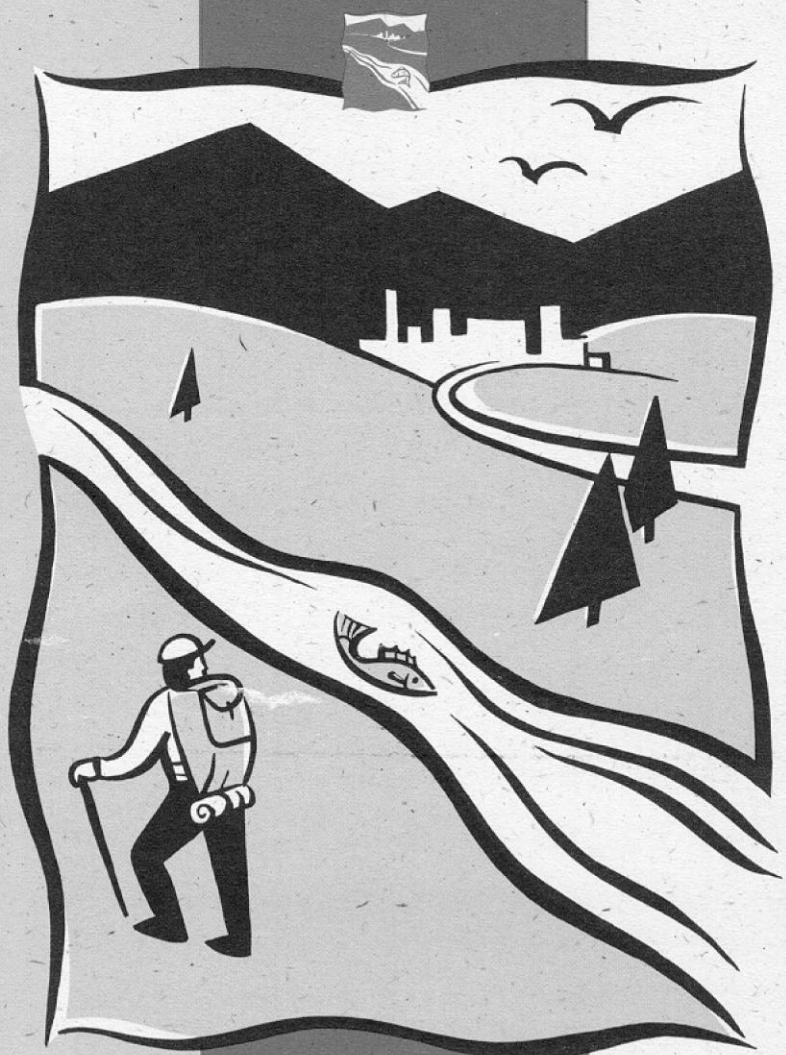
Fraser River Action Plan



Groundwater Mapping and Assessment in British Columbia

Volume I: Review and Recommendations

CANADA'S GREEN PLAN
LE PLAN VERT DU CANADA

Canada

DOE FRAP 1993-33

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GROUNDWATER MAPPING AND ASSESSMENT IN BRITISH COLUMBIA

VOLUME I: Review and Recommendations

DOE FRAP 1993-33

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DISCLAIMER

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Review and Recommendations for Groundwater Mapping and Assessment in British Columbia

EXECUTIVE SUMMARY

Piteau Associates Engineering Ltd. and Turner Groundwater Consultants were retained by the Resource Inventory Committee, Earth Science Task Force to review groundwater mapping and assessment in British Columbia. The study team have reviewed existing methods for the acquisition, processing, and dissemination of groundwater information in British Columbia and other jurisdictions. The results of this review and assessment are presented in a two-volume report: Volume I, entitled ***Review and Recommendations*** offers suggestions to facilitate the collection, management, and dissemination of groundwater information; Volume II, entitled ***Criteria and Guidelines*** has been prepared to encourage a consistent approach to groundwater mapping and assessment in British Columbia.

This project included surveying a broad group of individuals to obtain comments on groundwater mapping and assessment as well as holding a stakeholder workshop which provided a forum for discussion on this important issue.

The review of existing hydrogeological assessment methods and comments received from those concerned with the development, use, management and protection of groundwater resources resulted in the following consensus:-

- The ***establishment of a centralized core of high quality, up-to-date, and readily accessible groundwater information*** is essential. This will be achieved by consolidating and automating water-well reports and collecting and sharing groundwater data. Only when this has been completed can detailed mapping and the characterization of aquifers proceed.

- The ***establishment of a minimum set of data elements*** to foster the sharing of information between interested agencies is fundamental to the overall strategy for organizing and managing groundwater data.

In terms of improved access to groundwater information, this report provides recommendations for the establishment of a central groundwater information source and

allowing for access to this information by computer. Other recommendations to provide greater access to groundwater information and to increase public awareness on groundwater issues include publishing a groundwater data source book, releasing selected groundwater information and reports for public circulation, and the publication of brief fact sheets on groundwater and related issues in British Columbia.

It is also recommended that the Provincial Government set standards for groundwater mapping and data collection with support from the Federal Government. Local governments should accept a significant role in the management and protection of groundwater resources.

CHAPTER 1

Introduction

The Forest Resources Commission of British Columbia has concluded that Provincial resource inventories "... suffer from an uncoordinated approach by several ministries, both federal and provincial."

To meet the challenge put forward by the foregoing statement, a new initiative has been undertaken by the Resources Inventory Committee (RIC). This committee, composed of provincial resource management ministries and appropriate federal agencies, is responsible for reviewing existing resource inventory methodologies, identifying information gaps and overlaps, and integrating data required for land use planning.

The focus of the RIC and its various task forces is to meet the challenge of sustainable development and integrated resource management in the context of providing inventory information for effective land use planning and decision making.

Federal input to this project is administered under the auspices of the Fraser River Action Plan (FRAP) which calls for the reduction in contaminant loading to groundwater through identification of contaminant sources and the development and implementation of suitable control measures. To determine relationships between sources and contamination, it is desirable to develop uniform methodologies to integrate, interpret and present hydrogeological and water-quality data. Environment Canada wishes to fulfil these objectives by participating with the Resources Inventory Committee in this Groundwater Mapping and Assessment Project.

The Resource Inventory Committee is composed of six task forces of which the Earth Sciences Task Force (ESTF) is one. The resource components addressed by the ESTF are; terrain science, surficial geology, bedrock geology and hydrogeology. As part of their mandate, the Earth Sciences Task Force retained Piteau Associates Engineering Ltd. (PAEL) and Turner Groundwater Consultants (TGC), to carry out the following tasks:-

- Evaluate the application of knowledge with respect to groundwater mapping and assessment in the context of integrated resource management and land use planning.

- Provide procedures and recommendations for the collection, synthesis, analysis and presentation of groundwater related data for use by those concerned with the development, use, management and protection of the groundwater resource of British Columbia.

1.1 OBJECTIVES

Within the overall terms of reference for the project, the objectives of the Groundwater Mapping and Assessment study are:-

- To achieve a consensus on a minimum set of data elements that would facilitate the collection and sharing of groundwater and related data across interested agencies and the groundwater community.

- To identify implementation issues that should be resolved to encourage the collection of a minimum set of data elements throughout the groundwater community.

- To prepare a realistic and functional procedures manual outlining the minimum recommended standards with respect to groundwater mapping in British Columbia for use by those concerned with the development, use, management and protection of the groundwater resource. This will take into consideration existing federal and provincial resources.

1.2 SCOPE OF WORK

To evaluate groundwater mapping and assessment in British Columbia, the Piteau-Turner project team has completed, or addressed, the following tasks:

- Conducted a survey of the needs and concerns of identified groundwater information user groups. These groups included those involved with the development, use, management, and protection of the groundwater resource of British Columbia.

- Identified existing sources of groundwater related data in British Columbia and evaluated current data collection and mapping methods presently used in British Columbia and other jurisdictions.

- Organized and participated in a "stakeholder" workshop directed towards determining user needs.

- Prepared a comprehensive procedures manual outlining recommended minimum standards and levels of expertise required to carry out groundwater mapping and assessment in British Columbia.

- Prepared a demonstration groundwater map for the Aldergrove Area in the Fraser Valley.

The result of this program of work is presented in two volumes. Volume I reviews current groundwater activities in British Columbia; an assessment of existing groundwater information sources; groundwater mapping and assessment in other jurisdictions; results of "stakeholder" surveys; and provides for a recommended approach to groundwater mapping and assessment in British Columbia. Suggested criteria and guidelines for groundwater mapping and assessment are presented in Volume II.

1.3 ACKNOWLEDGEMENTS

This report has been prepared with assistance and suggestions provided by several knowledgeable individuals including Rod Zimmerman and other members of the Groundwater Section of the Ministry of Environment, Lands and Parks and Hugh Liebscher, Senior Hydrogeologist with Environment Canada. Paul Matysek and members of the RIC Earth Sciences Task Force planned and directed the project.

Dr. Allan Freeze, of R.Allan Freeze Engineering Inc. of White Rock, B.C., moderated a workshop on groundwater mapping and assessment, and reviewed the summary report. Dr. Robert Palmquist, of Applied Geotechnology Inc. of Bellevue, Washington, assisted with planning of the workshop and provided much of the USA based resource material.

The authors wish to acknowledge contributions from John Gilliland of Environment Canada, Dr. John Vaccaro, US Geological Survey in Tacoma, Washington, and Marilyn Blair, Washington State Department of Ecology, in Olympia, Washington.

CHAPTER 2

Sources of Groundwater Information in British Columbia

Statistics compiled in 1981 showed that 22% (600,000 persons) of the Province's population depended upon groundwater for water supply (Groundwater Section - MELP). Although the volume of groundwater extracted amounts to only 10% of total water consumption in British Columbia, it represents 25% of all the groundwater extracted in Canada because of the large quantities of water used in the province. The largest use of groundwater in the province is by industry (55%), followed by agricultural (20%), municipal (18%) and rural domestic (7%). Certain areas are entirely dependent upon groundwater for water supplies where there are no economically viable alternatives to groundwater.

Information from diverse sources is required to manage and protect groundwater resources to ensure its lasting availability and quality. The types of data required range from traditional hydrogeological data, to information on man's activities which may have an impact on the resource. Included in man's activities would be land use, agricultural management practices, and locations of transportation corridors which may pose a potential risk of contamination in the event of accidental chemical spills. Computer database programs and geographical information systems (GIS) enable manipulation of data from a multitude of sources. This information can be used as a tool for understanding the occurrence and distribution of groundwater and related resource information in addition to developing management practices for sustaining the resource.

Groundwater-related data sources in British Columbia were reviewed in the following manner:-

- Potentially useful sources of groundwater and related information was catalogued.
- The existing framework in which this information is captured, manipulated, and disseminated was assessed.
- The overall usefulness of the information for groundwater mapping and assessment was evaluated .

2.1 SOURCES OF GROUNDWATER MAPPING AND ASSESSMENT INFORMATION

Groundwater-related data sources in British Columbia were reviewed. These included those known to the project members, as well as a number of sources highlighted in previous reports to the RIC.

Synopses of information types required for groundwater mapping and assessment, along with comments regarding potential sources of this information and suitability with respect to groundwater mapping are provided in Appendix B. Brief descriptions and comments on the most significant sources of data are included in the following sections.

Water-Well Construction Reports-Well Construction Reports

Well construction and geological information obtained from well drillers' reports is a fundamental component of groundwater mapping and assessment. In British Columbia, these data are maintained at a central source by the Groundwater Section of MELP. The Groundwater Section has original paper copies of some 80,000 wells on file, and maintains a searchable computer listing of information on these wells, known as the Computerized Groundwater Data System, or CGDS. The master index of water well information currently resides on a VAX computer system. Subsets of the data are also available as EXCEL spreadsheets, which are compatible with both DOS and Apple MacIntosh operating systems.

The CGDS provides a means for tabulating data on well location and ownership, technical construction data, borehole lithology, and indicates other types of information available such as chemistry and aquifer test data. A summary of all "fields" used in the CGDS is presented in Table I. Only a limited number of well records in the CGDS include information in all "fields" because it is not available or has not been transferred from the well construction report into the computer. For example, lithology information has been entered into the CGDS for wells in the Fraser Valley, and some coastal areas, but not for wells in the interior of the province. Similarly, aquifer-test data or sieve analyses are rarely included with the database.

Although filing of well construction reports by drilling contractors is not compulsory in British Columbia, historically, records for a large proportion of wells drilled have been submitted to the Groundwater Section. However, due to shortage of personnel and other factors, few of the well logs submitted within the last five years have been field verified, or added to the CGDS.

