The Intrusion of Seawater into the Fractured Bedrock Aquifer on East Point Peninsula, Saturna Island

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Background

Saturna Island (here after referred to as the Island or Saturna), the most south-easterly of the Gulf Islands, is located in the southern end of the Strait of Georgia. The Island is approximately 35 km^2 and supports 359 full-time residents (Islands Trust, 2008). Like many of the Gulf Islands, the population of Saturna increases in the summer months with part-time seasonal residents and visitors. This increase in population leads to an increase in water use at a time when there is little precipitation and accompanying recharge of the groundwater aquifers.

Groundwater occurring in fractured sedimentary rock deposits provides a primary source of potable water on the Island. The Island has a Mediterranean-like climate, characterized by hot, dry summers combined with mild winters. The 'wet' season occurs between November and April each year, during which time three quarters of the annual precipitation falls (mostly as rain) on the island. Some of this precipitation percolates through the land surface to recharge the groundwater aquifers. During the 'dry' season between May and October, there is very little to no recharge of the aquifers from precipitation (Allen and Suchy, 2001a).

One of the more densely developed areas is the 2.5 km long East Point Peninsula (also referred to as "peninsula") at the eastern end of the Island. The peninsula is bound by the seawater of the Georgia Strait on the north, east and south sides. Groundwater is the primary source of potable water on East Point Peninsula. In some areas, this resource is supplemented with rainwater catchment or delivery of water from another source on the island to fill cisterns or tanks. Precipitation falling in the central, elevated area of the peninsula during the wet season recharges the groundwater resource (Allen and Suchy, 2001a).

We estimate that about 50-75 wells are currently in use on the peninsula. The BC Water Resources Atlas currently shows sixty-three wells recorded on East Point Peninsula (starting just west of Fiddler Road) (MoE, 2009). This atlas generates a map of well locations using the WELLS database which contains data from well construction records that have been voluntarily submitted to the Ministry of Environment. Although 63 wells are shown on the map, there are at least 12 wells on East Point Peninsula that are currently in use which are not recorded in the WELLs database. Conversely, some of the wells currently in the database are no longer in use or have been closed.

The outer area of the peninsula has been subdivided into 117 small residential lots, 53 of which are listed as vacant according to BC Assessment Authority data (Islands Trust, 2009). If these lots are developed using groundwater as a primary source of water, there will be an increased demand for groundwater in the peninsula that may impact the viability and sustainability of the local groundwater resource. The peninsula area is currently zoned as Rural General, Rural Residential, Commercial Recreation and Accommodation, and a small portion is zoned as Community Services (Islands Trust, 2009). This means future residences, farms, restaurants, pubs or visitor accommodation could be constructed depending on the zoning of each specific parcel of land. As this is a fragile environment with limited fresh water resources, if developments in this area are not carefully planned and managed, a decline in the quantity or quality of the groundwater resource, due to lack of infiltration of water through the subsurface relative to the groundwater use or through contamination, may result.

In coastal environments, such as those found on Saturna Island and the other Gulf Islands, the groundwater resource exists as a reservoir of fresh water overlying dense saline water (Figure 1). The freshwater exists above and below sea level. The zone where the fresh water and the saline water converge and mix is known as the interface or transition zone. Precipitation recharges the aquifer, and drives the groundwater to flow towards, and discharge to, the sea. While the position of the water table changes seasonably, so does the position of the salt water- fresh water interface. It is possible for wells to pump fresh water for many years if properly constructed and the pumping rate is kept at a low enough level as not to cause ‘upwelling’ of the saline water (Figure 2b). The intrusion of salt water into a freshwater aquifer can occur when the freshwater is pumped out of the aquifer faster than it is replenished, thereby reducing the amount of pressure above the saline water (Figure 2c). This reduction in fresh water pressure allows the pressure of the saline water to exceed the pressure of the freshwater, resulting in salt water moving into the fresh water aquifer (Delleur, 2007). Commonly referred to as ‘salt water intrusion' the impact of seawater on the fresh groundwater resource can be a major factor in limiting groundwater use in coastal environments.

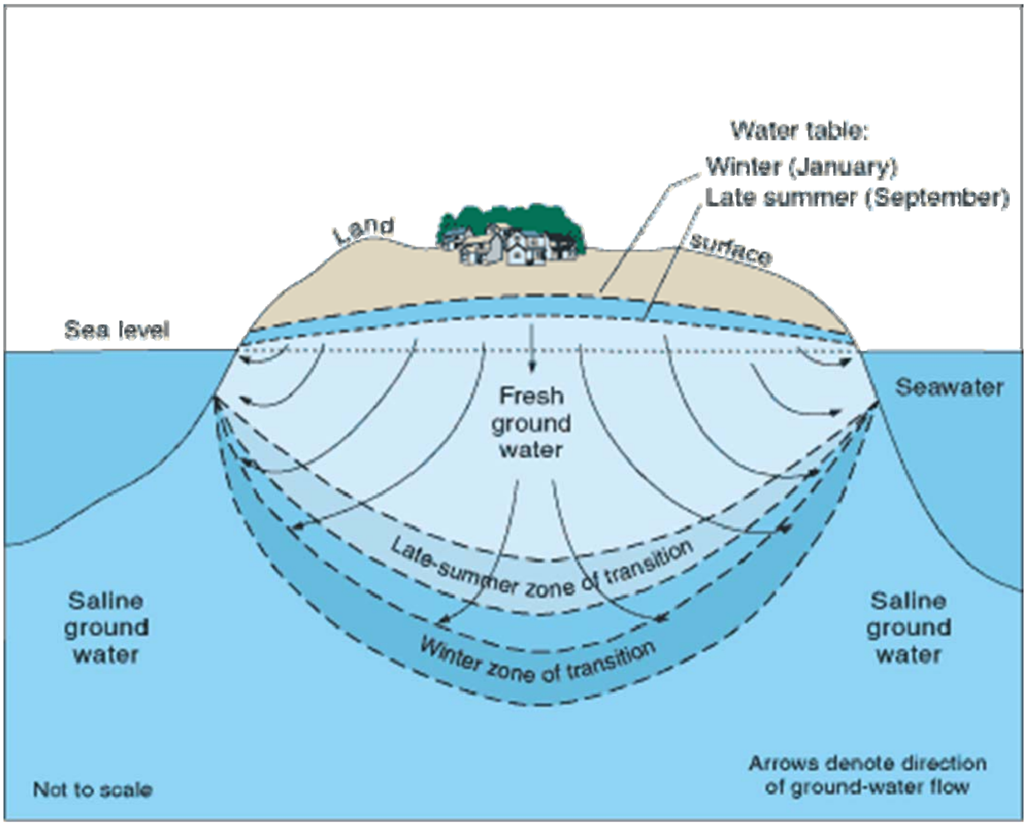

Figure 1. Cross section of an island aquifer illustrating the generalized groundwater flow patterns (USGS, 2000)

