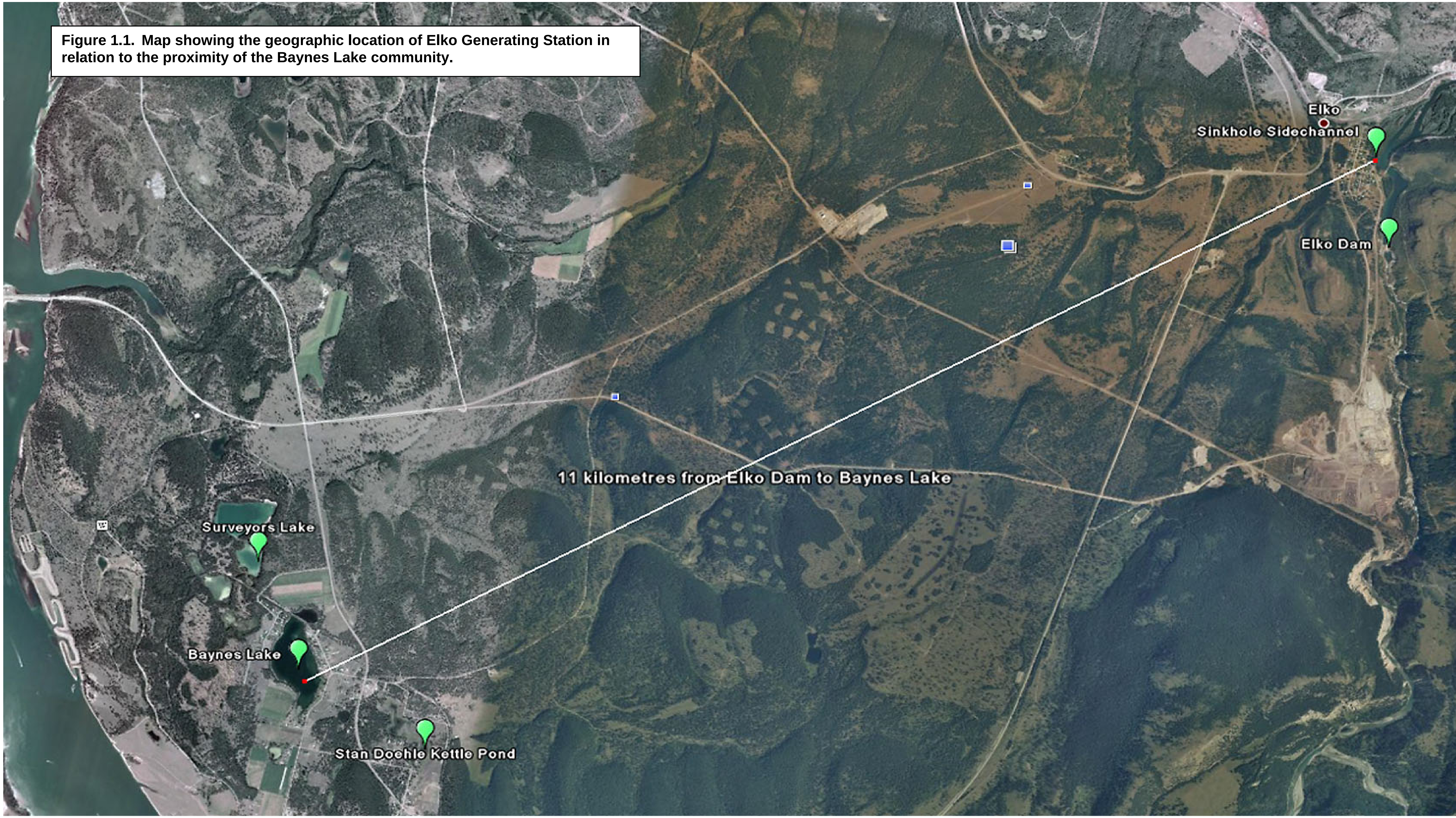


Figure 1.1. Map showing the geographic location of Elko Generating Station in relation to the proximity of the Baynes Lake community.



1.1 Objectives

The objectives of this monitoring program are to:

1) Assess the feasibility and cost of reducing the range of the headpond operation from 30 cm to 15 cm during non-freshet periods;

2) Assess the relationship between headpond levels, corresponding water levels above the side channel sinkholes, and the potential benefits of higher headpond water levels on aquifer recharging.

1.2 Management Hypotheses

The primary management hypotheses to be tested by the monitoring program are:

H_1: It is operationally feasible to operate the Elko Dam headpond within a 15 cm range during the non-freshet period.

H_2: Increased water depth over side channel sinkholes will increase the total volume of water infiltrating the side channel sinkholes.

*Note: H_2 was originally proposed in the Terms of Reference. However, this hypothesis could not be confirmed nor refuted within the scope or budget allocated and would be extremely difficult to test. An alternate methodology is described.

H_3: It is more cost-effective to implement operational changes in the Elko Dam headpond than reconfigure the side channel containing the sinkholes to maintain the desired water depth over the sinkholes.

2.0 Methodology

The methodology used during the study period (April 01, 2006 to December 31, 2008) to address the management questions and hypotheses for this study is divided into five components:

2.1 Operational Assessment

As a result of the Water Use Plans, members of the consultative committee had requested a review of the ability to manage headpond water levels within a closer tolerance range of the maximum normal operating level than currently exists. An overview assessment was conducted in 2007 to determine the feasibility and costs of reducing the range of headpond operation from 30 cm to 15 cm when the flashboards are installed.

This included, but was not necessarily limited to, the consideration of the following:

a) dam safety and integrity,
b) implications for power generation potential of the facility,
c) required maintenance/operational considerations; and,
d) practical feasibility and capital costs of operating the headpond within the reduced allowable range of elevation.

An operational assessment was conducted to determine if the existing water level controller had the ability to achieve this reduced range. This included an equipment review to determine if the current governors' control equipment was capable of achieving these tolerances, while taking into consideration all operational constraints that BC Hydro may face (inflows, ice cover, flashboard or other dam issues, generating unit maintenance issues).

Hourly stage elevation data for the Elko headpond for each calendar year (2006, 2007, and 2008) were obtained from BC Hydro Power Records as a means to compare hourly headpond elevation to determine if benefits could be gained by upgrading the generating station governor control system to increase the total number of wetted days/year for the sinkhole area.

2.2 Topographic Field Survey

The primary objective of this work was to complete a total station topographic and bathymetric survey to map absolute elevations of key areas within the side channel as they related to the location of the sinkholes and water flow into the sinkholes. Topographic data and physical measurements were analyzed to assess:

- potential benefits of the reduced headpond range operation to aquifer recharge rate;
- how headpond levels and annual operations influence water levels in the side channel and over the sinkholes.

To ensure that there was mutual agreement on the location of the key sinkholes amongst interested Consultative Committee members and knowledgeable local citizens, a pre-survey field trip was carried on May 01, 2006, prior to the start of field data collection. BC Hydro's regional Natural Resource Specialist (Dean den Biesen) met on site with local Baynes Lake residents Stan Doehle and Harley Greenwood and contracted surveyor Bill Sproule of SEL Survey and Design Ltd. to identify and mark sinkhole locations.

A series of site control points (horizontal and vertical control) were established using a TOPCON RTK GPS (± 5 mm + 1 ppm horizontal, 15mm + 1ppm vertical) and were explicitly tied into the Geodetic Canada Benchmark 79C109 located near the town of Elko.

Raw topographic and bathymetric survey data generated from the survey were collected using a robotic Leica Total Station (model 1100 series; 1105 TCRA) with a published accuracy of ± 1mm + 3ppm, in combination with a LIDAR-based laser scanner (Optech ILRIS-3D) with a published accuracy of ± 4mm (Appendix 1).

AutoCAD™ software was used to post process and model the raw data which were also used to create detailed maps to support a preliminary design and cost estimate for a side channel re-contouring program. It was also noted that a precise level total station survey would be required to increase the accuracy of the closed loop repeatability survey, and that this would quadruple the total cost of completing the survey.

The ideal methodology for the field data collection component of this monitoring study would be to collect physical data under two different water levels within the Elko headpond. The conditions should reflect a) the current operational procedures (level maintained at 20 cm below top of the flashboards; 30 cm operating range) as well as those recommended by the Consultative Committee (15 cm operating range).

The objective of collecting raw physical data under two different water levels was to provide directly comparable data under each condition to support the assessment of effects of headpond operations on the extent of water coverage in the side channel and water depth/infiltration rates at individual sinkholes.

2.3 Design and Cost Estimate for Side Channel Re-contouring

Topographic survey data generated from field data collection in combination with other available information were used to support a preliminary design and cost estimate for a side channel re-contouring program. The functional design of the re-contouring program reflected the objective of maximizing the surface water infiltration rate/volume into side channel sinkholes during non-freshet periods. Cost estimates and design drawings for a side channel recontouring program are presented in Section 3.3 of this report. This cost estimate and design takes into account all expenditures associated with the planning, design, construction, and required follow-up survey/monitoring that will be associated with implementation of a physical work in lieu of an operational change in the headpond. Potential fisheries and wildlife impacts/benefits associated with type of physical works program are also identified and discussed in the section.

2.4 Baynes Lake Water Level Monitoring

A non-WUP recommendation to integrate some level of water monitoring in the Baynes Lake area was proposed and supported by the CC during the November 4 2003 meeting held in Cranbrook. This recommendation was brought in after it was realized that the proposed monitoring study for the Elko Water Use Plan was not connected to an operational change and, therefore, not eligible for funding based on criteria for Water Use Plan monitoring studies. Recognizing the lack of information about the correlation between the Elk River headpond and the groundwater table in and around the community of Baynes Lake, the Consultative Committee supported the idea that a water level monitoring study should be undertaken to try and address this data gap. Given the difficulty in monitoring the level of subterranean aquifer flows, it was decided to monitor the level of three water bodies thought to be influenced by the same aquifer supplying Baynes Lake residents.

Onset Computer Corporation ® HOBO U20 Water Level Loggers (Appendix 2) were installed in the Baynes Lake area from 2006-2008. Hourly pressure readings were recorded at Baynes Lake, Stan Doehle's Kettle Pond, and Surveyors Lake (Figure 1.1) from July to December 2006 and 2007 and from April to October 2008.

Water Level Loggers were installed in home-made stand pipes and fastened to 13 mm rebar embedded into the substrate of each of the three aforementioned water bodies. Measurement points were established at each site and a level (Can-Measure CM24 Automatic Level) on a tripod and levelling rod were used to ensure that each stand-pipe station had no movement and that the water level loggers did not experience any drift.

All pressure data were converted to reflect water levels and post processed using the Onset software Hoboware Pro Version 2.3.0.

2.5 Cost Benefit Analysis

All the components collected during the monitoring study were integrated and summarized to provide a recommendation and expected costs and benefit(s) of reduced headpond operations and of a side channel re-contouring project. A brief cost benefit analysis is provided in Results and Discussion section of this report.

3.0 Results and Discussion

The results from this monitoring study will be used by BC Hydro to establish better estimates of the benefits and feasibility of modified headpond operations or side channel re-contouring. These may in turn warrant further management actions on the issue. If further actions are warranted, the results from this monitoring study will used to support in part future recommendations (in the next WUP) for implementation of either modified headpond operations or a physical reconfiguration of the side channel containing the sinkholes.

3.1 Operational Assessment

The present Elko Dam governors are very old, slow to respond, inaccurate, have coarse controls, and were never designed to operate within a 15 cm tolerance range. Elko Generating Station governors may take minutes to settle when a command is sent and do not necessarily settle at the commanded elevation. The maintenance of precise headpond levels is not possible with the present governors' travelling range (M. Eidsness, pers. comm.). It would however be feasible to reduce the range of headpond operations from 30 cm to 15 cm when the flashboards are installed if the governors were replaced or upgraded with new digital models.

GE Energy manufactures a gate shaft digital control upgrade kit for the governor systems at Elko. Table 3.1 shows the conversion cost of upgrading each of the two units.

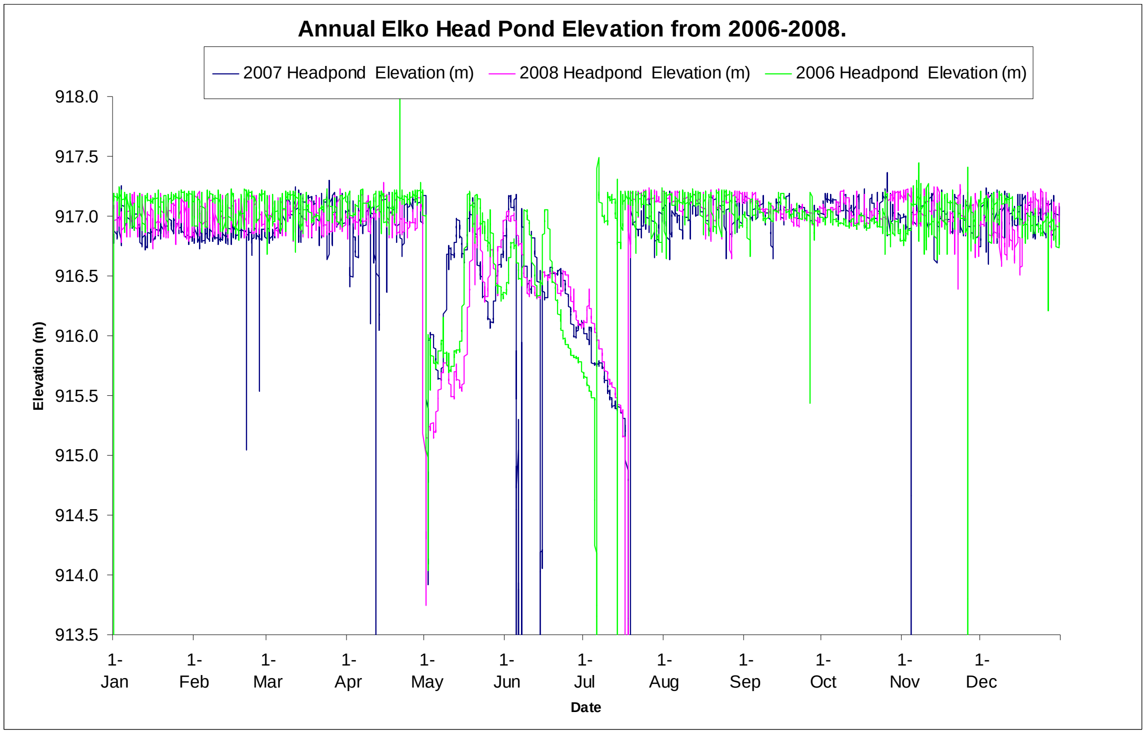
Table 3.1 Cost estimate for ELKO 505H Gatepro governor upgrade (based on 2008 quote).

Components/unit	$36,000.00	$72,000.00
Labour for install/unit	$25,000.00	$50,000.00
Recommended spare and optional parts/unit	$15000.00	$15,000.00
Total Cost		$137,000.00
Cost 5% contingency		$143,850.00

The total estimated cost to upgrade the governor system at Elko Generating Station is fairly significant for a facility that operates on a $300K/year operations and maintenance budget. Exploring options for an upgraded governor system through a complete facility redevelopment would be preferred over investing additional resources on an existing aged infrastructure (A. Laidlaw, pers. comm.).