Water Well Location Mapping

The locations of many of the wells included with the CGDS have been verified by MELP personnel and plotted on well-location maps. Water-well locations are denoted using a British Columbia Geographic System (BCGS) based well identifier. This number consists an alphanumeric code to identify the rectangular shaped portion of the Province in which the well is located, plus a number to indicate the well number. For example, the identifier, 092G.033.4.3.3 - 001, indicates well number 1 in BCGS map area "092G.033.4.3.3" and denotes the location of a well to within 2.5 x 2.5 kilometres. More detailed information on well locations is obtained from the aforementioned well location

maps and/or on maps included with the paper copies of the water well records. Well location maps are available for most settled areas of the province south of Prince George. Map coverage varies between a series of "old" maps which use an "X - Y" grid and are at varying scales, and a series of "new" maps varying in scale from 1:5,000 to 1:20,000. New well locations are added to each map by drawing in a symbol at the appropriate location, and writing in the well number next to it. The BCGS reference grid is part of the base maps on which the "new" maps are based. This grid has been superimposed onto the "old maps" to replace the old "X - Y" grid.

In many cases, where old and new well location numbers are shown, there are discrepancies and duplications in well numbering. These often lead to confusion, and limits the ease with which the maps can be used.

Water-Quality Information

Information on water quality is available from several sources including the SEAM database, Provincial Ministry of Health, and site specific studies carried out by private consultants, the Groundwater Section of MELP, and Environment Canada.

System for Environmental Assessment and Management (SEAM) Database

The SEAM database tracks water quality data for monitoring performed at permitted and non-permitted sites by provincial staff, including both surface and groundwater sites. The database consists of a location file with information for each unique sampling site and a file with the results of chemical analyses. Each water sampling site is given its own unique identifier number, which in some cases is used in other databanks to cross-reference back to this site. Data can be downloaded from SEAM onto a standard DOS diskette in popular spreadsheet and/or database formats.

MOH - Water Quality Check Program

Basic information on the potability of surface and groundwater supplies has been collected by the MELP, through the now defunct Water Quality Check Program. This province-wide program provided subsidized testing of water quality for private water supplies at some 20,000 sites throughout the province. Water samples analyzed under this program are tested for some basic ions only. Sodium, chloride, carbonate, bicarbonate, and sulphate are not analyzed. The majority of the water quality data from the Water Quality Check Program are in digital format. However, some of these reports are only available on paper.

MOH - Drinking and Recreational Water Quality

Water quality monitoring data for community water supply systems is collected by the MOH, and is available in digital format. Analyses are presently conducted by Zenon Laboratories, and are either for basic drinking water potability, or basic drinking water potability and tri halomethanes (THM's).

The most significant problem common to all of the sources of water quality data is incomplete cross-referencing which is required to match the results of a chemical analysis with the well from which the sample was obtained. This seriously limits the usefulness of the information with respect to mapping and assessment.

In addition, as the reason for sampling is not indicated in any of these databases, there is potential for misinterpretation of water quality information. For example, if results for nitrate analysis of four groundwater samples obtained from shallow wells next to feed lots spaced over a 5 km^2 area all indicate evidence of elevated nitrate, there is a danger of incorrectly concluding that groundwater resources in between the sampling points are also contaminated.

Water Level Information

The Groundwater Section operates some 149 groundwater observation wells throughout the province. At present, 82 of the observation wells are equipped with chart recorders and the remaining wells are monitored manually. Existing observation wells are discontinued and new observation wells are established as warranted and, in total, some 320 wells have been or are being monitored. Some of the observation wells are sampled regularly for chemistry; all data is input to the SEAM database.

Although monthly water-level readings are stored in EXCEL spreadsheet format, continuous water-level hydrographs are not available in a readily usable digitized format.

Other sources of groundwater data include the CGDS, which includes water level measured at the time a well was drilled, and other monitoring networks such as those established for ambient water-quality monitoring programs in specific areas, contaminated-sites investigations, and other sources. Where available through the Groundwater Section, these types of materials will be tabulated in their georeferenced database of well information.

Published and Unpublished Groundwater Documents

An important source of data with regard to groundwater mapping and assessment is contained in documents such as published and unpublished reports and memoranda

prepared by or for the Federal and Provincial governments, as well as reports and letters prepared by private consultants. Such information includes regional, subregional and local hydrogeologic interpretations, information on groundwater investigations such as test drilling, aquifer testing, water-quality analysis, etc. These documents often also contain large-scale maps of groundwater resources.

Limited amounts of published information on groundwater resources throughout the province is available through a variety of sources such as public and university libraries and Crown Publications in Victoria. Unpublished information, however, is much more difficult to obtain. The Groundwater Section maintains a geo-referenced database of some 3,000 reports, letters, and memoranda regarding groundwater resources in British Columbia While not comprehensive, this index provides a useful means of identifying some of the groundwater related memorandums, reports, and studies undertaken by the MELP and other Provincial agencies, as well as some reports and letters prepared by other government agencies and private consultants. Most of the latter were voluntarily forwarded to the Groundwater Section of MELP.

The National Topographic System (NTS) database listing is in an EXCEL spreadsheet, and is searchable by NTS map sheet number and words in the document description. Unfortunately, information has not been entered into the database in a systematic fashion, and it is not easily searched by author, topic, document name, study name, lead agency, time frame, or combinations of those criteria. Some 600 of the reports in the database have "Confidential" status, meaning that they were forwarded to the Groundwater Section under the condition that they would not be released to users outside of government. However, these reports can sometimes be obtained if subsequently authorized by the report writer.

Another potentially useful source of groundwater-related information is the groundwater assessment and well completion reports prepared by consultants for water utilities. Some 200 such reports for private utilities are on file with the Community Water Supply Section of the MELP, and some of these reports have a groundwater component which may consist of hydrogeological interpretation, well log, aquifer test, and water quality. Unfortunately, there is no registry for these reports, and it is difficult to determine if a report is available for a given region. Also, as private water utility reports are confidential, the utility which commissioned the work must authorize its release.

Groundwater-related reports prepared for public water utilities are not necessarily submitted to a provincial or federal government department. Application to the public body governing operation of the utility is necessary in such cases. Many reports for groundwater utilities on First Nations' lands are available on loan from Indian and Northern Affairs Canada. These reports are listed on a computer searchable database. As with reports for private and public water utilities, these can be an important and useful source of hydrogeological information.

With respect to groundwater mapping and assessment, the Inland Waters Branch of Environment Canada, are presently, or have in the past, studied trans-border aquifers, specifically Abbotsford, Hoppington, Brookswood, Fort Langley, Keremeos, Osoyoos, Grand Forks and have data and reports available.

Other Sources of Information

Depending upon the requirements and circumstances of a groundwater mapping and assessment related task, other sources of information may be needed. These range from information on oil and gas wells or geotechnical boreholes, surficial and bedrock geology mapping, soils mapping, climatological and hydrometric information, and base mapping. Sources for many of these types of information are set out in Appendix C.

2.2 AVAILABLE GROUNDWATER MAPS FOR BRITISH COLUMBIA

Compared to other provinces and states, relatively little mapping of the groundwater resources in British Columbia has been done. Areas in the province where groundwater mapping has been carried out include the Fraser Valley (Armstrong and Brown, 1953 and Halstead, 1986), the entire Fraser River Basin (GSC, 1993), the east coast of Vancouver Island (Halstead and Treichel, 1966), the Thornhill area near Terrace (Callan, 1972), and the Kalamalka-Wood Lake Basin near Vernon (Le Breton, 1974). There are numerous examples of other groundwater maps that have been prepared as part of a local or regional groundwater investigation by consultants or the Provincial Government. For example South Prince George - ARDA Research Project (Callan, 1972) and Mayne Island (Foweraker, 1974). However, few of these reports are available to the public in published form.

A brief description of a few samples of groundwater mapping that have been completed in British Columbia are described in the following sections.

Kalamalka-Wood Lake Basin, Hydrogeological Study

A series of four 1:12,000 scale (1" = 1000') maps covering the Kalamalka-Wood Lake Basin were prepared in the early 1970's by the British Columbia Water Resources Service. These maps accompany a report detailing the results of a hydrogeological study (Le Breton, 1974) and include landforms, surficial geology, bedrock geology, faults, lineations, water wells, springs, creeks, drainage basin divides, and water table contours. Information regarding well yields, flowing artesian or spring discharge rates, static water level is not included. It is noteworthy that this information is tabulated in an accompanying report which includes three hydrogeologic cross-sections and hydrograph records from monitoring wells throughout the study area.

East Coast of Vancouver Island Groundwater Potential Maps

A report on the groundwater resources of the Coastal Lowland of eastern Vancouver Island and adjacent Gulf Islands, from Nanoose Bay to Campbell River, was prepared by the Federal Government (Halstead and Treichel, 1966). This report included well location maps with symbols indicating depth and yields and where available, some general information on aquifer characteristics. In 1985, a series of thirty two 1:20,000 scale maps of regional groundwater potential for supplying irrigation water were prepared for the east coast of Vancouver Island. These map sheets provide coverage of an area extending from Duncan to Comox, and depict locations of selected wells, developed unconsolidated aquifers, unconsolidated aquifers with development potential, low permeability unconsolidated deposits, and bedrock aquifers.

The maps appear to be based mainly on surficial geology mapping and water well log information, and do not include any other types of information.

Fraser River Basin - Unconfined Aquifers

The GSC has recently prepared a series of 23 maps entitled Unconfined Aquifers, Fraser River Basin. These are at a scale of 1:250,000, and comprise a compilation of various kinds of surficial deposits, according to their potential as aquifers.

CHAPTER 3

Groundwater Mapping in Other Jurisdictions

Examples of groundwater mapping and assessment programs in other jurisdictions have been reviewed as part of this project. The purpose of the review is to assess current policies and trends with respect to groundwater mapping and assessment. The project team has examined the groundwater mapping and assessment methodologies developed by in Canada, USA, and other countries. All maps, reports, and publications reviewed during preparation of this chapter are listed with the references and background information.

This review is a sampling of current groundwater mapping and assessment practices. Several of the agencies contacted are considered to be on the leading edge with respect to data collection, analysis, and groundwater mapping programs, as well as the use of sophisticated computer analysis tools and geographic information systems. It is noted that there are many possible permutations of groundwater information, and there is no single "best" type of groundwater map, or method of assessment of the data.

3.1 Federal Government Policy

In Canada, the Federal Government provides minimal national guidance, demonstration projects, or policy within the realm of decision making on groundwater. To date, the Federal Government's role is mainly limited to dealing with problems on federal lands, northern territories, the Yukon and Northwest Territories, and trans-boundary groundwater issues. Ownership of groundwater as a natural resource goes to the provinces, who have to date developed, independent of any national guidance, their own policies and procedures. No guidelines for groundwater have yet been developed under Green Plan initiatives.

Attempts have been made in the United States of America to enact comprehensive legislation relating to groundwater. To date, none of this legislation has been successful. The only Federal statutes relating to groundwater are the Safe Drinking Water Act Amendments, which require the establishment of wellhead protection zones for public water supply wells, and the Sole Source Aquifer Program. The latter program requires that the United States Environmental Protection Agency (USEPA) review all federally assisted ventures in areas where aquifer systems are the sole water supply for more than 50% of the population.

While it has not established broad legislation, the Government of United States is now promoting groundwater management and protection through the USEPA). This agency's overall goal with respect to groundwater is "... to prevent adverse effects to human health

and the environment and to protect the environmental integrity of the nation's ground water" (USEPA, December 1992). This is being done through development of Comprehensive State Ground Water Protection Programs (CSGWPP), which are a focal point for partnerships between the USEPA, States, local governments, and Native American Tribes. As this concept is relatively new, no examples of its implementation are available for review.

Other relevant United States legislation includes the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA or "Superfund"), and subsequent amendments, and the Superfund Amendments and Reauthorziation Act of 1986 (SARA). CERCLA creates national policy and procedures for containing and removing releases of hazardous substances, and for identifying and cleaning contaminated sites. SARA left the objectives and the basic structure of CERCLA intact, but substantially expanded the scope of hazardous waste cleanup and the size of the cleanup fund, and imposed tougher and more specific cleanup requirements.

3.2 Provincial, State and Regional Government Policy

Due to the absence of national policy and leadership in groundwater issues by federal governments, provinces and many states have independently developed their own policies on groundwater. These policies range from proactive comprehensive groundwater management and protection acts in some states and Maritime Provinces, to more reactive programs that concentrate on specific problem areas.

The approach to groundwater protection and management varies throughout the United States where responsibility for groundwater has been delegated to a combination of departments such as Health, Ecology, Geological Surveys, Energy and Natural Resources, or Environment. For example, in Washington State, the Department of Ecology is active in collection and dissemination of information on water resources including groundwater, while the Department of Health oversees the Federally mandated Wellhead Protection Program.

Legislation was passed in Washington in the mid 1980's allowing designation of "Groundwater Management Areas" at the county or planning district level. This allows local governments to work in conjunction with the state to establish plans for management and protection of groundwater resources. Typically, these programs call for zoning and land-use restrictions, ambient groundwater quality monitoring, and tracking of changes in water quality.

