RAW WATER FOR AGRICULTURAL IRRIGATION STUDY – PHASE 2 HYDROGEOLOGICAL ASSESSMENT OF WEST DISTRICT ZONE B AND SOUTH DISTRICT

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1.0 Introduction

The Regional Municipality of Niagara (Region) retained Stantec Consulting Ltd. (Stantec) to investigate the feasibility of providing raw irrigation water for agricultural purposes in the Region. While agriculture is currently a predominant land use in the Region, there are opportunities to expand high value crop production. In order to pursue these opportunities, a Region-wide water resources and irrigation management plan is required to optimize crop production, ensure the sustainability of water resources, and protect natural environmental features in the area.

Phase I of the irrigation feasibility assessment (Stantec, 2005) divided the study area into four (4) main irrigation districts based on the locations of the different clusters of potential irrigation lands. The location of each irrigation district is shown in Figure 1 and are referred to as the East Irrigation District (Niagara-on-the-Lake); West Irrigation District Zone A (below the escarpment); West Irrigation District Zone B (above the escarpment); and South Irrigation District (Pelham). Stantec (2005) identified groundwater as the preferred source of irrigation water for the areas above the Niagara Escarpment, namely West Irrigation District Zone B and South Irrigation District.

To further assess the potential for groundwater-based irrigation above the Niagara Escarpment, Stantec undertook a phased hydrogeological study with the following objectives:

- Develop a conceptual understanding of the geology and hydrogeology;
- Determine the theoretical well yields in the study area;
- Determine if surplus groundwater was available for irrigation purposes; and
- Evaluate if water quality conditions were suitable for irrigation uses.

The first phase of the study was presented in Technical Memorandum 1 Stantec (2006), which included a background review of the geology and hydrogeology in Zone B and the South District, an estimation of theoretical well yields and a preliminary impact assessment. Technical Memorandum 1 was presented to the Technical Advisory Committee on November 15, 2006. Formal comments were received from the Niagara Peninsula Conservation Authority (NPCA), in a memo dated December 14, 2006, and from Agriculture and Agri-Food Canada, in an email dated March 29, 2007. Based on the comments received from the Technical Advisory Committee, Stantec proceeded to prepare this Hydrogeological Assessment Report. The Hydrogeological Assessment Report also incorporates new information derived from other components of this study, particularly with respect to irrigation demand requirements, that were not available at the time Technical Memorandum 1 was prepared.

This report is organized into ten (10) sections including this introduction. Section 2 presents a review of the site setting in each of the two study areas, while Section 3 describes the estimated groundwater demand in each area. Sections 4 and 5 present the geology and hydrogeology of the study area, respectively. The theoretical well yield and groundwater impact assessment are presented in Sections 6 and 7. Estimated well construction costs are provided in Section 8. Section 9 provides conclusions and recommendations based on the study results and references are provided in Section 10. All figures and tables referenced throughout this report are provided in Appendices A and B, respectively. Appendix C contains a summary of the Ministry of the Environment (MOE) Permit To Take Water (PTTW) licenses in the study area and Appendix D contains a summary of the irrigation demand calculations.

2.0 Site Setting

The locations of Western District Zone B (Zone B) and the South District relative to the remainder of the study area are shown on Figure 1. The site settings for each district are unique and described in detail below.

2.1 ZONE B

Zone B is a relatively narrow strip of land located above the escarpment with an area of about 65.7 km^2, extending from the western limit of the Town of Grimsby to the eastern limit of the Town of Lincoln, with a small portion of Zone B also extending into the Town of Pelham (Figure). The distribution of agricultural land use across Zone B is shown in Figure 2. A land use survey completed by Stantec as part of a concurrent study indicated that the Zone B area comprises approximately 16.4 km^2 (25% of study area) of lands that have a current crop type (i.e., grape, tender/pome fruit, greenhouse, nursery) that would benefit from irrigation infrastructure. The remaining lands in Zone B were mapped as idle, cash crop, pasture, or other non-agricultural use.

Figure 3 presents the surface topography of Zone B and surrounding area. The Niagara Escarpment forms the northern boundary of Zone B and is the predominate topographical feature in the area. In many places, the elevation of the Niagara Escarpment is up to 100 m higher than that of the Lake Ontario plain to the north. Relief within Zone B is generally flat to gently sloping with elevations ranging from 195 m above sea level (ASL) in the west to 170 ASL in the east. Several ridges, oriented roughly parallel to the face of the Niagara Escarpment, were also noted within Zone B that rise moderately above the surrounding landscape to elevations of approximately 210 mASL.

As shown in Figure 3, Zone B forms the headwaters of numerous surface water features that flow northerly over the face of the Niagara Escarpment. The larger watersheds intersected by Zone B include: Fifteen Mile Creek, Sixteen Mile Creek, Eighteen Mile Creek, Twenty Mile Creek and Forty Mile Creek. A complete listing of watersheds in Zone B is provided in Table 1.

2.2 SOUTH DISTRICT

The South District is an approximately 45.3 km^2 area in the central region of the Town of Pelham (Figure 4). The distribution of agricultural land across the South District is shown in Figure 4. The land use survey indicated that the South District comprises approximately 6.7 km^2 (15% of study area) of lands that have a current crop (grape, tender/pome fruit, greenhouse nursery) that would benefit from irrigation infrastructure. The remaining lands in Zone B were mapped as idle, cash crop, pasture, or other non-agricultural use. A significant portion of the eastern South District study area comprises non-agricultural land. The original delineation of the South District study area from Stantec (2005) was based on soils mapping for the area which included the urbanized area of Pelham. While irrigation over the urbanized area is clearly not of interest, the Study area boundary used in Stantec (2005) has also been adopted in this study for consistency.

Figure 5 presents the surface topography of the South District and surrounding area. The Fonthill Kame-Delta Complex is the prominent topographic feature of this area with a peak elevation at approximately 255 mASL, which is approximately 75 m above the generally flat surrounding lake plain, situated at an elevation of approximately 180 mASL.

As shown in Figure 5, the South District is drained to the south by Coyle Creek and Drapers Creek (Welland River Watershed), to the north by Twelve Mile Creek, to the west by Fifteen Mile Creek and to the east by two tributaries of the Welland Canal (Welland Canal Watershed). The Niagara Peninsula Conservation Authority (NPCA) has identified Twelve Mile Creek as a priority drainage feature as this creek is the only cold water system in the Region.

2.3 PRECIPITATION

Long-term annual precipitation means were available for the study areas from Agriculture and Agri-Food Canada. This particular source of precipitation data is consistent with that used in the NPCA Groundwater Study (WHI et al., 2005) and are based on measurements collected from 1961 through 1990. Precipitation data from Agriculture and Agri-Food Canada are provided based on “Eco Districts” that have been mapped for Canada. Zone B is situated in both Eco District 566 and 569 with mean precipitation values of 858.6 mm and 926.9 mm, respectively, while the South District is located entirely within in Eco District 569 (926.9 mm).

3.0 Groundwater Demand

The groundwater demands for Zone B and the South District were determined by reviewing domestic demand, permitted groundwater takings and potential irrigation demand based on the results of the agricultural land use survey. The following sections provide a summary of each type of demand.

3.1 EXISTING DOMESTIC GROUNDWATER DEMAND

Estimates of existing domestic groundwater demand were determined based on the approach used by WHI et al. (2005). This approach assumed that rural domestic use was on average 0.175 m^3/d/capita. It was further assumed that all of the rural population derived its water supply from domestic wells. Population estimates were based on a rural population density of 18.1 people/km^2 (WHI et al., 2005). The population density estimate of 18.1 people/km^2 was applied on a watershed basis in each of the study areas to determine the existing domestic demand by watershed, as summarized in Table 1.

In Zone B, the rural domestic demand ranged from approximately 92 m^3/yr in some of the smaller watersheds that are just intersected by Zone B to 16,660 m^3/yr in the Forty Mile Creek watershed. In the South District, the rural domestic demand ranged from 58 m^3/yr in the Welland Canal watershed to 18,075 m^3/yr in the Twelve Mile Creek watershed. A total domestic water demand of 75,939 m^3/yr and 52,423 m^3/yr was estimated for Zone B and the South District, respectively.

3.2 PERMITTED GROUNDWATER TAKINGS

A summary of Permit to Take Water (PTTW) information is presented in Table C.1 and Table C.2 (Appendix C) for Zone B and the South District, respectively. These data were provided by the Ministry of the Environment (MOE) for the study areas in October 2006 and assumed to have been current to the end of September 2006. Some discrepancies between permitted takings provided to Stantec by the MOE and those on file according to NPCA records were noted. The PTTW data presented in Appendix C are a combination of those provided to Stantec by the MOE and those on file with the NPCA.

Figures 6 and 7 present the locations of the permitted groundwater takings within Zone B and the South District, respectively, while Table 1 summarized the takings in both study areas in a total watershed demand context. Note that where the source type was described as “both” (i.e., surface and ground) in the PTTW database, it was assumed that the total permitted amount was derived from groundwater. It was further assumed that the maximum permitted amount was extracted annually.

Groundwater demand from PTTW users was estimated at 46,150 m^3/yr (Gavora Ditch watershed only) and 5,407,047 m^3/yr (Fifteen Mile and Upper Twelve Mile Creek watersheds) in Zone B and the South District, respectively.

3.3 IRRIGATION DEMAND

Results from the Water Consumption Study (Weather Innovations Incorporated [WII], 2007) and the Feasibility Study (Stantec, 2005) were used to determine unit peak and seasonal irrigation demands. Based on these studies, the peak and seasonal irrigation requirements were set as follows:

Crop Type	Peak Irrigation Demand (mm/day)	Seasonal Irrigation Demand (mm/yr)
Wine Grapes	5.5[A]	130[B]
Nurseries	3.0[A]	180[D]
Juice Grapes	5.5[A]	130[B]
Tender Fruit (e.g., peaches, cherries)	6.8[A]	280[B]
Greenhouses	7.0[A]	700[D]
Pome Fruit (e.g., apples, pears)	6.8[A]	280[C]

[A] Peak irrigation rates based on Consumption Study (WII, 2007) assuming Peak Demand=(ET_o *K_c)/Efficiency, where ET_o is standardized reference evapotranspiration, K_c is the crop factor, and Efficiency=76%.
[B] Seasonal irrigation rates determined based on Consumption Study (WII, 2007).
[C] Pome fruit was assumed to have the same seasonal irrigation demand as tender fruit.
[D] Modified from the Feasibility Study (Stantec 2006).

