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Ausable Bayfield Conservation Authority
71108 Morrison Line, R. R. # 3
Exeter, Ontario N0M 1S5

RE: Final Report for Well Head Protection Area Delineation Project

Dear Ms. Cathie Brown,

It is our pleasure to submit this Final Phase I Report ABCA / MVCA Groundwater Model Updates And Capture Zone Delineation. Waterloo Numerical Modelling Corp., International Water Supply, and B.M. Ross and Associates have brought together our expertise and experience to effectively accomplish this project.

Please do not hesitate to call if you wish to discuss anything further.

Sincerely,

Murray Ostrander, M.A.Sc., P.Eng
Principal
Waterloo Numerical Modelling Corp.

James Graham, M.A.Sc., P.Eng
Senior Hydrogeologist
Waterloo Numerical Modelling Corp.

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Appendix A: Figures

DISCLAIMER

The findings reported in this document are based on the tasks completed by Waterloo Numerical Modelling Corp, B.M. Ross and Associates, and International Water Supply, and also by other parties supplying data, information and interpretations. Best professional judgment, experience with similar investigations, and available data collected within the scope of work form the basis for this report. This report has been prepared using information understood to be factual and correct, and shall not be responsible for conditions arising from information or facts that were inaccurate, concealed, or not fully disclosed at the time of investigation.

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Executive Summary

With Source Protection Planning brought forward by the Ontario Ministry of Environment (MOE), a critical component of the planning process is updating the work completed in the previous groundwater studies within the Ausable Bayfield and Maitland Valley Source Protection Planning Area. Sixty one municipal wells exist within the municipalities included in the study area. Of the 61 wells, there are 54 municipal wells that are in operation for which Wellhead Protection Areas (WHPAs) were developed or updated during this study. This is the Phase I portion of the study for the Source Protection Planning Area. The Phase I provides the basis for the upcoming Phase II study.

The main objective of the Phase I study was to standardize the WHPA delineation within the study area which was done by standardizing the modelling approach for the municipal well fields. Three dimensional MODFLOW SURFACT models were developed for all the well fields of the study. MODFLOW SURFACT is an advanced groundwater modelling package that couples unsaturated and saturated subsurface conditions.

From 1999 to 2003 most municipal well fields in the study area were characterized with groundwater flow models in various MOE funded groundwater studies. These studies provide the basis for the work presented here. Many of the past models do not meet the needs of Source Water Protection since they were developed with simplified analytical models or represented only bedrock aquifers without the overlying unconsolidated geologic materials. For some municipal well fields, new groundwater characterization and new groundwater models were needed since they were not included in past studies. In many cases the previous geologic and hydrogeologic characterization required further development and enhancement so that the necessary groundwater models could be updated or constructed.

The updated models were constructed using the hydrogeologic units from ground surface down, to the bottom of the aquifers the municipal wells were taking their groundwater. It is necessary for the model to extend up to the ground surface for future source water protection investigations. Surface water boundaries interacting with the groundwater system were included in the groundwater models. The groundwater models were calibrated to provide good representation of the aquifer systems supplying groundwater to the municipal wells. Once calibrated, the models were used to develop the 2 (Zone B), 5 (Zone C), and 25 year (Zone D) time of travel WHPAs. Uncertainty analyses were included in the development of the WHPAs. Uncertainty analysis is a conservative approach which is used to account for the intrinsic variations that exist in natural hydrogeologic environments.

The most vulnerable municipal well fields of the study area are found in the south of Huron County such as the Towns of Hensall and Exeter. Here the geologic materials overlying the aquifers are thin by comparison to other areas and provide less protection for potential surface impacts. In contrast some other areas have thick glacial tills and glaciolacustrine deposits, which provide a protective overlying, cover as is the case with the Town of Zurich and Perth County. The Towns of Hensall and Exeter are not included in the current WHPA study since they are decommissioning their groundwater supply network. The ISI mapping provided in the study illustrates the areas which are more vulnerable and which are more protective.

List of Terms

Term	Description
analytical groundwater model	A simplistic software program that represents groundwater flow. Can be used to determine WHPAs in simple fashion.
ABCA	Ausable Bayfield Conservation Authority
aquifer	Geologic material though which water can easily travel. May consist of rock or soil.
aquitard	Geologic material though which water cannot travel easily. May be rock or soil.
boundary conditions	A parameter used in the model to represent flow entering or leaving the model area, such as precipitation infiltrating into the groundwater system. Boundary conditions can also represent a model edge past which groundwater does not flow.
capture zone	Defined as source areas or volume for the groundwater entering the municipal supply wells determined through analytical or numerical groundwater modelling. Capture zones usually not defined above the watertable. Usually defined in time periods, 25 year capture zone is the area or volume within the aquifer that is needed to supply the well with 25 years of pumping. Capture zones are used to define WHPAs.
coarse grained materials	Sand and gravel.
conceptual groundwater model	A conceptual idea or picture of how a groundwater system operates, i.e. what is the extent, thickness, depth, and permeability of an aquifer, where does the groundwater flow to, what is the source of the groundwater, the interactions of groundwater and surface water of the area, wells that are pumping groundwater etc.
CSI Database	"Contaminate Source Inventory" Database. A database of potential contaminant source in Ontario, managed presently by the Ministry of the Environment
fine grained materials	Clays, silts and fine grained sands
hydraulic conductivity	A measure of how well water can pass through a geologic material. Aquifer materials have higher conductivity values and can transmit water easily. Aquitard materials have lower conductivity values and cannot transmit water easily.
ISI	"Intrinsic Susceptibility Index". ISI is an index broken down into three categories of high (ISI

	<30), medium (ISI 30 to 80) and low (ISI >80) susceptibility. Regions of high susceptibility have a high likelihood of contaminants at surface reaching the watertable.
karst feature	Unusually larger void spaces in an aquifer. These are commonly found in some limestone rock aquifers.
MVCA	Maitland Valley Conservation Authority
MODFLOW	A numerical groundwater flow model developed by the United States Geological Survey.
MODFLOW SURFACT	An enhanced version of MODFLOW developed by Hydrogeologic Inc., Herndon, Virginia.
MODPATH	A groundwater pathline model that determines the direction of groundwater flow or the origin of groundwater sources. Developed by the United States Geological Survey and used in conjunction with MODFLOW.
MOE Water Well Record Database	Database of information from wells drilled in Ontario. Information includes geology, hydrogeology, well completion information, location information, etc. Managed by the Ministry of the Environment
numerical groundwater model	A complex, usually three dimensional, software program that represents groundwater flow, usually based on a conceptual groundwater model. For this study the main objective of the modelling is determine the WHPAs
Permit to Take Water Database (PTTW)	Database of permitted rates of water supply wells in Ontario. A permit is needed for wells withdrawing more than 50,000 litres per day. Managed by the Ministry of the Environment
porosity	The amount of void space in a geologic material. The geologic matrix, i.e. rock or soil makes up the majority of the volume (approximately 70% for soils and 95% for rock) in the subsurface. In aquifers below the watertable, porosity is filled with water. Above the watertable, the void space is filled with a combination of water and air. Porosity is higher in soil aquifers than in rock aquifers.
sink hole	Depression in the ground surface that can form from void spaces in the subsurface such as karst features.
Spills Database	Database contaminant spills that have been identified and catalogued in Ontario. Managed by the Ministry of the Environment

subcrops	
SWAT	"Surface to Wellhead Advection Time". Time it takes a molecule of water to travel from the ground surface to enter into the water supply well. SWAT capture zones extend from ground surface to the well screen of a water supply well.
TOT	"Time of Travel", Projected time of travel in the aquifer for WHPAs, identified as 2, 5, 10, and 25 years.
uncertainty analysis	Analysis that is done to account for the unknowns and approximations that are inherent in any engineering or scientific modelling results. Uncertainty analysis can be thought of as a "Safety Factor" or "Buffer" that is included in the analysis.
Waste Disposal Site Inventory	Database of landfills and other areas that waste have been disposed in for Ontario. Managed by the Ministry of the Environment
WHPA	"Wellhead Protection Area". WHPAs are surface areas defined as source areas for the groundwater entering the municipal supply wells. All water infiltrated the ground surface in the WHPA is considered to be eventually traveling to the water supply well

1.0 Introduction

The Source Water Protection Area for this study is the combined area of Ausable Bayfield Conservation Authority and the Maitland Valley Conservation Authority. This study does not include the Town of Seaforth, Amberly, Lucknow, and Whitechurch water supply systems (10 wells).

There are currently sixty-one (61) municipal wells in the Ausable Bayfield and Maitland Valley Source Water Protection Region (AB-MV SWP Region) as part of this study (see Table 1-1). Of the 61wells, there are thirty-eight (38) municipal wells that are currently in operation for which the Wellhead Protection Areas (WHPAs) were developed or updated for this study. There are six (6) standby wells and seventeen (17) decommissioned wells. Figure1-1 outlines the AB-MV Source Water Protection Region while Figure 1-2 shows the municipal wells that were included in the study and their status.

Table 1-1: Municipal Well Status

County	Township	Town	Well Name	Status	Comment	UTM East NAD83	UTM North NAD83	WellType
Huron	ACW	Benmiller Estates	Well No. 1	Active		449463	4841192	Bedrock
Huron	ACW	Century Heights	Well No. 1	Active		444224	4844002	Bedrock
Huron	ACW	Century Heights	Well No. 2	Active		444222	4844018	Bedrock
Huron	ACW	Dungannon	Well No. 1	Active		452159	4855638	Bedrock
Huron	ACW	Dungannon	Well No. 2	Active		452119	4855612	Bedrock
Huron	ACW	Huron Sands	Well No. 1	Active		441919	4866437	Bedrock
Huron	Bluewater	Carriage Lane	Well No. 1	Active		444154	4824369	Bedrock
Huron	Bluewater	Harbour Lights	Well No. 1	Active		442978	4824445	Bedrock
Huron	Bluewater	Zurich	Well No. 1	Active		449295	4807803	Bedrock
Huron	Bluewater	Zurich	Well No. 3	Active		449322	4807824	Bedrock
Huron	Central Huron	Auburn Hall	Well No. 1	Active		457114	4846512	Bedrock
Huron	Central Huron	Clinton	Well No. 1	Active		456553	4829713	Bedrock
Huron	Central Huron	Clinton	Well No. 2	Active		456616	4829724	Bedrock
Huron	Central Huron	Clinton	Well No. 3	Active		456540	4829749	Bedrock
Huron	Central Huron	Kelly	Well No. 1	Active		442021	4834729	Bedrock
Huron	Central Huron	McClinchey	Well No. 1	Active		441877	4836197	Bedrock
Huron	Central Huron	S.A.M.	Well No. 1	Active		444498	4826003	Bedrock
Huron	Central Huron	VandeWetering	Well No. 1	Active		442685	4828158	Bedrock
Huron	Huron East	Brucefield	Well No. 1	Active		458235	4819291	Bedrock
Huron	Huron East	Brussels	Well No. 1	Active	Church St.	479890	4843051	Bedrock
Huron	Huron East	Brussels	Well No. 2	Active	Turnberry St.	480106	4843934	Bedrock
Huron	Huron North	Belgrave	McCrae St.	Active		470484	4851090	Bedrock
Huron	Huron North	Belgrave	Jane St. Well	Active		470569	4851248	Bedrock
Huron	Huron North	Blyth	Well No. 1	Active		465626	4843000	Bedrock
Huron	Huron North	Blyth	Well No. 2	Active		465659	4843030	Bedrock
Huron	Huron North	Wingham	Well No. 3	Active		474816	4860316	Bedrock
Huron	Huron North	Wingham	Well No. 4	Active		475106	4859941	Bedrock
Perth	North Perth	Atwood	Well No. 1	Active	Danbrook	498108	4834821	Bedrock
Perth	North Perth	Atwood	Well No. 2	Active	Smith	498510	4834785	Bedrock
Perth	North Perth	Gowanstown	Well No. 1	Active		506361	4846441	Bedrock
Perth	North Perth	Listowell	Well No. 4	Active		503949	4842211	Bedrock
Perth	North Perth	Listowell	Well No. 5	Active		503251	4842312	Bedrock
Perth	North Perth	Listowell	Well No. 6	Active		503888	4841141	Bedrock
Perth	North Perth	Molesworth	Well No. 1	Active		494237	4847681	
Wellington	Minto	Clifford	Well No. 1	Active		501696	4868554	Bedrock
Wellington	Minto	Clifford	Well No. 3	Active		501739	4868044	Overburden
Wellington	Minto	Harriston	Well No. 1	Active		510811	4862209	Bedrock
Wellington	Minto	Palmerston	Well No. 1	Active		512074	4853260	Bedrock
Wellington	Minto	Palmerston	Well No. 3	Active		512528	4853806	Bedrock
Huron	ACW	Benmiller Estates	Well No. 2	Backup	Not hooked up	449443	4841181	Bedrock
Wellington	Minto	Clifford	Well No. 2	Backup	500 m from Primary	502123	4868388	Bedrock
Wellington	Minto	Clifford	Well No. 4	Backup	<100m Well 3	501750	4868045	Bedrock
Wellington	Minto	Harriston	Well No. 2	Backup	~1000 m to Well 1	509819	4862385	Bedrock
Wellington	Minto	Harriston	Well No. 3	Backup	<100m Well 1	510765	4862212	Bedrock
Wellington	Minto	Palmerston	Well No. 2	Backup	<100m Well 1	512074	4853265	Bedrock
Huron	ACW	Maitlandview	Well No. 1	Decommissioned		444530	4843695	Bedrock
Huron	Bluewater	Hensall	Well No. 1	Decommissioned		459499	4808853	Overburden
Huron	Bluewater	Hensall	Well No. 2	Decommissioned		459948	4809251	Overburden
Huron	Bluewater	Hensall	Well No. 4	Decommissioned		459506	4808831	Overburden
Huron	Bluewater	Zurich	Well No. 2	Decommissioned		449329	4807817	Bedrock
Huron	Morris-Turnberry	Belgrave	Jane St. Well	Decommissioned		470569	4851248	Bedrock
Huron	Huron North	Belgrave	Humphrey Well	Decommissioned		470050	4851392	Bedrock
Huron	Huron North	Wingham	Well No. 1	Decommissioned		475131	4859930	Bedrock
Huron	South Huron	Exeter	Spring Collectors - East	Decommissioned		462566	4800754	Overburden
Huron	South Huron	Exeter	Spring Collectors - North	Decommissioned		462566	4800754	Overburden
Huron	South Huron	Exeter	Well - Cudmore	Decommissioned		464801	4805278	Bedrock
Huron	South Huron	Exeter	Well - Moodie	Decommissioned		465498	4798654	Bedrock
Huron	South Huron	Exeter	Well - Morgan	Decommissioned		464472	4804256	Bedrock
Huron	South Huron	Exeter	Well- Hicks	Decommissioned		464197	4799504	Bedrock
Perth	North Perth	Atwood	Well No. 2 - Bowman	Decommissioned		498402	4835570	Bedrock
Perth	North Perth	Listowell	Well No. 1	Decommissioned		503214	4842272	Bedrock

From 1999 to 2003 most of the municipal well fields were characterized and WHPAs delineated for during the various groundwater studies conducted throughout the AB-MV SWP Region as part of the MOE funded groundwater studies. The team of International Water Supply, BM Ross and Waterloo Numerical Modelling Corp conducted the study of Huron County. Frontline and Waterloo Numerical Modelling Corp conducted the study of the Town of Exeter. Golder & Associates conducted the study of Wellington County (Township of Minto), with the assistance of Waterloo Numerical Modelling Corp. Waterloo Hydrogeologic Inc. (now Schlumberger Water Services) conducted the study of Perth County (Municipality of North Perth) and Bruce County. These studies and their reports were used as the baseline for this study. The groundwater flow models were updated to reflect a combination of new information and conceptual understanding where available.

New three-dimensional models were developed for those well fields previously not modelled or modelled with simple analytical and one layer models. New models were developed for the Brucefield, Clinton, Huron West, and Zurich well fields.

The previous WHPA delineation for the municipal well fields were developed using complex three dimensional groundwater models that represented only the saturated portion of the subsurface, below the watertable, and did not include the unsaturated zone. One of the main objectives of this study was to standardize the WHPA delineation within the study area. The advanced groundwater model MODFLOW SURFACT (Hydrogeologic, 2001) was used for modelling the groundwater flow regime while MODPATH (Pollock, 1994) was used for the particle tracking analysis needed for the WHPA delineation.

The new and updated models were constructed using the hydrogeolgic units that start from ground surface and go to the bottom of the aquifers from which the municipal wells were taking their groundwater. It is necessary for the model to extend up to the ground surface for the purpose of future Source Water Protection investigations. The models were used to delineate 2, 5, and 25 year WHPAs in this study. An uncertainty analysis was incorporated into the WHPA delineation to include the impacts of parameter variations on the results. This work forms the basis for future Source Water Protection investigations within the study area.

1.1 Previous Studies

As this study builds upon previous studies, and for completeness of this report, the following three sections are included in this report and are referenced from the original Municipal Groundwater studies.

1.1.1 Huron County

"County of Huron Groundwater Assessment and Municipal Source Protection Study" by International Water Consultants Ltd., B.M. Ross and Associates Ltd., Waterloo Numerical Modelling Corp., August 2003

A large component of the study involved the delineation of capture zones for the municipal wells. Calibrated numerical flow models were developed to simulate the groundwater flow and capture zones for the higher capacity wells. Analytical methods were used to delineate capture zones of lower capacity municipal wells. The numerical flow models were calibrated to data from the MOE water well record database and stream flow data where appropriate. Once the model was calibrated, it was used to predict and delineate the 50 day, 2-year, 10-year and 25-year zones of capture for each municipal well. An uncertainty analysis was incorporated into the delineation of all the capture zones determined by the numerical models to address the impact of parameter variations on the results. An uncertainty analysis was not conducted for the analytical models since conservative assumptions were already incorporated into the input parameters.

The Karst bedrock identified within the County presents a unique susceptibility feature. Due to the presence of this feature and the potential for sinkhole development, the implied ISI index may be modified to reflect the increased susceptibility from surface contamination.

A regional contaminant source inventory was compiled using various municipal and provincial databases which included; the MOE PCB database, MOE Waste Disposal Site Inventory, Technical Standards and Safety Authority Inventory of Underground Storage Tanks, MOE Spills Database, County of Huron Livestock Barn Permit Database and the MOE Water Well Record Database.

An assessment of the groundwater use on a regional scale was conducted using the MOE Permit to Take Water Database, municipal production records, relevant census and government data, along with a phone survey of large water users in the area. Based on population estimates, approximately 75% of the population depends on groundwater.

The study included a community consultation process, which targeted specific audiences and areas of interest. The study was promoted to the general public through news releases, a web site, a public open house and a series of interviews with study personnel on CKNX Radio.

1.1.2 Wellington County – Clifford, Harriston, & Palmerston

Similarly to that done for Huron County, the Wellington County study, by Golder Associates (August 2005) included characterization of the hydrogeologic conditions, WHPA delineation and aquifer vulnerability assessment. Please refer to their report entitled "County Of Wellington Groundwater Protection Study", Golder Associates (August 2005) for details of the study.

1.1.3 Perth County – Atwood, Listowel, & Gowanstown

Similarly to that done for Huron County, the Perth County study, by Waterloo Hydrogeologic, Inc. (April 2003) included characterization of the hydrogeologic conditions, WHPA delineation and aquifer vulnerability assessment. Please refer to their report entitled "Perth County Groundwater Study Final Report", Waterloo Hydrogeologic, Inc. (April 2003) for details of the study.

1.2 Municipal Wells

The following section provides a brief description of the municipal wells included in the groundwater study area (Figure 1-2). Further details on well construction and water use can be found in the project database which accompanies this report.

1.2.1 Township of Ashfield-Colborne-Wawanosh (ACW)

There are five municipal well systems located in the Township of ACW. They are referred to as Huron Sands, Benmiller Estates, Maitlandview Estates (Decommissioned), Century Heights, and Dungannon. The spatial outline of municipal wells for ACW is shown in Figure 1-2-1.

Huron Sands

The Huron Sands Well is located in the former Township of Ashfield in Front Concession Lot 19. The well (MOE # 3006921) was constructed in March 2001 to replace an existing well which supplied the Huron Sands settlement area. The new well is a nominal 203 mm diameter, 77.7 m deep rock well, with casing to a depth of 68.2 m below grade. The well was originally drilled to 94.5 m, however the broken limestone encountered during drilling caved upon completion to the above noted depth. The annular space around the casing is filled with hole plug from 15.2 m below grade to surface. The well operates under PTTW #01-P-1130 (expires in 2011) which allows for a maximum daily taking of 328 m^3/day. The average daily taking for the well is 20 m^3/day based on production records from 2002 - 2005. The well currently serves approximately 100 persons.

Benmiller Estates

The Benmiller Estates Well (MOE #3003514) was constructed in 1977. The well is located in Concession 1, Lot 1 of the former Township of Colborne, southeast of the Town of Goderich. The well is a nominal 152 mm diameter, 65.8 m deep rock well, with casing to a depth of 38.2 m below grade. There is no annual seal identified on the well record. The well operates under PTTW # 5867-5LMJ7A (expiry date unknown) which allows for a maximum daily withdrawal of 196.3 m^3/day. The average daily taking for the well is 59 m^3/day based on production records from 2001 - 2005. The well currently services a number of residential homes and the Benmiller Inn.

In December 2007 a new well was drilled for the purpose of being used as an observation well. If needed, this observation could be converted into a municipal well.

Maitlandview Estates

The Maitlandview Estates well was decommissioned in 2008 and therefore will not be discussed further.

Century Heights

The Century Heights Well is situated within the Century Heights Subdivision located in Concession 1, Western Division, Lot 1 of the former Township of Colborne. There are currently two operating municipal wells (Well #1: MOE #3003809 and Well#2: MOE #unknown). Well #1 was constructed in 1979 and is a nominal 152 mm diameter rock well. The well was completed to a depth of 68.8 m and is cased to a depth of 34.4 m below grade. There is no annular seal noted on the water well record. Well #2 is completed in the bedrock to a depth of 66 m.

The two wells operate under PTTW # 7587-5SBQU2 (expires in 2013) which allows for a combined maximum daily taking of 734.4 m^3/day. The average daily taking for the two wells was 160 m^3/day based on production records from 2001 - 2005. The well currently services residential homes in the subdivision.

Dungannon

There are two municipal wells in Dungannon that were constructed in 2002, Well #1 (MOE# unknown) is cased to the top of bedrock (33.2 m) and with an open hole in the bedrock to a total depth of 77.7 m. Well #2 (MOE # unknown) is also cased to the top of bedrock (35.1m) with an open hole in the bedrock to a total depth of 87.2m. The wells have a permitted rate of 438 m^3/d and operate under the PTTW #6111-5NCJFS (expires in 2013). The average daily taking for the two well system is 90 m^3/day based on production records from 2004 and 2005. The wells were not metered prior to 2004.

1.2.2 Municipality of Bluewater

There are three communities serviced by municipal wells in the Municipality of Bluewater with a total of seven wells. The wells are located in the communities of Bayfield (Carriage Lane and Harbour Lights), Zurich and Hensall. The distribution of municipal wells for Bluewater is shown in Figure 1-2-2.

Carriage Lane

The Carriage Lane Well (MOE # unknown) was constructed in 1989. The well is a nominal 203 mm diameter, 60.9 m deep, rock well with casing to 39.6 m below grade. There is no annular seal indicated on the water well record. The well operates under PTTW #93-P-0045 (expired in 2008) which allows for a maximum daily withdrawal of 348.5 m^3/day. The average taking for this system was 19 m^3/day based on records taken from 2002 – 2005.

Harbour Lights

The Harbour Lights Well was constructed in 1992 and is a nominal 152 mm diameter rock well (MOE # unknown). The well is completed to a depth of 32.9 m and is cased to 28.6 m below grade. There is no annular seal indicated on the water well record. The well operates under PTTW # 92-P-0090 (expired in 2002) which allows for a maximum daily withdrawal of 111.6 m3/day. The average taking for this system was 20 m^3/day based on records taken from 2002 – 2005.

Zurich

The Community of Zurich is serviced by two wells referred to as Well No. 1 and Well No. 3. Well No. 1 (MOE # 3001265) was constructed in 1963 and is a nominal 203 mm diameter rock well. The well is completed to a depth of 88.4 m and is cased to 66.4 m below grade. The annular space is sealed with concrete from surface to about 2.1 m below grade. Well No. 3 (MOE # A002404) is a rock well completed to a depth of 97.53 m below grade. Well No. 3 is cased to a depth of 93.57 m below grade.

These two wells operate under PTTW # 2321-679L6X (Expires Dec 1, 2014) which allows for a combined maximum daily withdrawal of 1152 m3/day. The average daily withdrawal for the community of Zurich is 546 m3/day based on production records from 2001 - 2005.

Well No. 2 (MOE #3001781) constructed in 1944 was decommissioned some time in 2006 and will not be discussed further.

Hensall

The municipal wells that supply the village of Hensall were decommissioned in 2008 and therefore will not be discussed further.

1.2.3 Municipality of Central Huron

There are eight municipal wells located in the Municipality of Central Huron. Three of the wells service the Town of Clinton. The remaining five wells service small residential systems. These wells are referred to as Auburn, Kelly, McClinchey, S.A.M. and Van de Wetering. The distribution of municipal wells for Central Huron is shown in Figure 1-2-3. The Dundass Well No. 1 is located within Central Huron, but was not included in this study.

Clinton

The Town of Clinton is serviced by three municipal wells referred to as Well No. 1, Well No. 2 and Well No. 3. Well No. 1 (unknown MOE#) is a nominal 203 mm diameter bedrock well completed to a depth of 99 m, with nominal 234 mm diameter casing to a depth of 30.5 m below grade. There is no MOE water well record identified for this well. The presence of an annular seal for this well is not known.

Well No. 2 (unknown MOE#) is a nominal 305 mm diameter rock well completed to a depth of about 108 m below grade. There is no MOE water well record for this well. The size and depth of casing in this well is unknown.

Well No. 3 (MOE #3000117) was constructed in 1951. The well is a nominal 305 mm diameter rock well completed to a depth of 109.7 m with casing to a depth of 29.3 m below grade. According to the water well record the annular space is sealed with concrete form 29.3 m to surface.

There is no known PTTW for the wells operating in the Town of Clinton. Average daily withdrawals from all three wells combined are 1968 m3/day based on production records from 2001 to 2005.

Auburn Hall

The Auburn Well (MOE # 3000941) services the Hamlet of Auburn and is located in Concession 14, Lot 44 of the former Township of Hullet. The well, constructed in 1961, is a nominal 100 mm diameter rock well completed to a depth 56.4 m with casing to 36.6 m below grade. There is no indication of the presence of an annular seal. This well operates under PTTW #02-P-1223 (expires in 2012) and allows for a maximum daily rate of 61.9 m3/day with an average taking of 9m3/day based on records taken from 2003 – 2005. The well services an estimated residential population of 30 persons.

McClinchey

The McClinchey Well (MOE# 3000335) was constructed in 1967 and services a residential area. The well is located in Concession 1, Lot 16 of the former Township of Goderich. The well is a nominal 130 mm diameter rock well completed to a depth of 43.3 m with casing to 30.2 m below grade. There is no indication of the presence of an annular seal. The well operates under PTTW #01-P-1198 (expired in 2004) which allows for a maximum daily withdrawal of 100.8 m3/day. The average daily withdrawal for the well is 8 m3/day based on records taken from 2001 - 2005.

Kelly

The Kelly Well (MOE #3004247) was constructed in 1981 and services a residential area. The well is located in Concession 1, Lot 20 of the former Township of Goderich. The well is a nominal 150 mm diameter rock well completed to a depth of 45.7 m with casing to 31.7 m below grade. There is no annular seal identified on the water well record. The well operates under a renewed PTTW # 2238-68TSSW (expired in 2006) which allows for a maximum daily withdrawal of 196.1 m^3/day. The average daily withdrawal for the well is 22 m^3/day based on records from 2001 - 2005.

S.A.M.

The S.A.M. Well (MOE # 3003848) was constructed in 1979 and services a residential area. The well is located in Bayfield Concession, Lot 75 of the former Township of Goderich. The well is a nominal 159 mm diameter rock well completed to a depth of 59.4 m with casing to 42.7 m below grade. There is no indication of the presence of an annular seal. This well operates under PTTW # 01-P-1197 (expired in 2007) which allows for a maximum daily withdrawal of 164 m^3/day. The average daily withdrawal for the well is 9 m^3/day based on records from 2001 - 2005.

Van de Wetering

The Van de Wetering Well (MOE # unknown) was constructed in 1989 and services residential area. The well is located in Concession 1, Lot 36 of the former Township of Goderich. The well is a nominal 150 mm diameter rock well completed to a depth of 42.1 m with casing to 27.1 m below grade. There is an annular seal of bentonite clay slurry from 27.1 m to surface. The well operates under PTTW # 8723-66JJLZ (expires in 2014) which allows for a maximum daily taking of 97.9 m^3/day. Production records from the year 2001 - 2005 indicate an average daily taking of 9 m^3/day.

1.2.4 Municipality of Huron East

There are three communities serviced by municipal wells in the Municipality of Huron East with a total of six wells. The wells are located in the communities of Brucefield, Brussels, and Seaforth. The distribution of municipal wells for Huron East is shown in Figure 1-2-4.

Brucefield

The Hamlet of Brucefield is serviced by one well referred to as Well No. 1 (MOE #3002561). The well was constructed in 1972 and is a nominal 203 mm diameter rock well completed to a depth of 88.4 m with casing to a depth of 23.5 m below grade. There is no indication of an annular seal on the water well record. The well operates under PTTW #72-P-0426 (expires in 2012) which allows for a maximum daily taking of 270 m3/day. The average daily taking for the well is 60 m^3/day based on production records from 2001 - 2005.

Brussels

The Village of Brussels is serviced by two wells referred to as Well No. 1 (Church St.) and Well No. 2 (Turnberry St.). Well No. 1 (MOE WWR unknown) was constructed in 1951 and is a nominal 250 mm diameter rock well completed to an estimated depth of 60 m. There is no water well record for this well and therefore amount of casing and presence of an annular seal cannot be confirmed. The average daily taking from this well is 520 m3/day based on production records from 2001 - 2005.

Well No. 2 (MOE # 3000116) was constructed in 1963 and is a nominal 250 mm diameter rock well completed to a depth of 60.4 m with casing to 12.2 m below grade. There is no indication of the presence of an annular seal. The average daily taking from this well is 17 m3/day based on production records from 2001 - 2005.

The two municipal wells operate under PTTW #7307-5YFSJ7 (expires in 2014) which allows for a maximum daily taking of 1,097 m3/day.

Seaforth

The Town of Seaforth is serviced by three municipal wells. These wells are not included in this study since there is a concurrent study is being completed by WESA.

1.2.5 Municipality of North Huron

There are three communities serviced by municipal well in the Municipality of North Huron with a total of six wells. The wells are located in the communities of Belgrave, Blyth, and Wingham. The distribution of municipal wells for North Huron is shown in Figure 1-2-5.

Belgrave

The Hamlet of Belgrave located on the border of North Huron and Morris-Turnberry municipalities was serviced by three wells; Humphrey Well, Jane Street Well, and McCrae Street Well. The Humphrey Well was decommissioned in 2008 and therefore will not be part of the following analysis. The Jane Street and McCrae Street wells are located in municipality of Morris-Turnberry.

The distribution of municipal wells for Belgrave is shown in Figure 1-2-5. Belgrave is currently serviced by two wells referred to as the McCrae Street Well and the Jane Street Well. The McCrae St. Well (MOE #3003252) was constructed in 1976 and is a nominal 150 mm diameter rock well completed to a depth of 38.1 m with casing to 21.2 m below grade. There is no indication of the presence of an annular seal on the water well record. There is no known PTTW for this location. The well primarily serves the south east portion of the Hamlet of Belgrave. The average daily taking from the well was 20.5 m3/day based on production records from 1997 to 1999.

The Jane Street well (MOE #3004377) was constructed in 1983 and is a nominal 150 mm diameter rock well completed to a depth of 42.4 m with casing to 19.7 m below grade. There is no indication of the presence of an annular seal on the water well record. There is no known PTTW for this location. The well primarily serves the north east portion of the Hamlet of Belgrave. The average daily taking from the well was 20.0 m3/day based on production records from 1997 to 1999

Blyth

The Village of Blyth is serviced by two wells referred to as Well No. 1 and Well No. 2. Well No. 1 (MOE # 3000113) was constructed in 1953 and is a nominal 203 mm diameter rock well completed to a depth of 73.2 m with casing to 19.6 m below grade. There is no indication of the presence of an annular seal. The average daily taking for this well was 201.3 m3/day based on production records from 2001. The average daily taking from this well and Well No. 2 was 527 m3/day based on 1997 to 1999 and 2001 production records.

Well No. 2 (MOE # 3002541) was constructed in 1972 and is a nominal 203 mm diameter rock well completed to a depth of 79.25 m with casing to 20.1 m below grade. There is no indication of the presence of an annular seal on the water well record. The average daily taking from this well was 334.2 m3/day based on production records from 2001.

These wells operate under PTTW # 92-P-0058 (expired Jan 15, 2008) which allows for a maximum daily combined taking of 1776 m^3/day.

Wingham

The Town of Wingham has three municipal wells referred to as Well No. 1, Well No. 3 and Well No. 4. Well No. 1 has not been used for municipal supply since November 2000 due to ongoing turbidity issues. This well was decommissioned in 2008 and therefore will not be part of the following analysis.

Well No. 3 (MOE# 3002721) was constructed in 1973 and is a nominal 305 mm diameter rock well completed to a depth of 102.1 m with casing to 41.5 m below grade. There is no indication of the presence of an annular seal on the water well record. The well operates under PTTW #73-P-0507 which allows for a maximum daily withdrawal of 6,546.2 m3/day. The average daily taking for the well was 180 m3/day based on production records for 2001.

Well No. 4 (MOE #3005985) was constructed in 1996 and is a nominal 311 mm diameter rock well completed to a depth of 92.3 m with casing to 66.1 m below grade. The water well record indicates that the annular space is sealed with cement grout from 66.1 m to surface. The well operates under PTTW #97-P-1053 which allows for a maximum daily withdrawal of 5,270 m3/day. The average daily taking from the well was 1,513 m3/day based on production records for 2001. Combined taking for Well No. 3 and Well No. 4 was 1,797.3 m3/day based on 1997 to 1999 and 2001 production records.

1.2.6 Minto Township

There are three communities within Minto Township with a total of ten wells. These wells are located in the communities of Clifford, Harriston, and Palmerston. The distribution of municipal wells for Minto Township is shown in Figure 1-2-6.

Clifford

There are four municipal wells located in the Town of Clifford, of which only two are actively used for municipal water supply. Well No. 1, also known as the Mill St. Well (MOE WWR unknown) is a bedrock well (54.6 m deep) that was the primary supply until Well #3 was installed. Well No. 2 (MOE WWR unknown) is completed in the bedrock (depth 50 m). At the time of this report, there has been an application submitted (and pending approval) to the Ministry of Environment to officially decommission Well No. 2. Well No. 3 (MOE WWR unknown) is now the primary supply well and is completed in a deep overburden unit (depth unknown). Well No. 4 (MOE WWR unknown) is approximately 10 m away from Well No. 3 and is completed in the upper bedrock (depth unknown).

Well No. 1 operates under PTTW # 6117-62MQDH (expires in 2014) with a maximum permitted rate of 1310 m3/day and an average taking 300 m3/day. Well No. 3 and Well No. 4 operate under PTTW # 8554-6DDJZH (expires in 2015) and has a maximum allowed rate of 655 m3/day and 1309 m3/day respectively. Well No. 3 is the primary well (average taking of 416 m3/day) while Well No. 4 operates as a standby well (Golder, 2006).

Harriston

There are three municipal wells located in the Town of Harriston. Well No. 1 (MOE WWR unknown) is the main supply well with Well No. 2 (MOE WWR unknown) and Well No. 3 (MOE WWR unknown) used as backup supply wells. The backup wells have a minimal pumping rate to maintain the integrity of the wells system. All three wells are completed in the bedrock aquifer to depths of 24, 59 and 26 m for Well No. 1, Well No. 2, and Well No. 3 respectively. These wells operate under PTTW # 99-P-2045 (expires July 14, 2009) and have maximum allowed rates of 981, 2100, and 1600 m3/day for Well No. 1, Well No. 2, and Well No. 3 respectively. The average taking for Well No. 1 was 1374 m3/day (Golder, 2006).

