Hydrogeological Review of Aquifers in Electoral Area H in Support of the Official Community Plan Update

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1.0 INTRODUCTION

1.1 Background

The Drinking Water & Watershed Protection program was established by the Regional District of Nanaimo (RDN) in 2008 to address education, science and policy development associated with water resource protection in the region. The RDN's current focus is related to watershed protection initiatives including: expanded water monitoring in key areas, improving the understanding of aquifer recharge and capacity, and policy development related to land use decision making.

Under a Standing Offer Agreement (SOA) for consulting hydrogeological services, Waterline Resources Inc. (Waterline) was requested to work collaboratively with the RDN to develop a scope and a fee budget for a hydrogeological review of aquifers located in Electoral Area H in support of the development of an undated Official Community Plan (OCP).

Electoral Area H is located within the Qualicum River and Little Qualicum Water Regions as defined in the Phase 1 Water Budget report (Waterline, 2013). The enclosed report provides a summary of the work completed by Waterline including conclusions and recommendations to support the development of the Electoral Area H OCP update.

1.2 Hydrogeology and Aquifer Recharge

Assessing hydrogeology and mechanisms for aquifer recharge can be complex in areas where multiple aquifers have been mapped and monitoring data is incomplete or does not exist. However; along coastal areas of British Columbia (BC), and specifically the east coast of Vancouver Island, recent geological history allows hydrogeologists to simplify our understanding of how water cycles through the various aquifers, streams and creeks on its journey into Georgia Strait. The following provides a list of important facts about hydrogeology in the region:

- All water at the surface and the shallow subsurface used for supply in Electoral Area H originates as precipitation (rain near the coast or snow in the mountains);
- Both surface and groundwater systems are gravity driven. That is to say that water entering an aquifer, river/creek/stream will eventually flow to Georgia Strait under the force of gravity if it is not captured by a water user along its path. It is only a matter of time and is directly dependant on the topography which creates the gradient, and for aquifers also dependant on the permeability of geologic materials.
- Deposition of unconsolidated (sand and gravel) aquifer materials along the coast of BC occurred in relatively recent geologic time (<70,000 years ago). Deposition of aquifer materials before and during glaciation has essentially created a layer-cake succession of unconsolidated sediment units over bedrock along the coastal mountains up to about 300 m above sea level.
- At the regional scale, geologic materials are generally connected (not always) and precipitation and snowmelt entering shallow aquifers will tend to recharge deeper

underlying aquifers, and/or discharge to adjacent creeks and rivers as it moves towards the ocean.

- Unconsolidated sediments in contact with bedrock also receive recharge from the adjacent bedrock through fractures which is referred to as “Mountain Block Recharge”. Isotopic and geochemical techniques exist that can help assess the origin of recharging water and differentiates mountain block recharge from direct vertical recharge, however, no such data exists within the RDN to complete such an analysis.

Developing an understanding of the hydrogeology involves a mapping exercise of the “plumbing system” from recharge to discharge. A thorough understanding of the geological setting is needed to assess the groundwater pathways and water level data is needed to determine the pressure which is the driving force in the aquifer system. To complete the analysis, sufficient well data (water levels, aquifer permeability, and groundwater chemistry) is required. Where data is available, statistically meaningful conclusions can be drawn and appropriate groundwater management strategies can be developed. As a simple example, the Provincial water well database indicates that over 360 water wells may be in use in Electoral Area H. However, there are only four BC Ministry of the Environment observation wells in the region to assess seasonal recharge to the various aquifers which is needed to manage the water resources. Additional water level data are also available from the volunteer monitoring network wells in the region.

The enclosed report focuses on improving the hydrogeological understanding of the mapped aquifers within Electoral Area H and makes a qualitative assessment of the sources and primary mechanisms for aquifer recharge and groundwater surface water interaction.

1.3 Project Scope Development

In collaboration with the RDN, Waterline developed a work plan to review hydrogeology information for aquifers in Electoral Area H to support the updating of the OCP. The focus of the study was as follows:

- Review hydrogeological studies and the hydrogeological monitoring data collected in Electoral Area H since the Phase 1 Water Budget Project was completed (Waterline 2013); this would include all data collected since January 2011. The review would allow an assessment of the aquifer response to the extremely dry conditions experienced from July to September 2015, which may provide some insight into the sources of aquifer recharge.
- Provide a qualitative assessment of aquifer recharge within Electoral Area H to help inform the OCP update process, and
- Provide a qualitative assessment of groundwater-surface water interactions to help inform the OCP update process.

1.4 Study Area Definition

The study area for the current work includes the aquifers mapped as part of the BC Aquifer Classification Database (MOE 2016) within the boundaries of Electoral Area H (Area H), as well as the upstream catchment that may be contributing recharge to those aquifers. Area H encompasses the Big Qualicum Water Region as was defined in the RDN Water Budget Study (Waterline 2013), with the exception of Aquifer 414 located in the northern most section of the Water Region, and the northern portion of the Little Qualicum Water Region, as shown on Figure 1. Specifically, the aquifers included in the present study are; Aquifer 416, Aquifer 421 and Aquifer 655 in the Big Qualicum water region; Aquifer 622, which straddles the Big Qualicum and Little Qualicum water regions; and Aquifer 661 located within the Little Qualicum Water Region.

2.0 OVERVIEW OF REGIONAL AQUIFER MAPPING AND PRECIPITATION DATA

2.1 Geological Survey of Canada – Nanaimo Lowland Study Reports

The Geological Survey of Canada (GSC) has recently completed the Nanaimo Lowland Groundwater Study in collaboration with the BC Ministry of the Environment (MOE), Ministry of Forests, Lands, and Natural Resource Operations (MFLNRO) and the Regional District of Nanaimo (RDN). The study area extends 60 km along the eastern coast of Vancouver Island from Deep Bay to Nanoose Bay. As part of the program, five geological cores were drilled and multi-levels monitoring wells were installed across the Nanaimo Lowlands, two of which are located in Area H.

The following reports by the GSC were used by Waterline to update the conceptual hydrogeological/aquifer models in the region:

- Bednarski (2015) provides a detailed description of the depositional history of the surficial sediments that form the surficial aquifer and aquitard sequences in the Nanaimo Lowland, including radio-carbon dating of sedimentary units. This work provided a critical update to the 50-year old surficial geology map (Fyles 1963).
- Crow et.al. (2014), presents downhole geophysical data for the drilling program boreholes used to differentiate between the various geological units.
- Knight et.al. (2015), presents chemostratigraphy data for the drilling program boreholes, which helps differentiate between the various pre-glacial and glacial events based on chemical signatures of the source material.
- Benoit et.al. (2015) presents a 3D hydrostratigraphic model of the Nanaimo Lowland aquifers based on a compilation of the information gathered in the other studies.

The GSC study reports provide a critical update to the complex geological and hydrogeological environment in the region. The applied scientific approach by the GSC provides better definition of geologic units and aquifer systems and was used to verify water well assignment (or reassignment) to the appropriate aquifers previously mapped by the Province. This first step was critical for the evaluation of aquifer recharge.

Figure 2 shows the geological sequence of the geological and hydrogeological units identified in the Nanaimo Lowland groundwater study (Benoit et al. 2015). Although the Area H aquifers have been mapped by the Province and various consultants, as will be shown, the two GSC boreholes located in Area H, do not entirely agree with previous hydrogeological models developed. For instance, two previously unmapped sand and gravel aquifers have been identified by the GSC study. One is a Quadra sand aquifer situated below Capilano Aquifer 665 between Nile Creek and the Qualicum River. The second, a sand and gravel aquifer in the Cowichan Formation, is located below the mapped Quadra sand Aquifer 662. Two of the four MOE Groundwater Observation Network (GOWN) wells in Area H are completed in these newly identified aquifers but had been incorrectly assigned to the mapped aquifer at the well location. The reassignment of the observation wells can significantly improve the understanding of these aquifers.

2.2 Precipitation Data and Water Use

Precipitation data was compiled by Waterline from the Qualicum River Fish Research, Station 10226565 (Government of Canada 2016) for the time period since the Phase 1 Water Budget Project (Waterline 2013) was completed, January 2011 to September 2016.

Figure 3 shows the monthly precipitation for this period compared with the Canadian Climate Normals for the same station. The annual distribution of precipitation in Area H shows wet winters and relatively dry summers.

Figure 4 shows the water use within Area H for the three water service providers: Deep Bay Improvement District (DBID), Bowser Water District (BWD), and Qualicum Bay Horne Lake Waterworks District (QBHLWD) as compared to monthly precipitation. This cycle of water use is likely also representative of rural groundwater users in Area H that are located outside the water service areas. This precipitation distribution is counter cyclical to water use. That is to say that the highest water use occurs in the summer season when precipitation is lowest.

For presentation purposes, the monthly precipitation data was compiled by Waterline into "water-years" and winter and summer "water-seasons". A water-year runs from October 1 to September 30. The winter water-season runs from October 1 to March 31 and the summer water season runs from April 1 to September 30. Water-years and water-seasons are often used for analysis of precipitation data to account for snow fall and snow melt, however it also serves to illustrate the seasonal variability in precipitation observed in Area H.

Figure 5 presents a graph of the water-year and water-season data compared to the Climate Normals data. The graph shows that although the summer of 2015 is the most notable in terms of drought conditions, the driest year recorded during that period was in 2013-2014. As will be discussed in the following sections, the prolonged dry period during the 2013-2014 water-year appears to have caused a greater impact to aquifer recharge and groundwater levels than the 2015 summer drought. The reason for this is that consistent aquifer recharge over longer periods is known to have a greater influence than shorter summer droughts. Summer droughts tend to have a greater impact on surface water resources; and water management practices (e.g.: water use reductions) are generally also applied to groundwater but are not always necessary. Since surface water can be seen and groundwater cannot, management strategies are often focussed on these short-term events. Figure 5 also shows that 2014-2016 water-year precipitation increased over the previous two years to near normal conditions.

As stated above, unconsolidated aquifers within Area H are entirely recharged by precipitation and the main unknown is how long it takes the precipitation to reach the aquifer. The following observations are typical for unconsolidated aquifer systems in Area H:

- Direct precipitation infiltrating near a well or a well connected to a river can see a response to precipitation events in the order of minutes to days,
- Precipitation recharging the aquifer from surface at some distance from the well can see a response to precipitation events in the order of weeks to years and can often be identified through seasonal variation in groundwater levels in the well, and
- Precipitation recharging the aquifer from a significant distance away from the well, through overlying or underlying aquifers, or through mountain block recharge can take years, decades or even hundreds of years to reach a well. This can sometimes be identified through correlation with longer term climate cycles like the Pacific Decadal Oscillation (PDO) with long-term water level and precipitation data but is many cases is simply not available or when available not conclusive. Environmental chemistry tracers such as stable and radio-active isotopes of various elements, or noble gases dissolved in groundwater can be used to identify this type of recharge but is outside the scope of the present study.

In order for Waterline to complete the analysis, the precipitation data was compared with the groundwater monitoring data collected in the Area H wells as an indicator of aquifer recharge. The following sections provides a summary of the available data and observations for each aquifer identified in Area H.

3.0 ASSESSMENT OF MAPPED AQUIFERS

3.1 Overview

There are five unconsolidated aquifers that have been mapped by MOE within Area H. The subsequent discussion focuses on describing each aquifer based on a review of the following information:

- Publicly available groundwater information,
- Recent hydrogeological and water system studies by various consultants,
- Water use data provided by the Area H water service providers,
- Observation well data (provincial and volunteer wells) downloaded on-line or provided by the RDN,
- Water Survey of Canada (WSC) flow data for Nile Creek,

- Precipitation data from the Qualicum River Fish Research, Station 10226565, and
- Surface water quality data provided by the RDN.

This data was considered in context with the new geological information obtained from the various GSC studies completed for the Nanaimo Lowland groundwater study.

3.2 Aquifer 416

Aquifer 416 is described by MOE (2000) as an unconfined aquifer associated with the Quadra sand Formation located between Mapleguard Point and Thames Creek (Figure 6). The aquifer footprint mapped by MOE encompasses an area of approximately 13.7 km^2. MOE has classified the aquifer as moderately productive with an average single well yield of 1.2 L/s. The aquifer has also been classified as moderately vulnerable with an average confining layer thickness of 5.1 m.

Based on Waterline's review, in contrast to the MOE Aquifer mapping data Aquifer 416 appears to be highly productive and possibly highly vulnerable due to its unconfined, or partially confined, nature near the DBID and BWD water supply wells. The Quadra sand appears to be exposed along a 10 to 20 m high cliff face extending along the shoreline from Deep Bay to Bowser (Fyles, 1963, and confirmed by Waterline during a site visit September 2016). Based on this information, the Quadra aquifer is open to atmosphere (unconfined) and has unrestricted (open) discharge into Georgia Strait. This natural "draining" of the Quadra aquifer effectively controls the "plumbing system" as we move up gradient in the watershed in the vicinity of the DBID wells and may have some implications to the approach to aquifer management and the OCP update.

3.2.1 Deep Bay Improvement District

The approximate location of the DBID well field is shown on Figure 6, the wells are completed in the Quadra sand Aquifer 416. DBID has seven supply wells with a total capacity of 47.28 L/s and serves approximately 600 connections (Kala 2010). DBID has indicated that they did not experience any reduction in well productivity during the drought in the summer of 2015 (Julie Pisani, pers. Comm, 2016). No long-term water level monitoring is currently being conducted within, or near the DBID supply well field, therefore it is not possible to assess the long-term effect of DBID water use on the aquifer. The nearest observation well to the DBID well field is OW310 which is located approximately 350 m to 400 m away.

Well construction details and borehole geological descriptions for the DBID wells are summarised by Pacific Hydrology Consultants LTD. (PHCL) 2007. Only DBID well 3-69 encountered a low permeability confining layer on top of the Quadra aquifer. All other DBID wells appear to be overlain by sand, sand and gravel or topsoil with a near-surface water table. This condition allows for rapid infiltration/recharge into the aquifer, making the aquifer highly vulnerable to surface contamination in the vicinity of the DBID wells.

GW Solutions (2014) conducted a 48-hour aquifer test in the DBID well field by simultaneously pumping three wells at a total rate of 22.8 L/s. The results from the test and subsequent analysis that are pertinent to this review are as follows:

- Very little drawdown was observed in the non-pumping wells in the well field, and ranged from no drawdown to 0.22 m of drawdown;
- No drawdown was observed in MOE Observation well OW310, located 400 m west of the nearest pumping well;
- When pumping ceased, the water level in the pumping and observation wells recovered almost immediately;
- The calculated aquifer transmissivity ranged from 1350 to 4300 m^2/day which confirm a highly transmissive/permeable aquifer system;
- Aquifer storativity values ranged from $2.5x10^{-4}$ to $2.2x10^{-2}$ which indicate that the aquifer in the vicinity of the DBID wells is semiconfined or unconfined. This is consistent with the MOE Aquifer Characterization Worksheet for Aquifer 416; and
- A single 47 mm precipitation event occurred during the test and water levels in all non-pumping wells being monitored within the DBID well field and OW310 responded quickly with a measurable increase in the water table. This observation further confirms that the Quadra aquifer is connected to surface and may be highly vulnerable to surface contamination in the vicinity of the DBID wells.

Despite only minor drawdown observed in the aquifer in adjacent observation/monitoring wells, the water level drawdown in the pumping wells during the test was significant; ranging from 55% to 76% of the available head. This indicates that the DBID wells are performing inefficiently and may require maintenance. Common sources of well screen inefficiencies include:

- improper well screen design;
- insufficient development during well construction;
- insufficient or non-existing well maintenance whereby:
    - fine sediment migration from the aquifer is accumulating around the well screen,
    - biological activity is causing bacterial slimes and biofouling,
    - chemical precipitates are forming on the well screen and plugging up the slotted well screen, or
    - a combination of the above.

Detailed water chemistry and a downhole camera survey would help to assess the condition of the well screen and determine the type of well treatment and redevelopment that may be required. Well treatments could include; mechanical surging, shock chlorination, or acid treatment depending on the problem.

Kala (2010) performed an aquifer test on the inactive Provincial observation well OW331 located within the DBID well field. The sustainable yield calculated from that test is 9.45 L/s; almost eight times larger than the average well yield of 1.2 L/s presented in the MOE (2000) Aquifer

Classification Worksheet. This information confirms that Aquifer 416 in the vicinity of the DBID well field is highly productive rather than moderately productive as indicated by MOE aquifer mapping classification

An exhaustive review of water quality data was not completed by Waterline. However; the electrical conductivity of water collected from the DBID wells (32 uS/cm to near 154 uS/cm) is low for groundwater and more closely resembles the typical electrical conductivities of surface water. Typical rainwater and surface water electrical conductivities range from 2 to 100 uS/cm and groundwater from 50 to 50,000 uS/cm (Sanders 1998). The electrical conductivities measured in the DBID wells are only slightly higher than the electrical conductivities from surface water collected in Thames Creek (20 uS/cm to 60 uS/cm) and Nile Creek (30 uS/cm to 80 uS/cm)(RDN 2014). The electrical conductivity data support the conclusion of rapid vertical recharge by precipitation and short residence time in the aquifer.

3.2.2 Bowser Waterworks District

The Bowser Waterworks District (BWD) system serves approximately 293 residential and 15 commercial customers (McElhanney 2008). The well field includes four wells completed in the Quadra sand Aquifer 416 (Figure 6). It is Waterline's understanding that the majority of the groundwater production is from a flowing artesian well; the two deeper wells are only pumper for maintenance and during higher water use periods; and one older supply well is no longer in use (Ken Carter, pers. Comm.). No water level monitoring is currently being conducted in the BWD supply wells. OW310, located approximately 2 km northwest of the BWD wells, is the only available well that can be used to assess background conditions in the aquifer.

The sustainable yield for the BWD wells reported in McElhanney 2008 are 10 L/s to 13 L/s, which is over ten times larger than the average reported well yield of 1.2 L/s presented in the MOE (2000) Aquifer Classification Worksheet. As with the DBID wells, the data in the vicinity of the BWD wells indicate that Aquifer 416 is highly productive rather than moderately productive as mapped by MOE.

Water quality data reviewed for the BWD water wells indicate very low total dissolved solids (TDS) ranging from about 40 mg/L to 60 mg/L (no electrical conductivity data available) which is similar to surface water. This supports the hypothesis that groundwater recharge is rapid and the residence time in the aquifer is relatively short.

3.2.3 MOE Observation Well 310

OW310 is located in the northwestern portion of Aquifer 416, approximately 350 m from the DBID well field and 2 km from the BWD well field (Figure 6). OW310 has been in operation as a Provincial groundwater monitoring well since February 1990. The Detailed Well Record for OW310 (WTN 37367), presented in Appendix A, describes a 17.1 m (56 ft) sequence of sand and gravel interpreted by Waterline to be Quadra sand, overlain by 0.9 m (3 ft) of topsoil and underlain by 7.3 m (24 ft) of till to the bottom of the hole interpreted by Waterline to be the Cowichan or

Dashwood till based on the GSC study. The well screen is located at the base of the Quadra unit from 13.2 m (43.2 ft) below ground surface (bgs) to 18.1 m (59.5 ft) bgs. (PHCL 2007). The geology presented in the record shows that there is no confining unit above Aquifer 416 at the OW310 location. OW310 was not affected by the aquifer testing completed by GW Solutions (2014). It can therefore be concluded that groundwater levels in OW310 are not affected by any major water users and represent the background non-pumping conditions in the aquifer.

From 2011 to September 2016 groundwater levels in OW310 varied from a high of 6.2 m below ground surface (bgs) on March 25, 2011 to a low of 9.8 m bgs on October 26, 2014. This corresponds to a saturated thickness in the aquifer varying from 11.9 m to 8.3 m at OW310. The lowest groundwater level recorded over the entire period of record is 10 m bgs which was recorded on November 29, 2001, corresponding to 8.1 m of aquifer saturated thickness.

Figure 7 shows the groundwater level in OW310 plotted against the precipitation data for the Qualicum River Fish Research, Station 10226565 (Government of Canada 2016). Figure 8 and Figure 9 shows the same data plotted at different time scales to illustrate the different mechanisms of aquifer recharge occurring in Aquifer 416 near OW310.

Figure 7 illustrates how OW310 responds to individual precipitation events. Groundwater levels rose immediately following individual precipitation events, and continued to rise for another 12 days to 21 days after the event. Groundwater levels continue to rise partly due to ongoing precipitation, and partly due to the time it takes precipitation to travel through the unsaturated zone to the water table. This response is similar to the response observed by GW Solutions (2014) during the DBID pump test, showing that Aquifer 416 is being recharged from direct precipitation in the vicinity of OW310.

Figure 8 presents groundwater levels for OW310 plotted against monthly precipitation. The groundwater levels in OW310 clearly respond to seasonal changes in precipitation. The delay between precipitation peaks and groundwater level peaks ranges from 3.5 months to 5 months. The delay is caused by the travel time from the recharge areas, likely originating up gradient of OW310. This indicates that Aquifer 416 has a definite hydraulic connection to surface and that direct infiltration from precipitation is a significant mechanism of aquifer recharge. The data from OW310 can only be definitively applied to the vicinity of the well. However due to the relative uniformity of the Quadra sand in Aquifer 416 noted in the borehole logs and in the absence of any other monitoring data; it will be assumed to be representative of recharge across similar elevations of Aquifer 416. The delayed response is beneficial as it essentially provides storage in the aquifer so that the peak water use occurs when groundwater levels are not at their lowest. This is in direct contrast to surface water systems in the region where water may flow to the ocean within weeks, causing surface water flows to be lowest during the summer peak water use period. Figure 10 presents the 2011 flow record WSC Station Nile Creek near Bowser, the only hydrometric data available in Area H. Flow in Nile Creek is assumed to be roughly representative of all surface water courses in the region and illustrates the very limited attenuation of precipitation in surface water systems along the east coast of Vancouver Island.

