Hydrogeological Investigation
In the Wynyard Area
Township 32, Ranges 17 to 21

Prairie Farm Rehabilitation Administration

File R3216 31 May 2002

Prepared for:

Agriculture and Agri-Food Canada
Prairie Farm Rehabilitation Administration
Regina, Saskatchewan

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Strategic Initiatives

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1.0 Introduction

1.1 General

The Prairie Farm Rehabilitation Administration (PFRA) has requested a hydrogeologic study of the area west of the Town of Wynyard. The study area covers roughly five townships extending from Range 17 to Range 21 in Township 32, west of the 2nd Meridian in Saskatchewan. Areas peripheral to Township 32; Townships 31 and 33 are also included.

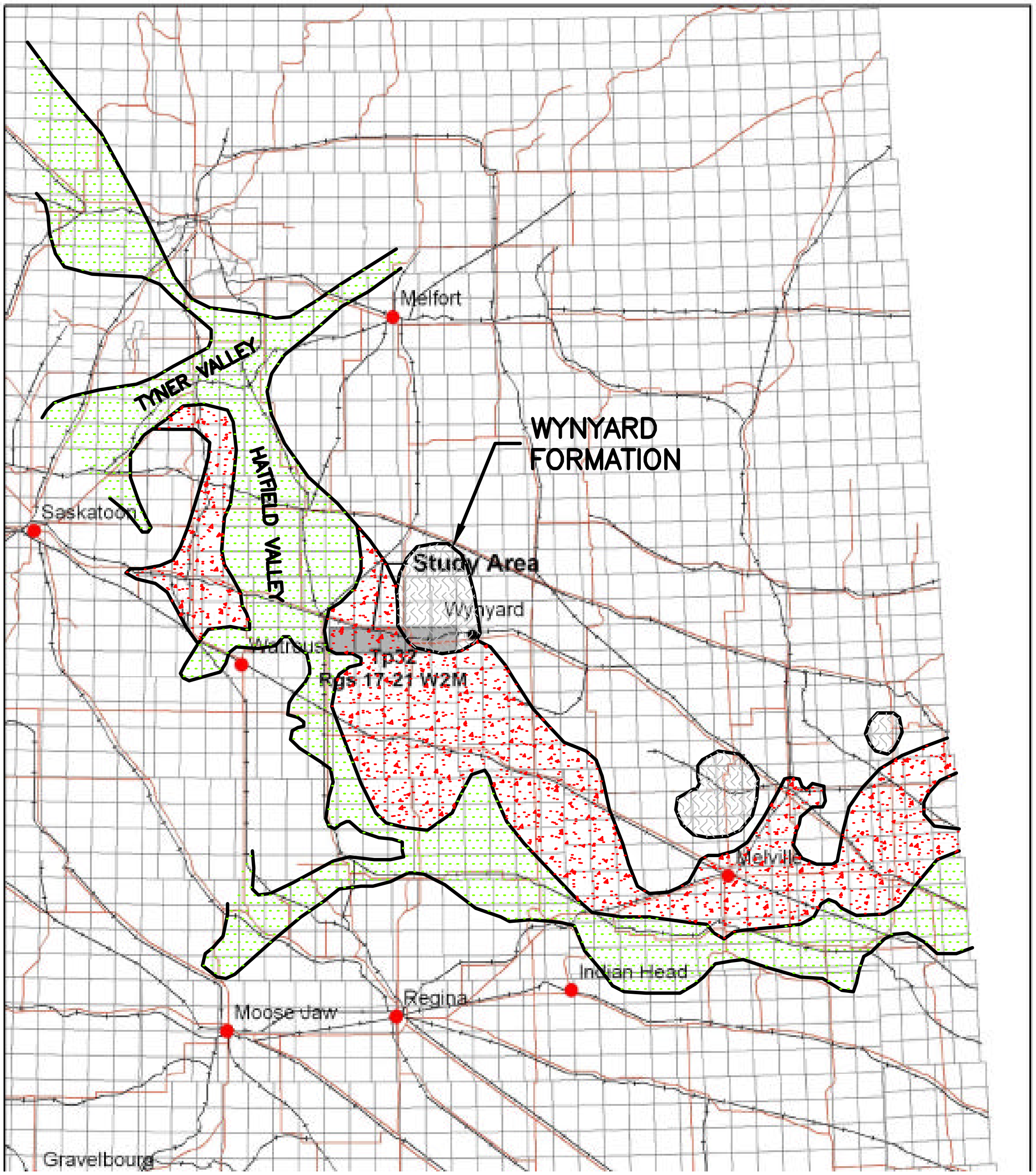
The Town of Wynyard and surrounding areas are located in a region where agricultural growth has been substantial in recent years and continued growth is expected in intensive livestock operations over the next several years. Farmers, towns and livestock producers in the region rely heavily on groundwater as their primary source of water.

A bedrock aquifer termed the Wynyard Formation Aquifer exists beneath the Town of Wynyard and surrounding areas, covering an area of approximately 800 km^2. The Hatfield Valley Aquifer system extends across the area south and west of the study area. The Hatfield Valley is a bedrock valley infilled with preglacial Empress Group sand, gravel, silt and clay deposits and overlain by glacial deposits. Figure 1.1 shows the location of the study area in relation to the Hatfield Valley Aquifer System and the Wynyard Formation Aquifer. Drawing No. R3216-1 shows the detailed site plan of the study area.

1.2 Objectives

The following investigations are focused on the further definition of the character and extent of the Wynyard Formation and Hatfield Valley Aquifers in the Wynyard area, with emphasis on identifying areas of higher yield potential or better quality groundwater for future development.

Approximate Location of Study Area



LEGEND:

WYNYARD FORMATION AQUIFERS ▨

UPPER EMPRESS GROUP AQUIFERS 🟥

LOWER EMPRESS GROUP AQUIFERS 🟩

LOCATION PLAN

CLIFTON ASSOCIATES LTD. **PROJECT NO: R3216** **FIGURE NO: 1.1**

R3216\FIGURE1.1.DWG

1.3 Terms of Reference

The terms of reference, as outlined in the request for proposals provided by PFRA and dated 30 January 2002, are summarized below.

Data Collection and Phase I Hydrogeological Review

The Phase I hydrogeologic review includes the following items:

- Compilation and review of all pertinent hydrogeological data, reports, maps and cross-sections.
- Preparation of base maps and preliminary geologic cross-sections to illustrate hydrogeologic structure, stratigraphy, water levels, flow directions, base of exploration and zones of existing well completions.
- Use the results of the compilation to define the targets for the Phase II test hole program.

The original scope called for one progress meeting to be held with PFRA staff at the completion of Phase I to discuss the results and the proposed field program. A second meeting was also requested with personnel from the Town of Wynyard and R.M.'s of Big Quill and Prairie Rose to coordinate siting of the drill targets and get input from these organizations prior to finalizing the field investigation plans.

Field Investigation

The field investigation includes the following items:

- Based on the results from the Phase I evaluation, identify drill targets for a field program consisting of five test holes and piezometers.
- Retain the services of a qualified driller, obtain site access, underground locates and drilling permits.
- Collect data from the test holes and piezometers to further define the geology, hydrogeology and well development potential at the selected sites. Cuttings should be geologically logged during drilling and each test hole E-logged following drilling. Piezometers should be developed by air lifting, pumping rates measured, head tests

completed and water samples taken. Water samples are to be analyzed for major ions, iron, manganese and nitrates.

- Drilling should in all cases proceed through the Hatfield or Wynyard Formation aquifer and into the underlying clay shale bedrock that forms the base of exploration. Drilling should not extend further than about 3 metres into the underlying shale.
- At the conclusion of the field work, the test hole sites are to be reclaimed in accordance with provincial regulations and to the satisfaction of the landowners.
- All test hole locations are to be determined by GPS and reported in geographic coordinates, latitude and longitude, NAD83 and geodetic datum. Locations should be accurate to within +/- 5 metres.

Clifton Associates Ltd.'s proposal dated 22 January 2002 addressed the above terms of reference. The scope was further clarified and defined through meetings with PFRA personnel (13 February 2002) and personnel from the Town of Wynyard and surrounding Rural Municipalities (18 February 2002). The following additional points were identified at these meetings.

- The study should focus on the Hatfield Valley Aquifer System and the Wynyard Formation Aquifer System through the transition area where the Wynyard Formation Aquifer ends and the Hatfield Valley Aquifer begins.
- The focus need not be exclusively on the Hatfield Valley Aquifer, but should be on areas where a balance between potential well yield and potential groundwater quality can be optimized.
- Locations of the targets may also be dictated by the R.M.'s economic development strategies. Locations near proposed intensive livestock developments, R.M. tank loadouts, etc. should be considered.
- All test holes and piezometers should be placed on road allowances wherever possible. Piezometer decommissioning will be subject to discussions with R.M.'s, Town of Wynyard or other interested parties. If no third parties are interested in taking over responsibility for the piezometers, then the piezometer will be decommissioned. Decisions on decommissioning the piezometers will be made during final meetings with PFRA, the Town of Wynyard and the R.M.'s of Big Quill and Prairie Rose.

Hydrogeological Evaluation and Report Preparation

The evaluation report contains the following:

- Discussion of the geology of the study area and how the geology influences the hydrogeology, water quality and potential well yields in the region. The groundwater development potential of the aquifers in the study area will be clearly described in terms of potential yield, aquifer recharge and water quality.
- A summary of the work objective and the approach taken to meet this objective.
- A general discussion of the geology, topography and hydrogeology of the study area and how they affect the groundwater conditions and development potential of the aquifers in the region.
- A brief discussion of field investigation procedures and equipment.
- Detailed findings from the field investigations including all driller's logs, E-logs, field observations and water sample test results.
- All relevant maps and cross-sections will be presented in the report both in hard copy and digital format.
- Recommendations regarding favourable areas for potential water supply development, well yield, well design and the possible need for further definition or future drilling should be provided in the report.

Finalization of the Report

Following PFRA review of the report, any changes suggested or required, will be completed. Comments that cannot be addressed directly in the report will be addressed in writing to PFRA. An additional meeting has been requested by PFRA for presentation of the report to the Town of Wynyard and the Rural Municipalities of Big Quill and Prairie Rose.

Seven (7) paper copies and one digital copy (in .pdf format) of the final report will be provided to PFRA.

2.0 Background Information

2.1 Terminology

The terms Wynyard Aquifer and Wynyard Formation Aquifer are the source of confusion when discussing the geology and hydrogeology of the area. This is partly because of the similarity of the names and partly because of the similarity in the textural and lithologic character of the units. The Wynyard Aquifer is a term used originally by the SRC (1982) to describe the Empress Group sediments which lie on the northwest flank of the Hatfield Valley and form a broad blanket aquifer at a higher stratigraphic level than the coarse Empress Group sediments that occupy the bottom of the main Hatfield Valley. The base of the Upper Empress Group sediments is variable and often lower than the Wynyard Formation Aquifer. The lithologic and textural composition of the Upper Empress Group sediments is typically coarser and more heterogeneous than the Wynyard Formation. The term Wynyard Aquifer will not be used in this report to avoid confusion with the Wynyard Formation Aquifer. Instead, the term Upper Empress Group is used to refer the blanket deposits that occur on the flank of the Hatfield Valley in the study area. The stratigraphic relationships between the Wynyard Formation and Empress Group sediments is discussed further in Section 2.3.

2.2 Regional Geologic History

The geology of the region is dominated by two features, the Wynyard Formation and the Hatfield Valley. The Tertiary-aged Wynyard Formation is the youngest bedrock unit in the area, overlying Cretaceous deposits of the Pierre Shale, and comprised of fine sand, silt, clay and gravel deposits. Sand and gravel deposits typically occur in the lower portions of the Formation and the upper portions of the Formation are typically comprised of silt and clay. The rock types found in the coarse clastic components of the Lower Wynyard Formation are typically quartzite and chert. The gravel occurs at the base of the succession, directly overlying the Pierre Shale. The Wynyard Formation has been eroded over most of the province but erosional remnants, termed outliers, occur in the Wynyard and Yorkton areas. The outlier in the Wynyard region underlies most of the Quill Lakes and covers an area of approximately 800 km^2.

Prior to the first glaciation, erosion on the bedrock surface formed a “badland like” topography consisting of a major valley, termed the Hatfield Valley, and numerous tributary valleys, plateaus and mesas adjacent to the main valley. The Hatfield Valley is a major feature that extends northwesterly across Saskatchewan and a portion of the valley runs west and south of the Wynyard area. Figure 1.1 shows the regional location of the Hatfield Valley in relation to the study area.

The main valley and tributary valleys were subsequently partially filled with sand, gravel, silt and clay materials deposited by rivers. The fluvial sediments that infill the Hatfield Valley are termed the Empress Group sediments. The lithologies found in the coarse clastic components of the pre-glacial sand and gravel deposits are typically quartzite and chert. Coarse deposits of sand and gravel that occupy the lowermost portion of the valley structure are informally termed Lower Empress Group.

As the first glaciation approached, the sediment loads carried by proglacial meltwater channels emptying into the Hatfield Valley increased substantially resulting in further infilling of the bedrock valleys. This was also accompanied by further erosion of the bedrock, in particular the Wynyard Formation, by glacial processes. The erosion and redeposition of the Wynyard Formation along portions of the Hatfield Valley formed broad blanket deposits of reworked sand, gravel, silt and clay. These deposits typically overlie both the sediments of Lower Empress Group deposits and the bedrock clay shale deposits marginal to the main Hatfield Valley. They are informally termed the Upper Empress Group deposits.

The Lower Empress Group deposits are often overlain by thick sequences of silt and clay which are stratigraphically equivalent to sand and gravel deposits occurring on the flanks of the valley. The silt and clay deposits within the valley and the sand and gravel deposits on the flanks are interpreted as facies equivalents of the Upper Empress Group. The lithologies found in the coarse clastic components of the Upper Empress Group typically include igneous, metamorphic and carbonate rock types as well as the quartzite and chert.

Subsequent glaciations further eroded both the Empress Group sediments and the bedrock formations during the glacial advances and deposited vast amounts of glacial till during the glacial recessions. The glacial tills, which cover much of southern Saskatchewan, have been divided into two broad groups termed the Sutherland Group and the Saskatoon Group. Both groups are comprised predominantly of unstratified deposits of eroded bedrock from many sources; from Precambrian aged igneous and metamorphic rocks to Paleozoic aged limestone and dolomite to Cretaceous aged clay shale. The Sutherland Group is the earlier till and has a higher proportion of shale bedrock fragments and clay within the matrix. The Saskatoon Group is the later till and has a higher proportion of calcareous material derived from the limestone and dolomite. Thin and isolated deposits of stratified sediments often occur within both the Saskatoon Group and the Sutherland Group. More widespread deposits of stratified materials often occur at the interglacial boundary between the Saskatoon and Sutherland Groups.

2.3 Regional Stratigraphic Relationships

The Wynyard Formation was deposited prior to the Empress Group sediments and prior to the development of the Hatfield Valley. It was deposited disconformably over the Pierre Shale. Both the Wynyard Formation and the Pierre Shale were subject to erosion during the development of the Hatfield Valley. The Wynyard Formation occurs as erosional remnants on structurally high areas of the Pierre Shale. The base of the Wynyard Formation is typically between elevations of 450 m and 470 m ASL.

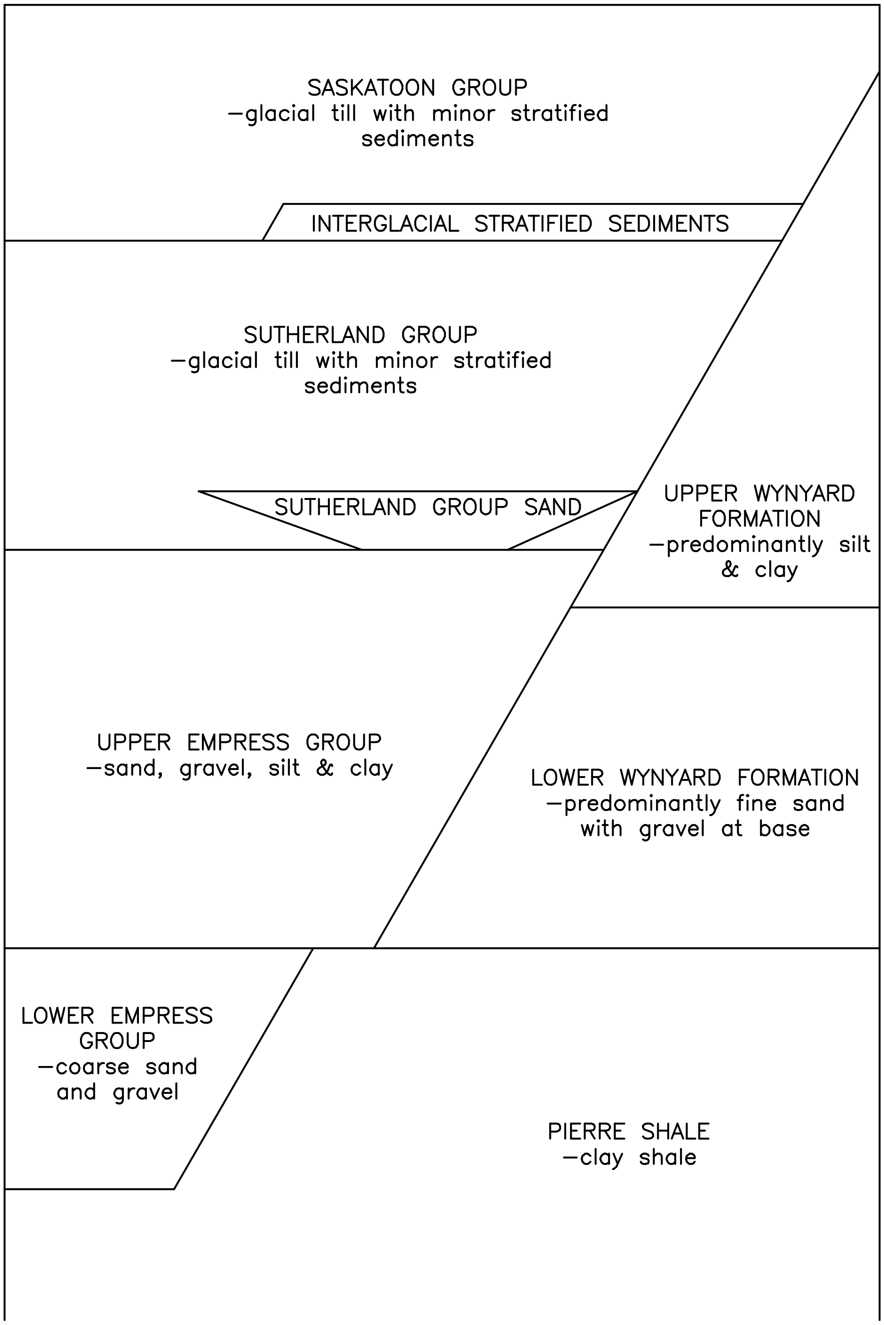
The Lower Empress Group is typically confined to the Hatfield Valley proper where it overlies clay shale and often underlies the silt or clay facies of the Upper Empress Group. The base of the Lower Empress sediments varies between 380 m and 410 m ASL in the study area.

The Upper Empress Group can overlie either Lower Empress, Pierre Shale or the flanks of the Wynyard Formation. These sediments are interpreted to represent late pre-glacial or early pro-glacial sediments derived from erosion and reworking of proximal formations such as the Wynyard Formation and more distal geologic terrains. Where it overlies the areas marginal to the Wynyard Formation, it is often coarse textured, while further toward the centre of the Hatfield Valley, where it overlies Lower Empress Group, it is often comprised of fine textured clay and silt. The base of the Upper Empress Group sediments is typically variable since it is a preglacial erosional surface and it occurs between 400 m and 490 m ASL.

Figure 2.1 provides a schematic illustration of the stratigraphic relationships in the study area.

2.4 Regional Physiography and Hydrogeology

The study area lies within the Quill Lakes Basin. This is a broad internal drainage basin flanked by the Touchwood Hills to the south and the Nut Mountain Uplands to the north. The surface topography has been shaped primarily from the last glaciation. The surface water quality in the areas surrounding the Quill Lakes is very poor due to the discharge of mineralized groundwaters and concentration of salts through evaporative processes at surface. Much of the groundwater discharge originates from two major confined aquifers of the region, the Hatfield Valley Aquifer System (Empress Group Aquifers) and the Wynyard Formation Aquifer.



