Water Quality and Delineation of a Wellhead Protection Area for the Myrtle Pond Community Well, Powell River, BC

Submitted to:

Dr. Paul Martiquet, Medical Health Officer
Coast Garibaldi Community Health Services Society

Prepared by:

Yao Cui, P.Geo.
Ministry of Health
Victoria, BC

Mike Wei, P.Eng.
Groundwater Section
Ministry of Environment, Lands and Parks
Victoria, BC

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Introduction

The Myrtle Pond well is located on Lot 4 / DL 1499 (Plan 13390), north of Highway 101 and west of Padgett Road, in the Powell River Regional District (Figures 1 and 2). It was constructed in 1993 to replace a failing well drilled in 1982 for the Myrtle Pond Water System which serves a community of approximately 40 households in the Myrtle Point area.

There has been a concern about water quality in the Myrtle Pond Water System. The PHCL (1993) report indicated, and past water users have complained of, the colour and iron content in the water. A recent investigation of water quality was conducted by Dave Kalyn (1998) of the Ministry of Environment, Lands and Parks in response to an elevated trihalomethanes (THM) level in treated water during a December 1997 sampling. In addition to testing results on total organic carbon, tannins, lignins, sodium and chloride levels found in water samples and occasional reports of hydrogen sulphide odour in tap water by the water users, the Coast Garibaldi Community Health Services Society has mentioned the presence of fecal coliform in tap water samples (it was later identified as contamination of a tap in a household, an isolated incident perhaps). There was also some concern that the source of the THM may be from land use activities in the recharge area of the Myrtle Pond well.

The Coast Garibaldi Community Health Services Society has requested technical assistance in developing a wellhead protection plan for the Myrtle Pond well. As a first step, a project was initiated to delineate a wellhead protection area for the Myrtle Pond well.

This report summarizes the known hydrogeology around the Myrtle Pond well, recent water quality data, aquifer vulnerability assessment, and the result of delineating a wellhead protection area for the Myrtle Pond well.

The project was carried out by the former Health Assessment Branch, BC Ministry of Health, in cooperation with the Groundwater Section, Water Management Branch, BC Ministry of Environment, Lands and Parks. The work was made possible through assistance from Len Clarkson, Dan Glover and Bob Weston of the Coast Garibaldi Community Health Services Society and staff in the Groundwater Section. The report has benefited from comments and suggestions by Frances Ladret of the Powell River Regional District, Len Clarkson, Bob Weston and Dan Glover.

Hydrogeologic Characteristics

General Surficial Geology

Based on previous studies (e.g., B.C. Ministry of Environment. 1978; McCammon, 1977), available well logs in the study area, and a field survey carried out during this investigation, surficial materials in the Myrtle Creek watershed can be characterized as the following, from the top layer to the bottom layers:

- A top layer of marine veneer of variable composition (mostly sand, some gravel and clay) and texture and varying thickness (20 metres or less),
- A confining layer of glacial till (part of the Vashon ground moraine) up to 36 metres,
- Layers of pre-Vashon sand, gravel and silt up to 90 metres,
- Layers of pre-Vashon tills, and
- Underlying bedrock of the Coast Plutonic Complex and volcanic rocks (Wheeler and McFeely, 1991), mostly granodiorite and basaltic rocks in nature.

