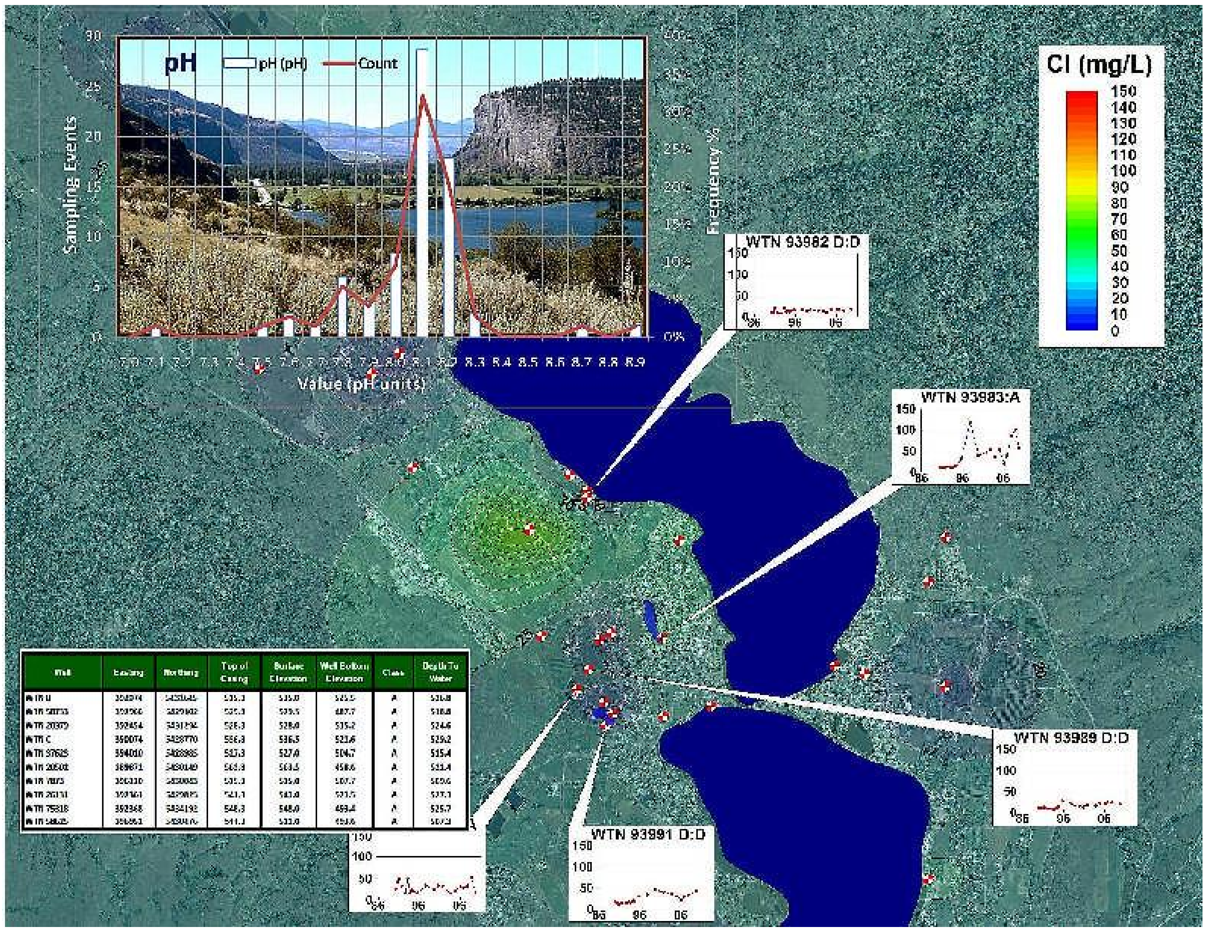
FINAL REPORT

Review of Ambient Groundwater Quality Monitoring Networks in the Okanagan Kootenay Region



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EXECUTIVE SUMMARY

Western Water Associates Ltd. is pleased to present this report which summarizes the results of a technical review of ambient groundwater quality monitoring networks maintained by the BC Ministry of Forests, Lands and Natural Resource Operations [MNRO] in the Okanagan/Kootenay Region. This work was completed under Contract CPNEN11021, which was issued by the Penticton Regional Office of MNRO.

Objectives of this Assignment

The primary objective of this assignment included the analysis of groundwater chemistry data for ambient networks located in Grand Forks, Osoyoos, Oliver and Eagle Rock, with a view to providing recommendations for any modification to the networks, if deemed necessary. The secondary objective of this assignment was to enhance the ability of MNRO staff to interpret data and to have the capability to present findings to colleagues as well as the general public. The software and training delivered as part of this assignment represent a tool not only for the assessment of historical data for each network, but can also be used to continually update and analyze information at each site, plus analyze data from other sites.

The Ambient Water Quality Monitoring [AWQM] networks in the Interior of British Columbia were established in the mid-1980s in several important aquifers including Grand Forks [MNRO Aquifer 158], Osoyoos [MNRO Aquifer 193/194], Oliver [MNRO Aquifer 254/255] and Eagle Rock [MNRO Aquifer 353]. The objectives of these ambient networks are to characterize water chemistry of the aquifer, identify any parameter that exceeds health standards, or is trending in a direction that would impact human or ecosystem health, and help raise awareness about the linkage between adverse land-use practices and water quality. The AWQM networks utilize public and/or private water wells in a given aquifer. The private wells are usually active water supply wells, whereas some of the monitoring networks have dedicated Provincially-owned monitoring wells.

Scope of Work Summary

To accomplish the main objectives, the scope of work for this project was briefly, as follows:

- Review and summarize water quality and geological information relevant to each aquifer that hosts one of the monitoring well networks

- Establish a database of water quality and lithology information for each aquifer and monitoring well network in an excel spreadsheet format that was usable by a software package that was selected specifically for the analysis of the data. Three working copies of the software and training on use of the software was included in the scope of work.

- Generate location maps, cross-sections and contour maps of geology, water levels and chemistry for each of the aquifers, specifically in the areas where the ambient networks are focused

- Analyze chemistry data for each of the ambient networks through the use of maps and plots showing visual identification of spatial trends and anomalies for each of the key chemical parameters included in the water quality data provided by MNRO.

- Compare water quality data against the Guidelines for Canadian Drinking Water Quality [GCDWQ] as well as to background [ambient] conditions for each aquifer. It was also necessary to analyze the water quality data using statistical methods to identify outliers [anomalous data].

- Prepare a report summarizing the methodology utilized and findings of the analysis, along with recommendations on how each network could possibly be improved.

Summary of Study Results

The methodology utilized for this assignment, which combines statistical analysis with the plotting of data in a spatial and temporal format, is very effective in identifying outliers, data gaps and trends in water quality data.

The degree of effort required to translate tables from the current spreadsheets used by MNRO into spreadsheets that are efficient for identification of statistical values and comparison against GCDWQ is considerable. Although this work was completed with macros, it is not a user-friendly process. The QA/QC process is also very detailed and not easily followed.

A comparison between the effectiveness of statistical methods for data validation and QA/QC, as opposed to visual methods utilizing the EnviroInsite© software, suggests the software is capable of identifying outliers as effectively as the statistical methods. The EnviroInsite© software represents a significant step-forward for MNRO staff, which enables the continual updating of any water quality database which is stored in MS Excel or MS Access and the ability to complete regular analysis of both spatial and temporal trends.

In conclusion, we believe that the EnviroInsite© software is capable of visually identifying outliers and therefore, more rigorous QA/QC of data is not warranted. However, should such additional QA/QC be required, it is recommended that commercial software for statistical analysis of water quality data be utilized. The EnviroInsite© software has been designed to work with a statistical package called EQUIS©, but there are other software packages available that will do the statistical analysis appropriately.

More specific conclusions and recommendations are provided in bullet form as follows:

C1 With the exception of Eagle Rock, all of the AWQM networks have been relatively successful in documenting baseline water quality conditions and identifying trends in parameters of interest related to the land use and aquifer setting.

C2 There are an insufficient number of sampling events and sampling locations available for the Eagle Rock AWQM Network to allow for appropriate spatial and temporal analysis.

C3 All AWQM networks have issues relating to consistency of parameters included for testing, with the frequency and regularity of sampling and with the application of consistent field methods for the collection of samples.

C4 Eagle Rock does not have appropriate up-gradient [background] sampling locations, or appropriate spatial coverage to the north, east and south of existing network footprint area.

C5 Grand Forks has at least two modes for background concentrations for many parameters; the source water from the Grandby River Watershed influencing background concentrations in the north of the aquifer and the source water from the Kettle River Watershed influencing concentrations at the southwest corner of the aquifer.

C6 The majority of sampling completed to date has been for total metals analysis, for comparison against acceptable concentrations and aesthetic objectives outlined in the GCDWQ. Sample results indicate a significant number of outliers for total metal concentrations for, among others, arsenic [As], iron [Fe], manganese [Mn] and uranium [U]. Total metals analysis for metals such as these can be significantly influenced by field sampling methods which do not remove turbidity.

C7 Within the Eagle Rock AWQM Network, WTN 38720 [Larkin Well #4] has significantly different chemistry than the other wells monitored in the network. In consideration of the up-gradient position of this well in comparison to the others, the chemistry infers the water quality in this area of the aquifer has been impacted.

C8 Within the Oliver AWQM Network, WTN 82376 has significantly higher NO_3 levels than other wells in the area. There is a localized source of nitrogen in this area that influences NO_3, NO_2 and NH_4 levels. This is likely related to agricultural activity in the area. In general NO_3 levels are decreasing in the area, possibly due to more awareness of sustainable application of fertilizers. SO_4 levels are also decreasing. There is also an upward trend in potassium [K], which could also be related to NPK (Nitrate, Phosphate, Potassium) type fertilizers.

C9 Elevated Uranium [U] also exists in the Oliver Network in wells to the southeast of Tugulnuit Lake. The variability in results suggests these levels could be associated with higher turbidity, which needs to be confirmed.

C10 Within the Osoyoos AWQM Network, there are elevated NO_3 levels to the north of the Town and along the highway, specifically in the immediate area of WTN 14402. There are also isolated areas where chloride [Cl] is elevated above background levels but still significantly lower than GCDWQ. These areas are believed to be where on-site sewage disposal is utilized.

C11 Within the Grand Forks AWQM Network, there are at least 2 areas where NO_3 [nitrate] levels are elevated. These include the north end of the aquifer in the area of WTN 35526 and in the south east in the area of WTN 59171, WTN 37623, WTN 7990 and WTN 7873. These same areas also have elevated potassium [K]. Elevated levels of both NO_3 and K could be related to fertilizer application. Nitrate levels are however are gradually decreasing in the aquifer.

C12 Point source contamination is suggested in the area of Boundary Hospital, due to elevated levels for Cl, NO_3, SO_4 and specific conductance.

C13 Point source contamination is also suggested in the area of the large industrial complex in the area of 2nd Street and 65th Avenue. There are trends in the nearby monitoring well, WTN 59167, of decreasing pH and increasing iron [Fe] and sodium [Na].

Based on the above conclusions, the following recommendations are provided:

R1 All AWQM networks should be more regularly sampled and the suite of parameters included should continue to include total metals for comparison against historical results and GCDWQ. However, the suite of parameters should be expanded to include major cations/anions, such that a charge balance check can be completed. Turbidity should also be included to identify where total metals results are potentially impacted by sediment in samples. Consideration should also be given to testing for dissolved metals, not as a replacement for total metals, but to compliment the total metals results and identify where the results for total metals analysis may be mis-leading.