The peak irrigation demand in each subwatershed was estimated by multiplying the parcel area by the peak irrigation requirement of the crop type grown on that parcel. In most instances, it was assumed that 85% of each parcel was under cultivation. One exception was made for greenhouses, where 30% of the land area was assumed to require irrigation. The peak irrigation estimates were used to assess if wells were capable of delivering the peak demand, which is discussed in more detail in Section 6.

The resulting peak irrigation demands for the crops listed above are presented on Figures 8 and 9 for Zone B and the South District, respectively. These figures show the spatial distribution of the agricultural parcels and the irrigation parcel demand based on the crop type and area being farmed. The peak day irrigation parcel demands range from <50 m^3/d to 1,948 m^3/d in Zone B and from 50 m^3/d to 1,784 m^3/d in the South District.

The average annual irrigation demand was also calculated by multiplying the seasonal irrigation demand (presented in above table) by the cultivated area of each parcel. These values were used as part of the groundwater impact assessment, which is discussed further in Section 7. The estimated seasonal irrigation demand for Zone B and the South District were 2,009,868 m^3/yr (64 L/s) and 1,051,582 m^3/yr (33 L/s), respectively. Table D.1 (Appendix, D) presents a summary of the annual demands by watershed while Table 1 presents the annual irrigation demands along with other groundwater demands in the two study areas.

4.0 Geological Setting

This section provides a review of the geology for the study area. The geologic descriptions of the overburden and bedrock are intended to distinguish between zones that are capable of producing groundwater (i.e., aquifer systems) and zones where groundwater movement is impeded (i.e. aquitards). Given that the overburden geological environments differ considerably between Zone B and the South District, a separate discussion of each is provided below. This is followed by a discussion of the bedrock.

4.1 REGIONAL OVERBURDEN GEOLOGY

This section provides an overview of the regional overburden geological conditions across the Niagara Peninsula followed by the local geological conditions in each of the study areas. Previous studies (Owen, 1972, Feenstra, 1981) have identified four (4) regional litho-stratigraphic units across the Niagara Peninsula, as follows:

> *<u>Lower Till Unit</u>* – consists of the Port Stanley Till in the vicinity of the study area and was deposited during the Port Bruce Stade. The Port Stanley Till occurs as a buried plain of fine-grained till consisting of very dense silt and sand with increasing gravel content towards the bedrock contact.
>
> *<u>Lower Glaciolacustrine Unit</u>* – deposited during the Mackinaw Interstade. The lower glaciolacustrine unit occurs as a buried plain comprising clay and silt with occasional sand lenses.
>
> *<u>Upper Till Unit</u>* – consists of the Halton Till Complex in the vicinity of the study area and was deposited during the Port Huron Stade. The Halton Till Complex occurs at surface over a broad area in Zone B and is a fine-grained till consisting primarily of silt and clay.
>
> *<u>Upper Glaciolacustrine Unit</u>* – the youngest of the stratigraphic units, was deposited during the Two Creeks Interstade and postglacial age. Within Zone B, this unit consists of the Haldimand Clay Plain. As the name suggests, the Haldimand Clay Plain comprises mostly clay and silt that was deposited in a deep water environment (Lake Warren). The Haldimand Clay Plain occurs at surface over much of Zone B and around the perimeter of the South District.

There are a number of localized areas across the Niagara Peninsula that deviate from the fine-grained overburden deposits that cover the majority of the area above the Niagara Escarpment, as described above. The most notable exception is the Fonthill Kame-Delta Complex (FKDC) that is situated in the South District. The geology of the FKDC is discussed separately in Section 4.3.

4.2 OVERBURDEN GEOLOGY - ZONE B

The overburden geology of Zone B is consistent with the regional quaternary geology interpretation described above. Figure 10 presents the surficial geology for Zone B as mapped by the Ontario Geological Survey (OGS, 2003). With few exceptions, the entire area is overlain with fine-textured soils consisting of glaciolacustrine deposits of silt and clay and clay or silt till. The glaciolacustrine deposits are associated with the Haldimand Clay Plain, which lies primarily between the Escarpment and Lake Erie. The clay and silt till, known as the Halton Till, is also observed at surface over much of Zone B.

Drilling information provided by the Ministry of the Environment (MOE) Water Well Information System (WWIS) (database extracted October 5, 2006), indicated that the surficial geology was consistent at depth. The drilling information is presented on Cross-section A-A' (Figure 11), which extends from west to east across Zone B. The cross-section location is presented on Figure 10. In general, a thin layer of clay is shown to overly bedrock. As shown in Figures 11 and 12, the thickness of overburden across Zone B is generally 5 m to 10m and occasionally >15 m. The overburden is absent in some locations within Zone B where bedrock outcrops at surface.

In areas where the surficial geology does not consist of fine-textured soils, the surficial geology mapping indicates that either bedrock outcrops at surface or coarse-textured sand and gravel is present. Bedrock outcrop is most prevalent near the northern edge of the Escarpment and covers approximately 14% of Zone B. A relatively narrow strip of coarse-textured sand and gravel was noted near the western end of Zone B, covering approximately 1% of the study area. The MOE WWIS indicated that coarse-textured soil is not prevalent at depth with only 3% of wells in Zone B screened in the overburden.

Due to the limited thickness and fine-grained composition of the overburden, it was concluded that there are no overburden aquifer systems of significance in Zone B.

4.3 OVERBURDEN GEOLOGY – SOUTH DISTRICT

The geology of the South District is considerably more complex than Zone B and does not conform to the regional quaternary geology presented in Section 4.1. The South District encompasses the Fonthill Kame-Delta Complex (FKDC), which rises above the surrounding landscape to heights of up to 75 m. The FKDC was deposited during the retreat of a re-entrant ice sheet along the edge of Lake Warren about 12,000 years ago (GLL, 1987). During the melting of the ice sheet a large amount of outwash sand and gravel was deposited in Lake Warren forming the Kame deposit. As the ice retreat continued, a delta was formed as the sediment-laden river entered Lake Warren. During the formation of the delta, coarser materials were deposited near the mouth of the river and the finer sediments were transported to the toe of the delta. The steeply sloped gravels on the northern side of the FKDC are ice contact gravels associated with the Kame. The southern side of the FKDC comprises the delta portion of the complex where gravel was deposited near the ice margin and progressively finer material was deposited further to the south.

Figure 13 presents the surficial geology of the South District as mapped by the Ontario Geological Survey (OGS, 2003). The core area of the South District consists of coarse-textured glaciolacustrine deposits of sand and gravel corresponding with the FKDC. Fine-textured silt and clay deposits were mapped at surface on the northern, eastern and western edges of the South District. Figure 17 presents the overburden thickness in the South District. The thickness of overburden material ranges over 100 m where the kame overlies a buried bedrock channel (Erigan channel), which is discussed further in Section 4.4.

WHI et al. (2005) constructed 15 cross-sections across the FKDC in an effort to further characterize the local geological and hydrogeological conditions. Three (3) of these cross-sections (H-H', J-J', and F1-F1') were further developed by WHI et al. (2005) to present a conceptual hydrostratigraphic framework for FKDC. These conceptual cross-sections are presented again in this report as Figures 14 to 16 with the cross-section locations shown on Figure 13. The overburden consists of thick beds of sand and gravel overlying clay-rich tills and glaciolacustrine clays. As shown, the continuity of the layers can be variable; however, the beds of fine-grained till may provide some protection to the bedrock aquifer system, where present.

The numerical groundwater flow model presented in WHI et al. (2005) divided the overburden system into five (5) hydrostratigraphic units, as follows:

> *Unit 1 - Ice Contact Sand and Gravel* – this unit is associated with the Kame and is most prominent on the northern side of the FKDC.
>
> *Unit 2 - Discontinuous fine-grained silt and clay till* –this is interpreted to be reworked Halton Till and Port Stanley Till that was eroded out during the advance of the re-entrant ice sheet and then re-deposited as the ice sheet retreated.
>
> *Unit 3 - Sand and Gravel* – this unit represents the glaciolacustrine deposits associated with the delta that built out in Lake Warren and were interpreted to become finer grained southward away from the Kame.
>
> *Unit 4 - Fine-grained till and glaciolacustrine sands, silts and clay* – this unit represents the fine-grained material situated beneath the Kame deposit and includes glaciolacustrine clay units (likely associated with the Haldimand Clay Plain), interbedded with two fine-grained till units (Halton Till and Port Stanley Till).
>
> *Unit 5 - Sand and Gravel* – this is a discontinuous unit overlying bedrock that is present wherever Unit 4 was eroded away by the re-entrant ice sheet. The sands and gravel are associated with either the kame or delta deposits.

Based on composition, Units 1, 3 and 5 are classified as aquifers, with Units 2 and 4 comprising aquitard material.

4.4 BEDROCK

4.4.1 Topography

The bedrock topography for Zone B and the South District are presented on Figures 18 and 19, respectively, along with the Paleozoic geology mapping completed by the Ontario Geological Survey (preliminary version). Over most of Zone B, the top of bedrock occurs at elevations ranging from 180 to 190 m AMSL. One exception is the eastern end of Zone B, where lower bedrock elevations, in the range of 155 to 165 m AMSL, are encountered.