Figure 9 present groundwater levels for OW310 plotted against winter (October to March) and summer (April to September) water-season precipitation totals (see Section 2.2). Notably, the groundwater levels in OW310 are observed as recovering during the 2015 summer drought. This may erroneously indicate that direct precipitation is not a large percentage of aquifer recharge. However, a closer analysis of the data shows that groundwater levels are correlated to winter precipitation and are largely independent of summer precipitation. Groundwater levels in the well dropped significantly following the dry winter of 2013-2014 but recovered to near background levels following the near normal winter precipitation of 2014-2015. This indicates that the majority of recharge to Aquifer 416 occurs in winter months, making Aquifer 416 more resilient than surface water resources to the forecasted climate change scenarios for eastern Vancouver Island which call for a modest decrease in annual precipitation but with drier summers and wetter winters (Associated Eng. 2007).

Even at the lowest recorded groundwater level during the 2011 to September 2016 period, 9.8 m bgs on October 26, 2014, there was still 8.3 m of saturated Quadra sand at OW310. This groundwater is likely largely made up of recharge from the preceding, 2013-2014, winter precipitation; although the 503.6 mm of precipitation that fell that winter is low compared to the 1026.6 mm normal winter precipitation, it represents a significant amount of water available for recharge in a season when evapotranspiration and water use is low. To simplify, if it did not rain at all for a whole winter the groundwater levels at OW310 would likely be significantly lower, than the observed low of 8.3 m in October 2014. There is not enough data to predict how low the groundwater level could get following a really dry winter, it is likely that some smaller component of groundwater is reaching OW310 though pathways that take longer than a year and would provide base flow to the aquifer. These longer pathways may be from direct precipitation recharging the aquifer from a significant distance and or through mountain block recharge. In the absence of geochemical tracer data described previously, it is not possible to definitively determine the source of this base flow recharge to the aquifer with any degree of certainty.

Guiton Environmental Consulting (GEC) 2014 describes the Quadra aquifer in the vicinity of OW310 as a “flow through aquifer” with short attenuation and limited storage of water in the aquifer. This conceptual model agrees with the observed groundwater level response to precipitation in the OW310 data and the electrical conductivity and TDS data from the DBID and BWD wells which indicate a short residence time in the aquifer. The conservative assessment is that groundwater levels in the Quadra sand Aquifer 416 are recharged primarily through direct precipitation rather than mountain block recharge and could be vulnerable to a multi-year winter drought.

3.2.4 BC Wells Database

Waterline conducted a cursory review of the BC water well database, there are 60 wells in the area mapped of Aquifer 416, including 14 wells in the rural residential subdivision on Cowland Road (see Figure 6) up gradient of both the DBID and BWD supply wells. Of those 14 wells, seven appear not to be completed in Quadra sand Aquifer 416 but rather have been drilled through the largely unsaturated Quadra sand (see WTN 55674, Appendix A) and underlying till aquitard to be completed in a deeper sand and gravel aquifer. The deep confined sand and gravel aquifer below the Quadra sand is thought to be the Cowichan Formation aquifer that will be discussed later in Section 3.5.1 along with OW426.

Only two of the 14 wells in the Cowland Road area were interpreted by Waterline to be completed in Aquifer 416; in those wells the Quadra Sand unit is exposed near the surface with no protective confining unit. The driller's logs for the five remaining wells did not contain enough information to make a determination regarding the aquifer from which the wells were drawing water.

3.2.5 Summary of Aquifer Characteristics

Figure 11 shows an annotated version of the hydrogeological cross-section presented by GW Solutions (2014) to illustrate Waterline's interpretation of the Quadra sand Formation Aquifer 416. The cross-section notes that the saturated thickness of the aquifer decreases up gradient of the DBID wells as was observed by driller's logs from the Cowland Road wells approximately 1.8 km away. The Quadra sand drains freely to the ocean, where it is exposed along a 10 m to 20 m high cliff face extending from Deep Bay to Bowser. The generally high permeability of the Quadra aquifer coupled with well drained conditions at higher elevations and open discharge near the ocean provides for short residence times of groundwater from recharge to discharge point.

The Quadra sand Aquifer 416 in this area behaves much the same as a surface water system collecting water from direct precipitation and flowing downhill to discharge to the ocean. The difference is the delayed response to seasonal precipitation in the aquifer that has been observed to be in the range of 3.5 months to 5 months, buffering seasonal fluctuations in precipitation. There is possibly an element of base flow in the aquifer with the attenuation of some components of precipitation taking over a year to pass through the system buffering the annual fluctuations in precipitation, however there is not enough information to confirm or quantify the base flow. This is in direct contrast to the Nile Creek system which shows precipitation attenuation in the order of days or weeks.

OW310 shows a pronounced seasonal variation in groundwater levels that correlated to winter precipitation and appears to be independent of summer precipitation. This is a key finding as the long-term availability of water supply in Aquifer 416 appears to be most susceptible to recurrent/repeated winter droughts, but appears to be less affected by recurrent summer drought conditions as observed between 2013 and 2015.

It is Waterline's interpretation that the majority of aquifer recharge is from direct precipitation infiltrating up gradient of the DBID and BWD well fields. There is insufficient information on the extent, thickness or continuity of a low permeability (confining) layer between the surface and the Quadra sand to define a specific recharge area. No confining unit was observed in six of the seven DBID wells or in the Cowland Road wells; it should therefore be assumed that recharge is diffuse occurring over most of the area mapped as Aquifer 416. There may also be a small component of mountain block recharge in the system but this is not reflected in the water chemistry reviewed by Waterline.

Uncertainty still remains with respect to exactly where infiltration and recharge enters the Aquifer system. As a result, the RDN should assume that all areas up gradient of the well fields are recharge areas. A preliminary assessment of significant recharge areas developed by Waterline (2013) based on remote sensing data, although useful for “conceptual water budget”, cannot be relied upon exclusively to map recharge areas and inform the OCP update process. The remote sensing helps identify impermeable surfaces and vegetative cover (i.e.: Leaf Area Index) but a more robust approach is needed to map a deeper section of surficial sediments. Although it may be possible to map coarse-grained soils that promote infiltration and recharge using ground or airborne geophysics, these surveys still need calibration using drill hole data. Given that the OCP needs to be updated immediately, Waterline suggests the RDN manage future community development on a site by site basis whereby proponents are required as part of the development permit to determine and maintain the recharge capacity of the land. This approach is similar to the requirements for conducting percolation tests for determining septic suitability which is critical for protecting the Quadra aquifer from contamination by septic systems. The data would need to be collected and reviewed so that accurate mapping of aquifer recharges areas can be completed.

In addition to detailed mapping of recharge areas, long-term performance monitoring is required for both the DBID and BWD wells fields. Presumably MFLNRO will require this information now that the Water Sustainability Act (WSA) is now in force as a condition to issuing licenses. However, to date, no specific regulation has been developed requiring long-term monitoring of supply wells. Waterline strongly recommends that monitoring wells within the DBID and BWD well fields be equipped with data loggers in order to fully assess the long-term response to groundwater use, as well as short and long-term recharge trends.

3.3 Aquifer 421

Aquifer 421 is described by MOE (2000b) as a confined aquifer associated with the Quadra sand Formation located northwest of Nile Creek and southeast of Thames Creek (Figure 12). The aquifer footprint mapped by MOE encompasses an area of approximately 6.2 km^2. MOE has classified the aquifer as low productivity with only one reported well yield of 0.25 US gpm or 0.015L/s. It is also classified as moderately vulnerable with a reported thickness of confining layer or 7.6 m (25 ft). The Aquifer Classification worksheet for Aquifer 421 was developed in 2000 based on information from only seven wells and is therefore preliminary. The Capilano sand and gravel Aquifer 665 is mapped as overlying Aquifer 421 with the exception of a small portion along Nile Creek which appears to have eroded through the Capilano deposits and into the Quadra Aquifer 421.

There are currently no BC observation wells completed in Aquifer 421. The BWD services properties along the coast in the Aquifer 421 area but the supply comes from wells completed in Aquifer 416 as discussed in Section 3.2.2.

3.3.1 BC Wells Database

There are only 12 wells identified in the BC wells database located between Thames Creek and Nile Creek (Figure 12). Eight of the 12 wells are completed in Capilano Aquifer 665 at depths of less than 6.7 m (22 ft) bgs. The Detailed Well Records for the four remaining wells are presented in Appendix A.

The driller reports indicate that the Quadra Formation is thin or absent between Nile and Thames creeks. This is in contrast to the 30 m to 70 m thick Quadra Sand found north of Thames Creek (Aquifer 416). The only units that could be definitively identified as Quadra sand are found in two wells close to Nile Creek (WTN14196 and WTN12763). Both wells indicate low productivity and WTN14196 located near the coast produced salt water from the unit interpreted as Quadra sand. Two water wells located at higher elevations (WTN84185 and WTN84189) registered to Land and Water BC Inc. confirm that the Quadra sand is absent or thin, however these wells were drilled in 2004 after Aquifer 421 was mapped by the MOE. The aquifer mapping for Aquifer 421 needs to be updated; it is Waterline's interpretation that there is no regional significant Quadra sand aquifer between Thames and Nile creeks.

It should also be noted that information presented in the Detailed Well Reports does not agree with the isopach thickness map of the Quadra Formation presented by Benoit et al. 2015. The GSC should be consulted regarding the continuity of Quadra sand in the area mapped as Aquifer 421.

3.3.2 Summary of Aquifer Characteristics

The Quadra sand unit does not appear to be regional extensive in the area mapped as Aquifer 421. The Quadra sand deposit between Thames and Nile creeks may have been eroded by glacial or post-glacial processes leaving the Vashon Till directly overlying the Cowichan-Dashwood Till in this region. The aquifer mapping for Aquifer 421 needs to be updated; it is Waterline's interpretation that there is no regionally significant Quadra sand aquifer between Thames and Nile creeks.

3.4 Aquifer 665

Aquifer 665 is described by MOE (2004) as a confined aquifer associated with the Capilano Formation located southeast of Thames Creek and northwest of the Big Qualicum River (Figure 12). The aquifer footprint mapped by MOE encompasses an area of approximately 22.8 km^2. MOE has classified the aquifer as low productivity with only two reported wells yielding of 0.5 L/s and 0.63 L/s. The aquifer has also been classified as moderately vulnerable with an average confining layer of 1.7 m and a median thickness of the confining layer of 0.6 m. The thickness of the confining layer is indicated to range from 0 to 7.6 m.

Although BC observation well OW427 had been identified by MOE as being completed in Aquifer 665, the GSC information indicates otherwise. GSC data for OW427 (Figure 13) indicates that the well is completed in the deeper unmapped Quadra aquifer. Waterline contacted MFLNRO to discuss the GSC well description for OW427 and the well information in the BC GOWN has been changed from completed in Aquifer 665 to completed in an unmapped aquifer.

3.4.1 BC Wells Database

There are 31 shallow wells in the BC Wells Database in the area mapped as Aquifer 665; seven of the wells are located between Thames and Nile creeks (Figure 12). Another 24 shallow wells are completed between Nile Creek and the Qualicum River.

A review of the driller's logs indicates that in most of the wells the Capilano sand and gravel units extend to surface suggesting unconfined conditions. This contradicts the MOE Aquifer classification report. Of the shallow 24 wells completed in Aquifer 665, only three logs indicate the presence of a confining unit. Of these, one log noted 6 m (20 ft) of hardpan (interpreted as till) and the two other logs described 0.9 m (3 ft) and 4 m (13 ft) of fill which is not a natural confining unit. These few thick units appear to have skewed the data used by MOE to determine if a significant confining layer is present, which would account for the discrepancy between the reported geometric mean thickness and the median thickness of the confining layer of 1.7 m and 0.6 m respectively. It is Waterlines opinion that since the confining unit appears to be largely absent and there is a noted connection between the aquifer and recent fluvial and deltaic sediments it would be more conservative to consider Aquifer 665 as unconfined and highly vulnerable to surface contamination.

All the wells in Aquifer 665 were driller before 1963. There are only two shallow wells (WTN12791 and WTN12792) that are located outside the areas currently serviced by either the BWD or the QBHLWD. No aquifer was encountered in WTN12791. Waterline assumes that the water service providers were established because the Aquifer 665 wells were not providing an adequate water supply for residents. MOE assessment of Aquifer 665 being low productivity is most likely correct.

3.4.2 MOE Observation Well 427

Figure 13 shows the GSC well log for OW427 (Crow et al. 2014) and Waterline annotations are provided in red. The well was drilled as part of the GSC 2012 Rotosonic drilling program for the Nanaimo Lowland groundwater study and subsequently established as a MOE observation well in 2013. Until recently the well was thought to be completed in Capilano Aquifer 665. However, the GSC log clearly indicates that the well screen is completed in the underlying Quadra sand Aquifer which has not been formerly mapped by MOE. The Capilano sediments were only intersected in the top 1.8 m (6 ft) of the borehole. The interpretation on Figure 13 agrees with the chemostratigraphy presented in Knight et al. 2015 and the radiocarbon dating described by Bednarski 2015.

Waterline has contacted MFLNRO to point out the inconsistency. As of the writing of this report, the well description for OW427 has been updated by MFLNRO from completed in Aquifer 665 to completed in an unmapped aquifer. Waterline believes that it is of critical importance to guide water management initiatives that water level monitoring in OW427 not be incorrectly attributed to the Capilano Aquifer (665), as it would greatly overestimate the productivity and minimise the vulnerability of the aquifer. Considerable error would be introduced which would significantly affect land management decisions and future WSA licence approvals.

The isopach map of the Quadra sediments presented by Benoit and Paradis 2015 indicate a significant thickness and areal extent of Quadra sand in the area between Nile Creek and Qualicum River. This currently "unmapped" Quadra aquifer could represent significant future groundwater source in the region. The Quadra sand unit in OW427 is 70 m (230 ft) thick with 25 m of saturated thickness. In addition, it is overlain by 7.5 m of lower permeability Vashon Drift sand, silt and clay; which potentially provides a protective confining unit overlying the Quadra aquifer.

The groundwater levels observed OW427 are presented on Figure 14. The fluctuation in water levels in the aquifer over the period of record is less than 1 m and is likely caused by changes in barometric pressure. No seasonal variation in groundwater levels is noted in the dataset, indicating that the aquifer is likely disconnected from surface at this location. Recharge to the aquifer is likely not through direct precipitation, but by precipitation recharging the aquifer from a significant distance away from the well, through overlying or underlying aquifers, or through mountain block recharge. These observations are consistent with the GSC and Waterline's interpretation that MOE OW427 is completed in the deeper confined Quadra aquifer (unmapped).

3.4.3 Summary of Aquifer Characteristics

The Capilano sand and gravel unit appears to be thin and the estimated aquifer yield is low. Due to the discontinuous nature or absence of a confining layer, Aquifer 665 should be considered as unconfined and potentially highly vulnerable to contamination from surface. Aquifer 665 is likely connected to surface water with the fluvial delta deposits of the Qualicum River and to a lesser extent Nile and Thames creeks.

No local groundwater monitoring data is currently being collected to help determine the source(s) of recharge to Aquifer 665. However, based our Waterline's detailed assessment of recharge mechanisms for aquifers exhibiting similar characteristics (unconfined or partially confined, shallow depth to groundwater, and connected to surface water), it can be assumed that recharge to Aquifer 665 is dominantly from direct infiltration of precipitation with minor or no contribution from mountain block recharge.

The "unmapped" Quadra aquifer could represent significant future groundwater source. The Quadra sand unit at OW427 appears to be 70 m (230 ft) thick with a 25 m (82 ft) saturated thickness with a 7.5 m (25 ft) thick confining layer (Vashon Till).

No aquifer testing data or long-term groundwater monitoring data exists to improve the understanding of aquifer productivity or recharge to Aquifer 665. However, the productivity of Aquifer 665 is low, it is vulnerable to surface contamination and the aquifer does not appear to be used as a primary water supply for many, if any, residents. Rather than putting any effort into better understanding Aquifer 665, Waterline recommends that future groundwater investigations between Nile Creek and the Qualicum River be focused on clarifying the extent and productivity of the Quadra sand aquifer which may have the potential to be developed into a regional significant water supply.

3.5 Aquifer 662

Aquifer 662 is described by MOE (2004b) as a confined aquifer likely to be associated with the Quadra Formation located between Qualicum River and Little Qualicum River (Figure 15). The mapped aquifer footprint encompasses an area of approximately 54.2 km^2. MOE has classified the aquifer as moderately productive with a geometric mean of reported well yields of 0.53 L/s and low vulnerability with an average confining layer of 19 m (62.8 ft).

There are currently no MOE observation wells completed in Aquifer 662. The BC observation well OW426 had been identified in the BC GOWN as being completed in Quadra sand Aquifer 662. However, based on Waterline's review of the GSC data for this study we have confirmed that OW426 it actually completed in the deeper unmapped Cowichan sand and gravel aquifer. Waterline contacted MFLNRO regarding the GSC information and the well description for OW426 has since been updated to unmapped aquifer.

3.5.1 MOE Observation Wells 425 and 426

The OW425 and OW426 wells were completed as part of the GSC's Nanaimo Lowland groundwater study. The GSC well log is presented as Figure 16 with Waterline annotations presented in red. The two wells are nested in a single borehole. OW425 is completed in a deep sand and gravel layer identified by the GSC as the Dashwood till. Until recently OW426 was thought to be completed in the Quadra sand Aquifer 662 but is now understood to be completed in the Cowichan Formation. These two monitoring wells were added to the BC Observation Well Network in 2013.

Figure 14 shows the groundwater level hydrograph for both OW425 and OW426. The groundwater levels in OW426 completed in the shallower Cowichan Formation may show a weak response to seasonal changes in precipitation. However, the period of record is too short to make a definitive assessment. If there is a weak response in the aquifer to seasonal changes in precipitation, it may indicate that the confining till layer encountered in the borehole is discontinuous or leaky and the Cowichan aquifer is at least partially connected to the overlying Quadra sand aquifer.

The OW425 well is completed in the deeper Dashwood Formation and appears to respond to seasonal fluctuations in precipitation. This response is unexpected as the well is completed in relatively deep sand and gravel lenses at 115 m (377 ft) bgs and below a 40 m (131 ft) layer of till. Waterline contacted MFLNRO and confirmed that the data has been correctly attributed to OW426 (pers. comm. Graeme Henderson). MFLNRO indicated that borehole was initially planned to extend into bedrock but the drilling was stopped due to technical problems. In another GSC well located on Hilliers Road near Coombs (GSC-BH-HIL, Crow et al. 2014), the GSC noted that the till/bedrock surface is a groundwater source. The groundwater levels in OW425 may be an indication that the well is completed near the bedrock surface and bedrock surface is a source of groundwater hydraulically connected to surface at this location.

3.5.2 BC Wells Database

There are approximately 250 wells in the BC Wells Database that are mapped in Aquifer 662, within Area H (Figure 15). Of these 250 wells, 27 wells are located in the Spider Lake area, where there is an overlying aquifer mapped as a late-stage, glacial-fluvial delta terrace (kame) deposit referred to as Vashon Aquifer 661 which will be discussed later.

A review of water well logs indicates that Aquifer 662 is highly complex and heterogeneous in comparison to typical Quadra sand aquifers in the region (e.g.: Aquifer 416). The majority of water wells in the database appear to be completed in three different but possible hydraulically connected aquifers. These three aquifers can be distinguished based on the geological information and the static water levels reported in the well logs. The circle representing each well on Figure 15 has been coloured by static water depth to illustrate the variation in static water levels. It is important to note that static water levels vary not only as a result of aquifer properties but also vary with elevation and overburden depth and can only be used to indicate a potential hydraulic difference between nearby wells, the well logs should be consulted to clarify the aquifer geology. The following provides a summary of the three aquifers observed in the area well logs:

- A Quadra sand aquifer dispersed throughout the region, with static water levels ranging from roughly 6 m to 36.6 m (20 ft to 120 ft) bgs.
- A highly productive, coarse sand and gravel aquifer with high static water levels (<6 m (20 ft) bgs), including the QBHLWD supply wells.
- A Cowichan Formation sand and gravel aquifer, similar to the aquifer encountered in OW426; observed in some wells near OW426 and in the area mapped as Aquifer 661. Static water levels are generally greater than 36.6 m (>120 ft bgs).

3.5.3 Qualicum First Nation – Volunteer Monitoring Wells

There are three volunteer monitoring wells located on the Qualicum First Nation (QFN); the wells are identified as Atlakim, Kumugwe and Dzunukwa. The wells are located in the area mapped as Quadra sand Aquifer 662, near the mouth Qualicum River; the approximate location of the QFN volunteer monitoring wells (QFN wells) is shown on Figure 15. No well construction information is available for these wells (Julie Pisani pers. comm.); therefore there is no information on the depth of the wells or any geological information for the wells. There is currently not enough information available to determine which aquifer the wells are completed in, this severely limits the interpretation of monitoring data.

Figure 16 shows the water level hydrographs for the QFN monitoring wells. The groundwater levels in the three QFN wells correlate directly to individual winter precipitation events over the period of record. During these months the initial response in the wells is immediate with some attenuation after the peak (the groundwater levels stay higher for a period of time even if there is no additional precipitation). Summer precipitation events produce much smaller peaks or no peak at all, likely because of the increase evapotranspiration in the summer season. There is no seasonal delay in the aquifer response in these wells as was observed in OW310 in the Quadra sand Aquifer 416, indicating that the recharge is primarily local. The response in these wells to precipitation is very similar to the response observed in Nile Creek (Figure 10) which is the only surface gauging data that is available in the region, indicating that the wells may be hydraulically linked to the Qualicum River. If a river stage gauge were installed on the Qualicum River, near the QFN wells, a comparison between the well and river hydrographs could help clarify if the water level in the wells are being influence by river stage or by direct precipitation in a small shallow system or both.