SCHEMATIC STRATIGRAPHIC COLUMN

CLIFTON ASSOCIATES LTD. PROJECT NO: R3216 FIGURE NO: 2.1

R3216\FIGURE2.1.DWG

The Hatfield Valley crosses the province in a northwest to southeast direction. There is no surface expression of the valley because the Empress Group sediments that infill the valley are covered by clay rich glacial till deposits that are typically greater than 100 m thick. Where the buried valley intersects topographically low areas, the normally sub-artesian head elevations in the aquifer become flowing artesian resulting in groundwater discharge. This is the case within the areas immediately southwest of the Quill Lakes.

The Wynyard Formation underlies the immediate areas surrounding the Quill Lakes proper. The lower portions of this formation also form a regional aquifer. This aquifer is exploited by the Town of Wynyard and several other agricultural and industrial users in the area immediately east of the study area (Range 16, Township 32). The Wynyard Formation Aquifer is also a confined aquifer with sub-artesian and flowing artesian head elevations. Flowing artesian discharge from this aquifer occurs in the topographically low area surrounding the Quill Lakes.

Groundwater discharge from the Hatfield Valley and Wynyard Formation Aquifers in the Quill Lakes region contribute significantly to the surface water in the Quill Lakes. The high net evaporation, characteristic of the prairie region, and closed drainage from the Quill Lake basin combined with mineralized groundwater discharge results in the highly alkaline nature of the surface water and shallow groundwater resources surrounding the lakes. Deeper groundwater sources are therefore essential sources of supply for domestic and industrial use in the region.

2.5 Data Sources

The primary sources of data for the geological compilation were the test hole logs and E-logs from the SaskWater (09 December 1998) water well database. There are approximately 200 water well records for Ranges 17 to 21 in Township 32. All of these records were reviewed and any record that had an E-log associated with it, was ordered in hard copy from SWC. There are sixty eight (68) E-logs for the study area and fourteen (14) of these logs were completed by the Saskatchewan Research Council (SRC) in the late 60’s and early 70’s during the research program aimed at defining the Hatfield Valley Aquifer System across the province. The later logs were particularly useful since the E-logs were correlated with “sidehole core” samples. These logs provide some of the best information both for comparison to water well driller’s logs and for comparison of the logs obtained in the field investigation.

Another source of data were the SRC water chemistry records. Fifteen records were obtained from the SRC for the study area or adjacent areas.

The Geology and Hydrostratigraphy maps of the Wynyard Area (72P) published by SRC in June 2000 were also utilized in the preliminary compilation to provide a regional context for the study. The SRC report entitled *Hatfield Valley Aquifer System in the Wynyard Region, Saskatchewan, 1982* was also used as a reference for descriptions of various formations and hydrogeologic characterization. Much of the map data presented in the later report is the same as the data presented on the 2000 edition of the Geology and Hydrostratigraphy maps for 72P. The later maps contain additional recent well records, but are less detailed than the 1982 Report.

Base maps were produced from portions of 1:50,000 scale NTS maps 72P/9, 10, 15 and 16.

3.0 Field Program Design

The field program was designed in three phases, (1) geologic compilation, (2) PFRA technical approval, (3) local government input. The first stage involved review of existing maps and reports and compilation of geologic sections through the study area. Five geologic sections were prepared, one through each range of the study area. All the preliminary sections were oriented more or less in the north-south direction. The sections and lithologic descriptions from driller’s logs and geologist logs were used to identify areas where significant thicknesses of coarse textured aquifer materials and high well yields were reported in the Empress Group or Wynyard Formation. Preliminary test hole locations were selected at five sites. Three of the locations were selected on the southwestern extremities of the Wynyard Formation Aquifer (in the Kandahar-Dafoe area) and two of the locations were selected farther west overlying the Upper Empress Group sediments of the Hatfield Valley in the Jansen area.

The proposed test hole locations and rationale for selecting the locations was discussed with PFRA at a meeting on 13 February 2002. The general locations were approved with the understanding that if the Rural Municipalities or Town of Wynyard had other preferred locations, these would be considered.

Meetings with the Town of Wynyard and the R. M.’s of Big Quill and Prairie Rose were held on 18 February 2002. The three locations selected in the R. M. of Big Quill were approved by the Town and the R. M. These sites were NW21-32-17-W2, NE9-32-18-W2 and

SE22-32-18-W2. All three sites were located in areas where the gravel at the base of the Wynyard Formation is thicker than surrounding locations.

The R. M. of Prairie Rose wanted to select the drill sites based on interest expressed in specific land locations by potential intensive livestock developments. The original sites at NE36-32-20-W2 and NW2-32-19-W2 were abandoned for SW16-33-19-W2 and NW36-32-21-W2. The site at SW16 was known to be near a well with a substantial thickness of sand. The site at NW36 was located approximately midway between a farm well that had intersected less than 6 m of gravel above the shale and an SRC test hole which had intersected over 45 m of sand and gravel above the shale.

4.0 Field Investigation

4.1 Drill Program and Piezometer Construction

Five bore holes were completed between 21 and 25 March 2002. Bore Hole logs BH101 to BH105 are appended to this report. Hayter Drilling Ltd. were contracted to complete the drilling. Two drill rigs and crews were used to complete the program because of the original 31 March 2002 deadline and because it was being run in conjunction with a similar program being completed in the Leroy area 10 miles to the north. One rig was a top drive wet rotary and the other was a conventional table drive rotary rig. Clifton Associates Ltd. personnel supervised the drilling and completed field logging of the test holes. Each test hole was logged from samples taken at 0.76 m depth intervals. Test holes were terminated after intersecting a minimum of 3 m of bedrock shale beneath the overlying stratified drift or glacial drift. Test holes were E-logged using a Widco single point resistivity and spontaneous potential logging tool. The E-logs for each test hole are shown on the appended test hole logs.

Piezometers were installed in Test Hole Nos. TH102 to TH105. No piezometer was installed in TH101 because no Empress Group sediments were encountered above the shale contact. Piezometer completion details are shown on each test hole log. The piezometer screens were set in sand or gravel zones that were typically intersected immediately above the bedrock contact. Piezometers were constructed with 50 mm diameter, schedule 40 steel casing with a 0.75 m length of 15 slot, stainless steel screen attached to the base. Once the screens were in place, the piezometer was backwashed with clean water to remove drilling fluids from the test hole. After backwashing, 12-20 silica sand was placed around the screens. The piezometer was then air lifted to remove backwash fluids, remove fines and ensure formation water was entering the piezometer. The conductivity of the water was measured during this development procedure. Piezometers were typically developed with air over a period of 2 to 4 hours, depending on how quickly they cleaned up and the conductivity stabilized. During the air lifting period, the yield of the piezometer was estimated by measuring the time required to fill a 5 gallon (20 litre) pail. This measurement provides a preliminary indication of formation yield.

Table 4.1 provides a summary of test hole elevations, depths and water levels.

Table 4.1
Test Hole and Piezometer Summary – Hatfield Valley Aquifer Assessment

Bore Hole #	Top Elev. (m)	Grd. Elev. (m)	Total Depth (m)	Piezometer Tip Elev. (m)	Water Elev. (m)
101	-	547.1	127.4	-	-
102	531.3	530.3	81.4	455.3	528.5
103	531.3	530.4	88.4	453.4	525.6
104	532.0	531.1	79.2	457.1	522.6
105	530.3	529.4	84.7	465.9	526.6

Drawing No. R3216-1 shows the study area, locations of test holes, locations of previous SRC test holes and farm wells and geologic cross-section locations.

4.2 Response Testing

Rising head tests were performed on each piezometer to obtain an estimate of hydraulic conductivity. These tests were conducted at the end of the air lifting period. The air line was quickly removed and a water level indicator was run down the piezometer in an attempt to measure the water level as it was recovering. In three out of the four rising head tests attempted, the water had recovered to more than 90 percent of the static water level by the time the first reading was taken, this was usually within 2 to 3 minutes of shutting off the air. These recoveries indicate very high hydraulic conductivities. In each of these tests, it is conservatively estimated that the minimum hydraulic conductivity is in the order of 1×10^{-4} m/s based on the rapid recovery and grain size of the aquifer material. The pump test conducted by PFRA in 1986 for the Town of Wynyard Well No. 9 provides the only available data on the aquifer parameters of the Wynyard Formation Aquifer. The hydraulic conductivity calculated from this pump test is 1.8×10^{-4} m/s.

A summary of piezometer details including screen length, test interval and calculated or estimated hydraulic conductivity is presented in Table 4.2 along with the measured yields from air lifting. Raw data and calculations of hydraulic conductivity are presented in Appendix A.

Table 4.2
Summary of Response and Yield Test Results

Bore Hole #	Screen Length (m)	Aquifer Thickness (m)	Hydraulic Conductivity (m/s)	Air-Lift Yield (Igpm)
102	0.76	44	$> 1 \times 10^{-4}$	25
103	0.76	42	$> 1 \times 10^{-4}$	25
104	0.76	10	2.3×10^{-5}	12
105	0.76	24	$> 1 \times 10^{-4}$	25

The pump rate of 25 Igpm observed in piezometers 102, 104 and 105 is approaching the maximum flow that can be delivered through a two inch piezometer pipe using the air compressor on a conventional rotary rig.

4.3 Water Sampling

A water sample was obtained from each piezometer and submitted to Enviro-Test Laboratories for major ion analysis. The major ion package includes major cations, major anions, fluoride, nitrate, iron, manganese, total alkalinity, hardness, total dissolved solids, electric conductivity and pH. The piezometers were purged of drilling fluids during air lifting and one additional well volume was removed by bailing prior to sampling. The analytical results are presented and discussed in Section 7.0 of this report.

4.4 GPS Survey

Two Trimble GPS receivers were used to obtain piezometer coordinates and elevations. The GPS base station was referenced to geodetic bench mark 795047 which was located in the northeast corner of NE36-33-19W2. The NAD83 UTM coordinates for the bench mark are 530,490.156 m East, 5,747,981.344 m North, Zone 13, Elevation 524.460 m. The survey provided an estimated vertical accuracy of +/- 0.5 m. All bore hole coordinates are referenced to this bench mark. The coordinates are listed in Table 4.3.

Table 4.3
Test Hole Location Summary – Hatfield Valley Aquifer Assessment

Bore Hole #	UTM Northing (m)	UTM Easting (m)	Grd. Elev. (m)	Latitude (d/m/s)	Longitude (d/m/s)	Legal Land Description
101	5738076.0	509516.6	547.1	51°47’36.47”	104°51’43.24”	NW36-32-21W2
102	5741530.9	524027.7	530.3	51°49’26.73”	104°39’04.91”	SE17-33-19W2
103	5731721.7	535477.1	530.4	51°44’07.04”	104°29’10.48”	NW09-32-18W2
104	5734160.0	544354.0	531.1	51°43’23.68”	104°21’26.61”	NE21-32-17W2
105	5733654.4	537101.6	529.4	51°45’09.21”	104°27’45.05”	SE22-32-18W2

5.0 Geology

5.1 General

The geological interpretation presented in this section is based upon the combined information from the existing water well and test hole records plus the additional information obtained from TH101 to 105 during the recent field investigation.

5.2 Structure on the Top of Bedrock

The structure on the top of the Pierre Shale provides useful information to help differentiate between the Upper Empress Group sediments and Lower Wynyard Formation sediments. The structure contour on the top of the Pierre Shale is presented in Drawing No. R3216-2. The plan shows that the top of the shale in the area immediately south of Big Quill Lake, (Ranges 17 and 18), is gently undulating and varies between 450 m and 470 m elevation. Further west (Ranges 19 and 20), a distinct structural high forms a narrow ridge that trends east-west. The elevations of the top of the shale are typically above 450 m along the ridge. North and south of the ridge, the top of the shale drops off sharply in the order of 30 m to 40 m. The top of the shale drops more than 80 m over 11 km off the southwest end of the ridge.

Test Hole Nos. TH101 to TH103 provided additional information to further define the character and extent of the ridge. These test holes also provided significant new information regarding the stratigraphic relationships between the Lower Wynyard Formation and the Upper Empress Group. These are discussed further under Section 5.3.

5.3 Stratigraphy

Eight geologic sections have been constructed through the study area to define the stratigraphic setting. Sections A-A’ to H-H’ are shown in Drawing Nos. R3216-3 to R3216-9. Sections A-A’ to E-E’ are constructed at an approximate north-south orientation. Sections F-F’ to H-H’ are constructed with an east-west orientation.

The stratigraphic units are described below beginning with the clay shale of the Pierre Shale which constitutes the base of exploration in the study area. Descriptions of various strata are developed from a combination of previous reports, driller’s water well logs, SRC geologic logs and the geologic logs from the recent drill program. Refer to Figure 2.1 for a schematic representation of the stratigraphic column in the study area.

Pierre Shale

The Pierre Shale is a non-calcareous, dark grey, clay shale. It occurs throughout the area at depths varying between 60 m where it underlies the Wynyard Formation to 150 m where it underlies the Lower Empress Group in the Hatfield Valley. Test Hole Nos. BH101 to BH105 all intersected the Pierre Shale.

Lower Wynyard Formation

The Wynyard Formation has informally been divided into two distinct units, lower and upper. The lower unit directly overlies Pierre Shale and often has a coarse gravel at the base of the unit which is up to 8 m thick. Fine to medium sand overlies the gravel. The gravel is not always present. The gravel is composed of quartzite and chert. The total thickness of the Lower Wynyard varies from 10 m to 40 m. The Lower Wynyard Formation is defined on Sections C-C’ to E-E’ in Drawing Nos. R3216-5 and R3216-6. It was intersected in TH102 to TH105 in the current investigation. The unit is progressively eroded westward and does not occur in Ranges 20 and 21. The Lower Wynyard Formation does not occur at elevations below 447 m ASL. Drawing No. R3216-10 shows an isopach of the Lower Wynyard Formation. The Lower Wynyard Formation constitutes the major bedrock aquifer in the area.

Upper Wynyard Formation

The Upper Wynyard Formation directly overlies the lower unit and is composed of silt and clay. The unit has been intensely oxidized in places and has distinct red, pink, light grey and brown colorations in the oxidized zones and a light grey color in the unoxidized zones. The Upper Wynyard Formation is up to 50 m thick as indicated on Section E-E’. It has been eroded further westward and is present only at one location (Blyth) on Section D-D’. The Upper Wynyard Formation does not occur at elevations below 470 m ASL.

Lower Empress Group

The Lower Empress Group sediments are present in two records within the study area, an SRC test hole NW13-32-31-21W2 and a U. of S. Farm well NW16-22-33-21W2. Both intersections are described as clean, coarse to very coarse sand. The elevations at the base of these intersections are 380 m and 408 m ASL at the SRC and U. of S. sites, respectively. These are the lowest (top of shale) elevations recorded in the study area. The occurrence of these intersections with 20 m to 40 m of interbedded fine sand, silt and clay directly overlying them also suggest that the intersections correlate with Lower Empress Group. Cross sections A-A’, F-F’ and H-H’ all show the stratigraphic position of the Lower Empress relative to the other stratigraphic units.

Upper Empress Group

This unit is widespread west of Section D-D’ within the study area. It is composed of silt and fine to coarse sand with minor gravel lenses. It is up to 50 m thick where it overlies the Lower Empress Group and the Pierre Shale, but thins to less than 3 m where it overlies the Lower Wynyard Formation. The Upper Empress Group overlies the Lower Empress Group sediments in the far western end of the study area, it overlies clay shale across much of Ranges 18 to 21 and it overlies Lower Wynyard Formation in the following locations on the east side of the study area:

- SRC NW13-10-32-18W2
- SRC SW15-30-32-18W2
- TH102 SE17-33-19W2
- TH103 NE9-32-18W2
- TH105 SE22-32-18W2

In each of the above locations, a gravel occurs at the top of a fine sand succession and the E-log shows a distinctive higher resistivity signature which is not typical of Wynyard Formation except at the absolute base of the formation where the gravel occurs. In the above test hole logs, it has been interpreted that Upper Empress Group sediments are onlapping over the Lower Wynyard Formation. All of these test holes are interpreted to represent the transition zone between Wynyard Formation and Empress Group sediments.

Drawing No. R3216-11 shows an isopach of the Empress Group. The Empress Group generally becomes thicker to the north, south and west of the clay shale structural high and thins to the east where it overlies the Lower Wynyard Formation. No Empress Group sediments are present east of Range 18. There are two areas on the west end of the study area where the Empress Group has been eroded by Sutherland Group glaciation, these are on the northwest and southeast slopes of the clay shale structural high as shown in Drawing No. R3216-11 and on Sections F-F’, G-G’ and H-H’. In Range 21, two test holes intersected thick sequences of fine sand, silt and clay overlying sand and gravel (NW13-32-31-21W2M and NE22-33-21W2M). These intersections are interpreted as Upper Empress Group (fine sand, silt and clay facies) overlying Lower Empress Group (sand and gravel). Drawing No. R3216-11 and Section A-A’ show the relationships between the fine sand, silt and clay facies and the sand and gravel facies of the Upper Empress Group.

Sutherland Group

The Sutherland Group consists primarily of clay rich glacial till within the study area. It becomes thin to non existent on the east side of the study area where the Upper Wynyard Formation is present. The top of the Sutherland Group is often marked by an oxidized till zone or directly underlies a thin, but widespread interglacial sand and gravel zone that separates the Sutherland Group from the Saskatoon Group. The Sutherland Group is also well defined on the E-logs by the lower resistivity than the Saskatoon Group. This results from the higher clay content of the Sutherland Group tills. The top of the Sutherland Group occurs at depths of 20 m to 50 m throughout the study area. The Sutherland Group becomes thicker and deeper toward the west end of the study area where it is typically in the order of 40 m thick and 40 m deep. Where glaciation has eroded the Empress Group, the Sutherland Group is up to 75 m thick.

A significant thickness of stratified sediments are present within the Sutherland Group at the west end of the study area. This unit is well defined in TH101 which encountered silt and fine sand from 72 m to 99 m and (a glacial till) from 99 m to 124 m prior to intersecting the shale. This intersection may also explain some of the anomalously thick sand intersections which occur in the nearby Bresch, SRC SE11-5-33-21W2, SRC SW3-4-32-20W2 test holes. These test holes intersected sand zones at elevations higher than expected for Empress Group, but the base of the sand in these test holes does occur where the base of the Empress Group is expected. Given the evidence in TH101 for a Sutherland Group stratified sediment zone, it is possible that the anomalous sand thickness in surrounding holes is due to a combined thickness of Empress Group and Sutherland sand units where Sutherland sand has partially eroded and is directly overlying Empress Group sand (see Sections G-G’ and B-B’).

Saskatoon Group

The Saskatoon Group is the uppermost geologic unit identified in the area and it is comprised predominantly of glacial till. The base of the Saskatoon Group is often marked by the presence of interglacial stratified sediments. Local lenses of stratified sediments are also found throughout the Saskatoon Group. The till of the Saskatoon Group characteristically has a higher carbonate content than the Sutherland Group tills. The thickness of the Saskatoon Group ranges from 60 m on the west end of the study area to less than 5 m thick on the east end, where it overlies the upper Wynyard Formation.

5.4 Extent and Thickness of Sand and Gravel Deposits

Drawing No. R3216-10 illustrates the thickness and extent of the Lower Wynyard Formation in the study area. The gravel at the base of the Lower Wynyard occurs sporadically, but appears to be more prominent in the areas immediately to the south of Big Quill Lake. At TH103, an intersection of 8 m of clean, coarse, cobbles and boulders provides some of the thickest and coarsest material encountered in the current test drilling program. At TH104 (Kandahar location), the sand and gravel is less than 4 m thick and has abundant fine sand and silt in the matrix. TH105 intersected 2 m of coarse sand and gravel at the base of the Formation and had several metres of clean medium grained sand above the coarse sand. Within the Lower Wynyard Formation, the areas around TH103 and TH105 offer the thickest and cleanest zones for potential well development.

There are two areas where the Upper Empress Group is thin to non-existent as shown in Drawing No. R3216-11. These areas should be avoided when looking for water well locations. In most of the areas where the Upper Empress Group is present, it is described as medium to coarse sand. Areas where the Empress Group becomes thicker than 30 m are typically areas where the Upper Empress Group overlies Lower Empress Group. In these areas, the Upper Empress Group is interbedded silt and fine sand and thus does not represent high yield potential. The top of the Lower Empress Group occurs at depths of greater than 130 m in the southwest corner of the study area. The sand and gravel in the Empress Group is thin and deep over much of Range 21. Upper Empress Group silt and fine sand predominates in this area. Development potential for high yield wells in this area is considered low. The current drill program did not identify any Upper Empress Group intersections, in TH101 the Empress Group was eroded and TH102 is interpreted to intersect the Lower Wynyard Formation. Farm well records and SRC test holes do however indicate significant intersections of sand and gravel belonging to the Upper Empress Group throughout Ranges 19 and 20. These areas probably offer good potential for high yield well development also but no testing of the aquifer was completed in these areas.