The bedrock topography in the South District is more variable, generally ranging from 120 to 160 m AMSL. The topographic lows in the bedrock are associated with the Erigan bedrock channel that extends through Fonthill and beneath 12 Mile Creek (Figure 20). Regionally, the Erigan channel represents one of three main passageways connecting Lake Erie to Lake Ontario. As shown in Figure 20, a topographic low present northwest of Fonthill (western branch) is separated from the Erigan channel by a bedrock high immediately to the north of Fonthill. As suggested by Flint et al. (1985), it is possible that the Erigan channel crossed the Niagara Escarpment through a double path similar to the two waterfalls separated by Goat Island on the present-day Niagara River. The channel elevation for the western branch is situated at about 145 m AMSL, compared with the eastern channel that is about 25 m lower (120 m AMSL). This suggests that the western branch was abandoned long before the eastern channel became inactive. The main branch of the Erigan channel (eastern branch) between Fonthill and St. Johns West is approximately 400 m wide.

The hydrogeological significance of the Erigan channel is assessed in Section 6.2.

4.4.2 Geology and Hydrostratigraphy

The bedrock geology is the same beneath Zone B and the South District and is all of sedimentary origin. The bedrock stratigraphy underlying the study area consists of a sequence of bedded dolostones and shales, with a regional southward dip of approximately 0.5%. The bedrock stratigraphic column for the study area is shown in Figure 20, and the general composition of the bedrock units is provided below in order of oldest to youngest. The horizontal conductivity information and relative unit thicknesses for each rock sequence were referenced from Smithville (2001b), GLL (1987) and Novakowski and Lapcevic (1988).

Queenston Formation – The Queenston formation is a thick red shale formation of Upper Ordovician age and is the oldest Paleozoic bedrock unit that subcrops in some locations at the base of the Escarpment. The unit is estimated to be over 500 m in thickness. This formation is interpreted to act as a regional barrier to vertical groundwater movement with hydraulic conductivities in the range of 10^{-10} to 10^{-11} m/s.

Cataract Group – The Cataract Group is a sequence of three sandstone and shale formations overlying the Queenston Formation. The Cataract Group is Lower Silurian in age and approximately 25 m thick. The lower formation in the Cataract Group is the Whirlpool formation, which consists of sandstone with shale partings. The contact between the Whirlpool and Queenston formations is a major disconformity with a horizontal hydraulic conductivity as high as 10^{-7} m/s. The Grimsby and Cabot Head formations have a lower hydraulic conductivity, typically in the order of 10^{-10} to 10^{-11} m/s.

Clinton Group - The Cataract Group is overlain by the Clinton Group, which consists of six formations with a combined thickness of about 22 m. The six formations include: the Thorold formation, a greenish grey sandstone about 2 m thick; the Neagha formation, a greenish-grey shale less than 2 m in thickness; the Reynales formation, a grey-blue thin to massive bedded dolostone ranging between 3 and 4 m in thickness; the Irondequoit formation, a white to tan colored massive to thin bedded limestone; the Rochester formation a dark bluish grey shale; and the Decew formation, a buff thin to medium bedded dolostone. The bulk permeability of the Clinton Group is similar to the rocks of the Cataract Group (i.e., in the order of 10^{-7} to 10^{-11} m/s).

Lockport Formation - The Lockport formation overlies the Clinton Group and consists of four members, including the Gasport (lowermost), Goat Island, Vinemount and Eramosa (uppermost) members. The Gasport member consists of a medium-bedded grey dolostone, the Goat Island member is a fine-textured grey dolostone, the Vinemount member is a fine-grained grey argillaceous dolostone and the Eramosa member is a brownish dolostone. Due to the regional stratigraphic dip to the south of about 4 m/km, the thickness of the Lockport formation is variable across Zone B. The Lockport formation generally becomes thicker to the south away from the face of the escarpment and ranges from not present along the northern edge of the escarpment (Zone B), where the Clinton Group forms the top of the rock sequence, to approximately 20 m along portions of the southern boundary of Zone B based on drilling results from Vineland and Lincoln Quarries. Both the Eramosa member and Vinemount members are virtually absent in Zone B. The Eramosa and Goat Island members form the top of the rock sequence over the majority of the South District. The Lockport formation ranges from not present at the northern tip of the South District to approximately 40 m thick at the south end. The Lockport Formation is the most permeable of the stratigraphic sequences with hydraulic conductivities in the range of 10^{-5} to 10^{-9} m/s (geometric mean hydraulic conductivity of 10^{-6} m/s).

Guelph Formation – Due the regional stratigraphic dip to the south of about 4 m/km, the Guelph formation is not present beneath Zone B and the majority of the South District. The Guelph formation is present in the southwestern corner of the South District study area and consists of a medium grey, fine-grained, thinly bedded dolostone. The permeability of the Guelph formation is comparable to the Lockport formation with hydraulic conductivities typically in the range of 10^{-5} to 10^{-8} m/s.

Based on the above, the Guelph and Lockport formations have fairly good water yielding potential and would be considered regional bedrock aquifer systems. The Clinton/Cataract groups and Queenston formation do not have good water yielding potential and would be considered regional aquitard features. In general, the weathered bedrock surface is typically more permeable than the underlying rock.

5.0 Hydrogeological Setting

The hydrogeological discussion provided below is based on information compiled from a number of sources including the MOE WWIS (2006), WHI et al. (2005), Blackport (2005), GLL (1987), Novakowski and Lapcevic (1985), Smithville (2001b) as well as a number of site-scale hydrogeological assessments including Jagger (1999a,b) and GLL (1998). The discussion is focused on further characterizing the groundwater resources beneath Zone B and the South District. The discussion begins with a brief review the regional bedrock hydrogeology, which is common to both study areas, followed by a more focused discussion of the hydrogeology of Zone B and the South District.

5.1 REGIONAL BEDROCK HYDROGEOLOGY

The work completed by Novakowski and Lapcevic (1988) suggests that the bedrock stratigraphic column in the area can be divided into several distinct flow systems. The uppermost system comprises the Lockport formation and this is the most hydraulically active system. Below the Lockport formation, the Clinton and Cataract groups comprise a low-permeability zone of virtually stagnant groundwater that slowly drains to the base of the Whirlpool formation. Groundwater movement below the Whirlpool formation is extremely limited within the massive low-permeability Queenston formation. Novakowski and Lapcevic (1988) also noted that natural gas was present in the Rochester formation. The presence of natural gas is a strong indicator that the Rochester formation is a significant regional barrier to vertical groundwater movement.

The most productive zones in the Lockport formation occur in the weathered zone near the overburden/bedrock interface and the fracture zone in the Goat Island member. Occasionally, other high-permeability zones are encountered in the Lockport formation; however, these tend to be variable and less predictable in nature.

5.2 HYDROGEOLOGY - ZONE B

Based on the geological and regional hydrogeological information provided above, the hydrostratigraphic sequence predominantly consists of the following:

> *Overburden Aquitard* – Approximately 85% of Zone B is overlain by fine-textured soil associated with either the Haldimand Clay Plain or the Halton Till. The thickness of this material typically ranges from 5 to 10 m and directly overlies the bedrock.
>
> *Bedrock Aquifer* – The bedrock aquifer primarily consists of the weathered zone in the shallow bedrock. The upper bedrock throughout Zone B primarily consists of the Goat Island and Gasport members of the Lockport formation.

> _Bedrock Aquitard_ – the remainder of the rock sequence beneath the Lockport formation is considered to behave like a regional aquitard with horizontal hydraulic conductivities typically ranging from 10^{-7} to 10^{-11} m/s.

The MOE WWIS indicates that of the 286 wells situated within Zone B, 97% are completed within the bedrock aquifer and the remaining 3% in the overburden. Groundwater wells completed in the overburden are shallow and interpreted to intersect random isolated pockets of sand and gravel that have no regional significance. Bedrock wells in Zone B are typically completed in the upper weathered zone of the Lockport formation.

Bedrock groundwater level data were provided from the NPCA from two Provincial Groundwater Monitoring Program (PGMP) wells located in or near Zone B (W0000073, W0000341), as well as monitoring completed in support of the local quarries. The NPCA wells are located in areas interpreted to be representative of ambient groundwater conditions. The well locations are presented on Figure 21 while the available hydrograph data are presented on Figure 22. Monitoring well W000073 was located in the Town of Grimsby just south of the Zone B boundary. This well is completed to 15.23 m BGS and screened in the Lockport formation. The hydrograph for this well showed a seasonal variation of approximately 2.5 m in groundwater elevation, with the peak level occurring in spring over the spring of 2002 and 2003. Monitoring well W0000341 is completed at the northern edge of the escarpment in the Clinton group to a depth of 7.66 m BGS. The hydrograph for W0000341 presents data from October 2004 through June 2006 and shows that water levels have been generally stable over this period. The instability in the water level data from approximately September 2005 to February 2006 was a function of the barometric pressure correction and not representative of actual water level fluctuation.

Longer term groundwater data collected from the Lincoln Quarry from 1979 to 2005 (Jagger 2005) and Vineland Quarry from 1979 to 1999 (Jagger, 1999a) indicated a fairly consistent seasonal trend with groundwater elevations typically highest in the spring, declining through the summer and fall. Seasonal fluctuations in the order of 4 to 5 m are not uncommon in the upper weathered zone of the Lockport formation. Longer-term trends in the data indicated that groundwater levels have been fairly stable in the vicinity of the quarries over the years. Some minor exceptions were noted in several monitoring wells at the Lincoln Quarry and these were interpreted to be potentially related to local quarry operations and not widespread changes in regional groundwater levels.

Figure 21 presents the potentiometric surface generated using static water level measurements provided in the MOE WWIS for wells completed in the bedrock. In general, groundwater flow is interpreted to be northerly toward the face of the Escarpment. Horizontal hydraulic gradients were estimated to range from 0.004 to 0.03 with higher gradients observed near the face of the Escarpment.

Jagger Hims (1999a) found that overburden thickness typically ranges from 0 m to 10 m and that the overburden comprised clay and silt with an estimated horizontal hydraulic conductivity of 10^{-7} to 10^{-9} m/s. Within the bedrock, the bulk hydraulic conductivity was estimated at 10^{-5} m/s to 10^{-8} m/s with an average of 4.9×10^{-6} m/s. Downward vertical hydraulic gradients from the overburden water table to the deep system of 0.026 to 0.646 m/m were estimated.

