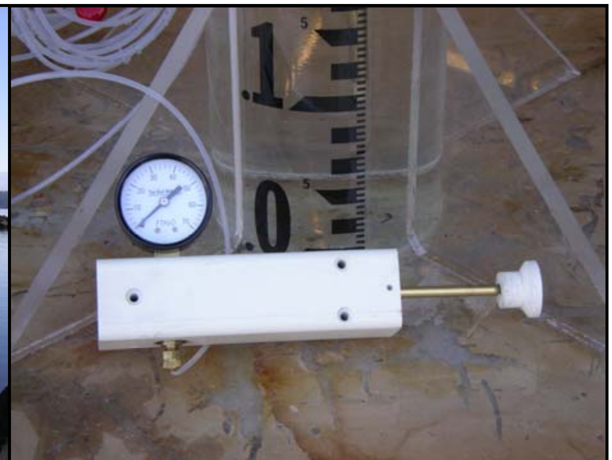
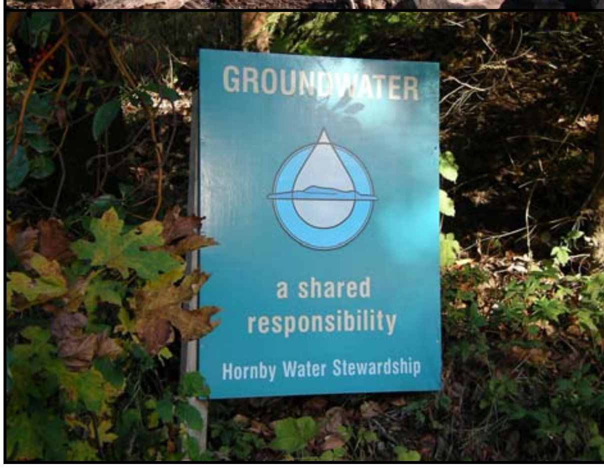
Hornby Island Domestic Well Monitoring Study

Final Report
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Vancouver Island Regional Operations Branch

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Executive summary

Monitoring of water quantity and quality in developed aquifers is essential to ensure that groundwater resources are used and managed sustainably. Monitoring groundwater level provides valuable information on storage and seasonal fluctuations in response to recharge and discharge within different aquifers, in addition to providing data to evaluate trends or changes in groundwater availability due to extraction of water from wells, surface-groundwater interactions, changes in land use, drought, and long-term climate cycles. Monitoring of seasonal and long-term variations in water levels in domestic wells can provide useful information to the well owners, and expands the spatial distribution of monitoring in key aquifers to augment data from dedicated observation wells.

In this study, the owners of four domestic wells in the Mount Geoffrey aquifer, Hornby Island, monitored their water levels for more than a year using submerged air-lines. A submerged air-line is a simple monitoring device that measures the pressure required to evacuate or empty an open-ended tube that has been inserted below the water line in a well. A gauge reads either pressure directly or the gauge converts the pressure to an equivalent height of water above the bottom end of the tube. When the length of tubing is known, the gauge reading can be used to determine the water level relative to the ground surface or other datum.

The domestic study wells are located in the Sandpiper Beach subdivision, down slope of provincial observation well 288 that has been active since 1984, and presently is instrumented with a float-type monitoring device and data logger that stores groundwater level readings on a continuous (hourly) basis. The intent of the study was to evaluate how well the air-line devices worked under field conditions, compile the groundwater level information from wells in different parts of the aquifer, and assess the potential correlation between seasonal fluctuations in the observation well and the domestic wells.

The accuracy of the air-line units was estimated by taking periodic measurements of water level in each well using an electric water level meter to compare to the air-line measurements. After calibration of the units (adjusting the estimated air-line length based on initial manual measurements) the devices had a median estimated error of ± 0.1 m, within the textbook range for this type of instrument. The hydrographs for all wells were plotted together and found to follow a similar seasonal pattern. Through involvement in the study, well owners developed a better understanding of, and interest in, water level fluctuations in their wells in response to seasonal precipitation and well usage. The study confirms the value of groundwater level monitoring in domestic wells, but highlights the need to properly install and calibrate the units so that the accuracy and usability of resulting the resulting data is maximized.

Acknowledgements

We would especially like to thank the domestic well owners on Hornby Island who participated in this project (not named for the sake of confidentiality). Eleanor Kneffel assisted with approaching well owners and identifying the monitoring locations. Mike Feduk, former Ministry of Environment (MoE) regional hydrogeologist (Vancouver Island and Gulf Islands region) initially developed the idea for this project. Brian Epps (MoE) assisted with set-up of the submerged air-line monitoring units in December 2005. MoE groundwater technicians Roberta Patterson (2006-2007) and Graeme Henderson (2007-present) conducted many of the field visits to observation well 288 and assisted with processing and validation of the observation well data. Advice on trouble-shooting operation of the Well Watcher units was provided by John Nicolas. We are also grateful to the Gabriola domestic well owners who allowed us to conduct field visits to their wells to gather more information on common use of the submerged-air lines for domestic well monitoring.

1 Introduction

Groundwater is an essential resource for domestic drinking water, agricultural and industrial use in British Columbia, making up approximately 25% of total water used provincially, and making up an even larger proportion of water used in areas where surface water sources, such as lakes and rivers are not found, or where these sources are at or near the limit of available withdrawals. In addition to meeting human needs, groundwater is also critical to freshwater ecosystems, contributing to stream base flow during low precipitation periods (B.C. Ministry of Environment, Lands and Parks, 1994; Berardinucci and Ronneseth, 2002).

In recent decades, population growth and development have placed increasing pressures on groundwater resources in many areas, highlighting the need to use and manage the resource in a sustainable manner. Quantification and description of the resource through aquifer mapping and classification, as well as establishment of long-term monitoring in key aquifers through a network of dedicated observation wells, have been important components of Ministry of Environment programs aimed toward this goal of sustainable groundwater use.

Water level monitoring can provide valuable information on groundwater storage and seasonal fluctuations in response to recharge and discharge within different aquifers, in addition to providing data to evaluate trends or changes in groundwater availability due to well withdrawals, surface-groundwater interactions, changes in land use, drought, and long-term climate cycles (B.C. Ministry of Environment, 2007; Taylor and Alley, 2001). Dedicated observation well networks, involving water quantity or quality monitoring in wells that are not otherwise in use, typically concentrate on monitoring at a single site or small number of sites within a localized area of an aquifer, therefore data obtained may not fully represent conditions over an aquifer's spatial extent. Monitoring active domestic wells constructed in the same aquifer as an observation well is a potential means of extending the spatial distribution of water quality or quantity data in the aquifer, without the expense of drilling and instrumenting new monitoring wells (Grieef and Hayashi, 2007).

Monitoring water levels in active wells can also provide useful information to the well owners and operators, including insight into seasonal water availability (e.g. available drawdown), changes in well productivity or capacity over time, and water level fluctuations in the well in response to patterns of usage. The data can also be used to establish a baseline of ground water level information from which to compare future changes.

Some methods commonly used to monitor groundwater levels, such as pressure transducers or float devices, may be prohibitively expensive for a private well owner, or may be unsuitable for use within an active well. One possible solution to these constraints is a type of device which uses an air-line, a pump and a pressure gauge to monitor changes in pressure related to changes in water level within a well. This type of device, referred to as a "submerged air-line monitor," or sometimes called a "bubbler," has been in common usage for many decades, can be used in active wells, and may be more economical than other types of monitoring equipment. However, the advantage of the lower cost may be countered somewhat by the potentially lower accuracy of an air-line compared to some other monitoring techniques (Dalton, *et al*, 1991).

This report outlines a year-long pilot project that involved domestic well owners on Hornby Island in monitoring water levels within their wells using submerged air-lines. In addition to the Hornby study sites, one-time field visits were made to several sites on Gabriola Island, where the air-lines are used for groundwater level monitoring in domestic wells.

1.1 Description of study area

Hornby Island, a small island approximately 30 km^2 in area, is located in Baynes Sound, off the east coast of Vancouver Island, approximately 31 km south of Courtenay (Islands Trust, 2008). The community is primarily rural residential, with some small-scale agriculture, artisans and commercial businesses focussed largely on the travel industry. The permanent year-round population of the island is around 1,070; however the summer population is typically much higher, including part-time residents and tourists (Islands Trust, 2008). As in many parts of the Gulf Islands, ground water, supplied from domestic and water supply system wells, is the primary source of water for household and other uses. There are four major identified aquifers on Hornby Island, differentiated primarily on the basis of topography, including coastal margins and locations of major topographic and hydrologic divides (Hodge, 2001).

The Mount Geoffrey aquifer, the largest classified aquifer on Hornby Island, has an approximate area of 19 km^2 and comprises much of the central part of the island from the eastern slopes of Mt. Geoffrey to the coast at Tralee Point on the northeast, Phipps Point on the northwest, and Tribune Bay and the Sandpiper Beach on the southeast (Hodge, 2001). The aquifer is made up of fractured bedrock of the Upper Cretaceous Nanaimo Group, Spray (mudstone, siltstone with sandstone interbeds) and Geoffrey (sandstone with shale interbeds and minor course conglomerate) Formations (Mustard, 1994; Hodge, 2001). Structurally, the sedimentary strata dip toward the northeast and important water-bearing zones are thought to occur in the shale layers or along the bedding planes and contact zones between layers of different sedimentary rock types (Mustard, 1994; Allen and Matsuo, 2002).

There are approximately 330 wells in the provincial database thought to be constructed in the Mt. Geoffrey aquifer, and the overall level of development of the aquifer is considered moderate, although locally some areas have a high well density, in particular within the Sandpiper and Galleon Beach subdivisions, where lot sizes are as small as 0.5 acre, many with both their own well and on-site sewage disposal (septic system) (Hodge, 2001). The aquifer is considered highly vulnerable to contamination; overburden, often described as “till” in well construction records, ranges in depth from 0 to 18 m (0 to 60 ft), however the median depth of the till is only 1.5 m or 5 ft, and this confining layer may be thin or absent in some areas. The median well depth is 33 m (109 ft) and the median estimated well yield is 0.23 L/s (3.0 gpm) ranging from 0.006 L/s to 3.8 L/s (0.08 gpm to 50 gpm)(Hodge, 2001). High well density and interference between adjacent well users are identified concerns in the area. Other noted concerns include water quality issues such as hydrogen sulphide gas (which creates a sulphurous odour or taste); high manganese and fluoride; and salt-water intrusion in some wells near the coast (Hodge, 2001; Allen and Pelude, 2001; Allen and Matsuo, 2002).

Since 1984, water levels within the Mount Geoffrey aquifer, have been actively monitored within Ministry of Environment observation well 288, located on Central Road at the intersection with Sandpiper Rd. As a dedicated observation location, well 288 is instrumented with a Thalimedes® device, a float and counterweight system which monitors ground water level on a continuous basis, recording the hourly average of readings taken every 15 minutes. This well is one of 53 active monitoring wells within the Vancouver Island and Gulf Islands region, part of the Ministry of Environment observation well program which monitors long-term trends in ground water level fluctuations within key aquifers. The well is also sampled periodically (every 1-3 years) to evaluate ambient groundwater quality.

1.2 Study objectives

The objectives of this project were to:

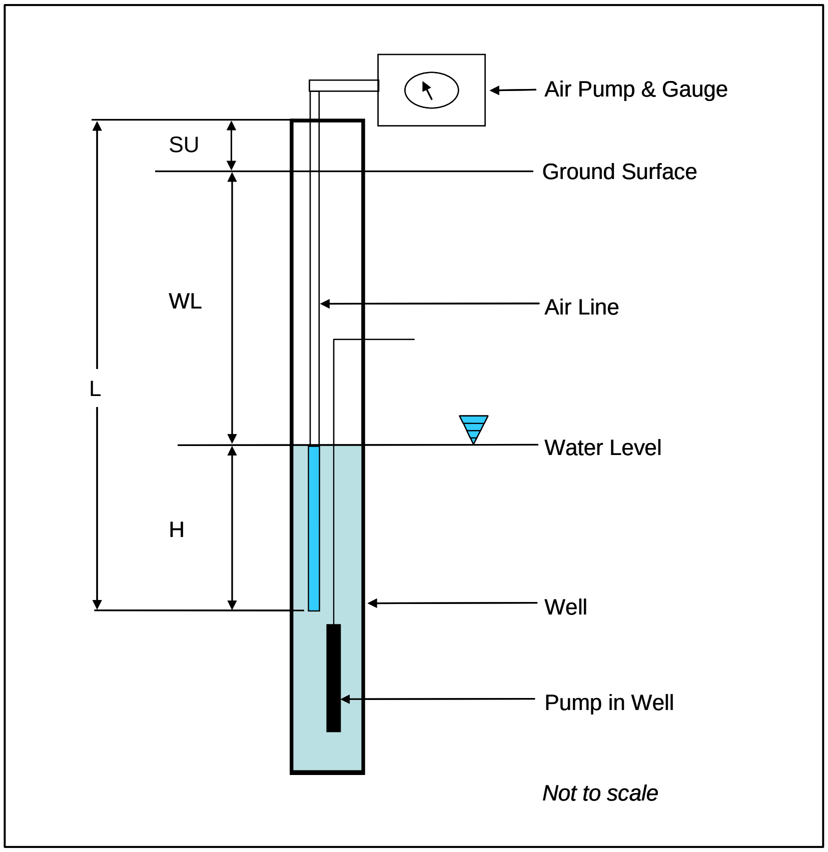
- Evaluate the accuracy of a simple, economical water level monitoring device under actual field conditions for a full annual cycle within domestic water wells in the Mt. Geoffrey aquifer;
- Compile and compare the information from weekly, or more frequent, monitoring of domestic wells at different locations in the aquifer;
- Compare groundwater levels measured in the domestic wells to water level fluctuations measured in observation well 288, which is constructed in the same aquifer, upslope of the domestic water level monitoring sites.

2 Methods

2.1 Principles of submerged air-line monitor operation

An air-line groundwater level monitor is a simple apparatus, made up of a pump and pressure gauge, attached to tubing which is inserted below the water line within the well (Dalton, et al, 1991). The air-line is open at the bottom end and can be fitted with weights to assist with maintaining the vertical alignment of the tube within the well. The recommended tubing is generally 0.95 cm (0.375 inches) or less in outside diameter. For this study, locally made (Gabriola Island) air-line units, marketed under the name Well Watcher® were used. The plastic tubing had a 0.318 cm (0.125 inch) outside diameter; therefore it was able to be easily inserted into each well through a bolt hole in the sanitary seal well cap. The above ground end of the air line is attached to the instrument, which consists of a small hand pump and pressure gauge. When there is no pressure within the instrument—when it has not been pumped recently—water will rise within the tubing to a height corresponding to the height of water in the well. When the instrument is pumped, water is evacuated from the tubing. The gauge measures the pressure required to displace the water and converts this to an equivalent height of water above the open end of the tubing, which is displayed on the gauge. The ground water level below ground can then be calculated using the gauge reading, the known depth to which the tubing has been inserted into the well, and the stickup of the well casing above the ground surface. For this study, the ground surface or zero datum was taken to be equivalent to the floor of the pumphouse. A schematic of an air line monitor installation is shown in Figure 1.

Figure 1. Schematic of air-line monitor operation. The tubing is inserted within the well to a known depth (L), and the pressure gauge measures the height of water (H) above open bottom end of the tubing. The water level, WL = L – (SU + H), where SU is the well casing stickup above the ground surface or datum.



2.2 Installation

Submerged air-line monitors were installed within four domestic wells in the Mt. Geoffrey aquifer in early December 2005. The locations of study wells are shown in Figure 2. Participants volunteered or were approached and agreed to be involved. The sites were distributed at various locations and elevations within the Sandpiper neighbourhood of the Mt. Geoffrey aquifer, which borders Sandpiper Road east of Central Road.

During installation, information was collected on each well, including the name and contact information for each well owner, the well depth and other information from the well construction record, if that was available, pump depth, casing stickup, coordinates (determined using a recreational Geographic Positioning System (GPS) device), elevation, description and pictures of the well location. The latitude and longitude coordinates from multiple field visits to each well site were averaged. Recreational GPS units are known to have limited accuracy, particularly when estimating site elevation (Resources Inventory Committee, 2001); hence, the elevation at each location was estimated from 20 m mapped topographic contours. For higher accuracy determination of the well head elevation, for example to conduct a detailed assessment of the direction of groundwater gradient and flow direction in the aquifer, an engineered topographical survey would be required.

All of the study wells had a sanitary seal type cap. The submerged air-line tubing was pre-measured using a surveyor's tape and marked at intervals (typically 5 m spacing). To install the instrument, one of the sanitary seal bolts was removed, and the weighted open end of the tubing was inserted into the hole. The tubing was inserted to an known depth, using the well depth and pump depth as a guide, so that the tube was sufficiently above the pump to avoid getting caught in wiring, but deep enough so that the tubing could be expected to be submerged throughout the monitoring period. Electrical tape was used to secure the tubing at the top and cover the gap made by the bolt hole so foreign materials were prevented from falling down into the well. Excess tubing was kept attached, and was bundled and placed with the pump and gauge unit adjacent to the well head, in case the air-line had to be inserted deeper within the well at a later date in response to changes in the water level. Three of the units (1 to 3) were installed on December 8, 2005. Unit 4 was installed the following day. Initial readings were taken at all stations following installation. Refer to Appendix A for photos of the instrumentation and set-up.

