Developing Additional Bedrock Water Supplies at Existing Municipal Well Sites: The Sniper Versus the Shotgun Approach

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Summary

The Region of Waterloo initiated a project in 2007 to optimize the security, quantity and quality of water from existing municipal bedrock well sites in Cambridge, Ontario. Hydrogeologic studies indicate the potential for developing larger, higher quality protected water supplies, from deeper bedrock aquifer zones than are currently accessed by the existing municipal wells. Existing wells are reconstructed with steel liners cemented into place to increase the isolation from potential anthropogenic sources of contamination. Two new boreholes are drilled and tested at the existing sites to evaluate the potential for constructing new production wells into the deep bedrock at each site. The best location is selected for reconstruction as a production well and the second location is converted to a multi-level monitoring well nest. The program has been very successful at achieving the project objectives, typically resulting in multiple wells completed to different depths in the same bedrock aquifer. Testing shows that the wells interact to some degree but the operator has the capability of blending the water sources from each depth to optimize both water quality and quantity produced from each well site. Water production from existing sites, previously producing 15 to 25 L/s of water, was improved to 50 to 60 L/s of higher quality water. Infrastructure is already in place and available for upgrade to effectively utilize these new water sources.

Introduction

The ideal bedrock well consists of a conduit of minimal diameter that draws high quality water from a specific selected interval in the bedrock. The approach to exploration for potable water supplies in Paleozoic bedrock aquifers has progressed significantly over the past few decades. Drilling techniques and well diagnostics have contributed to more accurate definition of water sources in micro-karstic limestone and dolostone bedrock aquifers.

The Region of Waterloo (Region) provides the City of Cambridge, Ontario with its municipal water supply from over 30 bedrock wells completed in the Guelph and Gasport limestone and dolostone formations, of Silurian age (Brunton, 2008). In the Cambridge area, these formations are approximately 100 to 150 m thick.

Most of these municipal wells were originally constructed prior to 1960 using cable tool drilling technology, where casings were typically driven to the top of the bedrock and then open bedrock boreholes were advanced into the upper bedrock. Some of these wells require upgrade and/or replacement to improve well construction and increase the security of water supply sources.

Recent hydrogeologic studies of these wells, using video and flow logging under normal pumping conditions, indicate that although bedrock wells may be over 60 m deep, much of the water comes from relatively shallow water sources characterized by relatively low capacity fractures in the bedrock. These studies also indicate the potential for developing larger, higher quality protected water supplies, from deeper bedrock aquifer zones. The Region initiated a project in 2007 to optimize the security, quantity and quality of water from existing municipal well sites using current well drilling and down-hole diagnostic technology.

Method

Well optimization is a step by step approach that evaluates the potential for selected existing municipal production well sites. Diagnostics are completed on the existing wells, which have limited capacities in the range of 15-25 L/s, to determine the condition of the well casings, total depths and depths of water producing zones. The wells are then re-constructed and re-developed, with steel liners cemented into place to isolate the shallow producing intervals of the bedrock aquifer from surface contaminant sources, as much as possible. Non-productive intervals in the lower portions of the wells are sealed to eliminate stagnant water zones. The existing municipal wells essentially become a shallow bedrock supply, which in Cambridge is often the Guelph Formation.

Exploration for deeper sources of water, that can produce 20 to 50 L/s of good quality water at depths of 50 to 140 m, then takes place on the existing well sites. Past experience has shown that the hydraulic properties of the bedrock aquifer in Cambridge can vary considerably over less than 10 m. As a result, two test boreholes are drilled at each site and subjected to a suite of down-hole diagnostic testing. The diagnostic testing is designed to assess the quantity and quality of significant water producing intervals and to evaluate which test borehole is the best location for the construction of a new deep bedrock municipal well, from a water quantity, quality and security of supply perspective.