R2 Standard protocols for field sampling and data validation should be implemented for the preservation of data quality. This includes more prescriptive sampling methods and QA/QC checking of data immediately after entering results in the EMS database, such that issues can be identified and the samples re-tested in the lab before disposal.

R3 At least 2 of the 4 closely clustered wells in the Eagle Rock AWQM Network could be removed from the monitoring schedule in lieu of the establishment of two additional monitoring locations to the north in the same aquifer.

R4 There are available wells at the south end of the Eagle Rock Aquifer that could be used for monitoring.

R5 The Oliver AWQM Network is functioning appropriately. If anything, more regular monitoring is prudent in WTN 53199, which is within the source area of recharge from the Park Rill Watershed. The Park Rill Watershed has considerable agricultural activity.

R6 Additional, more frequent and comprehensive monitoring is warranted in the Oliver Area within WTN 21867 to identify the source of nitrate in this area.

R7 For the Osoyoos AWQM Network, consideration should be given to removing some of the nested monitoring well locations from the monitoring schedule. There does not appear to be significant differences in chemistry results between the aquifer depths sampled. In lieu of the second sampling depth at each nested monitoring well, there could be additional wells sampled on the east side of the lake and on the west side to the north.

R8 Additional, more frequent and comprehensive monitoring is warranted in the Osoyoos Area within WTN 14402 and in nearby wells to identify the source of nitrate in this area.

R9 For the Grand Forks AWQM Network, consideration should be given to removing some of the nested monitoring well locations from the monitoring schedule. There does not appear to be significant differences in chemistry results between the aquifer depths sampled. In lieu of the second sampling depth at each nested monitoring well, there could be additional wells sampled at the extreme north end of the aquifer to better document the water quality coming from the north, or at the east end of the aquifer to have better spatial coverage down-gradient of the industrial and agricultural activities in this area.

R10 In Grand Forks, the type and fate of the waste stream at Boundary Hospital needs to be verified and, if it is determined that part of the waste stream is disposed of to ground, this activity should be stopped.

R11 The identification of spatial and temporal trends at these AWQM network sites in relation to land use as well as an understanding of the hydrogeology in the area, requires a knowledgeable hydrogeologist in the role as the final QA/QC step. This will greatly assist in the identification of field or laboratory errors that may have otherwise gone unnoticed, and will provide for the best chance to understand the meaning of the reported results.

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1. INTRODUCTION

This report presents the results of a technical review of ambient groundwater quality monitoring networks maintained by the BC Ministry of Forests, Lands and Natural Resource Operations [MNRO] in the Okanagan/Kootenay Region. This work was completed under Contract CPNEN11021, which was issued by the Penticton Regional Office. A contract for the work was executed between Sustainable Subsurface Solutions and MNRO on 11 January 2011. Sustainable Subsurface Solutions was merged with Western Water Associates Ltd in April 2011.

The primary objective of this assignment included the analysis of groundwater chemistry data for 6 ambient networks located in Grand Forks, Osoyoos [2], Oliver [2] and Eagle Rock, with a view to providing recommendations for any modification to the networks, if deemed necessary. The locations of the ambient networks reviewed in this assignment are shown in **Figure 1**.

The secondary objective of this assignment was to enhance the ability of MNRO Staff to interpret data and to have the capability to present findings to colleagues as well as the general public. The software and training delivered as part of this assignment not represent a tool not only for the assessment of historical data for each network, but also to continually update information at each site and to look at the site from different perspectives [cross-sections]. The software can also be used to develop databases for other sites.

2. BACKGROUND

Substantial costs are incurred to obtain and analyze samples. The costs for drilling, monitoring well installation and sampling of monitoring wells and the laboratory costs for analyzing samples are not trivial. The utility of such expenditures can be jeopardized by the manner in which reported results are interpreted as well as by problems in how samples were taken and analyzed. Considerable attention has been given to standardizing procedures for sampling and analyzing groundwater. Although following such standard procedures is important and provides a necessary foundation for understanding results, it neither guarantees that reported results will be representative nor necessarily have any real relationship to actual site conditions. In summary, comprehensive data analysis and evaluation by a knowledgeable professional should be the final quality assurance step, it may indeed help to find errors in field or laboratory work that went otherwise unnoticed, and provides the best chance for real understanding of the meaning of reported results.

In British Columbia ambient groundwater water quality monitoring networks AWQM networks utilize public and/or private water wells in a given aquifer which are sampled for a period of time to assess the groundwater quality in the aquifer. The private wells are usually active water supply wells [a pump permanently installed in the well], whereas some of the monitoring networks have dedicated provincially-owned monitoring wells. These data from these wells are used to analyze spatial and temporal variation of groundwater quality for a given aquifer. In the interior of British Columbia AWQM networks were established in several important aquifers including Grand Forks [MNRO Aquifer 158], Osoyoos [MNRO Aquifer 193/194], Oliver [MNRO Aquifer 254/255] and Armstrong/Eagle Rock [MNRO Aquifer 353]. The objectives of these ambient networks are to characterize the water chemistry of the aquifer, identify any parameter that exceeds health standards, or is trending in a direction that would impact human or ecosystem health, and help raise awareness about the linkage between adverse land-use practices and water quality.

The primary objective of this project is to analyze the groundwater quality data collected for these networks, report of the results of the analysis and make any recommendations such as continuation discontinuation, or modification of each network that would help the MNRO to better manage these networks.

Further to the report by Wei & Cui [MNRO, 2004] any enhancements of ambient water quality monitoring [AWQM] networks need to be carried out without great demands on finite government resources. It was also pointed out that the general public has an increased expectation for the right to know the nature of water quality in aquifers with BC. The high number of communities in BC that are reliant on groundwater as a drinking supply are also important considerations in designing and maintaining a provincial water quality monitoring network. Monitoring wells in these networks are to be sampled on a regular basis with consistent sampling procedures, lab analysis, QA/QC, data analysis and archiving. Groundwater conditions and trends should be reported regularly and consistently. A range of potential enhancement options was presented in the report as follows:

1. Develop a program that allows for various intensities of monitoring [priority and phased approaches];

2. Integrate the various groundwater quality monitoring programs to maximize available resources;

3. Integrate water quality monitoring with well or aquifer protection planning;

4. Standardize sampling protocols and analytical, plus Quality Assurance/Quality Control (QA/QC) protocols to ensure consistent and comparable water quality data;

5. Develop groundwater quality indicators with consideration of major groundwater quality concerns for specific areas; and,

6. Compile, link and integrate water quality data from different sources.

Other guiding principles of monitoring presented in the report included the targeting of community aquifers, monitoring jointly with other government agencies and or private organizations, the selection of appropriate parameters for testing, QA/QC measures applied to sampling and testing, and several aspects relating to data analysis including database design, validation of input data and documentation [metadata] analysis. A significant recommendation was the need to develop a GIS platform to analyze spatial and temporal data variation or trends of ambient groundwater quality and to assess how groundwater quality is affected by hydrology, geology, topography, climate, land use, and land cover.

The final recommendation in the report was for regular progress and technical reports, as well as the ability to provide quick summaries and participate in the exchange of information, if requested. The content and format of the report recommended was as follows:

1. Objectives of the monitoring program;

2. Geographic characteristics of monitoring area;

3. Hydrogeology and characteristics of aquifer;

4. Surficial geology, aquifer polygon and classification, depth or thickness, confined or unconfined, groundwater direction, flow rate, etc;

5. Land use characteristics;

6. Total records and wells selected for monitoring;

7. Mapping which shows sampling locations and a description of each well and surrounding environment [lithology, well construction, geographic, land use, etc.];

8. Methodologies of sample collection, lab analysis, and QA/QC [if standardized procedures, make references to those procedures, or include it in an appendix];

9. Number of samples collected, starting and ending dates of sampling;

10. Tabulate small data set or tabulate summary only and include detailed data on a disc; and,

11. Conclusions and recommendations.

Subsequent to Wei & Cui [2004] a review of the Provincial Observation Well Network was completed by Kohut [2009]. The purpose of the assignment was to develop a method or strategy to recommend where observation wells needed to be located in the Province to help protect, manage and sustain the grounder resources of British Columbia. Several conclusions presented in this report the primary focus was on the expansion of the network to a relatively small number of key areas in each ministry reaching where it was anticipated that observation well data would be needed to support local water services planning and water management decision meeting. One of the secondary conclusions was that the quality, continuity and available of water level and water quality information from the observation well network could be enhanced with water quality sampling protocols, timely interpretation of data and technological improvements such as telemetry stations and more reliable instrument patients such as pressure transducers. It was also identified the number of the monitoring wells in the current networks, due to their proximity to pumping wells, and the weapons just aquifers were not entirely suitable to monitor the effects of climate change water level changes etc.

The Kohut Report also provided a brief review of groundwater quality monitoring conducted within the current networks in the province. It was noted that sampling frequency for observation wells during the 2002 two 2008. Sampling of individual wells ranged greatly from a low of once in seven years to a high of twice yearly for six consecutive years was also noted that sampling frequency ranges widely among the regions and there is no standard schedule in place for covering all regions. More samples are analyzed for major physical and inorganic parameters following a standard suite of parameters that has not been adopted for all regions. Variations in sampling frequency and parameters tested for observation wells is buried among the reasons that appear to depend on several factors such as, number of existing observation wells, available resources for monitoring, site remoteness and accessibility, and objectives for sampling, protocols followed in regional priorities.

Of particular relevance to the current assignment are some observations provided in the report, which are paraphrased from another report which examined historical water chemistry data from observation wells in aquifers within the Province. The major conclusion was that sampling frequency needed to be increased to quarterly for new observation wells and in 1A aquifer observation wells with little or no monitoring history.

With regards to analytical parameters, some key issues identified in the report are as follows:

1. Analysis of dissolved metals in every sample. Gaps in data from sporadic sampling schedules impact trend analysis. When standard parameters are occasionally omitted from the analytical suite, this compounds the difficulties of data interpretation;

2. Discontinuing analysis of total metals;

3. Continued local or regional studies for appropriate non-standard analytes;

4. The need for a thorough review of the potential for contamination by organic contaminants, specifically regular analyses performed for organics such as BTEX, PAHs and pesticides;

5. The need for review of analytical results within seven days of being entered into the EMS database to provide opportunities for re-analysis of the submitted sample, if necessary;

6. Conducting a critical assessment of the measured parameters are regularly to ensure that they are and will continue to be appropriate for meaningful evaluation of the site; and,

7. Having a standard suite of parameters for testing at all networks.

In summary, there is considerable literature to support the completion of the work outlined in this assignment. The analysis completed in this report of each of the AWQM networks basically follows the prescribed methodology. Furthermore, the software used for spatial and temporal analysis has significant utility in completing the required tasks and for MNRO staff to present data effectively to colleagues and the general public.

3. SCOPE OF WORK

The overall objective of this assignment is to analyze water quality data and available hydrogeologic information each of the AWQM networks. The deliverable is a report on the statistical, spatial and temporal analysis of the data. Furthermore, based on an understanding of the purpose for each of the networks and the potential risks, provide specific recommendations for continuing, modifying of well locations, enhancing or changing the suite of monitored parameters [analytes], increased or decreased sampling frequency, etc, or discontinuing the networks. For each aquifer that hosts a network, provide concluding remarks and any recommendations.