The potential for groundwater recharge is limited in Zone B because most of the study area is overlain by fine textured soils comprising clay and silt. The model prepared by Blackport (2005), as part of the NPCA Groundwater Study completed by WHI et al. (2005), assigned a recharge rate of 10 cm/yr to these fine textured soils. GLL (1987) estimated a recharge rate in the order of 7.5 cm/yr through similar material in the Welland area. Higher groundwater recharge rates would be expected in areas where bedrock is exposed at surface; however, this comprises less than 14% of Zone B.

In terms of groundwater and surface water interaction, there have been a number of local studies completed in watersheds intersected by Zone B, including: the study of a portion of 20 Mile Creek in the Smithville area (Smithville, 2001a), as well as the Gavora Ditch (Jagger 1999b); and Spring Creek Watershed (Jagger, 1999a). Each of these studies concluded that the surface water features were intermittent with no flow occurring during dry summer months.

5.2.1 Groundwater Quality – Zone B

Groundwater quality data from the MOE water well records were used to provide a qualitative indication of water quality conditions across Zone B. These data were sorted based on whether the water quality was reported as fresh or anything other than fresh, respectively. The results of this analysis are presented graphically on Figure 23. It was determined that approximately 81% of the bedrock and 87% overburden wells yielded water that was described as fresh. Wells with quality issues were fairly evenly distributed across Zone B, with a slightly higher density noted near the west end of the study area. For those wells where quality issues were identified, elevated sulphur and mineral-related problems were indicated.

More detailed groundwater quality data were available from the monitoring completed in support of the Lincoln and Vineland quarries (Jagger 1999a/b, 2006) as well as from the MOE water well records. A summary of key parameters is provided in the table below for water quality in the overburden, dolostone bedrock (Lockport Formation) and shale (Rochester Formation). The water quality data were compared with the Canadian Quality Guidelines for the Protection of Agricultural Water Uses to assess its suitability for irrigation.

Parameter	Irrigation Guideline (mg/L)	Overburden (mg/L)	Dolostone (mg/L)	Shale (mg/L)
Ammonia	n/v	0.01 – 0.2	0.05 – 1.03	0.02 – 3.83
Chloride	100 – 700[a]	16 - 221	2 – 93	29 – 1,000
Iron	5	0.02 – 2.03	<0.02 – 0.66	0.02 – 5.43
Manganese	0.2	<0.02 – 0.64	0.02 – 1.67	0.02 – 0.34
Sodium	n/v	22 - 220	2 – 322	92 – 1,050
Sulphate	n/v	170 – 1,220	42 – 2,100	267 – 2,250
Total Dissolved Solids	500 - 3,500[b]	820 – 4,010	673 – 3,000	1,640 – 5,230

Notes: [a] chloride concentration in the range of 178 – 355 mg/L may cause foliar damage in grapes.

[b] total dissolved solids concentration should not exceed 500 – 800 mg/L for grapes.

In general, natural water quality is hard and mineralized. Water quality in the overburden and bedrock is characterized by frequently elevated concentrations of sulphate, sodium, chloride, iron, manganese and total dissolved solids. Water quality typically deteriorates with depth, with concentrations of total dissolved solids, hardness, chloride and ammonia typically increasing with depth. The concentration range for total dissolved solids is elevated in both the overburden and bedrock environments. Neither the overburden or shale formations have suitable ranges of total dissolved solids for grape crop irrigation. The range in total dissolved solids concentration in the dolostone bedrock also regularly exceeds the criteria set for grapes. The concentration of manganese has occasionally been detected above the irrigation quality guidelines in both the overburden and bedrock systems. The chloride concentration in groundwater from the overburden and shale environments also periodically exceeded the irrigation criteria set for grapes.

Based on the available water quality data, the dolostone bedrock (Lockport Formation) represents the only potentially suitable source of irrigation water in Zone B. However, even in the dolostone, total dissolved solids and manganese can be elevated and as a result its suitability from a quality perspective would need to be assessed on a parcel by parcel basis. It was noted that the water quality from the upper weathered portion of the dolostone was typically better than from the lower portions of the formation. This was attributed to mixing of poorer water quality from the underlying shale unit in wells completed in the lower dolostone bedrock formation.

5.3 HYDROGEOLOGY - SOUTH DISTRICT

Figure 24 presents the groundwater table map for the South District based on the static water level measurements provided in the MOE WWIS for wells completed in the overburden. Similarly, Figure 25 presents the potentiometric surface map based on bedrock water levels. In both instances a groundwater mound was observed in the central portion of the FKDC with outward radial flow toward the edges of the study boundary. The horizontal hydraulic gradient of the water table was estimated to range from 0.0275 m/m to 0.107 m/m while the horizontal hydraulic bedrock gradient ranged from approximately 0.0075 m/m to 0.025 m/m. Blackport

(2005) estimated the horizontal hydraulic gradient in the overburden and bedrock to be 0.02 and 0.006, respectively.

The groundwater mounding observed in the bedrock aquifer system, suggests that the FKDC is a regional groundwater recharge zone. A comparison of the overburden and bedrock groundwater contour maps (Figures 24 and 25) indicate that there is a downward gradient from the overburden to the bedrock over most of the area. Gartner Lee (1998) reported similar trends during a study related to the expansion of the Fonthill Pit in the South District. This study indicated that static water levels in the bedrock ranged from approximately 174-182 mASL, which were greater than 25 m lower than the water table. Blackport (2005) calculated downward vertical hydraulic gradients in the order of 0.3 to 0.5.

Groundwater level data were provided by the NPCA for five PGMP wells located in the South District (W0000361-A/B, W0000362-A/B, and W0000357). The locations of these wells are presented on Figure 24 and Figure 25 while the available hydrograph data are presented on Figure 26 along with available precipitation data (Welland Station, Environment Canada website). Nested well W0000361-2(shallow, 16.2 m BGS)/-3(deep, 32.7 mBGS) is completed in the Fonthill Kame. Hydrograph data from these wells indicated that there is a strong downward vertical hydraulic gradient, while the overall trends indicate that water levels have been stable over the screened intervals. Similar hydrograph stability trends were observed at nested well W0000362-2/3 (shallow/deep), which is also installed in the kame at depths of 6.48 mBGS and 14.85 mBGS; however, an upward vertical hydraulic gradient is observed at this location. Nested well W0000362-2/3 is located on the flank of the kame near the headwaters of a tributary to 12 Mile Creek which may explain the upward vertical hydraulic gradient in this area. Water levels at W0000357, which is also installed in the kame deposit to a depth of 46.94 mBGS, demonstrated a steadily increasing trend of approximately 0.83 m over the nearly 2-year monitoring period. From approximately September 2005 to February 2006 there is instability in the water levels at all of these wells and this appears to be a function of the barometric pressure correction rather than actual water level fluctuations.

Longer term groundwater level data from the Fonthill Pit area (Gartner Lee, 1998) has been collected since 1981. These data indicated that there has been no appreciable change in the groundwater flow system beneath the Fonthill Pit over the years, likely owing to the fact that aggregate extraction has remained well above the groundwater table.

Blackport (2005) estimated that the recharge through the coarse sand and gravel deposits ranged from 30 to 40 cm/yr. Recharge rates of 20 to 30 cm/yr were estimated for the flanks of the FKDC where less gravel and greater sand content was noted at surface. The recharge rate for the fine-grained glaciolacustrine deposits around the perimeter of the FKDC was estimated to be 10 cm/yr. The modeling results indicated that groundwater flow is toward two catchments, namely the Welland River to the south and Twelve Mile Creek to the north. Slightly more water was predicted to flow toward the northern Twelve Mile Creek system.

To develop an understanding of groundwater / surface water interaction, Blackport (2005) completed spot flow measurements of the streams flowing off the FKDC. These spot flows resulted in estimates of total groundwater discharge of 192 L/s (June 2003), 244 L/s (August 2004), and 396 L/s (May 2004). It was noted that the spot flow measurements from May and August 2004 were collected during 3 mm and 2 mm precipitation events, respectively, according to online precipitation data from Environment Canada for the Welland Station. As a result, these events suggest that the discharge estimates from May and August 2004 may not have been reflective of base flow conditions. In comparison to these flow measurements, no precipitation occurred the day of, or two days prior to the June 2003 spot flow measurements. These conditions suggest that the 192 L/s drainage estimate from June 2003 may provide the most reliable estimate of base flow conditions. However, given that the baseflow estimates have not been confirmed with additional data collection and to be conservative, a baseflow range of 192 L/s to 396 L/s was carried forward in the discussion of potential impacts resulting from additional groundwater extraction.

Assuming that a baseflow range of 192 L/s and 396 L/s is representative for the South District, and coupled with recharge estimates of 417 L/s based on the MODFLOW results from Blackport & Associates (2005), then the groundwater available for extraction without impacting base flows may range from 225 L/s to 21 L/s.

5.3.1 Groundwater Quality – South District

Groundwater quality data from the MOE water well records were used to provide a qualitative indication of water quality conditions across the South District. These data were sorted based on whether the water quality was reported as fresh or anything other than fresh. The results of this analysis are presented graphically on Figure 27. It was determined that approximately 89% of the bedrock and 95% overburden wells yielded water that was described as fresh in the vicinity of the South District. Wells with quality issues were fairly evenly distributed across the South District with no apparent clusters. Elevated sulphur was typically reported as a water quality issue in the water well records.

A limited set of more detailed water quality data were available from the work completed in support of the Fonthill Pit (Gartner Lee, 1998) as well as the groundwater study completed for the Fonthill- Kame Delta Complex (Blackport, 2005). A summary of key parameters is provided in the table below for water quality in the overburden, dolostone bedrock (Lockport Formation). The water quality data were compared with the Canadian Quality Guidelines for the Protection of Agricultural Water Uses to assess its suitability for irrigation.