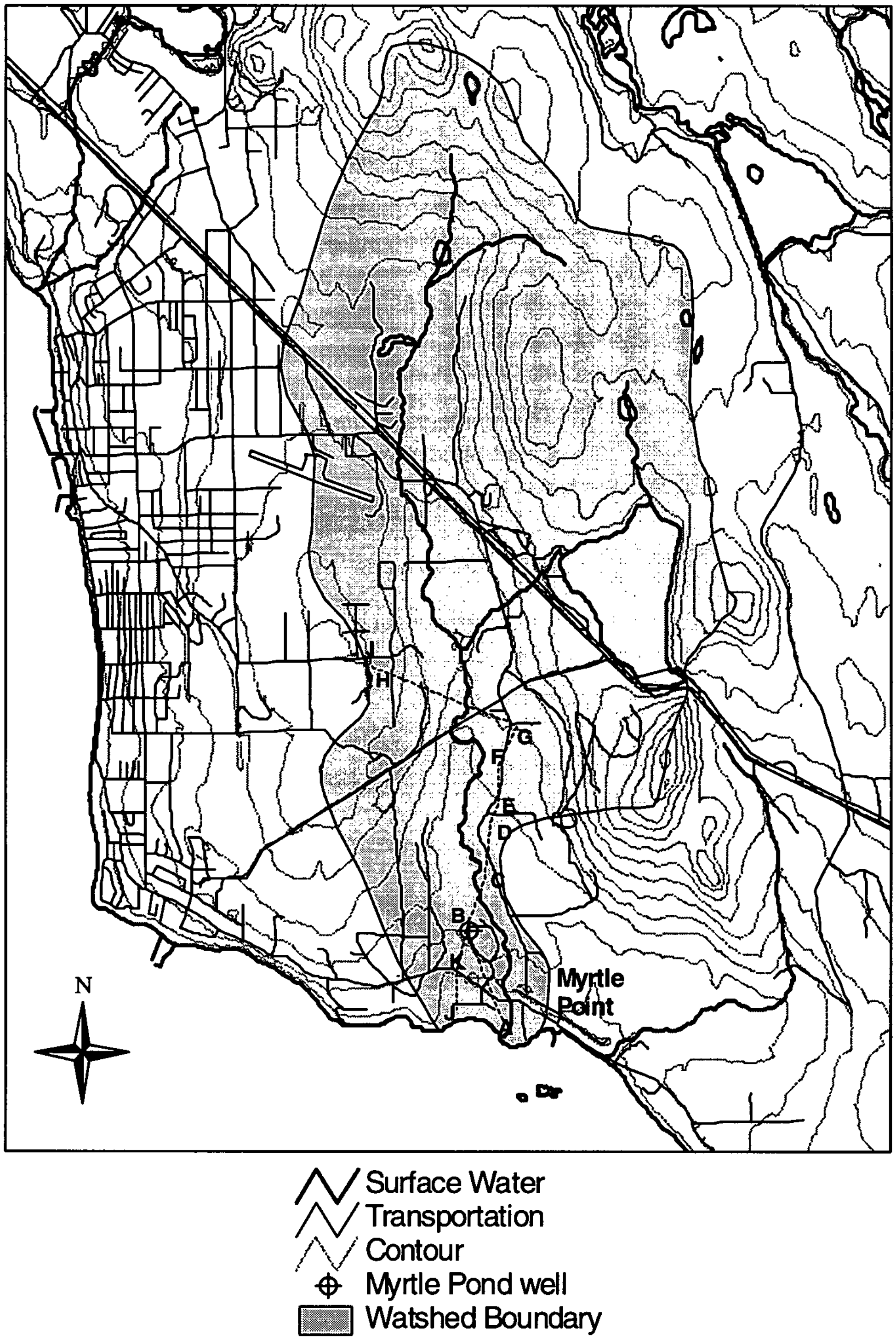


Figure 1. Study area in the Myrtle Creek watershed area
(Dashed lines with letters from A to K represent the locations for cross-section)

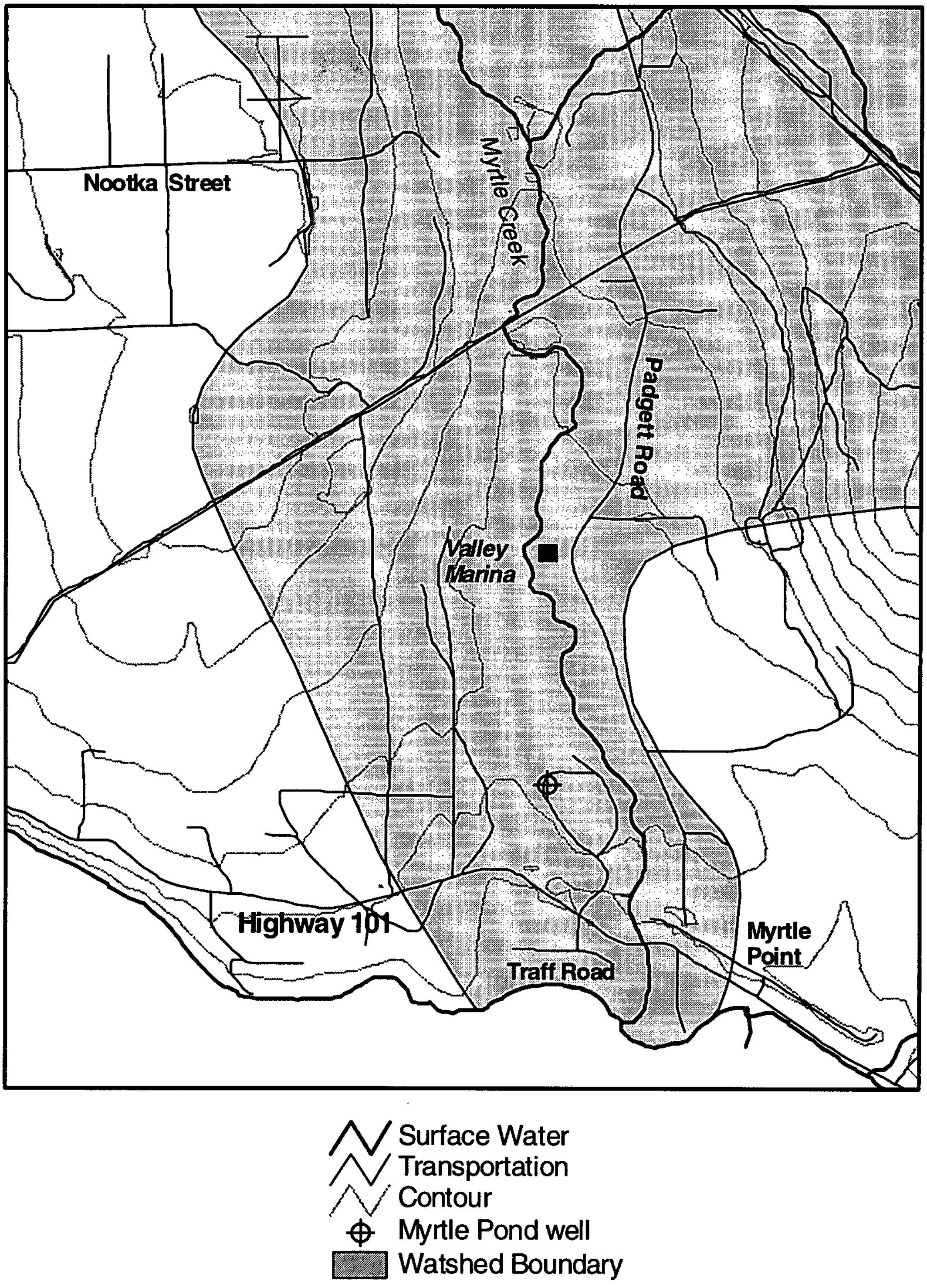


Figure 2. Myrtle Pond Well Study Area

Aquifer Characteristics

A review of more than 80 well records in the vicinity of the Myrtle Pond well (up to Nootka Street on the north and down to Traff Road on the south) reveals that there are at least two layers of granular aquifers (the marine veneer and the pre-Vashon sand and gravel) and one fractured bedrock aquifer in the study area. A confining layer of glacial till exists in most area, except on the bottom of the valley (north of the Valley Marina) where wells deeper than 20 metres below ground are not available to indicate or confirm the existence of this confining layer.