The GSC surficial geology map (Bednarski et al. 2015) has the area where the QFN wells are located mapped as Capilano/Vashon glaciofluvial delta terrace. Waterline suspects based on the well hydrographs that it is unlikely that the QFN wells are completed in the mapped Quadra sand Aquifer 662. It is more likely that the QFN wells are completed in the Capilano/Vashon glaciofluvial deposits or recent Qualicum River delta deposits. If these wells are going to continue to be used as monitoring wells at a minimum the depth of the wells needs to be determined, preferably using a downhole camera in case the wells are not screened at the bottom.

3.5.4 Qualicum Bay Horne Lake Waterworks District

The QBHLWD serves approximately 430 residential users, QFN, and commercial and industrial users (McElhanney 2012). QBHLWD pumps water from three supply wells including: WTN 110569 (Well 1), WTN 96521 (Well 2) and WTN 96893 (Well 3). The approximate location of the QBHLWB supply wells is shown on Figure 15. QBHLWD indicated that the performance of the water supply wells did not appear to be significantly affected during the 2013 dry water-year, nor during the summer drought of 2015 (QBHLWD pers. Comm.). No groundwater levels were provided to Waterline for this review.

The most complete geological description in the QBHLWD well field is provided on the driller's well log for Well 1 (Appendix A). The well is screened in a coarse sand unit from 23.9 m to 27.2 m (78.4 ft to 89.2 ft) bgs. The static water level at the time of drilling was 0.9 m (3 ft). The log shows a silt, sand and gravel from the bottom of the borehole to 0.9 m (3 ft) of ground surface. It is unclear if the silty units exhibit low enough permeability to be considered a confining unit.

Figure 15 shows the Aquifer 662 wells sorted by depth to water. The QBHLWD wells form part of a northwest-southeast trending linear group of wells with near surface water levels or flowing artesian conditions. Nearby wells have very different static water levels despite being drilled to a similar depths and may indicate a different "plumbing system". Waterline believes that the QBHLWD supply wells are completed in a permeable channel structure not directly connected to the regional Quadra aquifer system. If this interpretation is correct, it would greatly affect the well head protection plan that is currently being contemplated by QBHLWD. The conventional interpretation is that capture zones would extend uphill, but would be greatly affected by channel geometry which suggests a more lateral capture zone.

McElhanney (2012) indicates sustainable yields for the QBHLWD wells range from 21 L/s to 30 L/s. These yield values are considerably higher than those reported for DBID of 9.5 L/s (Kala 2010) or BWD 10 L/s to 13 L/s (McElhanney 2008); also indicating that the QBHLWD may be completed in a highly permeable unit.

In terms of groundwater quality, only a few reports were available for review on the QBHLWD Website. Historical concerns have been note in relation to elevated iron and manganese. The chemistry report from a water sample collected in 2011 indicates slightly higher electrical conductivity (146 uS/cm) and corresponding TDS (96 mg/L). Although not atypical of Quadra sand water chemistry, the water appears to be different in comparison to DBID the BWD wells. Currently, water quality analysis is only completed for bacteria and trace metal species. Waterline recommends that a more comprehensive water laboratory testing program, including all major anions and cations, in addition to bacteria and trace metals.

3.5.5 Summary of Aquifer Characteristics

Due to the complex nature of the geological environment, and the general lack of groundwater monitoring data, it is not possible to assess groundwater-surface water interaction and recharge mechanisms in Aquifer 662.

Water wells in the area appear to be completed in five different but possible hydraulically connected aquifers:

- A Quadra sand aquifer dispersed throughout the region, with static water levels ranging from roughly 6 m to 36.6 m (20 ft to 120 ft) bgs.
- A highly productive, coarse sand and gravel channel aquifer with high static water levels (<6 m (20 ft) bgs), including the QBHLWD supply wells.
- A Cowichan Formation sand and gravel aquifer, similar to the aquifer encountered in OW426; observed near OW426 and in the area mapped as Aquifer 661. Static water levels are generally greater than 36.6 m (>120 ft bgs).
- A deep Dashwood Formation sand and gravel aquifer, being monitored by OW425, may be at the bedrock surface, areal extent unknown.
- An aquifer with unconfirmed geology, including the QFN volunteer monitoring network wells, possible hydraulically connected to the Qualicum River. Likely restricted to the area near the mouth of the Qualicum River.

A number of well in the BC wells database appear to be completed in the Quadra sand aquifer, the productive sand and gravel channel aquifer and the Cowichan sand and gravel aquifer; these aquifers are likely being used as water supplies in the area. The Dashwood sand and gravel aquifer was only definitively observed in OW425 and likely is not being used as a water supply aquifer. The aquifer identified near the QFN wells was only observed in the vicinity of the QFN reserve, the wells may be currently being used as a water supply.

Groundwater potential studies and well head protection plans should consider the variable nature of the aquifer(s) in this area. Using available borehole logs to determine the local geological context of the project and not simply assuming the wells are completed in a large relatively homogeneous aquifer is imperative.

The Quadra sand appears to be moderately to highly productive, however no observation wells are being monitored to assess the long-term performance of the aquifer. The Quadra sand is well drained and partially saturated at higher elevations around Spider Lake. By definition confined aquifers are fully saturated, therefore the Quadra sand aquifer behaves hydraulically as a partially confined or unconfined aquifer despite the observed confining layer of Vashon Till, indicating that the Vashon Till is either discontinuous or leaky. This phenomenon has been observed in other coastal Quadra Aquifer such as the Gibsons Aquifer (Waterline 2013a).

The only BC GOWN observation well in the area mapped as Aquifer 662 is completed in a Cowichan Formation aquifer. No aquifer testing data is available to evaluate the groundwater potential of this aquifer; however, drillers logs indicate the well yields range from 3 L/s to 0.2 L/s indicating the aquifer has the potential to be at least moderately productive and could be developed as a water supply at higher elevations where the saturation of the Quadra sand is reduced.

Waterline believes that the QBHLWD supply wells are completed in a permeable channel structure not directly connected to the regional Quadra aquifer system. This should be investigated further as it would greatly affect the well head protection plan that is currently being contemplated by QBHLWD.

3.6 Aquifer 661

Aquifer 661 is described by MOE (2004b) as an unconfined aquifer consisting of brown sand and gravel, glacio-fluvial kame terrace and kame delta deposits formed during the Vashon Drift period (Figure 18). The aquifer area mapped by MOE is small and encompasses approximately 3.82 km^2. The aquifer is classified as moderately productive with an average well yield of 0.6 L/s. The aquifer is also classified as a high vulnerability aquifer with all but one well showing no confining unit.

Groundwater in Aquifer 661 is hydraulically connected to Spider Lake and therefore water wells in the area can induce infiltration (remove water directly) from Spider Lake. Aquifer 661 and Spider Lake are perched above a low permeability unit (Vashon Till) that hydraulically separates the aquifer from the underlying Quadra Sand Formation (Aquifer 662). The Quadra sand is only partially saturated in this area.

Figure 19 shows a conceptual cross-section of the relationship between Aquifer 661 and 662 (Waterline 2013). View 1, shows that groundwater elevation in Aquifer 661 are considerably higher than water levels in the underlying partially saturated Quadra sand aquifer (Aquifer 662) which confirms the high downward gradient and perched aquifer conditions.

3.6.1 BC Wells Database

There are 27 wells in the BC Wells Database in the area mapped as Aquifer 661. A preliminarily review of the geological information presented in the well logs indicates that although most of the wells are completed in the perched kame terrace unit, a few wells are completed in the underlying Quadra sand or Cowichan aquifers. Wells completed in these underlying aquifers are likely not hydraulically connected to Spider Lake.

3.6.2 Shayla Road Monitoring Well

The Shayla Road Volunteer Monitoring Well (Shayla well) is located on the northeastern edge of the area mapped as Aquifer 661. The water well log for the Shayla Well (WTN 87914) is presented in Appendix A. Based on the geological information presented in the borehole log and the static water level of 60.4 m (198 ft), the Shayla well is most likely completed in the Quadra sand (Aquifer 662) under the perched Vashon Aquifer (661).

The Shayla well was drilled to 75.6 m (248 ft) and did not extend to the bottom of the Quadra sand aquifer. At the time of drilling, there was approximately 15.2 m (50 ft) of saturated Quadra sand observed in the well. The saturated thickness in the aquifer may be greater as the total thickness of the aquifer was not determined. The Quadra sand is partially saturated at the Shayla well.

The RDN provided water level data for the Shayla Well which is presented as a hydrograph on Figure 20. The well is currently being used for household supply and the 0.6 m daily variation in water level is likely caused by the pump cycling. It appears that the logger may have been raised in the well on November 4th 2013, although this cannot be confirmed since no manual water level measurements were collected before that date. There is no apparent seasonal variation in water levels in the well; however, the seasonal response may be masked household use. As the well is completed deep below Aquifer 661 and isolated from the surface by the Vashon Till confining unit the lack of a significant seasonal response is expected. Water levels in the well declined approximately 0.6 m from January 2014 to January 2015 and have since recovered approximately 0.3 m from January 2015 to January 2016. Due to the short period of record and no information on household water use there is not enough information to determine if this represents a true water level change in the aquifer. The lack of seasonal water level response observed in this well could misinform the RDN if it was used to manage groundwater in the unconfined Vashon Drift Aquifer 661 and surface water resources in the vicinity of Spider Lake.

3.6.3 Summary of Aquifer Characteristics

Aquifer 661 is and unconfined sand and gravel aquifer which is most likely hydraulically connected to Spider Lake. Water wells in the area can therefore induce infiltration (remove water directly) from Spider Lake if pumped at a high enough rate. The water table in Aquifer 661 is expected to fluctuate seasonally with the level in Spider Lake and should also be considered highly vulnerable to contamination from surface. Recharge to the aquifer is likely entirely from local precipitation and the aquifer may also be connected to Horne Lake located up gradient via coarse glacial deposits between the two lakes. As insufficient borehole data exists, it is not possible to fully assess aquifer recharge characteristics. Discharge from Aquifer 661 is to Spider Lake and through groundwater use.

The Shayla well is not completed in the perched Vashon sediments of Aquifer 661. It is likely completed in the underlying Quadra sand aquifer. The lack of seasonal water level response observed in the Shayla well would misinform the RDN if it was used to manage groundwater in the unconfined Vashon Drift Aquifer 661 and surface water resources in the vicinity of Spider Lake.

Aquifer 661 is likely adequate for individual domestic use but larger scale groundwater abstraction is not recommended. Future development should consider developing groundwater sources in the deeper more productive, and less vulnerable, Quadra sand or Cowichan sand and gravel aquifers. As a cautionary note to drillers, care must also be taken when drilling and maintaining wells in the Spider Lake area in order to ensure hydraulic isolation is maintained along the wellbore between Aquifer 661 and the underlying, partially saturated, Quadra sand Aquifer 662. It is possible that a leaky well casing completed in the deeper Quadra or Cowichan aquifers could become a conduit for water to drain from Aquifer 661 and Spider Lake into the deeper unsaturated Quadra sand.

Currently, there are no monitoring wells completed in Aquifer 661. Monitoring well information is required to manage the aquifer and determine the long-term seasonal variability in groundwater levels and recharge. In addition, no water quality data is available for Aquifer 661. Given the direct communication with Spider Lake, water wells competed Aquifer 661 may be considered groundwater under the influence of pathogens (GARP) and requires further investigation.

4.0 CONCLUSIONS

4.1 General

The annual distribution of precipitation in Area H shows wet winters and relatively dry summers. This precipitation distribution is counter cyclical to water use whereby the highest water use occurs in the season when precipitation is lowest. Precipitation data from January 2011 to September 2016 were reviewed for this study. The data shows that although the summer of 2015 is the most notable in terms of drought conditions, the driest year recorded during that period was in 2013-2014.

The only mapped aquifer with sufficient data for a thorough analysis of aquifer response to precipitation is Aquifer 416. Groundwater levels is Aquifer 416, observed in OW310, show a pronounced seasonal variation in groundwater levels that correlated to winter precipitation and appears to be independent of summer precipitation. This is a key finding as the long-term availability of water supply in Aquifer 416 appears to be most susceptible to recurrent/repeated winter droughts, but appears to be less affected by recurrent summer drought conditions as observed between 2013 and 2015; making Aquifer 416 more resilient than surface water resources to the forecasted climate change scenarios for eastern Vancouver Island which call for a modest decrease in annual precipitation but with drier summers and wetter winters (Associated Eng. 2007).

Although there is only enough data to support this conclusion for recharge to Aquifer 416, potentially the same recharge pattern may exist in other Area H aquifer that are recharged primarily from precipitation including; the shallow Capilano Aquifer (665), portions of Quadra Aquifers 662, and the Vashon Kame Terrace aquifer (661).

Summer droughts tend to have a greater impact on surface water resources and water management practices (e.g.: water use reductions) are generally also applied to groundwater but are not always necessary. Groundwater management strategies in Area H should consider winter drought conditions.

A summary of the key finding from this hydrological review of Area H aquifers is presented in Table 1, at the end of this report. The table is organised by mapped aquifer, however information for the unmapped aquifers in Area H described in this report are included in a separate row divided by a dashed line under the mapped aquifer at the same location.

4.2 Data Quality and Implications to Groundwater Management

Several inconsistencies and errors were noted during Waterline's review of the groundwater data within Area H, where relevant these are included in Table 1. Waterline was able to reconcile some of the errors in discussion with MFLNRO and the GSC. The following presents a summary of the main inconsistencies that have or need to be addressed to improve management planning:

- OW427 was reported in the BC GOWN to be completed in the surficial Capilano Aquifer 665. However; the data collected by the GSC confirms that is actually completed in the deeper underlying Quadra Sand Aquifer. In discussion with MFLNRO, Waterline understands that the well description for OW427 has been changed from Aquifer 665 to reflect its completion in an unmapped aquifer.
- OW425/426 are nested wells. OW426 was reported in the BC GOWN to be completed in the Quadra sand Aquifer 662. However, the data collected by the GSC confirms that is located in a deeper Cowichan Formation sand and gravel aquifer. The aquifer description for OW426 has been change completed in an unmapped aquifer.
- The Shayla Road monitoring well was originally thought to be completed in the vulnerable unconfined, Vashon Glaciofluvial delta terrace aquifer; however, based on Waterline's review it is actually completed in the deeper, locally confined Quadra sand Aquifer 662. The lack of seasonal water level response observed in this well could misinform the RDN if it was used to manage groundwater in the unconfined Vashon Drift Aquifer 661 and surface water resources in the vicinity of Spider Lake.
- No well completion information is available for the QFN volunteer groundwater monitoring wells. It is unlikely that the QFN wells are completed in the Quadra sand Aquifer 662 mapped at their location.

- Several inconsistencies were discovered by Waterline on the MOE Aquifer Classifications Worksheets. For example, the Quadra sand Aquifer 421 does not appear to extend over the area mapped and may not be extensive enough to be mapped as an aquifer. In addition, Aquifer 665 is listed as confined and moderately vulnerable when the logs strongly suggest it is unconfined and highly vulnerable. Although it is the user's responsibility to confirm the accuracy of MOE maps, it can significantly affect groundwater management decisions made by the RDN or water users if the information is left unchecked.

5.0 RECOMMENDATIONS

The BC water well database indicates that over 360 water wells may be in use in Area H. There are only four MOE observation wells in the region to assess recharge to the various aquifers and long-term aquifer response to recharge and groundwater use; however only one of those well OW310 is completed in a mapped aquifer. Additional water level data are available from volunteer monitoring wells in the region. Some of those wells have no associated drilling reports, and may be completed in different aquifers than the one they were intended to monitor. Selecting appropriate, representative monitoring wells is critical to making properly informed groundwater management decisions. The well construction information, geological information from the drill logs and the aquifer the well is completed in should be clearly understood before the monitoring is initiated. Although not always economically feasible, purpose-drilled monitoring wells sited and installed by a hydrogeologist are preferable. The time and effort spent in collecting data should maximize the understanding of aquifer systems and advance the state of knowledge, especially as it relates to groundwater use and aquifer recharge. Waterline recommends that the RDN establish water management objectives and identify appropriate groundwater monitoring wells that will help meet those objectives and inform future OCP updates. This should include establishing a groundwater level monitoring location in each of the area aquifers and a water quality sampling program for each aquifer including all major anion and cations, bacteria and trace metals. If the water quality samples are taken at roughly the same time a comparison of the water chemistry may provide some insight into the source of aquifer recharge to the various aquifers.

In terms of aquifer management, Waterline recommends that all aquifers in the RDN be managed as any other municipal reservoir. The advantage of a groundwater system reservoir is that it may be less susceptible to summer droughts in addition to providing a natural filtering system for delivering high-quality, sediment-free water. Aquifers are water supply reservoirs, in the same way the Arrowsmith Dam and reservoir retains and provides water supply for the City of Parksville, for example. The Town of Gibsons has taken a leadership role in developing a system whereby the Gibsons Aquifer is in the process of being classified as an "Eco Asset" and is maintained and managed just like any other infrastructure (building, sidewalk, distribution piping, etc.). The concept is simple but effective, the aquifer value is being appraised to determine its dollar value and maintenance and upkeep costs.

The Provincial aquifer maps for Area H are in need of updating. As this is a Provincial responsibility, the RDN should consult with MFLNRO and/or MOE to discuss the enclosed updates. Based on discussions with MFLNRO, we understand that the MOE observation wells in the region are no longer being attributed to the wrong aquifer and are listed as being completed in an unmapped aquifer; however there is sufficient information in the GSC research to attribute the wells to specific aquifer formations.

Uncertainty still remains with respect to exactly where infiltration and recharge enters the various aquifer systems located within Area H. Taking a conservative approach, the RDN should assume that all areas up gradient of the DBID and BWD well fields are potentially important recharge areas. QBHLWD is located in a more complicated geological environment and should be studied separately. A preliminary assessment of significant recharge areas developed by Waterline (2013) based on remote sensing data. Although useful for developing a “conceptual water budget”, this information cannot be relied upon exclusively to map recharge areas and inform the OCP process. The remote sensing helps identify impermeable surfaces and vegetative cover (i.e.: Leaf Area Index) and estimate infiltration to the surficial sediments, however without a thorough understanding of the geology, the hydraulic connection to surface and the hydraulic connection between the various aquifers these types of maps are not adequate to understand the recharge to the aquifers being developed for water supplies.

Given that the OCP needs to be updated immediately, Waterline recommends that the RDN manage future community development on a site by site basis whereby proponents are required under development permit to determine and maintain the recharge capacity of the land. This approach is similar to the requirements for conducting percolation tests for determining septic suitability. This information is also required for protecting aquifer from contamination by septic systems. These data would need to be collected in a data base and reviewed so that more accurate mapping of aquifer recharges areas can be completed in the future.

In addition to detailed mapping of recharge areas, long-term performance monitoring is required for the larger water users in Area H. Presumably MFLNRO will require this information under the WSA which is now in force. Waterline recommends that monitoring wells within the DBID, BWD, and QBHLWD well fields be equipped with data loggers in order to fully assess the long-term response to groundwater use and short and long-term recharge trends.

Isotopic and geochemical techniques exist that can help assess the origin of recharging water and differentiates mountain block recharge from direct vertical recharge. Waterline recommends that the RDN consider initiating environmental tracer analysis as it would help determine the source and origin of aquifer recharge.

6.0 CLOSURE

Waterline is pleased to provide the enclosed report for this interesting and challenging project. We trust that the information provided herein provides some new information to support the OCP update process. However, should you require more information or have any questions or concerns, please do not hesitate to contact the undersigned at your convenience.

Respectfully submitted,

Waterline Resources Inc.