Parameter	**Irrigation Guideline** (mg/L)	**Overburden** (mg/L)	**Dolostone** (mg/L)
Ammonia	n/v	<0.05	<0.05 – 1.3
Chloride	100 – 700[a]	5.7 – 337	24 – 558
Iron	5	<0.05 – 1.65	0.49 – 0.57
Manganese	0.2	<0.001 – 0.54	0.035 – 0.037
Sodium	n/v	9 - 184	17 – 281
Sulphate	n/v	35 – 200	167 – 1,900
Total Dissolved Solids	500 - 3,500[b]	143 – 1,090	404 – 3,590

Notes: [a] chloride concentration in the range of 178 – 355 mg/L may cause foliar damage in grapes.

[b] total dissolved solids concentration should not exceed 500 – 800 mg/L for grapes.

Blackport (2005) indicated that groundwater shows a broad range of mineralization ranging from a less mineralized type Ca-Mg-HCO_3 to more mineralized Ca-Na-HCO_3 and Ca-Na-SO_4. Enriched tritium analysis indicated that the groundwater ranged in age from 6 years to greater than 50 years, with the oldest waters generally derived from the bedrock. Similar to Zone B, the water quality in the South District is characterized by frequently elevated concentrations of sulphate, sodium, chloride, iron, manganese and total dissolved solids. Total dissolved solids can be elevated in both the overburden and bedrock environments and regularly exceeds the irrigation criteria range for grapes (500 – 800 mg/L). The concentration of manganese has been detected above the irrigation quality guidelines in the overburden aquifer systems. The chloride concentration in groundwater from the overburden and bedrock environments also periodically exceeds the irrigation criteria set for grapes and other crops.

The overburden and bedrock water quality data for the South District is variable and may be suitable for irrigation purposes in some areas but not in others. The water quality would need to be evaluated on a parcel by parcel basis to determine its suitability for irrigation.

6.0 Theoretical Well Yields

The MOE water well record database included information on specific capacity for some, but not all records. Using water well records that provided a specific capacity result, an analysis of potential well performance for the bedrock and overburden was completed for both wells located within the Zone B and South District study areas. In an effort to improve the quality of the dataset, only those specific capacities that were calculated with a pumping test of at least 1-hour in duration were used in the analysis. The specific capacity was then multiplied by the available saturated thickness of the aquifer to determine the theoretical well yield. For bedrock wells, the available saturated thickness was calculated by summing the saturated thickness of the overburden and half of the saturated thickness of the bedrock for each well, minus 3 m to allow room for the installation of a pump. For overburden wells, the available saturated thickness was assumed to include the distance from the static level to the well bottom less 3 m for pump installation. The following provides a summary of theoretical well yields for each irrigation district.

6.1 ZONE B

Figure 28 presents the spatial distribution of specific capacities across the Zone B area. The majority of the specific capacities in the study area (75%) were less than 25 m^3/day per metre of drawdown, which is in agreement with WHI et al. (2005). Approximately 17% of wells had specific capacities ranging from 25 to 75 m^3/day per metre of drawdown, with the remainder exceeding 75 m^3/day per metre of drawdown. Available aquifer drawdown in Zone B bedrock wells ranged from 0.1 m to 30.2 m, with an average of 5.49 m.

Figure 29 presents the distribution of theoretical well yields within Zone B compared with the distribution of irrigation demand. In addition, a statistical analysis and summary of theoretical well yields compared with parcel irrigation demand is provided on Figure 30. As shown on Figure 30, there is a wide range in theoretical well yields across Zone B; however, the bulk of the theoretical yield estimates are less than 250 m^3/d. The median theoretical yields for overburden and bedrock wells were 17 m^3/day and 49 m^3/day, respectively. Only nine overburden wells with suitable data to determine the theoretical yield were available while 277 bedrock wells available, which highlights the importance of the bedrock in Zone B for providing domestic water supply. This trend is consistent with the geological interpretation of the study area that suggests that there are no significant overburden aquifer systems in Zone B.

In comparison to the theoretical yield estimates, the peak irrigation demand ranges from 23 to 1,948 m^3/day/parcel with a median peak irrigation demand of 486 m^3/day/parcel. Recognizing that the distribution of bedrock theoretical yields exhibited the characteristic shape of a log-normal distribution, the mean and standard deviation of the natural log transformed theoretical yield data were determined and cumulative probability density function plotted (Figure 30) to aid in estimating the probability of establishing a bedrock (Lockport Formation) well that could supply the required irrigation demand. The results of the probability analysis is presented graphically on Figure 30 and summarized as follows:

Irrigation Demand (m^3/d)	No. of Parcels in Zone B	Percentage of Parcels (%)	Probability of Establishing a Bedrock Supply (%)
0-50	2	1	48
50-100	2	1	48-29
100-200	7	5	29-15
200-300	20	14	15-9
300-400	20	14	9-6
>400	96	65	<6

Notes: Refer to Figure 30.

These data suggest that the probability of establishing a single well on each parcel to meet the irrigation demand is extremely low in Zone B (i.e., less than 50% in all cases and less than 6% for 96 of 147 parcels that would require more than 400 m^3/d).

The opportunity of establishing multiple irrigation wells on each parcel was considered in an effort to help compensate for the low individual well yields. This assessment was completed by considering: (1) the spacing that might be required between wells to avoid potential well interference issues; (2) the fact that most parcels already have an existing well for residential supply purposes; and (3) parcel size. Based on the unconfined Theis solution and using a median aquifer transmissivity of 17 m^2/day (calculated from specific capacity data), storativity of 0.001 (Freeze and Cherry, 1979), and aquifer thickness of 5 m, it was estimated (using the Aqtesolv software package) that approximately 1 m of aquifer drawdown (approximately 20% of the available drawdown) would occur at a distance of 200 m from a well pumping continuously at a rate of 50 m^3/day for 60 days (see predicted drawdown cone, Appendix E). A well spacing of 400 m would therefore be recommended to avoid potential well interference issues. Given the range of parcel sizes and considering that most parcels already have an existing residential well, the maximum number of irrigation wells that could fit on each parcel would typically range from 1 to 2 to avoid interference concerns. This would not be sufficient to meet the irrigation demand of over 90% of the parcels.

Based on these results, together with the water quality concerns presented above, it was concluded that groundwater is not a viable irrigation source for Zone B.

6.2 SOUTH DISTRICT

Figure 31 presents the distribution of specific capacities across the South District. The majority of the specific capacities in the study area (55%) were less than 25 m^3/day per metre of drawdown, which is in agreement with WHI (2005). Approximately 27% of wells had specific capacities ranging from 25 to 75 m^3/day per metre of drawdown, with the remainder exceeding 75 m^3/day per meter of drawdown. Available aquifer drawdown in South District bedrock wells ranged from 0.5 to 52 m, with an average of 21 m.

The hydrogeological significance of the Erigan channel was assessed by comparing wells thought to be completed within the Erigan channel with other wells completed in the South District. The MOE WWR indicated that 65 wells are positioned within the bedrock lows interpreted to be associated with the eastern and western branches of the Erigan channel. In total, 38 wells were completed in the overburden and 27 wells completed in the bedrock. The median specific capacity of the Erigan channel wells were 21 m^3/d/m in the overburden and 5 m^3/d/m in the bedrock. The ratio of overburden to bedrock wells is greater in the vicinity of the Erigan channel. Based on these data, the probability of establishing an overburden well in the vicinity of the Erigan channel is greater; however, the capacities of these wells are similar to other wells completed in the South District.

Figure 32 presents the distribution of theoretical overburden and bedrock well yields within the South District compared with the distribution of irrigation demand. In addition, a statistical analysis and summary of theoretical well yields compared with parcel irrigation demand is provided on Figure 33. As shown on Figure 33, there is a wide range in theoretical well yields across the South District between the overburden and bedrock wells; however the bulk of the estimated yields are less than 400 m^3/d. The median estimated well yield in the overburden and bedrock aquifer systems is 257 m^3/day and 272 m^3/day, respectively, suggesting that the bedrock wells yield slightly more than the overburden wells.

In comparison to the theoretical yield estimates, the irrigation demand ranges from 50 to 1,784 m^3/day/parcel with a median irrigation demand of 322 m^3/day/parcel. Recognizing that the distribution of theoretical yields exhibited the characteristic shape of a log-normal distribution, the mean and standard deviation of the natural log transformed theoretical yield data were determined and cumulative probability density function plotted (Figure 30) to aid in estimating the probability of establishing an overburden or bedrock well that could supply the required irrigation demand. The results of the probability analysis is presented graphically on Figure 33 and summarized as follows:

Irrigation Demand (m^3/d)	No. of Parcels in South District	Percentage of Parcels (%)	Probability of Establishing a Bedrock Supply (%)
0-100	7	10	76
100-200	15	21	76-61
200-300	13	18	61-52
300-400	7	10	52-45
400-500	3	4	45-39
500-600	6	8	39-35
>600	21	29	<35

Refer to Figure 33.

These results suggest that the probability of establishing a well in the overburden or bedrock are greater than 75% for 10% of the parcels with the lowest irrigation demands and greater than 52% for parcels with irrigation demands less than 300 m^3/d (35 of 72 parcels). The probability of establishing a well for the remaining 37 parcels with irrigation demands exceeding 300 m^3/d was typically less than 50%.

As with Zone B, the opportunity of establishing multiple irrigation wells on each parcel was considered. This assessment was completed by considering: (1) the spacing that might be required between wells to avoid potential well interference issues; (2) the fact that most parcels already have an existing well for residential supply purposes; and (3) parcel size. Based on the Theis unconfined solution and using a median aquifer transmissivity of 20 m^2/day (calculated from specific capacity data), storativity of 0.001 (Freeze and Cherry, 1979), and aquifer thickness of 25 m, it was estimated (using the Aqtesolv software package) that approximately 3.5 m of aquifer drawdown (approximately 15% of the available drawdown) would occur at a distance of 200 m from a well pumping continuously at a rate of 200 m^3/day for 60 days (see predicted drawdown cone, Appendix E). A reasonable well spacing would therefore be in the range of 400 m. Given the range of parcel sizes and considering that most parcels already have an existing residential well, the maximum number of irrigation wells that could fit on each parcel would typically range from 1 to 2 to avoid interference concerns. This would be sufficient to meet the irrigation demand of about 60% of the farm parcels.