Palmerston

There are three municipal wells located in the town of Palmerston. Well No. 1 (MOE WWR unknown) and Well No. 3 (MOE WWR unknown) are the primary supply wells. Well No. 2 (MOE WWR unknown) is approximately 5 m away from Well No. 1 and is used as a standby well. All three wells are completed in the bedrock. Well No. 1 and Well No. 2 are 43.6 m deep while Well No. 3 is 53.4 m deep. These wells operate under PTTW # 93-P-2001 (expires in 2013) with a maximum permitted rate of 1964 m3/day (combined for Well No. 1 and Well No. 2) and 2291 m3/day for Well No. 3. The average taking for Well No. 1 is 512 m3/day and Well No. 3 is 704 m3/day (Golder, 2006).

1.2.7 Municipality of North Perth

There are four communities within the Municipality of North Perth with a total of eight municipal supply wells. These are located in the communities of Atwood, Listowel, Gowanstown, and Molesworth. The distribution of municipal wells for North Perth is shown in Figure 1-2-7.

Atwood

There are two active municipal supply wells within the community of Atwood. In 2006, the municipal well known as the Well No. 1, also known as the Bowman Court well (MOE WWR 5002308) was decommissioned, and replaced by the Danbrook Municipal well (MOE WWR 5003961). Well No. 2, also known as the Smith well (MOE WWR 5000492) is 47.6 m deep and is completed in the bedrock. The Danbrook well operates under PTTW 2553-5YVHWB (expires May 31, 2009) and is permitted for 143 m3/day while the Smith well operates under PTTW 4277-5RWLHA (expires in 2013) and is permitted for 262 m3/day. The average annual takings from Well No. 1 was 36 m3/day and Well No. 2 was 33 m3/day based on the pumping history for 2001 to 2005.

Listowel

There are three active municipal supply wells within the community of Listowel. Well No. 1 was decommissioned in 2006. Well No. 4 (MOE WWR unknown) was drilled in 1948 to a depth of 92.6 m, Well#5 (MOE WWR 5000789) was drilled in 1962 to a depth of 92.66 m, and Well No. 6 (MOE WWR 5003702) drilled in 1989 to a depth of 118.57 m. All three municipal wells are completed in the bedrock aquifer system. These wells operate under PTTW 01-P-1182 (expires in 2011) and are permitted to take a combined rate of 3273 m/day. The average annual takings for these wells is 795, 693, and 819 m3/day for Well No. 4, Well No. 5, and Well No. 6 respectively based on average annual takings from 2001 – 2005.

Gownstown

There is one municipal supply well within the community of Gowanstown. Well No. 1 (MOE WWR 5001660) was drilled in 1964 and is completed in the bedrock aquifer. This well operates under PTTW 92-P-0063 (expires Nov 17, 2011) and is permitted for a rate of 71 m3/day. The average annual taking for this well is 11 m3/day based on records from 2002 – 2005.

Molesworth

There is one municipal supply well within the community of Molesworth. Well No. 1 (MOE WWR 5002441) was drilled in 1976 and is completed to a depth of 47.85 m in the bedrock aquifer. This well was operated privately until the Municipality of North Perth took over the maintenance and operation of the well in 2007. BM Ross completed an Engineers report (BM Ross, 2001) for the six-inch diameter well when it was operated by the residents of Molesworth. There is no known PTTW for this location and the average annual rate was estimated to be approximately30 m3/day based on number of houses, since there were no historical records of pumping rates at the time the groundwater models were developed.

2.0 Regional Aquifer / Resource Characterization

2.1 Previous Studies

The following MOE funded groundwater studies have been conducted within the ABCA/MVCA Source water Protection Area:

- Huron County: completed by the team of International Water Supply, BM Ross and Associates, and Waterloo Numerical Modelling Corp. in 2003;
- Town of Exeter: completed by the team of Frontline Environmental Management and Waterloo Numerical Modelling Corp., in 2003;
- Perth County: Completed by Waterloo Hydrogeologic, Inc (now Schlumberger Water Services) in 2002;
- Wellington County: Completed by Golder Associates in 2005.

The results of these studies are the basis of the present study. The aquifer and resource characterizations, mapping, and groundwater models developed in these studies were further expanded upon to include information such as new wells, decommissioned wells, and updated pumping rates.

2.2 Digital Elevation Model

The Digital Elevation Model (DEM) used in this project is the product of the Ministry of Natural Resource. The resolution of the DEM is 10 metres in the horizontal and is a seamless coverage of the entire study area (Figure 2-2).

2.3 Tile Drainage Network

An additional data source for this project, acquired from the Ministry of Natural Resource, is the tile drainage network. This includes the aerial coverage of the individual tile drainage along with the type of drainage installed. These types include Random, Systematic, and Unknown. This information was useful for model development as tile drainage can reduce effective recharge rates with the tiles diverting precipitation to surface water features that would otherwise infiltrate. The tile drainage network is shown in Figure 2-3.

2.4 Geology and Physiographic Regions

The geology and physiographic regions of the study areas has been detailed within the previous studies. For more detailed information, please refer to those individual reports. For illustrative purposes, the quaternary and bedrock geology regions are illustrated in Figure 2-5-1 and Figure 2-5-2. The following sections are referenced almost verbatim from the previous corresponding reports.

2.4.1 Huron County Geology

The Huron County landscape is dominated by till plains and moraines consisting of a heterogeneous mixture of clay, sand, pebbles and boulders deposited directly by continental glaciers. This results in the overburden geology generally consisting of three identified till units; St. Joseph Till, Rannoch Till, and Elma Till. The predominantly low permeable till overburden does not readily yield water to wells and therefore, the majority of the wells in the County are completed in the bedrock with less than 20% of the wells completed in the overburden material. The only municipal systems which draw water from overburden aquifers are located in the southern portion of the County in the communities of Hensall and Exeter.

The bedrock geology is dominated by the Dundee Formation, comprised of limestone, and the underlying Lucas Formation of the Detroit River Group, consisting of the limestone and dolostone. At several locations the Lucas Formation subcrops forming "windows" in the Dundee Formation. The Lucas Formation is considered to be the most permeable and therefore, the deeper wells in the area generally have higher yields as they penetrate through the Dundee Formation into the Lucas Formation. In areas of the County the Lucas Formation displays karst type features. The Karst bedrock is thought to occur generally in the southern portions of the County, from the Clinton area, southerly to encompass the Zurich and Hensall areas. The karst bedrock is porous resulting in high hydraulic conductivities along with the potential for formation of sinkholes.

2.4.2 Wellington County Geology

Most of the County is covered by varying thicknesses of glacial deposits, with bedrock exposed only in the deeper river valleys and along the margins of the study area in Flamborough and near the Niagara Escarpment.

The County of Wellington is underlain by Silurian limestones, dolostones and shales, which are layered sedimentary rocks formed in a shallow ocean that at one time, covered much of eastern North America. The Palaeozoic strata in this area exhibit a gentle regional dip towards the west and southwest, such that the younger formations are present only in the most western portion of the County. The principal bedrock aquifers in the study area are the Guelph, Amabel and Salina Formations.

Groundwater is present mainly in fractures and joints in these bedrock aquifers. Locally, finer grained units within the bedrock strata may restrict the vertical movement of groundwater between different bedrock aquifer layers. An example of this includes the Eramosa Member of the Amabel Formation, which has been observed to effectively confine the Amabel Formation aquifer in the southern part of the County. The Guelph and Amabel Formations are present throughout the county, while the Salina Formation is found only in Mapleton and Minto and in the westernmost part of Wellington North.

2.4.3 Perth County Geology

The Paleozoic bedrock in Perth Country is buried under some of the thickest Quaternary overburden in southern Ontario. Understanding the Quaternary deposits provides valuable information about potential aquifers and aquitards and the lateral continuity of these features. Quaternary sediments are thickest (about 100 m) along the buried bedrock valley through Atwood and Milverton, and they thin to zero along river valleys. Most of Perth County is covered by approximately 30 m of unconsolidated sediment.

The oldest Paleozoic bedrock subcropping below Perth County is the Salina Formation. This formation consists of some 120 to 200 m (400 to 600 ft) of interbedded shale, mudstone, dolostone, gypsum and salt. Subcropping west of the Salina Formation is the younger Upper Silurian aged Bass Islands Formation. It forms a narrow (1-3 km wide) subcrop band of oolitic dolostone along the far eastern edges of Perth. The unit is approximately 30 m thick.

The Bois Blanc Formation subcrops west of the Bass Islands Formation. This Devonian aged formation consists of cherty brown, fossiliferous limestone and is estimated to be approximately 45 m (150 ft) thick, and 10-13 km wide (Karrow, 1993).

The Detroit River Group, a 60 to 90 m thick unit overlies the Bois Blanc Formation. This Middle Devonian aged unit consists of the Lucas Formation, a microcrystalline limestone, and the Amherstburg Formation, a crinoidal limestone and dolostone. The Lucas Formation (the younger of the two formations) outcrops in the quarry walls of St. Marys (Karrow, 1977). The youngest bedrock to subcrop beneath Perth is the Dundee Formation, a grey to brown fossiliferous limestone that lies beneath the Detroit River Group.

2.5 Hydrogeology

The term hydrogeology refers to the occurrence and movement of water, namely groundwater, within the geologic formations like the ones discussed above. The following section describes the aquifers and groundwater flow patterns within the study area. The Ministry of Environment Water Well Record database was the main source of information used in the characterization of the hydrogeology. All wells drilled within the province require the submission of a water well record. The record includes such information as location, geologic formations encountered, water levels, and general quality of the water. The following sections are referenced verbatim from the previous corresponding reports.

2.5.1 Huron County Hydrogeology

The characterization of the aquifer within Huron County and surrounding area was based on over 6,000 wells. Only those wells with high reliability codes, as specified by the Terms of Reference in relation to location of the well were used for the characterization. The bedrock geology was further refined with the use of petroleum well logs within the county.

Within the County of Huron the majority of the wells are completed into the bedrock with less than 20% of the wells completed in the overburden materials. As previously described, the overburden geology is dominated by till type materials. Tills are generally associated with compacted low permeability silts and clays and are not considered aquifers. Potential aquifers are associated with areas of sand and gravel deposits of greater than two metres in thickness.

The only municipal wells completed in the overburden material occur in the southern portions of the County, in the communities of Hensall and Exeter. The remaining areas of sand & gravel throughout the County do not have sufficient permeability or thickness to support municipal withdrawals but may support takings for individual domestic wells. Aquifer tests carried out in the Hensall area show the overburden sand aquifer transmissivity ranging from 4 x10-3 to 2 x 10-2 m2/s with storativity values of 10-4 to 10-5.

The majority of the groundwater used within the County of Huron is from wells constructed in the bedrock formations. All of the bedrock formations within the County are considered bedrock aquifers. However, the limestones and dolomites of the Detroit River Group are considered to be the most permeable of all the bedrock units and are correspondingly the most productive aquifers in the County. Hydraulic conductivity values observed in the bedrock wells within the County are in the 10-4 to 10-5 m/s range although some local scale areas are reported to have values upwards to 10-3 m/s. The Dundee formation overlies the Detroit River Group, therefore, generally the deeper wells in the area have higher yields as they penetrate through the Dundee formation into the Detroit River Group. The Bois Blanc and Bass Island formations are considered to be in the same permeability range as the Dundee Formation.

The Dundee has been identified as low permeability aquitard in the central area of Huron near Clinton and Brucefield. The Dundee here provides a significant hydraulic separate between the overburden units and the Lucas. The groundwater in the overburden of some areas is perched.

As noted the Lucas Formation is associated with high hydraulic conductivity values. In areas of the County, the Lucas Formation has developed karst type features. Karst bedrock results from the chemical weathering and dissolution of limestone or dolomite, the type of bedrock common in Huron County. Water percolating through to the bedrock dissolves the limestone and carries away the solution. Over time, this persistent erosional process creates an extensive network of cavities, channels, and voids which results in very high hydraulic conductivity values. The presence of this karst bedrock is thought to occur generally in the southern portions of the County, from the Clinton area southerly, encompassing the Zurich and Hensall areas.

2.5.2 Wellington County Hydrogeology

The County of Wellington regional hydrogeologic mapping consists of: a shallow upper overburden aquifer; separated from an intermediate/deep overburden aquifer by an intervening glacial till aquitard; which in turn is underlain by a bedrock aquifer. Locally confining layers in the bedrock may serve to separate the bedrock into a number of aquifer units however for the purposes of the regional hydrogeological mapping products the bedrock has been considered a single hydrostratigraphic unit.

The base of the bedrock represents the various shale formations underlying the Amabel Formation. These units are relatively impermeable and are considered to mark the base of the hydrostratigraphic interval of interest in the study area.

Through Mapleton and Wellington North various overburden aquifers and aquitards units exist, as well as bedrock formations which dip gently towards the west-southwest. The area through Puslinch, the City of Guelph, Guelph- Eramosa and Erin consists of a single upper overburden aquifer, a contact aquifer formed at the weathered bedrock surface, and a series of bedrock units dipping gently towards the southwest. The municipal and communal wells shown on this section are completed in the Guelph and/or Amabel Formations.

Because the bedrock aquifers are widespread and continuous, bedrock wells can be found in almost all parts of Wellington County. By contrast, overburden wells tend to be concentrated in areas where significant amounts of sand and gravel are present. Thus, overburden wells are uncommon in the eastern part of Wellington North and in Minto where total sand and gravel thickness in the overburden is less than 10 m.

2.5.3 Perth County Hydrogeology

The geology and hydrogeology of Perth County was characterized and are presented in the depth to bedrock (overburden thickness), sand and gravel thickness, bedrock geology, and bedrock topography mapping. Extensive till units overlie bedrock throughout most of the County providing information about the prominent bedrock valley near Milverton and Atwood, as well as the drop in bedrock water levels in the southwest area of the County.

Perth County can be conceptualized as a three layer hydrogeologic model with an upper finegrained aquitard layer (overburden), a middle thin weathered bedrock aquifer layer, and a thick lower fractured bedrock aquifer. Approximately 80% of the water wells in Perth County are completed in bedrock.

The map shows that groundwater in the bedrock flows regionally from northeast (415 metres above sea level "masl") to southwest (220 masl) with a bedrock groundwater divide near the Easthope Moraine along a line running north of Shakespeare towards Gads Hill and the Ellice swamp.

Bedrock water levels decrease in elevation significantly near the contact between the Dundee and Lucas Formations. This also corresponds to an area understood to have karstic features (sinkholes). In Perth South and West Perth, bedrock water levels drop approximately 100 m over a distance of 10 to 20 km. This represents a hydraulic gradient of 0.01 to 0.005, which is very high relative to bedrock water level gradients across the rest of the County (0.002).

2.6 Intrinsic Susceptibility Index (ISI)

This index is an intrinsic measure of how easily an aquifer can be contaminated from land surface activities. It is based on the geologic and hydrological characteristics of the geologic formations which overlie the aquifer. The index is broken down into three categories of high, medium and low susceptibility. High susceptibility areas are those in which the upper most aquifer is close to, or at the ground surface and has little protection by aquitard type materials. These areas have the potential to allow contaminants from surficial activities to readily infiltrate and cause degradation of the water quality within the aquifer. Low susceptibility refers to areas where the upper most aquifer is deeper or is protected with significant amounts of low permeable aquitard materials. Susceptibility of the aquifer does not evaluate the type and intensity of the human activities at the land surface.

The ISI is based on a score which is derived by adding index values calculated for each hydrogeological unit to the first significant aquifer or alternatively to a deeper aquifer. The first significant aquifer has been defined by the MOE as the highest 2 m (1 m in absence of any 2 m interval) thick interval of saturated aquifer material. The index value is calculated by multiplying the thickness of each unit that lies above the aquifer and a representative K-Factor. The top of the aquifer is defined by aquifer top in the case of confined aquifer and by the watertable in the case of an unconfined aquifer. The K-Factor is based on the saturated vertical hydraulic conductivity of the hydrogeologic unit and is essentially an aquifer protection factor. For example a clay, having a low hydraulic conductivity, is assigned a high K-Factor compared to a gravel unit, which has a high hydraulic conductivity, which assigned a low K-Factor. The index value is calculated for each unit above the aquifer and then summed to provide an overall ISI value for each individual water well record. These individual values are then contoured to produce an ISI map that is continuous across the study area. The index is broken down into three categories of high (ISI <30), medium (ISI 30 to 80) and low (ISI >80) susceptibility.

The ISI map for the study area was derived using the procedures outlined in the 2002 MOE TOR. The ISI calculation for Huron County differed from the outlined procedures regarding how the K-Factor was applied to silts, tills, and clays that are less than 5 metres below ground surface. For these materials the K-Factor was set to a value of 3 versus the default values of 4 for silts, 5 for tills and 6 for clays. The study team believes this adjustment provides the level of protection warranted by the unique hydrogeologic conditions of Huron County. In a significant part of the northern portion of the County, the bedrock aquifers are overlain by thin overburden that varies from gravel to clay. At shallow depths, significant weathering and fracturing is common in fine grained material, which increases the permeability and reduces the protection they might provide to the lower bedrock aquifers. Once in the bedrock, there would be minimal attenuation potential. For these reasons the study team felt it necessary to adjust ISI calculation.

The ISI mapping was not updated during this project from the previous County studies, as the water well record database provided by MOE was not updated to include new wells drilled between the end of the previous groundwater studies and the initiation of this study. The digital ISI map for all three studies was not able to be stitched together during the edge-matching project by Waterloo Hydrogeologic Inc. in 2004 as there were slightly different methodologies used for the ISI mapping products for each of the three different Counties. As a result, the ISI maps are based on the County boundaries and the subsequent Wellhead Protection Area Vulnerability mapping was based on the County ISI mapping.

2.6.1 Abandoned Water Wells

Improperly constructed or abandoned wells may bypass the implied susceptibility of the aquifer as they could be a direct conduit to the aquifer. The ABMV SWPR has undertaken a project to map the MOE water well records and identify their current status: active, abandoned, decommissioned, or unknown (ABMV 2008). In those areas with a significant number of improperly abandoned boreholes within the WHPAs, would constitute an increased vulnerability score. For further information, refer to the ABMV 2008 study.

2.6.2 Karst Features / Sink Holes

The karst bedrock features described in Section 3.5.1 present0 an aquifer susceptibility characteristic that is not readily identified using the Terms of Reference protocol for determining the susceptibility index. Sinkholes, a common feature of karst areas, are created when overlying sediments collapse into the underground solution cavities formed in the bedrock. Sinkholes are funnel-shaped depressions in the land surface that connects the surface system with the bedrock aquifer. These create the potential for surface water and contaminants to rapidly flow into the bedrock aquifer with little opportunity for natural filtration to occur in the overburden sediments.

The karst area encompasses regions in which sinkholes have been identified by W.D. Hopper & Sons Ltd., along with locations that were identified by the MOE during two sinkhole studies conducted in 1981 and 1995. Reported sinkholes are located in Concession 9, Lot 4 of Tuckersmith Geographic Township and Concessions 13 and 14, Lot 9 of Ashfield Geographic Township. The Ausable Bayfield Conservation Authority has undertaken a study (WHI, 2007) to locate sinkholes and more accurately define the karst regions within the county. The result of this study should be incorporated into the development of groundwater protection strategies. The karst areas, in particular the sinkholes, should be given special consideration in the development of groundwater protection strategies, as they greatly increase the potential for surface contaminants to access the aquifer.

2.6.3 Huron County ISI

The Huron County ISI maps of the uppermost aquifer is shown in Figures 2-7-1 – 2-7-5. High to medium ISI values occur, as expected, in the eastern and southern portions of the County. These include areas such as Hensall (now on municipal water supplied from Lake Huron) where there is limited confining material overlying the aquifer and in areas in the east and northeast of the County where the overburden has limited thickness. The more western portions of the County have lower ISI values, which corresponds to the thicker till overburden materials in these areas. It should be noted that the development of the ISI mapping is based on broad regional data which is not suitable for detailed scale mapping. Therefore, this mapping should be used as a guide for identifying potentially sensitive areas with site-specific investigations required for development of potentially high risk land activities.

2.6.4 Wellington County ISI

The ISI for Wellington County was done by Golder Associates (2006) and was not modified in this study. Refer to their report for details of the ISI mapping. The ISI mapping, for the area surrounding the Wellington County municipal wells included in this study, is shown the vulnerability assessment figures of this report (See Section 5.0).

2.6.5 Perth County ISI

The ISI for Perth County was done by Waterloo Hydrogeologic Inc. (2003) and was not modified in this study. Refer to their report for details of the ISI mapping. The ISI mapping, for the area surrounding the Perth County municipal wells included in this study, is shown the vulnerability assessment figures of this report (See Section 5.0).

2.7 Municipal Permit to Take Water

The Permit to Take Water (PTTW) database supplied by the Ministry of Environment was modified by the Conservation Authority to better reflect actual water takings within the watershed (ABCA, 2006). The updated rates of the permitted wells were used in the three dimensional groundwater flow models where they fall within model domains (Figure 2-8). The municipal pumping wells along with their permitted rates and average annual rates are summarized in Table 2-1.

Table 2-1: Municipal Well Permitted Rates.

County	Township	Town	Well Name	MOE WWR	PTTW #	PTTW Expiry	Permitted Rate (m3/day)	Average Rate (m3/day)	Comments
Huron	ACW	Huron Sands	Well No. 1	3006921	01-P-1130	Sept 1, 2011	328	20	
Huron	ACW	Benmiller Estates	Well No. 1	3003514	5867-5LMJ7A	unknown	198.3	59	
Huron	ACW	Century Heights	Well No. 1	3003809	7587-5SBQU2	Nov 30, 2013	734.4	180	Combined PTTW
Huron	ACW	Century Heights	Well No. 2	unknown	7587-5SBQU2	Nov 30, 2013	734.4	180	Combined PTTW
Huron	ACW	Dungannon	Well No. 1	unknown	6111-5NCJFS	Jun 30, 2013	438	90	Combined PTTW
Huron	ACW	Dungannon	Well No. 2	unknown	6111-5NCJFS	Jun 30, 2013	438	90	Combined PTTW
Huron	Bluewater	Carriage Lane	Well No. 1	unknown	93-P-0045	Dec 31, 2008	348.5	19	Expired PTTW
Huron	Bluewater	Harbour Lights	Well No. 1	unknown	92-P-0090	Mar 31, 2002	111.6	20	Expired PTTW
Huron	Bluewater	Zurich	Well No. 1	3001265	2321-679L6X	Dec 1, 2014	1152	546	Combined PTTW
Huron	Bluewater	Zurich	Well No. 3	A002404	2321-679L6X	Dec 1, 2014	1152	546	Combined PTTW
Huron	Central Huron	Auburn Hall	Well No. 1	3000941	02-P-1223	Sep 15, 2012	61.9	9	
Huron	Central Huron	Clinton	Well No. 1	unknown	unknown	unknown	unknown	1968	Combined PTTW
Huron	Central Huron	Clinton	Well No. 2	unknown	unknown	unknown	unknown	1968	Combined PTTW
Huron	Central Huron	Clinton	Well No. 3	3000117	unknown	unknown	unknown	1968	Combined PTTW
Huron	Central Huron	McClinchey	Well No. 1	3000335	01-P-1198	Aug 31, 2004	100.8	8	Expired PTTW
Huron	Central Huron	Kelly	Well No. 1	3004247	2238-68TSSW	Dec 31, 2004	196.1	22	Expired PTTW
Huron	Central Huron	S.A.M.	Well No. 1	3003848	01-P-1197	Jul 15, 2007	164	9	Expired PTTW
Huron	Central Huron	VandeWetering	Well No. 1	unknown	8723-66JJLZ	Dec 31, 2014	97.9	9	
Huron	Huron East	Brucefield	Well No. 1	3002561	72-P-0426	Jun 15, 2012	270	60	
Huron	Huron East	Brussels	Well No. 1	unknown	7307-5YFSJ7	Apr 30, 2014	1097	520	Combined PTTW
Huron	Huron East	Brussels	Well No. 2	3000116	7307-5YFSJ7	Apr 30, 2014	1097	17	Combined PTTW
Huron	North Huron	Blyth	Well No. 1	3000113	92-P-0058	Jan 15, 2008	1776	527	Combined /Expired
Huron	North Huron	Blyth	Well No. 2	3002541	92-P-0058	Jan 15, 2008	1776	334.2	Combined /Expired
Huron	North Huron	Wingham	Well No. 3	3002721	73-P-0507	Jun 30, 2012	6546.2	180	
Huron	North Huron	Wingham	Well No. 4	3005985	97-P-1053	unknown	5270	1797.3	
Huron	Morris-Turnberry	Belgrave	McCrae St	3003252	unknown	unknown	unknown	20.5	
Huron	Morris-Turnberry	Belgrave	Jane St	3004377	unknown	unknown	unknown	20.0	
Wellington	Minto Township	Clifford	Well No. 1	unknown	6117-62MQDH	Mar 31, 2014	1310	300	
Wellington	Minto Township	Clifford	Well No. 2	unknown	80-P-2010	Mar 13, 2010		0	Decommissioned
Wellington	Minto Township	Clifford	Well No. 3	unknown	8554-6DDJZH	May 31, 2015	655	418	
Wellington	Minto Township	Clifford	Well No. 4	unknown	8554-6DDJZH	May 31, 2015	1309	0	Backup
Wellington	Minto	Harriston	Well No. 1	unknown	99-P-2045	July 14, 2009	981	1374	Primary
Wellington	Minto	Harriston	Well No. 2	unknown	99-P-2045	July 14, 2009	2100	0	Backup
Wellington	Minto	Harriston	Well No. 3	unknown	99-P-2045	July 14, 2009	1600	0	Backup
Wellington	Minto	Palmerston	Well No. 1	unknown	93-P-2001	Mar 31, 2013	1964	512	Combined PTTW
Wellington	Minto	Palmerston	Well No. 2	unknown	93-P-2001	Mar 31, 2013	1964	0	Combined/Backup
Wellington	Minto	Palmerston	Well No. 3	unknown	93-P-2001	Mar 31, 2013	2291	704	
Perth	North Perth	Atwood	Well No. 1	5003961	2553-5YVHWB	May 31, 2009	143	36	
Perth	North Perth	Atwood	Well No. 2	5000492	4277-5RWLHA	Oct 1, 2013	262	33	
Perth	North Perth	Gowanstown	Well No. 1	5001660	92-P-0063	Nov 17, 2011	71	11	
Perth	North Perth	Listowell	Well No. 4	unknown	01-P-1182	Nov 15, 2011	3273	795	Combined PTTW
Perth	North Perth	Listowell	Well No. 5	5000789	01-P-1182	Nov 15, 2011	3273	693	Combined PTTW
Perth	North Perth	Listowell	Well No. 6	5003702	01-P-1182	Nov 15, 2011	3273	819	Combined PTTW
Perth	North Perth	Molesworth	Well No. 1	5002441	unknown	unknown	unknown	30	Estimated taking

3.0 Groundwater Modelling

3.1 General Model Overview

Within the study area, multiple three dimensional groundwater flow models were built to develop the well head protection areas. Most of these models were originally developed as part of previous studies and updated here with new information where available. For Brucefield, Clinton, Huron West, and Zurich new models were developed for the present study. The models of the study area are listed in Table 3-1. The model edges extend beyond the Zone D WHPA to prevent the groundwater flow model boundaries exhibiting influence on the WHPA.

In 2008, it was identified that WHPAs were needed for the village of Molesworth (managed by the Municipality of North Perth) for Source Water Protection. The North Huron Model was extended to be able to delineate the WHPAs of the Molesworth.

Table 3-1: Groundwater Flow Models

MODEL NAME	COUNTY	MUNICIPAL WELL FIELDS
North Huron	Huron & Wellington	Belgrave, Blyth, Century Heights, Benmiller, Dungannon, Huron Sands, Molesworth, Wingham, Auburn Hall,
Zurich	Huron	Zurich
Clinton	Huron	Clinton
Brucefield	Huron	Brucefield
Huron West	Huron	Kelly, VandeWetering, S.A.M., McClinchey, and Carriage Lane
Minto Township*	Wellington	Clifford, Harriston, Palmerston
Atwood*	Perth	Atwood
North Perth*	Perth	Listowel, Gowanstown

* - models not modified in this study

Details of the new models are given below. For the existing models that were applied from previous studies, an overview of model details is given below. Refer to the reports of the previous studies for details of these models.

3.1.1 Conceptual Model Overview

The conceptual models were reviewed from the previous studies for completeness and consistency between the different municipalities. The conceptual models of past studies formed the basis for the development of the new models for Brucefield, Clinton, Huron West and Zurich.

Recharge and discharge to surface water features such as creeks, rivers, wetlands, etc., are critical components of hydrogeologic conceptualization. Significant surface water features in hydraulic connection with aquifer systems need to be included in the numerical models. Figure 3-1-1 shows the surface water features of the study area.

One significant change to past conceptual models was the identification of the perched groundwater system at Brucefield and Clinton which were identified with new information from the Provincial Groundwater Monitoring Network (PGMN). Monitoring wells in the area indicate the overburden groundwater is perched and the Lucas aquifer is unconfined, with hydraulic separation provided by the Dundee.

3.1.2 Model Domain and Grid Overview

Following the conceptual model review, the groundwater flow model domains were reviewed for existing models or developed for areas that did not have existing models. The model domains, where possible, extend to natural groundwater flow boundaries.

Some of the previous models (e.g. Clinton and Zurich) simulated only bedrock aquifer flow and did not include overburden layers. This is a justified approach because it was found that the overburden did not have a significant influence on bedrock aquifer flow. These models were updated to include overburden layers to accommodate future SWAT modelling.

3.1.3 Boundary Conditions Overview

The groundwater flow model boundaries allow water to enter / exit the model domain. These consist of recharge, rivers/creeks, regional flow boundaries, and pumping wells. In most cases regional model boundaries coincided with natural groundwater flow boundaries (i.e. Lake Huron, regional groundwater flow divides). In limited cases, regional groundwater flow lines or regional groundwater elevations have been applied where natural flow boundaries were not available or not feasible to apply. These model boundaries have been placed at a sufficient distance away from well fields so as not to influence model results.

The municipal pumping rates used in the groundwater flow models are listed in Table 2-1. Non-municipal groundwater PTTWs were also included where they fell within the model domains. The pumping rates for these PTTWs were taken as the representative rates from the PTTW database that ABCA provided.

3.1.4 Hydraulic Parameters Overview

The hydraulic parameters specified in the aquifer represent how water moves through the saturated portion of the groundwater model. These parameters are largely based on pumping tests and general ranges of aquifer / aquitard parameters. These parameters are adjusted, within their reasonable ranges, through the calibration process.

3.1.5 Calibration Overview

Model calibration involves minimizing the difference between simulated and observed groundwater elevations, on average, by adjustment of input parameters while maintaining those parameters within a feasible range. Observed water levels used in the calibration were obtained from bedrock well data in the MOE database. The steady state calibrations done for this study are based on data that was collected over many decades and may represent significant uncertainty when used to define a single unique steady-state water level configuration.

A correlation plot of simulated against observed heads graphically indicates the distribution about the straight line that represents a perfect model fit. Three measures expressing the average error of simulated heads help to quantify the model fit: the mean error, the mean absolute error and the root mean square error (Anderson and Woessner 1992; Table 4.2). The mean error indicates whether the model is over-predicting or under-predicting the heads in the system and should equal or be near zero.

To summarize, the typical industry standard for model calibration is:

- Head residuals plot closely on a 45 degree line
- The mean error is close to zero
- Scaled RMS error is less than 15%

3.1.6 Uncertainty Overview

An uncertainty analysis was incorporated into the delineation of the municipal WHPAs to incorporate the impact of parameter uncertainty on the results. Uncertainty analysis represents conservative but reasonable capture zones based on the information available. Those model parameters, for which the WHPA delineations were sensitive to, were varied in a range, above and below the calibrated value, but remained within reasonable limits of that parameter. The most sensitive parameters were found to be recharge and hydraulic conductivity as is usually the case with most groundwater modelling simulations. For hydraulic conductivity parameters the uncertainty range was typically assumed to be between a half or a full order of magnitude above and below the calibrated value. For the recharge parameters, the typical uncertainty range was assumed to be half and two times the calibrated value.

For some parameters the uncertainty ranges for hydraulic conductivity and recharge described above would result in unreasonably high or low values. In these situations a maximum or minimum reasonable value was chosen instead. For example, the calibrated hydraulic conductivity value of the bedrock in the Clinton model was 2×10^{-4} m/s. If this value was increased by half an order of magnitude it would be 7x10-4 m/s which is thought to be too high for a bedrock aquifer. In this case, a value of 5x10-4 m/s was assumed as the maximum value.

3.2 North Huron and Molesworth

3.2.1 Conceptual Model

The original North Huron model (Huron County 2003) represented the bedrock aquifer and not the overlying unconsolidated materials. The overburden layers were added in 2006 to the model so that vertical travel times from surface to the aquifer could be represented. This allows the models to be used to determine SWAT modelling as part of the next Phase of the Source Water Protection study.

The overburden was delineated into five layers of two aquifers and 3 aquitards which were defined using the geologic information of the MOE water well database. Laterally connected sandy and gravel material in the upper overburden define the aquifer in Layer 2 of the model. Laterally connected sandy and gravel material in the lower overburden define the aquifer in Layer 4 of the model. Layers 1, 3, and 5 represent low permeable materials within the overburden such as glaciolacustrine silts and clays and till with Layers 3 and 5 separating the aquifer units in Layers 2 and 4. Layer 6 represents the bedrock, which is defined upper bedrock surface and the bottom of the well screens as defined by data from MOE water well database.

See Appendix C for figures of the model.

3.2.2 Model Domain and Grid

The model presented in Huron County (2003) was updated to include the overburden layers as discussed above. The upper surface of the model is coincident with topography. The MNR DEM was used to define the top surface. The lower surface of the model represents the bottom of the bedrock aquifer, which is the same layer used in the Huron County (2003). The lower elevation of the bedrock model layer was specified as 100 m below ground surface.

The model grid has 263 rows by 362 columns. Maximum cell size is 300 m by 300 m. The minimum cell size is approximately 10 m in the area of the well fields.

3.2.3 Boundary Conditions

Western Boundary: The western model boundary coincides with Lake Huron and has a prescribed head of 176 m.

Eastern Boundary: The eastern boundary coincides with the 365 m water level elevation contour derived from bedrock wells in the MOE data base. A prescribed head of 365 m was applied to this boundary. This boundary is sufficient distance from well fields so as not to directly influence the numerical solutions at those locations.

Northern Boundary: This parallels the east west flow path originating at the 350 m water level contour and ending at Lake Huron. This is prescribed as a no-flow boundary condition, and is located a sufficient distance north of the Wingham Well Field and Maitland River so as not to directly influence the numerical solutions at those locations.

South Boundary: This boundary coincides with the Maitland River from Lake Huron to the southern-most bend in the river, at which point the boundary parallels a flow path between the 350 m water level contour and the Maitland River. The portion of the boundary that coincides with the Maitland River is prescribed as a river boundary condition, and the remainder as a no-flow boundary.

Rivers/Streams Boundaries: In addition to the Maitland River in the Southern Boundary, river boundary conditions were applied along other sections of the Maitland and other creeks within the model domain. These were prescribed where there was evidence of groundwater interaction as suggested by overburden thickness and water level contours generated from water the MOE data base. Seasonal or intermittent streams were not included.

The lower model boundary was prescribed as a no-flow boundary condition and the upper model boundary as a recharge boundary. Recharge was considered spatially variable and ranged from 5 mm/year to 150 mm/year.

The pumping wells were entered into the model in accordance with the average annual pumping as outlined in Section 2.7.

3.2.4 Hydraulic Parameters

The hydraulic conductivities, generally, of the overburden layers can be described as outlined in the table below. A ratio of horizontal to vertical hydraulic conductivity of 10:1 was used for the overburden and bedrock layers. Not all hydrogeologic units are continuous over the lateral extent of the model. Where hydrogeologic units pinch out or are absent in areas of particular model layer, the hydrogeologic properties of the layer below apply. This prevents numerical layers from pinching out to zero thickness.

Porosity was assumed to be 5% for the bedrock and 25% for the overburden. Typically, this is considered to be on the conservative side of the possible porosity range of geologic materials in groundwater studies in Southern Ontario.