Original Signed, Stamped and Dated

Bernadette Lyons, M.Sc.E., P.Eng
Senior Hydrogeological Engineer

Reviewed by:

Original Signed

Darren David, M.Sc., P.Geol.
Principal Hydrogeologist

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TABLES

Table 1: Summary Hydrogeological Review RDN Electoral Area H

Area Mapped as Aquifer # [Other Aquifers Identified]	Supplying water to…	Monitoring Locations	Characteristics Summarized in Waterline Report	Recharge areas	Recommendations
416 Quadra Sand Aquifer	▪ DBID ▪ BWD ▪ Rural residential private wells	BC OW310	▪ Highly productive – test in DBID well field reported a sustainable yield of 9.45 L/s, sustainable yields for BWW wells reported to be 10 L/s to 13 L/s ▪ Highly vulnerable – near surface water table, overlain by well-draining sand and gravel ▪ Short residence time of groundwater from recharge to discharge ▪ Well drained, thick unsaturated zone at higher elevations	▪ Recharged primarily by direct precipitation, upgradient of the DBID and BWW well fields and diffuse over most of the mapped area of Aquifer 416 ▪ Groundwater levels in OW310 respond to individual winter rainfall events ▪ Delayed response to seasonal precipitation of about 3.5 to 5 months ▪ Resilient to summer drought; vulnerable to multi-year winter drought	▪ Development permits that require the determination and maintenance of the recharge capacity of the land ▪ DBID and BWW monitor their production wells with level loggers ▪ Provincial aquifer mapping for Aquifer 416 needs to be updated (to more accurately reflect aquifer vulnerability)
[Unmapped Deeper Sand and Gravel Aquifer]	▪ At least 7 of the private wells in the rural residential subdivision on Cowland Road	None	▪ Little information is available ▪ Driller's logs indicate that this aquifer is separated from the overlying Quadra sand aquifer by a till unit	▪ Unknown, little data available	▪ More investigation needed to define this aquifer ▪ Consider initiating monitoring in aquifer for groundwater levels and water quality, including all major anions and cations, in addition to bacteria and trace metals
421 Quadra Sand Aquifer	▪ Unknown – only four wells in BC Wells Database potentially completed in this aquifer and may not be in use	None	▪ There appears to be no regionally significant Quadra sand aquifer between Thames and Nile Creek ▪ New wells completed since the MOE aquifer mapping indicate that Vashon Till may directly overlie the Cowichan-Dashwood Till in this region	▪ Unknown, little data available	▪ Provincial aquifer mapping for Aquifer 421 needs to be updated (the Quadra sand does not appear to be a regionally significant water supply aquifer in this area)
665 Capilano Sand and Gravel Aquifer, overlies 421.	▪ Potentially some rural residential wells; though the developed coastal area is serviced by QBHLWD (who are getting water outside this aquifer).	None [1] [1]OW427 is completed in a deeper unmapped confined Quadra aquifer	▪ Low productivity, largely unconfined, highly vulnerable ▪ Likely locally connected to surface water with the fluvial delta deposits of the Qualicum River, and to a lesser extent Nile and Thames Creeks ▪ Does not appear to be a significant water supply for existing residents or have potential for the future	▪ Assumed to recharge from direct infiltration of precipitation with minor or no contribution from mountain block recharge	▪ Provincial aquifer mapping for Aquifer 665 needs to be updated (to more accurately reflect aquifer vulnerability)
[Unmapped Quadra Sand Aquifer, between Nile Creek and the Qualicum River]	▪ No one	BC OW427 [1]	▪ The GSC identified the unit screened in OW427 as Quadra sand ▪ The Quadra sand at OW427 is 70 m thick with a 25 m saturated thickness ▪ The Quadra sand aquifer is confined in OW427 ▪ Areal extent of the Quadra sand is unknown, but could be significant in the area between Nile Creek and the Qualicum River	▪ Recharge likely not through direct precipitation, but by precipitation recharging the aquifer from a significant distance away from the well, through overlying or underlying aquifers, or though mountain block recharge	▪ Investigate and clarify the extent of the deeper unmapped Quadra sand aquifer below 665, as a potential significant groundwater source ▪ Enough information is contained in the GSC studies to attribute OW427 to the Quadra Formation in the BC GOWN database ▪ Consider collecting groundwater quality samples, including all major anions and cations, in addition to bacteria and trace metals

Table 2: Summary Hydrogeological Review RDN Electoral Area H, continued

Area Mapped as Aquifer # [Other Aquifers Identified]	Supplying water to…	Monitoring Locations	Characteristics Summarized in Waterline Report	Recharge areas	Recommendations
662 Quadra Sand Aquifer	▪ Rural residential private wells[2] [2]QBHLWD wells appear to be completed in a permeable channel structure not directly connected to the regional Quadra aquifer	Shayla Well (discontinued Sept 2016)[3, 4 & 5] [3]OW425 is completed in a deep unmapped aquifer [4]OW426 is completed in a unmapped Cowichan sand and gravel aquifer below the mapped Quadra sand aquifer [5]Shayla Well appears to be completed below Aquifer 661 in Aquifer 622	▪ There are potentially five different but possibly hydraulically connected aquifers in the area mapped as 662, a highly complex geological environment: o A Quadra sand aquifer dispersed throughout the region o A highly productive, coarse sand and gravel aquifer with high static water levels, including the QBHLWD supply wells. o A Cowichan Formation sand and gravel aquifer, o A deep Dashwood Formation sand and gravel aquifer, o An aquifer with unconfirmed geology, including the QFN volunteer monitoring network wells ▪ The Quadra sand aquifer is well drained and only partially saturated at higher elevations, beneath Spider Lake	▪ Unknown, little data available	▪ More investigation needed to define these five aquifer units ▪ Groundwater should consider the variable nature of the aquifer(s) in this area, using available borehole logs to determine the local geological context of the project and not simply assuming the wells are completed in a large relatively homogeneous aquifer ▪ Provincial aquifer mapping should be updated, but may require more data collection ▪ Initiate monitoring in the Quadra Sand Aquifer 662 for groundwater levels and water quality, including all major anions and cations, in addition to bacteria and trace metals
[Unmapped Coarse Sand and Gravel Channel Structure Aquifer]	▪ QBHLWD[2] (services the QFN reserve as well)	None	▪ The QBHLWD wells form part of a northwest-southeast trending linear group of wells with near surface water levels or flowing artesian conditions ▪ Nearby wells have very different static water levels despite being drilled to a similar depths and may indicate a different "plumbing system" ▪ The QBHLWD supply wells appear to be completed in a permeable channel structure not directly connected to the regional Quadra aquifer system ▪ Sustainable yields for the QBHLWD wells reported to range from 21 L/s to 30 L/s	▪ The inferred permeable channel structure that QBHLWD wells are accessing would have a more lateral capture zone (along the channel) rather than upgradient	▪ More investigation needed to better understand the coarse sand and gravel unit that is providing QBHLWD wells with water ▪ QBHLWD should monitor production wells with level loggers ▪ QBHLWD should undertake a more comprehensive water quality testing program, including all major anions and cations, in addition to bacteria and trace metals
[Unmapped Cowichan Sand and Gravel]	▪ Some privately owned rural residential wells, near OW426	BC OW426[4] (screened from 64 m bgs to 70 m bgs)	▪ The GSC identified the unit screened in OW426 as Cowichan Formation sand and gravel ▪ Aquifer is currently listed as being completed in an unmapped aquifer in the BC GOWN database ▪ Areal extent unknown ▪ Aquifer has the potential to be at least moderately productive and could be further developed as a water supply at higher elevations where the saturated thickness of the Quadra sand is reduced	▪ Does not respond to seasonal variation in precipitation, therefore not recharged by direct precipitation	▪ Enough information is contained in the GSC studies to attribute OW426 to the Cowichan Formation aquifer in the BC GOWN database ▪ Consider collecting groundwater quality samples, including all major anions and cations, in addition to bacteria and trace metals
[Unmapped Dashwood Sand and Gravel]	▪ No one	BC OW425[3] (screened from 115 m bgs to 118 m bgs the bottom of the borehole)	▪ The GSC identified the unit screened in OW425 as Dashwood Formation sand and gravel ▪ Aquifer is currently listed as being completed in an unmapped aquifer in the BC GOWN database ▪ May be at or near the bedrock surface ▪ Areal extent unknown	▪ Responds to seasonal variation in precipitation despite depth and 40 m of overlying till ▪ Appears to be hydraulically connected to surface at this location ▪ May indicate that the bedrock is recharging the aquifer at this location	▪ Enough information is contained in the GSC studies to attribute OW425 to the Dashwood Formation aquifer in the BC GOWN database ▪ Consider collecting groundwater quality samples, including all major anions and cations, in addition to bacteria and trace metals

Table 3: Summary Hydrogeological Review RDN Electoral Area H, continued

Area Mapped as Aquifer # [Other Aquifers Identified]	Supplying water to…	Monitoring Locations	Characteristics Summarized in Waterline Report	Recharge areas	Recommendations
Continued from Aquifer 662 [Unknown Geology]	▪ Unknown, possible some use by QFN	QFN Wells	▪ Based on the well hydrographs it is unlikely that the QFN wells are completed in the mapped Quadra sand Aquifer 662 ▪ May be completed in the Capilano/Vashon glaciofluvial deposits or recent Qualicum River delta deposits	▪ Responds almost immediately to precipitation events ▪ No seasonal delay in the aquifer response, indicating that the recharge is primarily local ▪ May be hydraulically connected to the Qualicum River	▪ At a minimum the depth of the monitoring wells should be determined ▪ Consider collecting groundwater quality samples, including all major anions and cations, in addition to bacteria and trace metals ▪ The Qualicum River is currently not gauged, if a gauge was installed the groundwater levels in the wells could be compared with the river stage to investigate the potential hydraulic connection
661 Vashon Drift Sand and Gravel	▪ Rural residential private wells	None[5] .	▪ Perched Vashon kame terrace, sand and gravel aquifer ▪ Unconfined, highly vulnerable to surface contamination ▪ Hydraulically connected to Spider Lake – aquifer discharges to Spider Lake but with enough pumping could remove water from Spider Lake ▪ Potential for this perched aquifer to drain into partially saturated Quadra sand aquifer below, due to erosion of aquitard or leaky well casings	▪ Little data available ▪ Recharge likely largely from local precipitation, however there is potentially a connection to Horne Lake	▪ Initiate monitoring in Aquifer 661 for groundwater levels and water quality, including all major anions and cations, in addition to bacteria and trace metals ▪ Likely adequate for individual domestic use, but larger scale groundwater supply development is not recommended

FIGURES

Waterline

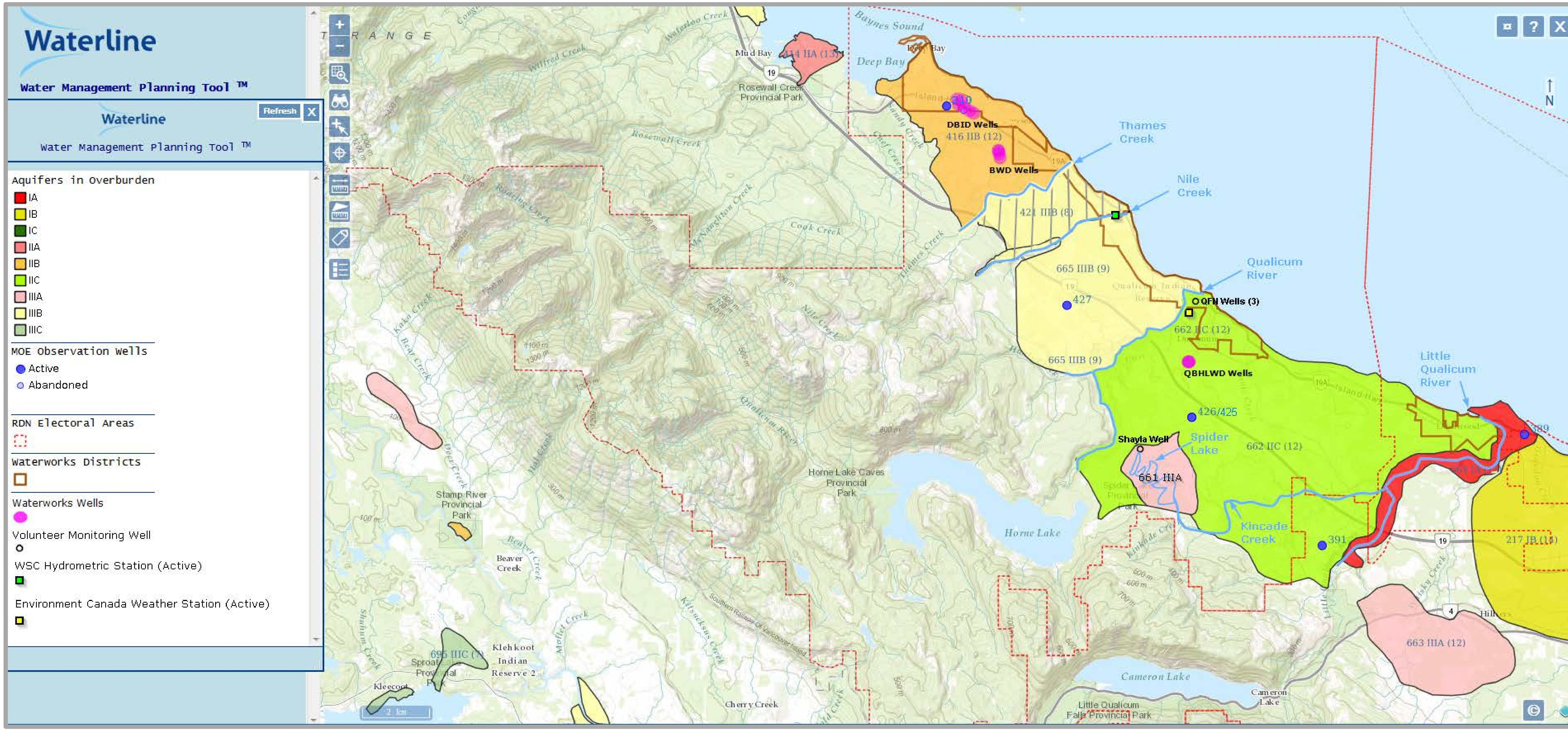

Figure 2: Mapped Aquifers – RDN Electoral Area H

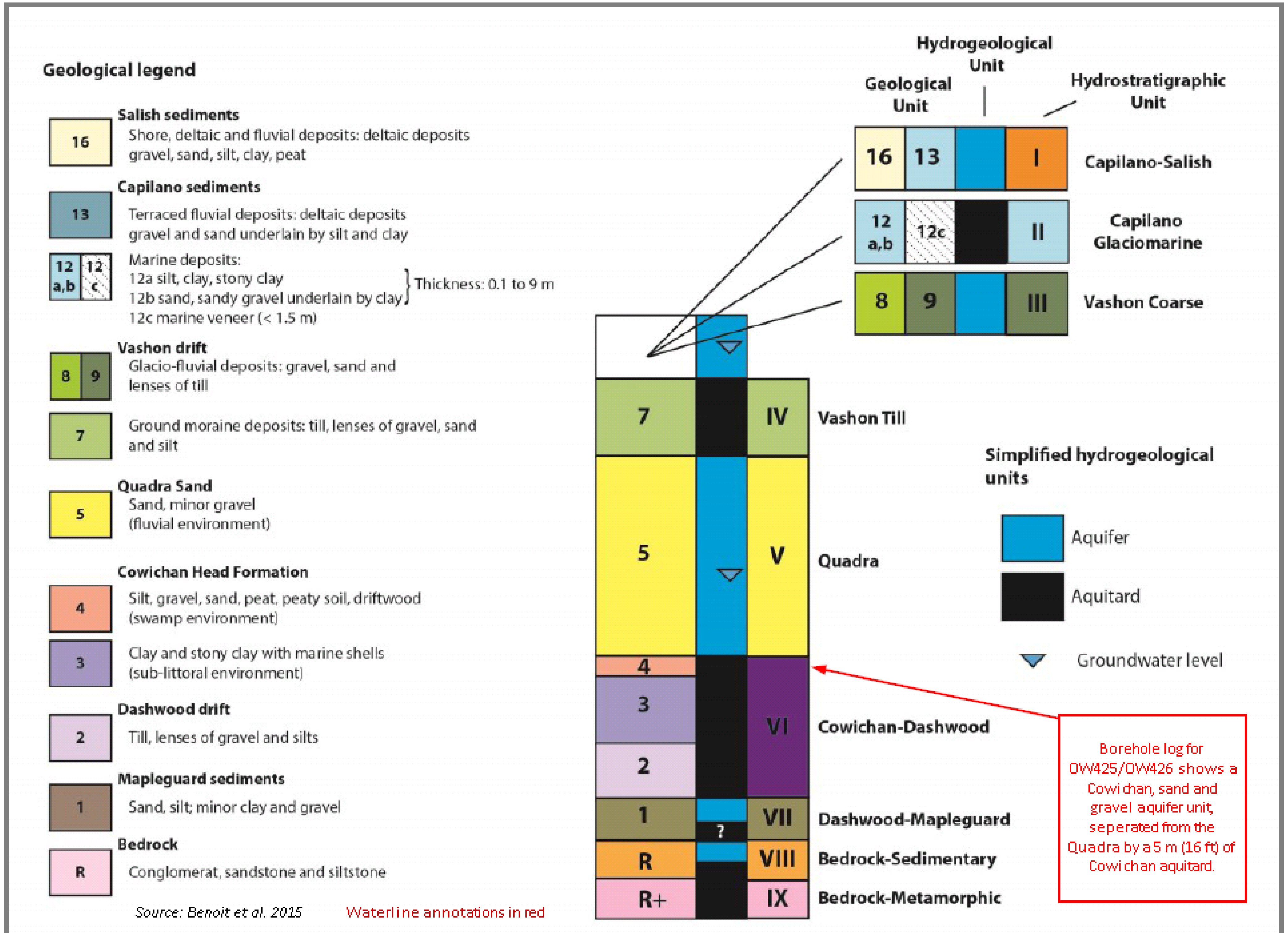

Figure 3: Mapped Hydrostratigraphy Nanaimo Lowland (Benoit et. al., 2015)

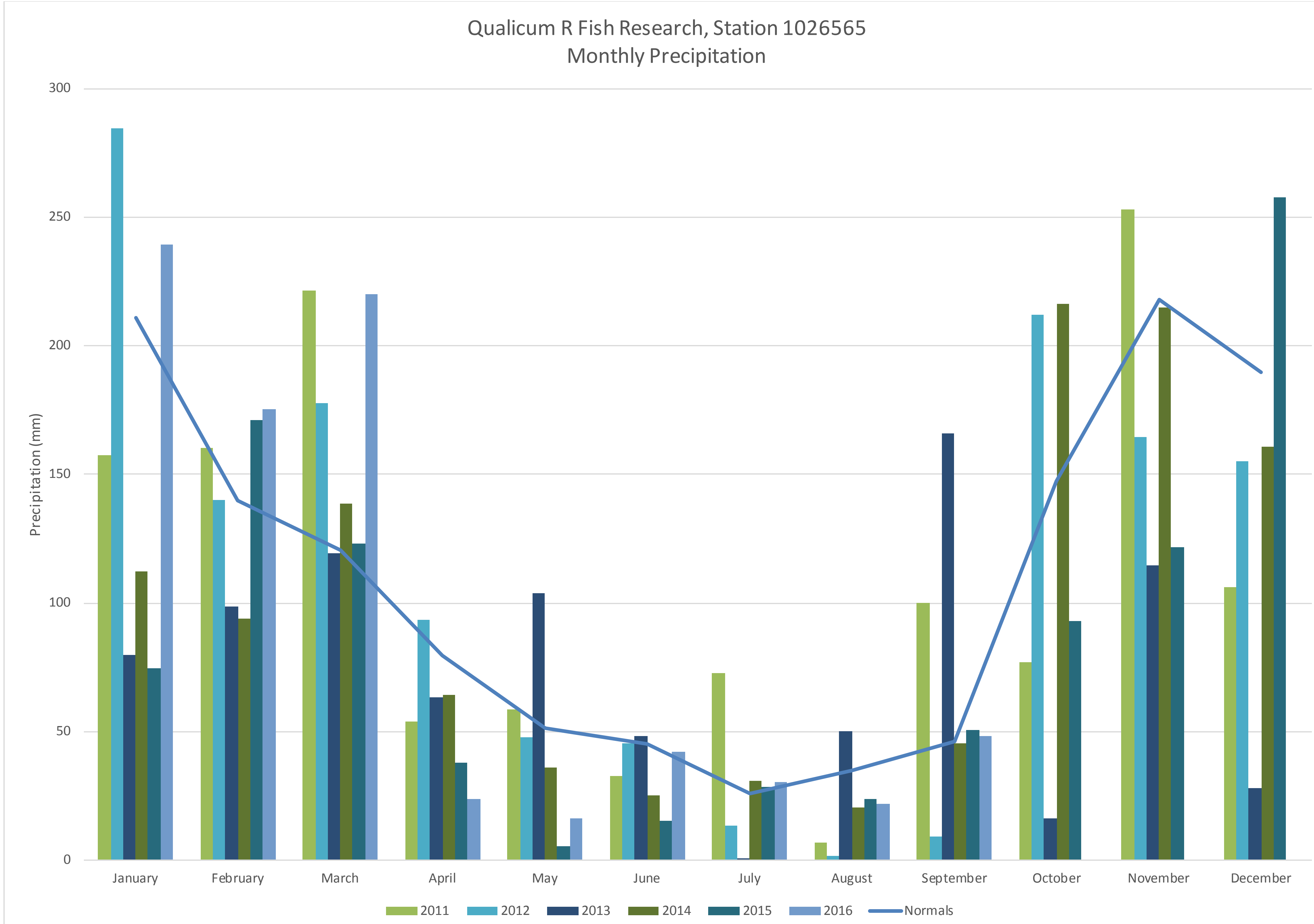

Figure 4: Qualicum River Climate Stn 1026565 and Monthly Precip.