An example of Canadian local government involvement in groundwater management and protection is the Regional District of Waterloo, where the entire population of some 400,000 people in this region depend completely on groundwater. After the groundwater source was threatened by contamination in the mid 1980's, and the value of the

groundwater resource was apparent, the District began to become active in its management and protection. The District now employs hydrogeologists, and has put into place a sophisticated framework to monitor, manage, and protect the groundwater resource.

3.3 Trends in Management of Groundwater Resource Information

Water Well Registries

Virtually every province and state in North America maintains some sort of inventory of drillers' water well construction reports, and filing of these reports is often compulsory. In some states, the well records are tabulated at the county level, and there is no central location for marshalling state-wide information. For example, Washington State Department of Ecology collects and stores the reports in four regions; although information from many of the well logs has been entered into various databases run by the United States Geological Survey (USGS), the Department of Ecology, and/or at the local level for designated groundwater management areas. However, there is no central sources for collection, indexing, and dissemination of this information.

Many provinces in Canada, including British Columbia, Alberta, Ontario, and New Brunswick, as well as the Yukon and Northwest Territories maintain centralized registries for well construction details. Most of these provinces index the information on computer databases. In some cases there have been delays in processing new well records, and significant backlogs have developed as is the case in Ontario and British Columbia. If computerized at all, many of the well log registries are on older model computers and rapid access to information on water wells, and automation of cross-referencing with digital mapping systems is difficult if not possible. This problem is may be overcome by downloading the required information to versatile GIS platforms.

The State of Ohio maintains a very innovative computerized well log system which combines a database of well log information with a digital image of the actual well logs and other reference materials such as location maps. Information on wells can be retrieved by directly searching the database on a number of key "fields". The system is designed to allow searching and retrieval of data from remote terminals. It will also automatically transmit copies of the requested well log images to any party requesting data via a facsimile gateway. The Washington State Department of Ecology is also examining the feasibility of digitally imaging their water well records.

Development of Minimum Set of Data Elements

While no trend towards the establishment of centralized groundwater information centres has been noted, there has been much discussion about developing a common data architecture to allow effective sharing of like information between regions, levels of

government, and other groundwater users. In Canada, the Federal-Provincial Working Group on Groundwater formulated guidelines for groundwater data management in December of 1991.

In the United States, the USEPA have developed a minimum set of data elements for groundwater information. The purpose of both programs is to provide a protocol for data collection, such that the information collected can be better utilized by all interested parties.

The data architecture recommended by the Canadian and American groups is set out in Tables II and III, respectively. It is noted that the Canadian guidelines were developed as a compilation of features of all existing systems across the country, and do not represent a "minimum" set of data elements because no single agency will use all of the features recommended. Conversely, the minimum set of data elements recommended by the USEPA comprise a "core" set of data elements to be collected in all instances.

Well Identification Programs

Because many different agencies collect, store, and maintain data from wells, many jurisdictions are developing standard systems for uniquely identifying wells so that the data collected can be shared readily. These programs involve some form of well tagging, to enable personnel visiting a well site to provide a positive identification. Washington State is phasing in a well tagging program. The tag is a rigid, stainless steel plate stamped with a six-digit, alphanumeric identification number. The identification number infers no locational or other significant information.

Dissemination of General Information on Groundwater

In order to increase awareness of groundwater related issues such as policy, research, and other associated issues, some government departments have been periodically issuing information circulars, one or two page "Fact Sheets", as well as lists of publications, and data source guides.

Development of Inter-Agency Partnerships

As with many resource management programs throughout the world, it is increasingly recognized that comprehensive management and protection of resources requires an interdependency between government agencies, research institutions, and private groups. Partnerships allow for many levels of cooperations, free flow of information, and exchange of ideas. For example, in the United States where control over land-use is exclusively at the local level, many states recognize the need for state-local partnerships in groundwater data management and resource protection efforts.

3.4 Types of Groundwater Maps

A groundwater map is a graphical representation of the occurrence and distribution of groundwater within a geographical relationship. Groundwater maps provide the basis for understanding the relationship between groundwater and the geological and hydrological environment.

Hydrologic Atlases

Many hydrologic atlases have been published by agencies such as the USGS in association with state governments, universities, as well as other agencies. Hydrologic atlases generally consist of a compilation of information on surface water, climate, and groundwater. They are sometimes published as a series of sheets including maps, cross-sections, graphs, tables, and textual information, or as a bound publication with pull out maps. Hydrologic atlas maps are generally prepared at scales ranging from 1:250,000 to 1:500,000.

The level of detail included with hydrologic atlases varies depending upon factors such as physical setting, amount of information available, and level of effort. Typical data elements included on the maps may include:-

- Isohyets of annual precipitation and average temperature
- Streamflow measurement stations
- Annual moisture balance
- Geological or groundwater units
- Locations for monitoring groundwater, surface water, and climate
- Potentiometric surface and groundwater flow directions

Examples of hydrologic atlases reviewed included maps of Water Resources of the Pecantonica - Sugar River Basin in Wisconsin at a scale of 1:1,000,000 (Hindall and Skinner, 1973), Groundwater Reconnaissance of the Green River Basin in Wyoming at a scale of 1:250,000 (Welder, 1968), and Hydrogeology of Wood County, Wisconsin at a scale of 1:100,000 (Batten, 1989). Most of the hydrologic atlases prepared by the USGS are available at the University of British Columbia Maps Library and at the GSC Library in Vancouver.

Groundwater Availability Maps

Many examples of groundwater availability mapping are available. Maps reviewed include examples from Alberta, Alaska, and Ohio. Map scales range from 1:63,360 in Ohio and Alaska to 1:250,000 in Alberta. These types of maps generally depict geology and probable groundwater yield.

The Alberta groundwater-probability maps have been prepared at a scale of 1:250,000. These maps depict the probable yield of major aquifers by colour. These are then superimposed onto a textural delineation of the geology. The Alberta maps also include locations of test wells, flowing wells, springs, groundwater divides, as well as information on climate and surface water. Horizontal sections are often included; these also show geology, probable well yields, and other features. The maps also include smaller map insets at 1:1,000,000 scale which show data density and generalized information on meteorology, geology, and hydrochemistry. The hydrogeological maps indicate probable groundwater yields based on bail-tests or pumping-tests, as well as locations of flowing seismic shot holes. A brief report describing hydrogeology, geology, and climatology of the mapped area is included with each 1:250,000 scale map. An example of a 1:250,000 scale map of groundwater potential is contained in a report on the hydrogeology of the Lesser Slave Lake area by the Alberta Research Council (Vogwill, 1977).

A groundwater map of Geauga County in Ohio has been prepared at a scale of 1:63,360 (Walker, 1990). This map contains annotated well locations showing well depth, aquifer type, well yield, depth to bedrock and probable well yield based on information from existing wells and geological interpretations.

Groundwater potential mapping in the Moose-Jaw/Regina Region of Saskatchewan has been prepared at a scale of 1:250,000. This map includes information on recurring soil types, terrain and geotechnical factors, groundwater recharge, water quality, and a colour coded weighted ranking in terms of probability of developing small amounts of water for livestock watering, or up to 10 homes. The map also show areas having groundwater potential from deeper-lying regional aquifers, but do not show locations of any individual water wells.

Maps of the Potentiometric and Water Table Surface

Examples of maps showing the potentiometric and/or water table surface include 1:100,000 scale maps prepared for Wood County (Batten, 1989), and Eau Claire County (Muldoon, 1992), in Wisconsin. These maps generally display groundwater and surface water divides, shallow and/or deep groundwater flow directions, geologic materials and, in some cases, general information on the hydrologic cycle.

Groundwater Vulnerability Maps

Examples of groundwater vulnerability mapping include a 1:63,360 scale depiction of pollution potential index for Portage Country in Ohio (Angle, 1990). The pollution potential index is formulated using the DRASTIC method which accounts for depth to the water table, net recharge, aquifer media, soil media, topography/slope, impact of vadose-zone media, and hydraulic conductivity.

The National Hydrology Research Institute (NHRI) in Saskatoon, Saskatchewan has developed the Aquifer Vulnerability Index (AVI) method for groundwater protection mapping. This technique has been applied to a portion of the Saskatchewan-Alberta border region (Van Stempvoort, et. al., 1992). This study involved the compilation of stratigraphy, identification of aquifers, and calculation of a the AVI for approximately 2,000 water well logs available for this pilot map area.

Data from drillers' well logs throughout the pilot map area were entered into a simple database using a PC-based spreadsheet. As with all well records in Alberta and Saskatchewan, the location of the well is determined to the nearest quarter, or sixteenth of a section. A program was then used to calculate the Universal Transverse Mercator (UTM) coordinates for the centre of the quarter or sixteenth section in which the well is located. A 1:250,000 map with iso-AVI lines was generated using the computer program SURFER (Golden Software Inc). Additional details regarding pilot scale aquifer vulnerability mapping along the Alberta-Saskatchewan border is included with the report.

3.5 Example Applications of Geographic Information Systems for Groundwater Mapping and Assessment

Most agencies responsible for the management of resource data, including the MELP, Water Management Division now utilize Geographical Information Systems (GIS) to manipulate and integrate information, or are in the process of implementing such applications. Geographical Information Systems have been very successfully applied to groundwater mapping and assessment because of their ability to rapidly process large amounts of data, present it on thematic maps, and carry out numerous analyses and interpretations.

Within the context of groundwater mapping and assessment, regardless of the GIS used or the type of computer platform on which it is operated, the main components of the system are databases which may include well and spring locations, hydrogeologic features, groundwater chemistry, and surficial and bedrock geology. In all instances, the calibre of the mapping depends on the quality of information within the databases.

An example of GIS applications reviewed was the RAISON (Regional Analysis by Intelligent Systems on a Microcomputer) developed by the Ontario Ministry of Environment. The RAISON integrates database, spreadsheet, and GIS capabilities that are particularly suitable for applications involving point data. It also provides an environment for displaying data and analytical results in the context of local geography. Data from the RAISON can be displayed graphically in the form of charts, graphs, maps, and cross-sections. As is the case with other geographical information systems, RAISON can display the results of various analyses in colours or symbols so that similar regions can be readily identified. This is extremely useful in conducting hydrogeologic analyses.

The RAISON has been applied to Essex County in southwestern Ontario. Base map information such as country and township boundaries, lots, and shorelines were digitized from a 1:100,000 scale map. Information on surface drainage and highways was obtained from digitized maps produced by the Geological Survey of Canada. The RAISON GIS application to Essex County extends from a top-level map showing the township boundaries and major roads, to township maps showing lots and concession details. This hierarchy of maps is integrated by using icons. In this way, the user can navigate through the system and zoom in on areas of interest.

CHAPTER 4

Groundwater Information and Mapping Needs in British Columbia

Initially, the project team intended to conduct a telephone survey of members of stakeholder groups in an effort to help prioritize the needs for groundwater mapping and assessment in the British Columbia. Seventeen individuals in Vancouver and Victoria were contacted and interviewed with respect to; types of groundwater information they use, where they obtain it, types of groundwater maps that would be useful in their work, at what scale, and what type of information they thought should be included on the maps. The individuals interviewed consisted of seven groundwater/environmental consultants, five municipal engineers, two geotechnical engineers, one water-well contractor, one health inspector, and one member of the business community.

With the initiation of the telephone survey, it became apparent that, a majority of those interviewed would like to see groundwater maps prepared at regional, local, and site specific scales. Almost all respondents indicated that they would like to see information on groundwater availability, vulnerability, water-table contours, and chemistry shown on the maps, along with areal extent of aquifers and recharge and discharge areas. Once the predictability of responses was determined, the telephone survey was discontinued. It was reasoned that while nearly every surveyed individual placed a high priority on initiating programs to promote groundwater mapping and assessment, a written questionnaire would provide a more objective means for evaluating stakeholder needs. The following is a summary of the more prevalent comments provided by those interviewed:-

- Environmental work is so site specific that groundwater maps will not be very helpful, unless very large scale
- Groundwater mapping would be very helpful with planning at feasibility level
- Groundwater data would be helpful to alert health inspectors of cases where problems with regional water chemistry exist and/or large scale land developments may be of concern

It was also noted that many stakeholder organizations, such as municipalities and federal governments, subcontract most of their detailed groundwater work to consultants. Therefore, they do not require access to detailed groundwater information. However, it was indicated that they might benefit from access to groundwater maps at the planning stage, in order to minimize conflicts between land-use and aquifer vulnerability to contamination, and to target potential aquifers for water supply development.

Many of the survey respondents indicated that rapid access to information on water wells would be beneficial. Several indicated the need for computerization and on-line access to groundwater information. One consultant indicated that they would be willing to pay for such services.