The scope of work for this assignment is outlined in the Contract CPNEN11021, specifically as follows:

- Review and summarize existing water well, water quality and geological information relevant to each aquifer that hosts one of the monitoring well networks;

- Establish a database of water quality and lithology information for selected wells in each aquifer in a excel spreadsheet format, suitable for use with EnviroInsite©, a software package specifically designed for the presentation of spatial and temporal hydrogeological data;

- Generate location maps, cross-sections and contour maps of geology, water levels and chemistry for each of the "aquifers", specifically in the areas where the ambient networks are focused;

- Analyze chemistry data for each of the ambient networks through the use of maps and plots showing visual identification of spatial trends and anomalies for each of the key chemical parameters included in the data provided by MNRO including: Alkalinity, Ammonia, Calcium, Chloride, Fluoride, Hardness, Iron, Magnesium, Nitrate, Nitrite, pH, Specific Conductance, Sulphate, Total Dissolved Solids and Uranium [plus any other parameters that pose a human health risk];

- Compare water quality data against the Guidelines for Canadian Drinking Water Quality [GCDWQ] as well as to background ambient conditions for each aquifer. Also analyze the data using statistical methods to identify statistical outliers. Outliers identified in the analysis to be further investigated with respect to potential causes. Water chemistry results that exceed GCDWQ guidelines and/or background ambient groundwater conditions will be further depicted on spatial and temporal maps. Aquifer characterization of each network is to include Stiff/Piper and Time History Plots;

- Prepare and submit a pdf copy of a Draft Report;

- Provide a final report that addresses comments provided by MNRO staff;
- Provide MNRO with all working and electronic files associated with the analysis of this project on a CD accompanying the final report; And,
- Provide 3 working & paid licenses of the ENVIROINSITE© Software [Version 7] and provide MNRO staff with training on the use of the software, specifically on inputting, modifying, contouring and plotting of data.

4. REVIEW OF NETWORK AREAS AND AQUIFERS

The purpose of this assignment is not to provide a detailed description of the hydrogeology of each AWQM network site, but to present an understanding of each site in sufficient detail to support the analysis of the water quality data. A considerable volume of effort has been undertaken by others to investigate and document the hydrogeological setting and physical characteristics of the aquifers that host each network, including assessment of the mechanisms and locations of recharge, hydraulic characteristics and water balance calculations.

The descriptions of the aquifers in the following sub-sections are therefore based predominantly on information provided by others. The scope of this assignment did not include any field work to verify well locations, water levels and land use.

4.1 Eagle Rock

This network is hosted in MNRO Aquifer 353, which is located in the North Okanagan, to the south of Armstrong and in the immediate area of the Spallumcheen Industrial Park, which is along the eastern flank of the Valley. The aquifer is hosted in a fan deposit and is unconfined along the edge of the Valley and confined towards the centre of the Valley by lacustrine sediments. There is substantial agricultural activity in the area where the aquifer transitions from unconfined to confined in nature. The majority of the unconfined portion of the aquifer is within the industrial park and large gravel extraction operations on the east side of Highway 97. In addition to on-site sewage disposal systems in this area, other potential sources of contaminants to this aquifer include industry [sawmill and fiberglass construction plants], commercial activities, hydrocarbon storage tanks and pipelines, plus a livestock market. The unconfined portion of the aquifer is locally recharged by precipitation and runoff from the highlands to the west. Flow in the confined portion of the aquifer is derived from adjacent valley-bottom aquifers that flow from north to south.

The aquifer covers a footprint area of roughly 7.8 km2 and hosts approximately 120 water wells with an average values of 47.2 m [155 ft] for depth, 12.8 m [42 ft] for static water level [SWL] and 2.5 L/s [39.5 USgpm] for yield. Wells in the eastern portion of the aquifer trend to shallower, higher yielding and more vulnerable, whereas wells located to the west are deeper and less vulnerable. Some wells at the western portion of the aquifer, where the transition occurs from unconfined to confined in nature, are flowing artesian at rates exceeding 22 L/s [50 USgpm]. There are several large yielding agricultural and public water supply wells that utilize this aquifer. Eagle Rock Improvement District [ERID] and Larkin Improvement District [LID] are the two most prominent water utilities. Data provided by LID and ERID indicate that the total quantity pumped using water district wells in the area is in the range of 1.3×10^8 to 1.5×10^8 Igal/yr, or 600,000 to 700,000 m^3/yr. Tolko Industries apparently have 6 monitoring wells and two extraction wells on their site, which covers a large portion of the very south end of the aquifer. Only anecdotal information exists regarding the location of these wells and water quality derived from the aquifer in this area. Agricultural users are generally located to the north and west portions of the aquifer. There also exists some higher density residential development to the north.

The aquifer has been classified as a 1A aquifer by MNRO, with a ranking of 14. The "1" designation denotes a combination of relatively high degree of development as compared to productivity of the aquifer, along with high demand and potentially high yields being available. The "A" designation denotes a relatively high vulnerability to contamination, especially in the eastern portion of the aquifer, which is unconfined.

The AWQM network at Eagle Rock was established in 2003 and includes 6 wells at 6 sites, all of which are completed in MNRO Aquifer 353. However, water quality in this aquifer has been monitored since July 1987. The objective of this monitoring network is to characterize the ambient groundwater quality and to monitor for nitrates [NO_3-N], in response to agricultural activity and sewage disposal to ground within the Industrial Park.

MNRO Observation Well 180 is located in the aquifer. This well is WTN 32340, which is also a water quality monitoring location included in the AWQN for Eagle Rock.

A plan view of the area showing the footprint area of the aquifer in the area of the AWQM network, the wells currently monitored for water quality and contours of reported static water levels [inferred direction of flow], is presented in **Figure 2**. The land use in the area, along with water wells and direction of flow are shown in **Figure 3**. A geological cross-section through the aquifer showing water levels and hydrogeological units is presented in **Figure 4.**

Based on major anion/cation concentrations derived from the EMS data, a Piper Plot of the water quality in the aquifer is presented in **Figure 5.** The groundwater in this aquifer is characterized as Ca-HCO_3 dominant.

The description of this aquifer and AWQM network are derived mainly from Ping et al (2007), Kohut (1979) and Monahan (2006). A summary of the well records utilized in the assessment of this area is included in **Appendix A**.

4.2 Oliver

The two networks in Oliver are hosted in MNRO Aquifer 254 and 255, which are situated within the base of the Okanagan Valley. Aquifer 254 is bounded to the north by Tugulnuit Lake and the south by Osoyoos Lake. The aquifer is approximately 15 km in length from north to south and covers a footprint area of roughly 19.2 km^2. Aquifer 255, also referred to as the Oliver North Aquifer, extends from Tugulnuit Lake to Vaseux Lake. This aquifer is approximately 8.5 km in length and covers a footprint area of 10.7 km^2. Apart from areas where recharge impacts localized flow gradients along the edges of the Valley [Vaseux Creek, Park Rill, etc], flow in both aquifers is from north to south.

Both aquifers are hosted in fluvial and glacio-fluvial floodplain deposits, which are generally hydraulically connected to flow in the Okanagan Channel. In some areas the aquifer is "locally" confined, where shallow finer grained silts effectively cap the aquifer, or where the depth to water becomes excessive along the edge of the valley in recharge areas. Aquifer 254 is generally unconfined in nature, shallow in depth and thickness and hydraulically connected to the Okanagan Channel. The area that recharges the aquifer is relatively small as compared to other valley-bottom aquifers in the Okanagan Valley. The upland recharge area to the west is minor and recharge from the east of the Valley is predominantly directed to the south end of the aquifer, directly into Osoyoos Lake. Some recharge from the east does occur along Wolfcub Creek, which ultimately reports to Tugulnuit Lake. Therefore, the majority of recharge in this aquifer is derived via lateral flow contribution from Aquifer 254m, which is immediately north. Lesser amounts of recharge are derived from losses along the Okanagan Channel, from irrigation return flow and from direct precipitation. Aquifer 255 receives substantial recharge from Vaseux Creek and Vaseux Lake, as well as via lateral flow from aquifers in the base of the Valley to the north of Vaseux Lake. Additional recharge is also contributed from the west via Park Rill Creek.

There is substantial agricultural activity all through the base of the Valley in the south Okanagan, including orchards and an increasing number of vineyards and vegetable plots. There is some industrial activity in the area, but not of particular significance. In addition to potential agricultural impacts on groundwater, on-site sewage disposal systems [either domestic or commercial] and fertilizer application on golf courses in the area, combine for a significant concern regarding nitrate loading in the aquifers.

The two aquifers cover a footprint area of roughly 29.9 km^2 and host in the neighborhood of 700 water wells, with average values of 18.9 m [62 ft] for depth, 7.3 m [24 ft] for static water level [SWL] and 2.5 L/s [39.5 USgpm] for yield. Wells in the northern part of Aquifer 255, immediately south of where Vaseux Creek enters the Valley are the both the deepest and have the greatest depth to SWL. Well adjacent to the Okanagan Channel and Tugulnuit Lake have the most shallow SWL and very likely source a substantial amount of their yield from these surface water bodies.

There are several large yielding public water supply wells operated by the Town of Oliver, 2 of which are located immediately south of Tugulnuit Lake, 5 located within 50 m of the Okanagan Channel [at various locations within and to the north and south of the Town], and one [Rockcliffe well] located 1.5 km to the west of the Channel at the intersection of 344th Avenue and 342nd avenue. There are also some high yielding irrigation wells in Aquifer 255 where the aquifer is recharged by Park Rill Creek. The Jackson Triggs Winery has a couple of higher yielding wells and the Osoyoos Indian Band recently completed two high capacity wells for their proposed Senkulmen Industrial Park, immediately south of the Jackson Triggs Winery.

Both Aquifer 254 and 255 have been classified as 1A aquifers by MNRO, with rankings of 16 and 15 respectively. The "1" designation denotes a combination of relatively high degree of development as compared to productivity of the aquifer, along with high demand and potentially high yields being available. The "A" designation denotes a relatively high vulnerability to contamination, especially in the lowest elevation portions of these aquifers next to the Okanagan Channel. Given the increased depth to SWL and evidence of some finer-grained and localized confining materials above the highest yielding portion of Aquifer 255, there is ongoing discussion regarding the down-grading of the vulnerability in this aquifer to “B”. This infers the aquifer is moderately vulnerable, as opposed to highly vulnerable.

The AWQM networks at Oliver were established in 2003 and include 12 water supply wells and one MNRO Observation Well. The objective of this monitoring network is to characterize the ambient groundwater quality and to monitor for nitrates [NO_3-N], in response to agricultural activity and sewage disposal to ground via domestic and commercial applications. MNRO Observation Well 322 is located in Aquifer 254. This well is WTN 62966, which is also a water quality monitoring location included in the AWQN for Oliver.

A plan view of the area showing the footprint area of the aquifers in the area of the AWQM network for Oliver, the wells currently monitored for water quality and contours of reported static water levels [inferred direction of flow], is presented in **Figure 6**. The land use in the area, along with water wells and direction of flow are shown in **Figure 7**. A geological cross-section through the aquifer showing water levels and hydrogeological units is presented in **Figure 8.**

Based on major anion/cation concentrations derived from the EMS data, a Piper Plot of the water quality in the aquifer is presented in **Figure 9.** The groundwater in this aquifer is characterized as Ca-HCO_3 dominant.

The description of this aquifer and AWQM network are derived mainly from Toews (2007), Golder et al (2009) and MNRO Aquifer classification worksheets. A summary of the well records utilized in the assessment of this area is included in **Appendix A**.