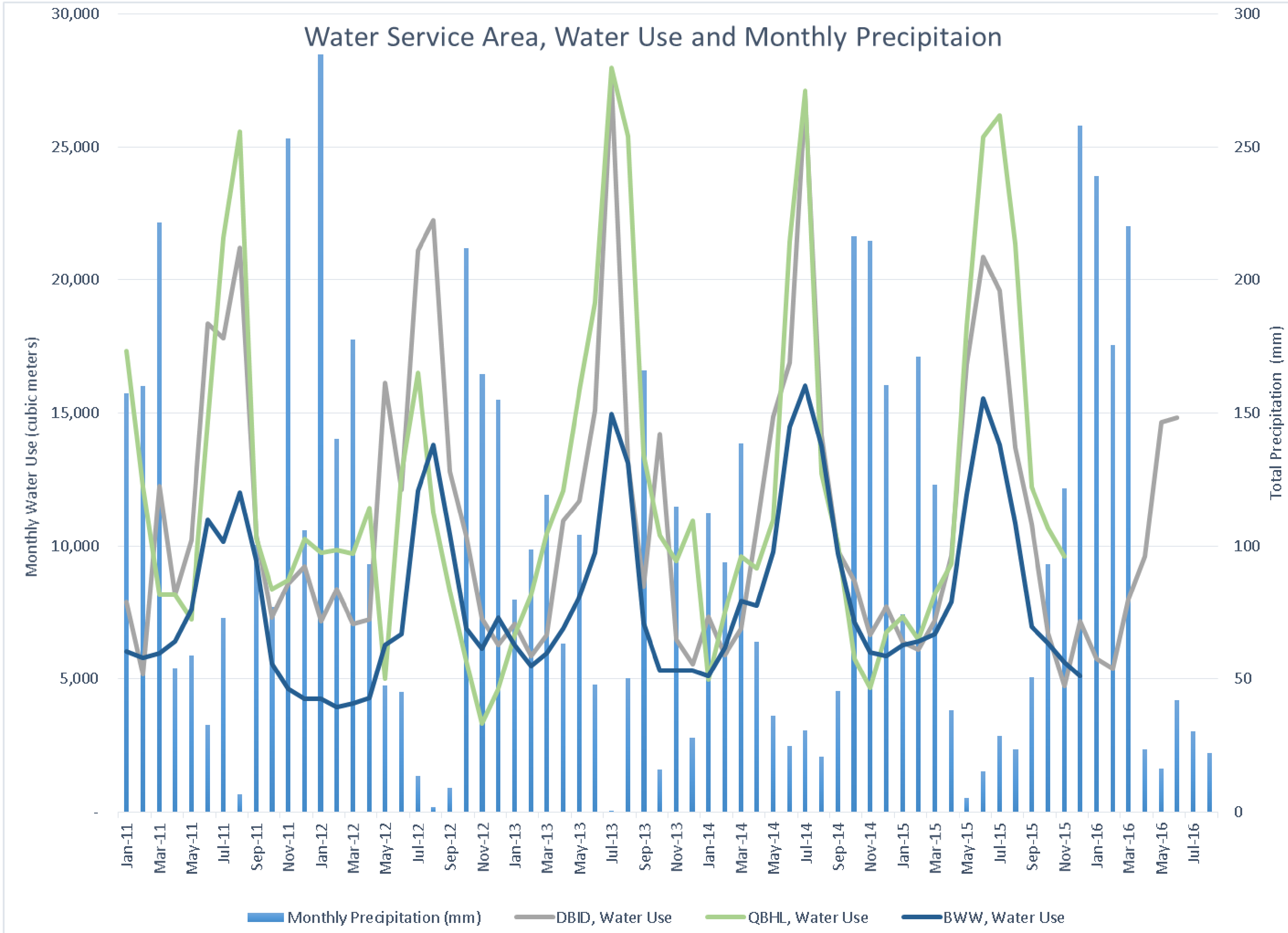

Figure 5: Water Use and Monthly Precipitation

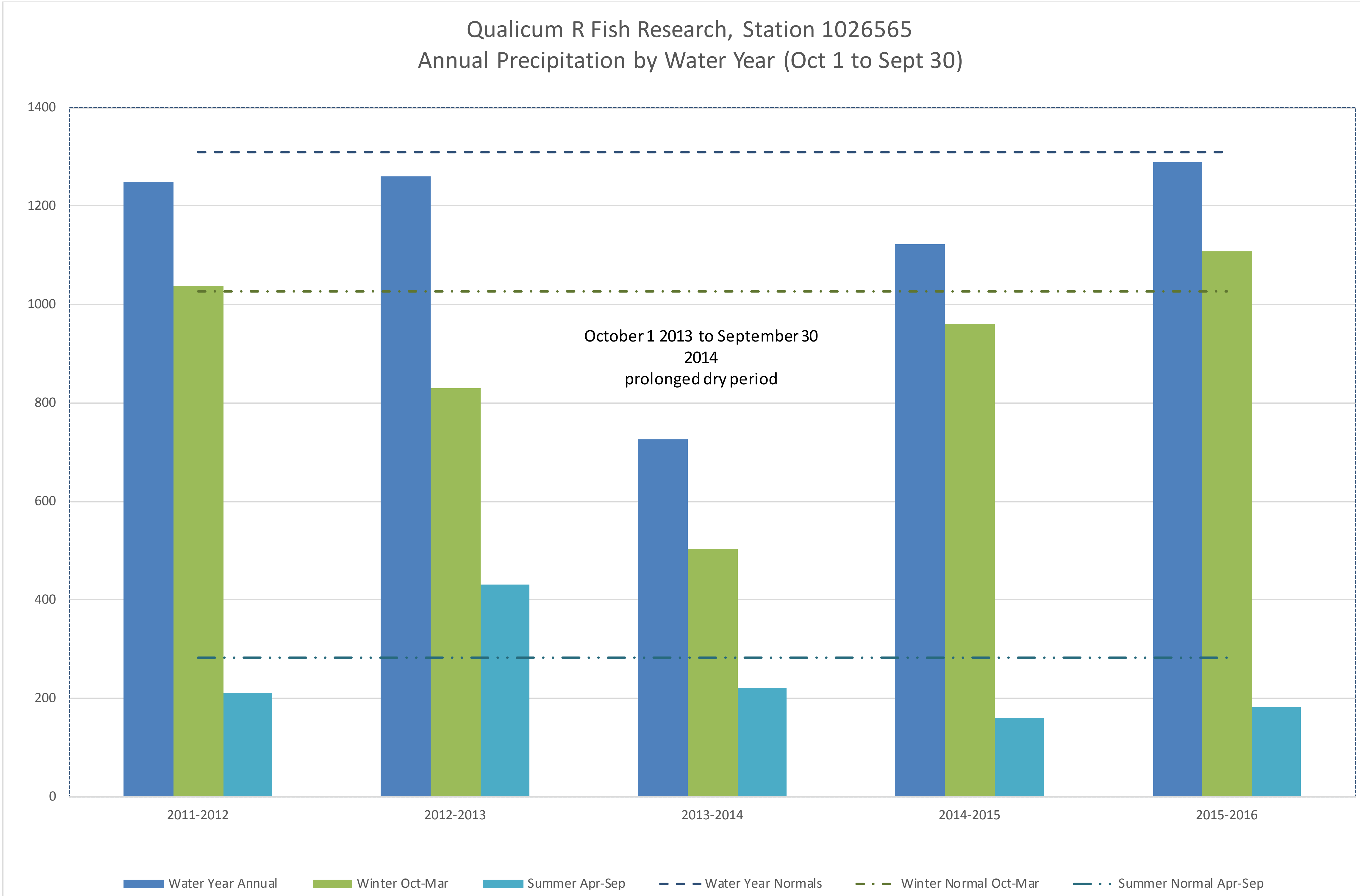

Figure 6: Qualicum River Climate Stn 1026565 and Annual Precip

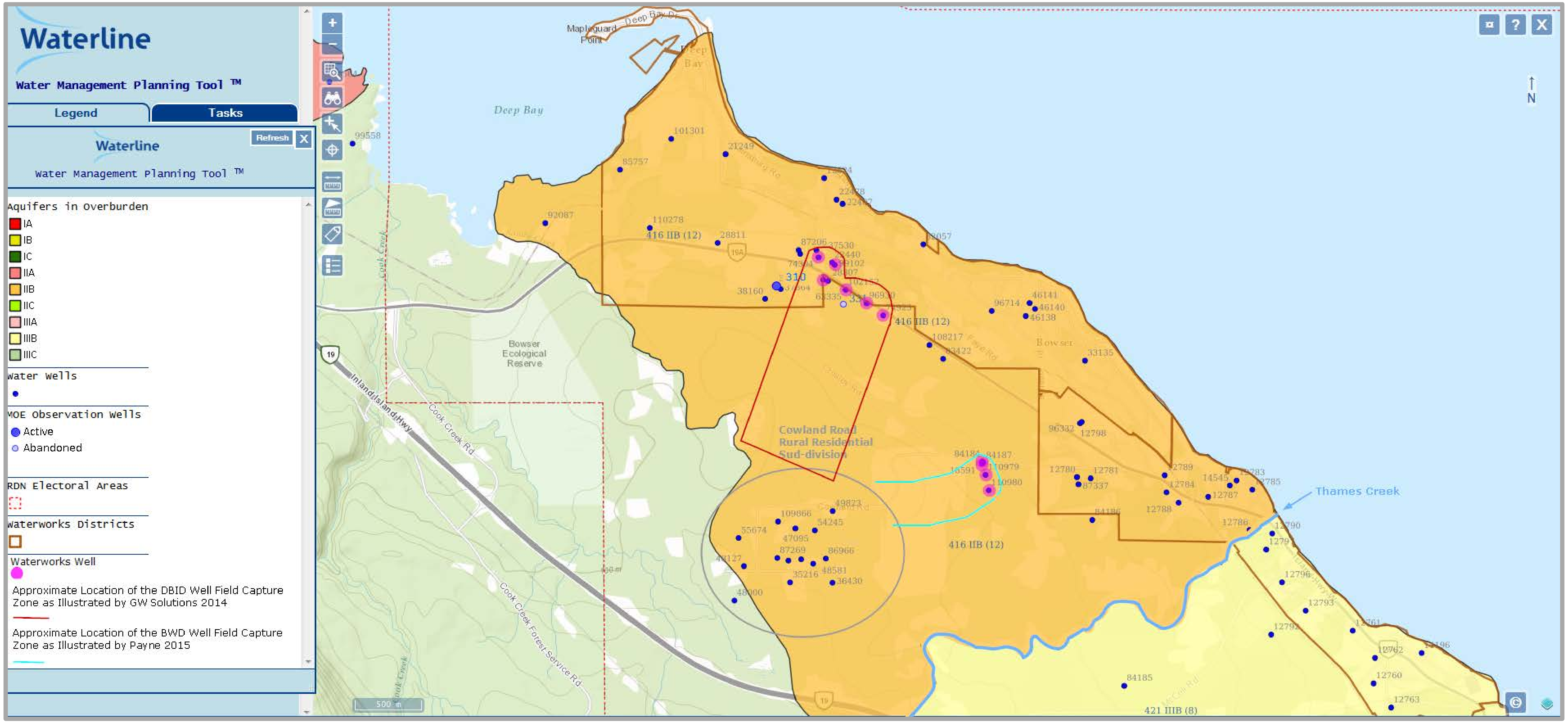

Figure 7: Aquifer 416 and Wells

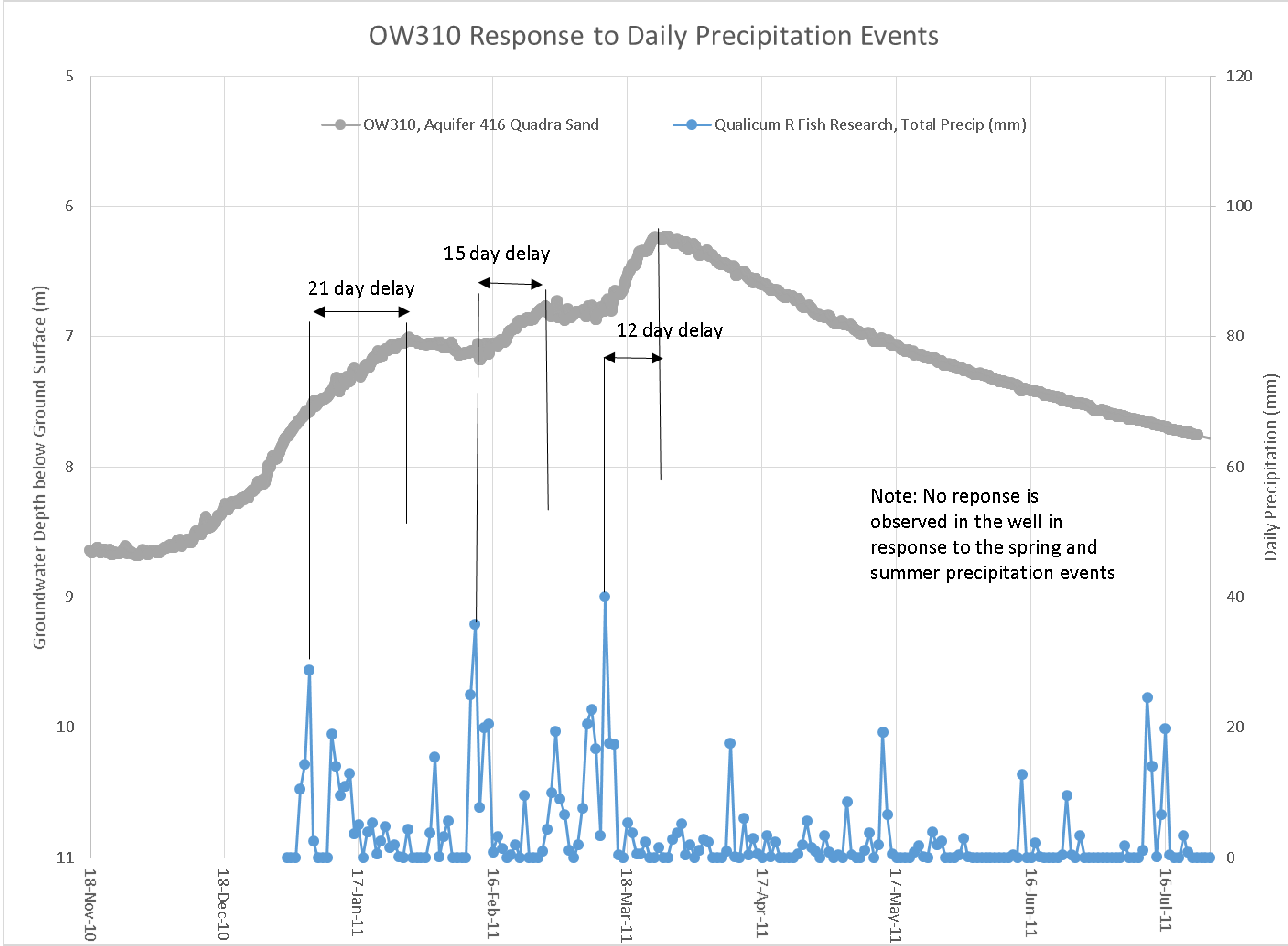

Figure 8: MOE OW310 Hydrograph and Daily Precipitation

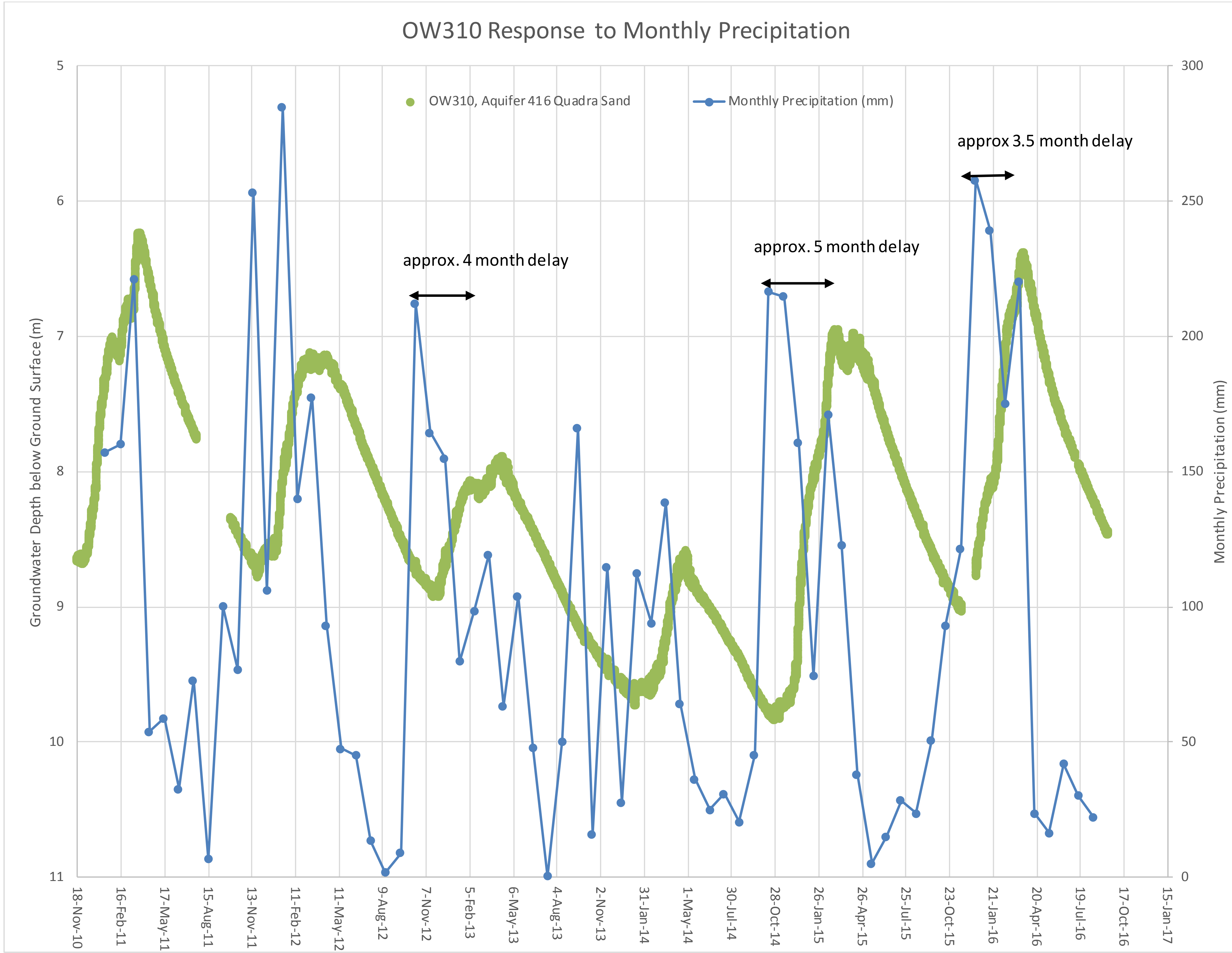

Figure 9: MOE OW310 Hydrograph and Monthly Precipitation

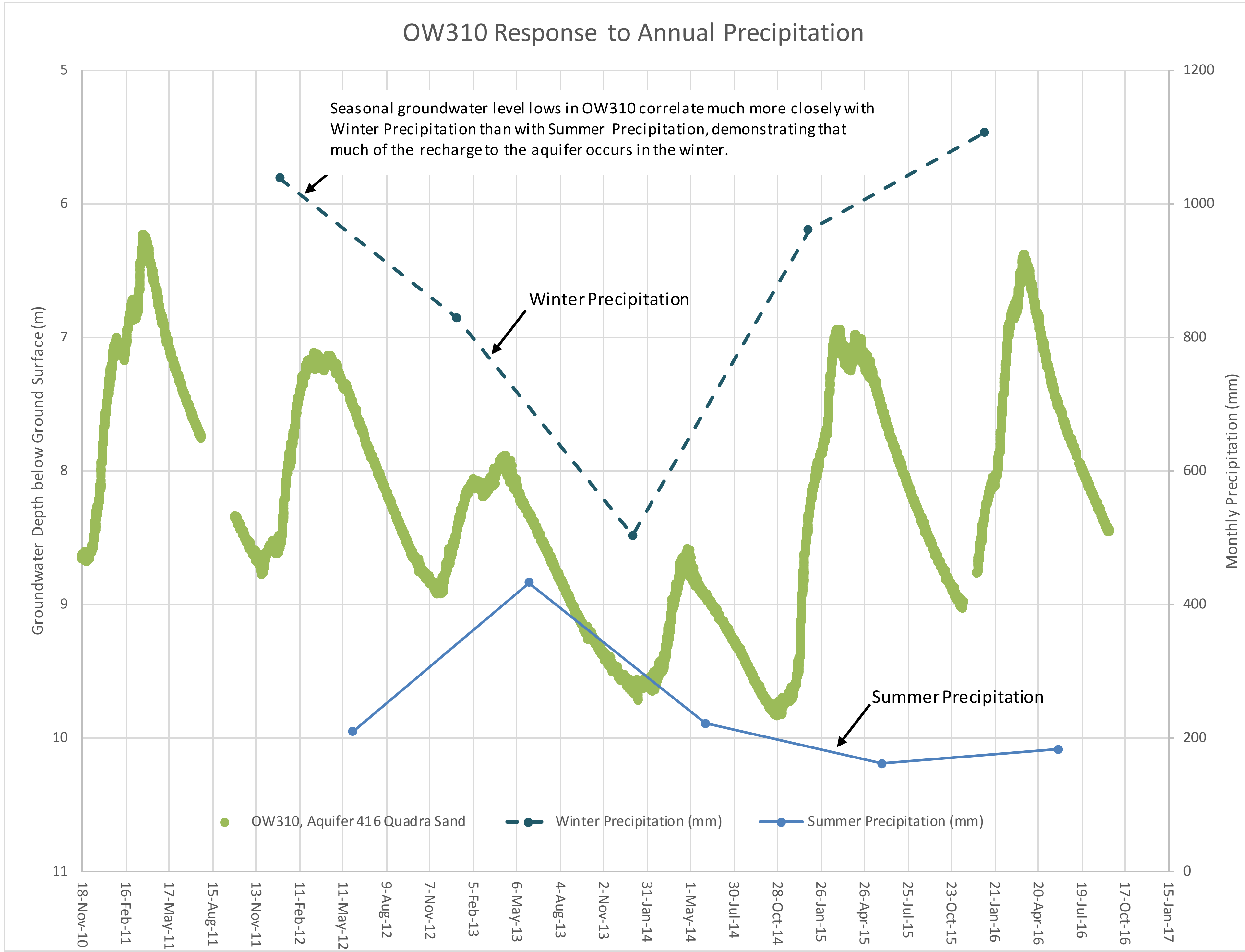

Figure 10: MOE OW310 Hydrograph and Annual Precipitation

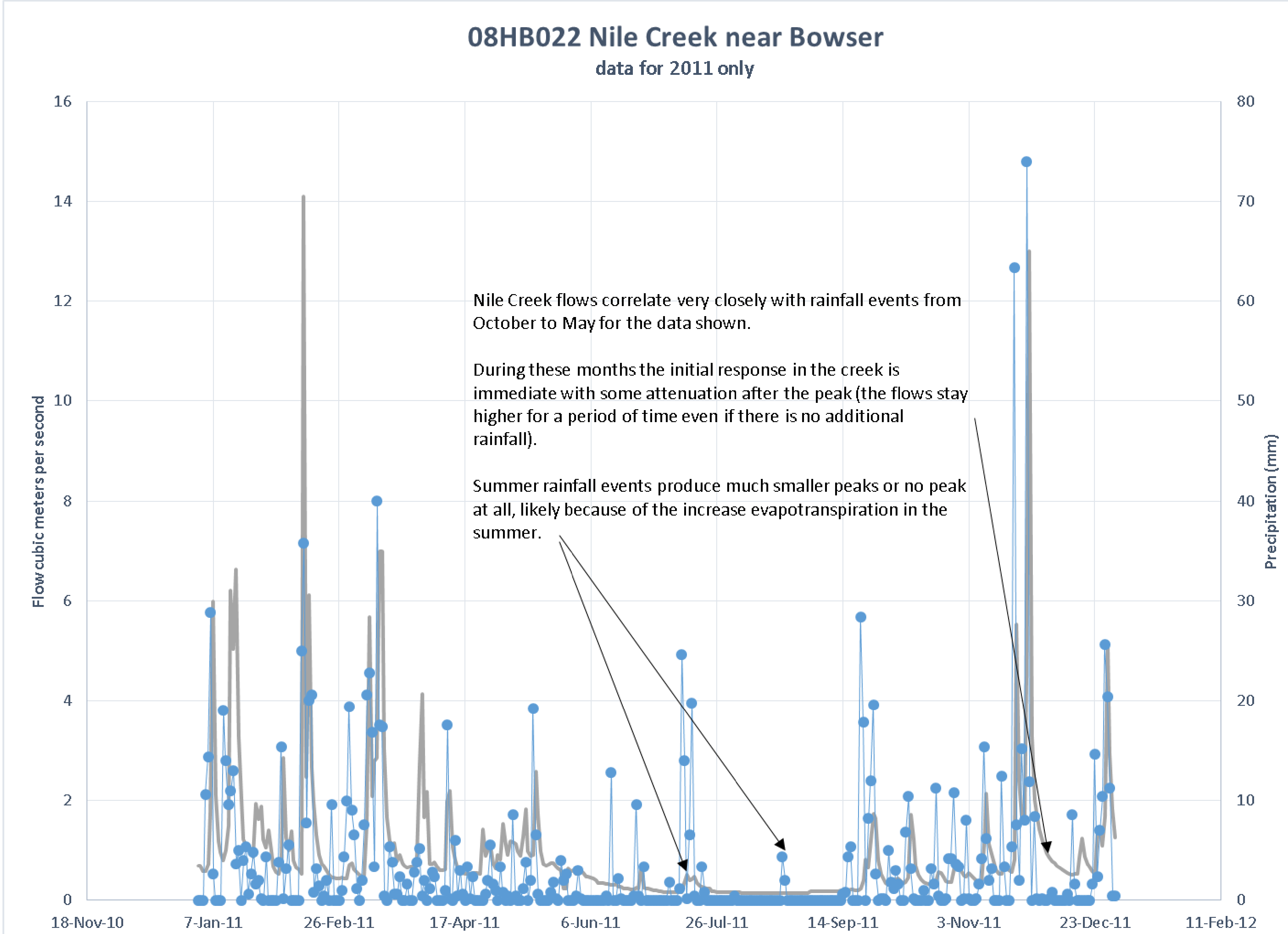

Figure 11: Nile Creek Hydrometric Station 08HB022

Deep Bay Village Well Field Assessment for Baynes Sound Investments June 16, 2014

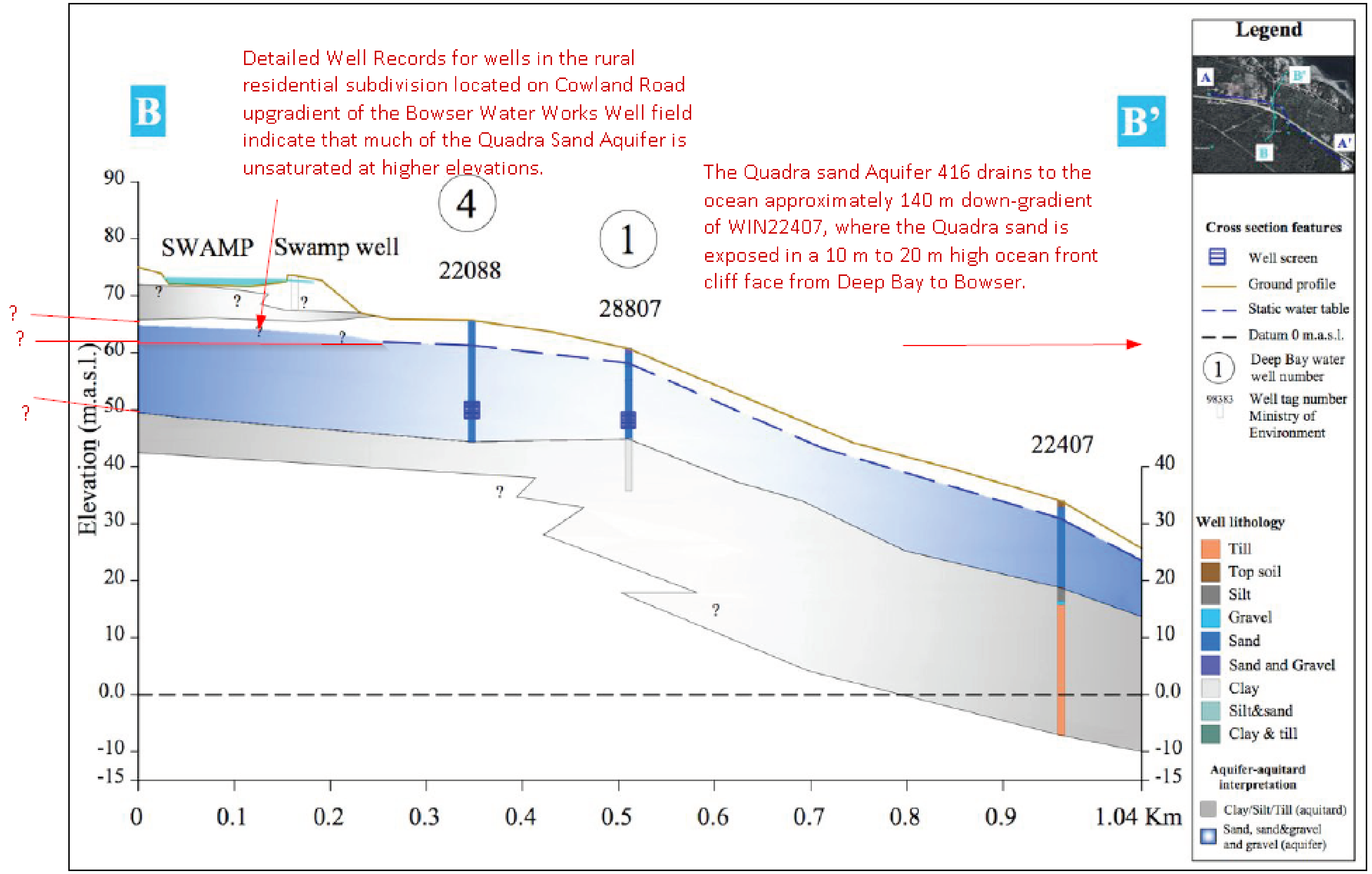

Figure 7. Hydrostatic cross-section B-B' is cut at the location shown in Figure 5

MOUNTAINS

Cross-section showing the Quadra Sand Aquifer 416 at the DBWW well field

OCEAN 140 m

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Source: Groundwater Solutions 2014

Waterline annotations in red

Figure 12: Hydrogeological Cross-Section (modified from GW Solutions, 2014)

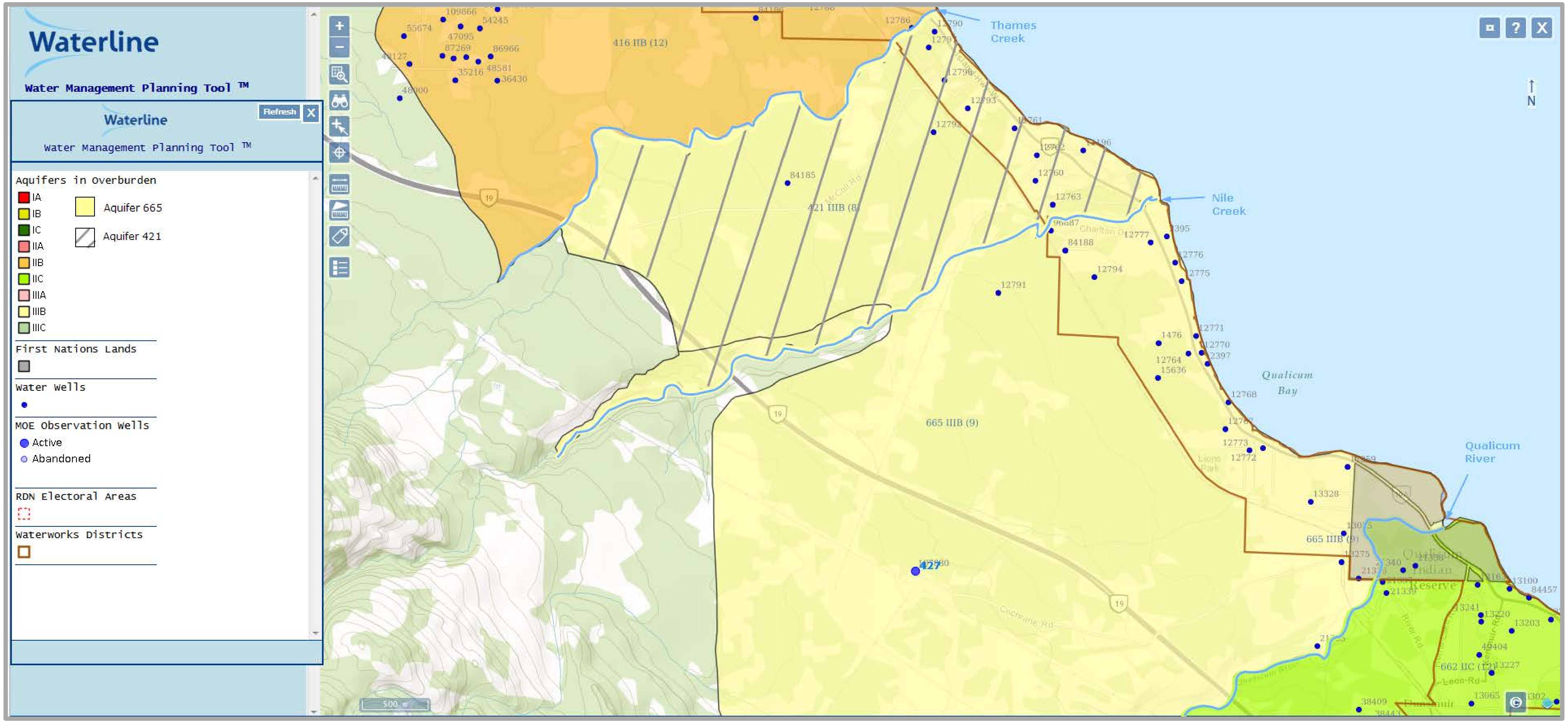

Figure 13: Aquifer 421/665 and Wells

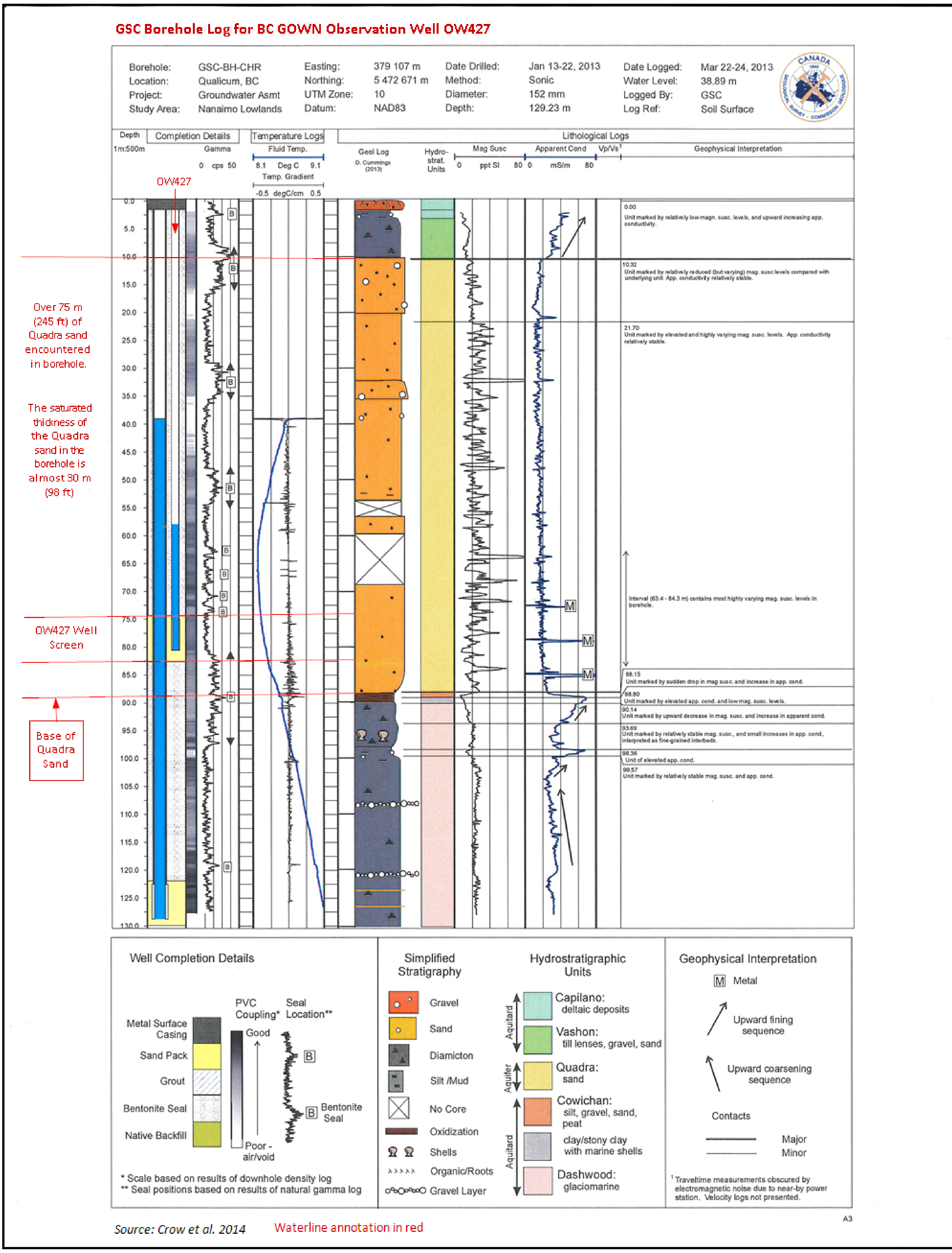

Figure 14: GSC Well Log OW427 (modified from Crow et.al. 2014)