6.0 Hydrogeology

6.1 General

Three major aquifers are present within the study area, they are:

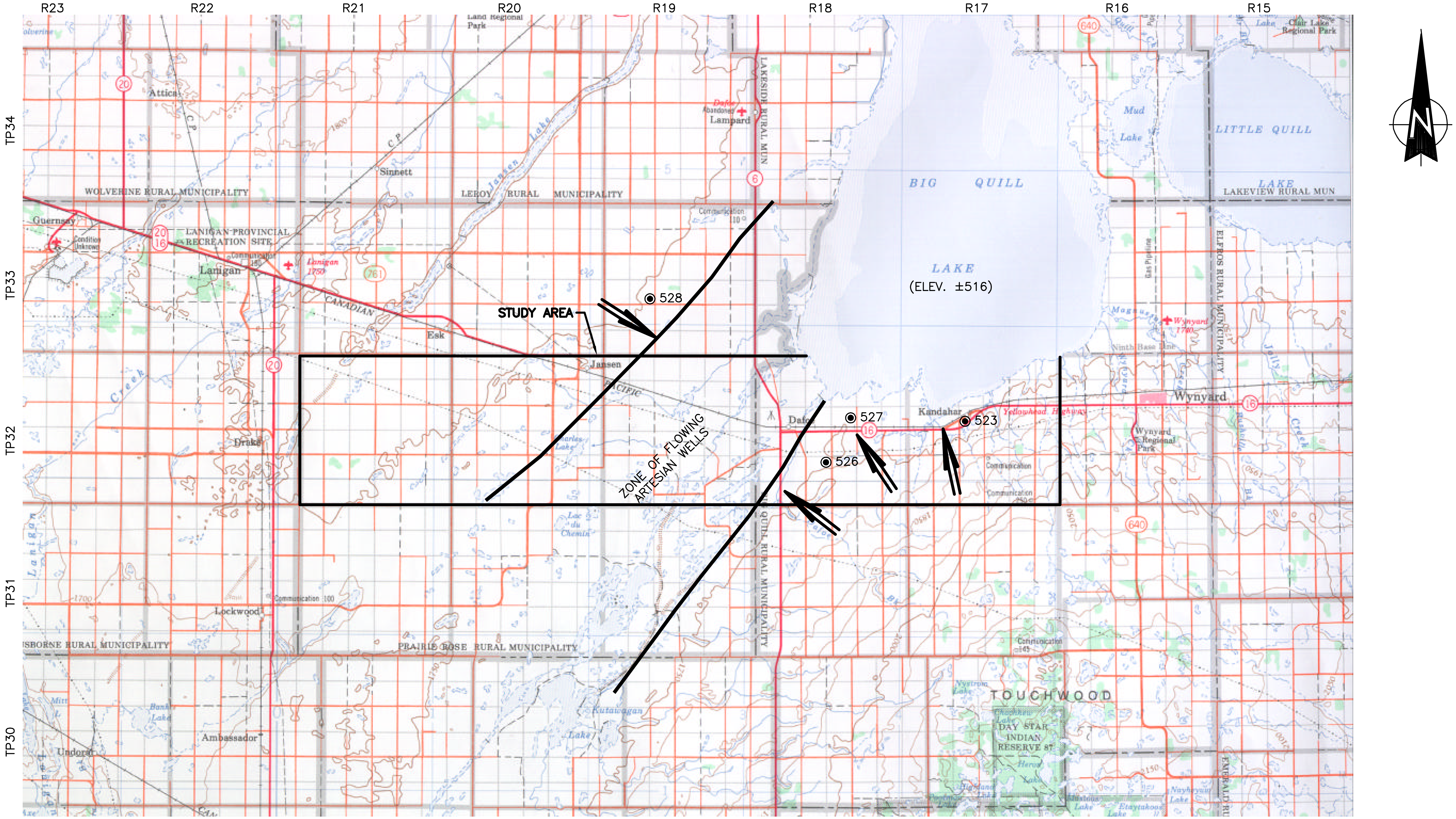
- Wynyard Formation Aquifer; this is comprised of the sand and gravel in Lower Wynyard Formation stratigraphic unit.
- Lower Empress Group Aquifer; this is the pre-glacial sand and gravel that occupies the deep central portion of the Hatfield Valley and is overlain by fine sand, silt and clay facies of the Upper Empress Group.
- Upper Empress Group Aquifer; this is the sand and gravel facies of the Upper Empress Group that lies on the flanks of the Hatfield Valley and marginal to the Wynyard Formation Aquifer.

The Wynyard Formation Aquifer and the Upper Empress Group Aquifer have an apparent direct hydraulic connection and are transitional into one another. They have very similar textural and lithologic properties and occur at similar elevations. The Upper Empress Group Aquifer and the Lower Empress Group Aquifer may have a hydraulic connection, however due to the lateral facies change from sand and gravel to fine sand, silt and clay in the Upper Empress Group the connection may be indirect. Water quality is one of the main distinguishing characteristics between each of the aquifers and this is discussed further in Section 7.0.

6.2 Wynyard Formation Aquifer

The Wynyard Formation Aquifer consists of the Lower Wynyard Formation. The extent and thickness of this aquifer is shown in previous cross sections and isopachs. The piezometric head elevations are listed in Table 4.1 and general groundwater flow directions are shown on Figure 6.1. Head elevations indicate groundwater flow toward Big Quill Lake (elevation 516 m ASL). A horizontal gradient of approximately 0.0017 m/m eastward is indicated between piezometer 102 and Quill Lake. Horizontal gradients from piezometers 104 and 105 northward to Quill Lake are slightly higher at 0.0045 m/m and 0.006 m/m, respectively.

Piezometers 102 to 105 were all installed in the gravel at the base of the Wynyard Formation. Piezometers 102, 103 and 105 all had very fast recoveries following air-lifting and therefore hydraulic conductivities could not be calculated for these piezometers. Each of these



0 5 10 15 20 Km

LEGEND:

GROUNDWATER ELEVATIONS FROM CURRENT INVESTIGATION (mASL)	◉ 527
REGIONAL GROUNDWATER FLOW DIRECTION	⇒

NOTES:

1. DRAWING DEVELOPED FROM NTS MAP 72P.

REGIONAL GROUNDWATER FLOW

FIGURE 6.1

R3216/FIGURE 6.1.DWG

piezometers pumped with air at approximately 25 Igpm which is approaching the maximum rate possible from a 50 mm diameter piezometer. The high pump rate and fast recovery of the piezometers and coarse gravel at the base of the Wynyard Formation suggests a hydraulic conductivity in the order of 10^{-4} m/s is not unreasonable. Piezometer 104 recovered slower than the other three and a rising head test was completed. The head test is provided in Appendix A. A hydraulic conductivity of 2.3 x 10^{-5} m/s was calculated. This hydraulic conductivity is considered realistic and possibly indicative of an abundance of fine sand and silt matrix in the formation[1].

There are several high yield wells in the Wynyard Formation Aquifer, they include the Town of Wynyard, Big Quill Resources and Potash Corporation of Saskatchewan. These wells are pumped in the 100 Igpm to 200 Igpm range. The Big Quill and PCS wells are in the study area while the Wynyard well is further east. The transmissivity calculated from a 24 hour pump test completed by PFRA on the Wynyard well No. 9 is 1.1 x 10^{-3} m^2/s and the storage coefficient is 1.1 x 10^{-4}. Given the aquifer thickness of 6 m at Well No. 9, a hydraulic conductivity of 1.8 x 10^{-4} m/s is estimated. This well has approximately 50 m of available drawdown.

No pump test data is available for the Big Quill or PCS wells, but the drawdown in the Big Quill well after being pumped for 24 hours at 180 Igpm (13.6 lps) was 9 m. The Theis equation was used to back calculate the hydraulic conductivity given the pump rate, time and drawdown as shown in Figure 6.2. A hydraulic conductivity of 3 x 10^{-4} m/s is estimated for the aquifer in the vicinity of the Big Quill well. This is approximately 50% higher than the hydraulic conductivity at the Town of Wynyard Well No. 9. The Big Quill well is approximately 10 km east of piezometers 103 and 105, whereas the Town of Wynyard well is 20 km east. Given the similarity of the gravel thickness, fast recovery, high air-lift yield and the proximity to the Big Quill well, it is assumed that a well developed in the vicinity of piezometers103 and 105 would have aquifer characteristics similar to the Big Quill well.

Using the hydraulic conductivity of 3 x 10^{-4} m/s and an assumed storage coefficient of 2 x 10^{-4}, a Theis analysis was completed for a theoretical well constructed in the vicinity of

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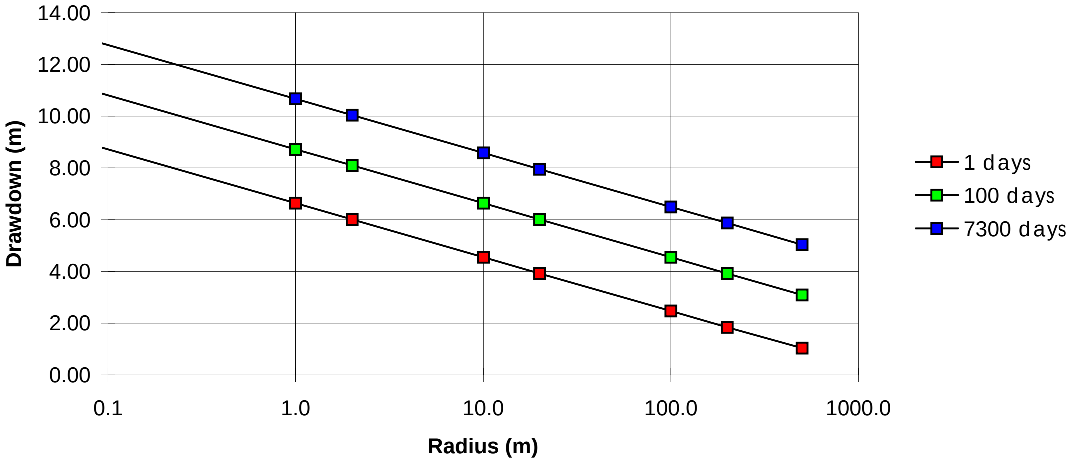
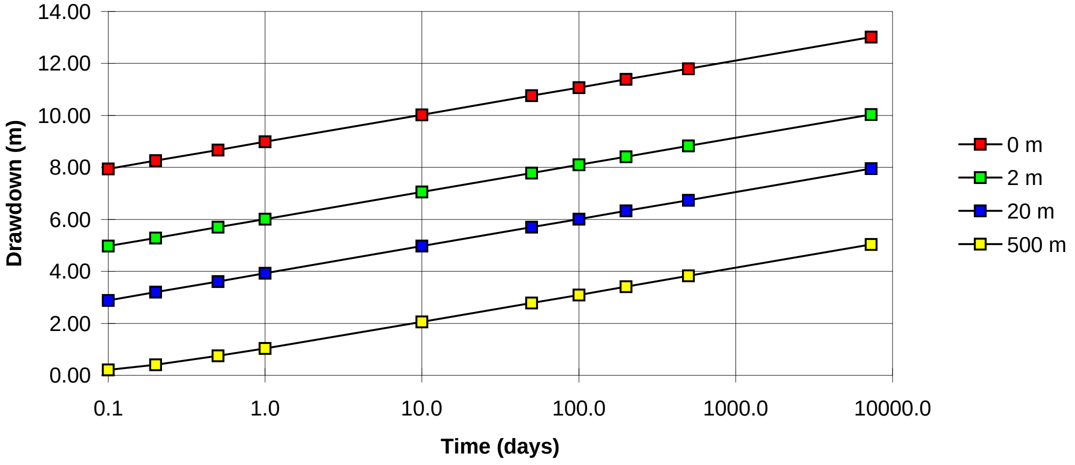
[1] The possibility of drilling mud intrusion causing the lower hydraulic conductivity was considered and since the hole was completed in less than eight hours, only 9 bags of drilling mud were used and the piezometer was developed with air for 5 hours it is not considered likely that the lower hydraulic conductivity in P104 was caused by mud intrusion.

Figure 6.2: Theis Analysis on Big Quill Resources Well

Client	PFRA		Pumpage rate	cu m/day	1180	180.3 Igpm
Project	Hatfield and Wynyard Formation		Aquifer Thickness	m	8	
Project Number	R3216		Hydraulic Conductivity	m/sec	3.00E-04	
Date / Time	31-May-02	13:34:09	Transmissivity	sq. m/day	207.36	
By	WAJ		Storage Coefficient		2.00E-04	
Comments	k est. from dd at 24 hrs		Confined Aquifer		y	

	Drawdown (metres)							
Radius (m) Time (days)	**0.075**	1	**2**	10	**20**	100	200	**500**
0.1	7.94	5.60	4.97	3.51	2.88	1.44	0.84	0.20
0.2	8.26	5.91	5.28	3.82	3.20	1.74	1.13	0.41
0.5	8.67	6.33	5.70	4.24	3.61	2.16	1.54	0.75
1	8.98	6.64	6.01	4.55	3.93	2.47	1.84	1.04
10	10.03	7.68	7.05	5.60	4.97	3.51	2.88	2.06
50	10.76	8.41	7.78	6.33	5.70	4.24	3.61	2.78
100	11.07	8.72	8.10	6.64	6.01	4.55	3.93	3.10
200	11.38	9.04	8.41	6.95	6.33	4.87	4.24	3.41
500	11.80	9.45	8.83	7.37	6.74	5.28	4.65	3.82
7300	13.01	10.67	10.04	8.58	7.95	6.50	5.87	5.04





piezometers 103 and 105. The analysis is shown in Figure 6.3. The aquifer is present from 78 m to 86 m at TH103 and the static water level of 5.7 m indicates an available drawdown of over 70 m at this location. The maximum potential yield based on these aquifer characteristics is 700 Igpm (53 lps) with a predicted drawdown at the well in the order of 50 m after 20 years of continuous pumping. This provides an allowance of 20 m for well losses due to inefficiency and well degradation. This maximum yield estimate does not consider long term sustainability and it is likely that the maximum sustainable yield would be 20% to 30% lower. Also, there is unlikely to be a demand for quantities in excess of 500 Igpm in the near future[2]. The higher hydraulic conductivity and approximately 20 m more available drawdown than the Wynyard Well no. 9 results in a theoretical well with a considerably higher potential yield than the wells closer to Wynyard.

Given the potential high yield from a well in this area, the interference effects are considerable. As indicated in Figure 6.3, at a distance of 10 km from a theoretical production well in an isotropic, infinite aquifer, the drawdown would be in the order of 9 m. A high yield production well in this area would require detailed analysis to determine adequate well spacing and sustainable yield for the aquifer.

The development potential in the area surrounding piezometer 102 is also considered very good since this piezometer also pumped at 25 Igpm during development and recovered very quickly. Extending the Theis analysis to the area surrounding piezometer 102, using an aquifer thickness of 3.5 m and an available drawdown of 55 m after accounting for well losses the maximum yield estimated for a well in this area is approximately 340 Igpm (26 lps). Figure 6.4 shows the Theis analysis for the area surrounding piezometer 102. This analysis assumes a hydraulic conductivity similar to that estimated for the Big Quill well.

The hydraulic conductivity at piezometer 104 is considerably lower than reported at the other locations. The estimated maximum potential yield at this location is 76 Igpm (5.7 lps). Figure 6.5 shows the Theis analysis for this location. The well development potential in the Wynyard Formation Aquifer around Kandahar is considered poor based on this test; however, within 800 m of this site, other test holes have indicated thicker and cleaner gravel formations so that the test at piezometer 104 may not be typical of the aquifer in this area.

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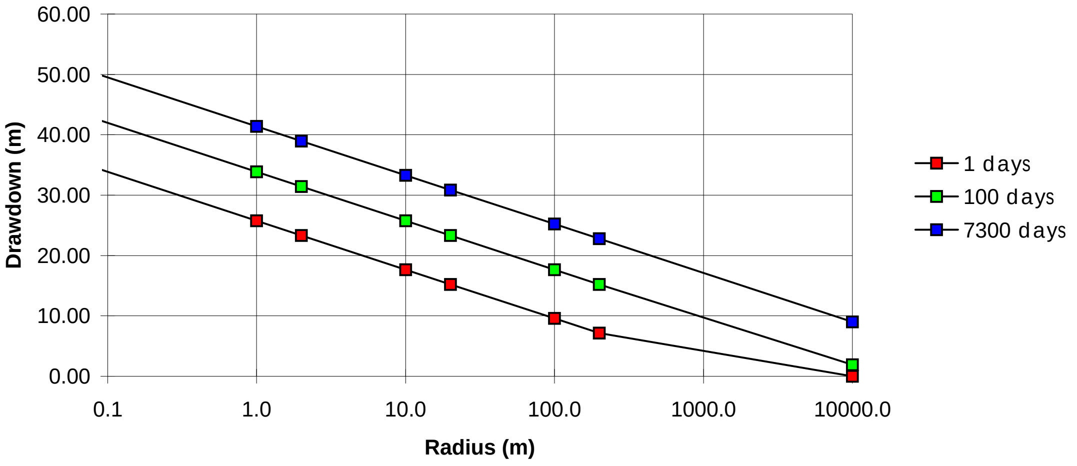
[2] The Town of Wynyard total annual consumption from 13 wells operated in 2000 was 768 dam^3, this is equivalent to approximately 320 Igpm on a continuous basis.