Test borehole diagnostic testing consists of static and dynamic video logging, static and dynamic flow logging, geophysical logging (gamma, resistivity and caliper) and zone-specific packer testing for flow and water quality. Where possible, the testing is undertaken at rates in excess of 15 L/sec. The diagnostic testing effectively defines productive intervals within the bedrock sequence, as well as zone-specific water quality. The zone-specific packer testing is of key importance as it is completed at relatively high flow rates of over 15 L/s in order to provide a more representative indication of the potential capacity of a new deep bedrock well, as compared to typical packer testing.
The first test borehole at each site is drilled through the entire limestone/dolostone sequence until the mineralized Cabot Head Formation (primarily shale) is encountered. Following analysis of the data from the first test borehole, a second test borehole is drilled at the site, typically

through the deepest zone of water production, as indicated by the data from the first test borehole. Diagnostic testing is then repeated on the second test borehole and the data is analyzed. If the data indicate the potential for the construction of a new production well at the site, the most suitable test borehole is selected for re-construction as a production well. The second test borehole is completed as a multi-level monitoring well nest, with screens placed in the primary water producing zones in the bedrock aquifer.

From the diagnostic data, individual water quality and specific capacity is defined for the water producing features in the bedrock. Designs for the new production wells at each site are developed to optimize quantity and quality. In general, the objective of the well design is to construct wells that focus production of water from very specific zones within the deep bedrock aquifer. The wells are generally constructed with 300 mm casings, cemented into place in the bedrock at depths on the order of 50 to 55 m. The remainder of the production wells generally consists of 30 to 60 m of 300 mm open boreholes in the bedrock to a specific depth. Non-productive zones in the lower portions of the test boreholes are sealed to eliminate stagnant water zones in the production wells and to minimize the potential for drawing mineralized water from deeper formations into the wells during pumping.

The relatively deep cemented well casings of the new production wells eliminate any issues with cascading water and isolate the productive intervals of the wells from the shallower producing intervals of the existing production wells and from surface contaminant sources. Analytical data indicates that the quality of water from the deep bedrock aquifer is typically better than that available from the existing shallower production wells, due to lower impacts from surface contaminants, such as road salt.

The selection of the intervals to be included in the final well represents a balance between well security, water quality and quantity. For example at one site, over 20 L/s of water from the lower 30 m of the well was eliminated due to the presence of hydrogen sulphide. In another well, a highly productive interval at the relatively shallow depth of 40 m was included in the well due to the relatively low capacity of the deeper interval.

If at the completion of the well construction and development, the well is determined to be a low efficiency source, additional development using interval specific acidification is completed. Instead of injecting acid into the entire open borehole, a 5 m packer interval is subjected to a specific quantity of acid under pressure for a relatively short period, followed by airlift surging and pumping, to enlarge the solution features and to remove fine materials that may be preventing water from entering the borehole.

Following completion of well construction/reconstruction, the existing and new wells are subjected to variable rate and constant rate pumping tests to define the sustainable productive capacity of the wells and bedrock aquifer. Samples are collected during the constant rate pumping tests to establish the suitability of the water quality for municipal water supply sources in accordance Ontario Ministry of Environment standards.

Examples

An example summary of the diagnostic obtained data from a test borehole is provided on Figure 1.

The diagnostic testing indicates that in most cases, water production from the bedrock aquifer occurs at very specific zones associated with formational contact disconformities, horizontal bedding plane fractures and/or karstic solution openings. These zones are, in many cases, separated by sequences of low permeability limestone/dolostone bedrock that creates effective vertical hydraulic isolation between zones.

Figure 2 shows a schematic of a typical well site, with two production wells on the same site, one drawing from the shallow bedrock and the second from the deep bedrock. In this configuration, at several of the sites, water can be produced from both the shallow and deep aquifer zones, if required, thereby increasing the overall water supply potential and water quality available from the Region's existing well sites.

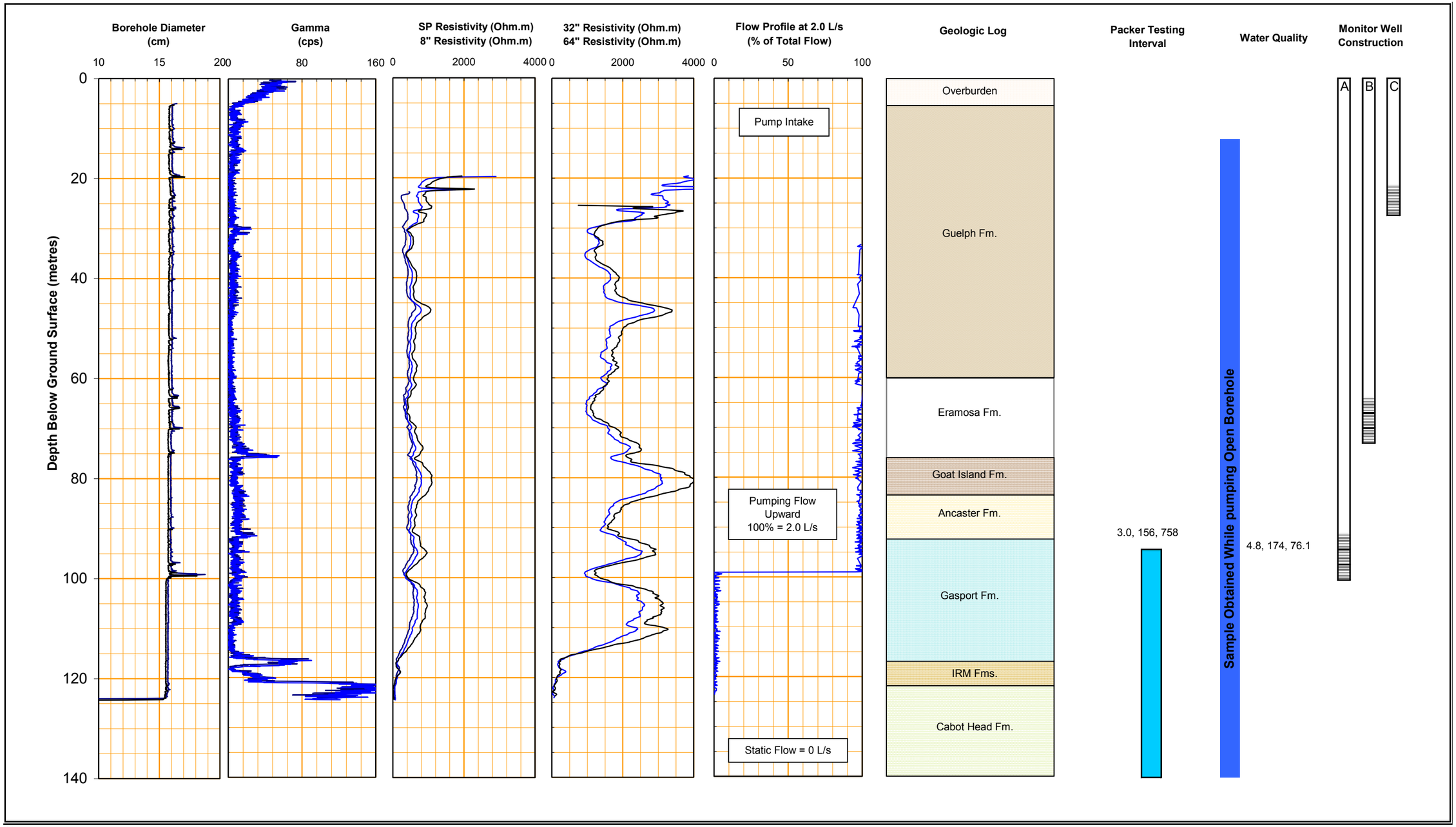
Conclusions

The program has been very successful at achieving the project objectives. The process of well optimization at existing sites has resulted in multiple wells completed to different depths in the same bedrock aquifer. Testing shows that the wells interact to some degree but the operator has the capability of blending the water sources from each depth to optimize both water quality and quantity produced from each well site. Water production from existing sites, previously producing 15 to 25 L/s of water, was improved to 50 to 60 L/s of higher quality water. Infrastructure is already in place and available for upgrade to effectively utilize these new water sources.

References

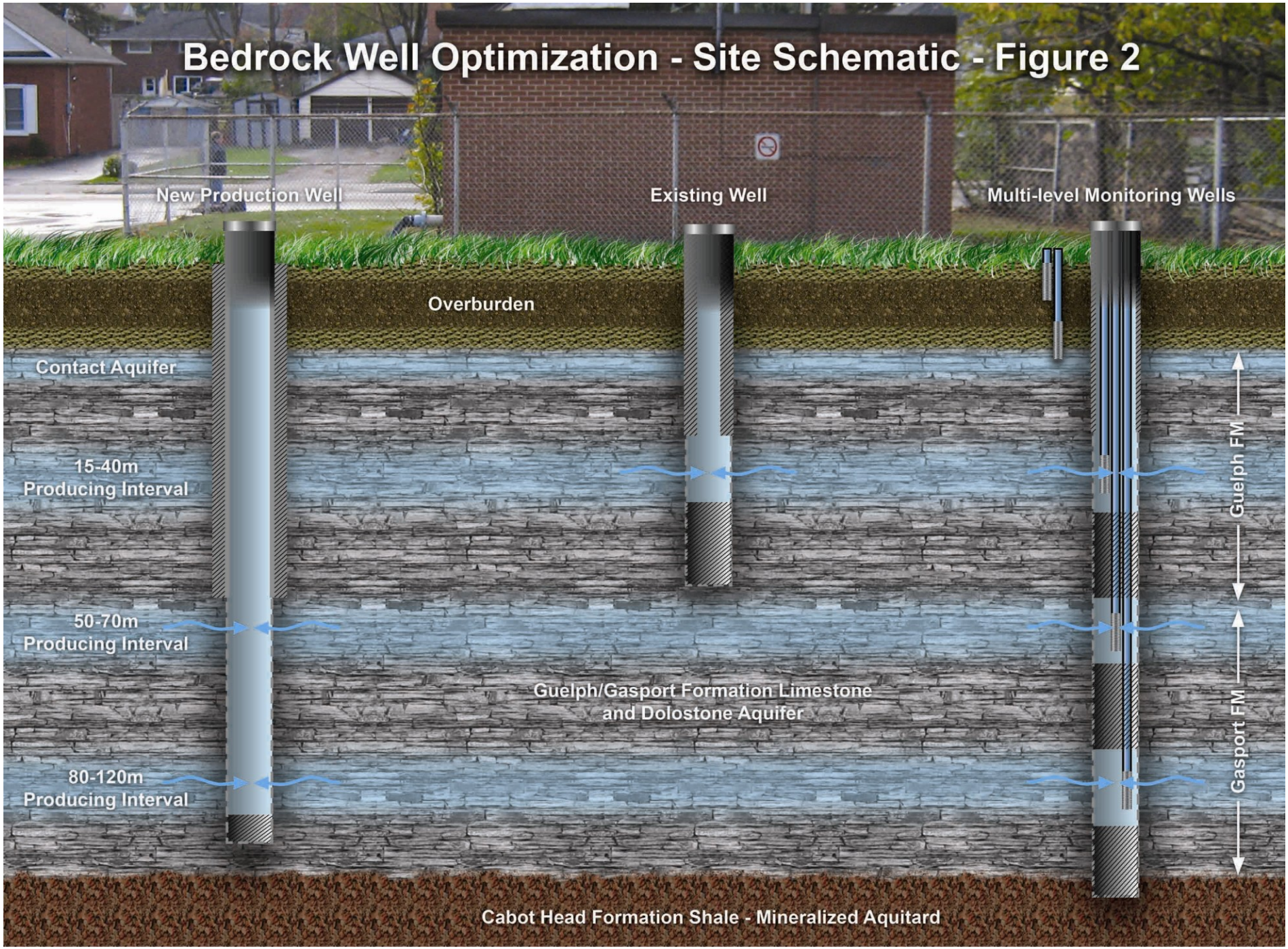
Ontario Geological Survey, Sedimentary Geoscience Section, Summary of Field Work and Other Activities, 2008. Open File Report 6226 p 31-1 to 31-18, **F.R. Brunton**. Project Unit 08-004. *Preliminary Revisions to the Early Silurian Stratigraphy of the Niagara Escarpment: Integration of Sequence Stratigraphy, Sedimentology and Hydrogeology to Delineate Hydrogeologic Units.*

Figure 1: Borehole Testing Summary



Notes:

1. IRM Fms. indicates Rochester, Irondequoit, Rockway, Merritton sequence of dolostone formations.
2. Water quality data is displayed as nitrate, chloride and sulphate in mg/L.


Bedrock Well Optimization - Site Schematic - Figure 2
New Production Well
Existing Well
Multi-level Monitoring Wells
Overburden
Contact Aquifer
15-40m
Producing Interval
50-70m
Producing Interval
80-120m
Producing Interval
Guelph/Gasport Formation Limestone
and Dolostone Aquifer
Guelph FM
Gasport FM
Cabot Head Formation Shale - Mineralized Aquitard