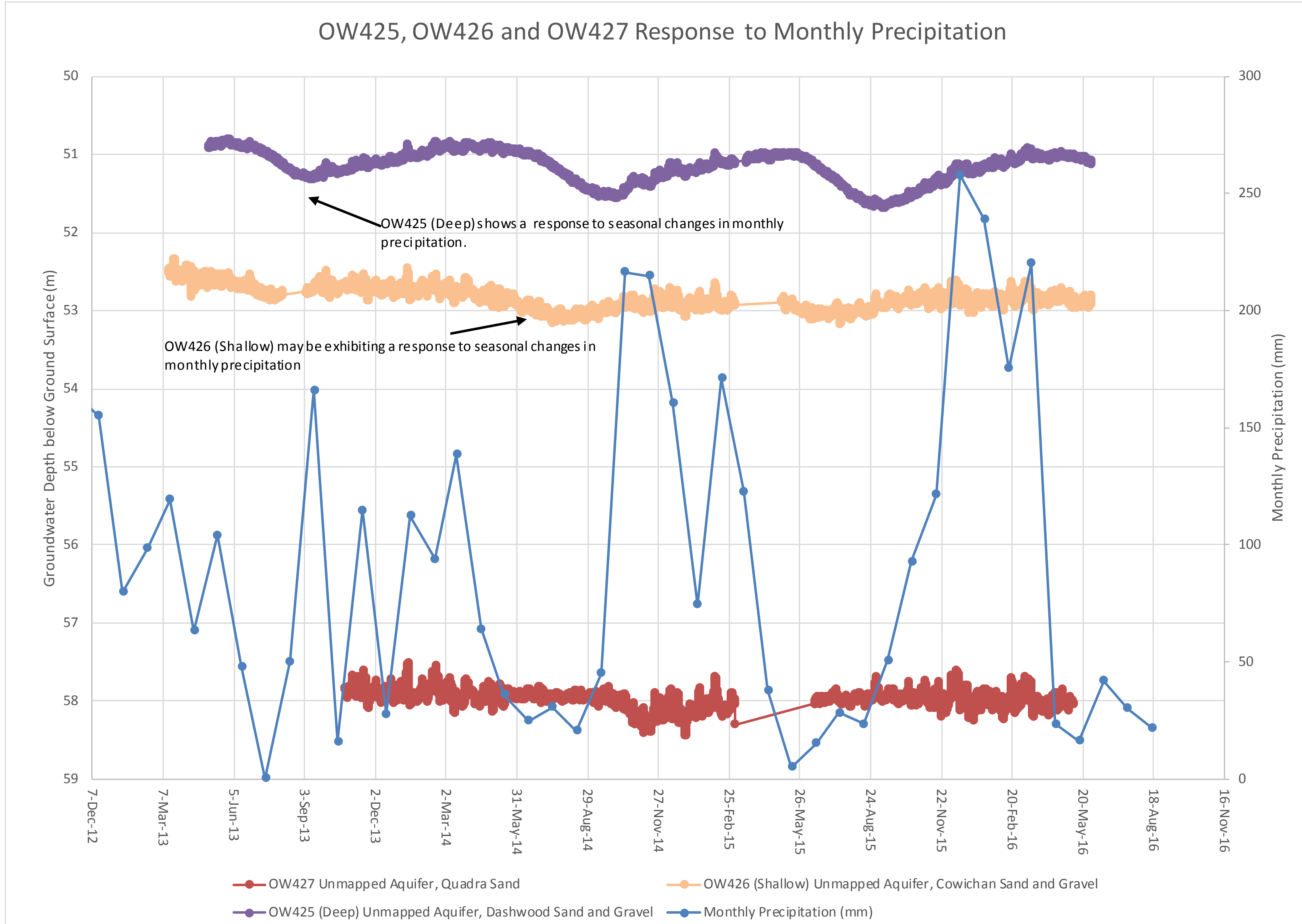

Figure 15: MOE OW425, OW426, and OW427 Hydrographs and Monthly Precipitation

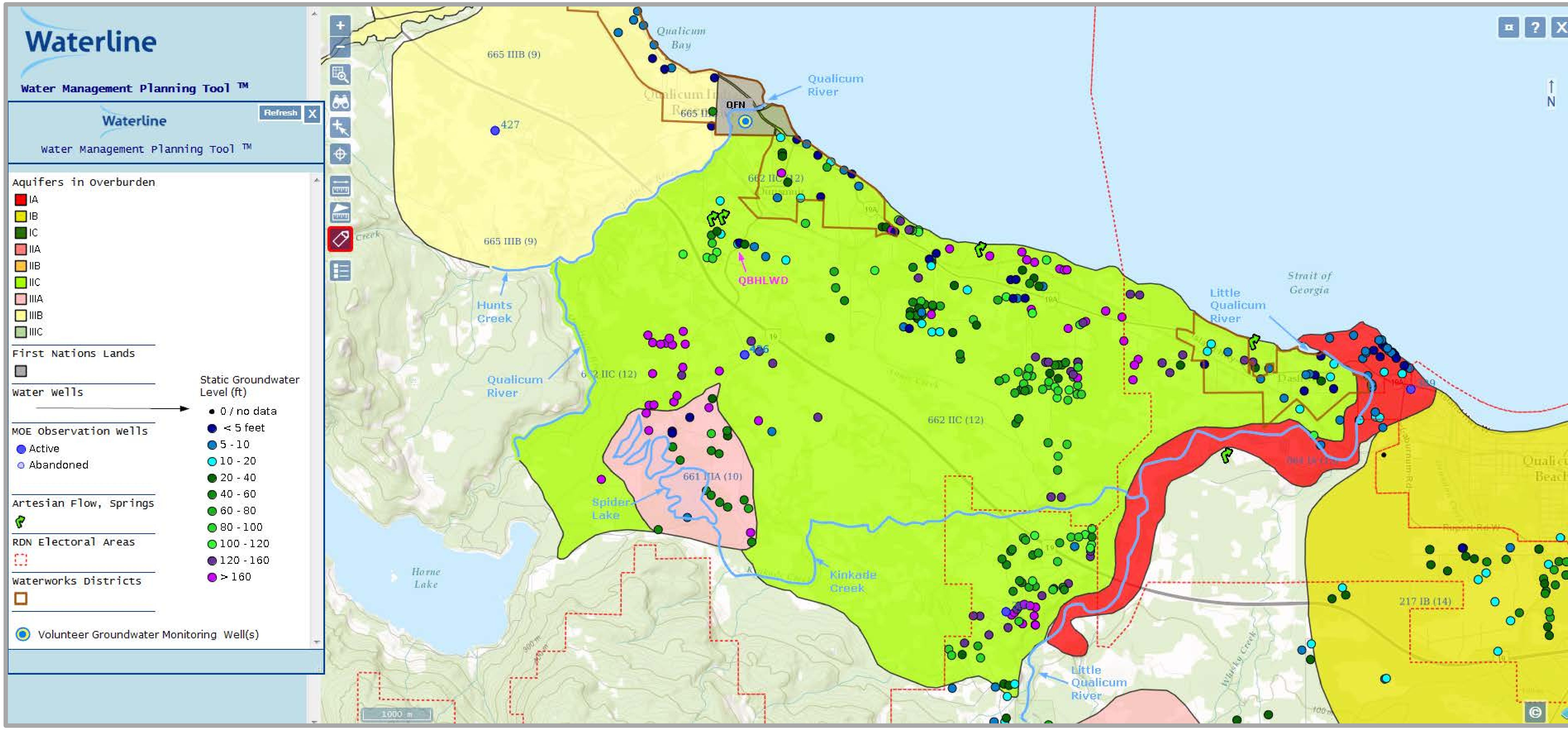

Figure 16: Aquifer 662 and Wells

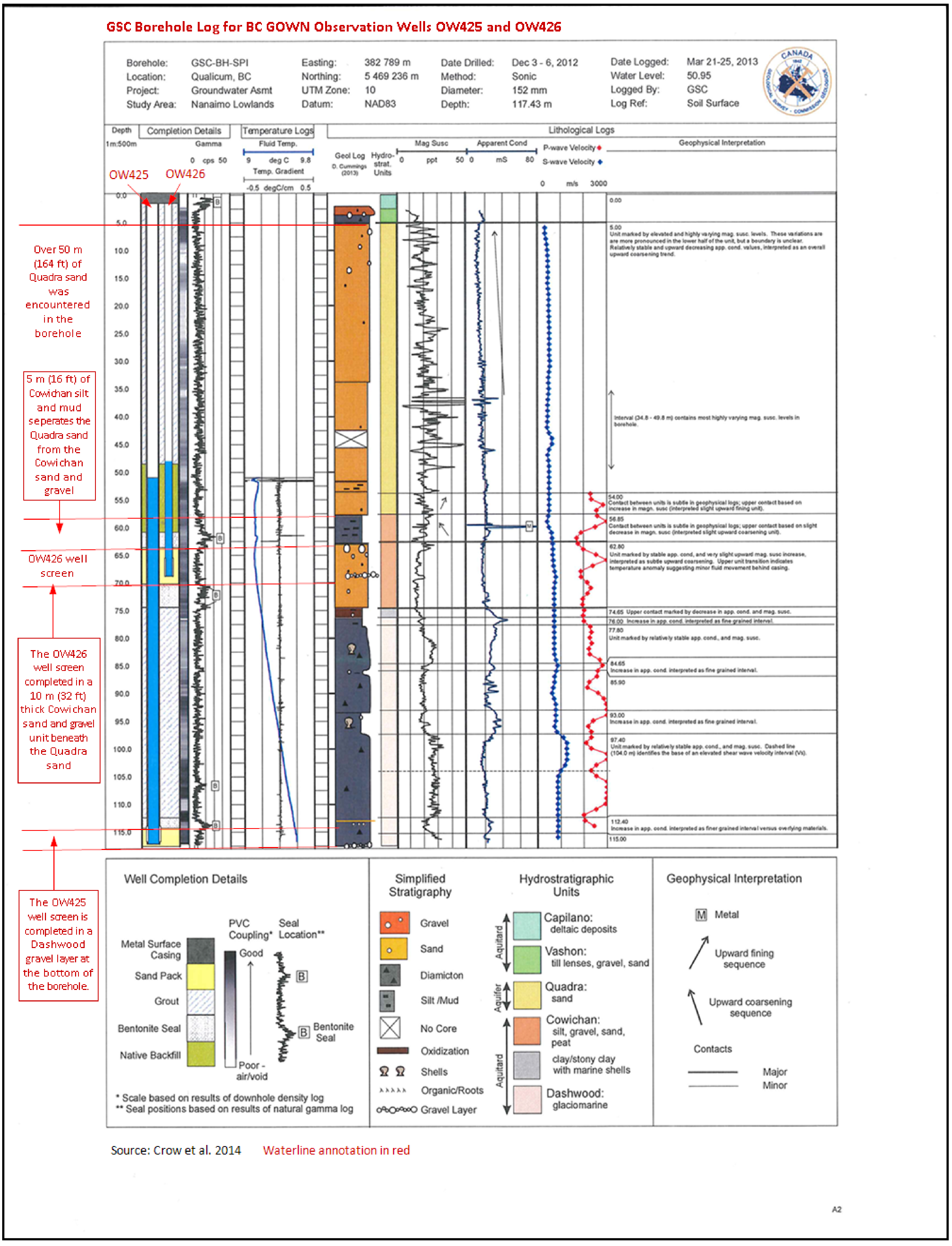

Figure 17: GSC Well Logs OW425 and OW426 (modified from Crow et.al. 2014)

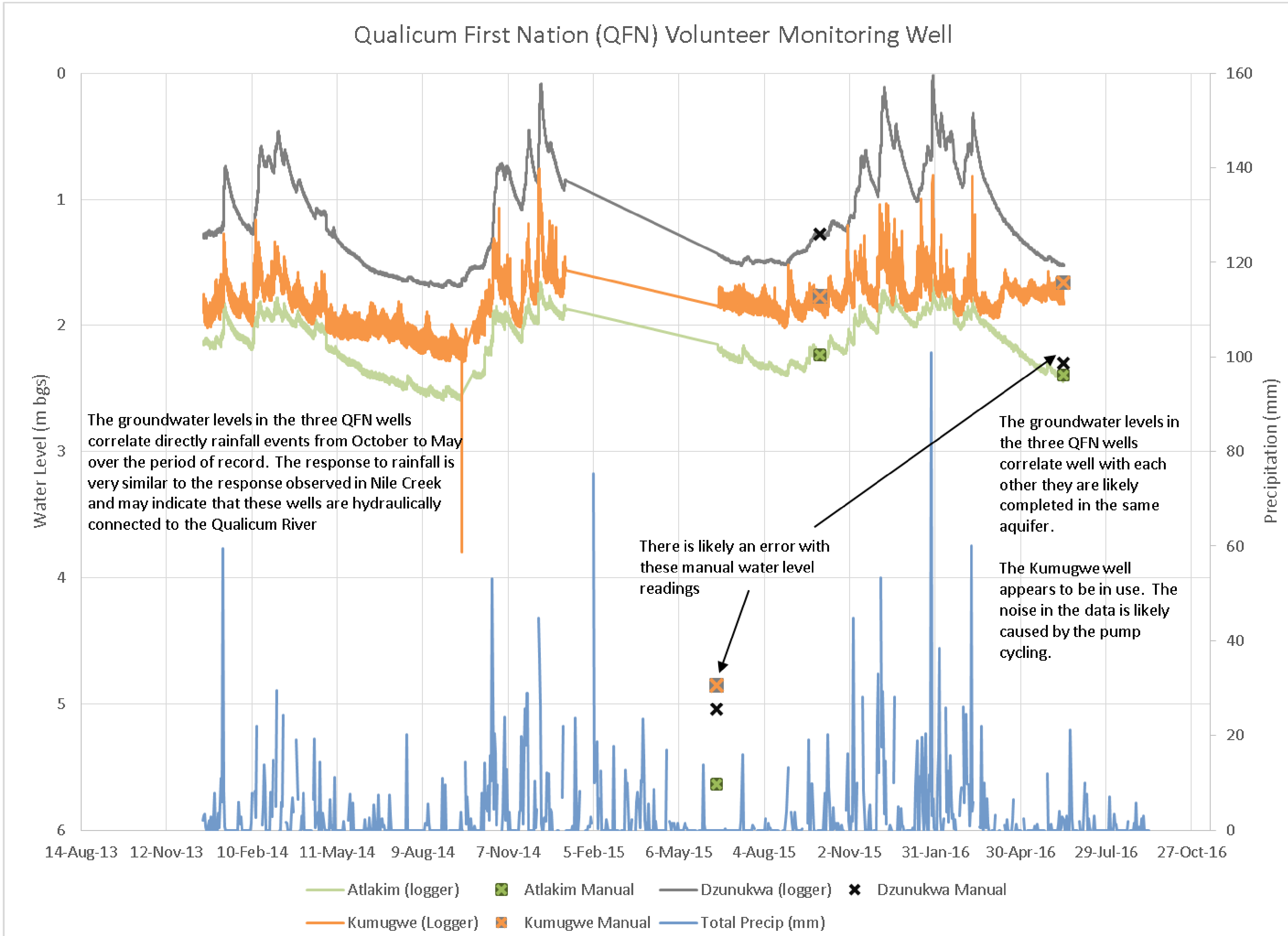

Figure 18: QFN Monitoring Well Hydrographs and Annual Precipitation

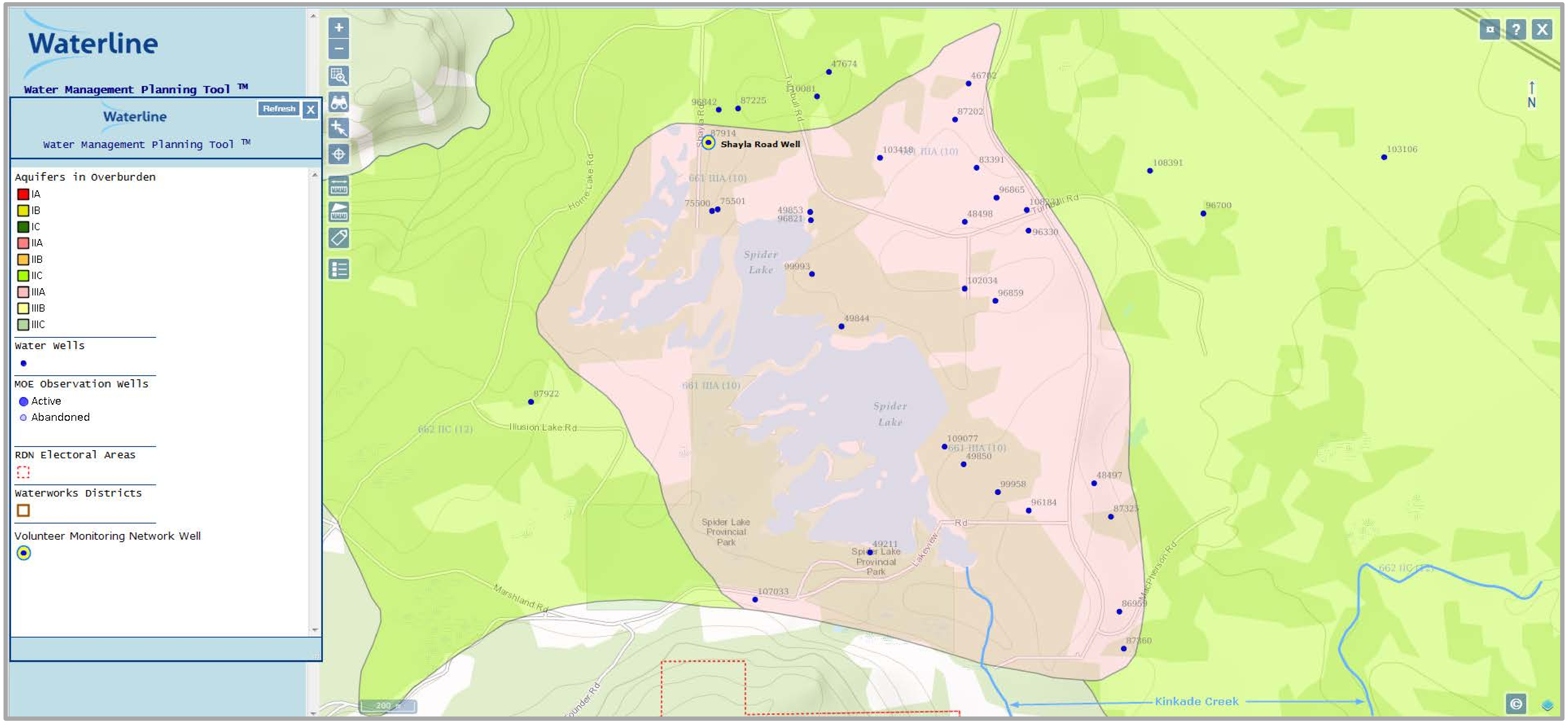

Figure 19: Aquifer 661 and Wells

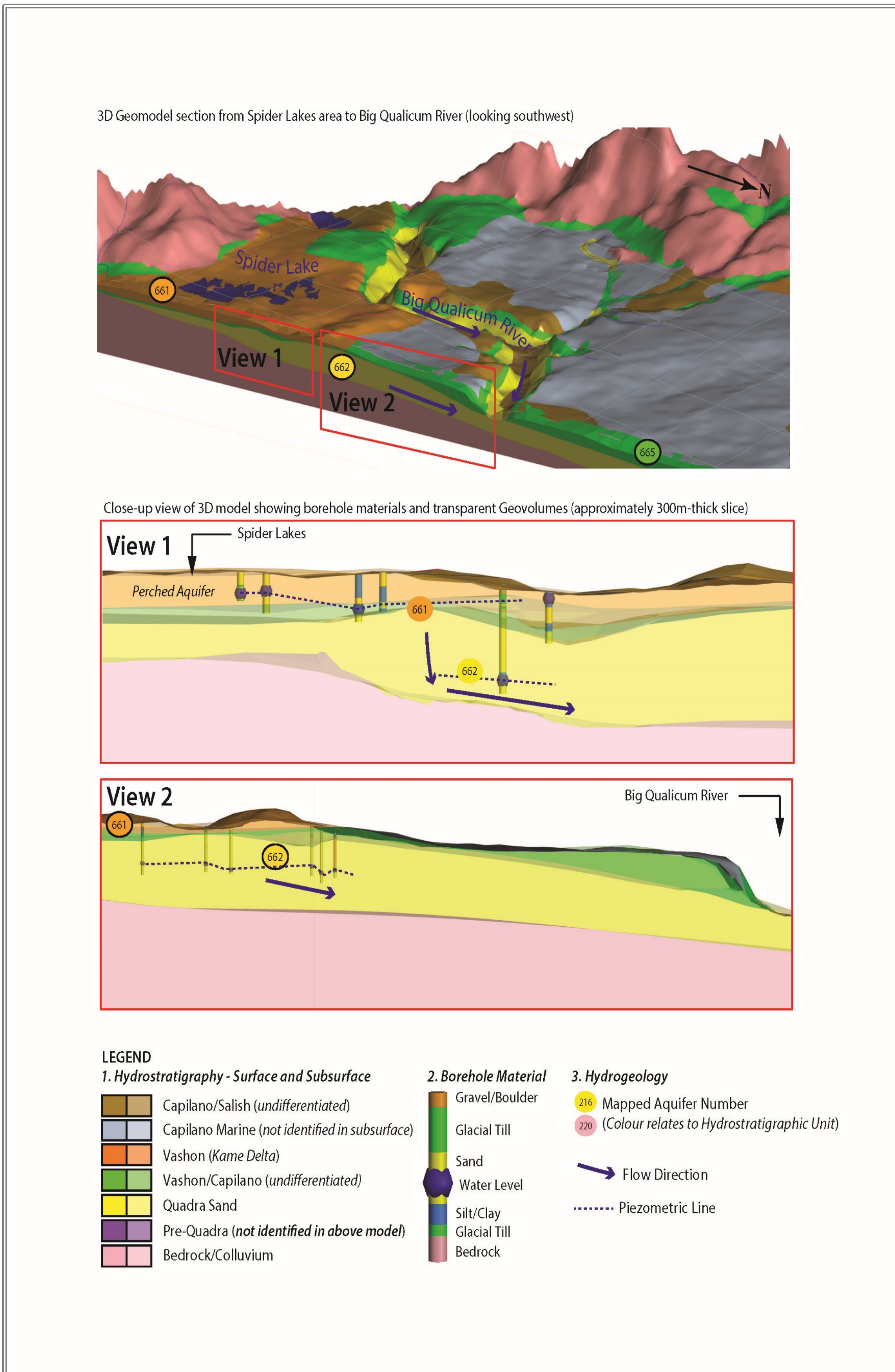

Figure 20: Conceptual Hydrogeological Cross-Section – Aquifer 661 and 662

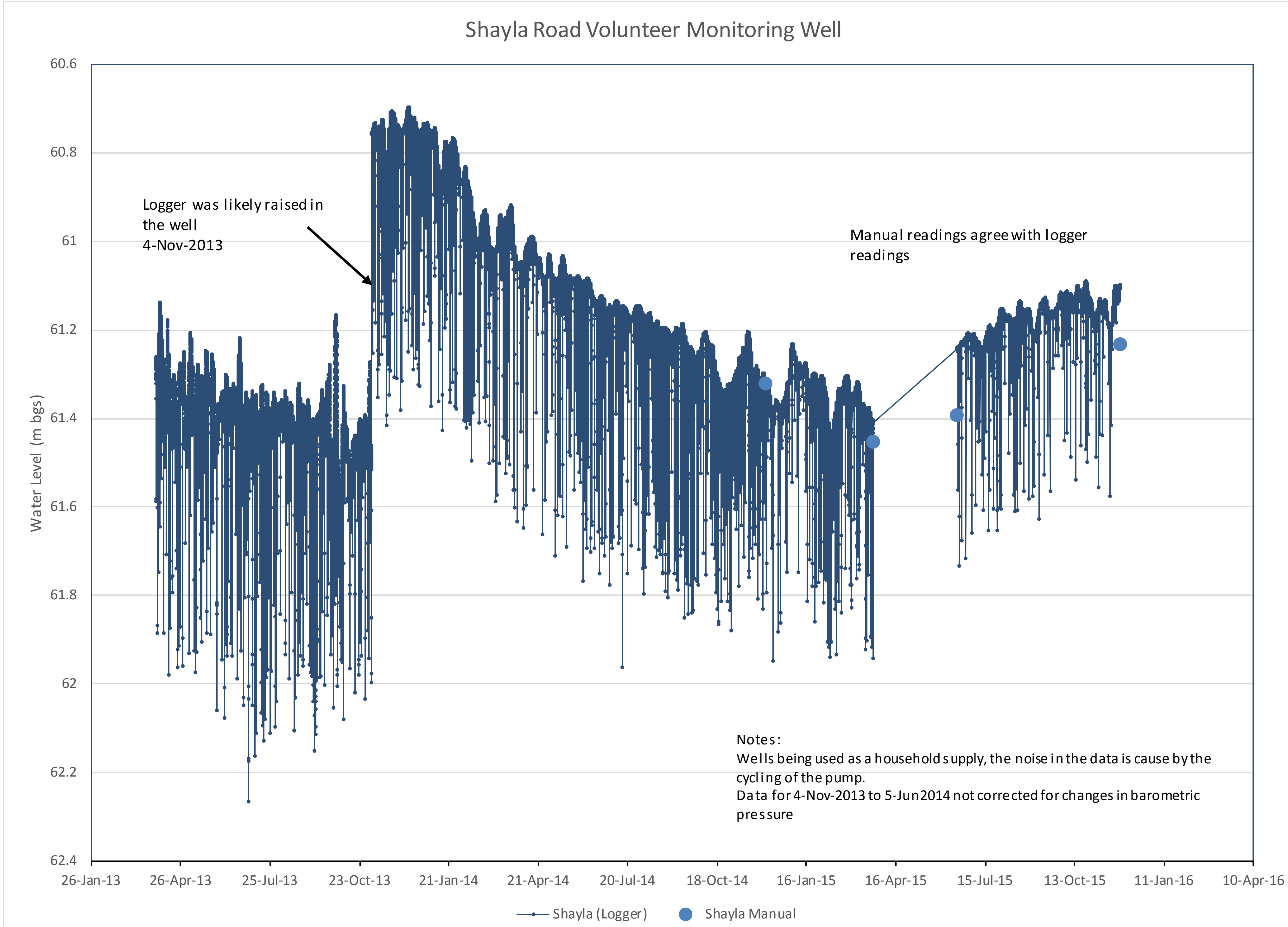

Figure 21: Shayla Road Monitoring Well Hydrograph

Appendix A

Selected Detailed Well Reports

Aquifer 416 Wells
Observation Well 310, OW310
Cowland Road

Report 1 - Detailed Well Record

Well Tag Number: 37367 Owner: DEEPBAY WATER WORKS Address: GAINSBURG RD. Area: BOWSER WELL LOCATION: NEWCASTLE Land District District Lot: Plan: 3H643 Lot: C Township: Section: Range: Indian Reserve: Meridian: Block: Quarter: Island: BCGS Number (NAD 83): 092F047144 Well: 1 Class of Well: Subclass of Well: Orientation of Well: Status of Well: New Licence General Status: UNLICENSED Well Use: Observation Well Observation Well Number: 310 Observation Well Status: Active Construction Method: Drilled Diameter: 8.0 inches Casing drive shoe: Well Depth: 83 feet	Construction Date: 1977-06-04 00:00:00 Driller: Nor-West Drilling Well Identification Plate Number: 2 Plate Attached By: Where Plate Attached: PRODUCTION DATA AT TIME OF DRILLING: Well Yield: 45 (Driller's Estimate) Gallons per Minute (U.S./Imperial) Development Method: Pump Test Info Flag: Y Artesian Flow: Artesian Pressure (ft): Static Level: 30 feet WATER QUALITY: Character: Colour: Odour: Well Disinfected: N EMS ID: E208101 Water Chemistry Info Flag: Y Field Chemistry Info Flag: Site Info (SEAM): Water Utility: Water Supply System Name: Water Supply System Well Name: SURFACE SEAL: Flag: Material:

Elevation: 0 feet (ASL) Final Casing Stick Up: inches Well Cap Type: Bedrock Depth: feet Lithology Info Flag: File Info Flag: Y Sieve Info Flag: Screen Info Flag: Site Info Details: Other Info Flag: Other Info Details:	Method: Depth (ft): Thickness (in): WELL CLOSURE INFORMATION: Reason For Closure: Method of Closure: Closure Sealant Material: Closure Backfill Material: Details of Closure:

Screen from	to feet	Type	Slot Size	
Casing from	to feet	Diameter	Material	Drive Shoe

GENERAL REMARKS:
WELL ESTABLISHED IN QUADRA SANDS AQUIFER.HOUSING & WATER LEVEL RECORDER INSTALLED FEB.22,1990.

LITHOLOGY INFORMATION:

From	0	to	3	Ft.	Br. soil and roots
From	3	to	10	Ft.	Br. sand and gravel
From	10	to	32	Ft.	Br. silty sand
From	32	to	40	Ft.	Br. sand
From	40	to	58	Ft.	Br. sand, making water
From	58	to	59	Ft.	Br. sand w/traces of clay
From	59	to	63	Ft.	Clay and till
From	63	to	83	Ft.	Blue clay

- Return to Main
- Return to Search Options
- Return to Search Criteria

BRITISH COLUMBIA

Report 1 - Detailed Well Record

Well Tag Number: 55674

Owner: JIM WILLOTT

Address: COWLANDS CRES

Area: BOWSER

WELL LOCATION:

NEWCASTLE Land District

District Lot: 109 Plan: 30254 Lot: 14

Township: Section: Range:

Indian Reserve: Meridian: Block:

Quarter:

Island:

BCGS Number (NAD 83): 092F047142 Well: 10

Class of Well:

Subclass of Well:

Orientation of Well:

Status of Well: New

Licence General Status: UNLICENSED

Well Use: Private Domestic

Observation Well Number:

Observation Well Status:

Construction Method: Drilled

Diameter: 6.0 inches

Casing drive shoe:

Well Depth: 100 feet

Elevation: 0 feet (ASL)

Final Casing Stick Up: inches

Well Cap Type:

Bedrock Depth: feet

Lithology Info Flag:

File Info Flag:

Sieve Info Flag:

Screen Info Flag:

Construction Date: 1986-01-01 00:00:00

Driller: Fyfe's Well Drilling

Well Identification Plate Number:

Plate Attached By:

Where Plate Attached:

PRODUCTION DATA AT TIME OF DRILLING:

Well Yield: 5 (Driller's Estimate) Gallons per Minute (U.S./Imperial)

Development Method:

Pump Test Info Flag:

Artesian Flow:

Artesian Pressure (ft):

Static Level: 50 feet

WATER QUALITY:

Character:

Colour:

Odour:

Well Disinfected: N

EMS ID:

Water Chemistry Info Flag:

Field Chemistry Info Flag:

Site Info (SEAM):

Water Utility:

Water Supply System Name:

Water Supply System Well Name:

SURFACE SEAL:

Flag:

Material:

Method:

Depth (ft):

Thickness (in):

WELL CLOSURE INFORMATION:

Reason For Closure:

Site Info Details: Other Info Flag: Other Info Details:	Method of Closure: Closure Sealant Material: Closure Backfill Material: Details of Closure:

Screen from	to feet	Type	Slot Size	
Casing from	to feet	Diameter	Material	Drive Shoe

GENERAL REMARKS:

LITHOLOGY INFORMATION:

From	0 to	20	Ft.	Brown sand and clay
From	20 to	40	Ft.	Loose brown sand
From	40 to	60	Ft.	Sand and gravel
From	60 to	80	Ft.	Cemented sand and gravel
From	80 to	100	Ft.	Coarse wet sand

- Return to Main
- Return to Search Options
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Information Disclaimer
The Province disclaims all responsibility for the accuracy of information provided. Information provided should not be used as a basis for making financial or any other commitments.

Deep Wells in Aquifer 421

Report 1 - Detailed Well Record

Well Tag Number: 12763

Owner: JAMESON

Address:

Area:

WELL LOCATION:

NEWCASTLE Land District

District Lot: Plan: Lot: 22

Township: Section: Range:

Indian Reserve: Meridian: Block:

Quarter:

Island:

BCGS Number (NAD 83): 092F047214 Well: 4

Class of Well:

Subclass of Well:

Orientation of Well:

Status of Well: New

Licence General Status: UNLICENSED

Well Use: Unknown Well Use

Observation Well Number:

Observation Well Status:

Construction Method: Unknown Constru

Diameter: 0.0 inches

Construction Date: 1950-01-01 00:00:00

Driller: Unknown

Well Identification Plate Number:

Plate Attached By:

Where Plate Attached:

PRODUCTION DATA AT TIME OF DRILLING:

Well Yield: 0 (Driller's Estimate)

Development Method:

Pump Test Info Flag:

Artesian Flow:

Artesian Pressure (ft):

Static Level:

WATER QUALITY:

Character:

Colour:

Odour:

Well Disinfected: N

EMS ID:

Water Chemistry Info Flag:

Field Chemistry Info Flag:

Site Info (SEAM):

Water Utility:

Water Supply System Name:

Casing drive shoe:

Well Depth: 165 feet

Elevation: 0 feet (ASL)

Final Casing Stick Up: inches

Well Cap Type:

Bedrock Depth: 160 feet

Lithology Info Flag:

File Info Flag:

Sieve Info Flag:

Screen Info Flag:

Site Info Details:

Other Info Flag:

Other Info Details:

Water Supply System Well Name:

SURFACE SEAL:

Flag:

Material:

Method:

Depth (ft):

Thickness (in):

WELL CLOSURE INFORMATION:

Reason For Closure:

Method of Closure:

Closure Sealant Material:

Closure Backfill Material:

Details of Closure:

Screen from	to feet	Type	Slot Size

Casing from	to feet	Diameter	Material	Drive Shoe

GENERAL REMARKS:

LITHOLOGY INFORMATION:

From 0 to 8 Ft. Sand and gravel

From 8 to 69 Ft. Sandy blue clay

From 69 to 110 Ft. Hard blue clay

From 110 to 125 Ft. Blue clay with gravel

From 125 to 128 Ft. Fine sand

From 128 to 140 Ft. Sandy blue clay

From 140 to 160 Ft. Coarse sand, silt, some gravel

From 160 to 165 Ft. Sandy shale

- Return to Main
- Return to Search Options
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Information Disclaimer

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BRITISH COLUMBIA

Report 1 - Detailed Well Record

Well Tag Number: 14196

Owner: JAMIESON CONSTRUCTIO

Address:

Area:

WELL LOCATION:

NEWCASTLE Land District

District Lot: Plan: Lot: 22

Township: Section: Range:

Indian Reserve: Meridian: Block:

Quarter:

Island:

BCGS Number (NAD 83): 092F047223 Well: 5

Class of Well:

Subclass of Well:

Orientation of Well:

Status of Well: New

Licence General Status: UNLICENSED

Well Use: Unknown Well Use

Observation Well Number:

Observation Well Status:

Construction Method: Drilled

Diameter: 6.0 inches

Casing drive shoe:

Well Depth: 248 feet

Elevation: 0 feet (ASL)

Final Casing Stick Up: inches

Well Cap Type:

Bedrock Depth: 160 feet

Lithology Info Flag: N

File Info Flag: N

Sieve Info Flag: N

Construction Date: 1954-01-01 00:00:00

Driller: Pacific Water Wells

Well Identification Plate Number:

Plate Attached By:

Where Plate Attached:

PRODUCTION DATA AT TIME OF DRILLING:

Well Yield: 15 (Driller's Estimate) Gallons per Hour (U.S./Imperial)

Development Method:

Pump Test Info Flag: N

Artesian Flow: .01

Artesian Pressure (ft):

Static Level:

WATER QUALITY:

Character:

Colour:

Odour:

Well Disinfected: N

EMS ID:

Water Chemistry Info Flag:

Field Chemistry Info Flag:

Site Info (SEAM):

Water Utility:

Water Supply System Name:

Water Supply System Well Name:

SURFACE SEAL:

Flag: N

Material:

Method:

Depth (ft):

Thickness (in):

WELL CLOSURE INFORMATION:

Screen Info Flag: N	Reason For Closure:
	Method of Closure:
Site Info Details:	Closure Sealant Material:
Other Info Flag:	Closure Backfill Material:
Other Info Details:	Details of Closure:

Screen from	to feet	Type	Slot Size

Casing from	to feet	Diameter	Material	Drive Shoe

GENERAL REMARKS:
YIELD 15 GPH SCREEN WAS SET 155 TO 160

LITHOLOGY INFORMATION:

From	0	to	0	Ft.	At 150' - 2 GPM - salty
From	0	to	0	Ft.	182' = 0.7 GPM
From	0	to	8	Ft.	Sand and gravel
From	8	to	15	Ft.	Sandy blue clay
From	15	to	69	Ft.	Sandy blue clay, some boulders
From	69	to	110	Ft.	Hard blue clay
From	110	to	125	Ft.	Blue clay with gravel
From	125	to	128	Ft.	Fine sand, some water
From	128	to	140	Ft.	Sandy blue clay
From	140	to	160	Ft.	Coarse sand, silt and some gravel
From	160	to	165	Ft.	Sandy shale
From	165	to	234	Ft.	Shaly sandstone
From	234	to	248	Ft.	Hard sandstone
From	0	to	0	Ft.	
From	0	to	0	Ft.	Note: screen was removed and hole deep-
From	0	to	0	Ft.	ened as salt water was coming in.

- Return to Main
- Return to Search Options
- Return to Search Criteria

BRITISH COLUMBIA

Report 1 - Detailed Well Record

Well Tag Number: 84185 Owner: LAND & WATER BC INC Address: Area: WELL LOCATION: NEWCASTLE Land District District Lot: 85 Plan: Lot: 32 Township: Section: Range: Indian Reserve: Meridian: Block: Quarter: Island: BCGS Number (NAD 83): 092F047213 Well: Class of Well: Water supply Subclass of Well: Domestic Orientation of Well: Status of Well: New Licence General Status: UNLICENSED Well Use: Unknown Well Use Observation Well Number: Observation Well Status: Construction Method: Drilled Diameter: 8 inches	Construction Date: 2004-03-01 00:00:00 Driller: Drillwell Enterprises Well Identification Plate Number: Plate Attached By: Where Plate Attached: PRODUCTION DATA AT TIME OF DRILLING: Well Yield: (Driller's Estimate) Development Method: Pump Test Info Flag: N Artesian Flow: Artesian Pressure (ft): Static Level: WATER QUALITY: Character: Colour: Odour: Well Disinfected: N EMS ID: Water Chemistry Info Flag: N Field Chemistry Info Flag: Site Info (SEAM): Water Utility: Water Supply System Name:

Casing drive shoe: Y Y

Well Depth: 220 feet

Elevation: feet (ASL)

Final Casing Stick Up: 36 inches

Well Cap Type: TACK WELL LID

Bedrock Depth: feet

Lithology Info Flag: Y

File Info Flag: N

Sieve Info Flag: N

Screen Info Flag: N

Site Info Details:

Other Info Flag:

Other Info Details:

Water Supply System Well Name:

SURFACE SEAL:

Flag: Y

Material: Bentonite clay

Method:

Depth (ft):

Thickness (in):

WELL CLOSURE INFORMATION:

Reason For Closure:

Method of Closure:

Closure Sealant Material:

Closure Backfill Material:

Details of Closure:

Screen from	to feet	Type	Slot Size

Casing from	to feet	Diameter	Material	Drive Shoe
0	220	8	Steel	Y
0	5	10	Steel	Y

GENERAL REMARKS:

LITHOLOGY INFORMATION:

From 0 to 2 Ft. FILL

From 2 to 13 Ft. BROWN TILL

From 13 to 102 Ft. GREY TILL

From 102 to 108 Ft. GREY SAND

From 108 to 115 Ft. TILL GREY

From 115 to 116 Ft. GRAVEL

From 116 to 141 Ft. TILL GREY

From 141 to 167 Ft. TILL VERY ROUGH COBBLES

From 167 to 170 Ft. COARSE GRAVEL SOME FINE SAND APPROX 10 GPM FLOWS

From 170 to 192 Ft. ROUGH TILL SEALS WATER

From 192 to 194 Ft. COARSE GRAVEL LOTS FINE SAND 30 GPM

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From   194 to   219 Ft.   CLAY, ROCKS, SAND LAYERS
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- Return to Main
- Return to Search Options
- Return to Search Criteria

Information Disclaimer

BRITISH COLUMBIA

Report 1 - Detailed Well Record

Well Tag Number: 84189

Owner: LAND & WATER BC INC

Address: CROSLEY ROAD

Area: BOWSER

WELL LOCATION:

NEWCASTLE Land District

District Lot: 85 Plan: Lot: 26

Township: Section: Range:

Indian Reserve: Meridian: Block:

Quarter:

Island:

BCGS Number (NAD 83): 092F047231 Well:

Class of Well: Water supply

Subclass of Well: Domestic

Orientation of Well:

Status of Well: New

Licence General Status: UNLICENSED

Well Use: Water Supply System

Observation Well Number:

Observation Well Status:

Construction Method: Drilled

Diameter: 10 inches

Casing drive shoe: Y Y

Well Depth: 116 feet

Elevation: feet (ASL)

Final Casing Stick Up: inches

Well Cap Type:

Bedrock Depth: 265 feet

Lithology Info Flag: Y

File Info Flag: N

Sieve Info Flag: N

Construction Date: 2004-03-18 00:00:00

Driller: Drillwell Enterprises

Well Identification Plate Number:

Plate Attached By:

Where Plate Attached:

PRODUCTION DATA AT TIME OF DRILLING:

Well Yield: 25 (Driller's Estimate) U.S. Gallons per Minute

Development Method:

Pump Test Info Flag: N

Artesian Flow:

Artesian Pressure (ft):

Static Level: 1 feet

WATER QUALITY:

Character:

Colour:

Odour:

Well Disinfected: N

EMS ID:

Water Chemistry Info Flag: N

Field Chemistry Info Flag:

Site Info (SEAM):

Water Utility:

Water Supply System Name:

Water Supply System Well Name:

SURFACE SEAL:

Flag: Y

Material: Bentonite clay

Method:

Depth (ft):

Thickness (in): 1 inches

WELL CLOSURE INFORMATION:

Screen Info Flag: Y	Reason For Closure:
	Method of Closure:
Site Info Details:	Closure Sealant Material:
Other Info Flag:	Closure Backfill Material:
Other Info Details:	Details of Closure:

Screen from	to feet	Type	Slot Size
106	116		100

Casing from	to feet	Diameter	Material	Drive Shoe
0	105	8	Steel	Y
0	15	10	Steel	Y

GENERAL REMARKS:
CUT SHOE, PULLED CASING BACKFILL TO 116'

LITHOLOGY INFORMATION:

From 0 to 10 Ft. BROWN LOOSE SILTY S & G (10)

From 10 to 14 Ft. SILTY S & G

From 14 to 18 Ft. GREY SILT, W/GRAVEL

From 18 to 70 Ft. GREY TILL, COBBLES, BOULDERS

From 70 to 77 Ft. CLAY, SOME ROCKS

From 77 to 79 Ft. GREY, COARSE GRAVEL, 4 GPM

From 79 to 89 Ft. GREY CLAY

From 89 to 95 Ft. GREY SAND & GRAVEL CLAY CHUNKS, WET

From 95 to 105 Ft. COARSE GRAVEL, CLAY

From 105 to 119 Ft. GREY GRAVEL, FINE SILTY SAND, LOOSER APPROX 20 GPM

From 119 to 126 Ft. CLAY, ROCKS, SEALED OFF WATER

From 126 to 131 Ft. GREY, SILTY SAND & ROCKS

From 131 to 195 Ft. GREY TILL, CLAYEY, COBBLES ROUGH DRILLING, TIGHT DRILLING

From 195 to 220 Ft. TILL, SOME SAND LAYERS, SOME SLIGHTLY WET GRAVEL LAYERS, VERY ROUGH

From 220 to 265 Ft. VERY ROUGH TILL, BOULDERS, GRAVEL LAYERS, CASING REFUSAL @ 236' OPEN HOLE TO 275

From 265 to 275 Ft. SHALE

- Return to Main
- Return to Search Options
- Return to Search Criteria

Information Disclaimer

QBHLWD Well

BRITISH COLUMBIA

Report 1 - Detailed Well Record

Well Tag Number: 110569

Owner: QUALICUM BAY HORNE LAKE WATER DISTRICT

Address: 480 HORNE LAKE ROAD

Area: QUALICUM BEACH

WELL LOCATION:

NEWCASTLE Land District

District Lot: 41 Plan: 31314 Lot: 24

Township: Section: Range:

Indian Reserve: Meridian: Block:

Quarter:

Island:

BCGS Number (NAD 83): 092F037442 Well:

Class of Well: Water supply

Subclass of Well: Domestic

Orientation of Well: Vertical

Status of Well: New

Licence General Status: UNLICENSED

Well Use: Water Supply System

Observation Well Number:

Observation Well Status:

Construction Method: Drilled

Diameter: 8 inches

Casing drive shoe: Y Y

Well Depth: 89.24 feet

Elevation: feet (ASL)

Final Casing Stick Up: inches

Well Cap Type:

Bedrock Depth: feet

Lithology Info Flag: Y

File Info Flag: N

Sieve Info Flag: N

Screen Info Flag: Y

Site Info Details:

Other Info Flag:

Construction Date: 1992-06-02 00:00:00

Driller:

Well Identification Plate Number:

Plate Attached By:

Where Plate Attached:

PRODUCTION DATA AT TIME OF DRILLING:

Well Yield: 332 (Driller's Estimate) U.S. Gallons per Minute

Development Method:

Pump Test Info Flag: N

Artesian Flow:

Artesian Pressure (ft):

Static Level: 3 feet

WATER QUALITY:

Character:

Colour:

Odour:

Well Disinfected: N

EMS ID:

Water Chemistry Info Flag:

Field Chemistry Info Flag:

Site Info (SEAM):

Water Utility:

Water Supply System Name:

Water Supply System Well Name:

SURFACE SEAL:

Flag: N

Material:

Method:

Depth (ft):

Thickness (in):

WELL CLOSURE INFORMATION:

Reason For Closure:

Method of Closure:

Closure Sealant Material:

Closure Backfill Material:

Other Info Details:	Details of Closure:

Screen from	to feet	Type	Slot Size
78.41	89.24		150

Casing from	to feet	Diameter	Material	Drive Shoe
0	75	8	Steel	Y
0	32.8	10	Steel	Y

GENERAL REMARKS:
WELL DRILLED BY THRUBER ENGINEERING LTD. EXPLORED TO 112FT BUT BACKFILLED WITH NATIVE SAND AND GRAVEL TO BOTTOM OF SCREEN.

LITHOLOGY INFORMATION:

From 0 to 3.3 Ft.

From 3.3 to 13.12 Ft. WATER BEARING brown

From 13.12 to 32.81 Ft. WATER BEARING brown

From 32.81 to 42.65 Ft. SILTY, GRAVELLY DRY grey

From 42.65 to 55.77 Ft. SILTY, SANDY WET brown

From 55.77 to 59.06 Ft. STRATIFIED SAND AND GRAVEL WATER BEARING brown

From 59.06 to 68.9 Ft. SAND AND GRAVEL brown

From 68.9 to 88.58 Ft. MEIDUM-COARSE WATER BEARING grey

From 88.58 to 101.71 Ft. FINE SAND AND MEDIUM GRAVEL WATER BEARING brown

From 101.71 to 109.91 Ft. WATER BEARING grey

From 109.91 to 111.88 Ft. SILTY SANDY DRY grey

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- Return to Search Criteria

Shayla Road Volunteer Monitoring Well

BRITISH COLUMBIA

Report 1 - Detailed Well Record

Well Tag Number: 87914 Owner: HUGHES Address: 1055 SHAYLA ROAD Area: QUALICUM BEACH WELL LOCATION: Land District District Lot: Plan: VIP 68091 Lot: 1 Township: Section: Range: Indian Reserve: Meridian: Block: 360 Quarter: Island: VANCOUVER ISLAND BCGS Number (NAD 83): 092F037421 Well: 6 Class of Well: Water supply Subclass of Well: Domestic Orientation of Well: Vertical Status of Well: New Licence General Status: UNLICENSED Well Use: Private Domestic Observation Well Number: Observation Well Status: Construction Method: Diameter: inches Casing drive shoe: Y Well Depth: 248 feet Elevation: 484 feet (ASL) Final Casing Stick Up: inches Well Cap Type: WELD ON	Construction Date: 2007-05-01 00:00:00 Driller: Red William's Drilling Well Identification Plate Number: 21911 Plate Attached By: Where Plate Attached: PRODUCTION DATA AT TIME OF DRILLING: Well Yield: 10 (Driller's Estimate) U.S. Gallons per Minute Development Method: Bailing Pump Test Info Flag: N Artesian Flow: Artesian Pressure (ft): Static Level: 198 feet WATER QUALITY: Character: Colour: Odour: Well Disinfected: Y EMS ID: Water Chemistry Info Flag: N Field Chemistry Info Flag: Site Info (SEAM): Water Utility: Water Supply System Name: Water Supply System Well Name: SURFACE SEAL: Flag: Y Material: Bentonite clay Method: Poured

Bedrock Depth: feet

Lithology Info Flag: Y

File Info Flag: N

Sieve Info Flag: N

Screen Info Flag: Y

Site Info Details:

Other Info Flag:

Other Info Details:

Depth (ft): 15 feet

Thickness (in):

Liner from To: feet

WELL CLOSURE INFORMATION:

Reason For Closure:

Method of Closure:

Closure Sealant Material:

Closure Backfill Material:

Details of Closure:

Screen from	to feet	Type	Slot Size

Casing from	to feet	Diameter	Material	Drive Shoe
2	227.9	6	Steel	Y

GENERAL REMARKS:

LITHOLOGY INFORMATION:

From 0 to 29 Ft. SAND & GRAVEL brown

From 29 to 55 Ft. SILT & GRAVEL grey

From 55 to 60 Ft. GRAVEL & SILT GRAVEL-CEMENTED brown

From 60 to 80 Ft. COARSE BR WASH

From 80 to 203 Ft. MED GRAINED, LOOSE, SOME GRAVEL

From 203 to 210 Ft. MED GRAINED, LOOSE, SOME GRAVEL, WB

From 210 to 238 Ft. FINE GRAINED, SOME SILT, WB

From 238 to 248 Ft. FINE GRAINED, VERY SILTY

- Return to Main
- Return to Search Options
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