4.3 Osoyoos

The two networks in Osoyoos are hosted in MNRO Aquifer 193 and 194, which are situated within the base of the Okanagan Valley. Aquifer 193 is on the west side of Osoyoos Lake and is bounded to the west by bedrock highlands, the south by the USA border and the north where Osoyoos Lake terminates. The aquifer is approximately 9.5 km in length from north to south long by 1.8 km in width at the widest point. The aquifer covers a footprint area of roughly 13.4 km^2. Aquifer 194 is on the east side of the Lake, extending from the USA border to the northeast limits of the Town of Osoyoos. The aquifer is 4.1 km in length and at the maximum is 1.2 km wide. For this study we have also included MNRO Aquifer 195 with Aquifer 193, for a combined footprint area of 3.95 km^2. Neither of these aquifers receives significant recharge for the adjoining uplands, as these areas are relatively small. The upland catchment area to the west of Osoyoos is very limited in extent and does not achieve sufficient elevation to accumulate significant snowpack to drive recharge. The uplands to the east of Osoyoos are higher in elevation and more extensive in area, but runoff and recharge from these areas is primarily directed south to the USA portion of Osoyoos Lake. Recharge to Aquifer 193 and 194 is primarily via direct precipitation and irrigation return flow. All of the larger yielding wells in the Osoyoos Area are close to the lake and derive groundwater that is induced flow from the base of the lake bottom sediments. The level in the Lake and static water levels in many wells on both sides of the lake infer that the gradient is very flat. There are some shallow wells that are completed above the elevation of the lake that derive water from locally perched aquifers.

Both aquifers can be described in more detail as outwash terraces consisting of stratified drift ranging in texture from fine sand to coarse gravel deposited by meltwater streams fed by melting following glaciation. There are no obvious confining layers above these aquifers. Observation wells established in 1969 and piezometers in 1989 have generally shown rapid response to precipitation and irrigation water.

Approximately 450 water wells, with average values of 16.1 m [53 ft] for depth, 5.7 m [18.7 ft] for static water level [SWL] and 2.76 L/s [43.8 USgpm] for yield. Wells located towards the edges of the valley, where the thickness of aquifer sediments are greatest, are generally the deepest. The shallowest wells are generally in close proximity to the Lake. Approximately 90 percent of the wells are older dug wells and 90 percent of yields have not been reported. Many of the older dug wells were completed with a backhoe by the owner and unscreened. The calculated median well yield is therefore misleading.

There are several large yielding public water supply wells operated by the Town of Osoyoos, all of which are within located within 200 m of the Lake. Three of these wells are located in Aquifer 194 on the east side of the Lake, between Cottonwood Drive and Maple Drive. There are other wells on the south west side of the Lake along Kingfisher Drive and 2-3 more wells to the north in the old public works yard at the confluence of Spartan Drive and 92 Avenue.

Both Aquifer 193 and 194 have been classified as IIA aquifers by MNRO, with rankings of 16 and 14 respectively. The "II" designation denotes a combination of relatively moderate degree of development as compared to productivity of the aquifer, along with high demand and potentially high yields being available. The "A" designation denotes a relatively high vulnerability to contamination.

The AWQM networks at Oliver were established in 2003 and include a total of 27 sampling sites, including 9 domestic wells, 7 nested piezometers, and 2 MNRO Observation wells. The wells are sampled annually. The Observation wells include Obs Well 101 [WTN 22731] and Obs well 96 [WTN 22769]. The objective of this monitoring network is to characterize the ambient groundwater quality and to monitor for nitrates [NO_3-N], in response to agricultural activity and sewage disposal to ground via domestic and commercial applications.

A plan view of the area showing the footprint area of the aquifers in the area of the AWQM network for Osoyoos, the wells currently monitored for water quality and contours of reported static water levels [inferred direction of flow], is presented in **Figure 10**. The land use in the area, along with water wells and direction of flow are shown in **Figure 11**. A geological cross-section through the aquifer showing water levels and hydrogeological units is presented in **Figure 12**.

Based on major anion/cation concentrations derived from the EMS data, a Piper Plot of the water quality in the aquifer is presented in **Figure 13**. The groundwater in this aquifer is characterized as Ca-HCO_3 dominant.

The description of this aquifer and AWQM network are derived mainly from Athanasopoulos (2009), Nasmith (1962) and MNRO aquifer classification sheets. A summary of the well records utilized in the assessment of this area is included in **Appendix A**.

4.4 Grand Forks

This network is hosted in MNRO Aquifer 158, which is located in Grand Forks, at the confluence of the Kettle and Grandby rivers. The aquifer is irregular in shape as it follows the base of the valleys along the two rivers, which are limited in extent by the surrounding bedrock hills. The entire aquifer is a floodplain which is underlain by alluvial and glacial drift units, consisting predominantly of sand, gravel, silt and clay (Wei et al., 1994). Recharge to the aquifer is derived from lateral flow contributions from the Grandby Valley [from the north] and more predominantly from the Kettle Valley [from the west]. Additional recharge is provided via the hydraulic connection between the aquifer and the rivers, as well as via infiltration of precipitation and irrigation return flow. Groundwater flow from the north and west converges in the central part of the Valley and the combined flow continues to the east.

The international border runs across the southern portions of the aquifer, subdividing it into ~95% area on the Canadian side, and the remainder on the US side; approximately 30% of the valley watershed lies south of the border.

According to Allen et al (2004), the stratigraphic sequences in Grand Forks valley are poorly understood. In other valleys in southern British Columbia, the basal units are commonly silt, clay and gravel, overlain by thick glaciolacustrine silts, capped by sand and gravel outwash and floodplain deposits. A working hydrostratigraphic model was proposed and subsequently used to investigate the impacts of climate change on groundwater for the aquifer using a groundwater model. The 6 hydrostratigraphic units are included in the following list.

1. Gravel [with or without sand]
2. Sand
3. Silt
4. Clay
5. Sandy and gravel
6. Bedrock

Allen [2000] further states that the hydraulic connection of the Kettle and Granby rivers to the shallow aquifer appears to be efficient as there does not appear to be any till or low permeability silt material overlying the highly permeable sand and gravel in the river beds. The upper stratigraphic unit of the aquifer consists of gravel, which appears to be closely linked with the Granby and Kettle Rivers as evidenced by the corresponding rising and falling of water levels in shallow wells situated close to the rivers. All wells completed in this shallow layer exhibit a static level approximately at river elevation, indicating that the groundwater regime is likely strongly linked to the surface water regime.

There is substantial agricultural activity in the area.

The aquifer covers a footprint area of roughly 39 km^2 and hosts approximately 500 water wells with average values of 17.1 m [56 ft] for depth, 11.6 m [38 ft] for static water level [SWL] and 1.8 L/s [28.5 USgpm] for yield.

There are several large yielding public water supply and irrigation wells operated by the City of Grand Forks and various irrigation/improvement districts [ID] such as Sion ID, Grand Forks ID, Covert ID and Big Y ID. The City of Grand Forks wells are clustered in 2 locales north of the Kettle River and Highway 3. Sion ID operates wells near the junction of Highway 3 and Highway 47. They also have a well in operation along NorthFork Road. They constructed a new well on Community Centre Road in 2006. Covert ID operates 3 wells along Highway 947 near the USA border. Grand Forks, Almond Garden ID and Big Y ID operate wells to the south of the Kettle River, generally along or close to Gilpen Road. There is a large capacity well where the Grandby River enters the Study Area from the north [Copper Ridge]. There are also large capacity wells used for a tree nursery located along Nursery Road, to the east of the City and adjacent to the River.

Aquifer 158 has been classified as IA by MNRO, with a ranking of 17. The "I" designation denotes a combination of relatively high degree of development as compared to productivity of the aquifer, along with high demand and potentially high yields being available. The "A" designation denotes a relatively high vulnerability to contamination, especially in the eastern portion of the aquifer, which is unconfined.

The AWQM network at Grand Forks was established in 1985 and includes a total of 28 sampling sites, including several of the irrigation and municipal water supply well and MNRO Observation Well 217 [WTN 14947]. There are also several locations where nested sampling piezometers have been established. The wells are sampled annually. The objective of this monitoring network is to characterize the ambient groundwater quality and to monitor for nitrates [NO_3-N], in response to agricultural activity and sewage disposal to ground via domestic and commercial applications.

A plan view of the area showing the footprint area of Aquifer 158 and the locations of wells monitored as part of the network, along with contours of reported static water levels [inferred direction of flow], is presented in **Figure 14**. The land use in the area, along with water wells and direction of flow are shown in **Figure 15**. A geological cross-section through the aquifer showing water levels and hydrogeological units is presented in **Figure 16.**

Based on major anion/cation concentrations derived from the EMS data, a Piper Plot of the water quality in the aquifer is presented in **Figure 17.** The groundwater in this aquifer is characterized as Ca-HCO_3 dominant.

The description of this aquifer and AWQM network are derived mainly from Wei et al (1994), Allen & Wei (2010), Allen 2004) and Allen (2001). A summary of the well records utilized in the assessment of this area is included in **Appendix A**.

5. METHODOLOGY

In addition to the water quality and borehole data provided by MNRO for each of the network sites, it was necessary to compile digital imagery, land use maps and digital elevation model [DEM] data for input into spreadsheets compatible with EnviroInsite© [V.7], a commercially available software package that is ideally suited for the analysis and presentation of hydrogeological data. The software combines easy to use input files [MS Excel, MS Access, text or ascii] which generate a spatial and temporal [time history] database for a given site [in this case each ambient network site]. The software combines powerful spatial graphics [geo-referencing], as well as a full suite of hydrogeologist's tools including the ability to do geo-statistical and geo-chemical analysis, contouring and prepare geological cross-sections.

The methodology utilized to complete this assignment is graphically summarized in the flow diagram presented in **Figure 18**. A description of each of the work tasks is as follows:

- Review information and prepare x, y, x data files in MS Excel 2007 format, of geological information including UTM coordinates, surface elevation, depths and thickness of hydrostratigraphic units encountered, static water level, depth of screened intake. Additional wells were included in the database for each network, where information regarding stratigraphy and static water level, added spatial value, specifically with the interpretation of the continuity of hydrostratigraphic units and contouring of water levels. These spreadsheets were used directly by the EnviroInsite© software;

- Transfer data from the MNRO water quality spreadsheets [data from the EMS database] into a MS Excel spreadsheets that are readable as a database of spatial and temporal observations by the EnviroInsite© software. The specific parameters included Alkalinity, Ammonia, Arsenic, Bicarbonate, Calcium, Chloride, Iron, Fluoride, Hardness, Iron, Magnesium, Manganese, Potassium, Nitrate, Nitrite, pH, Sodium, Specific Conductance, Sulphate, Total Dissolved Solids and Uranium;

- For each ambient network site, utilize the EnviroInsite© software to prepare trial spatial and temporal plots to allow for the visual identification of trends and outliers, as well as background concentrations for each of the chemical parameters. Background concentrations were generally lowest level, method detection limit, or at up gradient end of system;

- Transfer data from the MNRO water quality spreadsheets into task specific spreadsheets for comparison against the Guidelines for Canadian Drinking Water Quality [GCDWQ, 2010], as well as statistical analysis for the specified chemical parameters. Statistical analysis included the identification of max, min and average values [arithmetic mean], standard deviation and the ratio of max to background value [established in previous task] for each parameter. The Range of values determined appropriate interval and a combination chart was prepared for two data series; 1) the number of events per interval and, 2) percentage of frequency for each interval, Subsequently using a pivot table, the number of sample events were determined, In the end identified statistical outliers;

- Transformed [removed outliers] of data and then did final plots;

- Identify trends, exceedences spatial and temporal plots, data gaps;

- Summarize data for each site, data worth; and,

- Complete an evaluation of each monitoring network in comparison to the original objectives of that network.

6. REVIEW OF DATA INPUT REQUIREMENTS FOR EnviroInsite©

The EnviroInsite© [V.7] can handle virtually any database format. For small sites, it is most convenient to store the data in a spreadsheet such as Microsoft Excel. The data is read as a relational database, so it's important that the well, screen and constituent names are consistent in the different parts of the database file. For example each Well in the Screens worksheet must have at least one identical counterpart in the Wells worksheet. Likewise, each Well – Screen pair in the Observation table must have their counterpart in the Screens table. It is also important that the spreadsheet contain the same tab names and heading labels as in the spreadsheet template [site1.xls] that is provided with the software. The easiest way to start a new spreadsheet data file is to use the template site1.xls.