4.1 STAKEHOLDER WORKSHOP

A one-day workshop on groundwater mapping and assessment was held at the Delta Pacific Resort and Conference Centre in Richmond on February 25, 1993. The purpose of the workshop was to provide a forum for individuals wishing to exchange views and express their needs on groundwater information and to aid the project team to identify potential users of groundwater mapping. A total of 105 individuals representing all three levels of government, First Nations organizations, commercial interests, the consulting community, concerned citizens, environmental interest groups, as well as other organizations were invited to the workshop. Of the 105 invitations sent out, 31 people attended; their numbers break down as follows:-

Organization	Number Attending
Federal Government	
Department of Agriculture	1
Energy Mines and Resources Canada	1
Provincial Government	
Ministry of Health	5
Ministry of Environment, Lands and Parks	2
Environmental Protection Division, MELP	1
Ministry of Agriculture, Fisheries and Food	1
Municipal Governments	2
Environmental and Special Interest Groups	2
Water Well Drilling Contractors and Trade Groups	4
Consultants	7
Real Estate Board	1
Other	4
Total	31

In addition to the 31 attendees, 13 "resource people" participated in he workshop for the purpose of facilitation, coordination, and to provide background information on groundwater related issues in Canada, British Columbia, and Washington State.

The first part of the workshop included plenary sessions to introduce the main topics. Following these sessions, participants attended one of five "workgroups" where discussion of relevant topics ensued. The results of the workgroup discussions were then summarized and presented at a final plenary session by spokespersons from each group. The workshop concluded with a panel discussion. The proceedings of the workshop were recorded on audio tape. Detailed notes documenting the workshop proceedings are included with Appendix C along with a complete listing of attendees and resource people.

Comments related to groundwater mapping and assessment received from workshop attendees covered a broad range of issues, ranging from the need for groundwater legislation to suggestions on well tagging identification schemes. Most attendees seemed to reach consensus on the following points:-

- Groundwater is an important resource with a high economic value. Increased public awareness of the need to manage and protect this resource through education will be the driving force to motivate decision makers to give it a higher priority. Groundwater maps will be an important tool in convincing decision makers to the economic value of groundwater, and the need to sustain and protect this resource.

- Groundwater legislation would go a long way in helping to motivate proper management and protection of groundwater resources.

- High quality information is required to conduct any type of reliable groundwater mapping or assessment. As maps are interpretive, they should be updated periodically to account for new data that has come available, and new interpretations.

With respect to map scales and types of information presented during workgroup discussions, there was a preference by one group toward local and site specific maps. Smaller scale maps would also be desirable in certain instances, such as assessing the potential for broad health related impacts. It was also stated that groundwater recharge areas, depth to the water table, well yield, water quality and well density, lithology, and aquifer vulnerability should be mapped.

Points noted during a final panel discussion included:-

- Groundwater mapping is only part of the information systems overview.

- It must be decided what is the purpose of a groundwater map and who it is directed towards.

- Government agencies should refrain from mapping groundwater resources and concentrate on maintaining high quality databases of groundwater related information. Users with specific needs, or their consultants, can then access the data.

4.2 QUESTIONNAIRE

A survey to identify priority topics for groundwater mapping was distributed to people attending the workshop on groundwater mapping and assessment. Twenty-two questionnaires were filled out and returned. Consultants formed the largest portion of the respondents (41%), followed by representatives of the Provincial Government (23%). A breakdown of respondents follows:

Affiliation	Number of Respondents
Consultants	9
Provincial Government	5
Federal Government	2
Municipal Government	1
Educator/academic	1
Other	4
Total	22

Questionnaire recipients were asked to rank the relative priority of topics related to groundwater mapping on a scale of 1 (low) to 5 (high). The questions were categorized into those dealing with data administration, collection, management, interpretation, and presentation. Based on the survey responses, average rankings have been calculated, and are indicated in a summary of survey results presented as Appendix D.

With only 22 responses, the survey on groundwater mapping issues cannot be considered as an accurate representation of stakeholder needs. The results do, however, provide an indication that most issues highlighted by the survey are given medium to high priority. None of the issues received an average priority ranking of less than 3.2 (medium - high). Issues receiving highest priority ranking included:-

- Creation of a centralized source of groundwater information: average ranking (AR) 4.7

- Identification of areas susceptible to groundwater pollution: AR 4.6

- Groundwater legislation and regulations: AR 4.5

- Education on groundwater issues: AR 4.3

The lowest ranked items were the need for determining costs for dissemination of groundwater data (AR 3.3), and establishment of institutional arrangements with respect to a Provincial groundwater strategy (AR 3.2).

It is noted that due to lack of public awareness on groundwater issues, low response to a survey of this type is not surprising. This is expected to change in the future as public awareness of environmentally related groundwater issues increases, and new legislation is passed. With respect to the latter, pending contaminated sites legislation will increase awareness and the need for groundwater related information. This will also be the case when groundwater legislation is passed.

4.3 SUMMARY

The results of the telephone survey, stakeholder workshop, and questionnaire indicate that the need for protection and management of groundwater is considered a very high priority by a diverse group of individuals. Participants consistently stressed that there is need for increased public awareness to manage and protect this resource as well as for groundwater legislation. A very high priority was placed on the need for assessment of aquifer vulnerability and much improved access to high quality information on groundwater resources.

Many participants also stressed that groundwater maps are interpretive in nature, and should be amended regularly to account for new information and new interpretations. Maps should not be interpretations of groundwater "frozen in time".

The quality of information and the purpose for which it is gathered is extremely important, since a map is only as good as the information from which it is derived. It was felt that regulations will help to ensure that data is collected consistently to provide information of improved quality.

CHAPTER 5

Recommended Approach to Groundwater Mapping and Assessment in British Columbia

As the economic value of groundwater and the need to protect this vital resource becomes more apparent, the profile of groundwater related issues continues to increase. It is clear that this is the case in British Columbia where many stakeholders place a very high priority on conservation, management, protection and sustainability of groundwater resources. However, it is also clear that there are many obstacles to governments or other organizations working towards a comprehensive groundwater program; these include low public awareness, political indifference, difficult access to and/or lack of quality information, and the political difficulty of mounting new programs.

Improvements in our knowledge of groundwater are related to public and political awareness, available resources, and information on other resources through information exchange. As the amount of information on groundwater increases, public awareness will grow and decision makers will follow with policies, legislation, research and funding. The increased knowledge of groundwater will thereby stimulate greater public awareness and the exchange of information will continue.

Experience in other areas has shown that when an aquifer becomes seriously depleted or contaminated, the public becomes concerned. The publicity generated from the recent awareness of real or perceived contamination of the Abbotsford aquifer in the Lower Fraser Valley is a good example. The cost of decontaminating aquifers or developing alternate water supplies is often very high. This provides a strong rationale for proper groundwater management, including monitoring and proactive measures.

5.1 PLANNING STRATEGY

In order to facilitate advancements in groundwater mapping and assessment within the context of sustainable development and integrated resource management, it is recommended that existing, and future, planning documents prepared by public agencies responsible for groundwater in British Columbia be released to the public. Reaction and comment resulting from the release of these documents will help align the overall vision and objectives of the planning strategy and minimize duplication of effort.

As an example of this type of planning strategy, the Water Resource Data Management Task Force of the Washington State Department of Ecology has recently published a document entitled "Five-Year Water Resource Data Management Plan" (July 1992). In essence, this document sets out a vision for the future which sets out how the vision will be achieved. Linking data clients to decentralized data sources using a common data

sharing infrastructure is the key strategy recommended by the Task Force. The five-year plan sets out a series of projects designed toward the following objectives:-

- Development of a data framework for integrating all data regarding water resources, including both surface water and groundwater.

- Expand the framework with data to produce a library.

- Develop water resource relationships such as those between groundwater and streamflow.

While a plan of this scope and size is perhaps not appropriate for British Columbia, it does provide an example of a well thought out and comprehensive approach to the problems facing water resource management.

Detailed review of the long term policy and plans for water resources data management by responsible agencies in British Columbia is beyond the scope and mandate of this work. However, the following sections include recommendations that would likely become part of any such strategies, were they to be developed. These recommendations are based on feedback from stakeholders, the extensive experience of the project team in groundwater assessment in British Columbia, and current trends in groundwater mapping and assessment.

5.2 INSTITUTIONAL FRAMEWORK

As indicated previously, comprehensive management, protection, and conservation of groundwater requires multi-agency cooperation and interdependence. As land-use and zoning are normally controlled at the local level, it is believed that local governments must be encouraged to accept a significant role in the management and protection of the groundwater resource within their areas. Where possible, this should also involve citizen participation, as most successful mapping and groundwater protection programs carried out in other jurisdictions, have incorporated the concept of "stewardship" in managing the resource for common good. The current trend is for local governments to have up-to-date cadastral, zoning, demographic and related information incorporated into their databases, which are increasingly GIS compatible.

The Township of Langley and other local governments in the Fraser Valley are in the process of developing inventories of factors affecting environmental sensitivity of their lands and utilizing GIS to integrate such information, and plan to use it in the decision making process. The MOH is considering several options for accessing computerized data on septic tanks in the rural areas of the Lower Fraser Valley, and much of the information they require such as street address, legal description, size of house is already in the municipal database.

Provincial government agencies should encourage local governments, such as municipalities and regional districts, to perform information gathering and verification on their behalf. For example, municipal governments or regional districts could be given the status of Government Agent for the collection, verification, distribution and updating data on existing water wells, septic tanks, and relevant information. They could then transfer all collected data back to the Provincial Government, who could disseminate the information. This conceptual data collection and management plan would have the Provincial Government with support from the Federal Government setting standards, providing leadership on policy development, and co-funding programs being carried out by local governments with assistance from consulting groundwater specialists. When in place, this information would simplify the groundwater mapping and assessment process.

5.3 MAP SCALE

While no clear consensus on desired map scales was reached during the groundwater mapping workshop, it was clear that many participants favoured maps at a scale of 1:50,000 to 1:20,000 to provide site specific information. Smaller scale thematic maps at a scale of 1:250,000 were not considered to be very helpful in view of the nature of many groundwater regions in British Columbia. In contrast to a region such as Alberta, where data on groundwater are sufficiently distributed throughout the province, British Columbia's groundwater users are typically clustered around settlements and/or valley bottoms and water abstraction rates are very intense in these areas. If mapped at a small scale, information on much of the area shown on the maps would be of limited significance in terms of groundwater. Appropriate scales for groundwater mapping are discussed in more detail in Volume II, Criteria and Guidelines.

5.4 MINIMUM SET OF DATA ELEMENTS (MSDE)

A consensus regarding a minimum set of data elements for groundwater mapping and assessment was not reached from the stakeholder survey or workshop. However, much effort has been expended on developing MSDE through consultative means both in Canada by the Federal-Provincial Working Group on Groundwater (December 1991), and by the USEPA. The project team has reviewed MSDE developed for other jurisdictions, and together with their own experience with groundwater related studies within Canada and abroad, have developed a proposed minimum set of data elements for use in British Columbia.

The purpose of the proposed minimum set of data elements is to:-

- Provide a means for rapid identification and retrieval of groundwater data.
- Facilitate the exchange of groundwater data between government agencies and the private sector.

- Reduce the cost of software development for applications such as GIS and mathematical groundwater modelling.

- Facilitate regional groundwater surveys and assessments.

The recommended MSDE is made up of the "core" data requirements that should be collected for, and transmitted between, those who capture, process, map, and assess groundwater information.

The MSDE does not address issues involved in the implementation of computer systems for management of the data or selection of the appropriate software. Rowe and Dulaney (1991) provide a comprehensive overview of these activities.

Recommended Minimum Set of Data Elements

The recommended MSDE for groundwater mapping and assessment in British Columbia are set out in Table IV. In order to save storage space and improve the efficiency of the database, the MSDE are subdivided into the following separate ***entity files***:-

- Basic site information on borehole/spring attributes (one record per borehole/spring site).

- Lithology information (multiple records per site).

- Water quality information (multiple records per site).

- Water level, yield, field chemistry, etc. (multiple records per site).

- Aquifer pumping test information (multiple records per site).

Each ***entity file*** is linked to the other files by a unique well/spring identification number as highlighted in Table IV.

Many of the recommended data elements are presently included in the CGDS database maintained by the MELP Groundwater Section. Recommended additions to this list of fields include:-

- Designation of unique and non-intelligent well or spring identifiers.

- UTM coordinates of boreholes and springs.

- Accuracy of coordinates.

- A detailed description of well location (e.g. "inside pumphouse at ...").
- What the extracted water is used for (e.g. domestic, process, mining, aquaculture, etc.).
- Cross reference numbers for pump test report(s).
- Present status of well (non-active/active/abandoned/part of monitoring network/unknown).
- Repeat measurements of water level, field chemistry, and flow stored in a separate database, relationally linked to the basic site information database.
- Name of agency/individual responsible for sampling groundwater.
- Purpose for sampling groundwater.
- Sampling method.

Collection of MSDE for New Wells

Implementation of a MSDE policy for new wells is relatively straightforward, in that existing well log and water chemistry submission forms can be modified to allow space for the required information. Difficulties will be encountered with respect to reliable determination of site coordinates and correct identification of boreholes or springs when sampled for chemical analysis at a later date.

In terms of determining well coordinates, use of Global Positioning Systems (GPS) is gaining popularity with many agencies. This relatively low-cost method would require a groundwater technician or well driller to use a GPS device to determine the coordinates and elevation of the wellhead. Other methods still in use include estimating the coordinates from 1:20,000 or 1:50,000 scale maps or, referencing to a known point using surveying methods. Estimating from a map can be problematic due to error, and though accurate, surveying is costly.

Federal, Provincial, and Municipal Governments, as well as private agencies, collect and chemically analyze samples of groundwater for a multitude of purposes. Aside from being of some use to the agency collecting the sample, the results from such analyses will only be useful to others if they were aware of the data's existence. Therefore, in the future, information accompanying groundwater samples should include the unique well or spring identifier indicating the source of the sample. This unique identification number must be known to the individual gathering the groundwater sample. Other agencies have

solved this need for positive well identification by attaching a unique well identification tag to known wells showing a non-intelligent well number. It is recommended that a well tagging program be initiated in British Columbia. Tags would be affixed at the time the wells are field-verified and location coordinates determined.

Updating Existing Well Records to Include MSDE

Approximately 80,000 water wells in the Province are included in the CGDS database maintained by the Groundwater Section of the Ministry of Environment, Lands and Parks. In addition, there are some 10,000 logs for wells which have been drilled but have not been field verified or added to the database. Determination of UTM coordinates for these wells can be accomplished through re-verification in the field or by estimation from map coordinates. The method used would depend on the resources of the organization locating the sites, the relative importance of data obtained from the well or spring and the number of other sites in the area. In some instances, re-verification in the field may be justified. For example, a municipality may wish to field survey all well sites within its jurisdiction as part of a detailed groundwater management plan. At that time, the wells could be assigned a well identification tag. Alternatively, only those wells meeting certain criteria such as depth, quality of information, etc. could be field located. It should be noted that if UTM coordinates are accurately known, wellhead elevations can be approximated from digitized topographical maps by many GIS systems including the Government of British Columbia TRIM maps.

It is imperative that new and unprocessed existing wells be field verified and entered into the CGDS or its descendent. This currently includes at least 10,000 unprocessed well logs that have accumulated over the past five years in the regional offices of MELP.

Consistency in Expressing Data

All data stored in the databases should consistently use the same unit of measurement. If data are not expressed in consistent units, conversion programs will be required to make the data uniform. Such programs may be complex and may fail to convert all data resulting in errors.

5.5 CENTRALIZED SOURCE FOR GROUNDWATER INFORMATION

Based on the results of the Seminar on Groundwater Mapping and Assessment, and telephone and written surveys, it is clear that stakeholders in British Columbia place a high priority on improving access to high quality information on groundwater. Many people indicated a preference for a centralized source of information.

The Groundwater Section of MELP presently maintains much of the information on groundwater in British Columbia existing in the public domain. The following sections set

out a series of recommendations for improving the accessibility and usefulness of the information presently available, as well as augmentation with information from other sources. These recommendations are based on the assumption that the Groundwater Section will continue in its role as the clearinghouse for groundwater information in British Columbia.

Computerization of Well Information

Computerized groundwater information is presently maintained on several "platforms" by the Groundwater Section of MELP. For example, the master CGDS database for information on water wells resides on a VAX system, and "throw away" copies are available as an EXCEL spreadsheet on a PC/MAC system. Other data files such as the SEAM chemistry database, which include groundwater data, are also based on a VAX system, but in a completely separate area with no relational capabilities between the databases.

It is understood that the Ministry of Environment will soon adopt a single generation of database management system for working with groundwater and related information. The master CGDS will run on a UNIX computer system which is fully compatible with GIS applications. The data will be manipulated and stored using ORACLE database management software. As with other database management software products such as SYBASE and XBASE, ORACLE can be operated on more than one type of computer system including PC-DOS, UNIX, and MAC. This facilitates exchange of data between many computer types and organizations.

It is recommended that consideration be given to downloading the groundwater chemistry data in the SEAM database to the computer system used to manipulate water well information thus, allowing for the establishment of a groundwater chemistry database that will permit relational cross-referencing with the water well database. It is recognized that this will be a large effort requiring all groundwater data in SEAM to be cross-referenced to unique well identification numbers in the CGDS. This will involve many person hours of manual cross-checking.

Data from other institutional groundwater analysis programs should be collected and stored in accordance with the recommended minimum set of data elements. Whether this data is combined with the Groundwater Section's chemistry database or stored separately, it will be possible to readily access the information.

Although information from water well construction reports is tabulated within the database, the well log is often an important source of information not included with the MSDE. A rapid means for retrieving this information should be available. One potentially rapid and cost effective method would be to optically image well construction reports for on-line storage using regularly updated CD-ROM. The State of Ohio operates a system that

automatically transmits an image of the well log to parties requesting data via a fax gateway. It is recommended that the province examine the feasibility of implementing a similar well log retrieval system, or downloading of electronic files which can be reviewed or printed "off line".

Electronic Access to Groundwater Information

The Groundwater Section is currently experimenting with electronic access to groundwater information via a connection to the INTERNET computer network. While only a small amount of information is presently available from the Groundwater Section through this medium, there is great potential for rapid access to and exchange of information on groundwater.

In terms of user needs, the most important requirement is access to water-well construction records. However, because it is not possible to accurately determine the location of a well from the information provided by the BCGS well number, the information will be of limited use until such time the CGDS is updated to conform with the recommended MSDE.

Consideration should be given to offering access to groundwater information via high-speed modem connection to a Bulletin Board System operated by the Groundwater Section. This would be more convenient to most users of groundwater information such as drilling contractors, real estate agents, and others who do not have access to the INTERNET or knowledge on its use. It is noted that Environment Canada operates a computer bulletin board system for dissemination of hydrometric information from the HYDAT system.

Clearinghouse System for Groundwater Information

Much of the information on groundwater resources of British Columbia is contained in reports and memos by the Groundwater Section and private consultants. Many of these reports are in the public domain and are present in the Groundwater Section's extensive library.

It is recommended that consideration be given to transferring the contents of the NTS Index into a more user-friendly and publicly accessible format, and augmenting the index as much as possible with references to reports held by other agencies such as Community Water Supply Section of MELP, Environment Canada, Geological Survey of Canada, Indian and Northern Affairs Canada, municipalities and regional districts, and consultants. Wherever possible, efforts taken in the past to obtain copies of consultant's reports should be continued, even if the reports are confidential. If the index indicates the existence of a report, groundwater information users learn who the holder of the report is, and petition them for copies.

Most government departments and many consultants have catalogued or soon will be cataloguing their holdings. It would be possible to obtain from many such groups listings of relevant reports and studies underway in a readily compatible digital format.

Consideration should also be given to publishing a source book for groundwater information in British Columbia This could be similar to the Surficial Geology Map Index of British Columbia published by the Ministry of Energy, Mines and Petroleum Resources (Bobrowsky, et al, 1992).

Depositories for Groundwater Information

In addition to establishing a clearinghouse system for information relating to groundwater, consideration should also be given to issuing copies of appropriate documents relating to public and university libraries. This will enhance the potential for public exposure to such information and provide a road map to other repositories of information.

Outreach Programs

In order to raise awareness on groundwater issues, and provide a forum for continuing feedback and discussion from stakeholders, it is recommended that the MELP Groundwater Section, Environment Canada and/or the GSC, consider combining efforts to regularly issue brief information circulars. These would include discussions regarding research and investigations underway in the province, editorial comments and those sent in by stakeholders, and practical tips on items such as accessing groundwater information. Many groundwater agencies in other provinces and states prepare information sheets on groundwater issues. For example, the State of Ohio's Division of Water, Department of Natural Resources, has issued several such fact sheets. Examples of topics covered include groundwater level monitoring in Ohio, groundwater resource mapping, services of the groundwater resources section in Ohio, and methodology of evaluating groundwater pollution potential. Press releases and other forms of media could be employed to inform the general public as well.

5.6 MAPPING AND CHARACTERIZATION OF AQUIFERS

As part of the groundwater mapping and assessment review, criteria and guidelines have been developed as presented in Volume II. The criteria, general approach, and guidelines for application were developed to encourage a consistent approach to groundwater mapping and assessment in British Columbia. Potential users of the criteria and guidelines include provincial and federal agencies, local governments, and hydrogeological and engineering consultants. The guidelines include sections on the fundamental philosophy of mapping and assessment, data requirements, application of mapping criteria, and preliminary and detailed groundwater assessment procedures.

QA/QC for Data Processing and Mapping

Quality control and quality assurance protocols for data gathering, processing, and graphical output of groundwater data are a very important aspect of groundwater mapping and assessment. It is recommended that QA/QC protocols be established to ensure quality information and that such checks be carried out by suitably qualified personnel. Computerized checking of certain aspects of data can be incorporated through expert system interactive programs that would flag unusual or obviously incorrect data entries.

As indicated in Table IV, the recommended minimum set of data elements includes an indication of the degree of confidence assigned to certain key fields such as coordinates and elevation. If sufficiently important, these codes could be used for planning of data quality up-grades.

Minimum Qualifications and Training of Personnel

Groundwater mapping and assessment requires a multi-disciplinary approach. The quality assurance and quality control for data collection, processing and all major groundwater mapping programs should be coordinated by an experienced professional with at least five years relevant experience. This individual should be a member of the Association of Professional Engineers and Geoscientists of British Columbia. The project coordinator should be assisted by more junior hydrogeologists, technicians and computer applications specialists.

Formal training for geologists and geological engineers is currently available from a number of tertiary institutions, such as the University of British Columbia. Nearly all of these institutions offer some introductory courses in groundwater hydrology at an undergraduate level and more advanced courses in groundwater hydraulics, hydrogeology, low temperature geochemistry, computer modelling and related subjects at the post-graduate level. Most senior hydrogeologists in British Columbia have bachelor's degrees in either geology, engineering geology or civil engineering, and have subsequently gained practical on-the-job training under the direction of an experienced professional. Some have also had post-graduate training in hydrogeology.

At present, there are only a limited number of institutes and colleges which offer training in the field of groundwater at the technical level in Canada. British Columbia Institute of Technology (BCIT) offers courses in geology, and plans to initiate an advanced diploma course in applied waste management in civil engineering, in which courses in groundwater modelling and related environmental issues will be discussed. The Northern Alberta Institute of Technology (NAIT), based in Edmonton, offers a two year diploma program in groundwater technology.

A few years ago, the British Columbia Ground Water Association established a journeyman driller apprenticeship program for operators of water-well drilling equipment. While this program is not mandatory in this Province, many drillers have taken courses and are now certified water well contractors. As water well drilling contractors are responsible for interpretation of much of the lithological information presented in the water well construction reports, it is logical that they receive some training in identification of rock types and completion of well logs. It is recommended that in the future, water well drillers be certified before being permitted to drill boreholes and construct water wells in the Province. This training, and ongoing follow-up, would become an integral part of the QA/QC program for groundwater data collection. Once a need has been established for better training of technicians and water well drilling contractors, many technical institutes will likely follow through with appropriate courses.

CHAPTER 6

Example of Groundwater Mapping

A 1:20,000 scale map has been prepared to demonstrate the use of a computer database and automated drafting system for integrating and graphically depicting groundwater related information as shown in Figure 1. The map shows creeks, roads, surficial geology, well locations, and other significant features for the Aldergrove area in the Fraser Valley. In addition, a horizontal cross section has been produced as in Figure 2.

All information on roads and drainage depicted on the map was obtained from the electronic 1:20,000 scale TRIM map file for 92G.008 map area. It is noteworthy that discrepancies between this map and larger scale water-well location maps have been noted. One noticeable error with the TRIM map is the location of 272nd Street, which is shown some 100 m too far to the west.

Surficial geology was digitized from a 1:50,000 scale map and superimposed on the 1:20,000 scale map. Well locations were digitized into UTM coordinates and stored in dBase IV format.

It is noted that there is some disagreement between actual well locations and those depicted on the map. The most significant source of error is likely discrepancies between the maps from which water-well locations were digitized and the TRIM map. Since Figure 1 was prepared for demonstration purposes only, field verification of well location was not carried out.

It is noteworthy that many other types of information or interpretations could be shown on the map. For example, the map could include such items as land use, zoning, soils, aquifer boundaries, aquifer vulnerability, critical recharge areas. The decision as to what type of information required depends on the needs of the map user.

CHAPTER 7

Conclusions and Recommendations

Comments obtained from those concerned with the development, use, management and protection of the groundwater resource in British Columbia clearly indicates the requirement for a comprehensive management and protection strategy. However, the ability to make informed decisions is hampered by a lack of quality information. It is essential that priority be given to ***establishing*** a core of quality, up-to-date, and readily accessible groundwater information. This must be accomplished by consolidating and automating water-well reports, followed by the collection and sharing of groundwater data. Once this has been completed, detailed mapping and characterization of aquifers could proceed. Based on these conclusions, the following recommendations are set out in decreasing priority:-

- A minimum set of data elements (MSDE) be established for the collection and sharing of groundwater information. The MSDE shown in Table IV will be comprised of ***core*** groundwater information which in all cases should consist of the minimum amount of information collected or communicated. All water-well records on-file with the Groundwater Division should be checked to ensure they include the MSDE. Of utmost importance in this regard, water-well records should be updated to include location coordinates and elevations to facilitate spatial analysis and incorporation into computerized Geographic Information Systems (GIS). Existing groundwater chemistry information will be updated to conform to the MSDE.

- Access to groundwater information be improved through establishment of a central repository with data accessible by computer modem. In this respect, consideration should be given to publishing a groundwater information source book .

- The Provincial Government set standards for groundwater mapping and data collection with support from the Federal Government. Local governments accept a significant role in the management and protection of groundwater resources and carry out much of the required groundwater data collection.

- Implement a well-tagging program in selected areas of British Columbia. By including the appropriate unique well tag number with each measurement, sample, or groundwater observation, data can be readily stored, retrieved, and integrated with other computer systems.

- Implement a mandatory water well drillers' certification program to assure the quality of groundwater-related data collected by the drillers.

Efforts aimed at raising public awareness on groundwater issues should be pursued. This could be accomplished through issuing press releases and distributing groundwater information to the public in the form of information circulars or fact-sheets.

Although many examples of groundwater information from British Columbia and elsewhere have been reviewed, consensus with respect to appropriate map scales or attributes that should be shown on groundwater maps has not been reached. Groundwater information and mapping needs vary from user to user and will continue to change with time and rising awareness on groundwater related issues. It is anticipated that the Criteria and Guidelines, set out in Volume II, will facilitate a consistent approach to groundwater mapping and assessment in British Columbia.

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TABLES

TABLE I
SUMMARY OF FIELDS IN COMPUTERIZED GROUNDWATER DATA SYSTEM (CGDS), GROUNDWATER SECTION, MOELP

BCGS map area well no.
Old well coordinates and well no.
Legal location
Owner name
Owner address
Island name
UTM coordinates and elevation
Watershed code
Drilling contractor name and certificate number
Well construction date
Drilling method
Ground elevation
Well diameter
Total well depth
Depth to water
Artesian flow
Estimated well yield
Depth to bedrock
Screened interval
Slot size
Aquifer lithology
Well use
Water utility?
Pump test data run?
Groundwater report available?
Sieve analysis run?
Laboratorty analysis of water chemistry run?
Field chemistry measurements taken?
SEAM chemistry site no.
Comments
Lithology

? indicates a logical field (eg. yes or no)

TABLE II
SUMMARY OF DATA FIELDS RECOMMENDED BY FEDERAL–PROVINCIAL WORKING GROUP ON GROUNDWATER (1991)

SITE INFORMATION

- Well Identification
- Location UTM
- Location Lat/Long
- Location Accuracy
- Drainage Basin
- Map Series
- Aquifer
- Hydrostratigraphic Unit
- Physiographical Division
- Elevation
- Elevation Accuracy
- Well Site Description
- Well Status
- Comments re Status
- Purpose of Well
- Water Use
- Data Provided by/fields
- Contractor
- Comments

WELL CONSTRUCTION DETAILS

- Well Identification
- Date Well Completed
- Uncased Hole Diameter
  - from (metres
  - to (metres)
- Depth Completed Well
- Well Head Completion
- Drilling Method
- Casing
  - from
  - to
- Comments

FORMATION LOGGING

- Well Identification
- Grain Size Curve
- Effective Diameter
- Coefficient of Uniformity
- Borehole Log
  - Type
  - From
  - To
- Material
  - From
  - To
- Natural Gas Detected
- Comments

WATER LEVELS, WELL PERFORMANCE, AQUIFER YIELD

- Well Identification
- Artesian Head
- Water Found (depth)
- Water Bearing Fractures (depth)
- Static Level (pre)
- Drawdown
- Static Level (post)
- Method of Measurement
- Pump Test
- Test Date
- Start Time
- type of Drilling Fluid
- Drill Bit Diameter
- Apron Width
- Casing Dimensions
  - Nominal pipe diameter
  - Wall thickness
  - From
  - To
- Casing Design
  - Material
  - Coatings
  - Form
- Open Hole
  - Diameter
  - From
  - To
- Screen Dimensions
  - Nominal screen diameter
  - From
  - To
- Screen Make
- Screen Model/Number
- Screen Design
  - Material
  - Coatings
  - Form
- Screen Slot/Hole Size
- Slot/Perforation Method
- Screen Attachment Method
- Screen Fitting (Bottom)
- Screen Placement Method
- Filtration Medium
- Filter Pack/Formation Stabilizer
  - Material
  - From
  - To
  - Grain Size
- Filter Placement Method (cont ...)

WATER LEVELS, WELL PERFORMANCE, AQUIFER YIELD (cont)

- Development Duration
- Development Method
- Annular Sealing
  - Material
  - From
  - To
- Grouting Placement Method
- Seal Components
  - Component
  - Depth
- Plugging
  - Material
  - From
  - To
- Casing Left After Plugging
  - From
  - To
- Test Method
- Type of Test
- Test Duration
- Pump Intake During Test
- Method of Measuring Discharge
- Accuracy of Discharge Measurement
- Derived Parameters
  - Hydraulic Conductivity
  - Transmissivity
  - Storativity
  - Specific Capacity
- Observation Well ID
- Operating Recommendations
  - Pumping Rate
  - Pump Intake Depth
- Well–Owner Requirements
- Annual Allocation
- Annual Use
- Peak Withdrawal Rate (Approved)
- Flowing Conditions
  - Flowing
  - Flow
- Spring Flow
- Boundary Conditions
- Pump Type Installed
- Pump Capacity
- Pump Intake Depth
- Pump Location
- Date Installed
- Make
- Model
- Pump Riser Pipe Diameter
- Comments

PUMP TESTING INFORMATION (PUMPED WELL)

- Well Identification
- Elapsed Time
- Pumping Rate During Test
- Water Level While Pumping
- Water Level While Recovering
- Comments

WATER QUALITY SAMPLING INFORMATION

- Well Identification
- Agency Code
- Sample Purpose
- Sample Number
- Sample Date
- Sample Time
- Time Zone
- Comments

WATER QUALITY MEASUREMENTS

- Well Identification
- Sample Number
- Sample Date
- Sample Time
- Lab Identifier
- Variable Code
- Method Code
- Detection Limit
- Pretreatment Code
- Value Type Code
- Flag
- Value
- Unit Code

TABLE III
MINIMUM SET OF DATA ELEMENTS RECOMMENDED BY USEPA (1988 & 1992)

GEOGRAPHIC DESCRIPTOR GROUP

- Latitude
- Longitude
- Method of Measure for Latitude/Longitude
- Confidence Code for Latitude/Longitude
- Altitude
- Method of Measure for Altitude
- Confidence Code for Altitude
- State FIPS Code
- County FIPS Code
- Township, Range, Section, Quarter

WELL/SPRING DESCRIPTOR GROUP

- Unique Site Identifier
- Legal Contact: Name, Address, Telephone
- Date Well was Completed
- Construction Method
- Depth of Hole
- Depth to Top of Interval
- Depth to Bottom of Interval
- Depth to Top of Casing
- Depth to Bottom of Casing
- Type of Log
- Source of Log Data
- Location of Well Log
- Status of Well or Spring
- Use of Well or Spring
- Aquifer Code
- Hydrologic Unit
- Casing Material
- Depth of Well
- Source Agency

SAMPLE/ANALYSIS DESCRIPTOR GROUP

- Unique Sample Identification Number
- Purpose of Sample
- Confidence Factor
- Date of Sample
- Time of Sample
- Method of Taking Sample
- Type of Sample
- Depth to Water
- Date Water Level Measured
- Method of Water Level Measurement
- Source of Water Level Data
- Laboratory Identification Number
- Method of Analysis
- Date of Analysis
- Type of Analysis
- Parameter Measured
- Concentration/Value
- Measurement Quantification
- Confidence Code for Parameter Analyzed
- Conductivity
- pH
- Suspected Origin of constituent

HYDROGEOLOGIC DESCRIPTOR GROUP

- Type of Hydrogeologic Event (A hydrogeologic study is an example of an hydrogeologic event)
- Abstract of Hydrogeologic Event
- Location of Hydrogeologic Reports

TABLE IV

SUMMARY OF RECOMMENDED MINIMUM SET OF DATA ELEMENTS FOR GROUNDWATER MAPPING AND ASSESSMENT IN BRITISH COLUMBIA

FILE #1 – BASIC SITE INFORMATION

IDENTIFICATION (+)

UNIQUE WELL/SPRING I.D. NO.

* BCGS Map Area No. and Well No.
* Owner Name
Well/Spring/Piezometer Description Code

Location and Elevation:

* Legal Location
* Street Address
* City/Town
Postal Code
Verbal Description of Well/Spring Location
UTM Easting Coordinate
UTM Northing Coordinate
Method of Determining Coordinates
Accuracy of Coordinate Measurement
Collar Elevation
Method of Determining Elevation

General Info:

* Driller Number or Name
* Construction Date
* Construction Method
Present Status
* SEAM Site No. Code
* Purpose of Well/Borehole

Technical Details:

* Construction Method
* Total Depth
* Depth to Bedrock
* Diameter
Type of Surface Seal
Number of Screened Intervals
* Screened Intervals
* Screen slot size(s)
* Description of Completion Interval
Lithology Logged By
* Estimated Yield
Method of Yield Estimation

QA/QC:

Information Verified By
Date Verified
* Comments

FILE #2 – LITHOLOGY INFORMATION

UNIQUE WELL/SPRING I.D. NO.

* Depth
* Materials description

FILE #3 – WATER QUALITY INFORMATION

UNIQUE WELL/SPRING I.D. NO.

Agency and Indivual Responsible for Sampling
Purpose of Sample
Date Sampled
Laboratory
Laboratory Reference No.
Sampling Method
Constituent or Parameter Measured
Concentration/Value
Comments

FILE #3 – WATER LEVELS, YIELD, FIELD CHEMISTRY

UNIQUE WELL/SPRING I.D. NO.

Agency and Indivual Responsible for Sampling
* Date Observed
* Depth to Water Level
Spring/Artesian Flow
Field pH
Field Conductivity
Water Temp
Comments

FILE #4 – AQUIFER PUMPING TEST INFORMATION

UNIQUE WELL/SPRING I.D. NO.

Agency and Indivual Responsible for Running Pumping Test
Test Duration
Maximum Pumping Rate During Test
Reference No. for Pumping Test Report
Comments

Notes:

* indicates fields already included in CGDS data base managed by Groundwater Section, MOELP.

\+ Includes boreholes not used for abstraction of groundwater (ie. exploratory holes, holes completed with piezometers).

FIGURES

APPENDIX A

Glossary

APPENDIX A

Glossary

Aquifer — A geologic formation, group of formations or part of a formation, that contains sufficient saturated permeable material to yield significant quantities of water to wells, boreholes and springs. Several types of aquifers can exist:-

- Confined aquifer (artesian) - contains water under sufficient pressure that water levels in wells tapping it rise above the bottom of the confining bed.
- Unconfined aquifer - the water table is located within the formation.

Artesian — Refers to groundwater under sufficient hydrostatic head to rise above the aquifer containing it.

BCGS — British Columbia Geographic System

CGDS — Computerized Groundwater Data System

Groundwater — Subsurface water occurring below the water table in fully saturated geologic materials and formations.

MELP — BC Ministry of Environment, Lands and Parks

MSDE — Minimum set of data elements

PAEL — Piteau Associates Engineering Ltd.

Recharge Area — An area in which the hydraulic gradient has a downward component. infiltration moves downward in the deeper parts of an aquifer in a recharge area.

RIC — Resources Inventory Committee

Spring — A place where water flows from a rock or soil onto the land or into a body of water, without the agency of man being involved.

TGC	Turner Groundwater Consultants
Transmissivity (T)	Rate of horizontal water flow in cubic metres per second through a vertical strip of aquifer one metre wide, and extending the full saturated thickness of the aquifer, under a hydraulic gradient of one metre per metre at the prevailing water temperature (m^2/s).
Water Table	Surface along which the fluid pressure is atmospheric, and below which the fluid pressure is greater than atmospheric (eg. top of saturated zone).
Well	Shaft sunk in ground and lined with stone or other protection for obtaining subterranean fluids.

APPENDIX B

Summary of Sources of Groundwater and Related Data

APPENDIX B

TABLE B1 – SUMMARY OF SOURCES OF DATA ON WELLS, CHEMISTRY WATER LEVELS, AND GROUNDWATER REPORTS

BOREHOLE INFORMATION	
DESCRIPTION	AGENCY
WATER WELLS The MOE Groundwater Section is a central source for the following types of information: – Computerized index of water wells (CGDS) – possible to download data onto diskette, or via electronic mail – Water well location maps – Water well paper files which include some chemistry data	MOELP – Groundwater Section 4th Floor, 765 Broughton Street Victoria, B.C., 387–1115
OIL & GAS WELLS EMPR Maintain a file of all oil and gas wells drilled in the province. Bulk of the information is for the Peace River area, though there are some sites in the Fraser Valley, Gulf Islands, Queen Charlotte Islands, Nanaimo, Fernie Basin, and Cariboo Chilcotin. These lgos may be of limited usefulness, as overburden is generaly not well differentiated or described on logs. Most holes have downhole geophysical information available, though usually in bedrock only.	EMPR – Well Information Services Room 437, 617 Government Street Victoria, B.C., 356–2743
GEOTECHNIAL TEST HOLES Geotechnical boreholes provide useful information for groundwater mapping. However, there is no central source for this type of information. Ministry of Transport and Highways have extensive holdings of geotechnical information.	
GROUNDWATER CHEMISTRY	
DESCRIPTION	AGENCY
SEAM DATABASE Most groundwater chemistry data collected by the province is included in the SEAM DataBase. This includes analyses of groundwater samples obtained by MOE personnel as part of regional or site specific investigations. Groundwatwer data does not include an identifier to indicate the cooresponding well log record on file with the Groundwater Section so it is diffucult to relate data to a particular aquifer at a certain location. The SEAM database includes data from the Federal NAQUADAT database; however, as with other data on SEAM, cross referencing to well logs is difficult.	MOELP Laboratory Services and Systems Management Section 777 Broughton Street Victoria, B.C., 387–9962
WATER QUALITY CHECK PROGRAM The Water Quality Check Program provides subsidized laboratory analyses for private water users province wide, and many thousands of analyses are available as paper files. Water quality analyses include tests for selected chemical parameters, but do not include checks for sodium, chloride, carbonate, bicarbonate, and sulfate – all of which are necessary data elements for understanding the chemical evolution of groundwater. Chemisty data do not include a well identifier to cross reference to well log – therefore it is very difficult to determine the location or depth from which a groundwater analysis originates. Also, as water samples not obtained directly from source, may not be representative of true groundwater quality.	MOELP – Groundwater Section as above
MINSTRY OF HEALTH – DRINKING WATER QUALITY The MOH maintains a database of routine water quality monitoring data for private water utilities. However, data does not includes a water well identifier so it is difficult to determine origin of sample. Analyses include tests for basic potability, and in some cases THM's. Data is downloadable by diskette.	MOH – Public Health Protection Lower Main – 1520 Blanshard St. Victoria, B.C., 387–2696

APPENDIX B

TABLE B1 – SUMMARY OF SOURCES OF DATA ON WELLS, CHEMISTRY WATER LEVELS, AND GROUNDWATER REPORTS

OTHER Groundwater chemistry data is also available for specific groundwater related studies conducted throughout the province by the MOE Groundwater Section, private consultants, and Environment Canada.	
GROUNDWATER LEVEL INFORMATION	
DESCRIPTION	AGENCY
OBSERVATION WELL NETWORK The Groundwater Section maintains some 149 active groundwater observation stations, 82 of these have charts recorders and the others are manual. Charts are changed monthly. Charts themselves are not in digital format though the monthly water level readings are.	MOELP – Groundwater Section as above
CGDS Lists water levels measured by driller at time well was drilled – accuracy is problematic.	MOE – Groundwater Section, as above
OTHER Groundwater level data is also available for specific groundwater related studies conducted throughout the province by the MOE Groundwater Section, private consultants, and Environment Canada. Possible sources of such data are indicated in the section on groundwater studies.	
REPORTS ON GROUNDWATER CONDITIONS	
DESCRIPTION	AGENCY
NTS DATABASE The groundwater division maintains a computer searchable listing of reports for groundwater studies carried out in the province. This includes Ambient Water Quality Studies, consultants reports, and specific studies conducted by the Groundwater Section. This NTS database does not include citations to reports regarding private water utilities which are confidential. All reports in database are referenced to NTS grid.	MOELP – Groundwater Section 4th Floor, 765 Broughton Street Victoria, B.C., 387–1115
COMMUNITY WATER SUPPLY UTILITIES Hundreds of reports prepared by groundwater consultants for community water supplies are confidential, and can only be released with permission from the utility in question. While this has the potential to be a valuable source of groundwater information, there is no cataloque of reports on file, and enquiries must be on a site specific basis.	MOELP – Groundwater Section, or MOELP – Community Water Supply Section 3rd Floor – 765 Broughton Victoria, B.C., 387–6336
WATER UTILITY REPORTS – INDIAN RESERVES Several Indian Reserves throughout the province depend on groundwater supplies and many of these have had detailed investigations carried out by consultants. The federal government maintains a database of report titles on file, it is possible to georeference locations where groundwater studies have been carried out.	DIAND – Technical Services, PWC #680 – 1550 Alberni Street Vancouver, B.C., 666–5147
REGIONAL WATER QUALITY STUDIES – FEDERAL GOVERNMENT With respect to groundwater, Enviroment Canada's mandate is mainly to focus on trans–boundary aquifers. Studies have been conducted and are underway in Abbotsford, Hoppington, Brookswood, Keremeos, Osoyoos, and Grand Forks. Data for these areas is available in digital format, and some reports have been prepared.	Environment Canada – Inland Waters 224 West Esplanade North Vancouver, B.C., 666–3007

APPENDIX B

TABLE B2 – SUMMARY OF RELEVANT MAP TYPES

TOPOGRAPHY (BASE MAPS)			
SCALE	DESCRIPTION	AVAILABILITY	AGENCY
1:1,000,000	Water features, contours, relief, culture, roads, railways etc.	Entire province	GSC Maps, EMPR 100 West Pender Street Vancouver, B.C., 666–0271
1:500,000	Water features, contours, relief, culture, roads, railways etc.	Entire province	Maps–BC 1802 Douglas Street Victoria, B.C., 387–1441
1:250,000 (digital)	Water features, contours, relief, culture, roads, railways etc. as well as UTM Grid. Coverage available for entire province. Map sheets 92G, 92H, 92I and 92J available in ARCINFO format.	Entire province	GSC Maps, EMPR as above
1:100,000	Includes drainage relief, culture, and cadastral features and land status. Partial coverage of province only.	Portions of province only. (see Maps–BC Catalogue)	Maps–BC as above
1:50,000 (digital)	Water features, contours, relief, culture, roads, railways etc. as well as UTM Grid. Available in ARCINFO format.	Entire province	GSC Maps, EMPR as above
1:20,000 (digital)	Terrain Resource Information Management (T.R.I.M.) include seperate layers displaying man–made features, cultural, drainage, and contours.	To date, roughly one third of province mapped with TRIM	Maps–BC as above
Larger than 1:20,000	There are some 7,500 large scale topographic maps available with scales ranging 1:2,500 to 1:5,000. These maps show planimetric information, drainage, culture, and contour lines.	Portions of province only.	Maps–BC as above
SURFICIAL GEOLOGY			
SCALE	DESCRIPTION	AVAILABILITY	AGENCY
Varies but mostly 1:50,000	Much of the province's surficial geology has been mapped by various agencies such as GSC, MOELP, MOTH, EMPR, Agriculture Canada. All available mapping is tabulated in publication entitled "Surficial Geology Map Index of British Columbia" (January, 1992). Available from Crown Publications (OF 1992–13).	Portions of Province	MOTH, EMPR, MOELP, BC Hydro MOF
SOILS			
SCALE	DESCRIPTION	AVAILABILITY	AGENCY
1:50,000 (digital)	Provide data on parent material, soil drainage, texture, slope, and other related data for near surface soils. Available soils maps tabulated in "Surficial Geology Map Index of British Columbia" (as above), and "Index of Soil Surveys in British Columbia" (1988), by Agriculture Canada. There are some 31 soils maps in digital format.	Portions of province only	Agriculture Canada, Maps–BC MOELP
TERRAIN			
SCALE	DESCRIPTION	AVAILABILITY	AGENCY
1:50,000	Provide information about the distribution and characteristics of surficial materials, landforms, and geologic processes. These maps are not listed in "Surficial Geology Map Index of British Columbia".	Portions of province only – see Maps BC catalogue	Maps–BC as above

APPENDIX B

TABLE B2 – SUMMARY OF RELEVANT MAP TYPES

BEDROCK GEOLOGY			
SCALE	DESCRIPTION	AVAILABILITY	AGENCY
1:250,000 (digital)	The GSC are near completion of digitizing exposed bedrock geology mapping for the entire province at 1:250,000 scale; these files will be distributed as Open File works. Index maps showing locations where bedrock mapping has been carried out are available from the GSC. However, these indices are not up to date, and one should also check the information files at the GSC library.	Entire province	GSC Maps, EMPR as above
GROUNDWATER MAPS			
SCALE	DESCRIPTION	AVAILABILITY	AGENCY
Varies	Unpublished groundwater maps for Wood Lake area in Okanagan were prepared by the Province. Mapping of Fraser Valley published by NHRI (Halstead 1986). Most maps included in NTS Catalogue maintained by MOELP – Groundwater Section. Detailed mapping also done for south Nanaimo area during preparation of water management plan for the Nanaimo/Oyster River area. The Groundwater Section has also prepared Regional Groundwater Potential Maps for east coast of Vancouver Island at 1:20,000 scale. These maps show potential unconsolidated unconfined aquifers, developed unconsolidated aquifers, bedrock aquifers, low permeability unconsolidated deposits, and locations for selected wells with yields in excess of 1 L/s	Salmon River Valley, Ardmore, Terrace, Kalamalka Lake Basin, Fraser Valley, east coast Vancouver Island	MOE – Groundwater Section 4th Floor, 765 Broughton St. Victoria, B.C. 387–1115 NHRI – Environment Canada 224 West Esplanade, North Vancouver, B.C.

APPENDIX B

TABLE B3 – OTHER INFORMATION

HYDROMETRIC INFORMATION	
DESCRIPTION	AGENCY
Measured/estimated flows and water levels are available from the HYDAT system operated by Environment Canada, Inland Waters, Water Survey of Canada. This includes data from all WSC stations, as well as those operated by other agencies such as BC Hydro, and MOE. All data on HYDAT is on CD–ROM and can be downloaded to floppy disk. Environment Canada also operates a computer bulletin board system (BBS) and data from HYDAT can be downloaded directly. The BBS phone number is 666–2607 (use 2400 Baud, even parity, 8 data bits, 1 stop bit).	Environment Canada, Inland Waters 224 West Esplanade North Vancouver, B.C. 666–3977
CLIMATE INFORMATION	
DESCRIPTION	AGENCY
Statistical normals for rain, snow, total precipitation, and temperature up to 1980 published by Atmospheric Environment Service (AES), Environment Canada. A new issue of climate normals is expected soon. Apparently AES are in the process of implementing a program to publish climatic data on CD–ROM, though a delivery date is not yet known.	AES – Climate Information #700 – 1200 West 73rd Avenue Vancouver, B.C. 664–9156
BC Hydro operates two networks of climate monitoring stations throughout the province, with some 136 sites. The data collected are used for forecasting runoff at existing dam sites, as well as investigaton of undeveloped areas. Data is unprocessed, and statistical normals are not available. In the future, this data may be forwarded to AES for processing and publication.	BC Hydro, Burnaby Mtn. c/o Podium B, 6911 Southpoint Drive Burnaby, B.C., 293–5851 and 528–2747
The Hydrology Branch of the MOE maintain 7 high elevation climate stations for forcasting surface water flow information. Data is unprocessed, and statistical normals are unavailable. Data is available from Hydrology Division on diskette.	MOELP – Hydrology Branch 4th Floor, 765 Broughton Street Victoria, B.C., 356–5149

APPENDIX C

Seminar of Groundwater Mapping and Assessment

February 25, 1993

APPENDIX C

Seminar on Groundwater Mapping and Assessment

Delta Pacific Resort and Conference Centre, Richmond, B.C.
February 25, 1993

The first part of the workshop included large-group (plenary) sessions to introduce the main topics. After these sessions, participants attended one of five "workgroups" where discussion of relevant topics ensued. The results of the workgroup discussions were then summarized and presented at the next plenary session. The workshop concluded with a panel discussion. A brief description of relevant sessions of the workshop follows.

OPENING SESSION

Paul Matesyk - RIC

Mr. Matesyk provided background on overall RIC objectives, and specifically those with respect to groundwater mapping and assessment. These include:

- improved and integrated information management;
- minimization of duplication in data collection;
- development of standards for data storage and manipulation;
- developing a minimum set of data elements to facilitate collection and sharing of groundwater and related data across interested agencies and the groundwater community as a whole; and
- development of a manual, or minimum set of standards, for groundwater mapping.

Mr. Matesyk stressed that the last item on this list (the manual) will not be the "final word", rather a starting point for developing a consistent approach to mapping of groundwater resources in the province.

John Gilliland - Environment Canada, Ottawa

Mr. Gilliland provided a synopsis of his views on the current direction groundwater mapping and data management to "set the scene" on groundwater related work that the Federal Government is doing. Highlights of Mr. Gilliland's talk were as follows:

- With respect to water resource management at Federal level, the emphasis is on economics - ie. how to achieve objectives at the lowest possible cost.

- With respect to mapping and assessment of groundwater, we must take an "Ecosystems" or "Integrated Resource Management" approach - this is a theme of the Green Plan.

- Partnerships are necessary between government agencies and public and private organizations for management of our information resources.

- There is a trend of decentralization in collection and management of groundwater related information, as our knowledge of our resources increases.

Alan Kohut - Head, Groundwater Section, B.C. Environment

Mr. Kohut's presentation entitled "Blueprint for Change" included a summary of BC Environment's groundwater program. This included comments on the timing of groundwater legislation, collaborative efforts on groundwater related issues with the Ministry of Health, Ministry of Agriculture, the State of Washington, and the NHRI. Mr. Kohut stressed the need for local involvement in groundwater management, specifically siting landuse and activity planning, well head protection plans, and recharge area protection.

TECHNICAL SESSION

PART I GROUNDWATER MAPPING AND ASSESSMENT ISSUES IN NORTH AMERICA

John Gilliland - Environment Canada, Ottawa

Mr. Gilliland made two points with respect to groundwater mapping and assessment:

- Groundwater now has a tangible economic and environmental value, where as in the past is has been seen as being "free". As the realization that groundwater has tremendous value takes hold, the need for its mapping and assessment will become more apparent to decision makers

- A groundwater map is a compilation of information from various sources. The map's accuracy depends on the accuracy of the underlying database used to create the map. It follows that the database must be designed to fit the needs of the map, and the quality of the database has a tremendous impact on the accuracy and usefulness of the map.

Dr. Robert Palmquist - Applied Geotechnology Inc., Bellevue, WA.

In his talk entitled "Hydrologic Studies - An Expanded View", Dr. Palmquist indicated that in his experience, groundwater mapping is carried out in two stages:

- Stage I — Traditional employs a traditional approach of mapping the physical characteristics of aquifers, including thickness, tops, and chemistry etc.

- Stage II — Aquifer Management - Look at water budget, recharge areas, continuity between groundwater and surface water, aquifer susceptibility to contamination, soils, contaminant loading, and finally, vulnerability.

Dr. Palmquist noted that regulations drive the groundwater mapping and assessment process, and that education at the "grass roots" level is important. He also noted that it is important to remember that information from a diverse series of sources, in addition to the traditional ones, is required to generate useful groundwater maps.

Dr. Palmquist continued to speak on major contaminants and their sources. Highlights were as follows:

- 1990 EPA list of groundwater contaminants in descending order: nitrates, metals, pesticides, petroleum products, and organic compounds (ie. solvents).

- Number one source of groundwater contaminants are septic tank effluent disposal systems. These are ubiquitous, and also serve as household hazardous waste disposal systems. Other serious polluters include leaking underground storage tanks, municipal waste disposal sites, and agriculture.

Dr. John Vaccarro - USGS, Tacoma, WA

Dr. Vaccarro described groundwater related work done by the USGS, and indicated that their main interest is in groundwater supply. Highlights of his talk were as follows:

- Map scale determines the level of detail in a mapping study;

- Thickness and tops of aquifers are usually mapped;

- Lithological information from well logs forms an integral part of map;

- Experienced hydrogeologists are needed to carry out the mapping process, QA/QC can't be put aside; and

- Groundwater maps are by definition interpretive. It follows that they change with time, as base of knowledge expands.

Marilyn Blair - Washington Department of Ecology, Olympia, WA.

Ms. Blair described the steps that the State of Washington is taking to coordinate management of groundwater data. She described the Chelan Agreement, whose aim is to pull together interests, and improve management of groundwater data, regardless of how the data is to be used. The Chelan agreement includes the needs of a diverse number of groups including state, federal and local governments, public utilities, irrigation districts, and recreational and environmental interests.

The Department of Ecology has developed a 5 year plan to manage water resource data. Stage I of this plan comprises putting the framework in place to promote sharing of water resource data with a common data architecture. They have also developed a source book for water resource data to provide a road map to sources of information. The State is also setting up a clearinghouse to provide a location to obtain published studies, unpublished information, consultant documents, and results of pilot testing.

Mike Wei - BC Environment - Groundwater Section, Victoria, B.C.

Mr. Wei's talk concentrated on groundwater related issues in the province. Highlights of his talk included the following:

- How does one map groundwater in fractured bedrock?

- Impact of non-point contaminant sources (ie. pesticides and nitrates) on groundwater quality. Mapping of recharge and discharge areas, performance monitoring, and updating of monitoring protocols are important.

- Well abandonment is an important issue in the province. Improperly abandoned wells provide a direct conduit for groundwater contamination, and can be a physical hazard (ie. dug wells).

- High quality data is required to do groundwater mapping. Well logs are an important source of information. Databases with water well and water chemistry information should include links so that they can be cross referenced to other sources.

Allan Dakin - Piteau Associates Engineering Ltd., North Vancouver, B.C.

During Mr. Dakin's brief talk he stressed that public awareness of groundwater issues is the key component required to convince decision makers to devote resources to managing groundwater resources.

PART II POTENTIAL APPROACHES TO GROUNDWATER MAPPING

This portion of the workshop included presentations by Messrs. Turner, Tiplady, and Dakin who discussed methods for mapping groundwater resources, sources of information in B.C., as well as aspects of groundwater assessment. Much of the material covered during these talks is included in the manual for groundwater mapping and assessment that accompanies this report.

WORKSHOP DISCUSSION GROUPS ON ASPECTS OF GROUNDWATER MAPPING AND ASSESSMENT

Attendees and resource individuals broke up into five groups to discuss specific aspects of groundwater mapping and assessment and/or related issues according to the following themes: water supply (2 groups), environmental (2 groups), and groundwater information (1 group). After an hour's discussion, the large group reconvened, and discussion group leaders summarized the results of the discussions to the group. A summary of these presentations is included in the following.

Group 1 - Water Supply

This workgroup consisted of representatives of the following agencies:

pump installation contractor (1)
consultants (2)
federal government geoscientist (1)
provincial government representative (1)
concerned citizen (1)

Points arising from the discussion included:

- Public awareness of need to manage and protect groundwater is required before decision makers will place a higher priority on these issues;

- Legislation on protection and management of groundwater resources and the usefulness of groundwater mapping are linked. There is little reason to map the resource if there is no legislation to mandate its protection and management.

- Province should require tagging of new wells. Perhaps owners should purchase a permit to drill, and have a portion of their money refunded upon submission of driller's log.

Group 2 - Water Supply

This workgroup consisted of representatives of the following agencies:

Ministry of Health representatives (2)
water well drillers (2)
municipal engineer from District of Abbotsford (1)
representative of Real Estate Board of Victoria (1)

Points arising from the discussion included:

- We need groundwater legislation. This will follow from education of the public and politicians;

- In terms of protection of groundwater resources, the rural environment is the most important, as this is where problems with groundwater quality and quantity have the biggest impact;

- Provincial government should develop policies and guidelines regarding groundwater and aquifer protection, local governments can follow their lead;

- There was a preference in the group toward local and site specific maps, although smaller scale maps were also desirable in the case of assessing broad health related impacts;

- We should have the ability to retrieve selected types of information and show them on maps on an as required basis. This should include:-

  recharge areas
  depth to water table
  yield and/or specific capacity
  water quality and well density
  lithology
  aquifer vulnerability
  knowledge of locations for abandoned wells and disposal wells

- Groundwater maps should be compatible with maps showing non-groundwater features such as septic systems, landuse, etc.;

- Policies will follow legislation;

- If contaminated sites legislation comes through, there will be a need for groundwater maps, even if there is no groundwater legislation.

Group 3 - Groundwater Data

This workgroup consisted of representatives of the following agencies:

BC Environment (2)
Consulting firms (2)
Federal government (2)
US Federal Government (1)
Washington State Government (1)

This workgroup group presented the following summary of items that were discussed.

- It is very important that we all talk the same language with respect to groundwater information;
- Well location information will improve over time; don't confuse identification with location;
- Study done in Waterloo, Ont. estimates cost for a technician to locate an existing well is $75/well; this can be reduced to $25/well using GPS technology; contractors may be able to provide GPS locations;
- There is a five year backlog in unprocessed well logs in Surrey and Nanaimo regions;
- Most contractors care about the quality of data submitted;
- GPS is key to locating wells, and estimating elevation;
- Legislation should specify that one person should make up well logs. QA/QC is very important;
- User pay permitting system should be considered - users would pay for management of groundwater resource in their area. In Washington, a $100 permit is required to drill a well;
- Prior users' groundwater extractions should not be impacted by future users - this happens in B.C.;
- The province lacks any information on water usage - this is needed for effective management;
- We need to determine the value of groundwater resources in BC, and consider a royalty on extraction;

- New wells should be inspected by CWWA or CSA certified well inspectors;
- Initiative for effective groundwater management needs to come from outside of government;
- Problem with regulations is that they require enforcement - must have a system that minimizes confrontation;
- Management of groundwater is expensive;
- User groups want high quality data to make sound decisions;
- The Fraser Lowland could be mapped;
- Define map scale on he basis of the needs of the area to be mapped;
- The greatest need is to sell the program to senior level bureaucrats and politicians, as they are the prime audience;
- Monitoring wells are usually considered to be proactive - are they really?
- Monitoring groundwater is the "cheap choice" for groundwater management.

Workgroup 4 - Environmental

This workgroup consisted of representatives of the following agencies:

Ministry of Health (3)
Consultants (3)
BC Environment Official (1)

Points arising from this group's discussion included:

- Broad scale groundwater vulnerability maps would be helpful in terms of preserving quality of drinking water;
- Groundwater maps are by definition interpretive - they should be kept up to date with new information and interpretations;
- Needs maps to show vulnerable areas to be used as part of public education process.

Workgroup 5 - Environmental

The workgroup makeup was not recorded. Items discussed were as follows:

- Groundwater environmental issues should be divided into ecosystem issues and environmental health issues - the main focus is regulation driven;

- There is a need for groundwater legislation to promote:

  environmental and groundwater protection
  certification and licensing of water well drillers
  regulations on well construction and abandonment
  aquifer and well head protection;

- There is need for understanding and addressing groundwater quality issues - deal with impacts on fisheries and developments, salt water intrusion, risk of groundwater mining;

- There is a need for education of the public relating to handling of pesticides, aquifer protection, maintenance of septic systems, schools, familiarization of environmental and medical health officers with these problems;

- We need groundwater recharge maps;

- We need better quality data.

PANEL DISCUSSION

The workshop concluded with a 45 minute panel discussion whose purpose was to allow for more feedback from workshop attendees on groundwater mapping and related issues. The following individuals were included on the panel:

J.A. Gilliland	Hugh Liebscher
R.A. Freeze	Dick McNichol
R.A. Dakin	

Notable comments from panel members and the floor are indicated in the following:

Allan Freeze indicated that the message he was getting is that groundwater mapping is only part of the information systems explosion taking place.

John Gilliland stressed that we must look at who the map is aimed at. In his opinion, the most important use is to provide information to decision makers.

Hugh Liebscher indicated that he thought government should get away from groundwater mapping, and let this be done by the end users who have varying needs, or their consultants. Government's mandate should be limited to maintaining a high quality data base of groundwater related information so that those end users who have specific mapping needs can obtain the information they need. A comment was made from the floor that perhaps some sort of groundwater map should be available from the government for use by the "small user" who can not afford to undertake a mapping program.

The distinction between basic data and GIS systems was highlighted. There is a danger for misuse when data is overlain or processed with unknown algorithms.

There was a comment from the floor regarding the need for public involvement to raise awareness on groundwater related issues. A panel member noted that significant initiatives have been taken on this front in the USA. It was also noted that "there are lots of stakeholders who don't know that they are stakeholders".

There was a comment from a panel member regarding the use of groundwater models in aquifer management, as is done by the USGS. This should include a standardized modelling procedure with database connections and standardized database management.

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APPENDIX D

Summary of User Survey Questionnaire

Appendix D

Summary of User Survey Questionnaire

	Priority Ranking
Administration	
Development and Implementation of a Provincial Groundwater Strategy	
legislation	4.5
regulations	4.5
education	4.3
communication	4.2
interjurisdictional cooperation	4.2
policy	4.1
private and public sector involvement	4.1
management mechanisms	3.6
institutional arrangements	3.2
Average	4.1
Create a centralized source for groundwater information	4.7
Training and licensing of water-well drillers	4.2
Data Collection and Management	
Define a minimum set of groundwater data elements	4.2
Information exchange between data bases	4.1
Provision of on-line groundwater information	4.0
Determine costs for disseminating groundwater information	3.3
Data Interpretation and Presentation	
Establish standards for aquifer mapping	4.0
Prioritize areas for aquifer mapping	4.3
Map and classify major aquifers	3.0
Identify areas susceptible to groundwater pollution	4.6
Delineate major groundwater regions in British Columbia	3.7