Hourly headpond elevation readings for each year were supplied by BC Hydro Power Records (Figure 3.1). The graph shows that headpond elevations varied in the 30cm operating range. Based on the headpond elevation and hourly data provided by BC Hydro Power Records, it is hard to predict increased social and/or environmental benefits resulting from a reduced headpond operation range of 15 cm. Furthermore, many of the identified sinkholes are inundated during a large portion of each calendar year, based on the elevation data of the headpond (Table 3.2). It is estimated that reducing the headpond operating range to 15 cm would provide a maximum of up to 15% more water influencing the side channel sinkholes (see sections 3.2 and 3.4).

Figure 3.1 Mean hourly headpond elevations at Elko for 2006, 2007, and 2008.



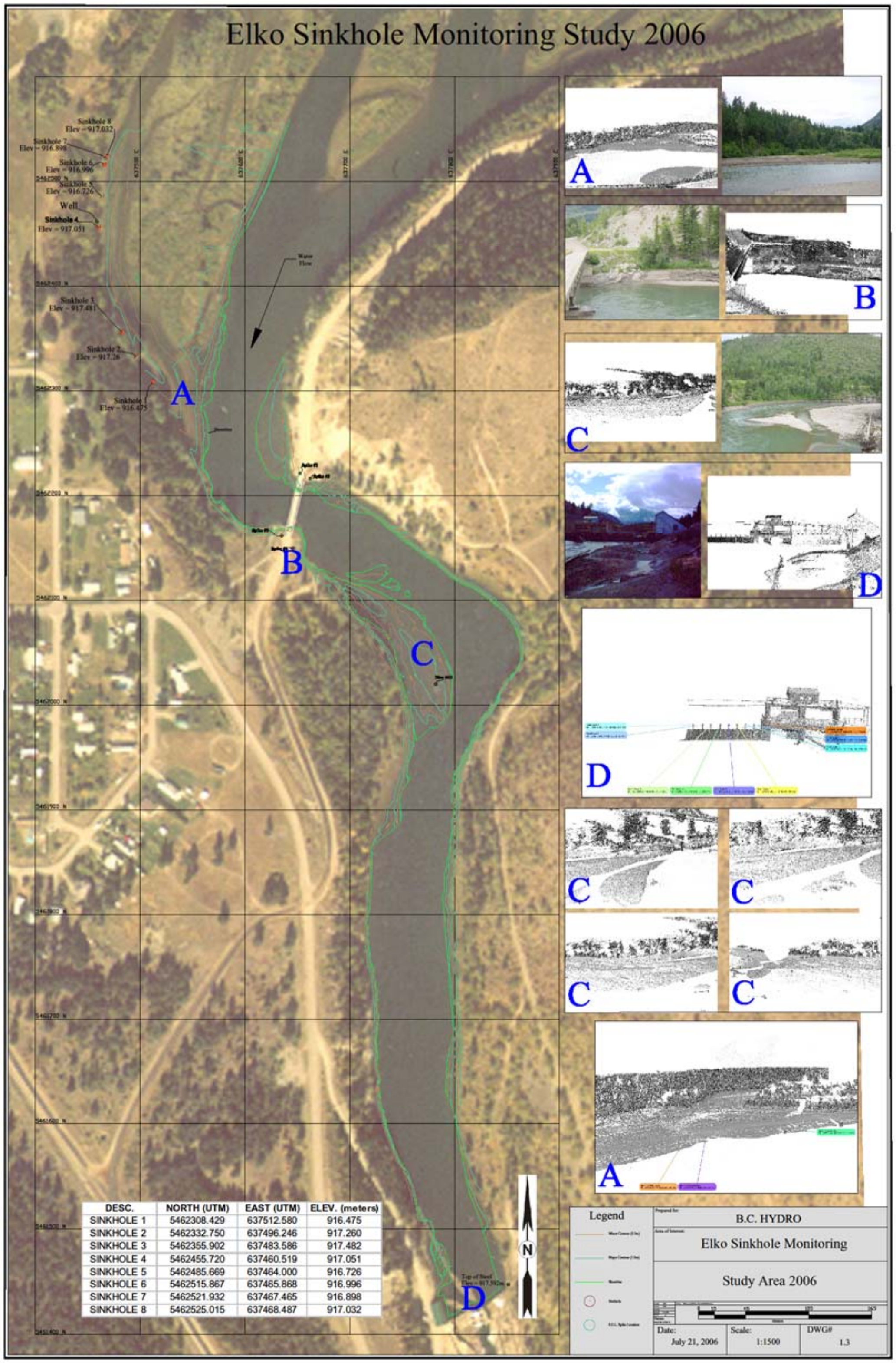
3.2 Topographic Field Survey

The elevation on each sinkhole surveyed was compared to headpond elevation levels obtained from BC Hydro Power Records. If the headpond elevation was higher than that of a sinkhole, the hole was assumed to be wetted. During freshet, water runs through the side channel and over the sinkholes wetting them. During this period, the flashboards are not installed so headpond levels are low though the sinkholes are wetted. To account for this, the average number of freshet days in a given year resulting in full inundation of the side channel sinkhole area was added to the number derived from the elevation comparison; An additional forty days was used in this study. Table 3.2 shows that, as expected, the lowest sinkhole (#1) has the most wetted days per year while sinkhole #3, the highest, has the least amount of time under water. The sinkholes range from being wetted 98% of the time on average over the three years to 11% depending on their elevation. The overall average wetted time across the sinkholes and years is 56%.

Table 3.2. Sinkhole locations, elevations, and number of days wetted per year.

Description	North (UTM)	East (UTM)	Elevation (m)	2006 (days/yr)	2007 (days/yr)	2008 (days/yr)
Sinkhole 1	5462308.429	637512.58	916.475	364	357	353
Sinkhole 2	5462332.75	637496.246	917.26	41	40	40
Sinkhole 3	5462355.902	637483.586	917.482	40	40	40
Sinkhole 4	5462455.72	637460.519	917.051	197	130	163
Sinkhole 5	5462485.669	637464	916.726	354	335	336
Sinkhole 6	5462515.867	637465.868	916.996	246	183	220
Sinkhole 7	5462521.932	637467.465	916.898	320	259	303
Sinkhole 8	5462525.015	637468.487	917.032	212	149	184

Figure 3.2. Elko headpond, Elk River side channel, and sinkhole locations.
NB See Appendix 3 for larger scale original drawing

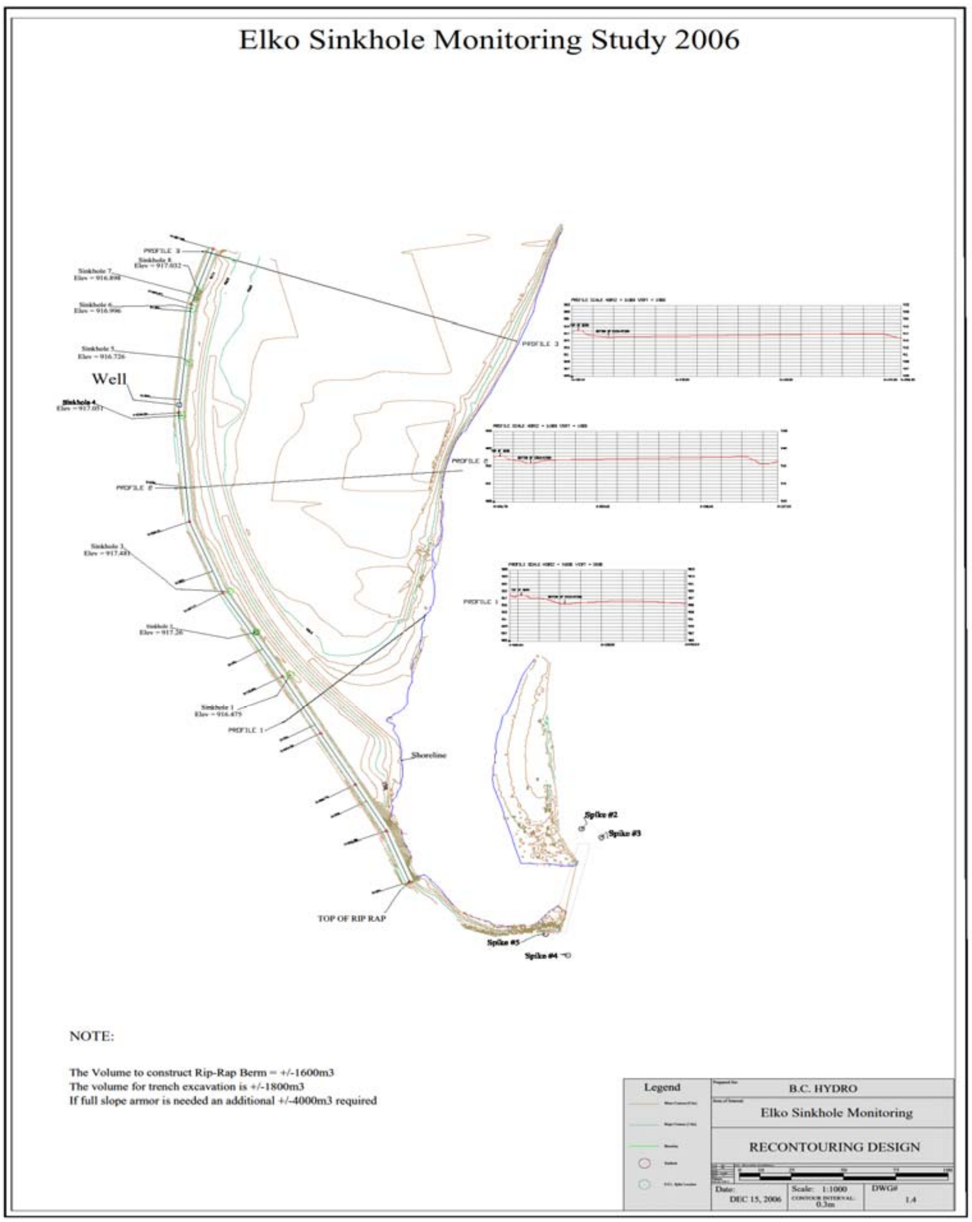


DESC.	NORTH (UTM)	EAST (UTM)	ELEV. (meters)
SINKHOLE 1	5462308.429	637512.580	916.475
SINKHOLE 2	5462332.750	637496.246	917.260
SINKHOLE 3	5462355.902	637483.586	917.482
SINKHOLE 4	5462455.720	637460.519	917.051
SINKHOLE 5	5462485.669	637464.000	916.726
SINKHOLE 6	5462515.867	637465.868	916.996
SINKHOLE 7	5462521.932	637467.465	916.898
SINKHOLE 8	5462525.015	637468.487	917.032

3.3 Design and Cost Estimate for Side Channel Re-contouring

A design and cost estimate were prepared to implement a side channel re-contouring option as a non-operational alternative to reducing the current headpond operating range during the non-freshet period. This option, shown in Figure 3.3, involves lowering the invert/outlet of the existing side channel , reducing the existing channel slope, and smoothing the exit of the channel to try and reduce the scour and sediment deposition potential.

Figure 3.3. Proposed side channel recontouring design. See Appendix 4 for original



The duration and velocity of varying flows over the years has resulted in localized erosion within the channel and has also accounted for deposition of sands and silts near the outlet of the side channel . Based on site observations, once the sand has been washed away, coarse gravels remain on the bar surface. Review of sediment transport information and permissible flow velocities resulted in the selection of the following channel design.

An estimated 2,000 m^3 of material would have to be excavated and relocated to a suitable waste area. Riprap armour is proposed on both the west and east margins of the side channel at the confluence with the mainstem Elk River. Using the Ministry of Transport riprap sizing methodology, the proposed riprap for a side channel slope of this nature would be capable of withstanding river flow velocities of 3.6 to 4 m/s.

Depending on the duration and magnitude of future Elk River flows, additional maintenance in areas of the side channel may be required from year to year. It is anticipated that in the future a stable backflow channel will form for the normal range of flows experienced in the Elk River. Should these normal flows be exceeded (primarily during the freshet period), additional movement of side channel materials can be expected. The annual maintenance for this back channel recontouring option is expected to be very low since the design accounts for freshet (average of 40 days per year).

Estimated supervision costs, engineering/design and survey costs, construction costs, equipment and time estimates for this recontouring option are shown in Table 3.3. The contingency percentages were selected based on past experiences of similar projects initiated by BC Hydro on other river systems within the Columbia Basin region. The cost estimate is based on information available to date and only concerns probable costs for budgetary purposes and a cost benefit analysis (Section 3.5). Actual costs depend on many factors which can change with time, including site and market conditions at the time of construction.

Table 3.3. Estimate of probable costs of recontouring Elk River side channel (based on 7 days of site work).

Task Description	Cost
Environmental Impact Assessment/Permitting	\$5,000
Engineering Suppport/Design	\$8,000
Equipment Mobilization/Demobilization	\$15,000
Temporary Road Construction	\$3,000
Construction	\$20,000
Transportation/Relocation of spoil material	\$5,000
On Site Supervision[1]	\$9,800
Environmental Monitoring/Remediation	\$7,000
Sub Total	**\$72,800**
Contingency (15%)	\$10,920.00
Total (excluding GST.)	**\$83,720**

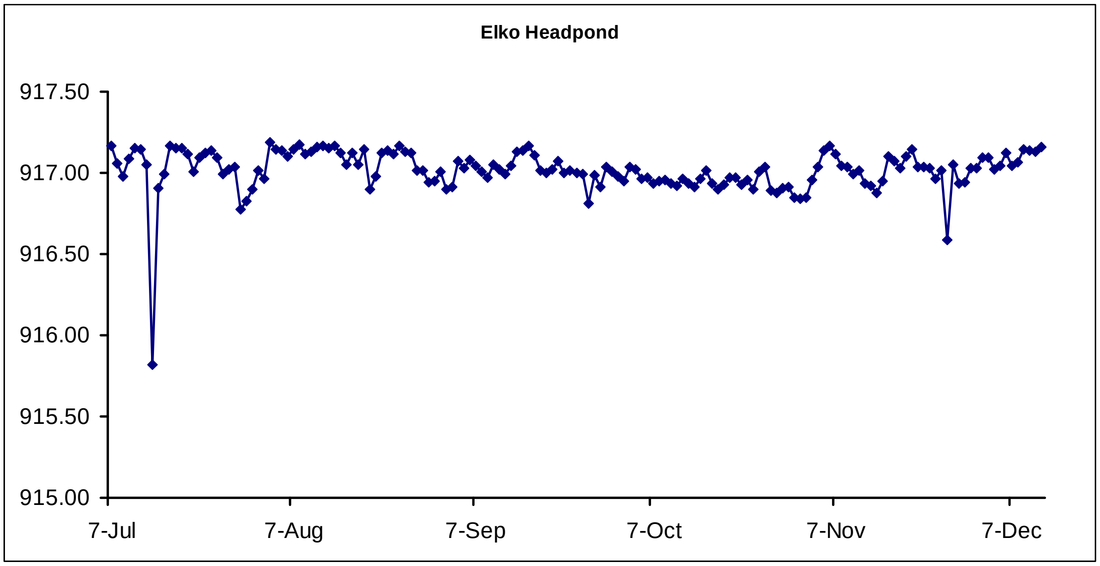
Notes:
[1] includes construction contract administration, survey control and survey documentation of completed works.