Table 3-2: North Huron Model Layer Aquifer Properties

MODEL LAYER	DESCRIPTION	HORIZONTAL HYDRAULIC CONDUCTIVITY	POROSITY
Layer 1	Overburden Aquitard	$1x10^{-4}$ to $1x10^{-6}$ m/s	0.25
Layer 2	Overburden Aquifer	$1x10^{-4}$ m/s	0.25
Layer 3	Overburden Aquitard	$1x10^{-5}$ m/s	0.25
Layer 4	Overburden Aquifer	$1x10^{-4}$ m/s	0.25
Layer 5	Overburden Aquitard	$1x10^{-6}$ m/s	0.25
Layer 6	Bedrock Aquifer	$2x10^{-5}$ to $1x10^{-4}$ m/s	0.05[1]

[1]Bedrock porosity was assumed to be 5%. Typically, this is considered to be on the conservative side of the possible porosity range of dolostone and limestone in groundwater studies in Southern Ontario.

3.2.5 Calibration

The model calibration was updated using the same process as the previous groundwater study (IWS, 2003). The statistics of the calibration are a residual mean error of 0.1 m and a normalized root mean square error of 2.5 % indicating the model is reasonably calibrated. The calibration plot follows the same trend as is shown in IWS (2003). The calibration statistics are given in the table below.

Table 3-3: North Huron Calibration Statistics

CALIBRATION PARAMETER	CALIBRATION VALUE
Number of Observation Points	1227
Residual Mean Error (m)	0.1
Absolute Residual Mean Error (m)	4.0
Root Mean Square (RMS) Error (m)	5.6
Normalized RMS (%)	2.5

3.2.6 Uncertainty Analysis

The calibrated model was modified by adjusting parameters as shown in table below. Each of these scenarios generate WHPAs, using MODPATH, and the resulting composite WHPAs (convex shape of all the individual WHPAs) were used in the well head protection area vulnerability analysis.

Table 3-4: North Huron Model Uncertainty Scenarios

UNCERTAINTY SCENARIO	PARAMETER	VARIATION
1	K1	Kmax
2	K1	-1 OM
3	K2	+1 OM
4	K2	-1 OM
5	K3	Kmax
6	K3	-1 OM
7	K4	Kmax
8	K4	-1 OM
9	R1	2x
10	R1	½x
11	R2	2x
12	R2	½x
13	R3	2x
14	R3	½x
15	R4	2x
16	R4	½x

Notes: OM - Order of Magnitude
K# - Conductivity Zone
R# - Recharge Zone
Kmax = 5x10-4 m/s

3.3 Zurich

3.3.1 Conceptual Model

The groundwater model developed in 2003 represented the bedrock aquifer and not the overlying unconsolidated materials. The overburden units were added to the model so that three-dimensional flow could be better represented. The overburden was delineated into five layers. These layers were defined using the geologic information of the MOE water well database. Layers 1 through 5 mostly represent lower permeable materials within the overburden such as glaciolacustrine silts and clays and tills which make up most of the Zurich model area, but some overburden aquifers exist in limited extent. Layers 6, 7, and 8 represent the bedrock aquifer.

3.3.2 Model Domain and Grid

The Zurich groundwater flow model has six geological layers, with the unconsolidated overburden material representing five model layers and the bedrock representing three model layers.

The uppermost layer (Layer 1) mostly represents till and other low permeability material at surface. Layer 2 represents aquifer in the east part of the model and till similar to that of Layer 1 in the west part of the model where the aquifer is absent. Layers 3 mostly represent the lower overburden aquitard.

Layer 4 represents aquifer and bedrock aquifer where the overburden aquifer is absent. Layer 5 represents aquitard and bedrock aquifer where the aquitard is absent.

Upper and lower surfaces of the overburden aquifers and aquitard layers were created from the geological records in the MOE database and from data available from previous studies.

Layers 6, 7, and 8 represent the bedrock. The thickness of Layer 5 and 6 is 25 metres each. The thickness for Layer 8 is 50 metres. See Appendix D for figures of the model.

The model grid has 128 rows by 153 columns. Maximum cell size is 200 m by 200 m. The minimum cell size is approximately 20 m in the area of the Zurich well field.

3.3.3 Boundary Conditions

Western Boundary: Lake Huron is located at the western edge of the model where a prescribed head of 176 masl was applied. Groundwater elevations in the bedrock unit adjacent the lake indicate there is a direct hydraulic connection between the lake and the aquifer system here.

Eastern Boundary: The regional groundwater divide for the bedrock aquifer to the east extends far beyond the extent of the County. Therefore, a prescribed head boundary, in both the overburden and bedrock, was placed at the regional groundwater elevation of 280 masl to avoid creating an unnecessarily large model. This boundary is approximately 13 km from the well field and is far enough from the well field as to not a have a direct influence on the flow solution.

Northern and Southern Boundaries: Boundary conditions are prescribed as no-flow since the model edges are parallel to the direction of regional groundwater flow. The boundaries are placed far enough from the town wells so as to not have a direct influence on the flow solution.

Top Surface: Vertical recharge was specified at 50 mm/yr in the low permeable material and 110 mm/yr where the upper aquitard is thin or not present and the top unit is the upper aquifer.

Rivers/Streams Boundaries: Significant area streams were applied as river boundary conditions where they exist within the model domain. These were prescribed where there was evidence of groundwater interaction as suggested by overburden thickness and water level contours generated from the MOE data base. Seasonal and intermittent streams were not included which includes many streams of the area.

3.3.4 Hydraulic Parameters

The hydraulic conductivity of the model is described in table below. A ratio of horizontal to vertical hydraulic conductivity of 10:1 was used for the overburden layers. A ration of 1: 1 applies for the bedrock layers.

Where hydrogeologic units pinch out or are absent in areas of particular model layer, the hydrogeologic properties of the layer below apply. This prevents numerical layers from pinching out to zero thickness.

Porosity was assumed to be 5% for the bedrock and 25% for the overburden. Typically, this is considered to be on the conservative side of the possible porosity range of geologic materials in groundwater studies in Southern Ontario.

Table 3-5: Zurich Model Layer Aquifer Properties

MODEL LAYER	DESCRIPTION	HORIZONTAL HYDRAULIC CONDUCTIVITY	POROSITY
Layer 1	Overburden Aquitard	$3x10^{-7}$ m/s	0.25
Layer 2	Overburden Aquifer	$5x10^{-4}$ m/s	0.25
Layer 3	Overburden Aquitard	$3x10^{-7}$ m/s	0.25
Layer 4	Overburden Aquifer	$5x10^{-4}$ m/s	0.25
Layer 5	Overburden Aquitard	$1x10^{-7}$ m/s	0.25
Layer 6, 7, 8	Bedrock Aquifer	$5x10^{-5}$ m/s to $1x10^{-4}$ m/s	0.05[1]

[1]Bedrock porosity was assumed to be 5%. Typically, this is considered to be on the conservative side of the possible porosity range of dolostone and limestone in groundwater studies in Southern Ontario.

3.3.5 Calibration

The model was calibrated to regional water level data from the MOE database. All bedrock wells included are those completed in the Lucas formation with the remaining wells completed in the overburden layers.

Calibration statistics are shown in table below and a correlation plot of simulated vs. observed water levels is shown in Appendix D. A value of -2.16 m for the mean error indicates that the model error is slightly under predicting observed heads, but the error is close to zero and is well balanced, on average. The scaled RMS is 6.3%, showing a good statical fit to observed groundwater elevations overall.

The model is under predicting some observation points located downgradient of the wellfield, but this is not an area of interest since it is away from the delineated WHPA. Further, the uncertainty analysis accounts for this like other parameter variabilities in the model domain.

Table 3-6: Zurich Model Calibration Statistics

CALIBRATION PARAMETER	CALIBRATION VALUE
Number of Observation Points	147
Residual Mean Error (m)	-2.16
Absolute Residual Mean Error (m)	5.13
Root Mean Square (RMS) Error (m)	7.76
Normalized RMS (%)	6.3

3.3.6 Uncertainty Analysis

The calibrated model was modified by adjusting parameters as shown in the table below. Each of these scenarios generated WHPAs, using MODPATH, and the resulting composite WHPAs (convex shape of all the individual WHPAs) were used in the well head protection area vulnerability analysis.

The WHPA delineation was found not to be sensitive to Layer 4 aquifer conductivity, Layer 5 aquitard conductivity, and bedrock conductivity zone adjacent Lake Huron. Therefore these parameters were not included in the uncertainty analysis.

Table 3-7: North Huron Model Uncertainty Scenarios

UNCERTAINTY SCENARIO	PARAMETER	VARIATION
1	K Layer 1 Aquitard	+1 OM
2	K Layer 1 Aquitard	-1 OM
3	K Layer 2 Aquifer	+1 OM
4	K Layer 2 Aquifer	-1 OM
5	K Layer 3 Aquitard	+1 OM
6	K Layer 3 Aquitard	-1 OM
7	K Bedrock	+1/2 OM
8	K Bedrock	-1/2 OM
9	Recharge, both zones	½ x
10	High Dundee K	+1 OM
11	Low Dundee K	-1 OM

Notes: OM - Order of Magnitude
K# - Conductivity Zone
R# - Recharge Zone

3.4 Clinton

3.4.1 Conceptual Model

A single model was developed for the regional groundwater system encompassing the Clinton well field. The well field is developed in the Lucas formation and wells are cased down to the top of the bedrock. The wells are open to both the Dundee and Lucas formations, but their water levels are representative of the bottom of the Lucas formation. Waterlevels in the area at the bottom 20 metres of the Lucas aquifer, with the top of the Lucas appearing to be unconfined. This is supported by observation wells surrounding the well field.

Characterization of the aquifer system indicates the Lucas and Dundee are vertically separated aquifer systems and that the Lucas is considerably more transmissive. The Dundee is considered to have a very low vertical permeability given the significant hydraulic separation that exists between the groundwater elevations above it in the overburden and below it in the Lucas. It is assumed that the Lucas formation supplies the groundwater entering the well field at Clinton.

The aquifer is recharged mostly from areas northeast of the well field and groundwater flows to the southeast eventually discharging to Lake Huron. The high transmissivity of the Lucas in the area is likely representative of highly permeable karst limestone (Huron, 2003). The low hydraulic gradient likely associated with the karst features extends north-easterly about 5 km from the well field and even a further distance in the south-easterly direction. For these reasons the Clinton well field is modeled separately from the other well fields of the County. The bedrock aquifer is overlain by 30 m of till. The till is stratified with alternating layers ranging in material of silty sands to clays. The resulting vertical recharge from infiltration is expected to be low in the direct area of the well field.

3.4.2 Model Domain and Grid

The Clinton groundwater flow model has seven layers which represent five hydrogeological units. The unconsolidated overburden material is represented by three model layers and the bedrock represented by four model layers.

The uppermost layer (Layer 1) represents till and other low permeability material at surface. Layer 2 represents aquifer in the north part of the model and similar material to that of Layer 1 in the south part of the model where the aquifer is absent. Layers 3 represent the lower overburden aquitard separating the Layer 2 aquifer from the bedrock. Upper and lower surfaces of the overburden aquifers and aquitard layers were created from the geological records in the MOE database and from data available from previous studies at the site.

Layer 4 represents the Dundee formation and Layers 5, 6, and 7 represent the Lucas formation. The thickness of Layer 5 - 7 were 20 metres each. The petroleum well logs were used to define the contact between the two bedrock units and the thickness of the units (Huron, 2003). See Appendix E for figures of the model.

The model grid has 161 rows by 193 columns. The maximum cell size is approximately 120 m by 120 m and the minimum cell size is approximately 15 m in the area of the Clinton well field. The model grid was aligned on the angle of groundwater flow with the upgradient direction being northeast of the wellfield.

3.4.3 Boundary Conditions

Northeastern Boundary: In the overburden the active model domain follows two streams here. In the bedrock a prescribed head of 221 masl was placed along the sharp hydraulic separation in regional bedrock groundwater elevations and is the apparent upgradient extent of the karst Lucas aquifer (Huron, 2003). This boundary is approximately 5 km from the well field.

Southwestern Boundary: In the overburden a prescribed head of 220 masl was placed for the aquifer discharge boundary here. This boundary is approximately 9 km from the well field and is far enough from the well field as to not have a direct influence on the flow solution. In the bedrock a prescribed head boundary was placed at the regional groundwater elevation of 201 masl in Lucas bedrock layers. The Lucas aquifer eventually discharges to Lake Huron which is approximately 15-20 km downgradient.

Northwestern and Southeastern Boundaries: These boundary conditions are specified as no-flow and are assumed to parallel the direction of regional groundwater flow. The boundaries are placed far enough from the well field so as to not have a direct influence on the flow solution.

Top Surface: Vertical recharge was specified at 10 mm/yr which is representative of the low permeable material at surface.

Rivers/Streams Boundaries: The Bayfield, Maitland, and Bannockburn Rivers were applied as river boundary conditions where they exist within the model domain. These were prescribed where there was evidence of groundwater interaction as suggested by overburden thickness and water level contours generated from water the MOE data base. Seasonal and intermittent streams were not included.

3.4.4 Hydraulic Parameters

The spatial distribution of hydraulic conductivity is needed to derive a solution to groundwater flow in the model. The hydraulic conductivity values of the model were determined through the model calibration process. The results of the well performance test for municipal wells were used as guidance for setting the conductivity values of Layers 5-7 (Lucas Formation). The conductivity values of the other layers were determined through the calibration process. The hydraulic conductivity values are shown in the table below.

Two hydraulic conductivity zones within Layers 5- 7 (Lucas formation) were defined in the model. The conductivity zone containing the well field was initially set to 2 x 10-4 m/s, which is representative of a very permeable bedrock aquifer. The zone to the southwest is assumed to have a higher transmissivity given the flatter groundwater gradients that are seen here which is reflected by the hydraulic conductivity value, $1x10^{-3}$ m/s determined by the calibration. This part of the aquifer is assumed to be very karst.

Where hydrogeologic units pinch out or are absent in areas of particular model layer, the hydrogeologic properties of the layer below apply. This prevents numerical layers from pinching out to zero thickness.

Porosity was assumed to be 5% for the bedrock and 25% for the overburden. Typically, this is considered to be on the conservative side of the possible porosity range of geologic materials in groundwater studies in Southern Ontario. A 5% value is particularly conservative for karst rock which is typical of the Clinton area.

Table 3-8: Clinton Model Layer Aquifer Properties

MODEL LAYER	DESCRIPTION	HORIZONTAL HYDRAULIC CONDUCTIVITY	POROSITY
Layer 1	Overburden Aquitard	$1x10^{-5}$ m/s	0.25
Layer 2	Overburden Aquifer	$1x10^{-4}$ m/s	0.25
Layer 3	Overburden Aquitard	$1x10^{-6}$ m/s	0.25
Layer 4	Bedrock Aquifer (Dundee)	$1x10^{-12}$ m/s	0.05
Layer 5-7 Zone 1	Bedrock Aquifer (Lucas)	$2x10^{-4}$ m/s	0.05
Layer 5-7 Zone 2	Bedrock Aquifer (Lucas)	$1x10^{-3}$ m/s	0.05

3.4.5 Calibration

The model was calibrated to regional water level data from the MOE database. All bedrock wells included are those completed in the Lucas formation with the remaining wells completed in the overburden layers.

Calibration statistics are shown in the table below and a correlation plot of simulated vs. observed water levels is shown in Appendix E. A value of 0.02 m for the mean error indicates that the model error is nearly zero and is well balanced, on average. The scaled RMS is 3.70%, showing an excellent statistical fit to observed groundwater elevations overall. Some scatter is seen in the residuals of Layers 5-7 which is expected given the heterogeneous nature of the Lucas groundwater flow field. This characteristic of highly fractured dolostone / limestone aquifers. The variability of flow field is most likely satisfactorily accommodated by the uncertainty analysis.

The model was best calibrated to a conductivity value of 2 x 10-4 m/s in Layers 5-7 for the zone containing the well field and a higher value of 1 x 10-3 m/s for the southwestern zone. The latter higher value indicates that more fractured bedrock features may exist in that zone. The conductivity of the Dundee was set to a value of $1x10^{-12}$ m/s by calibrating the model to the highest value for the Dundee that would still provide the observed hydraulic separation between the overburden and bedrock waterlevels.

As discussed in Huron (2003), an investigation of well field operations demonstrated approximately 2 metres of drawdown was observed from short term well pumping at a rate of 300 gpm. Simulated drawdown of the calibrated model closely matches this 2 metre observed drawdown with the same pumping rate. This gives a reasonable verification of the model calibration. It was found that the model was able to predict within +-0.5 m of the 2 metre drawdown within the conductivity range of 8 x 10-5 to 5 x 10-4 m/s (Huron, 2003). This range defines the Lucas conductivity range for the uncertainty scenario.

Table 3-9: Clinton Model Calibration Statistics

CALIBRATION PARAMETER	CALIBRATION VALUE
Number of Observation Points	123
Residual Mean Error (m)	0.02
Absolute Residual Mean Error (m)	2.70
Root Mean Square (RMS) Error (m)	3.53
Normalized RMS (%)	3.70

3.4.6 Uncertainty Analysis

The calibrated model was modified by adjusting parameters as shown in the table below. Each of these scenarios generated WHPAs, using MODPATH, and the resulting composite WHPAs (convex shape of all the individual WHPAs) were used in the well head protection area vulnerability analysis.

The model was most sensitive to the conductivity of the Lucas, as would be expected. Therefore this was the focus of the model uncertainty. In Scenarios 1 and 2 the values were varied within the range discussed in the calibration section (above). Scenario 3 represents the Lucas with only one conductivity zone compared to the calibrated model with two zones for the Lucas.

A low recharge scenario was not included since the calibrated recharge value of 10 mm/yr was assumed to be sufficiently low and conservative. A lower recharge rate for the Lucas was effectively represented by Scenario 4, with a lower Dundee conductivity value which reduces simulated leakage into the Lucas.

Table 3-10: Clinton Model Uncertainty Scenarios

UNCERTAINTY SCENARIO	PARAMETER	VARIATION
1	High Lucas K	Kmax
2	Low Lucas K	Kmin
3	One Lucas K zone	$K=2x10^{-4}$ m/s
4	Low Dundee K	-1 OM
5	No Overburden	bedrock K as calibrated model
6	High Recharge	5x

Notes: OM - Order of Magnitude
K# - Conductivity Zone
R# - Recharge Zone
Kmax = 5x10-4 m/s
Kmin = 8x10-5 m/s

3.5 Brucefield

3.5.1 Conceptual Model

The village of Brucefield is south of Clinton. In Huron (2003) this well system was modelled using a two dimensional analytical model. For this study, a three dimensional groundwater flow model, similar to the others, was developed for this well field.

The geology and hydrogeology conceptualization of the Brucefield model area is very similar to that of Clinton. The overburden is a mix of aquifer and aquitard and bedrock consisting of the impermeable Dundee overlaying the higher permeable Lucas. The overburden aquifers are perched and the Lucas aquifer is unconfined.

3.5.2 Model Domain and Grid

The Brucefield groundwater flow model has nine layers which represent five hydrogeological units. The unconsolidated overburden material is represented by three model layers and the bedrock represented by six model layers.

The uppermost layer (Layer 1) represents till and other low permeability material at surface. Layer 2 represents mostly aquifer but represents aquitard in the few areas where the aquifer is absent. Layer 3 generally represents the lower overburden aquitard which separates the Layer 2 aquifer from the bedrock. Upper and lower surfaces of the overburden aquifers and aquitard layers were created from the geological records in the MOE database and from data available from previous studies at the site.

Layers 4 - 6 represent the Dundee formation and Layers 7 - 9 represent the Lucas formation. The thickness of Layer 7 - 9 were 20 metres each. The petroleum well logs were used to define the contact between the two bedrock units and the thickness of the units (Huron, 2003). See Appendix F for figures of the model.

The model grid has 84 rows by 110 columns. The maximum cell size is approximately 200 m by 200 m and the minimum cell size is approximately 15 m in the area of the Brucefield well field. The model grid was aligned on the angle of groundwater flow with the upgradient direction being northeast of the wellfield.

3.5.3 Boundary Conditions

The groundwater flow in the overburden is dominated by streams. The majority of the model edge in the overburden parallels regional groundwater flow lines and are represented by no-flow boundaries. A portion of the northeast model edge has a prescribed head of 287 masl representing an aquifer recharge boundary here.

Bedrock Northeastern Boundary: **A** prescribed head boundary was placed at the regional groundwater elevation of 213 masl in Lucas bedrock layers as an aquifer recharge boundary. This boundary is approximately 6 km from the well field.

Bedrock Southwestern Boundary: A prescribed head boundary was placed at the regional groundwater elevation of 199 masl in Lucas bedrock layers. The Lucas aquifer eventually discharges to Lake Huron which is approximately 10 - 15 km downgradient.

Bedrock Northwestern and Southeastern Boundaries: These boundary conditions are specified as no-flow since the model edges parallel to the direction of regional groundwater flow. The boundaries are placed far enough from the town wells so as to not have a direct influence on the flow solution.

Top Surface: Vertical recharge was specified at 15 mm/yr which is representative of the low permeable material at surface.

Rivers/Streams Boundaries: The Bayfield River and its tributaries were applied as river boundary conditions where they exist within the model domain. These were prescribed where there was evidence of groundwater interaction as suggested by overburden thickness and water level contours generated from water the MOE data base. Seasonal and intermittent streams were not included.

3.5.4 Hydraulic Parameters

Hydraulic conductivities and porosity values have been applied in the Brucefield model similar to the Clinton model. The hydraulic conductivity values are shown in the table below.

Where hydrogeologic units pinch out or are absent in areas of particular model layer, the hydrogeologic properties of the layer below apply. This prevents numerical layers from pinching out to zero thickness.

Porosity was assumed to be 5% for the bedrock and 25% for the overburden. Typically, this is considered to be on the conservative side of the possible porosity range of geologic materials in groundwater studies in Southern Ontario.

Table 3-11: Brucefield Model Layer Aquifer Properties

MODEL LAYER	DESCRIPTION	HORIZONTAL HYDRAULIC CONDUCTIVITY	POROSITY
Layer 1	Overburden Aquitard	1×10^{-5} m/s (1×10^{-4} m/s for outwash sands at rivers)	0.25
Layer 2	Overburden Aquifer	1×10^{-4} m/s	0.25
Layer 3	Overburden Aquitard	1×10^{-6} m/s	0.25
Layer 4-6	Bedrock Aquifer (Dundee)	1×10^{-12} m/s	0.05
Layer 7-9	Bedrock Aquifer (Lucas)	1×10^{-4} m/s	0.05[1]

[1]Bedrock porosity was assumed to be 5%. Typically, this is considered to be on the conservative side of the possible porosity range of dolostone and limestone in groundwater studies in Southern Ontario.

3.5.5 Calibration

The model was calibrated to regional water level data from the MOE database. All bedrock wells included are those completed in the Lucas formation with the remaining wells completed in the overburden layers.

Calibration statistics are shown in table below and a correlation plot of simulated vs. observed water levels is shown in Appendix F. A value of -0.35 m for the mean error indicates that the model error is slightly under predicting observed heads, but the error is close to zero and is well balanced, on average. The scaled RMS is 4.83%, showing an excellent statistical fit to observed groundwater elevations overall. Some scatter is seen in the residuals of Layers 6-9 which is expected given the heterogeneous nature of the Lucas groundwater flow field which is characteristic of highly fractured dolostone / limestone aquifers. The variability of flow field is most likely satisfactorily accommodated by the uncertainty analysis.

Table 3-12: Brucefield Model Calibration Statistics

CALIBRATION PARAMETER	CALIBRATION VALUE
Number of Observation Points	104
Residual Mean Error (m)	-0.35
Absolute Residual Mean Error (m)	3.66
Root Mean Square (RMS) Error (m)	4.66
Normalized RMS (%)	4.83

3.5.6 Uncertainty Analysis

The calibrated model was modified by adjusting parameters as shown in the table below. Each of these scenarios generated WHPAs, using MODPATH, and the resulting composite WHPAs (convex shape of all the individual WHPAs) were used in the well head protection area vulnerability analysis.

The model was most sensitive to the conductivity of the Lucas, as would be expected. Therefore this was the focus of the model uncertainty.

Table 3-13: Brucefield Model Uncertainty Scenarios

UNCERTAINTY SCENARIO	PARAMETER	VARIATION
1	High Lucas K	+1/2 OM
2	Low Lucas K	-1/2 OM
3	High Dundee K	+2 OM
4	Low Dundee K	+1 OM
5	High R	2x
6	Low R	½ x

Notes: OM - Order of Magnitude
K# - Conductivity Zone
R# - Recharge Zone

3.6 Huron West

3.6.1 Conceptual Model

The villages of Harbour Lights, Huron Sands, Kelly, McClinchey, S.A.M., and VandeWetering are located along the shores of Lake Huron, and are all completed in the bedrock aquifer. In Huron (2003) these well systems were modelled using two dimensional analytical models. For this study, these well systems were incorporated into a three dimensional groundwater flow model (MODFLOW-SURFACT) similar to the other municipal well fields to explicitly represent the groundwater flow in the overburden materials.

The overburden was delineated into five layers as is described in Hydraulic Parameter Section 3.6.4. These layers were defined using the geologic information of the MOE water well database. There are deposits of sands and gravel along the shore of Lake Huron. Layers 1 through 5 represent a mixture of sands & gravel as well as lower permeable materials within the overburden such as glaciolacustrine silts and clays and tills. Layer 6 represents a 3 metre thick weathered bedrock zone and the top was defined as the upper bedrock surface. Layer 7 represents the bedrock which was given a uniform thickness of 50 metres.

3.6.2 Model Grid

The Huron West model has 7 layers representing five overburden (aquitard and aquifer layers) and two bedrock layers. The model grid has 184 rows by 112 columns. Maximum cell size is 200 m by 200 m. The minimum cell size is approximately 25 m by 25 m in the area of the well field. See Appendix G for figures of the model.

3.6.3 Boundary Conditions

Western Boundary: Lake Huron is located at the western edge of the model. A prescribed head boundary of 176 masl was used here. The groundwater elevations in the bedrock unit adjacent the lake indicate there is a direct hydraulic connection between the lake and the bedrock aquifer.

Eastern Boundary: The regional surface water divide and groundwater divide to the east extends approximately 6000 m beyond Lake Huron. Therefore, a prescribed head boundary was placed at the regional groundwater elevation of 220 masl to avoid creating an unnecessarily large model. This boundary is approximately 5 km from the closest well field and is far enough from the well field as to not have a direct influence on the flow solution.

Northern and Southern Boundaries: Boundary conditions are specified as no-flow and are assumed to parallel the direction of regional groundwater flow. The boundaries are placed far enough from the town wells so as to not have a direct influence on the flow solution.

Rivers/Streams Boundaries: In addition to the Maitland River in the Southern Boundary, river boundary conditions were applied along other sections of the Maitland and other creeks within the model domain. These were prescribed where there was evidence of groundwater interaction as suggested by overburden thickness and water level contours generated from the MOE data base. Seasonal and intermittent streams were not included.

Pumping Wells: The pumping wells were entered into the model in accordance with the average annual pumping as outlined in Section 2.7.

Bottom / Recharge Surface: The lower model boundary was prescribed as a no-flow boundary condition and the upper model boundary was a recharge boundary. Vertical recharge was specified coincident with the surficial geology and tile drainage network. The recharge was 2 mm/yr (tile drained fields almost completely intercepting precipitation), 50 mm/yr (non-tile drained areas with low permeability surficial geology), 200 mm/yr to 350 mm/yr surficial sands and gravels).

3.6.4 Hydraulic Parameters

Hydraulic conductivities were assigned to each of the layers, with the 5 uppermost layers corresponding to the overburden and bottom layer representing bedrock as shown in the table below. The uppermost layer was assigned hydraulic conductivities based on the surficial geology map. Where model layers were absent, hydraulic conductivities from the layer below were assigned to the model layer to prevent numerical layers from pinching out to zero thickness. A typical cross-section shows the model (Appendix G) and the numerical layers.

Initial estimates of hydraulic conductivities of the area surrounding the well field were referenced from the well performance test. One hydraulic conductivity zones represents the bedrock of the model. The main conductivity zone, which encompasses the well field, was initially set to 5x10-5 m/s.

Porosity was assumed to be 5% for the bedrock and 25% for the overburden. Typically, this is considered to be on the conservative side of the possible porosity range of geologic materials in groundwater studies in Southern Ontario.

Table 3-14: Huron West Model Layer Aquifer Properties

MODEL LAYER	DESCRIPTION	HORIZONTAL HYDRAULIC CONDUCTIVITY	POROSITY
Layer 1	Overburden Aquitard	$1x10^{-6}$ m/s	0.25
Layer 2	Overburden Aquifer	$1x10^{-4}$ m/s	0.25
Layer 3	Overburden Aquitard	$5x10^{-6}$ m/s	0.25
Layer 4	Overburden Aquifer	$1x10^{-4}$ m/s	0.25
Layer 5	Overburden Aquitard	$5x10^{-6}$ m/s	0.25
Layer 6	Weathered Bedrock	$3x10^{-5}$ m/s	0.05
Layer 7	Bedrock Aquifer	$2x10^{-5}$ m/s	0.05

3.6.5 Calibration

The model calibration was achieved using the same process as the other models of the study. A value of -0.60 m for the mean error indicates that the model error is nearly zero and is well balanced, on average. This is further shown by the correlation plot of head residuals (Appendix G) showing the residuals are distributed evenly along the 45 degree line. The normalized root mean square error of 8.6 % indicating the model is reasonably calibrated. The calibration statistics are given in the table below.

Table 3-15: North Huron Calibration Statistics

CALIBRATION PARAMETER	CALIBRATION VALUE
Number of Observation Points	175
Residual Mean Error (m)	-0.60
Absolute Residual Mean Error (m)	4.9
Root Mean Square (RMS) Error (m)	6.2
Normalized RMS (%)	8.6

3.6.6 Uncertainty Analysis

The calibrated model was modified by adjusting parameters as shown in table below. Each of these scenarios generated WHPAs, using MODPATH, and the resulting composite WHPAs (convex shape of all the individual WHPAs) were used in the well head protection area vulnerability analysis.

Table 3-16: Huron West Model Uncertainty Scenarios

UNCERTAINTY SCENARIO	PARAMETER	VARIATION
1	K1	-1 OM
2	K1	+1 OM
3	K2	-1 OM
4	K2	+1 OM
5	K3	-1 OM
6	K3	+1 OM
7	K4	-1 OM
8	K4	+1 OM
9	K5	-1 OM
10	K5	+1 OM
11	K6	-1 OM
12	K6	+1 OM
13	K7	-1 OM
14	K7	+1 OM
15	R	2x
16	R	½x

Notes: OM - Order of Magnitude
K# - Conductivity Zone
R - Recharge Zone

3.7 Town of Minto

The villages of Clifford, Harriston, and Palmerston are located in the Town of Minto in Wellington County. All three villages have municipal well systems that are completed in the bedrock aquifer, with the exception of Clifford where there is one well completed in deep overburden material. In the Wellington County Groundwater Study, these well systems were modelled using a single groundwater flow model. As the Wellington County Groundwater Study was completed just prior to the start of this project, the model was not updated or altered for this study as the municipal pumping rates used were current. The only exception to this was the requirement to generate WHPAs for backup wells. To generate these WHPAs, the primary wells were set to a zero pumping rate, and the secondary wells were set to the pumping rate of the primary wells. A Zone B capture zone (two year time of travel) was delineated and then modified for uncertainty in the parameters similar to the previous Wellington County Groundwater Study. This was done by increasing the calibrated capture zone size by 20 percent then rotated it by 5 degrees in the left direction and 5 degrees in the right direction and creating a composite capture zone incorporating these three cases.

3.8 Atwood

The previous three-dimensional MODFLOW groundwater flow model that was developed for the previous MOE groundwater studies (Waterloo Hydrogeologic Inc., 2003) was used for developing new capture zones for both municipal wells under the average pumping conditions (2001 to 2005 for the Smith Well and 2006 for the Danbrook well). The groundwater flow model was simulated in this study with MODFLOW-SURFACT (Hydrogeologic, 2002) to be consistent with the other models for the SWP Region. The structure of the original model was not modified. Pumping was adjusted from Waterloo Hydrogeologic Inc. (2003) by removing the decommissioned well which replaced with another municipal well (See Section 1.2.7).

3.8.1 Conceptual Overview of Model

The village of Atwood's municipal wells are located in the bedrock aquifer and are overlain by thick deposits of low permeable till. Regional groundwater flow is from East to West and is primarily in the bedrock aquifer system. The thick overlying till provides a good barrier to contamination from surface activities.

3.8.2 Numerical Model Development and Calibration

Model structure and calibration was not changed in this study.

3.8.3 Uncertainty Analysis

Using the new pumping for the Atwood well field, the model was modified by adjusting parameters as shown in the table below Each of these scenarios generated WHPAs, using MODPATH, and the resulting composite WHPAs (convex shape of all the individual WHPAs) were used in the well head protection area vulnerability analysis.

Table 3-17: Atwood Model Uncertainty Scenarios

UNCERTAINTY SCENARIO	PARAMETER	VARIATION
1	K1	+1 OM
2	K1	-1 OM
3	K2	+1 OM
4	K2	-1 OM
5	K3	+1 OM
6	K3	-1 OM
7	R1	2 x
8	R1	½ x

Notes: OM - Order of Magnitude
K# - Conductivity Zone
R# - Recharge Zone

3.9 Listowel & Gowanstown

The previous three-dimensional MODFLOW groundwater flow model that was developed for the previous MOE groundwater studies (Waterloo Hydrogeologic Inc., 2003) was used for developing new capture zones for both municipal wells under the average pumping conditions (2001 to 2005). The groundwater flow model was simulated in this study with MODFLOW-SURFACT (Hydrogeologic, 2002) to be consistent with the other models for the SWP Region. The structure of the original model was not modified.

3.9.1 Conceptual Overview of Model

A single model was developed for the regional groundwater system encompassing the Listowel and Gowanstown well fields. The wells are completed into the Detroit River Group formation. The overburden in this area consists of silty to sandy glacial tills and clay with very little coarse-grained material. The regional groundwater flow patterns in the bedrock aquifer are from east to west. In contrast to the bedrock groundwater flow patterns, groundwater flow in the overburden system typically flows from topographical highs to the surface water features (primarily the Maitland River and its tributaries).

3.9.2 Numerical Model Development and Calibration

Model structure and calibration was not changed in this study.

3.9.3 Uncertainty Analysis

Using the new pumping for the Listowel & Gowanstown well fields, the model was modified by adjusting parameters as shown in the table below. Each of these scenarios generated WHPAs, using MODPATH, and the resulting composite WHPAs (convex shape of all the individual WHPAs) were used in the well head protection area vulnerability analysis.

Table 3-18: Listowel & Gowanstown Model Uncertainty Scenarios

UNCERTAINTY SCENARIO	PARAMETER	VARIATION
1	K1	+1 OM
2	K1	-1 OM
3	K2	+1 OM
4	K2	-1 OM
5	K3	+1 OM
6	K3	-1 OM
7	R1	2 x
8	R1	½ x

Notes: OM - Order of Magnitude
K# - Conductivity Zone
R# - Recharge Zone

4.0 Well Head Protection Areas

Particle tracking is used to calculate the time of travel capture zones of the calibrated model and the uncertainty scenarios. Particles are placed around the screen of the municipal wells which then travel backwards through the flow field of the groundwater model using MODPATH. The backward tracking is a simple mathematical inversion. Here velocities of the groundwater flow model are multiplied by a negative value which results in the velocity reversing exactly. So instead of the particles flowing downgradient, the backwards tracked particle flows towards its origin which is the recharge source of the aquifer or regional boundary conditions for deep aquifers.

The time of travel capture zones that are mapped show a plan view of the three-dimensional particle tracking from the groundwater flow model. These zones refer to the travel within the groundwater system only, i.e. below the water table and typically inside the aquifer material.

Combining all of the individual capture zones from the calibrated model and the uncertainty models results in a composite capture zone called a Well Head Protection Area (WHPA). The WHPA is broken down into different zones based on travel times and distances as outlined by the MOE Assessment Report guidelines (Zone A – 100 m radius, Zone B – 2 year TOT, Zone C – 5 year TOT, and Zone D 25 year TOT).

Wellhead protection Area (WHPA) delineations were developed for all required municipal well systems within the ABMV SWP Region jurisdiction, except for Seaforth, Lucknow, Whitechurch, and Amberly (Section 1.0). Figure 4-1 shows the WHPAs for the entire source water protection region and separate figures were generated for each municipality.

See Appendix B for the local scale WHPAs for the well fields.