7.0 Impact Assessment – South District

Given that groundwater is not a viable irrigation source for Zone B, the impact assessment focuses on the South District. In an effort to understand the potential environmental impacts of extracting groundwater for irrigation, the amount of recharge required to balance pumping was completed at the watershed level. The annual volume of water required for irrigation was calculated by using the average seasonal irrigation demands for each crop type (Section 3.3) multiplied by the estimated area under cultivation. The results are summarized in Table 2 and discussed below.

The annual groundwater demand for each watershed ranges from 1,969 m^3/yr (<0.1 L/s) in the Drapers Creek watershed to 2,711,579 m^3/yr (86 L/s) in the Fifteen Mile Creek watershed. The total annual groundwater demand for the South District was estimated to be 4,980,842 m^3/yr (158 L/s), of which 33 L/s (21%) was estimated to be irrigation demand.

As discussed in Section 4.2, the work completed by Blackport (2005) indicated that the surplus water recharging the deeper groundwater system may range from 21 L/s to 225 L/s. This water may be available for extraction without impacting the function of surface water courses. Existing PTTW and rural domestic demands total approximately 125 L/s, suggesting that available additional water for irrigation ranges from zero (i.e., the existing demand already exceeds the rate of recharge to the deeper systems) to 100 L/s. The water balance for the South District would need to be further refined in order to determine if an additional irrigation demand of 33 L/s would be sustainable.

8.0 Estimated Well Construction Costs

An estimated cost to drill and construct a supply well in the South District based on the following assumptions:

- Well depth ranging from 30 m to 50 m. Drilling costs assume to including mob/de-mob, drilling, well casing/grout, and development. A cost to complete a 152 mm (6”) diameter and 203 mm (8”) diameter well are provided. A 152 mm diameter well is optimal for well yields of up to 6.3 L/s (545 m^3/day) and a 203 mm diameter well is optimal for well yields ranging from 6.3 L/s to 11 L/s (545 to 954 m^3/day).
- Installation of a 100 mm (4”) or 152 mm (6”) diameter submersible pump and pitless adapter;
- Pump testing and permitting; and
- Irrigation infrastructure costs were not considered.

Based on these assumptions, the cost per well was estimated at:

Construction of 152 mm (6”) Diameter Well

Well Construction	$22,000 to $25,000
Pump/Pitless Installation and Labor	$20,000
Pump Testing and Permitting	$25,000 to $35,000
Total Estimated Cost – 152 mm Diameter Well	**$67,000 to $80,000**

Construction of 203 mm (8”) Diameter Well

Well Construction	$30,000 to $40,000
Pump/Pitless Installation and Labor	$30,000
Pump Testing and Permitting	$25,000 to $35,000
Total Estimated Cost – 203 mm Diameter Well	**$85,000 to $105,000**

9.0 Conclusions and Recommendations

The hydrogeological assessment focused on two separate study areas referred to as Western District Zone B and the South District. Zone B is a relatively narrow strip of land located adjacent to the northern face of the escarpment, whereas the South District is situated on the Fonthill Kame-Delta Complex. Conclusions and recommendations for each study area are provided below:

Western District Zone B

It was concluded that establishing a groundwater sourced irrigation supply in Zone B was not feasible, based on the following:

1. The dolostone bedrock (Lockport Formation) was the only aquifer identified in Zone B. The probability of establishing a bedrock well, or multiple wells where space permits, in order to meet the irrigation demand of each parcel is typically less than 10% due to low well yields; and

2. Available water quality data indicated that the dolostone can contain elevated concentrations of total dissolved solids and manganese compared with the Canadian Water Quality Guidelines for the Protection of Agricultural Water Uses. Other parameters of potential concern include chloride and iron. As a result, even if a grower were able to establish a high yielding well(s) for irrigation, water quality is likely to be an issue.

South District

The following conclusions are presented for the South District:

1. The sand and gravel deposits of the Fonthill Kame-Delta Complex and the upper dolostone bedrock (Guelph and Lockport Formations) were identified as potentially suitable aquifer systems to establish wells for irrigation. The probability of establishing an irrigation supply decreases with increasing demand, from greater than 75% probability for parcels with irrigation demands of less than 100 m^3/day (10% of parcels) to less than 35% probability for parcels with irrigation demands of more than 600 m^3/day (29% of parcels);

2. The Erigan bedrock channel was not considered to be a significant hydrogeological feature, based on available water well information;

3. The overburden and bedrock water quality data for the South District is variable and may be suitable for irrigation purposes in some areas but not in others. The water quality would need to be evaluated at the parcel level to determine its suitability for irrigation. Specific parameters of concern include total dissolved solids, manganese, iron and chloride;

4. Based on the water balance calculations for the Fonthill Kame-Delta Complex, water infiltrates to the deeper aquifer systems at a rate ranging from 21 L/s to 225 L/s. Existing groundwater demand was estimated to be 125 L/s, suggesting that further refinement of the water balance would be required to understand if an additional irrigation demand of 33 L/s was sustainable; and

5. The cost to construct, permit and equip a 152 mm diameter irrigation well is estimated to be in the range of $67,000 to $80,000. The cost of a larger 203 mm diameter well is estimated to range from $85,000 to $105,000. The costs assume a well depth ranging from 30 m to 50 m and do not include any aboveground irrigation infrastructure costs.

Based on these findings, Stantec concluded that it was not feasible to establish a well-based irrigation supply for all parcels across the South District. Recognizing that some of the above conclusions are based on limited data, further study would be required to determine if there was an opportunity for some of the lower irrigation demand parcels (i.e., less than 300 m^3/day) to establish well-based irrigation systems. To further investigate this opportunity, Stantec recommends that the following studies be completed for the South District:

1. To provide additional water quality information, a private well survey and sampling program should be undertaken in the rural areas of the South District. Groundwater samples should be submitted for inorganic analysis of metals, major anions and general chemistry and compared to the irrigation quality guidelines to determine suitability. An effort should be made to match each sampled well with the corresponding MOE Water Well Record so that conclusions related to individual aquifer units can be made;

2. Additional stream flow data should be collected from the watercourses that originate from the Fonthill Kame-Delta Complex to augment the data previously collected by Blackport (2005). Stream flow measurements should be collected during wet and dry periods over several seasons to accurately determine the baseflow and runoff contribution to the watercourses. In addition, the gauge data from the St. John’s and Effingham tributaries should be incorporated into the baseflow estimates. This information, together with precipitation records and evapotranspiration data, is necessary to further refine the water balance;

3. Continuous groundwater level measurements should be collected at a select number of monitoring wells completed in the overburden and bedrock aquifer systems. This information will assist with calibrating the groundwater flow model and provide an indication of seasonal/annual groundwater levels;

4. A weather station should be established within the South District, ideally within the Twelve Mile Creek watershed since this is the most sensitive watershed within the South District. The climate data from this station would be used to further refine the water balance for the South District;

5. As indicated in Blackport (2005), the Fonthill Kame-Delta Complex should be modeled using a finite element model (i.e., FEFLOW) to allow for a more realistic representation of surficial topography, particularly in the vicinity of watercourses where an understanding of groundwater / surface water interaction is critical. The additional stream flow data should be used to calibrate the model. The model should include all PTTW users identified in the model domain and be used to simulate irrigation pumping conditions and to investigate potential impacts to surface water features, particularly during the summer high irrigation water demand period. This process will provide more quantitative insight into the sustainable groundwater yield in the South District; and

6. An effort should be made to more accurately quantify the actual takings of existing PTTW users in the South District. If large discrepancies occur between the actual and permitted takings, there may be an opportunity to revise the permits so that additional groundwater would be available for irrigation.

All of which is respectfully submitted,

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APPENDIX A

FIGURES

APPENDIX B

TABLES

TABLE 1
Watershed-Based Groundwater Demand

ZONE B

Watersheds Intersecting Study Area	Area	Area	Population Estimate	Rural Domestic Demand	Existing PTTW Demand*	Estimated Annual Irrigation Demand
	(km^2)	(m^2)	(persons)	(m^3/yr)	(m^3/yr)	(m^3/yr)
Bartlett/Konkle Creek	2.28	2,279,468	41	2,635	-	60,452
Beamsville Creek	2.44	2,444,335	44	2,826	-	137,650
Campden Creek	0.22	217,228	4	251	-	914
Eighteen Mile Creek	6.92	6,916,074	125	7,996	-	340,764
Fifteen Mile Creek	2.14	2,140,407	39	2,475	-	34,460
Forty Mile Creek	14.41	14,410,048	261	16,660	-	414,197
Gavora Ditch	7.03	7,027,452	127	8,125	46,150	151,536
Lake Ontario 24	0.60	602,681	11	697	-	48,791
Lake Ontario 25	0.54	541,391	10	626	-	1,567
Lake Ontario 29	0.60	600,700	11	694	-	1,524
Lake Ontario 31	0.16	164,378	3	190	-	8,560
Lake Ontario 32	1.06	1,056,309	19	1,221	-	59,631
Lake Ontario 34	0.08	79,361	1	92	-	29,656
Lake Ontario 38	0.50	504,450	9	583	-	4,005
Lake Ontario 39	0.11	105,774	2	122	-	6,772
Lake Ontario Creek	0.91	906,396	16	1,048	-	108,630
Prudhommes Creek	1.83	1,833,534	33	2,120	-	57,969
Sixteen Mile Creek	6.69	6,688,025	121	7,732	-	70,308
Spring Creek	5.78	5,779,860	105	6,682	-	86,753
Thirty Mile Creek	6.64	6,635,483	120	7,672	-	229,790
Twenty Mile Creek	3.05	3,049,814	55	3,526	-	77,359
Vineland Drain	1.70	1,700,020	31	1,965	-	78,580
Total	**65.68**	**65,683,186**	**1,189**	**75,939**	**46,150**	**2,009,868**