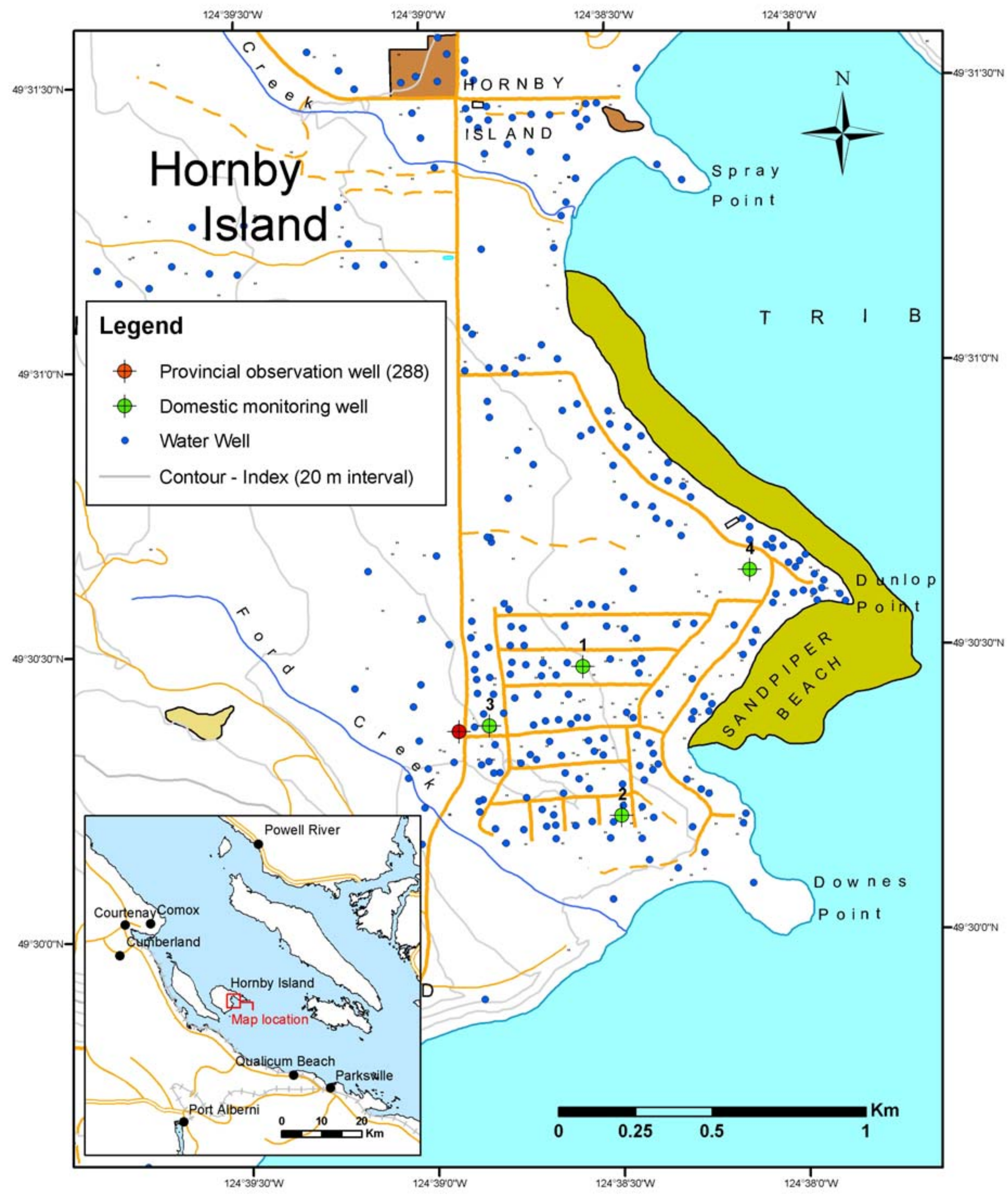
2.3 Calibration

During the year of domestic well monitoring using the air-lines, periodic water level measurements taken using an electric tape were obtained for comparison to the submerged air-line instrument readings. An electrical tape is generally considered more accurate method for measuring water level in comparison to a submerged air-line. Depending on the unit, electrical tape readings can be taken to the nearest 0.01 to 0.001 m and the overall accuracy is considered to be from 0.006 to 0.03 m (Dalton, et al, 1991). When the submerged air-lines were first installed, the probe diameter of the available electrical water level meter was too large to be inserted through a bolt hole in the well cap. Therefore, at the time of installation it was not possible to measure the water level using the electrical tape.

At well 1, during much of the year, the water flowed at a very low rate (trickle) from a discharge tube installed on the cap. The artesian condition of the well permitted an approximation of the actual water level. Artesian head above ground was not measured but assumed to be approximately level to the top of the casing.

On subsequent field visits, water depth readings were taken using a Solinst Model 102 water level meter with small diameter probe, described by the manufacturers as accurate within ± 1 cm. As a sanitary precaution the water level probe was wiped, disinfected with a 10% bleach solution, and rinsed with deionized water before and after use in each well. For the purposes of comparison between monitoring sites, groundwater level relative to the ground surface (depth below ground surface) was calculated.

Figure 2. Study monitoring locations, Mt. Geoffrey aquifer, Hornby Island



As described above, accurately knowing length of tubing deployed in the well was important for calculating the groundwater level relative to the surface. In some cases, obstructions in the well such as the pump torque arrestor or wiring, or hanging up of the plastic in the well bore, prevented the tube from being installed exactly vertically in the well. Therefore the initial estimate of tube length was adjusted by subtracting an error factor determined using the manual water level reading taken using the electric tape. The revised tube length was then used for subsequent calculations of water level. Electrical tape readings were taken at each field visit to compare to the air-line readings and to estimate the level of equipment error.

2.4 Monitoring

Participants assisted with installation of the equipment, and were provided with blank data sheets and instructions on how to measure and record values. They were asked to take a minimum of weekly static water level readings, at a similar time during the day. As the aim was to collect *static* water levels, the well owner would make a measurement at a time when the well pump was not in operation and ideally had not been pumping recently. Readings were collected by well owners from December 2005 to January 2007. Then, after the last field visit to the domestic wells, the air-line instruments were left installed so the owners could continue to use them. A summary of information related to the set-up of each domestic well for monitoring is included in Table 1.

Well 288 was active for the period from December 2005 to October 2006 when the instrumentation was removed so the observation well could be pumped for sampling. Due to operational problems with the Thalimedes instrumentation, continuous data for well 288 were not available for the period following sampling, and the remaining hydrograph from early October 2006 to January 2008 was determined solely using the available manual water level measurements.

2.5 Gabriola Island survey

Residents on many Gulf Islands are monitoring their well water levels using submerged air-lines or other methods. The Well Watcher® instrumentation is locally manufactured on Gabriola Island and over the past few years dozens of these units have been solid to island residents. To expand the Hornby Island study to a larger sample set, MoE staff conducted one-time-only field visits to nine sites on Gabriola Island in July 2007. Well owners were initially identified through local contacts and called to see if they would be willing to participate. At each site, basic information about the well and monitoring instrumentation was collected. Where possible (seven of nine sites) an electric water level meter with a small diameter probe was used to measure the manual water level, which was then compared to the air-line water level estimate. The field data and estimated accuracy of the air-line readings from these site visits are summarized in Appendix C.

Table 1. Hornby Island study well characteristics and air-line installation details

Well number	1	2	3*	4*	288
Well construction information (if available)					
Construction date	Feb 1984	Unknown	May 1991	Unknown	March 1984
Well depth (ft bgs)	261	160	200	70	253
Well depth (m bgs)	80	49	61	21	77
Casing stickup (m)	0.05	0.16	0.38	0.15	0.50
Diameter (m)	0.15	0.15	0.15	0.15	0.15
Estimated yield (L/min)	18.9	Unknown	1.9	Unknown	18.9
Estimated yield (USgpm)	5		0.5		5
Surface elevation (m asl)	20	32	38	5	44
Lithology	Sandstone and shale Water bearing fracture at 79 m (260 ft)	Unknown (no construction record); water-bearing fracture at ~12 m (40 ft) bgs.	Conglomerate and sandstone Estimated depth of water-bearing fractures 20 and 33 m (65 and 108 ft)	Unknown (no construction record)	Layered conglomerate, shale, and sandstone; depth of water-bearing fractures not reported.
Pump depth (ft bgs)	80	150	190	Unknown	Not applicable
Pump depth (m bgs)	24.4	45.7	57.9	Unknown	-
Air line installation date	8-Dec-05	8-Dec-05	8-Dec-05	9-Dec-05	Not applicable
Air line tube installation depth (m btoc)	15.00	20.00	20.00* 24.00	12.00* 15.00	Not applicable
Calibrated air line tube length (m bgs)	14.98	19.40	17.51* 21.43	11.09* 13.55	Not applicable

*Changes were made to set-up i.e. depth of tubing on date(s) following initial installation (see Table 2 for calibration dates)

Legend: bgs=below ground surface L/min=litres per minute USgpm=US gallons per minute asl=above sea level btoc=below top of casing

3 Results and discussion

3.1 Evaluation of air-line monitoring method

Manual water level measurements taken using an electrical tape were collected for comparison to the instrument readings six times during the study period. The comparison of electrical tape and submerged air-line readings is shown in Table 2. The table also shows multiple measurements for some monitoring dates. When there appeared to be a large difference between the air-line and the electrical tape water level, multiple readings were taken. The pressure gauge was read after waiting a short period and re-pumping. The level of error did not always decrease with successive measurements, and there seemed to be no direct relationship between the time spent pumping the instrument and the accuracy.

The difference between air-line and electrical tape readings ranged from a minimum of 0.04 m to a maximum of 1.39 m. The median error of the air-line values was ± 0.05 m.

The air-line accuracy is primarily determined by the accuracy of the pump gauge, and can also be affected by leaky fittings, holes or kinks in the air-line (Dalton, et al, 1991). It is possible to get various pump gauges that are suitable for a given pressure range. Under ideal circumstances the pressure gauge should be at the finest scale possible while being able to read over the full range of predicted water levels. If there is a large difference between minimum and maximum water levels, a coarser gauge must be used, which has a lower accuracy relative to one with a finer scale and more limited range of measurement. In this case, the gauges purchased were suitable for measuring within a range of 0 to 70 ft (0 to 30 psi). More accurate readings might have been obtainable from a gauge with a smaller range e.g. 0 to 35 ft (0 to 15 psi).

Overall the instrument accuracy was in the textbook range predicted for these types of instruments (Dalton, et al, 1991). Once the tubing length was recalculated using the manual (electric tape) water level, there appeared to be no significant correlation between instrument error and the length of tubing, well depth or water depth. The air-line tubing was made of plastic which stretched slightly over time, either from handling or due to the pull of the weights at one end, a factor which should be considered when using the instruments for an extended time period.

Although it is recognized that this study involved a very small sample size, the results suggests that the submerged air-line monitors may have reduced accuracy or usability under some conditions, including:

Artesian conditions As hydraulic head increases the pressure measured by the submerged air-line method increases. In this study it was not possible to accurately measure the height to which water would rise above the ground surface in one well that exhibited artesian conditions (a clear plastic tube sticking above the casing might be a way to facilitate this type of measurement). Artesian pressure is also known to fluctuate rapidly, which also makes it more challenging to accurately measure hydraulic head.

Table 2. Comparison of air-line and electrical tape water levels, Hornby Island

Date	Site number	Air-line water level (m bgs)	Electrical tape water level (m bgs)	Estimated error* (m)	
08-Dec-06	1	0.35	-0.05	0.40	A
11-Dec-05	1	0.51	-0.05	0.56	A
10-Feb-06	1	0.35	-0.05	0.40	A
02-May-06	1	0.20	-0.05	0.25	A
20-Jul-06	1	7.06	7.06	0.00	C
17-Aug-06	1	10.87	11.03	-0.16	
20-Oct-06	1	10.41	10.47	-0.06	
23-Jan-07	1	-1.17	-0.05	-1.12	A
Median		0.43	-0.05	0.25	
Minimum		-1.17	-0.05	(±) 0.06	
Maximum		10.87	11.03	(±) 1.12	
10-Feb-06	2	4.56	4.56	0.00	C
02-May-06	2	6.21	6.26	-0.05	
20-Jul-06	2	9.35	7.96	1.39	
20-Jul-06	2	7.82	7.95	-0.13	
17-Aug-06	2	9.25	9.38	-0.13	
20-Oct-06	2	9.95	10.07	-0.12	
20-Oct-06	2	10.11	10.07	0.04	
23-Jan-07	2	3.55	3.90	-0.35	
Median		8.54	7.95	-0.12	
Minimum		3.55	3.90	(±) 0.04	
Maximum		10.11	10.07	(±) 1.39	
10-Feb-06	3	1.97	1.97	0.00	C
02-May-06	3	5.78	5.46	0.32	
20-Jul-06	3	nc	18.82	nc	
20-Oct-06	3	nc	23.82	nc	
23-Jan-07	3	1.62	1.62	0.00	C
23-Jan-07	3	1.71	1.62	0.09	
23-Jan-07	3	1.92	1.62	0.30	
23-Jan-07	3	2.23	1.62	0.61	
23-Jan-07	3	1.16	1.62	-0.46	
Median		1.92	1.62	0.30	
Minimum		1.16	1.62	(±) 0.09	
Maximum		5.78	23.82	(±) 0.61	
10-Feb-06	4	0.88	0.88	0.00	C
02-May-06	4	1.33	1.12	0.22	
02-May-06	4	0.72	1.14	-0.41	
20-Jul-06	4	nc	3.05	nc	
17-Aug-06	4	3.81	3.81	0.00	C
17-Aug-06	4	3.03	3.73	-0.70	
17-Aug-06	4	3.64	3.58	0.06	
20-Oct-06	4	3.64	3.98	-0.34	
23-Jan-07	4	0.44	0.71	-0.27	
23-Jan-07	4	0.75	0.71	0.04	
23-Jan-07	4	0.90	0.71	0.19	
23-Jan-07	4	0.53	0.71	-0.18	
23-Jan-07	4	0.29	0.71	-0.42	
Median		0.89	1.12	-0.22	
Minimum		0.29	0.71	(±) 0.04	
Maximum		3.81	3.98	(±) 0.70	

*Difference between well watcher water level and manual water level measured using water level meter (electrical tape).

nc=not calculated, in cases where well watcher reading was not available

A=artesian condition C=manual water level used for instrument calibration

Deep wells	In deep wells, a significant length of tubing had to be installed, and the tubing was found to bunch up or get caught in the upper part of the well bore, affecting the accuracy of the estimate of tubing length below the top of casing or datum (calibration of the unit was done to refine the tube length estimate).
Wells in active use	Although the air-lines are considered appropriate for evaluating water levels in wells that are in use, it was found in some cases that the pump wires or associated equipment (i.e. torque arrestor) prevented installation of the tubing below the water level. Accidentally getting the tube caught within the wiring or pump works would be logistically challenging and costly to fix. This problem could be prevented by having a designated port and access tube or liner installed in the well, in which the instruments, including an electrical water level probe, could be placed (a designated access tube is highly recommended to prevent potential problems).
Cold conditions	One study participant noted that the air-line hand pump seized when temperatures were below freezing for a short period during the winter. This problem may be alleviated by keeping the pump and gauge in a warm/sheltered location, and is not likely to be a major concern for well owners on the coast, where winter temperatures tend to be moderate. If these types of devices are used within colder regions, winter conditions would likely be a more significant concern. Because it is a physical mechanism, freezing of moisture in the pump interferes with the pump function, compared to other devices with electronic or other components that may be more resilient below 0°C.
Cascading water in well	For calibration of the air-line (to obtain an accurate estimate of the depth of deployment of the tubing in the well) water level measurement using an alternate method, such as an electric tape, was more difficult to obtain where there was water cascading in the well from fractures above the water line, giving false readings from the electric water level meter.

3.2 Hydrographs

Ground water levels were calculated from the submerged air-line data and plotted with the water level readings from observation well 288 in Figure 3. Manual water level measurements taken using an electric tape are shown using different symbols for comparison to the other instrument readings. The plot shows that water level fluctuations in the five wells followed a similar pattern during the monitoring period. Compared to the hydrograph of data from well 288, the levels in some of the study wells (e.g. well 3) fluctuated widely between monitoring dates. This water level variability is thought to be in response to the effects of pumping of the well itself, likely measurement of a pumping (rather than static) water level. Overall, the deepest groundwater levels during the study period were observed in late October to early November, and the shallowest water levels were observed in December to January.

Statistics summarizing the water levels at the study sites are shown in Table 3. These statistics were calculated from the corrected (calibrated) instrument readings shown in Appendix C.

Table 3. Summary statistics on water level fluctuations in Hornby Island study wells

	Monitoring location				
Water level (m bgs)*	**288**	**1**	**2**	**3**	**4**
Median	12.63	0.78	7.36	5.16	1.33
Average	13.81	4.27	7.08	6.66	1.97
Minimum	11.44	-1.20	1.73	1.01	0.42
Maximum	17.76	14.76	17.88	18.38	4.40
Maximum (excluding outliers**)	nc	11.37	11.94	nc	nc
Range	6.32	15.96	16.15	17.37	3.98
Range (excluding outliers**)	nc	12.57	10.21	nc	nc
Well elevation (m asl)	44	20	32	38	5

nc=not calculated, bgs=below ground surface

**Based on air-line or continous float instrumentation (does not include manual measurements taken using the electric tape)*

***Removed possible outliers: Well 1 (October 1/06), Well 2 (August 10/06)*

Well 288, is at the highest elevation of all the study sites, and had the deepest median, average and minimum water level at 12.63 m, 13.81 and 11.44 m below ground surface (bgs) respectively. The annual range between high and low water level was 6.32 m, a smaller range in comparison to most of the domestic wells. With the exception of one sampling session, the observation well is not pumped during the year and therefore the range reflects a natural water level fluctuation in the aquifer during different seasons. For collection of water quality samples well 288 was pumped at roughly 10.5 litres/min (<3 US gallons per minute) for a total of less than two hours on October 4 and 5, 2006.

Well 1 had the highest observed ground water levels for much of the year, exhibiting artesian conditions (groundwater level above the height of the ground surface), during the winter and spring period. Water levels in well 1 declined to closer to that observed in the other mid-slope sites during May to early November, before returning to artesian conditions following the onset of winter rains. The median water level was 0.78 m bgs, the minimum water level was estimated to be 1.20 m *above* ground surface, the maximum (deepest) water level for well 1 was 11.37 m bgs and the annual range in water level was 12.57 m (excluding one outlier from Oct 1, 2010 that was thought to be taken after recent pumping).

Figure 3. Water level versus time for study wells in the Mount Geoffrey aquifer, Hornby Island

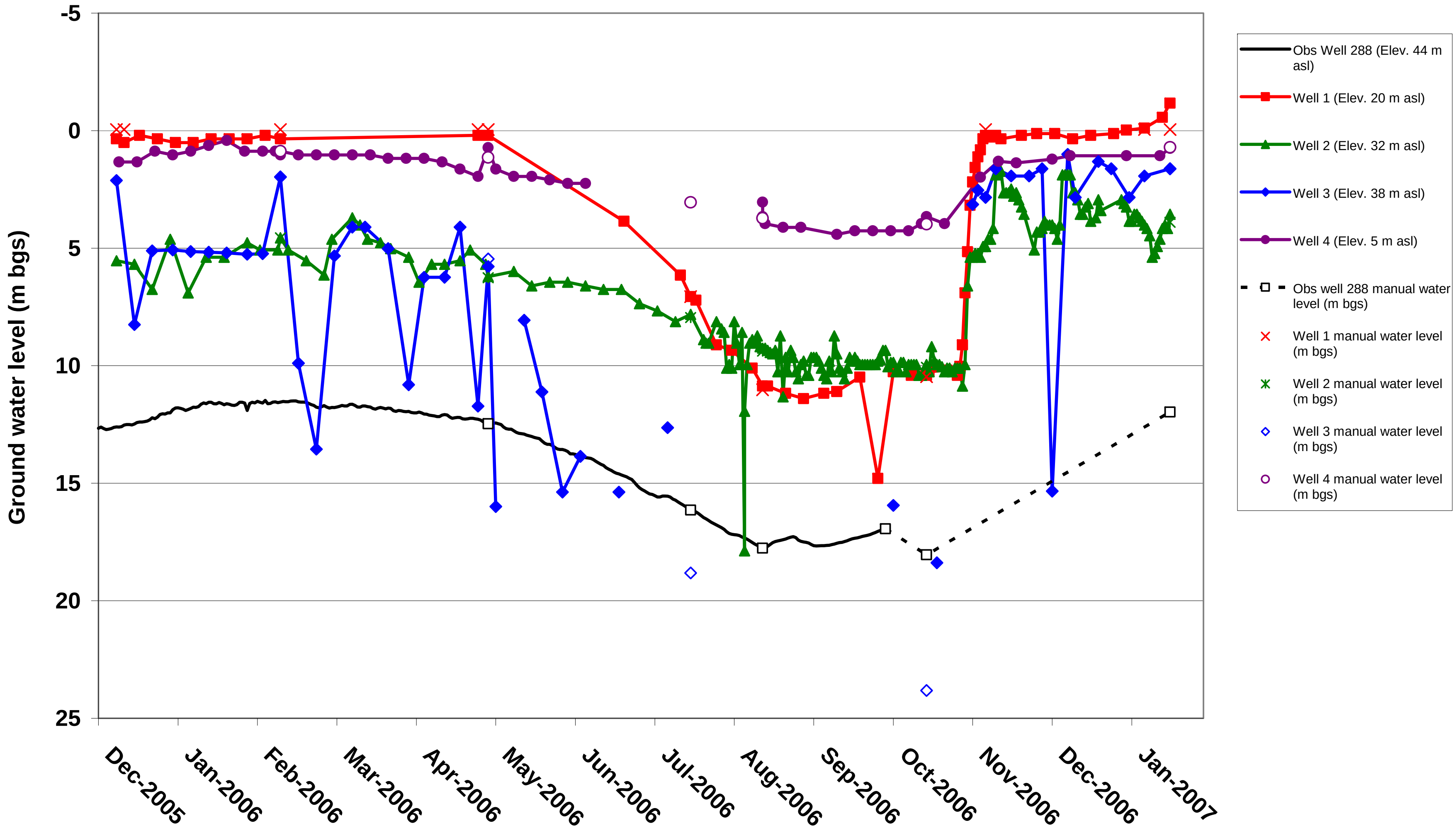
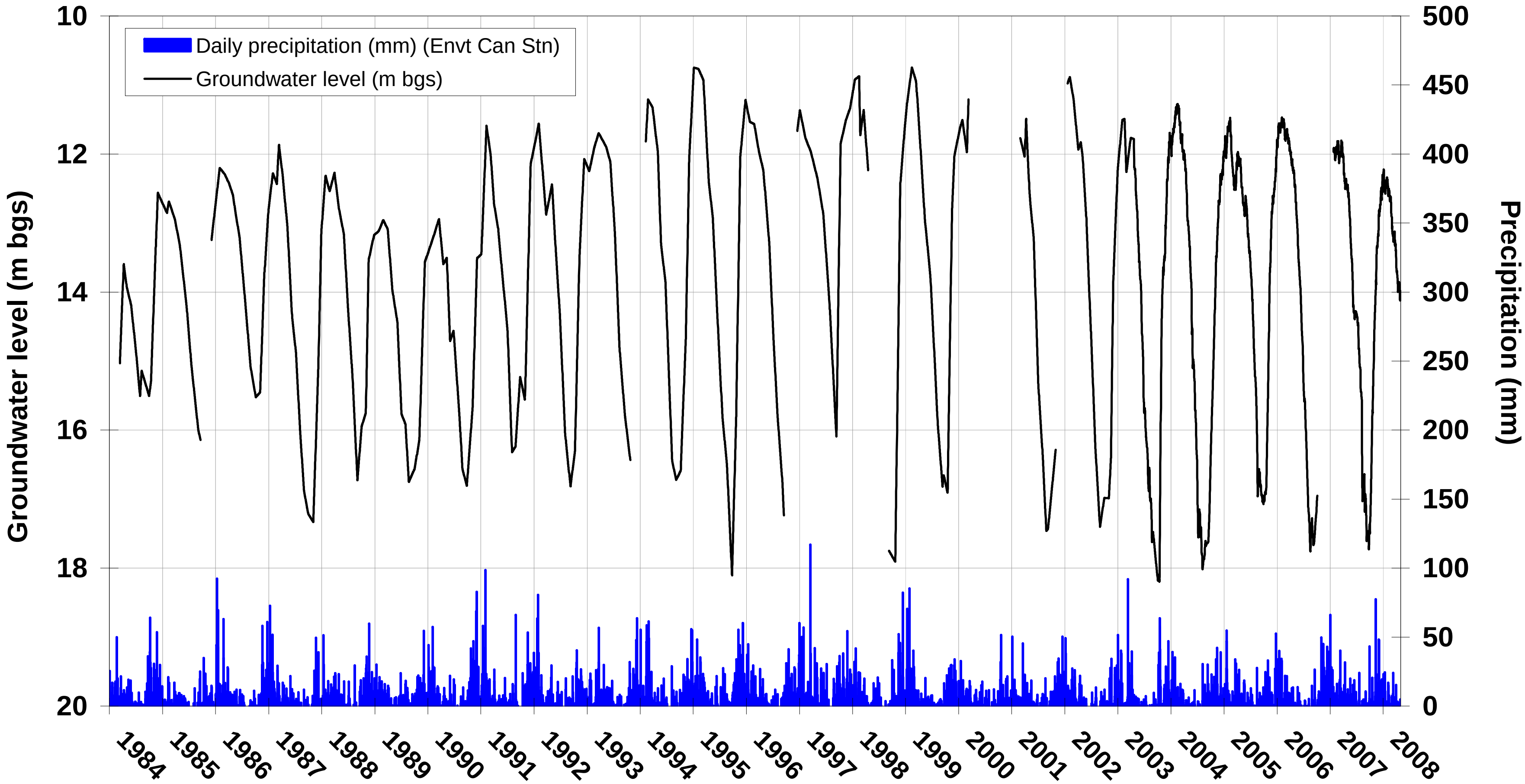


Figure 4. Well 288 hydrograph compared to daily average precipitation (March 1984 to April 2008)



Well 2 had a very detailed record and large number of data points collected by the well owner. A possible data outlier on August 10, 2006 (thought to have been taken soon after a well pumping cycle) was removed. Excluding this data point, the maximum water level observed was 11.94 m bgs. The minimum (shallowest) level was 1.73 m bgs. The median water level was 7.36 m bgs, the deepest median level of the domestic well sites. The annual range between the minimum and maximum water level was 10.21 m.

Well 3 had an annual fluctuation of 17.37 m between maximum and minimum water levels, the greatest range of all the domestic wells. It also appeared to exhibit the greatest influence from pumping. The pumping effect may be due to a low well capacity (i.e. water levels decline rapidly and the well recharges slowly after periods of pumping) or may have been more pronounced due to the choice of time when the readings were collected by the owner (some values may not have been true 'static' water levels if they were collected during or very soon after the well had been pumped, or if there was an influence from pumping of other nearby wells). The median water level in well 3 was 5.16 m bgs, the minimum water level was 1.01 m bgs, and the maximum water level was 18. 38 m bgs (the deepest of all monitoring sites). No air line data were available for well 3 from mid-July to early November. During this period the end of the tubing for well 3 was not submerged as it could not be advanced passed an unknown obstruction in the well column, and groundwater levels had declined below the depth to which the tubing was able to be installed. Cascading water from shallow fractures in the well, and the physical obstruction that prevented insertion of the electric probe deeper than 24 m also prevented staff from obtaining a consistent manual electric tape water level measurement during the summer period when water levels were lowest. For these reasons there is an overall lower level of confidence in both the manual and instrument readings from well 3, and it was not possible to determine if there were potential outliers.

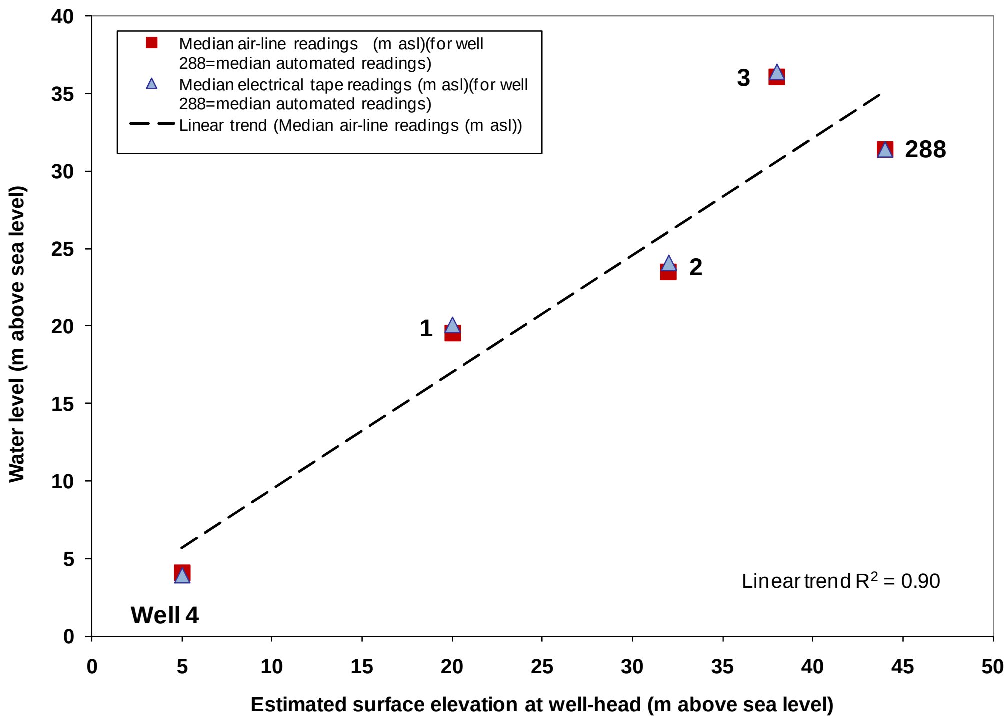
Well 4, had the lowest elevation relative to sea level, is located within a groundwater discharge zone, and exhibited the shallowest median water level at 1.33 m bgs. It also showed the narrowest annual range of groundwater level fluctuation from 0.42 to 4.40 m bgs (range 3.98 m). The instrumentation in well 4 had to be re-installed in August, as the original tubing was accidentally cut at the top of the well while the well owner was doing pump house maintenance. As a result, data were lost over the June to August period. Well 4 has an estimated yield of 1.9 L/s (0.5 USgpm), the lowest productivity of the wells for which a well construction record was available. No obvious outliers were observed in the data for Well 4.

In Figure 4 is the long-term hydrograph of monthly groundwater levels at well 288, from March 1984 to April 2008, compared to total daily precipitation measured at an Environment Canada weather monitoring station (Station ID 1026565, Qualicum River Fish Research Centre), located approximately15 km southwest of the observation well. The hydrograph shows a distinct seasonal change in ground water levels with as much as a 7 m or more variation between winter and summer each year. Over a longer-term period there can be up to 1 m variations in the summer low or the winter high water level from year to year. Peak high water levels lag approximately one month after peak daily winter precipitation. Annually, 2004 and 2005 were years of lower total precipitation (1062 mm and 1287 mm respectively). In comparison, 2006 saw the highest total precipitation (1478 mm) in more than six years. Putting the domestic well monitoring period in context of the longer-term trend, at the end of a year of monitoring (December 2005 to December

2006), water in most of the wells had risen to approximately the same level as the previous year, however in the last month of monitoring (January 2007) there was a slight rise above the previous winter's levels at all sites ranging from 0.3 m to as much as 1.0 m.

Average groundwater level (elevation or depth) is plotted as a function of the well elevation in Figure 5. The figure illustrates that, as expected, groundwater levels within the aquifer roughly follow the topographic gradient, and are deeper below the surface at high elevation and closer to the surface in lower elevation wells.

Figure 5. Estimated well head surface elevation for Hornby Island monitoring sites compared to average electrical tape and submerged air-line water level readings in meters above sea level (m asl)



3.3 Gabriola Island domestic well monitoring

In July 2007 MoE staff visited nine wells sites with air-line monitors installed. During the field visits it was observed that many well owners use the pressure data directly (i.e. observing and recording changes in pressure or water height above the bottom of the tube throughout the year) rather than calculating the depth of water below ground surface.

Two advantages of calculating the water depth from the air-line data is being able to compare readings taken when the instrument was set up differently (i.e. if tubing was pulled out or dropped further into the well) and to be able to more easily compare data from different monitoring sites. For example, if the pressure gauge reads 10 ft this just indicates that the tubing is submerged 10 ft into the water; there could be significant difference in water level depending on whether the tubing is 20 ft compared to 100 ft in length. The Gabriola Island field visits also illustrated the value of the calibration step. For example, the median discrepancy between electric tape and air-line readings was ± 2.11 m and the average error was ± 4.83 m for all sites. The best accuracy of ± 0.07 m was achieved after pulling out the tubing, re-measuring the length to the nearest centimetre using a surveyor tape, re-installing the tube and taking a new pressure measurement. The maximum discrepancy between air-line and electrical tape measurements was 21.65 m, where the well owner had only a rough approximation of the tube length.

One well owner had made his own air-line monitor using plastic tubing, a pressure gauge and a bicycle pump. In comparison to the other units, the tubing (similar to that used for wine making) had a wider diameter and was made of thicker plastic. This tubing seemed more resilient, easier to handle and may be less susceptible to stretching and damage such as getting cut, kinked or punctured in comparison to the thin tubing used in the other manufactured units.

The well owners on Gabriola Island had been monitoring their water levels using the air-line instruments for as little as a month to as long as 4 years. Very few of the people had plotted their monitoring results. Although it takes extra effort, there is potential value in plotting water level fluctuation over time to create a hydrograph, which can be compared from season to season or year to year. For example, it is often easier to observe patterns in data by looking at a graph in comparison to looking at raw numbers.

The Gabriola Island field visits suggest that, for this type of domestic well monitoring to provide the greatest value, well owners could be provided with more information on how to install the units, calibrate them, trouble-shoot problems, record and use the data.

4 Conclusions

This study evaluated the use of air-line monitors to measure water level over time within a small set of domestic wells in a Hornby Island aquifer compared to groundwater levels measured within a dedicated observation well in the same aquifer.

When the domestic well data were plotted with the data from observation well 288, the hydrographs for each well followed approximately the same pattern over the year-long monitoring period, suggesting there is a correlation between water levels in the observation well and in domestic wells within the same aquifer. Water levels in the aquifer were also related to elevation at the monitoring location; groundwater was shallower at lower elevation sites compared to at higher elevation where groundwater was deeper below the surface.

Based on comparison to manual water levels collected using an electric tape, the accuracy of the submerged air-line units ranged from 0.06 to 1.39 m, and the median error was ± 0.05 m. The measuring range of the pressure gauge is thought to be the main limiting factor affecting the instrument accuracy. Obtaining an accurate measurement of the water level using an electric water level meter to compare to the air-line measurement was difficult in cases where there was a narrow access port, physical blockage in the well that prevented insertion of the electric probe or where there was cascading water in the well that caused a false reading from the electric tape.