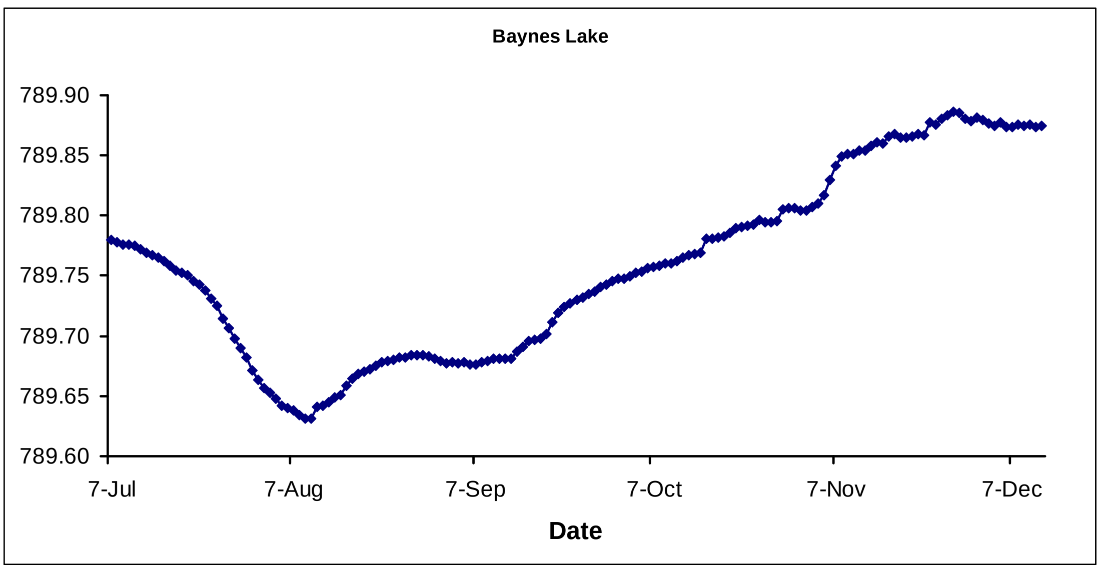
There is a diverse assemblage of wildlife found in the vicinity of the Elko dam because the area encompasses a diverse array of habitat types including low elevation forested slopes, a deeply incised canyon, open range land, cottonwood riparian forest, and wetland meadows (Robertson Environmental 2002). The wetland area (sinkhole side channel area) provides critical riparian habitat to a number of ungulate, amphibian, reptile, and bird species (Pandion Ecological 2005). While a potential recontouring option may be viewed as favourable for aquatic species by reducing or eliminating the fish standing potential associated with maintenance activities and Elk River inflow reductions, the potential impacts to other terrestrial and aquatic species are unknown. Should a recontouring option be selected, it is recommended that a more intense wildlife review be initiated to identify and mitigate all the impacts associated with a physical works option of this nature.

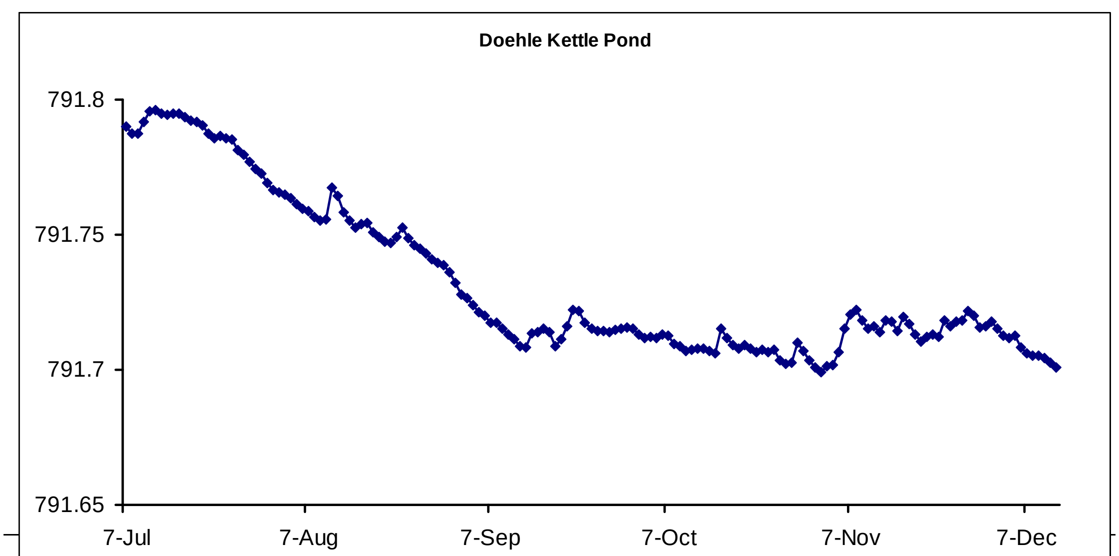
3.4 Water Level Monitoring

Hourly water levels were collected at Baynes Lake and Stan Doehle's Kettle Pond from July 07 to December 12, 2006. The daily mean level was compared to the daily mean level for the Elko headpond for the same time period and is shown in Figure 3.4. In general, a relationship between the Elk River headpond and the water levels in and around the community of Baynes Lake could not be established from the collected water level data.

Figure 3.4.1 Mean daily water level readings for July 07, 2006 to December 12, 2006.

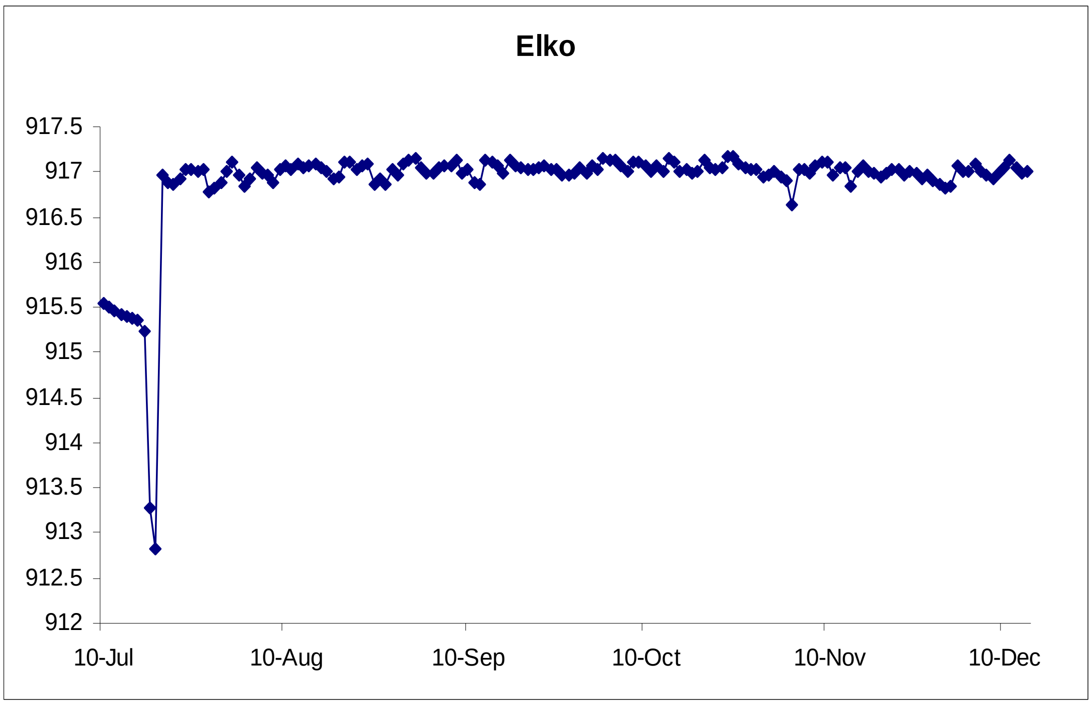


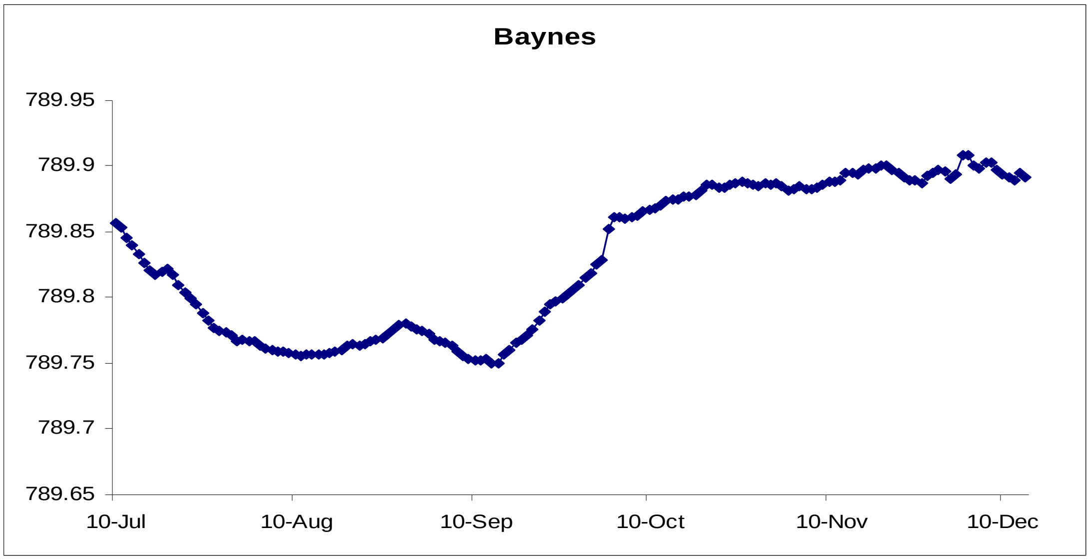


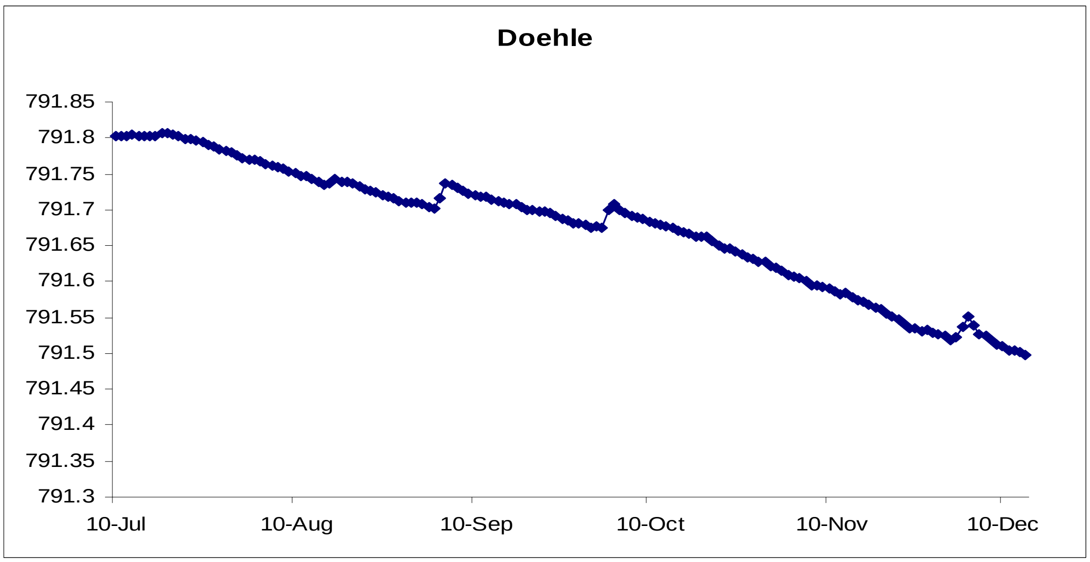


In 2007 hourly water level data was collected at Baynes Lake, Stan Doehle's Kettle Pond and Surveyor's Lake from July 10 to December 14 (fig 3.4.2). Similar to 2006, when those levels are compared to the hourly Elko headpond reading for the same time period, there are no apparent patterns developing that would suggest a relation between rate of change. The spike in July at Elko is when the flashboards were installed. The winter 2007 data sets are not presented in this report as ice cover and increasing water levels throughout the winter period caused the standpipes to shift and compromised the accuracy of the data collected.

Figure 3.4.2. Daily mean water level readings for July 10, 2007 to December 14, 2007.




Baynes
789.95
789.9
789.85
789.8
789.75
789.7
789.65
10-Jul
10-Aug
10-Sep
10-Oct
10-Nov
10-Dec