Figure 6.3: Theis Analysis on Theoretical Well around Piezometer P103

Client	PFRA		Pumpage rate	cu m/day	4580	699.7 Igpm
Project	Hatfield and Wynyard Formation		Aquifer Thickness	m	8	
Project Number	R3216		Hydraulic Conductivity	m/sec	3.00E-04	
Date / Time	31-May-02	13:34:47	Transmissivity	sq. m/day	207.36	
By	WAJ		Storage Coefficient		2.00E-04	
Comments	k est. from Big Quill Pump Test		Confined Aquifer	(y/n)	y	

	Drawdown (metres)							
Radius (m) Time (days)	**0.075**	1	**2**	10	**20**	100	200	**10000**
0.1	30.83	21.72	19.28	13.63	11.19	5.57	3.26	0.00
0.2	32.05	22.94	20.50	14.85	12.41	6.77	4.40	0.00
0.5	33.66	24.55	22.11	16.46	14.02	8.37	5.96	0.00
1	34.87	25.77	23.33	17.67	15.24	9.58	7.16	0.00
10	38.92	29.82	27.38	21.72	19.28	13.63	11.19	0.05
50	41.75	32.64	30.21	24.55	22.11	16.46	14.02	1.02
100	42.97	33.86	31.43	25.77	23.33	17.67	15.24	1.89
200	44.19	35.08	32.64	26.99	24.55	18.89	16.46	2.91
500	45.80	36.69	34.25	28.60	26.16	20.50	18.07	4.40
7300	50.51	41.40	38.97	33.31	30.87	25.22	22.78	9.03



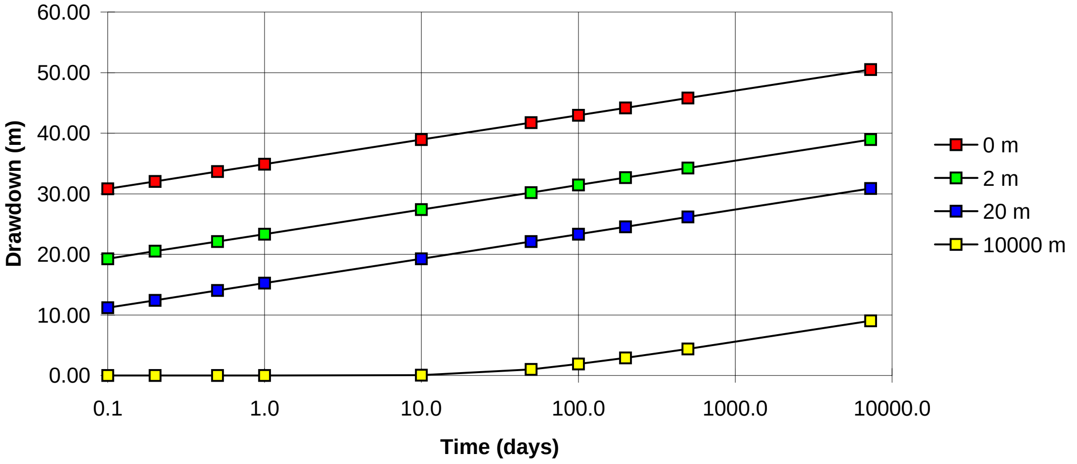
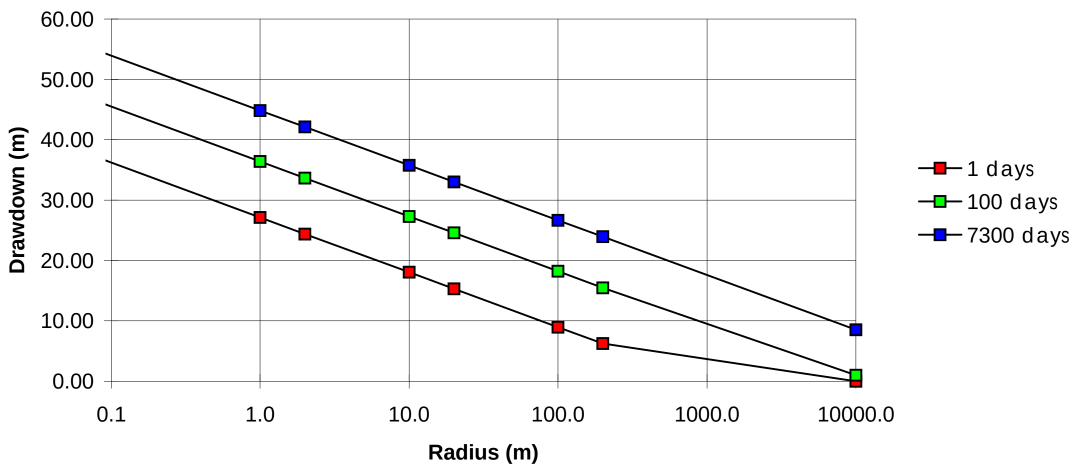


Figure 6.4: Theis Analysis on Theoretical Well around Piezometer P102

Client	PFRA		Pumpage rate	cu m/day	2250	343.8 Igpm
Project	Wynard Area Hydrogeological		Aquifer Thickness	m	3.5	
Project Number	R3216		Hydraulic Conductivity	m/sec	3.00E-04	
Date / Time	31-May-02	13:35:24	Transmissivity	sq. m/day	90.72	
By	WAJ		Storage Coefficient		2.00E-04	
Comments	k est. from Big Quill pump test		Confined Aquifer	(y/n)	y	

	Drawdown (metres)							
Radius (m) Time (days)	**0.075**	1	**2**	10	**20**	100	200	**10000**
0.1	32.98	22.76	20.02	13.67	10.94	4.69	2.26	0.00
0.2	34.35	24.13	21.39	15.04	12.30	6.00	3.42	0.00
0.5	36.16	25.94	23.20	16.85	14.11	7.78	5.11	0.00
0.92	37.36	27.14	24.40	18.05	15.31	8.97	6.27	0.00
10	42.07	31.85	29.11	22.76	20.02	13.67	10.94	0.00
50	45.25	35.02	32.29	25.94	23.20	16.85	14.11	0.37
100	46.62	36.39	33.66	27.30	24.57	18.21	15.48	0.99
200	47.99	37.76	35.02	28.67	25.94	19.58	16.85	1.91
500	49.79	39.57	36.83	30.48	27.74	21.39	18.66	3.42
7300	55.08	44.86	42.12	35.77	33.04	26.68	23.95	8.52



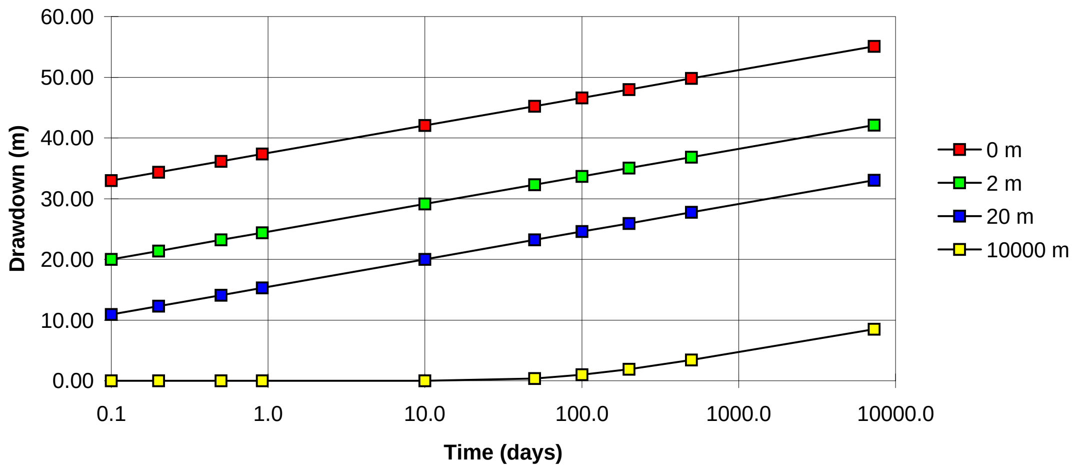
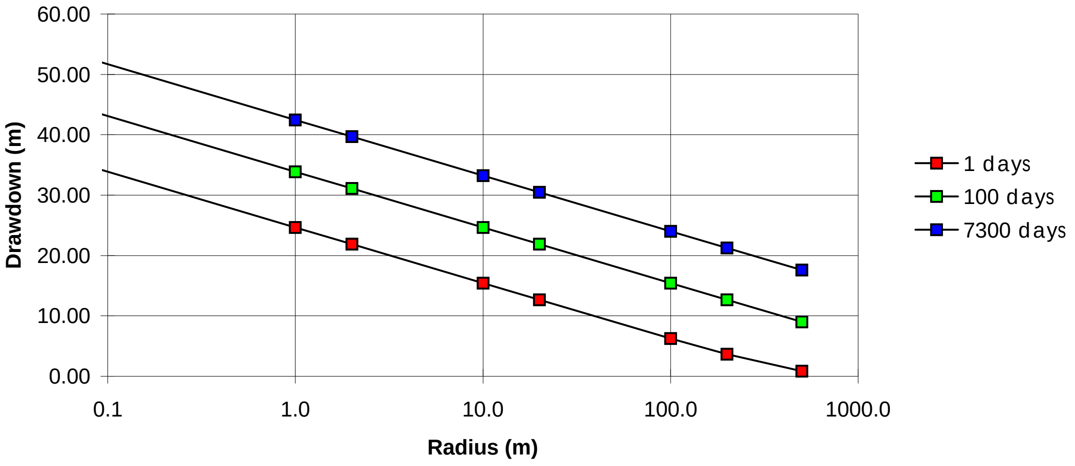
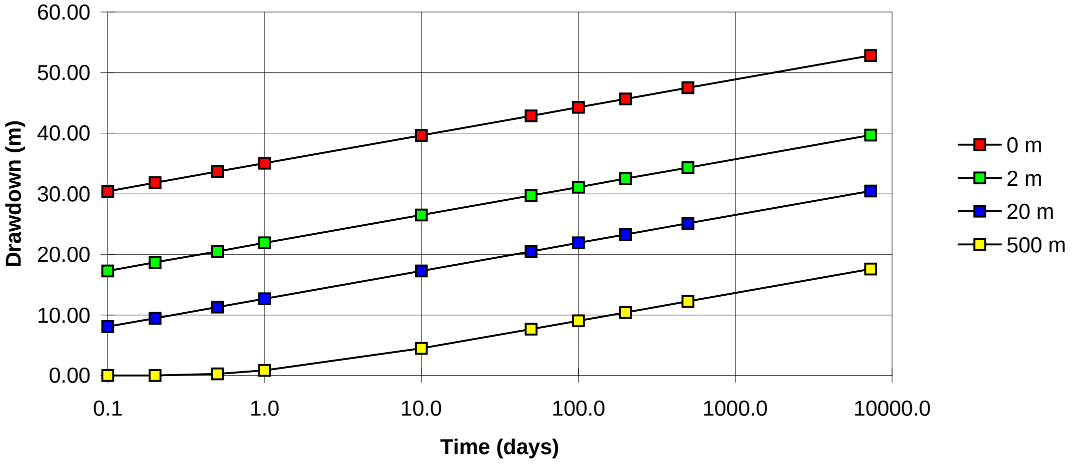


Figure 6.5: Theis Analysis on Theoretical Well around Piezometer P104

Client	PFRA		Pumpage rate	cu m/day	500	76.4 Igpm
Project	Hatfield and Wynyard Formation		Aquifer Thickness	m	10	
Project Number	R3216		Hydraulic Conductivity	m/sec	2.30E-05	
Date / Time	31-May-02	13:35:54	Transmissivity	sq. m/day	19.87	
By	WAJ		Storage Coefficient		2.00E-04	
Comments	k from rising head test at P104		Confined Aquifer	(y/n)	y	

	Drawdown (metres)							
Radius (m) Time (days)	**0.075**	1	**2**	10	**20**	100	200	**500**
0.1	30.42	20.05	17.27	10.83	8.07	2.08	0.43	0.00
0.2	31.81	21.44	18.66	12.22	9.45	3.24	1.11	0.02
0.5	33.64	23.27	20.50	14.05	11.28	4.93	2.44	0.29
1	35.03	24.66	21.88	15.44	12.66	6.27	3.64	0.86
10	39.64	29.27	26.49	20.05	17.27	10.83	8.07	4.51
50	42.86	32.49	29.72	23.27	20.50	14.05	11.28	7.63
100	44.25	33.88	31.10	24.66	21.88	15.44	12.66	9.01
200	45.64	35.27	32.49	26.05	23.27	16.83	14.05	10.39
500	47.47	37.10	34.33	27.88	25.11	18.66	15.89	12.22
7300	52.84	42.47	39.69	33.25	30.47	24.03	21.25	17.58





The Bjornsen well, located on SW27-32-17W2 is a high-yield irrigation well that has been pump tested at 300 Igpm. Geologic information suggests that this well is not completed into the Wynyard Formation Aquifer, but rather into a shallow interglacial aquifer. The present investigation is focused on more regional aquifers therefore this aquifer is not considered further.

6.3 Upper Empress Group Aquifer

Two test holes were planned to intersect the Upper Empress Group Aquifer; neither intersected significant thicknesses of Empress Group. Test Hole No. TH101 further defined an area where the Empress Group has been eroded as indicated on the isopach plan. Test Hole No. TH102 intersected a thin (2.5 m thick) upper Empress Group gravel overlying 40 m of Wynyard Formation, the piezometer was installed in the Wynyard Formation Aquifer.

Review of water well records indicates that there are numerous farm wells constructed in the Upper Empress Group Aquifer that yield 20 to 75 Igpm. Little reliable information is available regarding pump tests and sustainable yield in the aquifer in this area. Three areas do however stand out as areas where thick, coarse deposits of sand and gravel are noted. These locations are:

- SRC test hole SE11-5-33-20W2 (over 45 m of medium to coarse sand at a depth of 60 m);
- SRC test hole NE13-2-32-19W2 (approximately 13 m of very coarse sand and gravel at a depth of 64 m); and,
- Holfeld well NW15-33-19W2 (approximately 20 m of sand with 5 m described as coarse at a depth of 69 m).

Flowing artesian conditions are noted in several wells drilled in low areas off the southwest end of Big Quill Lake.

Zones of thick, coarse, sand and gravel exist in the Lower Empress Group in Range 21; however, the greater depth and poorer quality water make this area less attractive.

6.4 Lower Empress Group Aquifer

The Lower Empress Group Aquifer occurs on the west side of Range 21. It is present in two test holes, SRC NW13-32-31-21W2 and a U. of S. Farm well NW16-22-33-21W2. The stratigraphy and lithology is described in Section 5.3. No pump test information is available from these wells. This aquifer is deep, occurring at depths of greater than 100 m. Outside of the study area, aquifer parameters have been documented by SRC (1982). The typical transmissivities are estimated to range from 200 m^2/day to 2,500 m^2/day and storativity is in the 2.0 x 10^{-4} range. Water quality is typically poor, as described in Section 7.0. Depth and quality issues make this aquifer a less desirable water source if other alternatives exist.

7.0 Water Chemistry

Groundwater samples were obtained from piezometers 102 to 105. The samples were analyzed for major ions, iron, manganese and nitrate as per the terms of reference. The results are listed in Table 7.1. Table 7.1 also shows the Canadian Drinking Water Guidelines for comparison. All samples exceed the guidelines in TDS, sulphate, iron and manganese. The groundwater sample from piezometer 102 also exceeds the guidelines in sodium. The nitrate concentrations are below the guideline in all samples. The TDS, sulphate, chloride and sodium are all noticeably higher in the groundwater sample from piezometer 102. The groundwater sample from piezometer 105 exhibited the best quality of water from a drinking water perspective.

Historical water quality data was obtained for five samples from the Empress Group Aquifer and ten samples from the Wynyard Formation Aquifer in the same general region as the study area for comparison to groundwater samples from piezometers 102 to 105. The historic data is listed in Tables 7.2 and 7.3. Wynyard Formation water has an overall better quality than the Empress Group water.

The historic data has been plotted on a trilinear diagram along with the data from the current samples to determine which samples are similar to Wynyard Formation Aquifer and which samples are similar to Empress Group Aquifers water chemistry. Trilinear diagrams are useful because they plot the major cations and major anions in %meq/L. Milliequivalents per litre (meq/L) are equal to the molecular weight of the major ion multiplied by the concentration in mg/L. Groundwater samples from similar origins tend to plot within similar fields when expressed in meq/L regardless of the concentrations in mg/L. Figure 7.1 shows the trilinear plot comparing the groundwater samples from piezometers 102 to 105 to the historic Wynyard Formation Aquifer and Empress Group Aquifer data for the region.

Figure 7.1 indicates that the Wynyard Formation Aquifer typically has Ca-Mg bicarbonate type water while Empress Group Aquifers typically have Na sulphate type water. There is a trend or continuum between the two water types with a progressive increase in sulphate and sodium while calcium and bicarbonate decrease. There is also a slight decrease in magnesium

Table 7.1

File R3216

Water Quality Summary
Hydrogeologic Investigation - Wynyard Area

Parameter	Units	Detection Limits	Water Chemistry Test Results				Canadian Drinking Water Quality Guidelines 1998
Piezometer No.			102	103	104	105	
Depth (m)			75	77	74	63	
Date Sampled	y/m/d		2/3/25	2/3/25	2/3/25	2/3/25	
Physical Properties							
Conductivity	µS/cm	10	3000	2310	2260	2020	-
Laboratory pH	pH	0.1	7.7	7.4	7.4	7.4	6.5 - 8.5
Total Alkalinity	mg/L	5	390	437	422	420	-
Total Hardness	mg/L	-	873	1240	1100	1000	-
Total Dissolved Solids	mg/L	-	2330	1920	1740	1590	≤500
Major Ions							
Calcium	mg/L	1	178	261	206	199	-
Magnesium	mg/L	1	104	143	141	123	-
Potassium	mg/L	1	9	8	7	7	-
Sodium	mg/L	1	482	170	203	167	≤200
Carbonate	mg/L	5	<5	<5	<5	<5	-
Bicarbonate	mg/L	5	476	533	514	512	-
Hydroxide	mg/L	5	<5	<5	<5	<5	-
Chloride	mg/L	1	41	17	19	14	≤250
Sulfate	mg/L	0.5	1280	1060	908	828	≤500
Fluoride	mg/L	0.2	<0.2	0.2	<0.2	<0.2	1.5
Nitrate	mg/L	0.1	0.5	0.5	0.4	0.4	45
Iron	mg/L	0.005	1.41	3.48	7.99	2.2	≤0.3
Manganese	mg/L	0.001	0.320	0.786	2.60	1.01	≤0.05

Table 7.2
Historic Water Quality
Hydrogeologic Investigation - Wynyard Formation Aquifer

File R3216

Parameter	Units	Water Chemistry Test Results									
Piezometer No.		NE16-20-32-16-W2	NW4-8-32-17-W2	NW4-24-32-16-W2	NW13-16-32-17-W2	NW15-29-34-16-W2	SE2-15-30-10-W2	NW13-10-32-18-W2	NW3-1-33-19-W2	SW26-32-16-W2	SW7-17-34-16-W2
Depth (m)		90	79	90	66	45	21	83	72	51	16
Date Sampled	y/m/d	85/04/22	81/09/16	81/09/16	85/04/22	85/04/22	70/02/20			66/12/14	70/03/06
Phys. Prop.											
Conductivity	µs/cm	1890	2170	607	2400	2820	1480	2290	2800	1380	2650
Major Ions											
Calcium	mg/L	177	255	89	188	167	170	258	190	192	162
Magnesium	mg/L	112	131	29	153	114	99	139	96	65	125
Sodium	mg/L	122	133	7.1	200	370	40	152	406	36	330
Bicarbonate	mg/L	651	581	323	608	556	663	587	425	503	380
Chloride	mg/L	12	16	7	25	76	3	24	88	9.1	167
Sulfate	mg/L	646	932	86	1020	1150	370	1010	1280	402	1070

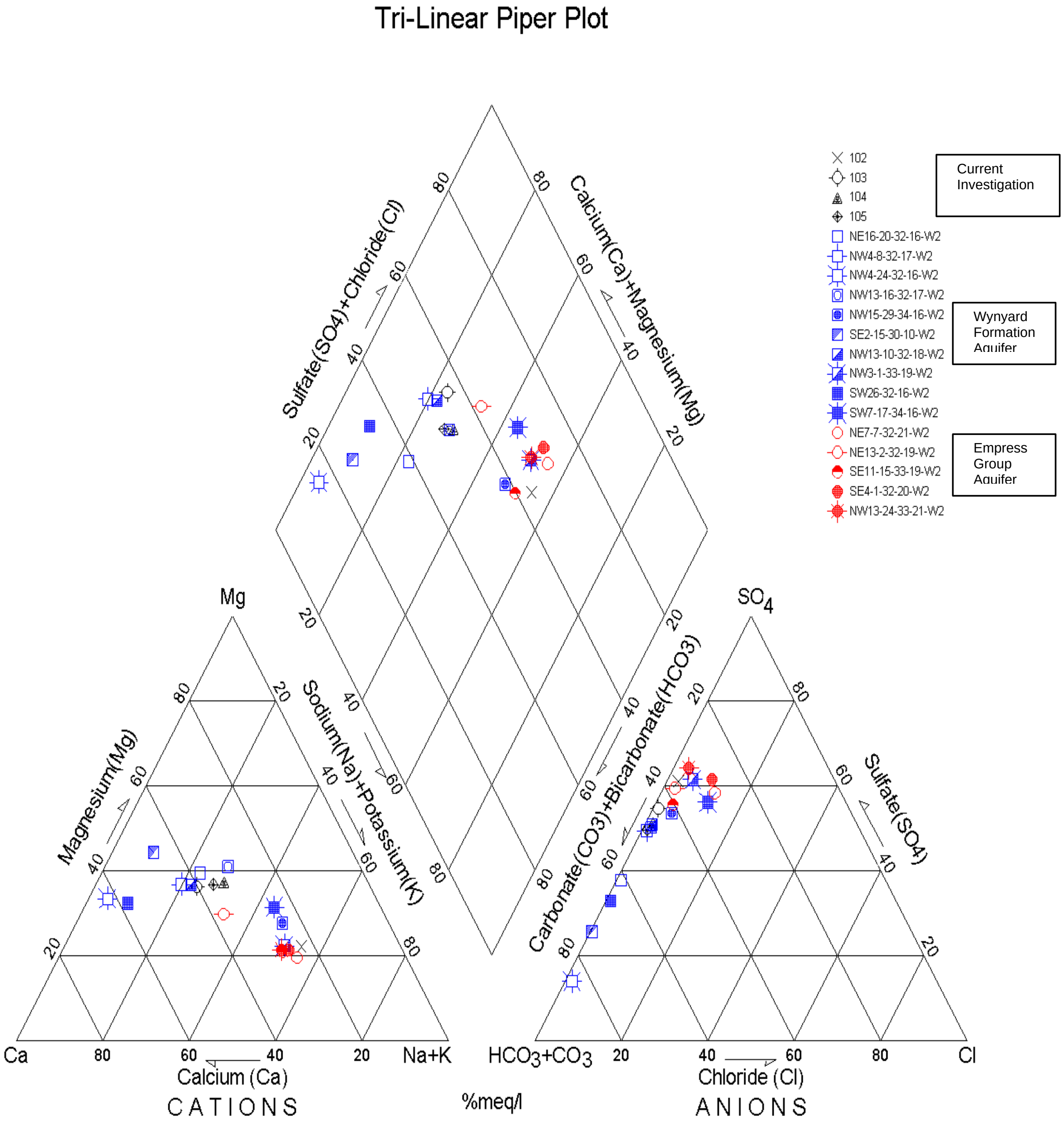
Table 7.3

File R3216

Historic Water Quality

Hydrogeologic Investigation - Empress Group Aquifers

Parameter	Units	Water Chemistry Test Results				
Stratum		Lower Empress	Upper Empress	Upper Empress	Upper Empress	Upper Empress
Piezometer No.		NE7-7-32-21-W2	NE13-2-32-19-W2	SE11-15-33-19-W2	SE4-1-32-20-W2	NW13-24-33-21-W2
Depth (m)		106	87	87	84	83
Date Sampled	y/m/d	6/29/71				
Physical Properties						
Conductivity	µs/cm	3450	2900	2760	2850	2960
Laboratory pH	pH	7.95	7.15	7.86	7.47	7.51
Total Alkalinity	mg/L	351	470	422	343	397
Total Hardness	mg/L	921	1340	828	1050	1000
Total Dissolved Solids	us/cm	2846	2812	2400	2948	2900
Major Ions						
Calcium	mg/L	208	298	190	234	228
Magnesium	mg/L	98	145	87	115	106
Sodium	mg/L	510	295	392	526	467
Potassium	mg/L	17	14.0	9.6	10.0	10
Iron	mg/L	0.3	n/d	8.4	3.30	3.8
Manganese	mg/L	n/a	n/d	0.15	0.31	0.26
Fluoride	mg/L	0.08	n/d	0.12	0.20	0.09
Nitrate	mg/L	1	nil	1.6	1.6	6.6
Chloride	mg/L	215	47	62	178	62
Bicarbonate	mg/L	428	573	515	419	484
Sulfate	mg/L	1370	1440	1140	1460	1540



Comparison of Historical Water Chemistry Data from the Wynyard Formation and Empress Group to Piezometers in Current Investigation.