4.1 Municipality of Ashfield-Colborne Wawanosh

There are four communities located in the Township of ACW. They are referred to as Huron Sands, Benmiller Estates, Dungannon, and Century Heights. Figure 4-1-1 shows the WHPAs for ACW.

4.2 Municipality of Bluewater

There are three communities serviced by municipal wells in the Municipality of Bluewater. They are referred to as Carriage Lane, Harbour Lights, and Zurich. Figure 4-1-2 shows the WHPAs for Bluewater.

4.3 Municipality of Central Huron

There are six communities located in the Municipality of Central Huron. These are referred to as the Town of Clinton, Auburn, Kelly, McClinchey, S.A.M. and VandeWetering. Figure 4-1-3 shows the WHPAs for Central Huron. The ZONE E, the two hour time of travel zone, for the Maitland River at Goderich has been included in the figure.

4.4 Municipality of Huron East

There are two communities serviced by municipal wells in the Municipality of Huron East. These are referred to as the communities of Brucefield and Brussels. The community of Seaforth is not included in this study. Figure 4-1-4 shows the WHPAs for Huron East.

4.5 Township of North Huron

There are three communities serviced by municipal well in the Township of North Huron. These are referred to as the communities of Belgrave, Blyth, and Wingham. Figure 4-1-5 shows the WHPAs for North Huron.

4.6 Township of Minto

There are three communities within Township of Minto. These wells are located in the communities of Clifford, Harriston, and Palmerston. Figure 4-1-6 shows the WHPAs for Minto.

4.7 Municipality of North Perth

There are four communities within the Municipality of North Perth. These are located in the communities of Atwood, Listowel, Gowanstown, and Molesworth. Figure 4-1-7 shows the WHPAs for North Perth.

5.0 Well Head Protection Area Vulnerability Assessment

As mentioned above, a wellhead protection area is the projection to ground surface of the composite capture zone surrounding a water well and defines where the well draws its water. This area is where protection measures are implemented to provide protection of the well from sources of contamination.

It should be noted that the risk of contaminants reaching the well is based on two factors. The time of travel within the aquifer, as defined by the capture zones, and the vulnerability of the aquifer to surface contaminants potentially traveling from the surface to the aquifer, as defined by the Intrinsic Susceptibility Index. The MOE Assessment Report guidelines specify that the WHPA and the ISI be overlaid resulting in the Wellhead Protection Area Vulnerability as shown in Table 5-1.

Table 5-1: Wellhead Protection Area Vulnerability Scores

GROUNDWATER VULNERABILITY CATEGORY FOR THE AREA	WHPA ZONE A	WHPA ZONE B	WHPA ZONE C	WHPA ZONE D
High	10	10	8	6
Medium	10	8	6	4
Low	10	6	4	2

5.1 Township of Ashfield-Colborne Wawanosh

There are four communities located in the Township of ACW. They are referred to as Huron Sands, Benmiller Estates, Dungannon, and Century Heights. Figure 5-1-1 shows the WHPAs for ACW.

5.2 Municipality of Bluewater

There are three communities serviced by municipal wells in the Municipality of Bluewater. They are referred to as Carriage Lane, Harbour Lights, and Zurich. Figure 5-1-2 shows the WHPAs for Bluewater.

5.3 Municipality of Central Huron

There are six communities located in the Municipality of Central Huron. These are referred to as the Town of Clinton, Auburn, Kelly, McClinchey, S.A.M. and VandeWetering. Figure 5-1-3 shows the WHPAs for Central Huron.

5.4 Municipality of Huron East

There are two communities serviced by municipal wells in the Municipality of Huron East. These are referred to as the communities of Brucefield and Brussels. The community of Seaforth is not included in this study. Figure 5-1-4 shows the WHPAs for Huron East.

5.5 Municipality of North Huron

There are three communities serviced by municipal well in the Municipality of North Huron. These are referred to as the communities of Belgrave, Blyth, and Wingham. Figure 5-1-5 shows the WHPAs for North Huron.

5.6 Minto Township

There are three communities within Minto Township. These wells are located in the communities of Clifford, Harriston, and Palmerston. Figure 5-1-6 shows the WHPAs for Minto.

5.7 Municipality of North Perth

There are four communities within the Municipality of North Perth. These are located in the communities of Atwood, Listowel, Gowanstown, and Molesworth. Figure 5-1-7 shows the WHPAs for North Perth.

6.0 Conclusions and Recommendations

The key aspects of the Phase I Study of the Ausable Bayfield and Maitland Valley Source Water Protection Planning Area are:

- The hydrogeolgic conceptualization of the study area was updated so that the groundwater models of the area could be further developed and provide consistent modelling approach across the Source Water Protection Area. The updated models are needed to address the issues that are to be examined as part of Source Water Protection investigations and future investigations.
- Three dimensional numerical models have been developed for municipal well fields in the study area. The models represent the hydrogeologic units starting from ground surface to bottom of the aquifer within which the municipal wells are screened. The models were developed using MODFLOW SURFACT which is an advanced groundwater flow model which simulates coupled unsaturated and saturated groundwater flow.
- The models have been sufficiently calibrated so as to give good representation of the aquifer systems that supply the groundwater to the municipal wells. To ensure this, the models were calibrated to accepted industry standards.
- WHPAs have been delineated for well fields within the study area for 2, 5, and 25 year time of travel. Uncertainty analysis was performed in the development of the WHPAs. The uncertainty analysis is a conservative approach which accounts for the intrinsic variations that exist in natural hydrogeologic environments.
- The most vulnerable municipal well fields are found in the south of the County of Huron in towns such as Hensall and Exeter. Here the geologic materials overlying the aquifers are thinner by comparison to other areas thus providing less protection for potential surface impacts. In contrast some other areas have thick glacial tills and glaciolacustrine deposits which provide a protective overlying cover as is the case with the Town of Zurich and Perth County. The ISI mapping provided in the study illustrate the vulnerable and protective areas.
- The WHPAs are to be used to develop the Threats Inventory of the municipal well fields. Threats within the WHPAs are to be identified and documented in the upcoming Phase II of the study.

7.0 References

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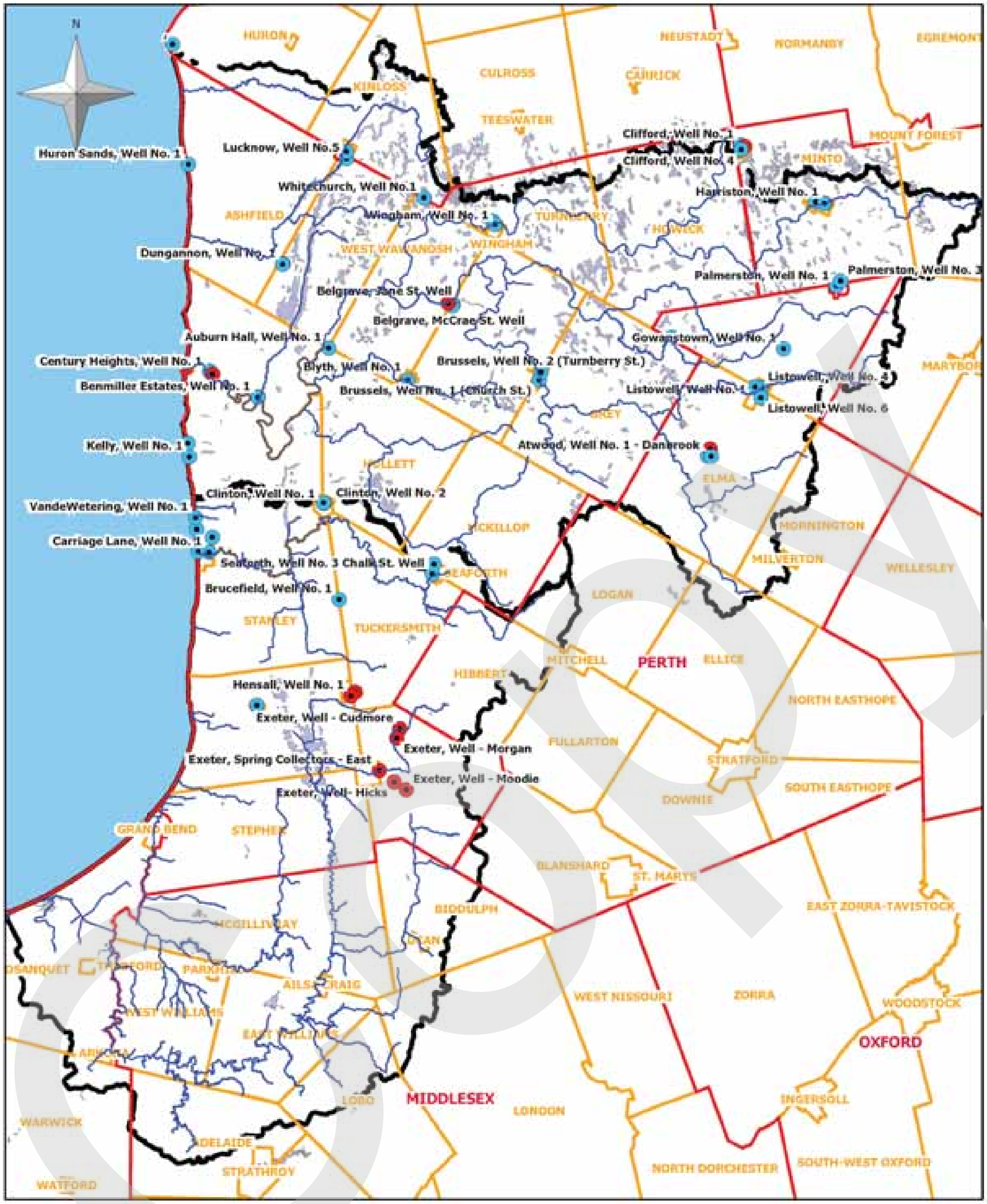
Appendix A
Figures



Major Rivers
Lines

MNR Wetlands
Areas

ABCA MVCA Boundary
Lines

Upper Municipality
Areas

Lower Municipality
Areas

Municipal Wells - ABCA MVCA
Points : Active
No
Yes

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

Ausable Bayfield & Maitland Valley Source Protection Region

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Water Well Records - Ministry of Environment
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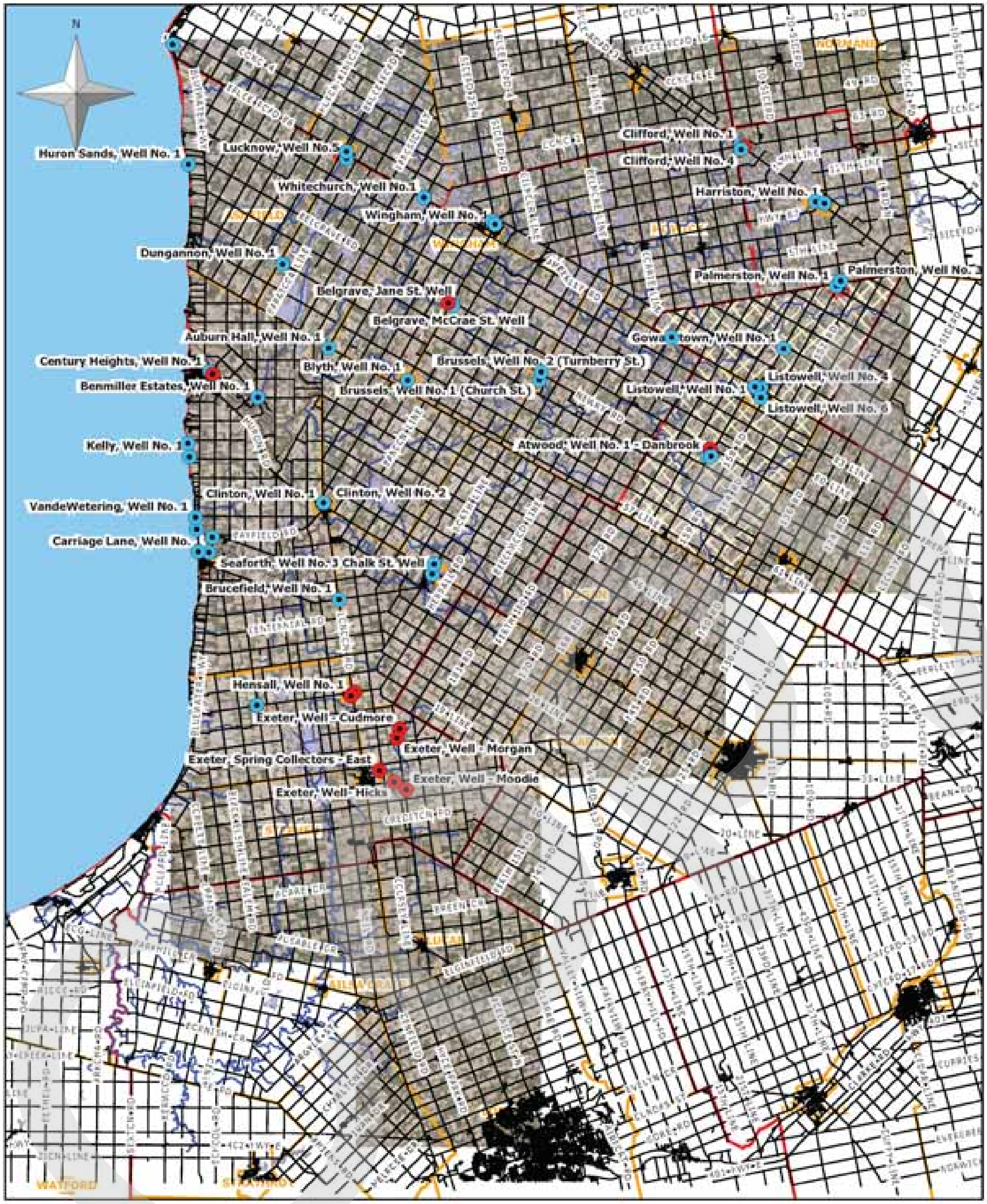
0 10 km

Figure 1-1

ABCA MVCA SWP Study Area



North Perth
Areas
Major Rivers
Lines
MNR Wetlands
Areas
Upper Municipality
Areas
Lower Municipality
Areas
Municipal Wells - ABCA MVCA
Points : Active
No
Yes

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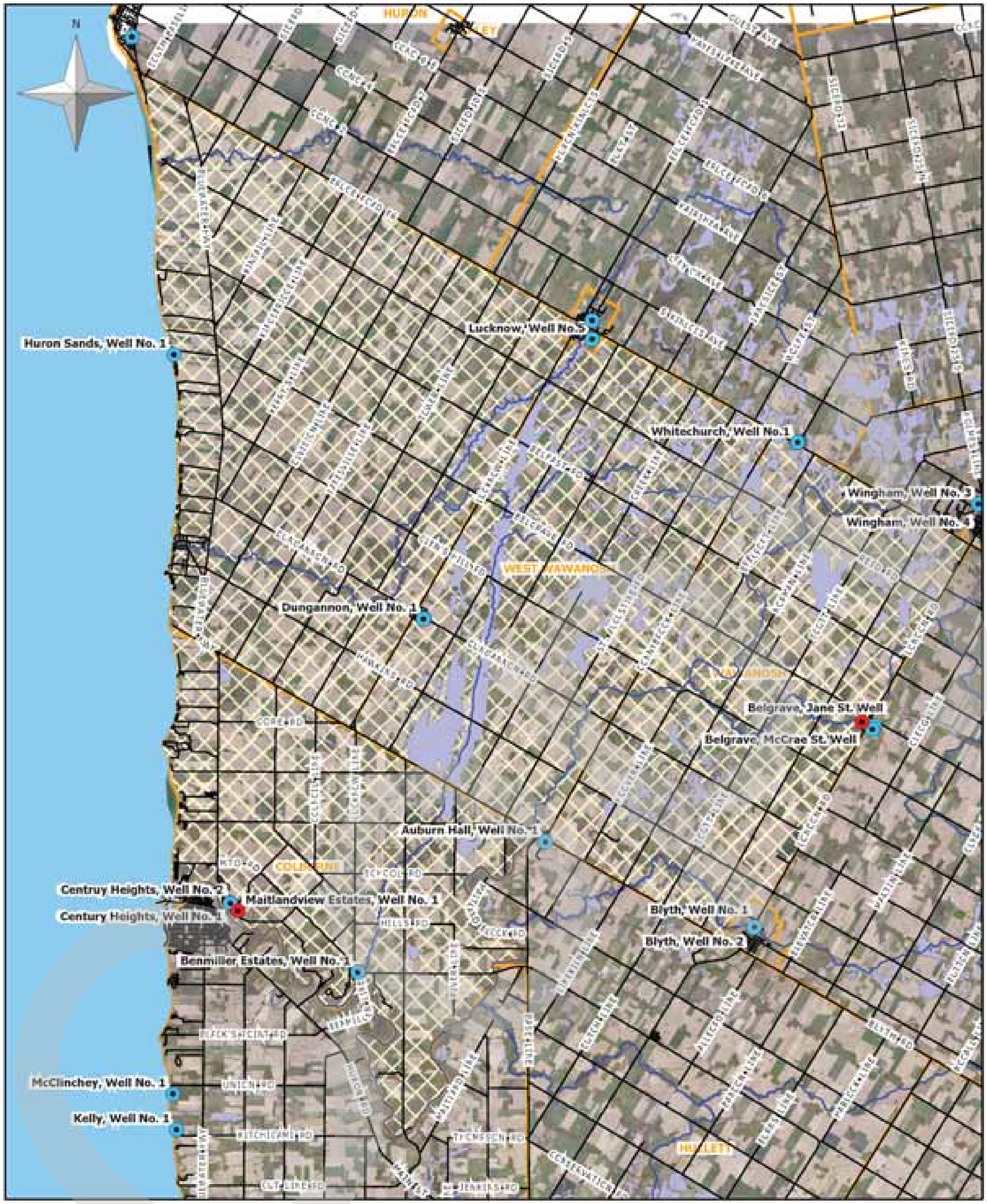
0 >5 km

Figure 1-2

Municipal Well Locations



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ACT FOR CLEAN WATER

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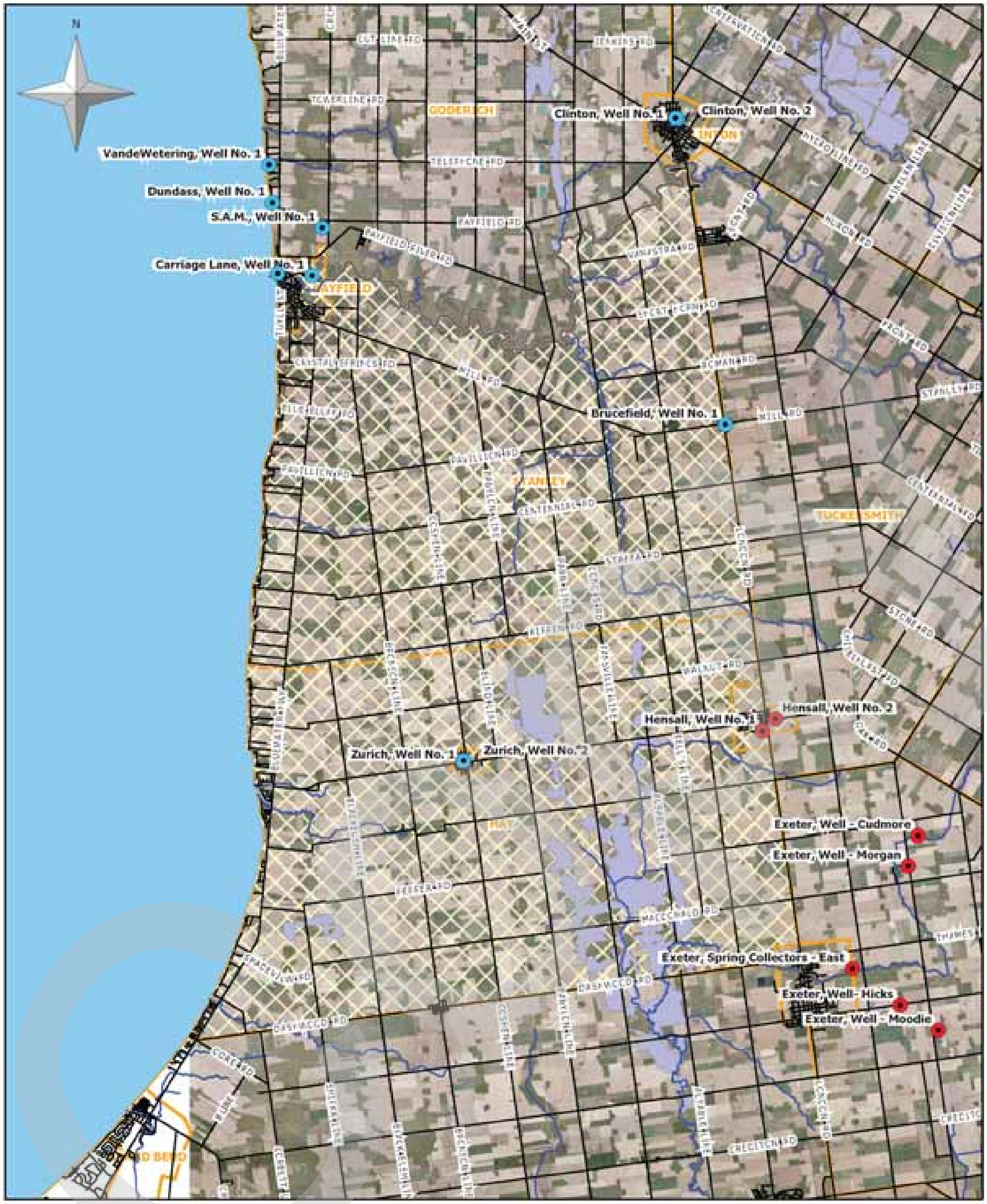
Figure 1-2-1

Municipal Wells - ACW



Bluewater
Areas
Major Rivers
Lines
MNR Wetlands
Areas
Lower Municipality
Areas
Municipal Wells - ABCA MVCA
Points : Active
No
Yes

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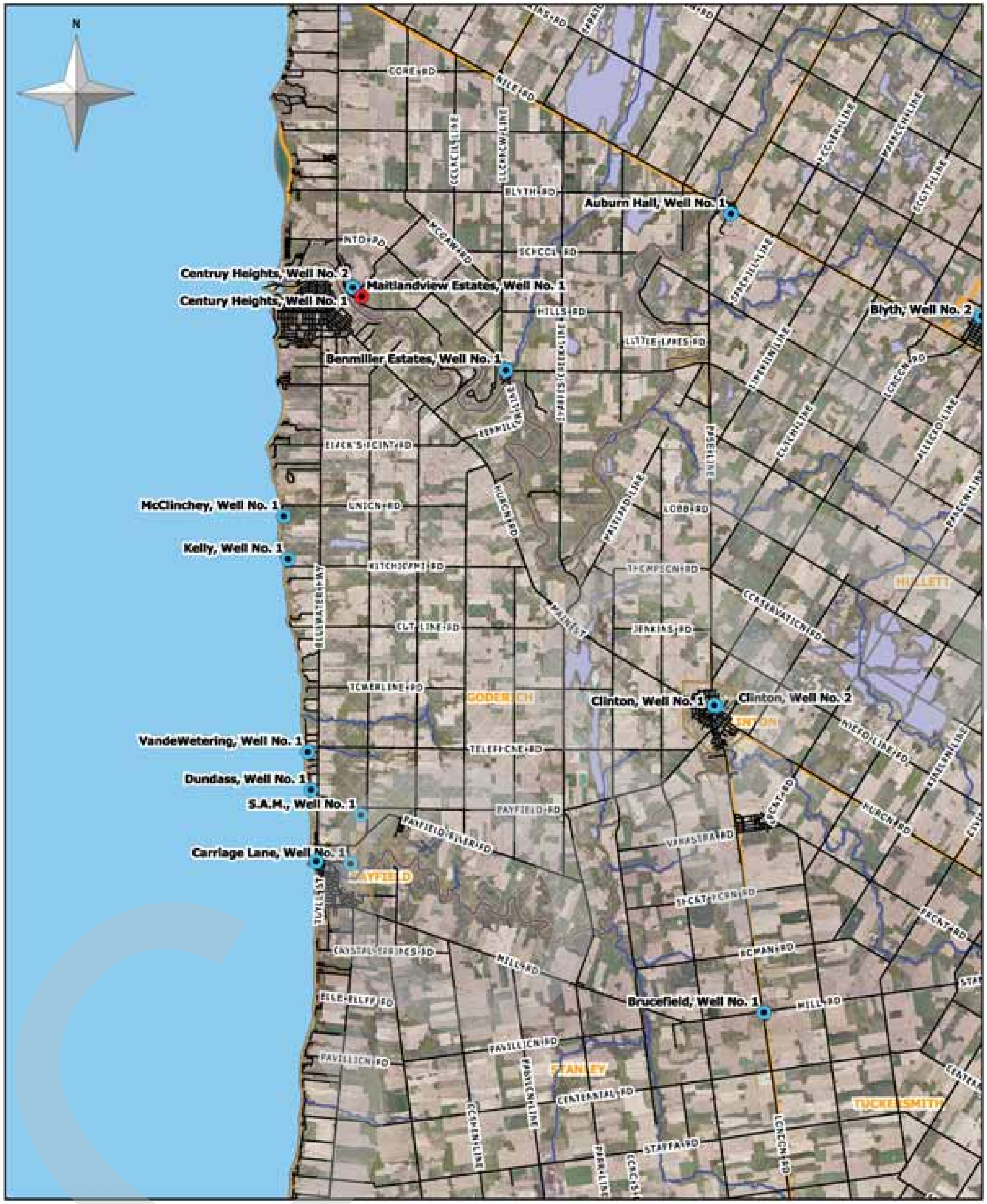
0 5 km

Figure 1-2-2

Municipal Wells - Bluewater



Central Huron
Areas
Major Rivers
Lines
MNR Wetlands
Areas
Lower Municipality
Areas
Municipal Wells - ABCA MVCA
Points : Active
No
Yes

DRINKING WATER
SOURCE PROTECTION
ACT FOR CLEAN WATER

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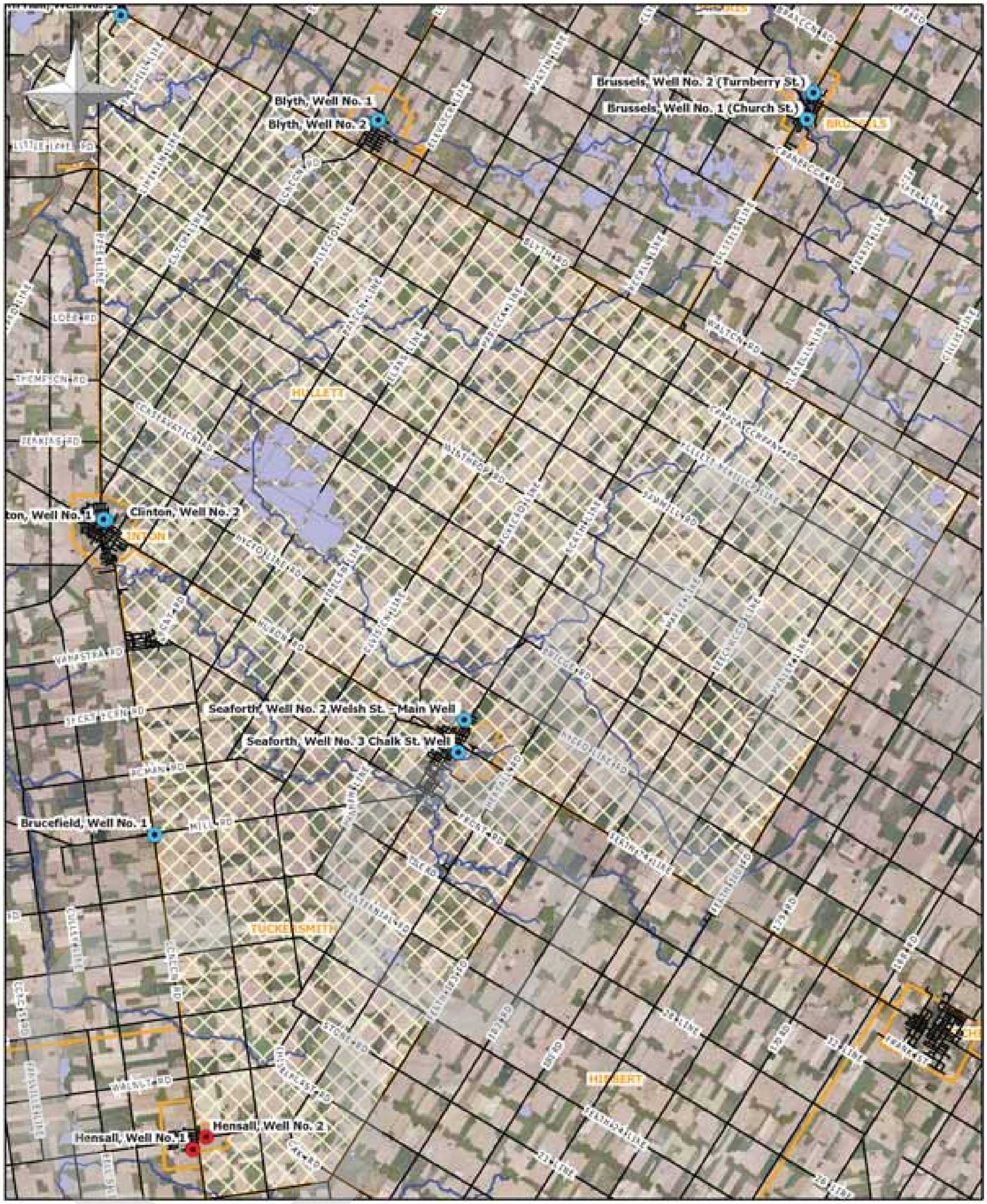
0 5 km

Figure 1-2-3

Municipal Wells - Central Huron



Huron East
Areas
Major Rivers
Lines
MNR Wetlands
Areas
Lower Municipality
Areas
Municipal Wells - ABCA MVCA
Points : Active
No
Yes

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

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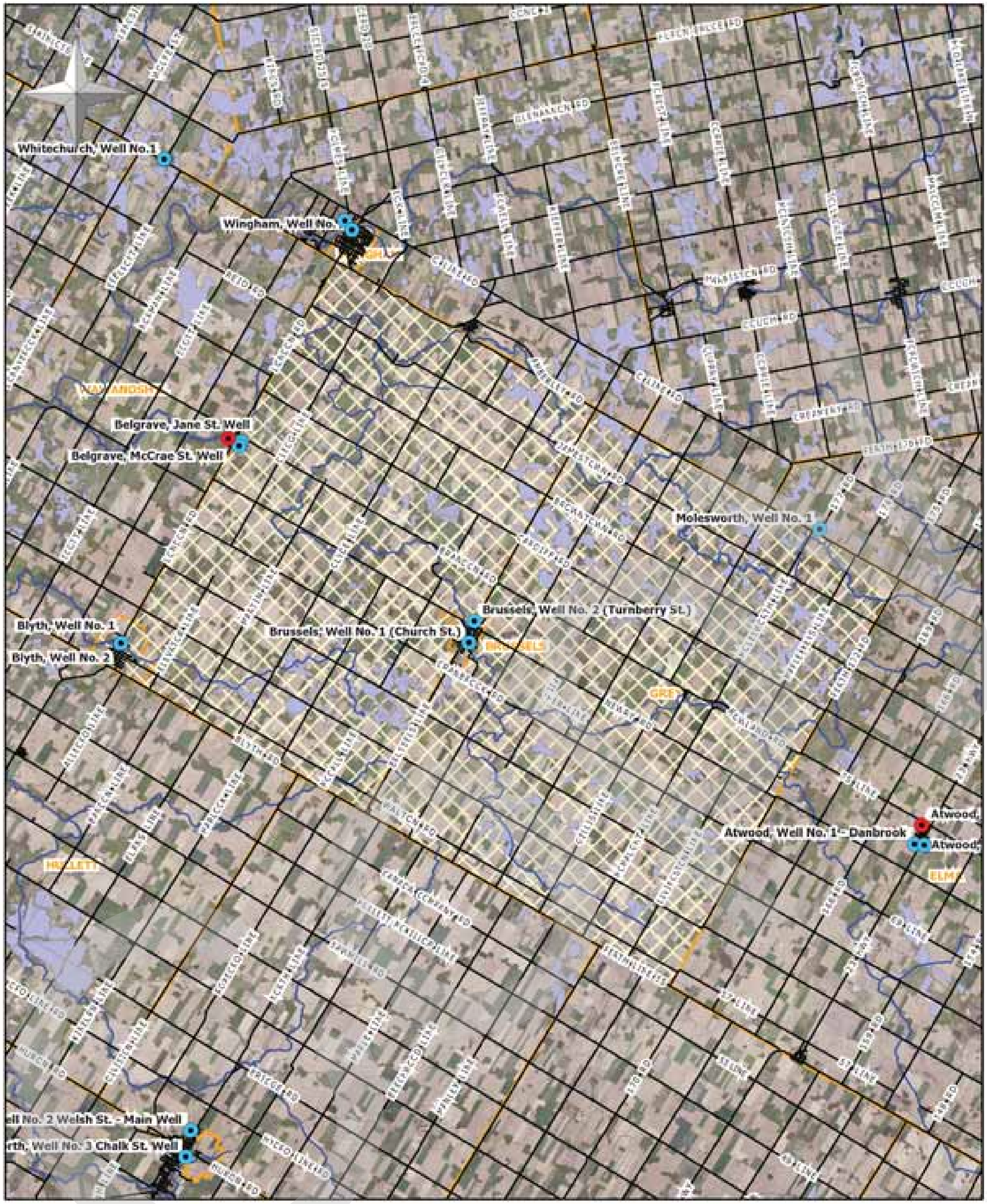
0 5 km

Figure 1-2-4

Municipal Wells - Huron East



North Huron
Areas
Major Rivers
Lines
MNR Wetlands
Areas
Lower Municipality
Areas
Municipal Wells - ABCA MVCA
Points : Active
No
Yes

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

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0 5 km

Figure 1-2-5

Municipal Wells - North Huron

Minto Township
Areas
Major Rivers
Lines
MNR Wetlands
Areas
Lower Municipality
Areas
Municipal Wells - ABCA MVCA
Points : Active
No
Yes

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

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0 5 km

Figure 1-2-6

Municipal Wells - Minto Township

North Perth
Areas
Major Rivers
Lines
MNR Wetlands
Areas
Lower Municipality
Areas
Municipal Wells - ABCA MVCA
Points : Active
No
Yes

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ACT FOR CLEAN WATER

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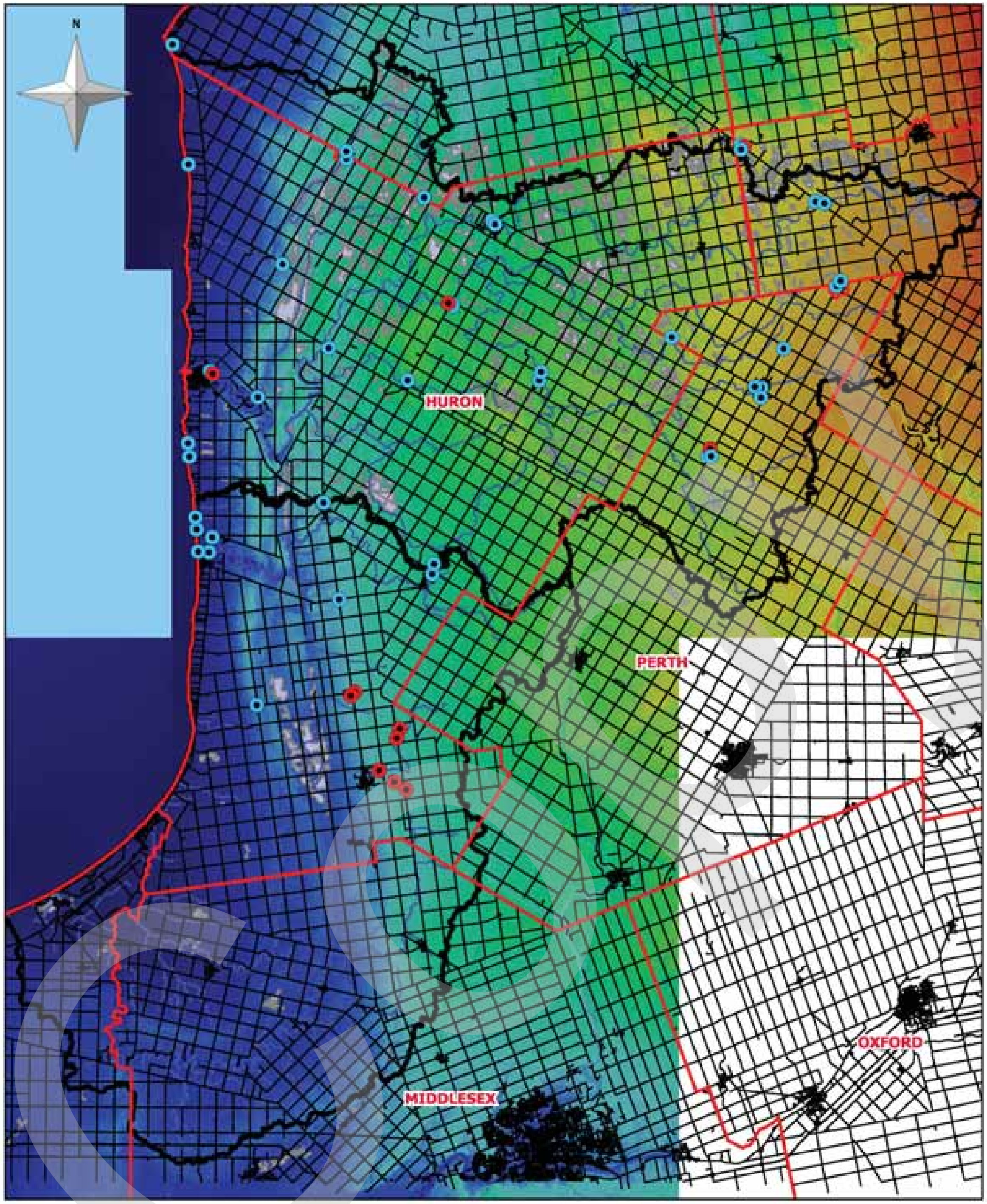
0 5 km

Figure 1-2-7

Municipal Wells - North Perth



Upper Municipality
Areas
MNR Wetlands
Areas
Major Rivers
Lines
ABCA MVCA Boundary
Lines
Ground Surface
m amsl
475
425
375
325
275
225
175
Municipal Wells - ABCA MVCA
Points : Active
No
Yes

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

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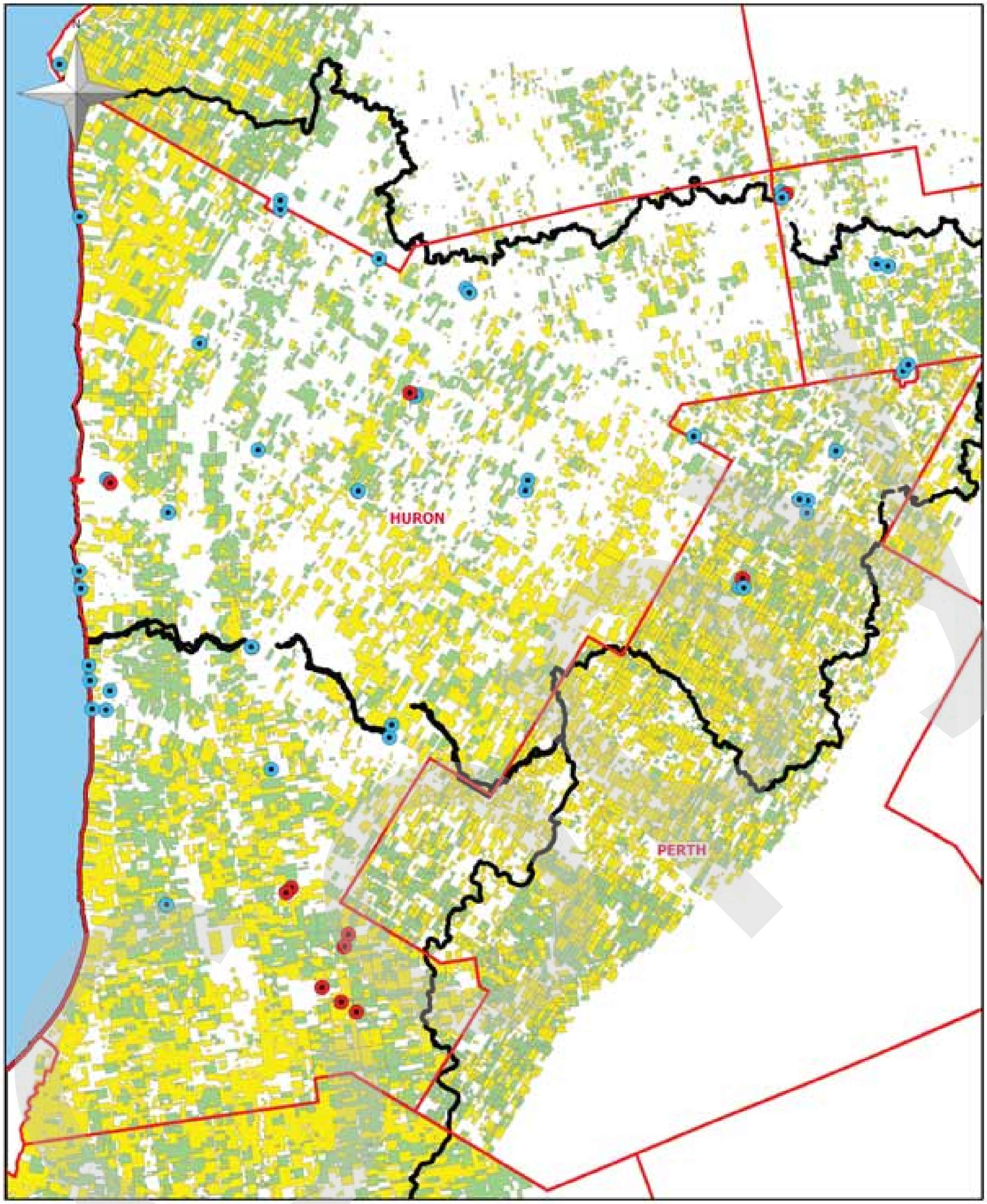
0 10 km

Figure 2-2

Digital Elevation Model



Upper Municipality
Areas
Tile Drainage
RANDOM
SYSTEMATIC
ABCA MVCA Boundary
Lines
Municipal Wells - ABCA MVCA
Points : Active
No
Yes

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

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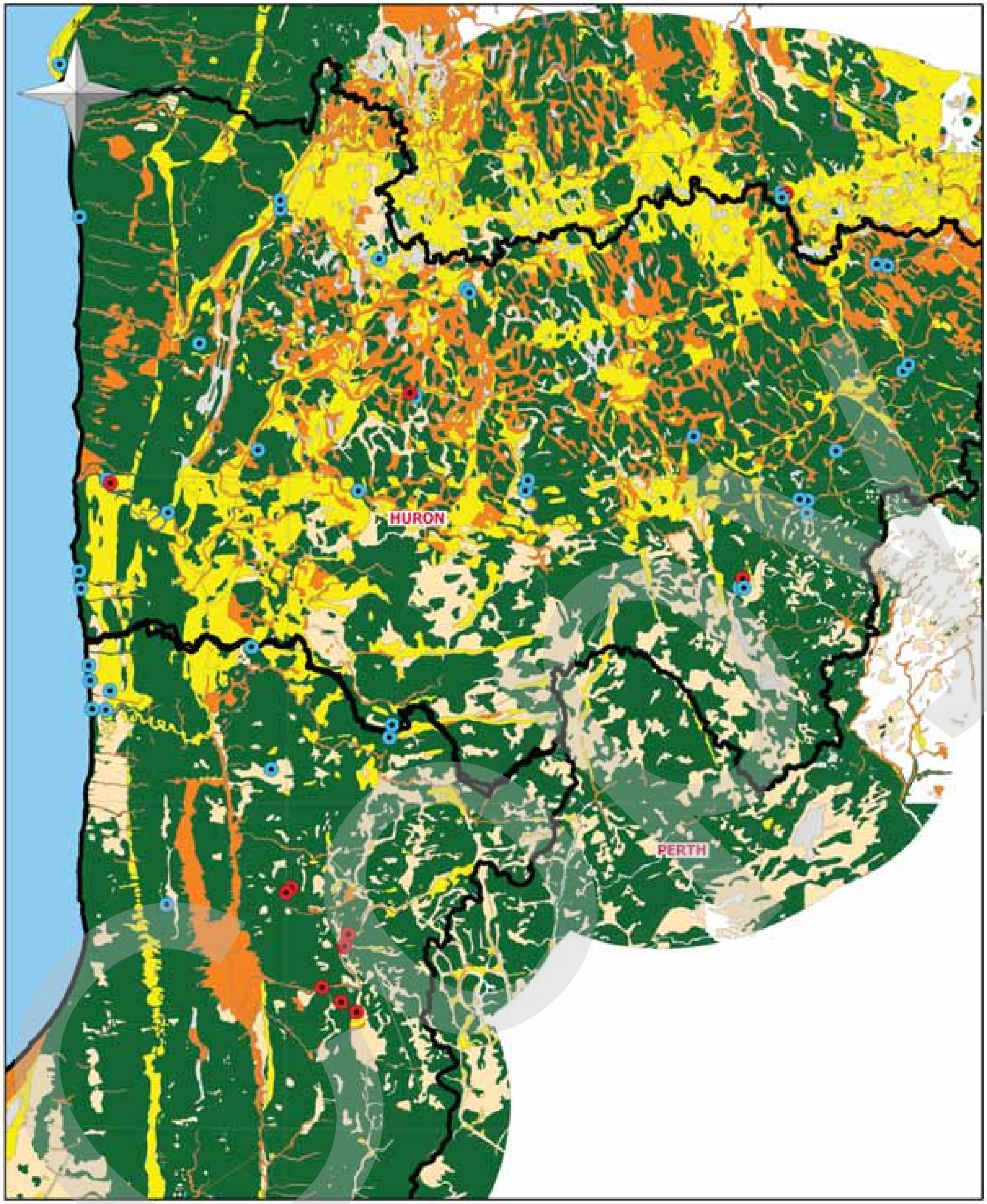
0 10 km

Figure 2-3

Tile Drainage



Quarterary Geology
- Paleozoic Bedrock
- diamicton
- fill
- gravel
- organic deposits
- sand
- silt

ABCA MVCA Boundary
- Areas

Municipal Wells - ABCA MVCA
Points : Active
- No
- Yes

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

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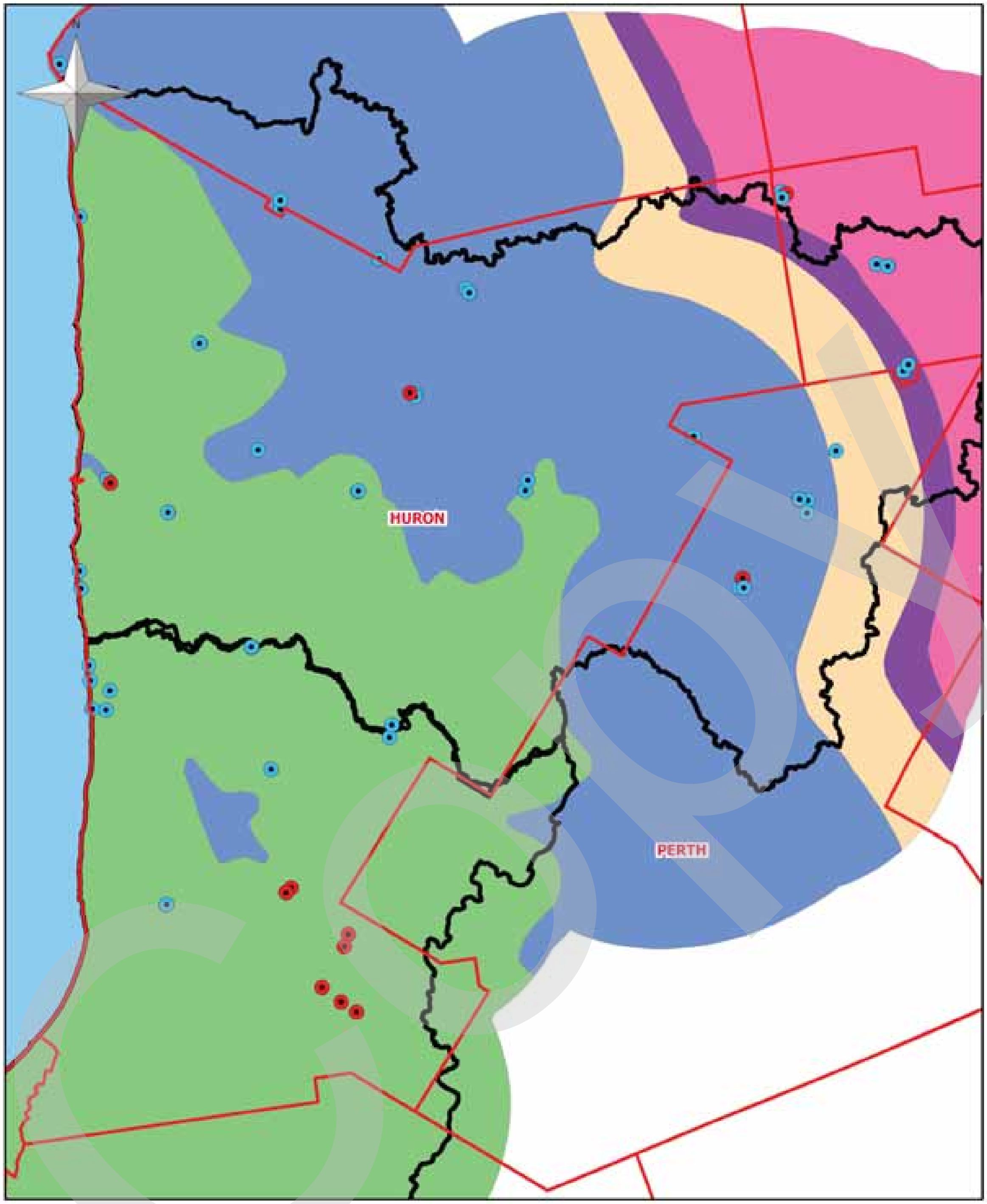
0 10 km

Figure 2-5-1

Quaternary Geology



Bedrock Geology Formations
- Bass Island Fm.
- Bois Blanc Fm.; Oriskany Fm.
- Detroit River Gp.; Onondage Fm.
- Dundee Fm.
- Guelph Fm.
- Salina Fm.

Upper Municipality
- Areas

ABCA MVCA Boundary
- Areas

Municipal Wells - ABCA MVCA
Points : Active
- No
- Yes

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ACT FOR CLEAN WATER

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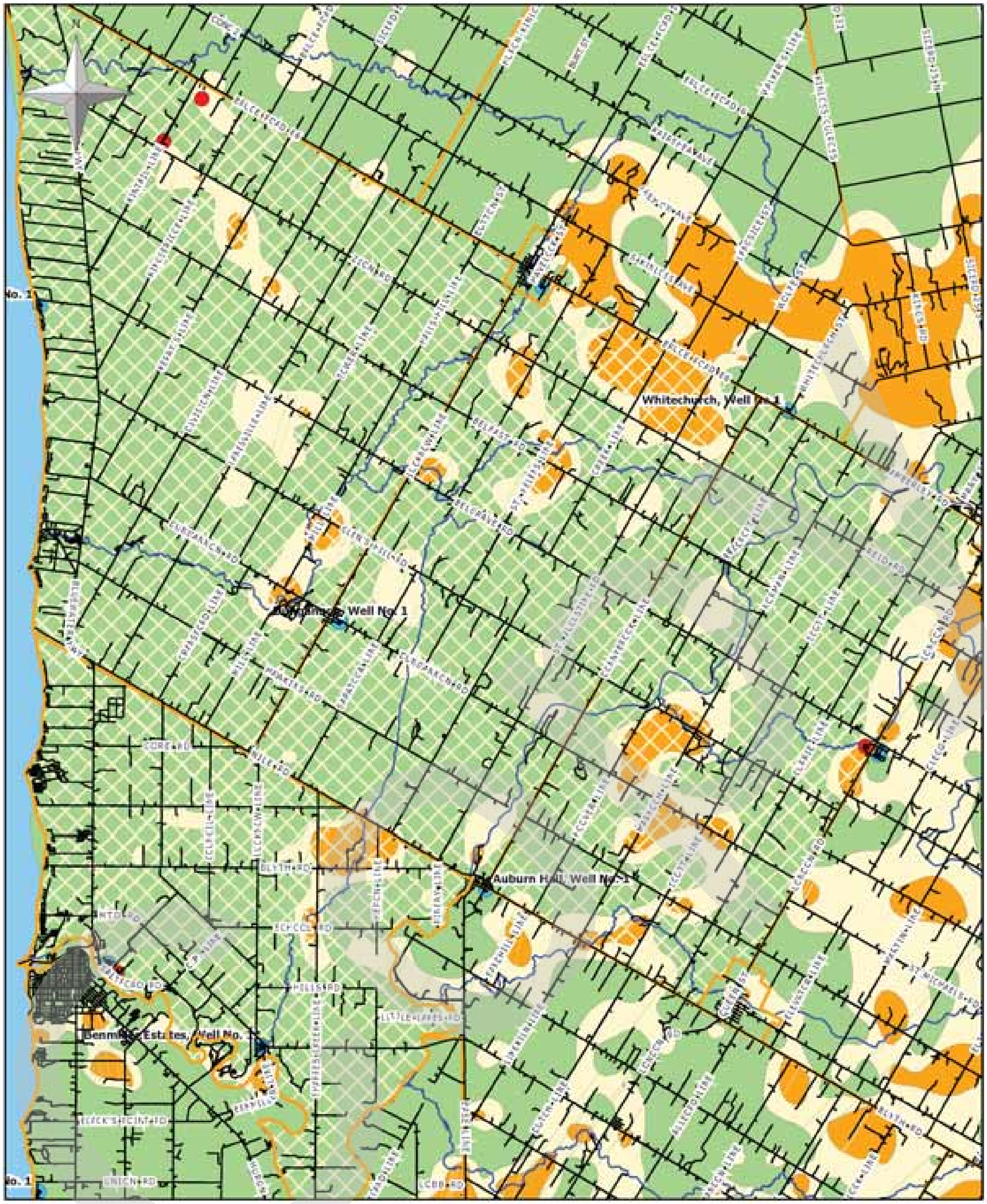
0 10 km

Figure 2-5-2

Bedrock Geology



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ACT FOR CLEAN WATER

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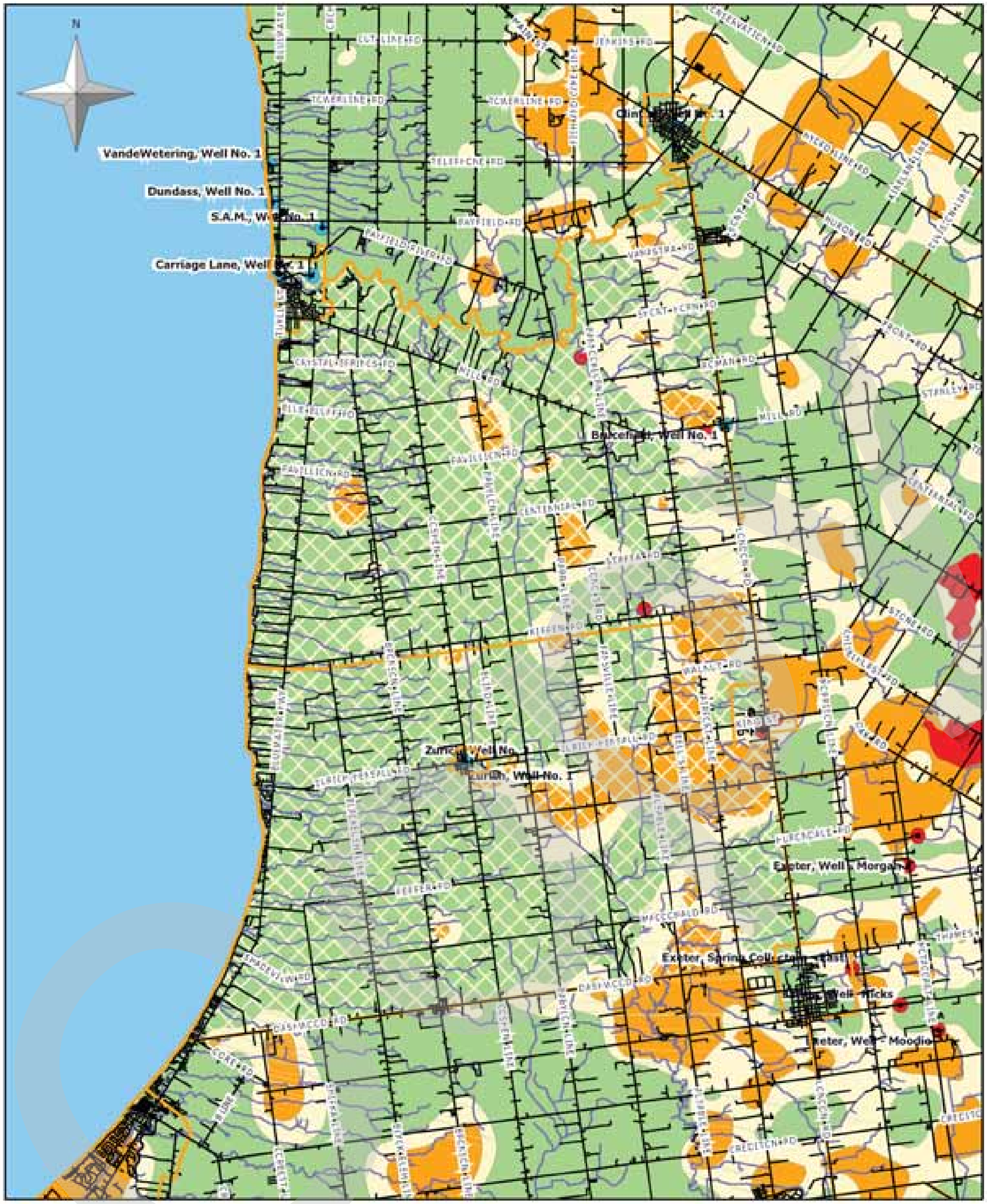
0 5 km

Figure 2-7-1

ISI - ACW



Sinkhole Study Capture Areas
- Points
- Areas

ISI
- High
- Medium
- Low

Bluewater
- Areas

Lower Municipality
- Areas

Municipal Wells - ABCA MVCA

Points : Active
- No
- Yes

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

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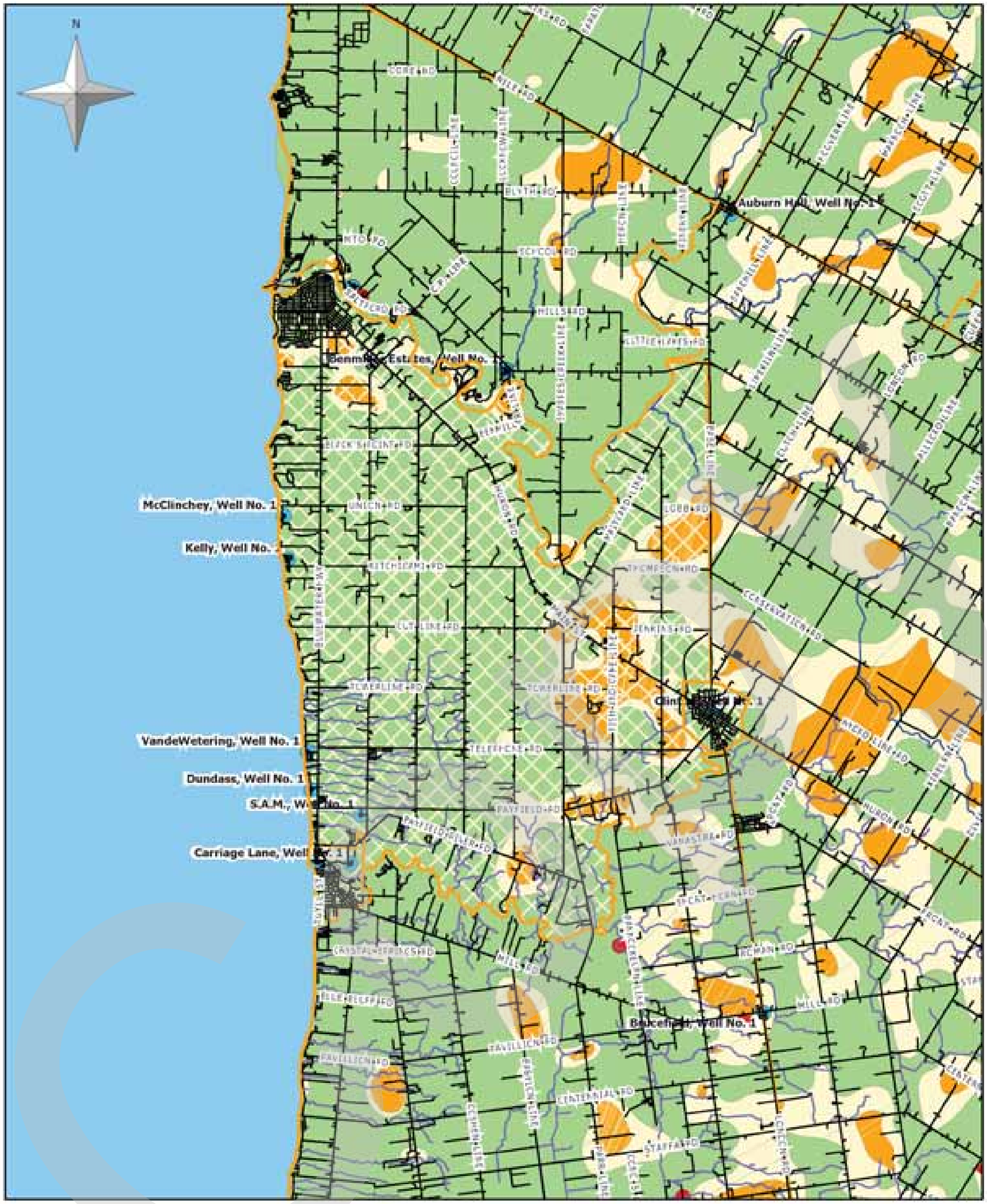
0 5 km

Figure 2-7-2

ISI - Bluewater



Sinkhole Study Capture Areas
- Points
- Areas

ISI
- High
- Medium
- Low

Central Huron
- Areas

Lower Municipality
- Areas

Municipal Wells - ABCA MVCA
Points : Active
- No
- Yes

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

Ausable Bayfield & Maitland Valley Source Protection Region

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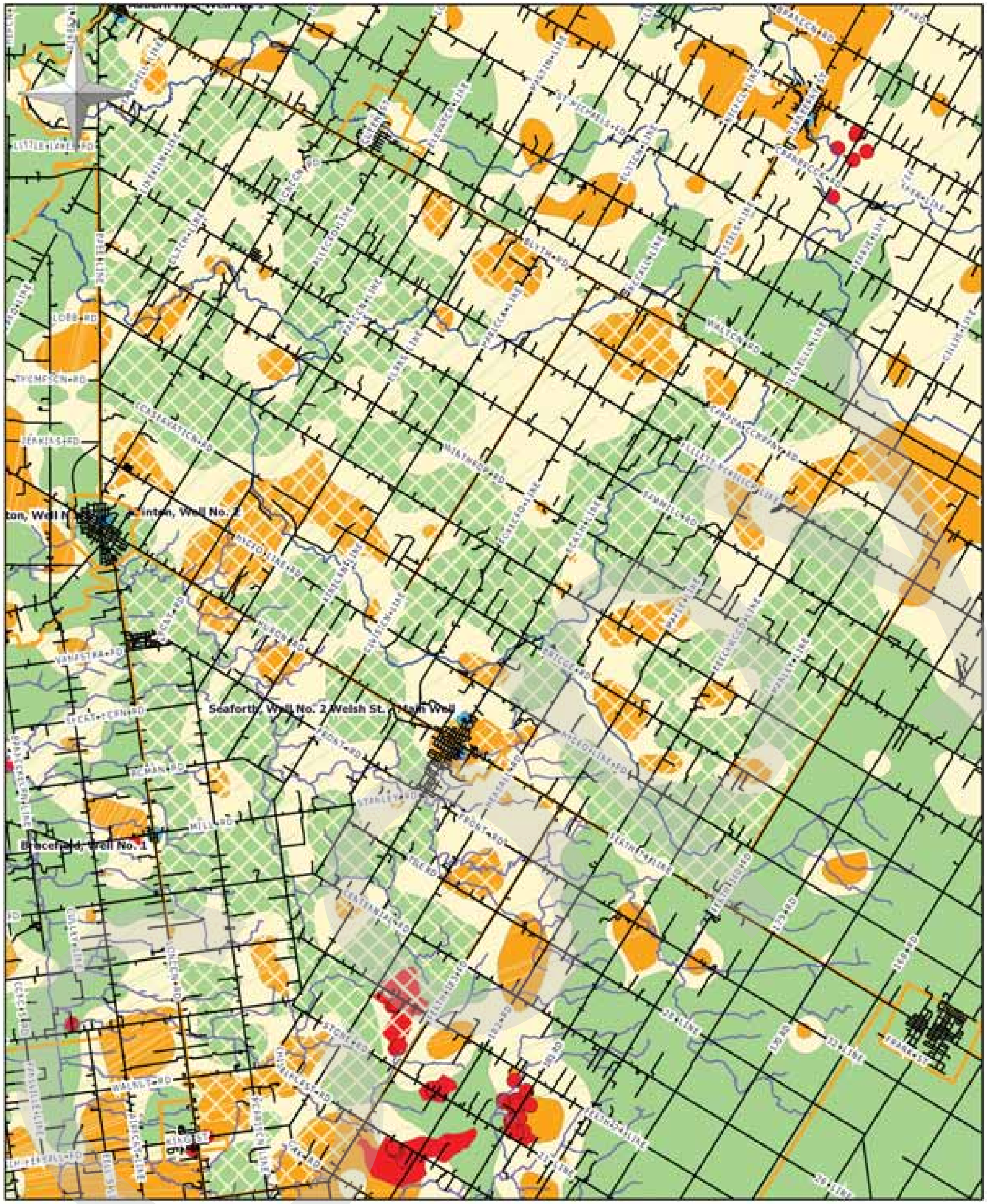
0 5 km

Figure 2-7-3

ISI - Central Huron



Sinkhole Study Capture Areas
- Points
- Areas

ISI
- High
- Medium
- Low

Huron East
- Areas

Lower Municipality
- Areas

Municipal Wells - ABCA MVCA
Points : Active
- No
- Yes

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

Ausable Bayfield & Maitland Valley Source Protection Region

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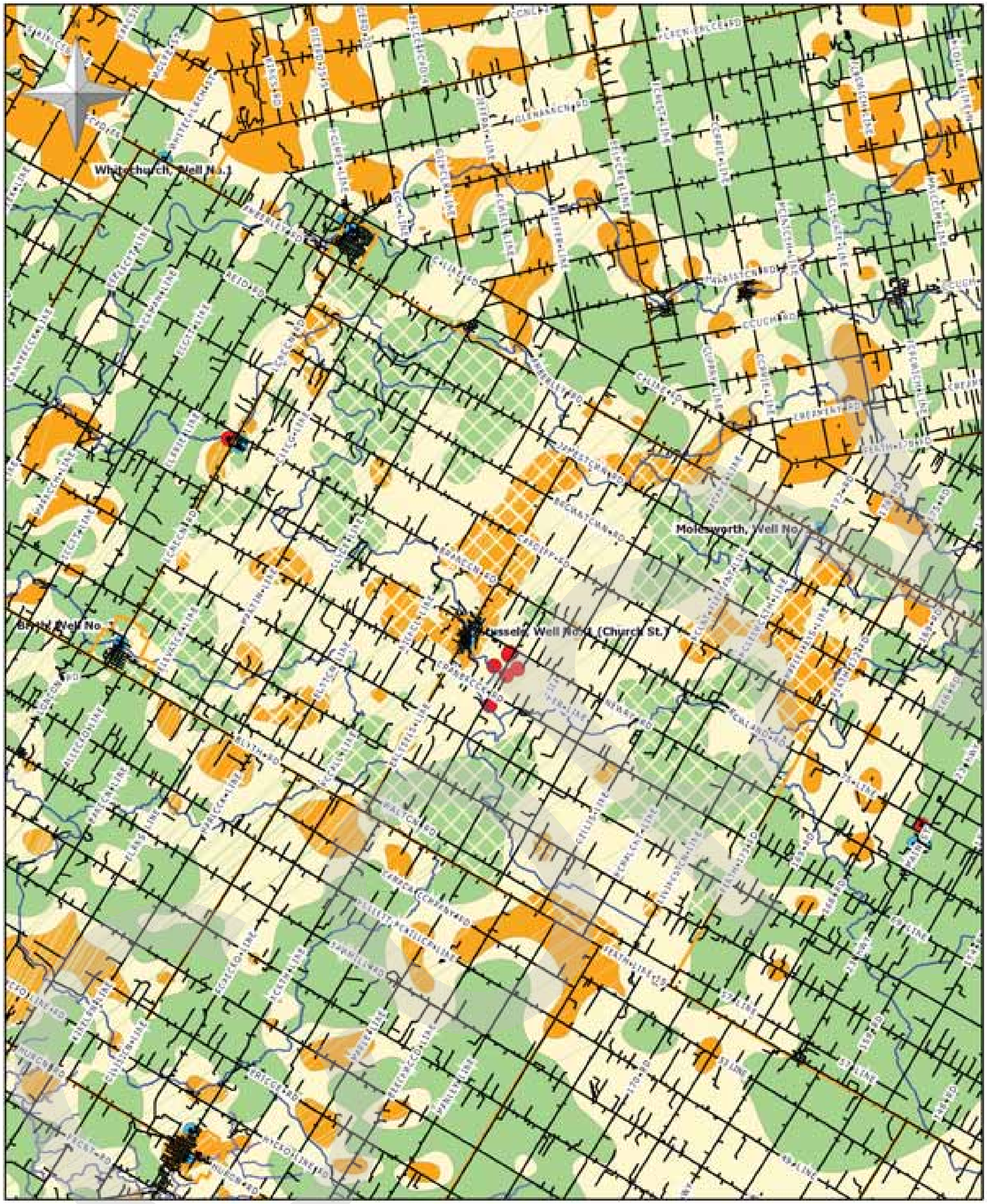
0 5 km

Figure 2-7-4

ISI - Huron East



Sinkhole Study Capture Areas
- Points
- Areas

ISI
- High
- Medium
- Low

North Huron
- Areas

Lower Municipality
- Areas

Municipal Wells - ABCA MVCA
Points : Active
- No
- Yes

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

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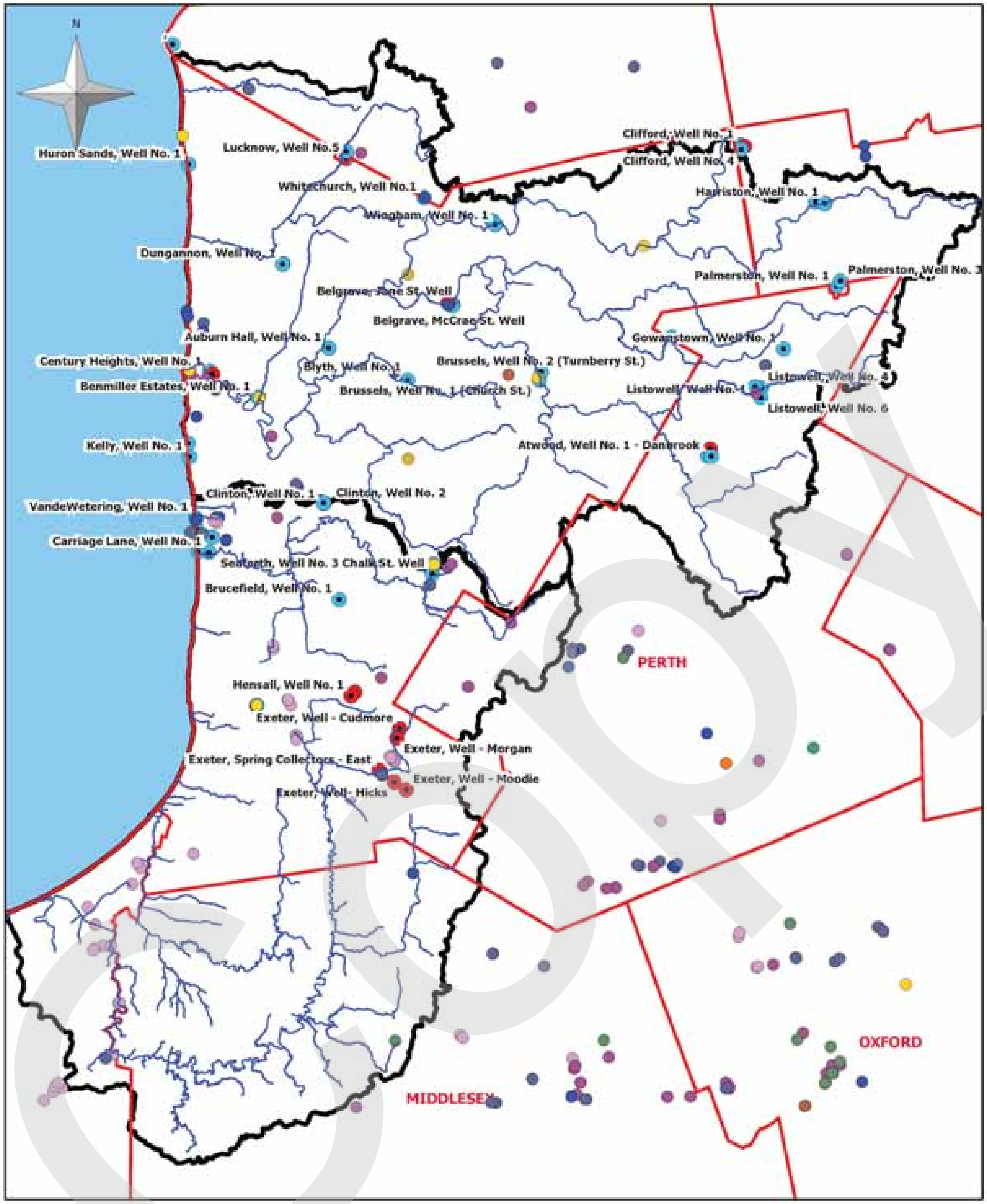
0 5 km

Figure 2-7-5

ISI - North Huron



ABMV GW PTTW 2006
- Agricultural
- Commercial
- Construction
- Dewatering
- Industrial
- Institutional
- Miscellaneous
- Recreational
- Remediation
- Water Supply

Municipal Wells - ABCA MVCA
- No
- Yes

Major Rivers
- Lines

Upper Municipality
- Areas

ABCA MVCA Boundary
- Areas

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

Ausable Bayfield & Maitland Valley Source Protection Region

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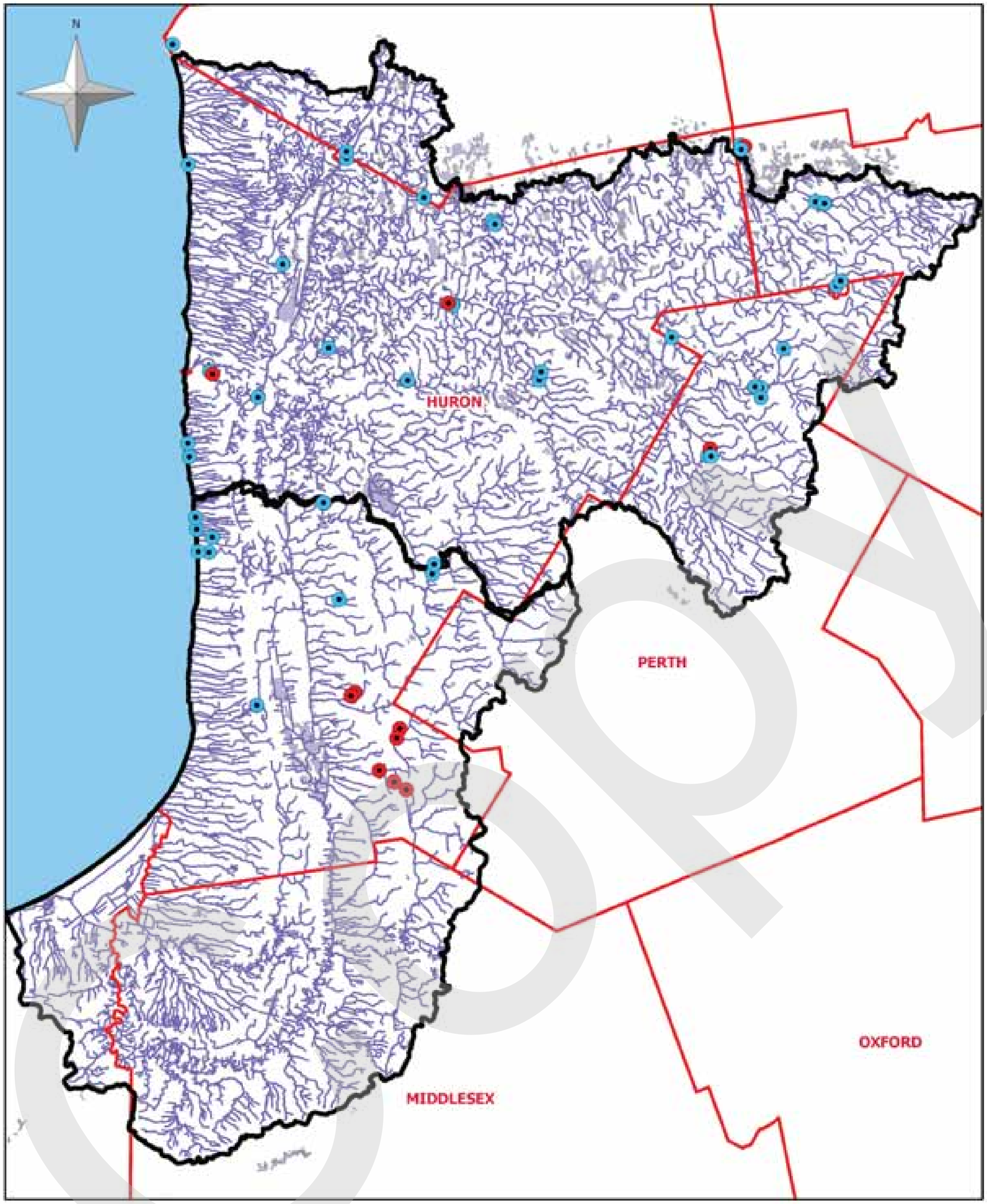
0 10 km

Figure 2-8

Permits to Take Water



Municipal Wells - ABCA MVCA
Points : Active
No
Yes
Rivers
Lines
MNR Wetlands
Areas
Text
Upper Municipality
Areas
ABCA MVCA Boundary
Areas

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

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0 10 km

Figure 3-1-1

Surface Water Features

ABMV_WHPA_UTM_20090806

Areas : ZoneName

- Zone A
- Zone B
- Zone C
- Zone D
- Zone E

Rivers

- Lines

Wetlands NAD83

- Areas

Lower Municipality

- Areas

Upper Municipality

- Areas

ABCA MVCA Boundary

- Areas

Municipal Wells - ABCA MVCA

Points : Active

- No
- Yes

DRINKING WATER SOURCE PROTECTION

ACT FOR CLEAN WATER

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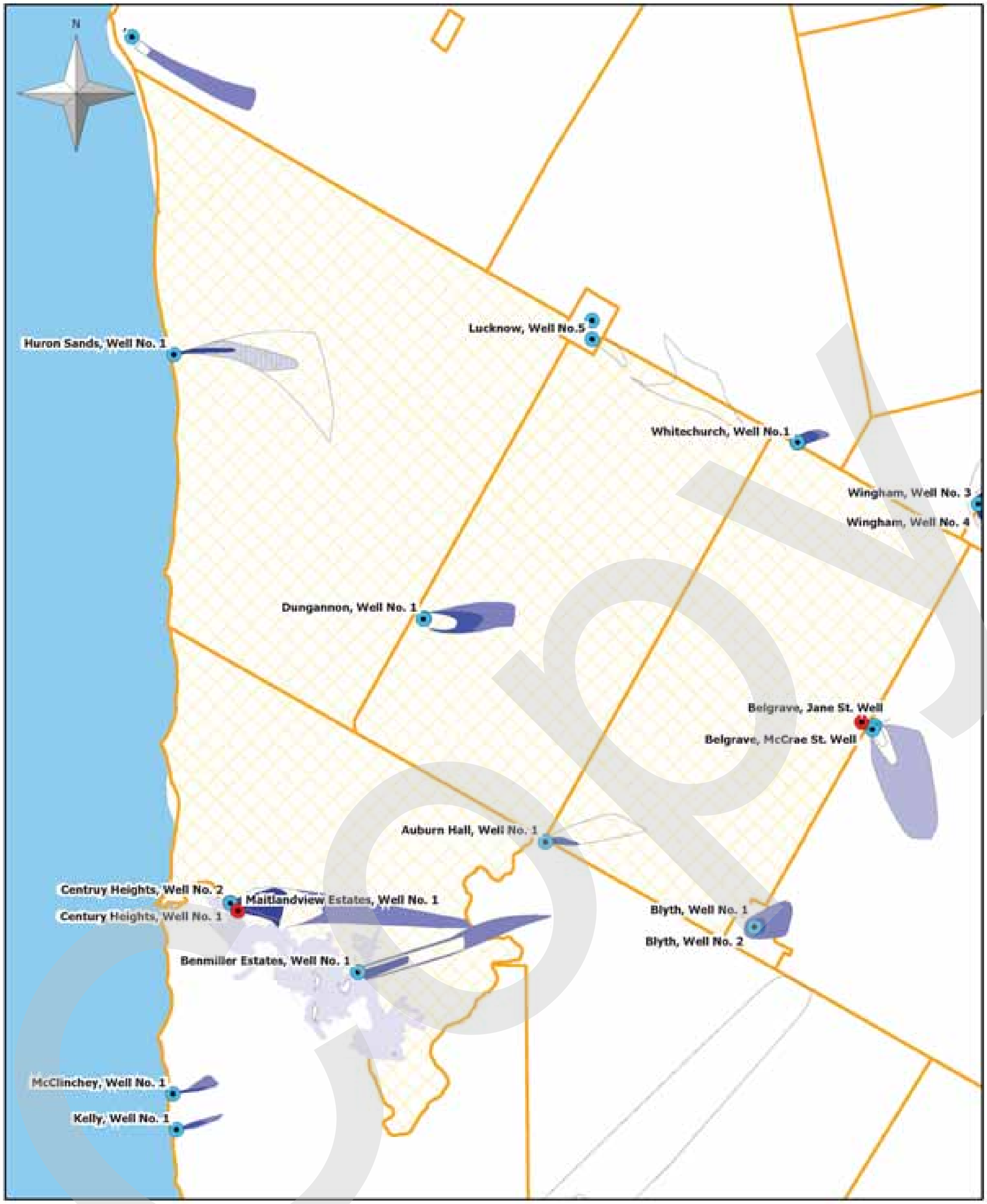
0 5 km

Figure 4-1

Well Head Protection Areas



ABMV WHPA
- Zone A
- Zone B
- Zone C
- Zone D
- Zone E

ACW
- Areas

Lower Municipality
- Areas

Municipal Wells - ABCA MVCA
Points : Active
- No
- Yes

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

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0 5 km

Figure 4-1-1

WHPA's - ACW

ABMV WHPA
- Zone A
- Zone B
- Zone C
- Zone D
- Zone E

Bluewater
- Areas

Lower Municipality
- Areas

Municipal Wells - ABCA MVCA
Points : Active
- No
- Yes

DRINKING WATER SOURCE PROTECTION
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0 — 5 km

Figure 4-1-2

WHPA's - Bluewater

ABMV_WHPA_UTM_20090806

Areas : ZoneName

- Zone A
- Zone B
- Zone C
- Zone D
- Zone E

Central Huron

- Areas

Lower Municipality

- Areas

Municipal Wells - ABCA MVCA

Points : Active

- No
- Yes

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ACT FOR CLEAN WATER

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0 5 km

Figure 4-1-3

WHPA's - Central Huron

ABMV WHPA
- Zone A
- Zone B
- Zone C
- Zone D
- Zone E

Huron East
- Areas

Lower Municipality
- Areas

Municipal Wells - ABCA MVCA
Points : Active
- No
- Yes

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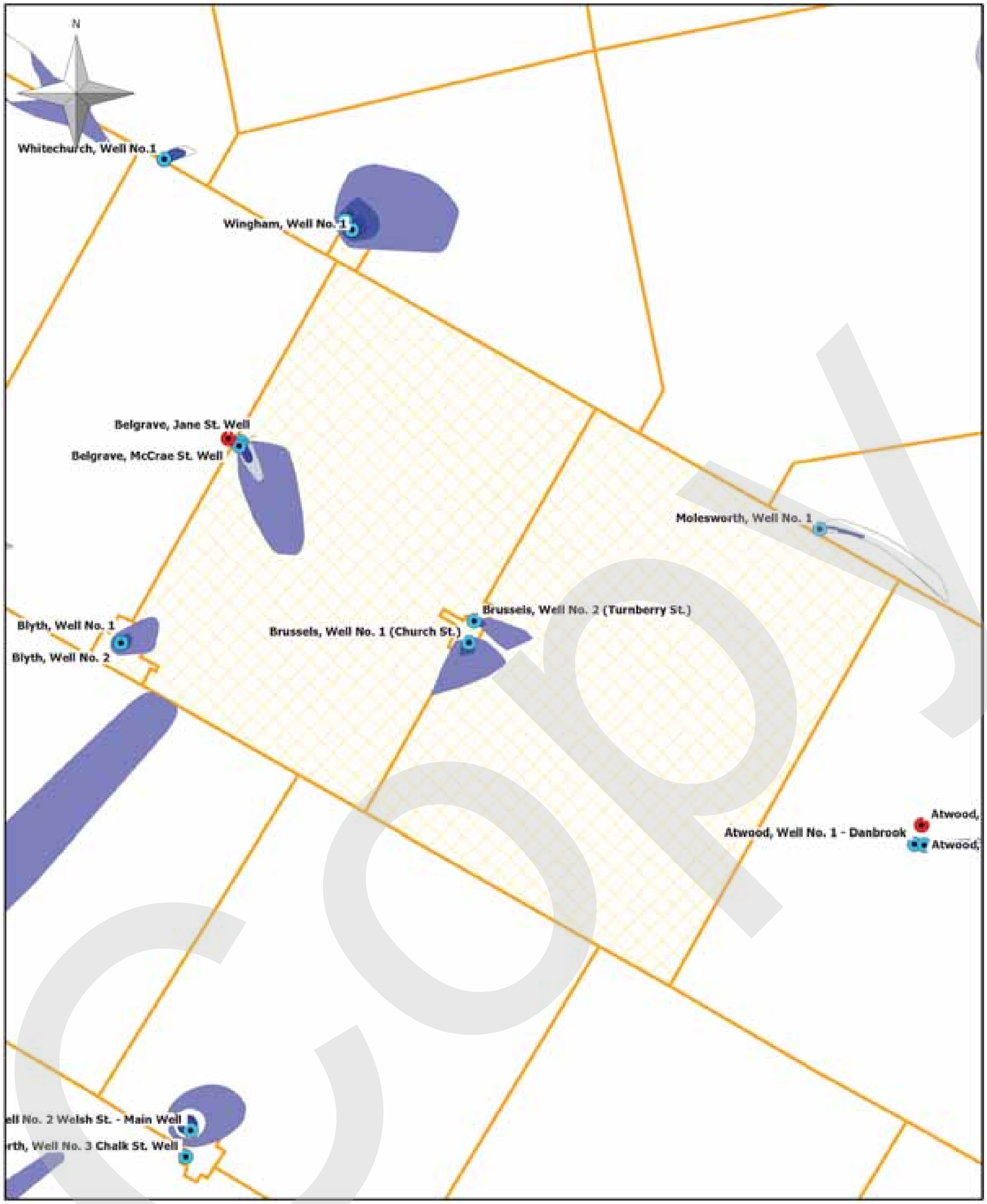
0 5 km

Figure 4-1-4

WHPA's - Huron East



ABMV WHPA
- Zone A
- Zone B
- Zone C
- Zone D
- Zone E

North Huron
- Areas

Lower Municipality
- Areas

Municipal Wells - ABCA MVCA

Points : Active
- No
- Yes

DRINKING WATER SOURCE PROTECTION

ACT FOR CLEAN WATER

Ausable Bayfield & Maitland Valley Source Protection Region

Study Team
Waterloo Numerical Modelling Corp.
International Water Consultants Ltd.
B.M. Ross and Associates Ltd.

Digital Mapping Sources:
Base Mapping Features - Ministry of Natural Resources
Water Well Records - Ministry of Environment
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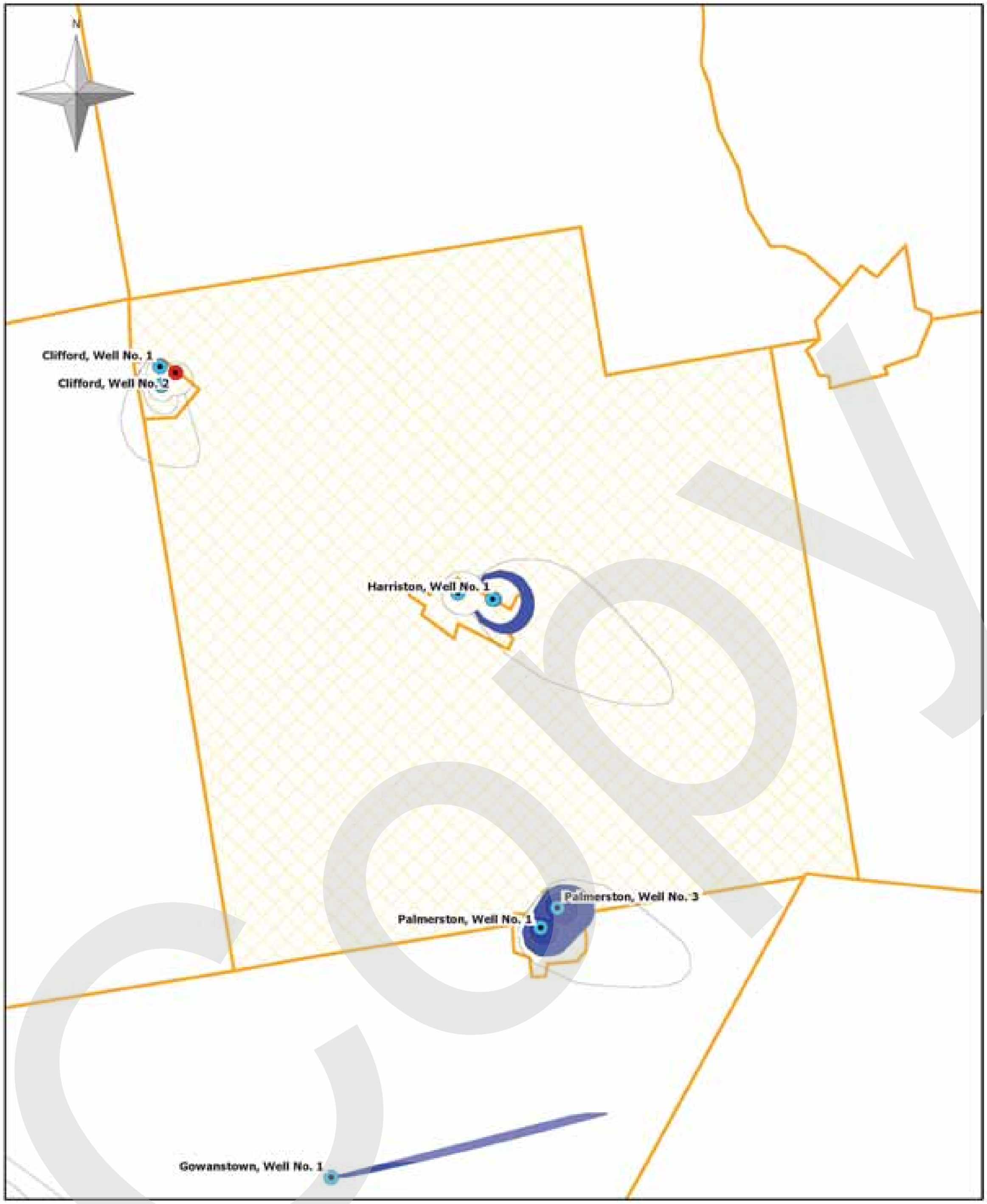
0 5 km

Figure 4-1-5

WHPA's - North Huron



ABMV WHPA
Zone A
Zone B
Zone C
Zone D
Zone E
Minto Township
Areas
Lower Municipality
Areas
Municipal Wells - ABCA MVCA
Points : Active
No
Yes

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

Ausable Bayfield & Maitland Valley Source Protection Region

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0 5 km

Figure 4-1-6

WHPA's - Minto Township

ABMV WHPA
Zone A
Zone B
Zone C
Zone D
Zone E
Lower Municipality
Areas
Municipal Wells - ABCA MVCA
Points : Active
No
Yes

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

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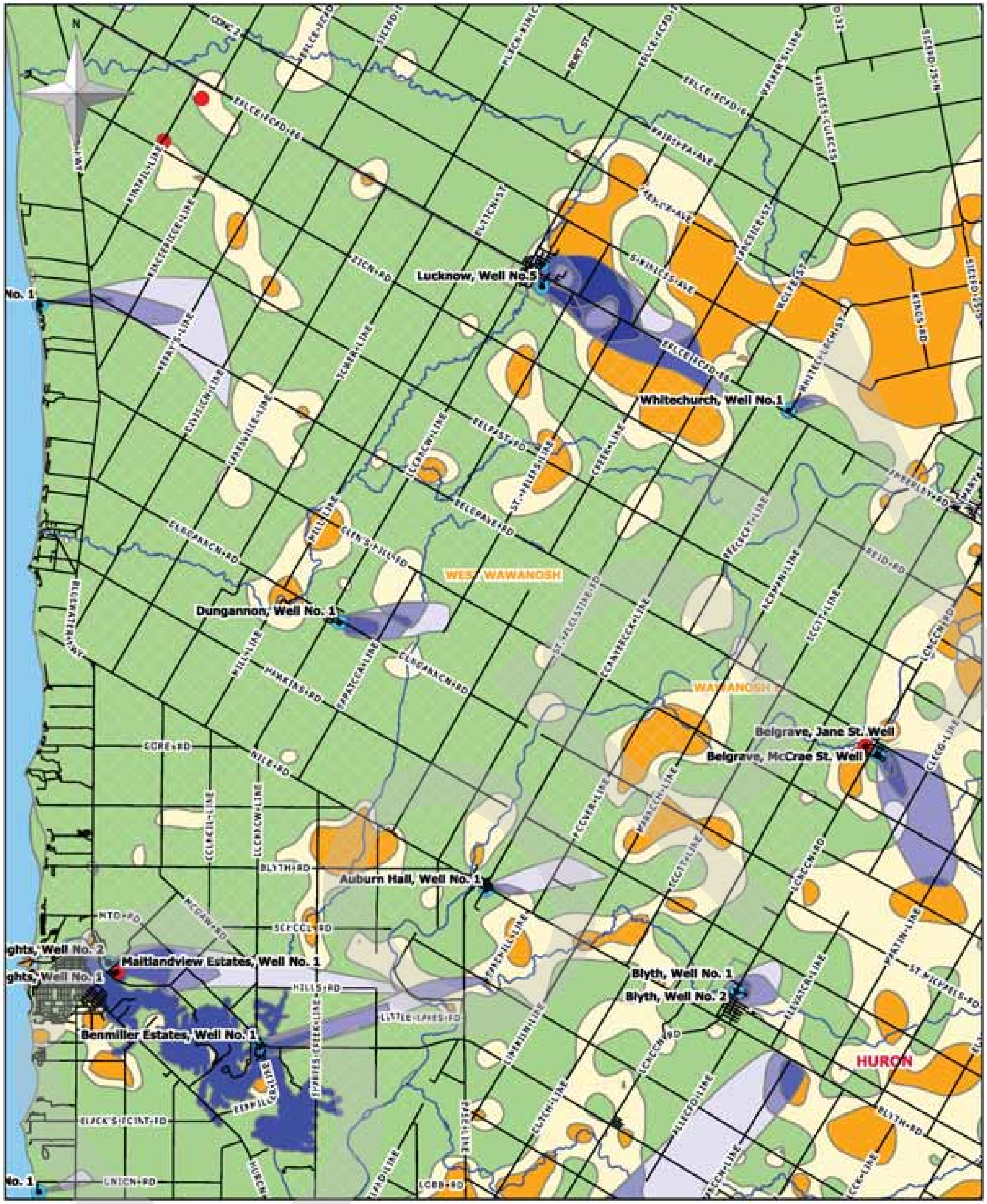
0 5 km

Figure 4-1-7

WHPA's - North Perth



WHPA Vulnerability
- 2
- 4
- 6
- 8
- 10

Sinkhole Study Capture Areas
- Points
- Areas

ISI
- High
- Medium
- Low

Municipal Wells - ABCA MVCA

Points : Active
- No
- Yes

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

Ausable Bayfield & Maitland Valley Source Protection Region

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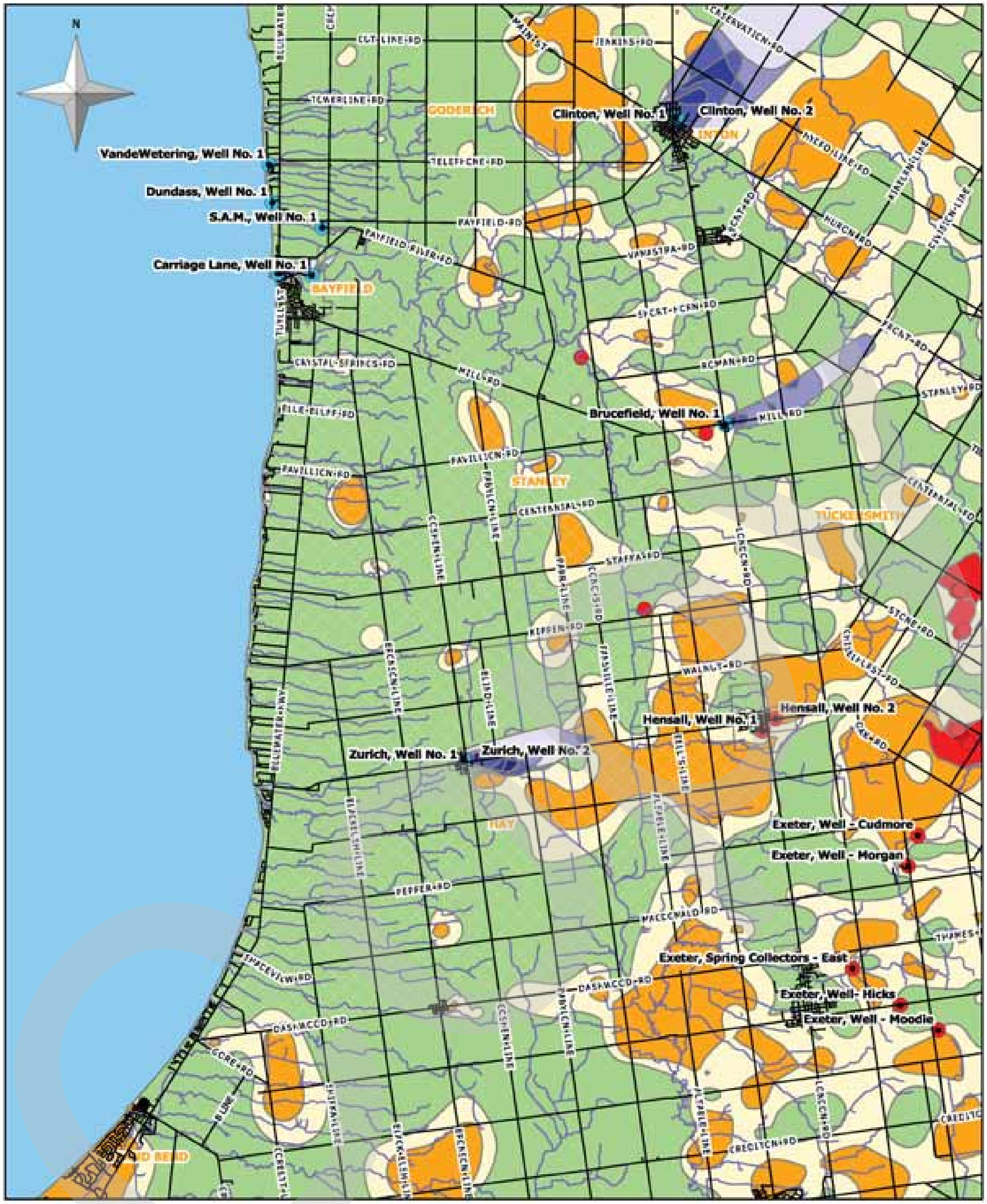
0 5 km

Figure 5-1-1

WHPA Vulnerability - ACW



WHPA Vulnerability
- 2
- 4
- 6
- 8
- 10

Sinkhole Study Capture Areas
- Points
- Areas

ISI
- High
- Medium
- Low

Municipal Wells - ABCA MVCA

Points : Active
- No
- Yes

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

Ausable Bayfield & Maitland Valley Source Protection Region

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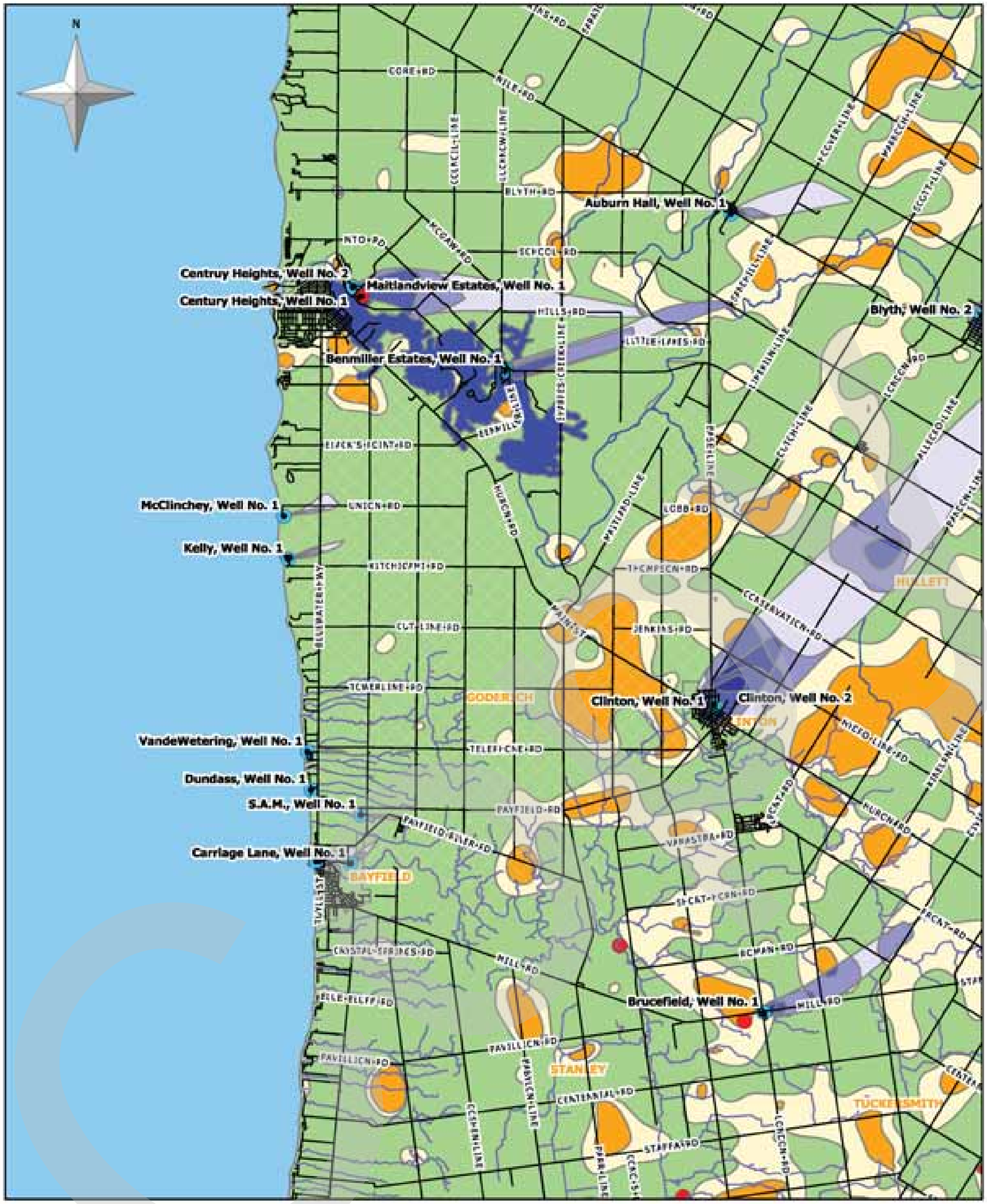
0 5 km

Figure 5-1-2

WHPA Vulnerability - Bluewater



WHPA Vulnerability
- 2
- 4
- 6
- 8
- 10

Sinkhole Study Capture Areas
- Points
- Areas

ISI
- High
- Medium
- Low

Municipal Wells - ABCA MVCA

Points : Active
- No
- Yes

DRINKING WATER SOURCE PROTECTION

ACT FOR CLEAN WATER

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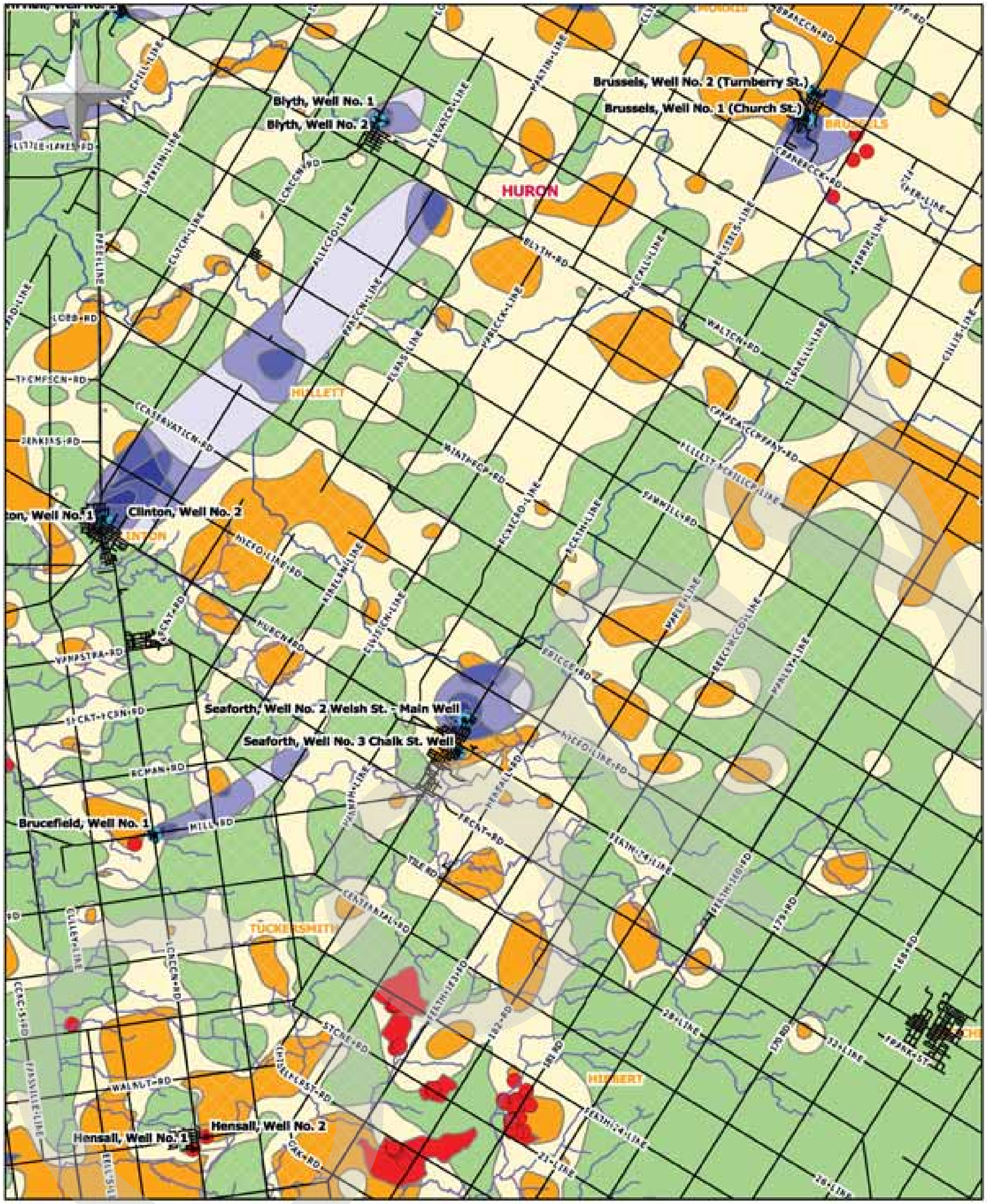
0 5 km

Figure 5-1-3

WHPA Vulnerability - Central Huron



WHPA Vulnerability
2
4
6
8
10

Sinkhole Study Capture Areas
Points
Areas

ISI
High
Medium
Low

Municipal Wells - ABCA MVCA
Points : Active
No
Yes

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

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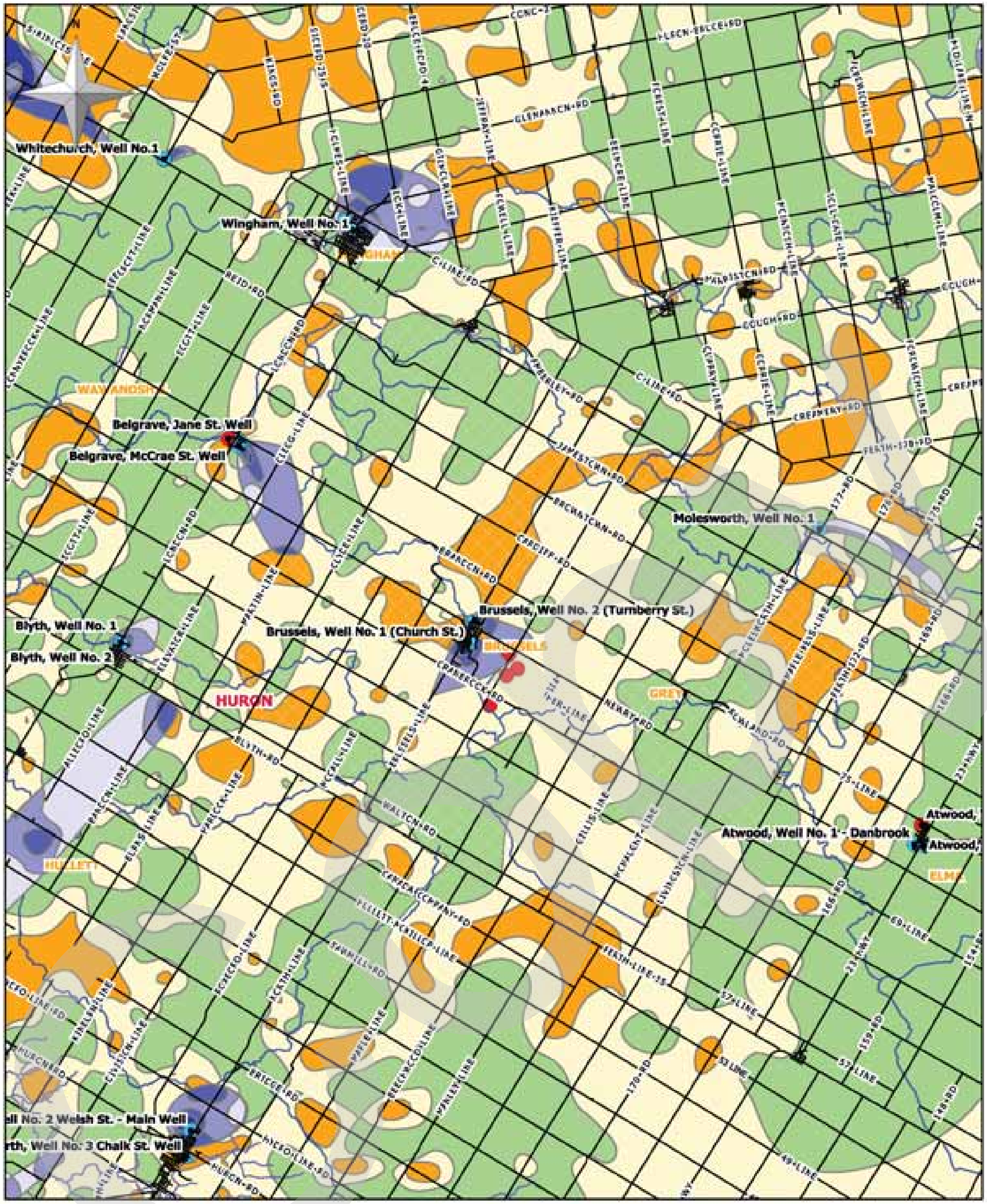
0 5 km

Figure 5-1-4

WHPA Vulnerability - Huron East



WHPA Vulnerability
- 2
- 4
- 6
- 8
- 10

Sinkhole Study Capture Areas
- Points
- Areas

ISI
- High
- Medium
- Low

Municipal Wells - ABCA MVCA
Points : Active
- No
- Yes

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

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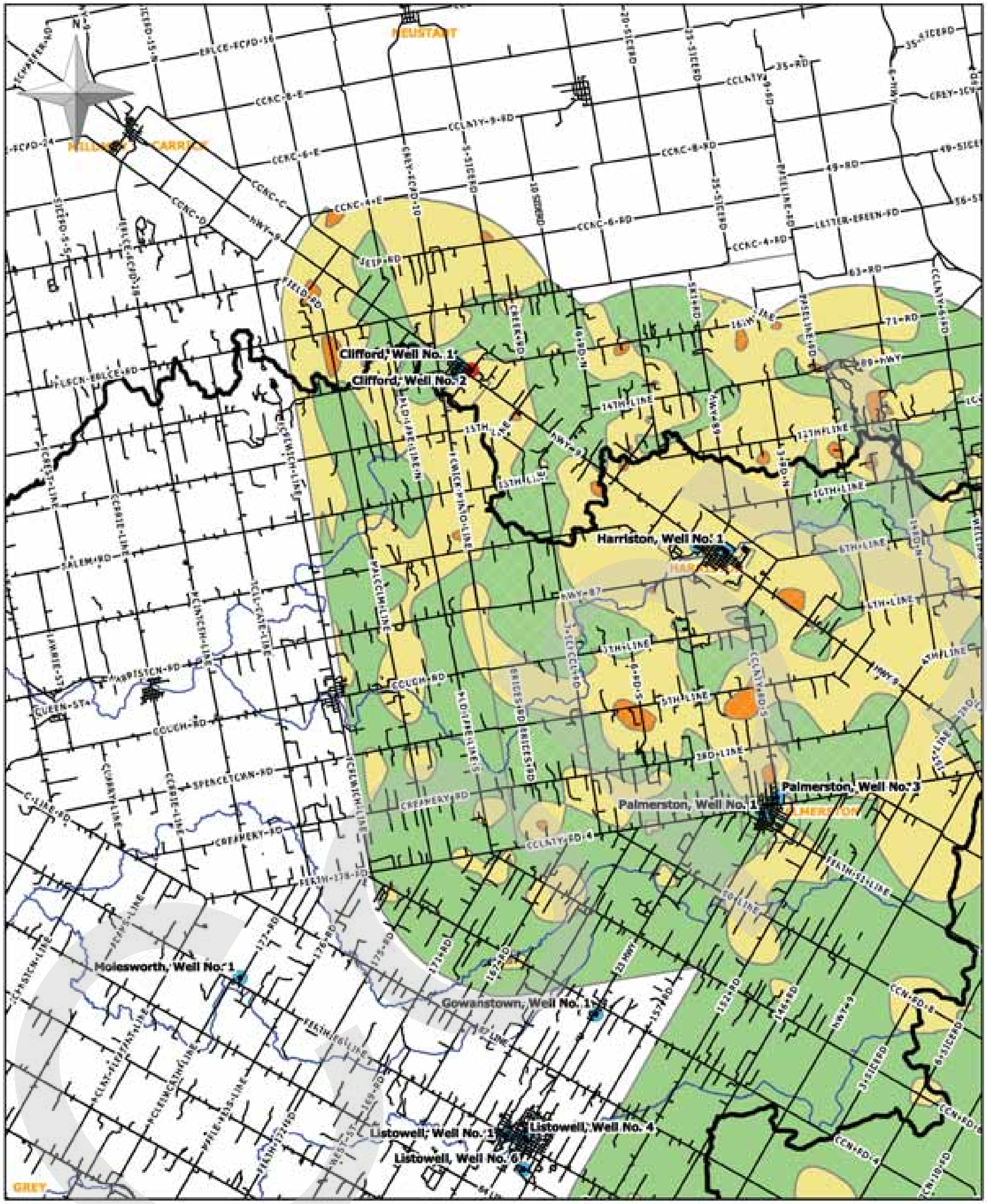
0 5 km

Figure 5-1-5

WHPA Vulnerability - North Huron



WHPA Vulnerability

- 2
- 4
- 6
- 8
- 10

Sinkhole Study Capture Areas

- Points
- Areas

ISI

- High
- Medium
- Low

Municipal Wells - ABCA MVCA

Points : Active

- No
- Yes

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

Ausable Bayfield & Maitland Valley Source Protection Region

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Water Well Records - Ministry of Environment
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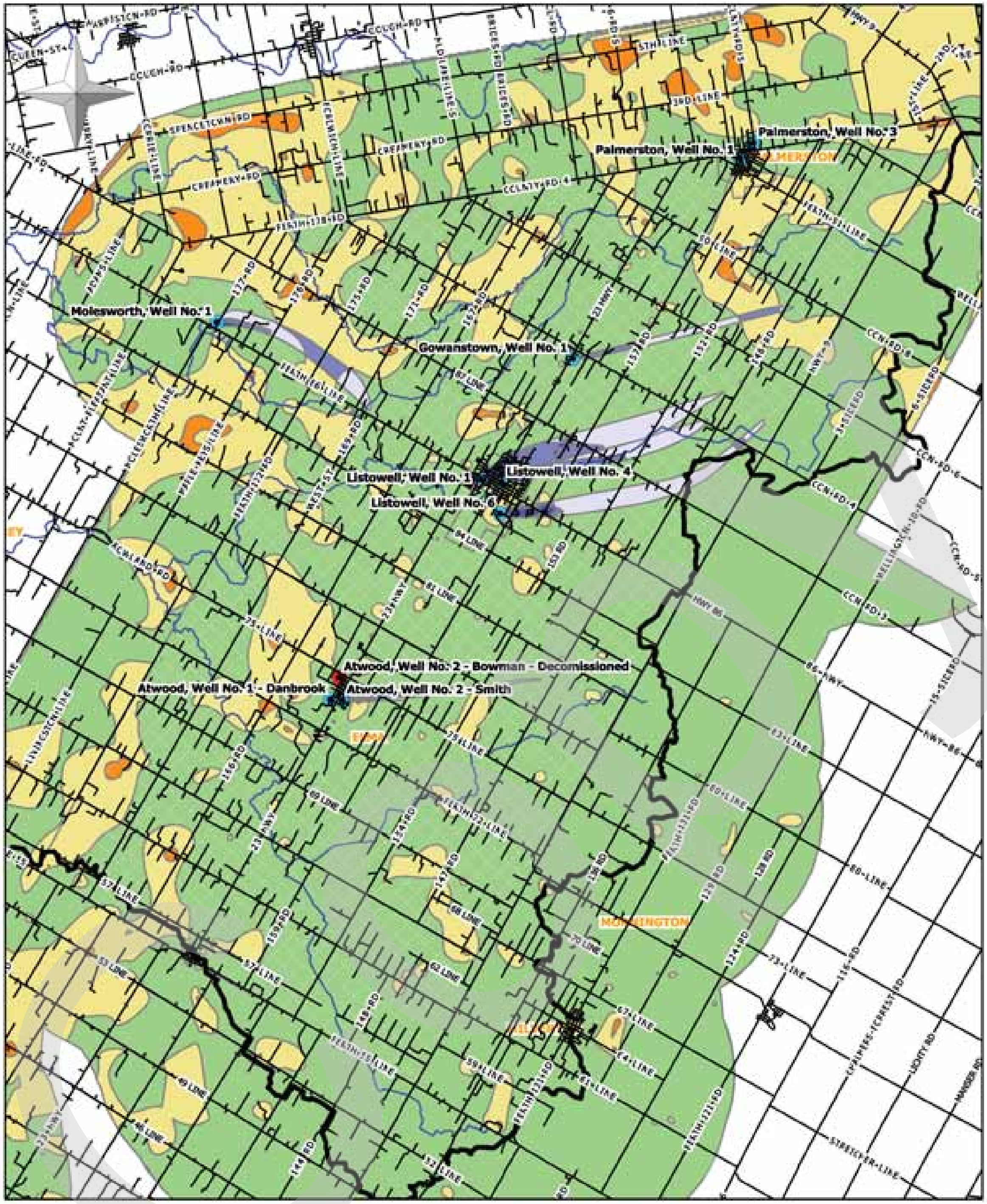
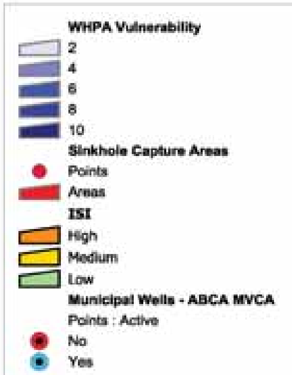
0 5 km

Figure 5-1-6

WHPA Vulnerability - Minto Township





DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

Ausable Bayfield & Maitland Valley Source Protection Region

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0 5 km

Figure 5-1-7

WHPA Vulnerability - North Perth

Appendix B
Wellhead Protection Areas, Local Scale

ABMV WHPA
Areas : ZoneName
Zone A
Zone B
Zone C
Zone D
Zone E
Rivers
Lines
Wetlands NAD83
Areas
Municipal Wells - ABCA MVCA
Points : Active
No
Yes

0 1000 m

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

Ausable Bayfield & Maitland Valley Source Protection Region

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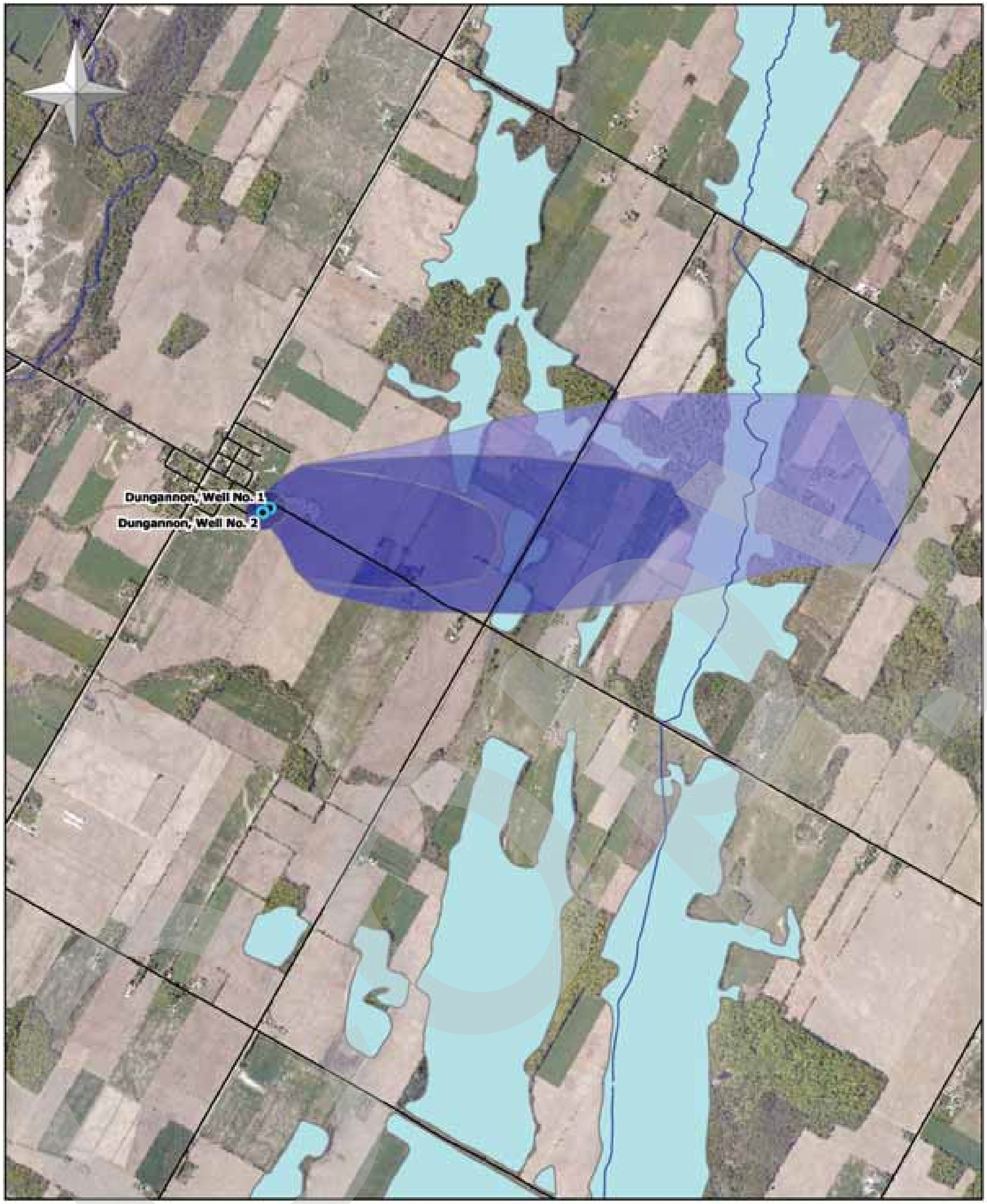
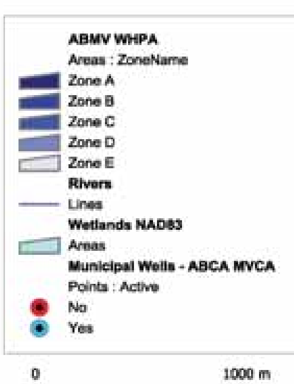
Figure 4-1-1-A

WHPA - Huron Sands





DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

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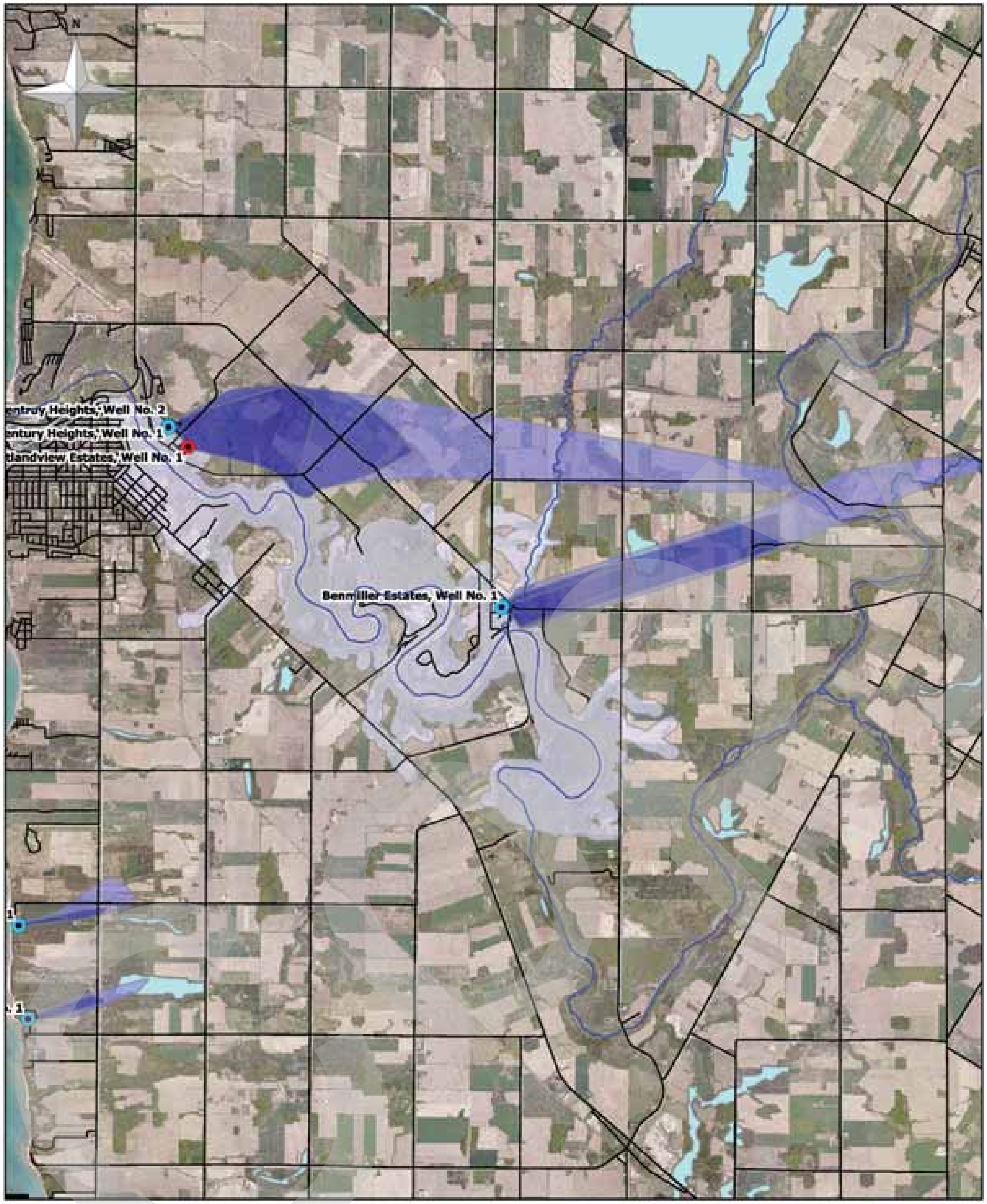
Figure 4-1-1-B

WHPA - Dungannon



DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

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Figure 4-1-1-C

WHPA - Century Heights and Benmiller

ABMV WHPA
Areas : ZoneName
Zone A
Zone B
Zone C
Zone D
Zone E
Rivers
Lines
Wetlands NAD83
Areas
Municipal Wells - ABCA MVCA
Points : Active
No
Yes

0 1000 m

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

Ausable Bayfield & Maitland Valley Source Protection Region

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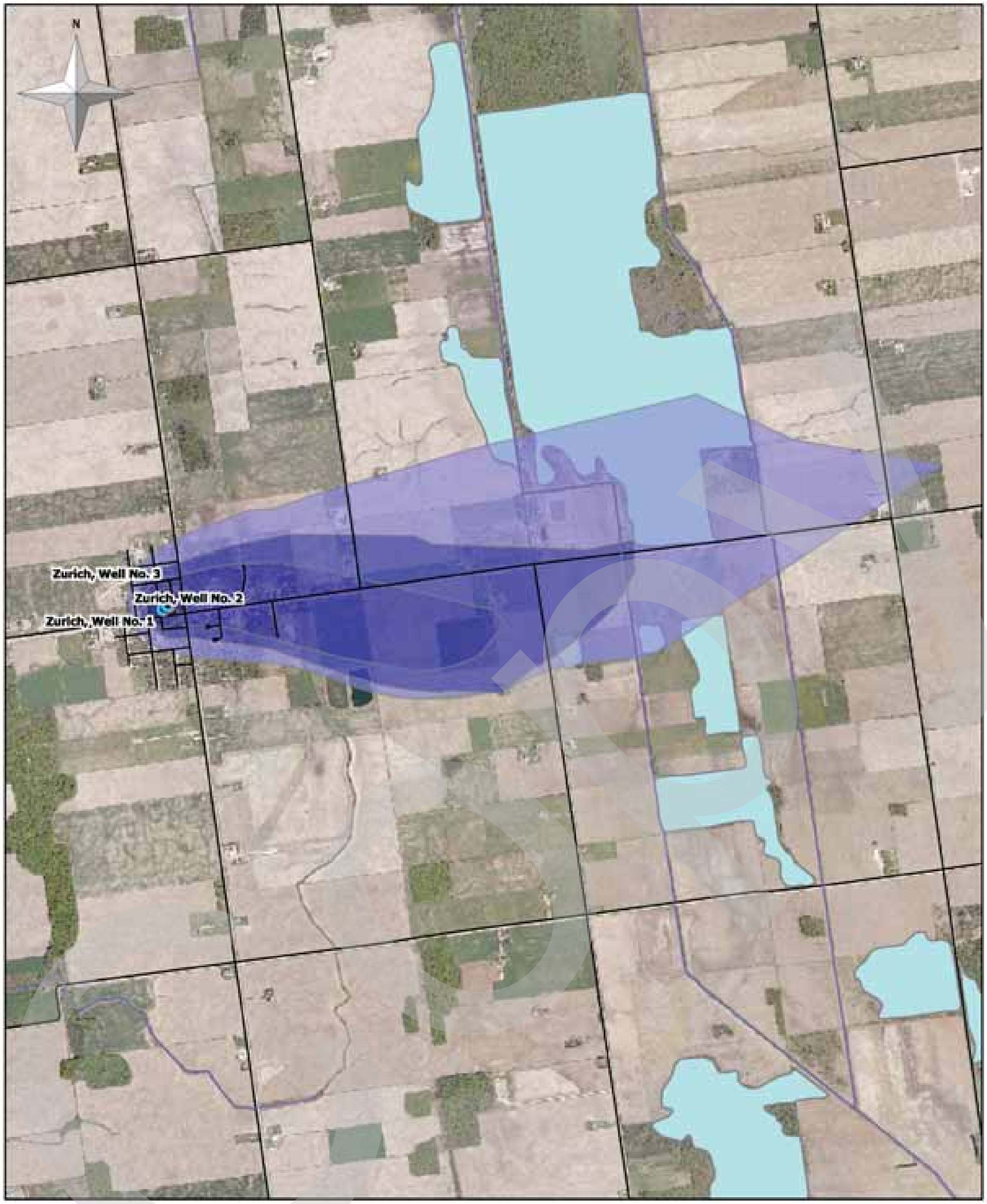
Figure 4-1-2-A

WHPA - Carriage Lane, S.A.M., & Harbour Lights



ABMV WHPA
Areas : ZoneName
Zone A
Zone B
Zone C
Zone D
Zone E
Rivers
Lines
Wetlands NAD83
Areas
Municipal Wells - ABCA MVCA
Points : Active
No
Yes

0 1000 m

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

Ausable Bayfield & Maitland Valley Source Protection Region

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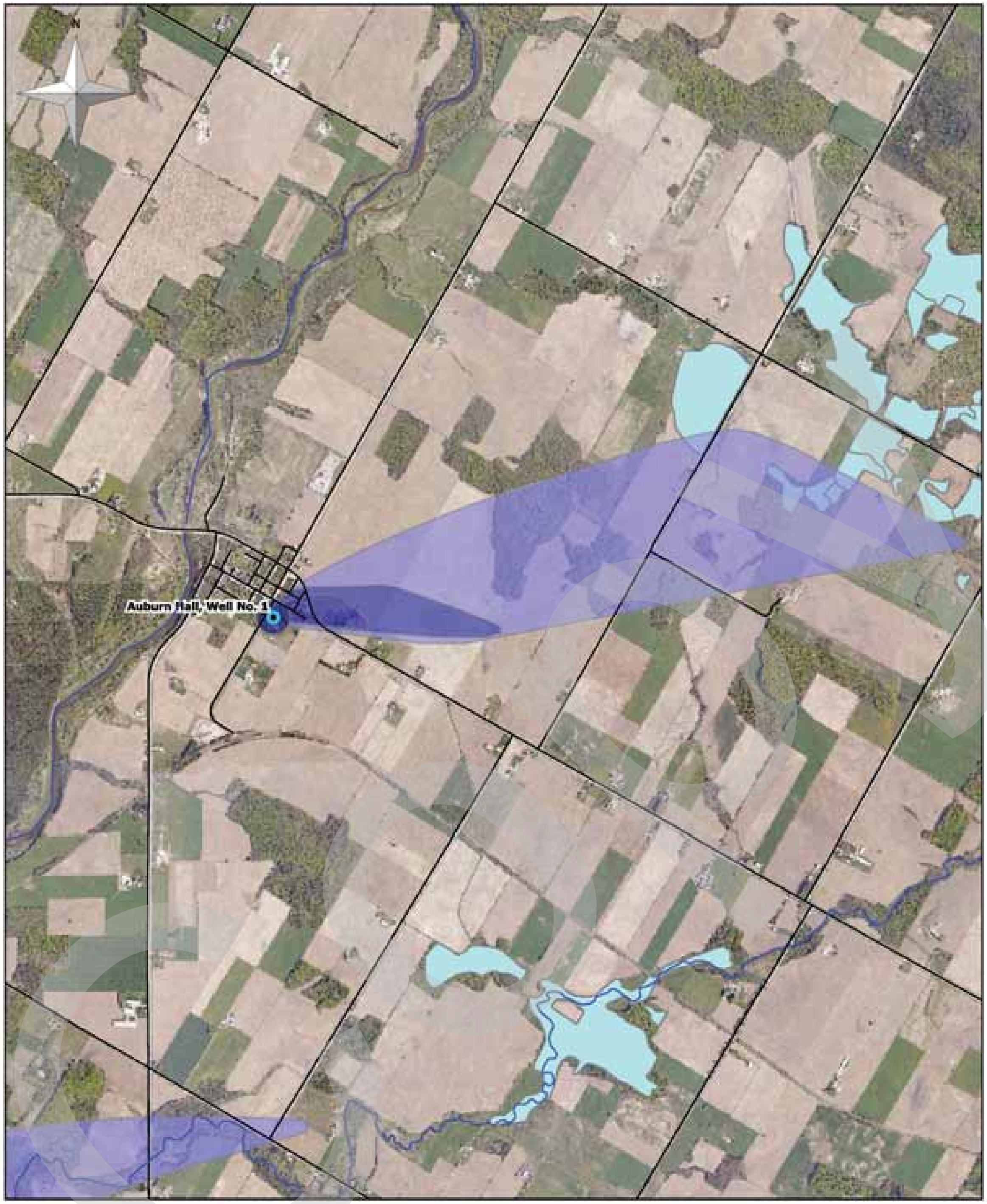
Figure 4-1-2-B

WHPA - Zurich



ABMV WHPA
Areas : ZoneName
Zone A
Zone B
Zone C
Zone D
Zone E
Rivers
Lines
Wetlands NAD83
Areas
Municipal Wells - ABCA MVCA
Points : Active
No
Yes

0 1000 m

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

Ausable Bayfield & Maitland Valley Source Protection Region

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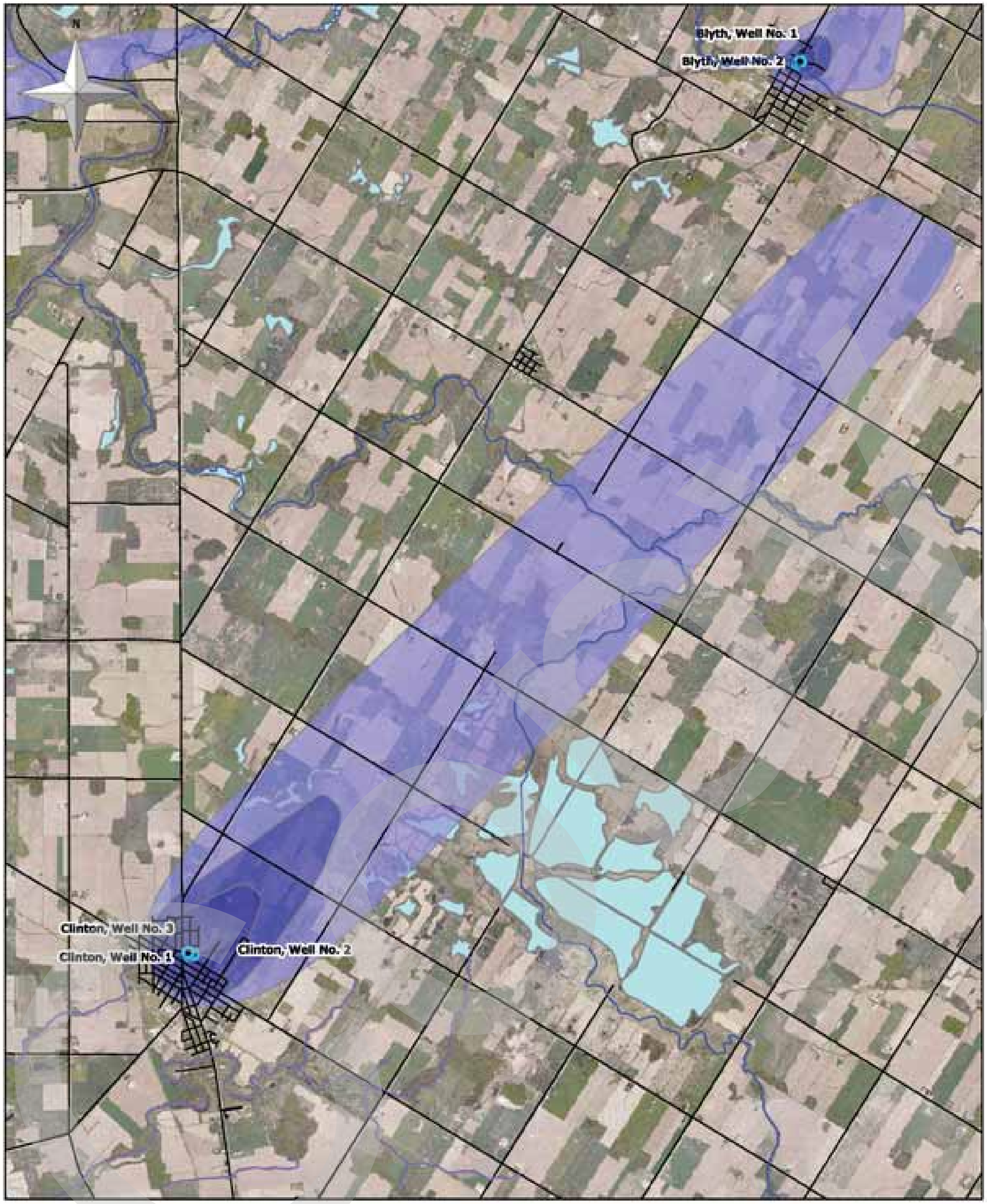
B.M. Ross and Associates Ltd.