Doehle
791.85
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10-Jul
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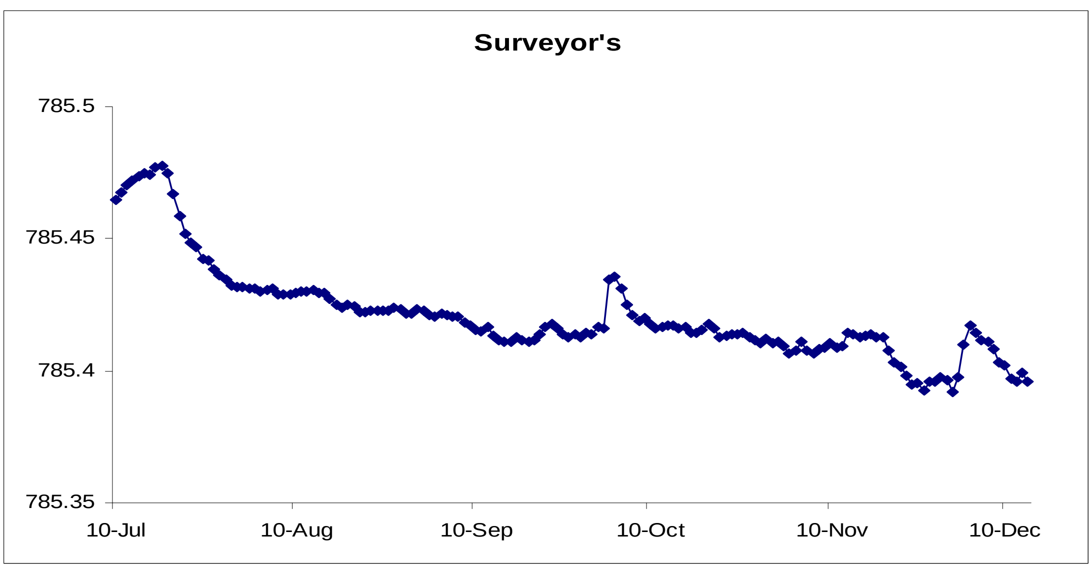
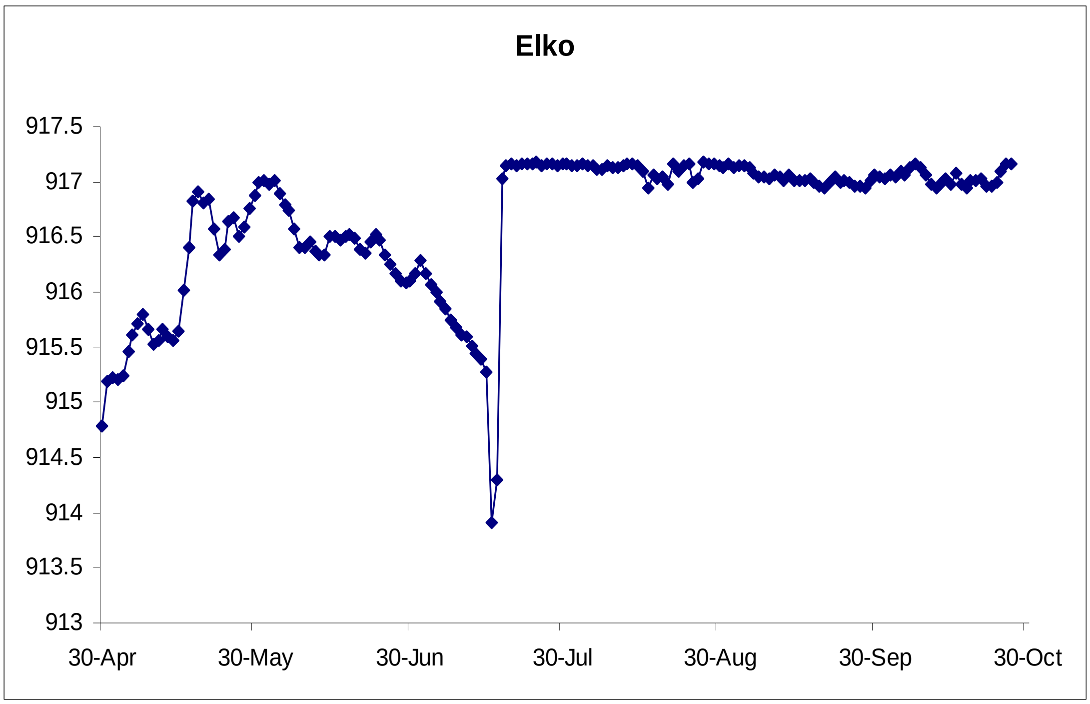
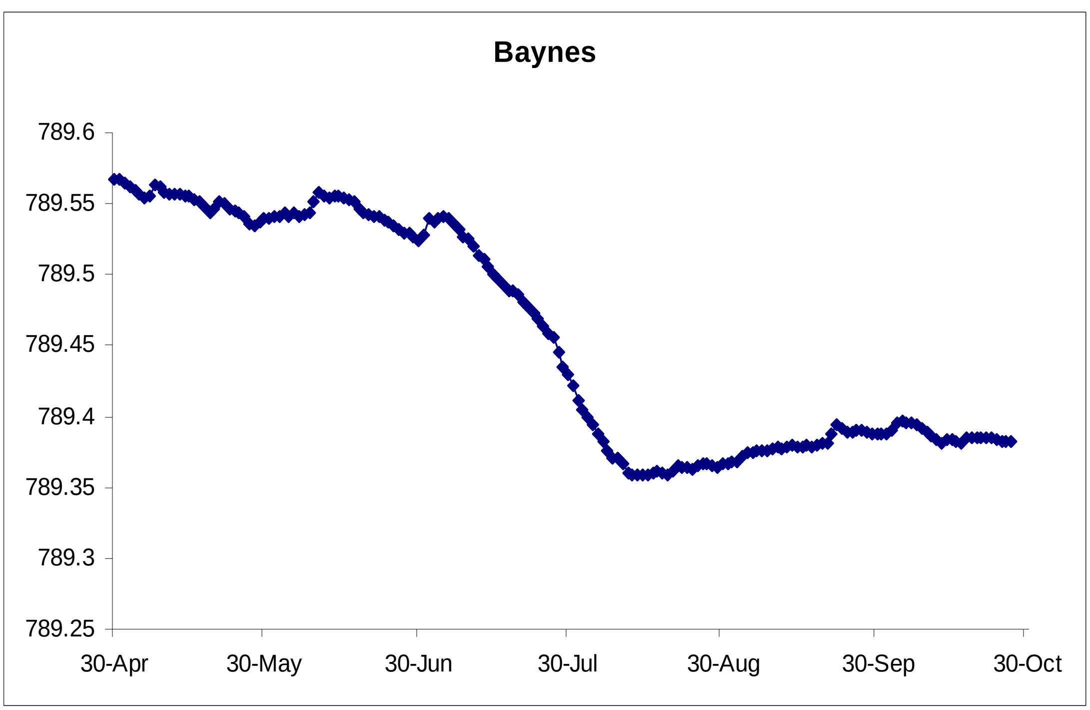
10-Dec

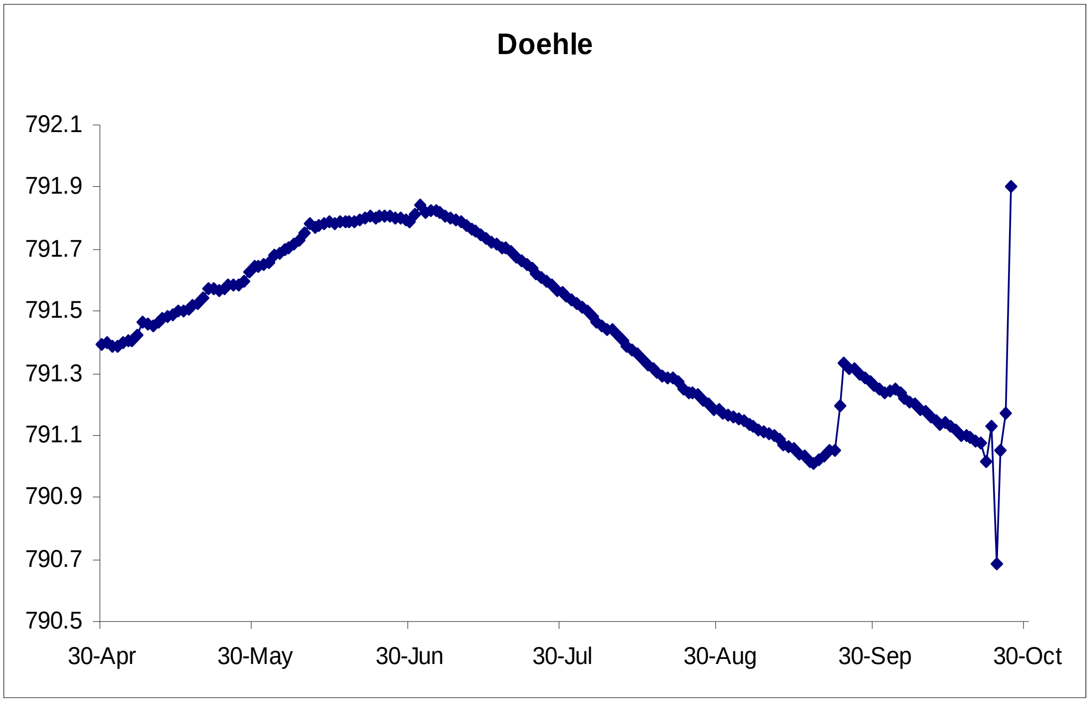

Surveyor's
785.5
785.45
785.4
785.35
10-Jul
10-Aug
10-Sep
10-Oct
10-Nov
10-Dec

In 2008 hourly water level data were collected at Baynes Lake, Stan Doehle's Kettle Pond and Surveyor's Lake earlier on from April 30 to October 27. Similar to the previous years, when daily means were compared to the daily mean Elko headpond reading for the same time period, there are no apparent patterns developing that would suggest a relation between rate of change. The spike in Elko water levels in July is due to flashboard installation.

Figure 3.4.3. Daily mean water level readings for April 30, 2008 to October 27, 2008.






Doehle
792.1
791.9
791.7
791.5
791.3
791.1
790.9
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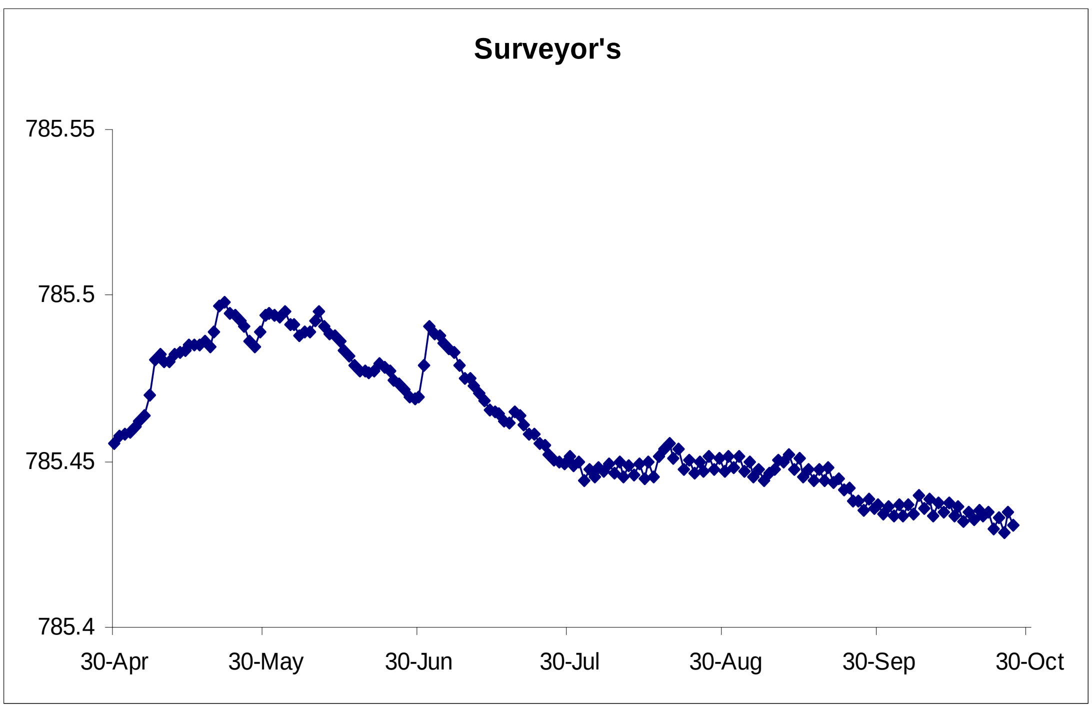
790.5
30-Apr
30-May
30-Jun
30-Jul
30-Aug
30-Sep
30-Oct


Surveyor's
785.55
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785.45
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30-Apr
30-May
30-Jun
30-Jul
30-Aug
30-Sep
30-Oct

Monitoring started earlier in 2008 than in previous years in an attempt to capture more of the spring-early summer period and to monitor what was predicted to be a “below normal” or “dry” year. If water levels were linked directly to Elko headpond elevations one would expect them to refill (or increase) once the flashboards went in around July 16.

Water level patterns for each of the monitoring sites stayed relatively flat or increased in the spring-early summer period and declined in the summer. Water levels did not recover throughout the late summer-early fall period, which may be attributed to the drier than normal conditions experienced for the summer and fall of 2008.

3.5 Cost Benefit Options

It is recommended that neither a reduced headpond operation nor a large scale side channel re-contouring project be considered by BC Hydro. As outlined in Section 3.0 of the report, both options are expensive for a facility that generates very little revenue annually. Without supporting data indicating a direct link between the Elko headpond operations and the water levels monitored in the Baynes lake community, it is even more difficult to provide a financial justification for either option.

4.0 Summary and Recommendations

Each management hypothesis is addressed in turn below.

H_1: It is operationally feasible to operate the Elko Dam headpond within a 15 cm range during the non-freshet period.

It is not possible to operate the headpond within a 15cm range with the current equipment at Elko Dam. To operate within this range, extensive upgrades would be required that are cost prohibitive.

H_2: Increased water depth over side channel sinkholes will increase the total volume of water infiltrating the side channel sinkholes.

This hypothesis was originally proposed in the Terms of Reference. However, it could not be confirmed nor refuted within the scope or budget allocated and would be extremely difficult to test as actual infiltration rates could not be linked to groundwater levels. There was no method within scope or budget that could measure the actual amount of water going into each sinkhole and if it did, where that water ended up. An alternate methodology to measure lake levels suggested to be influenced by groundwater and the headpond area sinkholes was employed. No relationship could be established between Elko Headpond levels and wetted sinkholes to the water levels in the monitored areas.

H_3: It is more cost-effective to implement operational changes in the Elko Dam headpond than reconfigure the side channel containing the sinkholes to maintain the desired water depth over the sinkholes.

Both of these options as described in methodology are cost prohibitive at this time.

It should be noted, that while the focus of the non-WUP commitment was to monitor water levels in the Baynes Lake area, the study did not actually monitor subsurface groundwater but rather water bodies that were thought to be influenced by groundwater aquifer recharging. This methodology was also used as a proxy for hypothesis 2 as actual infiltration rates of the sinkholes was impossible to quantify. In order to support or discount the suggestion that water passes through the sinkholes and supplies groundwater to the wells of Baynes Lake residents, one would have to be able to trace the water along its entire path. Even if the water did reach the wells in the Baynes lake community, it could take anywhere from ninety days to seven years to do so (insert ref where this comes from) so a correlation would be further compounded.

Despite the lack of scientific support in this and previous studies (Boyer 1992, Johanson 1976), there is long standing anecdotal support from several area residents that headpond levels influence the groundwater availability in the Baynes Lake community. Because of this, BC Hydro representatives attended a meeting on 22 September 2009 with members of the Sinkhole Committee and the Comptroller of Water Rights to discuss a draft version of this report. At this meeting the committee members informed that many of the area residents were satisfied with the water supply over the three year period the monitoring occurred. Therefore, BC Hydro agreed to endeavor to continue to operate the headpond levels in a similar manner into the future recognizing that maintenance or dam safety issues may prevent these optimal levels from occurring. That is, when possible, flashboards will be installed as soon as possible after freshet and headpond levels maintained within the 30cm range to operate the headpond at its maximum level for as much of the year as possible.

The Committee also made a request that a variation of the side channel re-contouring proposal be considered. They proposed that at a time when suitable equipment is on site, a small amount of material be removed from the channel that is acting as a berm. This proposal is much reduced in scope and would only involve a day or two of equipment time. Although it is not clear what effect this will have on sinkhole infiltration or groundwater supply, BC Hydro will conduct this work in 2010 under Committee supervision.

Though this program resulted in more data and understanding of the historic issue, the relationship between water levels at the headpond and within the side channel and available groundwater at Baynes Lake is still unclear.

5.0 Literature Cited

Clague, J.J. (1973). Late Cenozoic Geology of the Southern Rocky Mountain Trench, British Columbia. Ph. D. Thesis. Department of Geological Sciences, University of British Columbia.

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Personal Communications

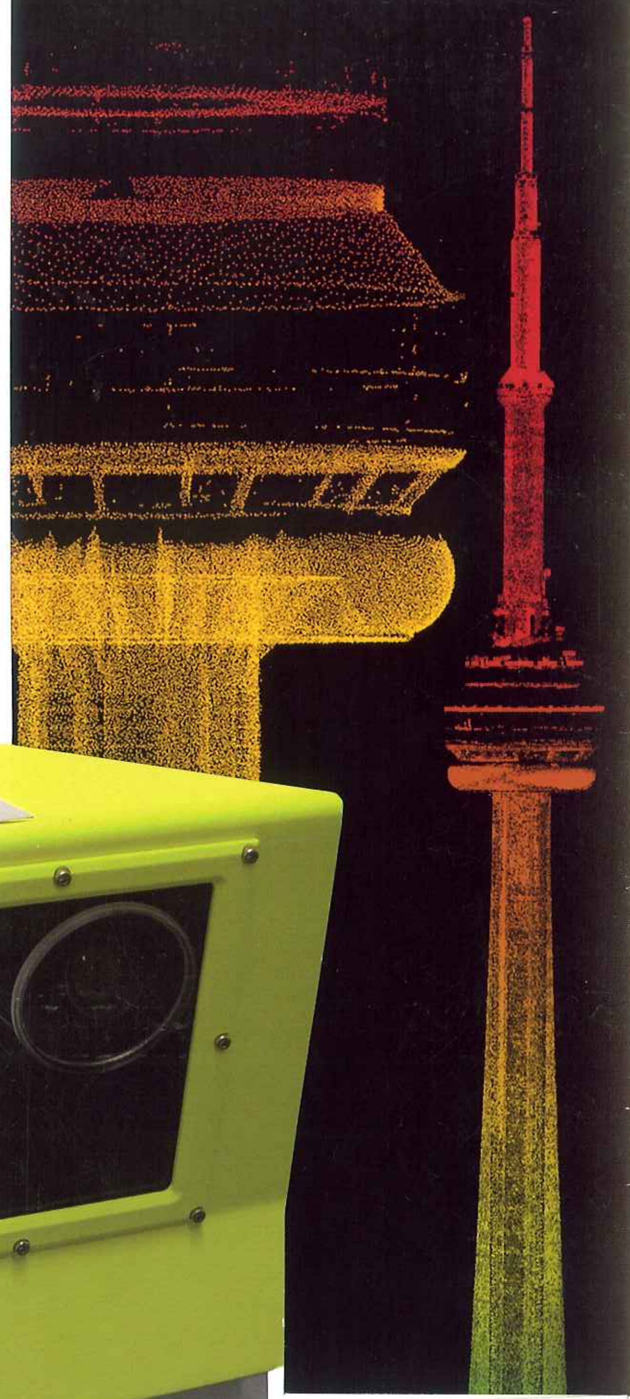
Al Laidlaw, Elko Generating Station Plant Manager, BC Hydro, Revelstoke, BC

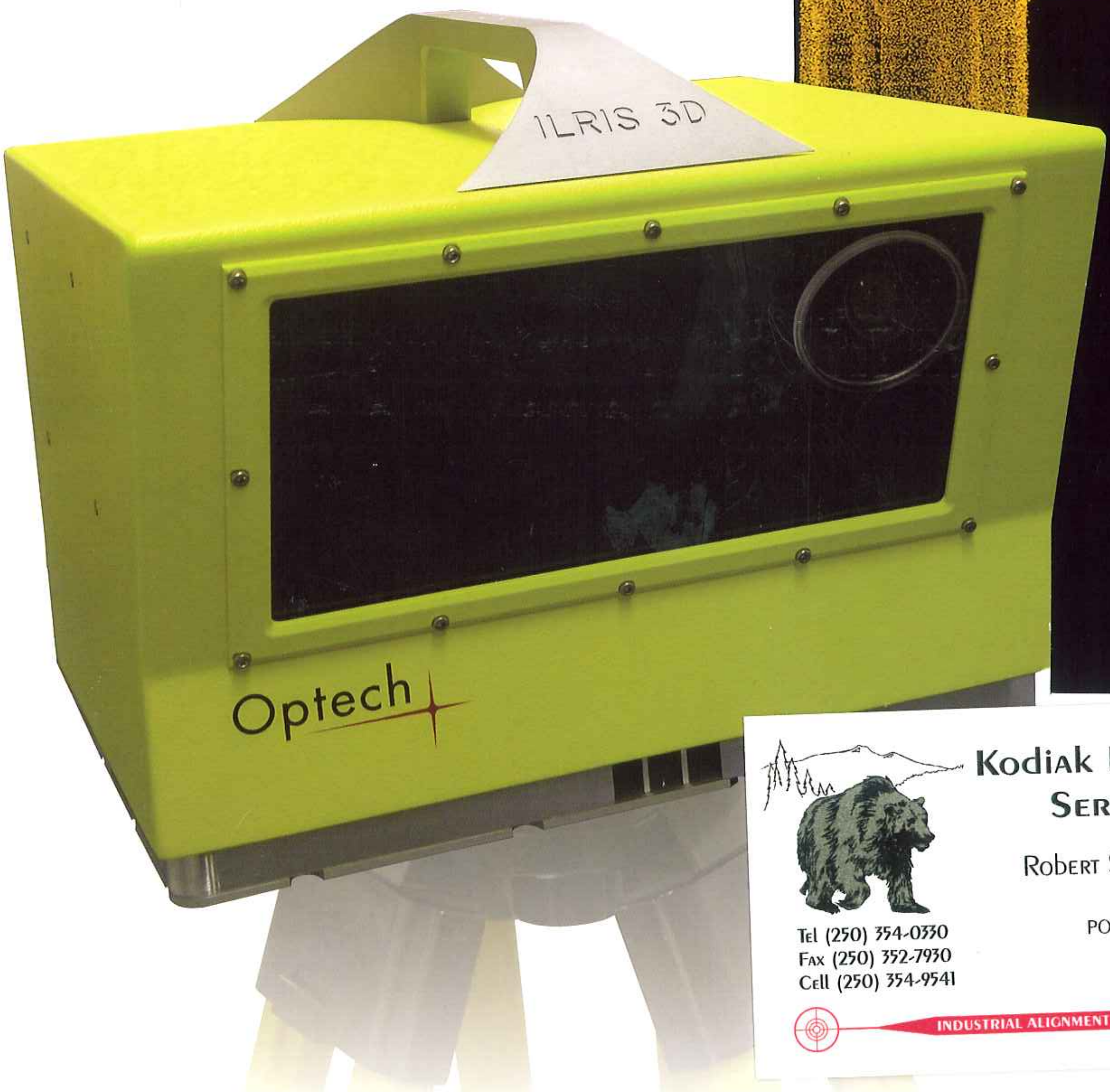
Mitch Eidsness, CPC Field Manager, BC Hydro, Cranbrook, BC

Appendix 1

Optech

ILRIS-3D





Kodiak Measurement Services Inc.

Robert Simmerling, P.Eng.

Tel (250) 354-0330
Fax (250) 352-7930
Cell (250) 354-9541

PO Box 192, Nelson, BC V1L 5P9
www.kodiakmeasurement.com
kodiakmeasurement@telus.net

INDUSTRIAL ALIGNMENT SPECIALISTS

CAPTURE EVERY DIMENSION

i3D

ILRIS-3D: Intelligent Laser Ranging and Imaging System

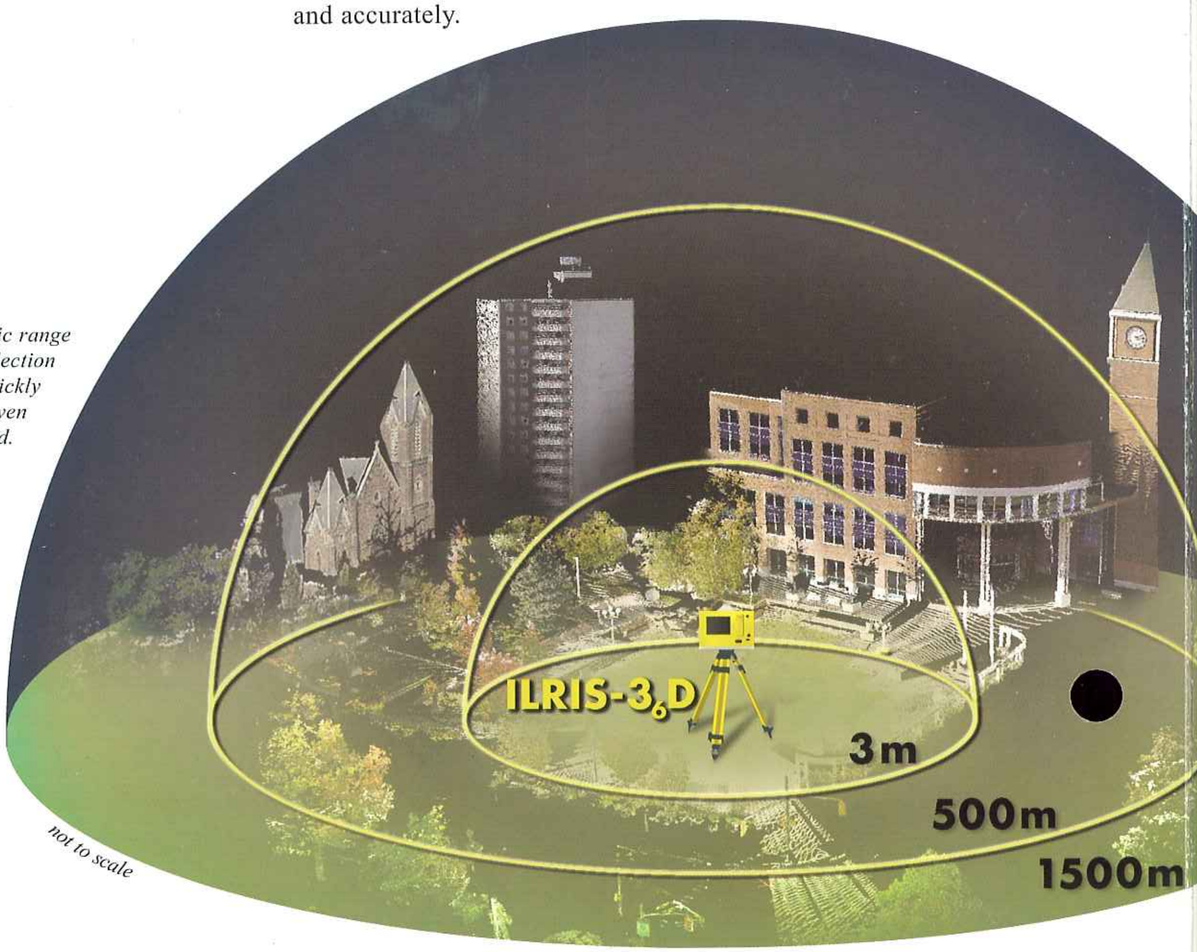
Optech's ILRIS-3D is a complete, fully portable, laser-based imaging and digitizing system for the commercial survey, engineering, mining and industrial markets.

A compact and highly integrated package with digital image capture and sophisticated software tools, ILRIS-3D is a 21st-century solution that addresses the needs of commercial users. ILRIS-3D is field-ready and requires no specialized training for deployment. About the size of a motorized total station, with an on-board 6 megapixel digital camera and large-format LCD viewfinder, ILRIS-3D has a visual interface similar to that of a digital camera. Field deployment is made extremely efficient by ILRIS-3D's high data rate and large dynamic range - from 3 m up to 1,500 m. ILRIS-3D is completely eyesafe in all modes of operation, even when its invisible beam is viewed directly through binoculars.

ILRIS-3D is deployed by a single operator. The modular design ensures that all functionality is available, making operation as easy as possible. Setup is rapid and simple - no leveling required - and the system is controlled via a wireless handheld PDA or laptop. The target area and scan status are displayed locally on screen, and data is written directly to removable media. Measurement area and spot density are user definable.

ILRIS-3D is designed for rugged field use, based on Optech's experience in designing and manufacturing laser-based industrial level monitors, object positioners and mining equipment. It is rated for operation from 0° C to 40° C, and is weatherproof for use outdoors. The system's Class 1 eyesafety rating, large dynamic collection range and compact size all ensure that difficult surveys can be completed quickly, safely and accurately.

The large dynamic range ensures the collection of accurate data quickly and efficiently - even when accessibility is limited.



Introducing the ILRIS-3$_6$D

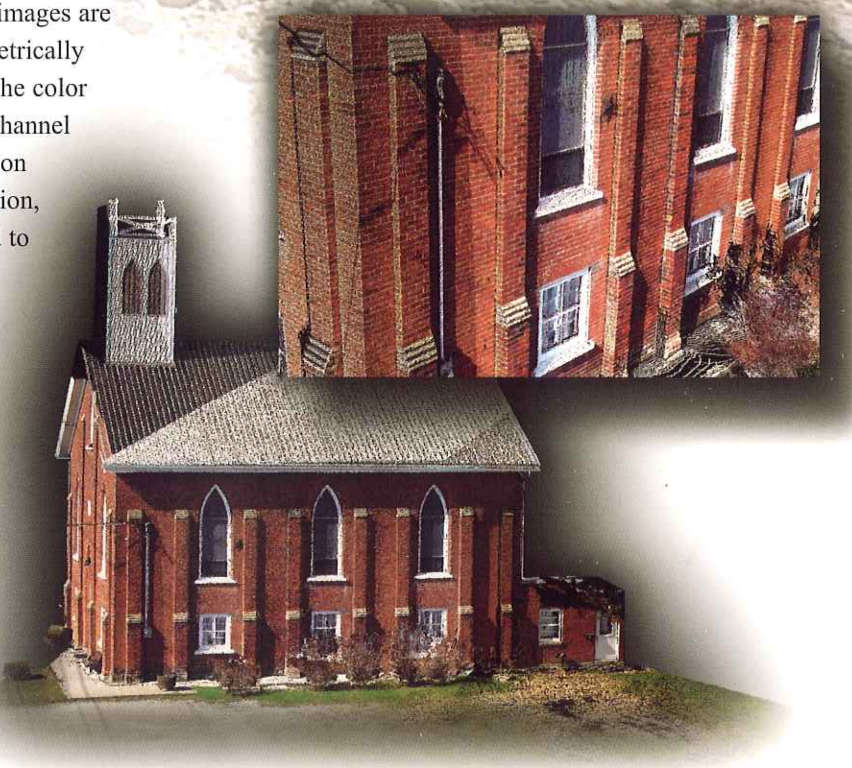
ILRIS-3$_6$D offers all of the capability of ILRIS-3D while providing the added functionality of a 360° x 360° field of view. ILRIS-3$_6$D comes equipped with a fully motorized panning and tilting base that allows for seamless coverage of large areas. The base is operationally integrated with the scanner and is controlled seamlessly through scanner control software.

An accurate on-board encoder ensures that the resulting data sets are seamless and accurately aligned. When the extended field of view is not required or when size and weight are of paramount importance, the user can easily remove the base and operate the scanner with a 40° x 40° field of view, with no loss of accuracy or functionality.

The ILRIS-3$_6$D has an industry leading 360° x 360° field of view

Color Channel: True Color Point Clouds

An on-board 6 megapixel camera allows for more accurate targeting, while the resulting images are used to automatically generate a geometrically accurate 3D point cloud that includes the color of each measurement. Optech's color channel technology provides seamless integration between the on-board sensors. In addition, other external imagers can be mounted to the system and the information can be added seamlessly and automatically to the resulting 3D data set.



Automated true color point clouds shown with the revolutionary new color channel option.

Power Options

ILRIS-3D Portable Field Power

The availability and reliability of field power in remote locations are key elements to efficiency that cannot be overlooked.

The ILRIS-3D battery/charging system shares the same technology that has been universally adopted worldwide by video and broadcast professionals.

Dual battery charger

Robust and Modular Battery System

- Two batteries provide scan time of approx. 2.5 hours
- Hot-swap capability, allowing the user to change batteries without interrupting scanner operation
- As many sets of two batteries that the user chooses can be used simultaneously
- Easily transportable, simple to set up and re-pack for transport
- Use anywhere in the world with universal 85-265 VAC, 50/60 Hz operation

Battery and holder

Economical Operation from Line AC

- Compact, rugged universal input voltage (85-256 VAC, 50/60 Hz) for operation where AC Mains voltage is available

AC power supply, shown with a penny

System Features

Eye safety

- Class 1 laser, eyesafe in all ranges, all conditions
- CDRH, US FDA and IEC Class 1

Product Approvals

ILRIS-3D carries Class 1 laser safety approval, as well as a CE marking. The unit has passed the most stringent tests for EMC (radiated and immunity), as carried out by an independent testing authority (Canadian Standards Association). The unit is also sealed for operation in wet and damp locations.

Sturdy backpack

Convenient and easy traveling case

Multi-Purpose Utility

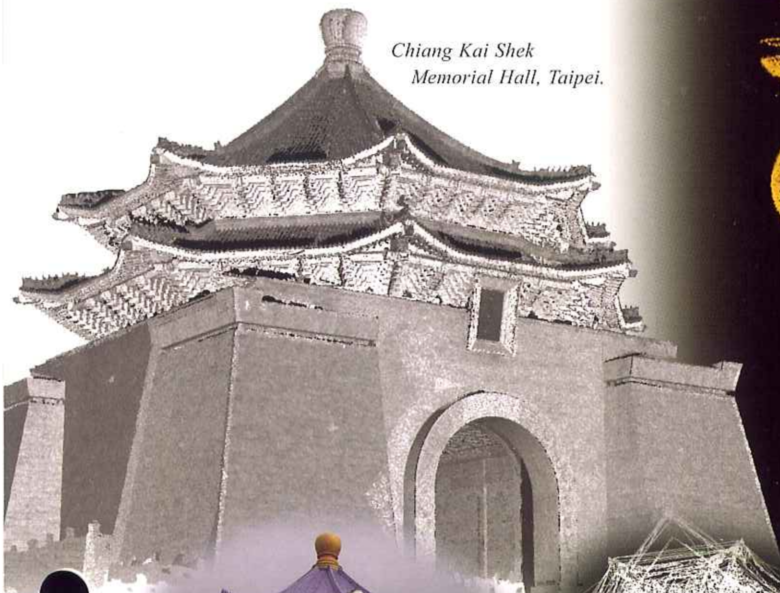
ILRIS-3D is the most versatile scanning system of its kind:

- Cross-deployable over a wide variety of applications and industries
- Convenient to use
- Quick to set up in any environment.

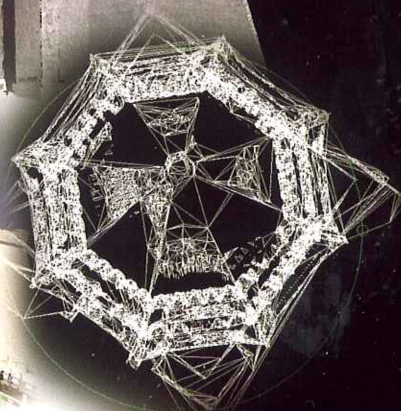
ILRIS-3D

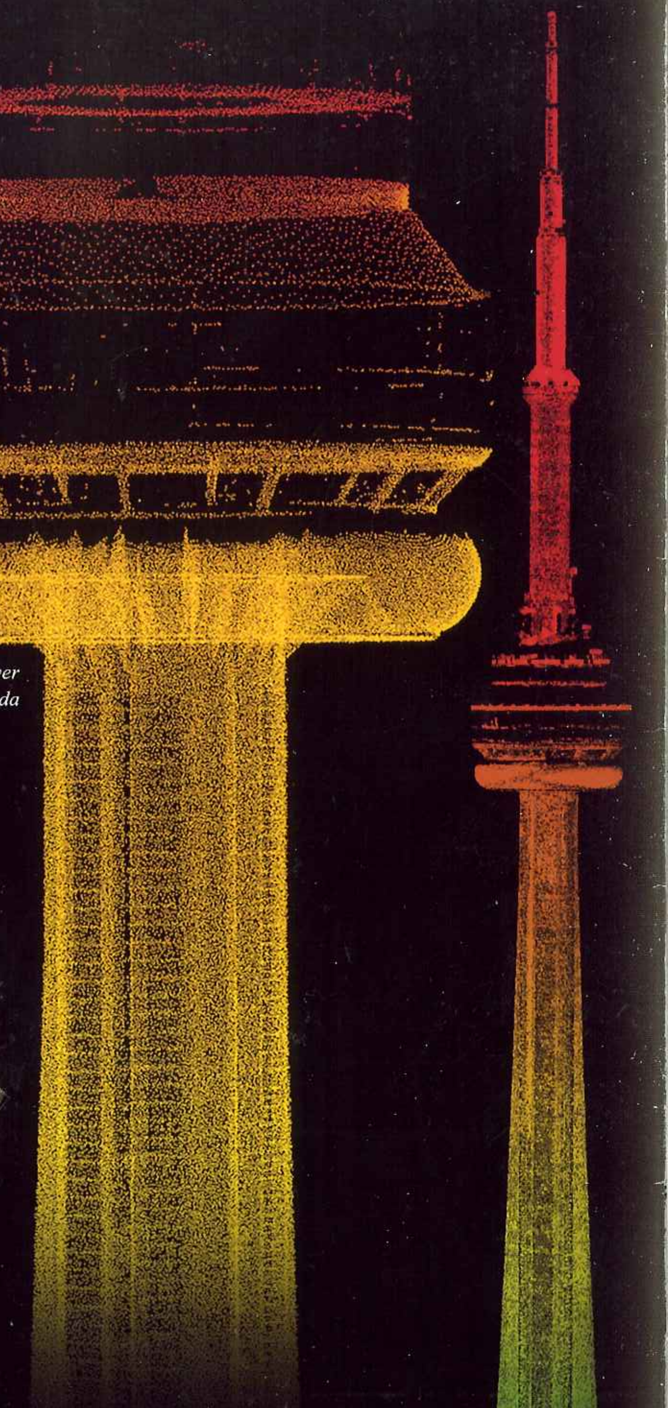
Finest Detail and Accuracy

A wealth of information on historical edifices can now be directly digitized, where range and accuracy limitations previously made this impossible or impractical. Millimetrically accurate polygonal models are rendered and exported in a variety of formats.



Chiang Kai Shek Memorial Hall, Taipei.





CN Tower Toronto, Canada

Above (clockwise): Solid model generated using PolyWorks® software from InnovMetric; wireframe model visualized using AutoCAD 2000; photo of survey scene.

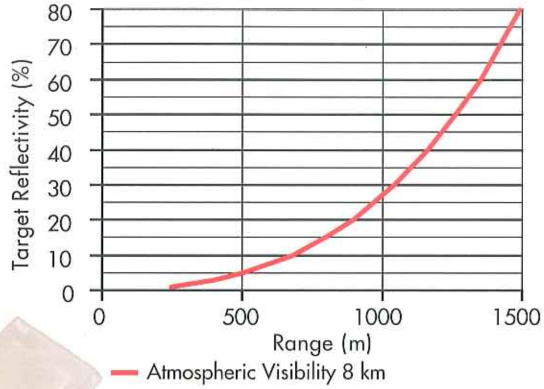
Industrial Grade Applications

ILRIS-3D offers quick conversion of scan data to CAD plan/elevation take-offs, facilitating rapid planning. All features such as utility location, road centerline and curb extents are accurately and completely located. Collateral data is also utilized in determining vegetation type, tree caliper size (and in some cases species), canopy volume, and more.

Survey scene and point cloud data of an intersection. Point cloud data courtesy: Northway-Photomap Inc.

ILRIS-3D Specifications

ILRIS-3D Range vs. Target Reflectivity



Performance

Dynamic scanning range

3 m - 1,500 m to an 80% target
3 m - 800 m to a 20% target
3 m - 350 m to a 4% target

Data sampling rate (actual measurement rate)	2,000 points per second
Beam divergence	0.00974°
Minimum spot step (X and Y axis)	0.00115°
Raw range accuracy*	7 mm @ 100 m
Raw positional accuracy*	8 mm @ 100 m
Laser wavelength	1,500 nm
Laser class (IEC 60825-1)	Class 1
Digital camera	Integrated digital camera, 6.6 megapixel (CMOS sensor) optional external camera
Scanner field of view (ILRIS-3_6D)	-20° through 90° (V) x 360°(H) -90° through 20° (V) x 360°(H)
Scanner field of view (ILRIS-3D)	40° x 40°

Physical Size

Scanner weight and physical size	13 kg, 320 (L) x 320 (W) x 220 (H) mm
Rotating base weight and physical size	8 kg, 300 (L) x 280 (W) x 127 (H) mm
Power supply and consumption	24 VDC, 75 W
Battery life (standard battery pack)	5 hours operation, hot-swappable for continuous operation
Data storage	Solid State, removable USB memory field interchangeable
External GPS and digital camera mounts	
Standard software	Data output to a variety of metafile and XZY coordinates, including active laser intensity photograph and digital photo

Environmental

Operating temperature	0°C to 40°C (for extended range, consult Optech)
Storage temperature	-20°C to 50°C

Eyesafety

Laser class	Class 1 laser product IEC 60825-1, US FDA 21 CFR 1040, Eyesafe in all modes of operation

*Note: All quoted accuracies are 1 Sigma, single shot, as performed under Optech test conditions. Details available on request.

All information is subject to change without notice.

Optech

100 Wildcat Road • Toronto, ON • Canada M3J 2Z9

Tel: [416] 661-5904 • Fax: [416] 661-4168

Web: www.optech.ca • Web: www.ilris-3d.com • Email: inquiries@optech.ca

Appendix 2

onset

CALIBRATION CERTIFICATE

LOGGER SERIAL NUMBER: 901205
CALIBRATION RESULT: PASSED

Report Number	901205_07_29_05_01
Certification Date	7/29/2005
Logger Type	HOBO Water Level Logger
Water Level Range	0 to 9m (0 to 30 ft)
Logger Part Number	U20-001-01
Logger Status	New
Full Scale Pressure Range	0 to 207 kPa (0 to 30 psi) Absolute
Calibrated Range	69 to 207 kPa (10 to 30 psi) Absolute, 0 to 40 °C

Onset Computer Corporation certifies that the pressure accuracy of the data logger listed above has been observed to be within its published pressure specifications. Onset Computer's calibrated reference instruments are traceable to NIST, and certification files are maintained at Onset Computer's corporate headquarters in Bourne, MA.

Test Equipment and Procedures

Pressure Regulator and Calibrator: TE1-9126 (Calibrated on 11/23/04)
Environmental Chamber: TE1-9125
Onset Calibration Software: D-9420-A
Onset Calibration Procedure: D-9421-A
Range of Applied Pressures: 69-207 kPa (10-30 psi) Absolute
Range of Applied Temperature: 0-40 °C (Nominal)

Test Data

Pressure (psia)	
Applied	Observed
14.999	14.994
20.998	21.004
28.999	29.003

Results

Specified Pressure Accuracy: PASSED

Typical: ± 0.1 %FS ± 0.21 kPa (± 0.03 psi)

Maximum: ± 0.3 %FS ± 0.62 kPa (± 0.09 psi)

Test Performed By: REC

Onset Computer Corporation

Tel: 508-759-9500

Sales: 1-800-LOGGERS

Fax: 508-759-9100

470 MacArthur Blvd.
Bourne, Massachusetts
02532 USA

Mailing: PO Box 3450
Pocasset, Massachusetts
02559-3450 USA

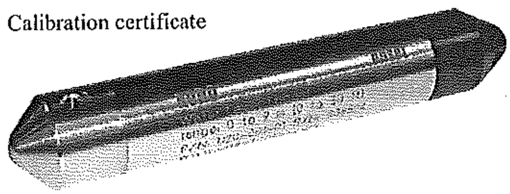
sales@onsetcomp.com

www.onsetcomp.com

HOBO® U20 Water Level Logger
(Part # U20-001-01)

Inside this package:

- HOBO U20 Water Level Logger
- Calibration certificate



Doc #8976-A, MAN-U20-001-01
Onset Computer Corporation

Thank you for purchasing a HOBO data logger. With proper care, it will give you years of accurate and reliable measurements.

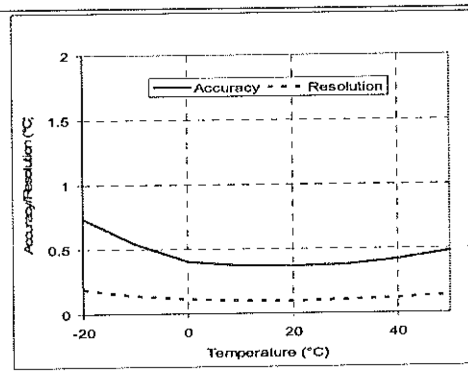
The HOBO Water Level Logger is designed to measure water level in wells, rivers, streams, and lakes. The logger uses a maintenance-free absolute pressure sensor and features a durable stainless steel housing and ceramic pressure sensor. The logger uses precision electronics to measure pressure and temperature. Using a reference water level, the HOBOware™ software automatically converts the pressure readings into water level readings. Furthermore, the software supports compensation for temperature, fluid density, and barometric pressure. The logger has enough memory to record over 21,700 combined pressure and temperature measurements.

The logger uses an optical USB communications interface (USB-Optic Base Station, part # BASE-U-3) for launching and reading out the logger. The optical interface allows the logger to be offloaded without breaking the integrity of the seals. The USB compatibility allows for easy setup and fast downloads.

A HOBOware™ software starter kit is also required for logger operation. Visit www.onsetcomp.com for compatible software.

Specifications

Pressure Sensor	
Operation range	0 to 207 kPa (0 to 30 psia); approximately 0 to 9 m (0 to 30 ft) of water depth at sea level, or 0 to 12 m (0 to 40 ft) of water at 3,000 m (10,000 ft) of altitude
Factory calibrated range	69 to 207 kPa (10 to 30 psia), 0° to 40°C (32° to 104°F)
Burst pressure	310 kPa (45 psia) or 18 m (60 ft) depth
Accuracy (typical error)*	0.1% FS, 2.1 cm (0.07 ft) water
Accuracy (maximum error)*	0.3% FS, 6.3 cm (0.21 ft) water
Resolution	< 0.02 kPa (0.003 psi), 0.21 cm (0.007 ft) water
Pressure response time 90%	< 1 second
Thermal response time (90%)†	Approximately 30 minutes in water to achieve full temperature compensation of the pressure sensor
Stability (drift)	0.3% FS, 6.3 cm (0.21 ft) maximum water per year (see "Recalibration" for information about stability)
* Absolute pressure sensor accuracy includes all temperature and hysteresis-induced errors. † Maximum error due to rapid thermal changes is approximately 0.5%.	
Temperature Sensor	
Operation range	-20° to 50°C (-4° to 122°F)
Accuracy	0.37°C at 20°C (0.67°F at 68°F), see Plot A
Resolution	0.1°C at 20°C (0.18°F at 68°F) (10-bit), see Plot A
Response time (90%)	3.5 minutes in water (typical)
Stability (drift)	0.1°C (0.18°F) per year
Logger	
Real-time clock	± 1 minute per month 0° to 50°C (32° to 122°F)
Battery	2/3 AA, 3.6 Volt Lithium, factory-replaceable
Battery life (typical use)	5 years with 1 minute or greater logging interval
Memory (non-volatile)	64K bytes memory (approx. 21,700 pressure and temperature samples)
Dimensions	2.46 cm (0.97 inches) diameter, 15 cm (5.9 inches) length; mounting hole 6.3 mm (0.25 inches) diameter
Weight	Approximately 210 g (7.4 oz)
Wetted materials	316 stainless steel, Viton® o-rings, acetyl cap, ceramic sensor
Shock/drop	Logger is sensitive to shocks. Handle with care and avoid any impact. Always use proper packaging when shipping the logger.
Logging interval	Fixed-rate or multiple logging intervals, with up to 8 user-defined logging intervals and durations; logging intervals from 1 second to 18 hours. Refer to HOBOware™ software manual.
Launch modes	Immediate start and delayed start
Offload modes	Offload while logging; stop and offload
Battery indication	Battery voltage can be viewed in status screen and optionally logged in datafile. Low battery indication in datafile.
CE	The CE Marking identifies this product as complying with all relevant directives in the European Union (EU).