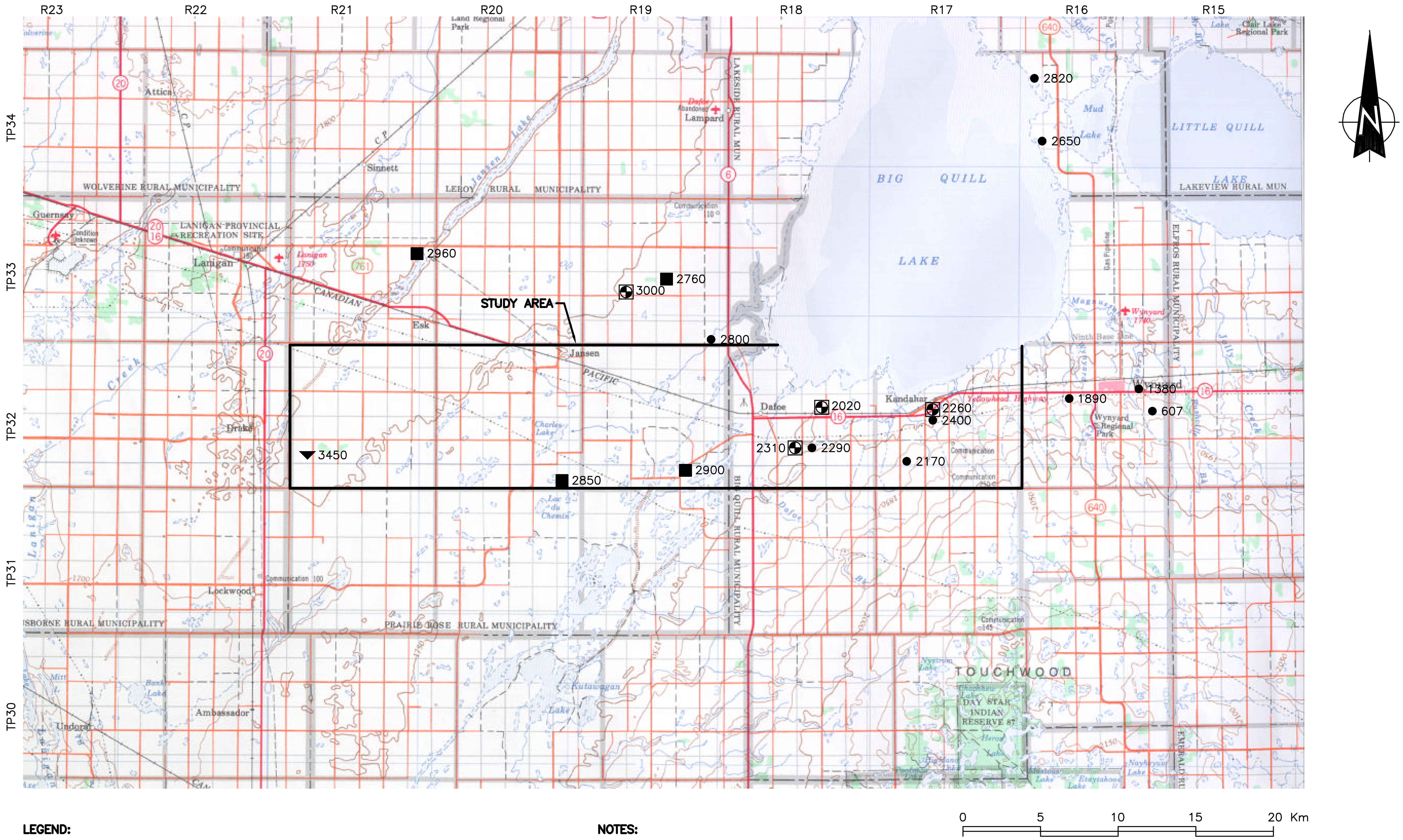
CLIFTON ASSOCIATES LTD. PROJECT NO: R3216 FIGURE NO: 7.1

as the sodium increases and a slight increase in chloride as the bicarbonate decreases. Groundwater samples from piezometers 103, 104 and 105 all plot within the field defined by the Wynyard Formation water while the groundwater sample from piezometer 102 plots within the field defined by Empress Group water. Geologically, all four samples have been interpreted to have been obtained from the Wynyard Formation Aquifer. The groundwater sample from piezometer 102 is anomalous considering the geologic interpretation; however, piezometer 102 is located on a narrow spine of Wynyard Formation that is surrounded by Empress Group Aquifer (see Drawing No. R3216-10) and it is therefore interpreted that groundwater chemistry at this location is more controlled by the Empress Group because it is surrounded by Empress Group groundwater to the north, south and west.

Total dissolved solids and conductivity values also provide an indication of water quality variations within the Wynyard Formation Aquifer, Upper Empress Group Aquifer and Lower Empress Group Aquifer. The historic data for conductivity is more complete than that for TDS; therefore, conductivity data has been used to show the areal variation in water quality across the study area. Figure 7.2 shows the sample locations and associated conductivity (µS/cm) from the current investigation and the historic water chemistry samples. The conductivity increases westward across the study area. This correlates with the good groundwater quality of the Wynyard Formation Aquifer on the east side, the intermediate to poor groundwater quality through the Upper Empress Group Aquifer in Ranges 19 and 20; and the highest conductivity (poor groundwater quality) sample from the Lower Empress Group (NE7-7-32-21W2M). The high conductivity is due to higher sodium and chloride concentrations than other samples as shown in Table 7.3.

8.0 Discussion

The geologic compilation of the farm well records, SRC test holes and the new information provided by TH101 to TH105 has provided a detailed geologic interpretation that has delineated a clay shale topographic high which forms an east-west trending ridge through the study area. This ridge has controlled both the erosion of the Wynyard Formation and the thickness and facies variation in the Empress Group. The contact between the Wynyard Formation and the Pierre Shale is disconformable and was developed prior to erosion of the Hatfield Valley; therefore, the base of the Wynyard Formation is nearly flat lying and the elevation ranges from 450 m to 470 m. Where the clay shale surface is lower than ± 450 m, the Wynyard Formation has been eroded during the pre-glacial formation of the Hatfield Valley. This criteria has been used to aid in interpretation of the area and it provides a useful



LEGEND:

CONDUCTIVITY (μS/cm) IN LOWER EMPRESS GROUP AQUIFERS	▼ 3450
CONDUCTIVITY (μS/cm) IN UPPER EMPRESS GROUP AQUIFERS	■ 2760
CONDUCTIVITY (μS/cm) IN WYNYARD FORMATION AQUIFERS	● 2290
CONDUCTIVITY (μS/cm) IN AQUIFERS TESTED IN THE CURRENT INVESTIGATION	⊕ 3000

NOTES:

1. DRAWING DEVELOPED FROM NTS MAP 72P.

CONDUCTIVITY OF GROUNDWATER SAMPLES
FROM THE WYNYARD REGION

FIGURE 7.2

R3216/FIGURE 7.2.DWG

means of separating the Upper Empress Group and Lower Wynyard Formation stratigraphic units. Sand deposits lying below this elevation have been assigned to the Upper Empress Group sediments.

The geologic compilation has also differentiated Upper and Lower Wynyard Formation units and Upper and Lower Empress Group units in order to provide a more detailed interpretation of the geology. These stratigraphic subdivisions have been informally adopted for this report after discussion with SRC personnel (Simpson, pers. com.)[3]. The interpretation provided by SRC covers the entire 72P map sheet whereas the present investigation covers only 5 townships, thus a more detailed interpretation is possible.

The hydrogeologic compilation has indicated that there are several high yield wells within the Wynyard Formation Aquifer on Ranges 17 and 18. The potential for developing high yield wells in this area is considered very good. Interference with existing users is a consideration and the areas around piezometers 103 and 105 are removed several kilometres from potential competing users. As indicated in Section 6.0, yields in excess of 500 Igpm are considered possible in this area, radial drawdowns of up to 9 m are predicted 10 km away if a high yield well is developed. These predicted drawdowns are based on limited information, no test wells or pump tests have been completed. Completion of a test well is recommended to provide verification of the aquifer parameters so that more reliable estimates of well yield, well spacing and distance drawdown relationships can be established.

Hydrogeologic setting in the western portion of the study area (Ranges 19 to 21) is not as well defined. Test Hole Nos. TH101 and TH102, completed in this area, provided information regarding the limits of the Upper Empress Group Aquifer, but did not provide information about the yield potential. Test Hole No. TH101 was completed in an area where the Upper Empress Group has been eroded and TH102 was completed in an area where a spine of Lower Wynyard Formation protrudes to the west. Well yield potential for the Upper Empress Group Aquifer has been estimated from existing information. Due to lower population density and fewer wells in this area, there are fewer well records and there is a need for further definition of the hydrogeology in this area.

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[3] SRC acknowledges the presence of upper and lower stratigraphic sequences within the Empress Group sediments and the Wynyard Formation; however, due to the broad regional correlations that are provided in SRC reports these subdivisions are not used.

Historic water chemistry compiled for the area indicates that the Wynyard Formation Aquifer water is calcium-magnesium bicarbonate type while the Upper Empress Group Aquifer is sodium sulphate type. Overall, the Wynyard Formation Aquifer has lower TDS, lower sulphate concentrations which make this water more potable than the Empress Group Aquifer.

9.0 Conclusions and Recommendations

The following conclusions can be drawn from the investigations:

- The Wynyard Formation Aquifer has proven high yield wells within the study area.
- The depth, thickness, water quality and estimated aquifer properties suggest very good development potential within the Wynyard Formation Aquifer in the vicinity of piezometers 103 and 105. Well yields in the order of 500 Igpm are estimated to be feasible in this area.
- Piezometers 103 and 105 are located away from other high yield or high demand users in the area.
- Within the Upper Empress Group Aquifer, there are three locations where thick, coarse sand and gravel deposits have been noted either in SRC test holes or farm well records. These are (1) SRC test hole at SE11-5-33-20W2, (2) SRC test hole at NE13-2-32-19W2, (3) Holfeld well at NW15-33-19W2.
- Within the Lower Empress Group Aquifer, there are several areas where well development may be possible, but due to excessive depth, low aquifer thickness, absence of the aquifer or potentially poor aquifer hydraulic conductivity well development is not recommended. These include; (1) Range 21 in Townships 31 to 33, (2) The southern quarter of Ranges 19 and 20 in Township 32.
- Water quality within the Upper and Lower Empress Group Aquifers is typically not as good as in the Wynyard Formation Aquifer. The Upper Empress Aquifer typically has higher TDS and sulfate concentrations than the Wynyard Formation Aquifer. The Lower Empress Group Aquifer typically has high sodium and chloride concentrations in addition to sulphate.

The following recommendations are provided for consideration of future developments in the study area.

- The area in the vicinity of piezometers 103 and 105 offers very good development potential at a relatively shallow depth, good quality and a reasonable separation distance from existing high demand users. Well development is recommended with 8 m of screen covering the interval from 78 m to 86 m. The observation well is in place, if development is being considered in the near future PFRA should be notified and responsibility for the observation well could be transferred to the developer.

- Test holes and piezometers should be completed in the vicinity of the following sites to get additional information regarding development potential in the Upper Empress Group Aquifer: (1) SE11-5-33-20W2, (2) NE13-2-32-19W2, (3) NW15-33-19W2.

- Abandonment of piezometers 102 and 104 are recommended unless municipal governments are willing to take over the responsibility for them. Piezometers 103 and 105 could be kept operational if well development is being considered in the area, but if no development is likely to occur in the near future these piezometers should also be properly abandoned.

10.0 Closure

The preceding report provides a hydrogeological framework for future development of groundwater resources in the area. This assessment has been made from existing information and five new test holes with piezometers. Clifton Associates Ltd. bears no responsibility for the accuracy of information obtained from third and fourth party sources such as water well records and test hole records.

The bore holes and associated laboratory testing indicate subsurface and groundwater conditions only at the specific locations and times investigated, only to the depth penetrated and only for the water quality parameters tested. The subsurface conditions may vary between the bore holes and with time.

Clifton Associates Ltd.

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Engineers and Geoscientists of Saskatchewan
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Symbols & Terms

Soil Descriptive Terms

A soil description for geotechnical applications includes a description of the following properties:

- texture
- color, oxidation
- consistency and condition
- primary and secondary structure

Texture

The soil texture refers to the size, size distribution and shape of the individual soil particles which comprise the soil. The Unified Soil Classification System (ASTM D2487-00) is a quantitative method of describing the soil texture. The basis of this system is presented overleaf. The following terms are commonly used to describe the soil texture.

Particle Size
(ASTM D2487-00)

Boulder	300 mm plus
Cobble	75 - 300 mm
Gravel	4.75 - 75 mm
Coarse	19 - 75 mm
Fine	4.75 - 19 mm
Sand	0.075 - 4.75 mm
Coarse	2 - 4.75 mm
Medium	0.425 - 2 mm
Fine	0.075 - 0.425 mm
Silt and Clay	Smaller than 0.075 mm

Relative Proportions
(CFEM, 3rd Ed., 1992)

Trace	1 - 10 %
Some	10 - 20 %
Gravelly, sandy, silty, clayey, etc.	20 - 35 %
And	>35 %
Gravel, Sand, Silt, Clay	>35 % and main fraction

Gradation

Well Graded	Having a wide range of grain sizes and substantial amount of all intermediate sizes.
Uniform or Poorly Graded	Possessing particles of predominantly one size.
Gap Graded	Possessing particles of two distinct sizes.

Particle Shape

Angular	Sharp edges and relatively plane sides with unpolished surfaces.
Subangular	Similar to 'angular' but have rounded edges.
Subrounded	Well-rounded corners and edges, nearly plane sides.
Rounded	No edges and smoothly curved sides.

Also may be flat, elongated or both.

The term “TILL” may be used as a textural term to describe a soil which has been deposited by glaciers and contains an unsorted, wide range of particle sizes.

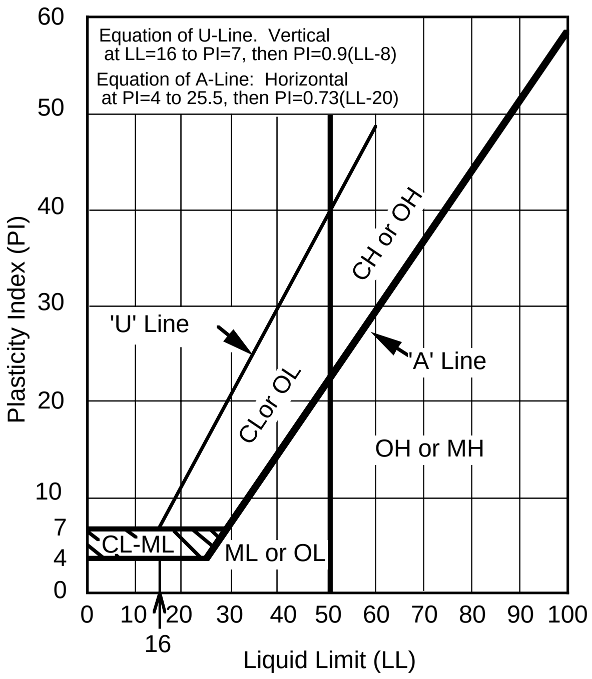
Color And Oxidation

The soil color at its natural moisture content is described by common colors and, quantitatively, in terms of the Munsell color notation; (eg. 5Y 3/1). The notation combines three variables, hue, value and chroma to describe the soil color. The hue indicates its relation to red, yellow, green, blue and purple. The value indicates its lightness. The chroma indicates its strength of departure from a neutral of the same lightness.

Departure of the soil color from a neutral color indicates the soil has been oxidized. Oxidation of a soil occurs in a oxygen rich environment where most commonly metallic iron, oxidizes and turns a neutral colored soil 'rusty' or reddish brown. Oxidized manganese gives a purplish tinge to the soil. Oxidation may occur throughout the entire soil mass or on fracture/joint/fissure surfaces.

Classification of Soils for Engineering Purposes

ASTM Designation D 2487-00 (Unified Soil Classification System)

Major divisions			Group Symbols	Typical names	Classification criteria			
Coarse-grained soils More than 50% retained on No. 200 sieve* (>0.075 mm)	Gravels More than 50% of coarse fraction retained on No. 4 sieve(≥4.75 mm)	Clean gravels <5% fines	GW	Well-graded gravel	If ≥ 15% sand add "with sand" to group name	Classification on basis of percentage of fines Less than 5% pass No. 200 sieve.......GW, GP, SW, SP More than 12% pass No. 200 sieve.....GM, GC, SM, SC 5 to 12% pass No. 200 sieve.......Borderline classifications requiring use of dual symbols	$C_u = \frac{D_{60}}{D_{10}} \geq 4$; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3	
			GP	Poorly graded gravel			Not meeting either C_u or C_c criteria for GW	
		Gravels with fines >12% fines	GM	Silty gravel			Atterberg limits below "A" line or PI less than 4	Atterberg limits plotting in hatched area are borderline classifications requiring use of dual symbols If fines are organic add "with orgnic fines" to group name
			GC	Clayey gravel			Atterberg limits on or above "A" line and PI > 7	
	Sands 50% or more of coarse fraction passes No. 4 sieve(<4.75 mm)	Clean sands <5% fines	SW	Well-graded sand	If ≥ 15% gravel add "with gravel" to group name		$C_u = \frac{D_{60}}{D_{10}} \geq 6$; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3	
			SP	Poorly graded sand			Not meeting either C_u or C_c criteria for SW	
		Sands with fines >12% fines	SM	Silty sand			Atterberg limits below "A" line or PI less than 4	Atterberg limits plotting in hatched area are borderline classifications requiring use of dual symbols If fines are organic add "with orgnic fines" to group name
			SC	Clayey sand			Atterberg limits on or above "A" line and PI > 7	
Fine-grained soils 50% or more passes No. 200 sieve* (≤0.075 mm)	Silts and Clays Liquid limit <50%	Inorganic	ML	Silt	If 15 to 29% coarse-grained, add "with sand" or "with gravel" as appropriate If > 30% coarse-grained , add "sandy" or "gravelly" as appropriate Class as organic when oven dried liquid limit is < 75% of undried liquid limit	Plasticity Chart  		
			CL	Lean Clay -low plasticity				
		Organic	OL	Organic clay or silt (Clay plots above 'A' Line)				
	Silts and Clays Liquid limit ≥50%	Inorganic	MH	Elastic silt				
			CH	Fat Clay -high plasticity				
		Organic	OH	Organic clay or silt (Clay plots above 'A' Line)				
	Highly organic soils		PT	Peat, muck and other highly organic soils				

*Based on the material passing the 3 in.(75 mm) sieve, if field samples contain cobbles or boulders, add "with cobbles or boulders" to group name

Consistency And Condition

The consistency of a cohesive soil is a qualitative description of its resistance to deformation and can be correlated with the undrained shear strength of the soil. The condition of a coarse grained soil qualitatively describes the soil compactness and can be correlated with the standard penetration resistance (ASTM D1586-99).