A primary benefit of this study involving volunteer well owners was the opportunity for increased awareness. Typically a domestic well may be checked or inspected on an infrequent basis or when problems occur. By using the air-line monitors, participants developed an interest in, and understanding of, changes in their well in response to natural seasonal water level variation in the aquifer, water usage, or activities in the well capture zone. For example, one participant noticed a significant increase in her well water level the day after she discharged a large volume of stored water to the ground surface during cleanout of her cistern. This suggests that her well responds rapidly to surface inputs, and may be recharged through shallow fractures. Another participant observed a significant increase in the water level after he had been away from the home on vacation. Monitoring thus provides rapid feedback on how water use and/or precipitation and recharge events influence well water levels. The collection of water level data over an extended period of many years can assist with the evaluation of long-term trends or changes, such as deepening water levels in response to increasing aquifer development and groundwater use. Problems with the well itself, such as diminished capacity over time, may also be discovered more quickly.

Although the air-line instrumentation has a lower cost compared to some other monitoring equipment, the degree of accuracy may be a drawback. Due to the estimated accuracy level (approximately ±0.05 m) the method is considered suitable for monitoring fractured bedrock aquifers in the Gulf Islands where annual water level fluctuations of 10 m or more are common. The method is likely less suitable for unconsolidated (sand and gravel) aquifers that show annual variation in the range of tens of cm's. The air-line method is also best used for dedicated monitoring in a single well, and not feasible for multiple well surveys. A comparison of different monitoring methods and devices is presented in Appendix E.

Working in and around wells necessitates that care be taken not to introduce contamination, either from materials falling into an opened well head, or from the instrumentation. A benefit of a submerged air-line is that it is designated for use in a single well, and is usually left installed, minimizing the opportunities for contamination to be introduced when the well head is opened up or cross-contamination occurring from use of the same instrument in multiple wells. To maintain sanitary conditions the electrical water level tape was disinfected and rinsed in between visits to each site. Proper installation of the equipment would have been easier if there was a dedicated conduit or access tube in each well where the tubing and water lines could be inserted.

This study showed that it is feasible for well owners to better understand their well and water supply by monitoring their well water levels. However, to maximize the quality of the data obtained, it is essential that the instrumentation be provided with detailed installation and operation instructions. Calibration of the pressure measurements to a reference level such as the ground surface or sea level also allows for further use of the data beyond the individual home owner to potential aquifer scale applications.

5 Recommendations

Based on the evaluation of the domestic well monitoring program in the Hornby Island Mount Geoffrey aquifer, and the selected group of private wells visited briefly on Gabriola Island, the following recommendations are proposed:

- Domestic well monitoring should continue to be encouraged, due to the benefits for the well owner to assist with effective management of their water supply;
- The submerged air-line monitoring method is not recommended in all situations. Other methods are preferable where there is a need for a higher level of accuracy, for example, to evaluate water level changes during a pumping test, where there is very small range between maximum and minimum water levels during the year, or for monitoring a community well or utility, where there is a large number of users reliant upon the data (a description of different monitoring methods is found in Appendix E);
- Care must be taken to reduce the risk of contamination being introduced when working in and around a well head. Disinfection of equipment used within multiple wells is necessary to ensure maintenance of sanitary conditions;
- Care must be taken when monitoring a well that is in use, and has a pump, water lines and other equipment installed. It is highly recommended that an equipment conduit or access tube, such as PVC piping, be permanently installed inside the well, for example when the pump is installed or serviced;
- Well owners using the submerged air-line method would benefit from additional training and detailed reference materials, to ensure that the equipment is properly installed, calibrated and used on a long-term basis. The collected monitoring values should be converted to hydraulic head measurements by the well owners, using calculation methods such as described in this report, so that the data are easily used and compared between sites in the same aquifer or area.

6 References

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Appendix A: Photos

Photo 1. Ministry of Environment staff Pat Lapcevic and Brian Epps testing a submerged air-line water level monitor using a demonstration well.

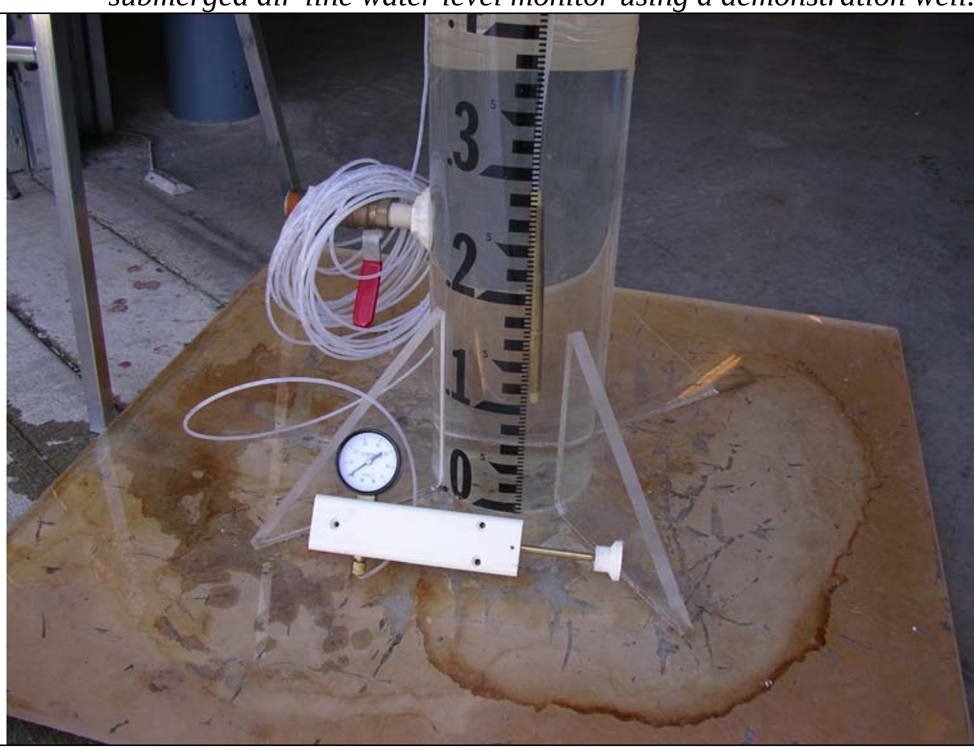


Photo 2. Close-up view of air-line unit showing pressure gauge, pump and tubing (note bronze metal weights on bottom end of tubing).

Photo 3. Well 1 with air-line installed.

Photo 4. Well 3 with air-line installed and electrical water meter inserted into the front bolt hole.

Appendix B: Example field data collection sheet

Domestic Well Level Monitoring Project - Field data sheet

Well Owner: ____________ **Well coordinates:** ____________

____

Location: ____________

____

Start Date: ____________ ____________ metres

Stick-up (SU): ____________ **Well Head Elevation:** m above sea level

Tubing Length (TL): ____________ metres below well head

L= TL - SU= ____________ metres below ground surface (m bgs)

Water level calculation: **WL = L - H** m bgs (calculate and enter on data sheet below)

Manual water level, ML (electric tape) ____________ m bgs Date/time: ____________

Correction factor, C = WL - ML ____________ m

L_{adj}=L - C ____________ m bgs

Notes: L_{adj} = Adjusted tube length (from first calibration) = estimated tube length minus the difference between manual water level taken using a water level tape and the air-line water level). Use L_{adj} for subsequent WL claculations.

Date (mmm-dd-yyyy)	Time (hh:mm)	L (mbgs)	Reading (feet of water)	H (m) (reading x 0.3048)		WL (mbgs)	Comments (manual water levels, observations, etc.)

Appendix C: Hornby Island domestic well monitoring data

Hornby Island Domestic Well Level Monitoring Project

Well 1 Elev. 20 masl			Stick-up (SU):	0.05	metres
Site number:	1		Tubing length (TL):	15.00	metres below top of casing
Start Date:	8-Dec-05		L= TL - SU	14.95	metres below ground surface
(Est. Elevation)	23	meters above sea level (masl, determined from recreational GPS)	E estimated error*:	-0.03	m
Well elevation:	20	meters above sea level (masl, estimated from topographic map contours	L_{adj} = L - E	14.98	metres below ground surface
			WL formula:	**WL = L_{adj} - H**	metres below ground surface

*Based on first reliable comparison of air-line to manual measurement (as indicated in "comments")

Date	Time	R, well watcher reading	H, converted well watcher reading (R x 0.3048)	WL, corrected air-line ground water level (L_{adj} - H)	M, manual water level	M_{adj}, manual water level (M - SU)	E, estimated error (WL - M_{adj})	Comments
Units		**(ft)**	**(m)**	**(m bgs)**	**(m btoc)**	**(m bgs)**	**(m)**	
08-Dec-05	11:40	48.0	14.63	0.35	0.00	-0.05	0.40	Static wlvl at toc, flowing at average rate of 0.48 L/min (0.13 USgpm)
11-Dec-05	10:45	47.5	14.48	0.51	0.00	-0.05	0.56	Static wlvl at toc
17-Dec-05	9:50	48.5	14.78	0.20				
24-Dec-05	9:15	48.0	14.63	0.35				
31-Dec-05	9:50	47.5	14.48	0.51				
07-Jan-06	9:11	47.5	14.48	0.51				
14-Jan-06	8:47	48.0	14.63	0.35				
21-Jan-06	10:05	48.0	14.63	0.35				
28-Jan-06	9:36	48.0	14.63	0.35				
04-Feb-06	8:56	48.5	14.78	0.20				
10-Feb-06	1:05	48.0	14.63	0.35	0.00	-0.05	0.40	Water level at or exceeding top of casing (artesian) throughout monitoring period
28-Apr-06	12:46	48.5	14.78	0.20	0.00	-0.05	0.25	Discontinued monitoring over Feb-April period. Well artesian when monitored on April 28
02-May-06	11:59	48.5	14.78	0.20	0.00	-0.05	0.25	Artesian - water flowing slowly from discharge tube attached to well head
24-Jun-06	15:00	36.5	11.13	3.86				
16-Jul-06	10:00	29.0	8.84	6.15				
20-Jul-06	13:54	26.0	7.92	7.06	7.11	7.06	0.00	This measurement used to determine instrument error as it is considered most accurate (first time that head measured was below ground surface, not artesian)
20-Jul-06	13:54	26.0	7.92	7.06	7.11	7.06	0.00	
22-Jul-06	12:15	25.5	7.77	7.21				
30-Jul-06	9:12	19.3	5.87	9.12				
05-Aug-06	7:40	18.5	5.64	9.35				
13-Aug-06	11:47	16.0	4.88	10.11				
17-Aug-06	10:45	13.5	4.11	10.87	11.08	11.03	-0.16	
19-Aug-06	10:55	13.5	4.11	10.87				
26-Aug-06	9:28	12.5	3.81	11.17				
02-Sep-06	12:12	11.8	3.58	11.40				
10-Sep-06	16:54	12.5	3.81	11.17				
15-Sep-06	9:12	12.8	3.89	11.10				
24-Sep-06	10:12	14.8	4.50	10.49				
01-Oct-06	6:30	0.6	0.19	14.79				Very low (outlier, possibly taken after recent pumping, remove from hydrograph)
07-Oct-06	8:20	15.5	4.72	10.26				
14-Oct-06	10:10	15.0	4.57	10.41				
20-Oct-06	12:58	15.0	4.57	10.41	10.52	10.47	-0.06	
21-Oct-06	9:16	15.5	4.72	10.26				
28-Oct-06	10:43	15.8	4.80	10.18				
31-Oct-06	9:10	15.5	4.72	10.26				
01-Nov-06	9:00	15.0	4.57	10.41				
02-Nov-06	8:40	16.3	4.95	10.03				
03-Nov-06	10:10	19.3	5.87	9.12				Heavy rain in morning
04-Nov-06	9:20	26.5	8.08	6.91				Heavy rain in morning
05-Nov-06	9:45	32.3	9.83	5.16				Heavy rain previous night (pump on during measurement)
06-Nov-06	10:10	38.8	11.81	3.17				Heavy rain previous night, intermittent during day
07-Nov-06	8:55	42.0	12.80	2.18				
08-Nov-06	19:10	44.0	13.41	1.57				
09-Nov-06	9:45	45.5	13.87	1.12				

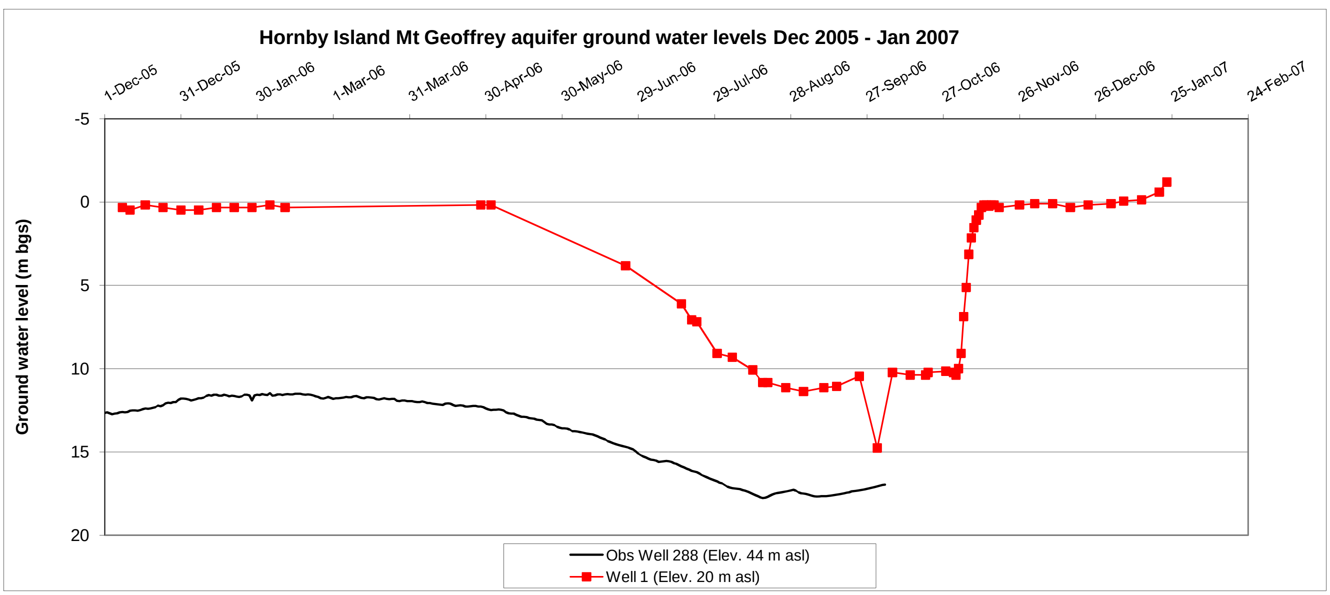
Hornby Island Domestic Well Level Monitoring Project

Well 1 Elev. 20 masl		Stick-up (SU):	0.05 metres
Site number:	1	Tubing length (TL):	15.00 metres below top of casing
Start Date:	8-Dec-05	L= TL - SU	14.95 metres below ground surface
(Est. Elevation)	23 meters above sea level (masl, determined from recreational GPS)	E estimated error*:	-0.03 m
Well elevation:	20 meters above sea level (masl, estimated from topographic map contours	L_{adj} = L - E	14.98 metres below ground surface
		WL formula:	**WL = L_{adj} - H** metres below ground surface

*Based on first reliable comparison of air-line to manual measurement (as indicated in "comments")

Date	Time	R, well watcher reading	H, converted well watcher reading (R x 0.3048)	WL, corrected air-line ground water level (L_{adj} - H)	M, manual water level	M_{adj}, manual water level (M - SU)	E, estimated error (WL - M_{adj})	Comments
Units		**(ft)**	**(m)**	**(m bgs)**	**(m btoc)**	**(m bgs)**	**(m)**	
10-Nov-06	9:15	46.5	14.17	0.81				Hard rain previous night
11-Nov-06	9:40	48.0	14.63	0.35				Hard rain previous night
12-Nov-06	11:50	48.5	14.78	0.20	0.00	-0.05	0.25	Power outage, well artesian (at top of casing, not flowing)
13-Nov-06	9:08	48.5	14.78	0.20				
14-Nov-06	9:15	48.3	14.71	0.28				
15-Nov-06	9:00	48.5	14.78	0.20				
16-Nov-06	8:45	48.5	14.78	0.20				
18-Nov-06	9:25	48.0	14.63	0.35				Pump on prior to measurement
26-Nov-06	8:35	48.5	14.78	0.20				Snow, power outage
02-Dec-06	9:12	48.8	14.86	0.13				
09-Dec-06	9:45	48.8	14.86	0.13				Heavy rain during day
16-Dec-06	10:35	48.0	14.63	0.35				Power outage, well not in use
23-Dec-06	9:25	48.5	14.78	0.20				Light rain
01-Jan-07	9:15	48.8	14.86	0.13				Light rain
06-Jan-07	9:05	49.3	15.01	-0.03				Rain
13-Jan-07	10:25	49.5	15.09	-0.10	0.00	-0.05	-0.05	Flowing artesian
20-Jan-07	9:35	51.0	15.54	-0.56				
23-Jan-07	10:15	53.0	16.15	-1.17	0.00	-0.05	-1.12	Well artesian, flowing at variable rate

Notes: Well is seasonally artesian. Water level taken to be level with top of casing when artesian conditions reported (during Ministry of Environment field visits and for well owner measurements).



Hornby Island Domestic Well Level Monitoring Project: Water level data

Well 2 Elev. 32 masl		Stick-up (SU):	0.16	metres
Site number	2	Tubing length (TL):	20.00	metres below well head
Start Date:	8-Dec-05	L= TL - SU	19.84	metres below ground surface
(Est. Elevation)	34 masl meters above sea level (masl, determined from recreational GPS)	E, estimated error*:	0.44	m
Well elevation:	32 meters above sea level (masl, estimated from topographic map contours	L_{adj} = L - E	19.40	metres below ground surface
		WL formula:	**WL = L - H**	

*Based on first reliable comparison of air-line to manual measurement (as indicated in "comments")

Date	Time	R, well watcher reading	H, converted well watcher reading (R x 0.3048)	WL, corrected air-line ground water level (L_{adj} - H)	M, manual water level	M_{adj}, manual water level (M - SU)	E, estimated error (WL - M_{adj})	Comments
Units	**(hh:mm)**	**(ft)**	**(m)**	**(m bgs)**	**(m btoc)**	**(m bgs)**	**(m)**	
08-Dec-05	12:40	45.5	13.9	5.54				
15-Dec-05	2:20	45.0	13.7	5.69				
22-Dec-05	1:00	41.5	12.6	6.75				
29-Dec-05	2:30	48.5	14.8	4.62				
05-Jan-06	3:30	41.0	12.5	6.91				
12-Jan-06	2:30	46.0	14.0	5.38				
19-Jan-06	3:00	46.0	14.0	5.38				
28-Jan-06	12:20	48.0	14.6	4.77				
02-Feb-06	3:00	47.0	14.3	5.08				
09-Feb-06	4:30	47.0	14.3	5.08				
10-Feb-06	12:18	48.7	14.8	4.56	4.72	4.56	0.00	
10-Feb-06	12:18	48.7	14.8	4.56	4.72	4.56	0.00	This manual measurement used to determine instrument error
13-Feb-06	11:10	47.0	14.3	5.08				
20-Feb-06	12:00	45.5	13.9	5.54				
27-Feb-06	10:30	43.5	13.3	6.14				
02-Mar-06	16:00	48.5	14.8	4.62				
10-Mar-06	18:00	51.5	15.7	3.71				
13-Mar-06	10:00	50.5	15.4	4.01				
16-Mar-06	10:30	48.5	14.8	4.62				
21-Mar-06	11:00	48.0	14.6	4.77				
25-Mar-06	11:30	47.2	14.4	5.02				
01-Apr-06	9:15	46.0	14.0	5.38				
05-Apr-06	16:30	42.5	13.0	6.45				
10-Apr-06	17:00	45.0	13.7	5.69				
15-Apr-06	12	45.0	13.7	5.69				
21-Apr-06	15:00	45.5	13.9	5.54				
25-Apr-06	14:30	47.0	14.3	5.08				
01-May-06	11:00	45.0	13.7	5.69				
02-May-06	13:13	43.3	13.2	6.21	6.42	6.26	-0.05	Manual wlvl measurement 6.42 m btoc = 6.26 m bgs
12-May-06	8:30	44.0	13.4	5.99				
19-May-06	16:00	42.0	12.8	6.60				
26-May-06	11:30	42.5	13.0	6.45				
02-Jun-06	15:30	42.5	13.0	6.45				
09-Jun-06	14:40	42.0	12.8	6.60				
16-Jun-06	16:00	41.5	12.6	6.75				
23-Jun-06	10:30	41.5	12.6	6.75				
30-Jun-06	16:00	39.5	12.0	7.36				
07-Jul-06	18:00	38.5	11.7	7.67				
14-Jul-06	9:30	37.0	11.3	8.13				
20-Jul-06	8:00	29.0	8.8	10.56				
20-Jul-06	10:40	33.0	10.1	9.35	8.12	7.96	1.39	Initial measurement
20-Jul-06	10:50	38.0	11.6	7.82	8.11	7.95	-0.13	Second measurement after additional pumping of instrument and evacuation of pressure tubing.
25-Jul-06	21:15	34.5	10.5	8.89				
26-Jul-06	8:15	34.0	10.4	9.04				
27-Jul-06	8:15	34.0	10.4	9.04				
30-Jul-06	9:15	37.0	11.3	8.13				
01-Aug-06	21:00	36.0	11.0	8.43				
02-Aug-06	9:00	35.5	10.8	8.58				
03-Aug-06	13:30	30.5	9.3	10.11				
04-Aug-06	12:30	31.0	9.4	9.95				
05-Aug-06	8:30	30.5	9.3	10.11				
06-Aug-06	9:30	37.0	11.3	8.13				
07-Aug-06	9:00	34.0	10.4	9.04				
08-Aug-06	9:30	31.0	9.4	9.95				
09-Aug-06	9:30	35.5	10.8	8.58				
10-Aug-06	9:00	5.0	1.5	17.88				Suspect value, not able to determine cause
10-Aug-06	14:00	24.5	7.5	11.94				
11-Aug-06	8:15	31.0	9.4	9.95				

Hornby Island Domestic Well Level Monitoring Project: Water level data

Well 2 Elev. 32 masl

Site number	2	
Start Date:	8-Dec-05	
(Est. Elevation)	34 masl	meters above sea level (masl, determined from recreational GPS)
Well elevation:	32	meters above sea level (masl, estimated from topographic map contours

Stick-up (SU):	0.16	metres
Tubing length (TL):	20.00	metres below well head
L= TL - SU	19.84	metres below ground surface
E, estimated error*:	0.44	m
L_{adj} = L - E	19.40	metres below ground surface
WL formula:	**WL = L - H**	

*Based on first reliable comparison of air-line to manual measurement (as indicated in "comments")

Date	Time	R, well watcher reading	H, converted well watcher reading (R x 0.3048)	WL, corrected air-line ground water level (L_{adj} - H)	M, manual water level	M_{adj}, manual water level (M - SU)	E, estimated error (WL - M_{adj})	Comments
Units	**(hh:mm)**	**(ft)**	**(m)**	**(m bgs)**	**(m btoc)**	**(m bgs)**	**(m)**	
12-Aug-06	13:40	34.0	10.4	9.04				
13-Aug-06	9:00	34.5	10.5	8.89				
14-Aug-06	8:30	34.0	10.4	9.04				
15-Aug-06	8:40	35.0	10.7	8.74				
16-Aug-06	9:30	33.5	10.2	9.19				
17-Aug-06	9:00	33.0	10.1	9.35				
17-Aug-06	9:35	33.3	10.1	9.25	9.54	9.38	-0.13	
18-Aug-06	12:00	33.3	10.1	9.25				
19-Aug-06	9:00	33.0	10.1	9.35				
20-Aug-06	8:30	32.7	10.0	9.44				
21-Aug-06	8:30	32.5	9.9	9.50				
22-Aug-06	8:30	33.0	10.1	9.35				
23-Aug-06	9:00	30.0	9.1	10.26				
24-Aug-06	8:10	35.0	10.7	8.74				
25-Aug-06	9:15	26.5	8.1	11.33				
26-Aug-06	8:15	32.0	9.8	9.65				
27-Aug-06	8:50	30.0	9.1	10.26				
28-Aug-06	8:15	33.0	10.1	9.35				
29-Aug-06	8:30	32.0	9.8	9.65				
30-Aug-06	8:30	30.0	9.1	10.26				
31-Aug-06	9:30	29.0	8.8	10.56				
01-Sep-06	10:00	31.0	9.4	9.95				
02-Sep-06	10:50	31.5	9.6	9.80				
03-Sep-06	8:30	29.5	9.0	10.41				
04-Sep-06	9:00	29.5	9.0	10.41				
05-Sep-06	9:30	32.0	9.8	9.65				
06-Sep-06	8:40	32.0	9.8	9.65				
07-Sep-06	9:00	32.0	9.8	9.65				
08-Sep-06	9:30	31.5	9.6	9.80				
09-Sep-06	9:45	30.5	9.3	10.11				
10-Sep-06	8:15	29.5	9.0	10.41				
11-Sep-06	9:50	29.0	8.8	10.56				
12-Sep-06	9:00	31.5	9.6	9.80				
13-Sep-06	10:00	30.0	9.1	10.26				
14-Sep-06	18:30	35.0	10.7	8.74				Power outage Sept. 13 (14 hrs) well not in use
15-Sep-06	9:15	32.5	9.9	9.50				
16-Sep-06	9:10	30.5	9.3	10.11				
17-Sep-06		30.0	9.1	10.26				
18-Sep-06	11:00	29.0	8.8	10.56				
19-Sep-06	12:15	30.5	9.3	10.11				
20-Sep-06	9:00	32.0	9.8	9.65				
21-Sep-06	8:30	31.5	9.6	9.80				
22-Sep-06	9:30	32.0	9.8	9.65				
23-Sep-06	9:00	31.5	9.6	9.80				
24-Sep-06	9:30	31.0	9.4	9.95				
25-Sep-06	9:00	31.0	9.4	9.95				
26-Sep-06	9:10	31.0	9.4	9.95				
27-Sep-06	9:15	31.0	9.4	9.95				
28-Sep-06	9:30	31.0	9.4	9.95				
29-Sep-06	9:00	31.0	9.4	9.95				
30-Sep-06	12:00	31.0	9.4	9.95				
01-Oct-06	10:30	31.5	9.6	9.80				
02-Oct-06	9:15	31.7	9.7	9.74				
03-Oct-06	16:45	33.0	10.1	9.35				
04-Oct-06	9:30	33.0	10.1	9.35				
05-Oct-06	10:20	30.7	9.4	10.05				
06-Oct-06	8:50	31.3	9.5	9.86				
07-Oct-06	8:45	31.3	9.5	9.86				
08-Oct-06	8:30	30.0	9.1	10.26				
09-Oct-06	8:15	30.3	9.2	10.17				
10-Oct-06	16:00	31.3	9.5	9.86				
11-Oct-06	8:50	31.3	9.5	9.86				
12-Oct-06	9:10	30.0	9.1	10.26				
13-Oct-06	9:00	31.0	9.4	9.95				

Hornby Island Domestic Well Level Monitoring Project: Water level data

Well 2 Elev. 32 masl

Site number	2		Stick-up (SU):	0.16 metres
Start Date:	8-Dec-05		Tubing length (TL):	20.00 metres below well head
(Est. Elevation)	34 masl	meters above sea level (masl, determined from recreational GPS)	L= TL - SU	19.84 metres below ground surface
Well elevation:	32	meters above sea level (masl, estimated from topographic map contours	E, estimated error*:	0.44 m
			L_{adj} = L - E	19.40 metres below ground surface
			WL formula:	**WL = L - H**

*Based on first reliable comparison of air-line to manual measurement (as indicated in "comments")

Date	**Time**	**R, well watcher reading**	**H, converted well watcher reading (R x 0.3048)**	**WL, corrected air-line ground water level (L_{adj} - H)**	**M, manual water level**	**M_{adj}, manual water level (M - SU)**	**E, estimated error (WL - M_{adj})**	**Comments**
Units	**(hh:mm)**	**(ft)**	**(m)**	**(m bgs)**	**(m btoc)**	**(m bgs)**	**(m)**	
14-Oct-06	9:30	31.0	9.4	9.95				
15-Oct-06	9:30	31.0	9.4	9.95				
16-Oct-06	11:30	31.0	9.4	9.95				
17-Oct-06	10:30	29.5	9.0	10.41				
18-Oct-06	9:30	29.5	9.0	10.41				
20-Oct-06	9:00	30.5	9.3	10.11				
20-Oct-06	12:15	31.0	9.4	9.95	10.23	10.07	-0.12	
20-Oct-06	12:25	30.5	9.3	10.11	10.23	10.07	0.04	
21-Oct-06	10:30	30.0	9.1	10.26				
22-Oct-06	9:45	33.5	10.2	9.19				
23-Oct-06	9:15	31.5	9.6	9.80				
24-Oct-06	9:00	31.0	9.4	9.95				
25-Oct-06	10:15	31.0	9.4	9.95				
26-Oct-06	9:30	30.7	9.4	10.05				
27-Oct-06	9:00	30.0	9.1	10.26				
28-Oct-06	10:00	30.5	9.3	10.11				
29-Oct-06	9:00	30.5	9.3	10.11				
30-Oct-06	10:00	30.0	9.1	10.26				
31-Oct-06	9:15	30.5	9.3	10.11				
01-Nov-06	9:00	30.5	9.3	10.11				
02-Nov-06	17:00	30.5	9.3	10.11				
03-Nov-06	9:15	28.0	8.5	10.87				
04-Nov-06	10:30	31.0	9.4	9.95				Emptied 600 gallon tank onto ground 100 ft from well
05-Nov-06	9:30	42.0	12.8	6.60				
06-Nov-06	8:40	46.0	14.0	5.38				
07-Nov-06	9:30	46.0	14.0	5.38				
08-Nov-06	11:00	46.5	14.2	5.23				
09-Nov-06	10:15	46.5	14.2	5.23				
10-Nov-06	8:50	46.0	14.0	5.38				
11-Nov-06	9:15	47.5	14.5	4.93				
12-Nov-06	9:00	47.5	14.5	4.93				
13-Nov-06	8:30	48.5	14.8	4.62				
14-Nov-06	8:15	48.5	14.8	4.62				
15-Nov-06	10:30	50.0	15.2	4.16				
16-Nov-06	9:30	57.5	17.5	1.88				
17-Nov-06	9:15	58.0	17.7	1.73				
18-Nov-06	8:30	58.0	17.7	1.73				
19-Nov-06	10:00	55.0	16.8	2.64				
20-Nov-06	9:30	55.0	16.8	2.64				
21-Nov-06	9:30	55.0	16.8	2.64				
22-Nov-06	9:45	55.5	16.9	2.49				
23-Nov-06	9:00	54.5	16.6	2.79				
24-Nov-06	9:30	55.0	16.8	2.64				
25-Nov-06	11:00	54.0	16.5	2.94				
26-Nov-06	11:30	53.0	16.2	3.25				
27-Nov-06	10:30	52.0	15.8	3.55				No measurements for Nov. 28-30 due to frozen pump mechanism
01-Dec-06	10:00	47.0	14.3	5.08				
02-Dec-06	11:00	49.5	15.1	4.32				
03-Dec-06	10:30	49.5	15.1	4.32				
04-Dec-06	10:00	50.0	15.2	4.16				
05-Dec-06	11:00	51.0	15.5	3.86				
06-Dec-06	14:00	50.5	15.4	4.01				
07-Dec-06	12:00	50.5	15.4	4.01				
08-Dec-06	9:30	50.5	15.4	4.01				
09-Dec-06	11:30	50.0	15.2	4.16				
10-Dec-06	10:30	48.5	14.8	4.62				
11-Dec-06	9:30	50.5	15.4	4.01				Electricity out
12-Dec-06	9:30	57.5	17.5	1.88				
13-Dec-06	10:30	57.5	17.5	1.88				
14-Dec-06	9:00	57.5	17.5	1.88				
15-Dec-06	0:00	57.5	17.5	1.88				
16-Dec-06	11:00	55.0	16.8	2.64				

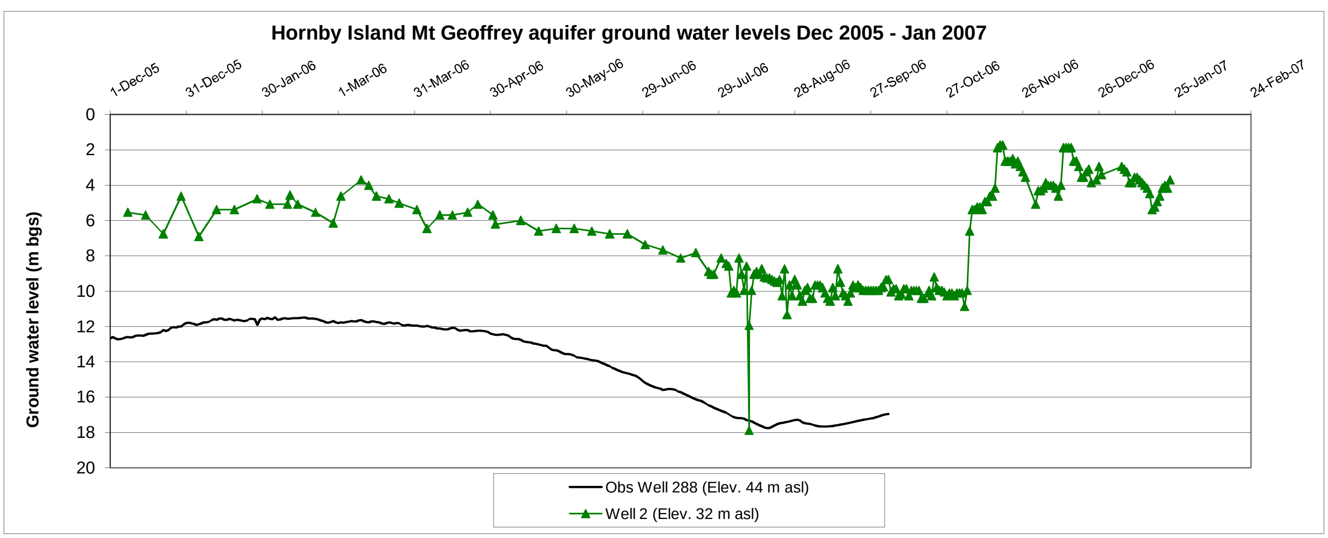
Hornby Island Domestic Well Level Monitoring Project: Water level data

Well 2 Elev. 32 masl		Stick-up (SU):	0.16	metres
Site number	2	Tubing length (TL):	20.00	metres below well head
Start Date:	8-Dec-05	L= TL - SU	19.84	metres below ground surface
(Est. Elevation)	34 masl meters above sea level (masl, determined from recreational GPS)	E, estimated error*:	0.44	m
Well elevation:	32 meters above sea level (masl, estimated from topographic map contours	$L_{adj} = L - E$	19.40	metres below ground surface
		WL formula:	**WL = L - H**	