A number of shallow wells (20 meters or less in depth) are located on the bottom of the valley and draw groundwater primarily from an upper granular aquifer, likely consisting of sediments of the marine veneer (see attached cross-section). These shallow wells provide water for single households. At higher elevations (e.g., 140 metres above sea level) along Nootka Street, deeper wells (e.g., 150 metres below ground) draw groundwater from a lower granular aquifer (mostly pre-Vashon sediments) to supply water for multiple households. At lower elevations (e.g., less than 70 metres above sea level) along the coastline, most single household wells draw groundwater from an aquifer which is less than 60 metres in depth and becomes shallower towards the coastline. At this same lower elevation and more than 100 metres below the ground there is a fractured bedrock aquifer from which the Myrtle Pond well draws water supply.

Myrtle Pond Well

The Myrtle Pond well is situated on a local hill higher than the surrounding area within a 200 metres radius. The well was drilled, starting with 200 millimetres diameter casing to a depth of 30.5 metres and then with 150 millimetres casing to a depth of 116 metres. The well was continued open hole in bedrock to its completed depth of 161 metres.

The driller's lithology for the Myrtle Pond well is list in Table 2.

Water Quality Issues for the Myrtle Pond Well

Trihalomethanes

A major concern of water quality for the Myrtle Pond well is THM. For the December 1997 sampling results, Kalyn (1998) concluded that the elevated THM level was caused by an incident of a high level of chlorine being added to the water and not likely from any land use activities in the local area. The concentrations for the four separate compounds in THM, including bromodichloromethane, bromoform, chloroform, and dibromochloromethane, are shown in Table 1.

Table 1. Selected chemical results from water samples of the Myrtle Pond well

Parameters Analyzed	Units	Dec. 3, 1997 Sampling	Jan. 6, 1999 Sampling	Jan. 12, 1998 Sampling	Feb. 5, 1999 Sampling
Bromodichloromethane	μg/L	76	69	10	73
Bromoform	μg/L	<10	<10	<10	<10
Chloroform	μg/L	159	132	22	129
Dibromochloromethane	μg/L	39	34	6	40
Sodium	mg/L	161			167
Chloride	mg/L	122			130

Three water samples were collected during January and February, 1999 and elevated THM levels were recorded twice. The interim Canadian drinking water quality guideline for total THM is 100 micrograms/Litre (μg/L) as a running annual average of quarterly samples (Health Canada, 1996). The Coast Garibaldi Community Health Services Society is currently collecting more data to calculate the annual average values.

THM are byproducts of the chlorination process, formed from the interaction of chlorine with humic and fluvic acid in raw water. While THM's role as a probable or possible cause of cancer is still a subject for debate, a recent California study appears to suggest a linkage between THM and spontaneous abortion or other types of miscarriage (e.g., Waller et al., 1998, Swan at al., 1998). Among individual THM, only high bromodichloromethane exposure (e.g., consumption of ≥5 glasses per day of cold tapwater containing ≥18 μg per litre bromodichloromethane) was identified associating with spontaneous abortion in the California study. Although this linkage has not been confirmed and further studies are pending, water users, especially pregnant women, should be informed of the potential risk of drinking water with elevated THM concentrations. The higher ratio of bromodichloromethane vs. total THM in the treated water samples from the Myrtle Pond well should be confirmed and the causes (e.g., additional bromide ions introduced by seawater intrusion) be further investigated.

Seawater Intrusion

The Myrtle Pond well contains brackish water with elevated sodium and chloride levels. These levels appear to be increasing over time (Figure 3). More water chemical data and records on water pumping rates over time are needed to confirm whether or not the elevated sodium and chloride levels were caused by seawater intrusion.

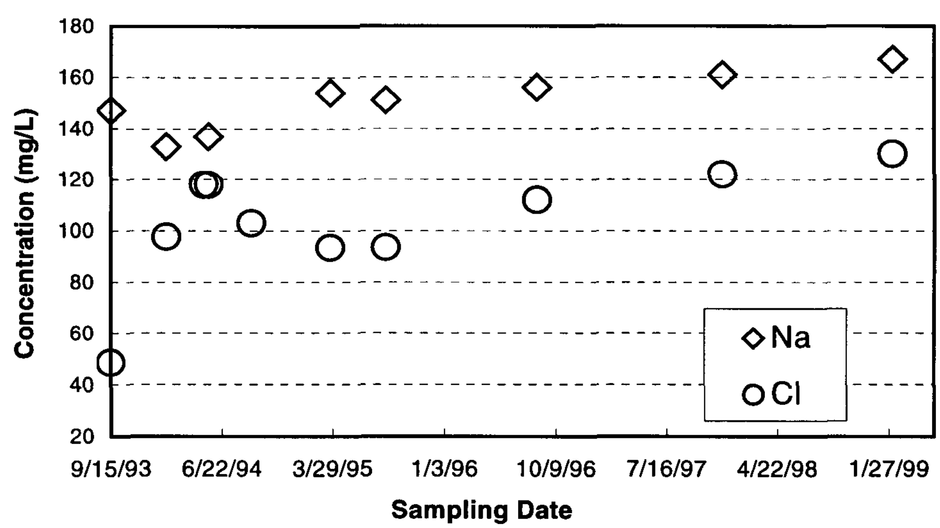


Figure 3. Sodium and chloride levels in the Myrtle Pond well

There is no direct health concern on the observed sodium and chloride levels in the Myrtle Pond well water, except that if there is a seawater intrusion, more bromide ions could be introduced, which potentially increases the chance of forming more THM, especially bromodichloromethane, if water is treated by chlorination.

Other Water Concerns

Hydrogen sulphide odour, iron, and colour found in the Myrtle Pond well water do not threaten the health of the water users, except that they cause aesthetic concerns with bad taste. It is likely that they are originated from the source water and can be reduced by a filtering and aeration water treatment system.

While not a direct health concern for the levels of total organic carbon, tannins and lignins found in the Myrtle Pond well water, they may increase the chance of forming THM if the water is treated by chlorination. It is most likely their sources are from surface water, although we cannot rule out the possibility of their originating from a sedimentary layer containing vegetation (see the Myrtle Pond well record in Table 2). The sources or causes of total organic carbon, tannins and lignins should be, if possible, eliminated, or the amount of total organic carbon, tannins and lignins should be reduced before water is treated again by chlorination.

Delineation of a Wellhead Protection Area

A key component in the development of a wellhead protection plan is the delineation of a capture zone or a wellhead protection area. The delineation of a wellhead protection area was carried out by identifying the hydrogeological parameters, selecting appropriate delineation methods and comparing results by different methods.

Hydrogeological Parameters

Based on the results of a pumping test on the Myrtle Pond well (PHCL, 1993) and a review of well records collected during this study, a few hydrogeological parameters were determined for the fractured bedrock aquifer from which the Myrtle Pond well draws groundwater. These hydrogeological parameters are used for delineating a wellhead protection area and are summarized here.

Transmissivity (T):

Transmissivity was calculated as 9.4×10^{-5} square metres per second (m^2/s), based on pumping test result of the Myrtle Pond well when the well was constructed (PHCL, 1993).

Aquifer thickness (b):

The main water bearing fractured bedrock was encountered at depth from 133.5 metres to 160.9 metres for the Myrtle Pond well, which gives an estimated aquifer thickness of approximately 27.4 metres. A more accurate estimation of the aquifer thickness is difficult to obtain because there are no wells deeper than 161 metres in the area which might help to identify the lower depth of the aquifer and its attitude.

Hydraulic conductivity (K):

Hydraulic conductivity is calculated as 3.43×10^{-5} m/s with the following equation:

$$K = T / b$$

Porosity (n):

Porosity is the ratio between the openings in the rock and the total rock volume. Since a value for porosity is not available from measurement of aquifer samples at this point, the other alternative estimation is from published measurements or "typical" porosity values for certain type of aquifer materials. From well logs collected and a geological survey conducted during this study, typical bedrock is identified as basaltic and granitic rocks. The often cited porosity for basalt or fractured crystalline rocks is 10% (Freeze and Cherry, 1979; Heath, 1983). A range of porosity values from 1% to 10% were used in the calculation.

Hydraulic gradient (i)

There is only one other well (Cogswell's well on Lot 24 / DL 1651) which was drilled into the bedrock aquifer and is located within 325 metres northeast of the Myrtle Pond well. However, the static water table is not known for the Cogswell's well. Due to a lack of data or deep wells in the area, a regional potentiometric map could not be constructed in order to estimate the hydraulic gradient for the fractured bedrock aquifer.

Using static water level data from the Myrtle Pond well and two shallow wells nearby (on Lot 27/DL 1651 and Lot 32/DL 1499), a local hydraulic gradient for that small area is estimated to be 0.0438. The use of water level data from wells completed into different aquifers is a major assumption we accepted for the capture zone delineation using uniform flow equations (the implications of this assumption are discussed later in this section).

Approximately 1 km north of the Myrtle Pond well, a hydraulic gradient is calculated as 0.0345 using three shallow wells on Lot 15, Lot A and Lot 4 of DL 1651. The small difference between these two hydraulic gradient values may indicate that at least along the bottom of Paradise Valley, groundwater in the shallower granular aquifer flows southward with a hydraulic gradient between 0.03 and 0.05.

A more accurate estimation of hydraulic gradient, at least for the granular aquifer, would be possible if well records with static water level data are available from the Southill Acres area.

Methods for Delineating a Wellhead Protection Area

There are many methods for delineating wellhead protection areas. For a confined, fractured bedrock aquifer, at least five methods can be used (U.S. EPA, 1991):

1) Arbitrary fixed radius,
2) Calculated fixed radius,
3) Flow-system mapping,
   - with time-of-travel (TOT) criterion,
   - with analytical equations,
4) Residence-time approach, and
5) Numerical flow/transport models.

Detailed discussion of these and other methods can be found in many publications (e.g., Kreitler and Senger, 1991; Risser and Barton, 1995; U.S. EPA, 1991, 1993, and 1994). In summary, the first two methods are easy to use and inexpensive, but they are not suitable for an accurate delineation of a wellhead protection area. While the last two methods, residence-time approach and numerical modelling, are accurate in delineating a wellhead protection area, they require data which are not available.

Due to considerable uncertainties in hydrogeological parameters, a combination of a few different methods is used in delineating a wellhead protection area for the Myrtle Pond well, including watershed boundary mapping, arbitrary fixed radius, aquifer vulnerability assessment, along with the flow-system mapping method (i.e., uniform flow equations and time of travel).

Wellhead Protection Area for the Myrtle Pond Well

Arbitrary fixed radius

A preliminary capture zone can be delineated by arbitrarily specifying a circular area around a community well. This method is used when there is negligible information about the well or where the hydrogeology is not well understood. In the Fraser Valley Groundwater Monitoring Program, Carmichael et al (1995) specified an arbitrary fixed radius of 300 metres for community wells with negligible information. The area within a 300 metres circle is also used here for the Myrtle Point well and is shown on Figure 5.

Uniform flow equation

The potentiometric surface in the vicinity of the Myrtle Pond well is considered to be sloping (e.g., hydraulic gradient = 0.0438). If a larger area is considered, regional potentiometric surface could be steeper. The uniform flow equation (Todd, 1980) has been widely used to define the capture zone to a pumping well in a sloping water table situation (Kreitler and Senger, 1991; U.S. EPA, 1994). The uniform flow equation assumes a uniform porous medium and is expressed as:

$$-Y / X = \tan(2\pi TiY / Q)$$

where X and Y are coordinates from the community well (Figure 4) and:

Q = pumping rate (1.82×10^{-3} m^3/s for the Myrtle Pond well)
T = transmissivity (9.4×10^{-5} m^2/s for the Myrtle Pond well)

Two equations can be derived from this equation to delineate the boundary of the capture zone (Figure 4):

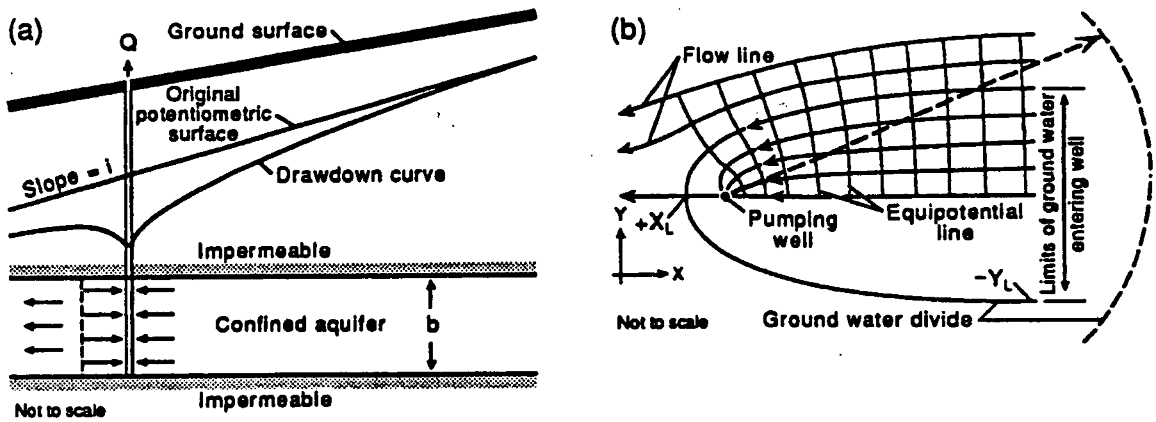
$$X_L = -Q / 2\pi Ti \quad \text{and} \quad Y_L = \pm Q / 2Ti$$

where:

X_L = the distance of the capture zone downgradient from the well
Y_L = the ultimate width of the capture zone

For the Myrtle Pond well, X_L is calculated approximately 61 metres and Y_L approximately ±191 metres. The distance (X_U) to the upgradient extent of the cone of depression is calculated as approximately 382 metres by using the following equation from Javendal and Tsang (1986):

$$X_U = Q / Ti$$



Uniform-flow equation: $-\frac{Y}{X} = \tan\left(\frac{2\pi Kbi}{Q}Y\right)$

Distance to down-gradient null point: $X_L = -\frac{Q}{2\pi Kbi}$

Boundary limit: $Y_L = \pm\frac{Q}{2Kbi}$

Where: Q = Well-pumping rate
K = Hydraulic conductivity
b = Saturated thickness
i = Hydraulic gradient
π = 3.1416

Figure 4. Flow to a well penetrating a confined aquifer having a sloping potentiometric surface : (a) vertical section; (b) plan view (adapted from Todd, 180).

Time of travel

The upgradient extent can be further defined by using a Time of Travel (TOT) equation with a specified travel time (e.g., 1 year, 5 years or 10 years). An equation for calculating time of travel for this sloping situation is provided by Kreitler and Senger (1991):

$$t_x = n / Ki \, [r_x - (Q / 2\pi Ti) \ln\{1 + (2\pi Ti / Q) \, r_x\}]$$

where:

t_x = travel time from point x to a pumping well (e.g., 5 years)
r_x = distance over which groundwater travels in t_x; r_x is positive (+) if the point is upgradient, and negative (-) is downgradient

Using a specified time of travel of 5 years and aquifer porosity of 10% and solving for r_x, the calculated upgradient distance is approximately 240 metres (Figure 5). However, either the time or travelling distance could vary significantly due to uncertainties in aquifer porosity and aquifer thickness. For example, changing porosity from 10% to 1% and keeping other parameter values the same, the upgradient distance changes from 240 metres to 2400 metres for the 5-year time of travel.

Drainage area as the capture zone area

Another way to delineate the capture zone of the Myrtle Point well is to delineate the drainage area above the well. Although the exact direction of groundwater flow can not be directly determined due to a lack of data, it can often be inferred from the topography. The drainage area above the Myrtle

Point well, as part of the watershed for Myrtle Creek, was delineated to outline the maximum extent of the capture zone (Figures 1 and 5).

Uncertainties in delineation of wellhead protection areas

The wellhead protection area delineated using the uniform flow equation is preliminary in nature for the following reasons:

1) There are uncertainties on the aquifer thickness and the estimation of porosity which could change the size and the shape of the delineated wellhead protection area significantly (the smaller the porosity, the larger the capture zone);

2) The hydraulic gradient and regional groundwater flow direction are uncertain (the higher the hydraulic gradient, the smaller the capture zone size, and *vice versa*); and

3) The overall hydrogeology and groundwater flow system are not well understood at this time.

While the drainage or watershed area above the Myrtle Pond well is more reliable as the wellhead protection area for the Myrtle Pond well, it is overly large and encompasses the other capture zones as well. As more hydrogeological information becomes available, the capture zone for the Myrtle Pond well can be further refined. The actual capture zone for the Myrtle Point well likely falls somewhere within the drainage area.

Vulnerability Assessment of the Myrtle Pond Bedrock Aquifer

The fractured bedrock aquifer from which the Myrtle Pond well draws groundwater has a overburden of over 116 metres thick, including a confining layer of clay and glacial till and cemented sand and gravel from 78 to 116 metres below the ground. This overburden should provide considerable protection of the underlying fractured bedrock aquifer from surface contamination, at least within the immediate area of the well.

One way to quantify the vulnerability of the aquifer is to use the Aquifer Vulnerability Index (AVI). AVI quantifies the vulnerability by the hydraulic resistance to vertical flow of water through the sediments above the aquifer (Ronneseth et al., 1995), by using the following equation:

$$c = \sum d^i / K_i, \text{ for layers 1 to i}$$

where

c = hydraulic resistance (days)
d = thickness of sedimentary layer in metres
K = hydraulic conductivity assigned (metres/day)

Where the hydraulic resistance above an aquifer is <100 years, the aquifer is considered to be vulnerable; where hydraulic resistance is >1000 years, the aquifer is not considered to be vulnerable.

The vulnerability of the fractured bedrock aquifer near Myrtle Pond well is estimated from the lithology from the Myrtle Pond well record (Table 2).

The hydraulic resistance to the top of the bedrock surface at the Myrtle Pond is 82,600 years (much greater than 1000 years), indicating a low vulnerability for the fractured bedrock aquifer.

In addition, a land use survey indicates that the area around the Myrtle Pond well is heavily vegetated and covered mainly by trees and bush. Land use is also not intensive, with less than six houses and only a few small farms or hobby farms (with domestic animals).

Table 2. Calculated hydraulic resistance based on Myrtle Pond well record

Depth below ground (m)	Lithology from well record	K (m/d)	d (m)	c (days)
0-1.5	Stoney top soil	-	1.5	
1.5-5.9	Stoney brown clay	0.000001	4.4	4400000
5.9-10.4	Brown silty sand & gravel	1	4.5	4.5
10.4-17.7	Sand & gravel (loose)	100	7.3	0.07
17.7-27.1	wet, tilly grey gravel (very silty)	1	9.4	9.4
27.1-29.3	Grey clay & silt layers	0.001	2.2	2200
29.3-38.4	Silty, very fine sand (wet)	1	9.1	9.1
38.4-40.2	Silty, very fine sand	1	1.8	1.8
40.2-48.5	Silty clay	0.000001	8.3	8300000
48.5-66.1	wet silt with vegetation	0.1	17.6	176
66.1-67.4	fine sand; water-bearing	1	1.3	1.3
67.4-77.7	Silty, very fine sand with layers of clay; water-bearing	0.1	10.3	103
77.7-94.2	clay	0.000001	16.5	16500000
94.2-100.0	till & boulders	0.00001	5.8	580000
100.0-103.6	tight till & layers of sand	0.00001	3.6	360000
103.6-116.1	cemented sand & gravel	1	12.5	12.5
116.1-133.5	green sandy shale (top of bedrock aquifer)			
133.5-136.6	fractured green & black sandy shale			
136.6-138.7	green & black shale with sandstone stringers			
138.7-146.3	fractured green & black shale with quartz lenses			
146.3-158.5	fractured black shale & quartz lenses			
158.5-159.7	black shale (sandstone mix)			
159.7-160.9	fractured light green shale			
160.9-163.1	Black shale			

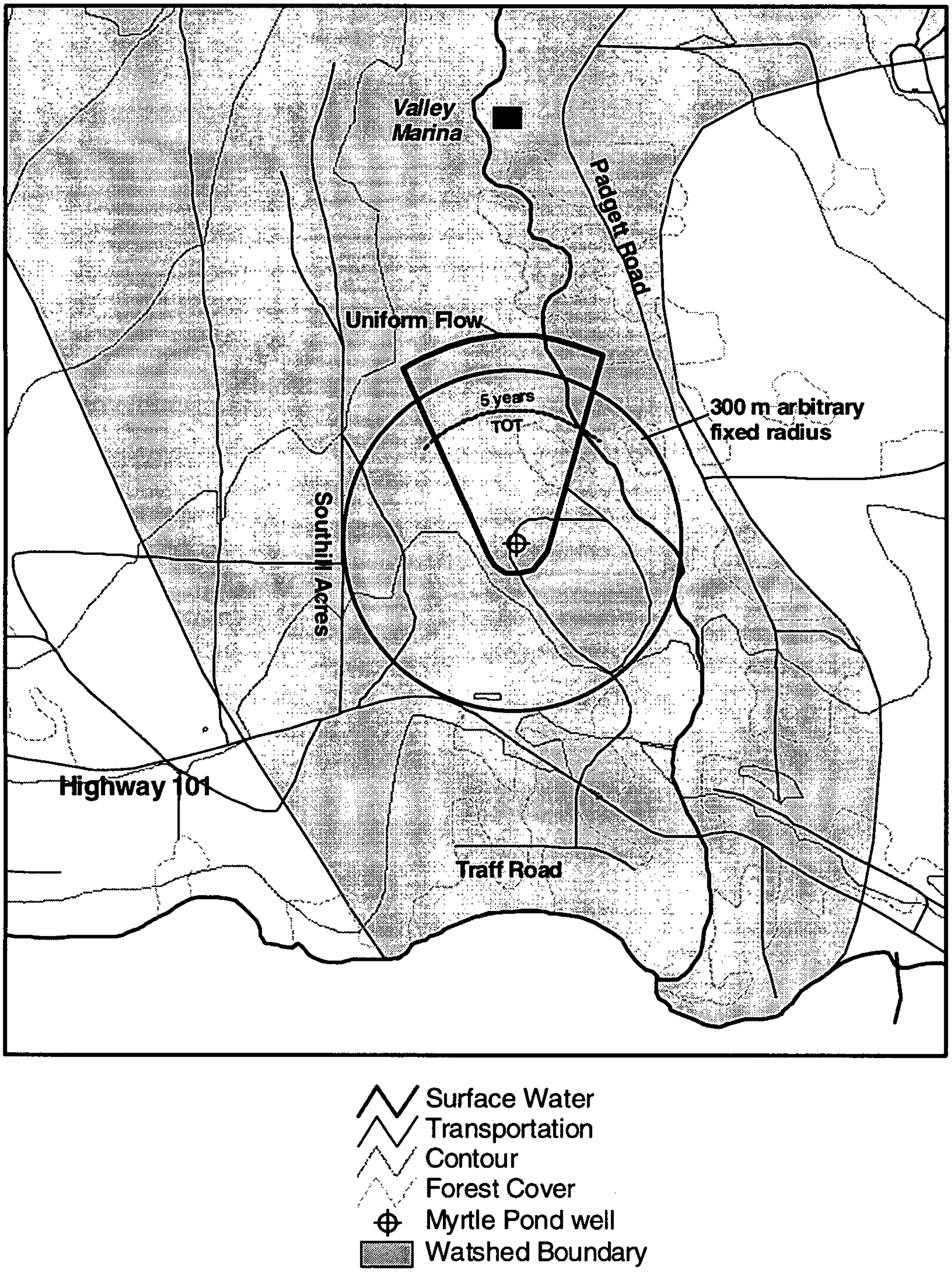


Figure 5. Wellhead Protection Area for the Myrtle Pond Well

Discussion of Results

The major water quality issue for the Myrtle Pond well was the occurrence of organic matter and the use of chlorination which caused the elevated levels of trihalomethanes. Chlorination for the Myrtle Pond Water System has been shut down and currently there is no elevated THM in the water.

The occurrence of organic matter (total organic carbon, tannins and lignins) in the water is puzzling in that the well is deep and groundwater in the fractured bedrock aquifer should be separated from shallow-seated water by the overburden of 116-metre sediments. There are currently no drinking water guidelines for total organic carbon, tannins and lignins and the levels detected in the Myrtle Pond well should not cause a health concern.

Organic matter and other aesthetic water quality issues (colour, odour, and hydrogen sulphide) can be addressed by water filtering and aeration. The on-site greensand filtering system was installed to deal with elevated iron and manganese in the failed Myrtle Pond well and may not suitable for filtering the water from the current Myrtle Pond well.

Brackish water, if caused by seawater intrusion, is a concern if chlorination continues to be used since additional bromide introduced by any seawater may increase the chance of forming more trihalomethanes.

The most reliable wellhead protection area for the Myrtle Pond well is the drainage area for the Myrtle Creek. Capture zone delineated by hydrogeological methods is preliminary due to a lack of hydrogeological data and uncertainties in available data. The actual capture zone for the Myrtle Pond well is probably quite small and manageable.

Given the apparent low vulnerability of the aquifer and nature of the water quality problem (not likely being from human-made sources), the development and implementation of a wellhead protection plan for the Myrtle Pond well, although important, may not guarantee the improvement the quality of the Myrtle Pond well water supply. A more practical approach would be to protect the groundwater resource as part of the land use planning for the general area, through an integrated watershed management program.

While effort should be directed on improving the current Myrtle Pond well, some alternative water supplies may be considered by the Powell River Regional District.

Recommendations

Water Quality and Monitoring

Aesthetic water quality could be improved by aeration to reduce colour, odour, and organic matter. Currently the Powell River Regional District is planning to install an aeration device on top of the water storage tank. The latest water quality data reviewed show that both iron and manganese levels in the Myrtle Pond well were below the guidelines for Canadian drinking water quality. However, if there is a concern about the aesthetic water quality caused by iron and manganese, the vendors who installed the on-site greensand filtering system should be contacted to re-activate the existing filtering system. This filtering system is capable of filtering other chemicals in the water as well if different filtering materials are used. In any case, the existing filtering system should be either used and maintained properly, or disconnected and decommissioned properly.

As an alternative to chlorination, chloramine can be used to disinfect water without causing significant levels of disinfection by-products that are of human health concern. Advice from a qualified water treatment professional should be sought before chloramine is used. Prior to constructing any treatment works, approval by the regional Public Health Engineer is required and a construction permit may be required as well.

The correlation between sodium and chloride levels and pumping rates should be monitored to assess seawater intrusion. In order to do this, the pumping rate or discharge rate should be monitored and recorded properly along with the pumping and non-pumping water levels in the well.

A comprehensive water quality analysis should be done on the well water on a minimum annual basis. The sample should be collected from the well head. Samples should also be collected at the same time of year, preferably during September-October, when the seasonal water levels are lowest. Sampling procedures should be documented.

Since the chlorination equipment has been shut off to reduce community exposure to THM, continued surveillance is required to monitor bacteriological water quality. Before the trihalomethane issue is solved and in the event that chlorination has to be used to disinfect water from contamination of micro-organisms or to improve aesthetic water quality, a few general tips are provided here for community members to reduce exposure to THM:

1. Use an activated charcoal filter, either on the tap or in a pour-through attachment to a water pitcher;
2. Boil tap water for one minute and let it cool before drinking;
3. Leave tap water standing in a pitcher in the fridge overnight; and
4. Obtain other approved water supplies (e.g., approved bottled water).

Water Supply Recommendations

A few options could be considered by the Powell River Regional District to improve the quality of domestic water for the Myrtle Pond Water System.

1) Maintain the existing Myrtle Pond well

In this option, the current Myrtle Pond well continues to be used to supply water for the Myrtle Pond Water System. Main cost for this option is on-going water sampling before water quality is accepted, plus the cost of installing aeration system and/or re-activating the existing greensand water filtering system. The potential cost of eliminating the sources or causes of organic matter is unknown and will depend on the nature of the sources or causes. The success rate is expected to be high if the water treatment systems are installed and maintained properly.

2) Consider another off-site well(s)

An existing off-site well or the amalgamation of a few existing domestic wells in the neighborhood could be used to supply water to the Myrtle Pond Water System. Costs may arise in converting domestic wells (purchasing wells from the owners, upgrading pumps, easements, legal fees, etc.), carrying out pumping test to determine the wells' capacity, and connecting the domestic wells to the Myrtle Pond Water System. Cost could be high and the success rate depends on the availability of suitable domestic wells.

3) Drill a new well

If existing wells don't have the water quantity or if the cost for maintaining the water quality of existing wells is too high, the Powell River Regional District may consider drilling of a new well in the overburden aquifer. Well logs for both the current Myrtle Pond well and the failed old Myrtle Pond well indicate a granular aquifer approximately at 60 – 78 metres below the ground. A shallower aquifer at the depth 29 – 38 metres may also exist in the area. Other potential locations for drilling new wells are also mentioned in PHCL (1993) and by Kalyn (1998) in area south of the Myrtle Pond well.

The cost for drilling and testing a 6-inch well with screen is in the range of $12,000 - $15,000, excluding engineering supervisory costs (base on $100/metre drilling to 80 metres, $1,000 for 3 metres screens, 10 hours of well development and 24-hour pumping test at $100/hour and plus 20% contingencies).

Success rate for drilling a new well should be high if an experienced driller is retained for the work and the work is supervised by a professional hydrogeologist. Along Traff Road, at least seven wells yielded 10 gallons water per minute or more. One well between highway 101 and Traff Road yielded more than 30 gallons water per minute. Concerns on water quantity during summer season can only be addressed through a pumping test once a well is drilled.

4) Connect with municipal water system

The Powell River Regional District might consider carrying out a cost-and-benefit analysis on connecting the Myrtle Pond Water System with the municipal water supply. High cost is expected; but this cost should be calculated with the consideration of benefits in bringing reliable domestic water supply to all the communities and households in the area. Success rate depends on land use development in the region and a coordinated planning process for the Myrtle Creek watershed.

For the above first three options, **the operation procedure and maintenance of the Myrtle Pond Water System should be documented properly.** The Water System should be maintained properly. A backup water supply well or system may also be considered.

Wellhead Protection

If the Powell River Regional District considers including groundwater protection in their land use planning for the Paradise Valley area, some steps could be taken to develop and implement such plans for the groundwater users in the area:

1) Form a community planning team,
2) Define the protection area,
3) Identify potential contaminants,
4) Develop and implement management strategies,
5) Develop a contingency plan, and
6) Monitor results and evaluate the plan.

For more details on how to protect groundwater resource through a protection planning process, please contact the local health authority.

Reference

B.C. Ministry of Environment. 1978. The soil landscapes of British Columbia. Edited by K.W.G. Valentine, P.N. Sprout, T.E. Baker and L.M. Lavkulich, Victoria, B.C.

Carmichael, V., M. Wei, and L. Ringham. 1995. Fraser Valley Groundwater Monitoring Program Final Report. Province of British Columbia.

Freeze, R.A., and J.A. Cherry. 1979. Groundwater. Prentice-Hall Publishing Co., Englewood Cliffs, NJ, 604 pp.

Health Canada, 1996, Guidelines for Canadian Drinking Water Quality. Sixth Edition.

Heath, R.C. 1983. Basic ground-water hydrology. U.S. Geological Survey Water-Supply Paper 2220. Republished in a 1984 edition by National Water Well Association, Dublin, OH.

Javendal, I. and C.F. Tsang. 1986. Capture-zone type curves: A tool for aquifer cleanup. Ground Water, 24(5): 616-625.

Kalyn, D. 1998. Trihalomethane contamination in the Powell River Regional District well - Myrtle Pond #2. Unpublished Memorandum, Groundwater Section, Water Management Branch, BC Ministry of Environment, Lands and Parks.

Kreitler, C.W., and R.K. Senger. 1991. Wellhead protection strategies for confined-aquifer settings. EPA/570/9-91-008, 168 pp.

McCammon, J.W. 1977. Surficial geology and sand and gravel deposits of Sunshine Coast, Powell River, and Campbell River area. British Columbia Ministry of Mines and Petroleum Resources, Bulletin (65).

PHCL. 1993. Construction and testing of a water well for Myrtle Pond waterworks. Prepared by Pacific Hydrology Consultants Ltd., Burnaby.

Ronneseth, K., M. Wei, and M. Gallo. 1995. Evaluating methods of aquifer vulnerability mapping for the prevention of groundwater contamination in British Columbia. Ministry of Environment, Lands and Parks, Water Management Division, Hydrology Branch, Groundwater Section. 17 p.

Risser, D.W., and G.J. Barton. 1995. A strategy for delineating the area of groundwater contribution to wells completed in fractured bedrock aquifers in Pennsylvania. U.S. Geological Survey, Water-Resources Investigations Report 95-4033.

Swan, S.H., Waller, K., Hopkins, B., Windham, G., Fenster, L., Schaefer, C., Neutra, R.R. 1998. A prospective study of spontaneous abortion: relation to amount and source of drinking water consumed in early pregnancy. Epidemiology, 9(2): 126-133.

Todd, D.K. 1980. Groundwater Hydrology. 2nd ed. John Wiley & Sons, New York, 535 pp.

US Environmental Protection Agency (EPA). 1994. Ground water and wellhead protection: Handbook. EPA/625/R-94-001.

US Environmental Protection Agency (EPA). 1993. Wellhead Protection: A guide for small communities. Seminar Publication EPA/625/R-93-002.

US Environmental Protection Agency (EPA). 1991. Delineation of wellhead protection areas in fractured rocks. Office of Water, Washington, DC. EPA 570/9-91/009.

Waller, K, Swan, S.H., DeLorenze, G., and Hopkins, B. 1998. Trihalomethanes in drinking water and spontaneous abortion. Epidemiology, 9(2): 134-140.

Wheeler, J.O., and McFeely, P. 1991. Tectonic assemblage map of the Canadian Cordillera and adjacent parts of the United States of America. Geological Survey of Canada, Map 1712A, scale 1:2 000 000.