Consistency Of Cohesive Soil (CFEM, 3rd Edit., 1992)

Consistency	Undrained Shear Strength (kPa) (CFEM, 3rd Edt., 1992)	Field Identification (ASTM D 2488-00)
Very Soft	<12	Thumb will penetrate soil more than 25 mm.
Soft	12-25	Thumb will penetrate soil about 25 mm.
Firm	25-50	Thumb will indent soil about 6 mm.
Stiff	50-100	Thumb will indent, but penetrate only with great effort (CFEM).
Very Stiff	100-200	Readily indented by thumbnail (CFEM).
Hard	>200	Thumb will not indent soil but readily indented with thumbnail.
Very Hard	N/A	Thumbnail will not indent soil.

Condition Of Coarse Grained Soil (CFEM, 3rd Edt., 1992)

Compactness Condition	SPT N - Index (Blows/300mm)
Very Loose	0 - 4
Loose	4 - 10
Compact	10 - 30
Dense	30 - 50
Very Dense	over 50

Moisture Conditions (ASTM D2488-00)

Description	Criteria
Dry	Absence of moisture, dusty, dry to touch
Moist	Damp but no visible water
Wet	Visible, free water, usually soil is below water table

Structure

The soil structure is the manner in which the individual soil particles are assembled to form the soil mass. The primary soil structure is the arrangement of soil particles as originally deposited. The secondary soil structure refers to any rearrangement of the soil such as deformation and cracking which has taken place since deposition.

Primary Soil Structure (Depositional)

A. Geometry

Stratum - A single sedimentary 'layer', greater than 10 mm in thickness, visibly separable from other strata by a discrete change in lithology and/or sharp physical break.
Homogeneous - Same color and appearance throughout.
Stratified - Consisting of a sequence of layers which are generally of contrasting texture or color.
Laminated - Stratified with layer thicknesses between 2 mm and 10 mm.
Thinly laminated - Stratified with layer thickness less than 2 mm.
Bedded - Stratified with layer thicknesses greater than 10 mm.
Very Thinly Bedded (Flaggy) - Stratified with layer thicknesses between 10 and 50 mm.
Thinly Bedded (Slabby) - Stratified with layer thicknesses between 50 and 600 mm.
Thickly Bedded (Blocky) - Stratified with layer thicknesses between 600 and 1200 mm.
Thick-Bedded (Massive) - Stratified with layer thicknesses greater than 1200 mm.
Lensed - Inclusions of small pockets of different soils, such as small lenses of sand material throughout a mass of clay.

B. Bedding Structures

Cross-bedding - Internal 'bedding' inclined to the general bedding plane.
Ripple-bedding - Internal 'wavy bedding'.
Graded-bedding - Internal gradation of grain size from coarse at base to finer at top of bed.
Horizontal bedded - Internal bedding is parallel and flat lying

Secondary Soil Structure (Post-Depositional)

A. Accretionary Structures

Includes nodules, concretions, crystal aggregates, veinlets, color banding and

Cementation - Chemically precipitated material, commonly calcite ($CaCO_3$), binds the grains of soil, usually sandstone. Described as weak, moderate, strong (ASTM D2488-00).
Salt Crystals - Groundwater flowing through the soil/rock often precipitates visible amounts of salts. Calcite ($CaCO_3$), glauber salts ($Na_2Ca(SO_4)_2$), and gypsum ($CaSO_4*2H_2O$) are common.

B. Fracture Structures

Fracture - A break or discontinuity in the soil or rock mass caused by stress exceeding the materials strength.
Joint - A fracture along which no displacement has occurred.
Fissure - A gapped fracture, which may open and close seasonally. Usually an extensive network of closely spaced fractures, giving the soil a 'nuggetty' structure.
Slickensides - Fractures in a clay that are slick and glossy in appearance, caused by shear movements.
Brecciated - Contains randomly oriented angular fragments in a finer mass, usually associated with shear displacements in soils.
Fault - A fracture or fracture zone along which there has been displacement.
Blocky - A cohesive soil that can be broken down into small angular lumps which resist further breakdown.

Symbols Used on Bore Hole Logs

Lithology Type

- ▤ CLAY
- ▥ SILT
- ▒ SAND
- ▒ GRAVEL
- ▩ COBBLES
- ▩ TILL-oxidized
- ▩ TILL-unoxidized
- ▒ PEAT
- ▩ TOPSOIL or ORGANIC SOIL
- ▒ COAL
- ▒ FILL (Undifferentiated)
- ▒ CONCRETE
- ■ ASPHALT
- ▤ CLAY SHALE
- ▤ SANDSTONE
- ▨ MUDSTONE
- ▒ BEDROCK (Undifferentiated)

Borehole Completion and Backfill Materials

- ■ Bentonite
- ▒ Concrete
- ▦ Cover
- ▩ Cuttings
- ▒ Grout
- ▒ Sand
- ▧ Slough
- □ Solid Pipe
- ▤ Slotted Pipe

Soil Sample Type

- ■ Thin Walled Tube
- ▩ Driven Spoon
- ▤ Disturbed
- ▥ Core (any type)
- ▨ No Recovery

Groundwater Symbols

▼ Piezometric elevation as determined by a piezometer installation

▽ Water levels measured in borings at the time and under the conditions noted

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Drawings

LEGEND:

E–LOG, GEOLOGIST LOG	⊖
E–LOG, DRILLER'S LOG	⊘
DRILLERS LOG ONLY	⦶
TEST HOLE LOCATION (2002)	◒
MONITOR WELL LOCATION (2002)	◈

NOTES:

1. DRAWING REFERENCED FROM NTS MAPS 72P/15, 72P/16, 72P/10 AND 72P/9.

0 0.5 1.0 2.0 4.0 Km

REV	DESCRIPTION	BY	APP	DATE

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CLIENT
PFRA

PROJECT
HATFIELD VALLEY AQUIFER
INVESTIGATION

TITLE
SITE LOCATION PLAN

DATE 02/02/15
APPD. BY
FILE NO. R3216001
SCALE 1:50000
DWN. BY LGB
DWG. NO. R3216–1

LEGEND:

E–LOG, GEOLOGIST LOG	⊖
E–LOG, DRILLER'S LOG	⊘
DRILLERS LOG ONLY	⦶
TEST HOLE LOCATION (2002)	◍
MONITOR WELL LOCATION (2002)	◈
POINT ELEVATION OF THE TOP OF PIERRE SHALE	⊖450.5
ELEVATION OF PIERRE SHALE (10m INTERVAL)	440

NOTES:

1. DRAWING REFERENCED FROM NTS MAPS 72P/15, 72P/16, 72P/10 AND 72P/9.

0 0.5 1.0 2.0 4.0 Km

REV	DESCRIPTION	BY	APP	DATE

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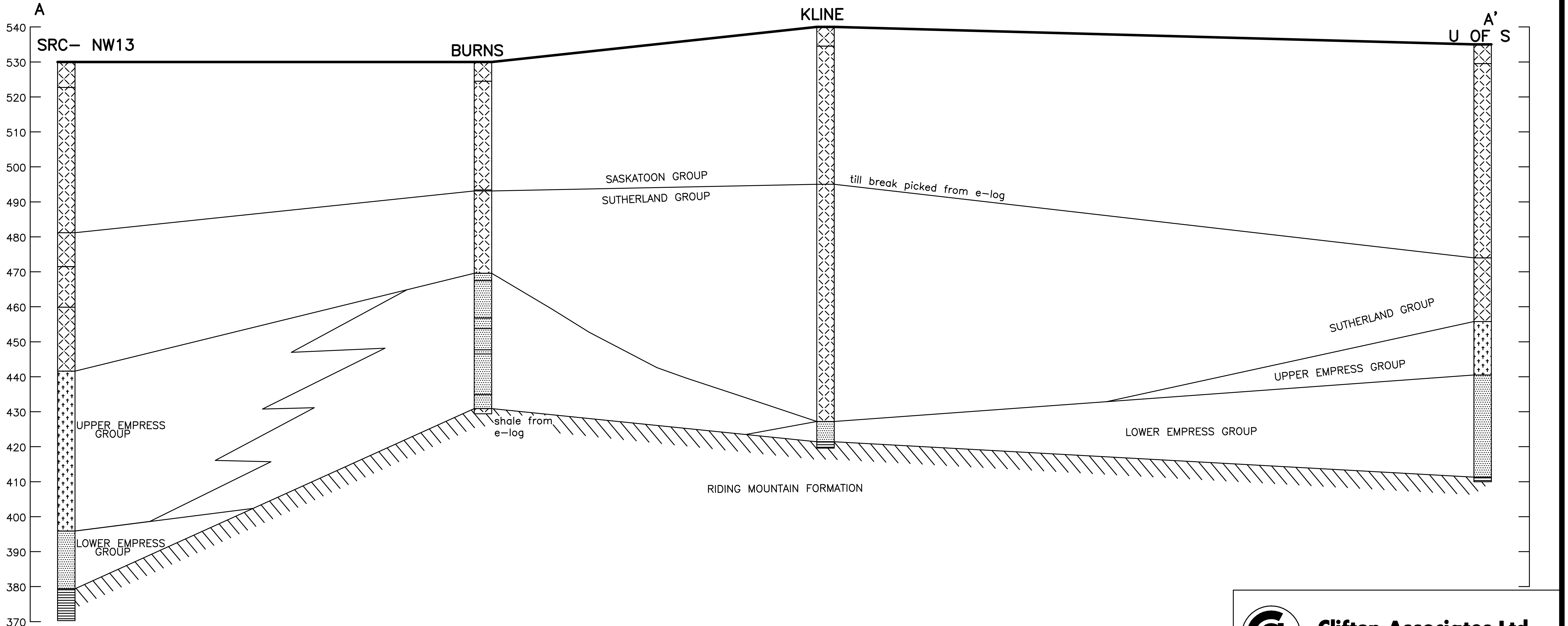
PFRA

PROJECT
HATFIELD VALLEY AQUIFER INVESTIGATION

TITLE
STRUCTURE CONTOUR –
TOP OF THE PIERRE SHALE

DATE 02/02/15	APPD. BY	FILE NO. R3216001
SCALE 1:50000	DWN. BY LGB	DWG. NO. R3216–2



STRATIGRAPHIC CROSS SECTION A–A'

SCALE: HORIZ 1:50000
VERT: 1:1000

THE BOUNDARIES BETWEEN SOIL STRATA HAVE BEEN ESTABLISHED ONLY AT BORE HOLE LOCATIONS. BETWEEN BORE HOLES THE BOUNDARIES ARE ASSUMED FROM GEOLOGICAL EVIDENCE AND MAY BE SUBJECT TO CONSIDERABLE ERROR.

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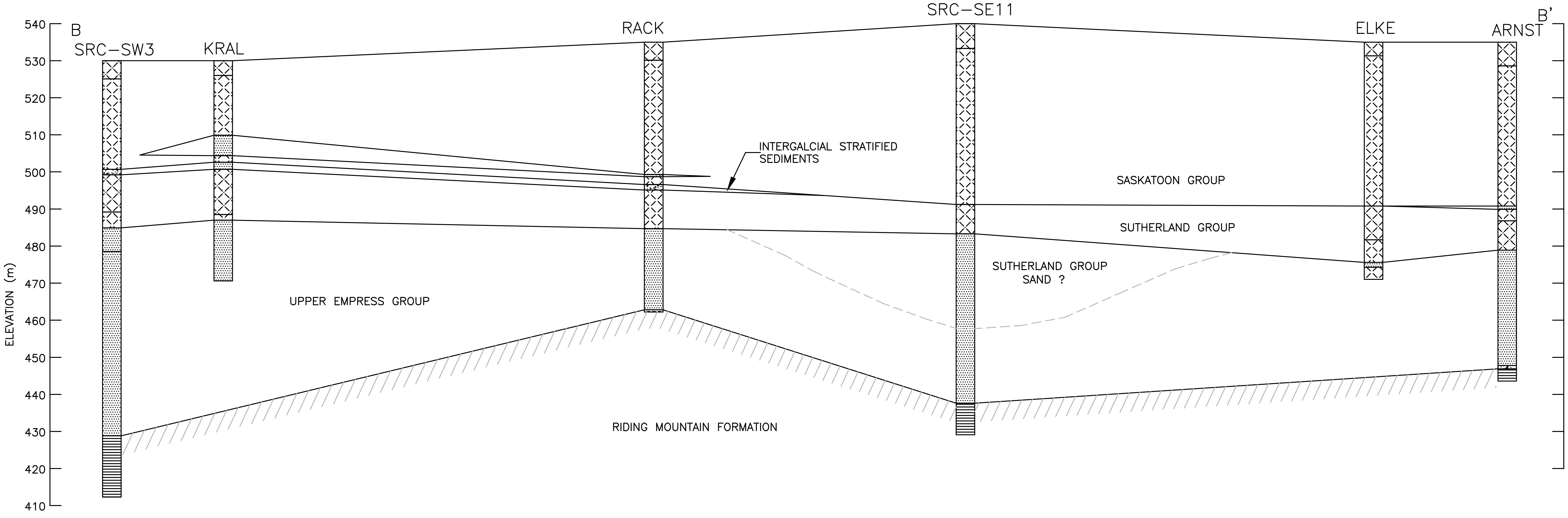
PROJECT
HATFIELD VALLEY AQUIFER INVESTIGATION

TITLE
STRATIGRAPHIC CROSS SECTION A–A'

DATE 02/02/20	APPD. BY	FILE NO. R3216003
SCALE AS NOTED	DWN. BY LGB	DWG. NO. R3216-3



STRATIGRAPHIC CROSS SECTION B–B'

SCALE: HORIZ 1:50000
VERT: 1:1000

THE BOUNDARIES BETWEEN SOIL STRATA HAVE BEEN ESTABLISHED ONLY AT BORE HOLE LOCATIONS. BETWEEN BORE HOLES THE BOUNDARIES ARE ASSUMED FROM GEOLOGICAL EVIDENCE AND MAY BE SUBJECT TO CONSIDERABLE ERROR.

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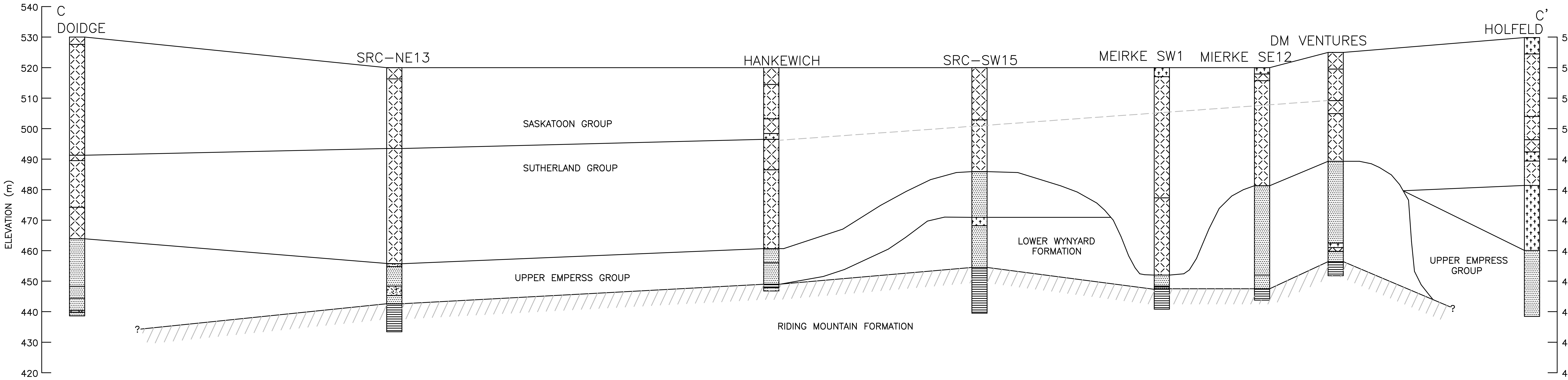
PROJECT
HATFIELD VALLEY AQUIFER INVESTIGATION

TITLE
STRATIGRAPHIC CROSS SECTION B–B'

DATE 02/02/20
APPD. BY
FILE NO. R3216004
SCALE AS NOTED
DWN. BY LGB
DWG. NO. R3216–4



STRATIGRAPHIC CROSS SECTION C–C'

SCALE: HORIZ 1:50000
VERT: 1:1000

THE BOUNDARIES BETWEEN SOIL STRATA HAVE BEEN ESTABLISHED ONLY AT BORE HOLE LOCATIONS. BETWEEN BORE HOLES THE BOUNDARIES ARE ASSUMED FROM GEOLOGICAL EVIDENCE AND MAY BE SUBJECT TO CONSIDERABLE ERROR.

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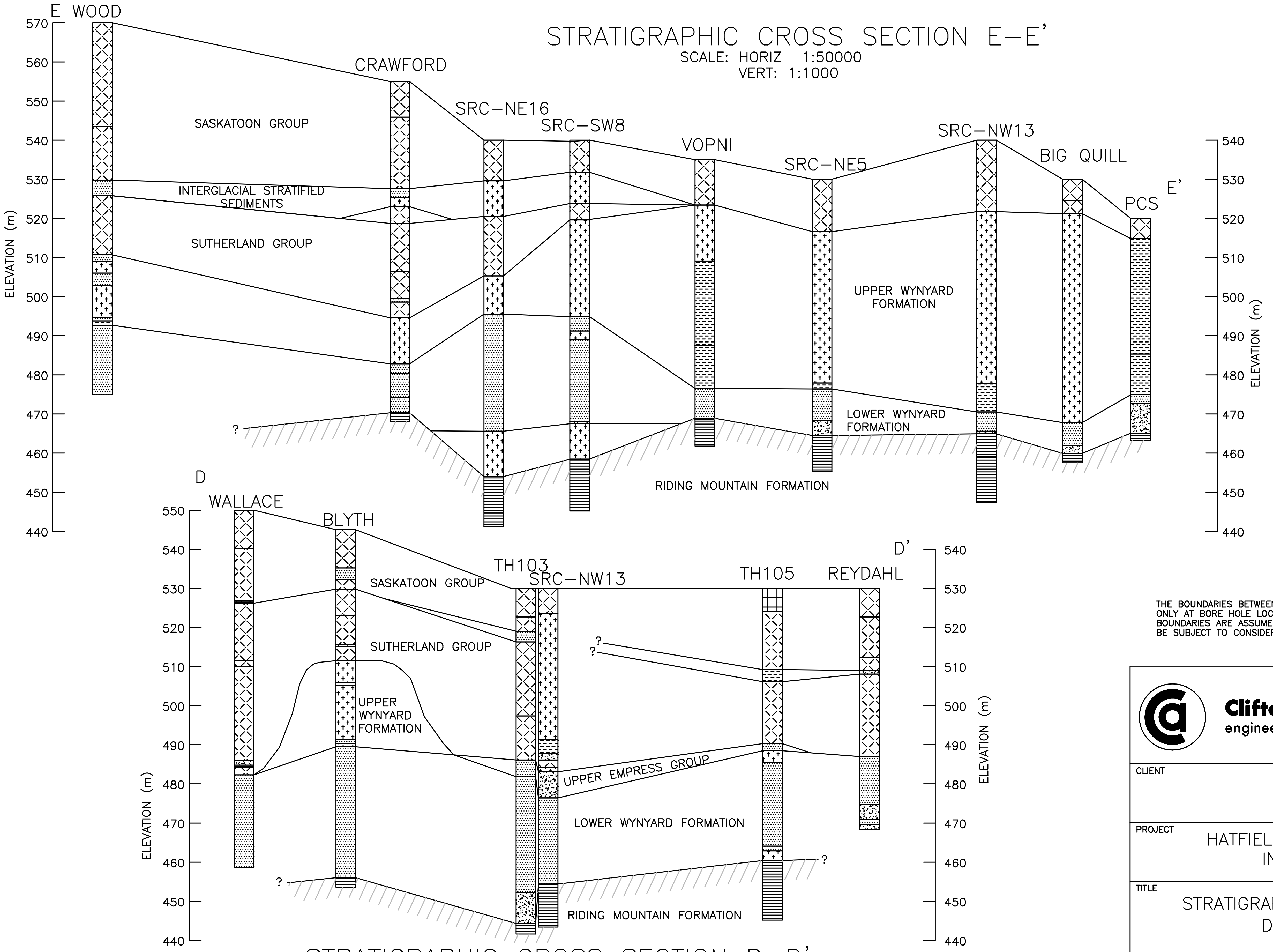
PROJECT
HATFIELD VALLEY AQUIFER INVESTIGATION

TITLE
STRATIGRAPHIC CROSS SECTION C–C'

DATE 02/02/20	APPD. BY	FILE NO. R3216005
SCALE AS NOTED	DWN. BY LGB	DWG. NO. R3216-5



STRATIGRAPHIC CROSS SECTION E–E'
SCALE: HORIZ 1:50000
VERT: 1:1000

STRATIGRAPHIC CROSS SECTION D–D'
SCALE: HORIZ 1:50000
VERT: 1:1000

THE BOUNDARIES BETWEEN SOIL STRATA HAVE BEEN ESTABLISHED ONLY AT BORE HOLE LOCATIONS. BETWEEN BORE HOLES THE BOUNDARIES ARE ASSUMED FROM GEOLOGICAL EVIDENCE AND MAY BE SUBJECT TO CONSIDERABLE ERROR.

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HATFIELD VALLEY AQUIFER INVESTIGATION

TITLE
STRATIGRAPHIC CROSS SECTION D–D' & E–E'

DATE	02/02/20	APPD. BY		FILE NO.	R3216006
SCALE	AS NOTED	DWN. BY	LGB	DWG. NO.	R3216-6

THE BOUNDARIES BETWEEN SOIL STRATA HAVE BEEN ESTABLISHED ONLY AT BORE HOLE LOCATIONS. BETWEEN BORE HOLES THE BOUNDARIES ARE ASSUMED FROM GEOLOGICAL EVIDENCE AND MAY BE SUBJECT TO CONSIDERABLE ERROR.

STRATIGRAPHIC CROSS SECTION F–F'

SCALE: HORIZ 1:50000
VERT: 1:1000

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TITLE
STRATIGRAPHIC CROSS SECTION F–F'

DATE 02/02/20	APPD. BY	FILE NO. R3216007
SCALE AS NOTED	DWN. BY LGB	DWG. NO. R3216–7

THE BOUNDARIES BETWEEN SOIL STRATA HAVE BEEN ESTABLISHED ONLY AT BORE HOLE LOCATIONS. BETWEEN BORE HOLES THE BOUNDARIES ARE ASSUMED FROM GEOLOGICAL EVIDENCE AND MAY BE SUBJECT TO CONSIDERABLE ERROR.

STRATIGRAPHIC CROSS SECTION G–G'
SCALE: HORIZ 1:50000
VERT: 1:1000

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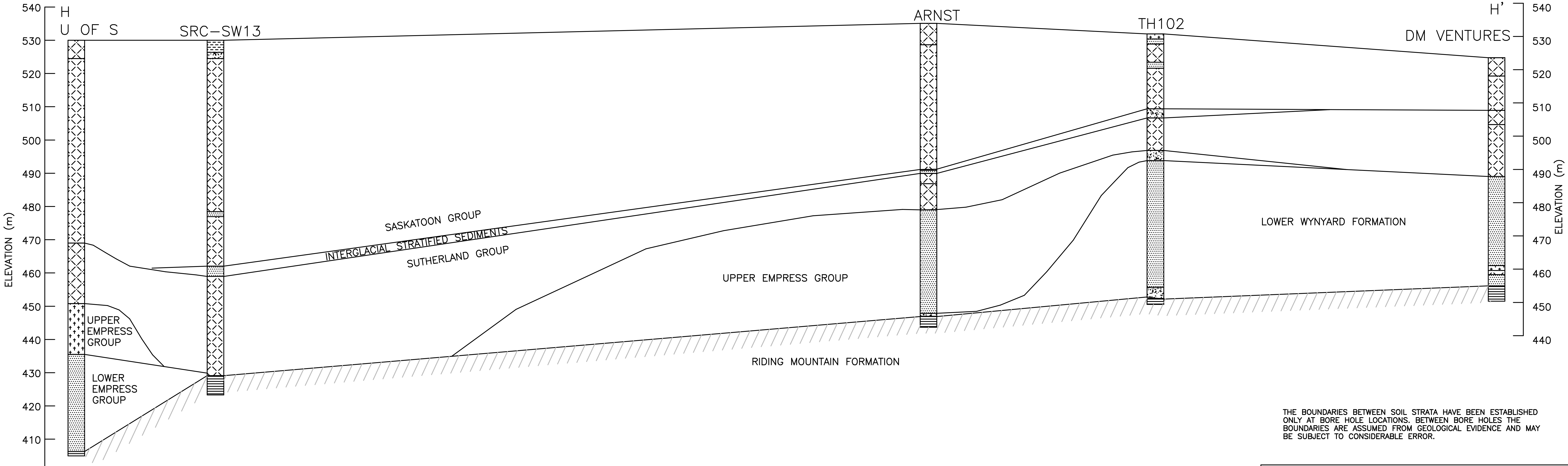
HATFIELD VALLEY AQUIFER
INVESTIGATION

TITLE
STRATIGRAPHIC CROSS SECTION
G–G'

DATE 02/02/20	APPD. BY	FILE NO. R3216008
SCALE AS NOTED	DWN. BY LGB	DWG. NO. R3216–8



THE BOUNDARIES BETWEEN SOIL STRATA HAVE BEEN ESTABLISHED ONLY AT BORE HOLE LOCATIONS. BETWEEN BORE HOLES THE BOUNDARIES ARE ASSUMED FROM GEOLOGICAL EVIDENCE AND MAY BE SUBJECT TO CONSIDERABLE ERROR.

STRATIGRAPHIC CROSS SECTION H–H'
SCALE: HORIZ 1:50000
VERT: 1:1000

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PROJECT	HATFIELD VALLEY AQUIFER INVESTIGATION
TITLE	STRATIGRAPHIC CROSS SECTION H–H'

DATE 02/02/20	APPD. BY	FILE NO. R3216009
SCALE AS NOTED	DWN. BY LGB	DWG. NO. R3216–9

LEGEND:

E–LOG, GEOLOGIST LOG	⊖
E–LOG, DRILLER'S LOG	⊘
DRILLERS LOG ONLY	⦶
TEST HOLE LOCATION (2002)	◉
MONITOR WELL LOCATION (2002)	◈
POINT THICKNESS OF WYNYARD FORMATION AQUIFER	⊖ 34
APPROXIMATE WESTERN LIMIT OF WYNYARD FORMATION AQUIFER	▨
ISOPACH CONTOUR OF WYNYARD FORMATION AQUIFER (10m INTERVAL)	—

NOTES:

1. DRAWING REFERENCED FROM NTS MAPS 72P/15, 72P/16, 72P/10 AND 72P/9.

0 0.5 1.0 2.0 4.0 Km

REV	DESCRIPTION	BY	APP	DATE

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HATFIELD VALLEY AQUIFER INVESTIGATION

TITLE
ISOPACH PLAN OF WYNYARD FORMATION AQUIFER

DATE 02/02/15	APPD. BY	FILE NO. R3216001
SCALE 1:50000	DWN. BY LGB	DWG. NO. R3216–10

LEGEND:

E–LOG, GEOLOGIST LOG	⊖
E–LOG, DRILLER'S LOG	⊘
DRILLERS LOG ONLY	⦶
TEST HOLE LOCATION (2002)	◍
MONITOR WELL LOCATION (2002)	◈
AREA WHERE NO EMPRESS GROUP IS PRESENT	▨
ISOPACH CONTOUR (10m INTERVAL)	40
AREA WHERE UPPER EMPRESS IS COMPRISED OF SILT (POOR AQUIFER) & OVERLIES LOWER EMPRESS AQUIFER	▨
POINT THICKNESS OF EMPRESS GROUP SEDIMENTS THICKNESS OF UPPER EMPRESS GROUP, AQUITARD THICKNESS OF LOWER EMPRESS GROUP AQUIFER	⊖ 62 46 16
POINT THICKNESS OF UPPER EMPRESS GROUP AQUIFER	⊖ 6

NOTES:

1. DRAWING REFERENCED FROM NTS MAPS 72P/15, 72P/16, 72P/10 AND 72P/9.

0 0.5 1.0 2.0 4.0 Km

REV	DESCRIPTION	BY	APP	DATE

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PROJECT
HATFIELD VALLEY AQUIFER INVESTIGATION

TITLE
ISOPACH PLAN OF EMPRESS GROUP AQUIFERS

DATE 02/02/15	APPD. BY	FILE NO. R3216001
SCALE 1:50000	DWN. BY LGB	DWG. NO. R3216–11

B	**Geological Logs, E-Logs and Piezometer Details**

Geoph Piez Log m CAL V2.ldf

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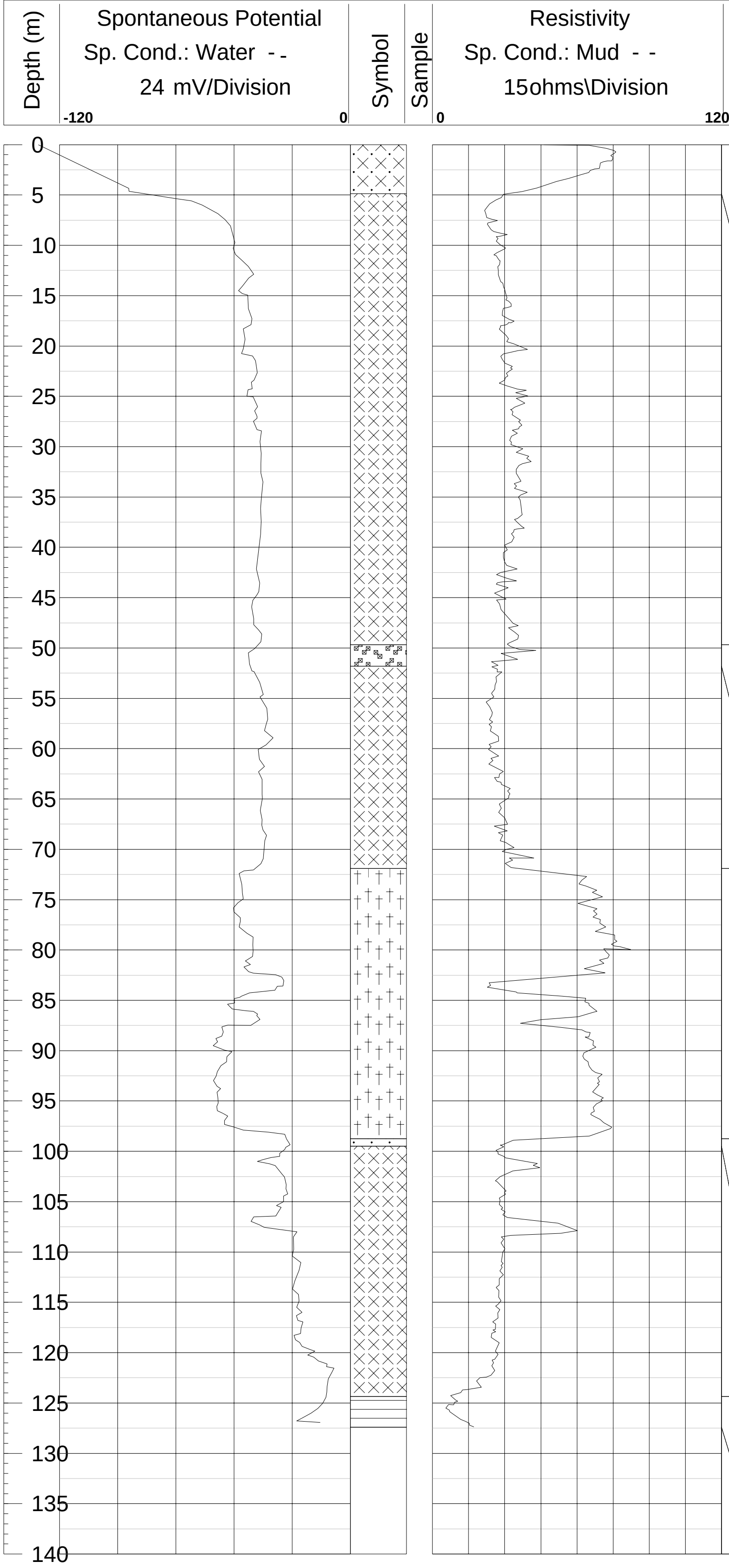
BORE HOLE LOG

Bore Hole: **101**
Page: 1 of 1

Client:	P.F.R.A.	Northing:	5738075.9- UTM	Contractor:	Hayter Drilling Ltd.
Project:	Wynyard Area Aquifer Investigation	Easting:	509516.6- UTM	Drill:	Unit #29
Location:	NW36-32-21 W2	Ground Elev.:	547.11 msl	Drilling Method:	Rotary
Project No.:	R3216	Date Drilled:	24 MARCH 2002	Logged by:	S.Gardner



Soil Description

TILL, OXIDIZED: Silty clay matrix, some sand and gravel, brown, firm, fissured, Fe

TILL, UNOXIDIZED: Grey, stiff, mostly massive, boulders @ 9 m and 31 m, sand and gravel seams from 24 m to 26.5 m and @ 44 m

COBBLES: Cobble or boulder lag, slow drilling

TILL, UNOXIDIZED: Grey, stiff, mostly massive, silty and soft below 70 m

SILT: little clay, interbedded with saturated sand and gravel seams, grey, unoxidized, no cohesion, clay stringer @ 84 m

TILL, OXIDIZED: Silty clay matrix, some sand, brown, stiff

TILL, UNOXIDIZED: Grey, stiff, mostly massive, sand seam @ 107 m

CLAY SHALE: H.P. Clay, little silt, dark grey, hard, non-calcareous

NOTES: No well installed

PIezometer Construction Details

No well installed

Geoph Piez Log m CAL V2.ldf

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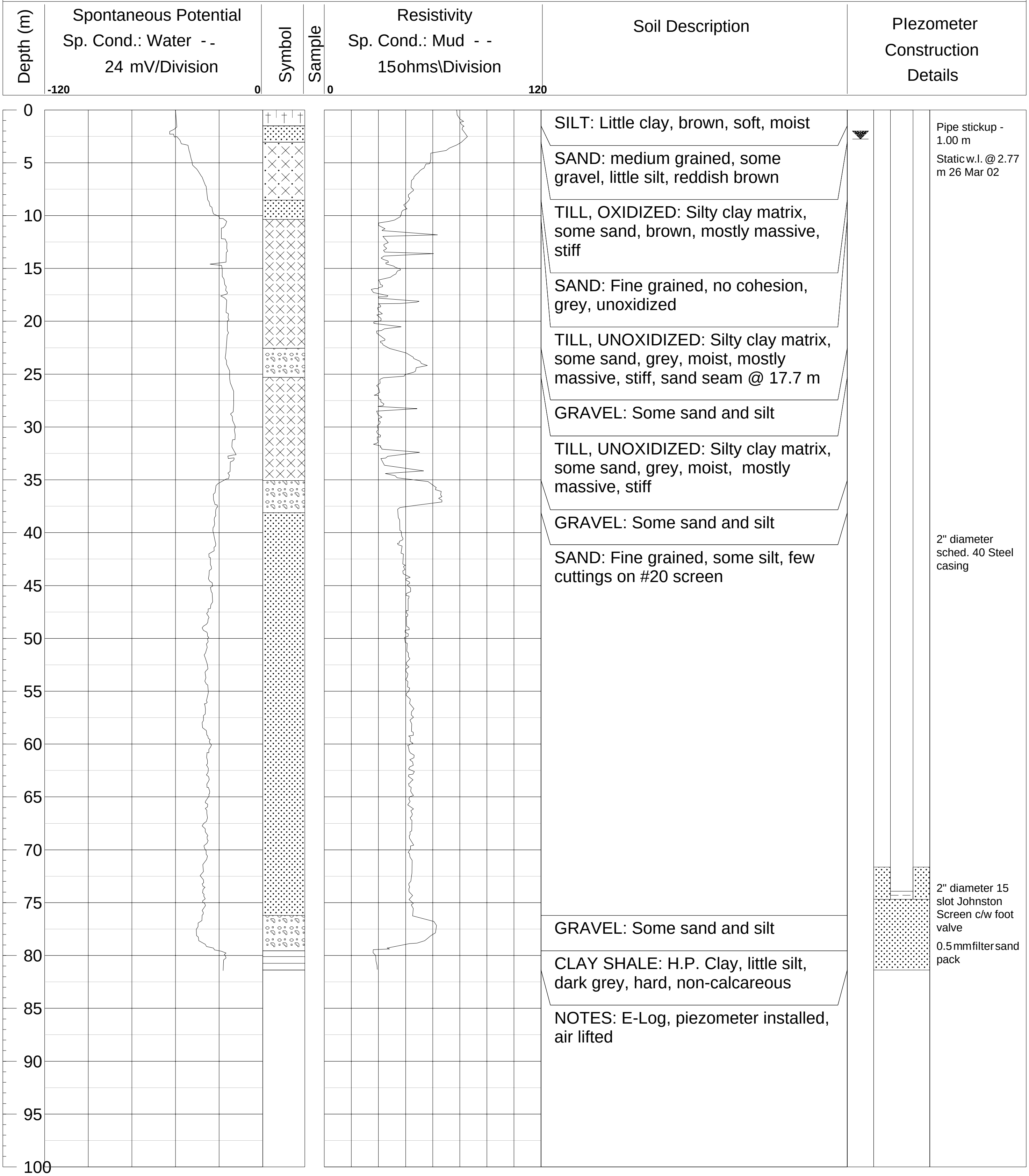
BORE HOLE LOG

Bore Hole: 102
Page: 1 of 1

Client: P.F.R.A.
Project: Wynyard Area Aquifer Investigation
Location: SE17 - 33 - 19 W2
Project No.: R3216
Northing: 5741530.9- UTM
Easting: 524027.7- UTM
Ground Elev.: 530.25 msl
Date Drilled: 23 MARCH 2002
Contractor: Hayter Drilling Ltd.
Drill: Unit #29
Drilling Method: Rotary
Logged by: C.Campbell



SILT: Little clay, brown, soft, moist

SAND: medium grained, some gravel, little silt, reddish brown

TILL, OXIDIZED: Silty clay matrix, some sand, brown, mostly massive, stiff

SAND: Fine grained, no cohesion, grey, unoxidized

TILL, UNOXIDIZED: Silty clay matrix, some sand, grey, moist, mostly massive, stiff, sand seam @ 17.7 m

GRAVEL: Some sand and silt

TILL, UNOXIDIZED: Silty clay matrix, some sand, grey, moist, mostly massive, stiff

GRAVEL: Some sand and silt

SAND: Fine grained, some silt, few cuttings on #20 screen

GRAVEL: Some sand and silt

CLAY SHALE: H.P. Clay, little silt, dark grey, hard, non-calcareous

NOTES: E-Log, piezometer installed, air lifted

Pipe stickup - 1.00 m

Static w.l. @ 2.77 m 26 Mar 02

2" diameter sched. 40 Steel casing

2" diameter 15 slot Johnston Screen c/w foot valve

0.5 mm filter sand pack

Geoph Piez Log m CAL V2.ldf

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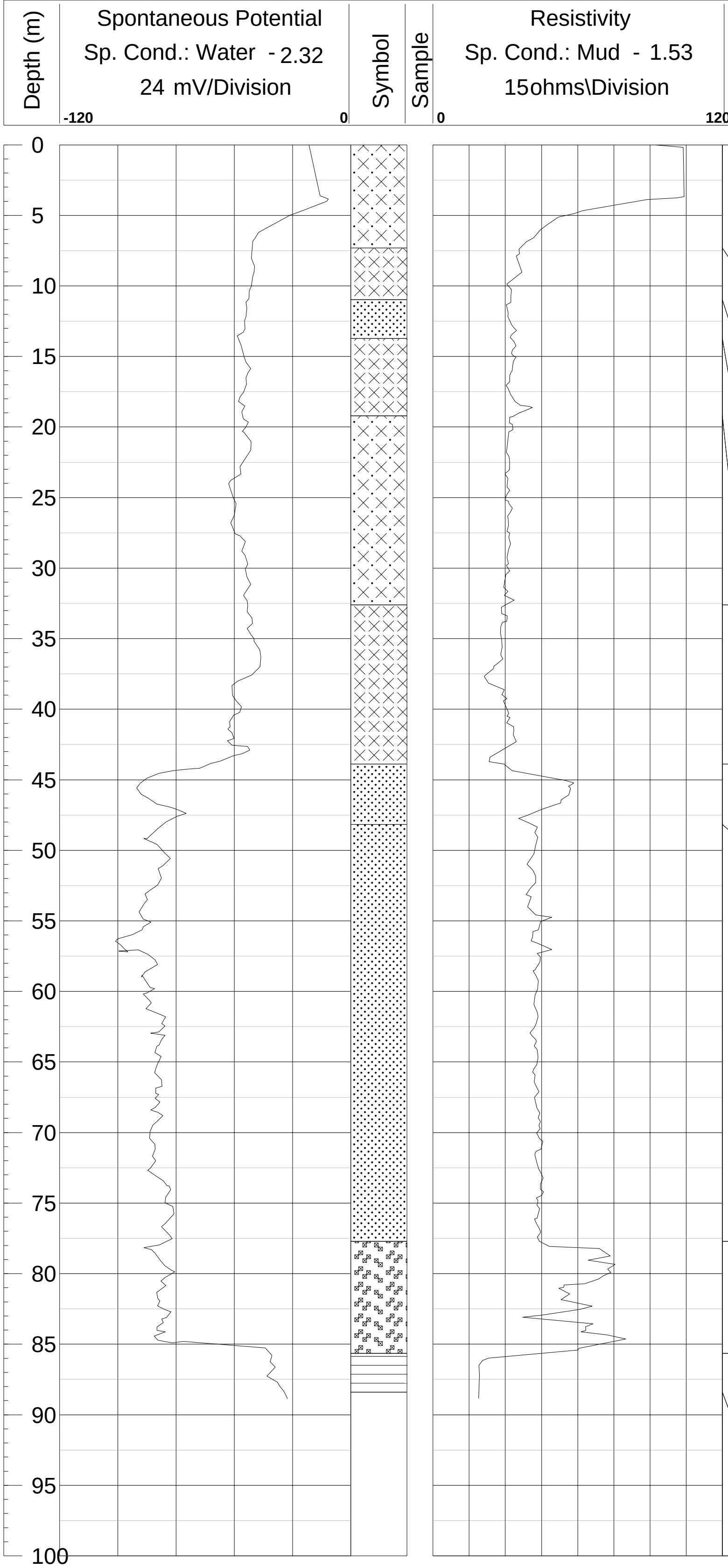
BORE HOLE LOG

Bore Hole: 103
Page: 1 of 1

Client:	P.F.R.A.	Northing:	5731721.7- UTM	Contractor:	Hayter Drilling Ltd.
Project:	Wynyard Area Aquifer Investigation	Easting:	535477.1- UTM	Drill:	Unit #29
Location:	NW09 - 32 - 18 W2	Ground Elev.:	531.40 msl	Drilling Method:	Rotary
Project No.:	R3216	Date Drilled:	23 MARCH 2002	Logged by:	S. Gardner



Soil Description

TILL, OXIDIZED: Silty clay matrix, some sand, brown, moist, stiff, blocky, Fe stains, boulders @ 0.5 m and 6.7 m

TILL, UNOXIDIZED: Grey, mostly massive, sand seams @10 m

SAND: Medium grained, no cohesion, oxidized

TILL, UNOXIDIZED: Clayey silt matrix, some sand, grey, moist, soft, mostly massive, sand seam @ 19 m, stiff below 28 m

TILL, OXIDIZED: Silty clay matrix, some sand, mottled, firm, fractured

TILL, UNOXIDIZED: Grey, mostly massive

SAND: Coarse grained, little gravel, sub-rounded, brown

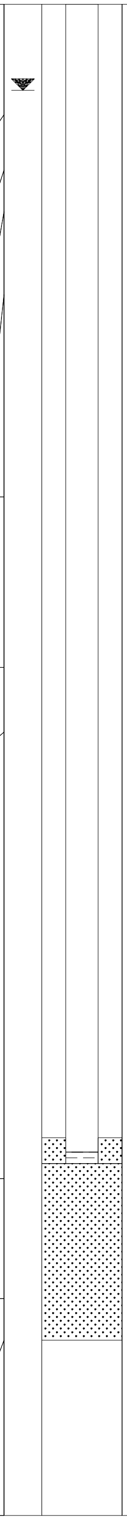
SAND: Fine grained, little silt, few cuttings on #20 screen

COBBLES: With boulders, coarse gravel, and sand, clay stringer @ 86 m

CLAY SHALE: H.P. Clay, little silt, dark grey, hard, non-calcareous

NOTES: E-Log, piezometer installed, air lifted

PIezometer Construction Details



Pipe stickup - 0.85 m

Static w.l. @ 5.70 m 26 Mar 02

2" diameter sched. 40 Steel casing

2" diameter 15 slot Johnston Screen c/w foot valve

0.5 mm filter sand pack

Geoph Piez Log m CAL V2.ldf

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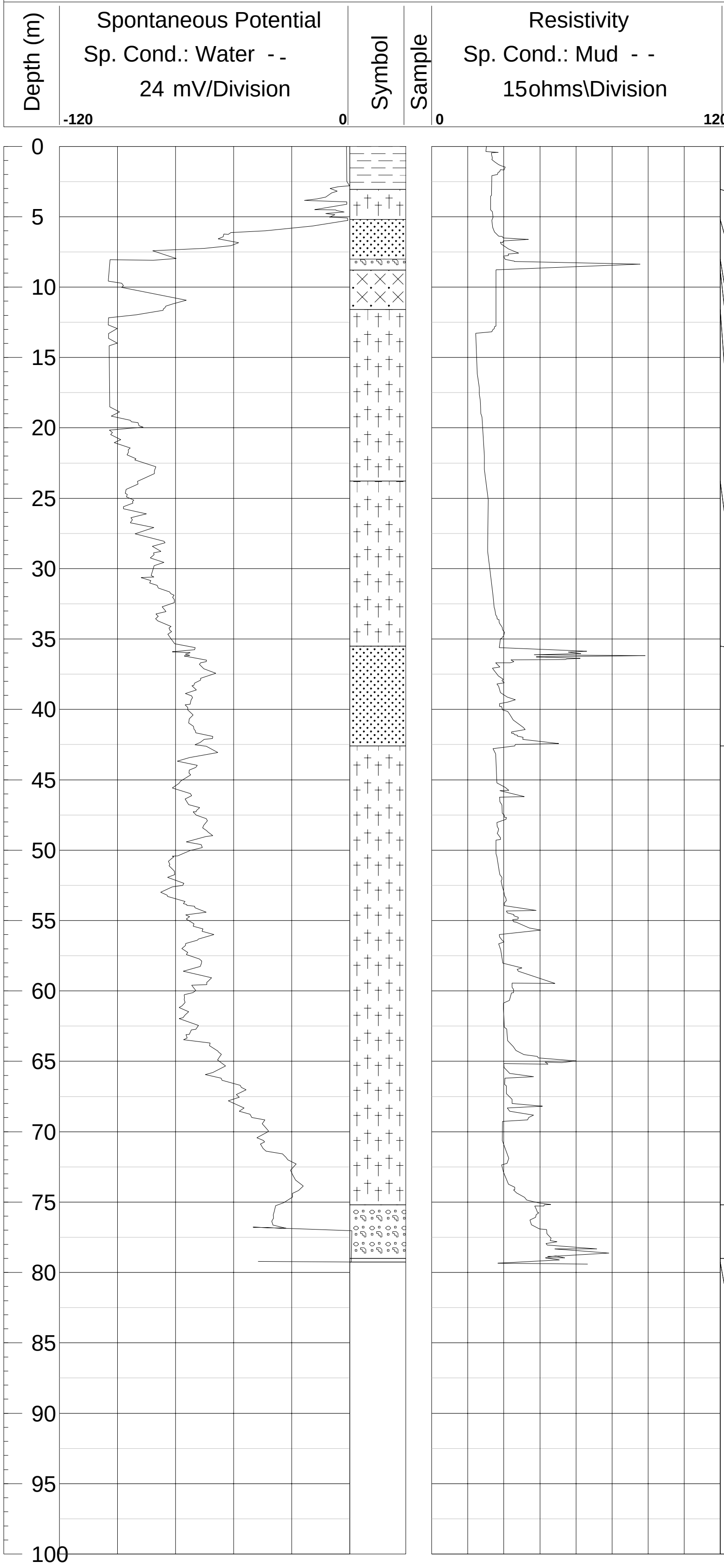
BORE HOLE LOG

Bore Hole: **104**
Page: 1 of 1

Client:	P.F.R.A.	Northing:	5734160.0- UTM	Contractor:	Hayter Drilling Ltd.
Project:	Wynyard Area Aquifer Investigation	Easting:	544354.0- UTM	Drill:	Unit #29
Location:	SE17 - 33 - 19 W2	Ground Elev.:	531.09 msl	Drilling Method:	Rotary
Project No.:	R3216	Date Drilled:	22 MARCH 2002	Logged by:	C.Campbell



Soil Description

CLAY: Little silt, brown, stiff, moist

SILT: Some clay, brown, oxidized, firm, moist

SAND: Well graded, some silt, brown, oxidized, no cohesion

GRAVEL: Fine grained, some sand

TILL, OXIDIZED: Silty clay matrix, some sand, brown, moist, stiff, fissured

SILT: Some sand, little clay, brown, oxidized, Fe, weathered shale @ 21m

SILT: Some sand, brown, oxidized, little cohesion

SAND: Coarse grained

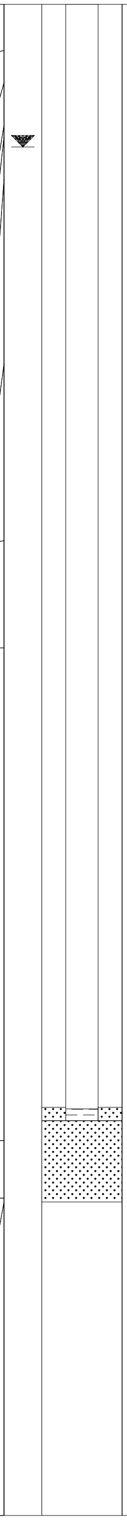
SILT: Some fine sand, little clay, grey, interbedded with oxidized sandy silt lenses

GRAVEL: Some sand and silt

CLAY SHALE: H.P. Clay, little silt, dark grey, hard, non-calcareous

NOTES: E-Log, piezometer installed, air lifted

PIezometer Construction Details



Pipe stickup - 0.91 m

Static w.l. @ 9.45 m 26 Mar 02

2" diameter sched. 40 Steel casing

2" diameter 15 slot Johnston Screen c/w foot valve

0.5 mm filter sand pack

Geoph Piez Log m CAL V2.ldf

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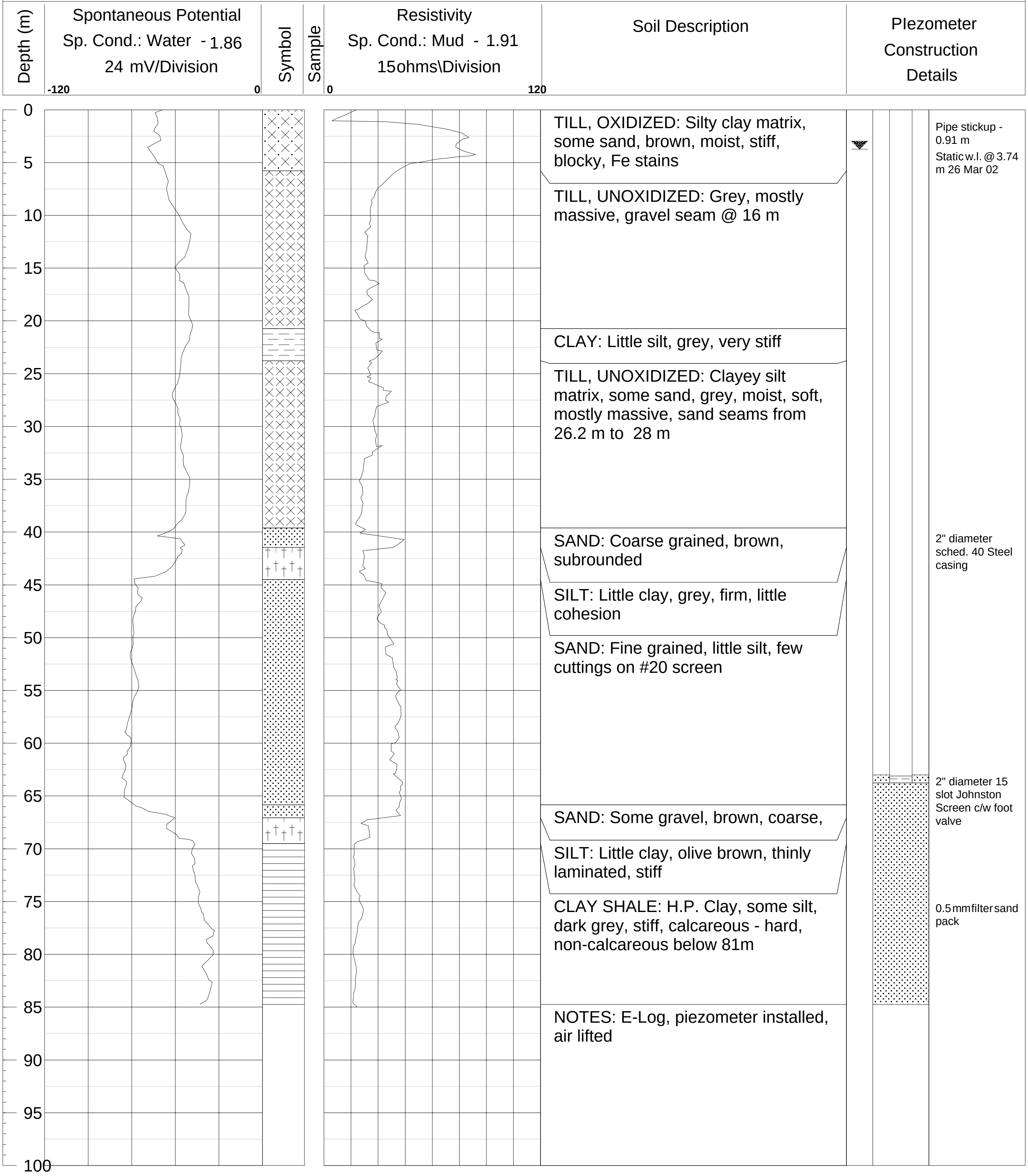
BORE HOLE LOG

Bore Hole: 105
Page: 1 of 1

Client: P.F.R.A.
Project: Wynyard Area Aquifer Investigation
Location: SE22 - 32 - 18 W2
Project No.: R3216
Northing: 5733654.4- UTM
Easting: 537101.6- UTM
Ground Elev.: 529.38. msl
Date Drilled: 22 MARCH 2002
Contractor: Hayter Drilling Ltd.
Drill: Unit #29
Drilling Method: Rotary
Logged by: S. Gardner



Soil Description

TILL, OXIDIZED: Silty clay matrix, some sand, brown, moist, stiff, blocky, Fe stains

TILL, UNOXIDIZED: Grey, mostly massive, gravel seam @ 16 m

CLAY: Little silt, grey, very stiff

TILL, UNOXIDIZED: Clayey silt matrix, some sand, grey, moist, soft, mostly massive, sand seams from 26.2 m to 28 m

SAND: Coarse grained, brown, subrounded

SILT: Little clay, grey, firm, little cohesion

SAND: Fine grained, little silt, few cuttings on #20 screen

SAND: Some gravel, brown, coarse,

SILT: Little clay, olive brown, thinly laminated, stiff

CLAY SHALE: H.P. Clay, some silt, dark grey, stiff, calcareous - hard, non-calcareous below 81m

NOTES: E-Log, piezometer installed, air lifted

Pipe stickup - 0.91 m

Static w.l. @ 3.74 m 26 Mar 02

2" diameter sched. 40 Steel casing

2" diameter 15 slot Johnston Screen c/w foot valve

0.5 mm filter sand pack

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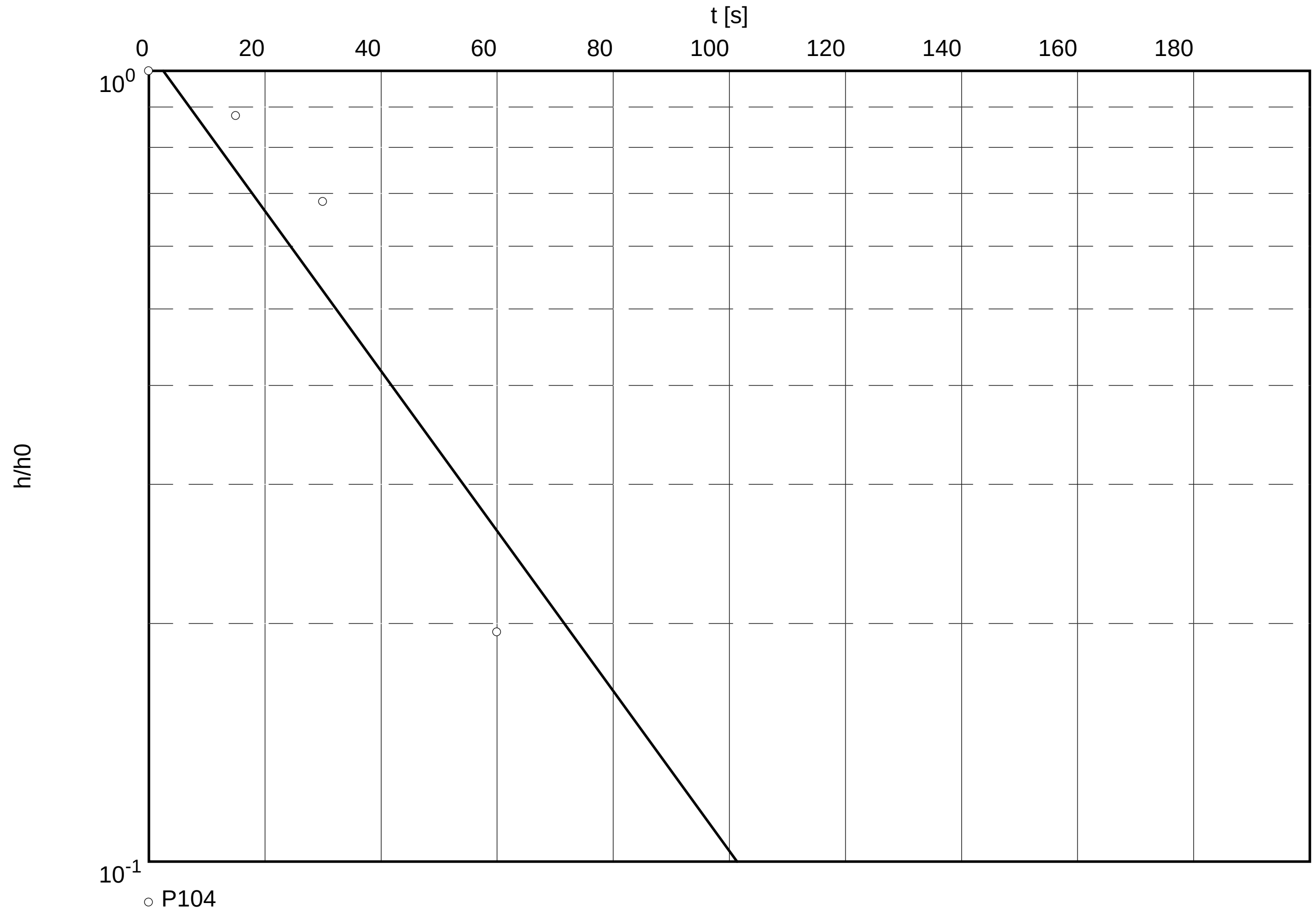
Appendix A

Clifton Associates Ltd. 340 Maxwell Crescent Regina, Saskatchewan ph. (306) 721-7611	slug/bail test analysis HVORSLEV's method	Date: 22.04.2002	Appendix A, Page 1
		Project: R3216 Wynyard	
		Evaluated by: WAJ	

Slug Test No.	Test conducted on: 22 March 2002
P104	



Hydraulic conductivity [m/s]: 2.21 x 10^{-5}

Clifton Associates Ltd. 340 Maxwell Crescent Regina, Saskatchewan ph. (306) 721-7611	slug/bail test analysis HVORSLEV's method	Date: 22.04.2002	Appendix A, Page 2
		Project: R3216 Wynyard	
		Evaluated by: WAJ	

Slug Test No.	Test conducted on: 22 March 2002
P104	P104

Static water level: 10.300 m below datum

	Pumping test duration [s]	Water level [m]	Change in Waterlevel [m]	
1	0	12.350	2.050	
2	15	12.100	1.800	
3	30	11.700	1.400	
4	60	10.700	0.400	
5	120	10.300	0.000	