*Based on first reliable comparison of air-line to manual measurement (as indicated in "comments")

Date	Time	R, well watcher reading	H, converted well watcher reading (R x 0.3048)	WL, corrected air-line ground water level (L_{adj} - H)	M, manual water level	M_{adj}, manual water level (M - SU)	E, estimated error (WL - M_{adj})	Comments
Units	**(hh:mm)**	**(ft)**	**(m)**	**(m bgs)**	**(m btoc)**	**(m bgs)**	**(m)**	
17-Dec-06	10:30	55.0	16.8	2.64				Electricity back on
18-Dec-06	14:00	54.0	16.5	2.94				
19-Dec-06	8:30	52.0	15.8	3.55				
20-Dec-06	12:30	52.0	15.8	3.55				
21-Dec-06	9:30	53.0	16.2	3.25				
22-Dec-06	10:00	53.5	16.3	3.10				
23-Dec-06	11:30	51.0	15.5	3.86				
25-Dec-06	10:30	51.5	15.7	3.71				
26-Dec-06	10:00	54.0	16.5	2.94				
27-Dec-06	12:00	52.5	16.0	3.40				Well not in use Dec. 28- Jan. 3
04-Jan-07	12:40	54.0	16.5	2.94				
05-Jan-07	10:00	53.5	16.3	3.10				
06-Jan-07	10:00	53.0	16.2	3.25				
07-Jan-07	10:00	51.0	15.5	3.86				
08-Jan-07	10:00	51.0	15.5	3.86				
09-Jan-07	10:00	52.0	15.8	3.55				
10-Jan-07	10:00	52.0	15.8	3.55				
11-Jan-07	10:00	51.5	15.7	3.71				
12-Jan-07	10:00	51.0	15.5	3.86				
13-Jan-07	10:00	50.5	15.4	4.01				
14-Jan-07	10:00	50.0	15.2	4.16				
15-Jan-07	10:00	49.0	14.9	4.47				
16-Jan-07	10:00	46.0	14.0	5.38				
17-Jan-07	10:00	46.5	14.2	5.23				
18-Jan-07	10:00	47.5	14.5	4.93				
19-Jan-07	10:00	48.5	14.8	4.62				
20-Jan-07	10:00	50.0	15.2	4.16				
21-Jan-07	10:00	50.5	15.4	4.01				
22-Jan-07	10:00	50.0	15.2	4.16				
23-Jan-07	10:00	51.5	15.7	3.71				
23-Jan-07	10:35	52.0	15.8	3.55	4.06	3.90	-0.35	

Notes: Initially did not have small diameter probe for measuring manual water level and well fitted with sanitary seal, therefore do not have static water level measurement for comparison on first day during set-up.



Hornby Island Domestic Well Level Monitoring Project: Water level data

Well 3 Elev. 38 masl

Site number: 3
Start Date: 08-Dec-05
(Est. Elevation): 33 meters above sea level (masl, determined from recreational GPS)
Well elevation: 38 meters above sea level (masl, estimated from topographic map contours)

*Based on first reliable comparison of air-line to manual measurement (as indicated in "comments")

**Based on first reliable comparison of air-line to manual measurement (as indicated in "comments")
Note: Tubing adjusted in well on July 28, therefore length measurement altered (see detailed notes below)

Stick-up (SU): 0.38 metres

Dec 8/05 to July 20, 2006

Tubing length (TL): 20.00 metres below well head
L= TL - SU: 19.62 metres below ground surface
E, estimated error*: 2.11 m
L_{adj} = L - E: 17.51 metres below ground surface
WL formula: **WL = L - H**

July 28, 2006 to January 23, 2007

Tubing length (TL): 24.00 metres below well head
L= TL - SU: 23.62 metres below ground surface
E, estimated error**: 2.19 m
L_{adj} = L - E: 21.43 metres below ground surface
WL formula: **WL = L - H**

Date	Time	R, well watcher reading	H, converted well watcher reading (R x 0.3048)	WL, corrected air-line ground water level (L_{adj} - H)	M, manual water level	M_{adj}, manual water level (M - SU)	E, estimated error (WL - M_{adj})	Comments
Units		**(ft)**	**(m)**	**(m bgs)**	**(m btoc)**	**(m bgs)**	**(m)**	
08-Dec-05	13:10	50.5	15.39	2.12				
15-Dec-05	16:55	30.4	9.27	8.25				
22-Dec-05	16:10	40.7	12.41	5.11				
30-Dec-05	23:34	40.8	12.44	5.08				
06-Jan-06	16:10	40.6	12.37	5.14				
13-Jan-06	16:35	40.5	12.34	5.17				
20-Jan-06	16:56	40.4	12.31	5.20				
28-Jan-06	11:30	40.2	12.25	5.26				Power outage 1am to 4am
03-Feb-06	21:05	40.3	12.28	5.23				
10-Feb-06	11:25	40.9	12.47	5.05				
10-Feb-06	11:50	51.0	15.54	1.97	2.350	1.970	0.00	This manual measurement used to determine instrument error
10-Feb-06	11:50	51.0	15.54	1.97	2.350	1.970	0.00	
17-Feb-06	16:40	25.0	7.62	9.89				
24-Feb-06	18:30	13.0	3.96	13.55				
03-Mar-06	20:00	40.0	12.19	5.32				
10-Mar-06	17:30	44.0	13.41	4.10				
15-Mar-06	12:15	44.0	13.41	4.10				
24-Mar-06	16:30	41.0	12.50	5.02				Well not in use March 16-March 21
01-Apr-06	19:45	22.0	6.71	10.81				
07-Apr-06	17:15	37.0	11.28	6.24				
15-Apr-06	19:00	37.0	11.28	6.24				
21-Apr-06	13:30	44.0	13.41	4.10				
28-Apr-06	15:55	19.0	5.79	11.72				
02-May-06	11:33	37.5	11.43	6.08				
02-May-06	11:45	38.5	11.73	5.78	5.840	5.460	0.32	Manual wlvl 5.84 mbtoc = 5.46 mbgs (pumphouse floor considered height of local grade)
05-May-06	16:05	5.0	1.52	15.99				
13-May-06	16:00	0.0	0.00					
16-May-06	16:35	31.0	9.45	8.07				
23-May-06	18:00	21.0	6.40	11.11				
31-May-06	17:00	7.0	2.13	15.38				
07-Jun-06	19:45	12.0	3.66	13.86				
15-Jun-06	17:25	0.0	0.00					
22-Jun-06	17:30	7.0	2.13	15.38				
29-Jun-06	15:35	0.0	0.00					
11-Jul-06	15:15	16.0	4.88	12.64				
18-Jul-06	15:50	0.0	0.00					Water level > indicated (aperature not immersed in water)
20-Jul-06	10:37	0.0	0.00		19.200	18.820	nc	Water level > indicated (aperature not immersed in water)
28-Jul-06	20:45	0.0	0.00					Deepened tubing placement, water level still not above the end of the tube, therefore not able to calculate error (see Jan 2007 calc)
01-Aug-06	17:35	0.0	0.00					
07-Aug-06	16:05	0.0	0.00					
13-Aug-06	16:00	0.0	0.00					
22-Aug-06	9:05	0.0	0.00					
30-Aug-06	12:35	0.0	0.00					

Hornby Island Domestic Well Level Monitoring Project: Water level data

Well 3 Elev. 38 masl

Site number: 3
Start Date: 08-Dec-05
(Est. Elevation): 33 meters above sea level (masl, determined from recreational GPS)
Well elevation: 38 meters above sea level (masl, estimated from topographic map contours)

*Based on first reliable comparison of air-line to manual measurement (as indicated in "comments")
**Based on first reliable comparison of air-line to manual measurement (as indicated in "comments")
Note: Tubing adjusted in well on July 28, therefore length measurement altered (see detailed notes below)

Stick-up (SU): 0.38 metres

Dec 8/05 to July 20, 2006

Tubing length (TL): 20.00 metres below well head
L= TL - SU: 19.62 metres below ground surface
E, estimated error*: 2.11 m
L_{adj} = L - E: 17.51 metres below ground surface
WL formula: **WL = L - H**

July 28, 2006 to January 23, 2007

Tubing length (TL): 24.00 metres below well head
L= TL - SU: 23.62 metres below ground surface
E, estimated error**: 2.19 m
L_{adj} = L - E: 21.43 metres below ground surface
WL formula: **WL = L - H**

Date	Time	R, well watcher reading	H, converted well watcher reading (R x 0.3048)	WL, corrected air-line ground water level (L_{adj} - H)	M, manual water level	M_{adj}, manual water level (M - SU)	E, estimated error (WL - M_{adj})	Comments
Units		(ft)	(m)	(m bgs)	(m btoc)	(m bgs)	(m)	
10-Sep-06	14:55	0.0	0.00					
23-Sep-06	16:40	0.0	0.00					
07-Oct-06	10:30	18.0	5.49	15.95				Water not in use Sep 28-Oct 6
15-Oct-06	20:10	0.0	0.00					
20-Oct-06	11:20	0.0	0.00		21.000	20.620	nc	First manual water level measurement
20-Oct-06	11:20	0.0	0.00		24.200	23.820	nc	Second reading, meter emitting stronger sound
24-Oct-06	16:30	10.0	3.05	18.38				
31-Oct-06	16:00	0.0	0.00					
07-Nov-06	12:40	60.0	18.29	3.14				
09-Nov-06	14:20	62.0	18.90	2.53				
12-Nov-06	13:35	61.0	18.59	2.84				
16-Nov-06	11:00	65.0	19.81	1.62				
22-Nov-06	11:00	64.0	19.51	1.92				
29-Nov-06	15:25	64.0	19.51	1.92				
04-Dec-06	11:15	65.0	19.81	1.62				
08-Dec-06	17:00	20.0	6.10	15.34				
14-Dec-06	15:25	67.0	20.42	1.01				
17-Dec-06	16:00	61.0	18.59	2.84				
26-Dec-06	14:40	66.0	20.12	1.32				
31-Dec-06	13:05	65.0	19.81	1.62				
07-Jan-07	11:15	61.0	18.59	2.84				
13-Jan-07	16:00	64.0	19.51	1.92				
23-Jan-07	10:55	65.0	19.81	1.62	2.000	1.620	0.00	New error estimate using manual water level to adjust tubing length estimate (back-entered same corrected L to previous air-line readings because Jan was first reliable manual level)
23-Jan-07	10:55	65.0	19.81	1.62	2.000	1.620	0.00	
23-Jan-07	10:57	64.7	19.72	1.71	2.000	1.620	0.09	
23-Jan-07	11:01	64.0	19.51	1.92	2.000	1.620	0.30	
23-Jan-07	11:02	63.0	19.20	2.23	2.000	1.620	0.61	
23-Jan-07	11:03	66.5	20.27	1.16	2.000	1.620	-0.46	

Hornby Island Domestic Well Level Monitoring Project: Water level data

Well 3 Elev. 38 masl

Site number	3
Start Date:	08-Dec-05
(Est. Elevation)	33 meters above sea level (masl, determined from recreational GPS)
Well elevation:	38 meters above sea level (masl, estimated from topographic map contours)

*Based on first reliable comparison of air-line to manual measurement (as indicated in "comments")

**Based on first reliable comparison of air-line to manual measurement (as indicated in "comments")

Note: Tubing adjusted in well on July 28, therefore length measurement altered (see detailed notes below)

Stick-up (SU):	0.38	metres
Dec 8/05 to July 20, 2006		
Tubing length (TL):	20.00	metres below well head
L= TL - SU	19.62	metres below ground surface
E, estimated error*:	2.11	m
L_{adj} = L - E	17.51	metres below ground surface
WL formula:	**WL = L - H**	
July 28, 2006 to January 23, 2007		
Tubing length (TL):	24.00	metres below well head
L= TL - SU	23.62	metres below ground surface
E, estimated error**:	2.19	m
L_{adj} = L - E	21.43	metres below ground surface
WL formula:	**WL = L - H**	

Date	Time	R, well watcher reading	H, converted well watcher reading (R x 0.3048)	WL, corrected air-line ground water level (L_{adj} - H)	M, manual water level	M_{adj}, manual water level (M - SU)	E, estimated error (WL - M_{adj})	Comments
Units		**(ft)**	**(m)**	**(m bgs)**	**(m btoc)**	**(m bgs)**	**(m)**	

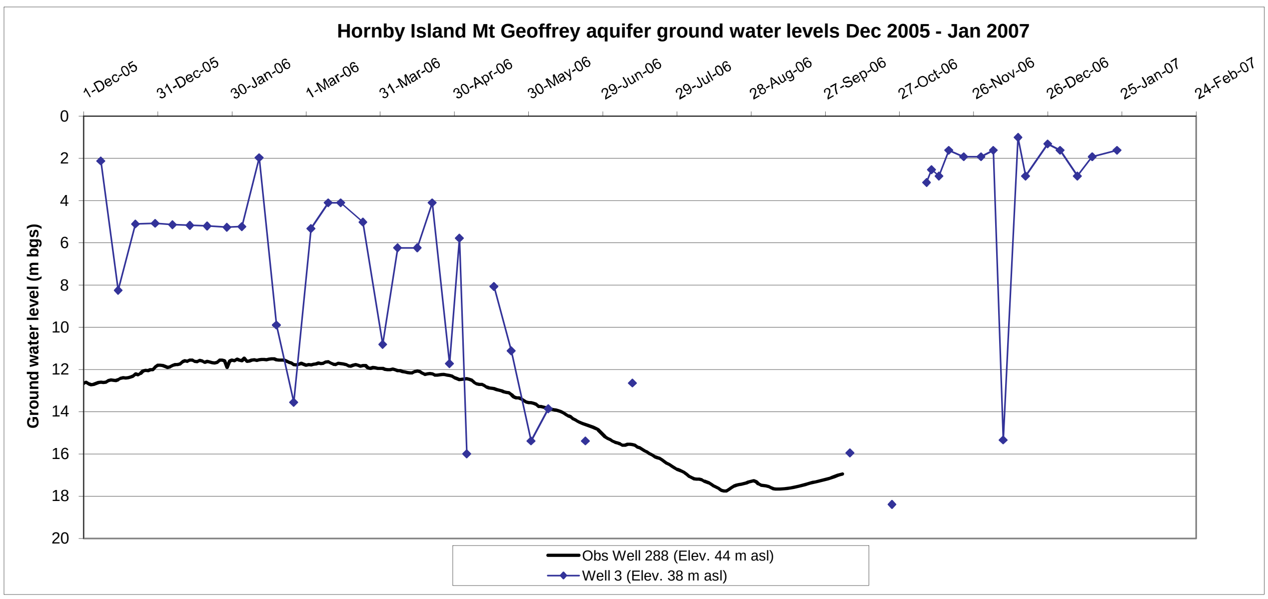
Notes:

Initially did not have small diameter probe for measuring manual water level and well fitted with sanitary seal, therefore do not have static water level measurement for comparison on first day during set-up.

Measurement method used by well owner: 20 vigorous pumps of well watcher each time, before reading gauge.

July 20 field calibration and trouble-shooting: Difficult to get manual measurement due to cascading water in well (heard). Strong signal at 18.8 to 19.5 m bgs, second strong signal at 28 m. Removed instrumentation, re-affixed markings on tubing at 5 m intervals, tested pressure gauge, holds pressure with tubing removed and valve outlet blocked with modified nut, tested coupling between instrument and tubing with soap and observed slight bubbling, installed new coupling, lowered tuping 25 m btoc, tubing encountered obstruction at 24.8 mbtoc, finished by affixing tubing at 24 mbtoc, current reading 0, indicating water level is below apperature of tube.

Oct 20 field calibration: Water level meter gives signal at 21 m btoc and slightly stronger at 24.2 m btoc. Cascading water in well may be occuring at shallower depths giving false reading of water level. Not able to advance cable for water level meter beyond 25 m depth. Water level assumed to be below tube apperature. Advise continuation of water level measurements until water level rises to immerse tubing.



Well 4 Elev. 5 masl

Site number	4	
Start Date:	9-Dec-06	
(Est. Elevation)	12	meters above sea level (masl, determined from recreational GPS)
Well elevation:	5	meters above sea level (masl, estimated from topographic map contours

*Based on first reliable comparison of air-line to manual measurement (as indicated in "comments")

**Based on first reliable comparison of air-line to manual measurement (as indicated in "comments")

Note: Tubing adjusted in well on Aug 18, therefore length measurement altered (see detailed notes below)

Stick-up (SU):	0.15	metres

Dec 9/05 to June, 2006

Tubing length (TL):	12.00	metres below well head
L= TL - SU	11.85	metres below ground surface
E, estimated error*:	0.76	m
L_{adj} = L - E	11.09	metres below ground surface
WL formula:	**WL = L - H**	

August 18, 2006 to January 23, 2007

Tubing length (TL):	15.00	metres below well head
L= TL - SU	14.85	metres below ground surface
E, estimated error**:	1.30	m
L_{adj} = L - E	13.55	metres below ground surface
WL formula:	**WL = L - H**	

Date	**Time**	**R, well watcher reading**	**H, converted well watcher reading (R x 0.3048)**	**WL, corrected air-line ground water level (L_{adj} - H)**	**M, manual water level**	**M_{adj}, manual water level (M - SU)**	**E, estimated error (WL - M_{adj})**	**Comments**
Units		**(ft)**	**(m)**	**(m bgs)**	**(m btoc)**	**(m bgs)**	**(m)**	
09-Dec-05	9:56	32.0	9.75	1.33				
16-Dec-05	11:05	32.0	9.75	1.33				
23-Dec-05	12:00	33.5	10.21	0.88				
30-Dec-05	10:00	33.0	10.06	1.03				
06-Jan-06	9:30	33.5	10.21	0.88				
13-Jan-06	10:30	34.3	10.45	0.63				
20-Jan-06	11:00	35.0	10.67	0.42				
27-Jan-06	11:30	33.5	10.21	0.88				
03-Feb-06	12:00	33.5	10.21	0.88				
08-Feb-06	10:00	33.5	10.21	0.88				
10-Feb-06	8:30	33.0	10.06	1.03				
10-Feb-06	10:00	33.5	10.21	0.88	1.030	0.88	0.00	Stickup = height of casing above floor of pumphouse (datum). Error based on estimate of tubing length (how much deployed), earlier and later water levels based on tubing length corrected based on manual reading from this date
10-Feb-06	10:00	33.5	10.21	0.88	1.030	0.88	0.00	New error estimate based on corrected tubing length using manual wlvl
17-Feb-06	9:00	33.0	10.06	1.03				
24-Feb-06	6:00	33.0	10.06	1.03				
03-Mar-06	10:00	33.0	10.06	1.03				
10-Mar-06	11:00	33.0	10.06	1.03				
17-Mar-06	12:00	33.0	10.06	1.03				
24-Mar-06	11:00	32.5	9.91	1.18				
31-Mar-06	11:30	32.5	9.91	1.18				
07-Apr-06	10:00	32.5	9.91	1.18				
14-Apr-06	11:00	32.0	9.75	1.33				
21-Apr-06	12:30	31.0	9.45	1.64				
28-Apr-06	10:30	30.0	9.14	1.94				
02-May-06	12:25	32.0	9.75	1.33	1.270	1.12	0.22	
02-May-06	12:35	34.0	10.36	0.72	1.290	1.14	-0.41	
05-May-06	11:30	31.0	9.45	1.64				
12-May-06	9:00	30.0	9.14	1.94				
19-May-06	10:30	30.0	9.14	1.94				
26-May-06	12:00	29.5	8.99	2.10				
02-Jun-06	11:00	29.0	8.84	2.25				
09-Jun-06	11:45	29.0	8.84	2.25				
20-Jul-06	13:00	nr	nc	nc	3.200	3.05	nc	No instrumentation in well (tubing broken)
17-Aug-06	12:03	32.0	9.75	5.09	3.960	3.81	1.29	Re-installed well watcher tubing to 15 m btoc, used this reading to adjust tubing length and estimated error for subsequent readings
17-Aug-06	12:03	32.0	9.75	3.79	3.960	3.81	-0.01	
17-Aug-06	12:15	34.5	10.52	3.03	3.880	3.73	-0.70	Second reading (manual vs. well watcher)
17-Aug-06	12:25	32.5	9.91	3.64	3.730	3.58	0.06	Third reading (note water level has been increasing in well based on repeated manual measurements, possible influence of stopped pump
18-Aug-06		31.5	9.60	3.95				

Well 4 Elev. 5 masl

Site number	4	
Start Date:	9-Dec-06	
(Est. Elevation)	12	meters above sea level (masl, determined from recreational GPS)
Well elevation:	5	meters above sea level (masl, estimated from topographic map contours

*Based on first reliable comparison of air-line to manual measurement (as indicated in "comments")

**Based on first reliable comparison of air-line to manual measurement (as indicated in "comments")

Note: Tubing adjusted in well on Aug 18, therefore length measurement altered (see detailed notes below)

Stick-up (SU): 0.15 metres

Dec 9/05 to June, 2006

Tubing length (TL):	12.00	metres below well head
L= TL - SU	11.85	metres below ground surface
E, estimated error*:	0.76	m
L_{adj} = L - E	11.09	metres below ground surface
WL formula:	**WL = L - H**	

August 18, 2006 to January 23, 2007

Tubing length (TL):	15.00	metres below well head
L= TL - SU	14.85	metres below ground surface
E, estimated error**:	1.30	m
L_{adj} = L - E	13.55	metres below ground surface
WL formula:	**WL = L - H**	

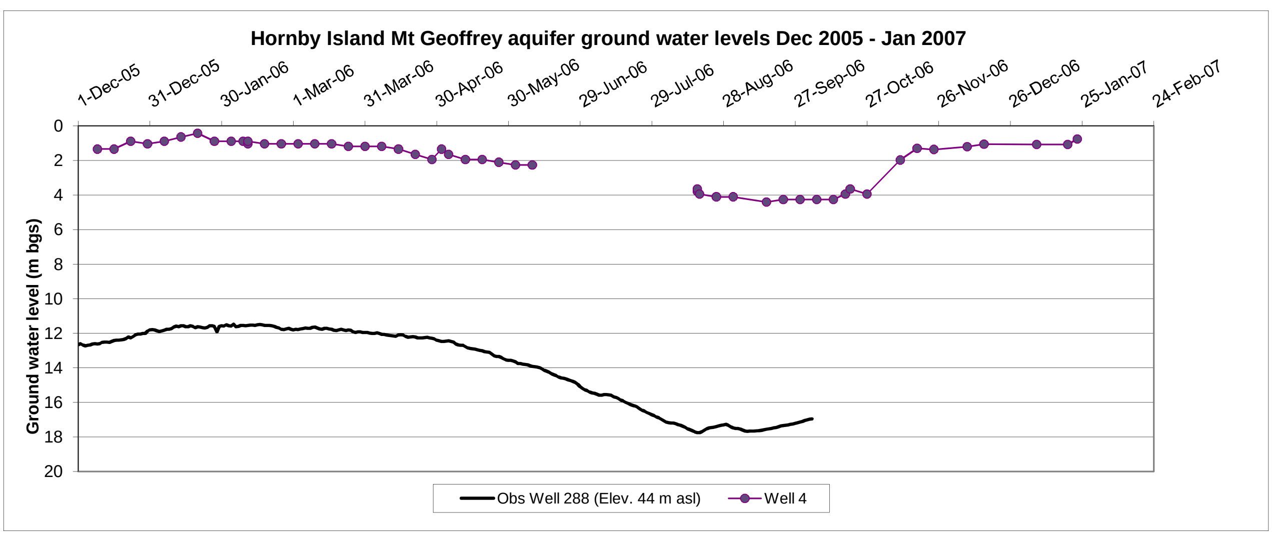
Date	Time	R, well watcher reading	H, converted well watcher reading (R x 0.3048)	WL, corrected air-line ground water level (L_{adj} - H)	M, manual water level	M_{adj}, manual water level (M - SU)	E, estimated error (WL - M_{adj})	Comments
Units		**(ft)**	**(m)**	**(m bgs)**	**(m btoc)**	**(m bgs)**	**(m)**	
25-Aug-06		31.0	9.45	4.10				
01-Sep-06	12:30	31.0	9.45	4.10				
15-Sep-06	11:00	30.0	9.14	4.40				
22-Sep-06	12:05	30.5	9.30	4.25				
29-Sep-06	15:00	30.5	9.30	4.25				
06-Oct-06	11:45	30.5	9.30	4.25				
13-Oct-06	14:00	30.5	9.30	4.25				
18-Oct-06	10:00	31.5	9.60	3.95				
20-Oct-06	13:27	32.5	9.91	3.64	4.130	3.98	-0.34	Pulled and re-measured tubing and re-installed, no change in reading
27-Oct-06	10:30	31.5	9.60	3.95				
10-Nov-06	10:00	38.0	11.58	1.96				
17-Nov-06	12:10	40.2	12.25	1.29				
24-Nov-06	13:00	40.0	12.19	1.36				
08-Dec-06	9:30	40.5	12.34	1.20				
15-Dec-06	11:00	41.0	12.50	1.05				
06-Jan-07	10:30	41.0	12.50	1.05				
19-Jan-07	11:00	41.0	12.50	1.05				
23-Jan-07	11:35	43.0	13.11	0.44	0.860	0.71	-0.27	
23-Jan-07	11:40	42.0	12.80	0.75	0.860	0.71	0.04	
23-Jan-07	11:42	41.5	12.65	0.90	0.860	0.71	0.19	
23-Jan-07	11:43	42.7	13.01	0.53	0.860	0.71	-0.17	
23-Jan-07	11:45	43.5	13.26	0.29	0.860	0.71	-0.42	

Notes:

December 8-9, 2006: Manual water level could not be determined on Dec. 8 because sanitary seal bolts not able to be removed and did not have a small diameter probe water level tape (well owner able to remove the following day). Initial well watcher reading was not calibrated to manual water level. Instrumentation set up the following day after MoE staff had been at site.

July 20, 2006 field check and trouble-shooting: Manual water level 3.2 mbtoc (2.794 mbgs). Well watcher damaged some time after June 9, tubing broken at top of well and some has fallen down into well, pressure gauge cracked. Not able to re-install well watcher during this field visit, need weights for end of new tubing.

August 17 field visit - installed new tubing/instrumentation.



Appendix D: Gabriola domestic well monitoring data summary

Gabriola Island Domestic Well Air-Line Monitoring (Field Data)

Well site no.	Date	Approx. date monitoring started with air-line method	Well depth (ft)	Well depth (m)	Stickup (m above local grade)	Length of tubing installed in well (ft below top of casing)	Length of tubing installed in well (m below top of casing)	Corrected tubing length (m below ground surface)	Pressure gauge reading	Gauge units	Equivalent height of water above tube aperature (feet)	Equivalent height of water above tube apperature (m)
G1	03-Jul-07	Aug-06	325	99.1	0.22	131	39.9	39.7	116.0	ft*	116.0	35.36
G1	03-Jul-07	Aug-06	325	99.1	0.22	131	39.9	39.7	97.0	ft*	97.0	29.57
G1	03-Jul-07	Aug-06	325	99.1	0.22	131	39.9	39.7	95.0	ft*	95.0	28.96
G1	03-Jul-07	Aug-06	325	99.1	0.22	131	39.9	39.7	93.0	ft*	93.0	28.35
G2	03-Jul-07	2003	120	36.6	0.00	100	30.5	30.5	76.0	ft*	76.0	23.16
G3	03-Jul-07	Aug-06	175	53.3	0.12	160	48.8	48.6	85.0	ft*	85.0	25.91
G3	03-Jul-07	Aug-06	175	53.3	0.12	169	51.5	51.4	87.0	ft*	87.0	26.52
G4	03-Jul-07	Jun-07	100	30.5	0.24	100	30.6	30.4	89.0	ft*	89.0	27.13
G5	03-Jul-07	2003	300	91.4	0.79	250	76.2	75.4	138.0	ft*	138.0	42.06
G5	03-Jul-07	2003	300	91.4	0.79	242	73.8	73.0	129.0	ft*	129.0	39.32
G6	03-Jul-07	2003	260	79.2	0.31	nr	nr	nr	nr	ft*	nr	nr
G7	03-Jul-07	2003	120	36.6	0.34	90	27.4	27.1	12.0	psi	27.7	8.45
G7	03-Jul-07	2003	120	36.6	0.34	85	26.0	25.7	7.8	psi	18.0	5.49
G8	03-Jul-07	Apr-04	150	45.7	0.09	135	41.1	41.1	74.0	ft*	74.0	22.56
G9	03-Jul-07	2005	200	61.0	-0.15	180	54.9	55.0	75.0	ft*	75.0	22.86

Legend: *ft=feet of water above tubing apperature psi=pounds per square inch

Gabriola Island Domestic Well Air-Line Monitoring (Field Data)

Well site no.	Date	Corrected air-line water level (m bgs)	Electrical tape water level (m btoc)	Electrical tape water level (m bgs)	Estimated error (air-line vs electrical tape wlvl)(m)	Comments, notes and owner observations regarding use of monitoring device, effectiveness, etc.
G1	03-Jul-07	4.35	11.49	11.27	-6.92	Tried additional measurements at same location (see below); did not re-measure manual water level however the pump did not turn on (it was possible to hear pump from the monitoring instrument location in the basement of the house).
G1	03-Jul-07	10.14	11.49	11.27	-1.13	
G1	03-Jul-07	10.75	11.49	11.27	-0.52	
G1	03-Jul-07	11.36	11.49	11.27	0.09	
G2	03-Jul-07	7.32	5.00	5.00	2.32	Not able to measure actual length of tubing installed.
G3	03-Jul-07	22.74	20.67	20.55	2.19	Initial measurements and calculations based on estimated tubing length.
G3	03-Jul-07	24.86	20.68	20.56	4.30	Second measurement calculated after re-measuring tubing length.
G4	03-Jul-07	3.24	3.41	3.17	0.07	Reliable tubing length (re-measured and re-installed).
G5	03-Jul-07	33.35	23.20	22.41	10.94	Not able to re-measure tubing, low confidence in reported tubing length.
G5	03-Jul-07	33.65	23.20	22.41	11.24	Changed tubing length by pulling it out of the well by 8 ft; error estimate increased following change.
G6	03-Jul-07	nr	20.61	20.31	nc	Not able to get well watcher reading as tubing broke just below coupling when we were trying to attach it to the pump.
G7	03-Jul-07	18.64	21.00	20.66	-2.02	Individual made his own pressure gauge system (not using commercially marketed unit).
G7	03-Jul-07	20.20	21.00	20.66	-0.46	Second measurement taken after pulling tubing a small distance out of the well.
G8	03-Jul-07	18.50	nr	nr	nc	Pressure gauge reads above the available increments (i.e. water level reading at approx. 74 ft, but gauge increments only go to 70 ft); not able to obtain manual water level because not able to get probe through open holes in well cap and other bolts rusted closed. Tried pulling out tubing from well by 10 ft resulting in no change in pressure gauge measured water level. Recommend that much more tubing should be pulled out of well so that the measured water level (head) is within the range of the pressure gauge. GPS well coordinates not available at location due to poor satellite reception.
G9	03-Jul-07	32.15	10.35	10.50	21.65	Wellhead located below local grade, within pit enclosure. Reported stickup is below ground surface, relative to bottom of pit stickup is 0.03 m. Actual tubing length not measured when unit was installed. Not able to get reduced error. Weak beep from water level tape at 3.80 m btoc (cascading water in well).
				Median error	0.09	
				Minimum error	-6.92	
				Maximum error	21.65	

Appendix E: Comparison of ground water level measuring methods

General considerations

The choice of method for monitoring groundwater levels in a well or piezometer depends on factors including whether or not the well is in use, accessibility of the well head, degree of accuracy needed and type of data required (e.g. continuous data compared to periodic measurements).

When collecting groundwater level data, care should always be taken to avoid introduction of contaminants to the well, either from the monitoring equipment itself or accidental introduction of foreign materials when working in and around an open well head. Clean monitoring equipment before and after use and keep working area around the well free of debris and clutter.

When the well or pump is serviced, the well can be fitted by a threaded access port in the cap and/or an equipment conduit, typically made of 1” diameter plastic (PVC) or metal pipe, that is installed inside the well down one side of the casing and secured near the top of the well bore. A conduit prevents monitoring equipment from getting caught up in the pump or wiring, which can result in loss of equipment or damage to the well.

Summary of groundwater level monitoring methods and appropriate use

Method	**Appropriate type of use**						**Estimated accuracy range (meters)**		
	Non-flowing well	**Flowing (artesian) well[1]**	**Pumping well (or well with pump installed)[2]**	**Needs calibration using secondary measurement method**	**Periodic (manual)**	**Continuous (automated)**	**0.03 to 0.1**	**0.006 to 0.03**	**0.003 to 0.006**
Acoustic probe	⦿	⦿	⦿	×	⦿				⦿
Submerged air-line	⦿	⦿	⦿	R	⦿		⦿		
Electrical tape	⦿	⦿	⦿	×	⦿			⦿	
Float	⦿	×	×	R	⦿	⦿	⦿	⦿	
Popper	⦿	⦿	×	×	⦿			⦿	
Pressure gauge (manometer)	×	⦿	⦿	×	⦿	⦿	⦿	⦿	
Transducer	⦿	⦿	⦿	R	⦿	⦿		⦿	⦿
Ultrasonic	⦿	⦿	⦿	×	⦿			⦿	⦿
Wetted tape	⦿	⦿	⦿	×	⦿				⦿

⦿=Yes; ×=No; R=Recommended (for greater accuracy)
[1]Casing extension may be required so water level is below top of casing in order to use measurement method indicated.
[2]Installation of monitoring equipment conduit recommended.
References: Adapted from Dalton, *et al*, 1991. Additional sources: Driscoll, 1986; Garber and Koopman, 1968; Leupold and Stevens Inc., 1984.

Method	Description of operation
Acoustic probe	Similar to the electric tape and popper monitoring methods, an electronic probe, attached to the end of a graduated metal tape, is lowered into the well and makes a sound when the electrodes in the probe make contact with the water.
Submerged air-line (bubbler)	An air-line or tube of known length is lowered into the well to below the deepest anticipated water level. The tube is open at the bottom, must be free of holes or kinks along its length, and is attached at the top of the well to a pressure gauge and air pump or air compressor using an air-tight coupling. The air pump or compressor is used to evacuate the water that naturally rises into the tube when the unit is not in use. Once the tube is evacuated, the gauge reads the pressure, which corresponds to the height of water above the open bottom end of the tube. Some gauges show a reading in feet, meters, or in pounds per square inch (psi) that can then be converted to feet by multiplying the measurement by 2.31 ft/psi (or 0.704 m/psi). The water depth below datum (e.g. top of casing) is determined by subtracting the gauge reading from the known tube length. Not as accurate as other methods, depending mainly on the relative accuracy of the pressure gauge. The method is not recommended where a high data resolution is required e.g. for analysis of water level change during a pumping test. This method is relatively inexpensive (<$200).
Electrical tape (water level meter)	The electrical tape is one of the most commonly used methods for groundwater level measurement. The instrument usually consists of a specially designed measuring tape made of Teflon, steel or other materials with insulated wires running down the sides and a probe on the end. When the probe is lowered into the well, the instrument gives an audible buzz or visible signal (meter or light indicator) in response to completion of an electrical circuit or changes in resistance, capacitance or self-potential that occurs when the probe touches water. The depth at which the signal is given can then be measured from the tape relative to the top of the casing or other datum. Many electrical tapes are battery operated. A high level of accuracy can be obtained for moderate cost ($500-$1000). Meters can be obtained with a range of probe sizes, marking increments and tape lengths for using in different applications. The electrical tape may not operate properly if there are hydrocarbons or other materials floating on the water surface and the unit can give false signal if there is water cascading in the well (some models have a shielded probe to prevent false signals). The length of the measuring cable often determines the cost of the unit.
Float	There are several different types of float instrumentation that vary in technological complexity from completely manual to those involving automated data capture using an electronic logger for collecting continuous measurements. Some units do not require electrical power to operate, while others rely on battery power. The instrument operation generally involves a float that is attached to a counterweight via a cable or steel tape. The float sits on the water and moves up and down in response to changes in the groundwater depth. For some instruments the depth to water is read from increments on the tape observed at the top of the well. For other float-type instruments friction from the cable, attached between the float and counterweight, moves a wheel or

Method	Description of operation
Float (continued)	pulley at the surface and an electronic sensor converts the distance of pulley movement to a relative change in water level. An example is the electronic Thalimedes® data loggers used in many wells in the B.C. observation well network. A Stevens recorder is an older float-type monitor that is able to collect data on a continuous basis. A float sits on the water and is attached to a cable that hangs over a pully mounted on a shelf at the top of the well. The pully moves up and down in response to changing water level and moves a cylindrical chart drum. A pen or stylus that is powered by either a battery or a quartz clock moves at a constant speed across the paper sheet mounted on the chart drum producing a graphic record of water level over time. The paper on the chart drum is periodically replaced (e.g. after a week or month of recording) and the pen is reset to the starting position. Float equipment has a moderate cost and provides high level of accuracy when properly calibrated, but is not appropriate to use in a well with a pump in it. Tangling of the float/counterweight cable and other physical problems with the instrumentation commonly occur when used in deep wells.
Popper	A simple method of water level measurement, involving use of a metal cylinder that makes a popping sound when it touches water surface. The cylinder is typically 2.5 to 4 cm (1 to 1.5 inch) in diameter and 5 to 8 cm (2 to 3 inches) long, is concave at the bottom and attached to a surveyor tape or measuring tape. The popper is lowered into the well to a few cm above the water level; it is then dropped onto the water surface and the operator notes the depth at which the popping sound is heard. Multiple measurements are taken and averaged. Taking multiple measurements increases accuracy level. Noise from an operating pump operation can interfere with hearing the popping sound.
Pressure gauge or manometer **(methods suitable for artesian wells)**	For flowing wells that have high artesian one way to estimate the water level (above ground surface) is to install a specially designed cap that seals the top of the well head and allows measurement of the shut-in pressure using a pressure gauge or manometer. The gauge may display pressure directly or may display the measurement converted to an equivalent height of water above ground. Consultation with a registered qualified well driller or hydrogeologist is recommended to ensure that confining the pressure at the well head does not cause water leakage around the well casing, disturbance of the seating of the casing, or other problems. Extension of the casing is often recommended for flowing (artesian) wells in which water level naturally rises above the ground surface by a few meters or feet. It involves welding another piece of casing of the same diameter onto the existing casing so that the top of the well is higher than the maximum height that water rises above the ground surface. The water level can then be measured using manual methods e.g. wetted tape or electronic tape (or simple ruler or measuring tape if the water level in the casing is visible). Extension of the casing also helps to prevent discharge and thus loss of water flowing under artesian pressure to the ground surface. (Note: Control of artesian flow is defined and required under Section 77 of the *Water Act*.)

Method	Description of operation
Transducer	A submerged pressure-sensitive diaphragm measures hydrostatic pressure that corresponds to the depth of water overlying the unit. When the depth of deployment of the transducer is known (cable length), the absolute water level relative to datum such as ground level or sea level can then be calculated manually or automatically using computer software designed for use with the equipment. Vented transducers have a vent tube that extends to the ground surface, allowing for automatic compensation for variations in atmospheric pressure. Non-vented units require separate barometric sensor to correct for atmospheric pressure variation. Newer units have additional sensors to measure water temperature, total dissolved solids, or other parameters, as well as water level. Most transducers are calibrated to a specific range of water level fluctuation (loss of data or reduced accuracy can result if the inappropriate range transducer is used). They are self-enclosed, with no mechanical parts, so they are less subject to error associated with physical problems. If connected to a data transmission cable, transducers can be installed and left in place, minimizing the need to continually access the well. They have a high level of accuracy, appropriate for continuous monitoring and for wells in active use (pumping). They are best used in conjunction with another method (e.g. electrical tape) for calibration. The vent cable for self-correcting (vented) units may become blocked. The cost is higher than some other monitoring methods (~$500-$3000). Computer hardware and software is required to download, correct and manage the data. This method is not suitable for well surveys where measurements are rapidly collected at multiple sites.
Ultrasonic	These types of units create a sonic or ultrasonic wave that measures the water level based on how long the wave pulse takes to travel down to the water and reflect back. The accuracy is affected by temperature along the wave path (e.g. variations in air temperature in the well) and by reflection of the sound wave from wires, pump equipment, sides of the casing or other obstructions. This is a rapid method to measure water level in deep wells and because the probe is not lowered into the well and does not touch the water surface directly, the chances of introducing contamination to the well are low. There is a moderate to high cost (~$900), therefore ultrasonic meters are used more commonly by tradespersons rather than by individual domestic well owners. There may be a lower accuracy than some methods, therefore it is generally not recommended when a high level of accuracy is wanted, e.g. for measuring groundwater level change during a pumping test.
Wetted tape	A simple but reliable method to determine water level. A slender metal weight (e.g. steel file) is attached to the end of a surveyors tape. The traditional tape is made of steel and marked at increments. The dipping end of the weight is coated with chalk and lowered part-way into the water, washing off some of the chalk. The water level is determined by subtracting the length of chalk washed off, from the total length that the tape was lowered, relative to a datum such as the top of the casing. A wetted tape is low in cost, can be made by hand and provides a moderately high accuracy. Cascading water from shallow fractures in the well can wash off the chalk and give a false measurement. Multiple attempts at measurement are often needed if the approximate water level depth is not initially known. Accuracy is increase with repeated measurements.

Appendix F: Glossary of terms

Ambient groundwater flow:	The rate and direction of flow of groundwater under unpumped, natural conditions.
Annual hydrograph:	A continuous graph showing the streamflow or groundwater level over a year or over multiple years.
Aquifer vulnerability:	An intrinsic measure of how easily an aquifer can be contaminated from activities at the land surface, based on the aquifer's geologic and hydrologic characteristics only. Vulnerability for an aquifer is typically defined independently from the type and intensity of the human activities at the land surface.
Aquifer:	A geological formation, group of formations, or part of a formation that comprises sufficient saturated permeable materials to yield economical quantities of water to wells and springs.
Aquitard:	A geologic formation, group of formations, or part of a formation that does not comprise sufficient permeable materials to yield economical quantities of water to wells and springs. An aquitard can, through leakage, contribute a significant amount of water over a large area to an aquifer. Aquitards typically consist of till, silt or clay.
Base flow:	The sustained low flow in a stream. Generally base flow is the inflow of groundwater to the stream. Flow in a stream during the dry season is often made up entirely of base flow.
Bedrock:	A general term for the rock, usually solid, that underlies soil or other unconsolidated sediments.
Cadastral maps:	Maps showing the legal property boundaries. Usually large scale maps.
Capture zone:	The land area around a pumping well which is the source of recharge that contributes water to the well. Also known as the recharge area for the well.
Catchment area:	The land area that drains water to an outlet point along a stream. Also called a drainage basin or watershed.
Community well:	A well supplying water to two or more dwellings or supplying any commercial premise serving the public.
Confined aquifer:	Where an aquitard overlies an aquifer, the low permeability of the aquitard can help inprotecting the underlying aquifer from impacts of human activities at the land surface. In those cases, an aquifer is said to be "confined."
Conglomerate:	A type of sedimentary rock made up of compacted or cemented rock particles of variouis sizes e.g. fine to coarse sand, gravel, and pebbles.

Database:	A collection of records and files that are logically organized to assist with the analysis and processing of data.
Discharge area:	The land area where groundwater flows back towards the land surface. Features that are common to discharge areas are springs, wetlands and shallow water tables.
Drainage basin:	The land area that drains water to an outlet point along a stream. Also called a catchment area or watershed.
Drainage divide:	The height of land that separates one watershed from neighbouring watersheds. Also called the watershed boundary or watershed divide.
Drawdown:	The difference between the static water level and the pumping water level.
Drilled well:	A well that is constructed with a drilling rig, such as an air rotary or cable tool drilling rig.
Dug well:	A well that is dug by hand or excavated by backhoe. Dug wells are usually shallow and often highly vulnerable to contamination.
Flowing artesian well:	A well where the water level is above the ground surface.
Fracture:	A break or crack in the bedrock.
GIS:	Geographic Information System. A computer software and database that stores and analyzes geographic data. ArcInfo is an example of a GIS system.
GPS:	Geographic Positioning System. For example, a GPS unit is a device that is able to determine the position (geographic coordinates) of a site on the earth's surface by using trilateration between a surface receiver and multiple satellites orbiting in the Earth's atmosphere.
Groundwater divide:	The highest elevation boundary of a groundwater basin.
Groundwater:	Water occurring beneath the ground.
Hydraulic conductivity:	A property of the aquifer that provides a measure of ease of flow of water through a cross sectional area under a unit hydraulic gradient. Hydraulic conductivity is usually expressed in metres per day or feet per day.
Hydraulic gradient:	The slope of the groundwater level or water table (for an unconfined aquifer), or the slope of hydraulic head measurements (for a confined aquifer).
Hydraulic head:	The level to which water rises in a well with reference to a datum such as sea level.
Hydrogeologic mapping:	Mapping groundwater and groundwater related features. Types of hydrogeologic maps include: a contour map of the water table, a map outlining the aquifer boundary and aquifer thickness, or a map showing the rate and direction of groundwater flow in an aquifer.

Hydrogeology:	The science of subsurface waters and related geologic aspects of surface waters.
Hydrograph:	A continuous graph showing the properties of stream flow or groundwater level over time.
Hydrologic cycle:	The continued circulation of water between the ocean, atmosphere, and land.
Igneous rocks:	Rocks that solidified from molten or partly molten materials, that is from a magma or lava.
Infiltration rate:	The rate at which water permeates the pores or interstices of the ground.
Leaching:	Refers to the movement of chemicals through soil by water.
Level of groundwater development:	The level of groundwater use from an aquifer relative to the aquifer's ability to replenish itself.
Lithology:	All the physical properties, the visible characteristics of mineral composition, structure, grain size, etc. which give individuality to a rock or sediment.
Maximum Acceptable Concentration (MAC):	The concentration established for certain chemicals that are known or suspected to cause adverse effects on health. These concentrations are derived to safeguard health assuming lifelong consumption of drinking water containing the chemical at that concentration.
Mean:	The arithmetic mean or average of a set of values is calculated by totalling the values in a set and dividing the total by the number of values in the set.
Median:	The value from a set of measurements that has an equal number of measurement above and below it. The median is a useful estimation of the average of a number of measurements when the data set includes extreme high or low values that could skew the average.
Metamorphic rocks:	Any rock derived from pre-existing rocks by mineralogical, chemical, and/or structural changes, essentially in the solid state, in response to marked changes in temperature, pressure, shearing stress, and chemical environment, generally at depth in the Earth's crust.
Monitoring wells:	Well that are typically 5 cm to 15 cm (2 inches to 6 inches) in diameter and are used strictly for monitoring the water quality of the aquifer. Monitoring wells are not pumped except to collect a sample.
Observation well:	A well used for the purpose of observing parameters such as water levels, pressure changes and water quality.
Overburden:	The loose soil, silt, sand, gravel, or other unconsolidated materials overlying bedrock, either transported or formed in place; regolith.

Permeability:	The capacity of a porous rock, sediment, or soil for transmitting a fluid; it is a measure of the relative ease of fluid flow. Permeability is usually expressed in metres squared (m^2) or feet squared (ft^2). It is closely related to the hydraulic conductivity.
Porosity:	The percentage of the bulk volume of a rock or soil that is occupied by interstices, whether isolated or connected, relative to the total rock or soil volume.
Precipitation:	Condensation of moisture in air masses generally forming rain or snow.
Primary porosity:	Pore spaces that were formed at the time the geologic deposit was formed. The pore spaces in a sand and gravel deposit are an example of primary porosity.
Pumping interference:	The condition occurring when a pumping well lowers the water level in a neighbouring well.
Pumping test:	A test that is conducted to determine aquifer or well characteristics. A pumping test is usually conducted to determine the transmissivity and storativity characteristics of an aquifer and the capacity of a well supply.
Purveyor:	A company or municipality that delivers and sells water to clients, usually the residents in the community.
Quality assurance:	The overall verification program which provides producers and users of data the assurance that predefined standards of quality at predetermined levels of confidence are met.
Quality control:	The overall system of guidelines, procedures and practices which are designed to regulate and control the quality of products or services with regards to previously established performance criteria and standards.
Range:	The difference between the highest and lowest values within a data set.
Recharge area:	Land area where water infiltrates into the ground and replenishes the aquifer.
Relief:	The maximum elevation difference within a watershed between its highest and lowest point.
Riparian area:	The strip of land adjacent to the stream.
Run-off:	The movement of water that flows overland or at very shallow depths to a stream or lake.
Saline groundwater:	Groundwater consisting of or containing high concentrations of salt (sodium chloride) due to natural or human causes.
Sandstone:	A sedimentary rock composed of mostly sand sized particles.

Sanitary seal:	A type of well cap that consists of two stacked semi-circular metal plates installed to cover a circular well opening. The upper and lower plates have a rubber gasket between them that expands against the sides of the well casing when six bolts (three on each side) are tightened to squeeze the plates together. The pump line and electrical lines often come up out of the centre of the sanitary seal cap.
Secondary porosity:	Pore spaces that are formed after the geologic deposit was formed. Fractures and cracks in bedrock are examples of secondary porosity.
Sedimentary rocks:	Rocks formed from consolidation of loose sediments such as clay, silt, sand, and gravel.
Shale:	A fine-grained sedimentary rock, formed by the consolidation of clay, silt, or mud. It is characterized by finely laminated (layered) structure and is sufficiently hardened so that it will not fall apart on wetting.
Sole source aquifer:	The only source of groundwater supply in an area.
Specific capacity:	The rate of discharge of water from a pumping well per unit of drawdown, commonly expressed in litres per second per metre of drawdown or gallons per minute per foot of drawdown. Specific capacity depends on the duration of discharge, and the properties of the well or aquifer.
Static water level:	The unpumped level of water in the well or in the aquifer.
Steady-state flow:	State of water flow where rate and direction does not change with time.
Storativity:	Volume of water stored or released from a column of aquifer with a unit cross section under a unit change in head.
Surficial deposits:	Deposits overlying bedrock and consisting of soil, silt, sand, gravel and other unconsolidated materials.
Till:	Predominantly unsorted and unstratified sediments, generally unconsolidated, deposited directly by and underneath a glacier without subsequent reworking by meltwater, and consisting of a heterogenous mixture of clay, silt, sand, gravel and boulders ranging widely in size and shape.
Time of travel:	The time it takes for a particular contaminant to be transported through groundwater flow to a specified location. Time of travel is commonly used to relate the distance of a contaminant source to a drinking water well (i.e. a gas station is located within a 1-year time of travel distance from a community well).
Topography:	The configuration of a surface including its relief and the position of its natural features.

Transmissivity:	The rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. Transmissivity is expressed as metres squared per second, feet squared per day, or gallons per day per foot.
Unconfined aquifer:	An aquifer where its upper boundary is defined by the water table. Where no aquitards overlie the aquifer, the aquifer is said to be "unconfined." Unconfined aquifers are generally more vulnerable to impacts from human activities at the land surface, particulary if the water table is shallow.
Unconsolidated deposits:	Deposits overlying bedrock and consisting of soil, silt, sand, gravel, clay and other materials which have either been formed in place or have been transported in from elsewhere. Synonymous with surficial deposits.
Uniform flow:	Flow in the same direction and rate.
Water balance:	The accounting of the input, output and change in storage of water in a watershed or aquifer. Typically determined on an annual basis. Also referred to as a water budget.
Water budget:	The accounting of the input, output and change in storage of water in a watershed or aquifer. Typically determined on an annual basis. Also referred to as a water balance.
Water table:	The top of the unconfined aquifer; water level where the pressure is equal to that of the atmosphere; water level in a shallow well.
Watershed boundary:	The height of land that separates one watershed from neighbouring watersheds. Also called the drainage divide.
Watershed:	The land area that drains water to an outlet point along a stream. Also called a catchment area or drainage basin.
Well cap:	Cover for the top of the well.
Well capacity or well yield:	The flow of water discharged from a well in gallons per minute or litres per second.
Well interference:	Drawdown of water level in a well caused by pumping of a neighbouring well.
Well protection:	Protection of the recharge (or capture zone) area of a pumping well.
Well screen:	A wire-wound or slotted filtering device that allows water, but not sediments, to enter a well.