SOUTH DISTRICT

Watersheds Intersecting Study Area	Area	Area	Population Estimate	Rural Domestic Demand	Existing PTTW Demand	Estimated Annual Irrigation Demand
	(km^2)	(m^2)	(persons)	(m^3/yr)	(m^3/yr)	(m^3/yr)**
Coyle Creek	11.49	11,487,881	208	13,282	-	78,580
Drapers Creek	1.70	1,703,211	31	1,969	-	-
Fifteen Mile Creek	12.02	12,019,439	218	13,896	1,985,102	712,581
Upper Twelve Mile Creek	15.63	15,634,361	283	18,075	1,895,150	260,421
Welland Canal North	4.50	4,498,046	81	5,200	-	-
Total	**45.34**	**45,342,939**	**821**	**52,423**	**3,880,252**	**1,051,582**

Notes

Rural domestic demand based on population density of 18.1 people/km2 and per capita use of 175 L/d (WHI et al., 2005)

* PTTW with source field listed as "both" were assumed groundwater

TABLE 2
Watershed-Based Recharge Availability Analysis
South District

SOUTH DISTRICT

Watersheds Intersecting Study Area	Area	Area**	Population Estimate	Rural Domestic Demand	Existing PTTW Demand	Estimated Average Annual Irrigation Demand		Total Demand	Surplus Recharge Required to Balance Demand
	(km^2)	(m^2)	(persons)	(m^3/yr)	(m^3/yr)	(m^3/yr)	(L/s)	(m^3/yr)	(mm/yr)
Coyle Creek	10.74	10,744,573	194	12,422	-	78,580	2	91,002	8
Drapers Creek	1.70	1,703,211	31	1,969	-	-	-	1,969	1
Fifteen Mile Creek	12.02	12,019,439	218	13,896	1,985,102	712,581	23	2,711,579	226
Upper Twelve Mile Creek	14.57	14,573,352	264	16,849	1,895,150	260,421	8	2,172,420	149
Welland Canal North	3.35	3,348,595	61	3,871	-	-	-	3,871	1
Total	**42**	**42,389,170**	**767**	**49,008**	**3,880,252**	**1,051,582**	**33**	**4,980,842**	**118**

Total Demand - South District (L/s)	**158**	
Baseflow Spot Flow Measurements [Blackport, 2005] (L/s)	192	*Low*
	244	*Mid*
	396	*High*
Annual Recharge Based on MODFLOW results [Blackport, 2005] (L/s)	417	
Estimated Excess Recharge [Recharge-Baseflow] (L/s)	225	*Using Low Baseflow*
	173	*Using Mid Baseflow*
	21	*Using High Baseflow*
Current Combined Domestic and PTTW Demand (L/s)	125	
Excess Recharge - Domestic and PTTW Demand (L/s) *Amount Available for Irrigation*	100	*Using Low Baseflow*
	48	*Using Mid Baseflow*
	-104	*Using High Baseflow*
Estimated South District Irrigation Demand (L/s)	33	
Remaining Excess Recharge After Meeting Irrigation Demand (L/S)	67	*Using Low Baseflow*
	15	*Using Mid Baseflow*
	-137	*Using High Baseflow*

Notes

Rural domestic demand based on population density of 18.1 people/km2 and per capita use of 175 L/d

* PTTW with source field listed as "both" were assumed groundwater

** Areas were adjusted to account for urbanized areas in Coyle Creek, Upper 12 Mile Creek, and Welland Canal North, which are considered to be serviced by surface water supplies

APPENDIX C

PTTW DETAILS

TABLE C.1
PTTW Details - Zone B

Permit[1]	Easting	Northing	Surface / Ground[2]	Purpose	Zone	Subwatershed	Max Litres Per Day	Days Taking Per Year	Assumed Days of Taking (d)	Annual Taking (m^3)
99-P-2041	622945	4776353	Ground	Instit.	Zone B	Gavora Ditch	50,000	Not Specified	365	18,250
01-P-2122[3]	623634	4776273	Ground	Rec.	Zone B	Gavora Ditch	225,000	124	-	27,900
									Sum Gavora Ditch Subwatershed	**46,150**

Notes

(1) Permit information extracted October 2006

(2) Where the source was described as "both" it was assumed that all taking was derived from groundwater sources

(3) Days of taking per year based on PTTW information provided by NPCA

TABLE C.2
PTTW Details - South District

Permit No.[1]	Easting	Northing	Surface / Ground [2]	Purpose	Zone	Subwatershed	Max Litres Per Day	Days Taking Per Year	Annual Taking (m^3)	Annual Taking (L/s)
03-P-2013	634783	4769473	Ground	Agric.	South District	Fifteen Mile Creek	681,000	365	248,565	8
1266-68DM4N	636455	4768053	Ground	Indust.	South District	Fifteen Mile Creek	206,400	30	6,192	0.2
1266-68DM4N	636547	4768048	Ground	Indust.	South District	Fifteen Mile Creek	71,000	30	2,130	0.1
99-P-2108C	635948	4767667	Ground	Indust.	South District	Fifteen Mile Creek	1,091,000	365	398,215	13
6334-6FJJZ4	634087	4768346	Ground	Agric	South District	Fifteen Mile Creek	764,000	15	11,460	0.4
03-P-2362[4]	635478	4766936	Ground	Comm.	South District	Fifteen Mile Creek	2,618,000	365	955,570	30
			Ground	Comm.	South District	Fifteen Mile Creek	2,724,000	90	245,160	8
			Ground	Comm.	South District	Fifteen Mile Creek	1,309,000	90	117,810	4
Sum Fifteen Mile Creek Subwatershed									**1,985,102**	**63**
01-P-2254[3]	639469	4767542	Ground	Water Supply	South District	Upper Twelve Mile Creek	164,000	365	59,860	2
	639457	4767536	Ground	Water Supply	South District	Upper Twelve Mile Creek				
02-P-2020	638254	4769489	Both	Water Supply	South District	Upper Twelve Mile Creek	190,000	365	69,350	2
02-P-2020	638284	4769487	Both	Water Supply	South District	Upper Twelve Mile Creek	240,000	150	36,000	1
03-P-2013	634882	4769670	Ground	Agric.	South District	Upper Twelve Mile Creek	1,135,000	365	414,275	13
	634601	4769536	Ground	Agric.	South District	Upper Twelve Mile Creek	3,048,000	365	1,112,520	35
6320-6QQRXQ	638664	4768825	Both	Comm.	South District	Upper Twelve Mile Creek	916,000	215	196,940	6
	638608	4768796	Both	Comm.	South District	Upper Twelve Mile Creek	17,000	365	6,205	0.2
Sum Upper Twelve Mile Creek Subwatershed									**1,895,150**	**60**

Notes

(1) Permit information extracted October 2006.

(2) Where the source was described as "both" it was assumed that all taking was derived from groundwater sources.

(3) PTTW info provided by NPCA indicated that permit 01-P-2254 has a maximum combined permitted daily rate of 164,000 L for the two sources.

(4) PTTW info provided by NPCA. Days taking per year was assumed based on general purpose of each source. UTMs are approximated.

APPENDIX D

IRRIGATION DEMAND CALCULATIONS

TABLE D1
Watershed-Based Annual Irrigation Demand

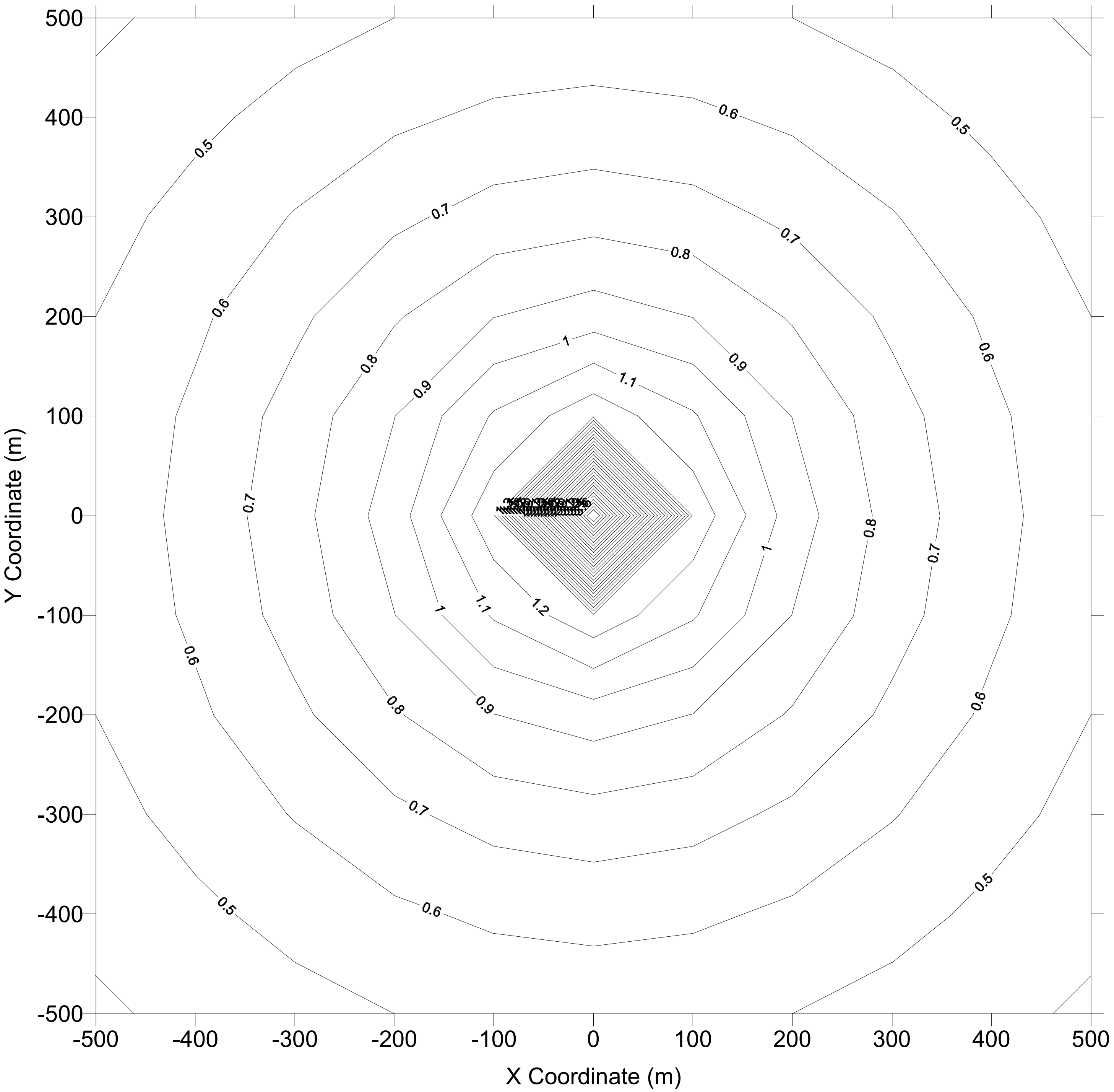
Land Use	**Grapes - Wine**	**Tender Fruit**	**Nurseries**	**Greenhouse**	**Grapes - Juice**	**Pome Fruit**		
Water Demand (m/yr)	0.130	0.280	0.180	0.700	0.1300	0.2800		
Area Factor	0.85	0.85	0.85	0.3	0.85	0.85		
Subwatershed Intersecting Study Area	**Area Used for Each Crop Type (m^2)**						**Total Cultivated Area (m^2)**	**Seasonal (Annual) Demand (m^3/yr)**
ZONE B								
Bartlett/Konkle Creek					547,073		465,012	60,452
Beamsville Creek	557,808				493,423	90,289	970,292	137,650
Campden Creek	1,290					3,242	3,853	914
Eighteen Mile Creek	1,938,056				1,145,785		2,621,265	340,764
Fifteen Mile Creek	44,532				267,321		265,076	34,460
Forty Mile Creek	732,928		99,118	40,965	1,607,313	553,917	2,556,574	414,197
Gavora Ditch	754,177				617,192		1,165,664	151,536
Lake Ontario 24	23,818				162,042	118,713	258,887	48,791
Lake Ontario 25						6,583	5,596	1,567
Lake Ontario 29					8,225	2,585	9,188	1,524
Lake Ontario 31					77,470		65,850	8,560
Lake Ontario 32						250,548	212,966	59,631
Lake Ontario 34	103,153					76,714	152,887	29,656
Lake Ontario 38	19,462					7,793	23,167	4,005
Lake Ontario 39					61,284		52,091	6,772
Lake Ontario Creek	983,073						835,612	108,630
Prudhommes Creek	524,608						445,917	57,969
Sixteen Mile Creek	383,763				252,507		540,829	70,308
Spring Creek					626,024	73,856	594,898	86,753
Thirty Mile Creek	476,295				426,928	546,151	1,231,967	229,790
Twenty Mile Creek	614,471				85,611		595,070	77,359
Vineland Drain	687,347	8,863				2,180	593,631	78,580
SOUTH DISTRICT								
Coyle Creek	272,759	701,994	744,172	49,460		1,823	1,477,474	78,580
Drapers Creek							0	0
Fifteen Mile Creek	295,127	1,518,570	668,355	362,572		725,895	2,835,527	712,581
Upper Twelve Mile Creek		452,395	474,694		185,093	250,715	1,158,462	260,421
Welland Canal North							0	0