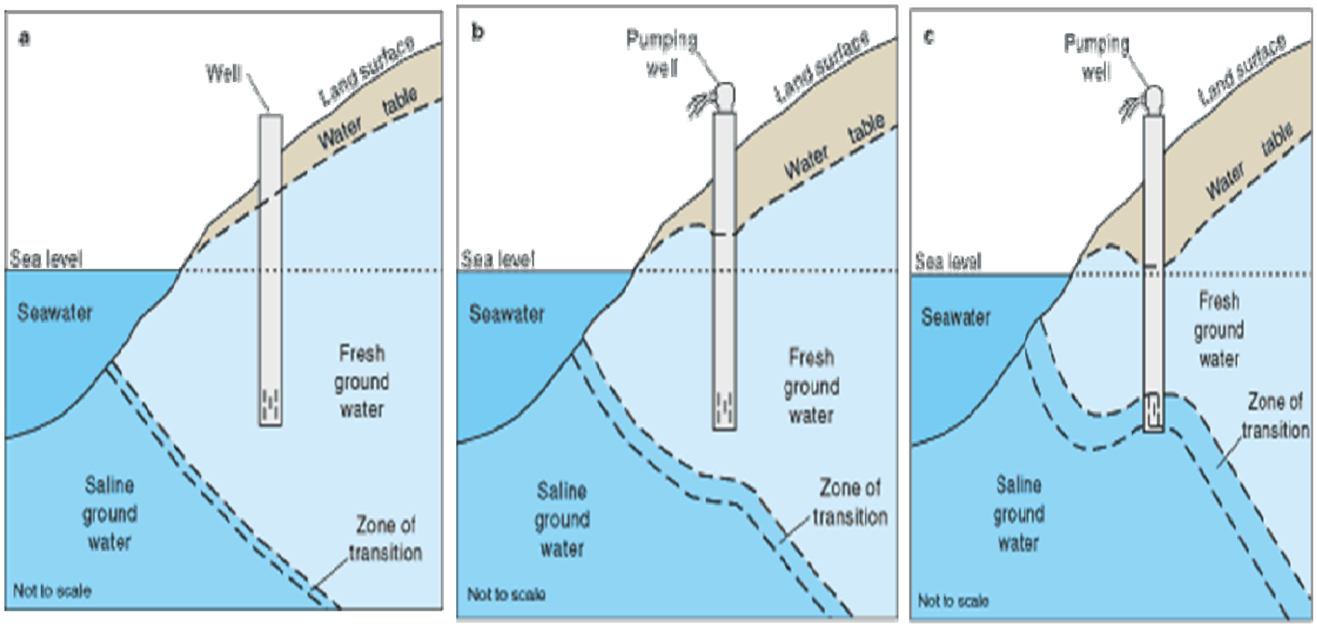

Figure 2. Cross section of (a) a well not being pumped in a coastal aquifer, (b) a well being pumped in a coastal aquifer with no impact from salt water, and (c) a well pumping saline groundwater in a coastal aquifer (USGS, 2000). Note the zone of transition is drawn up ('upwells") as well pumping occurs ((a) and (b)).

On East Point Peninsula, salt water intrusion is a major concern because the groundwater resource is relied on as a source of potable water. If this freshwater source is contaminated by saltwater, it can no longer be used as drinking water or for watering gardens or food crops. In addition, local ecosystems, reliant on the current state of fresh groundwater, would be impacted if the water became saline, potentially permanently altering the local environment.

Previous studies on Saturna Island have documented seawater intrusion affecting the quality of the groundwater on East Point Peninsula (Hodge, 1985; Allen and Suchy 2001a, b). Seawater intrusion is often indicated by the presence of increased concentrations of chloride in a freshwater aquifer over time. Chloride (Cl^-) is a major ionic (chemical) constituent of seawater. In this study, electrical conductivity (or specific conductance) is used as a surrogate for chloride concentration. Electrical conductivity is related to the amount of ions which are dissolved in the water. Dissolved ions, which include negatively changed anions (-) and positively charged cations (+), contribute to the electrical charge of the water. Dissolved ions occur naturally in both groundwater and sea water, however, in sea water the greatest concentration of dissolved ions are the chloride (Cl^-) ion and the sodium (Na^+) ion (Duke & Williams, 2008). As the amount or concentration of dissolved ions in the water increases, the electrical conductivity of the water increases. Increasing measurements of electrical conductivity in the groundwater of a coastal aquifer often indicates that saltwater has mixed with the fresh groundwater.

In July 2009, the Ministry of Environment was contacted by residents of East Point Peninsula with concerns that a leak in a water line had caused uncontrolled pumping of a well which had impacted neighbouring wells evidenced by unusual declines in groundwater levels in neighbouring wells and a “salty” taste to the groundwater. In August 2009, the Ministry of Environment initiated a field study to assess the current extent of seawater intrusion on East Point Peninsula, focussing primarily on the area that had likely been affected by this recent leak. This report documents the results of the field measurements and data analysis carried out in the study.

Objective

The objective of this study was to assess the current extent of salt water intrusion into the fresh groundwater on East Point Peninsula, Saturna Island. Recommendations of both a regulatory and non-regulatory nature on how the groundwater on the peninsula might be managed and protected are presented with a view to adopting a proactive approach to source water protection that will ensure that the groundwater resource remains viable and that its use is sustainable.

Methods

Electrical conductivity (EC) was measured from groundwater pumped from private wells located on the East Point Peninsula on August 5, 2009 and August 24, 2009 using a YSI 63/10FT conductivity meter, serial # 03B0389 AD which was calibrated with ReageCon conductivity standard solution with electrical conductivity of 1413 µS/cm @ 25°C.