Plot A

Accessories available

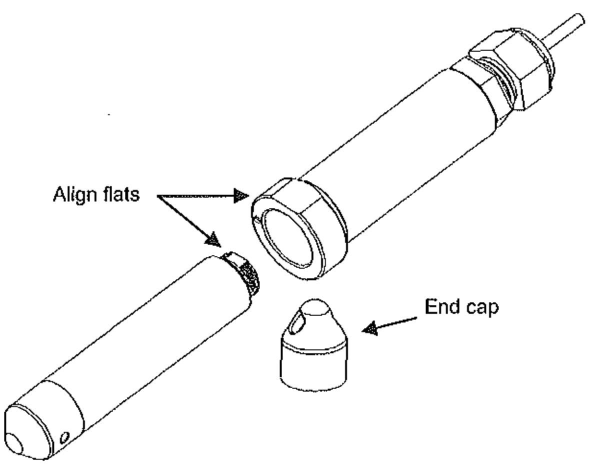
- 50-ft 1/16" Teflon®-Coated Stainless Steel Cable (Part # CABLE-1-50)
- 300-ft 1/16" Teflon®-Coated Stainless Steel Cable (Part # CABLE-1-300)
- Crimp sleeve for Teflon®-Coated Stainless Steel Cable (Part # CABLE-1-CRIMP)

Part #: MAN-U20-001-01, Doc #: 8976-C

Connecting the logger

The HOBO Water Level Logger requires an Onset-supplied USB-Optic Base Station (Part # BASE-U-3) to connect to the computer.

1. Install the logger software on your computer before proceeding.
2. Plug the base station cable into a USB port on the computer. If the base station has never been connected to the computer before, it may take a few seconds for the new hardware to be detected by the computer.
3. Unscrew the black plastic end cap from the logger by turning it counter-clockwise.
4. Insert the logger with the flat on the logger and the base station aligned. Gently twist the logger to be sure that it is fully seated in the base station. If the logger has never been connected to the computer before, it may take a few seconds for the new hardware to be detected by the computer.



5. Use the logger software to launch the logger.
6. You can check the logger's status, read out the logger while it continues to log, stop it manually with the software, or let it record data until the memory is full.

Refer to the software user's guide for complete details on launching, reading out, and viewing data from the logger, including multiple logging intervals and barometric compensation.

Important: USB communications may not function properly at temperatures below 0°C (32°F) or above 50°C (122°F).

Note: The logger consumes significantly more power when it is "awake" and connected to a base station. To conserve power, the logger will go into a low-power (sleep) mode if there has been no communication with your computer for 30 minutes. To wake up the logger, remove the logger from the base station, wait a moment, then re-insert the logger.

Note: The first time you launch the logger, the deployment number will be greater than zero. Onset launches the loggers to test them prior to shipping.

Protecting the logger

- **Important! Do not attempt to open the logger housing!** Unscrewing the stainless steel nose cone of the logger will cause serious damage to the pressure sensor and logger electronics. There are no user serviceable parts inside the case. Contact Onset technical support if your logger requires servicing.
- **This logger can be damaged by shock.** Always handle the logger with care. The logger may lose its calibrated accuracy or be damaged if it is dropped. Use proper packaging when transporting or shipping the logger.
- 316 stainless steel has good corrosion resistance, but **it can be damaged by contact with dissimilar metals or through crevice corrosion.** The logger should not be deployed in salt or brackish water, or the housing will eventually fail and water will destroy the electronics. If long-term deployment in salt water is required, place the logger in a sealed bladder containing a non-corrosive liquid. The pressure outside the bladder will be transmitted to the pressure sensor inside the logger. Always rinse the logger with fresh water after deployment in salt or brackish water.
- Check a materials-compatibility chart before deploying the logger in locations where untested solvents are present:
  - The logger is shipped with Viton® O-rings installed. Viton® has an excellent resistance to most solvents and is suitable for deployments in water that contain a mixture of most fuels, solvents and lubricants. However, the Viton® O-rings are sensitive to polar solvents (acetone, ketone), ammonia, and brake fluids.
  - The black acetyl cap is provided to help protect the communications window. Acetyl is resistant to most solvents, fuels, and lubricants.
  - The polycarbonate communications window is sealed as an additional barrier to water and dirt entering the logger housing.

Operation

A light (LED) in the communications window of the logger confirms logger operation. The following table explains when the logger blinks during logger operation:

When:	The light:
The logger is logging	Blinks once every one to four seconds (the shorter the logging interval, the faster the light blinks); blinks when logging a sample
The logger is awaiting a start because it was launched in Start At Interval or Delayed Start mode	Blinks once every eight seconds until logging begins

Sample and event logging

The logger can record two types of data: samples and events. Samples are the sensor measurements recorded at each logging interval (for example, the pressure every minute). Events are independent occurrences triggered by a logger activity, such as Bad Battery or Host Connected. Events help you determine what was happening while the logger was logging.

The logger stores 64K of data, and can record over 21,700 samples of pressure and temperature.

Barometric Compensation

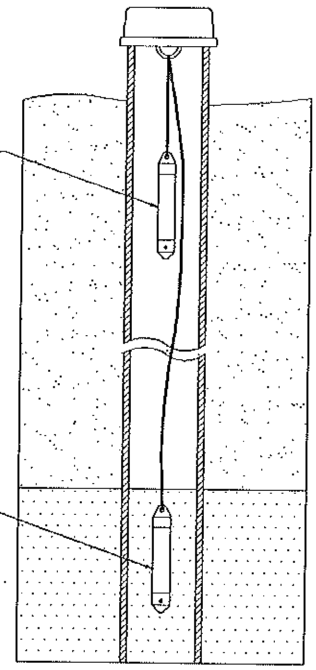
The HOBO Water Level Logger records absolute pressure, which is later converted to water level readings by the software. In this application, absolute pressure includes atmospheric pressure and water head. Atmospheric pressure is nominally 100 kPa (14.5 psi) at sea level, but changes with weather and altitude.

Left uncompensated, barometric variations could result in errors of 0.6 m (2 ft) or more. To compensate for barometric pressure changes, you can use another HOBO Water Level Logger as a barometric reference. The 0-9m (0-30 ft) HOBO Water Level Logger (U20-001-01) is a good barometric reference due to its smaller range, temperature-compensated accuracy, and rugged stainless steel case. The barometric reference is typically deployed in the same well or at the same location as the water level of interest, but rather than being placed in the water column, it is deployed above the water in air.

Fortunately, barometric pressure readings are consistent across a region (except during fast-moving weather events), so you can generally use barometric pressure readings that are taken within 15 km (10 miles) of the logger or more, without significantly degrading the accuracy of the compensation.

Deploying the Logger

- The HOBO Water Level Logger is designed to be easy to deploy in many environments. The logger uses an absolute pressure sensor, so no vent tube is required. The small size of the logger is convenient for use in small wells and allows the logger to be mounted and/or hidden in the field.



- The pressure sensor is temperature compensated over the range of 0° to 40°C (32° to 104°F). To obtain the highest level of accuracy, the logger should be allowed to come to full temperature equilibrium (approximately 30 minutes) before any reference levels are recorded. In addition, sudden temperature changes should be avoided. When deploying a HOBO Level Logger as a barometer, some consideration should be made to minimize the rate of temperature fluctuations. Ideally, the logger should be hung several feet below ground level in an observation well so that ground temperatures are stable. If that is not possible (or if a well is not used), try to put the logger in a location where it will not be subject to rapid daily temperature cycles.
- When deploying a HOBO Water Level logger in a well, make sure the well is vented to the atmosphere. Typically, a small hole can be drilled in the well cap to ensure that the pressure inside and outside the well is at equilibrium. If this is not possible, the barometric reference should be used inside the same well.
- Use a no-stretch wire to hang the water level logger. Any change in length of the wire will result in a 1-to-1 corresponding error in the depth measurement. Onset supplies a 1/16" Teflon®-coated stainless steel cable and cable crimp sleeves for this purpose.

  Regardless of the source, always pull-test a cable prior to deploying a logger in a well to be sure that it is up to the job.
- If possible, when deploying the logger in rivers, streams and ponds, use a stilling well. A simple stilling well can be constructed with PVC or ABS pipe. A properly constructed stilling well helps to protect the logger from currents, wave action, and debris.
- Periodically inspect the logger for fouling. Biological growth on the face of the pressure sensor will throw off the pressure sensor's accuracy.
- Be very careful not to exceed the burst pressure for the logger. The pressure sensor will burst if the maximum depth is exceeded (see specifications table). The logger should be positioned at a depth where the logger will remain in the water for the duration of the deployment, but not exceed the rated bursting depth.

Logger Calibration

The pressure sensor in each HOBO Water Logger is individually calibrated. During calibration, raw pressure sensor data is collected at multiple pressures and temperatures over the calibrated range of the logger (see the specifications table). This data is used to generate calibration coefficients that are stored in the logger's non-volatile memory. The calibration coefficients are then checked to be sure that the logger meets its stated accuracy over the calibrated range.

The pressure sensor can be used at pressures and temperatures that are outside of the calibrated range, but the accuracy can not be guaranteed. **Important: Never exceed the burst pressure of the sensor!**

Recalibration

All pressure sensors drift over time. The drift for the pressure sensor and electronics in the HOBO Water Level logger is less than 0.3% FS (worst case) per year. In most applications, drift is not a significant source of error, because the offset created by any drift is zeroed out when you take a manual reference level measurement and use the logger software to automatically calculate the level readings relative to the reference measurement. In effect, you are re-zeroing the sensor each time you apply a reference reading to the data file.

Pressure sensor drift matters only when absolute pressure values are needed, or if there are no recent reference level or depth measurements available. For example, if the logger is deployed for one year and no new reference level readings are taken during the deployment, it is possible that the sensor could have drifted as much as 0.3% FS by the end of the deployment. It is possible to determine the actual amount of drift during a deployment if a reference level is taken at the beginning and the end of a long-term deployment. The results of applying the two different reference levels (once at the beginning of the datafile, and again at the end of the data file) can be compared. Any difference between the files indicates the amount of sensor drift (assuming accurate reference levels).

You can check the differential accuracy of your loggers for water level measurements by deploying the loggers at two depths and comparing the difference in level readings. When verifying the accuracy this way, be sure to allow the loggers' temperature to stabilize at each depth. Use the logger software to convert the readings from pressure to level. The level readings should be taken close enough together that the barometric pressure does not change.

You can check the absolute pressure accuracy of your HOBO Water Level Logger by comparing its ambient pressure readings to a second HOBO logger. Their readings should be within each other's specified accuracy. Alternatively, you can check the pressure reading against an accurate local barometer. If you use a non-local source of barometric information, such as the NOAA website, adjust for altitude.

If you would like to have your logger's absolute accuracy verified against a NIST standard, or to have your logger recalibrated, contact Onset or your place of purchase for pricing and return arrangements.

Battery

The battery in the HOBO Water Level Logger is a 3.6 Volt lithium battery. The battery life of the logger should be about five years or more. Actual battery life is a function of the number of deployments, logging interval, and operation/storage temperature of the logger. To obtain a five-year battery life, a logging interval of one minute or greater should be used and the logger should be operated and stored at temperatures between 0° and 25°C (32° and 77°F). Frequent deployments with logging intervals of less than one minute, and continuous storage/operation at temperatures above 35°C will result in significantly lower battery life. For example, continuous logging at a one-second logging interval will result in a battery life of approximately one month.

The logger can report and log its own battery voltage. If the battery falls below 3.1 V, the logger will record a "bad battery" event in the datafile. If the datafile contains "bad battery" events, or if logged battery voltage repeatedly falls below 3.3 V, the battery is failing and the logger should be returned to Onset for battery replacement.

To have your logger's battery replaced, contact Onset or your place of purchase for return arrangements. Do not attempt to replace the battery yourself. Severe damage to the logger will result if the case is opened without special tools, and the warranty will be voided.

⚠ **WARNING:** Do not cut open, incinerate, heat above 100°C (212°F), or recharge the lithium battery. The battery may explode if the logger is exposed to extreme heat or conditions that could damage or destroy the battery case. Do not dispose of the logger or battery in fire. Do not expose the contents of the battery to water. Dispose of the battery according to local regulations for lithium batteries.

Service and Support

HOBO products are easy to use and reliable. In the unlikely event that you have a problem with this instrument, contact the company where you bought the logger: Onset or an Onset Authorized Dealer. Before calling, you can evaluate and often solve the problem if you write down the events that led to the problem (are you doing anything differently?) and if you visit the Technical Support section of the Onset web site at www.onsetcomp.com/support.html. When contacting Onset, ask for technical support and be prepared to provide the product number and serial number for the logger and software version in question. Also completely describe the problem or question. The more information you provide, the faster and more accurately we will be able to respond.

Onset Computer Corporation
470 MacArthur Blvd., Bourne, MA 02532
Mailing: PO Box 3450, Pocasset, MA 02559-3450
Phone: 1-800-LOGGERS (1-800-564-4377) or 508-759-9500
Fax: 508-759-9100
E-mail: loggerhelp@onsetcomp.com
Internet: www.onsetcomp.com

Warranty

Onset Computer Corporation (Onset) warrants to the original end-user purchaser for a period of **one year** from the date of original purchase that the HOBO® product(s) purchased will be free from defect in material and workmanship. During the warranty period Onset will, at its option, either repair or replace products that prove to be defective in material or workmanship. This warranty shall terminate and be of no further effect at the time the product is (1) damaged by extraneous cause such as fire, water, lightning, etc. or not maintained in accordance with the accompanying documentation; (2) modified; (3) improperly installed; (4) repaired by someone other than Onset; or (5) used in a manner or purpose for which the product was not intended.

THERE ARE NO WARRANTIES BEYOND THE EXPRESSED WARRANTY ABOVE. IN NO EVENT SHALL ONSET BE LIABLE FOR LOSS OF PROFITS OR INDIRECT, CONSEQUENTIAL, INCIDENTAL, SPECIAL OR OTHER SIMILAR DAMAGES ARISING OUT OF ANY BREACH OF THIS CONTRACT OR OBLIGATIONS UNDER THIS CONTRACT, INCLUDING BREACH OF WARRANTY, NEGLIGENCE, STRICT LIABILITY, OR ANY OTHER LEGAL THEORY.