TOTALS	**Grapes - Wine**	**Tender Fruit**	**Nurseries**	**Greenhouse**	**Grapes - Juice**	**Pome Fruit**	**Total Cultivated Area (m^2)**	**Seasonal (Annual) Demand (m^3/yr)**
ZONE B	7,844,782	8,863	99,118	40,965	6,378,197	1,732,571	13,666,291	2,009,868
SOUTH DISTRICT	567,886	2,672,960	1,887,221	412,031	185,093	978,433	5,471,463	1,051,582

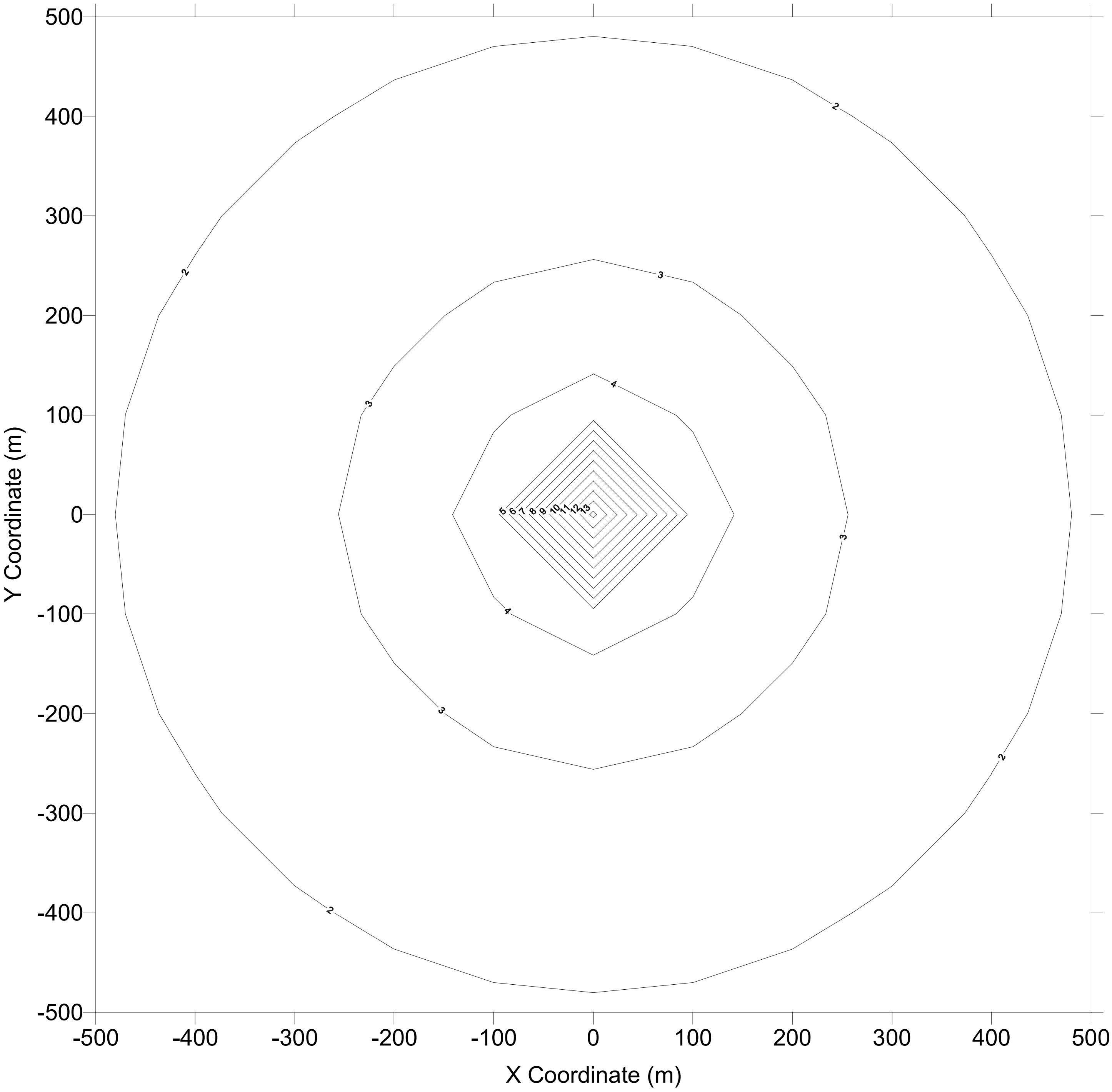
APPENDIX E

PREDICTED DRAWDOWN CONES USING AQTESOLV

Theis Confined Drawdown Cone - Zone B
T=17 m2/d, b=5, Q=50 m3/d, t=60 d



Theis Confined Drawdown Cone - South District
T=20 m2/d, b=25, Q=200 m3/d, t=60 d



APPENDIX F

MEMO ADDRESSING BENCH OPTIONS

Memo

Stantec

To:	Rajan Sawhney / Nathan Sherwood Kitchener Office	From:	Marty Cote / Roger Freymond Kitchener Office
File:	161110576/10	Date:	July 30, 2007

Reference: Irrigation Groundwater Availability - Niagara Peninsula Bench

INTRODUCTION

This memo was prepared to comment on the potential of establishing a groundwater-based irrigation supply on the Niagara Escarpment "Bench" area (the Bench). This area was not formally assessed as part of the Phase 2 Raw Water for Agricultural Irrigation Study (Stantec, 2007[1]) as it was located in Zone A, below the top of the Niagara Escarpment.

The Bench is a plateau feature of the Niagara Escarpment that is bounded by the Lincoln Township boundary to the west, 20 Mile Creek to the east, Regional Road 81 (King Street) to the north and the face of the escarpment to the south.

GROUNDWATER AVAILABILITY ASSESSMENT

It is our opinion that a groundwater-based irrigation supply is not feasible in the areas of the Bench, for the following reasons:

- Surficial geology mapping indicates that the bench area is covered by a layer of clay to silt textured till derived from glaciolacustrine deposits or shale. Bedrock is exposed in some areas. The clay or silt till material is on average approximately 9.3 m thick in this area and is not considered conducive to establishing irrigation supply;

- Bedrock mapping indicates that the bench area is underlain predominantly by the Queenston Shale. A relatively thin strip of bedrock belonging to the Clinton-Cataract Groups extends through the Bench area forming the midsection of the escarpment face and likely part of the "bench" physiography. These bedrock formations are typically characterized by poor water quality and low water yield, and would not support significant groundwater resource development; and

- A total of 78 water well records were located in the Bench area. Of these wells, 90% were completed into the bedrock and the remaining 10% in the overburden, suggesting that the overburden is rarely suitable for domestic well purposes.

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[1] Stantec Consulting Ltd. (Stantec), 2007. Raw Water for Agricultural Irrigation Study – Phase 2. Report prepared for the Regional Municipality of Niagara

We trust that this summary meets your current requirements pertaining to groundwater availability in the bench area. Please let us know if you require any additional information.

STANTEC CONSULTING LTD.

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Attachment: