

**Grey and Bruce Counties
Groundwater Study**

Final Report

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Prepared by:

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WHI Project # 3020337

Prepared for:

**County of Bruce
County of Grey
Ontario Ministry of the Environment**

August 5, 2003

Grey and Bruce Counties Groundwater Study
Steering Committee

Re: Final Report
Grey and Bruce Counties Groundwater Study

Dear Committee Members,

On behalf of our Consultant Team, it is with pleasure that we submit the Final Report for the Grey and Bruce Counties Groundwater Study. The report presents the characterization of regional groundwater resources, and the results of a contaminant sources inventory, groundwater use assessment and the Wellhead Protection Area modeling. Comprehensive data has been compiled, analysed and presented to highlight the significance of this information as it relates to the Objectives of the Groundwater Study.

Assimilating the results of such diverse and thorough analyses into a comprehensive report that outlines regional groundwater resource management and local groundwater protection measures has been a challenging but valuable undertaking. The groundwater protection measures will help municipalities develop plans to more adequately manage their groundwater resources.

We look forward to your comments on the methodology, analyses and results of this study.

Yours truly,
WATERLOO HYDROGEOLOGIC, INC.

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Executive Summary

Grey and Bruce Counties rely heavily on groundwater as a source of supply for its drinking water needs, and are fortunate that the quantity of groundwater available is capable of meeting the current water demand and that the water is of excellent quality. However, potential threats to the quantity and quality of this resource exist within the Counties. The Grey and Bruce Counties Groundwater Study was undertaken to develop an improved understanding of local groundwater conditions within the context of larger regional groundwater flow systems. This groundwater study has brought together and evaluated an extensive compilation of regional and local water resources information, which is reflected in the scope of work that has been completed.

The area encompassed by the study, as presented in Figure 1.1, includes the County of Grey, the County of Bruce, and a 5 kilometer buffer area around them. The study partners acknowledge that the basic groundwater functions (recharging, transmitting, assimilating potential contaminants, storing and discharging water) play an essential role in maintaining the health of an ecosystem. Better understanding these regional groundwater functions is helpful to provide a secure supply of clean water to municipal and communal water systems, as well as to individual groundwater users who do not have access to a municipal supply.

Existing and future land use practices exercised throughout the Counties may pose threats to the long-term sustainability of groundwater resources for both quantity and quality. This study provides a more thorough understanding of local and regional groundwater resources that will aid in the development of sound groundwater management and groundwater protection measures to help ensure the long-term sustainability of the resource.

The study partners reflect the regional and local relevance of groundwater in this study. They include the Ministry of the Environment (MOE), County governments, Conservation Authorities, and local consultants. The MOE is the project's major funding organization and provincial partner. The Grey County Planning Department, the Bruce County Planning Department, the Saugeen Valley Conservation Authority (SVCA) and the Grey Sauble Conservation Authority (GSCA) are also major partners to the study and have provided funding for its completion.

At the onset of the study and number of objectives were developed by the Study Partners. The objectives of the Grey and Bruce Counties Groundwater Study are provided below:

- Objective 1: To define and map local and regional groundwater conditions;
- Objective 2: To define groundwater intrinsic susceptibility;
- Objective 3: To compile a contaminant sources inventory;
- Objective 4: To complete wellhead protection area (WHPA) mapping for 48 municipal groundwater well systems;
- Objective 5: To conduct a contaminant source assessment within each WHPA;
- Objective 6: To develop a municipal action plan for implementing a groundwater protection strategy; and,
- Objective 7: To promote public groundwater awareness throughout the study area through open houses, local media news releases, and a project website.

Source protection is an excellent term to describe the different study objectives listed above. Source protection is the first of five barriers commonly applied to provide safe drinking water, as outlined in Report 2 of the Walkerton Inquiry (O'Connor, 2002). The other four barriers include

treatment, a secure distribution system, water quality monitoring, and well-planned responses to adverse conditions.

It is important to reflect on the detail incorporated into the regional mapping presented in this report and to consider appropriate uses for this information. A large portion of the groundwater and aquifer characterization mapping developed for this study was completed at a regional-scale. The mapping used point information to develop themes such as the depth to bedrock, sand and gravel thickness, water table elevation, and aquifer vulnerability. The point information used to develop this mapping is included as small dots on each relevant map. This has been done to remind the end users of these products that, although the mapping represents continuous surfaces, it was developed from point data that is not evenly distributed throughout the study area. The quality of the point data used in the mapping has been evaluated and is considered acceptable for its purpose, however it has not been field verified. As such, it is important to remember that the mapping is an interpreted representation of the real world.

The regional maps are presented at a scale of 1:650,000. This means that a 1 mm line is accurate to within 650 m, and a 1 cm by 1cm square is accurate to within 4.225 ha. This level of detail is not appropriate for site-specific interpretation, but it does provide valuable information for regional scale analyses.

This report was organized in sections to address the study objectives outlined above. The sections are organized by topic to coincide with the different regional and local study objectives. The study also includes a comprehensive groundwater protection strategy and provides detailed conclusions and recommendations. Brief descriptions of the topics included in each of the sections are provided in the following paragraph.

Section 2 presents the regional groundwater and aquifer characterization. This characterization was used to complete the groundwater susceptibility analysis, which is presented in Section 3. Section 4 presents the groundwater use assessment, which was completed to evaluate how groundwater is used throughout the Counties, and to develop a general regional water budget. A contaminant sources inventory was completed to identify potential contaminant sources throughout the Counties, and is presented in Section 5. Using the information generated in Sections 2, 3, and 4, groundwater modeling was completed to map, at a local-scale, time-of-travel municipal wellhead protection areas. The groundwater modeling and wellhead protection area mapping results are presented in Section 6. In Section 7, the WHPA boundaries are overlain with the groundwater susceptibility and potential contaminant sources and evaluated at a local-scale. Public consultation aspects of the study are presented in Section 8. A groundwater protection strategy is outlined in Section 9. Study recommendations are presented in Section 10. A glossary of technical terms and abbreviations is presented in Section 11, and references are presented in Section 12. Most of the figures for the study are presented in 11"x17" or 30"x36" format under separate cover so that these figures can be reviewed while reading through the report.

Groundwater and Aquifer Characterization

Groundwater is a safer and cleaner form of water supply, when compared to surface water. Understanding how groundwater moves through the Counties, and the factors that control this movement will help to manage the resource.

Information from many different data sources, including the Ministry of Environment, Ministry of Natural Resources, Ministry of Northern Development and Mines, Geologic Survey of Canada, Water Survey Canada, Grey and Bruce Counties, the Saugeen Valley Conservation Authority,

the Grey Sauble Conservation Authority, local municipalities and local consultants has been incorporated into a project database and GIS. The quality of the different sources of information was evaluated and data that was deemed inaccurate was not included in subsequent analyses.

In addition to the information referred to above, the project team compiled a volume of previous reports related to groundwater resources in Grey and Bruce Counties. These reports include local-scale hydrogeologic analyses (completed in support of the development of municipal groundwater supply wells, solid waste landfills, sanitary sewage works, and subdivision developments), First Engineer's Reports, reports supporting Permit To Take Water applications, and regional-scale assessments of groundwater resources within the Counties. These reports provide useful information on the geology and hydrogeology of the study area, and are presented in the References (Section 12).

As part of the regional analysis, maps were developed for the location and reliability of MOE water wells (Figures 2.1 and 2.2), ground surface topography (Figure 2.3), and the surface drainage and stream gauge locations (Figures 2.4A and B). The geology of Grey and Bruce Counties was investigated and presented in the Physiography map (Figure 2.5), the Quaternary geology map (Figure 2.6) and the bedrock geology and bedrock surface topography (Figures 2.7 and 2.8) maps.

Regional geologic cross-sections were developed to illustrate the bedrock and Quaternary geology, topography, and their relationships across the study area. The location of the regional cross sections was presented in Figure 2.9, and the cross-sections were presented in Figures 2.10 to 2.17. In particular, they show the parallel nature of the bedrock and ground surface topography, the thinning nature of the overburden going from west to east, approaching the rim of the Niagara Escarpment, and the distribution of sand and gravel units associated with the Port Huron Moraine, in the south central portion of the study area. Details of the geology and its relationship to the regional water table and hydrogeology are discussed throughout this report.

The nature of the overburden deposits in Grey and Bruce Counties was investigated and presented in the depth to bedrock (Figure 2.18), and sand and gravel thickness (Figures 2.19) maps. The hydrogeology of Grey and Bruce Counties was investigated and presented in the water table surface (Figure 2.20), bedrock equipotentials (Figure 2.21), and vertical gradients (Figure 2.22) maps. The water table elevation map and bedrock equipotential map show the inferred regional groundwater flow directions in the overburden and bedrock aquifers, and the recharge/discharge relationships that exist throughout the Counties.

The hydrogeology of Grey and Bruce Counties was conceptualized as a three-layered model with, from top to bottom, a fine-grained overburden aquitard layer, a thin weathered bedrock aquifer layer, and a thick unweathered bedrock aquifer. Details of the subsurface hydrogeologic conditions in the Counties were determined by examining 8 regional cross-sections and many local cross-sections. The aquifers of Grey and Bruce Counties are summarized in an overburden aquifer map (Figure 2.23) and a bedrock aquifer map (Figure 2.24). This conceptualization of regional hydrogeology was used as the basis for the development of the WHPA models, which are discussed in Section 6. Specific capacity of municipal wells was assessed, and presented in Figure 2.25, using data from pumping tests of at least a 24-hour duration. Groundwater quality throughout the Counties was evaluated through a review of raw water quality presented in the Engineer's Reports for the different municipal wells. Parameters that were considered in this analysis include chloride, nitrate, fluoride, iron, hardness, and turbidity. This groundwater quality assessment was presented in Figure 2.26.

Finally, the analysis presented in this report provides a summary of regional groundwater and aquifer characterization in Grey and Bruce Counties. To augment this analysis, four additional maps were created at a 1:200,000 scale to present the groundwater and aquifer characterization at a more detailed, larger scale. Figure 2.27 shows the study area, the location of the WWIS wells that were used for the data analysis and the ground surface topography. Figure 2.28 shows the regional Quaternary geology, and includes the overburden thickness contours. Figure 2.29 shows the regional bedrock geology, and includes the bedrock geology classes and bedrock topography contours. Figure 2.30 shows the regional overburden and bedrock aquifers, and includes the reliable water wells within the study area (along with their completion depth and geology), and the contours of sand and gravel thickness below the water table as an indication of overburden aquifer locations.

Intrinsic Susceptibility Analysis

The susceptibility of an aquifer to contamination is a function of the susceptibility of its recharge area to the infiltration of contaminants. Groundwater susceptibility can thus be defined as: *the tendency or likelihood for contaminants to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer*. Susceptibility is not an absolute property, but a relative indication of where contamination may enter the subsurface. It is also necessary to consider long-term effects on groundwater quality, perhaps over decades, in carrying out a susceptibility analysis.

Intrinsic susceptibility for the uppermost significant aquifer (the water table aquifer) was assessed using information contained within the MOE Water Well Information System and the location of identified karst features in Grey and Bruce Counties. The approach followed the method outlined in the MOE Technical Terms of Reference. This method considers the thickness of the different geologic strata as well as their permeability through the use of a K-factor. Polygons representing the identified karst areas (caves, sinkholes, sinking streams, sinking lakes, and karst pavement) within the Counties were overlain, incorporated into the GIS and given a high susceptibility value. Within the uppermost aquifer system, areas of low, medium, and high susceptibility were identified using the MOE susceptibility classes (low (ISI > 80), medium (30 ≤ ISI ≤ 80) and high (ISI < 30)).

Figure 3.1 present the map of Intrinsic Susceptibility, which was interpolated across the entire study area. In addition, a 1:200,000 map (Figure 3.2) was created on a 30" by 36" layouts to show Intrinsic Susceptibility at a more detailed, larger scale, and includes the identified karst areas and contaminant sources. High and medium susceptibility classes are the most important to consider, and Figure 3.1 shows that a substantial portion of the study area is classified as either high or medium susceptibility. The Bruce Peninsula is an area of medium to high susceptibility as a result of the thin and discontinuous nature of the Quaternary cover material providing little protection to the underlying bedrock. This is shown in the Canadian Parks Service field investigation of karst features of the Upper Bruce Peninsula. The remainder of the medium and high susceptibility areas trend from the base of the Bruce Peninsula to southern Grey County and roughly correspond to the occurrence of the Guelph and Amabel Formations underlying it. The higher susceptibility rating for these units is related to the fact that they are generally more permeable than other bedrock units in the area.

Areas of low susceptibility occur mainly in the southwest portion of Bruce County, and correspond to the clay and silt-rich Quaternary deposits of the Huron Slope. This fine-grained surface material restricts the downward movement of infiltrating surface water, making the underlying groundwater much less susceptible to associated contamination.

In areas of high susceptibility near municipal pumping wells, it is recommended that municipal planning measures be developed to restrict development, or to require local-scale hydrogeologic investigations that assess the vulnerability of the aquifer to contamination.

Groundwater Use Assessment

An improved understanding of groundwater use is essential to managing groundwater resources across the counties, evaluating different municipal well capture zones, and conducting a regional water budget. A regional groundwater use assessment was conducted using information on municipal, communal, agricultural, private and industrial water taking. Data for the groundwater use assessment was obtained from the MOE Permit to Take Water (PTTW) database, municipal water supply reports (Engineer's Reports), MOE Water Well Information System (WWIS), and Certificates of Approval. Population estimates, which were used to estimate domestic water use, were obtained from Statistics Canada. Land use information was provided by the Counties (Figures 4.1 and 4.2). An analysis was completed to evaluate the distribution and intensity of agricultural activities to assess potential impacts on groundwater quality, and concentrated on the extent, intensity, proximity and nature of agricultural activities.

The aforementioned data was used to complete a water budget analysis of the study area, to provide information about the quantity of groundwater currently being used in Grey and Bruce Counties. An analysis of the Permits To Take Water shows that there are 422 permits in the PTTW database and that these permits correspond to 553 water sources (wells, springs or ponds). Of the 422 PTTW, there are 254 PTTW using groundwater, of which 168 are active permits and 37 are large-scale users (having a maximum permitted rate of more than 200,000 L/day). Figure 4.3 presents the locations of the 254 groundwater permits in the Counties classified by maximum permitted rate. A survey was completed of the large-scale users, and municipal water works to gather information about actual water use. Based on maximum permitted rate, groundwater use by large-scale users is 207,617 m³/day in the Counties.

Estimates of the rural population of the study area were used to determine rural domestic groundwater use, which is 12,969 m³/day. The Engineer's Reports were used to determine municipal groundwater use, which is 18,614 m³/day. The PTTW database was used to estimate communal and campground groundwater use, which is 2,971 m³/day. Census Canada data was used to estimate agricultural groundwater use, which is 22,373 m³/day. A summary of the total daily and yearly groundwater taking for Grey and Bruce Counties is as follows:

- Large-scale User Groundwater Taking: 75.8 million m³/year (207,617 m³/day)
- Rural Groundwater Use: 4.7 million m³/year (12,969 m³/day)
- Municipal Groundwater Taking: 6.8 million m³/year (18,614 m³/day)
- Agricultural Groundwater Taking: 8.2 million m³/year (22,373 m³/day)
- Water Supply (communal and campground) 1.1 million m³/year (2,971 m³/day)
- Total Groundwater Taking: 96.6 million m³/year (264,544 m³/day)

Subsequently, a water budget analysis was completed using information on Canadian Climate Normals (1961-1990) from Agriculture and Agri-Food Canada. Based on average recharge, the water budget is summarized as follows:

- Precipitation: 8,483.0 million m³/year
- Evapotranspiration: 5,140.0 million m³/year
- Recharge: 975.0 million m³/year
- Runoff: 2,368.0 million m³/year

Recharge is, on average between 75 and 150 mm/year across the Counties, which results in average groundwater recharge of approximately 975 million m³/year. From this we see that the combination of rural, municipal, communal and agricultural groundwater use (20.8 million m³/year) is approximately 2.1% of available recharge, and that permitted groundwater use by large users (75.8 million m³/year) is approximately 7.8% of available recharge. This means that only a fraction (9.9%) of the available recharge is currently being used for water supply within the Counties. However, actual water taking by large users is mostly unknown. It may be much less than the permitted rate, but could be up to 4 times as large as the water takings of all other groundwater uses combined. As such, it is the one use of groundwater within the Counties that may pose a risk to the quantity of water available to public water supply, as well as water to maintain baseflow in rivers.

In summary, on a regional-scale, there appears to be adequate groundwater available to meet current and future needs. However, the analysis does not consider the effects that concentrated water taking may have on the groundwater system or overall ecosystem health. Additional analysis at a watershed or sub-watershed scale could provide more information about safe groundwater yield and impacts that future development activities may have.

Contaminant Sources Inventory

There are many different types of potential threats to groundwater quality, which may include organic chemicals, hydrocarbons (e.g. benzene in gasoline, TCE in solvents), inorganic cations (e.g. iron, manganese), inorganic anions (chloride, nitrate), pathogens (bacteria, viruses), and radionuclides (radon, strontium) (Fetter, 1999). It is important to know the location of potential contaminant sources to help ensure the long-term sustainability of the groundwater resource. This information can be used to identify areas where monitoring is required to safeguard groundwater resources. Contaminant information is best stored and maintained in a database that includes details about the potential contaminant source, its location (including address where available), and information about the quality of the data and the accuracy of the reported location. In the future, if a specific contaminant is identified in a domestic water well, the database could be used to identify the possible source of the contaminants. Information about the different potential contaminant sources throughout the Counties could also be used in the development of future groundwater resources.

Groundwater contamination may occur from either point sources or non-point sources of contamination. These terms generally describe the localization of the contaminant. A point source is typically a small-scale contaminant source area, such as a leaky underground fuel storage tank, or a landfill. Non-point sources, in contrast, are larger in scale and are typically more diffuse than point source contaminants. Non-point sources are primarily related to land use practices (fertilizer spreading, road salting), whereas point sources may be related to localized contamination events (contaminant leaks or spills).

The objective of the potential contaminant inventory was to prepare an inventory of known and potential sources of contaminants in Grey and Bruce Counties. This information was compiled using existing databases and other information as discussed below. Data for the potential contaminant sources inventory was obtained primarily from the Ministry of the Environment (MOE). Included in this information from the MOE was a database of private and retail underground fuel storage tanks from the Technical Standards and Safety Association (TSSA), as well as information from the MOE on spill occurrences, PCB storage, landfills and wastewater treatments plants in the Counties.

The results of the potential contaminant sources inventory are presented in Figure 5.1. There were 1309 records in the MOE Contaminant Sources Database. Of these records, 702 were identified as being within the study area, and of these, 237 that were located on the map (95 with UTM coordinates, 142 with addresses information). In addition, other information sources were used to identify the landfills and wastewater treatment plants within the study area, which added 154 potential contaminant sources to the database (Figure 5.1). Abandoned boreholes are not potential contaminant sources, but they do provide potential pathways for surface contamination to reach lower hydrogeologic units. An analysis of the WWIS revealed 526 potential abandoned boreholes within the study area (Figure 5.2).

As part of the WHPA Contaminant Assessment, maps were generated of each steady state capture zone showing the location of the WHPA and the regional road that transect the WHPA. Subsequently, each county road was driven as part of a “windscreen” survey of the WHPAs to identify any potential contaminant sources that were not part of the regional Contaminant Sources Inventory. This analysis added 339 potential sources to the MOE database (Figure 5.3). To augment these analyses, a map was created at a 1:200,000 scale (Figure 5.4) to present all of the potential contaminated sites at a more detailed, larger scale.

It is clear that many different potential contaminant sources exist throughout the study area. However, there are concentrations in the more developed areas. The inventory has been compiled within the project database, and should be maintained and updated as additional information is collected regarding specific contaminant sources and the locations of records that have been located with poor confidence.

Wellhead Protection Area Groundwater Modeling

Numerical models are developed, calibrated, and used to delineate the WHPA boundaries for the municipal wells in 45 systems that include:

- Township of Georgian Bluffs (Shallow Lake, Forest Heights, Maple Crest and Pottawatomi Village);
- Township of Chatsworth (Chatsworth and Walter’s Falls);
- Municipality of West Grey (Neustadt and Durham)
- Township of Southgate (Dundalk);
- Town of Hanover (Hanover);
- Municipality of Grey Highlands (Markdale, Feversham and Kimberley Springs);
- Municipality of Arran-Elderslie (Tara and Chesley);
- Town of South Bruce Peninsula (Huron Woods, Forbes, Trask, Robins, Winburk, Fiddlehead, Fedy, Cammidge & Collins, Gremik, Foreman and Thomson);
- Municipality of Brockton (Lake Rosiland, Chepstow);
- Municipality of Huron-Kinloss (Ripley, Lucknow, Point Clark, Blairs Grove, Murdock Glen, Huronville, and Whitechurch);
- Municipality of South Bruce (Mildmay and Teeswater); and,
- Municipality of Kincardine (Tiverton, Underwood, Scott Point, Kin Huron, Craig Estrick, Lake Huron Highlands and Point Head Estates).

The original Terms of Reference indicated that WHPA modeling was to be completed on the Town of Saugeen Shores municipal system. However, the Town recently completed a pipeline to connect the Miramichi Estates and Miramichi Shores developments to the existing surface water supply system. Also, the Geeson Avenue well in Walkerton was taken out of service. Markdale decommissioned one municipal well, and added 2 new municipal wells to the

groundwater supply system. As such, 45 of the 48 systems in the Terms of Reference were modeled.

All of these models were developed using Visual MODFLOW, and calibrated to steady-state water levels in the wells from the Water Well Information System database. These calibrated models were used to delineate WHPA boundaries for each of the municipal wells. The WHPA results are shown as a series of WHPA maps for each Municipality (Figures 6.1 thru 6.25). In addition, a map was created at a 1:200,000 scale (Figure 6.26) to present all of the WHPA boundaries at a more detailed, larger scale. They show the 50-day, 2-year, 10-year and 25-year time-of-travel capture zone. These results represent the current best estimate of the different capture zones. However, their sizes and shapes will change in the future as wells are added and removed, and as water demands change. As additional information becomes available, the validity of the different models should be evaluated to help ensure that protective measures continue to be directed in the appropriate areas. Incorporating additional geologic and pumping information into the model will not be difficult now that the models have been constructed and calibrated. The timing of future model review should be timed to coincide with the development and decommissioning of well fields in each of the different municipalities.

Integration of Study Results

As part of this groundwater study, three data layers were developed that have an impact on the groundwater quality that is withdrawn at each municipal well. These layers are the aquifer Intrinsic Susceptibility (Section 3), the potential contaminant sources inventory (Section 5), and the WHPA boundaries (Section 6). Integrating these themes in a GIS allows for simultaneous consideration of three important parameters that affect groundwater quality protection. GIS is widely used as a comprehensive system capable of assembling, storing, manipulating, and displaying geographically referenced information.

The description of the susceptibility of each municipal well to contamination, from the Engineer's Report for each wellfield, was combined with the WHPA boundaries and the Intrinsic Susceptibility results. For each wellfield, a map was developed (Figures 7.1 thru 7.22) to include these components of groundwater protection, and a discussion was provided to integrate the vulnerability of the wellfields and the extent of the recharge areas for the wells (WHPAs). Many of the municipal wellfield are located in areas of medium to high susceptibility. In some cases it is due to a lack of low permeability overburden above the bedrock aquifer. In other cases it is due to thicker units of high permeability overburden material, which does not provide adequate protection for the aquifer. However, regardless of the reason, areas of high and medium intrinsic susceptibility found within WHPA boundaries are very sensitive zones from a groundwater protection perspective, and should be addressed during the development of provisions to implement groundwater protection.

Public Consultation

To transfer study information to the public and solicit their input, a variety of different public consultation strategies were used. At the onset of the study it was understood that public involvement and subsequent buy-in to the importance of the Groundwater Study and its findings would be beneficial. A more environmentally aware public that appreciates the need to protect their groundwater resource will be more likely to endorse and support future groundwater protection strategies. Information from members of the community also provided insight about specific water resource issues that were of concern to them. This information was used during the development of the groundwater protection strategy.

To consult the public and make study results available to local stakeholders, the following specific strategies were implemented throughout the duration of the project:

- News releases to local newspaper and media outlets about groundwater issues in Grey and Bruce Counties and details related to the project progression;
- Two (2) public meetings timed to present preliminary results from the study the final study results; and,
- Development of a project website to transfer project information to the public and to convey study progress and final results (www.greybrucegroundwaterstudy.on.ca).

Section 8 of the report includes a discussion of each strategy applied during the study.

Groundwater Protection Strategy

A Groundwater Protection Strategy is a program of risk reduction to sustain the groundwater resource, both as a source of drinking water supplies and as an integral component of the ecosystem. The strategy can incorporate a number of different tools, which may include a combination of land use policies, regulatory controls, best management practices, public education, groundwater monitoring, land acquisition, conservation easements and spills contingency planning.

The protection of water quality and quantity depends on the collective actions of individuals, private industry, government and other agencies. Rural property owners are responsible for their own well and septic tank maintenance. Municipalities are responsible for the provision and maintenance of a safe drinking water supply in urban areas and for proper sewage collection and treatment. Conservation Authorities play an important role in water conservation through watershed planning and the protection of wetlands. Private industry is intrinsically responsible for best management practices in the utilization of water for the goods and services they provide. The farm industry in particular, has a vested interest in securing an adequate supply of water for livestock and crop watering.

Policies, such as those in a municipal Official Plan, serve to identify the public interest in water quality and quantity. An Official Plan may establish goals, set objectives for water protection (aquifer and well head protection), and provide the framework for land use development and implementation measures. The policies may also provide the rationale for the use of other planning tools such as zoning and site plan control. These are regulatory mechanisms that may be used to control development on a lot-by-lot basis, or an area-wide basis. Planning applications, such as development or land use changes, largely drive the implementation process.

Many tools are not retroactive and they do not enable a municipality to rectify a pollution problem by closing down an operation or forcing the relocation of an existing land use that may have the potential to contaminate an aquifer.

Best management practices may apply to a homeowner in the use and storage of solvents, pesticides, and the disposal of household hazardous wastes. For the agricultural industry it may include measures such as stream buffering from cattle grazing and the care with which manure and other fertilizers are applied.

The municipality may also utilize other statutes to complement the land use controls under the Planning Act. The Nutrient Management Act (2001), and the associated regulations, for example, set out the requirements for the preparation of nutrient management plans and the

control of intensive livestock operations. The Municipal Act may be used to enact site alteration or nutrient management by-laws.

Raising public awareness, through public educational programs, can have a major impact on water protection and may be more important than enforcement measures. It is through the voluntary actions and practices of people on a day-by-day basis that will help protect water resources (i.e. proper use, storage and disposal of fuels, solvents, and pesticides, regular water well maintenance, installation of water saving plumbing fixtures, etc.). Municipalities can work towards developing a 'water ethic' in their communities. This means instilling a collective awareness, responsibility, and commitment to protect water on an ongoing basis.

Specific recommendations about a groundwater protection plan that can be considered appropriate for Grey and Bruce Counties are described in Section 9, and include:

- That an organizational structure be established to oversee and coordinate the implementation of water protection measures;
- That land use planning documents be amended to establish the policy and regulatory framework for instituting effect land use controls for future development;
- That a spills and contingency plan be initiated early in the implementation process;
- That provision is made for the development and maintenance of a database that can be used in making decisions and incorporating new information in response to development and monitoring activities;
- That a public education and outreach program be developed for the ongoing education of the public, the operation of municipal water supply infrastructure and the administration and enforcement of regulatory and voluntary controls for water protection; and,
- That Best Management Practices be utilized where feasible as measures to minimize the potential contamination of private and municipal water supply sources.

Recommendations

The Grey and Bruce Counties Groundwater Study was undertaken to develop an improved understanding of local groundwater conditions within the context of larger regional groundwater flow systems. This was achieved through an analysis and integration of many sources of information on the geology, hydrogeology, and water taking practices throughout the study area. This study has provided a great deal of results on the characterization of the aquifer of the Counties, the Intrinsic Susceptibility of these aquifers, the WHPA boundaries that exist around municipal wellfields and the potential Contaminants that may impact the groundwater that supplies them. As such, a number of recommendations arise from this study, the most important of which are:

Recommendation 1: MOE Inspection of New Wells

It is recommended that all new municipal wells be inspected by the MOE to improve the reliability of the information in the WWIS database, and to improve future hydrogeologic assessments that use this database. It is also recommended that these new wells be georeferenced as a check on location accuracy.

Recommendation 2: Investigate Karst Along the Niagara Escarpment

Karst features are an important component of the Intrinsic Susceptibility mapping. As a result, they should be considered during the development of a Groundwater Protection Strategy, and

further study on the distribution of karst areas should be completed, to better understand their importance in groundwater vulnerability along the Niagara Escarpment.

Recommendation 3: Incorporating ISI Results into the Groundwater Protection Strategy

Medium and high susceptibility classes are the most important classes to consider in terms of aquifer vulnerability. As a result, it is recommended that medium and high susceptibility areas be considered as part of a Groundwater Protection Strategy.

Recommendation 4: Localized Understanding of Groundwater Use Impacts

A water budget of the Counties showed that, at a regional-scale, there is an abundance of groundwater (9.9% of the available recharge is being used for water supply). However, further investigation at a more local, sub-watershed scale should be considered. This may be completed in combination with watershed-based groundwater models, which can be used to delineate sensitive recharge areas that supply baseflow discharge, provide estimates of aquifer yield, optimize the location for the development of new well supplies, and aid in the evaluation of new PTTW applications..

Recommendation 5: Better Tracking of Actual Water Use for PTTW Permits

Permits to Take Water (PTTW) are contained within a different database than the Water Well Information System (WWIS) database, and actual groundwater use is unavailable. To facilitate better permit tracking, the information in the Permit to Take Water database should be linked to the WWIS.

Recommendation 6: Further Investigation of Potential Contaminant Sources

Further investigation of potential contaminant sources within the study area is recommended. This will provide a more complete database of potential contaminant sources within the Counties. As additional information is collected or becomes available, the information contained in the database of potential contaminant sources should be updated.

Recommendation 7: Use of the MODFLOW Models to Update WHPA Results

MODFLOW models were developed and calibrated to local conditions to define the WHPA boundaries for 45 municipal groundwater systems in Grey and Bruce Counties. However, groundwater use by each municipality changes over time due to changes in development, wellfield configuration, well pumping rates, and the development of new groundwater wells. It is recommended that these groundwater models be used to update WHPA boundaries as new information becomes available.

Recommendation 8: Develop and Implement a Groundwater Protection Strategy

It is recommended that Grey and Bruce Counties, in consultation with the MOE, develop and implement a Groundwater Protection Strategy that incorporates some of the different components described in the report. The importance of groundwater to Grey and Bruce Counties underscores the need to manage the resource. The Groundwater Protection Strategy should be developed to address the following components:

- Ensure that the data is properly managed;
- Use public education to foster groundwater protection;
- Acknowledge and protect Wellhead Protection Areas;
- Acknowledge and protect areas of medium and high vulnerability;
- Monitor groundwater quality;
- Encourage the use of Best Management Practices;

- Address well abandonment;
- Ensure that spill and contingency planning is in place;
- Incorporate groundwater protection planning into Official Plans; and,
- Encourage better enforcement of existing rules and regulations.

Specific information regarding each of the recommendations is provided in Section 10 of the Report.

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Gary Kuehl, Groundwater Use Assessment
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Teeswater, ON
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Contents

- **Tunnock Consulting**
North Bay, ON
Glenn Tunnock, Public Consultation and WHPA Planning
- **R.J. Burnside & Associates**
Orangeville, ON
Bindu Uppaluri, Regional Groundwater and Aquifer Characterization
Arunas Kalinauskas, Geographic Information Systems

Public Participation

The Consultant Team appreciates the time and effort of the citizens of Grey and Bruce Counties throughout the public consultation activities (e.g. public open houses, water use surveys and contaminant source surveys). Their participation provided constructive feedback on the progress of the study, and was helpful in completing a number of key components of this groundwater study.

1 Introduction

The Grey and Bruce Counties Groundwater Study was undertaken to develop an improved understanding of local groundwater conditions within the context of larger regional groundwater flow systems. The area encompassed by the Study is presented in Figure 1.1, and includes the County of Grey, the County of Bruce, and a 5 kilometre buffer area around them, which includes the nine (9) municipalities of Grey County:

- Township of Georgian Bluffs;
- City of Owen Sound;
- Municipality of Meaford;
- Township of Chatsworth;
- Town of The Blue Mountains;
- Municipality of West Grey;
- Township of Southgate;
- Town of Hanover; and,
- Municipality of Grey Highlands.

and, the eight (8) municipalities of Bruce County:

- Municipality of North Bruce Peninsula;
- Town of South Bruce Peninsula;
- Municipality of Arran-Elderslie;
- Town of Saugeen Shores;
- Municipality of Kincardine;
- Municipality of Brockton;
- Municipality of Huron-Kinloss; and,
- Municipality of South Bruce.

The study area excludes the Department of National Defense Land Forces Central Area Training Centre, and the Cape Croker and Saugeen First Nations Reserves.

The study partners acknowledge that the basic groundwater functions (recharging, transmitting, assimilating potential contaminants, storing and discharging water) play an essential role in maintaining the health of an ecosystem. Understanding these regional groundwater functions is necessary to provide a secure supply of clean water to municipal and communal water systems, as well as individual groundwater users who do not have access to a municipal supply.

Existing and future land use practices exercised throughout Grey and Bruce Counties (the Counties) may reduce the long-term sustainability of groundwater resources for both quantity and quality. This study provides a more thorough understanding of local and regional groundwater resources that will aid in the development of sound groundwater management and protection measures to help ensure the long-term sustainability of the resource.

The current study was developed using information from previous hydrogeologic studies completed at a regional-scale across the Counties, from local-scale studies completed within the various municipalities, and from a compilation of regional geologic and hydrogeologic information sources. Previous initiatives have helped create, amongst a core group of people within the Counties and the Conservation Authorities, an understanding of groundwater

processes and the importance of protective measures to help ensure that an abundant, clean groundwater supply is available in the future.

A Steering Committee was formed to oversee the completion of this study and is comprised of representatives from local municipalities, consultants, and conservation authorities and the Ministry of the Environment to address local and regional issues related to the completion of this study. This Steering Committee includes the following partners:

- the Grey County Planning Department;
- the Bruce County Planning Department;
- the Ministry of the Environment;
- the Saugeen Valley Conservation Authority;
- the Grey Sauble Conservation Authority;
- Henderson, Paddon & Associates; and,
- Goffco Limited.

1.1 Study Objectives

At the onset of the study, a number of objectives were developed by the Study Partners. The objectives of the Grey and Bruce Counties Groundwater Study are provided below:

- Objective 1: Define and map local and regional groundwater conditions;
- Objective 2: Define groundwater intrinsic susceptibility;
- Objective 3: Compile a contaminant sources inventory;
- Objective 4: Complete wellhead protection area (WHPA) mapping for the following 48 municipal well systems:
- Township of Georgian Bluffs (Shallow Lake, Pottawatomi Village, Forest Heights and Maple Crest subdivisions);
 - Township of Chatsworth (Chatsworth and Walter's Falls);
 - Municipality of West Grey (Neustadt and Durham)
 - Township of Southgate (Dundalk);
 - Town of Hanover (Hanover);
 - Municipality of Grey Highlands (Markdale, Feversham and Kimberley);
 - Municipality of Arran-Elderslie (Tara and Chesley);
 - Town of South Bruce Peninsula (Huron Woods, Forbes, Trask, Robins, Winburk, Foreman, Fiddlehead, Fedy, Cammidge & Collins, Gremik, and Thomson);
 - Municipality of Brockton (Lake Rosiland, Chepstow, Walkerton (Geeson Ave));
 - Town of Saugeen Shores (Miramichi Estates and Miramichi Shores);
 - Municipality of Huron-Kinloss (Ripley, Lucknow, Point Clark, Blairs Grove, Murdock Glen, Huronville, and Whitechurch);
 - Municipality of South Bruce (Mildmay and Teeswater); and,
 - Municipality of Kincardine (Tiverton, Underwood, Scott Point, Kin Huron, Craig-Eskrick, Lake Huron Highlands and Port Head Estates).
- Objective 5: Conduct a contaminant source assessment within each WHPA;
- Objective 6: Develop a municipal action plan for implementing a groundwater source protection strategy; and,
- Objective 7: Promote public groundwater awareness throughout the study area through open houses, local media news releases, and a project website.

1.2 Multi-Barrier Approach to Water Protection

It is important to understand where this groundwater study fits, in relation to other water resource endeavours geared towards providing a safe and secure water source for the Counties. Discussion related to the multi-barrier approach to water protection is included to provide this link.

The multi-barrier approach is an integrated system of procedures, processes and tools that collectively prevent or reduce the contamination of drinking water from source to tap, in order to reduce risks to public health (Canadian Council of Ministers of the Environment, 2002). Figure 1.3 illustrates the multi-barrier approach schematically, highlighting three key processes of source protection, treatment, and distribution.

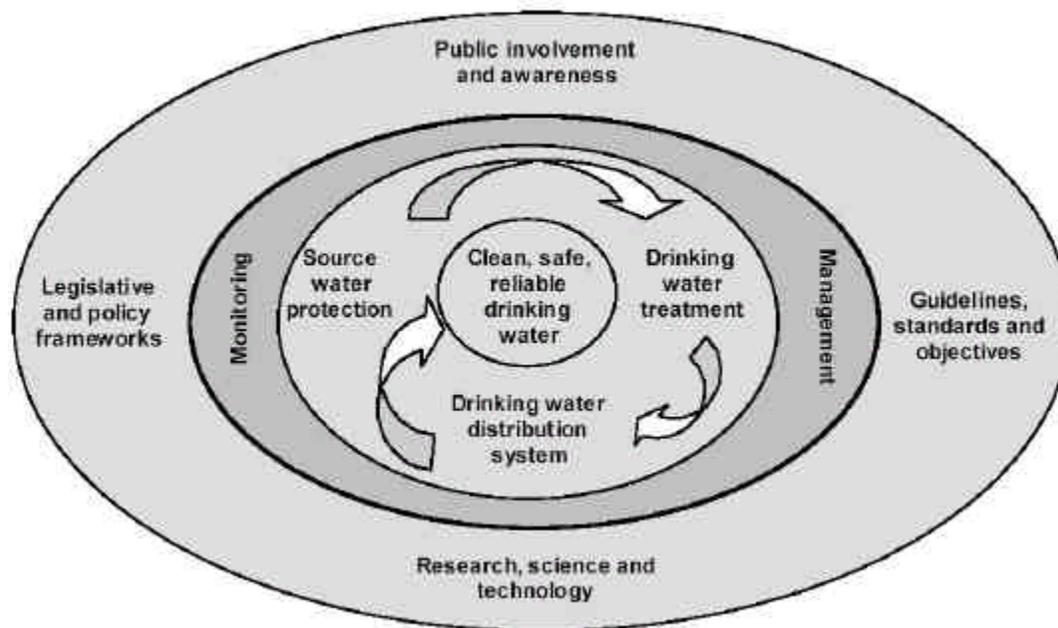


Figure 1.3: A Multi-Barrier Approach to Water Protection (CCME, 2002)

Source protection is the first of five barriers commonly applied to provide safe drinking water, as outlined in Report 2 of the Walkerton Inquiry (O'Connor, 2002). The other four barriers include treatment, a secure distribution system, water quality monitoring, and well-planned responses to adverse conditions.

Source protection is the first measure that can influence water quality to help provide safe drinking water. It is typically less costly than end-of-pipe treatment options, or developing alternative drinking water supplies. Developing source protection strategies is dependent on local willingness to implement various protection strategies, which can range from best management practices to legislation that influences land use in sensitive source water areas.

1.3 Notes Regarding the Regional Mapping

It is important to reflect on the detail incorporated into the regional mapping presented in this report, and to consider appropriate uses for this information. A large portion of the groundwater and aquifer characterization mapping developed for this study was completed at a regional-scale. The mapping utilized point information to develop themes such as the depth to bedrock,

sand and gravel thickness, water table elevation, and aquifer vulnerability. Point information used to develop this mapping is included as small dots on each relevant map. This has been done to remind the end users of these products that, although the mapping represents continuous surfaces, it was developed from point data that is not evenly distributed throughout the study area.

The quality of the point data used in the mapping has been evaluated and is considered acceptable for its purpose, however it has not been field verified. As such, it is important to remember that the mapping is a representation of the real world.

The regional maps are presented at a scale of 1:650,000. This means that a 1 mm line is accurate to within 650 m, and a 1 cm by 1cm square is accurate to within 4.225 ha. This level of detail is not appropriate for site-specific interpretation, but it does provide valuable information for regional-scale analyses.

1.4 Report Organization

This report was organized in sections to address the study objectives outlined above. The sections are organized by topic to coincide with the different regional and local study objectives. The study also includes a comprehensive groundwater protection implementation strategy and provides detailed recommendations and conclusions. Brief descriptions of the topics included in each of the sections are provided in the following paragraph.

Section 2 presents the regional groundwater and aquifer characterization. This characterization was used to complete the groundwater susceptibility analysis, which is presented in Section 3. Section 4 includes the groundwater use assessment, which was completed to evaluate how groundwater is used throughout the Counties, and to develop a general regional water budget. A contaminant sources inventory was completed to identify potential contaminant sources throughout the Counties, and is presented in Section 5. Using the information generated in Sections 2, 3, and 4, groundwater modeling was completed to map, at a local-scale, time-of-travel municipal wellhead capture zones. The groundwater modeling and wellhead capture zone mapping results are presented in Section 6. In Section 7, the capture zones are overlain with the groundwater susceptibility and potential contaminant sources and evaluated at a local-scale. Public consultation aspects of the study are presented in Section 8. A groundwater protection strategy is outlined in Section 9. Study conclusions and recommendations are presented in Section 10. A glossary of technical terms and abbreviations is presented in Section 11, and the references are presented in Section 12. All of the figures for the study are presented under separate cover so that these figures can be reviewed while reading through specific sections.

2 Regional Groundwater and Aquifer Characterization

2.1 Overview

To characterize regional groundwater and aquifer conditions in Grey and Bruce Counties, it was necessary to incorporate as much of the available data as possible from federal, provincial, municipal and conservation authority sources. These data were synthesized in a Geographical Information System (GIS) database that was developed for the study.

2.2 Methodology and Data Sources

The digital information and data layers used in this study are presented in Table 2.1 and include the following:

Table 2.1: SOURCES OF INFORMATION AND DATA LAYERS

	Information / Data Layer	Type of Data	Source
1	Climate	Weather	Environment Canada
2	Digital Elevation Model (DEM)	Topographic Elevation	Ministry of Natural Resources (MNR)
3	Stream Gauging Stations	Water Elevation & Flow	Water Survey Canada (WSC)
4	Cadastral Fabric (NRVIS) ¹	Lots & Concessions	Ministry of Natural Resources (MNR)
5	Quaternary Geology	Quaternary Geology	Ministry of Northern Development and Mines (MNDM), Geological Survey of Canada (GSC)
6	Bedrock Geology Mapping	Bedrock Geology	Ministry of Northern Development and Mines (MNDM), Geological Survey of Canada (GSC)
7	Water Well Information System	Well Completion and Geologic Information	Ministry of the Environment (MOE)
8	Permits to Take Water	Groundwater Takings	Ministry of the Environment (MOE)
9	Potentially Contaminated Sites Databases	Landfills, Fuel Storage Tanks, Spills, WWTPs	Ministry of the Environment (MOE)
10	Oil & Gas Wells	Deep Bedrock Geology	Ministry of Natural Resources (MNR)
11	Base Mapping (NRVIS) ¹	Map Reference Features	Ministry of Natural Resources (MNR), Ministry of the Environment (MOE)
12	Land Use Mapping	Spatial Distribution of Land Uses	County of Grey, County of Bruce

¹NRVIS – Natural Resources & Values Information System, Ministry of Natural Resources (MNR)

2.2.1 Climate

A regional water balance was completed as part of the groundwater use assessment. To accomplish this, it was necessary to obtain weather data from Environment Canada, which is summarized by Ecodistrict.

According to Environment Canada, there are 5 Ecodistricts that intersect the Study Area. The Bruce Peninsula is in Ecodistrict 550; the northern portion of Grey County and the middle of Bruce County are in Ecodistrict 551; the southern portion of Grey County is in Ecodistrict 556; and the southern portion of Bruce County is in Ecodistricts 557 and 558. Based on the

Canadian Climate Normals for the period from 1961 – 1990, the mean annual precipitation in the Counties is approximately 980 mm, of which approximately 25% is snowfall (as water). Precipitation is evenly distributed across the Counties, with a slight increase in average precipitation toward the south (Environment Canada, 1997).

2.2.2 Topography

A Digital Elevation Model (DEM) of the study area was developed to represent the ground surface topography. This DEM is an electronic representation of ground surface, which ranges from approximately 540 m above mean sea level (m amsl) along the Niagara Escarpment in the southeastern part of Grey County to 177 m amsl along the shores of Lake Huron and Georgian Bay. The information that was used to create this digital representation of ground surface elevation includes:

- DEM for the study area – MNR;
- Base Mapping (rivers, lakes and wetlands) – MNR; and,
- Water Well Information – MOE.

2.2.3 Surface Water

Surface water features that were used in characterizing groundwater and aquifer conditions within the Counties include the rivers, lakes and wetlands that help define the groundwater flow system and the surface water monitoring locations that describe groundwater discharge conditions. The surface water mapping was developed using the following information:

- NRVIS (rivers, lakes and wetlands) – MNR;
- Water Well Information – MOE; and,
- Stream Gauge Information – WSC.

2.2.4 Geology

The Quaternary and bedrock geology are important features that help in developing a better understanding of the occurrence and flow of groundwater across the study area. The Quaternary geology in the study area is represented by a wide variety of unconsolidated deposits that remained after several advances and retreats of glacial ice. These deposits underlie organic soils that have been mapped as agricultural soils. The following information was used to create the Quaternary Geology Map:

- Quaternary Geology Mapping – MNDM; and,
- Base Mapping – MNR.

The various bedrock formations in the study area that underlie overburden deposits (Quaternary geology) are predominantly limestone and dolostone, with some sandstone and shale. The following information was used to create the Bedrock Geology Map:

- Bedrock Geology Mapping – MNDM;
- Base Mapping – MNR; and,
- Oil and Gas Wells – MOE.

2.2.5 Hydrogeology

The MOE Water Well Information System (WWIS) database is an excellent source of data for regional geologic and hydrogeologic mapping. The WWIS database includes, but is not limited to, the following information:

- well location (easting, northing, and ground surface elevation);
- geologic units encountered with depth;
- water bearing zones and general water quality observations;
- well construction details;
- static water levels;
- pumping test information indicating aquifer & well performance (specific capacity);
- water use;
- date of well construction;
- driller identification; and,
- other details about the well.

This information, within the study GIS, can be used to develop:

- geologic and hydrogeologic maps;
- hydraulic conductivity estimates (from lithology);
- specific capacity estimates;
- water levels within aquifer units;
- groundwater probability maps;
- aquifer maps;
- hydraulic gradients; and,
- groundwater flow paths.

Using the information at each well, continuous mapping can be developed to characterize the geology/hydrogeology between well locations.

In Ontario, water well information is stored and managed in the Water Well Information System. A well record must be submitted to the MOE, in hardcopy format, when a new well is drilled. This process has been used since 1946. The location of the well is recorded with reference to Township, Lot and Concession, and includes a site drawing. The MOE enters this information into their database system from the hardcopy they receive. Prior to 1986, the location of the well (Universal Transverse Mercator (UTM) Easting and Northing) and its ground elevation were assigned by checking Lot/Concession information on a topographic map. After 1986, no attempt was made to assign UTM coordinates or ground elevations to well records. In 1999, the WWIS database contained 492,898 wells, of which 336,064 wells had been assigned coordinates, and 156,864 had not.

In many cases it is difficult to correlate geologic observations between well logs because each driller has a unique style of geologic interpretation and data recording. The MOE allows a maximum of 3 descriptors for each lithologic unit that is recorded in the well record, and there are 82 possible descriptors. As a result, there are 500,000 possible lithological names that can be used to describe a lithologic unit. Inconsistencies in lithologic reporting create difficulties for conceptual model development. Lithologic units are often described differently by different drillers (i.e. each driller may use 3 different descriptors to describe the same unit). For example, differentiating between the different tills throughout Grey and Bruce Counties is very difficult using the water well records. Sand and clay, gravel and clay, and hardpan are terms that may be used by drillers to describe a silty or clayey till.

Another source of error in the WWIS database results from inaccuracies in the manual entry of hardcopy information into electronic format, especially in the entry of well location and elevation.

Section 2.2.6 includes a methodology that was developed to address these types of errors so that the information can be used for regional-scale hydrogeologic analyses.

2.2.6 Data Reliability

Prior to developing a conceptual hydrogeologic model of Grey and Bruce Counties, all available WWIS data were reviewed and evaluated for reliability and quality for both well location and elevation. The WWIS database for the Counties contained a total of 23,290 wells. Before transmitting the WWIS data to the Counties, the MOE updated the location reliability codes for each record. It is understood that some wells in the database have such a large margin of error associated with their coordinates, they plot outside the Counties, or outside the Township cited on the record. These wells were isolated and made inactive. Wells with UTM Reliability codes greater than 6 (margin of error greater than 1 km) were made inactive, following the technical terms of reference for the study. The ground surface elevation recorded for each well record was also considered during data quality analysis. The database was queried to compare the reported well elevations to the ground surface elevation in the DEM. In cases where the difference between the reported elevation and the DEM was more than 10 m, the wells were made inactive.

Figure 2.1 presents a map of well reliability. Three categories of reliability are presented. There are 4,960 high reliability wells (location reliability < 4, and elevation reliability < ± 3 m), 10,693 medium reliability wells (location reliability = 5 or 6, and elevation reliability $\leq \pm 10$ m) and 7,637 unreliable wells (location reliability > 6, and/or elevation reliability > ± 10 m). Figure 2.2 shows the active wells throughout the study area, whereby overburden and bedrock wells are differentiated. Approximately 75% of the wells are completed in bedrock, and 25% are completed in the overburden. A greater percentage of wells are completed into bedrock in the northern half of Bruce County along the peninsula where the overburden is thin. A greater percentage of wells are completed into bedrock in the eastern half of Grey County where the overburden thins toward the Niagara Escarpment.

2.2.7 Previous Studies

Numerous reports related to groundwater resources investigation and conservation in Grey and Bruce Counties have been published over the past 25 years. These reports include local-scale hydrogeologic analyses, as well as regional-scale assessments of groundwater resources within the Counties. They provide a useful source of information on the geology and hydrogeology of the Counties.

Many local-scale hydrogeologic assessments have been completed in support of the development of municipal groundwater supply wells, solid waste landfills, sanitary sewage works, and subdivision developments. First Engineer's Reports and reports supporting Permit To Take Water applications are available for most of the municipal systems. Most of this information was obtained from the Southwest Region office of the MOE in London, and from local Municipalities. On a regional-scale, the Ministry of the Environment completed ground-water probability mapping of Grey and Bruce Counties, in 1980 and 1983, respectively. Several other provincial-scale reports and documents contain useful information pertinent to the study. Section 11 of this report lists the reference material that was gathered and compiled for this groundwater study, organized by geographic area.

Additional resources include the Geology of Ontario (Ontario Geological Survey, Vol. 4, Parts 1 and 2), which provides detailed descriptions of Quaternary sediments and bedrock units; the Physiography of Southern Ontario (Chapman and Putnam, 1984), which provides information on the physiography of the Counties; and, the Hydrogeology of Southern Ontario, which

provides useful information on the occurrence, distribution, quantity and quality of groundwater in Southern Ontario on a regional-scale (Singer et al., 1997).

2.3 Surface Features

2.3.1 Surface Topography

Ground surface elevation in the Grey-Bruce area ranges from approximately 540 m amsl in the southeastern part of Grey County to 177 m amsl along the shores of Lake Huron and Georgian Bay. Figure 2.3 presents a topographic map of the region based on the Digital Elevation Model. The highest elevations occur along the Niagara Escarpment, which parallels the Georgian Bay shoreline from Collingwood in the east to Tobermory on the northern tip of the Bruce Peninsula. Major embayments in the Escarpment include the bays leading to Wiarton and Owen Sound, and the Beaver and Bighead Valleys, which extend south from Thornbury and Meaford, respectively.

2.3.2 Surface Water

Figure 2.4A presents the surface drainage network within the Counties. Watercourses in the southcentral portion of the region are part of the Saugeen Valley watershed, which constitutes the largest watershed in the study area. To the east are portions of the headwaters of the Nottawasaga River, to the southeast are portions of the headwaters of the Grand River, and to the south are portions of the headwaters of the Maitland River. The remainder of the Grey-Bruce region consists of numerous smaller watersheds draining over short distances directly into Lake Huron or Georgian Bay. These include the Sauble, Sydenham, Bighead and Beaver watersheds, as well as the small rivers and creeks of the Bruce Peninsula. The watershed boundaries of the principal drainage basins are shown in Figure 2.4A.

2.3.3 Stream Flow

Portions of five conservation authorities are present in the Counties. The Saugeen Valley Conservation Authority (SVCA) is the largest of the five, and is contained entirely by the Counties. The Grey Sauble Conservation Authority (GSCA) is also contained entirely by the Counties, and includes four (4) river valleys north of the SVCA (the Sauble, the Sydenham, the Bighead and the Beaver rivers). A small area of the headwaters of the Nottawasaga Valley Conservation Authority occurs in the eastern part of Grey County, and includes a portion of the Niagara Escarpment from Craighleith south to Maple Valley. A small area of the headwaters of the Grand River Conservation Authority (GRCA) occurs in the southeastern part of Grey County, and includes the area around Dundalk. A small portion of the headwaters of the Maitland Valley Conservation Authority (MVCA) occurs in the southern part of Bruce County, and includes the area around Lucknow.

Figure 2.4B presents the locations of 13 stream gauging stations in the Counties. Information for these stations was obtained from the Water Survey of Canada (2002). Six (6) stations are found within the SVCA, five (5) are found within the GSCA, one (1) is found within the GRCA and one (1) is found on the Bruce Peninsula (see Table 2.2). Data collected at these stations was used to characterize stream baseflows within the Counties.

The average stream baseflow in the Counties is 105 mm/yr with a range that varies from 20 to 163 mm/yr. This value was obtained by dividing the lowest value of the July, August and September stream flow (the baseflow) by the drainage area of the stream upgradient of the station. The lowest stream flow value was used because it is believed to most accurately reflect stream baseflow, which is maintained predominantly by groundwater discharge.

Table 2.2: STREAM GAUGING STATIONS

	Station Name	Watershed	WSC ID	Average Baseflow (m³/s)	Drainage Area (km²)	Years of Data	Average Baseflow (mm/yr)
1	Saugeen River near Port Elgin	SVCA	02FC001	14.36	3960	87	114.4
2	Teeswater River near Paisley	SVCA	02FC015	1.87	663	26	88.9
3	Saugeen River near Walkerton	SVCA	02FC002	8.34	2150	87	122.3
4	Carrick Creek near Carlsruhe	SVCA	02FC011	0.35	163	41	67.7
5	South Saugeen River near Hanover	SVCA	02FC012	1.39	635	26	69.0
6	Saugeen River above Durham	SVCA	02FC016	0.75	329	21	71.9
7	Sauble River at Sauble Falls	GSCA	02FA001	1.89	927	44	64.3
8	Sauble River at Allenford	GSCA	02FA004	0.33	301	7	34.6
9	Sydenham River near Owen Sound	GSCA	02FB007	0.63	181	54	109.8
10	Bighead River near Meaford	GSCA	02FB010	0.84	293	44	90.4
11	Beaver River near Clarksburg	GSCA	02FB009	2.96	572	42	163.2
12	Grand River near Dundalk	GRCA	02GA041	0.04	62.9	16	20.1
13	Stokes River near Ferndale	Bruce Peninsula	02FA002	0.07	50.2	25	43.7

2.4 Geology

2.4.1 Quaternary Geology

The last period of glaciation in southern Ontario occurred from approximately 23,000 to 10,000 years ago, during the Wisconsin Substage of the Pleistocene Epoch. During this time, the Laurentide Continental Ice sheet advanced out of the Great Lakes basins (Lake Huron, Lake Erie and Lake Ontario) to cover southern Ontario. The locations of the ice lobes and their margins fluctuated until the final retreat of the glaciers, which started approximately 10,000 years ago. The surficial geology left by the glaciers is highly varied across the Counties, as illustrated in Figure 2.5. The physical features of the land surface are illustrated in Figure 2.6, the Physiography of Grey and Bruce Counties (from Chapman and Putnam, 1984).

Glacial deposits remaining after the last glaciation determine the current physiography of the region, the nature and distribution of surficial aquifers, groundwater discharge and recharge areas, and the sand and gravel deposits. Much of the study area is covered by till, which typically transmits water slowly (i.e. has a low hydraulic conductivity) because of its fine-textured character. In contrast, there are also sand plains, and glaciofluvial sand deposits (spillways), which have higher hydraulic conductivities because of their coarse-textured character. A summary of the Glacial Periods, from youngest to oldest, and the Quaternary deposits that result from them, is presented in Table 2.3.

Table 2.3: SUMMARY OF QUATERNARY DEPOSITS AND EVENTS IN THE STUDY AREA

Age	Glacial Period	Deposit or Event	Lithology	Morphologic Expression
10,000 - present	Post-glacial	Modern alluvium and organic deposits	Silt, sand, gravel, peat, muck, marl	Present day rivers and flood plains
12,000 – 10,000	Two Creeks Interstade	Lacustrine deposits	Silt and clay	Flat-lying surficial deposits
		Outwash	Sand, gravel, some silt	Mainly buried (end moraine)
		Ice Contact	Sand, gravel	Kames and eskers
13,000 – 12,000	Port Huron Stade	St. Joseph Till	Silt to silty clay till	Surficial till
15,000 – 13,000	Mackinaw Interstade	Elma till	Silt till	Lower stony till
16,000 – 15,000	Port Bruce Stade	Dunkeld Till	Silt till	Surficial till
		Elma Till	Silt till	Surficial till
18,000 – 16,000	Erie Interstade	Lacustrine deposits	Silts	Wildwood Silt deposits
20,000 – 18,000	Nissouri Stade	Catfish Creek Till	Stoney, sandy silt to silt till	Buried

(After Karrow, 1993; 1977)

The Catfish Creek Till is the oldest till in Grey and Bruce Counties. It was deposited during the Nissouri Stade as ice advanced from the north, approximately 20,000 – 18,000 years ago. Temperatures warmed and the ice sheet melted leaving large glacial lakes in the Erie and Huron basins during the Erie Interstade, approximately 18,000 -16,000 years ago.

At the beginning of the Port Bruce Stade, approximately 16,000 – 15,000 years ago, the climate cooled and a series of smaller ice lobes moved radially out of the Great Lake basins into southern Ontario. Grey and Bruce Counties, which sit between Lake Huron and Georgian Bay, were overridden by the Huron-Georgian Bay lobe of the Laurentide Ice Sheet. During this stade, the ice lobe deposited the Elma Till and the Dunkeld Till. The Elma till occurs as ground moraine and in the drumlins of the Teeswater drumlin field, and is associated with the Singhampton Moraine. The Dunkeld Till occurs as ground moraine within the Saugeen River Valley and is the core of the Walkerton Moraine. Elma Till is probably older and younger than the Dunkeld Till. Temperatures warmed again and the ice sheet retreated during the Mackinaw Interstade, approximately 15,000 – 13,000 years ago.

At the beginning of the Port Huron Stade, approximately 13,000 – 12,000 years ago, the climate cooled again and the Huron-Georgian Bay ice lobe readvanced and deposited the St. Joseph Till in the area. The St. Joseph Till occurs in the Wyoming Moraine, the Williscroft Moraine and the Banks Moraine, which parallel the Lake Huron and Georgian Bay shorelines, and roughly define the extent of the ice lobe advance. After the Post Huron Stade, the Laurentian Ice Sheet receded northward during the Two Creeks Interstade, approximately 12,000 – 10,000 years ago, and deposited lacustrine silts and clays, and ice-contact and outwash sands and gravels.

The dominant surficial features of the study area are presented below, and are based on the Physiography of Southern Ontario (Chapman and Putnam, 1984):

- The Bruce Peninsula consists largely of exposed dolostone plains, with thin overburden throughout. The soils are shallow, and are classified as Breypen series in the Ontario Soil Survey. The irregular topography of the bedrock surface results in many small lakes and swamps on the Peninsula;
- Coarse-textured glaciolacustrine deposits make up the sand plains of the Huron Fringe. This area comprises wave-cut terraces of glacial Lakes Algonquin and Nipissing along the Lake Huron shore, with minor sand plains also occurring along the Georgian Bay shoreline;
- Shale plains, known as the Cape Rich Steps, are located between Owen Sound and Nottawasaga Bay. This area consists of Paleozoic bedrock overlain by shallow overburden, with the plain being incised by the Beaver Valley (in the Thornbury area) and the Bighead Valley (in the Meaford area);
- The Port Huron Moraine system, consisting of glaciofluvial and ice-contact stratified deposits (kames), extending southwest from the head of the Beaver and Bighead Valleys covering the southcentral part of the study area. Meltwater stream deposits and spillways also occur throughout this physiographic region, as do drumlins in the vicinity of Dornoch. Huron clay loam is a common soil type on the moraine ridges;
- The southeast part of Grey County, extending to the southern tip of Beaver Valley and east to the Niagara Escarpment, consists mainly of drumlinized till plains, with a small drumlin field in the area of Dundalk. The till is a stone-poor, carbonate-derived silty to sandy deposit;
- A similar area located at the base of the Bruce Peninsula is known as the Arran drumlin field. The ground moraine is thin with many of the drumlins located directly on bedrock;
- Immediately south of the Arran drumlin field is an area of fine-textured, glaciolacustrine deposits of the Saugeen Clay Plain. It is underlain by deep stratified clay deposited in a bay of glacial Lake Warren. The Saugeen River, Teeswater River and Deer Creek have cut valleys through the clay up to 38 m (125 feet) deep; and,
- West of the Saugeen Clay Plain, and extending south along the Lake Huron shore, is an area of silty to clayey till of the Huron Slope. The till is generally up to 3 m thick, and overlies stratified clay. The clay matrix of the till is likely reworked material from the underlying clay beds.

2.4.2 Bedrock Geology

Understanding bedrock geology is a key component to understanding bedrock aquifers and regional groundwater movement. Descriptions of the bedrock units, and an understanding of groundwater quality parameters like hardness and salinity, help to identify regional aquifers and aquitards. Information on bedrock geology was compiled from numerous sources, including: mapping from the Ontario Geological Survey, reports on Paleozoic geology from various authors, and a review of well records in the WWIS.

General bedrock stratigraphy of the study area is presented in Table 2.4 and illustrated in Figure 2.7. Bedrock consists mainly of carbonate (limestone and dolostone) rocks of Ordovician to Devonian age. There are some shale units that are interbedded with the limestone and dolostone. These limestone, dolostone and shale units are part of the Michigan Basin marine sediments, deposited approximately 480 to 300 million years ago. The bedrock dips to the southwest at a regional slope of 5 to 7 m/km. Limestone and dolostone are quarried locally for aggregate and building stone, and shale is quarried for brick and tile. There is a general thinning of the overburden from west to east, resulting in bedrock exposure along the Escarpment. An indication of the depth to bedrock is also shown in the distribution of historical quarry

operations. With the exception of a few around Walkerton and Kincardine, all quarry operations are located in the area of Owen Sound and north on the Bruce Peninsula.

Table 2.4: BEDROCK GEOLOGY UNDERLYING THE STUDY AREA

Period	Group	Formation	Material Type	Approximate Thickness (metre)	
Quaternary		Overburden (glacially-derived gravel, sand, silt and clay)		0 – 100	
Middle Devonian		Dundee	Brown limestone	0 – 100	
	Detroit River	Lucas	Grey-brown limestone and dolostone	35 – 45	
		Amherstburg	Tan to grey-brown bituminous limestone	45 – 75	
Lower Silurian		Bois Blanc	Grey-green to grey-brown limestone	40 – 60	
Upper Silurian		Bass Islands	Dark-brown to buff dolostone	22 – 28	
		Salina	Interbedded grey-brown limestone and bituminous shale	up to 330	
Middle Silurian		Guelph-Eramosa	Buff to brown medium-bedded dolostone	4 – 100	
		Amabel	Blue-grey thick-bedded dolostone	13 – 25	
			Fossil Hill	Buff to grey-brown fossiliferous dolostone	0 – 24
			St. Edmund	Cream-buff thin-bedded dolostone	0 – 25
			Wingfield	Olive-green argillaceous dolostone and shale	2 – 15
			Dyer Bay	Grey-brown dolostone	0 – 7.6
Lower Silurian	Cataract	Cabot Head	Maroon to green-grey non-calcareous shale	10 – 39	
		Manitoulin	Grey fossiliferous dolostone	0 – 25	
Upper Ordovician		Queenston	Maroon shale	45 – 335	
		Georgian Bay	Blue-grey shale	125 – 200	
		Blue Mountain	Blue-grey non-calcareous shale	up to 60	

Most of the limestone and dolostone units have the potential to supply adequate quantities of water. However, the water has elevated hardness due to the carbonate composition of the bedrock. The Guelph and Amabel Formations are important bedrock aquifers that occupy a band, up to 30 km wide, which extends northwest of Shelburne to Sauble Beach and up the western side of the Bruce Peninsula. Poor water quantity and quality characterize the shale of the Queenston Formation, and poor water quality characterizes the Salina Formation, which has elevated hardness, sulphate and chloride.

2.4.3 Bedrock Topography

The purpose of the bedrock surface elevation mapping is to identify bedrock valleys in which useful overburden aquifers may be located and, to define bedrock highs and lows, which could control groundwater occurrence and movement. A map of the elevation of the bedrock surface is presented in Figure 2.8.

The bedrock surface elevation in the study area ranges from 540 m amsl in the southeast portion of Grey County, to 170 m amsl along the Lake Huron and Georgian Bay shorelines and to 120 m amsl south of Kincardine. In general, the bedrock elevation controls, and is parallel to, the overlying ground surface, shown in Figure 2.3. Prominent bedrock depressions or valleys are associated with the Beaver and Bighead Valleys, which are embayments in the Niagara Escarpment adjacent to Georgian Bay. A broad bedrock valley is also evident from Hanover to the Lake Huron shore at Southampton, and underlies the Saugeen River Valley. Parallel to this is a less prominent bedrock valley, beginning just northwest of Wingham.

These bedrock topography features can be seen in the regional and local cross-sections that are described in Section 2.4.5.

2.4.4 Karst Features

Karst is a distinctive type of topography, formed primarily by the dissolution of carbonate rocks, such as limestone and dolostone. Water infiltrating into the ground is mildly acidic reacting with carbon dioxide in the atmosphere and soil, and enlarges the openings in the subsurface, creating a subsurface drainage system. Over time, groundwater flow conduits enlarge, and aquifers with large conduits are created thereby lowering the water table below the level of surface streams. These surface streams and drains may begin to lose water to developing cave systems underground. As more surface drainage is diverted underground, streams may disappear and become replaced by closed basins called sinkholes. Sinkholes vary from small cylindrical pits to large conical or parabolic basins that collect and funnel runoff into karst aquifers (Ford and Williams, 1989).

Groundwater flow in karst areas is significantly different from that of other aquifers because of the solutionally enlarged conduits. In conventional carbonate (limestone, dolostone) aquifers, groundwater moves very slowly. In karst aquifers, groundwater flowing in enlarged conduits can have velocities approaching those of surface streams. The nature of this flow system makes karst areas highly susceptible to groundwater contamination (Ford and Williams, 1989).

Shallow karst aquifers are vulnerable to contamination because they can receive recharge in two ways. They can receive surficial recharge through the soil profile, and concentrated recharge from surface streams and drains that flow directly into the aquifer at sinkholes. Contaminants associated with agricultural activities, such as nitrates, bacteria and pesticides, are potential problems in karst areas as the rapid groundwater velocities allow contaminants to travel long distances through the aquifer in a very short period of time.

Karst areas are common along the Bruce Peninsula as a result of thinning overburden and exposed bedrock. Two studies were completed that document karst in the Counties. In Bruce County, a study was conducted for the Canadian Parks Service in the northern Bruce Peninsula to map karst areas along the Niagara Escarpment. This study completed a survey of the geomorphological features of the Peninsula within the former Township of St. Edmunds including karst, glacial, aeolian and fluvial features. Hardcopy maps from this study were georeferenced and used to develop a digital database of karst features on the Bruce Peninsula

(Canadian Parks Service, 1994). In Grey County, karst is considered a constraint on development when coupled with shallow overburden. Continued investigations on the location of karst features in the Counties will help to develop a GIS database of karst areas, which will provide valuable information for the assessment of groundwater vulnerability.

2.4.5 Regional Cross-Sections

General subsurface geologic and hydrogeologic conditions in the Counties were evaluated through the development of eight regional cross-sections. R.J. Burnside developed these regional cross-sections using SiteFX software. The locations of the cross-sections are shown in Figure 2.9, and individual cross-sections are presented in Figures 2.10 to 2.17. These cross-sections were prepared using the updated MOE water well record database, and show Quaternary and bedrock geology, water level elevation, surface water features, and bedrock topography. The cross-sections also show the parallel nature of the bedrock and ground surface topography, the thinning of the overburden from west to east toward the Niagara Escarpment, and some of the physiographic features of the study area. Details of the geology and the relationship of the geology to the regional water table and hydrogeology are discussed throughout this report.

Additional local cross-sections through each municipal system were also completed during the WHPA modeling phase of the study. Waterloo Hydrogeologic developed these local cross-sections using CSMapper, which is described below. The local cross-sections are smaller than the regional sections and provide local geologic information near the municipal wells. These results are presented in Section 6.

Description of CSMapper

CSMapper is a Windows based application that resides within the MapInfo GIS environment as an add-on application. CSMapper uses many standard GIS tools available for selecting and querying data. In addition, all GIS data are available to CSMapper, allowing spatial data such as topography (the DEM and bedrock surfaces), or borehole metadata to be directly displayed on cross-sections. A GIS is used to manage and visualize large information databases, make and confirm interpretations on-screen, and store layer definitions for use in model development.

Application of CSMapper is a four-step process:

- Select the boreholes to be displayed on the cross-section;
- Select the straight-line segment onto which the boreholes will be projected;
- Build the cross-section using CSMapper; and,
- Interpret the geology and save the interpretations to the GIS database.

Once the “*Interpretation Database*” has been populated, these data can be readily used within the GIS for interpolation of model layers. This provides a useful functionality for developing Visual MODFLOW models, which can use the geologic and hydrogeologic information in the GIS database to define model parameter values and boundary conditions.

The cross-sections mainly use water well records from the WWIS. However, oil and gas wells were also used to interpret deeper bedrock geology. The oil and gas wells were provided by the Ministry of Northern Development and Mines (MNDM) in Excel spreadsheets. The electronic data were recompiled to facilitate the inclusion of the oil and gas wells in the cross-sections. The oil and gas wells show the lower bedrock units sloping to the southwest. The oil and gas wells are denoted with a letter (F or T) preceding a six-digit number on the cross-sections.

2.4.6 Overburden Thickness

Overburden thickness throughout Grey and Bruce Counties is presented in Figure 2.18. There are similarities between the overburden thickness, the bedrock elevation (Figure 2.8) and ground surface elevation (Figure 2.3), indicating that the overburden thickness and ground surface elevation are both partially controlled by the underlying bedrock topography. Overburden thickness is an important hydrogeologic parameter to review, because it is one of the major parameters that controls the amount of protection for underlying surficial and bedrock aquifers. Overburden thickness and grain size distribution control the infiltration rate, and the rate of movement of surface contamination, into these aquifers.

Exposed bedrock occurs mainly along the Bruce Peninsula. Elsewhere, a maximum thickness of up to 80 metres is associated mainly with bedrock depressions. Two such bedrock depressions underlie the Beaver and Bighead Valleys, with a maximum overburden thickness of 60 m and 80 m, respectively. Although the overburden is less than 30 m thick under the current Beaver Valley, a swath of slightly thicker overburden extends past the tip of the valley as far southwest as Mount Forest, indicating a possible bedrock depression in this area not identified in the bedrock elevation data. Another area of thick overburden is associated with the bedrock valley underlying the Saugeen River, from Hanover to the Lake Huron shore at Southampton. Overburden thickness of up to 80 m occurring at the Lake Huron shore indicates that the underlying bedrock valley likely extends farther to the northwest, under the lake. Two additional areas of thick overburden occur in the region. One is between Walkerton and Kincardine, and is reflected in an area of higher ground surface elevations. The other is along the Lake Huron shore south of Kincardine. Neither area is associated with a bedrock depression.

Sand and gravel thickness throughout the study area is presented in Figure 2.19. The thickness was calculated by summing the total thickness of sand and/or gravel logged in the MOE water well records. The map is used to identify areas of thicker permeable material, identifying areas of potentially significant aquifers within overburden material. The map does not differentiate between sands and gravels above the water table and saturated material below the water table, and so it over-estimates potential aquifer thickness.

The data indicates that most of the study area is underlain by less than 10 metres of sand and gravel. Areas with greater than 30 metres in thickness are small and isolated, and typically are intersected by three or fewer water wells, further indicating the limited nature of individual sand/gravel zones. However, clusters of thicker sand and gravel material are associated with distinct Quaternary geology features shown on Figure 2.6, particularly the Port Huron Moraine system and glaciolacustrine sand deposits close to Lake Huron, and areas of thicker overburden (Figure 2.18) like the Beaver Valley and the Bighead Valley, and the bedrock depression underlying the Saugeen River Valley. The major bedrock valleys are not directly associated with thicker intervals of sand and gravel, which may be partly due to a lack of data since domestic wells are not typically drilled deeper than the first suitable aquifer. As a result, the full thickness of sand and gravel within the bedrock depressions is not likely represented.

2.5 Hydrogeology

Grey and Bruce Counties can be conceptualized as a three-layered hydrogeologic model with, from top to bottom, a fine-grained overburden aquitard layer, a thin weathered bedrock aquifer layer, and a thick unweathered bedrock aquifer. Details of the subsurface hydrogeologic conditions in the Counties were determined by examining eight (8) regional cross-sections and many local area cross-sections.

2.5.1 Water Table

A regional water table map is presented in Figure 2.20. This figure is based on the static water levels observed in wells drilled to depths of less than 15 m, and assumes all wells are under unconfined conditions. To augment the information available in the WWIS, the elevation of surface water streams, rivers and lakes and the DEM were used to constrain the developed water table map. By constraining the water table, it is possible to make sure that it does not exceed ground surface.

These data have been contoured to produce lines of equal water table elevation. In general, the elevation of the water table closely reflects the ground surface elevation (Figure 2.3). Water table elevations range from 540 m amsl in the eastern portion of the region, to 177 m amsl adjacent to Georgian Bay and Lake Huron. Water table gradients are generally consistent throughout the area, except for steeper gradients along the Niagara Escarpment. Groundwater flow divides also generally follow surface watershed boundaries shown on Figure 2.4.

2.5.2 Bedrock Equipotentials

A regional bedrock equipotential map is presented in Figure 2.21. This figure is based on static water levels in all bedrock wells. Overall, the bedrock equipotential contours closely reflect the bedrock surface elevation contours shown in Figure 2.8. Equipotential elevations range from 540 m amsl in the eastern portion of the region, to 177 m amsl adjacent to the Georgian Bay and Lake Huron shores.

Figure 2.21 also illustrates the hydraulic gradient and general flow directions of the deeper groundwater environment in the study area. Hydraulic gradients are generally consistent throughout the area, except for steeper gradients in the areas of the bedrock valleys (beneath the Beaver and Bighead Rivers) and bedrock depressions (beneath the Saugeen River Valley). Deeper groundwater flow is influenced more by bedrock topography than the shallow groundwater. The potentiometric surface generally parallels the elevation of the bedrock and, as a result, there is a general trend in groundwater flow toward the northwest across the region, which is interrupted by the bedrock depressions underlying the Saugeen, Bighead and Beaver Valleys.

2.5.3 Groundwater Flow

Groundwater flows from areas of high hydraulic head to areas of low hydraulic head, which results in groundwater flow directions that are perpendicular to the contours of groundwater equipotential, as indicated by the blue arrows. The flow directions shown on Figure 2.20 indicate that shallow groundwater flows generally in a northwest direction across the majority of Grey and Bruce Counties, toward Lake Huron. This is similar to the surface water drainage direction. As with surface water drainage, the groundwater flow direction is modified somewhat between Walkerton and Paisley, in response to the valley of the Saugeen River. Similarly, shallow groundwater flow is directed locally toward the Beaver and Bighead Valleys in the northern part of Grey County. On the Bruce Peninsula, groundwater flows either east toward Georgian Bay or west toward Lake Huron.

2.5.4 Recharge and Discharge Areas

Groundwater not only moves laterally through aquifers, but also moves vertically, in response to differences in hydraulic head between aquifers, called vertical gradients. These differences can be determined by comparing the water table elevations (Figure 2.20) of the shallow aquifers with the deeper potentiometric surface elevations (Figure 2.21) of the bedrock aquifers. Where the potentiometric surface elevation is higher than the water table elevation, groundwater flow is

upward, and deeper groundwater will recharge the shallow aquifers from below. In some cases, upward groundwater flow may result in discharge to the ground surface. However, if the water table elevation is higher than the bedrock potentiometric elevation, groundwater flow is downward, and shallower groundwater will recharge the deeper aquifers. Downward groundwater flow may not necessarily indicate recharge to the shallow aquifers from ground surface. Therefore, the areas of downward and upward vertical gradients within the aquifers only indicate potential areas of shallow groundwater recharge and discharge throughout the region. Recharge areas are more sensitive with respect to groundwater protection as they are not only areas of infiltration and recharge to the deeper groundwater aquifers, but are also areas where surface contamination can more easily enter deep aquifers.

Vertical gradients through the upper and lower aquifer units are identified in Figure 2.22. Areas of downward vertical gradients occur over the majority of the study area, and likely include areas of groundwater recharge, which generally correspond to upland areas between surface water courses. Areas of upward vertical gradients are scattered throughout the region and tend to occur along rivers, which generally correspond to areas of groundwater discharge. However, there are relatively few groundwater discharge areas associated with the Saugeen Clay Plain and the clayey till of the Huron Slope, as described in Section 2.4.1. The clayey surficial deposits in these areas restrict the upward movement of deeper groundwater.

2.5.5 Regional Aquifers

Groundwater is defined as the “subsurface water that occurs beneath the water table in soils and geologic formations that are fully saturated” (Freeze and Cherry, 1979). The water table defines the upper boundary of the groundwater zone. Groundwater is said to be under “unconfined conditions” when part of the soil is saturated and the water table is in direct contact with the atmosphere through the spaces within the unsaturated portion of the soil. When a saturated granular formation (aquifer) is overlain by an impermeable formation (aquitard) restricting the upward movement of water through the formation, the groundwater is said to be under “confined conditions”. If the overlying formation is semi-permeable permitting some limited movement of water through the formation, the groundwater may be said to be under “semi-confined” or “leaky-confined conditions”. Rates of groundwater flow through saturated formations depend on hydraulic conductivity (the ability to transmit water), and the hydraulic gradient (driving force). Groundwater flow also depends on the extent, conductivity and continuity of the aquifer materials.

Thick coarse-grained materials, such as sand and gravel, are the best overburden aquifers. Overburden is highly variable in thickness and composition, and areas of thicker overburden with high percentages of sand and gravel are the best aquifers. Such areas include the Port Huron Moraine, areas of glaciolacustrine sands, and bedrock depressions. The nature of the bedrock underlying an overburden aquifer can influence the quality of the water resource.

Areas of thick, saturated sand and gravel deposits within the study area are illustrated in Figure 2.23. Overburden aquifer locations thus correspond with areas of thickest overburden, as shown on Figure 2.18. Given the nature of the overburden material of the Port Huron Moraine, and the thick sand and gravel units associated with it, this Quaternary unit is a likely good source of groundwater.

The occurrence and movement of groundwater in bedrock aquifers is governed by the rock type, structure and, in some cases, the thickness and type of the overlying overburden. In sedimentary rocks such as those in the study area, groundwater occurs in bedding planes, fractures, crevices, vugs and other pore spaces characteristic of carbonate rocks.

Domestic bedrock wells are typically completed into the upper 10 to 30 metres of the bedrock. The required capacities for domestic wells are small, typically less than 0.8 L/s (10 igpm). Therefore, drilling usually stops when this volume of water is available. Higher capacity municipal wells are typically drilled deeper than domestic wells to maximize well capacity. The depth of the bedrock wells is determined by the thickness of the overburden plus the thickness of hard rock that needs to be penetrated to obtain the required water supply.

The distribution and depth of bedrock wells shown in Figure 2.24 represents the location of the bedrock aquifers in Grey and Bruce Counties. The surficial bedrock units are only presented in Figure 2.24 to provide a correlation with the bedrock wells, and may not necessarily correspond to bedrock aquifers. Bedrock wells are evenly distributed in the bedrock units throughout the region, however the wells may penetrate through the surficial bedrock unit to an underlying bedrock aquifer. For example, the wells located in the Bass Islands Formation in Figure 2.24 likely penetrate to the underlying Salina Formation, which is generally more permeable. Wells in the Guelph and Amabel Formations appear to intersect less bedrock than wells in other formations, indicating that they are more productive aquifers.

2.5.6 Specific Capacity

The specific capacity of a well is the ratio of the pumping rate to the drawdown (decline in water level) and is a measure of the well's productivity. Knowing the specific capacity of a well allows the theoretical calculation of its ultimate capacity, which is determined by multiplying the available drawdown (m) by the specific capacity (in L/s/m). The specific capacity of wells that have pumping test data of more than 24-hours in duration is illustrated in Figure 2.25. Wells having the highest specific capacities in the study area are adjacent to Williamsford, Hanover and Lucknow, and one well immediately north of Kincardine on the Lake Huron shore. These wells are located in areas overlain by, or adjacent to, fine grained glaciolacustrine deposits, as shown on Figure 2.6. These fine-grained surface aquitards may cause local confining conditions in lower aquifer units and thus significant upward groundwater gradients and lower recorded drawdown in pumped wells, resulting in high specific capacities for the selected wells.

2.5.7 Regional Groundwater Quality

The Ontario Drinking Water Standards (MOE, 2001) were designed to protect public health through the provision of safe drinking water. Water intended for domestic use should not contain disease-causing organisms, or unsafe concentrations of toxic chemicals or radioactive substances. Water should be aesthetically acceptable, and parameters such as taste, odour, turbidity and colour should be controlled.

Drinking water quality criteria must take into consideration several factors that may impact the quality of drinking water, public health, and technology available to treat the water. In the Ontario Drinking Water Standards, both 'standards' and 'objectives' are outlined. If a parameter is assigned a 'standard' there is a maximum acceptable concentration (MAC) assigned to the parameter. The MAC is a health-related standard established for parameters which, when present above a certain concentration, are known or suspected to cause adverse health effects. In contrast, 'objectives' (aesthetic objectives or operational guidelines) are established for parameters that may impair the taste, odour or colour of the water, or may interfere with good water quality control practices.

Regional groundwater quality was evaluated using information contained in the Engineer's Reports for each of the municipal wells in the study area. Included in the evaluation were chemical parameters (chloride, nitrate, and fluoride), parameters not directly related to health

(iron and hardness), and an indicator of potential surface water connection to the groundwater system (turbidity).

Figure 2.26 presents these groundwater quality indicators for the municipal systems in the study area. For each municipal well a chart is presented, which shows the results of the parameters that were sampled in the well water. All of the results reflect tests conducted on raw water samples (prior to treatment and distribution). For reference, the Ontario Drinking Water Standard limits and guidelines are also provided on Figure 2.26.

Chloride is an aesthetic objective parameter, which may originate naturally or be introduced anthropogenically (e.g. from road salt application). The aesthetic objective for chloride is 250 mg/L. None of the samples taken from municipal wells in the Counties exceeded this objective. The highest detected concentrations were observed in the Blair's Grove wells (125 mg/L), but other wells with elevated concentrations were found in Chatsworth (51.8 mg/L), Tara (44.5 mg/L), and Walter's Falls (42.5 mg/L).

Nitrate is a health related parameter that is known to cause methemoglobinemia (blue baby syndrome) in infants. Nitrates can originate from several sources including agricultural and residential fertilizers, wastewater disposal and landfill leachate. The maximum acceptable concentration is 10.0 mg/L. Nitrate concentrations recorded in the Engineer's Reports ranged from less than the analytical method detection limit, to 6.0 mg/L (the Lake Rosalind well).

Fluoride is a chemical that occurs naturally in many types of rocks, and due to soil weathering it is found in small amounts (generally less than 0.05 mg/L) in groundwater. However, it can also come from the infiltration of chemical fertilizers, and from septic system and sewage treatment effluents from communities with fluoridized water supplies. In high concentrations, fluoride can cause detrimental health impacts. The maximum acceptable concentration is 1.5 mg/L. The highest sampled concentration is 2.7 mg/L (the Huronville system), and there are many municipal wells in Grey and Bruce Counties that have concentrations above the MAC.

Hardness is an operational guideline parameter, which means that it is monitored and controlled to help ensure efficient treatment and distribution of the water. The divalent cations (calcium and magnesium) found in the limestone and dolostone aquifers throughout Grey and Bruce Counties produce the hard water. Hard water promotes scale deposits when the water is heated (i.e. hot water heaters, kettles) and it also leads to excessive soap consumption. However, there are no health effects associated with the elevated levels (MOE, 2001). All of the municipal wells in the Counties exceed the guideline of 80 to 100 mg/L. A value over 200 mg/L is considered tolerable, and over 500 mg/L is considered unacceptable. The highest levels were found in the Scott Point wells (1078 mg/L), far above the objective of 100 mg/L.

Iron is an aesthetic objective parameter, which means that it may interfere with good water quality control practices, but there are no known associated health risks (MOE, 2001). Elevated levels of iron may lead to staining of laundry or plumbing fixtures, and cause an undesirable taste in beverages. Of the 45 wells that were sampled for iron, 21 had recorded concentrations above the recommended limit.

Turbidity is a measure of the cloudiness in a sample of water that is caused by suspended fine particulate matter, and is measured using a light source and a sensor. It is an indicator that the groundwater system, from which the well draws its water, may be under the direct influence of surface water. The Ontario Drinking Water Standard for turbidity is 1.0 NTU (Nephelometric

Turbidity Unit), or the well water must be treated. Of the 51 municipal wells sampled, 18 had turbidity readings of greater than 1.0.

2.6 Regional Aquifer Characterization

Sections 2.2 to 2.5 provide an analysis of regional groundwater and aquifer characterization, for which mapping was completed at a scale of 1:650,000. Four (4) additional aquifer characterization maps were created at a more detailed larger scale of 1:200,000 and plotted on 30" by 36" layouts to present the regional aquifer characterization. Figure 2.27 shows the study area, and includes the location of the WWIS wells that were used for the data analysis, the regional cross-section locations, surface water features, and ground surface topography. Figure 2.28 shows the regional Quaternary geology, and includes the contours of overburden thickness. Figure 2.29 shows the regional bedrock geology, and includes the bedrock geology classes and bedrock topography contours. Figure 2.30 shows the regional overburden and bedrock aquifers, and includes the reliable water wells used in the analysis (along with their completion depth and geology), and the contours of sand and gravel thickness below the water table as an indication of overburden aquifer locations. These maps were developed to summarize the regional mapping that was completed as part of this groundwater study.

2.7 Summary of Regional Aquifer Characterization

Groundwater is one of the safest and cleanest forms of potable water supply, when compared with surface water. Understanding how groundwater moves through the study area and the factors that control this movement will help to manage this resource. Regional groundwater and aquifer characterization was presented in Section 2. Information from many different data sources, including the Ministry of Environment, Ministry of Natural Resources, Ministry of Northern Development and Mines, Geologic Survey of Canada, Water Survey Canada, Grey County, Bruce County, Saugeen Valley Conservation Authority, Grey Sauble Conservation Authority and local municipalities was incorporated into a project database and GIS. The quality of the different sources of information was evaluated and data that was deemed inaccurate was removed from subsequent analyses. As part of the regional analysis, water well locations and reliabilities (Figures 2.1 and 2.2), ground surface topography (Figure 2.3), surface drainage and stream gauge locations (Figures 2.4A and B) were presented. The surficial geology of the Counties left by the glaciers is presented in the Quaternary geology map (Figure 2.5) and the physiography of the Counties is presented in Figure 2.6. The bedrock geology is presented in the bedrock geology map (Figure 2.7), and the bedrock surface topography map (Figure 2.8).

Regional geologic cross-sections illustrate the Quaternary and bedrock geology, topography, and their relationships across the study area. The locations of the regional cross-sections are presented in Figure 2.9, and the cross-sections are presented in Figures 2.10 to 2.17. In particular, they show the similarity between the bedrock and ground surface topography, the thinning nature of the overburden from west to east toward the Niagara Escarpment, and the distribution of sand and gravel units associated with the Port Huron Moraine, in the south central portion of the study area. Details of the geology and its relationship to the regional water table and hydrogeology are discussed throughout this report.

The nature of the overburden deposits in Grey and Bruce Counties was investigated and presented in the depth to bedrock (Figure 2.18), and sand and gravel thickness (Figures 2.19) maps. The hydrogeology of Grey and Bruce Counties was investigated and presented in the water table surface (Figure 2.20), bedrock equipotentials (Figure 2.21), and recharge and discharge areas (Figure 2.22). The water table elevation map and bedrock equipotential map show regional groundwater flow directions in the overburden and bedrock aquifers, and the recharge/discharge relationships that exist throughout the Counties.

The hydrogeology of Grey and Bruce Counties was conceptualized as a three-layered model with, from top to bottom, a fine-grained overburden aquitard layer, a thin weathered bedrock aquifer layer, and a thick unweathered bedrock aquifer. Details of the subsurface hydrogeologic conditions in the Counties were determined by examining 8 regional cross-sections and many local cross-sections. The aquifers of Grey and Bruce Counties are summarized in an overburden aquifer map (Figure 2.23) and a bedrock aquifer map (Figure 2.24). This conceptualization of regional hydrogeology was used as the basis for the development of the WHPA models, which are discussed in Section 6. Specific capacity of municipal wells was assessed, and presented in Figure 2.25, using data from pumping tests of at least a 24-hour duration. Groundwater quality throughout the Counties was evaluated through a review of raw water quality presented in the Engineer's Reports for the different municipal wells. Parameters that were considered in this analysis include chloride, nitrate, fluoride, iron, hardness and turbidity. This groundwater quality assessment was presented in Figure 2.26.

Finally, the analysis presented in this report provides a regional summary of groundwater and aquifer characterization in Grey and Bruce Counties. To augment this analysis, 4 additional maps were created at a scale of 1:200,000 to present the regional aquifer characterization in a more detailed manner. Figure 2.27 shows the study area and the location of the WWIS wells that were used for the data analysis. Figure 2.28 shows the regional Quaternary geology, and includes the overburden thickness contours. Figure 2.29 shows the regional bedrock geology, and includes the bedrock geology classes and bedrock topography contours. Figure 2.30 shows the regional overburden and bedrock aquifers, and includes the reliable water wells within the study area (along with their completion depth and geology), and the contours of sand and gravel thickness below the water table as an indication of overburden aquifer locations.

3 Intrinsic Susceptibility Analysis

3.1 Overview

The susceptibility of an aquifer to contamination is a function of the susceptibility of its recharge area to the infiltration of contaminants. Groundwater susceptibility to contamination can thus be defined as: *the tendency or likelihood for contaminants to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer.* Susceptibility is not an absolute property, but a relative indication of where contamination is likely to enter the subsurface. It is also necessary to consider long-term effects on groundwater quality, perhaps over decades, in carrying out a susceptibility analysis.

A number of factors may influence the susceptibility of an aquifer. Areas of high recharge are generally more susceptible to groundwater contamination than areas where recharge is restricted. Unconfined aquifers having little cover of fine-grained material are susceptible to contamination, and fractured bedrock is highly susceptible because of increased pathways for contaminant movement. However, deeper aquifers confined by a relatively impermeable formation overlying them tend to be better protected. Water wells can provide a direct pathway for contaminants from the land surface to the groundwater, if they are not installed and maintained properly. In addition, wells intersecting two aquifers increase the chance of cross contamination between the aquifers. Thus, a major consideration in groundwater contamination is the location and condition of water wells.

Overburden geologic units generally provide the primary protection against groundwater contamination from the surface. Bacteria, sediment and other insoluble forms of contamination become trapped or sorbed on soil particles. Some chemicals are absorbed or react chemically with various soil constituents, thereby preventing or slowing the migration of these contaminants into the groundwater. In addition, plants and soil microorganisms use some potential contaminants, such as nitrogen, as nutrients for growth, thereby reducing the amount reaching the groundwater. These processes are known as natural attenuation processes.

These natural systems can fail if they are overloaded with contaminants. Large amounts of contaminants concentrated in small areas can thus cause local groundwater contamination, depending on the depth and type of soil above the water table. To help protect water wells against contamination, it is important to use the natural protection that soil provides by maintaining adequate separation distances between wells and potential sources of contamination. Wellhead protection strategies aim at mitigating or minimizing the potential for aquifer contamination through proper land use and groundwater management alternatives.

It is costly and time consuming to identify and remediate groundwater contamination after an aquifer has been impacted, and the aquifer may remain contaminated for years after the source of contamination has been removed. Therefore, it is often unfeasible to consider groundwater remediation as a solution. Prevention of groundwater contamination is the key, which includes identifying the major sources of potential contamination, and controlling them.

In the present regional groundwater study, a preliminary groundwater susceptibility assessment has been completed. In this section, a brief summary of the approach and results of the assessment are presented.

3.2 Methodology and Data Sources

The vulnerability of the groundwater resources in Grey and Bruce Counties was evaluated using an Intrinsic Susceptibility Index. The Intrinsic Susceptibility Index (ISI) is a calculated value that estimates the susceptibility of the groundwater resource to contamination at each WWIS well in the study area.

The following process was used to determine the intrinsic susceptibility:

- The geology of each well was evaluated to determine the “first significant aquifer”;
- The water table map (Figure 2.20) was used as a reference for determining this aquifer;
- The aquifer was classed as either confined or unconfined, depending on the location of the water table and the type of geologic material above it;
- The confined/unconfined nature of the aquifer determines the depth over which the ISI calculations were made;
- The ISI value was then calculated at each well by summing the multiplication of the thickness of each unit by the K-factor that represents its geology over this depth;
- The K-factors are defined in the Technical Terms of Reference for the study (MOE, 2001);
- Polygons representing the identified karst areas within the study area were overlain and assigned an ISI value of 20 (high susceptibility);
- Polygons representing overburden thickness of less than 6.0 meters were assigned an ISI value of 20 (high susceptibility); and,
- The ISI map was re-interpolated across the entire study area to provide a final ISI map.

Following the Technical Terms of Reference, the ISI value at each well in the WWIS was classified into one of 3 susceptibility groupings: low (ISI > 80), medium (30 ≤ ISI ≤ 80) and high (ISI < 30) (MOE, 2001). Appendix A presents the Process Sheet that describes the methodology for calculating the ISI value at all WWIS boreholes.

3.3 Intrinsic Susceptibility Results

The results of the intrinsic susceptibility analysis are presented in Figure 3.1. Medium and high susceptibility classes are the most important classes to consider, and Figure 3.1 shows that a large portion of the study area is characterized by medium or high ISI values. In addition, a 1:200,000 map was created on a 30” by 36” layout to show Intrinsic Susceptibility at a more detailed larger scale. Figure 3.2 shows the regional Intrinsic Susceptibility, and includes the identified karst areas and contaminant sources.

High susceptibility results from the presence of high permeability overburden units with little, or no, low conductivity layers protecting the first significant aquifer. In areas of high susceptibility located near municipal pumping wells, appropriate planning measures should be designed to restrict development in such areas. Such planning measures could include a requirement that developers must perform site-specific investigation of aquifer susceptibility, and demonstrate that the proposed development will have a negligible impact on the groundwater supply aquifer.

Areas of low susceptibility occur mainly in the southwest portion of Bruce County, and correspond to the fine-textured Quaternary deposits of the Huron Slope, which is illustrated in Figure 2.5. This fine-grained surface material restricts the downward movement of infiltrating surface water, making the underlying groundwater much less susceptible to associated contamination.

The Bruce Peninsula is an area of high susceptibility for impacts to groundwater. This is the result of the thin and discontinuous nature of the Quaternary cover material providing little protection to the underlying bedrock. This was definitively demonstrated in the karst field investigation and geomorphological inventory of the Upper Bruce Peninsula (Canadian Parks Service, 1994), which found karst caves, sinkholes, ponors (sinking streams), sinking lakes, springs and three types of karst pavement.

The remainder of the study area consists of a zone of high susceptibility trending from the base of the Bruce Peninsula to the southeast corner of Grey County. This corresponds roughly to the occurrence of the Guelph aquifer which underlies this area. The higher susceptibility rating for this unit is related to the fact that it is generally more permeable than other bedrock units in the area. The remainder of the study area is classified as being medium susceptibility.

3.4 Summary of Intrinsic Susceptibility Analysis

Groundwater intrinsic susceptibility for the uppermost significant aquifer was assessed using information contained within the MOE Water Well Information System and information on the location of identified karst features in Grey and Bruce Counties.

The approach followed the method outlined in the MOE Technical Terms of Reference. This method considers the thickness of the different geologic strata as well as their permeability through the use of a K-factor. Polygons representing the identified karst areas (caves, sinkholes, sinking streams, sinking lakes, and karst pavement) within the study area were overlain, incorporated into the GIS and given a high susceptibility value. Within the uppermost aquifer system, areas of low, medium, and high susceptibility were identified using MOE susceptibility classes (low ($ISI > 80$), medium ($30 \leq ISI \leq 80$) and high ($ISI < 30$)). Areas of medium or high susceptibility result from the presence high permeability units in the overburden with little, or no, low conductivity layers overlying the uppermost significant aquifer. Some areas of Bruce County were characterized by low susceptibility due to the thick units of fine-textured Quaternary deposits.

In areas of high susceptibility near municipal pumping wells, it is recommended that municipal planning measures be developed to restrict development, or to require local-scale hydrogeologic investigations that assess the vulnerability of the aquifer to contamination.

4 Groundwater Use Assessment

4.1 Overview

A groundwater use assessment was completed to estimate the degree, purpose and distribution of groundwater use in the study area to provide an overview of existing pressures on the quantity of local groundwater resources. To achieve these objectives, it was first necessary to analyze population statistics and agricultural land use within the Counties. By completing an estimate of existing groundwater use, the study will contribute to a future water budget study, which can investigate the factors influencing the availability of groundwater, and the potential future demands on water supply. There are two categories of water use: public supply and self supply. Within these categories, groundwater use in the study area can be grouped according to the following uses:

- public supply (municipal, communal, recreational);
- self supply (private domestic);
- self supply (agricultural-livestock, irrigation);
- self supply (industrial-manufacturing, commercial, institutional); and,
- self supply (industrial-mining).

To ensure sustainable growth, the rate of groundwater extraction should be based on the rate of groundwater recharge and the maintenance of satisfactory baseflow levels in local streams. If groundwater use exceeds groundwater recharge, an overdraft (or “mining”) will occur which would result in impacts to streams and reduce the total available groundwater resource. An understanding of the distribution of groundwater use in Grey and Bruce Counties is essential to managing this resource. This assessment of water use and the groundwater budget will assist in determining reasonable levels of water use.

4.2 Methodology and Data Sources

Data for the groundwater use assessment was obtained from various sources, including the MOE Permit to Take Water (PTTW) database, public water supply reports (Engineer’s Reports), the MOE Water Well Information System (WWIS), and Certificates of Approval. Information was also obtained from surveys of public water supply systems and large-scale permitted water users, whose permitted groundwater taking is greater than 200,000 L/day. A groundwater use assessment was undertaken to compile and evaluate the existing information, and to better understand the distribution of water taking throughout the Counties on a watershed level.

4.3 Population and Land Use

4.3.1 Population

The populations of Grey and Bruce Counties at the time of the 2001 census were 89,073 and 63,892, respectively. The population of the Counties, based on Municipality, is presented in Table 4.1. The City of Owen Sound is the largest urban center in the Counties, with a population of 21,431 (2001 Census). Other urban centers in Grey County include: Hanover (6,869), Meaford (4,524), Durham (2,647), Wiarton (2,349), Dundalk (1,972 people), Chesley (1,880), Thornbury (1,771), Markdale (1,433), and Paisley (1,033). Urban centers in Bruce County include Port Elgin (6,445), Kincardine (6,113), Walkerton (4,851), Southampton (3,075), Mildmay (1,150), Lucknow (1,136), and Teeswater (1,109). Although the First Nations Reserves (FNRs) are not part of the scope for this study, their population statistics are included in Table 4.1 to display the complete breakdown of the population of Grey and Bruce Counties.

Grey and Bruce Counties are primarily agricultural with activity that includes beef, dairy and hog operations, as well as cash-crop farming and an apple industry. Other industry within the Counties includes hardwood and softwood timber production, commercial fishing and year-round recreation and tourism.

Table 4.1: POPULATION ESTIMATES OF GREY AND BRUCE COUNTIES BY MUNICIPALITY

County	Municipality	2001 Census Population
Grey	Township of Georgian Bluffs	10,152
	Township of Chatsworth	6,280
	Municipality of West Grey	11,741
	Township of Southgate	6,907
	Town of Hanover	6,869
	Municipality of Grey Highlands	9,196
	City of Owen Sound	21,431
	Municipality of Meaford	10,381
	Town of The Blue Mountains	6,116
	89,073	
Bruce	Municipality of Arran-Elderslie	6,577
	Town of South Bruce Peninsula	8,090
	Municipality of Brockton	9,658
	Township of Huron-Kinloss	6,224
	Municipality of South Bruce	6,063
	Municipality of Kincardine	11,029
	Town of Saugeen Shores	11,388
	Municipality of Northern Bruce Peninsula	3,599
	FNR – Saugeen 29	677
	FNR – Neyaashiinigmiing	587
	63,892	

4.3.2 Land Use

Land use throughout the study area is presented in Figures 4.1 and 4.2. Information that was used to complete this mapping was provided by the Bruce County Planning Department and the Grey County Planning Department. The land uses have been divided into 10 categories:

- Agricultural/Special Agricultural
- Mineral Resource Extraction
- Hamlet
- Niagara Escarpment Plan Area
- Commercial
- Industrial
- Wetlands
- Inland Lakes/Shoreline
- Hazard Lands
- Urban/Urban Fringe

Much of Grey and Bruce Counties is designated as either i) agricultural/forestry/rural, or ii) parks/recreational/protected. The Niagara Escarpment, which is a striking feature of the study area running from the northern Bruce Peninsula to the northern portion of Grey County, is designated as parks/recreational/protected. There are also large areas through the Counties that are designated as lakes and wetlands. Scattered throughout the study area are urban areas, which can be identified as residential/commercial/institutional.

4.3.3 Agricultural Land Use

Potential impacts of agricultural activities on the natural environment include contamination from excessive nutrients, pathogens, sediment, pesticides and organic materials. These

contaminants could potentially affect the colour, smell and taste of water, and can be represented by four distinct components:

- **Extent** of agriculture within an area, which is represented by the fraction of agricultural land within the total area.
- **Nature of agricultural activity** There are two major interrelated biological systems involved in agricultural production activities: those related to crop production and those related to livestock production.
- **Intensity** of the agricultural activities as indicated by the levels of management (livestock type and quantity, tillage, nutrient amendments and pesticides) compared to levels normally used in agricultural enterprises.
- **Proximity** is an indication of the connection pathway between agricultural activities and the component of the agro-ecosystem resource under consideration. For example, crop production on tile drained land or adjacent to streams or drainage ditches is more likely to result in contamination of surface water than on land that is farther from surface drainage.

Data from the 2001 Census of Agriculture was used to assess each of these components. As a basis for comparison, a similar analysis was carried out for the Census Agricultural Region of Western Ontario. This region includes the Counties of Bruce, Grey, Huron, Perth, Simcoe, Halton, Wellington, Waterloo, Dufferin and Peel. Agricultural activities in Grey and Bruce Counties are relatively homogeneous across the 17 municipalities within the Counties. The results of the analysis have been summarized in Tables 4.2 and 4.3.

Extent

The total area of each municipality was calculated by summing the various townships in the new municipality configuration as documented in Agricultural and Rural Development Act (ARDA) Report No. 8 "Acreages of Soil Capability Classes for Agriculture in Ontario". The area of farmland is reported in the 2001 Census of Agriculture. Extent of agricultural operations is presented as a percentage of the total municipal land area that is designated farmland. Agriculture is the major land use throughout the Counties (~60% for Bruce County and ~52% for Grey County), which is approximately the same as the average percentage of land used for agriculture for the Western Ontario Region. This indicates that agricultural activities will have a major impact on all aspects of environmental quality.

Nature of Agricultural Activity

The nature of the agricultural activity was estimated using the farm type classifications in the 2001 Census of Agriculture. For this analysis the specific classes were grouped into livestock farms and crop farms. This shows that for much of the area, the percentage of livestock farms equals or exceeds the average for the Western Ontario Region. For livestock farms, the operators should minimize potential risks to water quality both from livestock operations (facilities, manure storage, application, etc.) as well as crop production activities (nutrient management, pesticides, sediment, etc.). Areas with a low percentage livestock farms will have a correspondingly high percentage of crop farms.

Intensity

Intensity was calculated by summing the portion of total farmland that is used for crops (annual and perennial). This measure provides an indication of the quantity of land on farms that receive most of the management attention by the farm operator. The Grey-Bruce area is quite variable

in terms of the proportion of cropland. The highest proportion of cropland is in the southwestern part of the region, while there is a relatively low percentage of cropland in the Bruce Peninsula.

Table 4.2: AGRICULTURAL ANALYSIS AND CHARACTERIZATION OF BRUCE COUNTY

Municipality Attribute	Northern Bruce Peninsula	South Bruce Peninsula	Saugeen Shores	Arran-Elderslie	Kincardine	Brockton	Huron-Kinloss	South Bruce	Bruce County	Western Ontario
Farmland as a percentage of total area	28	38	53	83	68	83	83	53	61	62
Land in crops (percentage of farmland)	15	38	60	50	60	60	60	60	50	71
Crop intensity (percentage of land in corn, soybeans, cereals)	20	20	70	45	60	60	70	70	52	66
Crop Intensity (average N required by major field crops kg/Ha)	68	66	43	63	48	55	48	63	57	58
Average number of cattle per ha farmland	0.45	0.60	0.45	1.0	0.60	1.0	0.60	0.68	0.67	0.59
Average number of hogs per ha farmland	0.03	0.03	0.03	0.30	0.50	0.90	0.50	0.90	0.40	1.14
Average number of hens per ha farmland	0.5	0.5	0.5	0.5	3	3	6	6	2.5	11.8
Percent farms classed as livestock (cattle, hogs, poultry, sheep, other)	70	78	50	83	70	70	50	78	69	66

Table 4.3: AGRICULTURAL ANALYSIS AND CHARACTERIZATION OF GREY COUNTY

Municipality Attribute	Georgian Bluffs	Meaford	The Blue Mountains	Chatsworth	Grey Highlands	West Grey	Southgate	Grey County	Western Ontario
Farmland as a percentage of total area	53	53	38	38	53	53	68	51	62
Land in crops (percentage of farmland)	38	50	60	50	50	60	60	53	71
Crop intensity (percentage of land in corn, soybeans, cereals)	30	30	30	30	30	45	45	34	66
Crop Intensity (average N required by major field crops kg/Ha)	68	63	43	63	55	55	63	59	58
Average number of cattle per ha farmland	0.60	0.45	0.30	0.68	0.45	0.60	0.68	0.54	0.59
Average number of hogs per ha farmland	0.03	0.13	0.50	0.13	0.13	0.30	0.30	0.22	1.14
Average number of hens per ha farmland	0.5	1.5	0.5	1.5	0.5	14	6	3.5	11.8
Percent farms classed as livestock (cattle, hogs, poultry, sheep, other)	83	70	28	78	78	78	70	69	66

Crop Intensity Factor

The intensity of cropping from the standpoint of nutrient loading was evaluated by calculating the average annual quantity of supplemental nitrogen required for annual crop production, as reported in the Census of Agriculture (based on 1995 – 1996 Field Crop Recommendations, OMAF Publication 296). Annual crops represent greater levels of intensity than perennials. Areas with a higher percentage of annual crops require relatively large quantities of supplemental nutrients, a mix of pesticides and substantial tillage.

For the Grey-Bruce area, annual crops are assumed to be in a 3 year intensive crop rotation, which provides maximum economic productivity in an environmentally sustainable fashion consisting of corn, soybeans and cereals. The calculation is based on area of cropland, which also includes the forage component of the rotation. Tables 2.6 and 2.7 show that there is little variation in the levels of supplemental nitrogen required. However, in more northerly areas, the values are somewhat higher. This occurs because of the predominance of corn and limited area of soybeans.

The average density of the various species of livestock per area of farmland was used to provide an indication of livestock intensity. It is instructive to note that the ruminant species (cattle and sheep) will typically spend a portion of their time on pasture where the manure is directly deposited and where they may have occasion to contaminate surface watercourses directly. In addition, manure handling for sheep and beef will most likely be in solid form. For dairy, there will be a mix of solid and liquid handling operations. Pigs and poultry will be raised in confinement. In most cases, the hog manure will be handled in liquid form while the poultry manure will be managed in solid form. Both of these types of operation frequently rely on feed (with added nutrients) that is purchased off farm and therefore, residual nutrients must also be managed.

Table 4.2 and 4.3 include the average number of cattle, hogs and hens per hectare of farmland for the Grey-Bruce area. Clearly, there is a wide range of intensity by this measure. While the relationship between the number of livestock and farm area is not as direct as with grazing animals, this representation provides an indication of the area available to manage the manure produced. Overall livestock intensity is a combination of each of these components (cattle, hogs and poultry), along with other livestock such as sheep and horses.

The agricultural land use analysis shows that agricultural activities are highly variable across the area. The variation in patterns of livestock activities may be important in assessing the potential impact of agricultural operations on water resources.

4.4 Groundwater Use Assessment Results

Groundwater use for Grey and Bruce Counties was obtained primarily from the MOE Permit to Take Water (PTTW) database. Water use in excess of 50,000 L/day (7 Imperial gallons per minute), requires a permit. The PTTW database includes information associated with each permit (e.g. issue date, expiration date, location, and maximum permitted pumping rates). Water takings from surface water (e.g. ponds, rivers or lakes), from groundwater (e.g. wells or springs), or from a combination of surface water and groundwater requires a permit.

There are 422 permits in the PTTW database for the study area, each of which may have multiple records, corresponding to separate water sources (i.e. well, spring or pond). The 422 permits correspond to 553 records in the PTTW database. These 422 permits can be further categorized according to water source:

- 168 permits are from a **surface water** source (pond); and,
- 213 permits are from a **groundwater** source (well or spring);
- 41 permits are from **combined** surface and groundwater sources.

For the groundwater use assessment, the 254 **groundwater** and **combined** permits were assessed. Figure 4.3 presents the locations of the groundwater permits in the Counties classified by maximum permitted rate. Of these 254 groundwater related permits, there are:

- 156 **active** permits (i.e. having an expiration date later than January 1, 2002);
- 96 **large-scale** permits (maximum permitted rate of greater than 200,000 L/day);
- 37 large-scale permits that are classified as commercial, industrial, de-watering; and,
- 33 permittees holding the 37 permits.

These 33 large-scale, active, industrial groundwater users were surveyed to obtain information on actual water taking. A copy of the questionnaire that was sent to these large-scale users can be found in Appendix B.

4.4.1 Rural Domestic Groundwater Use

Rural domestic groundwater use was determined using estimates of the rural populations in the Counties, and a water-use factor. The rural population was estimated for each township by subtracting the population of towns with a municipal groundwater supply from the township population. Township population statistics were obtained from the Statistics Canada 2001 Census, and the Engineer's Reports were used to estimate the population serviced by municipal groundwater. Table 4.4 summarizes the population on municipal groundwater and municipal surface water, and the net rural population using private groundwater wells.

TABLE 4.4: POPULATION STATISTICS BY MUNICIPALITY AND WATERSHED

County	Municipality	Municipal Population on Groundwater	Municipal Population on Surface Water	Rural Population on Groundwater	Total
Grey	Georgian Bluffs	667	–	9,485 ¹	10,152
	Chatsworth	650	–	5,630	6,280
	West Grey	2,447	–	9,294	11,741
	Southgate	1,972	–	4,935	6,907
	Hanover	6,600	–	269	6,869
	Grey Highlands	1,997	–	7,199	9,196
	Owen Sound	–	21,431	–	21,341
	Meaford	–	4,524	5,857 ¹	10,381
	The Blue Mountains	–	1,771	4,345 ¹	6,116
County Total		14,333	27,726	47,014	89,073
Bruce	Arran-Elderslie	2,622	1,033	2,922	6,577
	South Bruce Peninsula	840	2,349	4,901	8,090
	Brockton	5,081	–	4,577	9,658
	Huron-Kinloss	5,439	–	785	6,224
	South Bruce	2,200	–	3,863	6,063
	Kincardine	1,103	6,113	3,813	11,029
	Saugeen Shores	–	9,520	1,868	11,388
	Northern Bruce Peninsula	–	500	3,099 ¹	3,599
	IR – Combined	–	–	1,264 ¹	1,264
County Total		17,285	19,515	27,092	63,892
Watershed					
Saugeen Valley CA		25,597	16,201	35,413	
Grey Sauble CA		4,150	30,756	36,489	
Maitland Valley CA		2,230	–	322	
Grand River CA		158	–	395	
Nottawasaga Valley CA		220	283	1,487	
Watershed Total		32,355	47,240	74,106	

¹ This assumes rural population uses private water wells, even though some use surface water

Table 4.5 presents the results of rural domestic groundwater use in Grey and Bruce Counties. Population estimates were obtained from Table 4.4, and the water-use factor (175 L/day per person) was obtained from the Technical Terms of Reference (MOE, 2001). The results show that rural domestic groundwater use is 12,969 m³/day (4.73 million m³/year). It should be noted that some rural residents along the Georgian Bay shoreline use surface water for domestic use. As a result, the groundwater use in Table 4.5 is slightly overestimated.

Rural groundwater use was also estimated by watershed. This was accomplished by estimating the percentage of each township lying within the five conservation areas occurring in Grey and Bruce Counties, and multiplying rural population by the water-use factor. Watershed boundaries were obtained from the Saugeen River and Grey Sauble Conservation Authorities, which are presented in Figure 2.2.

TABLE 4.5: RURAL GROUNDWATER USE BY MUNICIPALITY AND WATERSHED

County	Municipality	Rural Population	Estimated Rural Groundwater Use (m ³ /day)
Grey	Georgian Bluffs	9,485	1,660
	Chatsworth	5,630	985
	West Grey	9,294	1,627
	Southgate	4,935	864
	Hanover	269	47
	Grey Highlands	7,199	1,260
	Owen Sound	–	–
	Meaford	5,857	1,025
	The Blue Mountains	4,345	760
County Total		47,014	8,228
Bruce	Arran-Elderslie	2,922	512
	South Bruce Peninsula	4,901	858
	Brockton	4,577	801
	Huron-Kinloss	785	137
	South Bruce	3,863	676
	Kincardine	3,813	667
	Saugeen Shores	1,868	327
	Northern Bruce Peninsula	3,099	542
	Indian Reserves	1,264	221
County Total		27,092	4,741
Total		74,106	12,969
Watershed			
Saugeen Valley CA		35,413	6,197
Grey Sauble CA		36,489	6,386
Maitland Valley CA		322	56
Grand River CA		395	69
Nottawasaga Valley CA		1,487	260
Watershed Total		74,106	12,969

4.4.2 Municipal Groundwater Use

There are 48 municipal groundwater systems in Grey and Bruce Counties, as defined in the Terms of Reference. However, due to changes in the use of these systems, six (6) were taken off-line and only 42 were analyzed for this groundwater study including 13 in Grey County and 29 in Bruce County. The majority of these systems are completed in bedrock, which is further

discussed for each system in Section 6, Groundwater Modeling. Information about each municipal system was obtained from Engineer's Reports, as well as from municipal surveys. The Engineer's Reports contain most of the following information:

- Water Works number, Certificate of Approval number and PTTW number;
- Design capacity, permitted capacity and population served;
- Total raw water flow (by month and year) and average daily flow (by month),
- UTM coordinates of the well(s) and the plant.

As part of the groundwater use assessment, the operator for each of the municipal groundwater supply systems in Grey and Bruce Counties was contacted and asked to provide the following information, to confirm and/or complete the data obtained from the Engineer's Reports:

- MOE well number, Certificate of Approval number and PTTW number; and,
- Average daily raw water flow rate for the last 5 years.

The results of the Municipal Water Supply Survey are summarized in Table 4.6. Appendix C contains the original survey results, along with data collected from the First Engineer's Reports.

TABLE 4.6: MUNICIPAL GROUNDWATER USE BY MUNICIPALITY AND WATERSHED

County	Municipality	Municipal Population on Groundwater	Municipal Groundwater Use (m³/day)
Grey	Georgian Bluffs	667	208
	Chatsworth	650	170
	West Grey	3,184	1,463
	Southgate	1,972	660
	Hanover	6,600	1,753
	Grey Highlands	1,997	3,490
	Owen Sound	-	-
	Meaford	-	-
	The Blue Mountains	-	-
	County Total	15,070	7,744
Bruce	Arran-Elderslie	2,622	1,262
	South Bruce Peninsula	840	198
	Brockton	5,081	5,756
	Huron-Kinloss	5,439	2,030
	South Bruce	2,200	1,047
	Kincardine	1,103	579
	Saugeen Shores	-	-
	Northern Bruce Peninsula	-	-
	First Nation Reserves	-	-
	County Total	17,285	10,872
Total		32,355	18,616
Watershed			
	Saugeen Valley CA	25,597	16,176
	Grey Sauble CA	4,150	1,237
	Maitland Valley CA	2,230	541
	Grand River CA	158	660
	Nottawasaga Valley CA	220	-
	Watershed Total	32,355	18,616

Surface water takings for municipal supply are not considered in the water budget for Grey and Bruce Counties. The majority of municipal surface water systems take water from Lake Huron or Georgian Bay, which does not significantly affect the water balance of the watersheds. The municipal populations in Grey and Bruce Counties that are serviced by surface water supply include the former Towns of Kincardine, Port Elgin and Southampton, which use water from Lake Huron for municipal supply, and the City of Owen Sound, the former Towns of Wiarton, Meaford and Thornbury, and the former Village of Lion's Head, which use water from Georgian Bay for municipal supply. The former Village of Paisley, in the Municipality of Arran-Elderslie, uses water from a reservoir on the Saugeen River for municipal supply.

4.4.3 Communal and Campground Groundwater Use

There are 10 permit holders in Grey and Bruce Counties that have active groundwater permits for water supply that relate to communal or campground use. Communal and campground use within the study area, based on maximum permitted rate, is 2,971 m³/day.

4.4.4 Industrial, Commercial and Dewatering Groundwater Use

The MOE Technical Terms of Reference state the need to estimate groundwater use by large-scale Industrial groundwater users. Large-scale groundwater use is defined as a permitted withdrawal of greater than 200,000 L/day. The following information was obtained from the PTTW database, to conduct a survey of large-scale groundwater users:

- Permit number;
- General and specific purpose;
- Maximum permitted water taking (L/day);
- Days per year of taking; and,
- Identity of the largest water users.

Large-scale groundwater users were surveyed by telephone, on their water taking, in the summer of 2002. To evaluate the volume of water being pumped at these locations and to collect additional information about the location and status of the pumping well, the following questions were asked:

- What is the location of your well(s)?
- What is your well currently being used for?
- Is there a secondary use for your well?
- What is the depth and diameter of the well?
- When was the well drilled?
- Who is the original owner of the well?
- What months of the year do you pump water?
- How many days a month do you pump water?
- How many hours a day do you pump water? and,
- What is the capacity of your pump?

The survey results are presented in Appendix B, and summarized in Table 4.7. Surveys were sent out to the 33 permittees that hold the 37 permits. Groundwater use for these permits included quarry operation (aggregate washing, quarry dewatering), aquaculture (fish hatchery operations), bottled water operations, golf course irrigation, forestry operations and recreation. Even though the water used for quarry and aquaculture operations is commonly discharged to surface water shortly after use, which returns the water to the hydrologic cycle, these operations are still required to have permits to take water. Results were obtained from 21 of the 33 permit

holders. In most instances, actual groundwater use was not known. To be conservative, the maximum permitted withdrawal rate was used to estimate the large-scale groundwater use in the water budget, which discussed in Section 4.5. Large-scale groundwater use within the study area, based on maximum permitted rate, is **241,694 m³/day**. However, some of the permit locations are within the 5 kilometre buffer, and therefore, large-scale groundwater use in the Counties is **207,617 m³/day**.

TABLE 4.7: LARGE-SCALE WATER USER SURVEY RESULTS

Large PTTW Holder	Permit	Municipality	Water Use	Reply	Maximum PTTW Rate (m ³ /day)
Georgian Aggregates	01-P-1036	Clearview	Aggregate washing	Yes	25,094
	96-P-5019	Clearview	Dewatering of quarry	Yes	5,460
E.C. King Contracting	77-P-1051	Saugeen Shores	Aggregate washing	Yes	2,621
	99-P-1125	Georgian Bluffs	Aggregate washing	Yes	6,480
Wayne Schwartz Constr	01-P-1106	Chatsworth	Aggregate washing	Yes	818
Robert A. Livingstone	84-P-1004	The Blue Mountains	Aquaculture	Yes	
Springhills Trout Farm	79-P-1207	Chatsworth	Aquaculture	Yes	7,855
MNR/Chatsworth Fishery	71-P-0158	Chatsworth	Aquaculture	Yes	6,546
	73-P-0153	Chatsworth	Aquaculture	Yes	9,819
Aquafarms 93	00-P-1365	Chatsworth	Commercial water	Yes	3,448
Trillium Springs Fish Farm	98-P-1101	Chatsworth	Fish hatchery	Yes	3,928
Lake Huron Fishing Club	85-P-1028	Saugeen Shores	Fish hatchery	Yes	720
	91-P-0011	Kincardine	Fish hatchery	Yes	2,062
Gibraltar Springs	92-P-0099	The Blue Mountains	Bottled water	Yes	1,473
Artemesia Waters Ltd.	99-p-1011	Grey Highlands	Bottled water	Yes	484
QTF Foods Inc.	93-P-0058	Kincardine	Food processing	Yes	65,472
Saugeen Golf Club	96-P-1018	Saugeen Shores	Irrigation – Golf Course	Yes	1,904
Walkerton Golf Club	64-P-0351	Brockton	Irrigation – Golf Course	Yes	546
Stone Tree Golf Club	98-P-1096	Owen Sound	Irrigation – Golf Course	Yes	1,650
Interforest Ltd.	97-P-1067	West Grey	Forestry Operation	Yes	7,965
Patricia Bain	65-P-0656	Chatsworth	Recreational	Yes	
Frank Beirnes	93-P-0060	Chatsworth	Bottled Water	Yes	455
Harold Sutherland	01-P-1082	Georgian Bluffs	Quarry Dewatering	Yes	2,160
Grey County, Hwy Dept	98-P-1100	Grey Highlands	Quarry Dewatering	Yes	7,200
Brick Brewing Company	92-P-0059	South Bruce	Brewing and Soft Drinks		2,724
	00-P-1030	South Bruce	Brewing and Soft Drinks		655
Tymatts Development Inc	01-P-1031	Clearview	Irrigation – Golf Course		2,159
Fairlee Juice	92-P-0057	Southgate	Bottled Water		598
Mel McKean Investments	91-P-0019	Clearview	Industrial		1,364
Steve McKague	00-P-1202	South Bruce	Aggregate Washing		7,680
Clearly Canadian	92-P-0005	South Bruce	Bottled Water		11,356
Salvatore Carapino	93-P-0070	South Bruce Pen.	Aquaculture		464
Bryan Van Den Bosch	99-P-1271	West Grey	Aquaculture		982
Tadcaster Developments	93-P-0023	Grey Highlands	Bottled Water		1,473
Robert Charter	80-P-1021	South Bruce	Aquaculture		3,496
Jim Taylor	92-P-0069	West Grey	Aquaculture		21,930
Al Boogerman	99-P-1128	West Grey	Aquaculture		22,653
33	37			21	241,694¹

¹ Four (4) permits are within the buffer area. Thus, Large-Scale water use in the Counties is 207,617 m³/day

4.4.5 Agricultural Groundwater Use

Agricultural groundwater water use was compiled by the Rob de Loe Consulting Services for the Ministry of Natural Resources for all of Ontario. The results for Grey and Bruce Counties are presented in Table 4.8 (de Loe, 2002).

In Table 4.8, the number of farms refers to farms reporting gross farm receipts over \$2500. Livestock refers to water used for animal drinking, washing and cooling, as well as washing barns, equipment and spillage losses. Field water use includes irrigation, crop spraying, equipment washing and other minor uses. The category 'fruit' refers to water use for irrigation, herbicide, insecticide, and fungicide sprays, as well as frost protection, sanitation and processing on fruit farms. 'Vegetables' refers to water used in vegetable farms including water used in irrigation, crop spraying, harvest water use, equipment washing, processing and other minor uses. Fruit, field, and vegetable crops are grown in the summer. 'Specialty crops' are grown both in the summer (nursery stock and sod), and year round (greenhouse crops and mushrooms). Water use associated with specialty crops includes irrigation, pesticide spraying, equipment washing and other minor uses. The total cited in Table 4.8 refers to the total water takings of Livestock farms, and Fruit, Field, Vegetable, and Specialty crops.

TABLE 4.8: AGRICULTURAL WATER USE BY MUNICIPALITY AND WATERSHED

Municipality	Number of Farms¹	Livestock (m³/day)	Field Crops (m³/day)	Fruits (m³/day)	Vegetables (m³/day)	Specialty Crops (m³/day)	Total (m³/day)
Georgian Bluffs	270	707.5	3.4	6.3	2.5	0.0	719.7
Chatsworth	353	862.8	5.1	36.2	54.3	170.3	1128.6
West Grey	583	1669.1	10.3	117.5	16.7	251.9	2065.5
Southgate	440	1347.6	8.6	0.0	56.0	166.5	1578.8
Grey Highlands	446	1026.7	6.5	110.7	11.7	124.9	1280.5
Meaford	303	615.7	4.1	1250.4	50.9	162.3	2083.5
The Blue Mountains	150	193.2	2.2	3449.6	4.4	0.0	3649.4
Arran-Elderslie	335	1663.7	10.1	0.0	7.1	0.0	1680.9
South Bruce Peninsula	142	406.7	1.4	114.4	8.1	19.5	550.2
Brockton	458	1700.0	15.7	0.0	6.8	35.2	1757.6
Huron-Kinloss	310	1010.2	15.5	54.4	190.9	0.6	1271.7
South Bruce	476	1892.3	17.7	0.0	423.9	0.0	2333.9
Kincardine	340	995.5	12.6	50.2	458.8	32.4	1549.4
Saugeen Shores	88	134.2	4.6	100.4	5.4	0.0	244.6
Northern Bruce Peninsula	81	351.5	1.1	0.0	0.8	125.1	478.5
Total	4,775	14,577	119	5,290	1,298	1,089	22,373
Watershed							
SVCA	3,032	9,891.7	88.1	352.6	1,110.4	596.9	12,039.6
GSCA	1,503	4,009.1	22.6	4,349.9	103.1	463.3	8,947.9
MVCA	127	414.2	6.4	22.3	78.3	0.3	521.4
GRCA	35	107.8	0.7	0.0	4.5	13.3	126.3
NVCA	78	154.1	1.1	565.2	2.1	15.0	737.6
Total	4,775	14,577	119	5,290	1,298	1,089	22,373

¹ Number of farms was calculated on a township level. An equal spatial distribution of farms throughout the township was assumed to estimate the number of farms in each of the watersheds in Grey and Bruce Counties.

In Grey and Bruce Counties, there are half as many farms in the GSCA as there are in the SVCA. This is a result of the poorer growing conditions on the Bruce Peninsula due to the limited soil coverage (shallow overburden). There is also more livestock, vegetable and specialty farming in the SVCA, whereas there is more fruit farming in the GSCA.

4.4.6 Other Groundwater Use

Other groundwater takers in Grey and Bruce Counties include construction projects (i.e. road building), pumping tests, and other short term pumping uses. Following the Technical Terms of

Reference (MOE, 2002), these short-term groundwater extractions were disregarded as they represent relatively small water use and do not represent continuous long-term pumping.

4.4.7 Total Groundwater Use

Table 4.9 presents groundwater use by municipality and watershed. Total groundwater use was calculated by summing groundwater use from domestic (rural and municipal), industrial and commercial (large-scale users), and agricultural sources. At the watershed level, 98% of groundwater taken in Grey and Bruce Counties occurs within the watersheds of the Saugeen Valley Conservation Authority and the Grey Sauble Conservation Authorities.

TABLE 4.9: TOTAL GROUNDWATER USE BY MUNICIPALITY AND WATERSHED

Municipality	Rural Domestic (m³/day)	Municipal Domestic (m³/day)	Communal / Campgrounds (m³/day)	Large-scale Users (m³/day)	Agricultural (m³/day)	Total (m³/day)
Georgian Bluffs	1,660	208	129	8,640	720	11,357
Chatsworth	985	170	–	32,869	1,129	35,153
West Grey	1,626	1,463	288	53,530	2,065	58,972
Southgate	864	660	416	598	1,579	4,117
Hanover	47	1,753	–	–	–	1,800
Grey Highlands	1,260	3,490	–	9,157	1,281	15,188
Owen Sound	–	–	–	1,650	–	1,650
Meaford	1,025	–	–	–	2,083	3,108
The Blue Mountains	760	–	1,308	1,473	3,649	7,190
Arran-Elderslie	511	1,262	197	–	1,681	3,651
South Bruce Peninsula	858	198	–	464	550	2,070
Brockton	801	5,756	–	546	1,758	8,861
Huron-Kinloss	137	2,030	267	–	1,272	3,706
South Bruce	676	1,047	–	25,911	2,334	29,968
Kincardine	667	579	–	67,534	1,549	70,329
Saugeen Shores	327	–	284	5,245	245	6,101
Northern Bruce Peninsula	542	–	82	–	479	1,103
First Nations Reserves	221	–	–	–	–	221
Total	12,969	18,614	2,971	207,617	22,373	264,544
Watershed						
SVCA	6,197	16,176	1,225	172,589	12,040	208,227
GSCA	6,386	1,237	211	33,737	8,948	50,519
MVCA	56	541	227	–	521	1,345
GRCA	69	660	–	48	126	903
NVCA	260	–	1,308	1,243	738	3,549
Total	12,969	18,614	2,971	207,617	22,373	264,544

4.5 Water Budget Analysis

4.5.1 The Hydrologic Cycle

The movement and recycling of water between the atmosphere, land surface and underground is called the hydrologic cycle. Understanding the hydrologic cycle, and in turn the flux of water moving into and out of a study area, is critical in properly managing water resources.

The hydrologic cycle consists of four main components; precipitation, evapotranspiration, surface water resources, and groundwater resources as shown in Figure 4.4. Water on the ground surface, in streams or in lakes can return to the atmosphere through evaporation. Water used by plants can be returned to the atmosphere through transpiration. Collectively known as

evapotranspiration, both evaporation and transpiration occur in greatest amounts during periods of high temperatures, high wind, low humidity, and bright sunshine.

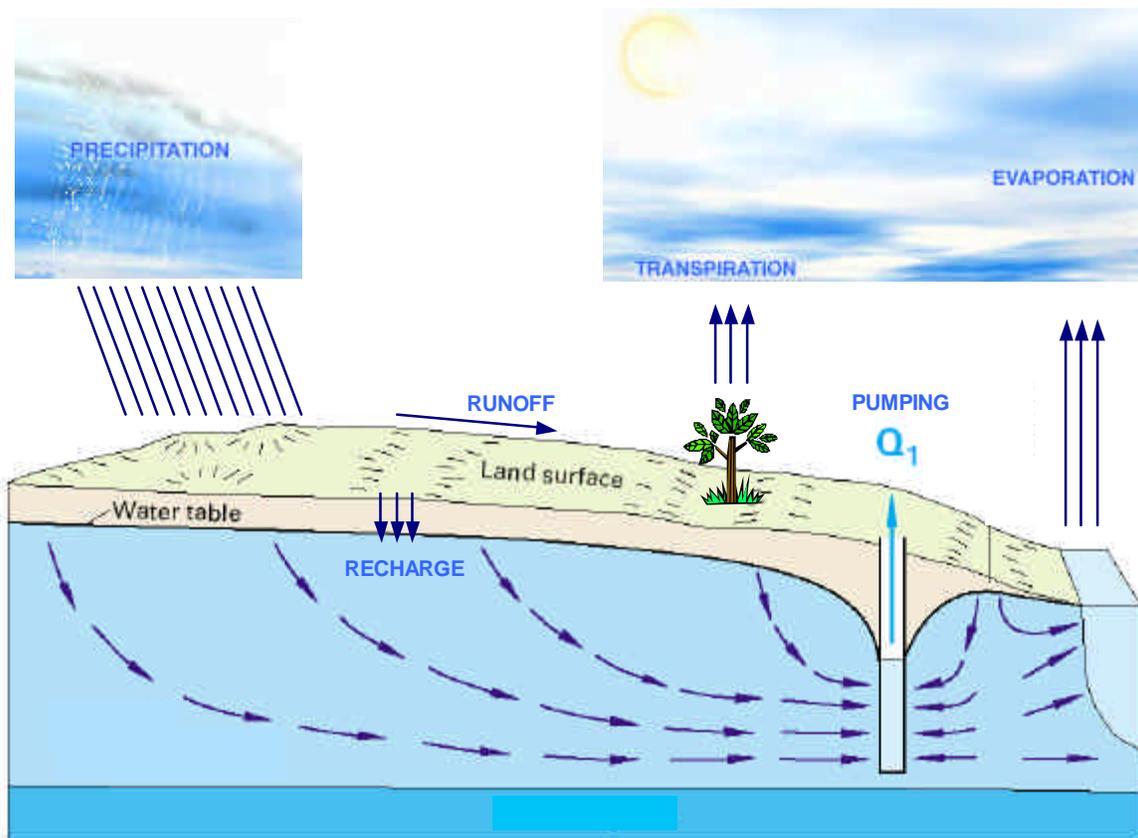


Figure 4.4: The Hydrologic Cycle

When water infiltrates the ground, gravity pulls the water down until it reaches the water table. This groundwater then moves very slowly through pore spaces towards surface water features such as rivers, streams, lakes and oceans.

4.5.2 Regional Water Budget Analysis

Establishing a water budget for a natural system is a complex problem because there are many factors that influence the parameters involved, namely precipitation, runoff, recharge and evapotranspiration. A generalized version of the water balance is as follows:

$$\text{Eq. 1 } \mathbf{GW(in) + SW(in) + Precipitation = SW(out) + GW(out) + ET + (Net\ storage)}$$

Where GW and SW denote groundwater and surface water respectively, (in) and (out) represent flow into and out of the Counties, ET is the evapotranspiration, and 'Net Storage' represents the amount of infiltrated water that does not return to a receiving stream, and is held in storage in the system. For instance, the positive totals for 'Net Storage' during the winter months (e.g. December to March) represent snow on the ground, whereas the negative values during the summer months (e.g. July to August) denotes water pulled from soil-water storage. When long term inflows and outflows are considered, the Net Storage term will approach zero.

Groundwater availability is of primary interest in the Grey and Bruce Counties study. Climate data, such as, precipitation and evapotranspiration data, was used to understand the inputs and outputs of the water budget, such as groundwater recharge. The total amount of groundwater takings, for domestic, industrial and other uses, was then compared to the amount of groundwater recharge, to determine the net amount of groundwater available to the Counties.

Since recharge and discharge areas do not follow municipal boundaries, it is difficult to evaluate a regional water budget over a portion of land that spans 5 different watersheds. The water budget must be determined on a watershed basis before it can be evaluated on a regional basis. To perform a water budget on a watershed basis, all components of the water budget must be determined for each watershed. The regional water budget for Grey and Bruce Counties represents a large-scale regional estimate, and further refinement is needed to evaluate water budgets at a more local-scale. We recommend this refinement should be directed at sub-watershed scales, so that stream flow data can be better utilized.

Precipitation, evapotranspiration and temperature data for the Grey and Bruce Counties study were obtained from climate normals originating from point-based weather station data acquired by Agriculture and Agri-Food Canada. The information obtained is based on data acquired over a 29-year period (1961- 1990), and is presented in Table 4.10. The data is regional in extent, and similar information exists for all of Canada. At a regional-scale, the components of the hydrological cycle provide reasonable estimates of the net available quantity of water. However, small scale variations are anticipated (Agriculture and Agri-Food Canada, 1997).

TABLE 4.10: CLIMATE DATA FOR GREY AND BRUCE COUNTIES (1961 TO 1990)

Precipitation¹													
Ecodistrict	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
550	77.5	51.4	57.6	62.4	64.3	67.3	60.4	80.9	92.4	79.5	84.8	92.5	870.4
551	97.6	68.2	63.9	61.8	70.3	77.5	76.2	92.3	96.9	85.2	94.3	107.1	990.5
556	78.8	65.9	76.4	69.2	74.8	80.5	77.4	97.7	89.5	84.2	93.4	91.6	988.5
557	105.3	74.3	70.2	71.8	76.0	78.4	77.1	93.7	101.4	90.8	100.1	113.6	1052.7
558	91.7	68.7	68.0	69.1	78.9	82.4	76.4	99.4	99.2	88.6	97.6	103.6	1022.9

Evapotranspiration²													
Ecodistrict	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
550	0.1	0.0	1.9	53.7	81.6	101.4	114.7	92.7	60.3	30.3	9.9	0.0	546.7
551	0.1	0.0	7.9	59.4	95.4	114.3	127.3	101.9	65.7	31.6	9.5	0.0	613.0
556	0.0	0.0	1.6	54.7	92.3	111.4	121.7	95.0	60.9	26.0	6.1	0.0	569.8
557	0.1	0.0	11.0	62.7	99.1	119.6	128.6	100.9	65.6	31.1	8.9	0.0	627.6
558	0.1	0.0	6.5	59.8	96.8	116.3	127.6	99.5	64.8	29.7	8.6	0.0	609.5

Temperature³													
Ecodistrict	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
550	-8.0	-7.9	-2.9	4.0	9.5	14.3	18.2	17.9	14.1	8.6	2.8	-4.1	5.5
551	-7.4	-7.0	-2.1	5.2	11.4	16.4	19.6	18.8	14.8	8.7	2.7	-4.1	6.4
556	-8.9	-8.3	-3.2	4.3	11.1	15.8	18.5	17.6	13.7	7.6	1.5	-5.4	5.4
557	-6.9	-6.7	-1.5	5.7	12.0	17.0	19.6	18.7	14.9	8.9	3.0	-3.5	6.8
558	-7.8	-7.4	-2.2	5.2	11.7	16.6	19.4	18.4	14.5	8.5	2.4	-4.4	6.2

¹ refers to average monthly precipitation (snow and rain) in mm

² refers to the average monthly evapotranspiration in mm

³ refers to the average monthly temperature in degrees Celcius

Based on the information in Table 4.10 and the percentage of Grey and Bruce Counties in each Ecodistrict, the average annual precipitation for the Counties is calculated to be 980 mm. Grey and Bruce Counties has an area of approximately 8,660 km², and therefore, the annual volume of precipitation that falls on the Counties is approximately 8,483 million m³.

Similar calculations were performed for evapotranspiration in the Counties, resulting in a rate of 594 mm/year and an annual volume of 5,140 million m³.

Recharge rates were estimated to range from 75 mm/year to 150 mm/year across the Counties, based on the calibration of the 22 MODFLOW models in Section 6. This estimate is consistent with the low stream flow measurements presented in Section 2. The resulting annual recharge volume ranges from 650 million m³ to 1,300 million m³.

Runoff was calculated as the difference between precipitation and the other components of the water budget. Based on the low recharge rate of 650 million m³, annual runoff volume was calculated to be 1,957 million m³/year.

4.5.3 Water Budget Summary

Using all the information compiled through the groundwater use assessment, a simplified water budget is presented. This water budget is to provide perspective to the amount of water entering and leaving the Counties, compared to the amount of groundwater being used. Water budget parameters for Grey and Bruce Counties on an annual basis are presented in Table 4.11.

TABLE 4.11: WATER BUDGET SUMMARY

Component	Low (10⁶ m³)	Average (10⁶ m³)	High (10⁶ m³)
Precipitation	8,483	8,483	8,483
Evapotranspiration	5,140	5,140	5,140
Recharge	650	975	1,300
Runoff	2,639	2,368	2,042

A summary of the total daily and yearly groundwater taking for Grey and Bruce Counties is as follows:

Large-scale User Groundwater Taking:	75.8 million m ³ /year (207,617 m ³ /day)
Rural Groundwater Use:	4.7 million m ³ /year (12,969 m ³ /day)
Municipal Groundwater Taking:	6.8 million m ³ /year (18,614 m ³ /day)
Agricultural Groundwater Taking:	8.2 million m ³ /year (22,373 m ³ /day)
Water Supply (communal and campground)	1.1 million m ³ /year (2,971 m ³ /day)
Total Groundwater Taking:	96.6 million m³/year (264,544 m³/day)

From this analysis, we see that the combination of domestic (rural), municipal, communal and agricultural groundwater use within the Counties is approximately 20.8 million m³/year, which is 2.1% of average available recharge. Large-scale groundwater use is approximately 75.8 million m³/year, which is 7.8% of average available recharge. This means that only a fraction of the available recharge is being used for water supply within the Counties. However, actual water taking by large-scale users is mostly unknown and may be much less than the permitted rate.

4.6 Summary of Groundwater Use

A regional groundwater use assessment was conducted using information on municipal, communal, agricultural, private and industrial water taking. Data for the groundwater use assessment was obtained from the MOE Permit to Take Water (PTTW) database, municipal water supply reports (Engineer's Reports), MOE Water Well Information System (WWIS), and Certificates of Approval. A survey was also completed of large-scale users (PTTW rate of more than 200,000 L/day), and municipal water works. The results of these surveys are presented in Appendix B and C, respectively. Finally, population estimates, which were used to estimate domestic water use, were obtained from Statistics Canada.

This information was used to complete a water budget analysis of the study area, to provide information about the quantity of groundwater currently being utilized in Grey and Bruce Counties. The results of the groundwater use assessment show that there are 422 permits in the PTTW database and that these permits correspond to 553 water sources (wells, springs or ponds). Of the 422 PTTW permits there are 254 PTTW using groundwater (168 are active permits), of which 37 are "large-scale users". Based on maximum permitted rate, groundwater use by large-scale users is 207,617 m³/day in the Counties.

Based on estimates of the rural population of the study area, domestic groundwater use is estimated to be 12,969 m³/day in the Counties. Municipal groundwater use was estimated to be 18,614 m³/day in the Counties. Communal and campground groundwater use was estimated to be 2,971 m³/day in the Counties. Finally, agricultural groundwater use was estimated to be 22,373 m³/day in the Counties.

Subsequently, a water budget analysis was completed using information on Canadian Climate Normals (1961-1990) from Agriculture and Agri-Food Canada. Recharge was estimated to range from 75 mm/year to 150 mm/year across the Counties. This results in a total volume of between 650 and 1,300 million m³/year being recharged to the groundwater environment.

The combination of domestic (rural), municipal, communal and agricultural groundwater use (20.8 million m³/year) is approximately 2.1% of available recharge. We also see that permitted water taking by large-scale users (75.8 million m³/year) is approximately 7.8% of available recharge. This means that only a fraction (9.9%) of the available recharge is being used for water supply within the Counties. However, actual water taking by large-scale users is mostly unknown and may be much less than the permitted rate. In spite of this, the actual water taking by large-scale users could be up to 4 times as large as the water takings of all other groundwater uses combined. As such, it is the one use of groundwater within the Counties that may pose a risk to the quantity of water available for public water supply, as well as to maintain baseflow in rivers.

In summary, on a regional-scale, there appears to be adequate groundwater available to meet current and future needs. However, the analysis does not consider the effects that concentrated water taking may have on the groundwater system or overall ecosystem health. Additional analysis at a watershed or sub-watershed scale could provide additional information about safe groundwater yield and impacts that future development activities may have.

5 Contaminant Sources Inventory

To complete a regional groundwater management study, it is important to understand the hydrogeologic setting, as discussed in previous sections of the report, and to identify potential sources of groundwater contamination. In this study, an inventory of the potential contaminant sources was completed. The potential for contamination from the identified sources was assessed with respect to possible impacts on groundwater supplies in the area. This section provides a description of the potential contaminant sources inventory.

5.1 Overview

There are many different types of potential threats to groundwater quality, which may include organic chemicals, hydrocarbons (e.g. benzene in gasoline, TCE in solvents), inorganic cations (e.g. iron, manganese) and anions (chloride, nitrate), pathogens (bacteria, viruses), and radionuclides (radon, strontium) (Fetter, 1999). It is important to know the location of potential contaminant sources, to help ensure the long-term sustainability of the groundwater resource. This information can be used to identify areas where monitoring is required to safeguard groundwater resources. The information is best stored and maintained in a database that includes details about the potential contaminant source, its location (including address where available), and information about the quality of the data and the accuracy of the reported location. In the future, if a specific contaminant is identified in a domestic water well, the database could be used to identify the possible source of the contaminants. Information about the different potential contaminant sources throughout the Counties could be used in the development of future groundwater resources.

Groundwater contamination may occur from either point sources or non-point sources of contamination. These terms generally describe the localization of the contaminant. A point source is typically a small-scale contaminant source area, such as a leaky underground fuel storage tank, or a landfill. Non-point sources, in contrast, are larger in scale and are typically more diffuse than point source contaminants. Non-point sources are primarily related to land use practices (fertilizer spreading, road salting), whereas point sources may be related to localized contamination events (contaminant spill). Both point and non-point contaminant sources are capable of impacting large volumes of groundwater. For example, one litre of a typical degreasing solvent such as trichloroethylene (TCE) can contaminate up to 29 million litres of groundwater. This is equivalent to the water required to fill 30 Olympic-sized swimming pools.

The objective of the potential contaminant inventory is to prepare an inventory of known and potential sources of contaminants in Grey and Bruce Counties. This information was compiled using existing databases and other information as discussed below.

5.2 Methodology and Data Sources

Data for the potential contaminant sources inventory was obtained primarily from the Ministry of the Environment (MOE). Included in this information from the MOE was a database of private and retail underground fuel storage tanks from the Technical Standards and Safety Association (TSSA), as well as information from the MOE on spill occurrences, PCB storage, landfills and wastewater treatments plants in the Counties.

The quality of the information available to complete the contaminant sources inventory, particularly the information in the previously compiled databases, is poor. As a result, many of the potential contaminant sources have unreliable locations, and many were not mapped.

The accuracy of the information is acceptable from a regional standpoint, and has been supplemented locally throughout much of the study area. In urban areas, within municipal wellfield capture zones, the locations of potential contaminants were verified, where possible, during the wellhead protection area (WHPA) contaminant sources assessment (see Section 7). The field surveys were conducted to verify the presence of different land uses that could adversely affect groundwater quality. During these surveys it was impossible to verify the location of spills that occurred in the past.

To address uncertainties in the locations of potential contaminant sources, the project database was updated to include a descriptor of the reliability of the contaminant location, ranging from “known location” to “poor reliability” to “unknown location”.

5.3 Contaminant Sources Inventory Results

Table 5.1 summarizes the results of the contaminant sources assessment. There are 1319 entries in the MOE Contaminant Sources Database for the study area. Of these, only 702 could be identified as being within the study area, using UTM coordinates or township/county information (leaving 617 records with an unknown location). Of the 702 records identified with the study area, there were 237 that could be mapped (95 with UTM coordinates, 142 with addresses).

TABLE 5.1: POTENTIAL CONTAMINANT SOURCES

Potential Source	Number of Records		
	Located	Not Located	Total
Fuel Storage	127	172	299
PCB Storage	22	5	27
Contaminant Spill Sites	78	210	288
Certificates of Approval	10	78	88
Total	237	465	702

A discussion of the specific types of contaminant sources in the database is presented below.

5.3.1 Fuel Storage Sites

Fuel storage tanks are large containers that store hundreds to thousands of litres of gasoline, fuel oil, or diesel. These storage tanks are located either above or below ground. For instance, gas stations commonly have many underground storage tanks that store diesel and gasoline. Underground storage tanks are susceptible to corrosion, and to the settling of the ground above, or around, the tanks. In the process of filling the tanks, there is also some risk of spillage. Holes, cracks, or breaks in the tanks can cause varying amounts of contaminants to enter the ground potentially over long periods of time. Identifying the locations of underground storage tanks, as well as the location of sites where storage tanks previously existed, provides information that can be used to assess potential groundwater contaminant sources.

The locations of underground storage tanks from the TSSA database are shown on Figure 5.1. A total of 299 records of storage tanks contained in the TSSA database are located within the study area. Of these records, 127 are reliably plotted on Figure 5.1. The remaining 172 records contained incomplete or incorrect address information. Furthermore, it is likely that many other

private fuel storage tanks exist throughout the Counties that have not been included in the database.

5.3.2 PCB Storage Sites

Polychlorinated biphenyls (PCBs) are mixtures of up to 200 chlorinated compounds that were widely used, in the 1960s and 1970s, as coolants and lubricants in the manufacture of electrical transformers and capacitors. There are no known natural sources of PCBs, and their manufacture was stopped in 1977 because of evidence they can cause harmful impacts to human health and the environment. PCBs are quite resistant to chemical, thermal or biological degradation, and as such they tend to persist in the environment. A total of 27 PCB sites were identified in the study area, and 22 of those are plotted on Figure 5.1.

5.3.3 Contaminant Spill Sites

Contaminant spills are of concern to rural and urban groundwater users because of their potential impacts on municipal and domestic groundwater supplies. However, the degree to which a spill impacts the environment is dependent on the area of the spill, the volume of contaminant released, and the type of contaminant. Spills recorded in the MOE database range from a few litres of dye spilled in a watercourse, to several hundreds of litres of heavy oil spilled in a parking lot. There are 300 spills of varying severity recorded in the MOE database. Among the spills, 12 were released to the air and were not considered, and 78 of the remaining 288 spills were located with good reliability, and plotted on Figure 5.1.

5.3.4 Certificate of Approval Sites

Certificates of Approval (CofAs) are permits issued by the Ministry of the Environment that allow the regulated discharge of contaminants into the natural environment. The contaminant sources database from the MOE contained 88 records of CofAs, of which 10 were located with good reliability. These 10 records correspond to landfill sites, sewage treatment plants, and potential waste generation sites, and are plotted on Figure 5.1.

5.3.5 Landfill Sites

To augment the information contained in the contaminant sources database, the open and closed landfills in Grey and Bruce Counties were added to the database. The locations of these landfill sites were obtained from the Waste Disposal Site Inventory (MOE, 1991) for Ontario, and finalized through discussions with the Steering Committee. There are 37 active landfill sites and 88 closed landfill sites in the study area, which are plotted on Figure 5.1.

5.3.6 Wastewater Treatment Plants

Municipal wastewater treatment plants in the Counties were also added to the contaminant sources database. The locations of these wastewater treatment plants were obtained by Gamsby and Mannerow, and confirmed using the Ontario Base Maps. There are 20 wastewater treatment plants in the study area, which are plotted on Figure 5.1.

5.3.7 Abandoned Boreholes

Ontario Water Resources Act, Regulation 903, Section 21 addresses well abandonment, and it states that, "when a well is to be abandoned, it shall be plugged with concrete or other suitable material so as to preclude the vertical movement of water or gas in the well between aquifers or between an aquifer and the ground surface." Abandoned or poorly constructed wells are a threat to groundwater aquifers. Abandoned wells can provide a route for surface contaminants to travel directly to a deep aquifer in a very short period of time.

Limited information about the locations of abandoned wells is currently available. The WWIS includes a data field that denotes wells that were drilled, but not used. These are likely wells that provided poor yield or poor quality water. Information regarding the decommissioning of these wells is not included in the database, and it is impossible to assess whether they were properly decommissioned. Since it is reasonable to assume that many of these wells were not properly decommissioned, their locations are included in Figure 5.2 as small dots. In total, 526 abandoned borehole are plotted. The status of well abandonment for these wells should be further evaluated, where possible, within areas that are deemed sensitive (high vulnerability areas and within WHPAs).

5.4 WHPA Contaminant Sources Assessment Results

To finalize the analysis of potential contaminant sources within the study area, WHPA assessments were completed for each of the WHPA boundaries. Local-scale contaminant source information was collected by Gamsby and Mannerow, which included ground-truthing of potential contaminant sources within each WHPA boundary. For an agricultural perspective, Dr. Bruce MacDonald completed a survey of agricultural land use in each WHPA boundary. To confirm the results of the ground-truthing of potential contaminant sources within each WHPA, both Grey and Bruce Counties propose to send a Contaminant Source Assessment Form (Appendix D) to the address of each potential contaminant source identified.

Table 5.2 summarized the results of the WHPA assessment, which are incorporated into the contaminant sources database. There were 339 potential contaminant sources identified within the WHPA boundaries. These sources are categorized as industrial/manufacturing, automotive, fuel storage, agricultural, landfills, hospital and other potential sources.

TABLE 5.2: WHPA CONTAMINANT ASSESSMENT RESULTS

Category	Records	Land Use
Industrial/manufacturing	13	Tool and die, aggregates, concrete, stone factory, aluminum, furniture, shoes, food co-ops, ice cream
Automotive	28	Repair shops, dealers, salvage yards, car wash
Fuel storage	14	Gas stations, airports
Agricultural/livestock	134	Crops/nursery, livestock operations
Landfill	1	Town landfills
Hospitals	4	General hospitals
Other	145	Dry cleaners, beauty salons, photo finishing, construction yards, medical/veterinary offices, cemeteries, golf courses, schools, clubs, funeral homes, well houses, offices, aggregate pits
Total	339	

Figure 5.3 shows the location of the potential contaminant sources that were mapped within the study area. These records were mapped with a combination of UTM coordinates, Grey and Bruce Counties lot/concession/township information, NRVIS roads information, and address matching using Internet mapping software.

These potential contaminant sources will be presented, in Section 7, on local-scale mapping in relation to the WHPA boundaries and intrinsic susceptibility areas. Understanding the locations of land uses that pose a risk to groundwater quality, in relation to high susceptibility areas and the WHPAs, provides a means to identify sensitive areas surrounding each municipal well.

5.5 Summary of Potential Contaminant Sources

The objective of the potential contaminant sources inventory was to prepare an inventory of known and potential sources of contaminants in Grey and Bruce Counties. There are 1309 records in the MOE Contaminant Sources Database. Of these records, there are 237 known contaminant source records that could be mapped. In addition to the information contained in the MOE database, other information sources were used to identify the landfills and wastewater treatment plants within the study area, which added 154 potential sources to the database. A local-scale contaminant sources assessment was completed in each WHPA boundary, which added 339 potential sources to the MOE database. Abandoned boreholes are not potential contaminant sources, but they do provide potential pathways for surface contamination to reach lower hydrogeologic units. The WWIS was analyzed for abandoned boreholes, and there are 526 within the study area.

To augment this analysis, Figure 5.4 was created at a 1:200,000 scale to present all of the potential contaminated site information at a more detailed larger scale.

As a result, the following potential contaminant sources were added to the database:

- fuel storage (UST) locations;
- automotive facilities;
- industrial/manufacturing facilities;
- PBC storage sites;
- contaminant spill sites;
- MOE Certificates of Approval;
- open landfills;
- closed landfills;
- wastewater treatment plants;
- hospitals;
- agricultural land uses;
- abandoned boreholes; and,
- other potential contaminant sources.

As additional information is collected or becomes available, the information contained in the database of potential contaminant sources should be updated. The information collected during this part of the study can be used to help identify the sources contaminants detected in the future, and can be used during the development of future water supplies.

6 Wellhead Protection Area Modeling

6.1 Methodology

The most defensible method for delineating wellhead protection areas (WHPAs) is through the application of numerical groundwater models. The physical relationships governing the movement of groundwater can be incorporated into numerical models to simulate the existing groundwater flow system. Numerical groundwater modeling also allows the integration of heterogeneous field data, which is very difficult to consider otherwise. Groundwater modeling should be considered an essential tool in all phases of groundwater investigations.

Once a calibrated model solution has been developed, groundwater velocities can be calculated at any point within the model using the simulated heads, the calibrated hydraulic conductivity, and porosity. These velocities define the pathline of imaginary "particles" of water from any release-point within the model domain. The travel time between any two points along the pathlines can also be calculated. Individual groundwater particles can be traced down the hydraulic gradient ("forward" particle tracking) or up the hydraulic gradient ("reverse" particle tracking). Time-related capture zones for pumping wells can be calculated by releasing many "reverse" particles originating in a circle around the well. The capture zone results form the basis for delineating WHPAs for the municipal well.

For the delineation of WHPAs, all models share the following numerical modeling approach. Wellfield specific details are contained in Sections 6.2 through 6.13, respectively, for each of the municipal groundwater systems that were modeled.

6.1.1 Conceptual Model Development

A conceptual model was developed to characterize the geology and hydrogeology surrounding each wellfield. This conceptual model was used as the basis for implementing the numerical groundwater flow model. Existing hydrogeologic and engineering reports, in addition to the principal data sources listed in Table 2.1, were used to develop and characterize the hydrogeologic environment.

Two cross-sections were created for each wellfield. The selection of the wells included in these cross-sections was based on the availability of data. The municipal production wells, and oil and gas wells, were included in the cross-sections (where available). Cross-sections were located through the wellfield, one parallel to the direction of groundwater flow, and one perpendicular to the direction of groundwater flow. Hydrogeologic interpretations were developed using previous interpretations and aquifer testing results (where available).

Using the regional-scale mapping and local cross-section analysis, overburden thickness and bedrock surface topography was defined. Areas with potentially higher or lower recharge rates were interpreted from cross-sections and other sources of information (i.e. previous studies and geologic maps). Hydraulic conductivity zones were defined for each aquifer based on cross-sections and other available information (i.e. aquifer test data). Water level maps, cross-sections, and NRVIS base maps were used to delineate the hydrogeologic boundaries for each numerical model.

Each numerical model was developed using a 3-layered hydrogeologic conceptual model, which is defined as follows:

- Layer 1 represents the overburden (Quaternary geology) above the bedrock;

- Layer 2 represents the weathered, or fractured, contact zone above the unweathered bedrock; and,
- Layer 3 represents the unweathered bedrock.

Model parameters, including transmissivity, specific capacity, pumping rates, and hydraulic conductivities, were all developed in consistent units, as follows:

- Transmissivity in m^2/day ;
- Porosity in m/m ;
- Specific Capacity in m^2/day ;
- Pumping Rates in IGPM and m^3/day ; and,
- Hydraulic Conductivity in m/s .

6.1.2 Numerical Model Selection

For the Grey and Bruce Counties Groundwater Study, Visual MODFLOW (Waterloo Hydrogeologic, 2002) was used to develop MODFLOW (Harbaugh et al., 2000) models of all the municipal groundwater systems. MODFLOW was selected because it simulates groundwater flow, and with MODPATH (Pollock, 1994), it simulates advective particle tracking. The resulting particle pathlines form the basis for defining the time-of-travel (TOT) WHPAs. Furthermore, Visual MODFLOW provides an easy-to-use graphical user interface for data input and output. The MODFLOW code, developed by the United States Geological Survey (USGS), is the most frequently applied groundwater modeling code in the world.

6.1.3 Model Grid

MODFLOW is a finite-difference code with particle tracking (MODPATH) and water balance (ZoneBudget) support programs. A complete description of the code can be found in the USGS MODFLOW User's Manual (Harbaugh et al., 2000). The finite-difference approach involves discretizing the model area into 'cells' by defining an array of rows, columns and layers. The finite difference model calculates the hydraulic head in each cell so that the volume of water entering each cell is equal to the volume of water exiting each cell.

An initial model grid of 200 m by 200 m cells was used to define each model domain. The model grid was refined around the municipal pumping wells and river cells to a minimum cell size of approximately 10 m by 10 m. Further refinement was implemented on a model-by-model basis to achieve an acceptable model calibration, which is discussed in Section 6.1.6.

6.1.4 Model Parameters

Geological information is represented in MODFLOW by 'zones', which correspond to areas within the model domain that contain similar property values, for example, a confining till or an outwash deposit. Physical information related to the conceptual geological model that is incorporated into the model, includes:

- spatially varied hydraulic conductivity;
- spatially varied porosity;
- spatially varied bottom elevation for each model layer; and,
- spatially varied thickness for each model layer.

Table 6.1 presents a summary of the range of parameter values used to represent the hydraulic conductivity and porosity for each of the model layers, which are based on the parameter values used to calibrate the 22 MODFLOW models.

TABLE 6.1: MODEL HYDROGEOLOGIC PARAMETER VALUES

Geological Unit	Hydraulic Conductivity (m/s)			Effective Porosity (vol/vol)		
	Min	Ave	Max	Min	Ave	Max
Overburden Zones:						
Clay or Peat	1e-9	1e-7	1e-6	0.15	0.3	0.5
Sand and Gravel	1e-5	1e-4	1e-3	0.25	0.3	0.35
Silt Till	1e-8	1e-6	1e-5	0.2	0.3	0.5
Kame Materials	1e-7	1e-5	1e-4	0.2	0.3	0.35
Exposed Bedrock	1e-7	1e-5	1e-3	0.05	0.1	0.15
Bedrock Contact Zone:						
Weathered bedrock	1e-7	1e-5	1e-3	0.05	0.1	0.15
Competent Bedrock:						
Dolostone	1e-8	1e-6	1e-5	0.05	0.1	0.15
Shale	1e-10	1e-8	1e-7	0.05	0.1	0.15

6.1.5 Model Boundary Conditions

Boundary conditions are incorporated in the model to control how the groundwater model interacts with the environment outside of the model domain. Boundary conditions are used to represent such features as streams, rivers and impermeable geologic contacts. MODFLOW is capable of simulating the following boundary conditions:

- spatially varied recharge and evapotranspiration;
- infiltration, or exfiltration, from surface water bodies such as streams and rivers;
- constant heads corresponding to the water elevation of lakes or reservoirs;
- pumping wells; and,
- no-flow boundaries corresponding to areas across which groundwater does not pass, for example, groundwater streamlines or impermeable geologic contacts.

In each WHPA model, boundary conditions were placed along divides in the groundwater flow system. In the overburden, they were placed along watershed or river boundaries, and in the bedrock they were placed along groundwater streamlines. No-flow boundaries were used where the groundwater flow direction is parallel to the model boundaries and beyond the area of influence of the pumping wells. River boundary conditions were applied throughout the model domain for rivers having perennial (year-round) flow, using a georeferenced map of the NRVIS rivers. The bedrock flow system, in Layer 3, was defined using constant head cells that were derived from the bedrock water level contour map (Figure 2.21).

Hydrologic input to the model domain from precipitation was represented by net recharge to Layer 1. A uniformly distributed recharge value of between 75 and 150 mm/yr was used to model this hydraulic boundary condition for each model.

6.1.6 Model Calibration

Calibrating a groundwater flow model allows it to be used to simulate groundwater flow that is statistically representative of field conditions. Models can be calibrated to steady-state or transient field-measured groundwater heads and flows. In this study, numerical models were calibrated to a set of groundwater heads that represent steady-state groundwater flow conditions.

Prior to numerical model calibration, the range of uncertainty in the parameters representing the conceptual hydrogeologic model was evaluated. Some parameters were known with a higher degree of certainty, such as hydraulic conductivities in wellfields where aquifer testing had previously been performed. Some parameters were known with less certainty, such as soil porosity.

Model calibration was conducted using an iterative, trial-and-error, approach. This involved a process where a flow simulation was carried out, the resulting groundwater heads were compared to observed heads, and the model input parameters were re-adjusted to achieve better agreement with observed (field-measured) conditions. This process was repeated until a satisfactory agreement between simulated and observed heads was achieved, as defined by the measures of calibration, which are discussed in Section 6.1.7.

The calibration data included static water level measurements, taken during the installation of wells contained in the MOE Water Well Information System (WWIS). This dataset was supplemented with local monitoring data where it was available. Since groundwater pumping is a small component of the regional water balance of the study area, the static water levels from the WWIS are considered representative of steady-state flow conditions. The water levels in all observation wells were imported into the MODFLOW model from a text file containing data associated with each well, such as easting, northing, average screen elevation and static water level elevation (potentiometric head).

6.1.7 Measures of Calibration

Model calibration results were evaluated using statistical measures that are based on the calibration residuals. The statistical parameters used to evaluate the model calibration are explained below, and include:

- Calibration Residual (r) – is the difference between the calculated value of head and the observed value of head at any point in the modeled hydrogeologic system.
- Mean Error (ME) – is the mean of all the residuals. This parameter can be misleading because the sum of a large negative residual and a large positive residual may be equal to zero. The Mean Error provides an indication of whether residuals are biased positively or negatively.
- Mean Absolute Error (MAE) – is the mean of the absolute values of all the residuals. This parameter will be larger than the mean error and provides the average error associated with each calibration point in the model.
- Root Mean Squared Error (RMS) – is the square root of the sum of the squares of all the residuals. Squaring the residuals increases the weighting that a poor residual will have on the overall calibration statistic. A low RMS is the best measure of a good model calibration.
- Scaled Root Mean Squared Error (Scaled RMS) – is the RMS error divided by the difference between the highest observed head and the lowest observed head within the model domain.

The final calibration graph of observed versus calibrated heads is presented in Appendix E for each WHPA model and the results are discussed.

6.1.8 Wellhead Protection Area Delineation

A Wellhead Protection Area, or WHPA, is the two-dimensional projection onto the ground surface of the three-dimensional volume of groundwater that is pumped from a wellfield. WHPA boundaries usually receive TOT designations such as 50-day, 2-year, 10-year, and 25-year.

These travel times reflect the time required for water to move to the well from different areas of the aquifer.

However, the capture zones are projected to ground surface, and in many instances the time-of-travel WHPA does not reflect the time required for water to travel from ground surface to the aquifer. This is particularly true when the wells that are being evaluated pump water from a deep aquifer that is overlain with fine-grained sediments (silts and clays).

During the WHPA delineation process, municipal pumping rates were adjusted to reflect future pumping conditions within each municipality to account for increased demand from population growth. These rates, for the 2-year, 10-year and 25-year WHPAs, were selected through consultation with personnel in each municipality. Rates were also adjusted for delineating the 50-day capture zone to account for larger than annual pumping rates, over the 50-day period.

The delineation of WHPAs in this study was performed with the following two objectives:

- to delineate 50-day, 2-year, 10-year, 25-year and steady-state TOT WHPAs using models which contain 'best estimate' values of hydrogeologic parameters; and,
- to delineate the area of uncertainty associated with each WHPA.

Uncertainty was evaluated by conducting additional simulations for each WHPA. The National Rivers Authority in the United Kingdom (NRA, 1995) has listed the following principal factors that lead to WHPA uncertainty:

- Uncertainty in point measurements of model parameters such as estimates of hydraulic conductivity at specific locations with pumping or slug tests;
- Uncertainty in the accuracy of such point measurements when applied to larger areas;
- Uncertainty in the relative distribution of model parameters;
- Errors due to deficiencies in conceptual models; and,
- Limitations of the model chosen to represent an aquifer system.

Uncertainties in WHPA mapping are an integral component of the WHPA solution.

6.1.9 WHPA Uncertainty Analysis Method

When making predictions with a groundwater model, different combinations of parameters may result in considerable variations in WHPAs for the same pumping wells. For example, WHPAs simulated under conditions of high recharge rates, high hydraulic conductivities, and low porosity may be much larger than WHPAs simulated under conditions of lower recharge rates and lower hydraulic conductivity, and higher porosity values. However, hydrogeologic parameters for both sets of conditions may result in an adequately calibrated numerical model, and may be within the plausible range of uncertainty associated with the input parameters.

This technique for the WHPA uncertainty analysis is based on a procedure that produces different, but equally likely, predictions of WHPAs consistent with the following:

- Simulated heads at calibration target locations are within target head ranges. In this study, this was evaluated using the Root Mean Squared Error of each uncertainty simulation;
- Model parameters are within physically realistic ranges; and,
- Model boundary conditions such as recharge and river discharge are within physically realistic ranges.

Two uncertainty simulations were performed with a range of parameter values defined in conditions 1 and 2 above. Hydraulic conductivity, recharge, and porosity values were varied through these simulations. The WHPAs defined for each of these simulations were digitally overlain to derive envelopes defining the best estimate WHPA and the uncertainty area.

The best estimate WHPA is defined using the model simulation with the most likely combination of parameters. This combination of parameters reflects the model calibration. The WHPA uncertainty area is the area that may be within the capture zone, but is not within the best estimate WHPA. The uncertainty area is mapped using the results from the uncertainty analysis scenarios.

6.1.10 Limitations of WHPA Modeling Results

The capture zones predicted using the numerical models are based on a number of assumptions, input parameters, and boundary conditions that are incorporated into each model. Each model is a representation of our understanding of the area surrounding the municipal wells, and in all cases our representation has been simplified to facilitate model development within the time and data constraints. The WHPA modeling results represent our best estimate of the actual WHPAs, and provide excellent guidance regarding the specific water source for each well.

As additional information becomes available, the numerical models can be revised and the WHPAs can be re-evaluated. Furthermore, water taking will be different in the future, as communities grow and additional groundwater wells are developed. Each of these factors will affect the shape and size of the different capture zones (and WHPAs).

Further discussion for each municipal system and the developed WHPA models is provided in the following sections.

6.1.11 Overview of Model Areas

Figure 6.1 presents the domains of the 22 models developed to determine the WHPA boundaries for 45 municipal groundwater systems in Grey and Bruce Counties. The original Terms of Reference indicated that WHPA modeling was to be completed on 48 municipal well systems. However, the Town of Saugeen Shores recently completed a pipeline to connect the Miramichi Estates and Miramichi Shores developments to the existing surface water supply system, and decommission the municipal wells. The Town of Walkerton has taken the Geeson Avenue well out of service. Markdale decommissioned one municipal well, and added 2 new municipal wells to the groundwater supply system. Thus, there are 12 municipalities in Grey and Bruce Counties, for which WHPA models were developed as follows:

- Grey County has 14 municipal systems, including 29 wells and 2 springs; and,
- Bruce County has 31 municipal systems, including 44 wells.

The 45 municipal groundwater supply systems were represented with 22 model areas, by combining the municipal systems that are within close proximity. The model areas are listed in Table 6.2, and specific design information for the municipal wells is presented in Appendix F.

TABLE 6.2: WHPA MODELS BY MUNICIPALITY AND MUNICIPAL WELL SYSTEM

County	Municipality	WHPA Model Name	Municipal Groundwater System	Wells
Grey	Georgian Bluffs	Shallow Lake	Shallow Lake	2
		Owen Sound	Forest Heights	2
			Maplecrest Subdivision	2
			Pottawatomi Village	2
	Chatsworth	Chatsworth	Chatsworth	3
		Walter's Falls	Walter's Falls	2
	West Grey	Neustadt	Neustadt	3
		Durham	Durham	2
	Southgate	Dundalk	Dundalk	3
	Hanover	Hanover	Hanover	2
			Lake Rosalind (Bruce C.)	1
	Grey Highlands	Markdale Model	Markdale	3
		Feversham Model	Beaver Heights	2
Kimberley Model		Kimberley-Amik-Talisman	2 ¹	
Bruce	Arran-Elderslie	Tara	Tara	2
		Chesley	Chesley	2
	South Bruce Peninsula	Sauble Beach	Fiddlehead	1
			Cambridge & Collins	1
			Robins	1
			Fedy	1
			Forbes	1
			Trask	1
			Huron Woods	4
			Foreman	1
			Thomson	1
			Winburk	1
	Gremik	1		
	Brockton	Chepstow	Chepstow	1
	Huron-Kinloss	Ripley	Ripley	2
		Huron West	Point Clark	2
			Blairs Grove	2
			Murdock Glen	2
			Huronville	2
		Lucknow	Lucknow	2
			Whitechurch	1
	South Bruce	Mildmay	Mildmay	2
		Teeswater	Teeswater	1
	Kincardine	Kincardine South	Tiverton	2
			Kinhuron	1
			Craig-Eskrick	1
			Lake Huron Highlands	2
Port Head Estates			1	
Kincardine North		Underwood	1	
	Scott Point	1		
2	12	22	45	75

¹. springs at Kimberley

6.2 Township of Georgian Bluffs

The Township of Georgian Bluffs is located in the County of Grey. Figure 6.2 shows the model domains and eight (8) municipal wells corresponding to the Shallow Lake and Owen Sound WHPA models.

6.2.1 Local Aquifer Characterization

Bedrock Geology

The bedrock geology on a regional-scale is described in Section 2.7.2 (Regional Groundwater and Aquifer Characterization). As observed from the map of the Bedrock Geology of Ontario¹ (1991), the surficial bedrock formations encountered within the Township of Georgian Bluffs are the Guelph Formation (dolostone), the Amabel Formation (dolostone), the Fossil Hill Formation (dolostone), the Cabot Head Formation (mainly shale) and the Queenston Formation (shale).

In the area of the Shallow Lake model, only the Guelph and Amabel Formations are encountered at the bedrock surface, whereas in the Owen Sound model area, the Guelph, Amabel, Fossil Hill, Cabot Head and Queenston Formations are all encountered at the bedrock surface, in order from southwest to northeast over the Niagara Escarpment.

Based on the WWIS and the oil and gas well database of the Ontario Petroleum Institute², the Shallow Lake municipal wells penetrate the Guelph, Amabel and Fossil Hill Formations. In the Owen Sound model area, the municipal wells penetrate the Amabel, Fossil Hill, Cabot Head and Queenston Formations, listed in order as encountered with depth. These bedrock units were represented as a single continuous unit in each WHPA model.

Quaternary Geology

The Quaternary, or overburden, geology in the Township of Georgian Bluffs mainly consists of a drumlinized till and dolostone plain and the Niagara Escarpment³. The main physiographic regions in the Township are the Bruce Peninsula, the Arran Drumlin Field and the Niagara Escarpment.

The Bruce Peninsula region covers most of the township and consists of a dolostone plain with thin overburden and a few drumlins. According to the Quaternary geology⁴ for the study area, the dolostone plain consists of dolostone of the Guelph, Amabel and Fossil Hill Formations. The thin overburden and drumlins on the plain consist of Bruce Till, a stony sandy silt till.

The Arran Drumlin Field region occurs in the southwest corner of the township, and consists of a drumlinized till plain with till moraines and clay plains. According to the Quaternary geology, the till plain and drumlins consist of the Elma-Catfish Creek Till, a stony, sandy silt till. The till moraines, called the Tara Strands, consist of the Bruce Till, a stony sandy silt till, which is likely the Elma-Catfish Creek Till.

On the east side of the township, below the Niagara Escarpment, is a shale plain with little overburden, as well as beach deposits along the Georgian Bay shoreline. According to the

¹ Bedrock Geology of Ontario, Southern Sheet, Map 2544, Scale 1:1,000,000, Ministry of Northern Development and Mines, 1991.

² Oil, Gas and Salt Resources Library, Digital Well Database, Ontario Petroleum Institute, Ministry of Natural Resources, 2002.

³ Chapman, L.J., and Putnam, D.F., 1984, Physiography of Southern Ontario, Ontario Geological Survey, Map P.2715, Scale 1:600,000.

⁴ Ministry of Natural Resources, NRVIS data, Quaternary Geology, Maps 2956 and 2957.

Quaternary geology, the shale plain is part of the Queenston Formation, and is partially covered by a stony till with a sandy silt matrix, likely related to the Bruce Till or Elma Till. In the south, between the Niagara Escarpment and the Owen Sound Harbour, there is a sand plain of glaciolacustrine and nearshore sand and silt. Along the Georgian Bay shoreline, the beaches and shorecliffs consist of glaciolacustrine and beach deposits of sand and gravel.

The Owen Sound model area is located in all three regions, the Arran Drumlin Field in the southern upland area, the Bruce Peninsula in the intermediate area, and the Niagara Escarpment region in the northern shoreline area. The Shallow Lake model area is located mainly in the Bruce Peninsula region, except for a glaciolacustrine sand plain of the Huron Fringe in the southwestern area of the model. There is also a small area of the Arran Drumlin Field in the southern part of the Shallow Lake model.

The MNR Quaternary geology was used to estimate the hydraulic conductivity zones for the WHPA modeling, as presented in Section 6.2.3.

Overburden Hydrogeology

In the County of Grey⁵, only 15% of the wells in the county obtain water from overburden. In the Bruce Peninsula, there are no significant overburden aquifers because the overburden is generally thin (less than ten metres thick) and consists of poorly-sorted tills, with well yields of less than 0.2 L/s. In the southern part of the municipality, some overburden aquifers are found in the moraines of the Tara Strands, in the Arran Drumlin Field.

Bedrock Hydrogeology

In the County of Grey⁵, most groundwater supplies come from bedrock aquifers, with well yields of 0.8 to 3.8 L/s common to the limestone and dolostone aquifers of the Guelph, Amabel and Fossil Hill formations, encountered in the Bruce Peninsula. The Guelph Formation, a fine crystalline dolostone, has low to moderate permeability, with well yields of 0.2 to 0.8 L/s. The shales of the Cabot Head, Manitoulin and Queenston formations have low permeabilities, with well yields of 0.2 to 0.8 L/s, and less than 0.2 L/s in the northern part of the county.

Local Cross-sections

Geologic cross-sections were generated using well information from the WWIS and are presented in Figures 6.3A to 6.3C. Each cross-section passes through at least one municipal well and is oriented either north-south or east-west, along the direction of the highest concentration of wells. Aquifer locations (screened intervals) and corresponding water levels are also shown on the cross-sections.

6.2.2 Municipal Well Systems

Owen Sound Water Systems

Due to their proximity, the Forest Heights Water System, the Maplecrest Water System and the Pottawatomi Village Water System were combined into one model, called the Owen Sound Model. The Forest Heights Water System is located south of the City of Owen Sound in the Township of Georgian Bluffs, and is comprised of two bedrock wells, Well #1 and Well #2, both constructed in 1985. The water supply system services a 19-lot residential subdivision of approximately 57 people⁶. The Maplecrest Water System is also located south of the City of Owen Sound in the Township of Georgian Bluffs, and is also comprised of two bedrock wells,

⁵ Ground-Water Probability of the County of Grey, Southern Ontario, Map 3111, Scale 1:100,000, Ontario Ministry of the Environment, 1980.

⁶ Engineer's Report for the Township of Georgian Bluffs: Forest Heights Water System, Gamsby & Mannerow Limited, Owen Sound, Ontario, January 2001.

Well #1 constructed in 1972 and Well #2 constructed in 1990. The water supply system services nine single residences and three four-plex apartments (approximately 53 people⁷). The Pottawatomi Village Water System is located west of the City of Owen Sound in the Township of Georgian Bluffs, and is comprised of two bedrock wells. Well #1, a standby well, and Well #2, both constructed in 1987, supply water to a 23-lot residential subdivision (approximately 58 people). Figure 6.2 shows the location of the Forest Heights wells, the Maplecrest wells and the Pottawatomi Village wells, their relationship to one another, and their proximity to local rivers and roads, and to township and model boundaries.

Shallow Lake Water System

The Shallow Lake Water System is located in the former Village of Shallow Lake in the Township of Georgian Bluffs, is represented in the Shallow Lake model. This system is comprised of two bedrock wells, Well #2, constructed in 1996, and Well #3, constructed in 1999. The water supply system services a population of 487 people⁸. Figure 6.2 shows the location of the Shallow Lake wells and their proximity to one another, as well as their proximity to local rivers and roads, and to the township and model boundaries.

Average Production Rates

Average pumping rates for each municipal well were estimated based on raw water flow rates averaged over the last five years and are presented in Appendix F. These pumping rates were used to represent the wells in the groundwater model.

6.2.3 Model Design (Shallow Lake, Owen Sound)

Model Grid

The model grid for the Owen Sound model consists of 246 columns and 228 rows, with model extents of 13 km by 16 km horizontally and 290 m vertically. In the Shallow Lake model, the grid consists of 89 columns and 85 rows, with model extents of 9.5 km by 7.5 km horizontally and 100 m vertically. Figure 6.2 presents the locations of the WHPA model domains with respect to the municipal boundary.

Model Boundaries

In the area of the Owen Sound Model, groundwater flow in the bedrock is generally from the southwest towards the northeast, where it discharges into the Owen Sound Harbour, as can be seen from Figure 2.21 of the bedrock equipotential contours. There are constant head boundaries upgradient of the flow system, having a maximum head of 280 m amsl, and downgradient of the flow system, having a minimum head of 177 m amsl, the level of Georgian Bay. The final recharge value used to obtain a reasonable model calibration was 115 mm/yr, which falls within the range of values typical for this region.

In the area of the Shallow Lake Model, groundwater flow in the bedrock is generally from the northeast and southeast towards the west, as can be seen from Figure 2.21 of the bedrock equipotential contours. There are constant head boundaries upgradient of the flow system, having a maximum head of 235 m amsl, and downgradient of the flow system, having a minimum head of 194 m amsl. The final recharge value used to obtain a reasonable model calibration was 85 mm/yr, which falls within the range of values typical for this region.

⁷ Based on an estimated 2.5 persons per residence (Engineer's Report, Town of South Bruce Peninsula, County of Bruce, design population estimates, 2001).

⁸ Engineer's Report for the Township of Georgian Bluffs: Shallow Lake Water System, Gamsby & Mannerow Limited, Owen Sound, Ontario, July 2001.

Hydrogeologic Properties

Final calibrated hydraulic conductivity values are presented in Table 6.3 for each geologic unit. These hydraulic conductivity values are consistent with those recorded in the literature for these materials (refer to Section 6.1.4).

TABLE 6.3: CALIBRATED VALUES OF HYDROGEOLOGIC PROPERTIES (GEORGIAN BLUFFS)

Geological Unit	Hydraulic Conductivity (m/s)
Overburden Zones:	
Clay or Peat	1e-7 to 5e-7
Sand and Gravel	3e-5 to 1e-4
Silt Till	1e-6 to 7e-6
Kame Materials	5e-7 to 2e-5
Exposed Bedrock	7e-6 to 5e-5
Bedrock Contact Zone:	7e-6 to 5e-5
Competent Bedrock Zones:	5e-6 to 6e-6

6.2.4 Model Results

Model Calibration

In the Shallow Lake model, the water levels of 253 observation wells within the model domain were used for calibration. In the Owen Sound model, the water levels of 472 observation wells within the model domain were used for calibration. The resulting calibration graphs for the Shallow Lake and Owen Sound models are presented in Appendix E, having values of normalized root mean squared (NRMS) of 9.2 % and 8.2 %, respectively. These NRMS values are less than 10%, therefore indicating that these MODFLOW models generally represent the groundwater flow conditions in the vicinity of the Shallow Lake and Owen Sound municipal water supply systems.

WHPA Results

Figure 6.2 shows the steady-state capture zones for each municipal well. The 50-day, 2-year, 10-year, 25-year, and steady state capture zones, developed for each municipal well, are presented and discussed in Chapter 7. Additional analysis using the WHPAs, potential contaminant sources, and intrinsic susceptibility results are also presented in Chapter 7.

6.3 Township of Chatsworth

The Township of Chatsworth is located in the County of Grey. Figure 6.4A shows the model domain and three (3) municipal wells corresponding to the Chatsworth WHPA model. Figure 6.4B shows the model domain and two (2) municipal wells corresponding to the Walter's Falls WHPA model.

6.3.1 Local Aquifer Characterization

Bedrock Geology

The bedrock geology on a regional-scale is described in Section 2.7.2 (Regional Groundwater and Aquifer Characterization). As observed from the map of the Bedrock Geology of Ontario⁹ (1991), the surficial bedrock formation encountered within the Township of Chatsworth is mainly the Guelph Formation (dolostone). In the northeastern area of the township, near the Niagara Escarpment, the Amabel Formation (dolostone), the Fossil Hill Formation (dolostone) and the Cabot Head Formation (mainly shale) are also encountered at the bedrock surface.

In the area of the Chatsworth model, the uppermost bedrock formations are the Guelph Formation and the Amabel Formation. In the Walter's Falls model area, the uppermost formations are the Amabel, Fossil Hill and Cabot Head Formations, as well as the Queenston Formation (shale) on the Niagara Escarpment, beyond the township boundary.

Based on the WWIS and the oil and gas well database of the Ontario Petroleum Institute¹⁰, the Chatsworth municipal wells penetrate the Guelph, Amabel and Fossil Hill Formations, and the Walter's Falls municipal wells penetrate the Amabel, Fossil Hill, Cabot Head and Queenston Formations, listed in order as encountered with depth. These bedrock units were represented as a single continuous unit in each WHPA model.

Quaternary Geology

The Quaternary, or overburden, geology in the Township of Chatsworth mainly consists of a drumlinized till plain with two till moraines crossing through from west to east¹¹. The main physiographic regions in the township are the Horseshoe Moraines and the Arran Drumlin Field.

The Horseshoe Moraines region consists of a drumlinized till plain, two till moraines, and spillways to the south of the till moraines, kame moraines to the west and south, and a till moraine to the north. According to the Quaternary geology defined by the MNR¹², the till plain and drumlins consist of a stony-bouldery till with a sandy silt matrix, which is likely the Elma Till, a stony, sandy silt to silt till. The two till moraines consist of the same till as the till plain, where the northern till moraine, called the Gibraltar Moraine, crosses through the centre of the township and the southern till moraine, called the Singhampton Moraine, crosses through the southern part of the township. The Gibraltar Moraine is flanked on its southern side by a spillway that follows the course of the North Saugeen River, and the Singhampton Moraine is flanked on its southern side by a spillway that follows the course of the Saugeen River.

⁹ Bedrock Geology of Ontario, Southern Sheet, Map 2544, Scale 1:1,000,000, Ministry of Northern Development and Mines, 1991.

¹⁰ Oil, Gas and Salt Resources Library, digital well database, Ontario Petroleum Institute, Ministry of Natural Resources, 2002.

¹¹ Chapman, L.J., and Putnam, D.F., 1984, Physiography of Southern Ontario, Ontario Geological Survey, Map P.2715, Scale 1:600,000.

¹² Ministry of Natural Resources, NRVIS data, Quaternary geology, Maps 2956 and 2957.

The Arran Drumlin Field region occurs in the northwest corner of the township, and consists of a drumlinized till plain with two small till moraines and discontinuous clay plains. According to the Quaternary geology, the till plain and drumlins consist of Elma-Catfish Creek Till, a stony, sandy silt till. The till moraines, called the Banks Moraines, consist of ice-contact stratified drift of sand, gravel and some silt, and the clay plains consist of glaciolacustrine clay and silt.

In the northeast corner of the township, the township borders on the Niagara Escarpment, beyond which is the Bighead River Valley. The Bighead River Valley appears to be a continuation of the drumlinized till plain in the Horseshoe Moraines region. Also along the Niagara Escarpment there are dolostone outcrops of the Amabel, Fossil Hill and Manitoulin Formations.

The Chatsworth model area is located in the Horseshoe Moraines region. The Walter's Falls model area is located on the boundary between the Horseshoe Moraines region and the Bighead River Valley, along the Niagara Escarpment. The MNR Quaternary geology was used to estimate the hydraulic conductivity zones for the WHPA modeling.

Overburden Hydrogeology

In the County of Grey⁵, only 15% of the wells in the county obtain water from overburden. In the north of Grey County and along the Niagara Escarpment, the overburden is generally thin and consists of poorly-sorted tills, with well yields of less than 0.2 L/s. Till deposits cover most of the county, which have low permeabilities and cannot readily transmit water.

Bedrock Hydrogeology

In the County of Grey¹³, most groundwater supplies come from bedrock aquifers, with well yields of 0.2 to 3.8 L/s. The limestone and dolostone aquifers of the Guelph, Amabel and Fossil Hill formations are encountered in the Chatsworth model area and commonly have well yields of 0.8 to 3.8 L/s. In addition to these aquifers, the shales of the Cabot Head and Queenston formations are also encountered in the Walter's Falls model area and generally yield less than 0.2 L/s.

Local Cross-sections

Geologic cross-sections were generated using well information from the WWIS and are presented in Figures 6.5A and 6.5B. Each cross-section passes through at least one municipal well and is oriented either north-south or east-west, along the direction of the highest concentration of wells. Aquifer locations (screened intervals) and corresponding water levels are also shown on the cross-sections.

6.3.2 Municipal Well Systems

Chatsworth Water System

The Chatsworth Water Works, located in the former Village of Chatsworth in the Township of Chatsworth, is represented in the Chatsworth model. This municipal system is comprised of three bedrock wells, Well #1 and Well #2, both constructed in 1983, and Well #3 constructed in 1978. Wells #1 and #2 are used interchangeably, reserving one as a standby, and Well #3 is only for emergency supply. The water supply system services a population of approximately 540 people¹⁴. Figure 6.5 shows the location of the Chatsworth wells and their proximity to one

¹³ Ground-Water Probability of the County of Grey, Southern Ontario, Map 3111, Scale 1:100,000, Ontario Ministry of the Environment, 1980.

¹⁴ Engineer's Report for the Township of Chatsworth: Chatsworth Water Works, Henderson, Paddon & Associates Limited, Owen Sound, Ontario, January 2001.

another, as well as their proximity to local rivers and roads, and to township and model boundaries.

Walter's Falls Water System

The Walter's Falls Water Works, located in the former Hamlet of Walter's Falls in the Township of Chatsworth, is represented in the Walter's Falls model. This municipal system is comprised of two bedrock wells, Well #1 and Well #2, both constructed in 1989. The water supply system services 44 residences and businesses and has a 20-year design population¹⁵ of 227. Figure 6.5 shows the location of the Walter's Falls wells and their proximity to one another, as well as their proximity to local rivers and roads, and to township and model boundaries.

Average Production Rates

Average pumping rates for each municipal well were estimated based on raw water flow rates averaged over the last five years and are presented in Appendix F. These pumping rates were used to represent the wells in the groundwater model.

6.3.3 Model Design (Chatsworth, Walter's Falls)

Model Grid

The model grid for the Chatsworth model consists of 146 columns and 141 rows, with model extents of 13 km by 14 km horizontally and 130 m vertically. In the Walter's Falls model, the grid consists of 164 columns and 167 rows, with model extents of 15 km by 12 km horizontally and 350 m vertically. Figure 6.5 presents the locations of the WHPA model domains with respect to the municipal boundary.

Model Boundaries

In the area of the Chatsworth Model, groundwater flow in the bedrock is generally from east to west, as can be seen from Figure 2.21 of the bedrock equipotential contours. There are constant head boundaries upgradient of the flow system, having a maximum head of 325 m amsl, and downgradient of the flow system, having a minimum head of 270 m amsl. The final recharge value used to obtain a reasonable model calibration was 100 mm/yr, which falls within the range of values typical for this region.

In the area of the Walter's Falls Model, groundwater flow in the bedrock is generally from southeast to northwest, as can be seen from Figure 2.21 of the bedrock equipotential contours. There are constant head boundaries upgradient of the flow system, having a maximum head of 435 m amsl, and downgradient of the flow system, having a minimum head of 240 m amsl. The final recharge value used to obtain a reasonable model calibration was 120 mm/yr, which falls within the range of values typical for this region.

Hydrogeologic Properties

Final calibrated hydraulic conductivity values are presented in Table 6.4 for each geologic unit. These hydraulic conductivity values are consistent with those recorded in the literature for these materials (refer to Section 6.1.4).

6.3.4 Model Results

Model Calibration

In the Chatsworth model, the water levels of 246 observation wells within the model domain were used for model calibration. In the Walter's Falls model, the water levels of 80 observation

¹⁵ Engineer's Report for the Township of Chatsworth: Walter's Falls Water Works, Henderson, Paddon & Associates Limited, Owen Sound, Ontario, January 2001.

wells within the model domain were used for model calibration. The resulting calibration graphs for the Chatsworth and Walter's Falls models are presented in Appendix E, having NRMS values of 10.4 % and 6.8 %, respectively. These NRMS values are less than or equal to 10%, therefore indicating that these MODFLOW models generally represent the groundwater flow conditions in the vicinity of the Chatsworth and Walter's Falls municipal water supply systems.

TABLE 6.4: CALIBRATED VALUES OF HYDROGEOLOGIC PROPERTIES (CHATSWORTH)

Geological Unit	Hydraulic Conductivity (m/s)
Overburden Zones:	
Clay or Peat	5e-8 to 9e-8
Sand and Gravel	1e-4
Silt Till	3e-7 to 1e-6
Kame Materials	1e-6 to 3e-6
Exposed Bedrock	1e-6
Bedrock Contact Zone:	1.4e-6 to 1e-4
Competent Bedrock Zones:	1.4e-6 to 4.5e-6

WHPA Results

Figure 6.4A and 6.4B show the steady-state capture zone for each municipal well. The municipal well production information and the pumping rates used for the calibration and the capture zone delineation are presented in Appendix F. The pumping rates used for model calibration correspond to the average production rate, over the last five years, for each well, plus the 20-year projected rate. The 50-day, 2-year, 10-year, 25-year, and steady state capture zones, developed for each municipal well, are presented and discussed in Chapter 7. Additional analysis using the WHPAs, potential contaminant sources, and intrinsic susceptibility results are also presented in Chapter 7.

6.4 Municipality of West Grey

The Municipality of West Grey is located in the County of Grey. Figure 6.6A shows the model domain and three (3) municipal wells corresponding to the Neustadt WHPA model. Figure 6.6B shows the model domain and two (2) municipal wells corresponding to the Durham WHPA model.

6.4.1 Local Aquifer Characterization

Bedrock Geology

The bedrock geology on a regional-scale is described in Section 2.7.2 (Regional Groundwater and Aquifer Characterization). As observed from the map of the Bedrock Geology of Ontario¹⁶ (1991), the surficial bedrock formations encountered within the Municipality of West Grey are the Salina Formation (dolostone and shale) and the Guelph Formation (dolostone). In the area of the Neustadt model, the uppermost formation is the Salina Formation, and in the Durham model area, the uppermost formation is the Guelph Formation.

Based on the WWIS and the oil and gas well database of the Ontario Petroleum Institute¹⁷, the Neustadt municipal wells only penetrate the Salina Formation, whereas the Durham municipal wells penetrate the Guelph Formation, the Amabel Formation (dolostone) and the Fossil Hill Formation (dolostone), listed in order as encountered with depth. These bedrock units were represented as a single continuous unit in each WHPA model.

Quaternary Geology

The Quaternary geology in the Municipality of West Grey mainly consists of a drumlinized till plain traversed by glacial meltwater spillways and kame moraines¹⁸. The main physiographic regions in the township are the Horseshoe Moraines and the Teeswater Drumlin Field.

The Horseshoe Moraines region covers most of the municipality and consists of a drumlinized till plain covered by spillways, kame moraines to the west and south, and a till moraine to the north. According to the Quaternary geology¹⁹, the till plain and drumlins consist of Elma Till, a stony, sandy silt to silt till. The till moraine is part of the Singhampton Moraine and also consists of Elma Till. The spillways consist of terraces of glaciofluvial outwash sand and gravel, which follow the path of the Saugeen River and its tributaries. The kame moraines, called the Saugeen Kames, consist of ice-contact stratified drift of undifferentiated sand, gravel and silt.

The Teeswater Drumlin Field region occurs in the southwest part of the municipality and consists of a drumlinized till plain, spillways of sand and gravel terraces, and kame moraines. According to the Quaternary geology, the till plain and drumlins consist of mainly Elma Till, a stony, sandy silt to silt till. The spillways generally follow the courses of the Beatty Saugeen and South Saugeen Rivers and their tributaries, and consist of glaciolacustrine fine sand. The kame moraines are sandhills that occur to the southwest and southeast of Neustadt, and are part of the Saugeen Kames. According to the Quaternary geology, these kame moraines mainly consist of ice-contact stratified drift of undifferentiated sand, gravel and silt.

¹⁶ Bedrock Geology of Ontario, Southern Sheet, Map 2544, Scale 1:1,000,000, Ministry of Northern Development and Mines, 1991.

¹⁷ Oil, Gas and Salt Resources Library, digital well database, Ontario Petroleum Institute, Ministry of Natural Resources, 2002.

¹⁸ Chapman, L.J., and Putnam, D.F., 1984, Physiography of Southern Ontario, Ontario Geological Survey, Map P.2715, Scale 1:600,000.

¹⁹ Ministry of Natural Resources, NRVIS data, Quaternary geology, Maps 2956 and 2957.

The Durham model area is located within the Horseshoe Moraines region and the Neustadt model area is located within the Teeswater Drumlin Field.

The MNR Quaternary geology was used to estimate the hydraulic conductivity zones for the WHPA modeling.

Overburden Hydrogeology

In the County of Grey⁵, only 15% of the wells in the county obtain water from overburden. In the southern part of the county, the significant overburden aquifers consist of sands and gravels of beach, outwash, lacustrine, ice-contact and glaciofluvial deposits, having variable well yields of 0.2 to 3.8 L/s. Such aquifers occur in ice-contact stratified drift deposits, such as the Saugeen Kames, and outwash deposits, such as spillways, which occur over and between the morainal ridges. Till deposits, which have low permeabilities and cannot readily transmit water, cover most of the county and often occur beneath other glacial deposits, such as spillways, sand plains and peat and muck deposits.

Bedrock Hydrogeology

In the County of Grey²⁰, most groundwater supplies come from bedrock aquifers, with well yields of 0.2 to 3.8 L/s. The limestone and dolostone aquifers of the Salina, Guelph, Amabel and Fossil Hill formations, encountered in the township, commonly have well yields of 0.8 to 3.8 L/s. Well yields greater than 3.8 L/s have been reported for wells in highly fractured dolostone in the vicinity of Durham.

Local Cross-sections

Geologic cross-sections were generated using well information from the WWIS and are presented in Figures 6.7A and 6.7B. Each cross-section passes through at least one municipal well and is oriented either north-south or east-west, along the direction of the highest concentration of wells. Aquifer locations (screened intervals) and corresponding water levels are also shown on the cross-sections.

6.4.2 Municipal Well Systems

Durham Water System

The Durham Municipal Water Works, located in the Municipality of West Grey, is represented in the Durham model. This municipal system is comprised of two bedrock wells, Well #1B constructed in 1987 and Well #2 in 1966, which services the residents of the former Town of Durham, having a population of approximately 2,647 people²¹. Figure 6.6 shows the location of the Durham wells and their proximity to one another, as well as their proximity to local rivers and roads, and to the township and model boundaries.

Neustadt Water System

The Neustadt Groundwater Supply System, located in the former Village of Neustadt in the Municipality of West Grey, is represented in the Neustadt model. This municipal system is comprised of three bedrock wells, Well #1 constructed in 1990, Well #2 in 1992 and Well #3 in 1993, which service approximately 537 people²² in Neustadt. Figure 6.6 shows the location of

²⁰ Ground-Water Probability of the County of Grey, Southern Ontario, Map 3111, Scale 1:100,000, Ontario Ministry of the Environment, 1980.

²¹ Population data from 2001 Community Profiles, Statistics Canada,

²² First Engineer's Report for the Township of West Grey: Neustadt Groundwater Supply System, Kitchener, Ontario, May 2001.

the Neustadt wells and their proximity to one another, as well as their proximity to local rivers and roads, and to the township and model boundaries.

Average Production Rates

Average pumping rates for each municipal well were estimated based on raw water flow rates averaged over the last five years and are presented in Appendix F. These pumping rates were used to represent the wells in the groundwater model.

6.4.3 Model Design (Neustadt, Durham)

Model Grid

The model grid for the Neustadt model consists of 119 columns and 128 rows, with model extents of 14 km by 16 km horizontally and 240 m vertically. In the Durham model, the grid consists of 137 columns and 162 rows, with model extents of 16 km by 17 km horizontally and 335 m vertically. Figure 6.6 presents the locations of the WHPA model domains with respect to the municipal boundary.

Model Boundaries

In the area of the Neustadt Model, groundwater flow in the bedrock is generally from south to north, as can be seen from Figure 2.21 of the bedrock equipotential contours. There are constant head boundaries upgradient of the flow system, having a maximum head of 360 m amsl, and downgradient of the flow system, having a minimum head of 266 m amsl. The final recharge value used to obtain a reasonable model calibration was 100 mm/yr, which falls within the range of values typical for this region.

In the area of the Durham Model, groundwater flow in the bedrock is generally from east to west, as can be seen from Figure 2.21 of the bedrock equipotential contours. There are constant head boundaries upgradient of the flow system, having a maximum head of 440 m amsl, and downgradient of the flow system, having a minimum head of 315 m amsl. The final recharge value used to obtain a reasonable model calibration was 100 mm/yr, which falls within the range of values typical for this region.

Hydrogeologic Properties

Final calibrated hydraulic conductivity values are presented in Table 6.5 for each geologic unit. These hydraulic conductivity values are consistent with those recorded in the literature for these materials (refer to Section 6.1.4).

TABLE 6.5: CALIBRATED VALUES FOR HYDROGEOLOGIC PROPERTIES (WEST GREY)

Geological Unit	Hydraulic Conductivity (m/s)
Overburden Zones:	
Clay or Peat	4e-7
Sand and Gravel	4e-4 to 8e-4
Silt Till	4e-6 to 6e-6
Kame Materials	4e-7 to 5e-6
Exposed Bedrock	--
Bedrock Contact Zone	8e-5 to 8e-4
Competent Bedrock Zones	3e-5 to 6e-5

6.4.4 Model Results

Model Calibration

In the Neustadt model, the water levels of 108 observation wells within the model domain were used for model calibration. In the Durham model, the water levels of 213 observation wells within the model domain were used for model calibration. The resulting calibration graphs for the Neustadt and Durham models are presented in Appendix E, having NRMS values of 7.3 % and 5.5 %, respectively. These NRMS values are less than or equal to 10%, therefore indicating that these MODFLOW models generally represent the groundwater flow conditions in the vicinity of the Neustadt and Durham municipal water supply systems.

WHPA Results

Figure 6.6A and 6.6B show the steady-state capture zone for each municipal well. The municipal well production information and the pumping rates used for the calibration and the capture zone delineation are presented in Appendix F. The pumping rates used for model calibration correspond to the average production rate, over the last five years, for each well, plus the 20-year projected rate. The 50-day, 2-year, 10-year, 25-year, and steady state capture zones, developed for each municipal well, are presented and discussed in Chapter 7. Additional analysis using the WHPAs, potential contaminant sources, and intrinsic susceptibility results are also presented in Chapter 7.

6.5 Township of Southgate

The Township of Southgate is located in the County of Grey. Figure 6.8 shows the model domain and three (3) municipal wells corresponding to the Dundalk WHPA model.

6.5.1 Local Aquifer Characterization

Bedrock Geology

The bedrock geology on a regional-scale is described in Section 2.7.2 (Regional Groundwater and Aquifer Characterization). As observed from the map of the Bedrock Geology of Ontario²³ (1991), the surficial bedrock formations encountered within the Township of Southgate are the Salina Formation (dolostone and shale) and the Guelph Formation (dolostone). In the area of the Dundalk model, the uppermost formation is the Guelph Formation. Based on the WWIS and the oil and gas well database of the Ontario Petroleum Institute²⁴, the Dundalk municipal wells penetrate the Guelph Formation, the Amabel Formation (dolostone) and the Fossil Hill Formation (dolostone), listed in order as encountered with depth. These bedrock units were represented as a single continuous unit in each WHPA model.

Quaternary Geology

The Quaternary, or overburden, geology in the Township of Southgate mainly consists of a drumlinized till plain with spillways and kames in the northwest²⁵. The main physiographic regions in the township are the Dundalk Till Plain and the Horseshoe Moraines.

The Dundalk Till Plain covers most of the township and consists of a poorly-drained drumlinized till plain, with spillways along the Saugeen River in the north and along the South Saugeen River in the southwest. According to the Quaternary geology²⁶, the till plain and drumlins consist of Elma Till, a stony, sandy silt to silt till. The spillways consist of glaciofluvial outwash sand and gravel, and glaciolacustrine fine sand. There are also two long eskers that cross through the township from northwest to southeast, which consist of ice-contact stratified sand and gravel.

The Horseshoe Moraines region, in the northwest corner of the township, mainly consists of spillways and kame moraines. According to the Quaternary geology, the spillways consist of glaciofluvial outwash sand and gravel, which generally follow the paths of tributaries to the Saugeen River. The kame moraines, called the Saugeen Kames, consist of ice-contact stratified drift of undifferentiated sand, gravel and silt.

The Dundalk model area is located within the Dundalk Till Plain region, being mostly covered by the drumlinized till plain and bordered to the north by a spillway along the Saugeen River. The MNR Quaternary geology was used to estimate the hydraulic conductivity zones for the WHPA modeling.

Overburden Hydrogeology

In the County of Grey⁵, only 15% of the wells in the county obtain water from overburden. In the southern part of the county, the significant overburden aquifers consist of sands and

²³ Bedrock Geology of Ontario, Southern Sheet, Map 2544, Scale 1:1,000,000, Ministry of Northern Development and Mines, 1991.

²⁴ Oil, Gas and Salt Resources Library, digital well database, Ontario Petroleum Institute, Ministry of Natural Resources, 2002.

²⁵ Chapman, L.J., and Putnam, D.F., 1984, Physiography of Southern Ontario, Ontario Geological Survey, Map P.2715, Scale 1:600,000.

²⁶ Ministry of Natural Resources, NRVIS data, Quaternary geology, Maps 2956 and 2957.

gravels of beach, outwash, lacustrine, ice-contact and glaciofluvial deposits, having variable well yields of 0.2 to 3.8 L/s. Such aquifers occur in ice-contact stratified drift deposits, such as the Saugeen Kames, and outwash deposits, such as spillways, which occur over and between the morainal ridges. Till deposits, which have low permeabilities and cannot readily transmit water, cover most of the county and often occur beneath other glacial deposits, such as spillways, sand plains and peat and muck deposits.

Bedrock Hydrogeology

In the County of Grey²⁷, most groundwater supplies come from bedrock aquifers, with well yields of 0.2 to 3.8 L/s. The limestone and dolostone aquifers of the Salina, Guelph, Amabel and Fossil Hill formations, encountered in the township, commonly have well yields of 0.8 to 3.8 L/s. Well yields greater than 3.8 L/s have been reported for wells in highly fractured dolostone in the vicinity of Dundalk.

Local Cross-sections

Geologic cross-sections were generated using well information from the WWIS and are presented in Figure 6.9. Each cross-section passes through at least one municipal well and is oriented either north-south or east-west, along the direction of the highest concentration of wells. Aquifer locations (screened intervals) and corresponding water levels are also shown on the cross-sections.

6.5.2 Municipal Well Systems

Dundalk Water System

The Village of Dundalk Water System is located in the Township of Southgate, is represented in the Dundalk model. This municipal system is comprised of three bedrock wells, Well #1 and Well #2, both constructed in 1960, and Well #3 constructed in 1975. The water supply system services the former Village of Dundalk, which has a population of 1,972 persons²⁸. Figure 6.8 shows the location of the Dundalk wells and their proximity to one another, as well as their proximity to local rivers and roads, and to the township and model boundaries.

Average Production Rates

Average pumping rates for each municipal well were estimated based on raw water flow rates averaged over the last five years and are presented in Appendix F. These pumping rates were used to represent the wells in the groundwater model.

6.5.3 Model Design (Dundalk)

Model Grid

The model grid for the Dundalk model consists of 169 columns and 178 rows, with model extents of 17.5 km by 16 km horizontally and 135 m vertically. Figure 6.8 presents the locations of the WHPA model domain with respect to the municipal boundary.

Model Boundaries

In the area of the Dundalk Model, groundwater flow in the bedrock is generally from northeast to southwest, as can be seen from Figure 2.21 of the bedrock equipotential contours. There are constant head boundaries upgradient of the flow system, having a maximum head of 523 m amsl, and downgradient of the flow system, having a minimum head of 475 m amsl. The final

²⁷ Ground-Water Probability of the County of Grey, Southern Ontario, Map 3111, Scale 1:100,000, Ontario Ministry of the Environment, 1980.

²⁸ Population data from 2001 Community Profiles, Statistics Canada

recharge value used to obtain a reasonable model calibration was 70 mm/yr, which falls within the range of values typical for this region.

Hydrogeologic Properties

Final calibrated hydraulic conductivity values are presented in Table 6.6 for each geologic unit. These hydraulic conductivity values are consistent with those recorded in the literature for these materials (refer to Section 6.1.4).

TABLE 6.6: CALIBRATED VALUES FOR HYDROGEOLOGIC PROPERTIES (DUNDALK)

Geological Unit	Hydraulic Conductivity (m/s)
Overburden Zones:	
Clay or Peat	6e-8
Sand and Gravel	5e-4
Silt Till	6e-7
Kame Materials	--
Exposed Bedrock	--
Bedrock Contact Zone	1e-4
Competent Bedrock Zones	3e-6

6.5.4 Model Results

Model Calibration

In the Dundalk model, the water levels of 176 observation wells within the model domain were used for model calibration. The resulting calibration graph for the Dundalk model is presented in Appendix E, having an NRMS value of 7.6 %. This NRMS value is less than 10%, therefore indicating that this MODFLOW model generally represents the groundwater flow conditions in the vicinity of the Dundalk municipal water supply system.

WHPA Results

Figure 6.8 shows the steady-state capture zone for each municipal well. The municipal well production information and the pumping rates used for the calibration and the capture zone delineation are presented in Appendix F. The pumping rates used for model calibration correspond to the average production rate, over the last five years, for each well, plus the 20-year projected rate. The 50-day, 2-year, 10-year, 25-year, and steady state capture zones, developed for each municipal well, are presented and discussed in Chapter 7. Additional analysis using the WHPAs, potential contaminant sources, and intrinsic susceptibility results are also presented in Chapter 7.

6.6 Town of Hanover

The Town of Hanover is located in the County of Grey. Figure 6.10 shows WHPA model domain and three (3) municipal wells corresponding to the Hanover WHPA model. The Hanover model also includes the Lake Rosalind municipal well located in the Municipality of Brockton in the County of Bruce.

6.6.1 Local Aquifer Characterization

Bedrock Geology

The bedrock geology on a regional-scale is described in Section 2.7.2 (Regional Groundwater and Aquifer Characterization). As observed from the map of the Bedrock Geology of Ontario²⁹ (1991), the surficial bedrock formation encountered within the Town of Hanover is the Salina Formation (dolostone and shale). In the area of the Hanover model area, the uppermost formation is also the Salina Formation. Based on the WWIS and the oil and gas well database of the Ontario Petroleum Institute³⁰, the municipal wells in the Hanover model area do not penetrate deeper than the Salina Formation. This bedrock unit was represented as a single continuous unit in the Hanover WHPA model.

Quaternary Geology

The Quaternary, or overburden, geology in the vicinity of the Town of Hanover in general consists of a till moraine and a drumlinized till plain separated by a large meltwater spillway³¹, which are features of the two main physiographic regions in the area: the Horseshoe Moraines and the Teeswater Drumlin Field.

In the area of the Hanover model, the main features of the Horseshoe Moraines are a till moraine in the northwest and a broad spillway in the northeast. According to the MNR Quaternary geology³², the till moraine, called the Singhampton Moraine, consists of Dunkeld Till, a silt till with a low stone content, and the spillway consists of glaciofluvial outwash sand and gravel. The broad spillway also contains a group of drumlins, possibly from the underlying Teeswater Drumlin Field to the south, as well as an esker in the middle of the drumlins.

The majority of the Hanover model area is covered by the Teeswater Drumlin Field region, which consists of a drumlinized till plain and spillways of sand and gravel terraces. According to the Quaternary geology, the till plain and drumlins consist of mainly Elma Till, a stoney, sandy silt to silt till. The spillways, which cover most of the till plain, generally follow the course of the Saugeen River and its tributaries, and predominantly consist of glaciofluvial outwash sand.

The MNR Quaternary geology was used to estimate the hydraulic conductivity zones for the WHPA modeling.

Overburden Hydrogeology

In the County of Grey⁵, only 15% of the wells in the county obtain water from overburden. In the southern part of the county, the significant overburden aquifers consist of sands and gravels of beach, outwash, lacustrine, ice-contact and glaciofluvial deposits, having variable

²⁹ Bedrock Geology of Ontario, Southern Sheet, Map 2544, Scale 1:1,000,000, Ministry of Northern Development and Mines, 1991.

³⁰ Oil, Gas and Salt Resources Library, digital well database, Ontario Petroleum Institute, Ministry of Natural Resources, 2002.

³¹ Chapman, L.J., and Putnam, D.F., 1984, Physiography of Southern Ontario, Ontario Geological Survey, Map P.2715, Scale 1:600,000.

³² Ministry of Natural Resources, NRVIS data, Quaternary geology, Maps 2956 and 2957.

well yields of 0.2 to 3.8 L/s. Such aquifers occur in outwash deposits, such as spillways, which occur over and between the morainal ridges. Till deposits, which have low permeabilities and cannot readily transmit water, cover most of the county and often occur beneath other glacial deposits, such as spillways, sand plains and peat and muck deposits.

Bedrock Hydrogeology

In the County of Grey³³, most groundwater supplies come from bedrock aquifers, with well yields of 0.2 to 3.8 L/s. The limestone and dolostone aquifers of the Salina formation, encountered in the in the area of the Hanover model, commonly have well yields of 0.8 to 3.8 L/s. Well yields greater than 3.8 L/s have been reported for wells in highly fractured dolostone in the vicinity of Hanover.

Local Cross-sections

Geologic cross-sections were generated using well information from the WWIS and are presented in Figure 6.11. Each cross-section passes through at least one municipal well and is oriented either north-south or east-west, along the direction of the highest concentration of wells. Aquifer locations (screened intervals) and corresponding water levels are also shown on the cross-sections.

6.6.2 Municipal Well Systems

Hanover Water System

Due to their proximity, the Hanover water supply system and the Lake Rosalind Water Works were combined into one model, called the Hanover model. The Hanover water supply system, located west of the Town of Hanover, uses water from the spring-fed Ruhl Lake and from two overburden wells, Well #1 constructed in 1961 and Well #2 in 1986. Fifty percent of the water supply comes from the lake and twenty-five percent from each of the wells, together supplying water to a population of 6,600 people³⁴ in the Town of Hanover.

Lake Rosalind Water System

The Lake Rosalind Water Works, located on the west side of Lake Rosalind in the Municipality of Brockton, is comprised of one overburden well. Well #3 was constructed in 1987 and services 68 residential lots (approximately 170 people³⁵). Figure 6.10 shows the location of the Hanover wells and the Lake Rosalind well, and their proximity to one another, as well as their proximity to local rivers and roads, and to the township and model boundaries.

Average Production Rates

Average pumping rates for each municipal well were estimated based on raw water flow rates averaged over the last five years and are presented in Appendix F. These pumping rates were used to represent the wells in the groundwater model.

6.6.3 Model Design (Hanover)

Model Grid

The model grid for the Hanover model consists of 120 columns and 108 rows, with model extents of 13 km by 11 km horizontally and 170 m vertically. Figure 6.10 presents the locations of the WHPA model domain with respect to the municipal boundary.

³³ Ground-Water Probability of the County of Grey, Southern Ontario, Map 3111, Scale 1:100,000, Ontario Ministry of the Environment, 1980.

³⁴ First Engineer's Report for the Town of Hanover, Hanover, Ontario, January 2001.

³⁵ Based on an estimated 2.5 persons per residence (Engineer's Report, Town of South Bruce Peninsula, County of Bruce, design population estimates, 2001).

Model Boundaries

In the area of the Hanover Model, groundwater flow in the bedrock is generally from east to west, as can be seen from Figure 2.21 of the bedrock equipotential contours. There are constant head boundaries upgradient of the flow system, having a maximum head of 305 m amsl, and downgradient of the flow system, having a minimum head of 260 m amsl. The final recharge value used to obtain a reasonable model calibration was 150 mm/yr, which falls within the range of values typical for this region.

Hydrogeologic Properties

Final calibrated hydraulic conductivity values are presented in Table 6.7 for each geologic unit. These hydraulic conductivity values are consistent with those recorded in the literature for these materials.

TABLE 6.7: CALIBRATED VALUES FOR HYDROGEOLOGIC PROPERTIES (HANOVER)

Geological Unit	Hydraulic Conductivity (m/s)
Overburden Zones:	
Clay or Peat	1e-7
Sand and Gravel	1e-4
Silt Till	5e-7
Kame Materials	5e-7
Exposed Bedrock	--
Bedrock Contact Zone	1e-5
Competent Bedrock Zones	9e-6

6.6.4 Model Results

Model Calibration

In the Hanover model, the water levels of 116 observation wells within the model domain were used for model calibration. The resulting calibration graph for the Hanover model is presented in Appendix E, having an NRMS value of 8.5 %. This NRMS value is less than 10%, therefore indicating that this MODFLOW model generally represents the groundwater flow conditions in the vicinity of the Hanover and Lake Rosalind municipal wells.

WHPA Results

Figure 6.10 shows the steady-state capture zone for each municipal well. The municipal well production information and the pumping rates used for the calibration and the capture zone delineation are presented in Appendix F. The pumping rates used for model calibration correspond to the average production rate, over the last five years, for each well, plus the 20-year projected rate. The 50-day, 2-year, 10-year, 25-year, and steady state capture zones, developed for each municipal well, are presented and discussed in Chapter 7. Additional analysis using the WHPAs, potential contaminant sources, and intrinsic susceptibility results are also presented in Chapter 7.

6.7 Municipality of Grey Highlands

The Municipality of Grey Highlands is located in the County of Grey. Figure 6.12A shows the model domain and three (3) municipal wells corresponding to the Markdale WHPA model. Figure 6.12B shows the model domain and two (2) municipal wells corresponding to the Feversham WHPA model. Figure 6.12C shows the model domain and two (2) springs corresponding to the Kimberley WHPA model.

6.7.1 Local Aquifer Characterization

Bedrock Geology

The bedrock geology on a regional-scale is described in Section 2.7.2 (Regional Groundwater and Aquifer Characterization). As observed from the map of the Bedrock Geology of Ontario³⁶ (1991), the surficial bedrock formations encountered within the Municipality of Grey Highlands are the Guelph Formation (dolostone), the Amabel Formation (dolostone), the Fossil Hill Formation (dolostone), the Cabot Head Formation (mainly shale), Queenston Formation (shale) and the Georgian Bay/Blue Mountain Formation (shale).

In the area of the Markdale model, only the Guelph Formation is encountered at the bedrock surface, whereas in the Feversham model area, both the Guelph and Amabel Formations are the uppermost bedrock formations. In the area of the Kimberley model, the Guelph, Amabel, Fossil Hill, Cabot Head, Queenston and Georgian Bay/Blue Mountain Formations are all encountered at the bedrock surface, in order from west to east over the Niagara Escarpment.

Based on the WWIS and the oil and gas well database of the Ontario Petroleum Institute³⁷, the Markdale municipal wells penetrate the Guelph, Amabel Formation and Fossil Hill Formations, and the Feversham municipal wells penetrate the Guelph, Amabel, Fossil Hill, Cabot Head and Queenston Formations, listed in order as encountered with depth. In the Kimberley model area, the springs are located at the interface of the Cabot Head dolostone and the Queenston shale. These bedrock units were represented as a single continuous unit in each WHPA model.

Quaternary Geology

The Quaternary, or overburden, geology in the Municipality of Grey Highlands consists of a drumlinized till plain outlined by the Niagara Escarpment in the northern, central and eastern areas of the municipality³⁸. The main physiographic regions in the municipality are the Horseshoe Moraines, the Dundalk Till Plain and the Beaver River Valley.

The Horseshoe Moraines region covers most of the municipality and consists of a drumlinized till plain with till moraines crossing through it and along the top of the Niagara Escarpment. According to the Quaternary geology defined by the MNR³⁹, the till plain and drumlins consist of Elma Till, a stony, sandy silt to silt till, as well as poorly-drained depressions with swampy areas in the northwest. The till moraines, which also consist of the Elma till, are the Gibraltar Moraine, which runs along the top of the escarpment in the north, and the Singhampton Moraine, which crosses through the centre of the municipality and along the top of the escarpment in the east. There are also spillways that follow the Beaver River and Rocky

³⁶ Bedrock Geology of Ontario, Southern Sheet, Map 2544, Scale 1:1,000,000, Ministry of Northern Development and Mines, 1991.

³⁷ Oil, Gas and Salt Resources Library, digital well database, Ontario Petroleum Institute, Ministry of Natural Resources, 2002.

³⁸ Chapman, L.J., and Putnam, D.F., 1984, Physiography of Southern Ontario, Ontario Geological Survey, Map P.2715, Scale 1:600,000.

³⁹ Ministry of Natural Resources, NRVIS data, Quaternary geology, Maps 2956 and 2957.

Saugeen River in the south, which consist of glaciofluvial outwash sand and gravel. The Saugeen Kames also appear in the Markdale area, which consist of glaciofluvial ice-contact sand and gravel.

The Dundalk Till Plain occurs in the southern part of the municipality and consists of a poorly-drained drumlinized till plain, with a spillway along the Saugeen River and a swampy area in the east. According to the Quaternary geology, the till plain and drumlins consist of Elma Till, a stony, sandy silt to silt till. The spillways consist of glaciofluvial outwash sand, and the swampy area consists of peat and muck.

In the northeast of the municipality, the vertical dolostone cliffs of the Niagara Escarpment form the steep sides of the Beaver River Valley. The valley sides are thinly covered by a stony-bouldery till with a sandy silt matrix, which is likely the Elma Till, and fan deposits of gravel, sand and silt.

The Markdale model area is located mainly in the Horseshoe Moraines region. The Feversham model area is located in both the Horseshoe Moraines and the Dundalk Till Plain. The Kimberley model area is located on the boundary between the Horseshoe Moraines region and the Beaver River Valley, along the Niagara Escarpment.

The MNR Quaternary geology was used to estimate the hydraulic conductivity zones for the WHPA modeling.

Overburden Hydrogeology

In the County of Grey⁵, only 15% of the wells in the county obtain water from overburden. In the north and along the Niagara Escarpment, the overburden is generally thin and consists of poorly-sorted tills, with well yields of less than 0.2 L/s. Till deposits, which have low permeabilities and cannot readily transmit water, cover most of the county and often occur beneath other glacial deposits, such as spillways, sand plains and peat and muck deposits. In the Bighead and Beaver River Valleys, the significant overburden aquifers consist of sands and gravels of beach, outwash, lacustrine, ice-contact and glaciofluvial deposits, having variable well yields of 0.2 to 3.8 L/s.

Bedrock Hydrogeology

In the County of Grey⁴⁰, most groundwater supplies come from bedrock aquifers, with well yields of 0.8 to 3.8 L/s common to the limestone and dolostone aquifers of the Guelph, Amabel and Fossil Hill formations. The shales of the Cabot Head, Queenston and Georgian Bay formations have low permeabilities, with well yields of 0.2 to 0.8 L/s. Well yields greater than 3.8 L/s have been reported for wells in highly fractured dolostone in the vicinity of Markdale.

Local Cross-sections

Geologic cross-sections were generated using well information from the WWIS and are presented in Figures 6.13A to 6.13C. Each cross-section passes through at least one municipal well and is oriented either north-south or east-west, along the direction of the highest concentration of wells. Aquifer locations (screened intervals) and corresponding water levels are also shown on the cross-sections.

⁴⁰ Ground-Water Probability of the County of Grey, Southern Ontario, Map 3111, Scale 1:100,000, Ontario Ministry of the Environment, 1980.

6.7.2 Municipal Well Systems

Markdale Water System

The Village of Markdale Water Works, located in the Township of Grey Highlands, is represented in the Markdale model. This municipal system is comprised of three bedrock wells, the Isla Street well constructed in 1973, and Wells #3 and #4 constructed in 2002. The water supply system services 652 residences in the former Village of Markdale (approximately 1,219 persons⁴¹), as well as a major ice cream manufacturer. Figure 6.12A shows the location of the Markdale wells and their proximity to one another, as well as their proximity to local rivers and roads, and to the township and model boundaries.

After completing the initial modeling of the Markdale system, Henderson, Paddon & Associates provided updated information on two new wells drilled in Markdale. These wells (Wells 3 and 4) were drilled in the southeast part of Town. The Markdale model was updated with this new information, re-calibrated, and an updated set of WHPA boundaries were generated.

Feversham Water System

The Feversham Water Supply System, located in the community of Feversham in the Township of Grey Highlands, is represented in the Feversham model. This municipal system is comprised of two bedrock wells, Well #2, constructed in 1974, and Well #3, constructed in 1982. The Feversham well #2 is a standby well. The water supply system services the Beaver Heights Subdivision with an estimated population of 133 persons⁴². Figure 6.12B shows the location of the Feversham wells and their proximity to one another, as well as their proximity to local rivers and roads, and to the township and model boundaries.

Kimberley Water System

The Kimberley-Amik-Talisman Water Supply, located in the former Hamlet of Kimberley in the Township of Grey Highlands, is represented in the Kimberley model. This municipal system is comprised of two bedrock springs, Spring #1 and Spring #2. In 1988, the individual water supply systems of the Hamlet of Kimberley, the Amik Subdivision and the Talisman Ski Resort (including recreational and residential areas) were amalgamated into one, serving a total population of approximately 645 persons⁴³. Figure 6.12C shows the location of the Kimberley springs and their proximity to one another, as well as their proximity to local rivers and roads, and to the township and model boundaries.

Average Production Rates

Average pumping rates for each municipal well were estimated based on raw water flow rates averaged over the last five years and are presented in Appendix F. These pumping rates were used to represent the wells in the groundwater model.

6.7.3 Model Design (Markdale, Feversham, Kimberley Springs)

Model Grid

The model grid for the Markdale model consists of 152 columns and 163 rows, with model extents of 15 km by 18 km horizontally and 190 m vertically. In the Feversham model, the grid consists of 150 columns and 116 rows, with model extents of 18 km by 12 km horizontally and

⁴¹ Engineer's Report for the Township of Grey Highlands: Village of Markdale Water Works, Henderson, Paddon & Associates Limited, Clarksburg, Ontario, March 2001.

⁴² Engineer's Report for the Township of Grey Highlands: Feversham Water Supply System, R. J. Burnside & Associates Limited, Collingwood, Ontario, March 2001.

⁴³ Engineer's Report for the Township of Grey Highlands: Kimberley-Amik-Talisman Water Supply, Henderson, Paddon & Associates Limited, Owen Sound, Ontario, January 2001.

215 m vertically. In the Kimberley model, the grid consists of 115 columns and 100 rows, with model extents of 8 km by 9.5 km horizontally and 350 m vertically. Figure 6.12 presents the locations of the WHPA model domains with respect to the municipal boundary.

Model Boundaries

In the area of the Markdale Model, groundwater flow in the bedrock is generally from southeast to northwest, as can be seen from Figure 2.21 of the bedrock equipotential contours. There are constant head boundaries upgradient of the flow system, having a maximum head of 490 m amsl, and downgradient of the flow system, having a minimum head of 385 m amsl. The final recharge value used to obtain a reasonable model calibration was 90 mm/yr, which falls within the range of values typical for this region.

In the area of the Feversham Model, groundwater flow in the bedrock is generally from east to west, as can be seen from Figure 2.21 of the bedrock equipotential contours. There are constant head boundaries upgradient of the flow system, having a maximum head of 520 m amsl, and downgradient of the flow system, having a minimum head of 430 m amsl. The final recharge value used to obtain a reasonable model calibration was 125 mm/yr, which falls within the range of values typical for this region.

In the area of the Kimberley Model, groundwater flow in the bedrock is generally from west to east, as can be seen from Figure 2.21 of the bedrock equipotential contours. There are constant head boundaries upgradient of the flow system, having a maximum head of 430 m amsl, and downgradient of the flow system, having a minimum head of 225 m amsl. The final recharge value used to obtain a reasonable model calibration was 125 mm/yr, which falls within the range of values typical for this region.

Hydrogeologic Properties

Final calibrated hydraulic conductivity values are presented in Table 6.8 for each geologic unit. These hydraulic conductivity values are consistent with those recorded in the literature for these materials (refer to Section 6.1.4).

TABLE 6.8: CALIBRATED VALUES FOR HYDROGEOLOGIC PROPERTIES (GREY HIGHLANDS)

Geological Unit	Hydraulic Conductivity (m/s)
Overburden Zones:	
Clay or Peat	5e-8 to 1e-7
Sand and Gravel	1e-4 to 2e-4
Silt Till	1e-7 to 6e-7
Kame Materials	1e-5 to 2e-5
Exposed Bedrock	5e-6 to 5e-5
Bedrock Contact Zone	5e-5 to 1e-4
Competent Bedrock Zones	4e-7 to 1e-5

6.7.4 Model Results

Model Calibration

In the Markdale model, the water levels of 219 observation wells within the model domain were used for model calibration. In the Feversham model, the heads of 235 observation wells within the model domain were used for model calibration. In the Kimberley model, the heads of 25

observation wells within the model domain were used for model calibration. The resulting calibration graphs for the Markdale, Feversham and Kimberley models are presented in Appendix E, having NRMS values of 8.5 %, 8.3 % and 8.5 %, respectively. These NRMS values are less than or equal to 10%, therefore indicating that these MODFLOW models generally represent the groundwater flow conditions in the vicinity of the Markdale, Feversham and Kimberley municipal water supply systems.

WHPA Results

Figure 6.12 shows the steady-state capture zone for each municipal well. The municipal well production information and the pumping rates used for the calibration and the capture zone delineation are presented in Appendix F. The pumping rates used for model calibration correspond to the average production rate, over the last five years, for each well, plus the 20-year projected rate. The 50-day, 2-year, 10-year, 25-year, and steady state capture zones, developed for each municipal well, are presented and discussed in Chapter 7. Additional analysis using the WHPAs, potential contaminant sources, and intrinsic susceptibility results are also presented in Chapter 7.

6.8 Municipality of Arran-Elderslie

The Municipality of Arran-Elderslie is located in the County of Bruce. Figure 6.14A shows the model domain and two (2) municipal wells corresponding to the Tara WHPA model. Figure 6.14B shows the model domain and two (2) municipal wells corresponding to the Chesley WHPA model.

6.8.1 Local Aquifer Characterization

Bedrock Geology

The bedrock geology on a regional-scale is described in Section 2.7.2 (Regional Groundwater and Aquifer Characterization). As observed from the map of the Bedrock Geology of Ontario⁴⁴ (1991), the surficial bedrock formations encountered within the Municipality of Arran-Elderslie are the Salina Formation (dolostone and shale) and the Guelph Formation (dolostone). In the area of the Chesley model, the uppermost formations are the Salina Formation and the Guelph Formation, from west to east, whereas in the Tara model area, the uppermost formation is the Guelph Formation. Based on the WWIS and the oil and gas well database of the Ontario Petroleum Institute⁴⁵, the Chesley municipal wells only penetrate the Salina Formation, whereas the Tara municipal wells penetrate the Guelph Formation, the Amabel Formation (dolostone) and the Fossil Hill Formation (dolostone), listed in order as encountered with depth. These bedrock units were represented as a single continuous unit in each WHPA model.

Quaternary Geology

The Quaternary, or overburden, geology in the Municipality of Arran-Elderslie consists a drumlinized till plain with a clay plain in the south and till moraines throughout⁴⁶. The main physiographic regions in the municipality are the Arran Drumlin Field, the Saugeen Clay Plain, and the Horseshoe Moraines.

The Arran Drumlin Field region, in the northern half of the municipality, consists of a drumlinized till plain with till moraines and disconnected clay plains. According to the Quaternary geology defined by the MNR⁴⁷, the till plain and drumlins consist of Elma-Catfish Creek Till, a stony, sandy silt till. The till moraines, called the Banks Moraines in the south and the Tara Strands in the northeast, are generally oriented east-west and consist of the Elma-Catfish Creek Till and some ice-contact stratified sand and gravel, according to the MNR Quaternary geology. On the south side of the till moraines are clay plains of glaciolacustrine clay and silt, likely related to the Saugeen Clay Plain to the south.

The Saugeen Clay Plain region, located in the southern half of the municipality, in the drainage basin of the Saugeen River, consists of deep stratified clay deposited by glacial Lake Warren. According to the Quaternary geology, the clay plain consists of glaciolacustrine clay and silt. There is a small group of drumlins on the clay plain northwest of Chesley, which consist of the Elma-Catfish Creek Till of the Arran Drumlin Field to the north. The Gibraltar Moraine continues across the clay plain from the Horseshoe Moraines in the east.

⁴⁴ Bedrock Geology of Ontario, Southern Sheet, Map 2544, Scale 1:1,000,000, Ministry of Northern Development and Mines, 1991.

⁴⁵ Oil, Gas and Salt Resources Library, digital well database, Ontario Petroleum Institute, Ministry of Natural Resources, 2002.

⁴⁶ Chapman, L.J., and Putnam, D.F., 1984, Physiography of Southern Ontario, Ontario Geological Survey, Map P.2715, Scale 1:600,000.

⁴⁷ Ministry of Natural Resources, NRVIS data, Quaternary geology, Maps 2956 and 2957.

The Horseshoe Moraines region occurs on the east side of the Chesley model area, beyond the municipality boundary, and consists of a till moraine and spillway overlying a till plain. The till plain, according to the Quaternary geology, consists of a stony-bouldery till with a sandy silt matrix, which is likely the Elma Till, a stony, sandy silt to silt till. The till moraine is part of the Gibraltar Moraine and consists of the same till as in the till plain. The spillway, south of the Gibraltar Moraine, and follows the course of the North Saugeen River, and consists mainly of glaciofluvial outwash sand and gravel.

The Chesley model area is located mainly in the Saugeen Clay Plain region, with part of the Horseshoe Moraines region on the east side. The Tara model area is located entirely in the Arran Drumlin Field region, in the area of the Tara Strands.

The MNR Quaternary geology was used to estimate the hydraulic conductivity zones for the WHPA modeling.

Overburden Hydrogeology

The majority of wells in Bruce County⁴⁸ obtained groundwater from bedrock aquifers. However, there are some overburden aquifers in the sands and gravels of kames, spillways, sand plains and beach ridges, with well yields ranging from 0.2 to 3.8 L/s. In the Arran Drumlin Field, overburden aquifers are found in the Tara Moraines and in kames along the Willscroft Moraine, southwest of Tara.

Bedrock Hydrogeology

Permeabilities of bedrock aquifers in Bruce County vary greatly depending on the degree of fracturing and dissolution of the rock. Well yields of 0.8 to 3.8 L/s are common in limestone and dolostone aquifers of the Salina, Guelph, Amabel and Fossil Hill formations. The alternating dolostone and shale of the Salina Formation is moderately permeable, with well yields of 0.8 to 1.9 L/s. The Guelph Formation, a fine crystalline dolostone, has low to moderate permeability, with well yields of 0.8 to 1.9 L/s in the southern part of the county.

Local Cross-sections

Geologic cross-sections were generated using well information from the WWIS and are presented in Figures 6.15A to 6.15B. Each cross-section passes through at least one municipal well and is oriented either north-south or east-west, along the direction of the highest concentration of wells. Aquifer locations (screened intervals) and corresponding water levels are also shown on the cross-sections.

6.8.2 Municipal Well Systems

Tara Water System

The Tara Water Works, located in the former Village of Tara in the Municipality of Arran-Elderslie, is represented in the Tara model. This municipal system is comprised of two bedrock wells, Well #2 constructed in 1960 and Well #3 constructed in 1978, which service 401 residences, businesses and institutions in the Village of Tara, a population of 841 people⁴⁹. Figure 6.14A shows the location of the Tara well #2 and the Tara well #3 and their proximity to one another, as well as their proximity to local rivers and roads, and to the township and model boundaries.

⁴⁸ Ground-Water Probability of the County of Bruce, Southern Ontario, Map 3101, Scale 1:250,000, Ontario Ministry of the Environment, 1986.

⁴⁹ Engineer's Report for the Municipality of Arran-Elderslie: Tara Water Works, Henderson, Paddon & Associates Limited, Owen Sound, Ontario, November 2000.

Chesley Water System

The Chesley Water Works, located in the former Town of Chesley in the Municipality of Arran-Elderslie, is represented in the Chesley model. This municipal system is comprised of two wells, a bedrock well in Victoria Park constructed in 1937 and an overburden well in Community Park constructed in 1948, which service the Town of Chesley having a population of approximately 1,781 people⁵⁰. Figure 6.14B shows the location of the Victoria Park well and the Community Park Well and their proximity to one another, as well as their proximity to local rivers and roads, and to the township and model boundaries.

Average Production Rates

Average pumping rates for each municipal well were estimated based on raw water flow rates averaged over the last five years and are presented in Appendix F. These pumping rates were used to represent the wells in the groundwater model.

6.8.3 Model Design (Tara, Chesley)

Model Grid

The model grid for the Tara model consists of 85 columns and 93 rows, with model extents of 10 km by 12 km horizontally and 150 m vertically. In the Chesley model, the grid consists of 168 columns and 133 rows, with model extents of 20 km by 15 km horizontally and 155 m vertically. Figure 6.14 presents the locations of the WHPA model domains with respect to the municipal boundary.

Model Boundaries

In the area of the Tara Model, groundwater flow in the bedrock is generally from east to west, as can be seen from Figure 2.21 of the bedrock equipotential contours. There are constant head boundaries upgradient of the flow system, having a maximum head of 246 m amsl, and downgradient of the flow system, having a minimum head of 219 m amsl. The final recharge value used to obtain a reasonable model calibration was 100 mm/yr, which falls within the range of values typical for this region.

In the area of the Chesley Model, groundwater flow in the bedrock is generally from east to west, as can be seen from Figure 2.21 of the bedrock equipotential contours. There are constant head boundaries upgradient of the flow system, having a maximum head of 293 m amsl, and downgradient of the flow system, having a minimum head of 230 m amsl. The final recharge value used to obtain a reasonable model calibration was 100 mm/yr, which falls within the range of values typical for this region.

Hydrogeologic Properties

Final calibrated hydraulic conductivity values are presented in Table 6.9 for each geologic unit. These hydraulic conductivity values are consistent with those recorded in the literature for these materials (refer to Section 6.1.4).

6.8.4 Model Results

Model Calibration

In the Tara model, the water levels of 125 observation wells within the model domain were used for model calibration. In the Chesley model, the heads of 137 observation wells within the

⁵⁰ Engineer's Report for the Municipality of Arran-Elderslie: Chesley Water Works, Henderson, Paddon & Associates Limited, Owen Sound, Ontario, November 2000.

model domain were used for model calibration. The WHPA models were calibrated such that the observed heads matched those simulated by the MODFLOW model to an acceptable degree. The resulting calibration graphs for the Tara and Chesley models are presented in Appendix E, having NRMS values of 9.6 % and 5.9 %, respectively. These NRMS values are less than or equal to 10%, therefore indicating that these MODFLOW models generally represent the groundwater flow conditions in the vicinity of the Tara and Chesley municipal wells.

TABLE 6.9: CALIBRATED VALUES FOR HYDROGEOLOGIC PROPERTIES (ARRAN-ELDERSLIE)

Geological Unit	Hydraulic Conductivity (m/s)
Overburden Zones:	
Clay or Peat	3e-7 to 5e-7
Sand and Gravel	6e-5 to 1e-4
Silt Till	1e-6 to 5e-6
Kame Materials	5e-6
Exposed Bedrock	1e-5
Bedrock Contact Zone	5e-4 to 8e-4
Competent Bedrock Zones	3e-5 to 7e-5

WHPA Results

Figure 6.14 shows the steady-state capture zone for each municipal well. The municipal well production information and the pumping rates used for the calibration and the capture zone delineation are presented in Appendix F. The pumping rates used for model calibration correspond to the average production rate, over the last five years, for each well, plus the 20-year projected rate. The 50-day, 2-year, 10-year, 25-year, and steady state capture zones, developed for each municipal well, are presented and discussed in Chapter 7. Additional analysis using the WHPAs, potential contaminant sources, and intrinsic susceptibility results are also presented in Chapter 7.

6.9 Town of South Bruce Peninsula

The Town of South Bruce Peninsula is located in the County of Bruce. Figure 6.16 shows the WHPA model domain and 14 municipal wells corresponding to the Sauble Beach WHPA model.

6.9.1 Local Aquifer Characterization

Bedrock Geology

The bedrock geology on a regional-scale is described in Section 2.7.2 (Regional Groundwater and Aquifer Characterization). As observed from the map of the Bedrock Geology of Ontario⁵¹ (1991), the surficial bedrock formations encountered within the Town of South Bruce Peninsula are the Salina Formation (dolostone and shale), the Guelph Formation (dolostone) and the Amabel Formation (dolostone). In the area of the Sauble model, the uppermost formation is mainly the Guelph Formation. Based on the WWIS and the oil and gas well database of the Ontario Petroleum Institute⁵², the municipal wells in the Sauble model penetrate the Guelph Formation, the Amabel Formation and the Fossil Hill Formation (dolostone), listed in order as encountered with depth. These bedrock units were represented as a single continuous unit in each WHPA model.

Quaternary Geology

The Quaternary, or overburden, geology in the Town of South Bruce Peninsula consists of a drumlinized dolostone plain in the north, a drumlinized till plain in the south and a sand plain along the Lake Huron shoreline⁵³. These three physiographic features correspond to the three main physiographic regions of the town: the Bruce Peninsula, the Arran Drumlin Field and the Huron Fringe, respectively.

The Bruce Peninsula region, in the north and east part of the town, consists of a dolostone plain with thin overburden and a few drumlins. According to the Quaternary geology defined by the MNR⁵⁴, the dolostone plain consists of dolostone of the Guelph, Amabel and Fossil Hill Formations. The thin overburden and drumlins on the plain consist of Bruce Till, a stony sandy silt till. Due to its irregular surface, the dolostone plain has many swamps and small lakes, consisting of bog deposits such as muck, marl and some peat, according to the Quaternary geology. In addition, a sand plain, related to the Huron Fringe region to the west, overlies the dolostone plain south of Colpoys Bay.

The Arran Drumlin Field region, in the south part of the town, consists of a drumlinized till plain. According to the Quaternary geology, the till plain and drumlins consist of the Elma-Catfish Creek Till, a stony, sandy silt till. In addition, along the border between the Arran Drumlin Field and the Huron Fringe region, occur various beaches associated with the glacial Lake Algonquin.

The Huron Fringe, located along the Lake Huron shoreline, consists of a sand plain with boulders, gravel bars and sand dunes, and is bordered on the east by beaches and shorecliffs of the glacial Lake Algonquin. According to the Quaternary geology, the sand plain consists of

⁵¹ Bedrock Geology of Ontario, Southern Sheet, Map 2544, Scale 1:1,000,000, Ministry of Northern Development and Mines, 1991.

⁵² Oil, Gas and Salt Resources Library, digital well database, Ontario Petroleum Institute, Ministry of Natural Resources, 2002.

⁵³ Chapman, L.J., and Putnam, D.F., 1984, Physiography of Southern Ontario, Ontario Geological Survey, Map P.2715, Scale 1:600,000.

⁵⁴ Ministry of Natural Resources, NRVIS data, Quaternary geology, Maps 2956 and 2957.

glaciolacustrine shallow water deposits of massive to bedded sand. The beaches and shorecliffs of Lake Algonquin consist of glaciolacustrine shoreline deposits of sand and gravel in beaches, bars and spits. Along the present Lake Huron shoreline, there are glaciolacustrine shoreline deposits of sand and gravel in beaches, bars and spits, related to the recent glacial Lake Nipissing or present Lake Huron. In addition, on the border between the Huron Fringe and the Bruce Peninsula regions, occurs a swampy area of bog deposits, between Boat Lake and the Saugeen River.

The Sauble Beach model area is located mainly in the Huron Fringe region, except for part of the Arran Drumlin Field in the south and part of the dolostone plain of Bruce Peninsula in the northeast. The MNR Quaternary geology was used to estimate the hydraulic conductivity zones for the WHPA modeling.

Overburden Hydrogeology

The majority of wells in Bruce County⁵⁵ obtained groundwater from bedrock aquifers. However, there are some overburden aquifers in the sands and gravels of kames, spillways, sand plains and beach ridges, with well yields ranging from 0.2 to 3.8 L/s. In the Bruce Peninsula, there are no significant overburden aquifers because the overburden is generally thin (less than ten metres thick) in this region. In the Arran Drumlin Field, overburden aquifers are found in the Tara Moraines. In the Huron Slope region, overburden aquifers occur in the sand plains and beach ridges east of Port Elgin and west of Hepworth.

Bedrock Hydrogeology

Permeabilities of bedrock aquifers in Bruce County vary greatly depending on the degree of fracturing and dissolution of the rock. Well yields of 0.8 to 3.8 L/s are common in limestone and dolostone aquifers of the Guelph and Amabel formations.

Local Cross-sections

Geologic cross-sections were generated using well information from the WWIS and are presented in Figures 6.17A to 6.17F. Each cross-section passes through at least one municipal well and is oriented either north-south or east-west, along the direction of the highest concentration of wells. Aquifer locations (screened intervals) and corresponding water levels are also shown on the cross-sections.

6.9.2 Municipal Well Systems

Sauble Beach and Oliphant Water Systems

The eleven municipal well systems in the Town of South Bruce Peninsula were combined into one model called the Sauble Beach model. These municipal well systems consist of the Fiddlehead Water Works #1, the Cammidge & Collins Water Works #2, the Robins Water Works #3, the Fedy Water Works #4, the Forbes Water Works #5, the Trask Water Works #6, the Huron Woods Water Works #7, the Foreman Water Works #8, the Thomson Water Works #9, the Winburk Water Works #10 and the Gremik Water Works #11.

The Fiddlehead Water Works #1 and the Cammidge & Collins Water Works #2 are located near the community of Oliphant, about 8 km north of Sauble Beach. The Fiddlehead Water Works is comprised of one bedrock well, constructed in 1971, which currently services 13

⁵⁵ Ground-Water Probability of the County of Bruce, Southern Ontario, Map 3101, Scale 1:250,000, Ontario Ministry of the Environment, 1986.

residential lots, approximately 33 people⁵⁶ (approved for 45 residential lots). The Cammidge & Collins Water Works is comprised of two bedrock wells. Well PW1-71, constructed in 1971, is currently not in use, but is available for future use if required. Well PW2-84, constructed in 1984, currently services 11 residential lots, approximately 28 people (approved for 15 residential lots).

The Thomson Water Works #9 and the Gremik Water Works #11 are located on the north end of Sauble Beach, on 7th Street and Gremik Crescent, respectively. The Thomson Water Works is comprised of one bedrock well, constructed in 1976, which currently services 22 residential lots, approximately 55 people (approved for 30 residential lots). The Gremik Water Works is comprised of one bedrock well, constructed in 1978, which currently services 45 residential lots, approximately 113 people (approved for 59 residential lots).

The Robins Water Works #3, the Fedy Water Works #4 and the Winburk Water Works #10 are located northeast of the centre of Sauble Beach, on Dorena Crescent, Fedy Drive and Bunnyview Drive, respectively. The Robins Water Works is comprised of one bedrock well, constructed in 1970, which currently services 31 residential lots, approximately 78 people (approved for 40 residential lots). The Fedy Water Works is comprised of one bedrock well, constructed in 1971, which originally serviced 11 residential lots in the Fedy subdivision (approved for 21 lots). Since 1996, the Fedy well has not been in use, and the Fedy customers have since been serviced by the Winburk Water Works. The Winburk Water Works is comprised of one bedrock well, constructed in 1978, which currently services 56 residential lots, including 10 of the Fedy lots, for a total of approximately 140 people (approved for 93 residential lots).

The Forbes Water Works #5 and the Trask Water Works #6 are located in Sauble Beach, on Manley Crescent and Davidson Drive, respectively. The Forbes Water Works is comprised of one bedrock well, constructed in 1969, which currently services 25 residential lots, approximately 63 people (approved for 34 residential lots). The Trask Water Works is comprised of one bedrock well, constructed in 1978, which currently services 29 residential lots, approximately 73 people (approved for 31 residential lots).

The Huron Woods Water Works #7 is located on the south end of Sauble Beach on Birch Street. The Huron Woods Water Works is comprised of three bedrock wells and one overburden well. The bedrock wells, Wells #1, #2 and #3, were constructed in 1969, 1973 and 1974, respectively. The overburden well, Well #6, was constructed in 1990. Wells #1 and #2 are standby wells, however in February 2001 Well #1 could not be operated and the pump requires rehabilitation as soon as possible. Two additional wells #4 and #5, constructed in 1976 and 1980, respectively, were never developed for use. The Huron Woods Water Works services 76 residential lots, approximately 190 people (approved for 141 residential lots; 122 in the Huron Woods subdivision and 19 in the Walker Estates subdivision).

The Foreman Water Works #8 is located southeast of Sauble Beach, on Foreman Drive, on the northeast side of Chesley Lake. The Foreman Water Works is comprised of one bedrock well, constructed in 1972, which currently services 17 residential lots, approximately 43 people (approved for 20 residential lots).

⁵⁶ Based on an estimated 2.5 persons per residence (Engineer's Report, Town of South Bruce Peninsula, County of Bruce, population estimates for design flows, Henderson, Paddon & Associates Limited, 2001).

Figure 6.16 shows the location of the municipal wells in the Town of South Bruce Peninsula and their proximity to one another, as well as their proximity to local rivers and roads, and to the township and model boundaries.

Average Production Rates

Average pumping rates for each municipal well were estimated based on raw water flow rates averaged over the last five years and are presented in Appendix F. These pumping rates were used to represent the wells in the groundwater model.

6.9.3 Model Design (Sauble Beach)

Model Grid

The model grid for the Sauble Beach model consists of 242 columns and 315 rows, with model extents of 15 km by 22.5 km horizontally and 160 m vertically. Figure 6.16 presents the locations of the WHPA model domains with respect to the municipal boundary.

Model Boundaries

In the area of the Sauble Beach Model, groundwater flow in the bedrock is generally from east to west, as can be seen from Figure 2.21 of the bedrock equipotential contours. There are constant head boundaries upgradient of the flow system, having a maximum head of 233 m amsl, and downgradient of the flow system, having a minimum head of 177 m amsl, the level of Lake Huron. The final recharge value used to obtain a reasonable model calibration was 75 mm/yr, which falls within the range of values typical for this region.

Hydrogeologic Properties

Final calibrated hydraulic conductivity values are presented in Table 6.10 for each geologic unit. These hydraulic conductivity values are consistent with those recorded in the literature for these materials (refer to Section 6.1.4).

TABLE 6.10: CALIBRATED VALUES FOR HYDROGEOLOGIC PROPERTIES (SOUTH BRUCE PENINSULA)

Geological Unit	Hydraulic Conductivity (m/s)
Overburden Zones:	
Clay or Peat	1e-7
Sand and Gravel	1e-3
Silt Till	4e-6
Kame Materials	--
Exposed Bedrock	3e-5
Bedrock Contact Zone	3e-5
Competent Bedrock Zones	3e-5

6.9.4 Model Results

Model Calibration

In the Sauble Beach model, the water levels of 527 observation wells within the model domain were used for model calibration. The resulting calibration graph for the Sauble Beach model is presented in Figure 6.16, having an NRMS value of 6.5 %. This NRMS value is less than or equal to 10%, therefore indicating that this MODFLOW model generally represents the groundwater flow conditions in the vicinity of the municipal wells in the Town of South Bruce Peninsula.

WHPA Results

Figure 6.16 shows the steady-state capture zone for each municipal well. The municipal well production information and the pumping rates used for the calibration and the capture zone delineation are presented in Appendix F. The pumping rates used for model calibration correspond to the average production rate, over the last five years, for each well, plus the 20-year projected rate. The 50-day, 2-year, 10-year, 25-year, and steady state capture zones, developed for each municipal well, are presented and discussed in Chapter 7. Additional analysis using the WHPAs, potential contaminant sources, and intrinsic susceptibility results are also presented in Chapter 7.

6.10 Municipality of Brockton

The Municipality of Brockton is located in the County of Bruce. Figure 6.18 shows the WHPA model domains and one (1) municipal well corresponding to the Chepstow WHPA model.

6.10.1 Local Aquifer Characterization

Bedrock Geology

The bedrock geology on a regional-scale is described in Section 2.7.2 (Regional Groundwater and Aquifer Characterization). As observed from the map of the Bedrock Geology of Ontario⁵⁷ (1991), the surficial bedrock formations encountered within the Municipality of Brockton are the Detroit River Group (mainly limestone and dolostone), the Bois Blanc Formation (mainly limestone) and the Bass Islands Formation (mainly dolostone) and the Salina Formation (dolostone and shale). In the area of the Chepstow model, the uppermost formations are the Detroit River Group, the Bois Blanc Formation, and the Bass Islands Formation, from west to east. Based on the WWIS and the oil and gas well database of the Ontario Petroleum Institute⁵⁸, the bedrock formations penetrated by the municipal wells in the Chepstow model are the Detroit River Group, the Bois Blanc Formation and the Bass Islands Formation, listed in order as encountered with depth. These bedrock units were represented as a single continuous unit in each WHPA model.

Quaternary Geology

The Quaternary, or overburden, geology in the Municipality of Brockton consists a clay plain in the north, a till moraine through the centre, and a drumlinized till plain in the south of the municipality⁵⁹. These three physiographic features correspond to the three main physiographic regions in the township: the Saugeen Clay Plain, the Horseshoe Moraines, and the Teeswater Drumlin Field, respectively.

The Saugeen Clay Plain region is located in the drainage basin of the Saugeen River and consists of deep stratified clay deposited by glacial Lake Warren. According to the Quaternary geology defined by the MNR⁶⁰, this region consists of glaciolacustrine clay and silt, and the sand plain, on the south side of the clay plain, consists of glaciofluvial outwash sand and gravel.

The Horseshoe Moraines region consists of a till moraine, a kame moraine, a sand plain and a till plain. The till moraine, called the Singhampton Moraine, crosses through the centre of the municipality and, according to the Quaternary geology, consists of Dunkeld Till, a silt till with a low stone content. The kame moraine, located west of Chepstow, consists of ice-contact stratified drift, including sand, gravel, silt, and till. According to the Quaternary geology, the sand plain, in the area of the Greenock Swamp, consists of lacustrine sand and silt, as well as disconnected areas of peat and muck. The till plain in the west consists of St. Joseph Till, a clayey silt to silt till with a very low stone content, and in the southwest, consists of Rannoch Till, a silt to sandy silt till.

⁵⁷ Bedrock Geology of Ontario, Southern Sheet, Map 2544, Scale 1:1,000,000, Ministry of Northern Development and Mines, 1991.

⁵⁸ Oil, Gas and Salt Resources Library, digital well database, Ontario Petroleum Institute, Ministry of Natural Resources, 2002.

⁵⁹ Chapman, L.J., and Putnam, D.F., 1984, Physiography of Southern Ontario, Ontario Geological Survey, Map P.2715, Scale 1:600,000.

⁶⁰ Ministry of Natural Resources, NRVIS data, Quaternary geology, Maps 2956 and 2957.

The Teeswater Drumlin Field region, in the southern part of the municipality, consists of a drumlinized till plain and spillways of sand and gravel terraces. According to the Quaternary geology, the till plain and drumlins consist of mainly Elma Till, a stoney, sandy silt to silt till. The spillways generally follow the courses of the Teeswater and Saugeen Rivers and their tributaries, and consist of glaciofluvial outwash gravel and gravelly sand.

The Chepstow model area is located mainly in the Horseshoe Moraines region and the Teeswater Drumlin Field region. The MNR Quaternary geology was used to estimate the overburden hydraulic conductivity zones for the WHPA modeling.

Overburden Hydrogeology

The majority of wells in Bruce County⁶¹ obtained groundwater from bedrock aquifers. However, there are some overburden aquifers in the sands and gravels of kames, spillways, sand plains and beach ridges, with well yields ranging from 0.2 to 3.8 L/s. In the Saugeen Clay Plain, there is a major overburden aquifer in the sand plain between Eden Grove and Ellengowan. In the Horseshoe Moraines, sand and gravel aquifers mainly occur in spillways in the Hanover-Walkerton area.

Bedrock Hydrogeology

Permeabilities of bedrock aquifers in Bruce County vary greatly depending on the degree of fracturing and dissolution of the rock. Well yields of 0.8 to 3.8 L/s are common in limestone and dolostone aquifers of the Salina, Guelph, Amabel and Fossil Hill formations. The alternating dolostone and shale of the Salina Formation is moderately permeable, with well yields of 0.8 to 1.9 L/s. The Guelph Formation, a fine crystalline dolostone, has low to moderate permeability, with well yields of 0.8 to 1.9 L/s in the southern part of the county.

Local Cross-sections

Geologic cross-sections were generated using well information from the WWIS and are presented in Figure 6.19A. Each cross-section passes through at least one municipal well and is oriented either north-south or east-west, along the direction of the highest concentration of wells. Aquifer locations (screened intervals) and corresponding water levels are also shown on the cross-sections.

6.10.2 Municipal Well System

Chepstow Water Systems

The Chepstow Water Works is located in the former Hamlet of Chepstow in the Municipality of Brockton and is comprised of one bedrock well. The Chepstow well was constructed in 1978 and services 14 residential lots in the Powers Subdivision (approximately 35 people⁶²).

The Chepstow Water Works was combined as a single model, called the Chepstow model. Figure 6.18 shows the locations of the Chepstow well and its proximity to local rivers and roads, and to the township and model boundaries.

⁶¹ Ground-Water Probability of the County of Bruce, Southern Ontario, Map 3101, Scale 1:250,000, Ontario Ministry of the Environment, 1986.

⁶² Based on an estimated 2.5 persons per residence (Engineer's Report, Town of South Bruce Peninsula, County of Bruce, design population estimates, 2001).

Average Production Rates

Average pumping rates for each municipal well were estimated based on raw water flow rates averaged over the last five years and are presented in Appendix F. These pumping rates were used to represent the wells in the groundwater model.

6.10.3 Model Design (Chepstow)

Model Grid

The model grid for the Chepstow model consists of 147 columns and 94 rows, with model extents of 24.5 km by 17 km horizontally and 215 m vertically. Figure 6.18 presents the locations of the WHPA model domains with respect to the municipal boundary.

Model Boundaries

In the area of the Chepstow Model, groundwater flow in the bedrock is generally from southeast to north-northwest, as can be seen from Figure 2.21 of the bedrock equipotential contours. There are constant head boundaries upgradient of the flow system, having a maximum head of 320 m amsl, and downgradient of the flow system, having a minimum head of 230 m amsl. The final recharge value used to obtain a reasonable model calibration was 100 mm/yr, which falls within the range of values typical for this region.

Hydrogeologic Properties

Final calibrated hydraulic conductivity values are presented in Table 6.11 for each geologic unit. These hydraulic conductivity values are consistent with those recorded in the literature for these materials (refer to Section 6.1.4).

TABLE 6.11: CALIBRATED VALUES FOR HYDROGEOLOGIC PROPERTIES (BROCKTON)

Geological Unit	Hydraulic Conductivity (m/s)
Overburden Zones:	
Clay or Peat	1e-7
Sand and Gravel	2e-4
Silt Till	6e-6
Kame Materials	1e-6
Exposed Bedrock	--
Bedrock Contact Zone	2e-4
Competent Bedrock Zones	1e-6 to 7e-6

6.10.4 Model Results

Model Calibration

In the Chepstow model, the water levels of 266 observation wells within the model domain were used for model calibration. The WHPA model was calibrated such that the observed heads matched those simulated by the MODFLOW model to an acceptable degree. The resulting calibration graph for the Chepstow model is presented in Appendix E, having an NRMS value of 6.4 %. This NRMS value is less than or equal to 10%, therefore indicating that this MODFLOW model generally represents the groundwater flow conditions in the vicinity of the Chepstow municipal well.

WHPA Results

Figure 6.18 shows the steady-state capture zone for each municipal well. The municipal well production information and the pumping rates used for the calibration and the capture zone delineation are presented in Appendix F. The pumping rates used for model calibration correspond to the average production rate, over the last five years, for each well, plus the 20-year projected rate. The 50-day, 2-year, 10-year, 25-year, and steady state capture zones, developed for the municipal well, are presented and discussed in Chapter 7. Additional analysis using the WHPAs, potential contaminant sources, and intrinsic susceptibility results are also presented in Chapter 7.

6.11 Township of Huron-Kinloss

The Township of Huron-Kinloss is located in the County of Bruce. Figure 6.20A shows the model domains and 10 municipal wells corresponding to the Ripley and Huron West WHPA models. Figure 6.20B shows the model domain and three (3) municipal wells corresponding to the Lucknow WHPA model.

6.11.1 Local Aquifer Characterization

Bedrock Geology

The bedrock geology on a regional-scale is described in Section 2.7.2 (Regional Groundwater and Aquifer Characterization). The bedrock surface encountered within the Township of Huron-Kinloss is the Detroit River Group, consisting of mainly limestone and dolostone, as observed from the map of the Bedrock Geology of Ontario⁶³ (1991). Based on the WWIS and the oil and gas well database of the Ontario Petroleum Institute⁶⁴, the other bedrock formations penetrated by the municipal wells in the Lucknow, Ripley and Huron West model areas, are the Bois Blanc Formation (mainly limestone) and the Bass Islands Formation (mainly dolostone), in order as encountered with depth. These bedrock units were represented as a single continuous unit in each WHPA model.

Quaternary Geology

The Quaternary, or overburden, geology in the Township of Huron-Kinloss consists mainly of till moraines and till plains⁶⁵. The main physiographic regions in the township are the Horseshoe Moraines, the Huron Slope, and the Huron Fringe.

The Horseshoe Moraines region occurs in the southeastern half of the township and consists of till and kame moraines, spillways of sand and gravel terraces, and till plains with a few drumlins. According to the Quaternary geology defined by the MNR⁶⁶, on the west side of the Horseshoe Moraines region, the till moraines consists of St. Joseph Till, a clayey silt to silt till with a very low stone content, and some Rannoch Till, a silt to sandy silt till, to the south, and are called the Wyoming Moraines. A spillway, which consists of glaciofluvial outwash gravel and gravelly sand, as well as modern alluvium such as silt, sand, gravel, crosses through the till moraines along the path of the Lucknow River. East of the till moraines is a kame moraine called the Wawanosh Moraine, which consists mainly of ice-contact stratified drift, including sand, gravel, silt, and till. To the east, this moraine merges with a drumlinized till plain, which consists of mainly Elma Till, a stoney, sandy silt to silt till.

The Huron Slope region occurs in the northwestern half of the township and consists of a clayey till plain modified by a narrow sand plain and glacial Lake Warren beaches. In this region, the till plain slopes from the Wyoming Moraine westward down to the shorecliff of glacial Lake Algonquin. According to the Quaternary geology defined by the MNR, this bevelled till plain consists of the clayey silt St. Joseph Till, and is bordered along its eastern side by twin beaches of the glacial Lake Warren. West of the beaches is a narrow strip of sand deposited over the till plain, which consists of near shore sand and gravel of the glacial Lake Warren, and varies in width from 500m to 1,200m (estimated from physiographic map).

⁶³ Bedrock Geology of Ontario, Southern Sheet, Map 2544, Scale 1:1,000,000, Ministry of Northern Development and Mines, 1991.

⁶⁴ Oil, Gas and Salt Resources Library, digital well database, Ontario Petroleum Institute, Ministry of Natural Resources, 2002.

⁶⁵ Chapman, L.J., and Putnam, D.F., 1984, Physiography of Southern Ontario, Ontario Geological Survey, Map P.2715, Scale 1:600,000.

⁶⁶ Ministry of Natural Resources, NRVIS data, Quaternary geology, Maps 2956 and 2957.

On the western border of the municipality, the Huron Fringe region occurs between the glacial Lake Algonquin Shorecliff and the current Lake Huron shoreline. The Huron Fringe region consists of terraces with boulders, gravel bars and sand dunes, as well as beaches and shorecliffs. According to the MNR Quaternary geology, the physiographic features in this region consist of beach and near shore sand and gravel of recent glacial Lake Nipissing.

The Lucknow model area is located in Horseshoe Moraines region, the Ripley model area is located on the border between the Horseshoe Moraines region and the Huron Slope region, and the Huron West model area is along the shore of Lake Huron in the Huron Slope and Huron Fringe regions. The MNR Quaternary geology was used to estimate the overburden hydraulic conductivity zones for the WHPA modeling.

Overburden Hydrogeology

The majority of wells in Bruce County⁶⁷ obtained groundwater from bedrock aquifers. However, there are some overburden aquifers in the sands and gravels of kames, spillways, sand plains and beach ridges, with well yields ranging from 0.2 to 3.8 L/s. In the Horseshoe Moraines, sand and gravel aquifers mainly occur in spillways. In the Huron Slope and Huron Fringe regions, overburden aquifers occur in the sand plains and beach ridges.

Bedrock Hydrogeology

Permeabilities of bedrock aquifers in Bruce County vary greatly depending on the degree of fracturing and dissolution of the rock. The limestone and dolostone of the Bois Blanc and Bass Island formations are moderately permeable, with well yields of 0.8 to 1.9 L/s.

Local Cross-sections

Geologic cross-sections were generated using well information from the WWIS and are presented in Figures 6.21A to 6.21F. Each cross-section passes through at least one municipal well and is oriented either north-south or east-west, along the direction of the highest concentration of wells. Aquifer locations (screened intervals) and corresponding water levels are also shown on the cross-sections.

6.11.2 Municipal Well Systems

Lucknow and Whitechurch Water Systems

Due to their proximity, the Lucknow Water Works and the Whitechurch Water Works were combined into one model, called the Lucknow model. The Lucknow Water Works is located in the former Village of Lucknow in the Township of Huron-Kinloss and is comprised of two bedrock wells. Well #4 constructed in 1959 and Well #5 in 1967, both supply water to a population of approximately 1,136 people⁶⁸.

The Whitechurch Water Works is located in the former Hamlet of Whitechurch, also in the Township of Huron-Kinloss, and consists of one bedrock well, constructed in 1961. The Whitechurch well supplies water to a population of approximately 335 people.

Figure 6.20B shows the location of the two Lucknow wells and the Whitechurch well and their proximity to one another, as well as their proximity to local rivers and roads, and to the township and model boundaries.

⁶⁷ Ground-Water Probability of the County of Bruce, Southern Ontario, Map 3101, Scale 1:250,000, Ontario Ministry of the Environment, 1986.

⁶⁸ Population data from 2001 Community Profiles, Statistics Canada

Ripley Water System

The Ripley municipal well system, located in the Village of Ripley in the Township of Huron-Kinloss, is represented in the Ripley model. The Ripley municipal well system is comprised of two bedrock wells. Well #1 constructed in 1947 and Well #2 in 1994, both supply water to a population of approximately 680 people⁶⁹. Figure 6.20A shows the location of the two Ripley wells and their proximity to one another, as well as their proximity to local rivers and roads, as well as to township and model boundaries.

Lakeshore Area Water System

The municipal wells in the western part of the Township of Huron-Kinloss were combined into one model called the Huron West model. These municipal wells, located along the Lake Huron shoreline, are called the Lakeshore Area Water Works. The Lakeshore Area Water Works consists of four well sites, the Point Clark wells, the Blairs Grove wells, the Murdock Glen wells and the Huronville South wells. Due to their vicinity, these well systems were combined into one model called the Huron West model. The entire Lakeshore Area Water Works services 1409 residential lots, approximately 3,523 people⁷⁰.

The Point Clark Development well site is comprised of two bedrock wells, Well #1 constructed in 1979 and Well #2 in 1994. The Blairs Grove well site is also comprised of two bedrock wells, Well #2 constructed in 1982 and Well #3 in 1994. The Blairs Grove well #2 is currently not in use (not equipped with a pump). The Murdock Glen well site is comprised of two bedrock wells, Well #1 constructed in 1983 and Well #2 in 1992. The Huronville South well site is also comprised of two bedrock wells, Well #1 constructed in 1980 and Well #2 in 1994.

Figure 6.20A shows the location of the eight Lakeshore Area wells and their proximity to one another, as well as their proximity to local rivers and roads, and to township and model boundaries.

Average Production Rates

Average pumping rates for each municipal well were estimated based on raw water flow rates averaged over the last five years and are presented in Appendix F. These pumping rates were used to represent the wells in the groundwater model.

6.11.3 Model Design (Huron West, Ripley, Lucknow)

Model Grid

The model grid for the Huron West model consists of 179 columns and 217 rows, with model extents of 14 km by 19 km horizontally and 240 m vertically. In the Ripley model, the grid consists of 124 columns and 111 rows, with model extents of 13 km by 12 km horizontally and 200 m vertically. In the Lucknow model, the grid consists of 246 columns and 174 rows, with model extents of 23.5 km by 12.5 km horizontally and 215 m vertically. Figure 6.20 presents the locations of the WHPA model domains with respect to the municipal boundary.

Model Boundaries

In the area of the Huron West Model, groundwater flow in the bedrock is generally from east to west, as can be seen from Figure 2.21 of the bedrock equipotential contours. There are constant head boundaries upgradient of the flow system, having a maximum head of 225 m amsl, and downgradient of the flow system, having a minimum head of 177 m amsl, the level of

⁶⁹ First Engineer's Report: Village of Ripley, Township of Huron-Kinloss, 2001, B.M. Ross and Associates Ltd.

⁷⁰ Based on an estimated 2.5 persons per residence (Engineer's Report, Town of South Bruce Peninsula, County of Bruce, design population estimates, 2001).

Lake Huron. The final recharge value used to obtain a reasonable model calibration was 75 mm/yr, which falls within the range of values typical for this region.

In the area of the Ripley Model, groundwater flow in the bedrock is generally from east to west, as can be seen from Figure 2.21 of the bedrock equipotential contours. There are constant head boundaries upgradient of the flow system, having a maximum head of 279 m amsl, and downgradient of the flow system, having a minimum head of 210 m amsl. The final recharge value used to obtain a reasonable model calibration was 75 mm/yr, which falls within the range of values typical for this region.

In the area of the Lucknow Model, groundwater flow in the bedrock is generally from southeast to northwest, as can be seen from Figure 2.21 of the bedrock equipotential contours. There are constant head boundaries upgradient of the flow system, having a maximum head of 311 m amsl, and downgradient of the flow system, having a minimum head of 240 m amsl. The final recharge value used to obtain a reasonable model calibration was 90 mm/yr, which falls within the range of values typical for this region.

Hydrogeologic Properties

Final calibrated hydraulic conductivity values are presented in Table 6.12 for each geologic unit. These hydraulic conductivity values are consistent with those recorded in the literature for these materials (refer to Section 6.1.4).

TABLE 6.12: CALIBRATED VALUES FOR HYDROGEOLOGIC PROPERTIES (HURON-KINLOSS)

Geological Unit	Hydraulic Conductivity (m/s)
Overburden Zones:	
Clay or Peat	1e-7 to 6e-7
Sand and Gravel	1e-4 to 2e-3
Silt Till	1e-7 to 6e-6
Kame Materials	1e-6 to 5e-6
Exposed Bedrock	--
Bedrock Contact Zone	1e-4 to 4e-4
Competent Bedrock Zones	4e-6 to 3e-4

6.11.4 Model Results

Model Calibration

In the Huron West model, the water levels of 168 observation wells within the model domain were used for model calibration. In the Ripley model, the heads of 71 observation wells within the model domain were used for model calibration. In the Lucknow model, the heads of 112 observation wells within the model domain were used for model calibration. The resulting calibration graphs for the Huron West, Ripley and Lucknow models are presented in Appendix E, having NRMS values of 7.3 %, 5.7 % and 5.8 %, respectively. These NRMS values are less than or equal to 10%, therefore indicating that these MODFLOW models generally represent the groundwater flow conditions in the vicinity of the municipal wells in Huron-Kinloss Township.

WHPA Results

Figure 6.20 shows the steady-state capture zone for each municipal well. The municipal well production information and the pumping rates used for the calibration and the capture zone delineation are presented in Appendix F. The pumping rates used for model calibration correspond to the average production rate, over the last five years, for each well, plus the 20-year projected rate. The 50-day, 2-year, 10-year, 25-year, and steady state capture zones, developed for each municipal well, are presented and discussed in Chapter 7. Additional analysis using the WHPAs, potential contaminant sources, and intrinsic susceptibility results are also presented in Chapter 7.

6.12 Municipality of South Bruce

The Municipality of South Bruce is located in the County of Bruce. Figure 6.22 shows the model domains and three (3) municipal wells corresponding to the Mildmay and Teeswater WHPA models.

6.12.1 Local Aquifer Characterization

Bedrock Geology

The bedrock geology on a regional-scale is described in Section 2.7.2 (Regional Groundwater and Aquifer Characterization). As observed from the map of the Bedrock Geology of Ontario⁷¹ (1991), the surficial bedrock formations encountered within the Municipality of South Bruce are the Detroit River Group (mainly limestone and dolostone), the Bois Blanc Formation (mainly limestone) and the Bass Islands Formation (mainly dolostone) and the Salina Formation (dolostone and shale). In the area of the Teeswater model, the Detroit River Group is the uppermost bedrock formation, whereas in the Mildmay model area, the uppermost formations are the Bois Blanc, Bass Islands and Salina Formations from west to east. Based on the WWIS and the petroleum well database of the Ontario Petroleum Institute⁷², the bedrock formations penetrated by the Teeswater and Mildmay municipal wells are the Detroit River Group, the Bois Blanc Formation and the Bass Islands Formation, in order as encountered with depth. These bedrock units were represented as a single continuous unit in each WHPA model.

Quaternary Geology

The Quaternary, or overburden, geology in the Municipality of South Bruce mainly consists of a drumlinized till plain traversed by glacial meltwater spillways⁷³. The main physiographic regions in the municipality are the Teeswater Drumlin Field and the Horseshoe Moraines.

The Teeswater Drumlin Field region occurs over most of the municipality and consists of a drumlinized till plain, spillways of sand and gravel terraces, and kame moraines. According to the Quaternary geology defined by the MNR⁷⁴, the till plain and drumlins consist of mainly Elma Till, a stoney, sandy silt to silt till. The spillways generally follow the courses of the Teeswater River and Formosa Creek and their tributaries, and consist of glaciofluvial outwash gravel and gravelly sand. Kame moraines and associated outwash occur in south and east parts of the municipality, such as the group of sandhills to the south of Mildmay and Neustadt, called the Saugeen Kames. According to the Quaternary geology, these kame moraines mainly consist of ice-contact stratified drift, including sand, gravel, silt, and till.

The Horseshoe Moraines region occurs on the western part of the municipality and consists of spillways, a kame moraine and a till plain. According to the Quaternary geology, the spillways consist of terraces of glaciofluvial outwash gravel and gravelly sand, which follow the path of the Teeswater River and its tributaries. The kame moraine, called the Wawanosh Moraine, consists of ice-contact stratified drift of sand, gravel, silt, and till, which merges with the till plain to the north and south. The till plain consists of Rannoch Till, a silt to sandy silt till, and Elma Till, a stoney, sandy silt to silt till.

⁷¹ Bedrock Geology of Ontario, Southern Sheet, Map 2544, Scale 1:1,000,000, Ministry of Northern Development and Mines, 1991.

⁷² Oil, Gas and Salt Resources Library, digital well database, Ontario Petroleum Institute, Ministry of Natural Resources, 2002.

⁷³ Chapman, L.J., and Putnam, D.F., 1984, Physiography of Southern Ontario, Ontario Geological Survey, Map P.2715, Scale 1:600,000.

⁷⁴ Ministry of Natural Resources, NRVIS data, Quaternary geology, Maps 2956 and 2957.

Both the Teeswater and Mildmay model areas are located in the Teeswater Drumlin Field region. The MNR Quaternary geology was used to estimate the overburden hydraulic conductivity zones for the WHPA modeling.

Overburden Hydrogeology

The majority of wells in Bruce County⁷⁵ obtained groundwater from bedrock aquifers. However, there are some overburden aquifers in the sands and gravels of kames, spillways, sand plains and beach ridges, with well yields ranging from 0.2 to 3.8 L/s. In the Teeswater Drumlin Field, sand and gravel aquifers are found in the Saugeen kames and spillways along the southern boundary. In the Horseshoe Moraines, sand and gravel aquifers mainly occur in spillways in the Hanover-Walkerton area.

Bedrock Hydrogeology

Permeabilities of bedrock aquifers in Bruce County vary greatly depending on the degree of fracturing and dissolution of the rock. The limestone and dolostone of the Detroit River Group are moderately to highly permeable, having solution cavities, such as joints and caverns that are well developed in places, resulting in average well yields of 0.8 to 3.8 L/s. The limestone and dolostone of the Bois Blanc and Bass Island formations are moderately permeable, with well yields of 0.8 to 1.9 L/s.

Local Cross-sections

Geologic cross-sections were generated using well information from the WWIS and are presented in Figures 6.23A and 6.23B. Each cross-section passes through at least one municipal well and is oriented either north-south or east-west, along the direction of the highest concentration of wells. Aquifer locations (screened intervals) and corresponding water levels are also shown on the cross-sections.

6.12.2 Municipal Well Systems

Mildmay Water System

The Mildmay Water System, located in the former Village of Mildmay in the Municipality of South Bruce, is represented in the Mildmay model. The Mildmay Water System is comprised of two bedrock wells, Well #1 constructed in 1968 and Well #2 in 1989, which services the former Village of Mildmay and adjacent development, having a population of approximately 1,200 people⁷⁶. The Mildmay well #2 is a standby well. Figure 6.22 shows the location of the two Mildmay wells and their proximity to local rivers and roads, as well as its proximity to the township and model boundaries.

Teeswater Water System

The Teeswater Water System, located in the former Village of Teeswater in the Municipality of South Bruce, is represented in the Teeswater model. The Teeswater Water System is comprised of an artesian bedrock well, Well #3 constructed in 1996, and services the former Village of Teeswater and adjacent development, having a population of approximately 1,000 people⁷⁷. Figure 6.22 shows the location of the Teeswater well and its proximity to local rivers and roads, as well as its proximity to the township and model boundaries.

⁷⁵ Ground-Water Probability of the County of Bruce, Southern Ontario, Map 3101, Scale 1:250,000, Ontario Ministry of the Environment, 1986.

⁷⁶ Engineer's Report for the Municipality of South Bruce: Mildmay Water System, Maitland Engineering, Wingham, Ontario, May 2001.

⁷⁷ Engineer's Report for the Municipality of South Bruce: Teeswater Water System, Maitland Engineering, Wingham, Ontario, May 2001.

Average Production Rates

Average pumping rates for each municipal well were estimated based on raw water flow rates averaged over the last five years and are presented in Appendix F. These pumping rates were used to represent the wells in the groundwater model.

6.12.3 Model Design (Mildmay, Teeswater)

Model Grid

The grid for the Mildmay model consists of 87 columns and 87 rows, with model extents of 11 km by 13 km horizontally and 240 m vertically. In the Teeswater model, the grid consists of 88 columns and 105 rows, with model extents of 12 km by 15 km horizontally and 200 m vertically. Figure 6.22 presents the locations of the WHPA model domains with respect to the municipal boundary.

Model Boundaries

In the area of the Mildmay Model, groundwater flow in the bedrock is generally from south to north, as can be seen from Figure 2.21 of the bedrock equipotential contours. There are constant head boundaries upgradient of the flow system, having a maximum head of 360 m amsl, and downgradient of the flow system, having a minimum head of 290 m amsl. The final recharge value used to obtain a reasonable model calibration was 95 mm/yr, which falls within the range of values typical for this region.

In the area of the Teeswater Model, groundwater flow in the bedrock is generally from southeast to northwest, as can be seen from Figure 2.21 of the bedrock equipotential contours. There are constant head boundaries upgradient of the flow system, having a maximum head of 322 m amsl, and downgradient of the flow system, having a minimum head of 270 m amsl. The final recharge value used to obtain a reasonable model calibration was 100 mm/yr, which falls within the range of values typical for this region.

Hydrogeologic Properties

Final calibrated hydraulic conductivity values are presented in Table 6.13 for each geologic unit. These hydraulic conductivity values are consistent with those recorded in the literature for these materials (refer to Section 6.1.4).

TABLE 6.13: CALIBRATED VALUES FOR HYDROGEOLOGIC PROPERTIES (SOUTH BRUCE)

Geological Unit	Hydraulic Conductivity (m/s)
Overburden Zones:	
Clay or Peat	3e-7 to 5e-7
Sand and Gravel	6e-5 to 1e-4
Silt Till	1e-6 to 5e-6
Kame Materials	5e-6
Exposed Bedrock	1e-5
Bedrock Contact Zone	5e-4 to 8e-4
Competent Bedrock Zones	3e-5 to 7e-5

6.12.4 Model Results

Model Calibration

In the Mildmay model, the water levels of 75 observation wells within the model domain were used for model calibration. In the Teeswater model, the heads of 53 observation wells within the model domain were used for model calibration. The resulting calibration graphs for the Mildmay and Teeswater models are presented in Appendix E, having NRMS values of 6.2 % and 8.1 %, respectively. These NRMS values are less than or equal to 10%, therefore indicating that these MODFLOW models generally represent the groundwater flow conditions in the vicinity of the Mildmay and Teeswater municipal wells.

WHPA Results

Figure 6.22 shows the steady-state capture zone for each municipal well. The municipal well production information and the pumping rates used for the calibration and the capture zone delineation are presented in Appendix F. The pumping rates used for model calibration correspond to the average production rate, over the last five years, for each well, plus the 20-year projected rate. The 50-day, 2-year, 10-year, 25-year, and steady state capture zones, developed for each municipal well, are presented and discussed in Chapter 7. Additional analysis using the WHPAs, potential contaminant sources, and intrinsic susceptibility results are also presented in Chapter 7.

6.13 Municipality of Kincardine

The Municipality of Kincardine is located in the County of Bruce. Figure 6.24 shows the WHPA model domains and nine (9) municipal wells corresponding to the Kincardine South and Kincardine North WHPA models.

6.13.1 Local Aquifer Characterization

Bedrock Geology

The bedrock geology on a regional-scale is described in Section 2.7.2 (Regional Groundwater and Aquifer Characterization). The main surficial bedrock formation encountered within the Municipality of Kincardine is the Detroit River Group, consisting of mainly limestone and dolostone, as observed from the map of the Bedrock Geology of Ontario⁷⁸ (1991). In the northeastern part of the municipality, the Bois Blanc Formation (mainly limestone) and the Bass Islands Formation (mainly dolostone) are encountered at the bedrock surface. Based on the WWIS and the oil and gas well database of the Ontario Petroleum Institute⁷⁹, the bedrock formations penetrated by the municipal wells in the Kincardine South and Kincardine North model areas are the Detroit River Group, the Bois Blanc Formation and the Bass Islands Formation, in order as encountered with depth. These bedrock units were represented as a single continuous unit in each WHPA model.

Quaternary Geology

The Quaternary, or overburden, geology in the Municipality of Kincardine consists mainly of a till plain⁸⁰. The main physiographic regions in the township are the Horseshoe Moraines, the Huron Slope, and the Huron Fringe.

The Horseshoe Moraines region occurs in the southeastern part of the municipality, where the Wyoming till moraine passes through a till plain. According to the Quaternary geology defined by the MNR⁸¹, the till moraine and till plain both consist of St. Joseph Till, a clayey silt to silt till with a very low stone content.

The Huron Slope region, which occurs over most of the municipality, consists of a clayey till plain, bordered in the southeast by twin beaches of the glacial Lake Warren and in the west by the shorecliff of glacial Lake Algonquin. In the southern part of the municipality, a narrow strip of sand occurs on the west side of the Lake Warren beaches. According to the Quaternary geology, the sand plain and Lake Warren beaches consist of near shore sand and gravel of the glacial Lake Warren, and the till plain consists of the clayey silt St. Joseph Till.

On the western border of the municipality, the Huron Fringe region occurs between the glacial Lake Algonquin Shorecliff and the current Lake Huron shoreline. The Huron Fringe region consists of terraces with boulders, gravel bars and sand dunes, as well as beaches and shorecliffs. According to the Quaternary geology, the physiographic features in this region consist of beach and near shore sand and gravel of recent glacial Lake Nipissing.

The Kincardine South model area is mainly located in Huron Slope region, with the Horseshoe Moraines region in the eastern upland area and the Huron Fringe region in the western

⁷⁸ Bedrock Geology of Ontario, Southern Sheet, Map 2544, Scale 1:1,000,000, Ministry of Northern Development and Mines, 1991.

⁷⁹ Oil, Gas and Salt Resources Library, digital well database, Ontario Petroleum Institute, Ministry of Natural Resources, 2002.

⁸⁰ Chapman, L.J., and Putnam, D.F., 1984, Physiography of Southern Ontario, Ontario Geological Survey, Map P.2715, Scale 1:600,000.

⁸¹ Ministry of Natural Resources, NRVIS data, Quaternary geology, Maps 2956 and 2957.

shoreline area. The eastern half of the Kincardine South model area is located in the Huron Slope region, and the western half in the Huron Fringe region.

The MNR Quaternary geology was used to estimate the overburden hydraulic conductivity zones for the WHPA modeling.

Overburden Hydrogeology

The majority of wells in Bruce County⁸² obtained groundwater from bedrock aquifers. However, there are some overburden aquifers in the sands and gravels of kames, spillways, sand plains and beach ridges, with well yields ranging from 0.2 to 3.8 L/s. In the Horseshoe Moraines, sand and gravel aquifers mainly occur in spillways. In the Huron Slope and Huron Fringe regions, overburden aquifers occur in the sand plains and beach ridges.

Bedrock Hydrogeology

Permeabilities of bedrock aquifers in Bruce County vary greatly depending on the degree of fracturing and dissolution of the rock. The limestone and dolostone of the Detroit River Group are moderately to highly permeable, having solution cavities, such as joints and caverns that are well developed in places, resulting in average well yields of 0.8 to 3.8 L/s. The limestone and dolostone of the Bois Blanc and Bass Island formations are moderately permeable, with well yields of 0.8 to 1.9 L/s.

Local Cross-sections

Geologic cross-sections were generated using well information from the WWIS and are presented in Figures 6.25A to 6.25E. Each cross-section passes through at least one municipal well and is oriented either north-south or east-west, along the direction of the highest concentration of wells. Aquifer locations (screened intervals) and corresponding water levels are also shown on the cross-sections.

6.13.2 Municipal Well Systems

Kincardine South

The municipal well systems in the southern part of the Municipality of Kincardine were combined into one model called the Kincardine South model. These municipal well systems consist of the Port Head Estates Well Supply, the Lake Huron Highlands Well Supply, the Craig-Eskrick Well Supply, the Kinhuron Well Supply and the Tiverton Well Supply.

The Port Head Estates Well Supply is comprised of one bedrock well, Well #1 constructed in 1991, which services 4 residential lots, approximately 10 people⁸³. The Lake Huron Highlands Well Supply is comprised of two bedrock wells, Well #1 constructed in 1971 and Well #2 in 1981, which services 43 residential lots, approximately 108 people. The Lake Huron Highlands well #1 is a standby well.

The Craig-Eskrick Well Supply is comprised of one bedrock well, Well #1 constructed in 1981, which services 30 residential lots, approximately 75 people. The Kinhuron Well Supply is comprised of one bedrock well, Well #1 constructed in 1971, which services 30 residential lots, approximately 75 people. The Tiverton Well Supply is comprised of two bedrock wells, the Dent

⁸² Ground-Water Probability of the County of Bruce, Southern Ontario, Map 3101, Scale 1:250,000, Ontario Ministry of the Environment, 1986.

⁸³ Based on an estimated 2.5 persons per residence (Engineer's Report, Town of South Bruce Peninsula, County of Bruce, design population estimates, 2001).

Well constructed in 1971 and the Briar Hill Well in 1981, which services 250 residential lots, approximately 625 people.

Figure 6.24 shows the location of the Port Head Estates well, the two Lake Huron Highlands wells, the Craig-Eskrick well, the Kintahuron well and the two Tiverton wells, and their proximity to one another, as well as their proximity to local rivers and roads, and to township and model boundaries.

Kincardine North

The municipal well systems in the northern part of the Municipality of Kincardine were combined into one model called the Kincardine North model. These municipal well systems consist of the Underwood Well Supply and the Scott Point Well Supply.

The Underwood Well Supply is comprised of one bedrock well, Well #1 constructed in 1972, which services 35 residential lots and 10 commercial lots, approximately 113 people⁸⁴. The Scott Point Well Supply is comprised of one bedrock well, Well #1 constructed in 1970, which services 39 residential lots, approximately 98 people.

Figure 6.24 shows the location of the Underwood well and the Scott Point well, and their proximity to one another, as well as their proximity to local rivers and roads, and to township and model boundaries.

Average Production Rates

Average pumping rates for each municipal well were estimated based on raw water flow rates averaged over the last five years and are presented in Appendix F. These pumping rates were used to represent the wells in the groundwater model.

6.13.3 Model Design (Kincardine North, Kincardine South)

Model Grid

The model grid for the Kincardine North model consists of 196 columns and 166 rows, with model extents of 17.5 km by 14 km horizontally and 270 m vertically. In the Kincardine South model, the grid consists of 229 columns and 300 rows, with model extents of 18 km by 15.5 km horizontally and 295 m vertically. Figure 6.24 presents the locations of the WHPA model domains with respect to the municipal boundary.

Model Boundaries

In the area of the Kincardine North Model, groundwater flow in the bedrock is generally from southeast to northwest, as can be seen from Figure 2.21 of the bedrock equipotential contours. There are constant head boundaries upgradient of the flow system, having a maximum head of 260 m amsl, and downgradient of the flow system, having a minimum head of 176 m amsl, the level of Lake Huron. The final recharge value used to obtain a reasonable model calibration was 80 mm/yr, which falls within the range of values typical for this region.

In the area of the Kincardine South Model, groundwater flow in the bedrock is generally from east to west, as can be seen from Figure 2.21 of the bedrock equipotential contours. There are constant head boundaries upgradient of the flow system, having a maximum head of 271 m amsl, and downgradient of the flow system, having a minimum head of 176 m amsl, the level of

⁸⁴ Based on an estimated 2.5 persons per residence (Engineer's Report, Town of South Bruce Peninsula, County of Bruce, design population estimates, 2001).

Lake Huron. The final recharge value used to obtain a reasonable model calibration was 125 mm/yr, which falls within the range of values typical for this region.

Hydrogeologic Properties

Final calibrated hydraulic conductivity values are presented in Table 6.14 for each geologic unit. These hydraulic conductivity values are consistent with those recorded in the literature for these materials (refer to Section 6.1.4).

TABLE 6.14: CALIBRATED VALUES FOR HYDROGEOLOGIC PROPERTIES (KINCARDINE)

Geological Unit	Hydraulic Conductivity (m/s)
Overburden Zones:	
Clay or Peat	1e-6
Sand and Gravel	9e-5 to 1e-4
Silt Till	4e-6 to 1e-5
Kame Materials	--
Exposed Bedrock	1e-4
Bedrock Contact Zone	9e-5 to 1e-4
Competent Bedrock Zones	1e-5 to 3e-5

6.13.4 Model Results

Model Calibration

In the Kincardine North model, the water levels of 87 observation wells within the model domain were used for model calibration. In the Kincardine South model, the heads of 364 observation wells within the model domain were used for model calibration. The resulting calibration graphs for the Kincardine North and Kincardine South models are presented in Appendix E, having NRMS values of 4.7 % and 5.5 %, respectively. These NRMS values are less than or equal to 10%, therefore indicating that these MODFLOW models generally represent the groundwater flow conditions in the vicinity of the municipal wells in the Municipality of Kincardine.

WHPA Results

Figure 6.24 shows the steady-state capture zone for each municipal well. The municipal well production information and the pumping rates used for the calibration and the capture zone delineation are presented in Appendix F. The pumping rates used for model calibration correspond to the average production rate, over the last five years, for each well, plus the 20-year projected rate. The 50-day, 2-year, 10-year, 25-year, and steady state capture zones, developed for each municipal well, are presented and discussed in Chapter 7. Additional analysis using the WHPAs, potential contaminant sources, and intrinsic susceptibility results are also presented in Chapter 7.

6.14 Summary

Numerical models were developed for 45 municipal well systems in Grey and Bruce Counties, which include:

- Township of Georgian Bluffs (Shallow Lake, Forest Heights, Maple Crest and Pottawatomi Village);
- Township of Chatsworth (Chatsworth and Walter's Falls);
- Municipality of West Grey (Neustadt and Durham)
- Township of Southgate (Dundalk);
- Town of Hanover (Hanover);
- Municipality of Grey Highlands (Markdale, Feversham and Kimberley Springs);
- Municipality of Arran-Elderslie (Tara and Chesley);
- Town of South Bruce Peninsula (Huron Woods, Forbes, Trask, Robins, Winburk, Fiddlehead, Fedy, Cammidge & Collins, Gremik, Foreman and Thomson);
- Municipality of Brockton (Lake Rosiland, Chepstow);
- Municipality of Huron-Kinloss (Ripley, Lucknow, Point Clark, Blairs Grove, Murdock Glen, Huronville, and Whitechurch);
- Municipality of South Bruce (Mildmay and Teeswater); and,
- Municipality of Kincardine (Tiverton, Underwood, Scott Point, Kin Huron, Craig Estrick, Lake Huron Highlands and Point Head Estates).

The original Terms of Reference indicated that WHPA modeling was to be completed on the Town of Saugeen Shores municipal system. However, the Town recently completed a pipeline to connect the Miramichi Estates and Miramichi Shores developments to the existing surface water supply system. Also, the Geeson Avenue well in Walkerton was taken out of service. Markdale decommissioned one municipal well, and added 2 new municipal wells to the groundwater supply system. As such, these municipal wells are being decommissioned so that no WHPA modeling was needed.

All of these models were developed using Visual MODFLOW, and calibrated to steady-state water levels in the wells from the Water Well Information System database. These calibrated models were used to delineate WHPAs for each of the municipal wells.

The WHPA results are shown as a series of WHPA maps for each Municipality. In addition, a 1:200,000 map (Figure 6.26) was created on a 30 in. by 36 in. layout to show the WHPA boundaries from a more regional perspective, at a more detailed larger scale. They show the 50-day, 2-year, 10-year and 25-year time-of-travel capture zone. These results represent the current best estimate of the different capture zones. However, their sizes and shapes will change in the future as wells are added and removed, and as water demands change. As additional information becomes available, the validity of the different models should be evaluated to help ensure that protective measures continue to be directed in the appropriate areas. Incorporating additional geologic and pumping information into the model will not be difficult now that the models have been constructed and calibrated. The timing of future model review should be timed to coincide with the development and decommissioning of well fields in each of the different municipalities.

7 Integration of Study Results

7.1 Overview

As part of this groundwater study, three data layers were developed that have an impact on the groundwater quality that is withdrawn at each municipal well. These layers are the aquifer intrinsic susceptibility, the potential contaminant sources inventory, and the WHPA boundaries. Integrating these themes in a GIS allows for simultaneous consideration of three important parameters that affect groundwater quality protection. GIS is widely used as a comprehensive system capable of assembling, storing, manipulating, and displaying geographically referenced information.

7.2 Methodology and Data Sources

7.2.1 Intrinsic Susceptibility Overlay

Regional aquifer intrinsic susceptibility mapping was presented in Section 3. The mapping was completed using the methodology outlined in the Technical Terms of Reference (MOE, 2001). Areas of high susceptibility represent zones where water moves more quickly to the aquifer than in areas of low susceptibility. In areas of low susceptibility, ground surface contamination is less likely to impact the aquifer of concern. Areas of high and medium intrinsic susceptibility found within WHPA boundaries are very sensitive zones from a groundwater protection perspective. In areas of high susceptibility, it is recommended that appropriate municipal planning measures be designed to restrict development within WHPA boundaries, and that suitable policies be developed for the appropriate County and local Official Plans.

7.2.2 Potential Contaminant Sources Overlay

Regional-scale potential contaminant sources mapping was presented in Section 5. Further local-scale ground-truthing was conducted throughout each of the WHPA boundaries that were delineated in Section 6. During the ground-truthing, field technicians drove through the steady-state capture zone identifying land uses that are more likely to impact groundwater quality. The specific land uses outlined by the MOE (2001) include:

- Dry cleaners and Laundromats;
- Fuel storage and distributing operations;
- Industrial manufacturers;
- Golf Courses;
- Landfills;
- Salvage Yards;
- Rail Yards; and,
- Other land uses.

7.2.3 Wellhead Protection Area Overlay

The WHPAs for each municipal well, generated using three-dimensional MODFLOW models, were presented in Section 6. For each wellfield, the 50-day, 2-year, 10-year, 25-year and steady state capture zones were mapped. A WHPA boundary is the two-dimensional projection onto the ground surface of the three-dimensional volume of groundwater that is pumped from a wellfield. Water that recharges the groundwater environment within a WHPA boundary will be pumped from the well at some time in the future. WHPAs represent the most sensitive area surrounding a municipal wellfield.

Figures 7.1 to 7.22 present the integration of these overlays for the municipal groundwater systems that were modeled. Understanding the locations of land uses that pose a risk to groundwater quality, in WHPAs that have medium to high susceptibility, provides a means of identifying the most sensitive areas that surround each municipal well. These issues will be discussed, by township, in the following sections.

7.3 Township of Georgian Bluffs

Figures 7.1 and 7.2 present the overlays described above for the municipal wells in the Township of Georgian Bluffs, along with other base mapping features that are discussed in the following sections. In the Engineer's Reports completed by Gamsby & Mannerow (2001), for the Forest Heights Water System, the Maple Crest Water System, the Pottawatomi Village Water System and the Shallow Lake Water System, the susceptibility to contamination of the aquifers in the vicinity of the municipal systems is summarized below.

7.3.1 Shallow Lake Water System

Figure 7.1 presents the integration of study results for the Shallow Lake system. The Shallow Lake wells are located in medium-textured soils in an area with rolling surface topography. The WHPAs transect Highway 70 east of Owen Sound. Land use is largely agriculture, mainly pasture land with some cropland and significant areas of swamp and bush. The agriculture is largely devoted to cattle production with solid manure handling systems. There are some areas of reforestation, which likely recognizes the best land use for the capability of the soil.

According to the Engineer's Report, the raw water quality from the Shallow Lake Wells #2 and #3 is generally poor, both bacteriologically and chemically. "Bacteriological concentrations, turbidity and DOC are consistently high." The water quality changes rapidly with weather conditions, indicating the influence of surface water on the groundwater. Potential sources of microbiological contamination of the groundwater were not mentioned in the report. However, possible sources of microbiological contamination could be municipal or private sewer systems. The report also states that a petroleum (BTEX) plume was identified in 1999 upgradient from the Shallow Lake wells, however no BTEX was detected in the municipal wells.

Shallow Lake Wells #2 and #3 draw water from a fractured bedrock aquifer in an area of karst topography. The well record for Well #3 indicates that there is 2.7 m of clay overlying the fractured limestone aquifer, which could provide some degree of natural protection for the aquifer from surface activities, because of the low permeability of clay. However, due to the shallowness of the aquifer, this natural protection could be limited.

The Intrinsic Susceptibility mapping shows that the area surrounding the WHPA boundaries are designated as medium susceptibility, which is likely a result of the thin layer of clay overlying the bedrock aquifer. In areas of medium susceptibility, it is recommended that appropriate municipal planning measures be developed to restrict development within WHPA boundaries.

Shallow Lake Well #1 was disconnected from the system in 1999. The Engineer's Report recommends that if this well is not to be used as a future source of water, it should be decommissioned according to MOE guidelines, so that it will not become a conduit of surface contamination to the aquifer.

7.3.2 Forest Heights Water System

Figure 7.2 presents the integration of study results for the Forest Heights system. Wells #1 and #2 of the Forest Heights System obtain water from the combined overburden and bedrock aquifers. The WHPAs are located in an area mapped as Tecumseth sand, within which land use

includes low intensity farmland and swamps. There appears to be some degree of natural protection for the aquifer due to the presence of 10.6 m to 11.5 m of sandy clay in the overburden near the wells, which overlies the gravel and limestone/shale aquifer. Due to the low permeability of clay, it likely acts as an aquitard to protect the aquifer from surface activities. According to the Engineer's Report, the raw water quality from the Forest Heights wells is generally good, with the only concern being elevated turbidity levels, possibly due to elevated levels of iron and manganese. Potential sources of contamination to the groundwater were not mentioned in the report.

However, on a regional-scale, the Intrinsic Susceptibility mapping shows that the area surrounding the WHPA boundaries are designated as high susceptibility, which is likely a result of higher permeability material regionally above the bedrock aquifer. In areas of high susceptibility, it is recommended that appropriate municipal planning measures be designed to restrict development within WHPA boundaries.

7.3.3 Maple Crest Subdivision Water System

Figure 7.2 presents the integration of study results for the Maple Crest system. Wells #1 and #2 are located in grassed areas of the Maple Crest Subdivision and obtain water from the same bedrock aquifer. The WHPAs are located in an area mapped as Tecumseth sand, which includes areas mapped as Breyden soils (shallow, variable soils with bedrock outcrops). Land use appears to be a mixture of pasture and bush with some residential development. According to the Engineer's Report, there is concern of elevated levels of total coliform in raw water samples. In the vicinity of the wells, the potential sources of contamination to the wells could be private septic systems or abandoned wells. However, since there is no apparent evidence of septic effluent impacting the aquifer, the three privately-owned wells in the subdivision, which are no longer in use, could be possible sources of microbiological contamination. Recommendations were made in the report to properly decommission these wells according to MOE guidelines.

According to the MOE Water Well Record for Well #1, 13.0 m of silty sand overburden overlies the shale aquifer. According to the records for Well #2 and Well #3, there is a thickness of 7.0 m and 6.7 m, respectively, of clay in the overburden, which overlies the shale aquifer. The low permeability of clay likely provides some degree of natural protection for the aquifer near Wells #2 and #3, whereas the aquifer near Well #1 does not have the same protection. Maple Crest Well #3 is no longer in use and was disconnected from the system. The Engineer's Report recommends that if this well is not to be used as a future source of water, it should be decommissioned according to MOE guidelines, so that it will not become a conduit of surface contamination to the aquifer.

However, on a regional-scale, the Intrinsic Susceptibility mapping shows that the area surrounding the WHPA boundaries are designated as high susceptibility, which is likely a result of the thin overburden above the bedrock aquifer. In areas of high susceptibility, it is recommended that appropriate municipal planning measures be developed to restrict development within WHPA boundaries.

7.3.4 Pottawatomie Village Water System

Figure 7.2 presents the integration of study results for the Pottawatomie Village system. Wells #1 and #2 are located in grassed areas in the subdivision and obtain water from the same bedrock aquifer. The 50-day WHPA is located in an area mapped as clay loam, the 2-year WHPA crosses an area of variable soil with rock outcrops (mapped as Breyden), and the 25-year WHPA contains an area of silty clay loam with some sand. According to the Engineer's Report,

there appears to be some degree of natural protection for the aquifer due to the presence of 25.6 m to 27.4 m of sandy stony clay overburden near the wells, which overlies the shale aquifer. The low permeability of clay likely acts as an aquitard to protect the aquifer from surface activities, and, it is unlikely the wells be impacted by surface contamination.

However, on a regional-scale, the Intrinsic Susceptibility map shows that the area surrounding the WHPA boundaries is designated as medium to high susceptibility. According to the Aquifer Evaluation for the municipal wells, the overburden material surrounding the wellfield is sand, and "The Physiography of Southern Ontario" indicates that the area is mapped as a sand plain. Thus the medium to high susceptibility is likely a result of thin, coarse-grained overburden material. In areas of medium or high susceptibility, it is recommended that appropriate municipal planning measures be developed to restrict development within WHPA boundaries.

7.4 Township of Chatsworth

Figures 7.3 and 7.4 present each of the overlays described above for the municipal wells in the Township of Chatsworth, along with other base mapping features, which are discussed in the following sections. In the Engineer's Reports completed by Henderson, Paddon & Associates (2001) for the Chatsworth Water Works and the Walter's Falls Water Works, the susceptibility to contamination of the aquifers in the vicinity of the municipal systems is discussed and is summarized below.

7.4.1 Chatsworth System

Figure 7.3 presents the integration of study results for the Chatsworth system. The WHPAs are large and are oriented eastward toward the recharge areas adjacent to the Niagara Escarpment. Land use in the vicinity of the Chatsworth wells can give an indication of potential sources of contamination to groundwater. To the west of Wells #1 and #2 is the floodplain and lowlands of the Spey River, and to the east and southeast are agricultural lands. There is also a small subdivision 200 to 300 m southeast of the wells that are serviced by private septic systems. The Engineer's Report recommends that the municipality obtain the land that recharges Wells #1 and #2 in order to act as a protective zone for the wells.

Chatsworth Wells #1 and #2 both draw water from a shale aquifer. According to the records for Well #1 and Well #2, there is 2.7 m and 2.9 m of clay, respectively, overlying the bedrock aquifer. Due to the low permeability of clay, it likely acts as an aquitard to protect the aquifer from surface activities. However the protection may be limited due to the shallowness of the aquifer. The raw water quality from the Chatsworth wells is generally good. However, concerns were expressed of a past chemical spill on Highway 10, located southwest of the wells. The report recommends that the risk of contamination to the aquifer associated with the spill be evaluated. Recommendations were also made to investigate the impact of the Spey River, which may be recharging the aquifer.

Chatsworth Well #3 is no longer in use and is for emergency purposes only. Recommendations were made in the Engineer's Report to remove the discharge piping for this well in order to prevent a cross connection to the distribution system. Well #3 is located in a subdivision, however potential contamination impacts were not discussed in the report. The well record for Well #3 indicates that there is 14 m of clay overlying the bedrock aquifer, which could provide some degree of protection to the aquifer, due to the low permeability of clay.

On a regional-scale, the Intrinsic Susceptibility mapping shows that the area surrounding the WHPA boundaries are designated as medium to high susceptibility, which is likely a result of the thin overburden above the bedrock aquifer. In areas of medium or high susceptibility, it is

recommended that appropriate municipal planning measures be developed to restrict development within WHPA boundaries.

7.4.2 Walter's Falls System

Figure 7.4 presents the integration of study results for the Walter's Falls system. The WHPAs are small and oriented eastward toward the recharge areas of the Niagara Escarpment. In the Engineer's Report for the Walters Falls wells, there was concern expressed about the presence of bacteria, nitrate and chloride in raw water samples, which is likely due to the impact of agricultural practices in the area. Both wells are located within a cultivated field and are susceptible to contamination from fertilizers and manure spreading. The wells are located in an area of medium textured soils, mapped as Osprey loam. Land use is a mix of swampland with soft maple, cedar and poplar species, some upland hardwood bush and low intensity farmland in close proximity.

Based on test drilling, there is a total thickness of clay and silt till of 1.8 m overlying the fractured dolostone aquifer, which is located at a depth of 8.5 m. There is a limited thickness of clay and till in the overburden and the presence of substantial boulders, which may limit the protection that the overburden provides to the bedrock aquifer. In addition, the bedrock aquifer is relatively shallow, which increases the susceptibility of the aquifer to contamination. The Engineer's report also states that the wells are under the influence of surface water contamination, either from the Walter's Falls Creek, or from the recharge of contaminated water from local agricultural activities. Recommendations were made for the municipality to obtain the land or control the land use in the area required as a protective zone for the wells, and to improve the long-term security of the aquifer.

This is corroborated by the regional-scale Intrinsic Susceptibility mapping, which shows that the area surrounding the WHPA boundaries are designated as high susceptibility. This is likely a result of the thin overburden above the bedrock aquifer. In areas of medium or high susceptibility, it is recommended that appropriate municipal planning measures be developed to restrict development within WHPA boundaries.

7.5 Municipality of West Grey

Figures 7.5 and 7.6 present each of the overlays described above for the municipal wells in the Municipality of West Grey, along with other base mapping features, which are discussed in the following sections. In the Engineer's Reports completed by KMK Consultants Limited (2001), for the Neustadt Groundwater Supply System, and by D. J. Peach and Associates (2001), for the Durham Municipal Water Works, the susceptibility to contamination of the aquifers in the vicinity of the municipal systems is discussed and is summarized below.

7.5.1 Neustadt Groundwater Supply System

Figure 7.5 presents the integration of study results for the Neustadt system. The WHPAs are long and thin, and according to the Engineer's Report, the recharge areas for the Neustadt wells are not explicitly protected. The wells are each located in grassed areas surrounded by agricultural land consisting of rolling topography with mixed crop, bush and pastureland. The area in the vicinity of the well has livestock facilities. The majority of the area within the WHPAs is devoted to cash crops and some bush. There are a few residences to the east of Well #1 which are presumed to have septic systems, the closest one being 60 m from the well. There are cattle operations located approximately 100 m northeast and 180 m west of Wells #2 and #3 with visible manure piles.

The well record for Well #1 indicates that there is 17.6 m of clay with sand, gravel and stones overlying the limestone/shale aquifer, which is located at a depth of 32 m. The well records for Well #2 and Well #3 indicate that there is 7 m of clay, silt and gravel overlying the limestone/shale aquifer, which is located at a depth of 11 m. Due to the low permeability of clay, it likely acts as an aquitard to protect the aquifer from surface activities. According to the Engineer's Report, the raw water bacteriological quality from the Neustadt wells is generally good, however hardness levels are high.

However, on a regional-scale, the Intrinsic Susceptibility mapping shows that the area surrounding the WHPA boundaries are designated as medium to high susceptibility. This is likely a result of the higher permeability material above the aquifer on a regional-scale, which increases the risk of contaminants impacting the aquifer. In areas of medium or high susceptibility, it is recommended that appropriate municipal planning measures be developed to restrict development within WHPA boundaries.

7.5.2 Durham Municipal System

Figure 7.6 presents the integration of study results for the Durham system. The WHPAs are long and thin, and are oriented eastward toward the recharge areas in the vicinity of McWilliams. According to the Engineer's Report, the recharge area for the Durham wells is not explicitly protected. The wells are located in residential areas, which are possibly serviced by a municipal sewer system. There is a gravel pit located approximately 300 m southeast of Well 1B. Due to limited overburden protection and the shallowness of the aquifer, the land use in the vicinity of the wells could pose a risk of contaminating the aquifer.

The well record for Well #1A indicates that there is sand and gravel, and 0.9 m of shale, overlying the limestone aquifer, located at a depth of 11.5 m. The well record for Well #1B indicates that there is 4.2 m of clay overlying the limestone aquifer, located at a depth of 6.7 m. The record for Well #2 indicates that the limestone surface is encountered at a depth of only 0.3 m in this artesian well. Natural protection of the aquifer from surface activities is limited by the limited overburden thickness and the relative shallowness of the bedrock aquifer. The chemical, physical and bacteriological quality of the raw water from both wells is very good, with the exception of hardness. The good groundwater quality may be attributed to the absence of agricultural and industrial land uses upstream of the wells, as well as the strong upward gradient in the aquifer.

Durham Well #1A was abandoned due to borehole instability. The Engineer's Report recommends that the well be properly decommissioned according to MOE guidelines, so that it will not become a conduit of surface contamination to the aquifer. Well #1 is also not in use but is available for emergency supply. If Well #1 is abandoned in the future, it should also be properly decommissioned.

The Intrinsic Susceptibility map shows that the area surrounding the WHPA boundaries are designated as high susceptibility. This is likely a result of the high conductivity materials overlying the bedrock aquifer. In areas of high susceptibility, it is recommended that appropriate municipal planning measures be developed to restrict development within WHPA boundaries.

7.6 Township of Southgate

Figure 7.7 presents each of the overlays described above for the municipal wells in the Township of Southgate, along with other base mapping features, which are discussed in the following sections. In the Engineer's Reports completed by Triton Engineering Services (2001)

for the Village of Dundalk Water System, the susceptibility to contamination of the aquifers in the vicinity of the municipal systems is discussed and is summarized below.

7.6.1 Village of Dundalk Water System

Figure 7.7 presents the integration of study results for the Dundalk system. The WHPAs are large, encompassing much of Dundalk and are oriented northeastward toward the recharge areas along the Niagara Escarpment. According to the Engineer's Report, the recharge area for the Dundalk wells is not explicitly protected. Well #1 is located in a small grassy area with residential areas to the north and west and commercial areas to the south and east. Dundalk is serviced by a municipal sewage collection and treatment system. Well #2 is located in a residential area with a hydro transformer station adjacent to the well and an abandoned rail line to the south of the well. Well #3 is located in a grassy area between a residential area to the northeast and an industrial area to the south. There is a landfill 500 m southwest of the well.

The land uses surrounding the wells are not considered to be sources of excessive risk of contamination to the aquifer, as the aquifer is relatively deep and has some overburden protection. The well record for Well #1 indicates that there is 17.7 m of hardpan (silt till) overlying the limestone aquifer, which is located at a depth of 28.5 m. The well record for Well #2 indicates that there is a combined thickness of 15.2 m of hardpan (silt till) and sandy clay, overlying the limestone aquifer, which is located at a depth of 47.2 m. The well record for Well #3 indicates that there is a combined thickness of 27.4 m of hardpan (silt till) and clay with stones, overlying the limestone aquifer, which is located at a depth of 34.7 m. Land use in the 50-day and 2-year WHPAs is urban. There are some patches of swamp within the urban area. Soils of the area are medium-texture silt loam (mapped as Listowel and Harriston soils). The area in the 10-year WHPA is a combination of low intensity livestock production with some annual crops and swamp land. Farther out, land uses are similar with low intensity livestock production using solid manure systems, interspersed with areas of swampland.

The Engineer's Report indicates that the raw water bacteriological quality from the Dundalk wells is generally poor with respect to total coliform and *E. coli*, prior to treatment. The report also states that, in the fall of 2000, elevated levels of arsenic and selenium were found in shallow groundwater samples (from weed control sprays) in front of the transformer station property. The area was subsequently remediated, and since then, raw water from Well #2 is monitored annually for arsenic and selenium. The Engineer's report also recommends regular testing of 2,4,6 trichlorophenol (found in pesticides), radionuclides, and trihalomethanes for each well, as these chemicals were detected in all three wells in the past.

The Intrinsic Susceptibility mapping shows, that at a regional-scale, the area surrounding the WHPA boundaries are designated as medium to high susceptibility. This is likely a result of the higher permeability material above the limestone aquifer on a regional-scale, which increases the risk of contaminants impacting the aquifer. In areas of medium or high susceptibility, it is recommended that appropriate municipal planning measures be developed to restrict development within WHPA boundaries.

7.7 Town of Hanover

Figure 7.8 presents the integration of study results for the Hanover system, along with other base mapping features, which are discussed in the following sections. In the Engineer's Reports completed by B.M. Ross and Associates (2000) for the Hanover Water Supply, the susceptibility to contamination of the aquifers in the vicinity of the municipal wells is discussed and is summarized below.

7.7.1 Hanover System

The WHPAs for the Hanover wells are oriented in a northwesterly direction, and encompass portions of the Marl Lakes and Ruhl Creek. Well #2 is located southeast of the Marl Lakes and Well #1 is located about 650 m west of Well #2, 300 m west of the Marl Lakes. Land use around the Marl Lakes is residential, with some low density agriculture including pasture land and some cash crops in the surrounding vicinity. The surface soils in the area are relatively coarse textured well-sorted glacial outwash, which indicates fairly rapid infiltration and good internal drainage. There is also a municipal airport within the WHPA.

Despite the presence of an agricultural area near the wells, the raw water quality from the Hanover wells is generally good, according to the Engineer's report. This is likely due to the natural protection of a clay layer overlying the aquifer. The well record for Well #1 indicates that there is 8.2 m of clay overlying the sand and gravel aquifer located at a depth of 10.3 m. The well record for Well #2 indicates that there is a total of 32 m of clay overlying the gravel aquifer located at a depth of 43 m.

However, on a regional-scale, the Intrinsic Susceptibility mapping shows that the area surrounding the WHPA boundaries are designated as medium susceptibility. This is likely a result of the higher permeability material above the aquifer on a regional-scale providing potential conduits for contaminants to impact the aquifer. In areas of medium susceptibility, it is recommended that appropriate municipal planning measures be developed to restrict development within WHPA boundaries.

7.8 Municipality of Grey Highlands

Figures 7.9 to 7.11 present the overlays described above for the municipal wells in the Municipality of Grey Highlands, along with other base mapping features, which are discussed in the following sections. In the First Engineer's Reports completed by Henderson, Paddon & Associates (2001), for the Village of Markdale Water Works and the Kimberley-Amik-Talisman Water Supply, and by R. J. Burnside & Associates (2001), for the Feversham Water Supply System, the susceptibility to contamination of the aquifers in the vicinity of the municipal systems is discussed and is summarized below.

7.8.1 Village of Markdale System

Figure 7.9 presents the integration of study results for the Markdale system. The WHPAs are large, encompassing much of the Markdale, and are oriented eastward toward the recharge areas of the Rocky Saugeen River. Protection of the bedrock aquifer in the vicinity of the Markdale wells is limited, due to the absence of low permeability material (such as clay) in the overburden. In addition, the bedrock aquifer is relatively shallow in the vicinity of the Terra Drive Well, thus increasing the susceptibility of the aquifer to contamination. According to the MOE water well record for the Isla Street Well, there is 22 m of sand and gravel overlying a gravel or dolomite aquifer. According to the record for the Terra Drive Well, there is 1.2 m of sand overlying the dolomite/shale aquifer.

The Engineer's Report indicates that the raw water quality from the Isla Street Well is generally good. However, the Terra Drive Well has regular occurrences of microbiological contamination of raw water samples, and appears to be under the influence of surface water, such as from a tributary to the Rocky Saugeen River about 100 m north of the well. The microbiological contamination could also be due to septic field leachate from a low-density residential area located upgradient from the well. Because of these problems, the Terra Drive well was decommissioned and two (2) new wells were developed for the Village of Markdale.

This is corroborated by the Intrinsic Susceptibility mapping, which shows that the area surrounding the WHPA boundaries are designated as high susceptibility. This is likely a result of the thin overburden material overlying the bedrock aquifer. The WHPAs are principally located in an area of medium-textured glacial till, mapped as Harriston soil. The WHPAs also contains an area of bottom land associated with a surface drainage channel and several areas of organic soils. The 50-day and 2-year WHPAs are located within the urban area interspersed with some areas of swamp. The 10-year WHPA is mainly rolling topography interspersed with areas of swamp. The managed land use is agriculture, predominantly forage and pasture production for beef with some areas of cereal production. There is also an area of aggregate extraction within the 10-year WHPA.

In areas of high susceptibility, it is recommended that appropriate municipal planning measures be developed to restrict development within WHPA boundaries.

7.8.2 Feversham Water Supply System

Figure 7.10 presents the integration of study results for the Feversham (Beaver Heights) system. The WHPAs are long and thin, and are oriented southeastward toward the recharge areas at the watershed divide between the Beaver, Saugeen and Mad Rivers. Land use in the vicinity of the Feversham wells provides an indication of possible sources of contamination to groundwater. The land use on the north, east and south sides of Wells #2 and #3 is residential and on the west side is pasture. The residential areas are serviced by private septic systems, which could be potential sources of contamination to the aquifer. The land slopes to the northwest towards the Beaver River, located 250 m from the wells.

For the area within the 50-day and 2-year WHPA, the land ranges from swampy to rough land and depressions including some unimproved pasture and reforestation. This area includes soils mapped as highly variable (Donnybrook soils) in close proximity to the well, trending to medium-textured Osprey loam farther away from the well. In the area of medium-textured soils, the topography becomes more rolling and the land use is mixed agriculture (cattle production with solid manure systems, pasture and forage production). The area is also interspersed with depressional areas of swampland. The Engineer's Report states that the wells are not likely under the direct influence of surface water as they are greater than 100 m from the Beaver River. However, there is a thin layer of coarse-grained material surrounding the wells, which puts into question whether the water being pumped from the well is under the direct influence of surface water.

The well records for Well #2 and Well #3 indicate that there is 6 m of gravel overlying the limestone/shale aquifer. Due to the lack of low permeability materials in the overburden, the natural protection to the bedrock aquifer may be limited. In addition, the bedrock aquifer is relatively shallow, thus increasing the susceptibility of the aquifer to contamination. Well #1 is no longer in use. If this well is not to be used as a future source of water, it should be decommissioned according to MOE guidelines, so that it will not become a conduit for contamination of the aquifer.

The Intrinsic Susceptibility mapping shows, that at a regional-scale, the area surrounding the WHPA boundaries are designated as medium susceptibility. This is likely a result of the moderately permeable material above the limestone aquifer on a regional-scale. In areas of medium or high susceptibility, it is recommended that appropriate municipal planning measures be developed to restrict development within WHPA boundaries.

7.8.3 Kimberley Springs System

Figure 7.11 presents the integration of study results for the Kimberley Springs system. The WHPAs are very localized, and are located on the side of the valley of the Beaver River, in a steeply sloping area mapped as eroded silty clay loam (Vincent soil). The entire area is moderately to well treed roughland. Kimberley Springs #1 and #2 occur at the bottom of a vertical bedrock face, near a dolostone/shale interface, where the dolostone is more fractured than the shale. According to the Engineer's Report, the raw water samples from both springs regularly contain total and fecal coliform levels, as well as elevated turbidity levels related to high precipitation events. The report concludes that "the springs are under the influence of surface water and surface contamination and require full water treatment".

This is corroborated by the Intrinsic Susceptibility mapping, which shows that the area surrounding the WHPA boundaries are designated as high susceptibility. This is likely a result of the thin overburden material overlying the bedrock aquifer, which is representative of the face of the Niagara Escarpment. In areas of high susceptibility, it is recommended that appropriate municipal planning measures be developed to restrict development within WHPA boundaries.

7.9 Municipality of Arran-Elderslie

Figures 7.12 and 7.13 present the overlays described above for the municipal wells in the Municipality of Arran-Elderslie, along with other base mapping features, which are discussed in the following sections. In the Engineer's Reports completed by Henderson, Paddon & Associates Limited (2000) for the Chesley Water Works and the Tara Water Works, the susceptibility to contamination of the aquifers in the vicinity of the municipal systems is discussed and is summarized below.

7.9.1 Tara System

Figure 7.12 presents the integration of study results for the Tara system. The WHPAs are long and thin, and are oriented eastward toward the recharge areas in the vicinity of Keady Creek. According to the Engineer's Report, the raw water quality of the Tara wells is generally good. However, due to occasional detections of toluene, trichloroethylene, tetrachloroethylene and xylene in raw water samples from both Well #2 and Well #3, concern was expressed of possible future contamination of these wells. Levels of sodium, hardness, dissolved organic carbon, organic nitrogen and aluminium were also of concern. Recommendations were made to drill a new water well in a location better protected from surface activities, either by the presence of an aquitard and/or by land use control.

The well record for Well #2 indicates that there is 8.2 m of stony till in the overburden overlying the bedrock aquifer, which is located at depths of 79 m and 109 m. The record for Well #3 indicates that there is 1.8 m of stony till in the overburden overlying the bedrock aquifer, located at depths of 61 m and 96 m. Even though these are deep bedrock wells, the lack of low permeability materials in the overburden indicates that there may be limited natural protection for the bedrock aquifer.

This is corroborated by the Intrinsic Susceptibility mapping, which shows that the area surrounding the WHPA boundaries are designated as high susceptibility. This is likely a result of the high conductivity material overlying the bedrock aquifer. In areas of high susceptibility, it is recommended that appropriate municipal planning measures be developed to restrict development within WHPA boundaries.

Tara Well #1 is no longer in use due to petroleum odour in the well. The Engineer's Report recommends that this well should be decommissioned according to MOE guidelines, so that it will not become a conduit of surface contamination to the aquifer.

7.9.2 Chesley System

Figure 7.13 presents the integration of study results for the Chesley system. The WHPAs are long and thin, and are oriented eastward toward the recharge areas between the North Saugeen River and Deer Creek. Land use in the vicinity of the Chesley wells can give an indication of potential sources of contamination to groundwater. The Community Park well is surrounded by the Community Park, which is owned by the municipality. Therefore, the municipality can control the surface activities within the park and thus provide some protection to the aquifer. The Victoria Park well does not have the same protection as the Community Park well because it is not surrounded by municipally-owned land. There is an industrial unit to the south of the well and a residential area to the north.

In August 2000, the sanitary sewer system in Chesley was determined to be in very poor condition and is likely leaking sewage into the ground. However, the raw water quality from both wells does not show this contamination, which could be due to the thick clay overburden protecting the aquifer. According to the MOE water well record for the Community Park well, there is more than 11.3 m of clay overburden overlying the sand and gravel aquifer, which is located at a depth of 12.1 m. According to the record for the Victoria Park well, there is more than 24 m of clay in the overburden overlying the limestone aquifer, which is located at a depth of 36.5 m. Due to the low permeability of clay, it likely acts as an aquitard to protect both the overburden and bedrock aquifers from surface activities.

The Intrinsic Susceptibility mapping shows, that at a regional-scale, the area surrounding the WHPA boundaries are designated as medium susceptibility, and the steady-state capture zone touches areas of high susceptibility. On a regional-scale, there is likely higher permeability material that could provide a potential conduit for contaminants to impact the bedrock aquifer. In areas of medium or high susceptibility, it is recommended that appropriate municipal planning measures be developed to restrict development within WHPA boundaries.

It is suspected that private wells could be a potential source of contamination to the municipal wells, and should be abandoned in accordance with MOE guidelines.

7.10 Town of South Bruce Peninsula

Figures 7.14A to 7.14D present the overlays described above for the municipal wells in the Town of South Bruce Peninsula, along with other base mapping features, which are discussed in the following sections. In the Engineer's Reports completed by Henderson, Paddon & Associates (2001) for each of the eleven municipal well systems in the Town of South Bruce Peninsula, the susceptibility to contamination of the aquifers in the vicinity of the municipal systems is discussed and is summarized below.

7.10.1 Fiddlehead System

Figure 7.14A presents the integration of study results for the Fiddlehead system. The WHPAs are short and thin, due to the low pumping rate of the well. These WHPAs are located in areas of outwash deposit mapped as Plainfield sand and Grandby Sandy Loam, overlain by areas of swamp and scrub bush. The landform is rolling and there are a limited number of residential areas within and close to the capture zones. There is no indication of agricultural activities and the CLI agricultural capability rating would suggest that there is no potential for agriculture.

The Engineer's Report expresses concerns about the occasional detection in the past of total coliform and E. coli in raw water samples from the Fiddlehead well, as well as frequent high levels of iron, which result in turbidity problems during treatment. The report also states that the recharge area for the Well #2 is not explicitly protected. A low-density residential area with private septic systems surrounds the well. This surrounding land use is a potential source of contamination to the aquifer, which has little overburden protection. This is corroborated by the Intrinsic Susceptibility mapping, which shows that the area surrounding the WHPAs is designated as high susceptibility. According to the MOE water well record for the Fiddlehead well, there is 10 m of sand overlying the limestone aquifer, which is located at a depth of 26 m. Therefore, the limestone aquifer has little natural protection from surface contamination due to the absence of low permeability materials in the overburden. In areas of medium or high susceptibility, it is recommended that appropriate municipal planning measures be developed to restrict development within WHPA boundaries.

7.10.2 Cammidge & Collins System

Figure 7.14A presents the integration of study results for the Cammidge & Collins system. Similar to the Fiddlehead well, the WHPAs are short and thin, and located in areas of outwash deposit (sandy loam), overlain by areas of swamp and scrub bush. The Engineer's Report for the Cammidge & Collins Water Works #2 expresses concerns about the occasional detection in the past of total coliform in raw water samples from Well #2, as well as elevated levels of iron and turbidity. The report also states that the recharge area for the Well #2 is not explicitly protected. A low-density residential area with private septic systems surrounds the well. This surrounding land use is a potential source of contamination to the aquifer, which has little overburden protection. This is corroborated by the Intrinsic Susceptibility mapping, which shows that the area surrounding the WHPAs is designated as high susceptibility. According to the MOE water well record for Well #2, there is only 1.5 m of sandy clay overlying the limestone aquifer, which is located at a depth of 48.8 m. In areas of medium or high susceptibility, it is recommended that appropriate municipal planning measures be developed to restrict development within WHPA boundaries.

Cammidge & Collins Well #1 was abandoned, and the Engineer's Report recommends that, if this well is not to be used as a future source of water, it should be decommissioned according to MOE guidelines, so that it will not become a conduit of surface contamination to the aquifer.

7.10.3 Robins System

Figure 7.14B presents the integration of study results for the Robins system. The WHPAs are long and thin and are oriented eastward toward the recharge areas between the Rankin and Sauble Rivers. According to the Engineer's Report, raw water bacteriological quality is occasionally poor in the Robins well, with respect to total coliform. As well, fluoride and iron levels are occasionally high. The report also states that the recharge area for the well is not explicitly protected. A low-density residential area with private septic systems surrounds the well and the Sauble River is located approximately 50 m west of the well. This surrounding land use is not considered to be a source of risk of contamination to the aquifer, as the aquifer is relatively deep and has some overburden protection. The well record indicates that there is 9.1 m of sandy hardpan material overlying the limestone aquifer, which is located at a depth of 27.4 m.

7.10.4 Forbes System

Figure 7.14B presents the integration of study results for the Forbes system. The WHPAs are short and thin, and are oriented eastward and upgradient toward the Sauble River. According to the Engineer's Report, raw water bacteriological quality is generally good in the Forbes well.

However, iron levels are often high. The report also states that the recharge area for the well is not explicitly protected. A low-density residential area with private septic systems surrounds the well. This surrounding land use is not considered to be a source of risk of contamination to the aquifer, as the aquifer is relatively deep and has some overburden protection. According to the well record, there is 9.1 m of clay with boulders overlying the limestone aquifer, which is located at a depth of 18.2 m.

7.10.5 Trask System

Figure 7.14B presents the integration of study results for the Trask system. The WHPAs are long and thin, and are oriented southeastward toward the recharge areas of the Sauble River around Maryville Lake. According to the Engineer's Report, raw water bacteriological quality is generally poor in the Trask well, with respect to total coliform. However, fluoride and sodium levels are often high. The report also states that the recharge area for the well is not explicitly protected. A low-density residential area with private septic systems surrounds the well. This surrounding land use is not considered to be a source of risk of contamination to the aquifer, as the aquifer is relatively deep and has some overburden protection. According to the water well record, there is 9.1 m of clay with boulders overlying the limestone aquifer, which is located at a depth of approximately 102 m.

7.10.6 Thomson System

Figure 7.14B presents the integration of study results for the Thomson system. The WHPAs are short and thin, and are oriented eastward and upgradient toward the Sauble River. According to the Engineer's Report, raw water bacteriological quality is generally good in the Thomson well. However, barium, fluoride and hardness objectives have been exceeded in the past. The report also states that the recharge area for the well is not explicitly protected. A low-density residential area with private septic systems surrounds the well. This surrounding land use is not considered to be a source of risk of contamination to the aquifer, as the aquifer is relatively deep and has some overburden protection. According to the well record, there is 4.5 m of clay with stones overlying the limestone aquifer, which is located at a depth of 24.3 m.

7.10.7 Winburk System

Figure 7.14B presents the integration of study results for the Winburk system. The WHPAs are long and thin, and are oriented southeastward toward the recharge areas of the Sauble River around Gould Lake. According to the Engineer's Report, raw water bacteriological quality is generally poor in the Winburk well, with respect to total coliform. However, iron and fluoride levels have been occasionally high in the past. The report also states that the recharge area for the well is not explicitly protected. A low-density residential area with private septic systems surrounds the well. This surrounding land use is not considered to be a source of risk of contamination to the aquifer, as the aquifer is relatively deep and has some overburden protection. According to the well record, there is 8.5 m of hardpan with boulders overlying the limestone aquifer, which is located at a depth of 42.6 m.

7.10.8 Fedy System

According to the Engineer's Report, raw water bacteriological quality is generally good in the Fedy well. However, iron levels are occasionally high. The report also states that the recharge area for the well is not explicitly protected. A low-density residential area with private septic systems, and some vacant land, surround the well. This surrounding land use is not considered to be a source of risk of contamination to the aquifer, as the aquifer is relatively deep and has some overburden protection. According to the MOE water well record for the well, there is 18.3 m of clay with boulders overlying the limestone aquifer, which is located at a depth of 44.2 m.

When the Fedy distribution system was connected to the Winburk system in 1996, the Fedy well was put out of service. The Fedy well could possibly be used as a backup for the Winburk system when needed. If this well is not to be used as a future source of water, it should be decommissioned according to MOE guidelines, so that it will not become a conduit of contamination to the aquifer.

7.10.9 Gremik System

Figure 7.14B presents the integration of study results for the Gremik system. The WHPAs are short and thin, and are oriented eastward and upgradient toward the Sauble River. According to the Engineer's Report, raw water bacteriological quality is generally good in the Gremik well. However, fluoride levels are occasionally high. The report also states that the recharge area for the well is not explicitly protected. A low-density residential area with private septic systems, and vacant land, surround the well. This surrounding land use is not considered to be a source of risk of contamination to the aquifer. However, according to the well record, there is only 2.1 m of clay with stones overlying the limestone aquifer, which is located at a depth of 16.7 m.

7.10.10 Huron Woods System

Figure 7.14C presents the integration of study results for the Huron Woods system. The WHPAs are long and thin, and are oriented southeastward toward the recharge areas of the Sauble River around Maryville Lake. According to the Engineer's Report, raw water bacteriological quality is generally acceptable in the Huron Woods wells, however iron and hardness levels are often high. The report also states that the recharge area for the well is not explicitly protected. A low-density residential area with private septic systems, and vacant land, surround the wells. This surrounding land use is not considered to be a source of risk of contamination to the aquifer, as the aquifer is relatively deep and has some overburden protection.

The well record for Well #1 indicates that there is 21 m of clay with boulders overlying the limestone/shale aquifer, which is located at a depth of 33.5 m. The well record for Well #2 indicates there is 25.6 m of clay with stones overlying the limestone aquifer, which is located at a depth of 33.5 m. At Well #3, there is 33.5 m of clay with stones overlying the limestone aquifer, which is located at a depth of 35.3 m, and at Well #6, there is 6.4 m of sandy clay with stones overlying the gravel overburden aquifer located directly beneath. Due to less clay overlying the overburden aquifer at Well #6, it likely has less protection than the deeper bedrock aquifer, which is overlain by more clay. Wells #4 and #5 were never developed for use, and if these wells are not to be used in the future, they should be properly decommissioned according to MOE guidelines, so that they will not become conduits of contamination to the underlying aquifers.

7.10.11 Foreman System

Figure 7.14D presents the integration of study results for the Foreman system. The WHPAs are small and oriented southward toward Chesley Lake. According to the Engineer's Report, raw water bacteriological quality is generally poor in the Foreman well, with respect to total coliform. However, iron, hardness and colour objectives have been exceeded in the past. The report also states that the recharge area for the well is not explicitly protected. Agricultural land surrounds the well, which is considered to be a source of risk of contamination to the aquifer, as the overburden provides little protection to the aquifer. According to the MOE well record for the well, the 71.6 m of overburden contains stony hardpan, gravely clay with boulders and hardpan with boulders. These materials are not considered to have low permeabilities, and as a result the overburden likely provides little protection to the underlying limestone aquifer, which is located at a depth of 72.5 m. Recommendations were made in the Engineer's report for the

municipality to obtain the land that recharges the well, in order to provide a protective zone for the well.

For each of these systems, on a regional-scale, the Intrinsic Susceptibility mapping shows that the area surrounding the WHPA boundaries are designated as medium to high susceptibility. This is likely a result of the fact that the uppermost significant aquifer is located in the overburden above the hardpan/clay protective layer. Though some protection may be afforded deeper bedrock wells, the uppermost significant aquifer is not well protected. The risk of deeper contamination is present in the form of abandoned private wells or “windows” in the aquitard, which have not been properly decommissioned and sealed. In areas of medium susceptibility, it is recommended that appropriate municipal planning measures be developed to restrict development within WHPA boundaries.

7.11 Municipality of Brockton

Figures 7.15 and 7.8 present the overlays described above for the municipal wells in the Municipality of Brockton, along with other base mapping features, which are discussed in the following sections. In the Engineer’s Reports completed by B.M. Ross and Associates (2000) for the Chepstow Water Works and the Lake Rosalind Water Works, the susceptibility to contamination of the aquifers in the vicinity of the municipal systems is discussed and is summarized below.

7.11.1 Chepstow System

Figure 7.15 presents the integration of study results for the Chepstow system. The WHPAs are long and thin, and are oriented southeastward toward the recharge areas of the Teeswater River between Greenock and Allens Creek. According to the Engineer’s Report, raw water bacteriological quality is generally good in the Chepstow well. The well is located in the Powers Subdivision, with residential lots to the north and south of the well. The Teeswater River is located 200 to 300 m downgradient to the north of the well. The residential lots are serviced by private septic systems and the closest septic system is 30 to 60 m south of the well. The well record indicates the overburden thickness of clay and hardpan materials is 15.8 m, below which is the limestone aquifer. The low permeability materials in the overburden likely act as an aquitard to protect the bedrock aquifer from surface activities.

The area within the 10-year WHPA is located in cash crop agricultural land (medium textured mineral soils) with some low density beef operations and bush area. The area within the 25-year WHPA is agricultural but more intensive, including confinement livestock that relies heavily on cash crop operations.

On a regional-scale, the Intrinsic Susceptibility mapping shows that the area surrounding the WHPA boundaries are designated as medium to high susceptibility. This is likely a result of the fact that the uppermost significant aquifer is located in the overburden above the protective aquitard. Though some protection may be afforded deeper bedrock wells, the uppermost significant aquifer is not well protected. The risk of deeper contamination may come from discontinuities in the aquitard above the bedrock aquifer. In areas of medium susceptibility, it is recommended that appropriate municipal planning measures be developed to restrict development within WHPA boundaries.

7.11.2 Lake Rosalind System

Figure 7.8 presents the integration of study results for the Lake Rosalind system. The WHPAs for the Lake Rosalind well are oriented in a northwestward direction, toward the recharge area for Marl Lakes. Land use northwest of Marl Lakes is low density agriculture, with some pasture land

and cash crops. The surface soils in the area are relatively coarse textured well-sorted glacial outwash, which indicates fairly rapid infiltration and good internal drainage.

According to the Engineer's Report, high levels of total coliform bacteria have been detected in the past in raw water samples from the Lake Rosalind well. The well is located 120 m west of Lake Rosalind, and there is agricultural land to the west of the well. The well supplies water to a residential area with private septic systems. According to the record for Well #3, there is only 1.5 m of clay overlying the overburden sand aquifer, which is located at a depth of 13.4 m. Due to the limited thickness of clay in the overburden, natural protection of the aquifer from surface activities may be limited. In addition, the Engineer's report states that the overburden aquifer is relatively shallow and is likely under the influence of surface water.

On a regional-scale, the Intrinsic Susceptibility mapping shows that the area surrounding the WHPA boundaries are designated as medium susceptibility. This is likely a result of the higher permeability material above the aquifer on a regional-scale providing potential conduits for contaminants to impact the aquifer. In areas of medium susceptibility, it is recommended that appropriate municipal planning measures be developed to restrict development within WHPA boundaries.

7.12 Township of Huron-Kinloss

Figures 7.16 to 7.18 present the overlays described above for the municipal wells in the Township of Huron-Kinloss, along with other base mapping features, which are discussed in the following sections. In the Engineer's Reports completed by B.M. Ross and Associates (2001) for the Ripley water system, the Lakeshore Area Water Works, the Lucknow Water Works and the Whitechurch Water Works, the susceptibility to contamination of the aquifers in the vicinity of the municipal systems is discussed and is summarized below.

7.12.1 Village of Ripley System

Figure 7.16 presents the integration of study results for the Ripley system. The Ripley WHPAs are long and narrow. They stretch through predominately cash crop agricultural operations on a relatively fine textured surface material. In this area most of the productive land is tile drained which will shunt any potential contaminants that move through the rooting zone out to the surface drainage network. The fine textured soils managed with conservation tillage can have well developed cracks, which can result in preferential flow from the surface to depths well below the rooting zone. The presence of tile drains was not confirmed in this survey. In addition to cash crops there is some low density livestock production (chiefly cattle with solid manure handling systems. There do not appear to be any livestock handling facilities directly on top of this capture zone.

According to the Engineer's Report, there is no apparent history of adverse bacteriological quality of the raw water supply from the Ripley wells. The report also states that land use around wells is residential, commercial and institutional, and there are underground fuel tanks for a municipal firehall and a service station located 15–20 m and 35 m from the wells, respectively. According to the MOE water well record for Well #1, there is 12.1 m of clay and hardpan overlying the limestone aquifer, which is located at a depth of 36.5 m. According to the record for Well #2, there is 10.4 m of clay overlying the limestone aquifer, located at a depth of 41.4 m. Due to the low permeability of clay, it likely acts as an aquitard to protect both the overburden and bedrock aquifers from surface activities. Due to the presence of low permeability materials in the overburden and the depth of the aquifer, the bedrock aquifer is probably protected from surface activities.

This is corroborated by the Intrinsic Susceptibility mapping, which shows that the area surrounding the WHPA boundaries are designated as low to moderate susceptibility. The low conductivity overburden overlying the bedrock aquifer may be providing natural protection to the aquifer. In areas of medium susceptibility, it is recommended that appropriate municipal planning measures be developed to restrict development within WHPA boundaries.

7.12.2 Huronville South System

Figure 7.17A presents the integration of study results for the Huronville South system. The Huronville South wells are both located in a municipal park, where the adjacent land use is residential, serviced by individual Class 4 sewage disposal systems. There is also a gravel pit located approximately 300 m southeast of the wells and Lake Huron is approximately 150 m to the west. The borehole log for Well #1 indicates a total thickness of clay and hardpan materials of 33.5 m above the limestone aquifer located at 47.4 m depth. These low permeability materials probably act as an aquitard to protect the bedrock aquifer from surface activities. The log for Well #2 could not be found, however due to the vicinity of the wells, Well #2 likely has similar aquitard materials as encountered in Well #3.

The WHPA is long and narrow, and transects the Penetangore River south of Kincardine. The 2-year WHPA is located in the area mapped as coarse textured sandy loam (Fox soils), within which the land use is residential. The remainder of the WHPA is located in rolling fine-textured soils, which include depressional areas, bush, surface drainage channels. The principal land use is cash crop agriculture with some areas devoted to livestock production, which use solid manure handling systems.

7.12.3 Murdock Glen Wells

Figure 7.17A presents the integration of study results for the Murdock Glen system. Land use in vicinity of the wells is residential, serviced by individual Class 4 sewage disposal systems, and agricultural lands are more than 250 m east of the wells. Lake Huron is approximately 200m to the west of the wells. The borehole log for Well #1 indicates a total thickness of clay and hardpan materials of 58.2 m above the limestone aquifer located at 60.2 m depth. The log for Well #2 indicates a total thickness of clay of 37.1m above the limestone aquifer located at 61.1 m depth. These low permeability materials probably act as an aquitard to protect the bedrock aquifer from surface activities.

The WHPAs are long and narrow and located in fine-textured soils of the Brookston series, which are poorly drained soil with small areas of imperfectly drained soils. The 50-day WHPA is in an area of bush with some summer residences below the escarpment. The remainder of the WHPA is on level to depressional land, for which the principle land use is cash crop production. In the 25-year WHPA, there is some low intensity livestock operations with solid manure handling systems and pasture land.

7.12.4 Blairs Grove Wells

Figure 7.17B presents the integration of study results for the Blairs Grove system. Land use in vicinity of the Blairs Grove wells is residential, serviced by individual Class 4 sewage disposal systems. The Pine River is located approximately 100 m to the east of the wells and further to the south, being separated from the wells by open land. Lake Huron is approximately 350 m west of the wells. The borehole log for Well #3 indicates a total thickness of clay and hardpan materials of 43.5 m above the limestone aquifer located at 47.4 m depth. These low permeability materials probably act as an aquitard to protect the bedrock aquifer from surface activities. The log for Well #2 could not be found, however due to the vicinity of the wells, Well #2 likely has similar aquitard materials as encountered in Well #3.

The WHPAs are long and narrow, and the 50-day and 2-year WHPAs are located in deposit of coarse-textured outwash, mapped as Sullivan soil. Land use consists of cedar bush/swamp and summer residences. The 25-year WHPA transects the escarpment through an area of imperfectly drained fine-textured soil into an area of level poorly drained Brookston soil. Land use is predominantly cash crops with a low intensity of livestock principally beef and dairy with solid manure handling systems.

7.12.5 Point Clark System

Figure 7.17B presents the integration of study results for the Point Clark system. Land use in vicinity of the Point Clark wells is residential, serviced by individual Class 4 sewage disposal systems. There are also agricultural lands approximately 250 m east of the wells and Lake Huron is approximately 600m to the west. The borehole log for Well #1 indicates a total thickness of clay of 53.6 m above the limestone aquifer located at 58.8 m depth. The log for Well #2 indicates a total thickness of clay and hardpan materials of 37.1 m above the limestone aquifer located at 54.2 m depth. These low permeability materials probably act as an aquitard to protect the bedrock aquifer from surface activities.

The WHPAs are long and narrow, and draws recharge from the agricultural area north of highway 86 along Boyd Creek. The 50-day WHPA is located in an areas leading from the old beach line up the escarpment to the level agricultural land consisting of cedar bush and some summer recreational homes. Land use in the 10-year WHPA is cash crop agricultural land (medium textured mineral soils) with some low density beef operations. There is also some bush area within this part of the capture zone. Within the steady-state WHPA, land use is agricultural but more intensive, and includes confinement livestock relying heavily on cash crop operations.

For each of these well systems, the Intrinsic Susceptibility mapping shows that the area surrounding the WHPA boundaries to be designated as low to moderate susceptibility. The low conductivity overburden overlying the bedrock aquifer may be providing natural protection to the aquifer. In areas of medium susceptibility, it is recommended that appropriate municipal planning measures be developed to restrict development within WHPA boundaries.

7.12.6 Lucknow System

Figure 7.18 presents the integration of study results for the Lucknow system. The Lucknow WHPAs are large due to the high pumping rate, and it is bisected by Highway 86. Most of the land is in agriculture, low intensity mixed farming with cash crops and beef operations. These are located on gently rolling medium textured soils. They have mainly solid manure handling systems. Part of the capture zone is quite rolling with significant areas of swamp and depressional recharge. The soils in this area are formed on highly variable coarse textured materials. The only land use of note was two areas of aggregate extraction within the 2 year travel zone. According to the Engineer's Report, due to the depth of the bedrock aquifer, the presence of thick layers of aquitard materials, and a history of good microbiological water quality, Lucknow Wells #4 and #5 appear to be adequately protected. Well #4 is located in a community park and adjacent land use is residential, probably serviced by municipal sanitary sewers. Well #5 is located in a residential area, probably serviced by municipal sanitary sewers, and is within 100 m of agricultural lands to the south and east. The borehole log for Well #4 indicates a 16.2 m thickness of clay and hardpan materials above the limestone aquifer located at 53.3 m depth. The log for Well #5 indicates a 31 m thickness of clay and hardpan materials above the aquifer located at 47.5 m depth. These low permeability materials probably act as an aquitard to protect the bedrock aquifer from surface activities.

However, on a regional-scale, the Intrinsic Susceptibility mapping shows that the area surrounding the WHPA boundaries are designated as medium to high susceptibility. This is likely a result of the fact that the uppermost significant aquifer is located in the overburden above the protective aquitard. Though some protection may be afforded deeper bedrock wells, the uppermost significant aquifer is not well protected. The risk of deeper contamination may come from discontinuities in the aquitard above the bedrock aquifer. In areas of medium susceptibility, it is recommended that appropriate municipal planning measures be developed to restrict development within WHPA boundaries.

7.12.7 Whitechurch System

Figure 7.18 presents the integration of study results for the Whitechurch system. The WHPAs are small and narrow, and land use is dominated by low density mixed livestock (beef with solid manure handling systems) and cash crops. Other parts of the WHPAs are occupied by swamp and bush. According to the Engineer's Report, due to the proximity of septic systems and agricultural activities and some history of adverse microbiological water quality to the Whitechurch well, "there is some potential for microbiological contamination at the wellhead". The well is located behind a community centre and the adjacent land use is residential, commercial and agricultural. Private sewer systems are also used in the area and the septic tank for the community centre is approximately 10 m from well. However, due to the presence of significant clay in the overburden and a history of good bacteriological quality of the raw water, the report concluded that the aquifer is a secure groundwater supply. The well log indicates a 24 m thickness of clay and hardpan materials above the limestone aquifer located at a depth of 43.3 m to 55.2 m. These low permeability materials probably act as an aquitard to protect the bedrock aquifer from surface activities.

Similar to the Lucknow system, the regional Intrinsic Susceptibility mapping shows that the area surrounding the WHPA boundaries is designated as medium susceptibility. This is likely a result of the fact that the uppermost significant aquifer is located in the overburden above the protective aquitard. Though some protection may be afforded deeper bedrock wells, the uppermost significant aquifer is not well protected. The risk of deeper contamination may come from discontinuities in the aquitard above the bedrock aquifer. In areas of medium susceptibility, it is recommended that appropriate municipal planning measures be developed to restrict development within WHPA boundaries.

7.13 Municipality of South Bruce

Figures 7.19 and 7.20 present the overlays described above for the municipal wells in the Municipality of South Bruce, along with other base mapping features, which are discussed in the following sections. In the Engineer's Reports completed by Maitland Engineering (2001) for the Mildmay Water System and the Teeswater Water System, the susceptibility to contamination of the aquifers in the vicinity of the municipal systems is discussed and is summarized below.

7.13.1 Mildmay Water System

Figure 7.19 presents the integration of study results for the Mildmay system. The WHPAs are large and are oriented southward toward the recharge areas between the Teeswater River and Otter Creek. According to the Engineer's Report, Otter Creek is located 20 m downgradient (northeast) of the Mildmay wells. Land use upgradient of the wells is mainly residential serviced by municipal sewers, and a small chicken farm (no outside manure storage). Farther away from the well, the WHPA includes low density agricultural operations with solid manure handling systems, swamp, reforestation and bush. The soils are mainly loam to silt loam with areas of organic deposits. The borehole log for Well #1 indicates a total thickness of clay and silt of 12.8

m located above the limestone aquifer located at 33.5 m depth. The log for Well #2 indicates a total thickness of clay and silty clay of 11.9 m located above the limestone aquifer located at 32.6 m depth. These low permeability materials likely act as an aquitard to protect the bedrock aquifer from surface activities.

On a regional-scale, the Intrinsic Susceptibility mapping shows that the area surrounding the WHPA boundaries are designated as medium susceptibility. This is likely a result of the higher permeability material above the aquifer on a regional-scale providing potential conduits for contaminants to impact the aquifer. In areas of medium susceptibility, it is recommended that appropriate municipal planning measures be developed to restrict development within WHPA boundaries.

7.13.2 Teeswater Water System

Figure 7.20 presents the integration of study results for the Teeswater system. According to the Engineer's Report, The Teeswater River is located 30 m downgradient to the north of Teeswater well. The land upgradient from the wells is mainly residential serviced by private septic systems, and County Road 16 (Elora Street). The log for the well indicates a total thickness of clay and silt of 3.4 m above the limestone aquifer located at 4.0 m depth. This limited thickness of low permeability materials likely provides minimal protection to the shallow bedrock aquifer underlying it. However, the well is a flowing artesian well of more than 50 L/s, therefore the aquifer is strongly confined, indicating a confining layer exists which likely protects to the aquifer from surface activities. This confining layer may consist of the clay and silt layer as well as the upper limestone having low permeability. Also the confined conditions cause a strong upward gradient, which also limits the downward flow of contaminants.

The area within the 50-day WHPA is within the village and includes a feed mill, a fertilizer blending plant and water purifying plant for the local creamery. Land use within the 2-year WHPA is mainly low intensity agriculture, and includes the former Teeswater landfill, which was closed more than 30 years ago. Land use in the 10-year and 25-year WHPAs is agriculture, predominantly low density beef production with solid manure handling systems, and includes a fairly large hog operation and some larger cattle operations.

This is corroborated by the Intrinsic Susceptibility mapping, which shows that the area surrounding the WHPA boundaries are designated as medium to high susceptibility. This is likely a result of the limited thickness of overburden overlying the bedrock aquifer. In areas of medium susceptibility, it is recommended that appropriate municipal planning measures be developed to restrict development within WHPA boundaries.

7.14 Municipality of Kincardine

Figures 7.21 and 7.22 present the overlays described above for the municipal wells in the Municipality of Kincardine, along with other base mapping features, which are discussed in the following sections. In the Engineer's Reports completed by B.M. Ross and Associates (2001) for each of the municipal well systems the Municipality of Kincardine, the susceptibility to contamination of the aquifers in the vicinity of the municipal systems is discussed and is summarized below.

7.14.1 Tiverton Well Supply

Figure 7.21A presents the integration of study results for the Tiverton system. According to the Engineer's Report for the Tiverton system, land use in the vicinity of the Dent Well is agricultural, and the Briar Hill Well is surrounded by residential, agricultural and a ravine. There are also municipal sanitary sewers in the vicinity of each well. The soils near the wells are

mapped as coarse-textured soils (Berrien sandy loam), while the soils farther away from the wells are mapped as lacustrine, silt loam (Elderslie soil). The borehole log for Dent Well indicates a layer of clay and hardpan materials 33 m thick above the limestone aquifer; the log for Briar Hill Well indicates a layer of clay and hardpan materials 9.4 m thick. The report states that these low permeability materials likely protect the bedrock aquifer from surface activities.

This is corroborated by the Intrinsic Susceptibility mapping, which shows that the area surrounding the WHPA boundaries are designated as low susceptibility. The low conductivity overburden overlying the bedrock aquifer may be providing natural protection to the aquifer. In areas of medium susceptibility, it is recommended that appropriate municipal planning measures be developed to restrict development within WHPA boundaries.

7.14.2 Kinhuron Well Supply

Figure 7.21B presents the integration of study results for the Kinhuron system. The WHPA is located in an area mapped as fine-textured soils. The 2-year WHPA is located in a swampy area with mixed cedar and other species. The 10-year WHPA is located on level crop land with small depressional swamp areas. Land use is primarily cattle and cash crop operations, in an area of rolling topography with a surface drainage channel. According to the Engineer's Report, land use around the Kinhuron well is agricultural and residential, where residences use private sewer systems (Class 4). The nearest tile field is approximately 100 m from the well. The borehole log for the well indicates a 10 m thick layer of hardpan and a 32 m thick layer of rock above the limestone aquifer. The report states that these low permeability materials likely to protect the bedrock aquifer from surface activities, "as demonstrated by the low concentrations of nitrate, nitrite and THM in the treated water".

7.14.3 Craig-Eskrick Well Supply

Figure 7.21B presents the integration of study results for the Craig-Eskrick system. The WHPAs are long and narrow, and located in an area which trends from coarse-textured soils near the wells to fine-textured soils away from the wells. Land use in the 2-year WHPA is cedar bush. The 10-year WHPA passes through the Kincardine Airport and under Highway 21, and terminates in an area of cash crop land use with patches of bush. According to the Engineer's Report, land use in vicinity of the Craig-Eskrick well is agricultural and residential, where residences use private sewer systems (Class 4). The nearest tile field is approximately 25 m from well. The borehole log for the well indicates a layer of clay and hardpan materials 28 m thick above the limestone aquifer. The report states that these low permeability materials likely protect the bedrock aquifer from surface activities, "as demonstrated by the low concentrations of nitrate, nitrite and THM in the treated water".

7.14.4 Lake Huron Highlands Well Supply

Figure 7.21B presents the integration of study results for the Lake Huron Highlands system. The WHPAs are located in an area mapped as fine-textured soils. The 2-year WHPA is located in a swampy area with mixed cedar and other species. The 10-year WHPA is located on rougher topography dissected by surface drainage channels. The land use is roughland pasture, which trends into areas of mix of cash crop and livestock with solid manure handling systems. According to the Engineer's Report, land use in vicinity of the Lake Huron Highlands wells is agricultural and residential, where residences use private sewer systems (Class 4). The nearest tile field is approximately 30 m from well. The borehole log for Well #1 indicates a layer of hardpan materials 12.8 m thick above the limestone aquifer, and the log for well #2 indicates a layer of shale 20 m thick above the limestone aquifer. The report states that these low permeability materials likely protect the bedrock aquifer from surface activities, "as demonstrated by the low concentrations of nitrate, nitrite and THM in the treated water".

7.14.5 Port Head Estates Well Supply

Figure 7.21B presents the integration of study results for the Port Head Estates system. The WHPAs are long and narrow, and located in an area of low intensity pasture land, with some scrub bush, mixed hardwood and conifer forest. Directly upgradient of the wellhead is a gravel extraction operation. The 10-year WHPA is located on the east side of Highway 21, and terminates in an area with sparse beef productions. According to the Engineer's Report, land use in vicinity of the Port Head Estates well is agricultural and residential, where residences use private sewer systems (Class 4). The nearest tile field is approximately 30 m from well. The borehole log for the well indicates a layer of clay and hardpan materials 13.3 m thick above the limestone aquifer. The report states that these low permeability materials likely protect the bedrock aquifer from surface activities, "as demonstrated by the low concentrations of nitrate, nitrite and THM in the treated water".

7.14.6 Underwood Well Supply

Figure 7.22A presents the integration of study results for the Underwood system. According to the Engineer's Report, land use in vicinity of the Underwood well is commercial and institutional. There are also municipal sanitary sewers in the area. However, farther upgradient from the well the land use consists of pasture and cropland, which includes a livestock facility with a solid manure handling system. The soils in the area are mapped as silty clay (Chesley and Elderslie soils). The log for the well indicates a layer of clay and hardpan materials 44 m thick above the limestone aquifer. The report states that these low permeability materials likely protect the bedrock aquifer from surface activities.

7.14.7 Scott Point Well Supply

Figure 7.22A presents the integration of study results for the Scott Point system. According to the Engineer's Report, land use in vicinity of the Scott Point well is residential, where residences use private sewer systems (Class 4). Farther away from the well, land use is mainly low intensity pasture. The nearest tile field is approximately 25 m from well. The borehole log for the well indicates a layer of clay and shale 25 m thick above the aquifer. The report states that these low permeability materials likely protect the bedrock aquifer from surface activities. However, the area within the WHPAs is mapped as a medium-textured outwash material (Brisbane soil).

However, for each of these 6 well systems (Kinhuron, Craig-Eskrick, Lake Huron Highlands, Port Head Estates, Scott Point and Underwood), the Intrinsic Susceptibility mapping, on a regional-scale, shows that the area surrounding the WHPA boundaries are designated as medium to high susceptibility. This is likely a result of the fact that the uppermost significant aquifer is located in the overburden above the hardpan/clay protective layer. Though some protection may be afforded deeper bedrock wells, the uppermost significant aquifer is not well protected. The risk of deeper contamination is present in the form of abandoned private wells or "windows" in the aquitard, which have not been properly decommissioned and sealed. In areas of medium susceptibility, it is recommended that appropriate municipal planning measures be developed to restrict development within WHPA boundaries.

7.15 Summary

After completing the MODFLOW modeling, the WHPA results were integrated with the results of the Contaminant Sources Inventory and the Intrinsic Susceptibility Analysis. The WHPAs for each municipal well, from Section 6, show the area from which the wells obtain their water supply; the Intrinsic Susceptibility from Section 3 shows the vulnerability of the uppermost significant aquifer surrounding the wellfield; and, the Contaminant Sources from Section 5

present one potential risk of contaminating the groundwater entering the wells. Maps were generated of each steady state capture zone showing the location of the WHPA and the location of any potential contaminant sources, along with the regional road that transect the capture zone. Subsequently, each county road was driven as part of a “windscreen” survey of the WHPAs to identify any potential contaminant sources that were not part of the regional Contaminant Sources Inventory.

The description of the susceptibility of each municipal well to contamination, from the Engineer’s Report for each wellfield, was combined with the WHPA boundaries and the Intrinsic Susceptibility results. For each wellfield, a map was developed to include these components of groundwater protection, and a discussion was provided to integrate the vulnerability of the wellfields and the extent of the recharge areas for the wells (WHPAs). Many of the municipal wellfields are located in areas of medium to high susceptibility. In some cases it is due to a lack of low permeability overburden above the bedrock aquifer. In other cases it is due to thicker units of high permeability overburden material, which does not provide adequate protection for the aquifer. However, regardless of the reason, areas of high and medium intrinsic susceptibility found within WHPA boundaries are very sensitive zones from a groundwater protection perspective, and should be addressed during the development of provisions to implement groundwater protection.

8 Public Consultation

8.1 Methodology

To transfer study information to the public and solicit their input, a variety of different public consultation strategies were used. At the onset of the study it was understood that public involvement and subsequent buy-in to the importance of the Groundwater Study and its findings would be beneficial. A more environmentally aware public that appreciates the need to protect their groundwater resource will be more likely to endorse and support future groundwater protection strategies. Information from members of the community also provided insight about specific water resource issues that were of concern to them. This information was used during the development of the groundwater protection strategy and helped to focus the study on local concerns and issues.

To consult the public and make study results available to local stakeholders, the following specific strategies were implemented throughout the duration of the project:

- News releases to local newspaper and media outlets about groundwater issues in Grey and Bruce Counties and details related to the project progression;
- Two (2) public meetings timed to present preliminary results from the study the final study results; and,
- Development of a project website to transfer project information to the public and to convey study progress and final results (www.greybrucegroundwaterstudy.on.ca).

The following paragraphs provide details about the different public consultation strategies used during the study and their results.

8.2 Media News Releases

During the study a series of Press Releases were issued to local media outlets. These media outlets included local radio stations, newspapers and television stations. Media releases provide a cost-effective means of presenting study information in a venue that is accessible by many local residents. Each release included details regarding study progress, upcoming public meetings, and general groundwater facts pertinent to Grey and Bruce Counties. The releases also included contact information ensuring that project personnel were available to respond to specific project related questions.

An archive of media news releases is stored on the project website, which can be found at (<http://www.greybrucegroundwaterstudy.on.ca/results.htm>), and in Appendix G.

8.3 Public Meetings

To directly interact with the public two (2) public open houses were incorporated into the public consultation strategy. Drawing from discussions with the Project Steering Committee, a public meeting was arranged to include a presentation on study objectives and progress, along with a question and answer period, for the first meeting set.

The meeting was conducted on Tuesday August 27, 2002 in the Chesley Community Centre (129 4th Avenue Southeast, Chesley, ON). There were two (2) presentations, one at 3:00 p.m., and one at 7:00 p.m. Members of the Steering Committee and the Consulting Team were present to answer question related to the Groundwater Study. In total, more than 50 people interacted with the Project Team and Steering Committee. The meetings were successful at transferring study information to the public. All information presented at the public meetings was

incorporated into the project website, in recognition that every resident in the study area would not be able to attend the meetings. Furthermore, the website was promoted as a tool that residents could use during the study to peruse study progress, and at the conclusion of the study the final report and mapping would be available for the public to review.

The second meeting was scheduled to present the study conclusions and recommendations. It was conducted on February 13, 2003 in the Chesley Community Centre under the same format as the first meeting. Information presented at the second meeting was added to the website to help ensure the results were accessible to everyone.

8.4 Study Website (www.greybrucegroundwaterstudy.on.ca)

At the beginning of the study a website was developed to convey the purpose of the project and to bolster public awareness about groundwater resource issues. As the study progressed, the website was updated. Updates were completed periodically, depending on the completion of specific study milestones.

Throughout the study the website has been used to distribute information to residents of the study area, and to bordering and nearby counties such as Huron, Perth, Wellington, Dufferin and Simcoe Counties. Two of these counties have already conducted similar groundwater studies, and three are in the process of completing groundwater studies concurrently with the Grey and Bruce Counties Groundwater Study.

The website will exist after the study has been completed, and the final report will reside on the website in Adobe (*.PDF) format for interested parties to access. Web links to the study website have been added to the Grey and Bruce County websites, and to the SVCA and GSCA websites to promote its existence.

8.5 Summary

Public consultation aspects of the study were designed to provide an understanding of public opinion on the issues related to groundwater protection for Grey and Bruce Counties, and to transfer study related information to residents of the study area and surrounding counties. The overall process was designed to provide a forum for community education and awareness and to provide a foundation for future related endeavors. Public consultation included a review of similar outreaches conducted within or near the county, public meetings, and press releases. As part of public consultation a website was developed to convey groundwater resource related information and to transfer information about the progress of the study to interested stakeholders.

9 Groundwater Protection Management Strategy

9.1 Introduction

Humans can live for a month without food, but will die in less than a week without water (de Villiers, 1999). Water is continually being recycled throughout the hydrosphere. Water falls as rain or snow and replenishes the lakes, rivers, and groundwater supplies. Water is removed from plant matter (transpiration) and surface water bodies (evaporation), to be returned once again as precipitation. During any part of this hydrologic cycle, water is susceptible to the impact of human activities. As urban populations continue to grow, the need for clean and safe water supplies also grows.

Municipalities have recognized the vulnerability of water resources that supply both individual and municipal wells within their communities. Based on provincial protocols, studies were initiated across Ontario to characterize regional aquifers, to assess their intrinsic susceptibility to contamination, to inventory contaminant sources, and to define wellhead protection areas (WHPAs). With this information, municipalities and planning authorities can design a source protection strategy for drinking water. Such strategies are based on the principle that measures to prevent contamination are less expensive than measures to treat contaminated water and remediate water supplies, and are strongly favoured by the public (O'Connor, 2002).

The protection of water quality and quantity depends on the collective actions of individuals, private industry, government and other agencies. Rural property owners are responsible for maintaining their own well and septic tanks. Municipalities are responsible for the provision and maintenance of safe drinking water supplies in urban areas, and for proper sewage collection and treatment. Conservation Authorities play an important role in water conservation through watershed protection and management. Private industry is intrinsically responsible for best management practices in the utilization of water for the goods and services they provide. The farm industry in particular, has an interest in securing an adequate supply of water for livestock and crop watering.

Table 9.1 below lists common issues that can be addressed during the development of provisions to implement groundwater protection. This list is not intended to be complete, but is intended to highlight the variety of potential threats to the health of groundwater systems. This table also provides some insight into the policies, legislation, and guidelines that exist, which address specific issues regarding source protection, and whether any incentive programs currently exist to aid in these initiatives. The issues are grouped into 3 categories:

- groundwater susceptibility;
- contamination threat; and,
- data availability and jurisdictional issues.

As noted in Table 9.1, there are many policies and incentive programs that are already in-place to help protect groundwater resources. In concert with these existing initiatives, Table 9.2 outlines a number of tools that the Counties or a Conservation Authority can apply to further enhance groundwater protection. A brief discussion about each tool is provided below the table.

Table 9.1: SUMMARY OF GROUNDWATER RESOURCE MANAGEMENT ISSUES

	Issue	Implication	Policy/ Legislation	Incentive Programs
1	Improperly Constructed and Decommissioned Wells	Conduit to aquifers	MOE Reg. 903	Healthy Futures
2	Well Inspection	Conduit to aquifers		
3	Karstic Sinkholes	Conduit to aquifers		
4	Sewage Sludge Spreading	Non-point source of nutrients	MOE	
5	Nutrient Storage	Point source of nutrients		OFA
6	Nutrient Loading	Non-point source of nutrients		Farm Plans
7	Road Salting	Non-point source of chloride		
8	Fuel/Chemical Storage	Point source of chemicals	MOE Environmental Protection Act	Local BMP's and incentives
9	Absence of Monitoring Data	Difficult to assess water quality		
10	Lack of Household Hazardous Waste Pickup	Potential point source of chemical pollution		
11	Data Management	Disorganized data that is not used		
12	Poor Communication Between Government Levels	Disorganized data and difficulty implementing programs		

Table 9.2: GROUNDWATER RESOURCE MANAGEMENT TOOLS

	Tool	Applicability	Relative Value	Relative Cost
1	Education	All Issues	Medium	Low
2	Best Management Practices	Contamination threat issues	Medium	Low
3	Land Acquisition	Contamination threat and susceptibility issues	High	High
4	Conservation Easements	Contamination threat issues	Medium	Medium
5	Incentive Programs	Contamination threat issues	High	High
6	Municipal Site Leadership	Contamination threat issues	Medium	Medium
7	Integrated Information Management	Contamination threat and data management issues	Medium	High
8	Water Quality Monitoring	Contamination threat and data management issues	Medium	High
9	Municipal Sewer By-Law	Contamination threat issues	Medium	Medium
10	Official Plan Amendments	Contamination threat issues	High	High
11	Spills Contingency Plan	Contamination threat issues	Medium	Low

Education

Many different means of communicating messages to promote awareness and responsible stewardship of groundwater resources are available. Different education-oriented initiatives include:

- Groundwater information papers that can be distributed by mail with other county or local municipal mailings (taxes, water bills);
- Supplemental education aides can be provided to teachers throughout the Counties, with a fact sheet related to the reliance on groundwater within the Counties. Groundwater can be incorporated into the Ontario curriculum as part of the following Science and Technology

Units: Air and Water in the Environment, Grade 2; Soils in the Environment, Grade 3; Rocks, Minerals, and Erosion, Grade 4; Water Systems; Grade 8

(www.edu.gov.on.ca/eng/document/curricul/scientec/scientec.html);

- A Children's Groundwater Festival, similar to those conducted in Waterloo Region and Oxford County, can be initiated to increase groundwater awareness (www.cwec.ca);
- The Grey Bruce Clean Water Festival, which was started in 2001 and usually runs until September of each year in Chesley, focuses on Grade 4 students in all schools in Grey and Bruce Counties (www.waterfestival.ca);
- In some jurisdictions, signs labeled "Attention Groundwater Protection Area" or "You are Entering a Well Head Protection Area" have been constructed to promote awareness. The signs typically include a number to call in the event of a contaminant spill; and,
- A website, similar to the project website (www.greybrucegroundwaterstudy.on.ca) can be developed to provide general groundwater information and specific details about how groundwater is utilized within the counties.

Best Management Practices

Utilizing best management practices (BMPs) can greatly reduce the risk that different actions have on groundwater resources. Providing information about BMPs in sensitive areas such as WHPAs can help protect groundwater resources.

Land Acquisition

Acquiring land in a highly sensitive area should provide complete control over the land use practices within the area. In many cases this option is not feasible due to costs and other factors. Land can be acquired prior to the development of a new water supply, or future water supplies can be developed in areas where land is owned by the municipality.

Conservation Easements

A conservation easement is a voluntary agreement between a landowner and a conservation body to "conserve, maintain, restore or enhance" the natural features of a property by placing conditions on its management. The easement is a legal document that is registered on the title of the property, and binds the present owner and all future owners to the terms of the agreement. A conservation easement does not give the easement holder title to the property.

For landowners, a conservation easement is a way to protect the special attributes of their property by placing a permanent development restriction on the property, while retaining ownership. This tool has been available since 1995, when the Conservation Lands Act was revised to allow private landowners to enter into conservation easement with charitable conservation organization, municipal councils, native bands and conservation authorities. Prior to this, landowners could only enter into conservation easements with the Crown and its agencies.

Incentive Programs

Incentive programs can be used to encourage specific actions throughout the Counties or within specific sensitive areas such as WHPAs. A variety of incentive programs currently exist, such as those administered by the Ontario Ministry of Agriculture and Food (Healthy Futures). Additional incentives, focused in higher risk areas, can be used to properly decommission abandoned boreholes, upgrade existing chemical storage, properly maintain septic systems, compensate for loss of land use or productivity, and provide hazardous waste disposal.

Municipal Site Leadership

By adopting an active role and implementing BMPs at municipal sites, the Counties and their member municipalities will have much more credibility when asking other land users to adopt similar policies. In many instances, public lands reside in the most sensitive areas from WHPA perspectives. An audit of each well house and the area around the well, and the subsequent removal of potential contaminant sources such as paints, oils, fuels, lawn chemicals, and other contaminants can be completed.

Integrated Information Management

An information management system is essential to incorporate all available information during decision-making. A relational database linked to a GIS can bring together water quality, Permits To Take Water, WHPAs, groundwater vulnerability, land uses, potential and known contaminant sources. Information can also be implemented in a web application for distribution to county residents.

Water Quality Monitoring

The development of “sentinel wells” to provide water quality monitoring that could detect adverse water quality conditions upgradient of the production wells provides a warning system of potential well contamination. Sentinel wells are typically located a distance, in groundwater time-of-travel, of 2 to 5 years up gradient of the production well to provide opportunity to investigate and mitigate water quality concerns. Threshold levels, with associated action plans are important facets of this groundwater management tool.

Municipal Sewer By-Law

A sewer by-law provides a means to control the substances that are discharged to the sewer. Sewers can leak and be a source of contamination to groundwater. Furthermore, as part of the by-law, inspections could be carried out to help ensure suitable chemical storage. An inventory of chemical storage provides additional information that can be used to promote BMPs.

Official Plan Amendments

Official Plan amendments can address specific land uses and can define different sensitive groundwater zones. These zones can include WHPAs and areas of high intrinsic susceptibility. Restrictions, or the requirement of site-specific information prior to the approval of specific land uses, provide a direct means of controlling land uses in sensitive areas.

Spill Contingency Plan

A spill contingency plan promotes quick and deliberate responses to contaminant spills. A spill contingency plan typically includes information about specific responsibilities of individuals and organizations and contact numbers needed in the event of a spill.

9.2 Groundwater Protection Strategy Approach

A Groundwater Protection Strategy is a program of risk reduction to sustain the groundwater resource, both as a source of drinking water supplies and an integral component of the ecosystem. The strategy can incorporate a number of different tools. These tools may include a combination of land use policies, regulatory controls, best management practices, public education, monitoring, land acquisition, and spills contingency planning.

Policies, such as those in a municipal Official Plan, serve to identify the public interest in water quality and quantity. An Official Plan may establish goals, set objectives for water protection (aquifer and well head protection), and provide the framework for land use development and

implementation measures. The policies may also provide the rationale for the use of other planning tools such as zoning and site plan control. These are regulatory mechanisms that may be used to control development on a lot-by-lot basis, or an area-wide basis. Planning applications, such as development or land use changes, largely drive the implementation process.

Many tools are not retroactive and they do not enable a municipality to rectify a pollution problem by closing down an operation or forcing the relocation of an existing land use that may have the potential to contaminate an aquifer.

Best management practices may apply to a homeowner in the use and storage of solvents, pesticides, and the disposal of household hazardous wastes. For the agricultural industry it may include measures such as stream buffering from cattle grazing and the care with which manure and other fertilizers are applied.

The municipality may also use other statutes to complement the land use controls under the Planning Act. The Nutrient Management Act (NMA, 2001), and the associated regulations, for example, set out the requirements for the preparation of nutrient management plans and the control of intensive livestock operations. The NMA requires all farm operations to have a nutrient management plan. This ensures that all nutrients on the farm (from livestock, biosolids, legume fixation and chemical fertilizers) are used with the best possible efficiency for crop production. This program also deals with various proximity hazards by requiring setbacks in nutrient applications from the surface drainage network and wells.

Raising public awareness, through public educational programs, can have a major impact on groundwater protection and may be more important than enforcement measures. It is through the voluntary actions and practices of people on a day-by-day basis that will help protect water resources (i.e. proper use, storage and disposal of fuels, solvents, and pesticides, regular water well maintenance, installation of water saving plumbing fixtures). Municipalities can work towards developing a 'water ethic' in their communities. This means instilling a collective awareness, responsibility, and commitment to protect water on an ongoing basis.

The approach to developing a protection strategy is based on a number of assumptions:

- Water is the single most important resource for a healthy community and, as a result, a preventative or proactive approach is more appropriate than a reactive approach (i.e. prevent contamination as opposed to cleaning it up);
- Water is not confined by political boundaries;
- While the focus is on groundwater protection, the linkage to surface water resources (i.e. water cycle) necessitates a broad-based approach;
- Existing risks can be reduced through redevelopment or relocation of land uses that may threaten water quality;
- Water quantity (well yields) will remain constant;
- Impacts can be monitored through development decisions and the collection of data and that the strategy will be adjusted, where necessary; and,
- A source protection strategy is a risk management tool that will not provide an absolute solution, but rather, will minimize potential negative impacts over the short and long term.

9.3 Experiences in Other Jurisdictions

Source protection is not new in Ontario or other jurisdictions across North America. Groundwater protection programs are becoming more common in communities across North America due to the increased impetus to provide and protect clean drinking water. Many municipalities that rely on groundwater are taking proactive measures to safeguard the quality of their water from past, present, and future land uses.

9.3.1 Oak Ridges Moraine (Ontario)

The Regional Municipalities of Durham, Peel, and York, in co-ordination with the Province of Ontario, developed a conservation plan for the Oak Ridges Moraine that includes a management strategy for groundwater. The Oak Ridges Moraine Conservation Act (2001), and the associated Ontario Regulation complement the strategy by restricting land uses in WHPAs and in areas of high aquifer vulnerability. The groundwater management strategy identified 'data collection and management, data analysis and policy development and implementation' as three broad action areas. The regulation prohibits the storage of petroleum products, pesticides, inorganic fertilizers, road salt, hazardous or liquid industrial wastes, severely toxic contaminants (O.R. 347), animal manure in wellhead protection areas along with waste disposal sites, snow dumps, animal agriculture and the storage of agricultural equipment. Similar restrictions on land use activities apply to areas of high aquifer vulnerability.

9.3.2 New Brunswick

New Brunswick enacted the Wellfield Protected Area Regulation under the Clean Water Act as the basis for establishing 'Protection Areas' around municipal wellfields. Protection areas (Zones A, B and C) are based on groundwater travel times of 100 to 250-days, 250-days to 5-years and 5 to 25-years. Different land uses are restricted within each protection area. Within Zone A, prohibited uses/activities include transformer substations, storage of liquid petroleum products, pesticides, fertilizers, livestock grazing or stabling, liquid or dry animal manure composting. Residential uses are permitted but they must be serviced. Existing commercial, industrial and institutional buildings are permitted but no expansions are allowed to any residential or non-residential uses.

In Zones B and C, groundwater may be extracted from the aquifer (quantity limited) by wells that are not municipal wells. Restrictions are relaxed on uses prohibited in Zone A, when they are located in Zones B and C (i.e. liquid manure may be stored, but in a clay lined pit; livestock may be grazed if fenced; limited quantities of petroleum products may be stored; pesticide use is permitted to manufacturer's specifications).

In Zone C larger quantities of chemicals may be stored, and fertilizers may be applied. New residential, commercial, and industrial buildings may be constructed if communally serviced or where the number of residents and employees serviced by septic tanks does not exceed 25/ha. Drainage patterns for wetland areas cannot be modified without conducting an impact study on the hydrology and hydrogeology. The province has parallel restrictions to protect sensitive aquifer areas. Of interest is a maximum floor area size limit of 185 m² for a single detached dwelling and a prohibition against any conversion of a single to a multiple unit in the highest sensitivity area. In this area, fertilizer application is limited to inorganic applications.

9.3.3 Regional Municipality of Waterloo (Ontario)

The Region of Waterloo, where all communities and the rural areas are primarily dependant on groundwater for their water supply source, adopted Official Plan Amendment #12 to their Official

Plan. This amendment, now approved, provides for wellhead protection through land use restrictions in four 'sensitivity areas', which correspond to the time-of-travel within each of the zones. Certain (Category A) uses are prohibited in all four sensitivity areas (i.e. lagoons, land fill sites, disposal of abattoir and rendering wastes, auto wrecking, and salvage yards). An extensive list of uses in Categories B and C are prohibited in Wellhead Protection Sensitivity Areas 1, 2 and 3. Local municipalities are not permitted to redesignate land in local Official Plans for any of the uses prohibited in the respective sensitivity areas.

9.3.4 Oxford County (Ontario)

An approach similar to that adopted in the Region Municipality of Waterloo has been taken in Oxford County as part of the current update of the County Official Plan. However, the scope of uses differs somewhat from the Regional Municipality of Waterloo. Activities banned in WHPA's include earthen manure storage facilities, the bulk storage of tires, the refining of petroleum products, the bulk storage of chemicals or hazardous substances (except on-farm storage), the warehousing of cleaning products, pesticides, herbicides and fungicides, and the storage/warehousing of bulk storage of petroleum products.

Underground storage tanks, sumps such as dry wells and machine pits and automotive repair pits would not be permitted in the two highest sensitivity rankings, while above ground storage with secondary containment would be permitted. New development on wells and septic tanks would not be permitted in a WHPA, without meeting certain performance requirements including a disclosure report identifying the scope of the use, a detailed hydrogeological study with an associated mitigative plan, and a spill and contingency plan. Intensive livestock operations, manure storage and application are not permitted in a sensitivity 2 or 3 WHPA.

9.3.5 Alberta, Newfoundland & Labrador, Prince Edward Island

Wellhead protection measures in some other provinces, such as Alberta, Newfoundland & Labrador, and Prince Edward Island, are based on minimum separation distances as opposed to land use restrictions. Distances vary for storage of petroleum tanks (15 to 50 m); septic tanks (10 to 16 m); and sewage lagoons (100 m).

9.3.6 Nova Scotia

In Nova Scotia, the Water Act has been used as the basis for establishing 'Protected Water Areas' (PWA), which are equivalent to a WHPA, tailored to individual communities. A three-zone time-of-travel system is used for a PWA. For example, within a PWA, open fires are not permitted (April to October). Restrictions on forestry operations apply on the quantity of timber removed and setbacks of the operation. Chemical pest control products are prohibited in Zone 1 and aerial spraying is barred within a 150 m radius of a wellhead. Landfill and animal waste disposal is prohibited. The use of any vehicle, except a municipal service vehicle, is prohibited in Zone 1. Peat, gravel, rock and mineral extraction, and agricultural operations are prohibited in Zone 1. Intensive livestock operations in Zones 2 and 3 are permitted where they comply with the Provincial animal manure spreading guidelines and where the nitrogen level for all fertilizer applications does not exceed a prescribed standard.

9.3.7 The United States

Source protection in the United States (US) falls under the Federal Safe Drinking Water Act (1986), which sets the regulatory and management framework for the activities of State governments, who are largely responsible for implementation of the upper tier legislation.

Municipalities at all levels are expected to prepare protection plans, preferably on a watershed basis. The primary goal is to reduce or eliminate the potential threat to drinking water supplies within source water protection areas through federal, state, or local regulatory or statutory controls, or through voluntary measures involving the public.

Contingency planning involves water supply replacement strategies in the event of contamination. The approach typically involves the delineation of water protection areas, conducting a contaminant source inventory, and determining the intrinsic susceptibility of the source to contamination. Ordinances at the municipal level are used to govern land use activities in restricted areas. A typical Source Water Protection Plan (SWPP) includes an education and outreach campaign, a best management practices program, sign posting in the WHPA, a hazardous waste disposal program, the establishment of a water protection steering committee, and a zoning constraint overlay in the communities zoning ordinance.

The best management practices program focuses on the storage and usage of petroleum products by businesses on a voluntary or mandatory basis. A mandatory program requires a survey and compliance with the State level best management practices rules. The sign posting alerts travellers to the presence of a WHPA and how to notify emergency personnel if a contamination event should occur.

In a WHPA, prohibited land uses include hazardous waste disposal facilities, solid waste landfills, outdoor storage of road salt, junkyards, snow dumps and wastewater or septage lagoons.

9.4 Developing a Groundwater Protection Strategy

Measures applied as part of a groundwater protection strategy vary across different regions of Canada and the US. Typically, the approach that is adopted depends on local hydrologic and hydrogeologic conditions, soil structure, land use activities, legislative experience and the importance of water in the public policy agenda.

The most successful approaches depend on a package of protection measures that are both voluntary and regulatory. This is essential since much of the landscape has been developed and municipalities have limited authority to implement retroactive land use controls. Also, the resources may not exist to expropriate or acquire lands or buildings that constitute a potential or actual threat to contamination or which could serve as a buffer area (for instance, in the highest sensitivity area of a WHPA).

The development of a Groundwater Protection Strategy (Strategy) should consist of measures which provide an affordable and reasonable level of protection, and which can be adapted to changing circumstances. The following tables provide a description of the diverse initiatives and activities that can be considered during the development of a groundwater protection strategy.

Table 9.3 summarizes the role of the organizing committee in developing a protection strategy, where the purpose is to oversee the development and implementation of the strategy. Table 9.4 summarized the role of managing water protection-related information in developing a protection strategy, where the purpose is to incorporate the most pertinent data. Table 9.5 summarized the role of education in developing a protection strategy, where the purpose is to create an awareness of the ongoing need for groundwater protection. Table 9.6 summarized the impact of the WHPA boundaries the development of the protection strategy. Table 9.7 summarized the impact of the high vulnerability areas on the development of the protection strategy. Tables 9.8

through 9.10 summarize the impact of the groundwater monitoring, BMPs and spills contingency planning on the protection strategy.

The MOE and the Counties of Grey and Bruce should consider these issues in moving forward with Groundwater Protection Strategies.

Table 9.3: GROUNDWATER PROTECTION STRATEGY: ORGANIZATIONAL STRUCTURE

Item	Scope of Activities or Options	Rationale
Objective: to establish an appropriate organisational structure for the Groundwater Protection Plan program delivery	<p>Create a water protection advisory committee at the local municipal level and/or county level to provide ongoing advice to elected officials and the community on water protection measures. Committee may review monitoring activities, may provide a co-ordinating role amongst various agencies with mandates for 'water conservation or protection' and may serve to oversee the implementation of various features of the Groundwater Protection Strategy. This may include dealing with cross-boundary controls or issues i.e. adjacent municipality or county.</p> <p>Review the municipal management structure to ensure that it has the capability, resources and authority to implement a Groundwater Protection Strategy. This involves assigning responsibility by elected officials to their planning, public works and other staff for implementation of Groundwater Protection Strategy measures</p>	<p>Provides for current and ongoing responsibility for ensuring safe drinking water.</p> <p>Establishes accountability structure</p>

Table 9.4: GROUNDWATER PROTECTION STRATEGY: DATA MANAGEMENT

Item	Scope of Activities or Options	Rationale
Objective: To provide the best possible data base on which to make decisions related to water protection	<p>Design and maintain a community-accessible data base on water protection-related information e.g.</p> <ul style="list-style-type: none"> • Updated inventory of contaminant sources • Water well records • Hydrological and hydrogeological studies and investigations • Nutrient management plans • Permits to take water • Septic tank re-inspections • Water quality tests • Communal systems: location/ownership/service area/size • Initiate GIS-based mapping system for data entry on water resource information 	<p>Data base will facilitate improved decision making on planning applications and other development decisions with water protection implications</p> <p>Provides graphic (updated) information base to support municipal/community decision making on water resource matters</p>

Table 9.5: GROUNDWATER PROTECTION STRATEGY: EDUCATION

Item	Scope of Activities or Options	Rationale
Objective: to create a greater awareness on the ongoing need for groundwater protection and to develop a community 'water ethic'	Establish vision statement and logo for Groundwater Protection Strategy at a Council or Community level	Brings a focus to all Groundwater Protection Strategy related activities and a tangible goal.
	Establish the scope of topical matters for an 'education based' water protection program to prevent the contamination of drinking water: e.g. <ul style="list-style-type: none"> • Maintenance of septic tanks and wells and septage disposal • Managing communal systems • Managing above and below ground storage tanks • Managing livestock wastes • Managing vehicle washing • Safe storage and usage of household solvents, chemicals, fuels and hazardous wastes • Application of agricultural fertilisers, pesticides and fungicides • Livestock grazing and watering • Safe use of household pesticides and herbicides • Safe use of road salts • Disposal of hazardous wastes • Managing pet and wildlife wastes • Managing stormwater and drainage runoff • Plugging abandoned wells • Stewardship of private wetlands and recharge areas • Clean-up of contaminated sites 	Enables community to establish priority list of issues related to Groundwater Protection Strategy
	Initiate a newsletter or comparable news organ for distribution to householders and businesses that provides information or advice on water protection and conservation measures. Could be sent out with tax or utility bills.	One of several techniques for information dissemination
	Create a 'Safe Drinking Water Week' with several events designed to raise public awareness i.e. media campaign, trade show, demonstration projects, shopping centre displays	One of several techniques for information dissemination
	Work with school boards to develop/modify curriculum on topical issues for groundwater protection and conservation	One of several techniques for information dissemination
	Create informational handout or 'Fact Sheet' on measures for groundwater protection. Display at municipal offices, libraries and other public places	One of several techniques for information dissemination
	Convene a Town Hall meeting in the community to discuss water protection issues and community initiatives	One of several techniques for information dissemination
	Participate/sponsor event in a community event e.g. fall fair, winter carnival, home builders show etc., that focuses on groundwater protection/conservation	One of several techniques for information dissemination

Table 9.5: GROUNDWATER PROTECTION STRATEGY: EDUCATION

Item	Scope of Activities or Options	Rationale
	Partner with MOE, OMAF, MNR on a householder workshop on a selected topic(s) on groundwater protection	One of several techniques for information dissemination
	Include a 'State of the Groundwater Resource' statement as part of the mayor's annual report	One of several techniques for information dissemination
	Certify and maintain municipal staff accreditation for persons who perform operational work in water treatment and distribution facilities	Ensures the qualification of assigned staff to provide for safe drinking water
		Ensures that there is an elevated awareness and skills level in 'city hall' for staff with responsibility for water protection other than utility operators
	Review, maintain, update reference materials and publications/videos in municipal libraries on water resource, water protection subjects	Provides accessible information to the broader public
	Build in feature to municipal websites with URL linkages on municipal water protection initiatives and consumer information sources	Highlights water as an important public policy issue

Table 9.6: GROUNDWATER PROTECTION STRATEGY: WELLHEAD PROTECTION AREAS

Item	Scope of Activities or Options	Rationale
Objective: to protect municipal wellhead areas from potential contamination	Amend county and local Official Plans to incorporate policies for groundwater protection. Plan may include goal, objectives, policy statements and implementation measures for wellhead protection. Approach would be to describe a WHPA, description of time-of-travel as it relates to provincial protocols and land uses restrictions that apply to one or more sensitivity zones. See example in Appendix H	Establishes framework for variety of implementation measures municipality(ies) may use to protect groundwater
	Amend zoning by-laws for local municipalities to incorporate provisions for restricting land uses in WHPA	Establishes legal controls on land use activities in WHPA
	Co-ordinate policy development and regulatory control to address cross municipal boundary or county issues	Ensures consistency in policy and regulatory approach and provides for uniform and universal protection across WHPA
	Post signs on roads at entry points WHPA to alert travellers to the presence of a WHPA and how to notify emergency personnel if a contamination event should occur	Raises public's awareness of location on the ground of a WHPA and the importance of protecting a WHPA
	Inform all property owners, by mail, which own property in a WHPA of the presence of the WHPA and the applicable land use controls. This is in addition to the formal processes under the Planning Act, since all property owners may not participate in the planning process	Raises property owner's awareness of location on the ground of a WHPA and the importance of protecting a WHPA

Table 9.7: GROUNDWATER PROTECTION STRATEGY: HIGH AQUIFER VULNERABLE AREAS

Item	Scope of Activities or Options	Rationale
Objective: to protect high aquifer vulnerable areas from potential contamination	Amend county and local Official Plans to incorporate policies for groundwater protection. Plan may include goal, objectives, policy statements and implementation measures for high aquifer vulnerable areas. Approach would be to describe land uses restrictions that apply to one or more sensitivity zones. See example in Appendix H	Establishes framework for variety of implementation measures municipality (ies) may use to protect groundwater
	Co-ordinate policy development and regulatory control to address cross municipal boundary or county issues	Ensures consistency in policy and regulatory approach and provides for uniform and universal protection
	Amend zoning by-laws for local municipalities to incorporate provisions for restricting land uses in high aquifer vulnerable areas	

Table 9.8: GROUNDWATER PROTECTION STRATEGY: MONITORING

Item	Scope of Activities or Options	Rationale
Objective: to oversee post development impacts	Maintain an inventory of test results from monitoring of development impacts required as a condition of development approval	Enables municipality to determine development impacts and require mitigation measures where results do not meet acceptable performance standards
	Monitoring programs which generate data/information should be added to data base	Improves the information upon which subsequent applications and land use decisions will be made

Table 9.9: GROUNDWATER PROTECTION STRATEGY: BEST MANAGEMENT PRACTICES

Item	Scope of Activities or Options	Rationale
Objective: to institute measures for groundwater protection	Review haulage routes for dangerous goods and revise routes to direct the transport of dangerous goods away from WHPA and high aquifer vulnerable areas	Serves to reduce the potential for a spill of a contaminant into a groundwater capture zone
	Acquire lands/properties and buildings within Sensitivity Zone 1 of a WHPA or establish a conservation easement to restrict or establish a 'no development zone'	Serves to institute absolute control on any and all land uses that may contaminate a municipal water supply
	Direct aerial spray activities ('crop dusting') away from WHPA	Serves to reduce the potential contamination of a municipal water supply
	Establish maintenance program for sanitary and storm water sewers passing through a WHPA to ensure that the integrity of the seals and infrastructure are maintained. Where feasible, sewer mains should be relocated outside of a Sensitivity Zone 1 or 2 WHPA	Serves to reduce the potential contamination of a municipal water supply
	Review Emergency Measures Preparedness Plans to incorporate provision for dealing with a dangerous goods spill incident in a WHPA or a high aquifer vulnerability area	Serves to reduce the potential contamination of a municipal water supply
	Initiate a septic tank re-inspection program in WHPA and high aquifer vulnerability areas	Serves to reduce the potential contamination of a municipal water supply
	Stage a hazardous wastes collection program annually with a particular emphasis on WHPA and high aquifer vulnerability areas	Serves to reduce the potential contamination of a municipal water supply

Table 9.9: GROUNDWATER PROTECTION STRATEGY: BEST MANAGEMENT PRACTICES

Item	Scope of Activities or Options	Rationale
	Review utilities rights-of-way pesticide spraying practices with utility companies where such ROWs traverse WHPA and high aquifer vulnerability areas and encourage/negotiate modification of practices where necessary	Serves to reduce the potential contamination of a municipal water supply
	Encourage farm community, landscaping firms and golf course operators in WHPA and high aquifer vulnerability areas to review activities which might lead to releases of nutrients (fertilizers, manure), nitrogen or pesticides to groundwater or stormwater runoff	Serves to reduce the potential contamination of a municipal water supply
	Encourage clean up of 'brownfields' and other known or potentially contaminated sites. Remove underground (USTs) and above ground storage tanks (ASTs) that have been abandoned or are no longer used	Serves to reduce the potential contamination of a municipal water supply
	Review/enact Property Standards by-law or consider Yard Clean-up by-law under the Municipal Act as a means to clean-up properties and remove derelict motor vehicles	Serves to reduce the potential contamination of a municipal water supply
	Review/enact Site Alteration By-law under the Municipal Act to govern excavation activities and other activities which may affect erosion or sedimentation that may discharge contaminants into a municipal water supply	Serves to reduce the potential contamination of a municipal water supply
	Review winter control de-icing policy/procedures to minimize road salting in WHPA and high aquifer vulnerability areas	Serves to reduce the potential contamination of a municipal water supply
	Review sewer use by-law for contaminant discharge standards and ensure that provision is made for grit, gas and oil interceptors in site plans for industrial and commercial uses with potential contaminant discharges	Serves to reduce the potential contamination of a municipal water supply
	Install sentry wells for industrial and commercial uses to monitor contaminant discharges where septic systems or dry wells are utilized as part of the industrial processes in the general vicinity of a WHPA or and high aquifer vulnerability areas as a condition of development or redevelopment	and high aquifer vulnerability areas
	Conserve woodlots in WHPA and high aquifer vulnerability areas	Enhances water retention and water quality in areas of potential recharge
	Cap unused or abandoned water wells	Serves to reduce the potential contamination of a municipal water supply

Table 9.10: GROUNDWATER PROTECTION STRATEGY: SPILL AND CONTINGENCY PLANNING

Item	Scope of Activities or Options	Rationale
Objective: to respond expeditiously to spills and provide alternative water supply source	Develop a 'Spill Response Plan' for oil or hazardous materials. This should identify who does what at the local municipal, county and provincial level in reporting and responding to spills. This should include provision for minor and major spills and the identification of Transport Canada (CANUTEC) as the agency to identify unknown or the handling methods of chemicals	A clear spill response plan is necessary to guide the public and municipal officials through the process
	A spill response plan should be developed for industrial and commercial land uses as a condition of site development where the use is considered to have the potential for a spill during the transport or storage of contaminant products or as part of the processing operation	Serves to reduce the potential contamination of a municipal water supply
	A contingency plan should be developed to provide an alternative water supply where a municipal supply is threatened by a spill or contaminant on a short term basis i.e. pending acceptable clean-up. This should include provision for a bottled water supply (supplier, trucking and delivery) and implementation procedures (public notification) of a boil-water order. Consideration should also be given to a supplier for a pre-packaged water treatment system for an emergency or short-term solution. In a worst case scenario, a long term contingency option may require consideration for connection to a supply source from another community	A dependable supply of water is essential for householders and particularly for health care, social and educational institutions within the community.

9.5 Summary

Water resources management is a concern that has an impact on many interests in a community, both public and private. As such, a successful approach to protecting groundwater will require a coordinated and cooperative approach on an ongoing basis. The measures put into place should be done to affect a permanent approach to groundwater protection.

Some measures will be more difficult to implement than others. However, implementing these measures will likely be less costly than developing an alternative source of water. Developing a “water ethic” in the community is a paradigm where all residents will adopt water protection as routine aspects of their daily lives. The prescription of options suggested in this report will require elected officials and private authorities to establish priorities for implementation. The following recommendations should serve to provide some direction in this regard.

1. That an organizational structure be established to oversee and coordinate the implementation of water protection measures.
2. That land use planning documents be amended to establish the policy and regulatory framework for instituting effective land use controls for future development.
3. That a spills and contingency plan be initiated early in the implementation process.
4. That provision be made for the development and maintenance of a database that can be used in making decisions and incorporating new information in response to development and monitoring activities.
5. That a public education and outreach program be developed for the ongoing education of the public, the operation of the municipal water supply infrastructure and the administration and enforcement of regulatory and voluntary controls for water protection.
6. That Best Management Practices be utilized where feasible as measures to minimize the potential contamination of private and municipal water supply sources.

10 Recommendations

10.1 Overview

The Grey and Bruce Counties Groundwater Study was undertaken to develop an improved understanding of local groundwater conditions within the context of larger regional groundwater flow systems. At the onset, the objectives of the study were to:

- Objective 1: Define and map local and regional groundwater conditions;
- Objective 2: Define groundwater intrinsic susceptibility;
- Objective 3: Compile a contaminant sources inventory;
- Objective 4: Complete WHPA mapping for the municipal groundwater systems;
- Objective 5: Conduct a contaminant source assessment within each WHPA;
- Objective 6: Develop an action plan for implementing groundwater source protection; and,
- Objective 7: Promote public groundwater awareness throughout the study area.

These objective were completed and the results are presented in this report and accompanying maps. During the completion of the study, numerous recommendations arose that relate to specific study objectives, which are discussed in the following sections.

10.2 Groundwater and Aquifer Characterization Recommendations

Regional groundwater and aquifer characterization was completed across the study area. During this work, information was incorporated into a project database. To help ensure that additional information is incorporated into the database in a consistent manner, the database should be maintained by a single data warehouse. The regional characterization should be made available to other end users that may be conducting geologic and hydrogeologic investigations within the Counties.

Recommendation 1: MOE Inspection of New Wells

It is recommended that all new municipal wells must be inspected by the MOE at the time of drilling, and georeferenced as a check on location accuracy. This will improve the reliability of the information in the WWIS database, and future hydrogeologic assessments that use this database. The aquifer characterization that was completed was developed primarily with the water wells from the MOE's Water Well Information System. There is a large degree of location and elevation uncertainty associated with many of the wells drilled in the past. The most important wells in the WWIS are municipal wells, which are often the deepest wells in the database. The inspection of all new municipal wells by the MOE will have the added benefit of reducing elevation uncertainty because the well elevation can then be checked against the Province's Digital Elevation Model of the Counties.

Recommendation 2: Investigate Karst Along the Niagara Escarpment

An improved understanding of the groundwater flow throughout the County was developed through the regional aquifer characterization. Groundwater, in general, flows from east to west, and there is significant recharge along the Niagara Escarpment where the overburden is thin and karst features are more common. These karst features (caves, sinkholes, sinking streams and lakes, springs and karst pavement) are an important component of the Intrinsic Susceptibility mapping that was completed for the study area. As a result, they should be considered during the development of a Groundwater Protection Strategy, and further study on the distribution of karst areas should be completed, to better understand their importance in groundwater recharge and groundwater vulnerability along the Niagara Escarpment.

10.3 Groundwater Intrinsic Susceptibility Recommendations

Groundwater intrinsic susceptibility for the uppermost significant aquifer was evaluated using the MOE Water Well Information System and information on karst areas within the Counties. Throughout most of the study area, the uppermost groundwater flow system was considered to have medium or high susceptibility. Some areas of Bruce County were characterized by low susceptibility due to the thick units of clay and silt-rich Quaternary deposits.

Recommendation 3: Incorporating ISI Results into the Groundwater Protection Strategy

Medium and high susceptibility classes are the most important classes to consider in terms of aquifer vulnerability. They result from the presence of high permeability overburden units with little, or no, low conductivity layers overlying the aquifer. These areas are of significance when they are located near municipal pumping wells. As a result, it is recommended that medium and high susceptibility areas be considered as part of a Groundwater Protection Strategy, as discussed above in Section 10.7.

10.4 Groundwater Use Assessment Recommendations

A regional groundwater use assessment was conducted using information on municipal, communal, agricultural, private and large-scale industrial water taking. An analysis of the Permits To Take Water database shows that there are 254 PTTW using groundwater, of which 37 are large-scale users. Based on maximum permitted rate, large-scale use in the Counties is 75.8 million m³/year. Estimates of the rural population of the study area were used to determine rural domestic groundwater use, which is 4.7 million m³/year. The Engineer's Reports were used to determine municipal groundwater use, which is 6.8 million m³/year. The PTTW database was used to estimate communal and campground groundwater use, which is 1.1 million m³/year. Census Canada data was used to estimate agricultural groundwater use, which is 8.2 million m³/year. As a result, total groundwater use within the Counties is 96.6 million m³/year.

Recommendation 4: Localized Understanding of Groundwater Use Impacts

A regional water budget of the study area concludes that the Counties receive an average of between 650 and 1,300 million m³/year (75 - 150 mm/year) of recharge. Although this indicates that at a regional-scale there is an abundance of groundwater (9.9% of the available recharge is currently being used for water supply within the Counties), further investigation at a more local, sub-watershed scale should be considered. This may be completed in combination with watershed-based groundwater models, which can be used to delineate sensitive recharge areas that supply baseflow discharge, provide estimates of aquifer yield, optimize the location for the development of new municipal well supplies, and aid in the evaluation of new Permit To Take Water applications for groundwater use.

Recommendation 5: Better Tracking of Actual Water Use for PTTW Permits

Currently, Permits to Take Water (PTTW) are contained within a different database than the Water Well Information System (WWIS), and actual groundwater use is unavailable. To facilitate better permit tracking, the information in the Permit to Take Water database should be linked to the WWIS. Where possible, WWIS well identification numbers have been linked to specific permits, however this should be completed at a Provincial level to ensure consistency between different jurisdictions.

10.5 Potential Contaminant Sources Inventory Recommendations

Potential contaminant sources were mapped within the study area using information collected from the MOE database. This assessment included contaminant spills, fuel storage sites, PCB storage areas, and MOE Certificates of Approval. Of the 1037 records in the database, 237

were located and mapped. Location information and the accuracy of each record was incorporated into the project database. In addition, 37 active landfills, 88 closed landfills, and 20 wastewater treatment plants were located and added to the database. An analysis of the WWIS database determined that there are 526 potentially abandoned boreholes within the study area, which could provide a route of contamination from the ground surface to lower aquifers. Finally, a contaminant assessment within each WHPA was completed, which georeferenced 339 additional potential contaminant source locations.

Recommendation 6: Further Investigation of Potential Contaminant Sources

The WHPA contaminant assessment indicates that there are many more potential contaminant sources within the Counties than are contained in the MOE database and the other information sources that were surveyed. Further investigation of potential contaminant sources within the study area is recommended. This will provide a more complete database of potential contaminant sources within the Counties. As additional information is collected or becomes available, the information contained in the database of potential contaminant sources should be updated. This database should continue to be maintained by each County.

10.6 WHPA Specific Recommendations

A large component of this groundwater study was the development of 22 MODFLOW models to define the WHPA boundaries for 45 municipal groundwater systems in Grey and Bruce Counties. These models were all based on the same 3-layered conceptualization of the groundwater environment around each wellfield, for which the model domain was chosen to represent the flow conditions on a sub-regional scale (i.e. containing the rivers, lakes and streams within a sub-watershed). Each model was calibrated to the water levels from the WWIS wells within the model domain. As such, these models provide a good representation of the steady-state groundwater flow field within the model domain, and are well suited to defining the recharge area (time-related capture zones) for the municipal wells contained within them.

Recommendation 7: Use of the MODFLOW Models to Update WHPA Results

It is recommended that Grey and Bruce Counties use these groundwater models to update WHPA boundaries as new information becomes available. Groundwater use by each municipality changes over time due to changes in development, wellfield configuration, well pumping rates, and the development of new groundwater wells. This was evident during the finalization of the WHPA model for Markdale, whereby one well (Terra Drive) was removed from the model and two new wells (#3 and #4) were added to the model. The groundwater model, once it was calibrated, was easily used to provide updated WHPA boundaries based on new information about wellfield configuration. These groundwater models are also useful tools for identifying potential locations for new municipal wells, in conjunction with the GIS database of medium and high vulnerability areas and potential contaminant sources.

10.7 Groundwater Protection Strategy Recommendations

Recommendation 8: Develop and Implement a Groundwater Protection Strategy

It is recommended that Grey and Bruce Counties, in consultation with the MOE, develop and implement a Groundwater Protection Strategy that incorporates some of the different components described in the report. A Protection Advisory Committee comprised of representatives similar to those involved during the current study should oversee the refinement and implementation the Strategy. The knowledge of the Steering Committee for the current study can be used during the implementation of the Strategy. An advisory committee can provide the guidance necessary to evaluate different Strategy options and to coordinate between each County and its member municipalities. The importance of groundwater to Grey

and Bruce Counties underscores the need to manage the resource. The Protection Advisory Committee should evaluate the following Groundwater Protection Strategy components:

- Data Management;
- Public Education;
- Wellhead Protection Areas;
- Areas of High Vulnerability;
- Groundwater Monitoring;
- Best Management Practices;
- Proper Well Decommissioning;
- Spill and Contingency Planning;
- Official Plans; and,
- Enforcement of Existing Rules and Regulations.

8.1 Ensure that Groundwater Data is Properly Managed

Data management facilitates improved decision making on planning applications and other development decisions with water protection implications. The ability to overlay different types of information within a GIS (Geographic Information System), such as WHPAs and locations of fuel storage tanks, provides decision makers with the information necessary to evaluate future planning initiatives and potential risks to groundwater resources. Data should be managed at one location, with coordination between other parties that may use the information. As additional data and metadata becomes available, the database should be revised to incorporate this information. Land Information Ontario (LIO) may be able to accommodate these needs. However, since the mandate of LIO is very broad, a local role will likely be required to dynamically maintain the database. Upper tier municipalities have found that an active data management role is essential for proactive groundwater management.

8.2 Use Public Education Initiatives to Foster Groundwater Protection

Education initiatives are recognized to be an excellent, cost-effective means of fostering change with regards to groundwater protection and resource management. Education promotes current and ongoing responsibility for ensuring safe drinking water. Working through different avenues, the importance of protecting groundwater can be promoted. The County should continue to provide groundwater information on their website, and should consider supplementing the website with additional information to promote conservation and protection measures. The Internet provides a means for many County residents to access information at their leisure. Developing groundwater information for inclusion with municipal and County mailings should also be considered. Reminders in mailings can be used to promote specific initiatives, and also point residents to other information sources such as the County website and other agencies.

8.3 Acknowledge and Protect Wellhead Protection Areas

WHPAs represent the most critical areas surrounding a well. The WHPAs that were delineated for this groundwater study include the 50-day, 2-year, 10-year, and 25-year WHPAs for the different municipal wellfields. A part of the future Groundwater Protection Plan should include the acknowledgement of these wellhead protection areas.

Throughout this study the time-of-travel through the groundwater environment has been an important concept in defining the susceptibility and protection of groundwater resources. With this in mind, the Protection Advisory Committee should consider different protection measures

based on the time-of-travel for the different WHPAs. Greater protection should be established in the more sensitive (shorter time-of-travel) zones.

8.4 Acknowledge and Protect High Aquifer Vulnerability Areas

Much of the groundwater resources of Grey and Bruce Counties have been characterized as having a high susceptibility. These areas are concentrated in the Bruce Peninsula, along the Niagara Escarpment, and in areas where the overburden is very thin. The Protection Advisory Committee should consider protection measures in these areas since they represent zones where surface contaminants could quickly migrate to the bedrock and pose a risk to groundwater users in the area. This could be accomplished by defining these areas as a sensitivity Zone 2. In areas of thick overburden, intrinsic susceptibility mapping of the production aquifer should be undertaken to better understand the vulnerability of the production aquifers.

8.5 Monitor Groundwater Quality

Sentinel monitoring wells help to identify groundwater contaminants before they can impact a well. The Protection Advisory Committee should consider sentinel wells, located within each WHPA. Where possible, the wells should be located near the 2-year time-of-travel WHPA. Sentinel well monitoring should be conducted semi-annually. Specific chemical and physical constituents to be monitored can be finalized after an initial analysis of Ontario Drinking Water Standard (ODWS) parameters is completed. Based on the review of water quality at the different municipal wells, fluoride, chloride, nitrate, heavy metals, and other chemicals related to nearby land uses should be considered in the monitoring program. Trigger levels for each monitoring well should be established to help ensure water quality concerns are identified. Triggers should address situations where a specific chemical concentration is consistently increasing or exceeds a ODWS threshold. Chemical constituents that are non-health related (such as hardness) should be differentiated from health related parameters.

Different municipal wells should be assigned different priorities during any sentinel well program, since it may not be feasible to construct and maintain sentinel wells for each municipal well. Municipal wells that serve larger numbers of residents, and wells in areas serviced by a single well must should be balanced against municipal wells that serve small numbers of residents, and systems with multiple wells capable of supplementing the municipal system. It is appropriate to provide initial guidance related to the priority that should be assigned to developing sentinel wells for specific municipal systems. Note that the prioritization provided below was completed at a preliminary level, and that further refinement of the different priority levels would be appropriate.

8.6 Encourage the Use of Best Management Practices

Best management practices can reduce the risk that specific actions have on groundwater. Wherever possible, BMPs should be developed and encouraged. A comprehensive list of BMPs is provided in Section 9. Within sensitive areas, the Protection Advisory Committee should consider incentives to promote the implementation of BMPs. At wellheads, the Counties and the municipalities should take a leadership role by implementing BMPs. It is important that local government set an example for others to follow.

At each municipal well, the following measures should be considered:

- No application of fertilizers or pesticides;
- No vehicles within 25 m of the well (where this is not feasible, no vehicles should be permitted on the property the well is on);
- Construct a fence surrounding the well property;

- No storage of solvents, paints, salt, or other hazardous material within 25 metres of the wellhead;
- Appropriate site grading away from all wells;
- Properly decommission any wells (pumping and observation) that have been abandoned; and,
- Procedures to follow with telephone numbers to call in the event of a spill or emergency.

Where possible, the 25 m buffer distance should be enlarged to include all of the property on which the municipal well is situated.

The following are examples of environmental programs that apply to the agricultural community.

Environmental Farm Plans – a program designed to encourage individual farmers to evaluate the environmental hazards associated with all aspects of their farm and farming operations and to identify measures to eliminate or minimize the risks. This program is associated with an incentive program to assist farmer in making the most urgent changes. The farm plan is an ongoing record of environmental stewardship and is facilitated by a regional coordinator and standardized through evaluation and acceptance by a peer review committee. This activity deals with the kinds of risks associated with the farm enterprise.

Best Management Practices – a series of educational booklets documenting a broad range of practices which can be incorporated into farm operations to reduce environmental risk. The booklets provide guidance as to which practices are best suited to individual farm situations and how best to adapt them. These booklets deal with the kinds of risks associated with components of the farm enterprise.

Nutrient Management Act (NMA) (Bill 81) and associated regulations - This is a program to categorize farm operations and define the nature of regulation and timing for implementation of a nutrient management plan. This will ensure that all nutrients on the farm (from livestock, biosolids, legume fixation and chemical fertilizers) are used with best possible efficiency for crop production. This program also deals with various proximity hazards by requiring setbacks in nutrient applications from the surface drainage network and wells. As such, it considers, to some extent, the risks of sediment transport by water erosion.

It is important to note that surface water quality considerations have been the primary consideration in the development to date of nutrient management protocols. While good nutrient management practices will provide a measure of protection to all water resources (both surface and ground), efforts are currently under way to provide specific attention to groundwater issues related to nutrients. In addition, the current act deals specifically with nutrient management issues; additional efforts are being directed to management practices which will minimize risks from pathogens.

Some aspects of the Nutrient Management Protocols associated with the NMA are currently under review (the latest update was released March, 2003). As a consequence, it is not possible to make definitive statements about the relationship between this act and associated protocols and a groundwater protection strategy. However, it is useful to note that the NMA and associated protocols propose the following categories of farm in the consultation draft stage (November 2002).

For farms with a livestock component to the operation are defined by number of nutrient units. A nutrient unit means the amount of nutrients that give the fertilizer replacement value of the lower of 43 kg of nitrogen or 55 kg of phosphate as nutrient as established by reference to the nutrient management protocol. Generally the source of these nutrients is from animal waste.

The categories listed are taken from the consultation draft (November, 2002) but the descriptions have been modified to reflect the current situation as per the March, 2003 release and subsequent clarification (Derek Nelson, personal communication).

Category 1: In the November draft this category was for farms with up to 30 nutrient units – it has been reduced to farms with 5 nutrient units or less (annual maximum) - exempt from the act and regulations;

Category 2 (under review): 30 to 150 nutrient units (annual maximum);

Category 3 (under review): 150 to 300 nutrient units (annual maximum);

Farms with 6 to 299 nutrient units (annual maximum) – the categories of livestock farms in this size range have been referred to the provincial advisory committee for confirmation, revision, amalgamation or other treatment and also to determine a timeframe for implementation of the regulations.

Category 4: 300 or more nutrient units (annual maximum)

Categories of farm with no livestock component (from the November, 2002 consultation draft) have all been referred to the provincial advisory committee for confirmation, revision, amalgamation or other treatment and to determine a timeframe for implementation of the regulations. These categories include:

Category 5 (under review): Greenhouse and container nurseries; a farm unit or operation which is capable of generating or receiving greenhouse and container nursery leachate;

Category 6 (under review): Non-agricultural source material generators and users; a farm unit or operation which is capable of generating or receiving a non-agricultural source material as defined in the protocol;

Category 7 (under review): Miscellaneous agricultural sources material sources and users; a farm unit or operation that is capable of generating or receiving an agricultural source materials as set out in the protocol;

Category 8 (under review): Commercial fertilizer users; a farm unit which land applies only commercial fertilizers;

Category 9 (under review): An intermediate operation.

The phasing of the NMA and regulations depends on the category of operation. Based on information from OMAF (March 21, 2003) and Derek Nelson (personal communication) the following timings have been announced.

- The current category 1 farms (5 nutrient units or less) are exempt from the NMA and regulations.
- July 1, 2003; is the current implementation date of the proposed regulations for (i) all new livestock farms, (ii) livestock farms expanding into the large category and (iii) farms expanding within the large category.

- In 2005; all existing large livestock farms (300 or more nutrient units annual maximum) are to be covered by the nutrient management regulations.

While not all categories and times of implementation of regulations associated with the NMA are available, the categories will ultimately provide definitions of agricultural operations directly linked to regulations. It would appear useful to refer to these categories as they are finalized to assess the implications of agricultural operations of groundwater.

8.7 Address Well Abandonment

Proper well decommissioning is controlled under MOE Regulation 903, which requires proper abandonment of all wells. However, in the past this regulation has not been strictly enforced, and improperly abandoned wells exist throughout the Counties.

Improperly decommissioned wells pose a threat to groundwater quality. Surface contamination can move through an abandoned or poorly constructed well very quickly, circumventing protective till within the overburden. Where feasible the Counties should identify improperly abandoned wells and work with MOE to have them properly sealed, for which the estimated cost to properly decommission a well is on the order of \$3,000 to \$6,000 per well. These efforts should be focussed in highly sensitive areas such as the 2-year capture zones, and should be linked to funding opportunities such as those provided by the OMAF “Healthy Futures” program.

8.8 Ensure Spills and Contingency Planning is in Place

A clear spill response plan is necessary to guide the public and municipal officials in the event of a spill. A spill contingency plan promotes a quick and deliberate response to a contaminant spill. A plan should include information about specific responsibilities of different individuals and organizations and contact numbers that should be called in the event of a spill. Businesses should be encouraged to develop of spill and contingency plans and information regarding who should be contacted can be distributed to all businesses or targeted to businesses that are in WHPAs.

8.9 Incorporate Groundwater Protection Planning into Official Plans

In addition to the strategies recommended for consideration above, the Counties and the Protection Advisory Committee should consider incorporating groundwater resource protection policies into the County Official Plans. Appendix H includes additional information and example language that could be used if the County Official Plans are to be amended as part of a Groundwater Protection Strategy.

8.10 Better Enforcement of Existing Rules and Regulations

Stricter enforcement of rules and regulations that pertain to groundwater and water wells will improve the security of groundwater supplies throughout the Counties. Current guidelines related to well abandonment and proper decommissioning (Reg. 903) are in place, however it is evident that landowners are not aware of the requirements of the Regulation and that enforcement of the Regulation is not occurring. Information could be distributed to the public, informing them about Reg. 903, and that only licensed drillers are permitted to construct wells.

11 Glossary

This glossary is intended to provide a definition of the terms that are used throughout the text of this Final Report, as well as the acronyms used to represent scientific terms, and the units of measure used to define parameter values.

11.1 Glossary

Aquifer – (1) A geologic formation, a group of formations, or a part of a formation that is water bearing. (2) A geological formation or structure that stores or transmits water, or both, such as to wells and springs. (3) An underground layer of porous rock, sand, or gravel containing large amounts of water. Use of the term is usually restricted to those water bearing structures capable of yielding water in sufficient quantity to constitute a usable supply. (4) A sand, gravel, or rock formation capable of storing or conveying water below the surface of the land. (5) A geologic formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.

Aquifer Capability – The maximum rate of withdrawal that can be sustained by an aquifer without causing an unacceptable decline in the hydraulic head of the aquifer, or causing unacceptable changes to any other component of the hydrologic system. Capability is calculated at a watershed scale in terms of a water budget.

Aquifer Recharge Area – An area in which water can infiltrate the soil and replenish an aquifer relatively easily. Aquifer recharge areas allow precipitation to reach an aquifer by infiltration. Recharge areas are often much smaller than the total aquifer area and are therefore very important to the aquifer. Artificially increasing runoff in a recharge area through paving or clearing can devastate an aquifer.

Aquifer Susceptibility (or Vulnerability) – An intrinsic property of a groundwater system that depends on the sensitivity of that system to human and/or natural impacts. Intrinsic Vulnerability depends solely on the hydrogeologic properties of an aquifer. Specific Vulnerability depends on hydrogeologic properties of an aquifer and an imposed contaminant load.

Biosolids – The end product from the processes used to treat wastewater, often from municipal, industrial or institutional sources. Biosolids are primarily organic materials but can contain other trace elements such as metals.

Digital Elevation Model (DEM) – A model of terrain relief in the form of the matrix. A digital representation of the ground surface topography.

Geographic Information System (GIS) – A computer software system with which spatial information may be captured, stored, analyzed, displayed, and retrieved.

Groundwater – Water that infiltrates the earth's surface. Groundwater originates as precipitation and is suspended by the soil for varying lengths of time depending on soil type, vegetation cover, and land use. Groundwater is responsible for feeding vegetation and for recharging aquifers.

Hydraulic Conductivity (K) – A coefficient of proportionality describing the rate at which water can move through an aquifer or other permeable medium. In the Standard International System, the units are cubic meters per day per square meter of medium (m³/day/m²) or m/day (for unit measures).

Hydrogeologic – Those factors that deal with subsurface waters and related geologic aspects of surface waters.

Hydrogeology – The part of geology concerned with the functions of water in modifying the earth, especially by erosion and deposition; geology of ground water, with particular emphasis on the chemistry and movement of water.

Hydrologic Cycle (Water Cycle) – The circuit of water movement from the earth's atmosphere to the earth and back through sequential stages such as precipitation, runoff, infiltration, evaporation, transpiration, etc. The hydrologic cycle has many different variations. Typically, water vapour in the atmosphere falls to the earth as rain. It is then transported to an open body of water via streams and rivers or through runoff or aquifer discharge. It is then evaporated and returns to the atmosphere as vapour. Alternately, once water enters the soil it may be absorbed by plants and returned to the atmosphere through transpiration (evaporation of water from the leaves of a living plant).

Hydrology – The science of earth's water resources. The scope of hydrology includes water's occurrence, distribution, circulation, physical and chemical properties, and reactions with and effects on the environment.

Lithology – (Geology) (1) The scientific study of rocks, usually with the unaided eye or with little magnification. (2) Loosely, the structure and composition of a rock formation. (3) The description of rocks, especially sedimentary Clastics and especially in hand specimen and in outcrop, on the basis of such characteristics as colour, structures, mineralogic composition, and grain size.

Moraine – An accumulation of boulders, stones, or other debris carried and deposited by a glacier. Moraines, which can be subdivided into many different types, are deposits of Glacial Till. Lateral Moraines are the ridges of till that mark the sides of the glacier's path. Terminal Moraines are the material left behind by the farthest advance of the glacier's toe. Each different period of glaciation leaves behind its own moraines.

Non-Point Source Pollution (NPS) – Pollution discharged over a wide land area rather than from a specific location. Non-point source pollution actually originates from numerous small sources. It is quickly spread out and diffused, and it generally infiltrates the soil contaminating the groundwater or is deposited by runoff into rivers and lakes. NPS is much more difficult to measure and control than pollution from a specific point such as a sewer drain or a smoke stack. Agricultural chemicals and exhaust deposits in streets are examples of non-point source pollution.

Overburden – Any loose unconsolidated material, which has been deposited upon solid rock (i.e. sand or clay).

Permits to Take Water (PTTW) – Permits issued by the Ministry of the Environment for large-volume surface or groundwater withdrawals. Permit sets out the location, source maximum volume, number of days of extraction, expiry date of permit.

Pumping Test – A method used to determine the hydraulic characteristics of an aquifer whereby water is pumped from a well and the discharge from the well, and the drawdown of the water level are measured over time. These values are used in an appropriate well flow equation to quantify the hydraulic characteristics of an aquifer and the capacity of a well.

Recharge – The addition of water to the groundwater system by natural (precipitation and infiltration) or artificial processes.

Relational Database – A collection of data stored in a number of data tables that are linked by common relationships that can be easily and efficiently converted into information through database queries and other operations.

Runoff – Rainwater that does not infiltrate the soil but flows across the earth's surface into a body of water. The proportion of rainwater that penetrates the soil varies considerably

depending on soil type and area covered by impervious materials. Runoff has the potential to “carry” contaminants resting on the earth’s surface into streams, lakes, reservoirs, etc. A watershed with a high percentage of its area covered by impervious materials (pavement and buildings) will have a comparatively high rate of runoff. Runoff is especially problematic in agricultural areas where residues from agricultural chemicals and high concentrations of animal waste rest on the earth’s surface.

Till (Glacial) – Unstratified drift, deposited directly by a glacier without reworking by meltwater, and consisting of a mixture of clay, silt, sand, gravel, and boulders ranging widely in size and shape.

Transmissivity – The rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient.

Water Budget - A water budget is general model of the complete hydrological cycle. For this study, the water budget provides estimates of: the quantity of water cycling through the study area (average annual precipitation); the quantity of water returned to the atmosphere by evapotranspiration, the quantity of water contributed annually to surface water resources, and the quantity of water that contributes to groundwater resources.

Water Resources – The supply of groundwater and surface water in a given area. Water resources is a general term used to describe all of the usable water in a specific geographical area.

Water Table – The level of groundwater saturation. The depth of the water table is determined by the quantity of groundwater and the permeability of the earth material and fluctuates accordingly. The water table is often the upper surface of an unconfined aquifer.

Watershed – A region or area over which water flows into a particular, lake, reservoir, stream, or river; a drainage basin. Watersheds are separated by ridges or areas of high ground. The boundary between two watersheds is a line connecting points of runoff divergence. Generally, a river or stream runs through a watershed collecting runoff. The stream then flows into another watershed downstream or into the sea.

Watershed Management – The process of analyzing and maintaining the land and water resources of a watershed in order to conserve those resources for the benefit of the watershed’s residents. Since watersheds are defined by natural hydrology, watershed management is the most logical water conservation approach. Many problems are better solved at the watershed level than by addressing individual problems within a watershed. Effectively managing a watershed requires knowledge of it attainable only through thorough research. The watershed’s natural resource base, health status, threats, and land use patterns as well as the needs of its residents must be understood. Good watershed management takes advantage of community resources and involves cooperation of various community organizations and residents.

11.2 List of Acronyms

amsl	above mean sea level
AO	Aesthetic Objective
ARDA	Agricultural and Rural Development Act
BTEX	Benzene-Toluene-Ethylbenzene-Xylene (petroleum)
CA	Conservation Authority
CCME	Canadian Council of Ministers of the Environment
CofA	Certificate of Approval
DEM	Digital Elevation Model
DND	Department of National Defense
EC	Environment Canada
ET	Evapotranspiration
FNR	First Nations Reserve
GIS	Geographic Information System
GSC	Geological Survey of Canada
GSCA	Grey Sauble Conservation Authority
GRCA	Grand River Conservation Authority
GUDI	Groundwater Under the Direct Influence (of Surface Water)
GW	Groundwater
ID	Identification
IR	First Nations Reserve
ISI	Intrinsic Susceptibility Index
LPRCA	Long Point Region Conservation Authority
MAC	Maximum Acceptable Concentration
MNDM	Ministry of Northern Development and Mines
MNR	Ministry of Natural Resources
MODFLOW	Modular Finite-Difference Groundwater Flow Model (USGS)
MOE	Ministry of the Environment
MVCA	Maitland Valley Conservation Authority
NRMS	Normalized Root Mean Squared Error
NRVIS	Natural Resource and Values Information System (MNR)
NTU	Nephelometric Turbidity Unit
OFA	Ontario Federation of Agriculture
OMAF	Ontario Ministry of Agriculture and Food
PCB	Polychlorinated Biphenyl
PTTW	Permit To Take Water
PWQO	Provincial Water Quality Objectives
SVCA	Saugeen Valley Conservation Authority
SW	Surface Water
TCE	Trichloroethylene
TSSA	Technical Standards and Safety Association
TOR	Terms of Reference
TOT	Time of Travel
USGS	United States Geological Survey
UST	Underground Storage Tank
UTM	Universal Transverse Mercator
WHPA	Wellhead Protection Area
WWIS	Water Well Information System
WWTP	Waste Water Treatment Plant

11.3 Units of Measure

cm	centimetres
ha	hectares
igpm	imperial gallons per minute
in	inches
km	kilometres
km ²	square kilometres
L	litre
L/day	litres per day
L/s	litres per second
L/s/m	litres per second per metre
m	metres
m ³ /s	cubic metres per second
m ³ /day	cubic metres per day
mg/L	milligrams per litre
mm	millimetres
mm/yr	millimetres per year

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Appendix A

ISI Process Sheet

Appendix A - Process Sheet for Calculating Intrinsic Susceptibility

Theory

Mapping of the groundwater susceptibility should be undertaken using the MOE Water Well Information System (WWIS) as a primary data source. Vulnerability mapping is a tool that can be used to make planning decisions to protect groundwater resources. The susceptibility of an aquifer to contamination is a function of the susceptibility of its recharge area to the infiltration of contaminants, which can be evaluated using an Intrinsic Susceptibility Index (ISI).

ISI is calculated on a well-by-well basis by summing the product of the thickness of each unit (b) in the well log and a corresponding K-factor (see Schedule C of the MOE Terms of Reference or Table A1 below), as represented in following the equation. The thickness (b) used is from the ground surface to the water table for the shallow unconfined aquifer system and from the ground surface to the top of any lower confined aquifer.

$$ISI = \sum_{i=1}^i b_i \cdot K_{Fi}$$

where:

- i = the number of geologic units recorded in the water well record (borehole)
- b = the thickness of each geologic unit recorded in the water well record.
- K_F = the Representative K-Factor as outlined in the MOE Terms of Reference:

Calculation

The ISI is calculated step-by-step, for each borehole, as follows:

1. Determine the location of the water table in the borehole,
2. Determine the geologic unit in the borehole which contains the water table,
3. Determine the type of material (aquifer / aquitard) in this unit:
 - a. If aquifer material (sand, gravel), then the aquifer is UNCONFINED,
 - b. If not, determine if the aquifer is CONFINED,
4. Continue sequentially through the underlying units of the borehole until the aquitard bottom is found (top of aquifer):
 - a. If the aquitard bottom is greater than 4 metres below the water table, the aquifer is CONFINED,
 - b. If not, the aquifer is UNCONFINED,
5. Calculate ISI, where the total depth to the first significant aquifer is:
 - a. For an UNCONFINED aquifer, from ground surface to the water table,
 - b. For a CONFINED aquifer, from ground surface to the bottom of the aquitard.
6. Multiply each borehole's geologic unit thickness by the associated K-Factor to create the K-Product.
7. Sum all the K-Product values for each borehole to create the ISI-Total for each well.

8. For Grey and Bruce Counties, change the ISI-Total Value of wells that fall in a karst feature's area to 20
9. Change area with and overburden thickness of less than 6.0 meters to an ISI values of 20.
10. Class ISI values as HIGH (<30), INTERMEDIATE (30-80) and LOW (>80)
11. Assign a category to each class: HIGH=1, INTERMEDIATE=2, LOW=3
12. Grid categories using Natural Neighbour (25 m aggregation, 50 m cell size, orange=1, yellow=2, green=3).
13. Plot ISI map at 1:100,000 scale.
14. Overlay data points used for interpolation.

Table A1 Generic Representative Permeability (K-Factor)

Geomaterial	Representative K-Factor (dimensionless)*	K-Value (m/s) @75% range**	Highest K-Value (m/s)
Gravel Weathered dolomite/limestone Karst Permeable basalt	1	1.00E-01 1.00E-06 1.00E-03 1.00E-03	0.1
Sand	2	1.00E-2	1.00E-2
Peat (organics) Silty sand Weathered clay (<5m below surface Shrinking/fractured & aggregated clay Fractured igneous & metamorphic rock Weathered shale	3	1.00E-3 1.00E-4 1.00E-4** 1.00E-4** 1.00E-5 1.00E-5***	1.00E-3
Silt Loess Limestone/dolomite	4	1.00E-6 1.00E-6 1.00E-6	1.00E-6
Weathered/fractured till Diamicton (sandy, silty) Diamicton(silty, clayey) sandstone	5	1.00E-7 1.00E-7*** 1.00E-8*** 1.00E-7	1.00E-7
Clay till Clay (unweathered marine)	8	1.00E-9*** 1.00E-10	1.00E-9
Unfractured igneous & metamorphic rock	9	1.00E-13	1.00E-13
<p>* Representative K-Factors are relative number and do not correspond directly to the exponent or index of the observed K-Values for the geomaterial in the group.</p> <p>** Correspondence with descriptors of observed K-Values in Freeze & Cherry 1979. Derived using the length of the line to determine the 75% value and rounding to the highest K-Value.</p> <p>*** Estimated value based on field studies in Ontario.</p> <p>Note: When actual study data is available, this chart should be used to assign the corresponding K-Values for locally defined geomaterial (e.g. Maryhill Till) and then apply the appropriate Representative K-Factor in the calculation of the index of the groundwater intrinsic susceptibility to contamination.</p>			

Schedule C of the MOE Terms of Reference, November 2001.

Appendix B

Large Groundwater Users Survey

Appendix B: Results of Large PTTW Holder Survey for Grey and Bruce Counties

Large PTTW Holder	Original Owner	Location	PTTW No.	Water Source	Water Use	Average daily flowrate (m ³ /day)	Max Permit Flow (m ³ /d)
Craigeith Ski Club	(same)	Town of The Blue Mountains	80-P-1022	Georgian Bay and spring-fed pond	Snow making	Dec to Feb max 225 gpm 2-10 hrs/day 0-5 days/week depends on weather	6546.24
Georgian Aggregates & Construction Inc.	(same)	Township of Clearview (Simcoe County)	01-P-1036	Ponds	Aggregate washing	May to Oct 10-11 hr/d, 5 d/wk 2500-3000 gpm	3273 21821
	Seeley & Arnill		96-P-5019	Quarry water (pumped into wash ponds)	Dewatering of quarry recycled into wash ponds	250 gpm – Pump1 84 gpm – Pump2 pump year-round	1636.56 549.884 3273.12
			96-P-5019				
E.C. King Contracting Ltd.	(same)	Chapel's Pit, Town of Saugeen Shores	77-P-1051 (municipal water for ready-mix)	Pond	Aggregate washing	Pond used 8-9 months/year	2620.8
			Well	Domestic use only	Small flows unknown		
	(same)	Clarksburg Pit, Town of The Blue Mountains	76-P-1016	Pond	Aggregate washing	Pond used 8-9 months/year	1698
				Well	Ready-mix & orchard irrigation	Well pumps 2500gal / week	
	Walter Mair (Fiegrist Haulage) before 1990	Mair's Pit, Township of Chatsworth	90-P-1013	Spring-fed pond	Aggregate washing	No water taking for 14 years	1363.8
	(same)	Sarawak Pit, Township of Georgian Bluffs	99-P-1225	Quarry water	Dewatering of quarry	Quarry dewatered every 5-6 years	6480
Quarry water				Aggregate washing	No aggregate washing for 12 yrs		
Wayne Schwartz Construction Limited	(same)	Township of Chatsworth (Former Sullivan Township)	01-P-1106	Groundwater-fed pond	Aggregate washing	June to September 500gal/min 8 hours/day 3-4 days/month	818.28
Robert A. Livingstone	(same)	Town of The Blue Mountains	84-P-1004	Spring	Feeds two fish hatchery ponds	Continuous flow	
Alvis Fogels, Springhills Trout Farm	Springhills Trout Farm	Township of Chatsworth (Former Village of Holland)	79-P-1207	Spring (on escarpment)	Feeds two indoor buildings	Flow is variable (90 to 2000 gpm, avg 300-800 gpm)	7855.488

Appendix B: Results of Large PTTW Holder Survey for Grey and Bruce Counties (continued)

Large PTTW Holder	Original Owner	Location	PTTW No.	Water Source	Water Use	Average daily flowrate (m ³ /day)	Max Permit Flow (m ³ /d)
MNR/Chatsworth Fish Culture Station	MNR	Township of Chatsworth (Former Sullivan Township)	71-P-0158 (main station?)	Two springs	Used for fish culture	Summer flows 200-300 gpm	6546.24
			73-P-0153 (substation)	Well	Used for fish culture	Aug to mid-May 1500 gpm 24 hrs/day	9819.36
Bryan Van Den Bosch	(same)	Priceville, Township of Grey Highlands	99-P-1271	Well	Not in use	Pump capacity 150 gpm	982.08
Glenbriar Bottled Water Co. Ltd. (sold to local farmer)	Dave George, Glenbriar Bottled Water Co. Ltd.	Municipality of South Bruce (between Teeswater and Formosa)	91-P-0007	Well	Never used	No pump	201.6
Sandy Gott, Aquafarms 93	Alex Plomp	Feversham, Township of Grey Highlands	00-P-1365 00-P-1365 00-P-1365	Well 1 & 3	Commercial use – drinking water	Use up to max permitted rate 24 hrs/day 7 days/week 12 months/year	1309.248 981.936
				Well 2	Commercial use – drinking water	Use up to max permitted rate 0-12 hrs/day 0-6 days/week 12 months/year	174.566
			77-P-1011 77-P-1011 77-P-1011	3 wells	See 00-P-1365	See 00-P-1365	35747.42 216.0 324.0
			Spring	Not in use	Not in use		
Frank Beirnes	(same)	Township of Chatsworth	93-P-0060	Spring-fed stream	Potential use for bottled water	Not in use	454.6
				2 test wells (near spring)	Pumping tests	Tested at 50 gpm and 20 gpm	
Trillium Springs Fish Farm	Constructed in 1960's, bought and renamed in 1980's	Township of Chatsworth (Former Village of Holland)	82-P-1009 82-P-1009 98-P-1101 98-P-1101	Pond (flows through indoor facility and discharges)	Fish hatchery	500 gal/min (permitted)	654.624 3273.12

Appendix B: Results of Large PTTW Holder Survey for Grey and Bruce Counties (continued)

Large PTTW Holder	Original Owner	Location	PTTW No.	Water Source	Water Use	Average daily flowrate (m ³ /day)	Max Permit Flow (m ³ /d)
Lake Huron Fishing Club	Port Elgin's old water reservoir	Upper Avenue in Port Elgin	85-P-1028	Spring-fed pond	Fish hatchery	Use pond water 24 hrs/day 7 days/week Sept to Apr	720.1
	old salt mine in 1800's (apparently 3 original wells)	Reunion Park, Town of Kincardine	91-P-0011	Well (re-lined in 1990)	Fish hatchery	24 h/d, 7 d/wk, 12 mo/yr, 120 to 285 gpm	2062.1
Georgian Triangle Anglers Association	(same)	Nottawasaga Valley Conservation Authority, 99 acres off the Bruce Trail	90-P-1001 90-P-1001	Spring	Fish hatchery	Continuous flow	229.118 196.387
Gibraltar Springs	Larry Eagles	Town of The Blue Mountains	92-P-0099 92-P-0099 92-P-0099	3 wells	Bottled water	May to August 16 h/d, 5 d/wk Sept – April 24 h/d, 7 d/wk approx. 67 gpm ea	491.04 491.04 491.04
Artemesia Waters Ltd.	Canlim Inc.	Township of Grey Highlands	99-P-1011	1 well (spring-fed)	Bottled water and one household	Pumps 70 gpm, 24 h/d, 7 d/wk, 12 mo/yr	483.84
John Robertson	Canadian High Country Spring Water Ltd.	Township of Grey Highlands	95-P-1002	1 well	Six trailers, one household, one shop	Pump rate 2000 gal/min	
				Spring	Bottled water?	Not in use currently	1035.576
Michael Smyth		No response	93-P-0057		Bottled water	No response	327.312
Formosa Springs Brewery Ltd.	Formosa Springs/ Denbrock-Terry Inc	No response	85-P-1021 85-P-1022		Bottled water	No response	1636.56 425.506
	Northern Algonquin Brewing Co. Ltd.		90-P-1080 90-P-1080 92-P-0059		Brewing and Soft Drinks		164.4 217.92 2724.0
	Brick Brewing Company Limited		00-P-1030 00-P-1030		Brewing and Soft Drinks		218.88 435.84
Saugeen Springs RV Park (Jim Dillon)	Aylmer Sazabo, Saugeen Springs RV Park	Municipality of West Grey (formerly Bentinck)	93-P-0077	Well	Water supply for the park/campground	Apr-Dec, as req'd 24 h/d, 7 d/wk (meter reads avg. 20 to 30 m ³ /d)	288.0
					Private home	Year round	

Appendix B: Results of Large PTTW Holder Survey for Grey and Bruce Counties (continued)

Large PTTW Holder	Original Owner	Location	PTTW No.	Water Source	Water Use	Average daily flowrate (m ³ /day)	Max Permit Flow (m ³ /d)
Homestead Resort	1028541 Ont Ltd / Homestead Resort	Township of Southgate	99-P-1200 99-P-1200	Well	Water supply for resort complex	Apr-Oct, Dec-Feb 24 h/d, 7 d/wk as required	6.813 408.823
Pike Lake Golf Centre Ltd.	(same)	Municipality of West Grey (formerly Normanby)	97-P-2008	Well	30 homes (future 62 homes max)	24 h/d, 7 d/wk, 12 mo/yr as req'd May 5000 gpd Feb 2400 gpd Capacity 100 gpm	648.0
QTF Foods Inc.	Bruce Foods Inc.	Tiverton, Municipality of Kincardine	93-P-0058	Well (supplements municipal water use)	Food processing	Used minimally, capacity unknown Full production: Aug to Dec Light production: Feb to May	65472.0
Gardner Orchards Ltd.		Municipality of Meaford	73-P-0426 73-P-0426 73-P-0426	3 ponds (man-made)	Irrigation – Fruit Orchards	4 mo/yr 2 d/wk, 8 h/d 500 gpm	1091.04
Saugeen Golf Club	(same)	Town of Saugeen Shores (formerly Saugeen Township)	96-P-1018 96-P-1018 96-P-1018	Spring-fed pond	Irrigation – Golf Course	Pump 4.5 mo/yr (May-Sep) capacity 900 gpm Permitted: 150 d/yr, 10 h/d	165.0 588.46 1150.56
Walkerton Golf & Country Club Ltd.	(same since 1925)	Municipality of Brockton (formerly Brant Township)	64-P-0351	Well	Irrigation – Golf Course	May to September as required pumps 75-80 gpm 2-18 h/d, 0-7 d/wk capacity 200 gpm	545.52
Stone Tree Golf & Fitness Club	(same)	City of Owen Sound	98-P-1096 98-P-1096 98-P-1096	3 spring-fed man-made ponds	Irrigation – Golf Course	May to September 300-600 gpm 0-7 d/wk varies with precip.	550.0 550.0 550.0
Tymatts Development Inc.	Atkinson Irrigation (?)		01-P-1031 01-P-1031 01-P-1031 01-P-1031	3 groundwater transfer wells	Irrigation – Golf Course		1309.0 281.0 373.0 196.0

Appendix B: Results of Large PTTW Holder Survey for Grey and Bruce Counties (continued)

Large PTTW Holder	Original Owner	Location	PTTW No.	Water Source	Water Use	Average daily flowrate (m ³ /day)	Max Permit Flow (m ³ /d)
Formosa Seniors Non-Profit Housing Co.	(same)	Formosa, Municipality of South Bruce	90-P-1007	Well	Water Supply for 25 apartment units	pump as needed 24 h/d, 7 d/wk, 12 mo/yr	78.554
Town & Country Nursery			91-P-0004 91-P-0004		Irrigation – Nursery		907.0 16.4
Ronald K. Hills			89-P-1015 89-P-1015		Agricultural		1363.8 181.84
Shane Ardiel			00-P-1010 00-P-1010		Agricultural		218.208 218.208
Double Diamond Construction Ltd.	(same)	Port Elgin	98-P-1088	Excavation dewatering	Dewatering of sewer excavations	Expired in 1999 (temporary permit)	13092.48
Petro-Canada Products Ltd.			89-P-1007	Excavation dewatering	Remedial excavation	Permit expired in 1990	200.0
Interforest Ltd.	(same)	Municipality of West Grey (formerly Bentinck)	97-P-1067 97-P-1067 97-P-1067 97-P-1067	1 well (dug)	Domestic services and boiler feed	24 h/d, 7 d/wk, 12 mo/yr capacity 100 gpm	6546.24 327.312 545.52 545.52
				3 ponds?	Fire protection	As needed	
					Sprinkling logs	6 mo/yr, 24 h/d	
					Filling vats	12 mo/yr, 5 d/wk	
Mel McKean Investments Ltd.		Town of The Blue Mountains	91-P-0019	Spring-fed pond	Aggregate washing	Not used in 2 yrs Quantity unknown	
Lotowater Limited			01-P-1004		Miscellaneous		3600.0
			01-P-1233	Well	Pumping Test		5236.992
Patricia F. Bain	(same)	Township of Grey Highlands (former Osprey Township)	65-P-0656 65-P-0656	Spring-fed pond	Originally for recreation (swimming)	Not in use (no pump)	
				Well		Small quantities	
H. Bye Construction Ltd.		Township of Southgate (former Egremont Twp)	97-P-1080	Man-made pond	Dewatering pit (has been pumped 2-3 times in 35-40 years, say once every 10-15 years)	Plan to dewater pit in fall of 2002 for 3 weeks 24 h/day	3927.744
Harold Sutherland Construction			01-P-1082	Spring-fed pond	Recycled for use onsite		2160.0
			90-P-1004				216.0

Appendix C

Municipal Groundwater Users Survey

Appendix C: Results of Municipal Water Supply Survey for Grey County

Municipal Well Name	MOE Well No.	Date of C of A	Certificate of Approval No.	PTTW No.	Maximum Permitted Rate (m ³ /day)	Average flowrate (m ³ /day)	Years for average flow rate	Pumping Test Data (Y/N)
TOWNSHIP OF GEORGIAN BLUFFS								
Shallow Lake Water System:		Jan 9/02	3508-549SRG			163.9	1999 – 2001	N
Well #2	unknown	Mar 8/96	7-0102-96-006	96-P-1002	696	either Well #2 or Well #3		
Well #3	2514177	Apr 22/99	amendment	96-P-1002	696	in use at one time		
Forest Heights Water System:		Feb 8/02	6411-56VQ5X			15.19	1997 – 2001	N
Well #1	2508479	May 30/86	7-0156-85-006	98-P-1026	38.5	both wells in use		
Well #2	2508481			98-P-1026	38.5	at the same time		
Maplecrest Subdiv Water System:		Jan 25/02	5323-55EPSK			7.03	1997 – 2001	N
Well #1	2503973	Nov 7/88	7-1302-88-006	98-P-1027	47.55	both wells in use		
Well #2	unknown			98-P-1027	25.50	at the same time		
Pottawatomie Village Water Sys:		Feb 8/02	0872-56TQX4					N
Well #1	2509008	Dec 14/87	7-1696-87-006			standby		
Well #2	unknown			98-P-1025	93.0	21.84	1997 – 2001	
TOWNSHIP OF CHATSWORTH								
Chatsworth Water Works:		2002	5751-574KBV			161	1997 – 1999	
Well #1	unknown	Jan 16/84	(under appeal)	84-P-1023	818.208	either Well #1 or Well #2		
Well #2	Unknown		7-0001-83-846	84-P-1023	818.208	in use at one time		
Well #3	2507128	Apr 27/78	7-1104-77-786	96-P-1067	125.015	emergency standby only		
Walter's Falls Water Works:		2002	3642-5ALLTL			8.71	1997 – 1999	
Well #1 (TW-1/89)	2510458	Jul 12/91	7-1776-90-917	91-P-0014	795	either Well #1 or Well #2		
Well #2 (TW-2/89)	2510467			91-P-0014	795	in use at one time		
MUNICIPALITY OF WEST GREY								
Neustadt Water Supply System:		Feb 16/94	9056-54MHVO					N
Well #1	unknown		7-0445-93-946	94-P-0008	276	54	1998 – 2000	
Well #2	unknown			94-P-0008	916	25	1998 – 2000	
Well #3	unknown			94-P-0008	527	50	1998 – 2000	
Durham Municipal Water Works:		Mar 20/89	7-0286-89-006					N
Well #1B	2508882			92-P-0051	1363.8	752.6	1997 – 2001	
Well #2	2500906			78-P-1032	1636.5	581.0	1997 – 2001	

Appendix C: Results of Municipal Water Supply Survey for Grey County (continued)

Municipal Well Name	MOE Well No.	Date of C of A	Certificate of Approval No.	PTTW No.	Maximum Permit Rate (m ³ /day)	Average flowrate (m ³ /day)	Years for average flow rate	Pumping Test Data (Y/N)
TOWNSHIP OF SOUTHGATE								
Dundalk Water Works:			0535-53ZSU2			660	1997 – 2001	N
D1	2500898		7-0466-82-006	not req'd*		182	1997 – 2001	
D2	2500897		7-0793-81-006	not req'd*		82	1997 – 2001	
D3	2505043		7-0720-76-006	76-P-1013	1182	396	1997 – 2001	
TOWN OF HANOVER								
Town of Hanover Water Works:			5623-53VJU7					N
Well #1	1400668	Jan 25/02	7-0300-87-006	63-P-2588	4546	868.6	1997 – 2001	
Well #2	1406414			88-P-1002	8182.8	884.5	1997 – 2001	
MUNICIPALITY OF GREY HIGHLANDS								
Markdale Water Works:			9722-53THK7					
Isla Well	2504533		6-0265-73-693	76-P-1002	2618	2180	2001	N
Terra Well	2504534			76-P-1002	1309	1090	2001	N
Kimberley-Amik-Talisman Water Supply:			7-0643-93-947	94-P-002	1125	100	2001	N/A
Spring #1	N/A							
Spring #2	N/A							
Feversham (Beaver Heights) Water Supply:			2519-53TQBS					
Well #2	2504880		7-1006-74-001	96-P-1071	45.8	38.2	2001	N
Well #3	unknown		7-1042-74-006	96-P-1071	98.2	81.8	2001	N

* Wells commissioned prior to the requirement for a Permit To Take Water.

Appendix C: Results of Municipal Water Supply Survey for Bruce County

Municipal Well Name	MOE Well No.	Date of C of A	Certificate of Approval No.	PTTW No.	Maximum Permitted Rate (m ³ /day)	Average flowrate (m ³ /day)	Years for average flow rate	Pumping Test Data (Y/N)
MUNICIPALITY OF ARRAN-ELDERSLIE								
Tara Water Works:		May 23/02	9840-59WH59			362.3	1997 – 2001	
Well #2	1402117	May 8/79	7-0077-79-006			171.6	2000 – 2001	N
Well #3	1404886	Oct 26/60	60-B-622	79-P-1195	727	270.5	2000 – 2001	N
Chesley Water Works:								
Victoria Park Well	1401005	Jan 23/02	1450-543K4V	00-P-1355	982	175.8	1997 – 2001	N
Community Park Well	unknown			00-P-1355	982	644.0	1997 – 2001	N
TOWN OF SOUTH BRUCE PENINSULA								
Fiddlehead Well	1402710	Feb 7/02 Jan 23/02 Jul 7/78 Nov 5/71	9866-56WRJD 0606-53VLPL 7-0144-77-786 7-0569-70-716	00-P-1111 95-P-1014	327	7.4	1997 – 2001	N
Cambridge-Collins Water Works:		May 30/02	2066-5AFLSY					
Well #1 (PW1-71)	1402833	Feb 8/02	8620-56WG6D			not in use		N
Well #2 (PW2-84)	1406211	Jan 29/02 Dec 31/02 Oct 29/84 Dec 20/71	5390-55MSAY 0166-4Y6QZA 7-0713-83-846 7-0724-71-006	85-P-1007	60.75	4.7	1997 – 2001	N
Robins Well	1402630	May 30/02 Feb 7/02 Jan 17/02 Feb 5/97 Jan 20/77 Mar 15/71	5150-5AJHDL 8453- 56WGWX 7081-55MRM4 7-0568-70-977 7-0998-76-776 7-0568-70-716	95-P-1055	141.75	19.2	1997 – 2001	N
Fedy Well	1402717	May 30/02 Jan 17/02 Oct 30/96	5708-5AFPV9 7361-55MS9T 7-1036-96-006 7-0430-71-006	90-P-1044 see Winburk	117.8	Decommissioned in 1996 (Fedy subdivision now serviced by Winburk Well)		N
Forbes Well	1402347	May 30/02 Jan 17/02 Dec 12/96	3230-5AFNRRN 4011-55MS75 7-0841-95-006	95-P-1016	69	15.6	1997 – 2001	N

Appendix C: Results of Municipal Water Supply Survey for Bruce County (continued)

Municipal Well Name	MOE Well No.	Date of C of A	Certificate of Approval No.	PTTW No.	Maximum Permitted Rate (m ³ /day)	Average flowrate (m ³ /day)	Years for average flow rate	Pumping Test Data (Y/N)
TOWN OF SOUTH BRUCE PENINSULA (continued)								
Trask Well	1405022	May 30/02 Jan 17/02 Dec 12/96	5019-5AFQZH 4691-55MS97 7-0955-95-006	95-P-1017	80	20.3	1997 – 2001	N
Huron Woods Water Works:		May 30/02	3048-5AJMYE			49.1 (#3+#6)	1997 – 2001	N
Well #1 (standby)	1402346	Jan 17/02	1802-55M5AB	93-P-0004	104.6	standby		
Well #2 (standby)	1403336	Sep 10/91	7-0803-81-917	93-P-0004	52.3	standby		
Well #3	1403732	Feb 4/82	7-0803-81-826	93-P-0004	130.9			
Well #4	1404410	Jun 13/77	7-0333-77-006		not in use			
Well #5	1405497	Aug 22/70	7-0556-70-746		not in use			
Well #6	1405682	Jul 25/69	7-0470-69-006	93-P-0004	457.6			
Foreman Well	1403056	May 30/02 Feb 14/02 Jan 17/02 Nov 8/96	7491-5AJP3V 8399-56WRU9 1703-55MS7U 7-0874-72-736	00-P-1109	163.4	9.8	1997 – 2001	N
Thomson Well	1404411	May 30/02 Feb 8/02 Jan 16/02 Oct 17/77	7287-5AJQ9C 0707- 56WUHG 0108-55MS8E 7-1072-76-776	00-P-1107	196.0	6.3	1997 – 2001	N
Winburk Well	unknown	May 30/02 Feb 8/02 Jan 16/02 Oct 30/96 Mar 3/83 May 24/78 Jul 14/71	0342-5AFRL6 0354- 56WBRG 8076-53VQ37 7-1036-96-006 7-0026-83-006 7-1159-77-786 7-0430-71-006	90-P-1044 00-P-1110 (includes Fedy)	262.1	31.3	1997 – 2001	N
Gremik Well	1405077	Jun 10/02 Jan 31/02 Aug 30/79	6868- 5AFMGU 2756-53YP5W 7-0477-79-006	00-P-1108	328.3	19.0	1997 – 2001	N

Appendix C: Results of Municipal Water Supply Survey for Bruce County (continued)

Municipal Well Name	MOE Well No.	Date of C of A	Certificate of Approval No.	PTTW No.	Maximum Permitted Rate (m ³ /day)	Average flowrate (m ³ /day)	Years for average flow rate	Pumping Test Data (Y/N)
MUNICIPALITY OF BROCKTON								
Geeson Avenue Well	1405166	Nov 8/79	4047-53YN25 original CofA	99-P-1052	50	13.0	2000 – 2002	N
Chepstow-Powers Subdivision Well	1404829		8086-57RILE	99-P-1051	50.4	14.5	2000 – 2001	N
Lake Rosalind Well	1406588		9289-5DEJ6W 7-0623-88-007	no permit		28.7	2000 – 2002	N
TOWNSHIP OF HURON-KINLOSS								
Village of Ripley:			5844-58VSGN 7-0832-95-006	95-P-1006	864	313	1998 – 2001	N
Well #1	1401617							
Well #2	1408736							
Lakeshore Area Water Works:								
Point Clark Development Wells:			0586-58WJ8P 7-0968-95-967	95-P-1028	3273.12	561	1998 – 2001	N
PCD Well #1	1405108							
PCD Well #1	1408712							
Blairs Grove Wells:			0586-58WJ8P 7-0968-95-967	93-P-0055	2620.8	58 no pump	1998 – 2001	
BG Well #2	?							
BG Well #3	1408715							
Murdock Glen Wells:			0586-58WJ8P 7-0968-95-967	91-P-0080 95-P-1053	196.56 1814.4	311	1998 – 2001	
MG Well #1	1406036							
MG Well #2	1408241							
Huronville South Wells:			0586-58WJ8P 7-0968-95-967	92-P-0061 95-P-1029	271.3 3927.744	246	1998 – 2001	
HS Well #1	1405554							
HS Well #2	1409043							
Lucknow Water Works:			1183-59FP2K 7-0423-84-006 7-0202-68-006	78-P-1052	681.9	70 446	1999 – 2001 1999 – 2001	N
Well #4	1401878							
Well #5	1401880							
Whitechurch Water Works:			5920-547JVC	61-P-0450	227.28	25	2001	N
Well #1	1401736							

Appendix C: Results of Municipal Water Supply Survey for Bruce County (continued)

Municipal Well Name	MOE Well No.	Date of C of A	Certificate of Approval No.	PTTW No.	Maximum Permitted Rate (m ³ /day)	Average flowrate (m ³ /day)	Years for average flow rate	Pumping Test Data (Y/N)
MUNICIPALITY OF SOUTH BRUCE								
Mildmay Water System:								
Well #1	1402162	Mar 2/87 Dec 22/86	7-0126-87-006 7-1353-86-006	01-P-1230 68-P-0088	1637.3 545.5	624.8	1997 – 2001	N
Well #2 (standby)	1407200	Dec 20/89	7-1724-89-006	01-P-1230 00-P-1372	1637.3 982.0	standby		N
Teeswater Well (artesian)	1408942	Jun 11/97	7-1098-96-976	96-P-1059	1309.2	421.8	1997 – 2001	N
MUNICIPALITY OF KINCARDINE								
Tiverton Well Supply:								
Dent Well	1402695		7-0187-80-006 7-1017-97-006	93-P-0051	393.12	280.3	1998 – 2001	
Briar Hill Well	1404483			93-P-0050	524.16			
Underwood Well	1402991		7-1017-86-006 7-1027-72-006	73-P-0401	90.92	25.6	1999 – 2001	
Scott Point Well	1402494		7-0434-92-006		77.76	26.6	1999 – 2001	
Kinhuron Well	1402680		5646-549RHP 7-0576-71-006	81-P-1027	72.736	29.1	1998 – 2001	
Craig-Eskrick Well	1405699		8146-549R9S 7-0849-81-820	00-P-1297		24.3	1998 – 2001	
Lake Huron Highlands Well Supply:								
Well #1	1402790		5857-55HGYH 7-0983-73-736	00-P-1386 81-P-1030	116.378	standby		
Well #2	1405703		7-0637-81-007	(expired)		183.6	1998 – 2001	
Port Head Estates Well	1408079		8737-54APYX 7-0569-92-006	92-P-0033	294.624	9.2	1998 – 2001	

Appendix D

Contaminant Source Assessment Form

**Grey and Bruce Counties
Groundwater Study
Business/Chemical Use Inventory**

Date: _____

Please fax to (fax #) by: _____

1. Facility Information

Facility Name: _____ “ Completed at time of visit
 Street Address: _____ “ Left for business to complete
 Georeferenced Location: Latitude: _____ Longitude: _____ “ Not completed
 Person Interviewed: _____
 Title: _____ Phone: _____
 Name for the Mailing: _____ Title: _____
 Mailing Address: _____
 City: _____ Prov: _____ Postal Code: _____
 Did you know your facility is located close to a municipal well? “ Yes “ No
 If known, please indicate any previous facilities on the

2. Type of Service/Product

NAICS code: _____
 (refer to Terms of Reference, *Schedule D*)

Facility Type:
 “ Office “ Restaurant “ Medical “ Agriculture: Livestock Operations
 “ Gas Station “ Industry “ Dry Cleaner “ Agriculture: Crops/Nursery
 “ Computers “ Waste Management “ Automotive “ Printer/Photo Processor
 “ Manufacturing “ Other _____

3. Materials Handling

How do you dispose of waste? “ On site “ Off site
 Is spill cleanup equipment available? “ Yes “ No
 Is there a septic system on site? “ Yes “ No “ Unknown
 Are there floor drains in the shop? “ Yes “ No “ Unknown

 Any wells on site? Industrial Use Well “ Number of Wells: _____
 Abandoned/Unused Well “ Number of Wells: _____
 Irrigation Well “ Number of Wells: _____
 Drainage Well “ Number of Wells: _____
 Drinking Water Well “ Number of Wells: _____
 Observation Well “
 Is there an Environmental Mgt System in Place? “ Yes “ No Date Initiated _____

Microbiological Contaminants Storage								
	Estimated Volume				Type of Storage Container			Physical State
	Earthen	Concrete	Metal	(Sol/Liq/Gas)				
Biosolids (e.g., pulp/paper waste)	_____	_____	_____	_____	_____	_____	_____	_____
Septage	_____	_____	_____	_____	_____	_____	_____	_____
Sewage Sludge	_____	_____	_____	_____	_____	_____	_____	_____
Agricultural Manure	_____	_____	_____	_____	_____	_____	_____	_____
Other Animal Waste	_____	_____	_____	_____	_____	_____	_____	_____
Organic Contaminants Storage								
	Liquid	<25L	25-250L	250-2500L	>2500L	Above	Below	Physical
	Solid	(<5 gal)	(5-50 gal)	(50-500 gal)	(>500 gal)	Ground	Ground	State
		<25Kg	25-250Kg	250-2500Kg	>2500Kg	Tank	Tank	(Sol/Liq/Gas)
Petroleum Products	“	“	“	“	“	“	“	_____
Insecticides/ Herbicides	“	“	“	“	“	“	“	_____
Brake/Transmission Fluid	“	“	“	“	“	“	“	_____
Acids/Bases/Caustics	“	“	“	“	“	“	“	_____
Paints/Dyes/Stains	“	“	“	“	“	“	“	_____
Cleaning Solutions (soap, detergents, etc.)	“	“	“	“	“	“	“	_____
Chlorinated Solvents (degreasers, dry cleaning fluid, TCE, etc.)	“	“	“	“	“	“	“	_____
Other Solvents (MEK, MIBK, acetone, varsol, etc.)	“	“	“	“	“	“	“	_____
Film Chemicals	“	“	“	“	“	“	“	_____
Registered Wastes (PCBs, asbestos, etc.)	“	“	“	“	“	“	“	_____
Inorganic Contaminants Storage								
	Estimated Volume							Physical State
								(Sol/Liq/Gas)
Fertilizers	_____							_____
Salt	_____							_____
Other _____	_____							_____

5. Landscape Application of Materials

	Yes	No	Estimated Area of Application
Nutrients (manure, biosolids)	“	“	_____
Fertilizers	“	“	_____
Pesticides	“	“	_____
Salt (e.g., paved surfaces)	“	“	_____
Other _____	“	“	_____

Comments: _____

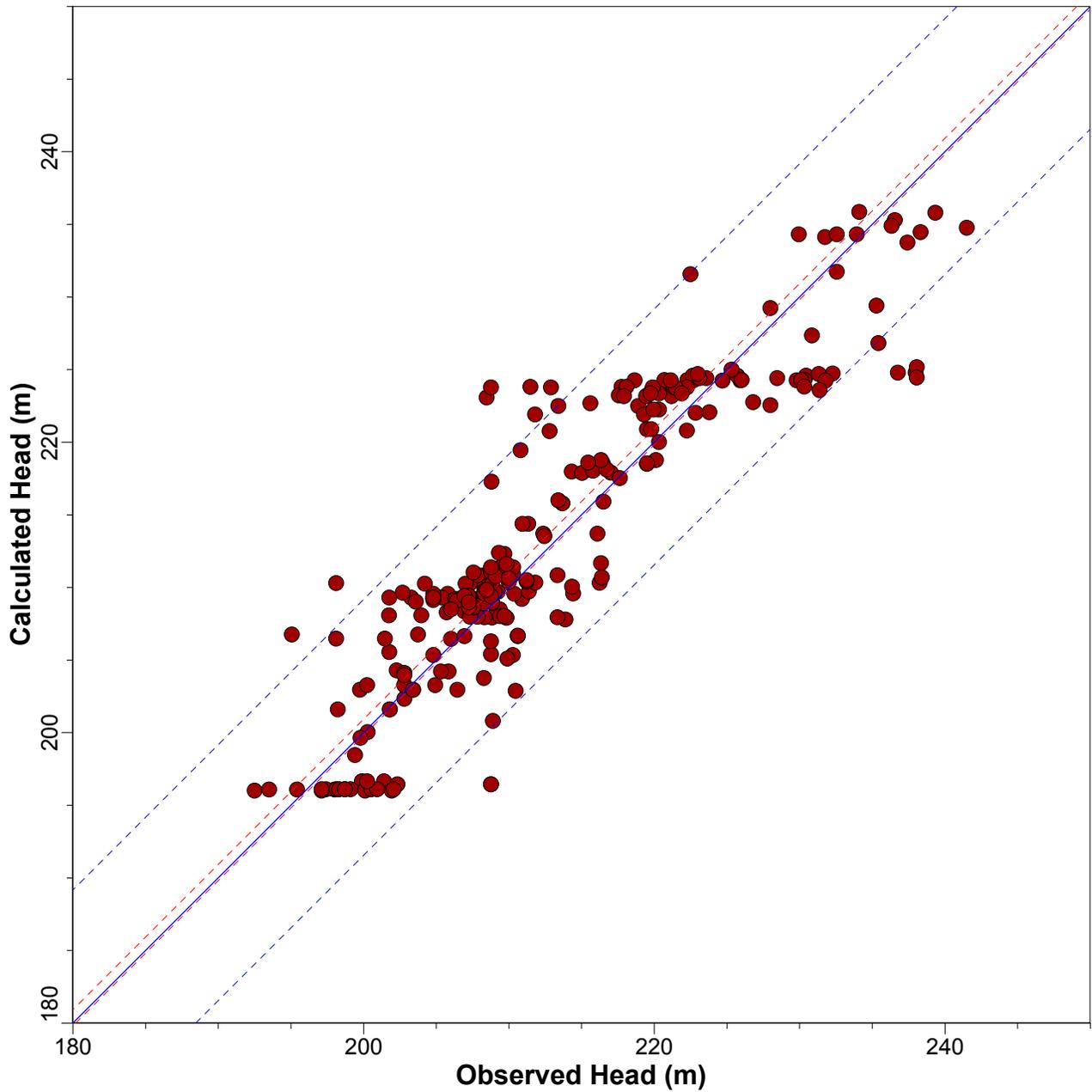
Appendix E

WHPA Model Calibration Graphs

Appendix E – Calibration Plots for 22 MODFLOW Models

- Figure E1: Shallow Lake Model Calibration Plot
- Figure E2: Owen Sound Model Calibration Plot
- Figure E3: Chatsworth Model Calibration Plot
- Figure E4: Walter's Falls Model Calibration Plot
- Figure E5: Neustadt Model Calibration Plot
- Figure E6: Durham Model Calibration Plot
- Figure E7: Dundalk Model Calibration Plot
- Figure E8: Hanover Model Calibration Plot
- Figure E9: Markdale Model Calibration Plot
- Figure E10: Feversham Model Calibration Plot
- Figure E11: Kimberley Model Calibration Plot
- Figure E12: Tara Model Calibration Plot
- Figure E13: Chesley Model Calibration Plot
- Figure E14: Sauble Beach Model Calibration Plot
- Figure E15: Chepstow Model Calibration Plot
- Figure E16: Ripley Model Calibration Plot
- Figure E17: Huron West Model Calibration Plot
- Figure E18: Lucknow Model Calibration Plot
- Figure E19: Mildmay Model Calibration Plot
- Figure E20: Teeswater Model Calibration Plot
- Figure E21: Kincardine South Model Calibration Plot
- Figure E22: Kincardine North Model Calibration Plot

Calculated vs. Observed Head : Steady state



Num.Points : 253

Max. Residual: 14.97188 (m) at 2509176/2509176

Min. Residual: 0.08842749 (m) at 1401518/1401518

Residual Mean : 0.3603808 (m)

Absolute Residual Mean : 3.364527 (m)

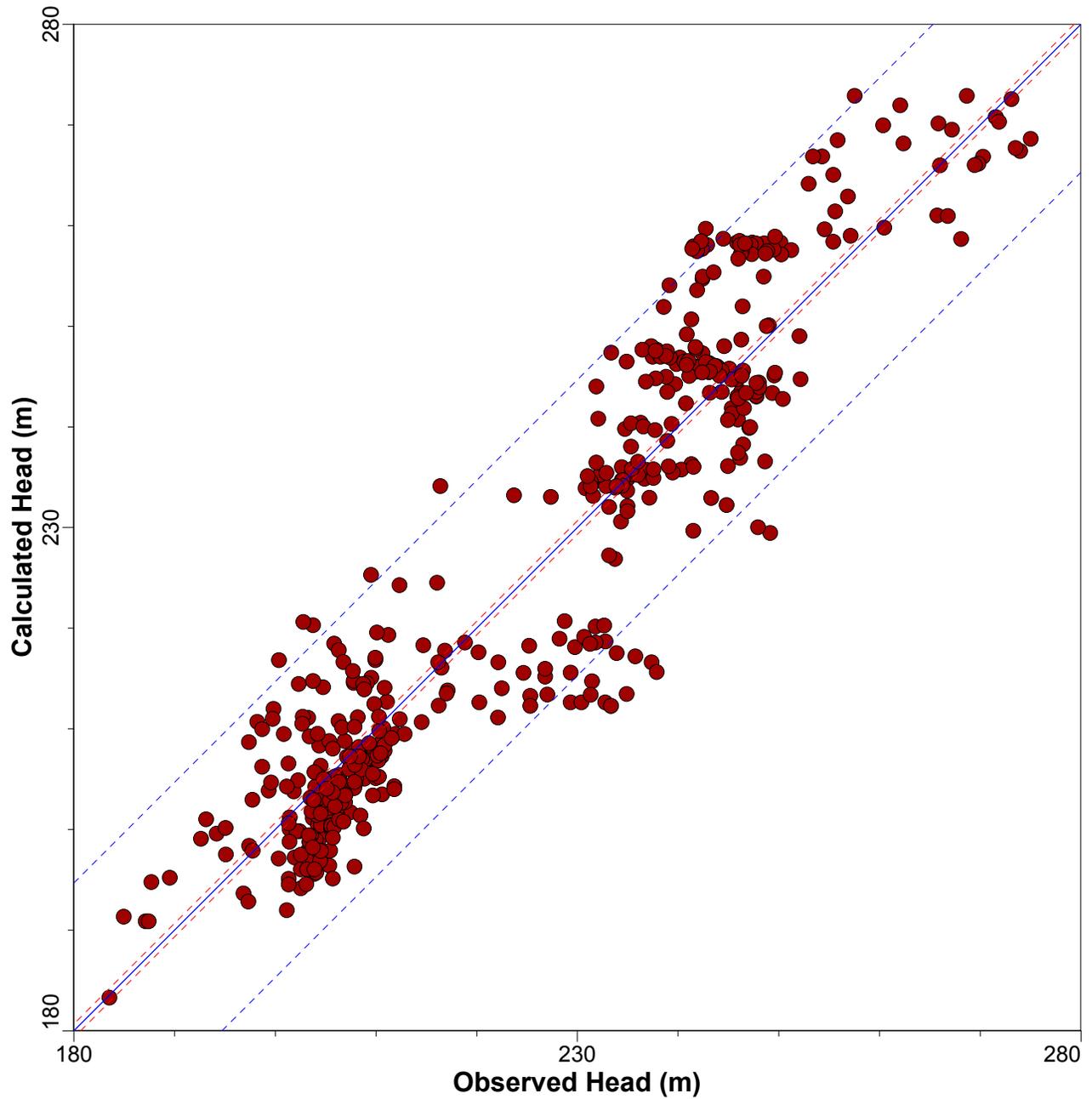
Standard Error of the Estimate : 0.2827553 (m)

Root mean squared : 4.503045 (m)

Normalized RMS : 9.189886 (%)

Figure E1: Shallow Lake Model Calibration Plot

Calculated vs. Observed Head : Steady state



Num.Points : 472

Max. Residual: -22.26986 (m) at 2508544/2508544

Min. Residual: -0.05048501 (m) at 2505971/2505971

Residual Mean : -0.002767668 (m)

Absolute Residual Mean : 5.91374 (m)

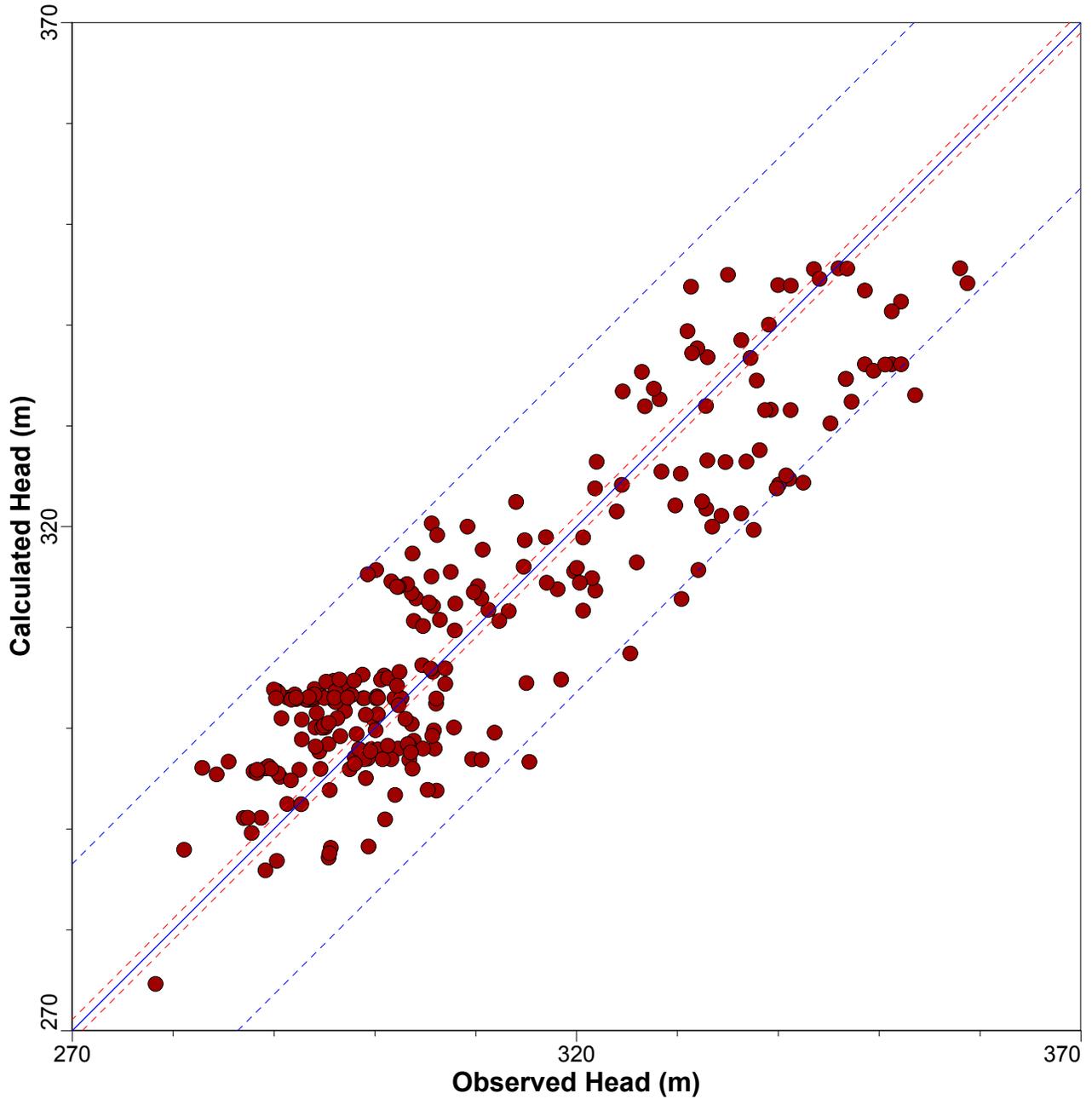
Standard Error of the Estimate : 0.3451294 (m)

Root mean squared : 7.490184 (m)

Normalized RMS : 8.188141 (%)

Figure E2: Owen Sound Model Calibration Plot

Calculated vs. Observed Head : Steady state



Num.Points : 246

Max. Residual: -20.53858 (m) at 2509845/2509845

Min. Residual: -0.0819707 (m) at 2508853/2508853

Residual Mean : 0.05771673 (m)

Absolute Residual Mean : 6.993441 (m)

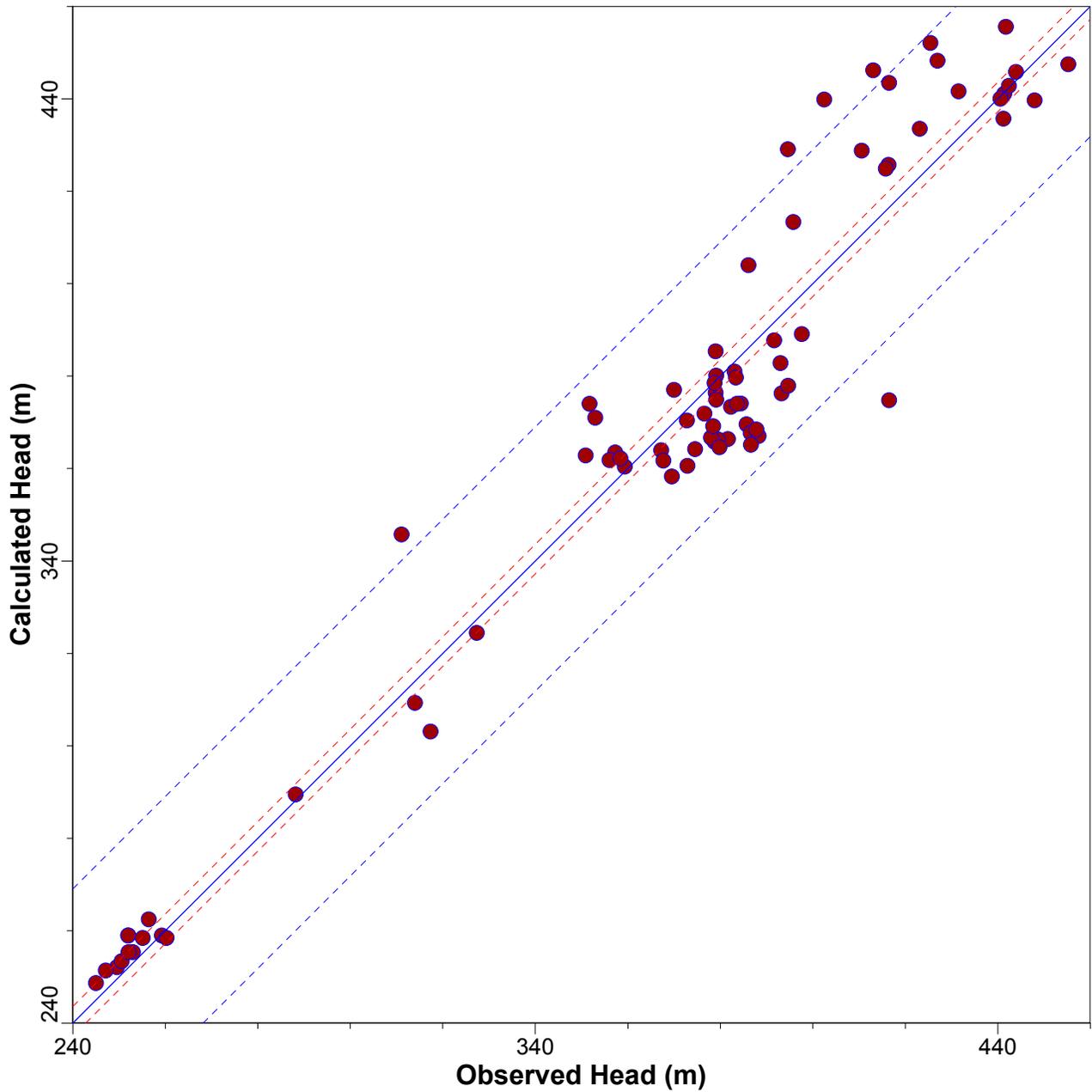
Standard Error of the Estimate : 0.5356909 (m)

Root mean squared : 8.385088 (m)

Normalized RMS : 10.41988 (%)

Figure E3: Chatsworth Model Calibration Plot

Calculated vs. Observed Head : Steady state



Num.Points : 80

Max. Residual: -41.74701 (m) at 2508707/2508707

Min. Residual: -0.2981284 (m) at 2503793/2503793

Residual Mean : 0.4419597 (m)

Absolute Residual Mean : 10.76556 (m)

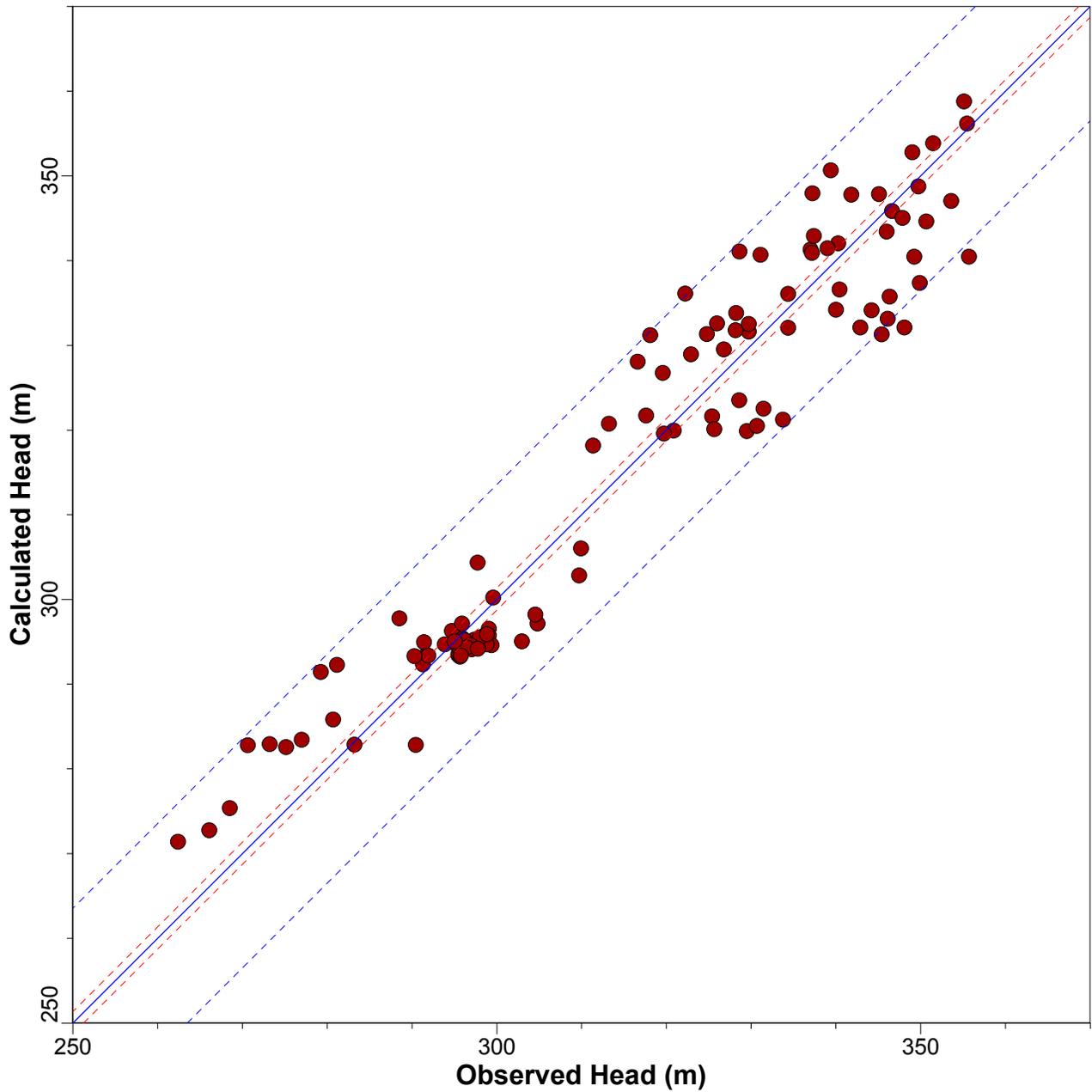
Standard Error of the Estimate : 1.603149 (m)

Root mean squared : 14.25595 (m)

Normalized RMS : 6.78096 (%)

Figure E4: Walter's Falls Model Calibration Plot

Calculated vs. Observed Head : Steady state



Num.Points : 108

Max. Residual: -16.01205 (m) at 1400935/1400935

Min. Residual: -0.003174238 (m) at 2508659/2508659

Residual Mean : 0.04282801 (m)

Absolute Residual Mean : 5.491535 (m)

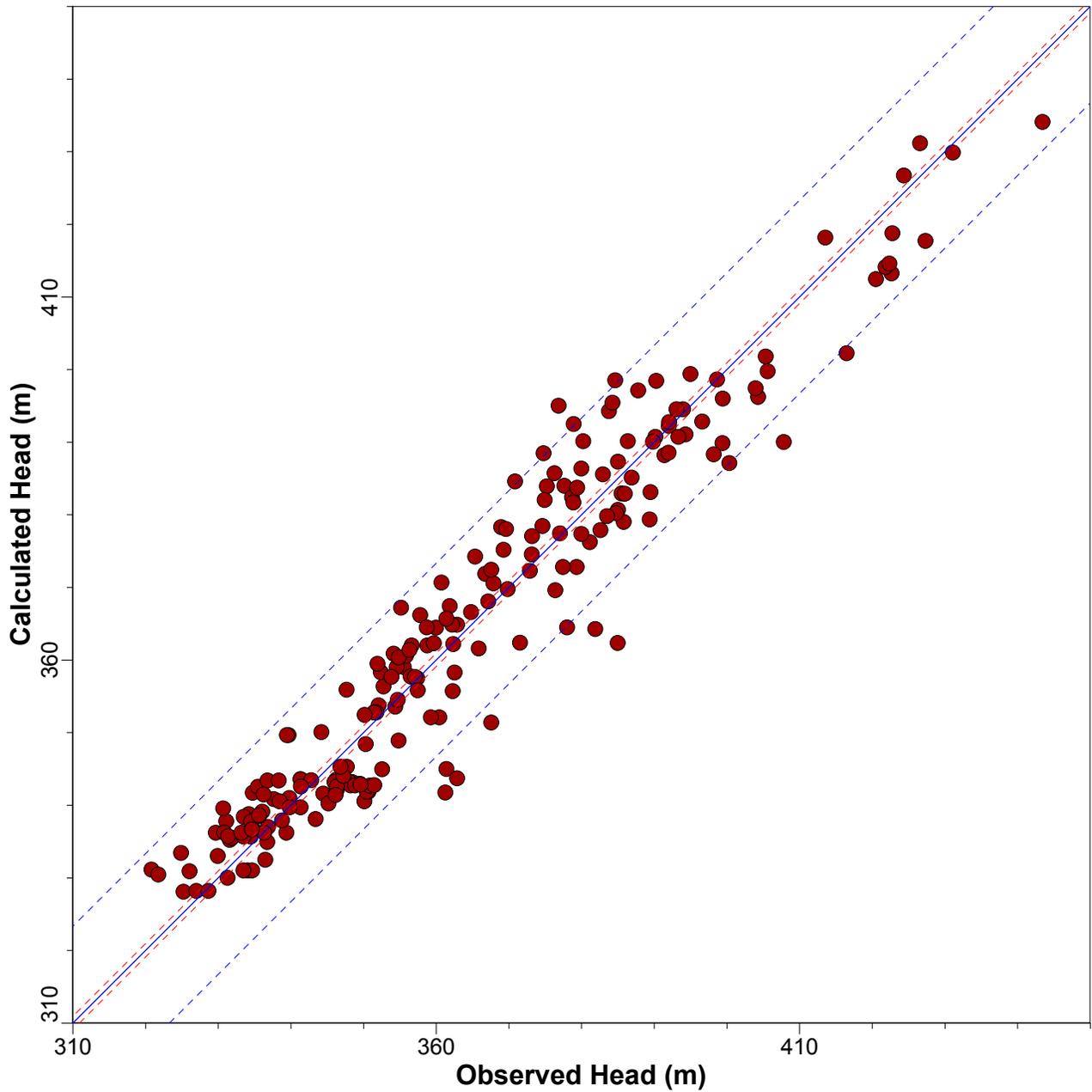
Standard Error of the Estimate : 0.6559306 (m)

Root mean squared : 6.785135 (m)

Normalized RMS : 7.274413 (%)

Figure E5: Neustadt Model Calibration Plot

Calculated vs. Observed Head : Steady state



Num.Points : 213

Max. Residual: -22.66153 (m) at 2501261/2501261

Min. Residual: -0.05847021 (m) at 2508311/2508311

Residual Mean : 0.02513299 (m)

Absolute Residual Mean : 5.333184 (m)

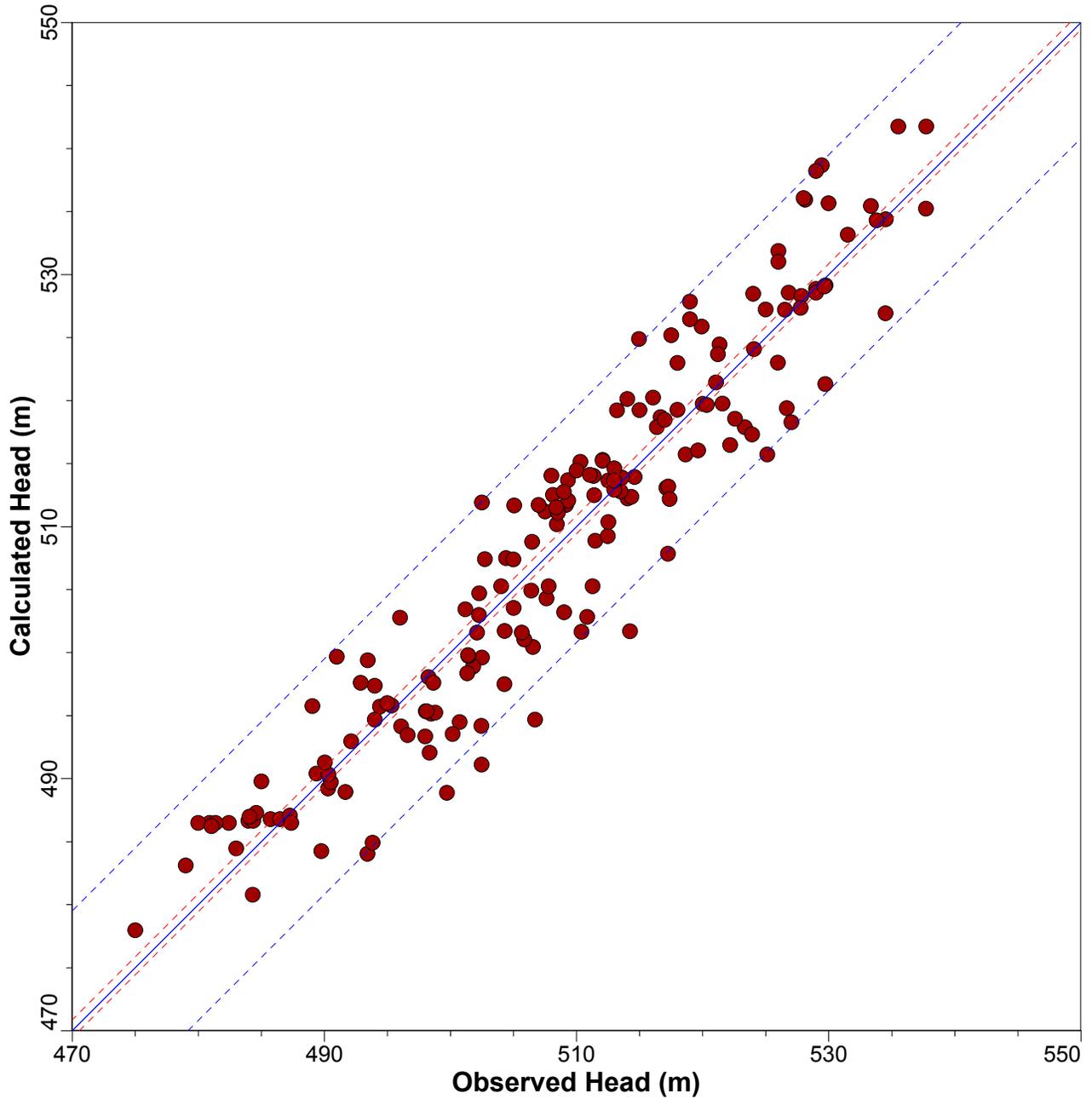
Standard Error of the Estimate : 0.4651484 (m)

Root mean squared : 6.772709 (m)

Normalized RMS : 5.523782 (%)

Figure E6: Durham Model Calibration Plot

Calculated vs. Observed Head : Steady state



Num.Points : 176

Max. Residual: -12.5604 (m) at 2500085/2500085

Min. Residual: -0.004250894 (m) at 2504108/2504108

Residual Mean : 0.1541871 (m)

Absolute Residual Mean : 3.817364 (m)

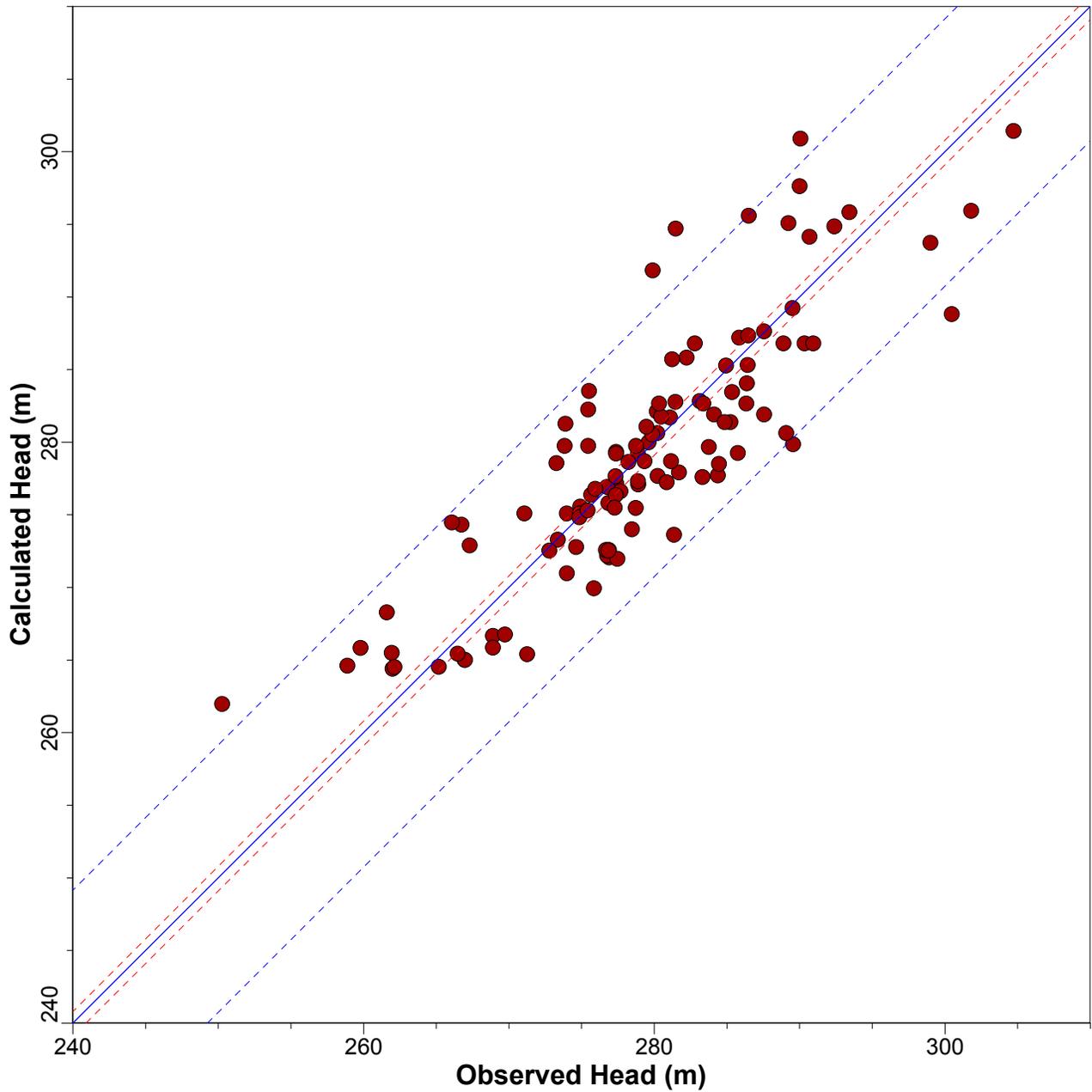
Standard Error of the Estimate : 0.3595786 (m)

Root mean squared : 4.759276 (m)

Normalized RMS : 7.585951 (%)

Figure E7: Dundalk Model Calibration Plot

Calculated vs. Observed Head : Steady state



Num.Points : 116

Max. Residual: 13.21765 (m) at 2505052/2505052

Min. Residual: -0.03681665 (m) at 2500218/2500218

Residual Mean : -0.05730328 (m)

Absolute Residual Mean : 3.549696 (m)

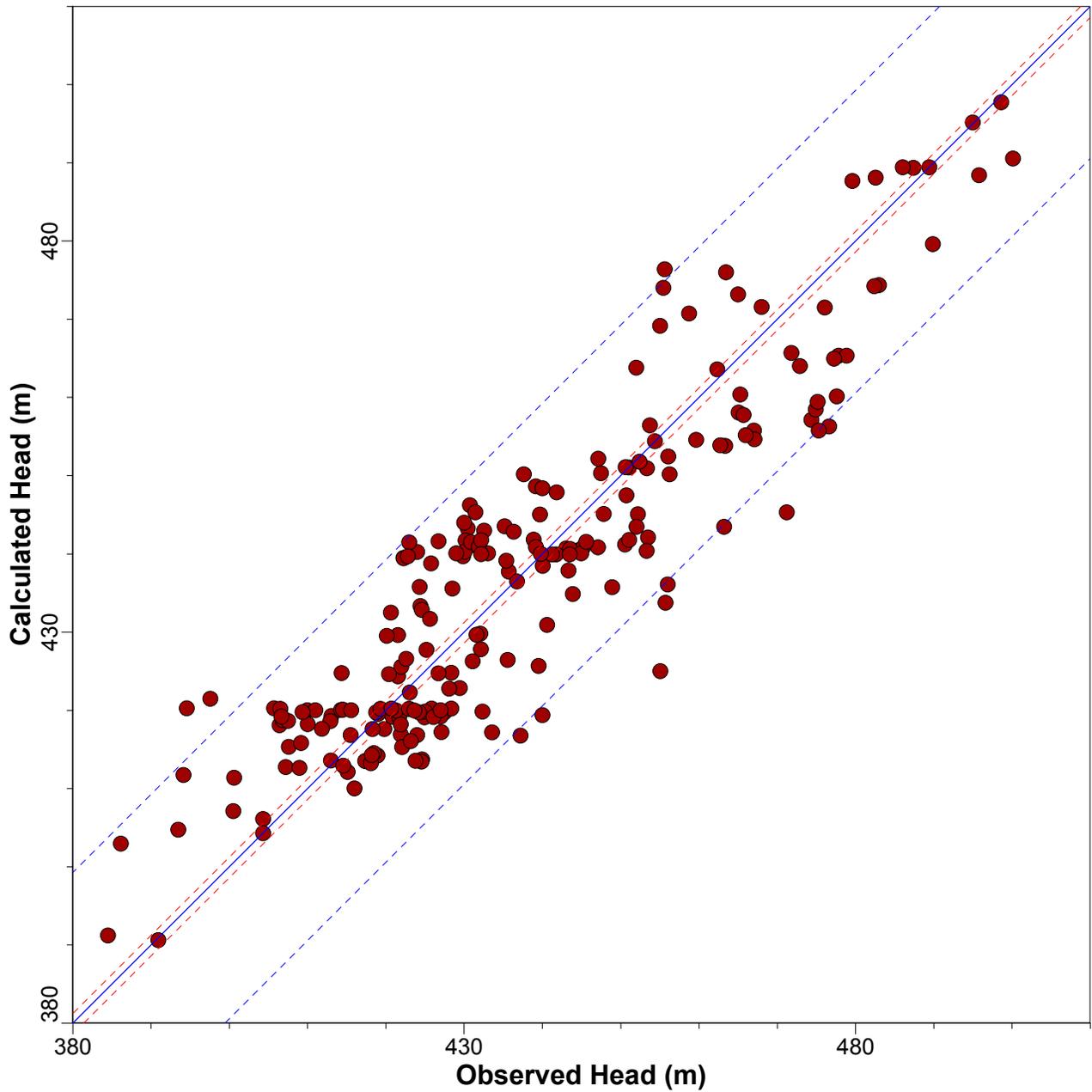
Standard Error of the Estimate : 0.4312598 (m)

Root mean squared : 4.625101 (m)

Normalized RMS : 8.493748 (%)

Figure E8: Hanover Model Calibration Plot

Calculated vs. Observed Head : Steady state



Num.Points : 219

Max. Residual: -30.0688 (m) at 2508569/2508569

Min. Residual: -0.02301874 (m) at 2501228/2501228

Residual Mean : -0.07747985 (m)

Absolute Residual Mean : 8.00404 (m)

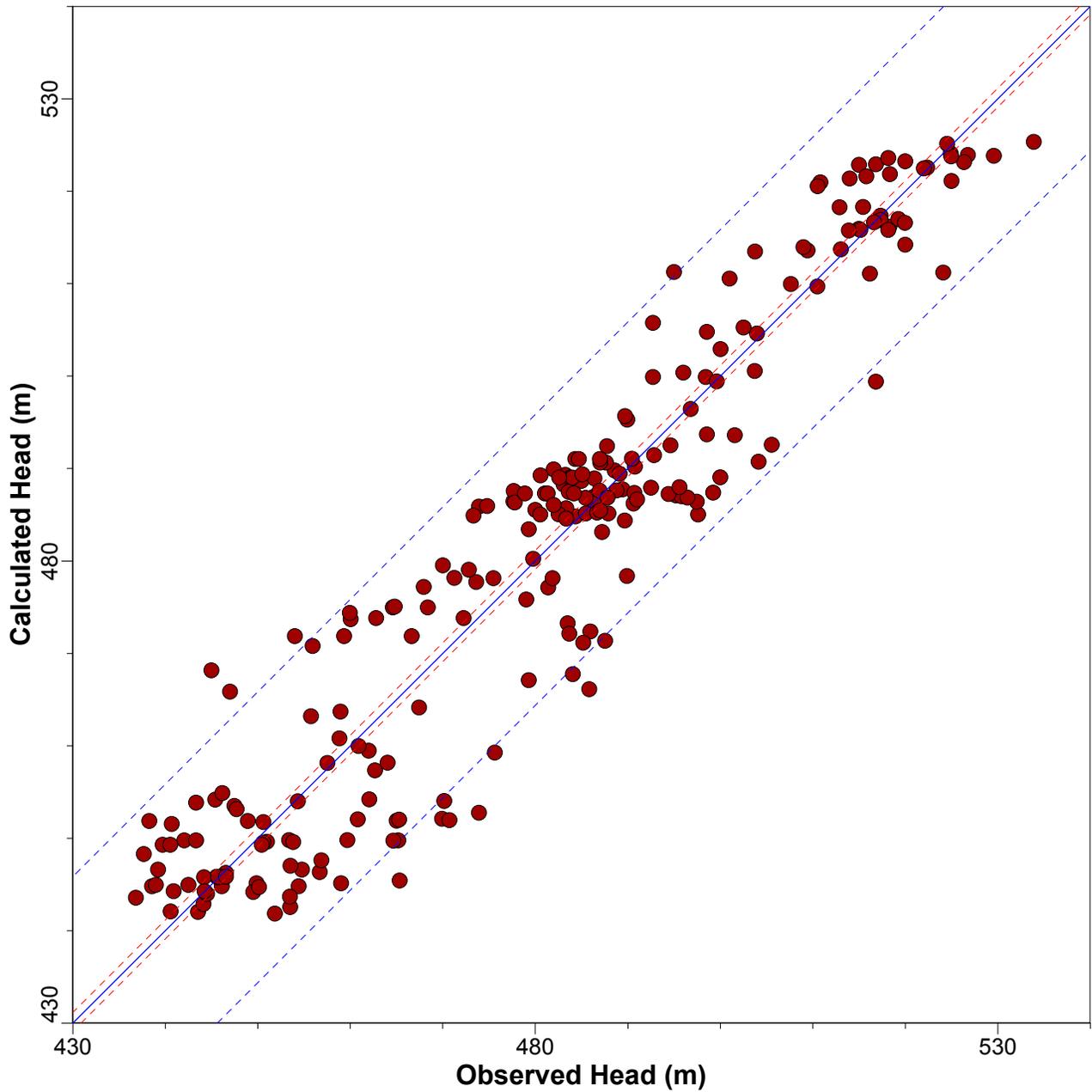
Standard Error of the Estimate : 0.6671373 (m)

Root mean squared : 9.850469 (m)

Normalized RMS : 8.517113 (%)

Figure E9: Markdale Model Calibration Plot

Calculated vs. Observed Head : Steady state



Num.Points : 235

Max. Residual: 23.15726 (m) at 2508233/2508233

Min. Residual: -0.00515918 (m) at 2508179/2508179

Residual Mean : 0.1270131 (m)

Absolute Residual Mean : 6.265718 (m)

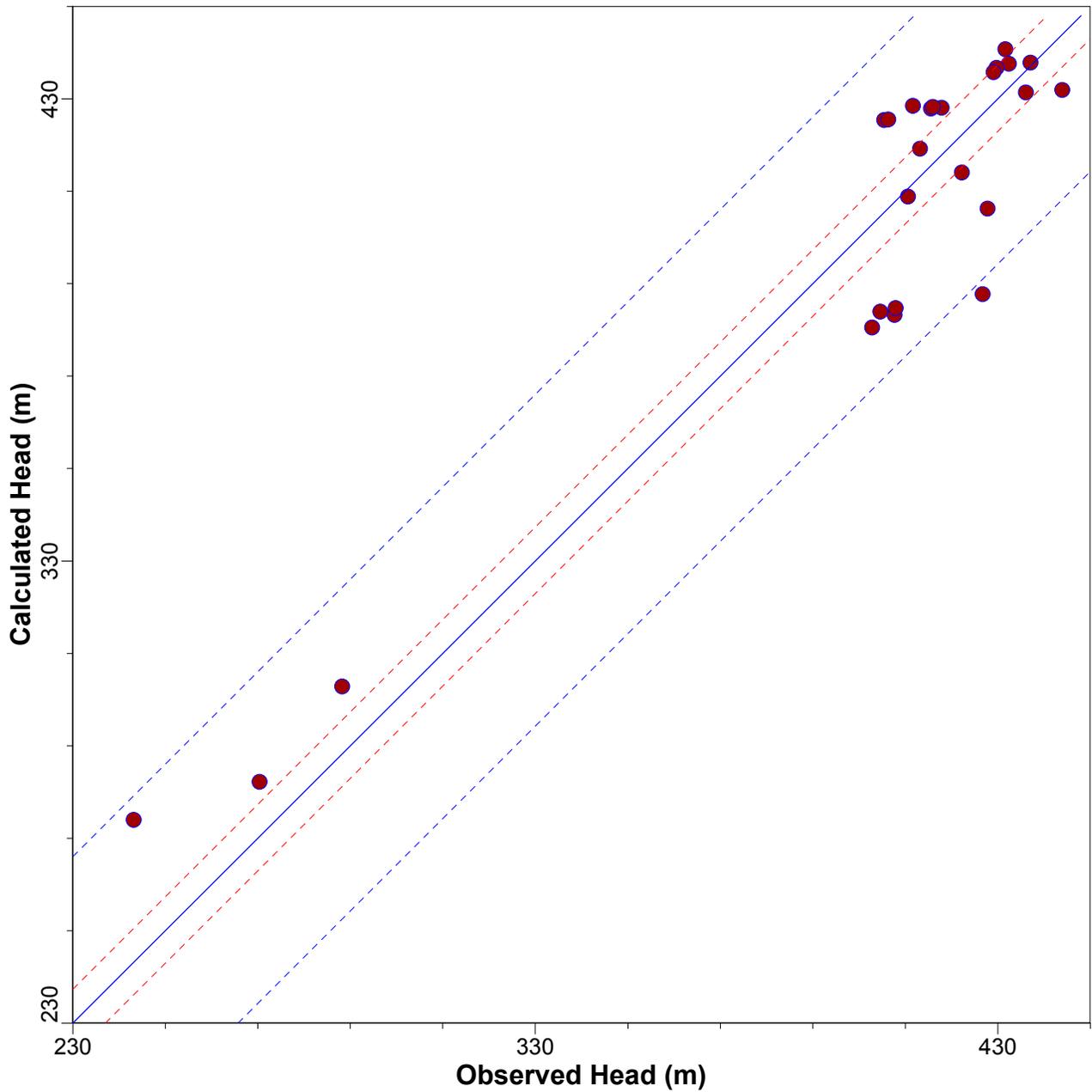
Standard Error of the Estimate : 0.5238469 (m)

Root mean squared : 8.014323 (m)

Normalized RMS : 8.255636 (%)

Figure E10: Feversham Model Calibration Plot

Calculated vs. Observed Head : Steady state



Num.Points : 25

Max. Residual: -39.0714 (m) at 2504007/2504007

Min. Residual: 0.6898401 (m) at 2501076/2501076

Residual Mean : 0.1582888 (m)

Absolute Residual Mean : 14.41662 (m)

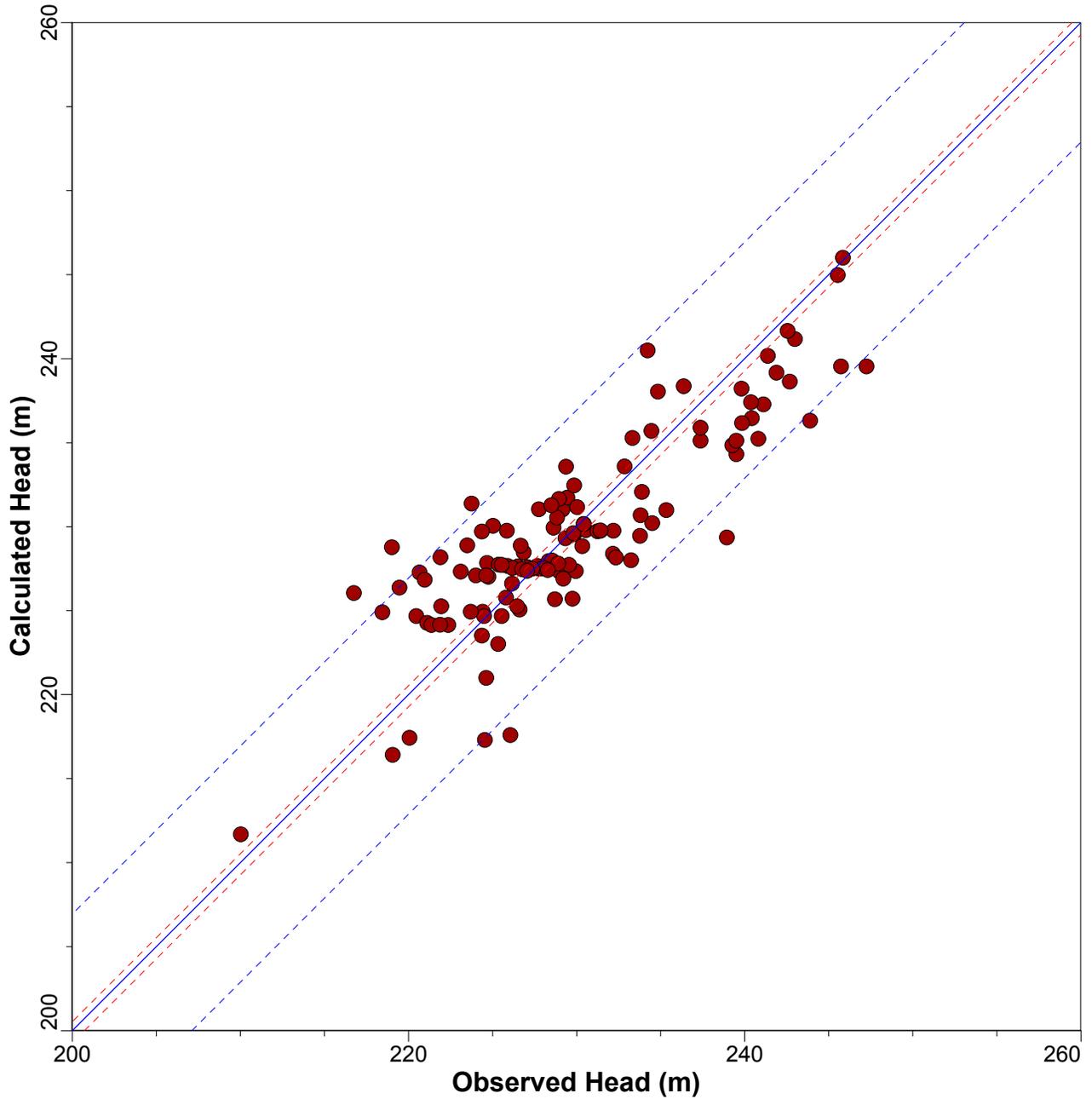
Standard Error of the Estimate : 3.483723 (m)

Root mean squared : 17.06742 (m)

Normalized RMS : 8.502464 (%)

Figure E11: Kimberley Model Calibration Plot

Calculated vs. Observed Head : Steady state



Num.Points : 125

Max. Residual: 9.735227 (m) at 1400596/1400596

Min. Residual: -0.03804812 (m) at 1404995/1404995

Residual Mean : -0.09232055 (m)

Absolute Residual Mean : 2.775992 (m)

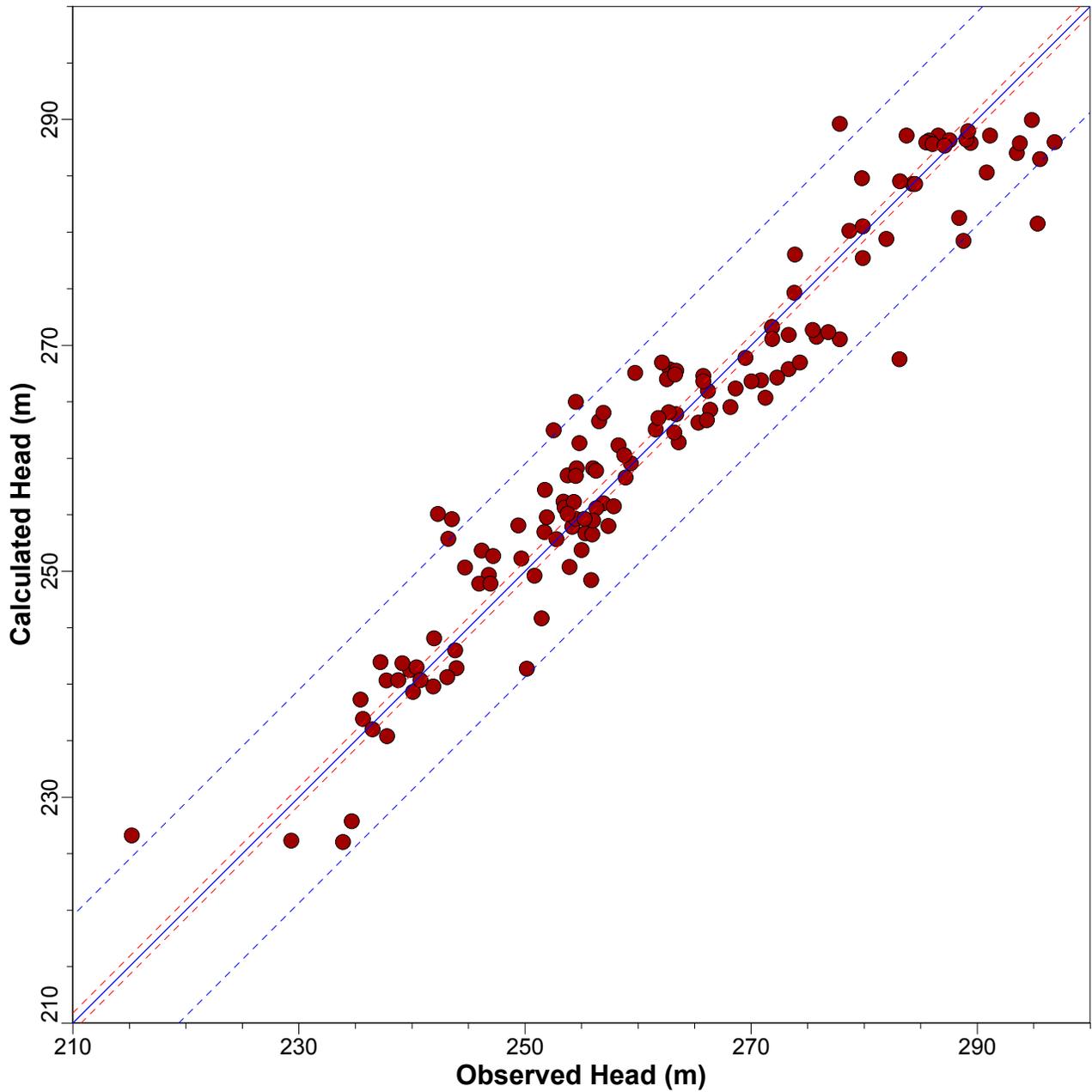
Standard Error of the Estimate : 0.3206915 (m)

Root mean squared : 3.572263 (m)

Normalized RMS : 9.595115 (%)

Figure E12: Tara Model Calibration Plot

Calculated vs. Observed Head : Steady state



Num.Points : 137

Max. Residual: -14.58641 (m) at 2508605/2508605

Min. Residual: -0.03050583 (m) at 2502369/2502369

Residual Mean : 0.07915274 (m)

Absolute Residual Mean : 3.644412 (m)

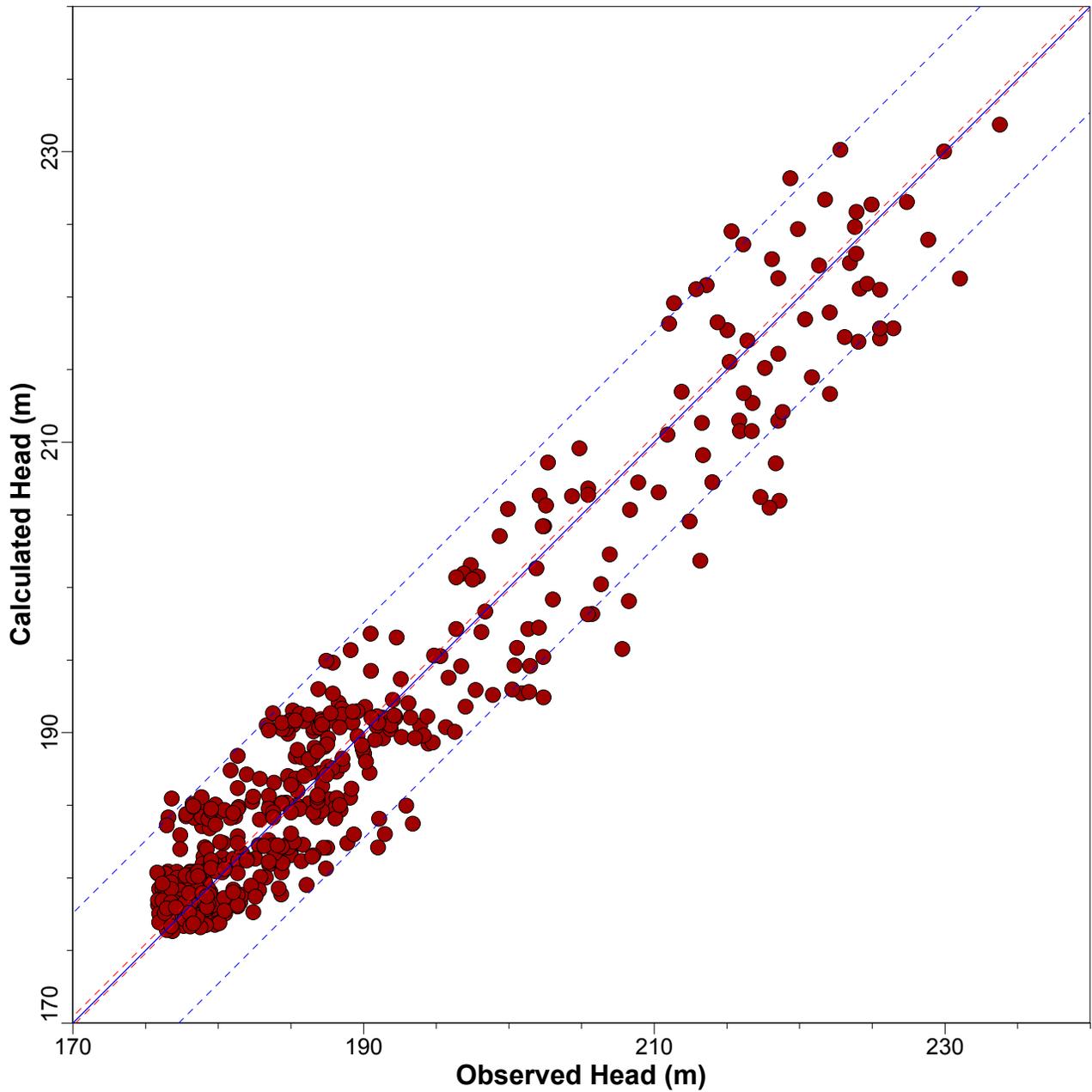
Standard Error of the Estimate : 0.4114936 (m)

Root mean squared : 4.799452 (m)

Normalized RMS : 5.88024 (%)

Figure E13: Chesley Model Calibration Plot

Calculated vs. Observed Head : Steady state



Num.Points : 527

Max. Residual: -12.65941 (m) at 1404424/1404424

Min. Residual: 0.001565967 (m) at 1402362/1402362

Residual Mean : 0.1372773 (m)

Absolute Residual Mean : 2.918251 (m)

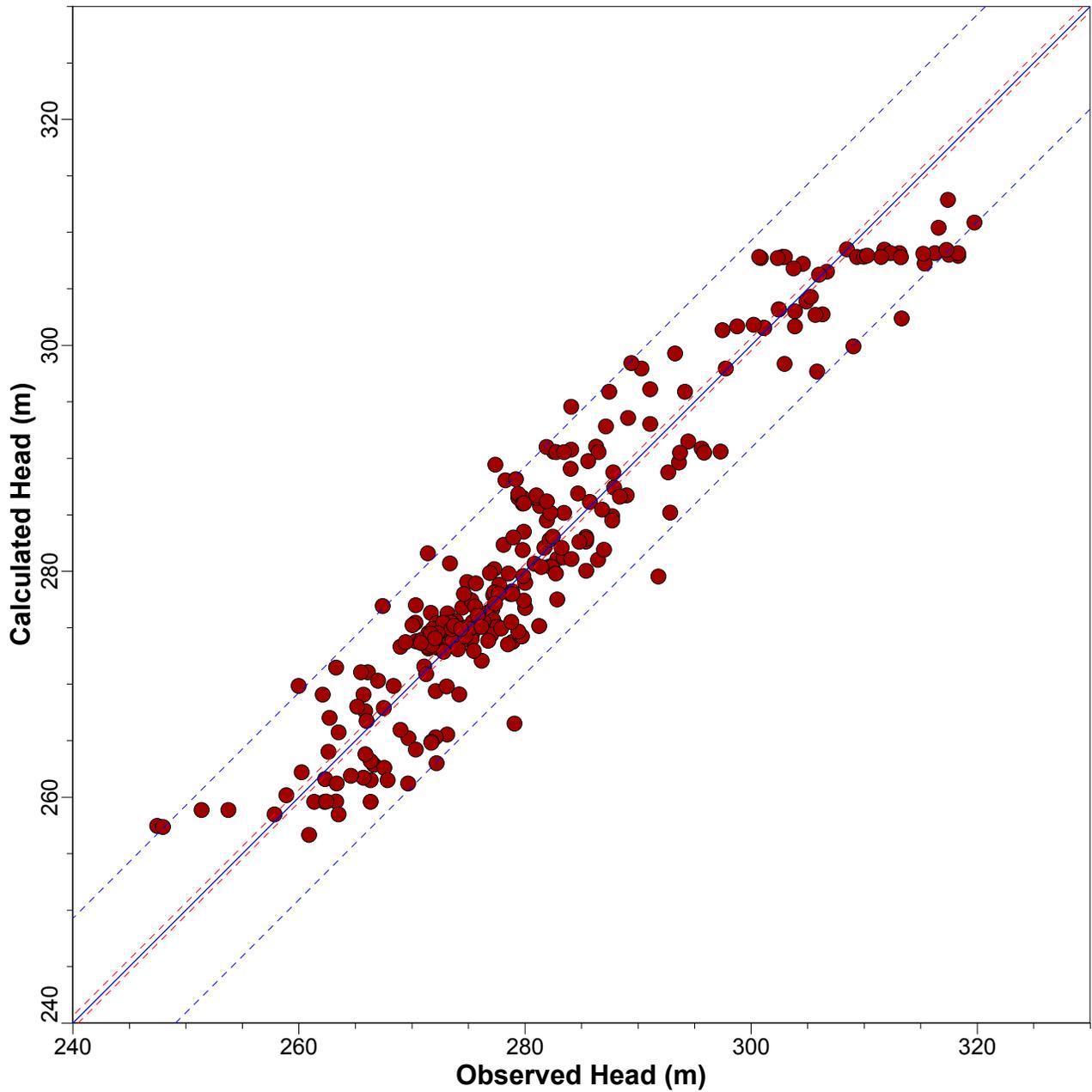
Standard Error of the Estimate : 0.1650612 (m)

Root mean squared : 3.788115 (m)

Normalized RMS : 6.534207 (%)

Figure E14: Sauble Beach Model Calibration Plot

Calculated vs. Observed Head : Steady state



Num.Points : 266

Max. Residual: -12.59266 (m) at 1404975/1404975

Min. Residual: -0.003563882 (m) at 1400893/1400893

Residual Mean : 0.09303402 (m)

Absolute Residual Mean : 3.71229 (m)

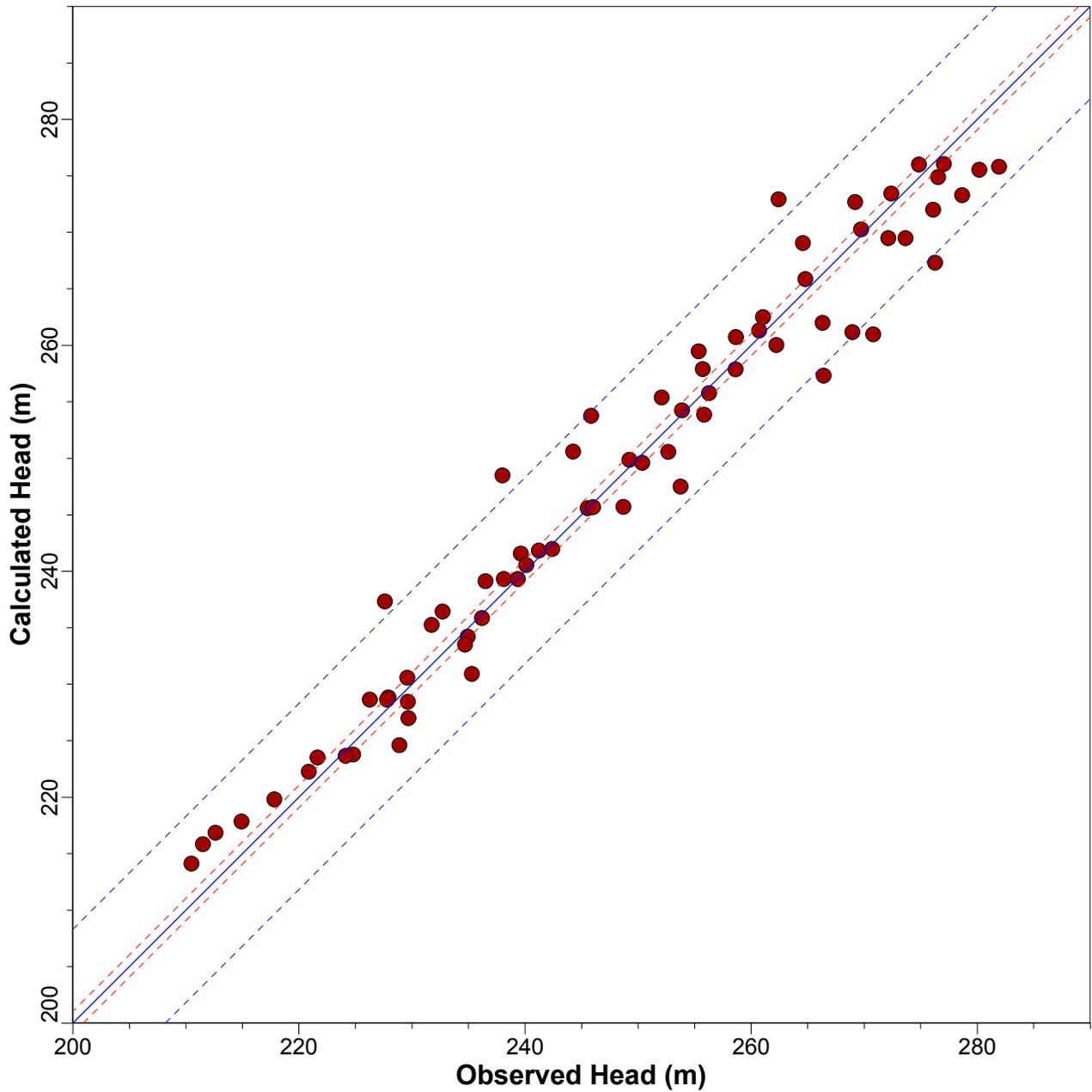
Standard Error of the Estimate : 0.2868558 (m)

Root mean squared : 4.670601 (m)

Normalized RMS : 6.460564 (%)

Figure E15: Chepstow Model Calibration Plot

Calculated vs. Observed Head : Steady state



Num.Points : 71

Max. Residual: 10.48843 (m) at 1407717/1407717

Min. Residual: 0.01992998 (m) at 1401592/1401592

Residual Mean : 0.06889785 (m)

Absolute Residual Mean : 3.031532 (m)

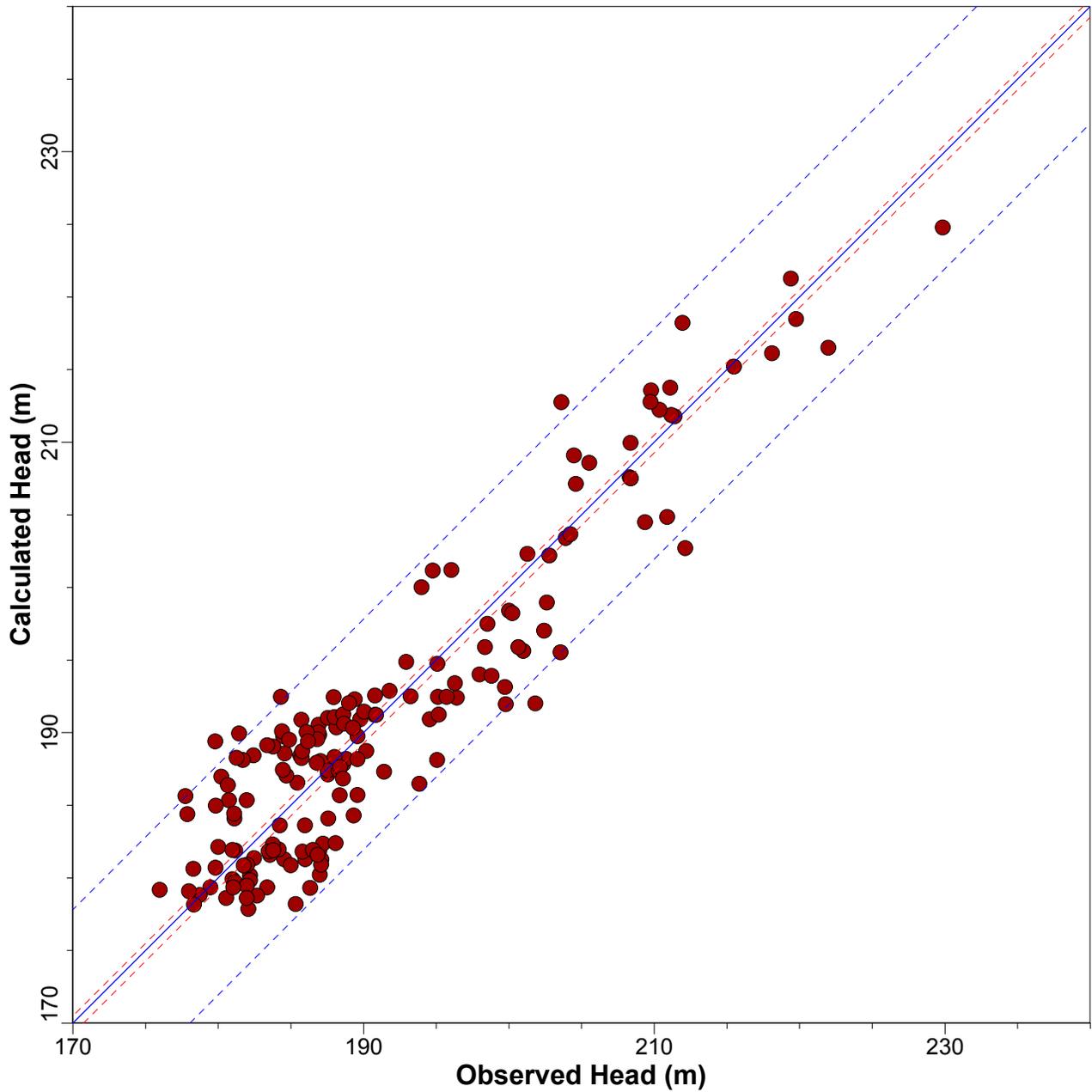
Standard Error of the Estimate : 0.4897673 (m)

Root mean squared : 4.098266 (m)

Normalized RMS : 5.736077 (%)

Figure E16: Ripley Model Calibration Plot

Calculated vs. Observed Head : Steady state



Num.Points : 168

Max. Residual: -9.841044 (m) at 1405209/1405209

Min. Residual: 0.07864714 (m) at 1404249/1404249

Residual Mean : -0.1267605 (m)

Absolute Residual Mean : 3.31373 (m)

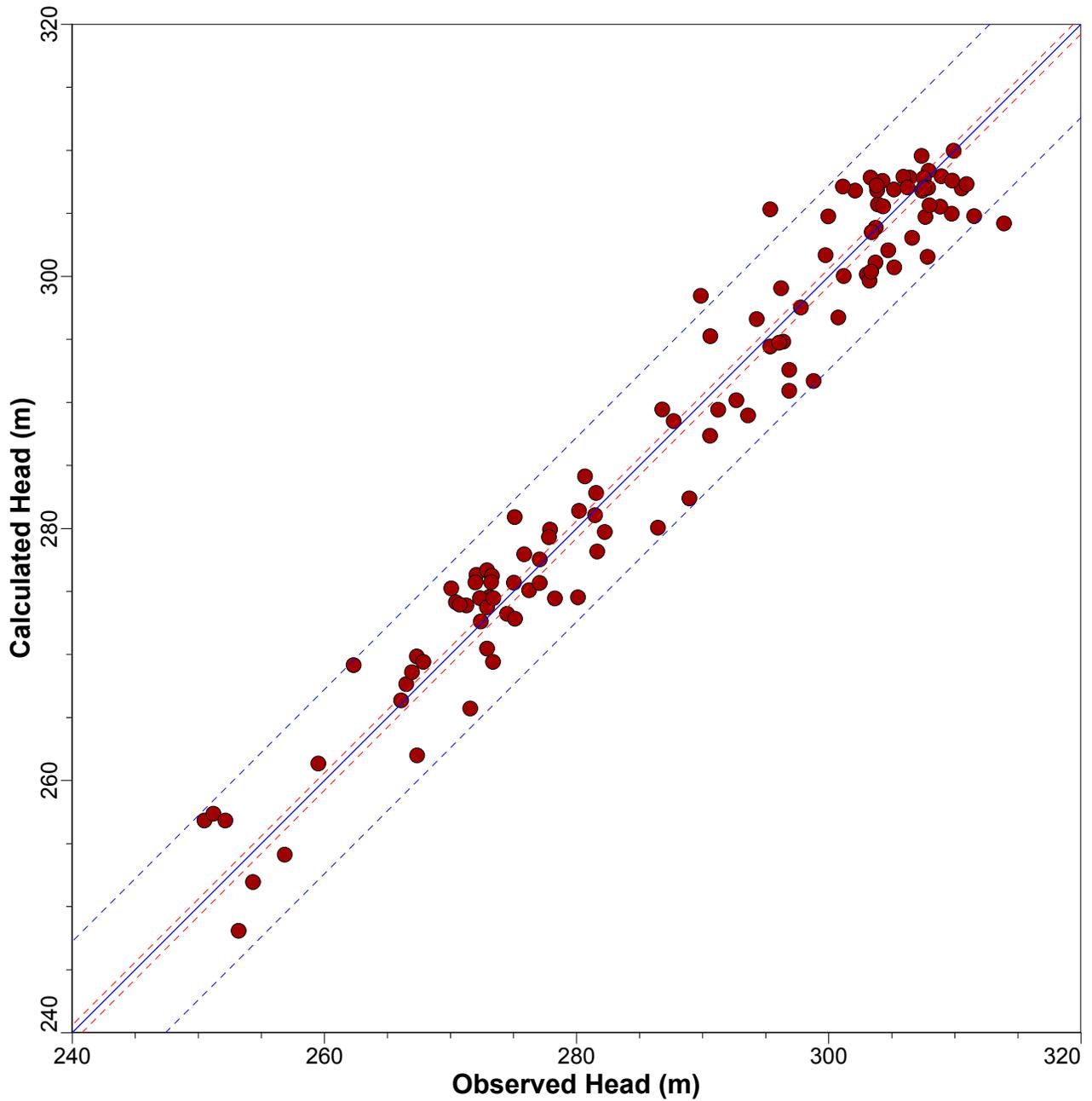
Standard Error of the Estimate : 0.3124501 (m)

Root mean squared : 4.039734 (m)

Normalized RMS : 7.498095 (%)

Figure E17: Huron West Model Calibration Plot

Calculated vs. Observed Head : Steady state



Num.Points : 112

Max. Residual: 9.935118 (m) at 1401754/1401754

Min. Residual: 0.04976587 (m) at 3001674/3001674

Residual Mean : -0.08738528 (m)

Absolute Residual Mean : 3.013834 (m)

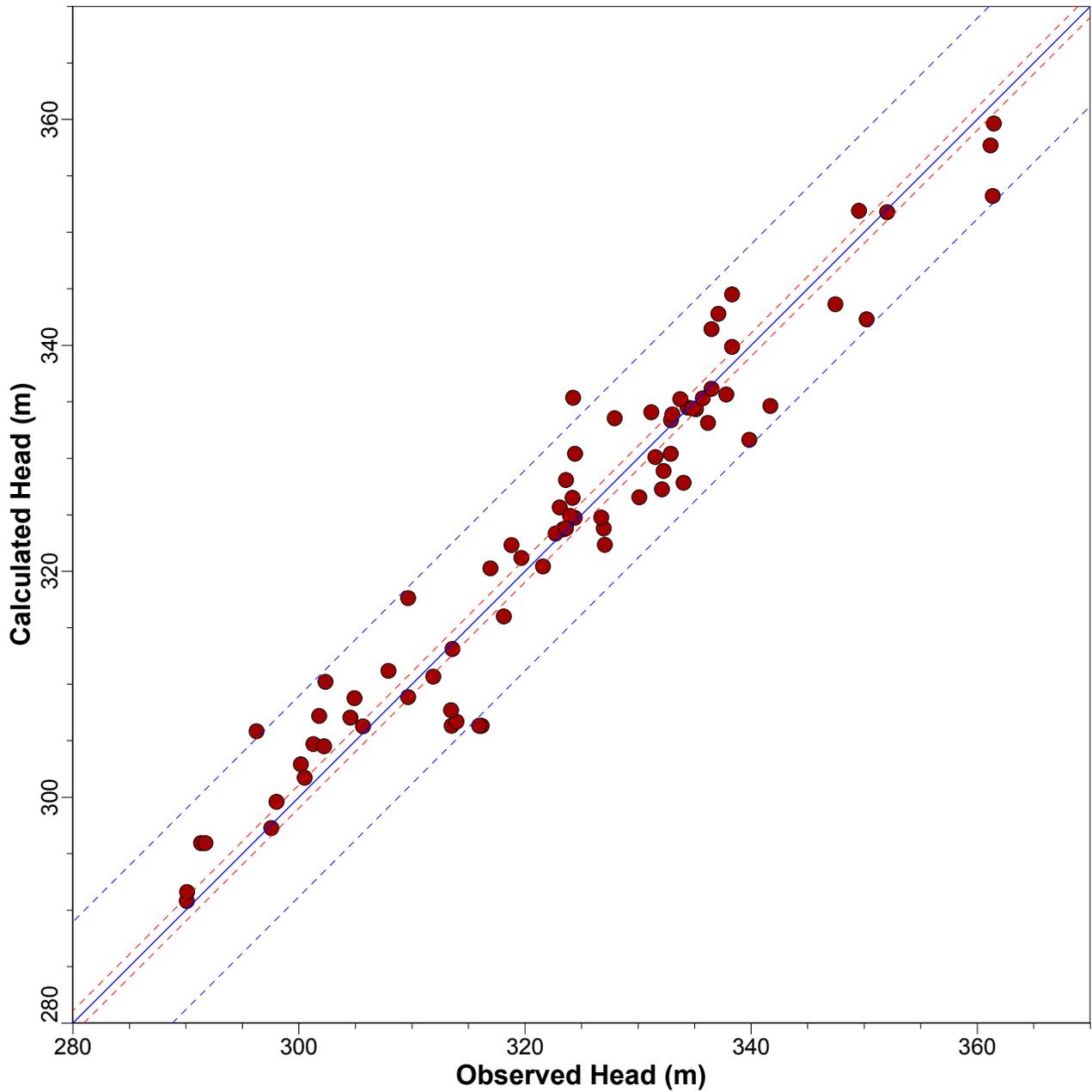
Standard Error of the Estimate : 0.3485598 (m)

Root mean squared : 3.673345 (m)

Normalized RMS : 5.793481 (%)

Figure E18: Lucknow Model Calibration Plot

Calculated vs. Observed Head : Steady state



Num.Points : 75

Max. Residual: 11.06353 (m) at 1406275/1406275

Min. Residual: 0.06166965 (m) at 1400946/1400946

Residual Mean : 0.07046253 (m)

Absolute Residual Mean : 3.437172 (m)

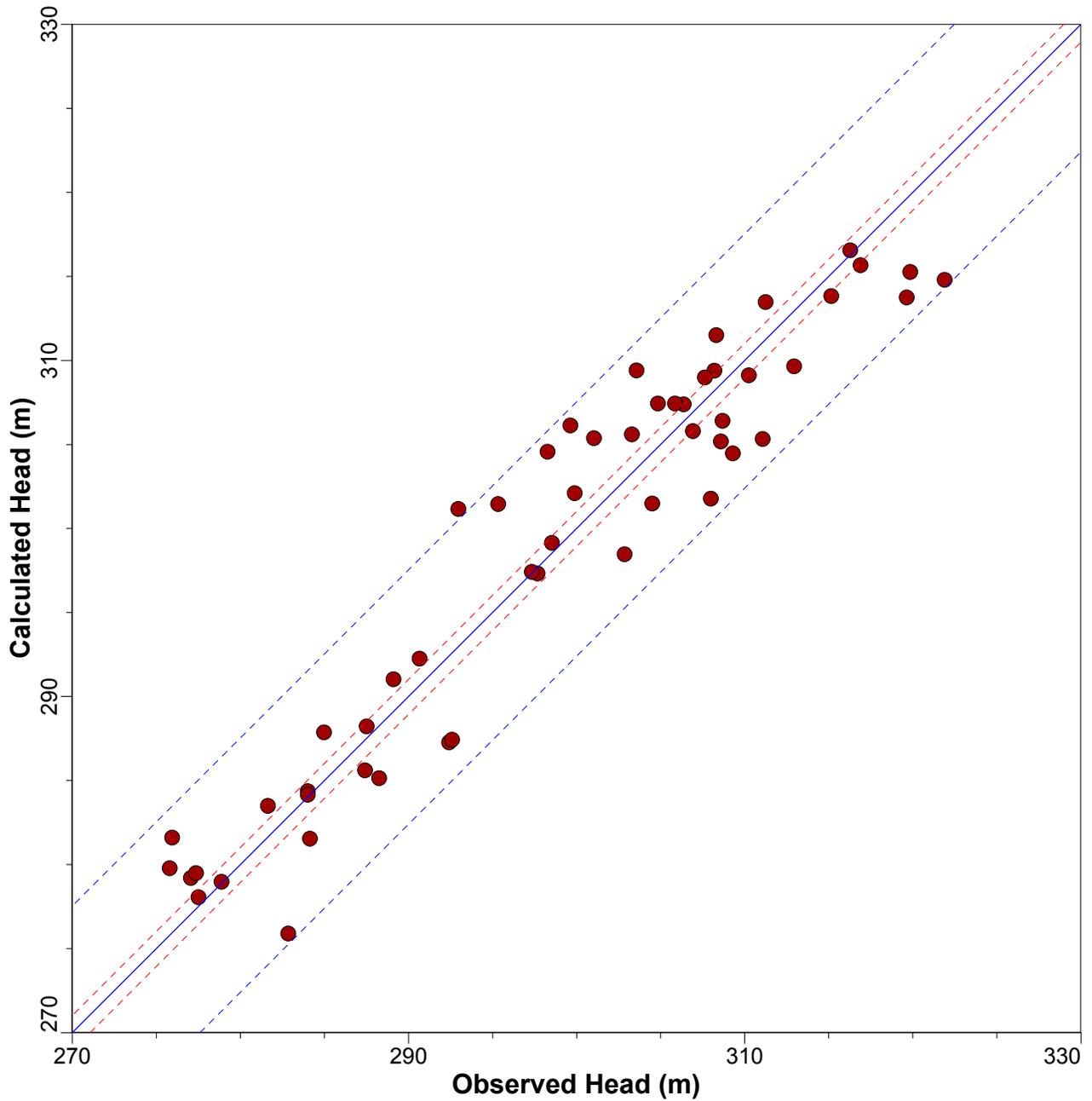
Standard Error of the Estimate : 0.5145026 (m)

Root mean squared : 4.42648 (m)

Normalized RMS : 6.198943 (%)

Figure E19: Mildmay Model Calibration Plot

Calculated vs. Observed Head : Steady state



Num.Points : 53

Max. Residual: 8.175419 (m) at 1404447/1404447

Min. Residual: 0.05123584 (m) at 1405384/1405384

Residual Mean : -0.02882573 (m)

Absolute Residual Mean : 3.028138 (m)

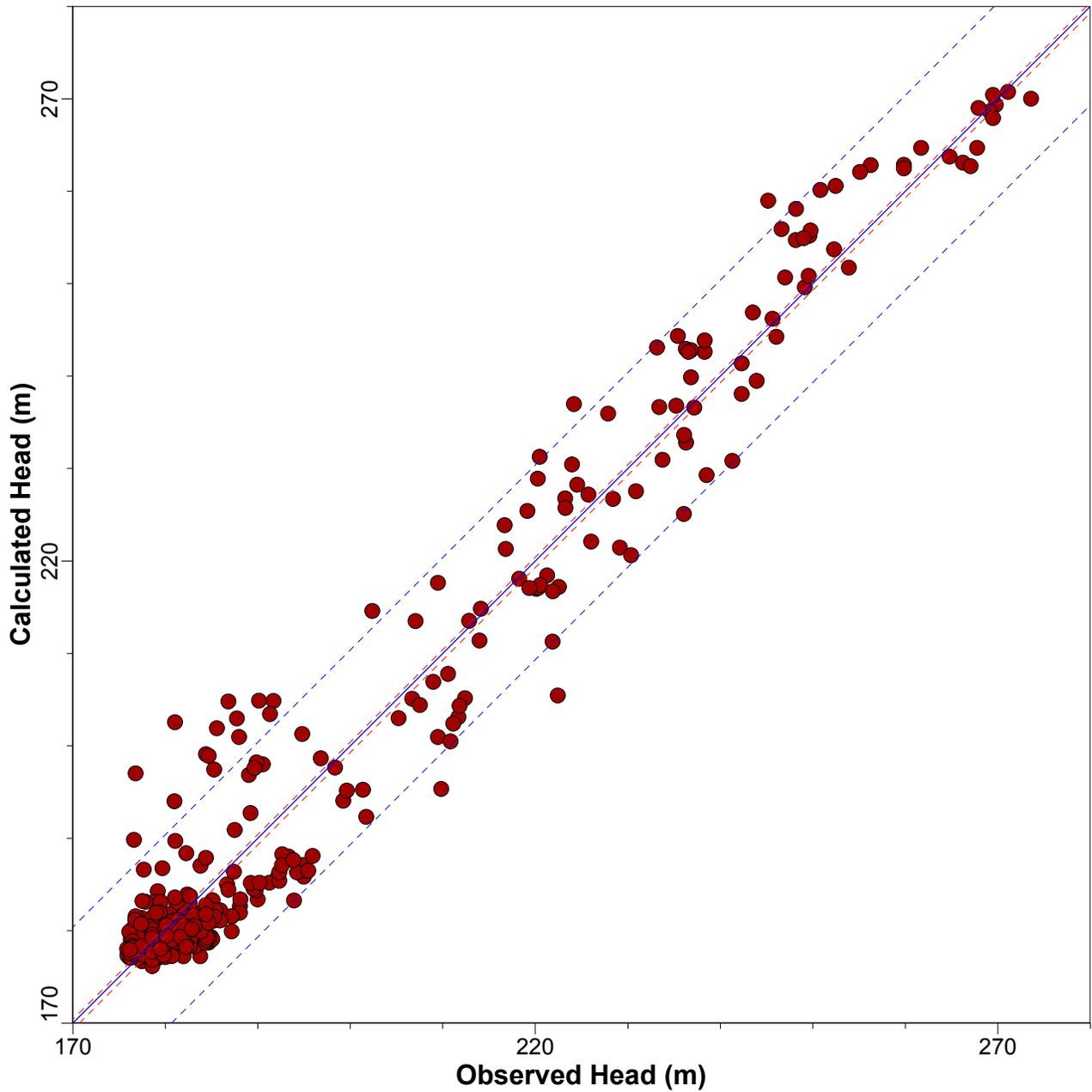
Standard Error of the Estimate : 0.5176458 (m)

Root mean squared : 3.732908 (m)

Normalized RMS : 8.098118 (%)

Figure E20: Teeswater Model Calibration Plot

Calculated vs. Observed Head : Steady state



Num.Points : 364

Max. Residual: 21.47186 (m) at 1407870/1407870

Min. Residual: 0.02096812 (m) at 1402483/1402483

Residual Mean : -0.1486421 (m)

Absolute Residual Mean : 3.919334 (m)

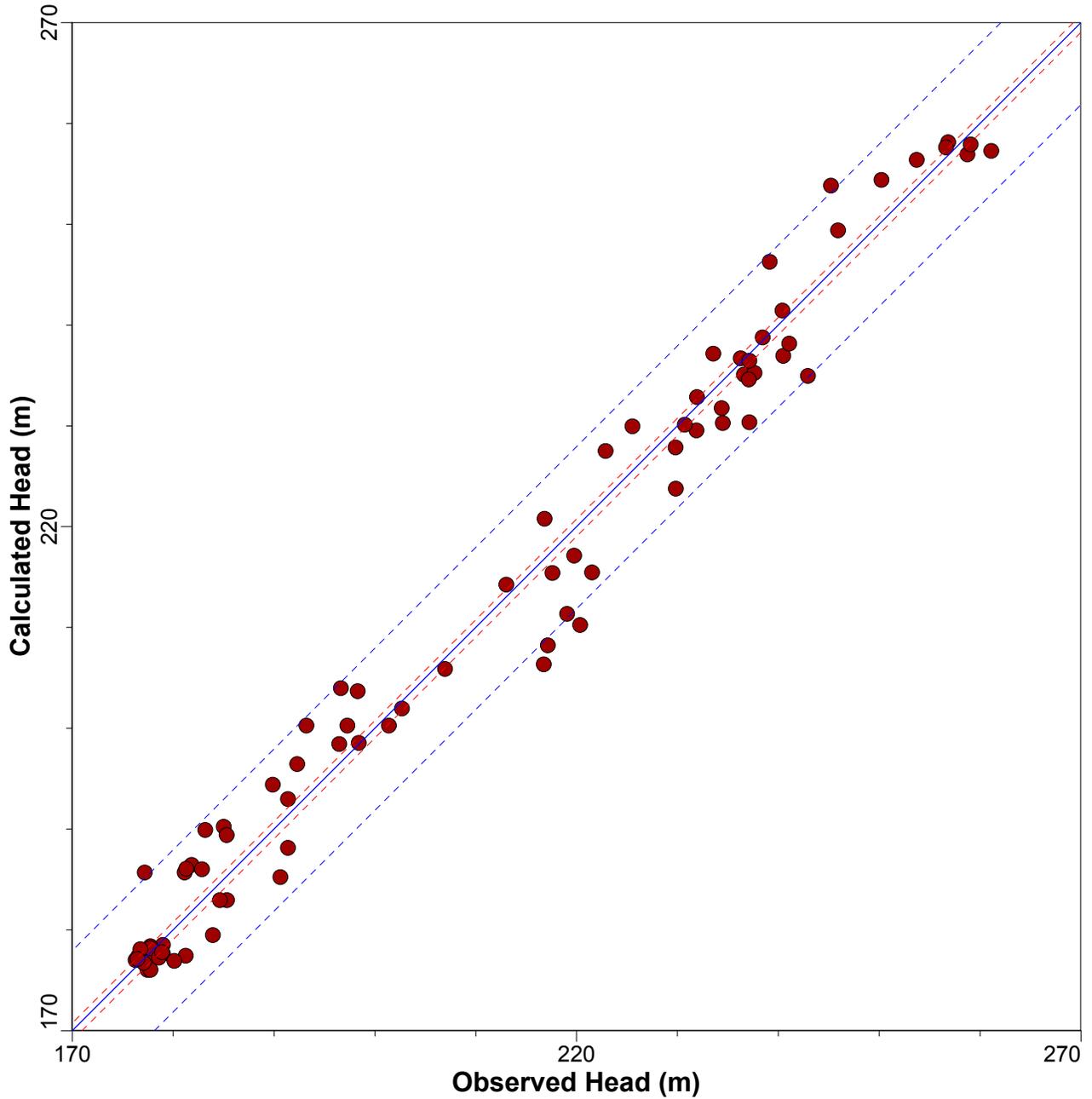
Standard Error of the Estimate : 0.2819059 (m)

Root mean squared : 5.373086 (m)

Normalized RMS : 5.499261 (%)

Figure E21: Kincardine South Model Calibration Plot

Calculated vs. Observed Head : Steady state



Num.Points : 87

Max. Residual: -10.43931 (m) at 1400820/1400820

Min. Residual: -0.005983521 (m) at 1406129/1406129

Residual Mean : -0.1011085 (m)

Absolute Residual Mean : 3.0896 (m)

Standard Error of the Estimate : 0.4331119 (m)

Root mean squared : 4.017787 (m)

Normalized RMS : 4.736348 (%)

Figure E22: Kincardine North Model Calibration Plot

Appendix F

Municipal Well Information

Appendix F: Municipal Well Information

County	Township/Municipality	Municipal Wells	Max. Permitted (Litre/day)	Average Flow Rate (m3/day)	Year Avg	Source	2021 Flow Rate (m3/day)	
Grey	Township of Georgian Bluffs	Shallow Lake#2	696000	163.9	1999-2001	Survey	189.5	
		Shallow Lake#3	696000	(well #2 or #3 in use at one time)				
		Forest Heights#1	38500	15.19	1997 - 2001	Survey	17.6	
		Forest Heights#2	38500	(combined)				
		Maplecrest#1	47550	7.03	1997 - 2001	Survey	8.1	
	Township of Chatsworth	Pottawatomi Village#1	combined?	standby			Survey	
		Pottawatomi Village#2	93000	21.84	1997 - 2001			25.2
		Chatsworth#1	818208	161	1997 - 1999	Eng report	186.1	
		Chatsworth#2	818208	(well #1 or #2 in use at one time)				
		Chatsworth#3	125015					
	Municipality of West Grey	Walter's Falls#1	795000	8.71	1997 - 1999	Eng report	10.1	
		Walter's Falls#2	795000	(well #1 or #2 in use at one time)				
		Neustadt #1	276000	54	1998-2000	eng report	62.4	
		Neustadt #2	916000	25	1998-2000	eng report	28.9	
		Neustadt #3	527000	50	1998-2000	eng report	57.8	
	Township of Southgate	Durham#1B	1363800	752.6		survey	870.0	
		Durham#2	1636560	581		survey	671.6	
		Dundalk#1	--	182.0	1997-2001	survey & eng report	210.4	
	Town of Hanover	Dundalk#2	--	82.0	1997-2001	survey & eng report	94.8	
		Dundalk#3	1181960	396.0	1997-2001	survey & eng report	457.8	
		Hanover#1	4546000	868.6	1997-2001	survey	1004.1	
	Township of Grey Highlands	Hanover#2	8182800	884.5	1997-2001		1022.5	
		Markdale_Isla	2618496	2180	2001	survey	2520.1	
		Markdale_Terra	1309248	1090	2001		1260.0	
		Beaver Heights#2	45824	38.2	2001	survey	44.2	
		Beaver Heights#3	98194	81.8	2001		94.6	
	Bruce	Municipality of Arran-Elderslie	Kimberley#1	n/a	100	2001	survey	115.6
			Kimberley#2	n/a	(combined)			
			Tara#2	--	171.6	2000-2001	survey	198.4
		Town of South Bruce Peninsula	Tara#3	727360	270.5	2000-2001		312.7
			Chesley_Victoria	1307520	175.8	1997-2001	survey	203.2
			Chesley_Community	2615040	644	1997-2001		744.5
Fiddlehead#1			327000	7.4	1997-2001	survey	8.6	
Cammidge&Collins#2			60750	4.7	1997-2001	survey	5.4	
Robins#3			141750	19.2	1997-2001	survey	22.2	
Fedy#4			118000					
Forbes#5			69000	15.6	1997-2001	survey	18.0	
Trask#6			80000	20.3	1997-2001	survey	23.5	
Huron Woods#1			104600	10	estimate	survey	11.6	
Huron Woods#2			52300	5	estimate		5.8	
Huron Woods#3			130900	10	1997-2001		11.6	
Huron Woods#6			457700	39	1997-2001		45.1	
Foreman#8			163440	9.8	1997-2001	survey	11.3	
Thomson#9			196000	6.3	1997-2001	survey	7.3	
Winburk#10			262080	31.3	1997-2001	survey	36.2	
Gremik#11			328320	19	1997-2001	survey	22.0	
Municipality of Brockton		Lake Rosiland#3	--	28.7	2000-2002	survey	33.2	
		Chepstow	50400	14.5	2000-2001	survey	16.8	
Township of Huron-Kinloss		Ripley#1	864000	313	1998-2001	survey	361.8	
		Ripley#2	combined	(combined)				
		Point Clark#1	3273120	561	1998-2001	survey	648.5	
		Point Clark#2	combined	(combined)				
		Blairs Grove#2	2620800	58	1998-2001	survey	67.0	
		Blairs Grove#3	combined?	no pump				
		Murdock Glen#1	196560	311	1998-2001	survey	359.5	
		Murdock Glen#2	1814400	(combined)				
		Huronville#1	271296	246	1998-2001	survey	284.4	
		Huronville#2	3927744	(combined)				
	Lucknow#4	--	70	1999-2001	survey	80.9		
	Lucknow#5	681900	446	1999-2001	survey	515.6		
	Municipality of South Bruce	Whitechurch#1	227280	25	2001	survey	28.9	
Mildmay#1		545520	624.8	1997-2001	survey	722.3		
Mildmay#2		982000						
Teeswater#3		1309200	421.8	1997-2001	survey	487.6		
Municipality of Kincardine		Tiverton_Dent	393120	280.3	1998-2001	survey	324.0	
	Tiverton_BriarHill	524160	combined					
	Underwood#1	90920	25.6	1999-2001	survey	29.6		
	Scott Point#1	77760	26.6	1999-2001	survey	30.7		
	Kinhuron#1	72736	29.1	1998-2001	survey	33.6		
	Craig-Eskrick#1	--	24.3	1998-2001	survey	28.1		
	Lake Huron Highlands#1	116378	183.6	1998-2001	survey	212.2		
	Lake Huron Highlands#2	combined	well #2					
Port Head Estates#1	294624	9.2	1998-2001	survey	10.6			

* Bruce County Planning Dept.

Appendix G

Press Releases

Press Release

July 2002

Grey County

Bruce County

Groundwater and Wellhead Protection Studies

Water is a precious and irreplaceable resource. In recognizing the need for safe water, communities across Ontario are now undertaking measures for the long-term management and protection of their water supply. The County of Grey and the County of Bruce have now initiated a study to determine the characteristics of groundwater and to establish wellhead protection areas. This cost of this study is being shared by the Ministry of the Environment and Energy and the County governments.

Since groundwater is the primary source of drinking water for many of the communities in these Counties, the study will first define local and regional groundwater conditions. This will be followed by an assessment of aquifers that are particularly susceptible to contamination and the identification of potential contaminant sources. A key focus will be to determine the wellhead protection area for 78 municipal wells and two springs serving 48 communities throughout the Counties. These are the areas where water is captured from groundwater or surface water sources to supply the well.

Groundwater is water found in the tiny spaces between soil particles and cracks in the bedrock. Aquifers are the underground areas of soil and rock where substantial quantities of groundwater are found and are the source for wells and springs. It is important to understand the size of aquifers, the direction of the water flow and the time taken for water to travel

underground in order to determine the extent of the wellhead protection area for each municipal well. Once this is known, pro-active methods of managing and protecting groundwater resources will be recommended.

Public information sessions will be held during the study to provide an opportunity for interested residents to learn more about the project and to provide their comments to the study team.

For further information about the study, please visit our website at:
www.greybrucegroundwaterstudy.on.ca

If you have any questions, please feel free to contact.

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County of Bruce
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or

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County of Grey
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Grey and Bruce Counties Groundwater Study

Public Meeting and Open House

Water is a precious and irreplaceable resource. The County of Grey and the County of Bruce are now conducting a study to characterize the groundwater flow systems, to identify areas susceptible to contamination, and to define protection areas for existing municipal well supplies within the counties. This will lead to measures to protect the aquifers and wells that provide the source of the water we use on a daily basis. This will also help 48 communities with municipal groundwater supplies within the Counties to establish wellhead protection areas around their wellfields. These are the areas surrounding municipal wells and springs that are susceptible to contamination if they are not protected.

If you are concerned about protecting the quality and quantity of groundwater in your community, please check your calendar and plan to attend an open house and public meeting. This important meeting will be held on **Tuesday, August 27, 2002** in the Community Centre (129 4th Avenue Southeast) in Chesley. To assist you in planning your day, the same format has been planned for both the afternoon and evening. In the afternoon, the open house will run from 3:00 to 5:00 pm with a formal presentation to be made at 3:30 pm. In the evening, the open house will run from 7:00 to 9:00 pm with a formal presentation at 7:30 pm. There will be a question and answer period following each presentation. Members of the Steering Committee and the Consulting Team will be in attendance to help you with any questions or concerns that you may have. We look forward to seeing you there.

For further information about the study, please visit our website at: www.greybrucegroundwaterstudy.on.ca. If you have any questions, please feel free to contact.

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February 3, 2003

Grey and Bruce Counties Groundwater Study

Public Open House #2

The Grey and Bruce Counties Groundwater Study Team today announced the organization of a second public meeting to be held at the Chesley Community Centre on Tuesday, February 18, 2003. The purpose of the Open House will be to present the draft study findings to residents and businesses of the Counties.

The primary objectives of the Study are to define existing groundwater and aquifer resources, to delineate wellhead protection areas for municipal wells and to develop groundwater protection strategies for municipal groundwater systems in Grey and Bruce Counties. Groundwater resources have been mapped regionally across the study area, and wellhead protection areas (WHPAs) have been developed for 76 municipal well systems in 45 communities throughout the counties. Groundwater use and groundwater vulnerability have also been assessed within the study area. These results will be presented at the Open House.

The meeting will be held at the Chesley Community Center (1294th Ave SE, Chesley, Ontario) from 3:00 pm to 5:00 pm, and 7:00 pm to 9:00 pm. The meeting format will consist of a formal presentation followed by the opportunity for questions.

Persons wishing to learn more about the Study prior to the meetings can visit the project web site at www.greybrucegroundwaterstudy.on.ca. If you have any questions, please feel free to contact:

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Appendix H

Sample WHPA Ordinance

Example Planning Policies for an Official Plan

A. Wellhead Protection

Goal for Wellhead Protection

To provide for the protection of municipal water supplies from contamination associated with certain land uses and to secure the long-term protection of a potable water supply for existing residents and businesses.

To prohibit land uses from being established in Wellhead Protection Areas or to ensure that certain uses can be established within an acceptable level of risk to groundwater quality.

Identification of Wellhead Protection Areas (WHPA)

WHPAs are shown as “Wellhead Constraint Areas” on Schedule ‘x’ to the Official Plan. A WHPA includes four time-related zones which were determined through a hydrogeological investigation. These include the 50 day, 50 day - 2 year, 2 - 10 year and 10 - 25 year zones, with the 50 day zone being ranked as the highest level of sensitivity (i.e. Sensitivity Zone 1 - based on the importance of the well to the water supply and the other categories ranked on a descending basis of sensitivity (Sensitivity Zones 2, 3 and 4)).

A WHPA shall be considered as a special protection area within which certain land uses may or may not be permitted in accordance with the underlying land uses designation and the following policies.

A WHPA may be modified by amendment to this Plan where the geographic extent of the WHPA in general, or any of the time-related zone boundaries are modified through further study, or where a municipal well is abandoned. Establishment of a new WHPA shall be subject to an amendment to this Plan concurrently with the Class Environmental Assessment process.

Scope of Land Use Categories

For the purposes of this Plan, Table 1 sets out the scope of prohibited land uses in each Sensitivity Zone (i.e. “•” - indicates a zone in which use is prohibited), with Zone 1 representing the highest level of sensitivity and Zone 4 the least level of sensitivity. No land in any local municipal Official Plan shall be designated or re-designated for any use prohibited in a Sensitivity Zone as set out in Table 1.

Table 1: Prohibition of Land Uses by Sensitivity Zone for Wellhead Protection
Sensitivity Zones (‘.’ - indicates zones in which use is prohibited)

Land use or activity	Zone 1	Zone 2	Zone 3	Zone 4
Wastewater or septage lagoon Solid waste landfill site, organic soil conditioning sites Snow storage and disposal facilities Hazardous waste disposal facility Auto wrecking and salvage yards Disposal of abattoir and rendering wastes Generation and storage of hazardous or liquid industrial wastes Warehousing and bulk storage of petroleum products (oils and fuels), petroleum solvents, pesticides, herbicides, fungicides, chemicals or hazardous substances except on-farm, storage for agricultural production or for use for an individual household Bulk storage of tires Outdoor storage of road salt Earthen manure storage facilities Construction equipment Contaminants listed in Schedule 3 (Severely Toxic Contaminants) of Ontario Regulation 347
On-site (private) sewage disposal system Groundwater heat pump Gas or oil pipeline New sewage collection main	.			
Storage of animal manure except by an individual for personal or household use Animal agriculture except by an individual for personal or household use Storage of agricultural equipment except by an individual for personal or household use Sand and gravel extraction, peat extraction Underground storage tanks (USTs) and any in-ground process-related piping of chemicals and lubricants, sumps such as dry wells and machine pits, and automotive repair pits Above ground storage tanks (ASTs) with Secondary containment	.	.		

Table 1: Prohibition of Land Uses by Sensitivity Zone for Wellhead Protection**Sensitivity Zones ('.' - indicates zones in which use is prohibited)**

Land use or activity	Zone 1	Zone 2	Zone 3	Zone 4
Land application of biosolids or septage	
Foundries				
Non-ferrous metal smelting and refining				
Metal casting operations				
Metal finishing operations (electroplating, electrocoating, galvanizing, painting, application of baked enamel)				
Assembly of aircraft and aircraft parts, motor vehicles, truck, bus bodies, trailers, rail cars, mobile homes, ships and boats				
Vehicle stampings				
Commercial or industrial dry cleaning of textiles and textile products				
Leather tanning and finishing				
Wood and wood product preservation and treatment				
Automobile service stations and gas bars or card-lock facilities				
Manufacturing of unfinished fabricated metal products and parts				
Manufacturing of cable and wire				
Manufacturing of jewellery and precious metals				
Manufacturing of engines, engine parts, steering and suspension parts, wheels and brakes				
Manufacturing of agricultural, commercial and industrial machinery				
Manufacturing of chemicals, resins, paints, varnish, printing inks, adhesives, plastics and reinforced fibreglass plastic				
Manufacturing of pharmaceuticals and medicines				
Manufacturing of electronic components such as semiconductors, printed circuit boards and cathode ray tubes				
Manufacturing of wet electrical equipment and wet batteries				
Manufacturing of motor vehicle wiring				
Manufacturing and dyeing of textiles				

Table 1: Prohibition of Land Uses by Sensitivity Zone for Wellhead Protection
Sensitivity Zones (‘.’ - indicates zones in which use is prohibited)

Land use or activity	Zone 1	Zone 2	Zone 3	Zone 4
Market gardening farms	
Intensive livestock operations and associated manure storage facilities and land application of manure				
Automated production of baked goods, dairy, canned goods, frozen foods, processed food and meat				
Automated manufacturing of soft drinks, distilleries, breweries and wine making				
Photographic developing facilities				
Printing of newspaper, packaging and books				
Repair of photographic equipment, electrical motors, electrical equipment, vending machines, small motors, appliances, computer equipment and jewellery				
Repair of motor vehicles, water craft, rail vehicles, trucks, buses and machinery				
Golf courses				
Airports				
Transit terminals				
Medical, health and other laboratories				
Storage, repair yards and facilities for contractors				
Asphalt paving and roofing contractor yards				
Lawn care contractors				
Funeral homes				
Cemeteries				
Machinery equipment and rental outlets				
Retails sale of agricultural fertilisers and pesticides				
Manufacturing of rubber products				
Manufacturing or electrical appliances, equipment, motors, lighting fixtures, lamps				
Manufacturing of electric light bulbs and tubes				
Manufacturing of dry batteries				
Manufacturing of soaps and toiletry preparations				
Manufacturing of plastic and foam parts and products				
Furniture, casket, cabinet and other wood products manufacturing and assembly				
Glass and glass products manufacturing				
Manufacturing of paper, newsprint, boxes				

Existing Uses, Enlargements, Extensions or Change of Uses

Land uses in Table 1 existing within a WHPA at the time of the coming into force of zoning by-law amendments adopted in accordance with the policies for Wellhead Protection Areas, will be recognised as legal non-conforming uses within the zoning by-law. Once these uses, cease to exist, such legal conforming status will be lost and such uses will no longer be permitted. A legal non-conforming status for market gardens will not be lost because of discontinuous use if the discontinuity of use is due solely to crop rotation practices.

When considering enlargements or extensions or a change of use, conditions shall be imposed that will minimise the degradation or groundwater (or surface water) quality, as appropriate.

Exceptions

Uses denoted with a “*” in Table 1 may be permitted in Zone 3 subject to the following performance standards provided such uses are permitted in the underlying land use designation:

1. The preparation of a disclosure report specifying the nature of the proposed use, its associated required services and facilities, the activities and operations to be conducted on-site and the substances to be used or stored on-site
2. The preparation of a detailed hydrogeological study using protocols acceptable to the Ministry of the Environment that predicts the net groundwater and/or surface water quality impacts likely to occur on the subject property, or down gradient properties and on the municipal well. The cumulative impacts of development in the WHPA will also be addressed in the report. The study report shall include mitigation measures for the design, construction and post-construction monitoring of the proposed use and where the impacts of the use cannot be adequately mitigated within an acceptable risk to groundwater and (surface water) quality to the satisfaction of the municipality, the use shall not be permitted.
3. The preparation of a spill prevention and contingency plan outlining design measures, facilities and procedures to avoid and mitigate the effects of spillage of any contaminants.

The cost of the disclosure report, the hydrogeological study and the spill prevention and contingency plan will be borne by the proponent.

Intensive Livestock Operations – Exception

Despite the policy prohibiting, new or expanding intensive livestock operations and associated manure storage facilities and land application may be permitted in a Sensitivity 2, 3 or 4 WHPA, where farming is a permitted use, subject to meeting the requirements of the *Nutrient Management Act, 2001* and regulations thereunder or a Nutrient Management By-law, whichever is the prevailing control. Such uses shall not be permitted where there are no nutrient management controls in place.

Abandoned Wells

Prior to new development, proponents will be required to carry out an investigation for abandoned water wells within any WHPA and provide for the proper sealing of same.

Development Criteria

Development may be permitted in a Wellhead Protection Area where the use is permitted in the underlying land uses designation, where it is not a prohibited use under the Wellhead Protection policies of this Plan and where it meets the required performance standards.

The cost of any studies or investigations required as a condition of development shall be borne by the proponent.

Where stormwater or drainage controls are required for any development, such studies shall be integrated with source protection measures for WHPAs.

In addition to meeting the requirements for water quality, any proponent of development shall meet the water quantity requirements of this Plan.

Consideration will be given to the technical merit of a development proposal as well as to how its approval will serve to enhance water quality or source protection.

The municipality may consult with any technical agency deemed appropriate in the review of a development proposal in a WHPA.

Best Management Practices

The municipality will promote the use of best management practices in farming, other industries and commercial enterprises as a means to minimise the risk of land use activities in and around a WHPA.

Monitoring

The municipality or a delegated authority will maintain a data base of information collected as part of the development review process and such information may be used to enhance the decision making process for future applications.

The municipality may undertake to implement a program to establish a system of sentinel monitoring wells within municipal WHPAs in order to help identify contaminants in the groundwater before they reach the municipal well.

Adjacent Lands

Despite the above policies, the municipality may limit other land uses outside of the WHPA, but in the general vicinity where they are considered to have a potential impact on source protection.

Zoning By-law

The zoning by-law shall incorporate appropriate requirements to implement the policies for wellhead protection. More specifically, the zoning by-law shall implement the use prohibitions and performance requirements and other policies described as set out in Table 1. The By-law shall require a rezoning for any use designated as '•' or '••' in a WHPA subject to first meeting the performance requirements and development criteria outlined above. The zoning by-law may set out minimum distance separations between a municipal well and any land use, building or structure whether the use is located within a WHPA or is in the vicinity of a WHPA.

Site Plan Control

A municipality shall require site plan control as a condition of the approval of any use of land within a WHPA. Site plan control shall be used as a means of incorporating mitigating and remedial measures, proper siting and containment of storage facilities, lot grading and drainage and site design plans identified through the development review process.

B. Aquifer Protection

Goal for Aquifer Protection

To provide for the protection of sensitive aquifers from contamination associated with certain land uses.

To prohibit land uses from establishing in vulnerable aquifer areas or to ensure that certain uses can be established within an acceptable level of risk to groundwater quality.

Identification of Aquifer Protection Areas

High aquifer vulnerable areas are shown as a “High Aquifer Protection Area” on Schedule ‘X’ to the Official Plan. A High Aquifer Protection Area illustrates aquifers which are highly susceptible to contamination owing to porous soil or other geological conditions that increase the rate of migration of contaminants from surface activities to the aquifer. Schedule ‘X’ also illustrates Moderate and Low Aquifer Protection Areas. These areas are also susceptible to contamination and warrant protection, but at a lesser level.

Where a WHPA overlaps an Aquifer Protection Area, the policies of the WHPA shall take precedence.

An Aquifer Protection Area shall be considered as a special protection area within which certain land uses may or may not be permitted in accordance with the underlying land uses designation and the following policies.

An Aquifer Constraint Area may be modified by amendment to this Plan where the geographic extent of the Area in general, is modified through further study.

Scope of Land Use Categories

For the purposes of this Plan, Table 2 sets out the scope of prohibited land uses in an Aquifer Protection Area. No land in any local municipal Official Plan shall be designated or re-designated for any use in Category A Table 2.

Uses Category B and C listed in Table 2 may be permitted in Moderate and Low Aquifer Protection Areas subject to meeting specified performance requirements.

Table 2: Prohibited Land Uses in Aquifer Protection Areas

Land Use or Activity	Aquifer Protection Area
<p>Category A</p> <p>Wastewater or septage lagoon</p> <p>Solid waste landfill site, organic soil conditioning sites</p> <p>Snow storage and disposal facilities</p> <p>Hazardous waste disposal facility</p> <p>Auto wrecking and salvage yards</p> <p>Disposal of abattoir and rendering wastes</p> <p>Generation and storage of hazardous or liquid industrial wastes</p> <p>Warehousing and bulk storage of petroleum products (oils and fuels), petroleum solvents, pesticides, herbicides, fungicides, chemicals or hazardous substances except on-farm, storage for agricultural production or for use for an individual household</p> <p>Bulk storage of tires</p> <p>Outdoor storage of road salt</p> <p>Earthen manure storage facilities</p> <p>Construction equipment</p> <p>Contaminants listed in Schedule 3 (Severely Toxic Contaminants) of Ontario Regulation 347</p> <p>Storage of animal manure except by an individual for personal or household use</p> <p>Animal agriculture except by an individual for personal or household use</p> <p>Storage of agricultural equipment except by an individual for personal or household use</p> <p>Sand and gravel extraction, peat extraction</p> <p>Underground storage tanks (USTs) and any in-ground process-related piping of chemicals and lubricants, sumps such as dry wells and machine pits, and automotive repair pits</p> <p>Above ground storage tanks (ASTs) with secondary containment</p>	<p>land uses which are permitted in the underlying land use designation are permitted in a High Aquifer Protection Area except for those uses set out in Category A.</p>
<p>Category B</p> <p>Storage of animal manure except by an individual for personal or household use</p> <p>Animal agriculture except by an individual for personal or household use</p> <p>Storage of agricultural equipment except by an individual for personal or household use</p> <p>Sand and gravel extraction, peat extraction</p> <p>Underground storage tanks (USTs) and any in-ground process-related piping of chemicals and lubricants, sumps such as dry wells and machine pits, and automotive repair pits</p>	<p>land uses which are permitted in the underlying land use designation are permitted in a Moderate or Low Aquifer Protection Area subject to meeting specified performance requirements.</p>

Table 2: Prohibited Land Uses in Aquifer Protection Areas

Land Use or Activity	Aquifer Protection Area
<p>Above ground storage tanks (ASTs) with secondary containment</p> <p>Land application of biosolids or septage</p> <p>Foundries</p> <p>Non-ferrous metal smelting and refining</p> <p>Metal casting operations</p> <p>Metal finishing operations (electroplating, electrocoating, galvanizing, painting, application of baked enamel)</p> <p>Assembly of aircraft and aircraft parts, motor vehicles, truck, bus bodies, trailers, rail cars, mobile homes, ships and boats</p> <p>Vehicle stampings</p> <p>Commercial or industrial dry cleaning of textiles and textile products</p> <p>Leather tanning and finishing</p> <p>Wood and wood product preservation and treatment</p> <p>Automobile service stations and gas bars or card-lock facilities</p> <p>Manufacturing of unfinished fabricated metal products and parts</p> <p>Manufacturing of cable and wire</p> <p>Manufacturing of jewellery and precious metals</p> <p>Manufacturing of engines, engine parts, steering and suspension parts, wheels and brakes</p> <p>Manufacturing of agricultural, commercial and industrial machinery</p> <p>Manufacturing of chemicals, resins, paints, varnish, printing inks, adhesives, plastics and reinforced fibreglass plastic</p> <p>Manufacturing of pharmaceuticals and medicines</p> <p>Manufacturing of electronic components such as semiconductors, printed circuit boards and cathode ray tubes</p> <p>Manufacturing of wet electrical equipment and wet batteries</p> <p>Manufacturing of motor vehicle wiring</p> <p>Manufacturing and dyeing of textiles</p>	
<p>Category C</p> <p>Market gardening farms</p> <p>Intensive livestock operations and associated manure storage facilities and land application of manure</p> <p>Automated production of baked goods, dairy, canned goods, frozen foods, processed food and meat</p> <p>Automated manufacturing of soft drinks, distilleries, breweries and wine making</p>	<p>land uses which are permitted in the underlying land use designation are permitted in a Moderate or Low Aquifer Protection Area subject to meeting specified performance requirements.</p>

Table 2: Prohibited Land Uses in Aquifer Protection Areas

Land Use or Activity	Aquifer Protection Area
Photographic developing facilities Printing of newspaper, packaging and books Repair of photographic equipment, electrical motors, electrical equipment, vending machines, small motors, appliances, computer equipment and jewellery Repair of motor vehicles, water craft, rail vehicles, trucks, buses and machinery Golf courses Airports Transit terminals Medical, health and other laboratories Storage, repair yards and facilities for contractors Asphalt paving and roofing contractor yards Lawn care contractors Funeral homes Cemeteries Machinery equipment and rental outlets Retail sale of agricultural fertilisers and pesticides Manufacturing of rubber products Manufacturing of electrical appliances, equipment, motors, lighting fixtures, lamps Manufacturing of electric light bulbs and tubes Manufacturing of dry batteries Manufacturing of soaps and toiletry preparations Manufacturing of plastic and foam parts and products Furniture, casket, cabinet and other wood products manufacturing and assembly Glass and glass products manufacturing Manufacturing of paper, newsprint, boxes	

Performance Standards

Land uses in Categories B and C in Table 1 may be permitted in Moderate and Low Aquifer Protection Areas subject to the following performance standards provided such uses are permitted in the underlying land use designation:

1. The preparation of a disclosure report specifying the nature of the proposed use, its associated required services and facilities, the activities and operations to be conducted on-site and the substances to be used or stored on-site

2. The preparation of a detailed hydrogeological study using protocols acceptable to the Ministry of the Environment that predicts the net groundwater and/or surface water quality impacts likely to occur on the subject property, on down gradient properties and the aquifer. The cumulative impacts of development in the aquifer will also be addressed in the report. The study report shall include mitigation measures for the design, construction and post-construction monitoring of the proposed use and where the impacts of the use cannot be adequately mitigated within an acceptable risk to groundwater and (surface water) quality to the satisfaction of the municipality, the use shall not be permitted.
3. The preparation of a spill prevention and contingency plan outlining design measures, facilities and procedures to avoid and mitigate the effects of spillage of any contaminants.

The cost of the disclosure report, the hydrogeological study and the spill prevention and contingency plan will be borne by the proponent

Intensive Livestock Operations

Despite the policy limiting intensive livestock operations and associated manure storage facilities and land application, new or expanding operations will be permitted in a Moderate or Low Aquifer Protection Area where farming is a permitted use, subject to meeting the requirements of the *Nutrient Management Act, 2001* and regulations thereunder or a Nutrient Management By-law, whichever is the prevailing control. Such uses shall not be permitted where there are no nutrient management controls in place.

Existing Uses, Enlargements, Extensions or Change of Uses

Land uses in Table 1 – Category A existing within a High Aquifer Protection Area at the time of the coming into force of zoning by-law amendments adopted in accordance with the policies for Wellhead Protection Areas, will be recognised as legal non-conforming uses within the zoning by-law. Once these uses cease to exist, such legal conforming status will be lost and such uses will no longer be permitted.

When considering enlargements or extensions or a change of use for a Category B or C use from Table 1, conditions may be imposed that will minimise the degradation of groundwater (or surface water) quality, as appropriate e.g. compliance with performance standards.

Development Criteria

Development may be permitted in an Aquifer Protection Area where the use is permitted in the underlying land uses designation, where it is not a prohibited use under the Aquifer Protection policies of this Plan and where it meets the required performance standards.

The cost of any studies or investigations required as a condition of development shall be borne by the proponent.

Where stormwater or drainage controls are required for any development, such studies shall be submitted with an application for development..

In addition to meeting the requirements for water quality, any proponent of development shall meet the water quantity requirements of this Plan.

Consideration will be given to the technical merit of a development proposal as well as to how its approval will serve to enhance water quality or source protection.

The municipality may consult with any technical agency deemed appropriate in the review of a development proposal in an Aquifer Protection Area.

Best Management Practices

The municipality will promote the use of best management practices in farming, other industries and commercial enterprises as a means to minimise the risk of land use activities in and around an Aquifer Protection Area.

Monitoring

The municipality or a delegated authority will maintain a data base of information collected as part of the development review process and such information may be used to enhance the decision making process for future applications.

The municipality may undertake to implement a program to establish a system of sentinel monitoring wells where deemed appropriate in order to help identify contaminants in the groundwater before they reach the municipal well.

Adjacent Lands

Despite the above policies, the municipality may limit other land uses outside of an Aquifer Protection area, but in the general vicinity where they are considered to have a potential impact on the aquifer.

Zoning By-law

The zoning by-law shall incorporate appropriate requirements to implement the policies for aquifer protection. More specifically, the zoning by-law shall implement the use prohibitions and performance requirements and other policies described as set out in Table 1. The By-law shall require a rezoning for any use designated as a Category B or C us subject to first meeting the performance requirements and development criteria outlined above.

Site Plan Control

A municipality shall require site plan control as a condition of the approval of any use of land within the Aquifer Protection Areas as a means of incorporating mitigating and remedial measures, proper siting and containment of storage facilities, lot grading and drainage and site design plans identified through the development review process.