There are six tabs [separate tables] in the spreadsheet. The documentation that comes with the software includes a detailed explanation of the fields that must be filled in for each table. A complete database schema for the software is provided in **Figure 19**. A summary of the individual tables and fields within each table is as follows:

Table	Fields
Wells	Name, location, surface/bottom elevations, class
Screens	Well/screen name and bounding elevation interval
Observations	Well/screen name, measured value, date, constituent, data flag and media
Constituents	analyte, units, media, standard
Borings	Well name, soil or boring log description, top/bottom elevation or depth
Stratigraphy	Well name, strata, top/bottom elevation or depth
Point Values, Fill, Geophysics	Well name, parameter, elevation, value

Any other spatial information such as digital elevation files [DEM], bedrock contour files, feature class [shape] files etc, can be imported directly. Images, such as old air photos, a print screen capture, or Google Earth/Maps, can be easily imported and geo-referenced within the software.

For this assignment, the digital imagery and DEM data were derived from 1:20,000 NTS Map sheets available on-line from GEOBC. Information on the location of observation wells in each ambient network was provided by MNRO. It was necessary to analyze each well log to determine the elevation of each stratigraphic unit and the depth of screen interval. The observations table within the input file is intended to contain data on the hydrogeologist's interpretation of stratigraphic units. When constructing the stratigraphy table unit intervals must lie in the same order from top to bottom in every well. When a particular unit is missing at a well location, the software will interpret that the unit has zero thickness at that location. Missing intervals below a given borehole location are also interpreted to have zero thickness. The geologist's interpretation of the expected elevation interval of missing units should be entered in order to prevent the interpretation of stratigraphy as extending only to the bottom of the borehole.

Input files can be MS Access [*.accdb] or MS Excel [*.xlxs]. Output files from EI have the extension *. Xml.

It is possible to add wells and graphics but not observations while working in the software with a data set open. It is also possible to directly browse the data set while running the software.

The largest data workbook is the observations tab, which utilizes a single row of data for each observation. For example, each of the 20 parameters for a single sample event requires a dedicated line in the table. In addition to water quality data, water levels for each well were added as observations. Although, not completed as part of this assignment, it will be possible to enter water level data from MNRO Observation Wells in each AWQM network and plot long term water level fluctuations.

7. WATER QUALITY DATA ASSESSMENT

In reality, the assessment, or validation of the data is merely a process of checking for transcription and conversion errors, with the ultimate intention being to summarize the data and conveying the essential information contained in the data to the end user. The analysis completed on the EMS data provided by MNRO was completed using MS Access and MS Excel to copy data to task-specific spreadsheets. Subsequent analysis was completed using Excel to identify max, min, mean, mode, skewness, kurtosis, standard deviation and normality. Most of the data exhibited a central tendency, but was not normally distributed and therefore it was not possible to use statistical methods to identify extreme outliers. The premise for the statistical analysis completed on the data is the 2006 USEPA document EPA QA/G-9S, entitled "Data Quality Assessment: Statistical Methods for Practitioners".

The main purpose of water quality data assessment was to; 1) look for sample results that exceed selected parameters in the Guidelines for Canadian Drinking Water Quality [GCDWQ], and 2) identify and remove visual outliers using the EnviroInsite Software. Once these outliers were identified, the data was transformed by removing [censoring] the outliers.

7.1 Data Input Validation

EMS data were initially provided by MNRO is an Excel spreadsheet with unique columns of data for each AWQM Network site for EMS ID, Sample Date, Type of Sample, and columns for water quality test results for various parameters that were measured over various time periods.

Preliminary validation of the data was completed by reviewing the data for consistency between each AWQM site data, specifically by examining the list of parameters, the ordering within the file and the format of the data [consistent dates, parameter naming convention, values, measurement unit, type of samples, etc]. Each data set was found to have blank values.

The EMS data sets contained water quality test results for 101 parameters, most of which were not specified in the scope of work for analysis. The number of parameters tested for at each AWQM network site varied significantly. For this study, only 20 parameters were selected for analysis. The data set is unique in that the detection limit for the laboratory testing method varies considerably between parameters and in some cases changes over time for the same parameter. The number of sampling events also varied considerably between certain parameters and sampling locations. Four stand-alone spreadsheets, one for each site, were prepared.

For the EnviroInsite Software, which was used for visual identification of trends and outliers, the data was copied from the original EMS data sets into Access and then, using queries for each of the 20 parameters of interest via a macro, a table was created containing the lab result, well location and date of sampling. The new table in Access was subsequently exported to an Excel table which was in a format acceptable by the EnviroInsite Software. For each parameter, values were sorted in increasing numerical order, which positioned blanks at the bottom of list.

7.2 Statistical Analysis and Identification of Outliers

For this assignment, the statistical analysis of the data called for the copying of the original EMS data tables to new MS Excel spreadsheets and subsequent modification to remove all data not related to the 20 parameters of interest. A column for Well Tag Numbers [WTN] was added to associate each sampling location with a corresponding EMS number. Threshold criteria from the Guidelines for Canadian Drinking Water Quality [GCDWQ] were then added for each of the parameters, including Maximum Acceptable Criteria [MACs] and Aesthetic Objectives [AOs].

As water quality data sets are exceedingly fraught with errors due to sampling, handling [custody and holding time], as well as laboratory error, it is critical to evaluate the reliability, or quality of the data, using some level of statistical analysis and to identify as well as remove outliers that may strongly influence the dataset. Given a major deliverable for this assignment is contoured plots of spatial data based on average values for each well location, bad data can significantly influence these plots and the analysis plus recommendations generated.

A normal distribution is one of the most common probability distributions used in the analysis of environmental data. However, it is common for aqueous chemistry data to exhibit frequency distributions that are non-negative and skewed with heavy or long right-tails. There are many statistical methods and complex software programs that are available for the analysis of aqueous chemistry data, however most of these assume that the data is normally distributed, or that the data is log-normally distributed and can be transformed. Such tests for distribution include the Shapiro Wilk *W* Test, Filliben`s statistic, the Studentized Range Test, Geary`s Test, the Chi-Square Test and the Lilliefors Kolmogorov-Smirnoff Test (USEPA, 2006).

Therefore, prior to attempting statistical methods to identify outliers, it was necessary to first characterize the data set and determine if the data was normally distributed. Basic statistical analyses were completed such as ordering [difference based on current value minus previous value], min, max, central tendency [mean, mode, geomean], verification of normal distribution, outliers and trends between neighboring values. Also included in this stage of data analysis were comparisons against GCDWQ and identification of possible background concentrations for each parameter of interest at each AWQM network site.

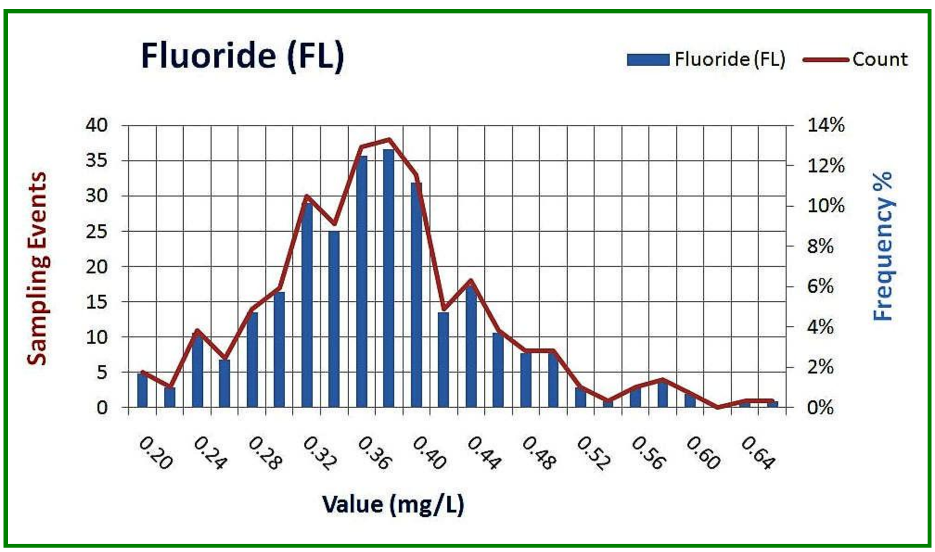
It was determined in almost all cases that the data was not normally distributed and therefore it was deemed inappropriate to identify statistical outliers using statistical outlier methods. It was therefore necessary to utilize a more visual outlier identification method, specifically the histogram. Histograms provide a visual method of identifying the underlying distribution of the data and often can reveal detailed information about data sets that may not be apparent from a statistic method - for example extreme values and multiple modes can be identified. The details of the data are lost, but an overall picture of the data is obtained.

For each AWQM network site, the range of data for each parameter at that site was divided into several bins or classes into which the data are sorted. A histogram is a bar graph conveying the bins and the frequency of data points in each bin. The two most common normalizations are relative frequencies [frequencies divided by sample size] and densities [relative frequency divided by the bin width]. Both types of histograms were used for this assignment.

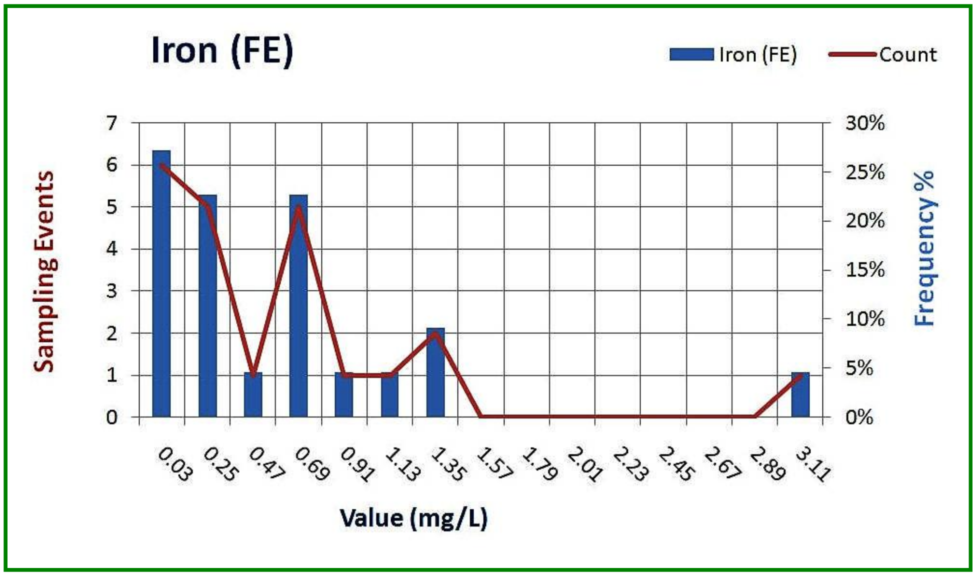
The output of the statistical analysis and identification of outliers process is a summary table for all sites as shown in **Table 1**. There are also more detailed statistical tables for each AWQM network presented in **Table 2** through **Table 5**. One of the main conclusions to be drawn from these tables is that the data is generally not normally distributed. Where mean, mode and median converge to a proximal value, this indicates that the data is more likely to be normally distributed. Where these values are divergent, the data is inferred to be non-normally distributed and less predictable.

Examples histogram plots of normally distributed, obvious outlier and multiple mode distribution of data are provide in the following graphs:

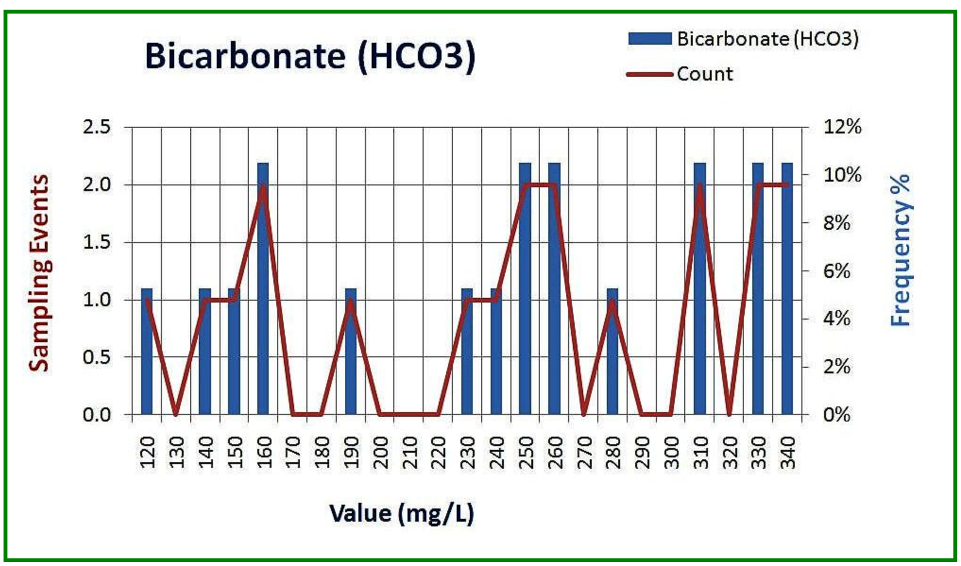
Example Histogram Plot of Normally Distributed Data for Osoyoos



Example Histogram Plot of Statistical Outlier for Iron at Eagle Rock



Example histogram plot of multiple modes for Bicarbonate in Oliver



7.3 Comparison Against GCDWQ

Water chemistry data provided by MNRO for all sampling locations in each of the AWQM networks were compared against the current guidelines for drinking water quality, specifically the Guidelines for Canadian Drinking Water Quality (2010). The suite of parameters included in the comparison included the following:

- Alkalinity [total]
- Ammonia [dissolved] - NH_4
- Bicarbonate - HCO_3
- Calcium [total] - Ca
- Chloride [dissolved] - Cl
- Fluoride [dissolved] - Fl
- Hardness [total]
- Iron [total] - Fe
- Magnesium [total] - Mg
- Manganese [total] - Mn
- Nitrate [nitrogen total] – NO_3
- Nitrite [dissolved] - NO_2
- pH
- Specific conductance
- Sulfate [dissolved] - SO_4
- Total dissolved solids - TDS
- Uranium [total] - U

Data for other water quality parameters in the raw data set from MNRO were not included in the comparison against water quality standards. The results of this analysis are presented in **Table 6**. Some parameters do not have maximum acceptable concentration [MAC], Interim MAC, or Aesthetic Objective [AO] thresholds in the GCDWQ. The background concentrations for each of the required parameters are also included in this table.

At first glance, the table infers there are many exceedences at all AWQM network sites for iron [total], arsenic [total] and manganese [total]. It is postulated that these results are artificially elevated due to turbid field samples, however turbidity is not a parameters that has been monitored. Similar water quality studies in BC have identified turbidity-driven "spikes" for total metals [Dessouki, 2009]. However, in this study, other total metals such as uranium and potassium do not show the same variability and hence potential co-variability with turbidity. Correlation plots of Total Dissolved Solids [TDS] versus iron, manganese and arsenic suggest that there is poor correlation between these parameters. Therefore, TDS is not a good surrogate for turbidity.

There was insufficient data for cation/anion charge balance calculations, specifically very infrequent results for bicarbonate, which is a major anion.

There are relatively few parameters that exceed the GCDWQ standards. Nitrate is consistently above acceptable limits in one well in Oliver [WTN 21867], and in a few wells in Grand Forks. There are also single sample event exceedences for nitrate in Grand Forks [n=9] and Osoyoos [n=15]. Manganese and iron are elevated in Eagle Rock.

Those parameters in the data set not considered include: silver (total/dissolved), aluminum (total/dissolved), boron (total/dissolved), barium (total/dissolved), beryllium (total/dissolved), bismuth(total/dissolved), bromide (dissolved), cadmium (total/dissolved), cobalt (total/dissolved) chromium (total/dissolved), copper (total/dissolved), fluoride (total), lithium (total), molybdenum (total/dissolved), Kjeldhal Nitrogen (total/dissolved), nickel (total/dissolved), ortho-phosphate (dissolved), phosphporous (total/dissolved), lead (total/dissolved), sulphur (total/dissolved), niobium (total/dissolved), selenium (total/dissolved), silica (dissolved), tin (total/dissolved), strontium (total/dissolved), tellurium (total/dissolved), titanium (total/dissolved), thallium (total/dissolved), vanadium (total/dissolved), zinc (total/dissolved) and zirconium (total/dissolved).

7.4 Trial Spatial Plots for Identification of Temporal Outliers

EnviroInsite was used to generate trial spatial plots using uncensored data to identify background water quality, as well as spatial and temporal trends, plus visual clustering and visible outliers. To accomplish this, plots of contoured average values for each parameter of interest were generated which also included smaller temporal plots for the same parameter adjacent to each well. The trial plots were then reviewed to visually identify outliers based on the following:

- Average value for a specific well location was biased by an outlier or based on a limited number of sampling events
- Average value and temporal values were not consistent with nearest neighbor value or with spatial and temporal trend
- Consistent lower limits representative of a laboratory non-detect. Consistent lower bound to plotted results was interpreted as detection limit and not a background concentration for the parameter of interest
- Multiple modes of water quality based on heterogeneity or direction of flow in aquifer.
- Typically first and last data points were not removed due to the potential for the data being part of a trend prior to sampling at the location in question, or the beginning of a yet un-identified trend

Contouring was done using the default interpretation routine used by EnviroInsite, which is the inverse distance method. Contour intervals were typically chosen by dividing the difference between the maximum and minimum level, by a number between 5 and10. This reduced the number of colors [and gradational differences between them] used in plotting, which enhanced the visual interpretation.

Examples of visual outliers are presented in **Figure 20** through **Figure 23**.

7.5 Data Transformation

Based on the combined results of the statistical data analysis and the visual identification of temporal trends using EnviroInsite, erroneous readings or "outliers" were removed [censored]. A summary of the candidate outliers and transformation completed on each data set in provided in **Table 7**.

The original data sets used for the trial plots have been copied to the disk accompanying this report. It may be that further, more complex, multi-parameter correlation assessment may determine that the outliers are valid data points, presumably related to un-documented events, or as a result of factors that have not been considered.

In addition to the suspected relationship between turbidity and total metals results, it is apparent that some of the outliers are very likely related to mislabeling of samples. An obvious example of this occurs in Grand Forks between WTN 7962 and WTN A, where the results for all parameters for a sampling event on 18 September 2007 are inter-changed and appear in temporal plots as a high outlier in one well and a low outlier in the other. There are also suspected transcription errors, where outliers are an order of magnitude variant, inferring a wrong decimal point during entering of data.

The outputs of this work are the data input files for the EnviroInsite Software. The input files are small in size, with the exception of the observation workbook [tab], which ranged from 288 lines [for 5 wells] to 4474 lines for Grand Forks [43 wells]. Printouts are provided in **Appendix C** for EnviroInsite input files for each site including workbooks [tabs] for wells, screens, constituents, stratigraphy, and the first page only of observations. Copies of the un-censored data files [input and output] for each AWQM network site are included, along with the final input and output files, on the disk which accompanies this report.

7.6 Quality Assurance / Quality Control [QA/QC]

The following tools were incorporated to aid in Quality Assurance & Quality Control [QA/QC] of data:

- Automation of data assembly where possible, using MS Access and macros;

- Adjusting data sources to be comparable with each other [such that ordering of columns & parameter listings were consistent]. Blank columns were added in to some spreadsheets to ensure consistent column position for each parameter;
- Adding header numbers to columns to facilitate consistent referencing;
- Assigning labels to the parameters to facilitate/simplify referencing;
- Maintaining consistency using a building block process by developing a template for one parameter at one site, duplicating it for the remaining parameters at that same site, then using the same complete file format/structure at other network sites;
- Cross-checking, using macros and linked spreadsheets to compare data values between new data files and original source data files; and,
- Updates/Changes, as required, were applied to all files simultaneously to maintain consistency.

Copies of all source data files, MS Excel spreadsheets and MS Access databases used for data conversion, analysis and QA/QC are provided on the disk that accompanies this report. A listing of the files and brief metadata are provided in **Appendix B**.

8. SOFTWARE TRAINING

Three licenses for EnviroInsite© [V.7] were provided to MNRO staff in Penticton and training on how to use the software was provided. The purpose of the training was to allow MNRO staff to use the software to communicate the findings of this study to colleagues and the general public. The training was also geared towards development of a tool that could be used for analysis of other hydrogeological data for other sites that presumably could be collected by MNRO independently of the AWQM Networks.

The training included the following:

- how to prepare input files in MS Excel;
- how to import and geo-reference images;
- how to produce spatial contour and temporal plots for chemistry;
- how to use plan view for generation of cross-sections ;
- how to prepare input files for cross-sections and interpret hydrostratigraphic units using geo-statistical analysis; and,
- how to prepare piper plots, stiff diagrams, scatter plots and time history charts.

9. AMBIENT NETWORK ANALYSIS

Based on the site-specific objectives for the 6 networks and the guiding principles of monitoring outlined by Wei & Cui [2004], a qualitative evaluation matrix was developed to assist with the analysis of each network. The matrix is a spreadsheet divided into 5 fundamental network objectives including:

1. Spatial and depth coverage;
2. Suite of analytes and lab methods;
3. Sampling frequency;
4. Field methods and validation of data; and,
5. Analysis and reporting.

The matrix is based on standard performance evaluation principles, which include the selection of measurement criteria and subsequent use of these criteria to determine the current performance or operational status of what is being evaluated [in this case an AWQM network]. The remainder of the process includes identification of changes that have occurred, followed by an assessment of what options, if any, are appropriate in response to the changes noted.

For this assignment, the measurement criteria selected included the following:

a. Number, location of background water quality wells sufficient;
b. Coverage in areas of suspected impacts appropriate;
c. Spatial modes exist in aquifer chemistry;
d. Appropriate coverage in all formations, either hydraulically isolated ,or not;
e. Indicator parameters capable of identifying existing or potential water quality issues;
f. Continuity in parameters tested and the lab detection limits;
g. Possible to do a cation/anion charge balance on the resultant chemistry;
h. Opportunity to use surrogate monitoring methods/parameters;
i. Appropriate frequency for primary and secondary well locations and analytes;

j. Make sense to sample for seasonal variability;

k. Lab results subjected to immediate QA/QC analysis, such that re-testing is possible of samples that still reside at the laboratory; and,

l. Data regularly analyzed for gaps, trends, etc and is the information used appropriately to communicate with government agencies, water users and the general public

A template of the evaluation matrix, including more specific details regarding each criteria, is presented in **Table 8**.

A summary of the water quality trends for the 20 parameters for all networks included in this assessment is presented in **Table 9.**

9.1 Eagle Rock

The AWQM network at Eagle Rock has 6 wells that are clustered in the Industrial Park Area at the south end of the aquifer within the portion that is unconfined. The majority of these wells [4] are located within a small green area measuring 100 m by 100m that is bounded by Spallumcheen Way, Crosier Rd and Pleasant Valley Road. We refer to this area as Monitoring Well Area 1 [MWA1]. Three of the 4 wells in MWA1 are public water supply wells operated by Eagle Rock [ERID] and Larkin Improvement District [LID] and the 4th is MNRO Observation Well 180. Two more wells operated by LID are used as monitoring wells: one located 350 m to the west of MWA1, along Crozier Road. Another is located 1.2 km southeast of MWA1, along Highway 97, within the log storage yard of the Tolko Mill. There are no nested wells [multiple level at a single location] in this network. The density of monitoring wells is 1.3 wells/km^2 and only approximately 33 percent of this aquifer is monitored, the majority of monitoring locations being to the south and mid-gradient with regards to the direction of flow through the aquifer.

A total of 6 sampling events have been completed in this network since July 1997. A total of 35 samples, corresponding to approximately 5.8 samples per monitoring well have been collected. This is a relatively sparse data set in terms of number of wells and number of sampling events, upon which to complete a spatial and temporal assessment. The frequency of sampling has varied from yearly to every 5 years. The suite of parameters tested for during each sampling event has varied from a minimum of 8 parameters to a maximum of 19 for each sampling event. Of the 20 parameters of interest in this study, all have been regularly included in the sampling events, except HCO_3 [bicarbonate].

Spatial analysis of average values for each parameter infers that there are no spatial trends that are consistent with aquifer boundaries, recharge areas and direction of flow. WTN 38720 [LID Well 4], consistently shows higher concentrations for all parameters except NO_3. Initially, this well showed higher values for NH_4, but these have declined.

Temporal analysis infers that NH_4 and pH are trending downwards and Ca, Cl, Fe, Mn, NO_3 and specific conductance are trending upwards. The current values for Fe are above GCDWQ standards in WTN 38720 [LID Well #4] and WTN 32340 [Obs Well 180]. Mn is also elevated above GCDWQ in well [LID Well #4]. The data set for HCO_3 is insufficient in size to allow for temporal analysis.

The original objective of the monitoring network in this area was to monitor NO_3 and characterize ambient water quality. The available information infers that the network has appropriately documented NO_3 levels in the immediate area of MWA1. However, there is insufficient spatial coverage in this aquifer to establish background water quality and to determine if other areas of the aquifer have also been impacted by NO_3, specifically those areas to the north where agricultural land use is equally dominant and the aquifer is unconfined.

The most up-gradient well in the existing network is WTN 38720 and this well shows elevated concentrations for most of the parameters of interest relative to the other wells in the network. It is apparent that this well has been impacted by industrial activities. There are also indicators of impact at WTN 28325 and WTN 56810 [NO_3 elevated or increasing]

Based on the network evaluation matrix as a guideline, consideration should be given to modifying the network as follows:

1. The proximity of the 4 wells clustering in MWA1 infers that there is redundancy in sample results. At least 2 of the 4 wells in this area could be eliminated;

2. Based on spatial and temporal trends for various parameters in WTN 38270, the frequency and suite of analytes for analysis at this well should be increased to the maximum allowable [yearly and all 20 analytes];

3. All wells should be sampled for all of the 20 parameters of interest during each sampling event;

4. Turbidity and the corresponding dissolved fraction for each parameter of interest should also be included;

5. Anecdotal information suggests that Tolko has several wells at their mill site that are dedicated to an annual sampling program that is tied to the renewal of operational permits with MNRO. Data from these wells exists back to the mid 1990s. Consideration of historical data from these wells and incorporation of some of these wells into the AWQM network will enhance the coverage of the south end of the aquifer and assist with the analysis of issues related to WTN 38270; and,

6. Additional monitoring wells should be established at the north end of the aquifer in the area of Pleasant Valley Cross Road, between Pleasant Valley Road and Highway 97. Several domestic wells already exist in this area.

The Network Evaluation Matrix for Eagle Rock is presented in **Table 10** and spatial as well as temporal plots for the various parameters are presented in **Appendix D**.

9.2 Oliver

The 2 AWQM networks at Oliver have 13 wells combined, most of which are located within close proximity to the Okanagan Channel, or Tugulnuit Lake. The exception to this are WTN 21867, WTN 82376 [Town of Oliver Rockcliffe Well] and WTN 53199, which is a well at Sportsman's Corner that was constructed and tested by MNRO in 1980 that is no longer monitored. The density of monitoring well coverage in this network is 2.1 wells/km^2, is average as compared to the density of monitoring in other AWQM networks. The spatial coverage in this network is very good in the north and central portions of the aquifer as there are monitoring wells available at the 2 dominant recharge areas to the aquifer well [Park Rill and Vaseux Creeks] and the placement of wells covers flow through the aquifer along the majority of the flow path. The lower 25 percent of this aquifer, between the Town of Oliver and Osoyoos Lake, has no monitoring well coverage. The majority of the monitoring wells in this network are municipal water supply wells operated by the Town of Oliver. There are no nested [multiple level at a single location] wells in this network.

A total of 10 sampling events have been completed in this network since 1985, with 2 events only prior to 2003 and sampling completed annually every year since then. A total of 63 samples, corresponding to approximately 4.8 samples per monitoring well have been collected. This is a relatively sparse data set in terms of number of wells and number of sampling events. While the spatial coverage and number of water quality results are adequate for a spatial analysis, the data set has limited utility for a temporal assessment. The suite of parameters tested for during each sampling event has varied from a minimum of 1 parameter [pH] to a maximum of 20 for each sampling event. Of the 20 parameters of interest in this study, all have been regularly included in the sampling events, except HCO_3. At least one well, WTN 53199 [Sportsman's Corner] has data for only one sampling event, when it was constructed and tested in 1980.

Spatial analysis of average values for each parameter infer several natural chemistry trends in the two aquifers [MNRO 254 + 255], generally following the direction of flow in the aquifer from north to south. Due to the contouring method employed by the EnviroInsite software and the low mineralization in WTN 49935 at the north end [recharge] versus the elevated mineralization in WTN 21867 at the south end, the visual trend could be misleading. There is no visual trend for As. There are also elevated values for Fl, Mn, Na and SO_4 at WTN 53199, suggesting that the ambient water quality from up-gradient of Sportman's Corner within the Park Rill catchment is influenced by land use activity in that area, prior to entering the area covered by the network. There are also higher levels of U at WTN 83011/83010, to the southwest of Tugulnuit Lake, which are above GCDWQ. WTN 21867 [Oliver Rockcliffe Well] consistently shows higher concentrations for all parameters, with NO_3 values exceeding GCDWQ on some occasions.

Temporal analysis infers that NH_4 and K are trending upwards. The data set for HCO_3 is insufficient in size to allow for temporal analysis.

The original objective of the monitoring network in this area was to monitor NO_3 and characterize ambient water quality. The available information infers that the network has appropriately documented NO_3 levels, both spatially and temporally.

Based on the network evaluation matrix as a guideline, consideration should be given to modifying the network as follows:

1. Based on spatial and temporal trends for various parameters in WTN 62966, the frequency and suite of analytes for analysis at this well should be increased to the maximum allowable [yearly and all 20 analytes];
2. The Sportsman's Corner Well [WTN 53199] should be included in the monitoring network;
3. All wells should be sampled for all of the 20 parameters of interest during each sampling event;
4. Turbidity and the corresponding dissolved fraction for each parameter of interest should also be included;
5. Anecdotal information suggests that The Town of Oliver has several additional wells available for monitoring including, for example, CPR, Lions and Miller Road wells. Consideration of historical data from these wells and incorporation of some of these wells into the AWQM network will enhance the spatial coverage in this aquifer; and,
6. Additional monitoring wells should be established at the south end of the network area, between Oliver and Osoyoos Lake to verify that NO_3 impacts at the south end of the existing coverage do not extend further down-gradient. There are several candidate wells located in this area, but the unconfined aquifer becomes relatively thin in this part of the Valley and many of the existing wells penetrate confined aquifers in this area. It may be necessary to construct dedicated multi-level [nested] observation points in this area.

The Network Evaluation Matrix for Oliver is presented in **Table 11** and spatial as well as temporal plots for the various parameters are presented in **Appendix E**.

9.3 Osoyoos

The 2 AWQM networks at Osoyoos have 27 wells combined, including 9 domestic water wells, 7 nested piezometer sites constructed by MNRO in 1989 and 4 monitoring wells that are also used for water supply. The density of monitoring well coverage in this network is 0.7 wells/km^2, which is below average as compared to other AWQM networks. However, the spatial coverage in this network is relatively very good. The majority of the monitoring wells in this network are in close proximity to either Osoyoos Lake or other smaller surface water bodies such as Peanut Lake and Elks Hall Lake.

A total of 24 sampling events have been completed in this network since 1985, with sampling completed annually, except for 2010. A total of 433 samples, corresponding to approximately 18 samples per monitoring well have been collected. The data set for these AWQM networks is significantly populated and there is sufficient data for spatial and temporal analysis. The suite of parameters tested for during each sampling event has varied from a minimum of 1 parameter [pH] to a maximum of 20 for each sampling event. Of the 20 parameters of interest in this study, all have been regularly included in the sampling events, except HCO_3.

Spatial analysis of average values for each parameter of interest do not infer any trends across each aquifer that would be related to groundwater flow direction, specifically chemistry differences that could be differentiated between areas of recharge and discharge. There are no identifiable trends or elevated point values for Alkalinity, As, NH_4, Ca, Fl, hardness, Mg, Na, NO_2, SO_4 and pH.

There are several indications of impacts in the aquifer as noted by clustering of elevated values for certain parameters in relation to suspected up-gradient contaminant sources. The most relevant of these is extensive elevated NO_3 levels along Highway 97 to the north of the Town of Osoyoos, with the highest values being centered in proximity to WTN 14402. Lower NO_3 levels, but still high and of concern with regards to drinking water quality, also exist in the areas along Osoyoos Lake [WTN 93982, WTN B, WTN 82537] and to the west of Peanut Lake in WTN 93990, 93989D and WTN 93987, plus in the area of Elks Hall Lake in WTN 93991.

Elevated K is noted in WTN 14402 on the west side of the lake and in WTN 14406 on the east side. Both of these areas are within or down-gradient of agricultural areas. The possible source of elevated K could be NPK type fertilizers used for agriculture. There are also elevated levels of Cl, in WTN 19166 and WTN C. These are interpreted as being due to on-site [domestic] sewage disposal systems in these areas. Further investigation is necessary to verify if this is the case. Contouring suggests that HCO_3 is elevated in the area of WTN 93982 S/D, WTN B and WTN 23677. The interpretation of HCO_3 is based on a very limited data set; however the possible reasons for the higher levels in these areas should be investigated.

Also of potentially significant importance is the elevated Fe levels in many wells located in close proximity to surface water [Lake Osoyoos, Peanut Lake and Elks Hall Lake]. It is possible that the elevated values seen at these location is due to turbidity in collected samples, with the exception of consistent high levels in WTN 93984 S. This needs to be further investigated.

The original objective of the monitoring networks in this area was to monitor NO_3 and characterize ambient water quality. The available information infers that the network has appropriately documented NO_3 levels, both spatially and temporally.

Based on the network evaluation matrix as a guideline, consideration should be given to modifying the network as follows:

1. Based on spatial and temporal trends for various parameters in WTN 14402, the frequency and suite of analytes for analysis at this well should be increased to the maximum allowable [yearly and all 20 analytes];

2. All wells should be sampled for all of the 20 parameters of interest during each sampling event; and,

3. Turbidity and the corresponding dissolved fraction for each parameter of interest should also be included.

The Network Evaluation Matrix for Osoyoos is presented in **Table 12** and spatial as well as temporal plots for the various parameters are presented in **Appendix F**.

9.4 Grand Forks

The AWQM network at Grand Forks includes 21 sample points at 28 sites that provide appropriate spatial coverage of the 2 dominant recharge areas [from north and southwest], the dominant agricultural areas [south, west and northwest] and the down-gradient portions of the aquifer to the east. Assuming one sample location at each nested monitoring site, the density of monitoring well coverage in this network is 1.8 wells/km^2, which is average. Approximately half of the monitoring wells in this network are dedicated monitoring wells constructed by MNRO in 1989. Many of these locations are nested wells and are located to the south of the Kettle River along Carson Road. Several monitoring wells are also municipal or irrigation wells operated by the City of Grand Forks and the various water utilities in the area [Sion, Covert and Almond Gardens IDs]. There are also some domestic wells in strategic locations that are used as monitoring wells.

A total of 21 sampling events have been completed in this network since 1985, with 2 events only prior to 1998 and sampling completed annually every year since then. A total of 443 samples, corresponding to approximately 18.5 samples per monitoring well have been collected. The data set for the AWQM network is the most populated of all of the networks addressed and there is sufficient data for spatial and temporal analysis. The suite of parameters tested for during each sampling event has varied from a minimum of one parameter [pH] to a maximum of 20 for each sampling event. Of the 20 parameters of interest in this study, all have been regularly included in the sampling events, except HCO_3.

Spatial analysis of average values for each parameter infers only a limited number of trends which are attributable to natural flow in the aquifer. Such trends include higher TDS, hardness and specific conductance levels in the north, presumably indicative of higher mineralized groundwater from the Grandby Valley entering the area from the north. There are no identifiable trends or elevated point values for As, HCO_3, Fl, Mg and NO_2.

There are several indications of impacts in the aquifer as noted by clustering of elevated values for certain parameters in relation to suspected up-gradient contaminant sources. The most relevant of these is extensive elevated NO_3 levels in the southeast corner of the network area, centered around WTN 59170, WTN 59171, WTN 37623 to the south of the airport and WTN 7990 and WTN 7873 to the east of the airport. These areas are within intensive agriculture areas, or immediately down-gradient with respect to the direction of groundwater flow. There are also elevated values for K and U in these areas. The possible source of elevated K could be NPK type fertilizers used for agriculture.

A second area of suspected impacts is to the immediate east and south of the large industrial complex along 2nd St and 65th Avenue. There are elevated values for Na and Fe, as well as lower values for pH in this area.

A third area of suspected impacts is at Boundary Hospital. There are indications of elevated Cl, SO_4, specific conductance, and NO_3. There is also elevated alkalinity in a wider area in the north that includes the Hospital and WTN 7962.

Temporal analysis infers that NO_3 levels are declining in most areas and Cl increasing in many others. The data set for HCO_3 is insufficient in size to allow for temporal analysis.

The original objective of the monitoring network in this area was to monitor NO_3 and characterize ambient water quality. The available information infers that the network has appropriately documented NO_3 levels, both spatially and temporally.

Based on the network evaluation matrix as a guideline, consideration should be given to modifying the network as follows:

1. Based on spatial and temporal trends for various parameters in WTN 35526, WTN 14947, WTN 58625, WTN 7873, WTN 59170/59171 and WTN 37623, the frequency and suite of analytes for analysis at these wells should be increased to the maximum allowable [yearly and all 20 analytes];

2. All wells should be sampled for all of the 20 parameters of interest during each sampling event;

3. Turbidity and the corresponding dissolved metal fraction for each parameter of interest should also be included; and,

4. Sion ID Well #4 should be included as a permanent monitoring well in the network.

The Network Evaluation Matrix for Grand Forks is presented in **Table 13** and spatial as well as temporal plots for the various parameters are presented in **Appendix G**.

10. CONCLUSIONS AND RECOMMENDATIONS

In conclusion, the methodology utilized for this assignment, which combines statistical analysis with the plotting of data in a spatial and temporal format, is very effective in identifying outliers, data gaps and trends in water quality data.

The degree of effort required to translate tables from the current spreadsheets used by MNRO into spreadsheets that are efficient for identification of statistical values and comparison against GCDWQ, is considerable. Although this work was completed with macros, it is not a user-friendly process. The QA/QC process is also very detailed and not easily followed.

A comparison between the effectiveness of statistical methods for data validation and QA/QC, as opposed to visual methods utilizing the EnviroInsite© software, suggests the software is capable of identifying outliers as effectively as the statistical methods. The EnviroInsite© software represents a significant step-forward for MNRO staff, which enables the continual updating of any water quality database which is stored in MS Excel or MS Access and the ability to complete regular analysis of both spatial and temporal trends.

In conclusion, we believe that the EnviroInsite© software is capable of visually identifying outliers and therefore, more rigorous QA/QC of data is not warranted. However, should such additional QA/QC be required, it is recommended that commercial software for statistical analysis of water quality data be utilized. The EnviroInsite© software has been designed to work with a statistical package called EQUIS©, but there are other software packages available that will do the statistical analysis appropriately.

More specific conclusions and recommendations are provided in bullet form as follows:

C1 With the exception of the Eagle Rock, all of the AWQM networks have been relatively successful in documenting baseline water quality conditions and identifying trends in parameters of interest related to the land use and aquifer setting;

C2 There are an insufficient number of sampling events and sampling locations available for the Eagle Rock AWQM Network to allow for appropriate spatial and temporal analysis;

C3 All AWQM networks have issues relating to consistency of parameters included for testing, with the frequency and regularity of sampling and with the application of consistent field methods for the collection of samples;

C4 Eagle Rock does not have appropriate up-gradient [background] sampling locations, or appropriate spatial coverage to the north, east and south of existing network footprint area;

C5 Grand Forks has at least two modes for background concentrations for many parameters; the source water from the Grandby River Watershed influencing background concentrations in the north of the aquifer and the source water from the Kettle River Watershed influencing concentrations at the southwest corner of the aquifer;

C6 The majority of sampling completed to date has been for total metals analysis, for comparison against acceptable concentrations and aesthetic objectives outlined GCDWQ. Sample results indicate a significant number of outliers for total metal concentrations for, among others, arsenic [As], iron [Fe], manganese [Mn] and uranium [U]. Total metals analysis for metals such as these can be significantly influenced by field sampling methods which do not remove turbidity;

C7 Within the Eagle Rock AWQM Network, WTN 38720 [Larkin Well #4] has significantly different chemistry than the other wells monitored in the network. In consideration of the up-gradient position of this well in comparison to the others, the chemistry infers the water quality in this area of the aquifer has been impacted;

C8 Within the Oliver AWQM Network, WTN 82376 has significantly higher NO_3 levels than other wells in the area. There is a localized source of nitrogen in this area that influences NO_3, NO_2 and NH_4 levels. This is likely related to agricultural activity in the area. In general NO_3 levels are decreasing in the area, possibly due to more awareness of sustainable application of fertilizers. SO_4 levels are also decreasing. There is also an upward trend in potassium [K], which could also be related to NPK type fertilizers;

C9 Elevated Uranium [U] also exists in wells to the southeast of Tugulnuit Lake in the Oliver AWQM Network. The variability in results suggests these levels could be associated with higher turbidity, which needs to be confirmed;

C10 Within the Osoyoos AWQM Network, there are elevated NO_3 levels to the north of the Town and along the highway, specifically in the immediate area of WTN 14402. There are also isolated areas where chloride [Cl] is elevated above background levels but still significantly lower than GCDWQ. These areas are believed to be where on-site sewage disposal is utilized;

C11 Within the Grand Forks AWQM Network, there are at least 2 areas where NO_3 levels are elevated. These include the north end of the aquifer in the area of WTN 35526 and in the south east in the area of WTN 59171, WTN 37623, WTN 7990 and WTN 7873. These same areas also have elevated potassium [K]. Elevated levels of both NO_3 and K could be related to fertilizer application. However, nitrate levels are gradually decreasing in the aquifer;

C12 Point source contamination is suggested in the area of Boundary Hospital, due to elevated levels for Cl, NO_3, SO_4 and specific conductance; and,

C13 Point source contamination is also suggested in the area of the large industrial complex in the area of 2nd Street and 65th Avenue. There are trends in the nearby monitoring well, WTN 59167, of decreasing pH and increasing iron [Fe] and sodium [Na].

Based on the above conclusions, the following recommendations are provided:

R1 All AWQM networks should be more regularly sampled and the suite of parameters included should continue to include total metals for comparison against historical results and GCDWQ. However, the suite of parameters should be expanded to include major cations/anions such that a charge balance check can be completed. Turbidity should also be included to identify where total metals results are potentially impacted by sediment in samples. Consideration should also be given to testing for dissolved metals, not as a replacement for total metals, but to compliment the total metals results and identify where the results for total metals analysis may be misleading;

R2 Standard protocols for field sampling and data validation should be implemented for the preservation of data quality. This includes more prescriptive sampling methods and QA/QC checking of data immediately after entering results in the EMS database, such that issues can be identified and the samples re-tested in the lab before disposal;

R3 At least 2 of the 4 closely clustered wells in the Eagle Rock AWQM Network could be removed from the monitoring schedule. In lieu of these wells, establish two additional monitoring locations to the north in the same aquifer;

R4 There are available wells at the south end of the Eagle Rock Aquifer that could be used for monitoring;

R5 The Oliver AWQM Network is functioning appropriately. If anything, more regular monitoring is prudent in WTN 53199, which is within the source area of recharge from the Park Rill Watershed. The Park Rill Watershed has considerable agricultural activity;

R6 Additional, more frequent and comprehensive monitoring is warranted in the Oliver Area within WTN 21867 and nearby wells, to identify the source of nitrate in this area;

R7 For the Osoyoos AWQM Network, consideration should be given to removing some of the nested monitoring well locations from the monitoring schedule. There does not appear to be significant differences in chemistry results between the aquifer depths sampled. In lieu of the second sampling depth at each nested monitoring well, there could be additional wells sampled on the east side of the lake and on the west side to the north;

R8 Additional, more frequent and comprehensive monitoring is warranted in the Osoyoos Area within WTN 14402 to identify the source of nitrate in this area;

R9 For the Grand Forks AWQM Network, consideration should be given to removing some of the nested monitoring well locations from the monitoring schedule. There does not appear to be significant differences in chemistry results between the aquifer depths sampled. In lieu of the second sampling depth at each nested monitoring well, there could be additional wells sampled at the extreme north end of the aquifer to better document the water quality coming from the north, or at the east end of the aquifer to have better spatial coverage down-gradient of the industrial and agricultural activities in this area;

R10 In Grand Forks, the type and fate of the waste stream at Boundary Hospital needs to be verified and, if it is determined that part of the waste stream is disposed of to ground, this activity should be stopped; and,

R11 The identification of spatial and temporal trends at these AWQM network sites in relation to land use as well as an understanding of the hydrogeology in the area, requires a knowledgeable hydrogeologist in the role as the final QA/QC step. This will greatly assist in the identification of field or laboratory errors that may have otherwise gone unnoticed, and will provide for the best chance to understand the meaning of the reported results.

11. LIMITATIONS AND USE OF THIS REPORT

This report has been provided by Western Water Associates Ltd. for the particular purpose outlined in the work scope presented in the preamble of this document. Any use which a third party makes of this report, or any reliance on or decisions to be made based on it, are the responsibility of such third parties. Western Water Associates Ltd. accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this report. Additional restrictions and limitations that apply to this assignment are outlined in the attached Report Limitations.

12. CLOSURE

We trust that the professional opinions and advice presented in this document are sufficient for your current requirements. Please note that there are restrictions and limitations that apply to the scope of our services, as outlined in the attached page of Report Limitations. Should you have any questions, or if we can be of further assistance in this matter, please contact the undersigned.

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Attachments

RA/ra/pa

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