The following procedure was used:

1. The water was accessed prior to any treatment system or water softener. In some cases it was not possible to access the water prior to the outflow entering a pressure tank and the water was tested after the pressure tank.
2. If the sampled water did pass through a pressure tank, the tank was thoroughly flushed out so that the measurement represented fresh groundwater.
3. The water was run for 5-15 minutes until the temperature and electrical conductivity measurements stabilized.
4. The water was run through a bucket containing the conductivity probe, thereby ensuring a continuous flow of groundwater was maintained.

At each site, if the wellhead was accessible, GPS coordinates were obtained for the well. Some of the well-owners provided information such as well construction records, well depth and the results of previous chemical analysis of their well water.

The concentration of chloride (in milligram per litre - mg/L) was calculated for each of the wells tested using the relationship between electrical conductivity and chloride that was determined from a previous study (Figure 3) (Allen and Suchy, 2001a). In the Allen and Suchy

(2001a) study, 40 wells were sampled in the East Point Peninsula area where both electrical conductivity was measured in the field and chloride analysed in laboratory samples.

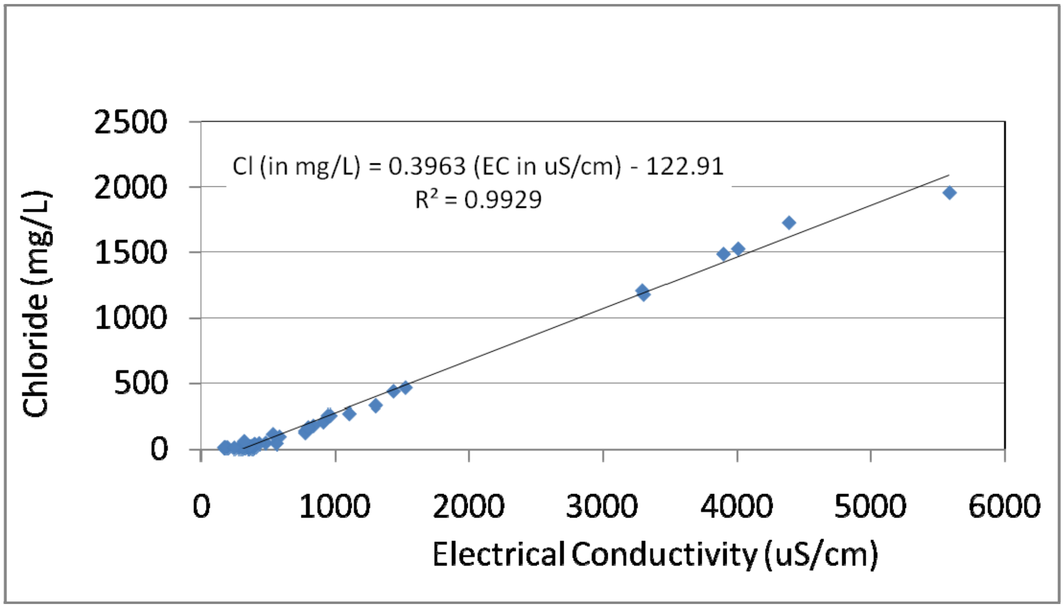

Figure 3. Graph showing relationship between chloride concentration and electrical conductivity measurements using data from Allen and Suchy (2001a).

Results and Discussion

The electrical conductivity (EC) (µS/cm) of well water was measured on August 5, 2009 and August 24, 2009 at a total of 27 separate well sites. Two sites (1 and 19) were tested on both dates. All of the electrical conductivity measurements were converted to chloride concentrations using the relationship in Figure 3. Overall, electrical conductivity of the groundwater varied from 317 µS/cm to 6850 µS/cm and calculated chloride concentrations ranged from 3 mg/L to 2592 mg/L (Table 1). In this study, the Guideline for Canadian Drinking Water Quality (GCDWQ) aesthetic objective for chloride was used as an indication of potable water (Health Canada, 2008). This objective states that the chloride concentration in potable or fresh water should be less than or equal to 250 mg/L. Aesthetic objectives (or operating limits) are not established for human health-related reasons, however it is generally accepted that measured concentrations of chloride above 100-250 mg/L in groundwater in coastal aquifers is indicative of mixing with seawater (e.g. Barlow, 2003; Jefferson County, 2002; USGS, 2000).

Table 1. Summary of measurements of electrical conductivity from wells on East Point Peninsula

Site Number	Sampling Date	Electrical Conductivity (µS/cm)	Calculated Chloride (mg/L)
1a	August 5, 2009	6830	2584
1b*	August 24, 2009	6850	2592
2	August 5, 2009	353	17
3	August 5, 2009	317	3
4	August 5, 2009	425	46
5	August 5, 2009	317	3
6	August 5, 2009	385	30
7	August 5, 2009	462	60
8	August 5, 2009	360	20
9	August 5, 2009	423	45
10	August 5, 2009	1000	273
11	August 5, 2009	1312	397
12	August 5, 2009	347	15
13	August 5, 2009	1091	309
14	August 5, 2009	1929	642
15	August 5, 2009	333	9
16	August 5, 2009	1044	291
17	August 5, 2009	1074	303
18	August 5, 2009	3791	1379
19a	August 5, 2009	3278	1176
19b*	August 24, 2009	4136	1516
20	August 24, 2009	4007	1465
21	August 24, 2009	1050-1100**	293-313
22	August 24, 2009	1542-1620**	488-519
23	August 24, 2009	691	151
24	August 24, 2009	1598	510
25	August 24, 2009	791	191
26	August 24, 2009	949	253
27	August 24, 2009	322	5

*electrical conductivity was measured at site on both dates.

**reading did not stabilize, range indicated, average used in data analysis.

Figure 4 shows the spatial distribution of calculated chloride concentrations determined from the field measurements of electrical conductivity in this study. The wells tested were primarily located in the northern portion of the middle and west parts of the peninsula (along Tumbo Channel Road). Overall, the western part of the peninsula (the peninsula on the left half of Figure 4) indicated electrical conductivity less than 440 µS/cm and calculated chloride concentration less than 50 mg/L. In the middle part of the peninsula most of the wells indicated electrical conductivity greater than 940 µS/cm and concentrations of chloride greater than 250 mg/L. Four wells indicated electrical conductivity over ~2800 µS/cm or calculated chloride concentrations of greater than 1000 mg/L.

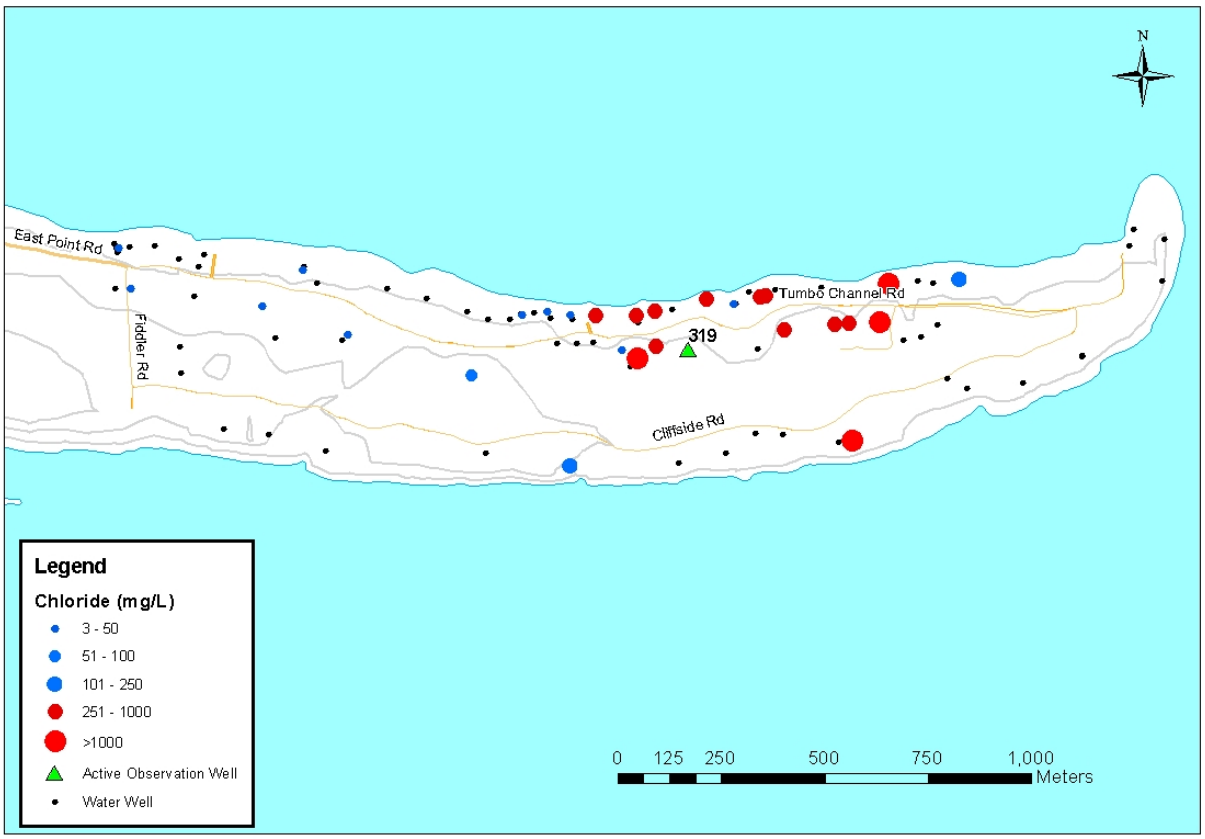

Figure 4. Distribution of chloride concentrations calculated from electrical conductivity measurements of groundwater from private wells on East Point Peninsula.

The occurrence of saline water in the groundwater of the peninsula has been noted since the mid 1980s. Hodge (1985) noted "moderate concentrations of chloride" in the wells on the East Point Peninsula. A detailed study by Allen and Suchy (2001a) indicated groundwater samples collected from the East Point Peninsula contained chloride concentrations between 34 and 2,801 mg/L and noted several wells had been closed due to unacceptably high concentrations of salt in the water.

To assess whether or not the extent of seawater intrusion has increased over the years, the current data set (Table 1) was compared to measurements collected in 1982 (Hodge, 1985) and 1997 & 1998 (Allen and Suchy, 2001a). Based primarily on the 2009 data set, the peninsula was divided into three sections: West, Middle and East; to better focus discussion of the groundwater resource on the East Point Peninsula. Results from these three studies that have investigated saltwater intrusion on East Point Peninsula in the last few decades are summarized in Figure 5.

Hodge (1985) reported on 10 measurements of chloride in well water on East Point Peninsula. Some of these were field measurements and others were laboratory analyses. At all of the wells, measured chloride concentrations in the groundwater were less than 500 mg/L (Figure 5a). In the west zone, 5 samples were less than or equal to 50 mg/L chloride and one sample had 51-100 mg/L chloride. In the middle zone, 2 samples had chloride measurements of 51-100 mg/L and the third sample had a measurement 101-500 mg/L. The one well tested in the east zone had a chloride concentration less than 50 mg/L. One sample result from the Hodge study was reported as being in a range from 101-500 mg/L in the Hodge study, and is included in this study (Figure 5a), in a range of 101-250 mg/L.

Allen and Suchy (2001a) measured the chloride concentration in groundwater by laboratory analysis in a total of 21 wells during field surveys carried out in 1997 and 1998 (Figure 5b). The five wells tested in the west zone all showed measured concentrations of chloride less than 50 mg/L. In the middle zone, of the 12 wells sampled, 75% of the results indicated chloride concentrations less than 250 mg/L, 2 samples indicated chloride concentrations between 251-1000 mg/L and only 1 sample contained chloride at a concentration greater than 1000 mg/L. In the east zone 3 of the 4 wells tested indicated chloride concentrations greater than 251 mg/L (Figure 5b).

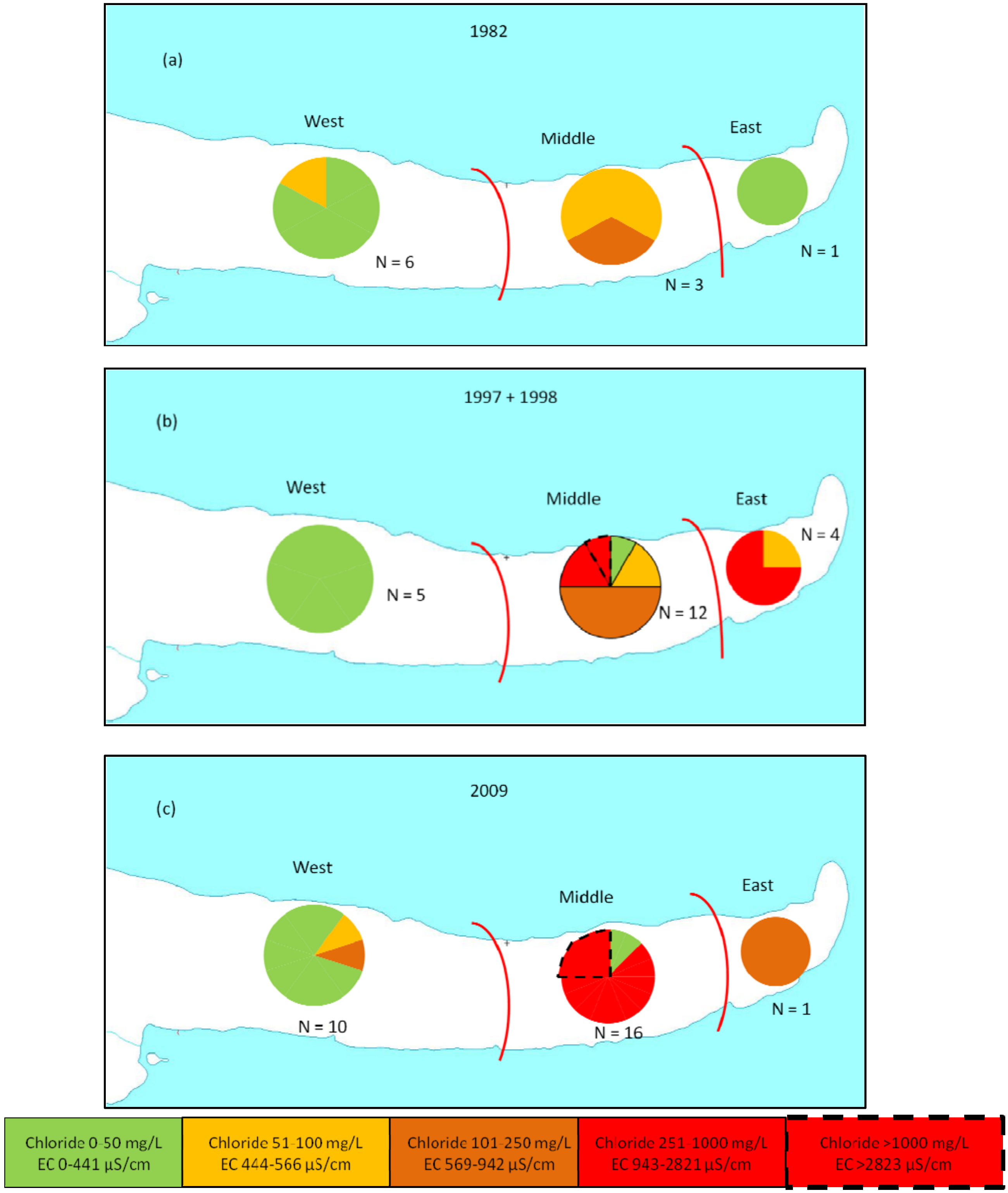

Figure 5. Measurements of chloride concentration in groundwater from pumped wells in three studies (a) Results from Hodge (1985); (b) Allen and Suchy (2001a); and (c) this study.

In the 2009 study, electrical conductivity was measured in groundwater from 27 wells (Figure 5c). The electrical conductivity measurements were converted to chloride concentration using the relationship in Figure 3. In the west zone, all 10 wells that were tested indicated calculated chloride concentrations less than 250 mg/L. In the middle zone, 90% (14 of 16) of the samples showed calculated chloride concentrations greater than 251 mg/L and 25 % (4 of 16) with concentrations greater than 1000 mg/L. In the east zone, the only well tested showed a calculated chloride concentration between 101 and 250 mg/L.

Variations in chloride concentration in groundwater between different wells sampled at different times can generally be attributed to a number of different factors: (1) Natural variation of the source rock, (2) Differences in analytical techniques of measurements (3) Seasonal variation due to recharge of the groundwater resource by precipitation, and (4) Mixing of water sources. The time of year when the water samples were collected for the Hodge study and the Allen and Suchy study is not known. Both the results from the laboratory and the Hach field analysis from the Hodge study were grouped together. Allen (2009) measured the chloride concentration at six wells on East Point Peninsula between 2002 and 2007 and found a wide range in the magnitude of the variation of chloride concentration. For example at one site in the west part of the peninsula there was variation in chloride between 25 mg/L and 30 mg/L while at another site in the east part of the peninsula variations between 465 mg/L and 4440 mg/L were noted. Hence while our comparison of data collected from the three studies (Hodge, Allen and Suchy and this study) was used to examine changes in the concentration of chloride in well water pumped from groundwater wells on East Point Peninsula over time, it is limited to a general overall review of existing data. Additionally, since we can surmise that the primary cause of saltwater intrusion is pumping groundwater excessively; with the absence of pumping or water use data and the general nature of our comparison, we cannot determine which specific pumping wells may possibly have led to the intrusion of salt water.

In summary, in the west zone, the groundwater continues to be predominantly fresh with chloride concentrations less than 250 mg/L. In the middle zone, saltwater intrusion appears to have impacted the fresh groundwater resource. The intrusion of seawater is likely due to excessive pumping of wells and has steadily impacted the groundwater quality to the present day. However, without a better understanding of groundwater extraction rates it is not possible to determine which specific wells or properties have impacted the overall resource or when the impact may have occurred. In all three studies, there is insufficient data to comment on the impact of saltwater intrusion in the east zone of the peninsula.

Although saline water has historically been found in the groundwater in this area, the operation and use of groundwater wells can play a large role in increasing or decreasing future impacts. Continued operation of saline wells contributes to the degradation of the freshwater resource. Additionally, pumping of freshwater wells, particularly at high extraction rates, may result in salt water intrusion in the aquifer due to the reduced static fresh groundwater head while pumping, and therefore the reduced pressure of freshwater against the salt water interface. Proper operation of wells should include controlled low pumping rates during the dry season when freshwater demands are highest and the incorporation of water storage systems in order to pump and store water in the wet months, for use in the dry months.

Ministry of Environment Observation Well #319

The Ministry of Environment (MoE) currently operates a groundwater monitoring well on East Point Peninsula (Figure 4) which was established in 1992 and is identified as Observation Well 319. The well is located on private property and is on loan to the Province. Well #319 was drilled in 1990, is 110 m (360 ft) in total depth and is completed with 4 m (11 ft) of surface casing and 106 m (349 ft) open borehole drilled into the Nanaimo Group fractured sandstone and shale bedrock. Between October 1992 and 2005 the well was equipped with a Stevens® chart recorder which measured water level in the well by recording the movement of a float on the water surface with a pen onto a paper chart at the surface. In September 2005 the Stevens® chart recorder and associated equipment was replaced by a Thalamedes® float/data logger system. This system records the movement of a float on the water surface electronically in a data logger housed at the top of the well casing. Currently, the data-logging system measures water level every 15 minutes and the data logger stores the average of four readings each hour. The water chemistry is analyzed periodically (generally every 3 years) by removing the monitoring equipment and temporarily installing a pump in the well to obtain a sample which is sent to a laboratory for analyses. Field measurement of conductivity, temperature and pH are also obtained during sampling.

The hydrograph for the complete record of time for this well (1992-2009) is shown in Figure 6(a). Overall, the groundwater level in this observation well appears to be impacted by three factors: (1) seasonal variations in groundwater recharge patterns, (2) on-going tidal fluctuations and (3) groundwater use (pumping in nearby wells). The groundwater in this part of the peninsula appears to vary seasonally by 1.5 - 2 metres (see period 1992-1994) with the highest levels in the winter months and the lowest in the summer. Tidal influences cause up to 1.5 m of daily total change in water level in the well (Figure 6(b); Westberg, 2008). The influence of tides on the groundwater levels on East Point is important to note as it suggests caution must be taken in attributing changes in water level less than 1.5 meters to pumping interference. Between November 2007 and March 2008 the water level measured in Observation well 319 was about 4 m lower than similar time periods in previous years. Similarly between February and March 2009 and April and July 2009 the water level measured was about 3-6 m below normal. In all three cases, this is likely drawdown response due to pumping in a nearby well and not from tidal fluctuations.

In 1992, at the time that the Stevens recorder was installed in Observation Well 319, field parameters were measured from water obtained after pumping the well for about 150 minutes at 1.5 gpm. In 2002, 2006, and 2008 a water sample was obtained from the well and field parameters were measured. The 1992 field measurement indicates conductivity of 450 µS/cm and a chloride concentration of 46 mg/L. In the three samples in 2002, 2006 and 2008 electrical conductivity ranged between 845 and 1150 µS/cm and chloride concentrations ranged between 158 and 246 mg/L (Figure 7). The provincial monitoring well shows that while there is about 100 mg/L variation in chloride concentration in the past 6 years the water remained “fresh”.

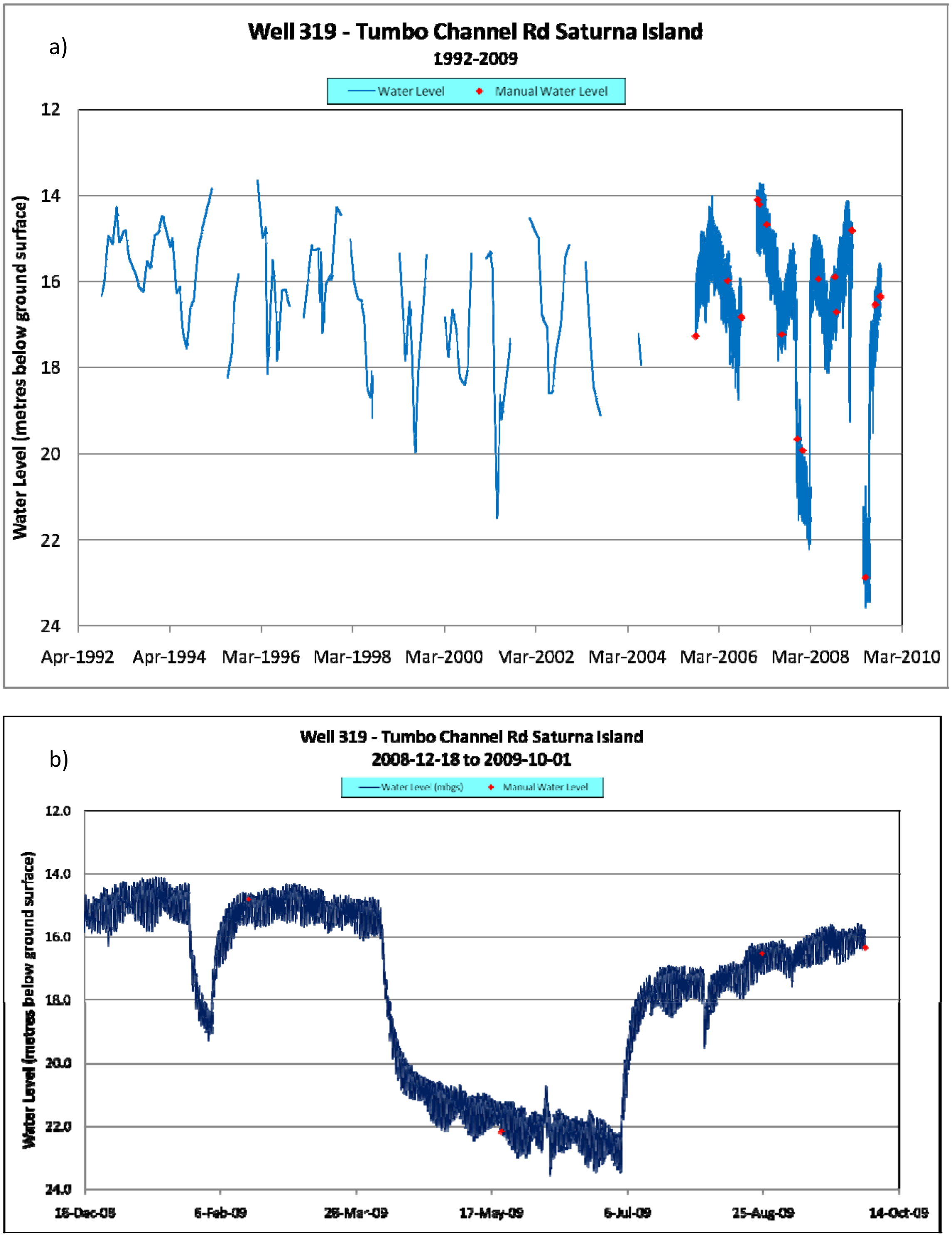

Figure 6. Hydrographs for Observation Well 319: (a) complete record of water level measurements in the monitoring well between May 1992 and August 2009 and (b) water level variation between December 2008 and October 2009, highlighting the water level decline between April and July 2009.

The groundwater samples collected from Observation Well #319 were collected during the dry season. The sample collected in 1992 was collected October 3; the sample collected in 2002 was collected July 29; samples collected in 2006 and 2008 were collected on September 19 and October 14, respectively. Seasonality does not appear to be a factor when comparing the analytical results from the observation well samples.

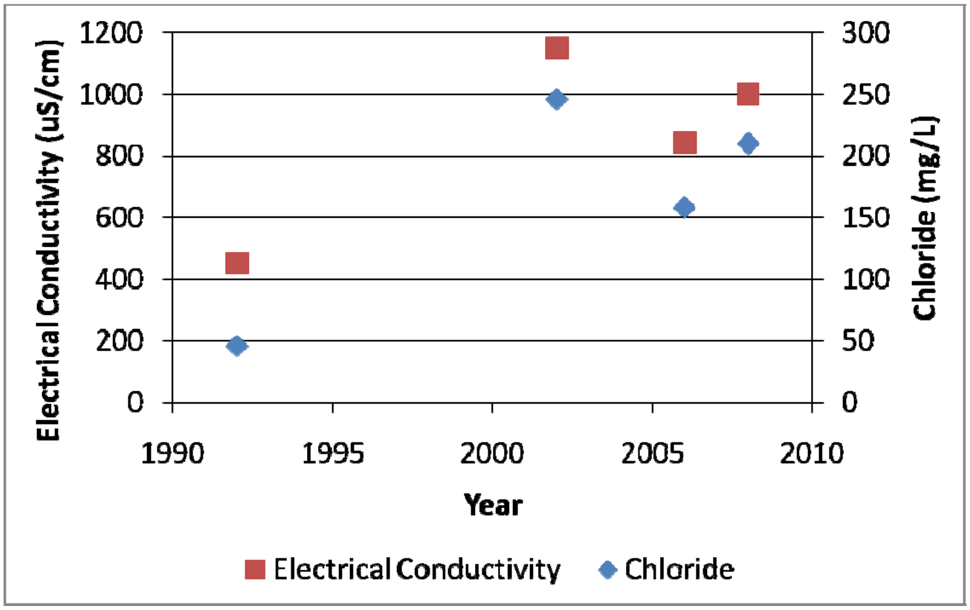

Figure 7. Measurements of electrical conductivity and chloride concentration in MoE Observation Well 319.

Summary and Recommendations

This study has shown that there is evidence to indicate that the quality of the groundwater on East Point Peninsula has been impacted by the intrusion of sea water over time and mixing of the fresh and saline waters. However, groundwater remains a viable source of potable water on the peninsula and will likely continue to be viable in the future if the resource is managed and protected with care and diligence by both current and future groundwater users.

The main factors affecting the use and protection of the groundwater resource on the peninsula include: (1) geography and hydrogeology suggesting limited recharge and low hydraulic gradients, (2) increased population leading to increased water use in the dry season when there is no recharge to the aquifer, (3) unsustainable current and future demands on the resource as a result of lack of data, information and consideration in planning of development, (4) pumping induced sea water intrusion and (5) unknown impacts of climate change, in particular the impact of rising sea level. In this study we focussed primarily on an assessment of salt water intrusion and hence focus our recommendations to reduce that impact.

We recommend, in order to help mitigate further salt water intrusion in areas that are already affected and prevent salt water intrusion in areas that have not yet been impacted, both regulatory and non-regulatory measures should be considered. While it may be easier to affect new water systems (i.e. wells and water systems not yet constructed), lasting changes will only occur if existing well owners voluntarily modify their water systems. Some measures might include:

- *Changes to well construction and operation practises*

  The recent water line leak that prompted this study suggests that the largest threat to the long-term viability of the groundwater resource as a source of potable water is uncontrolled pumping. Assessing and modifying the operation of existing wells will prevent future incidents of uncontrolled pumping. Some modifications to standard well operation might include:

  (a) Incorporating storage to water systems to eliminate “on-demand” only pumping.
  (b) Installing “Low-level pump shut-off devices” to limit the maximum drawdown level in a well.
  (c) Limiting pumping rates and encouraging lower pumping rates.
  (d) Monitoring groundwater levels and water quality in private wells.
  (e) Setting a limit on the total depth of new wells drilled close to the seashore, taking into consideration the difference in ground elevation on the northern and southern sides of East Point Peninsula.

- *Encourage rainwater catchment/use and storage*

  By encouraging the use of rainwater catchment systems during the wet months, the increased water demand in the dry months may be partially or entirely satisfied. Catchment and storage of rainwater can be used to water gardens and used as drinking water (provided the water is properly disinfected) in the drier summer months, which are also the months that water use increases due to dry conditions and increased population on the island.

- *Issue Orders under the Water Act to cease pumping of water impacted by seawater intrusion*

  Section 78(2) of the *Water Act* states:

  A person must not operate a well in a manner that causes or is likely to cause

  (a) the intrusion of salt water or contaminated water into

  (i) an aquifer from which that well draws ground water, or

  (ii) any well that draws ground water from that aquifer, and

  (b) a significant adverse impact on

  (i) the quality of the ground water in that aquifer, or

  (ii) the existing uses made of the ground water from any well that draws from that aquifer.

  An engineer under the *Water Act*, has the authority to issue Engineer's Orders and provide direction on well operation so that salt water intrusion into an aquifer does not continue to occur. A directive may include requiring an assessment of the well operation by a person listed as a Qualified Professional under the *Water Act;* continued testing, monitoring and reporting of water quality results to the Ministry; or other actions taken that the engineer considers advisable.

- *Voluntary de-activation of wells which are pumping saline water*

  The vulnerable groundwater resource must be protected by not using saline wells. The establishment of a minimum concentration of chloride as an indicator of salt water intrusion would help in determining whether or not a well that has turned brackish or saline, should cease being used. It would also help determine whether or not a newly drilled well should be closed. Currently the Guidelines for Canadian Drinking Water Quality have a 250 mg/L aesthetic guideline. It is a requirement under the *Water Act* that the operation of a well must not cause salt water *intrusion* in the aquifer that that well, or any other well, draws from. Encouraging voluntary de-activation of wells which are pumping salty groundwater will help to protect the resource.

- *In the future, all wells on East Point Peninsula may require licensing/permitting*

  It is expected that the *Water Act* will be modernized and incorporate some form of licensing or permitting of groundwater extraction. *Living Water Smart* has committed the provincial government to the following statement, "By 2012, government will regulate ground water use in priority areas and large groundwater withdrawals" (Ministry of Environment, 2008). If the Gulf Islands, or Saturna Island, is identified as a priority area, then the Ministry of Environment would have the legislative framework to regulate the extraction of groundwater in this sensitive area.

- *Provincial government policy incorporating source protection considerations*

  Currently on Saturna Island, the Ministry of Transportation approves subdivision of land requests which incorporates "proving" the availability of water on all parts of the sub-divided land. The Vancouver Island Health Authority requires community water systems to obtain source approval of their water source. Both of these agencies could adopt a policy of *not* accepting treated salty groundwater as a potable water source and therefore reduce the reliance on the groundwater resource by encouraging other water sources (i.e., rainwater catchment and storage).

Considering the volume of water demand created from a community water system on the East Point Peninsula, well-specific restrictions should be placed on the flow rate and elevation of the pump in the well; all wells, including community water system wells, should be equipped with pumps that have low level shut offs and flow restrictors to prevent over pumping of the aquifer. Conditions such as incorporating storage, closing wells not pumping potable water, monitoring rate of extraction and groundwater quality could be required at regular intervals to assess ongoing well operation. These conditions could be placed on water system Operating Permits and subdivision approvals.

- *Capital Regional District or Islands Trust By-laws*

  Currently, the regulation of water use is under the mandate of the provincial government while land use and development, zoning and building regulations are under the mandate of municipal government. By-laws which require water systems for new construction and land development be comprised of a combination of rain water collection, water storage and groundwater may reduce complete reliance on groundwater resources. The Groundwater Bylaws Toolkit (Okanagan Basin Water Board, 2009) is an excellent resource to assist local government in the development of groundwater protection bylaws.

  An example of the establishment of local government policy to protect groundwater quality from further degradation due to seawater intrusion can be found in Jefferson County (2002). This policy establishes Seawater Intrusion Protection Zones (SIPZ) and incorporates voluntary and mandatory measures related to well drilling, subdivision approval and issuance of building permits.

- *Education and outreach*

  Providing local well drillers and pump installers with information about the unique issue of salt water intrusion in this area may help ensure that wells are located appropriate distances from the seashore and appropriate target depth for drilling, and that the pumps are at an acceptable depth and are pumping at a rate that is sustainable for the area. This information can also be passed on by realtors to prospective clients so the clients can be made aware of the fragile and vulnerable groundwater resource in the peninsula, the already present issue of salt water intrusion and the potential impact to the water resource if more wells are added or operated in a manner that could impact the resource.

Current residents (both full and part-time) should also be educated about the fragile groundwater resource. Information about proper well operation, the benefits of storage capacity, probable impacts to the aquifer from over pumping the well (i.e. pumping in order to water lawns), and impacts to the aquifer and other well users when pumping saline water would assist property owners in the design and operation of a sustainable groundwater pumping system.

Education programs should include encouraging the use of water conservation measures in private homes, commercial ventures and community buildings (i.e. low-flow plumbing fixtures, grey-water use, rapid leak detection and repair); promotion of water storage capacity and discouraging or restricting outdoor water use during the dry season.

- *Further study and monitoring and the development of a community database of private well water levels and chemistry results*

  There is a considerable amount of data that has been collected to date on both the groundwater quality and water levels on East Point Peninsula. The observation well level data is available to the public at http://a100.gov.bc.ca/pub/gwl/disclaimerInit.do. It would be beneficial to capture the chemistry data from private wells that well owners have commissioned. However, the current usual suite of chemistry analyses does not include chloride and bicarbonate, both of which are essential to better understand the groundwater on East Point Peninsula. Monitoring groundwater extraction rates and quantities through metering would be useful to better understand the link between the groundwater pumping and water quality. Ongoing monitoring of electrical conductivity and chloride concentrations will help determine the long-term impact of seawater intrusion particularly in light of predicted rises in sea level from climate change.

Acknowledgements

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Glossary

Aquifer: The *Water Act* defines an aquifer as: (a) a geological formation, (b) a group of geological formations, or (c) a part of one or more geological formations that is water bearing and capable of storing, transmitting and yielding water.

Calibration: A method whereby the reliability of an instrument is checked by a measurement against a known standard value.

Drawdown: A measure of the decrease in water level in a well due to pumping.

Electrical Conductivity: A measure which varies depending on the total quantity of dissolved chemical material in the water. The ability of the water to conduct an applied electrical current varies with the amount of dissolved chemicals in the water.

Fracture: A break in the rock through which groundwater may flow.

Hydrograph: A graph of water level versus time. This type of graph is often used to illustrate the change in groundwater level in a well over time.

Ion: An atom or group of atoms that carries a positive or negative charge as a result of having lost or gained one or more electrons.

Salt water Intrusion: The advancement of salt water into a fresh groundwater system.

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