Ambient Groundwater Quality Monitoring and Assessment in BC: Current Status and Future Directions

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

Mike Wei, P.Eng.
Water Management Branch
Ministry of Environment, Lands and Parks
Victoria, BC

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Table of Figures

Figure 1. Well purge results ................................................................................................................. 4
Figure 2. Integrating ambient groundwater monitoring network ....................................................... 10
Figure 3. Monitoring intensity .......................................................................................................... 10
Figure 4. Groundwater sample distribution in the Water Quality Check Program ....................... 13
Figure 5. Aquifer priority mapping results. ..................................................................................... 14
Figure 6. Water Quality Check Program: Fluoride in Groundwater .................................................. 15
Figure 7. Water Quality Check Program: Nitrate in Groundwater ..................................................... 16
Figure 8. Water Quality Check Program: Arsenic in Groundwater .................................................... 17
Figure 9. Water Quality Check Program: Sodium in Groundwater ................................................... 18
Figure 10. Water Quality Check Program: Coliform in Groundwater ............................................... 19

Figure III-1. Groundwater sample distribution in the Water Quality Check Program ................ III-2
Figure III-2. Median pH values of groundwater samples from WQCP ........................................... III-3
Figure III-3. High and low pH values of groundwater samples from WQCP ............................... III-3
Figure III-4. Median hardness values of groundwater samples from WQCP ............................... III-4
Figure III-5. Median specific conductance values of groundwater samples from WQCP .......... III-5
Figure III-6. Fluoride results of groundwater samples from WQCP ............................................. III-6
Figure III-7. Nitrate results of groundwater samples from WQCP ............................................... III-7
Figure III-8. Arsenic results of groundwater samples from WQCP ............................................. III-8
Figure III-9. Barium results of groundwater samples from WQCP ............................................. III-10
Figure III-10. Boron results of groundwater samples from WQCP ............................................. III-11
Figure III-11. Lead results of groundwater samples from WQCP ............................................. III-12
Figure III-12. Sodium results of groundwater samples from WQCP ........................................ III-13
Figure III-13. Median sodium concentrations of groundwater samples from WQCP ........... III-14
Figure III-14. Total coliform results of groundwater samples from WQCP ............................... III-15
Figure III-15. Median total coliform counts of groundwater samples from WQCP ................ III-15
EXECUTIVE SUMMARY

The Ambient Groundwater Quality Monitoring and Assessment Program (AGQMAP) has been carried out by the Groundwater Section, Water Management Branch, BC Ministry of Environment, Lands and Parks (MoELP) since 1985 in specific areas, including Langley-Abbotsford, Osoyoos, Grand Forks and Cowichan Estuary. Ambient groundwater quality monitoring is useful for establishing baseline groundwater characteristics and for investigating long-term trends or impacts to groundwater quality from human activities. This review focuses on this particular monitoring activity in BC and is intended to identify areas where improvements could be made and to provide a strategic framework for enhancing and expanding ambient groundwater quality monitoring in BC.

AGQMAP was initiated to target non-point source contamination in the Langley-Abbotsford, Osoyoos and Cowichan Estuary areas and later expanded to include Grand Forks (since 1989). MoELP continues to monitor nitrate contamination in these areas. Monitoring of seawater intrusion in the Cowichan Estuary was discontinued in 1997.

Over the years, AGQMAP has accumulated a large volume of groundwater quality data which has been used to effectively track groundwater quality trends, identify contamination sources, and provide important groundwater information to decision makers and local communities. As a result, government agencies and some local communities are taking actions to implement remedial measures or to develop aquifer protection plans.

It has been suspected and this review confirmed that nitrate contamination exists in other part of the province. There are groundwater quality concerns of other contaminants as well. As part of this review, data from Aquifer Classification Mapping database and the Water Quality Check Program were used to identify additional areas and groundwater quality parameters for monitoring. These data were summarized by NTS 1:50,000 scale map sheets and linked to a Geographic Information System (ArcView GIS). GIS spatial query, statistics and overlay generated a series of thematic maps to prioritize monitoring. Part of the target areas and monitoring parameters include:

- Arsenic: 100 Miles House, Chase, Kamloops, Sunshine Coast, Bowen Island, Vanderhoof, Vernon, and Williams Lake,
- Fluoride: Armstrong, Duncan, Enderby, Gabriola Island, Ladysmith, Nanaimo, Okanagan Fall, Penticton, Salmon Arm, Saltspring Island, and Vernon
- Nitrate: Armstrong, Kamloops, Salmon Arm, Vernon, and Williams Lake, and
- Sodium: Gabriola Island, Hornby Island, Ladysmith, Lantzville, Saltspring Island, and Williams Lake.

Having considered current monitoring activities and resources available for future monitoring, we propose a strategic framework for expanding ambient groundwater quality monitoring to other areas in BC, to include: 1) targeting community aquifers which are vulnerable to contamination and have high water use demand, 2) carry out monitoring jointly with other agencies such as local health authorities, and 3) vary the intensity of monitoring depending on priority.

Recommendations are also made for improving existing ambient groundwater quality monitoring activities, including QA/QC measures, sampling strategies, collection of background information, data compilation, data quality, database design, data analysis, reporting and information dissemination.
ACKNOWLEDGEMENTS

This work was initiated while the author was on secondment with the Groundwater Section, Ministry of Environment, Lands and Parks (MoELP) in 1998. We appreciate the assistance from Bruce Mackenzie and Andrew Faulkner, Information System Branch of MoELP, for providing access to water quality data and GIS maps on the servers.

We also thank Bill Hodge, Al Kohut, Carl Lee, Kevin Ronneseth, and Rod Zimmerman in the Groundwater Section for their review and discussions.

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INTRODUCTION

There are more than 12,600 community water systems in British Columbia and 45% use groundwater to provide drinking water for a population over 750,000. To manage and protect the groundwater resources, groundwater quality in the province is monitored and evaluated by many public and private organizations for a wide variety of objectives. A summary of these monitoring programs was reported by Piteau Associates (1989a).

Ambient groundwater quality monitoring is referred to as monitoring groundwater conditions and quality which may be affected by human activities or from natural influences. The purposes and goals of ambient groundwater quality monitoring (AGQM) programs vary somewhat from one jurisdiction to the next. In general they are designed to establish baseline characteristics and to investigate long-term trends of groundwater quality by testing physical, chemical, and biological parameters of water samples. In correlation to human health, ecological conditions and designated water uses, information from AGQM can be used for:

- Water resource development, management and protection,
- Real estate and land development,
- Landuse management, and
- Assessing causes and sources of pollution.

Table 1. Summary of on-going groundwater monitoring activities in BC

<table>
<thead>
<tr>
<th>On-Going Groundwater Monitoring Activity</th>
<th>Agency</th>
<th>Scope</th>
<th>Objective of Monitoring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacteria and water quality of community well water systems</td>
<td>Local health authorities; Health Canada</td>
<td>All community systems in BC; from &quot;tap&quot;; bacteria generally weekly; water chemistry once every few years.</td>
<td>Compliance to drinking water guidelines.</td>
</tr>
<tr>
<td>Ambient groundwater quality in specific areas impacted by nitrate contamination</td>
<td>MoELP (WMB)</td>
<td>Domestic and monitoring wells in Abbotsford, Langley, Osoyoos, and Grand Forks areas; from &quot;source&quot;; annually.</td>
<td>Ambient status and long-term trends.</td>
</tr>
<tr>
<td>Observation Wells</td>
<td>MoELP (WMB)</td>
<td>Many of the 150 observation wells in BC; once every few years.</td>
<td>Baseline status and long-term trends.</td>
</tr>
<tr>
<td>Groundwater quality in the Abbotsford-Sumas aquifer at the Canada-USA border</td>
<td>Environment Canada</td>
<td>Border area of the Abbotsford-Sumas aquifer.</td>
<td>Ambient status and long-term trends.</td>
</tr>
</tbody>
</table>

Note: MoELP = BC Ministry of Environment, Lands and Parks; WMB = Water Management Branch; and PPB = Pollution Prevention Branch.

In BC, AGQM has been carried out since 1985 for Langley-Abbotsford, Osoyoos and Cowichan Estuary and since 1989 for Grand Forks. A few other ongoing monitoring programs collect ambient groundwater samples as well (examples shown in Table 1). Over the years, a large volume of groundwater quality data have been collected, along with experience gained through these monitoring activities.

Today we are facing an interesting and challenging situation where advancing technologies (e.g., monitoring equipment, data processing power and new technology such as Geographic Information Systems) are coupled with a shrinking monitoring budget and ever increasing demands on groundwater resources. To effectively continue AGQM, monitoring needs to be improved and integrated. Testing parameters and targeting locations need to be prioritized.
This review focuses on ambient groundwater quality monitoring activities carried out by Water Management Branch in MoELP and is intended to provide a strategic framework for expanding groundwater quality monitoring in BC and to propose an updated monitoring strategy.
REVIEW OF AMBIENT GROUNDWATER QUALITY MONITORING IN BC

In 1984, the Groundwater Section identified that major concerns of groundwater quality were the elevated nitrates levels and seawater intrusion. As a result, the Ambient Groundwater Quality Monitoring and Assessment Program (AGQMAP) was initiated in April 1985 to target three areas: Langley-Abbotsford area (nitrates), Osoyoos (nitrates), and Cowichan Estuary (seawater intrusion). A fourth area (Grand Forks, for nitrates) was included later in 1989. A summary of monitoring results for these four areas is included in Appendix I.

Monitoring Areas and Monitoring Wells

The four ambient groundwater monitoring areas (Table 2) were selected based on previous experience, input from the regional water management staff and water chemistry data from Environment Canada’s NAQUADAT and the Water Quality Check Program (WQCP).

Table 2. Ambient groundwater monitoring areas in BC

<table>
<thead>
<tr>
<th>Area (Concerns)</th>
<th>No. of Monitoring Sites</th>
<th>Sampling Period</th>
<th>Sampling Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Langley-Abbotsford (Nitrates)</td>
<td>15 domestic, 12 monitoring</td>
<td>1985 - present</td>
<td>1/year, 2/year</td>
</tr>
<tr>
<td>Osoyoos (Nitrates)</td>
<td>11 domestic, 12 monitoring</td>
<td>1987 - present, 1989 - present</td>
<td>1 - 2/year, 1/yr</td>
</tr>
<tr>
<td>Cowichan Bay (Seawater Intrusion)</td>
<td>7 domestic, 2 obs wells</td>
<td>1985 - 1990, 1980 - present</td>
<td>1/year, monthly for fall, 1/year, monthly for fall</td>
</tr>
<tr>
<td>Grand Forks (Nitrates)</td>
<td>12 domestic, 12 monitoring</td>
<td>1989 - present</td>
<td>1/year - domestic, 1 - 2/year - monitoring</td>
</tr>
</tbody>
</table>

When AGQMAP started, information on flow direction, recharge rates, background water quality were not well understood and these factors were not major considerations in selecting monitoring wells. Instead, availability of domestic wells and areal coverage were major factors in selecting sites. Ambient groundwater quality was monitored mainly through existing private domestic wells. Monitoring wells were also constructed in strategic locations for added coverage. In Abbotsford and Grand Forks, there are piezometers constructed to various depths to monitor water quality variation with depth (Sather, 1989b; Chwokja, 1991).

Reconnaissance field surveys have also been carried out in Merritt (Chwojka, 1992), Armstrong (Hodge, 1992a), Oliver (Hodge, 1992b), and Keremeos-Cawston for nitrates (Hodge, 1991). Elevated nitrates levels were detected in Oliver and Armstrong. Due to limited resources, ambient monitoring was not carried out in these areas.

Sampling Procedures

Sampling procedures for domestic wells have been consistent. Groundwater samples were collected from tap after the domestic wells were purged up to 5 minutes. Procedures for sampling domestic wells are included in Appendix II and were based on Carmichael et al. (1995).

Between 1985 and 1990, ambient monitoring wells were sampled by bailing. After 1990, monitoring wells were purged using a suction pump before sampling. Since 1992, the monitoring wells have been sampled with a 2-inch diameter submersible Redi-Flow pump. Water temperature, specific conductance, colour and odour were recorded for every purge and a sample collected after 1 to 5 well volumes have been removed and the field parameters have stabilized. Purge times varied from 5 to 30 minutes, depending on well conditions and rate of stabilization of field parameters. Parameters were gradually stabilized after two well volumes were pumped. Typical purge results are shown in Figure 1. Sampling
procedures for monitoring wells and *Water Quality Sampling* forms documenting sample collection for domestic and monitoring wells are included in Appendix II.

![Graph](image)

**Figure 1. Well purge results**

**Sample Analysis**

Samples were analyzed in the field and in the laboratory. In the field, portable testing kits were used to measure pH (Hach model AL-94/AY), nitrate-nitrogen (Hach NI-11), and specific conductance (Beckman conductivity meter). Field testing was used to monitor water quality during pumping and to provide a check against the laboratory results.

In laboratory analyses, groundwater samples were tested for the basic physical and chemical parameters which included a metal scan by using Inductive Coupled Plasma method (ICP). A complete list of groundwater quality parameters is included in Appendix I. These parameters were tested in all four monitoring areas. Testing of micro-organisms was not included because fecal contamination of well water fell under Ministry of Health’s mandate.

Currently, Environment Canada’s laboratory (Environmental Conservation Branch, Pacific Environmental Science Centre) is used for groundwater sample analysis. The minimum detection limits of ICP method for arsenic, cadmium, lead and selenium are close to or higher than the Guidelines for
Canadian Drinking Water Quality (Health Canada, 1996). Graphite Furnace (GFAA) should be used for these parameters of health concerns.

**External QA/QC**

External QA/QC samples (blind duplicate samples) were sent to the laboratories, along with the rest of the samples in the same batch, to check the laboratories’ accuracy and precision in analysis; every laboratory has internal QA/QC measures as well. There were no external QA/QC measures for sampling and sample analyses before 1995. Duplicate samples have been collected since 1995. Usually one duplicate is collected among 10-15 samples during each field trip. Due to the small numbers of samples collected during each trip, it was not cost-effective to implement a more comprehensive QA/QC to include blanks and reference samples. Analyses of pH, specific conductance, and nitrates in the field also provide an important water quality check to the laboratory results.

**Data Archiving**

Groundwater chemistry data were uploaded into EMS (Environmental Monitoring System, MoELP’s monitoring database) by laboratories after the samples were analyzed. EMS provides a centralized data archiving service which facilitates data transfer. However, external QA/QC results are not entered by the laboratory and may become lost or unable to associate with analytical results in EMS. There are also groundwater quality data from other sources which have not been uploaded into EMS. Multiple EMS users having editing privilege may also cause database errors or even collapse.

**Data Analysis and Result Reporting**

Efforts on ambient groundwater quality monitoring have historically focused on sampling, not on data analysis, data management or reporting. Data results from the laboratories were not checked; paper copies were filed in binders and dug up for plotting and analysis on an as required basis when issues came up. Since 1995, data results from the laboratory have been checked as soon as they arrived in the office. Data analyses included checking the results for any anomalies (e.g., dissolved concentrations greater than total concentrations, specific conductance value less than the Total Dissolved Solids value, etc.), calculating the cation/anion charge balance, and checking the results of the duplicate samples; acceptance criteria for duplicate samples were those adopted from Carmichael et al (1995).

EMS provides limited data analysis and result presentation functions. There is need to compile and relate other information to groundwater quality data in order to make meaningful interpretation of groundwater results. This information may include surficial geology, hydrogeological characteristics of the aquifer, surface water quality data, geochemical data, landuse, and could be in the forms of database files as well as digital maps. Most of this information are not included in EMS, which is not designed to accommodate this kind of information.

Groundwater Section currently downloads data from EMS into spreadsheets on desktop computers for data analysis. However, there is not a centralized database management or data analysis system on desktop computers. Data files were in various forms and scattered on staff’s desktop and on the LAN. Although Aquifer Classification Mapping (using ARC/INFO) has been completed for all the four monitoring areas, a Geographic Information System (GIS) has not been created for compiling and analyzing ambient groundwater quality data for the four areas.

There have been regular reports in the form of internal memoranda on initial surveys of monitoring areas and previously existed groundwater quality data (e.g., Hodge, 1985a and 1985b; Kohut, 1987; Wei, 1987; Zimmerman, 1990b), field surveys (e.g., Sather, 1989a), annual monitoring activities (e.g., Kohut, 1992; Kohut et al., 1989; Kwong, 1986; Sather, 1988 and 1989; Zimmerman, 1990a, 1991), data inventory, groundwater quality trends and sources of contamination (e.g., BC Environment, 1996 and in
More comprehensive reports were completed neither consistently nor on a regular basis. Examples of comprehensive reports are seen for the Grand Forks area for monitoring results between 1989 and 1990 (Wei, 1992 and Wei et al., 1993).

**Funding**

Funding has not been consistent and has decreased over the time. Initially, funding for groundwater sampling and lab analyses was from Water Quality Section budget. Since 1995, this budget was turned over to the regions and funding for the Section was terminated. The shortfall in the last few years was made up with funds from Water Management, Environment Protection in Surrey and Penticton, and Ministry of Health in Grand Forks and Langley.

**Discussion**

Since 1985, ambient groundwater quality monitoring in BC has been implemented for the Langley-Abbotsford, Osoyoos, Cowichan Estuary and Grand Forks areas. For the Cowichan Estuary area, results indicate no high levels of chloride in the deeper wells which monitor the lower aquifer. Chwokja (1997) recommended discontinuing this monitoring program, with the exception of the two observation wells. Observation well 297, completed into the lower aquifer, has since been returned to the property owner for private use.

For the Langley-Abbotsford, Osoyoos and Grand Forks monitoring areas, monitoring results indicate that certain parts of the aquifers in the monitoring areas show nitrate-nitrogen above the Guidelines for Canadian Drinking Water Quality (Health Canada, 1996). Major sources of nitrate-nitrogen were identified as manure, chemical fertilizer and possibly septic systems. Ambient groundwater monitoring will continue in these areas. Remedial measures and development of well and aquifer protection plans at the local level have been recommended (BC Environment, 1996). In Grand Forks, an Aquifer Protection Committee has been formed to develop protection measures for the aquifer. In Abbotsford, the City of Abbotsford has recently conducted a contaminant survey within the recharge areas of their municipal wells.

The existing AGQM program for the Langley-Abbotsford, Osoyoos, Cowichan Bay and Grand Forks areas has served their initial objective, addressed specific groundwater quality concerns for each area, and accumulated a large volume of groundwater quality data.

However, the existing AGQM program needs to be enhanced and expanded to become more effective, particularly in providing resource decision makers with up-to-date information on the water quality in BC. Results from a preliminary analysis of data from WQCP (Appendix III) and historical water quality surveys show that nitrate contamination exist in other areas (e.g., Oliver, Armstrong, Kamloops, Salmon Arm, Vernon and Williams Lake) and there are other ambient water quality concerns (e.g., arsenic in the Sunshine Coast and Bowen Island, high TDS groundwater in the Lower Mainland, bacteria in Saanich). Ambient groundwater monitoring will become more relevant if groundwater quality results are regularly and timely reported to identified clients (see Appendix IV), especially communities that are implementing protection programs to monitor the effectiveness of mitigative measures. Reporting, distribution, and dissemination of timely and accurate groundwater information, in turn, would require data of high quality and a database management system capable of handling geo-referenced data and with adequate data analysis functions. To effectively use available and expected monitoring budget, we need to develop a new monitoring framework which involves integrated use of resources and collaboration with other agencies and communities in the regions.

As a result of this review, strategy and recommendations are also proposed to deal with some of the technical issues in monitoring, including: sampling and testing procedures, QA/QC measures, database management and data analysis (e.g., statistics, GIS), result presentation, and reporting.
PROVINCIAL AMBIENT GROUNDWATER QUALITY MONITORING NETWORK

A review of current ambient groundwater quality monitoring activities in BC indicates that the monitoring network needs changes to increase coverage, promote partnership and stewardship, and make the network more relevant and effective. The ultimate goal in enhancing the AGQM network would be to ensure an adequate knowledge of water quality in the various communities in BC and that these communities have clean and safe water supplies. To achieve this, an AGQM network should provide decision makers and land-owners with the most current and accurate information regarding baseline groundwater quality data. Specifically, the monitoring should:

1. Provide independent ambient or baseline groundwater quality data for parameters which are of concern to health, aquatic life and biota;
2. Identify high quality or sensitive groundwater sources that may warrant more stringent protection measures;
3. Identify areas where groundwater quality changes over time;
4. Determine sources and mechanism of groundwater contamination;
5. Identify areas that warrant more intense studies;
6. Provide baseline water quality and water quantity data for projects designed to determine whether landuse or major projects are affecting groundwater quality and as standards for cleaning up of contaminated sites; and
7. Provide possible point and non-point source pollution inventory data to be used by provincial environmental protection agencies or other regulatory programs.

Guiding Principles of Monitoring

Any enhancements of the AGQM network need to be carried out without great demands on resources in this fiscal climate. The public’s increasing expectation for the right to know the nature of water quality in aquifers in BC, and the high number of communities in BC reliant on groundwater as a drinking supply are also important considerations in designing a provincial AGQM network. The following guiding principles are suggested:

- Develop an AGQM program that provides various intensities of monitoring (priority and phased approach);
- Establish monitoring sites based on community aquifers;¹
- Involve partners in sponsoring, planning, and participating in AGQM and in sharing resources and data;
- Integrate the various groundwater quality monitoring programs to maximize available resources;
- Integrate groundwater quality monitoring with well protection or aquifer protection planning;
- Standardize sampling protocols and analytical and QA/QC methodologies to ensure consistent and comparable water quality data;
- Develop groundwater quality indicators, with consideration of major groundwater quality concerns for specific areas;
- Use GIS to facilitate database management, analysis, and presentation of results; and
- Compile, link and integrate water quality data from different sources (e.g., EMS, WSACS, and WELL); and
- Have regular and appropriate reporting of results to improve decision making on groundwater protection and resource management.

Monitoring Framework: A Community Aquifer Approach

Target Community Aquifers

¹ See definition of community aquifer on the next page.
Ambient groundwater quality monitoring should include community aquifers which are heavily developed and aquifers that are potential to be impacted by non-point source pollution (all IA, IB, and IIA aquifers). A community aquifer is defined as one where:

- There are established communities living on or near the aquifer; and
- Groundwater from the aquifer is used for domestic and/or other purposes.

Among 383 aquifers mapped as of December, 1999, 54 aquifers are considered as heavily developed and moderately to highly vulnerable to contamination from landuse activities (Table 3, more detail in Appendix V). A community aquifer approach would allow us to focus on water quality related to drinking water supplies.

**Table 3. Summary of target aquifers based on aquifer classification mapping to 1998**

<table>
<thead>
<tr>
<th></th>
<th>I</th>
<th>II</th>
<th># of Aquifers</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>17</td>
<td>32</td>
<td>49</td>
</tr>
<tr>
<td>B</td>
<td>5</td>
<td>N/C</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>54</td>
</tr>
</tbody>
</table>

Carry out monitoring jointly with other government agencies and/or private organizations

Various groundwater quality monitoring programs exist across the province to accommodate different goals and are operated under different programs, by different government agencies, and/or private organizations (e.g., see Piteau, 1989a and Table 1). Some of the monitoring wells currently sampled by these programs could be used as part of the ambient monitoring network.

As a first step, observation wells (sampled by the Groundwater Section), community wells (sampled by regional health authorities), and existing ambient monitoring wells or proposed new ambient monitoring wells located in a community aquifer, should be included in the ambient monitoring network (Figure 2).

Incorporating observation wells and community wells in IA, IIA, and IB aquifers can potentially increase the network to hundreds of wells. This number is not as intimidating as it first appears because all the community wells are already being sampled by local health authorities and water purveyors and the sampling frequency is only once every 2-3 years. Incorporating community wells into the ambient groundwater quality monitoring network requires negotiating with individual health authorities, getting their corporation in adopting a common, minimum standard for sample collection, collecting water chemistry samples from source and providing them access to EMS. This will take time but discussion can begin in the central Kootenay, Langley, Coast Garibaldi health authorities where a history of partnerships in groundwater monitoring has already been established. This concept can be further extended to include capturing of groundwater chemistry data from lands under Federal and First Nations jurisdiction (e.g., from Health Canada and DFO enhancement fish hatcheries).

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1 For an explanation of the BC Aquifer Classification System, see web page: [http://www.elp.gov.bc.ca/wat/aquifers/aqmaps/index.html](http://www.elp.gov.bc.ca/wat/aquifers/aqmaps/index.html)
Multiple levels of monitoring Intensity

Depending on the priority of the aquifer and groundwater quality concerns, the intensity of ambient groundwater quality monitoring could be divided into at least three different levels: high, moderate and low (Figure 3).

High intensity monitoring may include community aquifers in officially designated Groundwater Management areas (GWMA) where intensive management planning is occurring. Intensive monitoring would include higher sampling frequency than once a year as well as other investigations (filed sample assessments) to determine causes, sources, and quantify loadings, etc. Only the Abbotsford-Sumas aquifer can be considered to being monitored to that intensity. Moderate intensity monitoring would include the three current AGQMP areas being monitored where there are some areal coverage and annual sampling to monitor long-term trends. Low intensity monitoring might include sampling one or two sites in the aquifer every few years to monitor long-term trends and document background quality.

Regular and consistent sampling, analysis, data management and reporting
Monitoring wells are to be sampled on a regular basis with consistent sampling procedures, lab analysis, QA/QC, data analysis and archiving. Groundwater conditions and trends should be reported regularly and consistently. Where monitoring is carried out jointly with other agencies (e.g., local health authorities), sampling protocols, analysis and reporting formats need to be established.

Benefits

A community aquifer approach, with existing community wells (which are already being sampled periodically by the local health authorities) forming part of the ambient monitoring network, would allow us to obtain and share the best possible results without excessive increases in funding for groundwater quality monitoring:

1) Expand ambient groundwater quality monitoring into other areas of the province without substantial increase of costs;
2) Reduce repeat sampling of the same well;
3) Set common sampling and analysis procedure and standards with other agencies, such as local health authorities;
4) Capture water quality data from local health regions that are compatible and comparable;
5) Share resources and results; and
6) Report results to support land use and water resource decisions in the community.

Key to Success

The success of expanding ambient monitoring to the proposed framework relies on the collaboration and communication between different agencies (e.g., local health authorities) and local communities. If the ultimate goal is to protect groundwater resources for communities, the community aquifers should be monitored under the ambient groundwater monitoring network, with consistent sampling procedure, frequency, and sample analysis. The awareness of groundwater protection should be further promoted to increase the community involvement in the planning of aquifer protection.

Targeting Areas and Testing Parameters

With the understanding that significant effort and time are needed for coordinating monitoring work between government agencies and dealing with multiple levels of monitoring intensity, this section proposes some directions where scarce resources or funding could be focused on in terms of targeting new monitoring area and testing parameters.

Methodology in Selection of Targeting Areas and Testing Parameters

Targeting areas and testing parameters are selected based on assessing the results from Aquifer Classification Mapping and the Water Quality Check Program.

Physical, chemical and biological parameters, representative of water quality and as indicators of contamination, should be selected on the basis of known major groundwater quality concerns in specific geographic locations where community aquifers are identified or mapped. A major source of this information is the Water Quality Check Program (WQCP) data. WQCP was carried out between 1977 and 1993 by MoELP, providing subsidized laboratory analyses to BC residents to have their drinking water analyzed with a limited range of water quality parameters. As a result, more than 14,000 water quality records were collected (see Appendix III for more details on WQCP) and at least 12,000 of them were for groundwater samples. These groundwater quality data cover probably the widest range of the whole province with an extended period of time. Data analyses were performed on water quality parameters which are believed to be health concerns or as general indication of water quality. Summary results are shown in Table 4.
Table 4. Summary results from the Water Quality Check Program

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Number of Samples Analyzed</th>
<th>Percent of samples exceeding Drinking water guidelines or of water quality concern</th>
<th>Recommended Testing parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>12034</td>
<td>10.1% (pH&lt;6.5); 6.1% (pH&gt;8.5)</td>
<td>No</td>
</tr>
<tr>
<td>Hardness</td>
<td>11929</td>
<td>5.4% (&gt;500 mg/L)</td>
<td>No</td>
</tr>
<tr>
<td>Specific Conductance</td>
<td>12058</td>
<td>10.9% (&gt;1000 μS/cm)</td>
<td>Yes</td>
</tr>
<tr>
<td>Fluoride</td>
<td>8595</td>
<td>3.1% (&gt;1.5 mg/L)</td>
<td>Yes</td>
</tr>
<tr>
<td>Nitrate-nitrogen</td>
<td>12039</td>
<td>1.5% (&gt;10 mg/L)</td>
<td>Yes</td>
</tr>
<tr>
<td>Arsenic</td>
<td>2124</td>
<td>2.2% (&gt;0.05 mg/L)</td>
<td>Yes</td>
</tr>
<tr>
<td>Barium</td>
<td>10544</td>
<td>0.65% (&gt;1.0 mg/L)</td>
<td>No</td>
</tr>
<tr>
<td>Boron</td>
<td>10628</td>
<td>0.69% (&gt;5 mg/L)</td>
<td>No</td>
</tr>
<tr>
<td>Cadmium</td>
<td>2110</td>
<td>0.24% (&gt;0.005 mg/L)</td>
<td>No</td>
</tr>
<tr>
<td>Lead</td>
<td>2244</td>
<td>1.7% (&gt;0.03 mg/L)</td>
<td>No</td>
</tr>
<tr>
<td>Sodium</td>
<td>2133</td>
<td>5.1% (&gt;200 mg/L)</td>
<td>Yes</td>
</tr>
<tr>
<td>Total Coliform</td>
<td>11682</td>
<td>15.3% (&gt;10 CFU)</td>
<td>Yes</td>
</tr>
</tbody>
</table>

The lack of geo-referencing information for individual sample means the groundwater quality data from WQCP can only be summarized on 1:50,000 NTS map sheets. The distribution of groundwater samples across the province is shown in Figure 4. Grouping and summarizing of the WQCP data for different parameters are shown on thematic maps (Figures 6 to 10). Conclusions drawn from the analysis of WQCP data are only used for screening groundwater quality parameters and to target general areas for possible investigations and monitoring.

The Aquifer Classification Mapping is a system developed by the Groundwater Section in 1994 to identify, map and categorize aquifers using data from the provincial water well database (Kreye et al, 1994). In targeting areas and testing parameters, mapped aquifers are grouped into three monitoring priorities, according to the classification of the aquifers: high (IA, IIA and IB aquifers), medium (IIIA, IIB and IC aquifers), and low (IIIB, IIC and IIIC aquifers). Most of type I and type II aquifers (heavily and moderately used aquifers) can be considered as community aquifers while type A and type B aquifers have high to moderate vulnerability, respectively. The three priority groups of aquifers are summarized on 1:50,000 NTS map grids for BC as well (Figure 5).

Thematic maps (Figure 6 to 10) are generated by using ArcView GIS to query and overlay groundwater quality results from WQCP and monitoring priority grouping for community aquifers from Aquifer Classification Mapping, on the same base of 1:50,000 NTS map grids. Information presented on these thematic maps would assist in prioritizing planning and implementation of ambient groundwater monitoring in the province.
Figure 4. Groundwater sample distribution in the Water Quality Check Program
In each of the Figures from 5 to 10, the pie charts indicate percentages of the three monitoring priority groups and the size of each pie is proportional to the area size (in square kilometres) for all aquifers within an NTS map grid. For Figure 6 to 10, the size of the inner circle (with a dot in the centre) indicate the percentage of samples exceeding drinking water guidelines for the water quality parameter interest.

![Aquifer Priority Mapping Results](image_url)

**Figure 5. Aquifer priority mapping results.** The size of the pie chart represents the projected area (in square kilometres) of all the aquifers in one 1:50,000 NTS map grid.

**Proposed Testing Parameters for Target Areas**
**Fluoride**

Over 3% of the samples from WQCP had fluoride exceeding the maximum acceptable concentration (1.5 mg/L) of the Canadian drinking water quality guideline. A small amount of fluoride (e.g., 1 mg/L) can help prevent dental caries (Health Canada, 1996). At high concentration, fluoride can cause bone diseases such as dental fluorosis.

Ambient groundwater quality monitoring should target fluoride for community aquifers in the following areas where elevated fluoride has been identified (Figure 6):

- Penticton and Okanagan Fall,
- Enderby and Salmon Arm,
- Vernon and Armstrong, and
- Nanaimo, Gabriola Island, Ladysmith, Duncan, and Saltspring Island.

The objective of monitoring fluoride in these areas is to quantify the level of high fluoride in groundwater and to investigate the sources of fluoride, in order to provide local health authority information as whether water treatment is needed or residents should be advised.

---

**Figure 6. Water Quality Check Program: Fluoride in Groundwater**

**Nitrates**
In addition to the Langley-Abbotsford, Grand Forks, and Osoyoos areas where ambient groundwater quality monitoring for nitrate is currently on-going, monitoring of nitrates should also include the Oliver, Vernon, Williams Lake, Armstrong, Salmon Arm and Kamloops areas (Figure 7). The objective of nitrate monitoring is similar to that for the existing monitoring area (e.g., to monitor the trend of nitrate contamination in groundwater and to investigate the sources of nitrate contamination).

Elevated arsenic in groundwater has been reported for the Sunshine Coast area and igneous rocks are considered as the sources (Carmichael, 1995). There were also scattered occurrences of arsenic exceeding drinking water guidelines in Vernon, Chase, Kamloops, 100 Mile House, Williams Lake, Quesnel, Vanderhoof, and Burns Lake (Figure 8). Geologically, this area is characterized by arc, back-arc and oceanic volcanic rocks or meta-volcanic rocks (Wheeler and McFeely, 1991). Other less frequent occurrences of elevated arsenic included Sooke, Lower Fraser Valley (e.g., Whonock, Chilliwack, Surrey, and Aldergrove), Fairmont Hot Springs, and Wycliffe (not shown in Figure 8).

The scope of arsenic in drinking water for the whole province is less known since only approximately 2000 samples had arsenic analysed, compared with more than 12,000 groundwater samples were collected.
in WQCP. Additional groundwater quality monitoring should be directed at areas where elevated arsenic levels have been reported, to investigate the magnitude and the sources of arsenic.

Area where community aquifers were mapped include Chase, 100 Mile House, Williams Lake, and Vanderhoof (Figure 8).

Figure 8. Water Quality Check Program: Arsenic in Groundwater

**Sodium**
There were only 2133 samples that had sodium analyzed and approximately 5% of these samples had sodium higher than 200 mg/L, the aesthetic objective of drinking water guideline. Community aquifers or community wells in the following areas should include sodium in groundwater sampling: Williams Lake, Ladysmith, Gangs on Saltspring Island, Lantzville, Hornby Island, and Gabriola Island (Figure 9).

![Figure 9. Water Quality Check Program: Sodium in Groundwater](image)

% of samples Na > 200 mg/L (> 20 samples)
- 2 - 5
○ 5 - 10
○ 10 - 22

Aquifer Priority Grouping
- High (IA, IIA & IB Aquifers)
- Medium (IIA, IIB & IC Aquifers)
- Low (IIB, IIC & IIC Aquifers)

Micro-organisms

Most WQCP samples were tested for total coliform. More than 15% of the tested samples contained total coliform organisms above 10 CFU (Colony Forming Units per 100 mL water). Ambient groundwater quality monitoring should include effective indicators of fecal micro-organisms (e.g., fecal coliform) to investigate fecal contamination of groundwater and the nature of fecal contamination (e.g., septic systems). If total coliform is to be used as a starting point on targeting fecal contamination, information on Figure 10 may be considered on the selection of monitoring areas.
Barium, boron and cadmium had fewer samples (< 0.7%) exceeding drinking water guidelines and as a result are not targeted for specific monitoring areas, although it is recommended that these parameters be included in any monitoring program to be implemented.

There were only 2244 samples had lead analysed and at least 1.7% of the samples had lead exceeding drinking water guidelines. Due to the random occurrences of elevated lead and their likely sources to be water distribution systems and industries, ambient groundwater monitoring for lead is not recommended.

Water quality parameters which were not tested by WQCP should also be considered and may include chloride, radon, and organic solvents. A review of other information, such as consultants’ water supply reports and water quality data collected by Health Canada and local health regions, would be needed to identify target areas for these parameters.

**Figure 10. Water Quality Check Program: Coliform in Groundwater**

*Other parameters*

% of samples coliform > 10 (> 30 samples)
STRATEGY FOR IMPROVING AMBIENT GROUNDWATER QUALITY MONITORING

Changes should be made to improve the existing ambient groundwater monitoring. The expansion of ambient groundwater quality monitoring across the province also requires an updated monitoring strategy. Recommendations made here are meant to be complementary to the existing monitoring strategies being used in this province.

Sampling and Monitoring

The Groundwater Section should consider developing a comprehensive groundwater sampling procedures manual and make it available to all government agencies and private organizations that are involved in groundwater quality monitoring in the province. A tailored version of the manual could be produced for all the participants of ambient groundwater sampling to provide detailed procedures and accommodate specific equipment used.

The Groundwater Section has developed a Water Quality Sampling form and two standard sampling protocols (Appendix II) for observation wells, piezometers, and domestic wells developed by in 1996. These documents could be adopted as minimum standards for sampling and form the basis of this new sampling manual. A few recommendations are provided here for consideration.

Background Information of Monitoring Area

Before field sampling in a new area, the following information should be collected and analysed to characterize the known groundwater conditions and aquifers on the area:

- Well records,
- Well location maps,
- Surficial geology maps,
- Aquifer characteristics,
- Aerial photos and/or landuse map is better if available,
- Existing groundwater and/or surface water quality data and reports,
- Hydrogeological characteristics of the area, and
- Regional contacts (MoELP staff, health authority staff, well owners, etc.) for update on type and intensity of groundwater use, available domestic wells for sampling and types of groundwater quality issues.

Criteria of Selecting Monitoring Wells

In a community aquifer based ambient groundwater quality monitoring network, community wells and domestic wells, in addition to existing observation wells or monitoring wells should be included in the network to monitor the aquifer. A few criteria for selecting these wells may include:

1. Previous groundwater quality data are available for the wells;
2. Well records are available;
3. Preliminary field survey is conducted to check suitability of well for sampling; and
4. Wells are completed at the proper depths and are located in the proper locations: e.g., shallow well for monitoring localized or surface impact, and deep well for monitoring long term impact, geological sources or seawater intrusion and downgradient side of potential contamination sources to capture contamination and upgradient side to establish background baseline.
Ambient groundwater quality monitoring wells should be tagged in the field for positive identification. The tag allows the well in the field to be correlated with the well information in the WELL database.

**QA/QC Measures**

Some minimum QA/QC procedures can be established, including:

- Field testing kit should be decontaminated and calibrated regularly;
- Sampling equipment, containers and preservatives should be decontaminated;
- Number of duplicates, references and blank in total of samples collected should be specified (e.g., minimum percentage of all samples collected are duplicates, references and blanks);
- A chain-of-custody form could be used to handle the shipping of samples;
- There should be a clear understanding and agreement with the analytical laboratory to ensure that samples collected as a batch (with all samples, duplicates, references and blanks) will be indeed analyzed as a batch in the lab; and
- All results should be checked immediately.

**Laboratory Analysis**

MoELP is currently using Environment Canada’s laboratory (Environmental Conservation Branch, Pacific Environmental Science Centre) for groundwater sample analysis. Groundwater samples collected by other government agencies or private organizations may be sent to other laboratories. If other laboratories are used, analytical procedures of the other laboratories can be documented and results can also be archived in EMS.

While laboratories are responsible for decontaminating and calibrating laboratory equipment and facility, certain QA/QC measures could be used to minimize or identify possible sources of errors:

- To include duplicate samples,
- To insert references and blank in sample batch, and
- To check internal consistency of data (e.g., with adjacent sample, concentrations of dissolved metals vs. concentrations of total metals, ionic balance, etc.).

The MoELP monitors the performance of Environment Canada’s laboratory and results are available upon request.

As indicated earlier in the review section, the minimum detection limits of ICP method used in the Environment Canada lab for arsenic, cadmium, lead and selenium are close to or higher than the Guidelines for Canadian Drinking Water Quality (Health Canada, 1996). Graphite Furnace (GFAA) should be used for these parameters.

**Data Management and Analysis**

The purpose of database management is to check data quality, properly archive all the data collected to facilitate data retrieval, and data analysis. Currently, ambient groundwater quality data are uploaded into EMS directly by analytical labs and then downloaded to the LAN or desktop by the Groundwater Section for data analyses. Groundwater quality data from the Observation Wells are handled the same way. There are also groundwater quality data from other sources uploaded into EMS (e.g., Water Quality Check Program, Fraser Valley Groundwater Monitoring Program, contaminated sites, etc.).

**Compilation of Ambient Groundwater Quality Data**
There is essential information which must be included as part of the database files to ensure that the databases created are useful and meaningful to others, such as:

1) Accurate geographic locations of monitoring wells (e.g., coordinates in Albers projection; latitude, longitude; UTM northing and easting) or maps showing locations with sufficient geo-references (e.g., 1:20,000 TRIM base maps);
2) A survey (mapping) or at least a text description of landuse or landcover surround a monitoring well (within a 300 meter radius or with reference to the recharge area); and
3) Digitized aerial photos or satellite imagery.

**Data Validation**

Data validation is a process to check data quality and to manipulate data based on pre-defined precision and accuracy needs.

**Data entry**

If data are manually entered or collected from other sources, the data should be checked for input errors and anomalies (e.g., ionic balance, ionic ratio, ion-conductivity relationship, mineralization-discharge relationship; characters in numerical fields, numbers beyond parameter or testing ranges, etc.). Various database coding and validation system could be designed and used to automate data quality checking process.

**Significant number**

Data should be recorded in a database and used with proper significant figures. A decision on significant figures must be made for each groundwater quality testing parameters based on pre-defined precision requirements and the precision of measuring instruments.

**Rounding**

Many computer software packages (e.g. MS Excel) can be used for data rounding when it’s necessary. However, users can also program a procedure (e.g., in a database or spreadsheet) to decide how data are rounded off.

**Anomalies**

Anomalies or outliers tend to not conform with the general pattern of a data set thus may cause distortion of results in some statistical analyses. While there are anomaly- or outlier- insensitive statistic technique (e.g., median, instead of mean) that could be used in some cases, it should be acknowledged and explained why anomalies or outliers are excluded or retained and what are the difference of results if outlier-sensitive statistical methods are used.

**Less than detection limits**

For data which are below minimum detection limits (MDL) of analytical techniques, special care should be taken for data storage and statistical analysis. Less than MDL data and empty records (not analyzed or tested) are two different things and should be distinguished. There should be an explanation on how less than MDL data are treated in statistical analysis, e.g., excluded, included but treated as zero, half of MDL or MDL/(2^0.5) (Horung and Reed, 1990).

**Database Design**
An ambient groundwater monitoring program includes multiple sites and multiple samplings, to capture both spatial and temporal variations of groundwater quality. The resulting database is usually large and complicated. A relational database management system should be properly designed for data archiving. The following recommendations are provided:

1) Standardize database structure, field naming, and units;
2) Standardize data formats (e.g., NTS 999A/99), unique and consistent key field (for sample or well ID);
3) A simple and flexible graphic user interface;
4) Allow single record update and batch file update;
5) Build-in search engines (e.g., based on geographic locations, water quality parameters, well numbers, etc.); and
6) Database normalization: to minimize duplication of information through effective table design.

Metadata

There should be a descriptive text file to accompany each database when archiving or distributing a database. This metadata or “readme” file can include the following information:

1) Database structure (i.e., fields or columns) and explanation;
2) Database items, units, minimum detection limits, analytical methods, QA/QC, and laboratory used (if any of these are not shown in database in detail);
3) A list of coding (if any) and detailed explanation;
4) Additional explanation about information which may not easily deciphered by users or may result in different interpretation;
5) Disclaimers, cautions or warnings; and
6) Other additional information could be listed including: sampling procedures, devices used, and personnel involved.

Geographic Information System in Groundwater Database Management

Often there is a need to analyze temporal and spatial variation or trends of ambient groundwater quality and to assess how groundwater quality is affected by hydrology, geology, topography, climate, landuse, and landcover. Much of this related information is geo-referenced and the analysis involves the identification and assessment of spatial relationship. A Geographic Information System (GIS) can be used as a tool to integrate geo-referenced information in multiple layers, link groundwater quality data to related information and facilitate query, display, spatial analysis and result presentation.

The application of GIS in ambient groundwater quality monitoring could be considered at two different levels:

1) for each individual monitoring area
   • to assist the selection of sampling stations,
   • to track sampling and sample analysis,
   • to identify location, spatial distribution and area of groundwater pollution
   • to correlate groundwater quality with other information such as geology, landuse changes, and topography, and
   • to identify sources of groundwater pollution; and

2) for the whole province
   • to identify major groundwater quality trends across the province,
• to compare regional differences, and
• to assist the allocation of resources and prioritize monitoring efforts.

Data Analysis

While some clients, such as groundwater consultants and university researchers, may want unprocessed groundwater quality data, others, such as planners, are only interested in summarized data or even conclusions of ambient groundwater quality monitoring results such as significant differences, correlation and trends of groundwater quality data. A few types of data analyses are listed in Table 6.

For various data analyses, many statistical techniques, graphical methods, GIS spatial analysis tools and computer modelling could be applied.

Some minimum analyses that should always be performed are:

1) Compare results to existing water quality guidelines (MoELP, 1998) and determine if water quality meets intended use of the water;
2) Plot relevant water quality parameters over time to determine if there are any trends or temporal patterns;
3) Compare water quality results from various sites (if available) to determine if there are any spatial or depth patterns; and
4) Evaluate what action needs to be taken.

Table 6. Type of data analysis.

<table>
<thead>
<tr>
<th>Type of Analysis</th>
<th>Purpose</th>
<th>Intensity of Monitoring (Figure 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Status</td>
<td>To define the baseline groundwater quality.</td>
<td>High</td>
</tr>
<tr>
<td>Trends</td>
<td>To identify whether groundwater quality is improving or worsening, and to predict groundwater quality from past groundwater quality trends.</td>
<td>✓</td>
</tr>
<tr>
<td>Causes/Impact</td>
<td>To assess the magnitude of groundwater pollution, to assess impact of groundwater pollution on public health, to correlate spatial relationship between certain variables, and to identify sources/causes of groundwater pollution.</td>
<td>✓</td>
</tr>
<tr>
<td>Groundwater Quality Indices</td>
<td>To simplify complex set of water quality variables, and to disseminate groundwater quality information to the public.</td>
<td>✓</td>
</tr>
<tr>
<td>Risk Assessment</td>
<td>To assess public risk resulted from groundwater, and to determine whether remediation is necessary or not.</td>
<td>✓</td>
</tr>
</tbody>
</table>

Reporting

As an ambient groundwater monitoring program starts and progresses, certain type of information will be collected or generated, depending on monitoring intensity for a specific area (Table 7). This information should be reported or made available in an appropriate formats for different clients or objectives. Some general formats for reports are discussed below.

Table 7. Monitoring intensity and type of information to be reported

<table>
<thead>
<tr>
<th>Type of information</th>
<th>Monitoring Intensity (Figure 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High</td>
</tr>
<tr>
<td>Monitoring location</td>
<td>✓</td>
</tr>
</tbody>
</table>
Progress and Technical Reports

This would be regular, interim, progress reports on ongoing projects, a quick summary of available data as requested, memos, or exchange of information.

This type report should have the following minimum contents:

1) Objectives of the monitoring program;
2) Geographic characteristics of monitoring area;
3) Hydrogeology and characteristics of aquifer: surficial geology, aquifer polygon and classification, depth or thickness, confined or unconfined, groundwater direction, flow rate, etc.;
4) Landuse characteristics;
5) Total well records and wells selected for monitoring;
6) A map showing sampling locations and description of each well and surrounding environment (lithology, well construction, geographic, landuse, etc.);
7) Methodologies of sample collection, lab analysis, and QA/QC (if followed standardized procedures, make reference to those procedures, or include it in an appendix);
8) Number of samples collected, starting and ending dates of sampling;
9) Tabulate small data-set or tabulate summary only and include detailed data in a diskette; and
10) Conclusions and recommendations.

Comprehensive reports should also be provided every three to five years. A comprehensive report keeps track of groundwater quality trends, identifies the sources of contamination, assesses the effect of different landuse practices and well conditions (poor well construction and well-head protection, elevated arsenic levels from wells drilling into volcanic bedrock, etc.) on groundwater quality, and provides remedial or protection recommendations.

Public Information Release

Either upon request or under certain circumstances deemed necessary, groundwater quality data would be disseminated and released to the general public. The type of reports should be brief, informative, jargon free, easy to understand, and entertaining. The format could be brochures, posters, information booths, web pages, and video or audio clips put on CD-ROM or other hypertext-based media.

Reports to Potential Contributors of Groundwater Contamination

The audience of this type of reports is usually the land owners, land users, water purveyors and customers, or others who carry out activities on an aquifer. The report for this group should be brief and emphasize those parameters which displayed significant trends, either indicating improvement or deteriorating groundwater quality. The formats should be easy to follow, brief, and striking with sound explanation of trends to encourage or discourage certain type of landuse practices.

Reports to Land Planners and Developers
The report for this group should be brief overview, with summarized data and simplified maps readily available. The format could be both overview report and detailed technical report, including both paper copies and digital copies of summary data and simplified maps.

**Information Release to Scientists and Technical Staff**

This user group consists of those who are involving researches in assessment and management of resources, environmental and environmental health impact in universities, governments and research institutes. The report for this user group should be brief and informative: what has been done, what’s available in what format or accessibility, cost, and contact person. The format could be newsletters, e-mail listing, and web-pages. At the end, some users from this group may ask for details on methodologies of sampling and analysis, QA/QC, raw data, and brief interpretation.

**Evaluation of monitoring program**

The effectiveness of ambient groundwater quality monitoring in any particular area should be evaluated from time to time. Sometimes the whole monitoring program might have to be re-designed to accommodate new or changed goals of ambient groundwater quality. There should be documentation if a monitoring program is discontinued or a monitoring well is deleted or added in a monitoring network. Operational activities and results should be reviewed from time to time. Clients should also be surveyed periodically to check whether monitoring results are being used and monitoring objectives are being met.
SUMMARY

Review of Existing Ambient Groundwater Quality Monitoring

The Ambient Groundwater Quality Monitoring and Assessment Program has been carried out by the Water Management Branch, MoELP for four areas in BC, targeting specific contaminants:

- Langley-Abbotsford, 27 wells, monitoring nitrates, since 1985,
- Osoyoos, 23 wells, monitoring nitrates, since 1987,
- Grand Forks, 24 wells, monitoring nitrates, since 1989, and
- Cowichan Estuary, 9 wells, monitoring seawater intrusion, since 1989, discontinued.

The program has shown its effectiveness in tracking groundwater quality trends and identifying contamination sources in those areas. The existing program for the three areas monitoring nitrates will be continuing as neither the nitrate level in the groundwater nor the landuse activities in the areas indicate trends implying that monitoring should be terminated.

Expansion of Ambient Groundwater Quality Monitoring

A query on the Aquifer Classification Mapping database and a preliminary analysis on groundwater quality data collected through the Water Quality Check Program reveal nitrate contamination in other parts of the province and groundwater quality concerns of other contaminants as well. Due to scarce resources, we propose a new framework for expanding ambient groundwater quality monitoring in BC:

- Target community aquifers,
- Carry out monitoring jointly with other government agencies (e.g., local health authorities) and private organizations (e.g., water purveyors), and
- Use multiple levels of monitoring intensities.

By overlying results from WQCP and Aquifer Classification Mapping, a series of thematic maps are generated in ArcView GIS. These thematic maps are then used to select monitoring areas and groundwater quality parameters.

In addition to areas and parameters listed in Table 8, monitoring of micro-organisms is recommended for most areas where agricultural landuse activities may potentially compromise water quality in community aquifers.

Improving Monitoring

Recommendations are made for improving existing ambient groundwater quality monitoring and to provide a updated strategy for the proposed expansion of monitoring, including:

- Develop a common sampling protocol and manual,
- Undertake QA/QC measures in every step of monitoring,
- Select representative monitoring wells in a community aquifer,
- Characterize a monitoring area by collecting and analyzing background information before sampling,
- Compile groundwater quality data along with accurate and sufficient geo-referencing,
- Ensure data quality by using consistent data validation methods and pre-defined precision and accuracy needs,
- Standardize database design and metadata to ensure easy access, meaningful and useful of archived data,
- Use GIS to integrate data and facilitate data analysis and result presentation,
- Provide a wide range of data analyses and reports to meet the information needs of different clients, and
- Evaluate the effectiveness of monitoring from time to time.

Table 8. Targeting areas and testing parameters

<table>
<thead>
<tr>
<th>Area</th>
<th>Arsenic</th>
<th>Fluoride</th>
<th>Nitrate</th>
<th>Sodium</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 Miles House</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Armstrong</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Burns Lake</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chase</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duncan</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enderby</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gabriola Island</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Hornby Island</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kamloops</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Ladysmith</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Lantzville</td>
<td>✓</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Nanaimo</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Okanagan Fall</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oliver</td>
<td></td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Penticton</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salmon Arm</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Salt Spring Island</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sunshine Coast</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Quesnel</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vanderhoof</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Vernon</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Williams Lake</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
REFERENCES


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Kohut, A.P. 1981. *Saltwater Intrusion Problem - Cowichan Bay*. Ministry of Environment, Groundwater Section, Victoria, BC.


APPENDIX I. AMBIENT GROUNDWATER QUALITY MONITORING IN BC

Ambient Groundwater Quality Monitoring and Assessment Program (AGWQMAP) in BC was initiated in 1985 to monitor nitrate contamination of groundwater in the Langley-Abbotsford and Osoyoos areas and seawater intrusion in the Cowichan Estuary. In 1989, nitrate monitoring for the Grand Forks was included.

Langley-Abbotsford Area

The Langley-Abbotsford area is located in the Lower Fraser Valley. Fast urbanization has converted the Langley-Abbotsford area from essentially a farmland into a semi-urban over the last decade. Ambient groundwater monitoring was initiated to investigate reported occurrence of nitrate-nitrogen in groundwater.

The monitoring area encompasses three major unconfined unconsolidated aquifers: Brookswood, Hopington and Abbotsford aquifers (Table I-1). Aquifer boundaries were delineated based on known extent of surficial sand and gravel deposits.

Table I-1. Aquifers in the Langley-Abbotsford area.

<table>
<thead>
<tr>
<th>Aquifer Name</th>
<th>Aquifer Materials</th>
<th>Aquifer Classification</th>
<th>Aquifer Ranking Value</th>
<th>Size (km²)</th>
<th>Productivity</th>
<th>Vulnerability</th>
<th>Demand</th>
<th>Litho-stratigraphic Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abbotsford-Sumas Aquifer</td>
<td>sand and gravel</td>
<td>I A</td>
<td>20</td>
<td>100</td>
<td>high</td>
<td>High</td>
<td>high</td>
<td>Sumas Drift</td>
</tr>
<tr>
<td>Hopington Aquifer</td>
<td>sand and gravel</td>
<td>I A</td>
<td>21</td>
<td>43</td>
<td>high</td>
<td>High</td>
<td>high</td>
<td>Fort Langley Formation; Sumas Drift</td>
</tr>
<tr>
<td>Langley/Brookswood Aquifer</td>
<td>sand and gravel</td>
<td>I A</td>
<td>17</td>
<td>38</td>
<td>moderate</td>
<td>High</td>
<td>high</td>
<td>Sumas Drift</td>
</tr>
</tbody>
</table>

In addition to the threat of nitrate contamination from agricultural landuse activities (manure and chemical fertilizers) and septic systems, groundwater quality in this area could also be compromised by industrial and commercial activities.

Both MoELP and Environment Canada (e.g., Liebscher et al., 1992) have been involved in the monitoring of groundwater quality in the area. Currently there are 19 active ambient monitoring wells at 10 sites operated by MoELP with more than five years of groundwater quality data. Aquifers in this area were also included in a comprehensive study of groundwater monitoring program in the Fraser Valley by Carmichael et al. (1995).

A recent review of the groundwater quality data indicates that seven of the 19 monitoring wells have nitrate exceeding the 10 mg/L drinking water guideline (BC Environment, in draft). While seven wells show improving trends, four wells show deteriorating trends and eight wells show no trends. Good correlation exists between nitrate and calcium, nitrate and chloride, as well as nitrate and specific conductance, indicating the possible source of the nitrate to be animal wastes (Sather, 1988).

MoELP and Environment Canada continues to monitor the groundwater quality in this area. The City of Abbotsford has recently conducted a contaminant survey within the recharge areas of their municipal wells and has established the Abbotsford-Sumas Aquifer Stakeholder Group to develop a groundwater protection plan. An International Task Force has been established to examine water quality concerns on both sides of the border and has made recommendations to improve the situation.
Osoyoos

Osoyoos is one of the three target areas selected for nitrate investigation initiated in 1985. The Osoyoos area is located in the Okanagan valley near the U.S. border. The monitoring area encompasses approximately five square miles and surrounds part of Osoyoos Lake.

The Osoyoos area is underlain by two shallow aquifers and one confined aquifer consisting of loamy sand and gravel deposits with glacial-fluvial outwash material (Hodge, 1985a and 1985b). Recharge to wells is through infiltration of precipitation and recharge to wells close to Osoyoos Lake is from the lake under pumping conditions (Hodge, 1985b). These aquifers are important sources of drinking and irrigation water supply and are highly vulnerable to contamination.

Landuse in the Osoyoos area is characterized by orchards and other agricultural activities which may cause nitrate contamination (York, 1994). Other potential contamination sources include a sanitary landfill, and a wastewater disposal pond used for irrigating a golf course. Since the aquifers discharge into Osoyoos Lake and may therefore affect the water quality of the lake.

Table I-2. Summary of active ambient groundwater quality stations in Osoyoos

<table>
<thead>
<tr>
<th>Station</th>
<th>Well Type</th>
<th>Well Depth (m)</th>
<th>Sampling Frequency</th>
<th>Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-1 (P-1)</td>
<td>Piezometer</td>
<td>10.7</td>
<td>Annually since 1989</td>
<td>no trend</td>
</tr>
<tr>
<td>A-1 (P-2)</td>
<td>Piezometer</td>
<td>8.85</td>
<td>Annually since 1989</td>
<td>no trend</td>
</tr>
<tr>
<td>B-1 (P-1)</td>
<td>Piezometer</td>
<td>13.37</td>
<td>Annually since 1989</td>
<td>up</td>
</tr>
<tr>
<td>B-1 (P-2)</td>
<td>Piezometer</td>
<td>10.57</td>
<td>Annually since 1989</td>
<td>up</td>
</tr>
<tr>
<td>B-4 (P-1)</td>
<td>Piezometer</td>
<td>6.25</td>
<td>Annually since 1989</td>
<td>down</td>
</tr>
<tr>
<td>B-5 (P-1)</td>
<td>Piezometer</td>
<td>6.86</td>
<td>Annually since 1989</td>
<td>down</td>
</tr>
<tr>
<td>B-7 (P-1)</td>
<td>Piezometer</td>
<td>8.7</td>
<td>Annually since 1989</td>
<td>up</td>
</tr>
<tr>
<td>B-7 (P-2)</td>
<td>Piezometer</td>
<td>10.7</td>
<td>Annually since 1989</td>
<td>up</td>
</tr>
<tr>
<td>B-8 (P-1)</td>
<td>Piezometer</td>
<td>6.09</td>
<td>Annually since 1989</td>
<td>no trend</td>
</tr>
<tr>
<td>B-8 (P-2)</td>
<td>Piezometer</td>
<td>7.21</td>
<td>Annually since 1989</td>
<td>up</td>
</tr>
<tr>
<td>B-9 (P-1)</td>
<td>Piezometer</td>
<td>7.12</td>
<td>Annually since 1989</td>
<td>no trend</td>
</tr>
<tr>
<td>Cimbali</td>
<td>Domestic</td>
<td>3.66</td>
<td>Annually since 1987</td>
<td>down</td>
</tr>
<tr>
<td>Dammer</td>
<td>Domestic</td>
<td>3.66</td>
<td>Annually since 1987</td>
<td>no trend</td>
</tr>
<tr>
<td>Gaetz</td>
<td>Domestic</td>
<td>4.57</td>
<td>Annually since 1987</td>
<td>up</td>
</tr>
<tr>
<td>Gooding</td>
<td>Domestic</td>
<td>3.66</td>
<td>Annually since 1987</td>
<td>up</td>
</tr>
<tr>
<td>Peel</td>
<td>Domestic</td>
<td>5.49</td>
<td>Annually since 1987</td>
<td>down</td>
</tr>
<tr>
<td>Mayers</td>
<td>Domestic</td>
<td>4.57</td>
<td>Annually since 1987</td>
<td>down</td>
</tr>
<tr>
<td>Morley</td>
<td>Domestic</td>
<td>?</td>
<td>Annually since 1987</td>
<td>down</td>
</tr>
<tr>
<td>Stadjudar</td>
<td>Domestic</td>
<td>3.66</td>
<td>Annually since 1987</td>
<td>down</td>
</tr>
<tr>
<td>Thom</td>
<td>Domestic</td>
<td>?</td>
<td>Annually since 1987</td>
<td>no trend</td>
</tr>
<tr>
<td>Trudel</td>
<td>Domestic</td>
<td>5.49</td>
<td>Annually since 1987</td>
<td>down</td>
</tr>
<tr>
<td>Wight</td>
<td>Domestic</td>
<td>3.66</td>
<td>Annually since 1987</td>
<td>no trend</td>
</tr>
</tbody>
</table>

In 1985, there were 358 well records on file and less than 150 wells were utilized in the monitoring area. Domestic wells are shallow, generally less than 15 meters. Many hand-dug wells had no records on Groundwater Section files. Currently there are 23 active groundwater monitoring wells at 18 sites (Table I-2). The majority of the water quality monitoring wells are located within the aquifer west of Osoyoos Lake.
During August 22 and August 30, 1985, a field survey was conducted and results summarized by Hodge (1985b). Of the 70 Hach analyses nitrate-nitrogen was detected in 41 water samples and a total of six water samples had nitrate-nitrogen levels over 9.9 mg/L, with a maximum concentration recorded in a domestic water supply well at 45 mg/L nitrate-nitrogen. Laboratory analysis of the same samples showed similar results. Nitrate-nitrogen concentrations were particularly high in Osoyoos Town production wells 1, 2, and 3. Nitrate-nitrogen contamination could be linked to agricultural activities, such as irrigation and fertilization of orchards. Sources of nitrate contamination from sewage waste were not evident as high chloride concentration was not observed.

Groundwater quality indicators monitored since 1987 include nutrients, major ions, trace elements, dissolved solids and temperature.

A recent analysis of the water quality data by Hodge (BC Environment, in draft) indicates that for nitrate-nitrogen nine wells show improving trends, seven wells show deteriorating trends, and seven wells show no changes. The nine wells showing an improving trends suggest that some orchardists and residents are adopting improved management practices for chemical fertilizer use. The nitrate levels in local portions of the aquifer were elevated with three of the 23 wells exceeding the drinking water guideline.

Continuing monitoring of the groundwater quality of these aquifers is recommended and local community is encouraged to develop well and aquifer protection plans (BC Environment, in draft).

Cowichan Bay Estuary

Groundwater quality monitoring program was initiated for the Cowichan Estuary area with concerns over seawater intrusion. There are three surficial aquifers in the monitoring area: an upper, a middle and a lower aquifer. Groundwater is used as drinking water supply and for industry, mostly from the lower aquifer. Over pumping of production wells, as a result of increasing development in the area, could lead to potential seawater intrusion in the lower aquifer. In the upper aquifer. Saltwater intrusion occurs due to tidal inundation during fall when tides were high but river flow was low (Kohut, 1981).

Table I-3. Aquifers in the Cowichan Bay area.

<table>
<thead>
<tr>
<th>Aquifer Name</th>
<th>Aquifer Materials</th>
<th>Aquifer Classification</th>
<th>Aquifer Ranking Value</th>
<th>Size (km²)</th>
<th>Productivity</th>
<th>Vulnerability</th>
<th>Demand</th>
<th>Litho-stratigraphic Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Cowichan River A Aquifer</td>
<td>sand and gravel</td>
<td>I A</td>
<td>14</td>
<td>18.3</td>
<td>high</td>
<td>high</td>
<td>high</td>
<td>Salish Sediments</td>
</tr>
<tr>
<td>Lower Cowichan River B Aquifer</td>
<td>sand and gravel</td>
<td>II B</td>
<td>12</td>
<td>11.0</td>
<td>high</td>
<td>moderate</td>
<td>moderate</td>
<td>Capilano Sediments</td>
</tr>
<tr>
<td>Lower Cowichan River C Aquifer</td>
<td>sand and gravel</td>
<td>III C</td>
<td>10</td>
<td>7.9</td>
<td>high</td>
<td>low</td>
<td>low</td>
<td>Vashon Drift</td>
</tr>
</tbody>
</table>

Sampling was carried out on an annual basis from 1985 to 1994 for two observation wells and six domestic wells (Table I-3).
Water quality data collected over the ten years of sampling indicate no high levels of chloride in the deeper wells which monitoring the lower aquifer. Chwokja (1997) recommended to discontinue this monitoring program, with the exception that the two observation wells are retained for monitoring. Obs well 297, completed into the lower aquifer has since been turned over to the property owner for private use.

**Grand Forks**

The monitoring area is situated in the Kettle River valley bordered which is filled with terraced glaciofluvial deposits consisting mostly of gravel, sand, silt and clay. The maximum thickness is unknown but reaches 123 meters based on available well records. These deposits become finer with depth and towards the east in the study area. The upper coarse section of the deposits, consisting mostly of sand and gravel with some silt and clay, forms a productive unconfined aquifer: about 25 km² in size and classified as IA with a ranking value of 17. This aquifer supplies groundwater for domestic, irrigation and industrial uses to the Grand Forks area.

The Kettle River valley is characterized by intensive agricultural landuse activities. Households outside of the Grand Forks city limits are on septic systems. Investigation of nitrate in groundwater was initiated in 1989 for the Grand Forks area due to elevated levels of NO₃ found in groundwater in previous studies (Wei, 1987 and 1988).

A field reconnaissance survey was conducted in May, 1989 to determine the areal extent of NO₃ occurrence in groundwater and summarized by Sather (1989). Approximately 100 wells were sampled and field analyzed for temperature, specific conductance, pH, iron (Fe), chloride (Cl), alkalinity, hardness, and NO₃-N using a Beckman conductivity meter and Hach testing kits (model AL-94/AY and NI-11). From this survey, 14 domestic wells were selected for monitoring temporal NO₃-N trends, in addition to the construction of nested piezometers at 3 sites. The 14 domestic wells and piezometers were sampled for NO₃ and other chemical constituents in 1989 and 1990. A preliminary landuse survey was conducted in October, 1991 for correlating existing landuse with areas of NO₃ contamination in the aquifer. These results were summarize by Wei (1992). Further monitoring and investigation in this area are recommended to better understand nitrate occurrence and behavior in groundwater for formulating effective strategies to protect the aquifer.

MoELP continues to monitor the groundwater quality in the Grand Forks area with partnership funding from the local health authority. Recently an Aquifer Protection Committee has been formed to develop protection measures for the aquifer.
APPENDIX II. SAMPLING PROCEDURES

The following sampling procedures and form have been developed by the Groundwater Section for use by their field staff:

- Sampling Procedures for Domestic Wells
- Sampling Procedures for Observation Wells
- Sampling Form