Limitation of Liability. The Purchaser's sole remedy and the limit of Onset's liability for any loss whatsoever shall not exceed the Purchaser's price of the product(s). The determination of suitability of products to the specific needs of the Purchaser is solely the Purchaser's responsibility. **THERE ARE NO WARRANTIES BEYOND THE EXPRESSED WARRANTY OFFERED WITH THIS PRODUCT. EXCEPT AS SPECIFICALLY PROVIDED IN THIS DOCUMENT, THERE ARE NO OTHER WARRANTIES EXPRESS OR IMPLIED, INCLUDING BUT NOT LIMITED TO, ANY IMPLIED WARRANTIES OF MERCHANTIBILITY OR FITNESS FOR A PARTICULAR PURPOSE. NO INFORMATION OR ADVICE GIVEN BY ONSET, ITS AGENTS OR EMPLOYEES SHALL CREATE A WARRANTY OR IN ANY WAY INCREASE THE SCOPE OF THE EXPRESSED WARRANTY OFFERED WITH THIS PRODUCT.**

Indemnification. Products supplied by Onset are not designed, intended, or authorized for use as components intended for surgical implant or ingestion into the body or other applications involving life-support, or for any application in which the failure of the Onset-supplied product could create or contribute to a situation where personal injury or death may occur. Products supplied by Onset are not designed, intended, or authorized for use in or with any nuclear installation or activity. Products supplied by Onset are not designed, intended, or authorized for use in any aeronautical or related application. Should any Onset-supplied product or equipment be used in any application involving surgical implant or ingestion, life-support, or where failure of the product could lead to personal injury or death, or should any Onset-supplied product or equipment be used in or with any nuclear installation or activity, or in or with any aeronautical or related application or activity, Purchaser will indemnify Onset and hold Onset harmless from any liability or damage whatsoever arising out of the use of the product and/or equipment in such manner.

Returns

Please direct all warranty claims and repair requests to place of purchase.

Before returning a failed unit directly to Onset, you must obtain a Return Merchandise Authorization (RMA) number from Onset. You must provide proof that you purchased the Onset product(s) directly from Onset (purchase order number or Onset invoice number). Onset will issue an RMA number that is valid for 30 days. You must ship the product(s), properly packaged against further damage, to Onset (at your expense) with the RMA number marked clearly on the outside of the package. Onset is not responsible for any package that is returned without a valid RMA number or for the loss of the package by any shipping company. Loggers must be clean before they are sent back to Onset or they may be returned to you.

Repair Policy

Products that are returned after the warranty period or are damaged by the customer as specified in the warranty provisions can be returned to Onset with a valid RMA number for evaluation.

ASAP Repair Policy. For an additional charge, Onset will expedite the repair of a returned product.

Data-back™ Service. HOBO data loggers store data in nonvolatile EEPROM memory. Onset will, if possible, recover your data.

Tune Up Service. Onset will examine and retest any HOBO data logger.

Part #: MAN-U20-001-01, Doc #: 8976-C, Patent #: 6,826,664

Barometric Compensation Assistant:

This white paper presents application and technical details for the Barometric Compensation Assistant (BCA), a Post-Processor designed for use with HOBOware Pro on the PC or Mac.

Post-Processors Overview

All available Post-Processors exist in the Processors directory in the HOBOware Pro installation. All available Post-Processors are accessible from the Plot Setup Dialog in HOBOware. Each has a set of dependencies; channel-types it needs to become available when a particular dataset is displayed in the Plot Setup Dialog. A user can select a Post-Processor from the list and click the Process button, allowing them to progress through the logic contained in the Post-Processor. Upon completion of a Post-Processor, one or more new channels are added to the list of available channels to plot.

Application Details

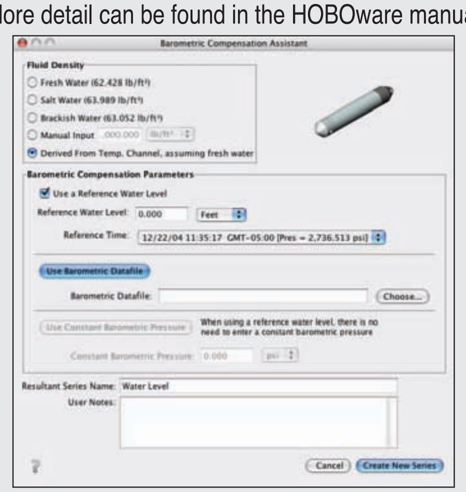
This section includes details on how the user would be expected to prepare data for use with the Barometric Compensation Assistant. The BCA supports all HOBO U20 Water Level Loggers. The details of how to use the assistant are left to the HOBOware Manual. Included here is the definition of how depth will be determined from pressure readings, how the water density will be factored into that computation, and how that density will be temperature-compensated.

The following HOBO data loggers can be used to provide the barometric data file.

- HOBO U20 Water Level Logger (0-13 ft and 0-30 ft models)
- HOBO Weather Station & Micro Station with Pressure Sensor attached
- HOBO Energy Logger Pro with Pressure Sensor attached
- HOBO U30 with Pressure Sensor attached

User Interface

This dialog associated with the BCA allows information about the barometric data, time, reference water depth, and water density to be gathered and used in the calculation of the new "Water Level" or "Sensor Depth" channel. Components of the dialog are shown and described below. More detail can be found in the HOBOware manual.



Fluid Density Panel

This panel allows the user to input the density of the fluid in which the logger was deployed. Four choices are provided: Fresh Water, Brackish Water, Salt Water, Manual Input, and Derived from Temperature Channel. If Manual Input is selected, the Water Density text field and associated units combo box will be enabled. This control will be generally initialized to Fresh Water. As with all controls in the BCA, it initializes to the last value used. If temperature was not logged, the "Derived From…" radio button will be disabled.

Water Density Text Field

This control is disabled unless the Manual Input element of the Specific Gravity ComboBox is selected. Once enabled, it will be configured to accept only positive floating-point values. The last value entered in this field will be saved as a hidden preference and displayed the next time the dialog is rendered.

Use A Reference Water Level Checkbox

Indicates whether the user has a manually measured reference water level. This measurement is necessary to maximize accuracy.

Reference Water Level Text Field

The user selects the manual depth or height measurement in this box. Negative values indicate the distance below a fixed reference point, generally a well cap. Positive values indicate the water height above a reference point, generally sea level. An associated Combo Box determines the units.

Reference Time Combo Box

This allows the user to pick the Reference Water Level time of measurement from the list of times in the downwell pressure channel.

Use Barometric Datafile Button and Text Field

The Choose button associated with these controls launches a file chooser with a datafile filter. Once the file is chosen, the dataset contained in the file will be checked to determine if it has a pressure channel that can be used for compensation. If no pressure channel is found, the user is asked to pick another file until a file with a proper pressure channel is found. Once the file has been selected, the pathname is displayed in the text field.

Use Constant Barometric Pressure Button and Text Field

This button enables the user to input a constant barometric pressure and specify its units.

Create New Series Button

Pressing this button causes the BCA to gather all user-data from the user interface and generate the new Water Level or Sensor Depth channel.

Cancel Button
Pressing this button causes the dialog to be dismissed.

Technical Details
This section presents the details of how the Pressure values are computed, and how Pressure and Temperature values are converted to Water Level or Sensor Depth depending on the information supplied by the user. Where relevant to the discussion, equations are included.

Glossary of Terms
T_{raw}	Raw 12-bit Temperature value from logger
T_{real}	Temperature value after being run through the transfer function
T_{ref}	Temperature value at the reference time
P_{raw}	Raw 14-bit Pressure value from logger
P_{real}	Pressure value after being run through the transfer function, which is a function of raw pressure and raw temperature.
P_{baro}	Barometric pressure at the reference time selected by user
P_{const}	Constant value for barometric pressure
P_{hyd}	Hydraulic Pressure
D_{ref}	Calculated reference water depth at the reference time, extracted from the downwell pressure data
D_{baro0}	Calculated barometric "depth" at the reference time, extracted from the barometric pressure data
$D_{real}[\ ]$	An array of actual computed sensor depth values
L_{meas}	Manually measured reference water level from a fixed reference, such as a well cap or sea level.
$L_{real}[\ ]$	An array of actual computed water level values
p	Density
p_{ref}	Density of fluid at time of reference
k	Barometric compensation constant

Pressure Calculation
Barometric compensation is performed by a set of Java classes that encapsulate the process of performing the conversion of pressure values to true depth readings. Before performing barometric compensation, the raw values from the logger must be converted into real pressure. HOBOware's communications interface is responsible for extracting the raw A/D pressure and temperature data (raw counts) from the logger and performing the initial processing into real pressure and temperature, as follows.

1. Extract raw 12-bit Temperature values (T_{raw}) from logger.
2. Extract raw 14-bit Pressure values (P_{raw}) from logger.
3. Extract transfer function/calibration constants (K_n … K_2, K_1, K_0 and J_n … J_2, J_1, J_0) from the EEPROM inside the logger.
4. Apply transfer function to the T_{raw} data to generate T_{real}.
5. Apply transfer function to the P_{raw} data to generate P_{real}.
6. Store T_{real} and P_{real} values in separate channels in the resultant dataset.

The resultant dataset is then passed to the HOBOware user interface for post-processing in the BCA. This post-processing is described next.

Water Level / Sensor Depth Calculation
There are several options for computing water level or sensor depth that can be grouped into two categories, using or not using a reference water level. The recommended method is to use a measured reference water level, therefore it is presented first.

Using a Reference Water Level
Note that this option results in the calculation of a Water Level relative to a fixed reference point, not a Fluid Depth.

First, a temperature and density corrected depth array is computed. This is the depth assuming all pressure is from hydraulic head (no air pressure).

To compute this array, first the fluid density is computed. This is either determined by the user-selected density, or is computed from the temperature at the reference time, via:

$$p = (999.83952 + 16.945176\, T_{ref} - 7.9870401e\text{-}03\, T_{ref}^{2} - 46.170461e\text{-}06\, T_{ref}^{3} + 105.56302e\text{-}09\, T_{ref}^{4} - 280.54253e\text{-}12\, T_{ref}^{5}) / (1 + 16.879850e\text{-}03\, T_{ref}) \quad [1]$$

Density is converted to lb/ft^3 via:

$$p = 0.0624279606\, p \quad [2]$$

The array of downwell pressure values, P, are then converted to a density dependent fluid depth array, D[], via:

$$D[\ ] = FEET\_TO\_METERS * (KPA\_TO\_PSI * PSI\_TO\_PSF * P) / p \quad [3]$$

Where,

FEET_TO_METERS = 0.3048
KPA_TO_PSI = 0.1450377
PSI_TO_PSF = 144.0

The density dependent depth value at the reference time is then extracted from the array:

$$D_{ref} = D[\text{Ref Time}]$$

The remaining steps to compute water level values can be done in one of three ways, as follows.

Using a Barometric Datafile
If the user chooses to compensate with a barometric datafile, the following steps are taken.

The Pressure value in the barometric dataset closest to the selected reference time is determined. If there is not a time in the barometric pressure channel that coincides with the reference time, a value is determined via linear interpolation. This reference pressure is referred to as P_{baro0}.

Next, the fluid density at the reference time is determined. This is either the user-entered density, or is computed from Equations 1 & 2, resulting in p_{ref}.

The pressure at the reference time is converted to a barometric "depth" using Equation 3, resulting in D_{baro0}.

The compensation constant, k, is determined by:

$$k = L_{meas} - (D_{ref} - D_{baro0}) \quad [4]$$

At this point, the compensation constant is applied to each downwell barometric depth reading in the array, D. An important step here is to determine the proper barometric pressure value to use. Since the BCA does not require that the barometric pressure channel have the same sample times as the downwell pressure channel, individual values for barometric pressure, P_{baro}, may sometimes be interpolated between the points closest to the downwell pressure value of interest.

Loop through the entire downwell channel, applying the compensation constant to the density dependent fluid depth values computed above. This is the step that adjusts the density dependent depth values for fluctuations in barometric pressure. This is determined by:

$$L_{real}[\ ] = D[\ ] - D_{baro}[\ ] + k \quad [5]$$

Where $L_{real}[\ ]$ is an array of the actual water level values (from a fixed reference point), D is the density dependent fluid depth array computed earlier, D_{baro} is the barometric depth at the time index in the array (using Equation 3), and k is the compensation constant. The values of L_{real} are stored in a new Water Level channel and added to the list of available channels to plot.

Using No Barometric Data

If the user chooses not to use a barometric datafile, the process of generating a water level is simple, although less accurate. The resultant water level values in this case do not take into account fluctuations in barometric pressure. In this case, the compensation constant is defined as:

$$k = L_{meas} - D_{ref} \quad [4]$$

Loop through the entire downwell channel, applying the compensation constant to the density dependent fluid depth values computed above. The array of actual water level values is computed using:

$$L_{real}[\ ] = D[\ ] + k \quad [5]$$

The values of L_{real} are stored in a new Water Level channel and added to the list of available channels to plot.

Using a Constant Barometric Pressure

The equations used to generate water level using a reference water level and a constant barometric pressure result in the constant pressure term falling out. Since the constant barometric pressure value does not affect the resulting water level, this option is intentionally disabled in the BCA.

Not Using a Reference Water Level

If no reference water level data is available, the only option is to compute sensor depth below the water surface. This can be done using a barometric datafile or a constant barometric pressure value supplied by the user. Using a barometric datafile is the more accurate of the two methods and is presented first.

Using a Barometric Datafile

Loop through the entire downwell data array. First, generate the fluid density, p, for each time in the array. This is either determined by the user-selected density, or is computed from the temperature at the reference time, using Equations 1 & 2.

Next, compute the hydraulic pressure at each time, $P_{hyd}[\ ]$, using:

$$P_{hyd}[t] = P_{real}[t] - P_{baro}[t] \quad [6]$$

Where $P_{real}[\ ]$ is the array of measured downwell pressure values and $P_{baro}[\ ]$ is the array of measured barometric pressure values.

Finally, convert the hydraulic pressure to sensor depth, D_{real}, using Equation 3. The values of D_{real} are stored in a new Sensor Depth channel and added to the list of available channels to plot.

Using a Constant Barometric Pressure

The first step is to grab the value of constant barometric pressure, P_{const}, and convert to kPa if necessary.

Next, loop through the entire downwell data array. First generate the fluid density, p, for each time in the array. This is either determined by the user-selected density, or is computed from the temperature at the reference time, using Equations 1 & 2.

Next, compute the hydraulic pressure at each time, $P_{hyd}[\ ]$, using:

$$P_{hyd}[t] = P_{real}[t] - P_{const} \quad [7]$$

Where $P_{real}[\ ]$ is the array of measured downwell pressure.

Finally, convert the hydraulic pressure to sensor depth, D_{real}, using Equation 3. The values of D_{real} are stored in a new Sensor Depth channel and added to the list of available channels to plot.

About Onset

Onset Computer Corporation has been producing small, inexpensive, battery-powered HOBO data loggers since 1981, and has sold over 1,000,000 loggers that are used throughout the world by over 50,000 customers. The company manufactures a broad range of data logger http://www.onsetcomp.com/data-logger and weather station products that are used to measure temperature, humidity, light intensity, voltage, and a broad range of other parameters. Onset data loggers are used in a wide range of research, commercial, industrial, and renewable energy applications.

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Appendix 3 *Wall map not available electronically

Appendix 4 *Wall map not available electronically