Figure 4-1-3-A

WHPA - Auburn Hall



ABMV WHPA
Areas : ZoneName
Zone A
Zone B
Zone C
Zone D
Zone E
Rivers
Lines
Wetlands NAD83
Areas
Municipal Wells - ABCA MVCA
Points : Active
No
Yes

0 1000 m

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

Ausable Bayfield & Maitland Valley Source Protection Region

Study Team
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International Water Consultants Ltd.
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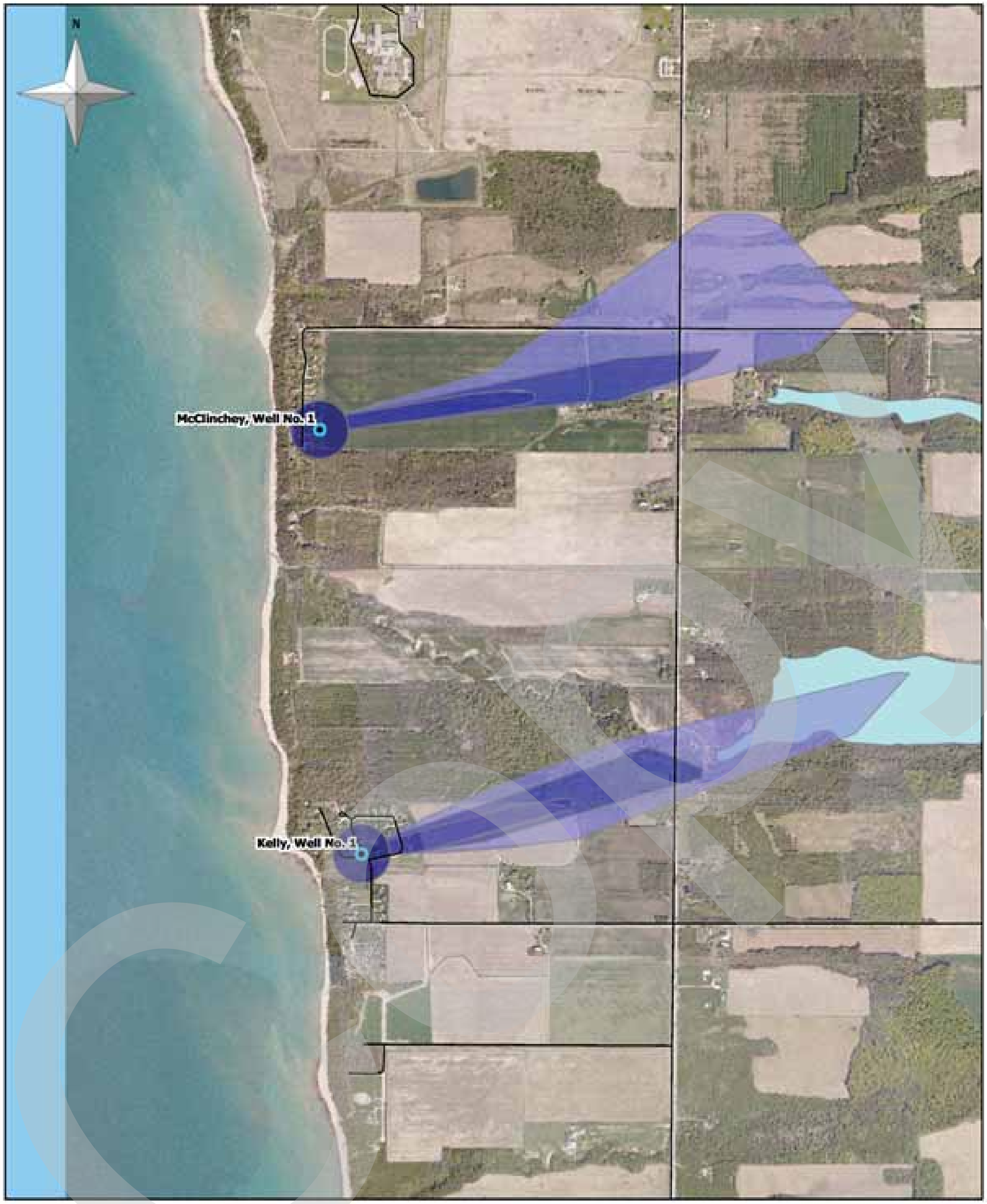
Figure 4-1-3-B

WHPA - Clinton



ABMV WHPA
Areas : ZoneName
Zone A
Zone B
Zone C
Zone D
Zone E
Rivers
Lines
Wetlands NAD83
Areas
Municipal Wells - ABCA MVCA
Points : Active
No
Yes

0 1000 m

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

Ausable Bayfield & Maitland Valley Source Protection Region

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International Water Consultants Ltd.
B.M. Ross and Associates Ltd.

Figure 4-1-3-C

WHPA - Kelly & McClinchey

ABMV WHPA
Areas : ZoneName
- Zone A
- Zone B
- Zone C
- Zone D
- Zone E

Rivers
- Lines

Wetlands NAD83
- Areas

Municipal Wells - ABCA MVCA
Points : Active
- No
- Yes

0 1000 m

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

Ausable Bayfield & Maitland Valley Source Protection Region

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International Water Consultants Ltd.
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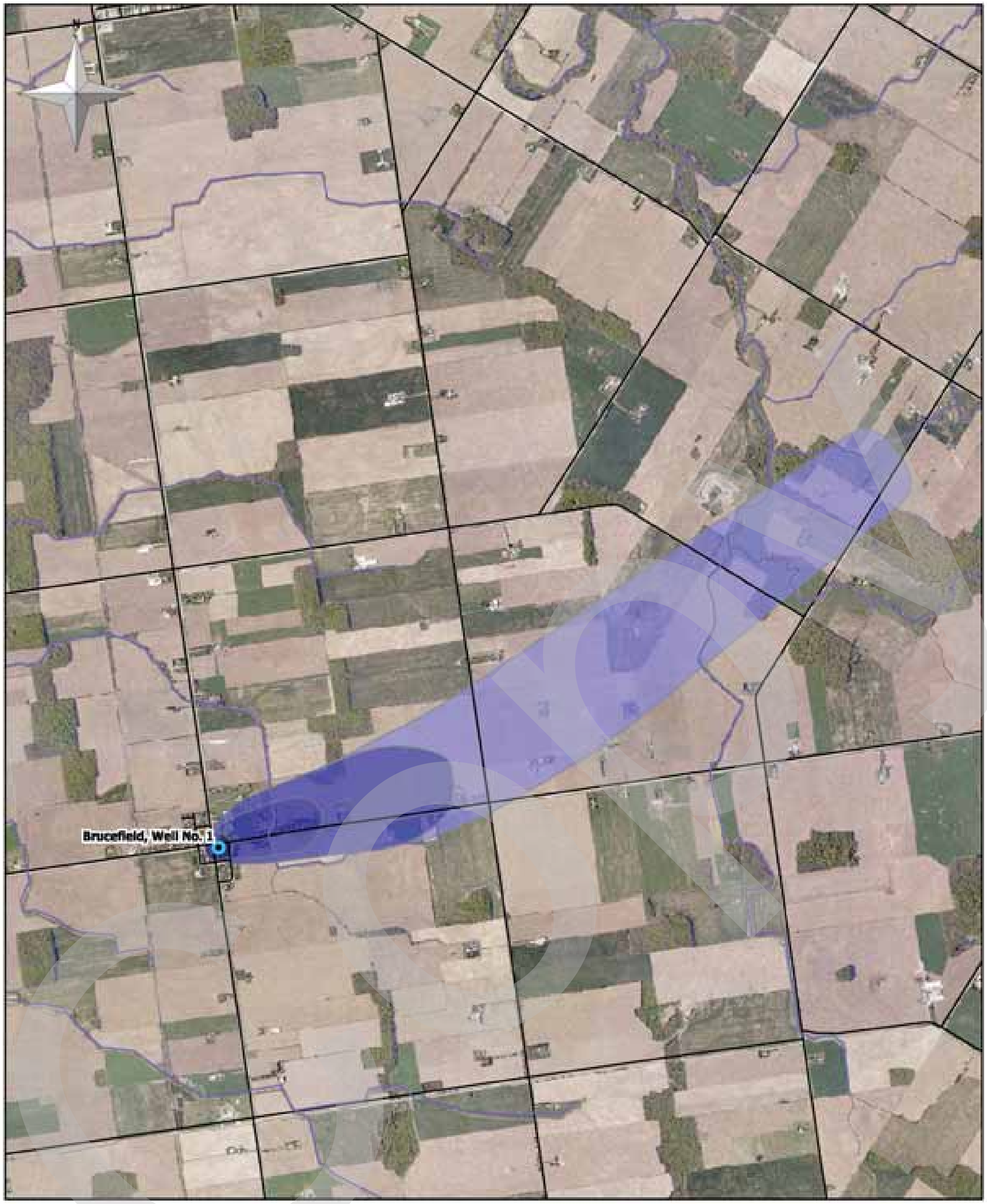
Figure 4-1-3-D

WHPA -VandeWetering



ABMV WHPA
Areas : ZoneName
Zone A
Zone B
Zone C
Zone D
Zone E
Rivers
Lines
Wetlands NAD83
Areas
Municipal Wells - ABCA MVCA
Points : Active
No
Yes

0 1000 m

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

Ausable Bayfield & Maitland Valley Source Protection Region

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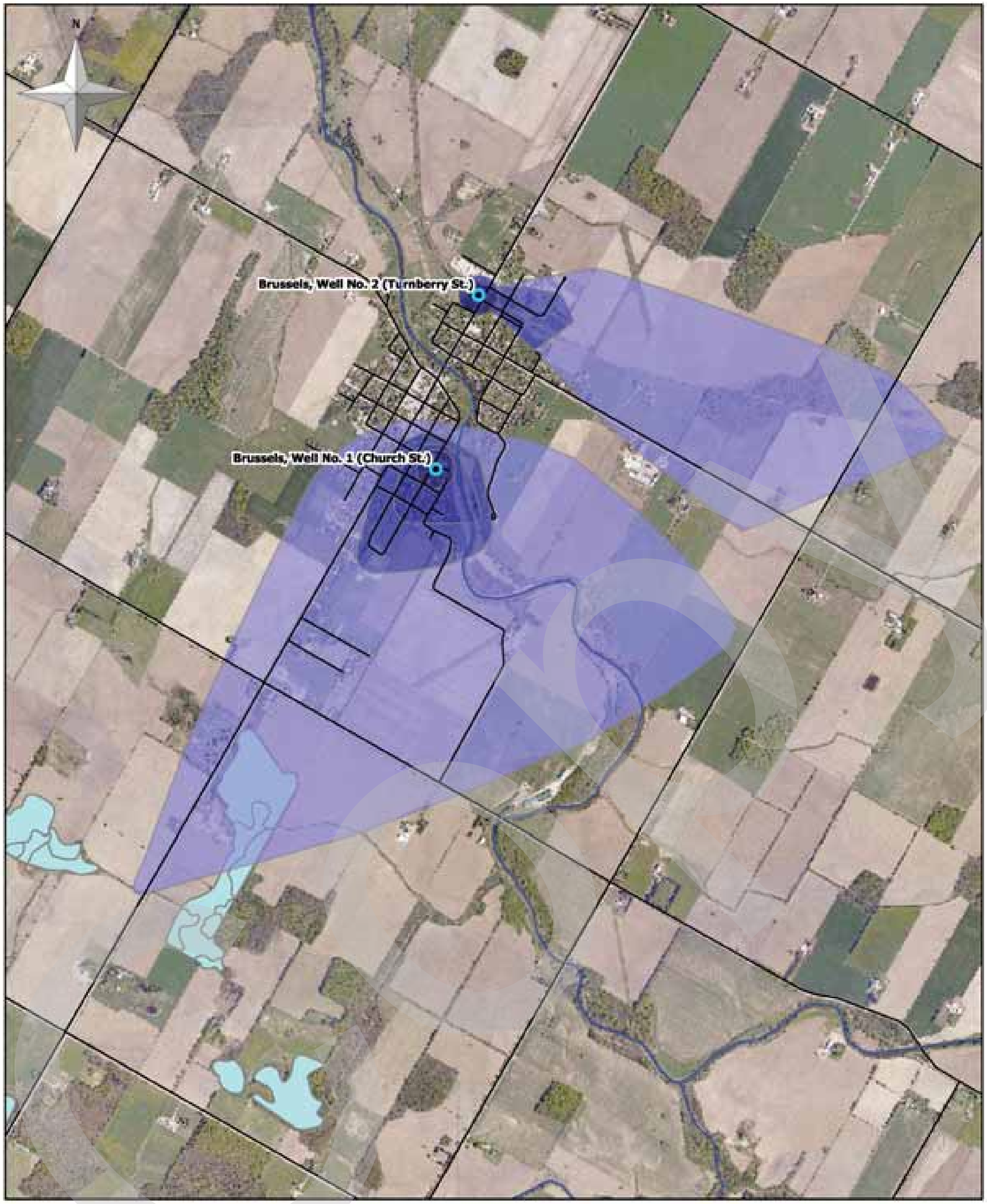
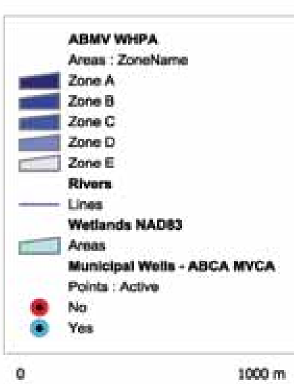
International Water Consultants Ltd.
B.M. Ross and Associates Ltd.

Figure 4-1-4-A

WHPA - Brucefield





DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

Ausable Bayfield & Maitland Valley Source Protection Region

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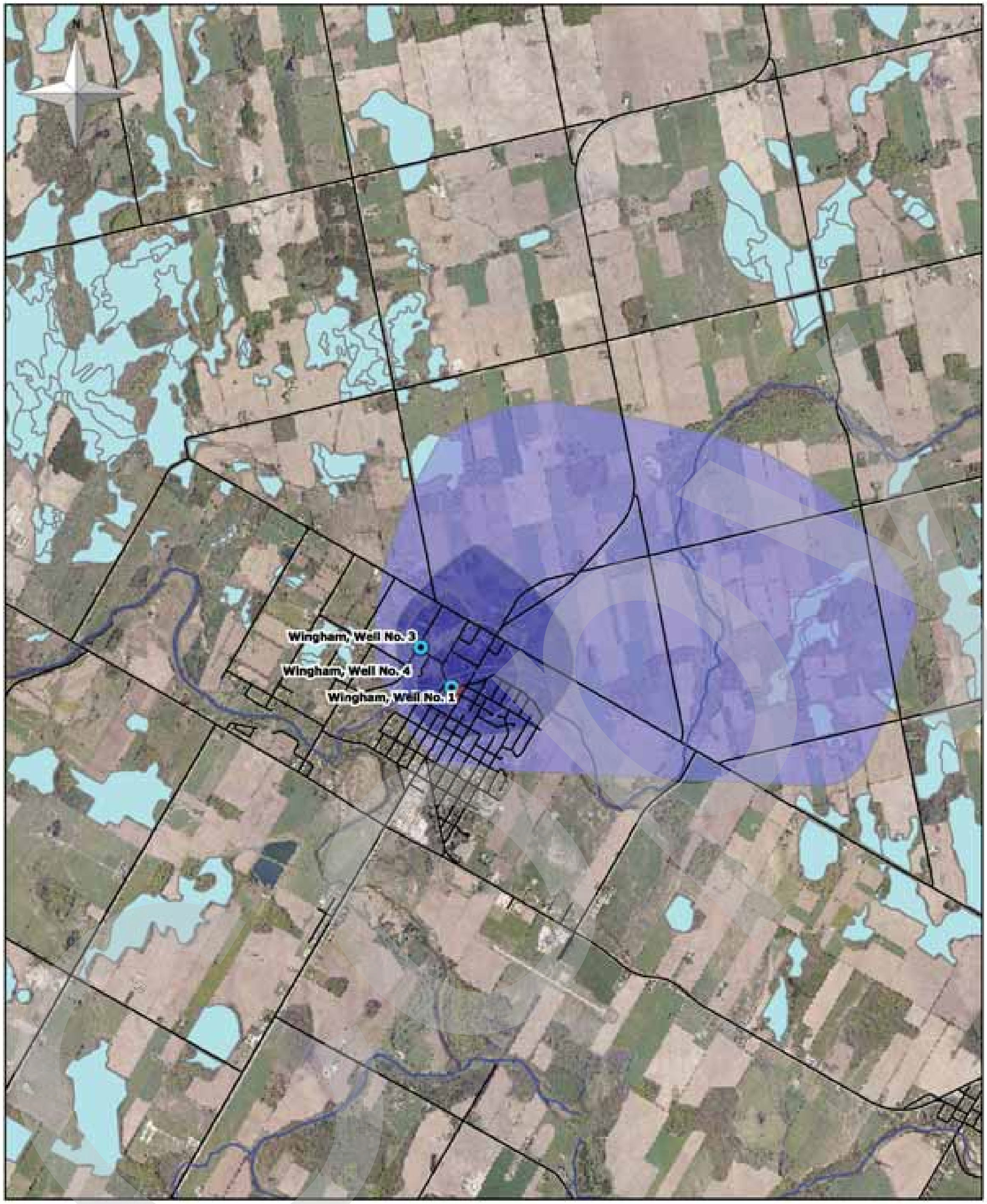
Figure 4-1-4-B

WHPA - Brussels



ABMV WHPA
Areas : ZoneName
Zone A
Zone B
Zone C
Zone D
Zone E
Rivers
Lines
Wetlands NAD83
Areas
Municipal Wells - ABCA MVCA
Points : Active
No
Yes

0 1000 m

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

Ausable Bayfield & Maitland Valley Source Protection Region

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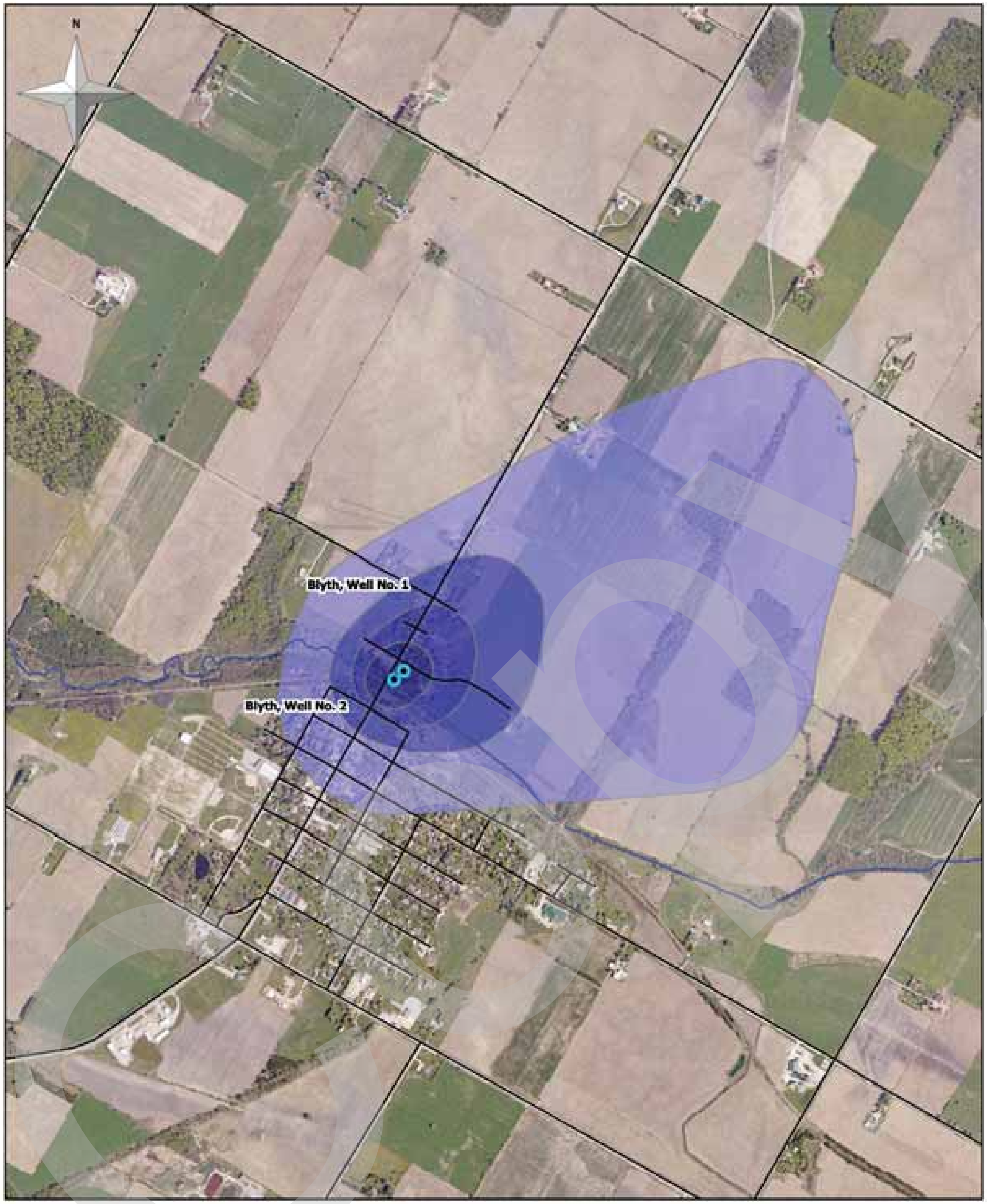
Figure 4-1-5-A

WHPA - Wingham



ABMV WHPA
Areas : ZoneName
Zone A
Zone B
Zone C
Zone D
Zone E
Rivers
Lines
Wetlands NAD83
Areas
Municipal Wells - ABCA MVCA
Points : Active
No
Yes

0 1000 m

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

Ausable Bayfield & Maitland Valley Source Protection Region

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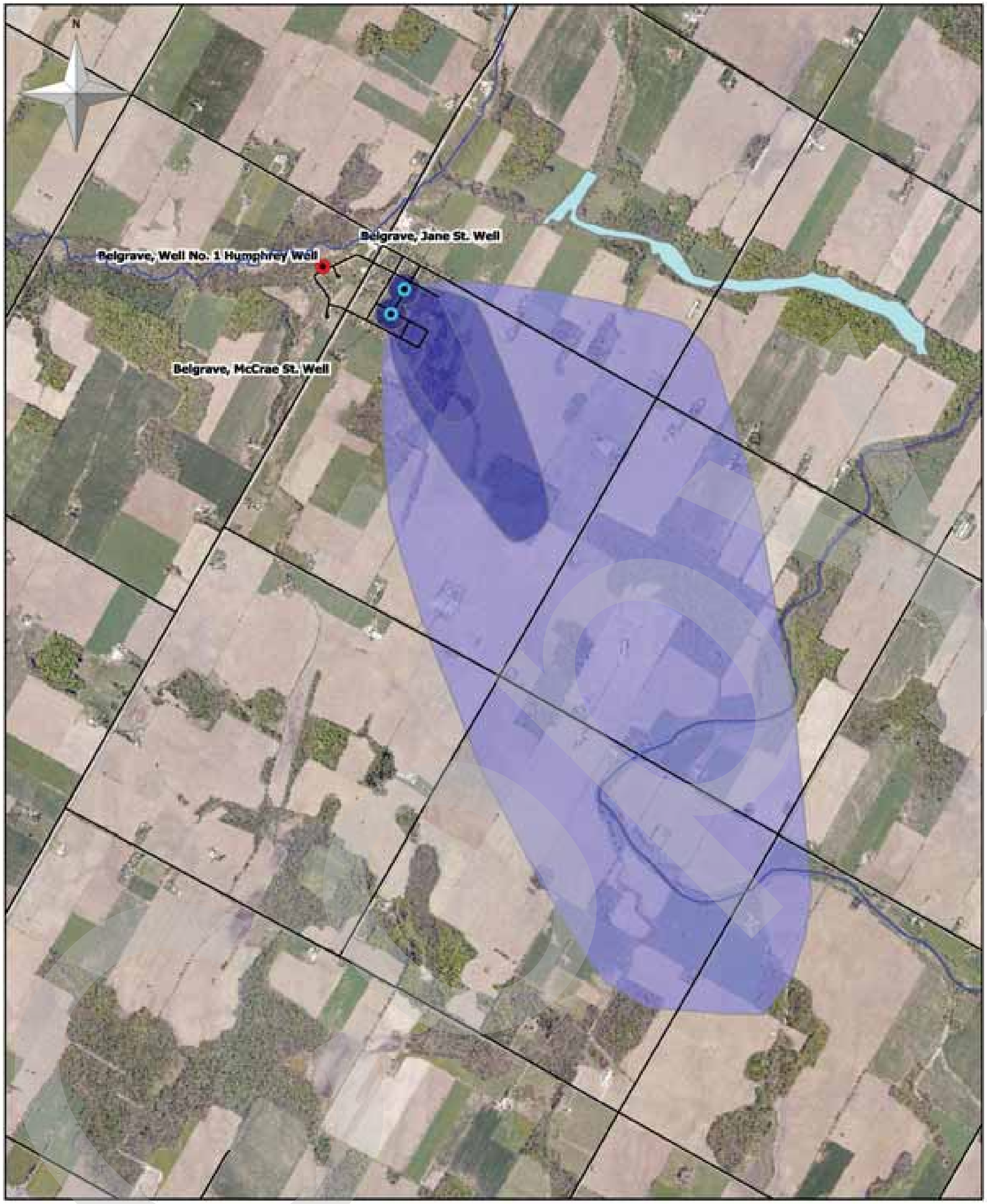
Figure 4-1-5-B

WHPA - Blyth



ABMV WHPA
Areas : ZoneName
Zone A
Zone B
Zone C
Zone D
Zone E
Rivers
Lines
Wetlands NAD83
Areas
Municipal Wells - ABCA MVCA
Points : Active
No
Yes

0 1000 m

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

Ausable Bayfield & Maitland Valley Source Protection Region

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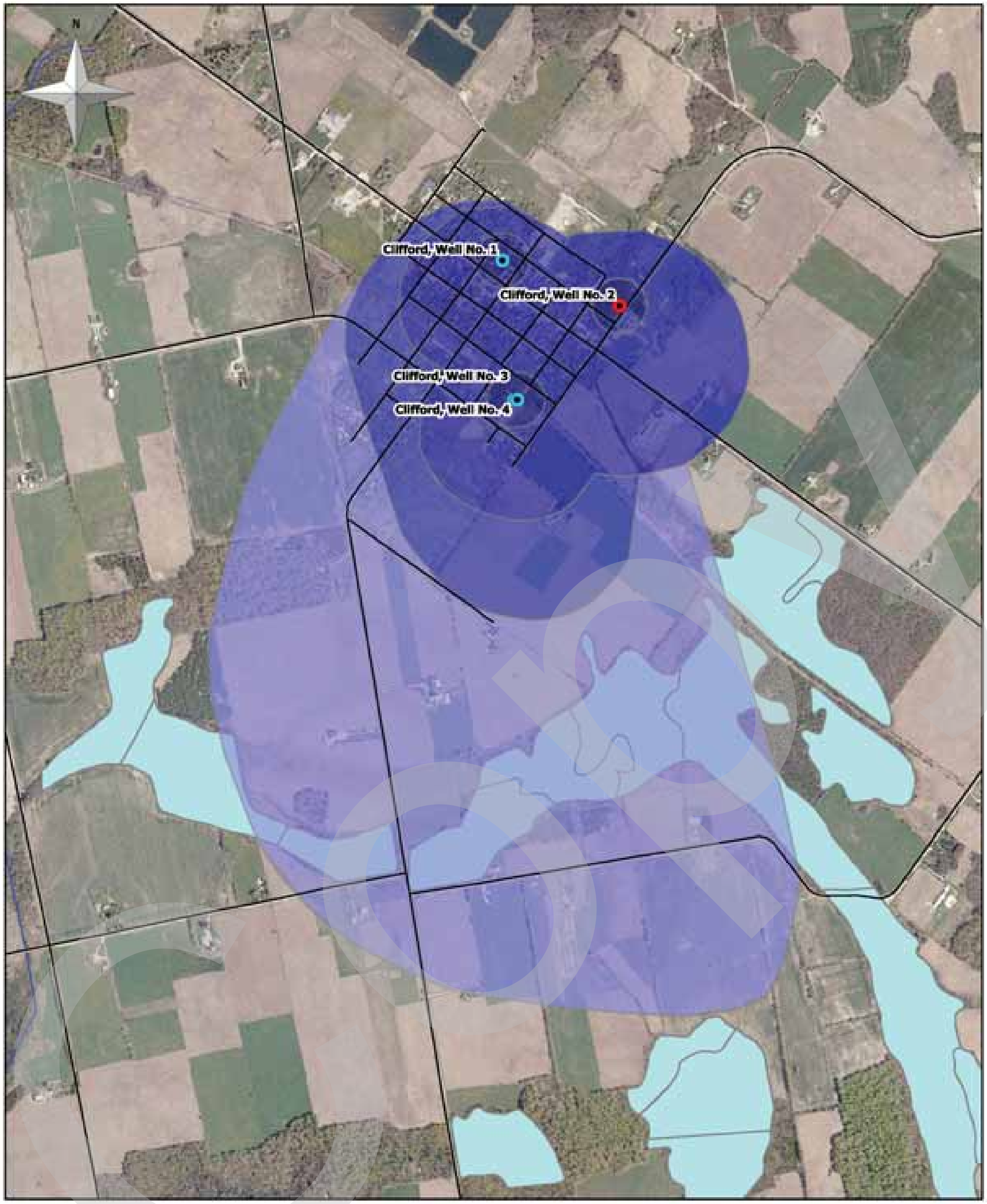
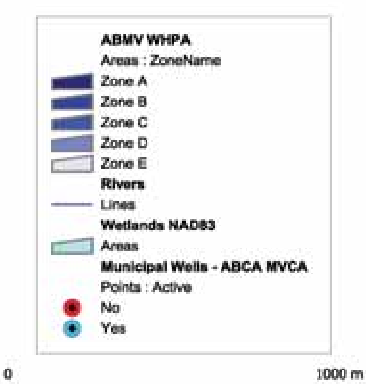
Figure 4-1-5-C

WHPA - Belgrave





DRINKING WATER SOURCE PROTECTION

ACT FOR CLEAN WATER

Ausable Bayfield & Maitland Valley Source Protection Region

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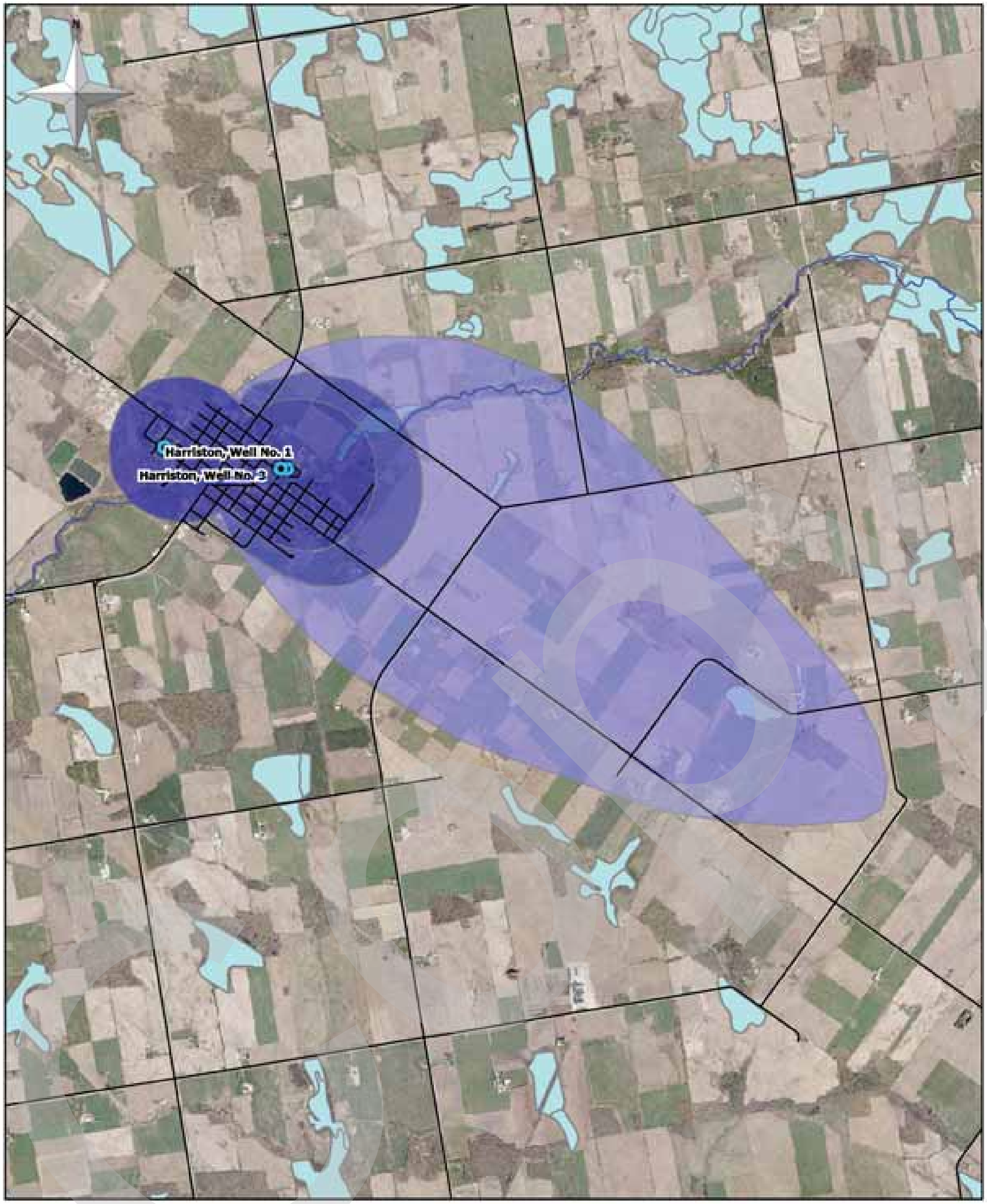
Figure 4-1-6-A

WHPA - Clifford



ABMV WHPA

Areas : ZoneName

- Zone A
- Zone B
- Zone C
- Zone D
- Zone E

Rivers

Lines

Wetlands NAD83

Areas

Municipal Wells - ABCA MVCA

Points : Active

- No
- Yes

0 1000 m

DRINKING WATER SOURCE PROTECTION

ACT FOR CLEAN WATER

Ausable Bayfield & Maitland Valley Source Protection Region

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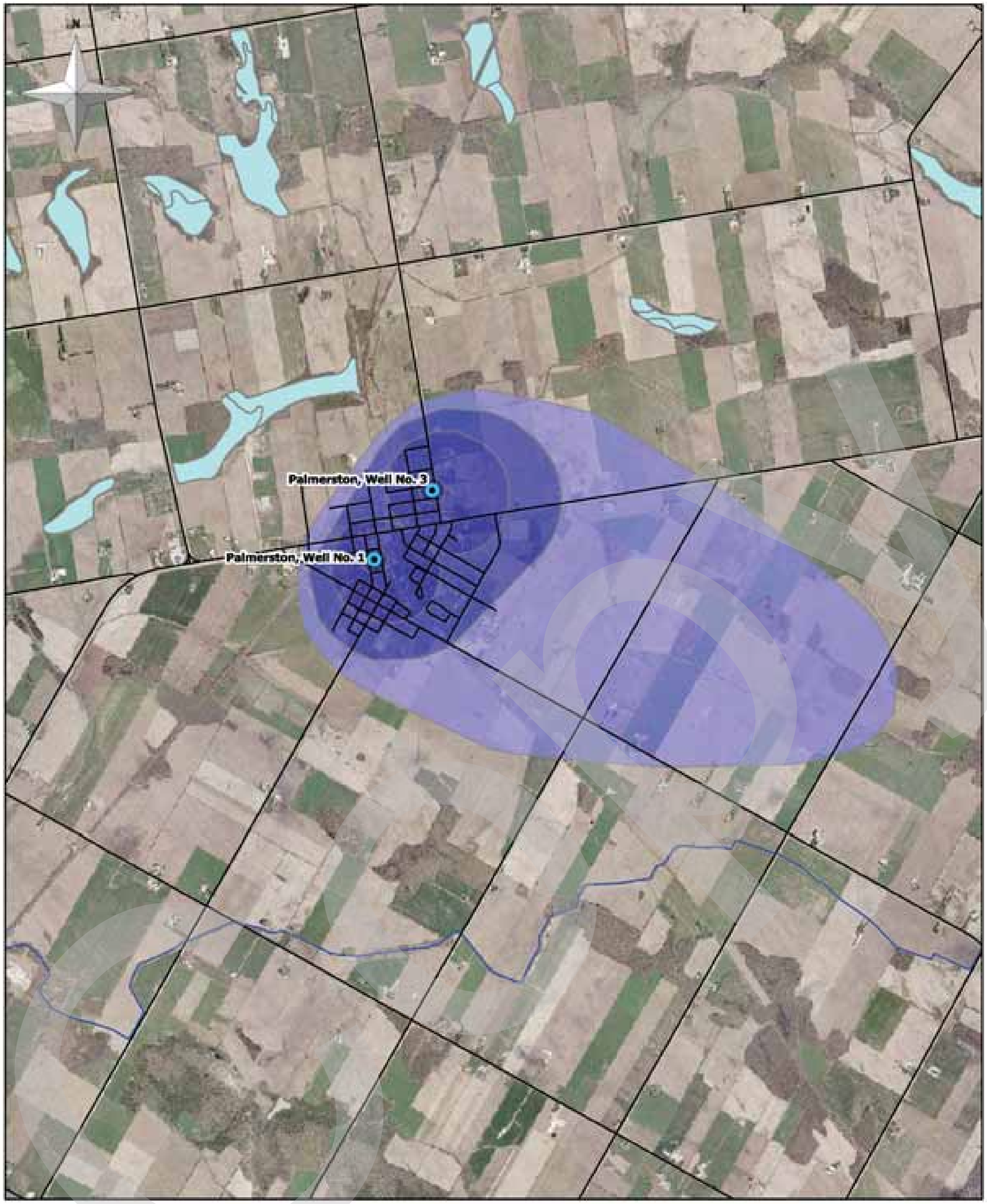
Figure 4-1-6-B

WHPA - Harriston



ABMV WHPA
Areas : ZoneName
Zone A
Zone B
Zone C
Zone D
Zone E
Rivers
Lines
Wetlands NAD83
Areas
Municipal Wells - ABCA MVCA
Points : Active
No
Yes

0 1000 m

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

Ausable Bayfield & Maitland Valley Source Protection Region

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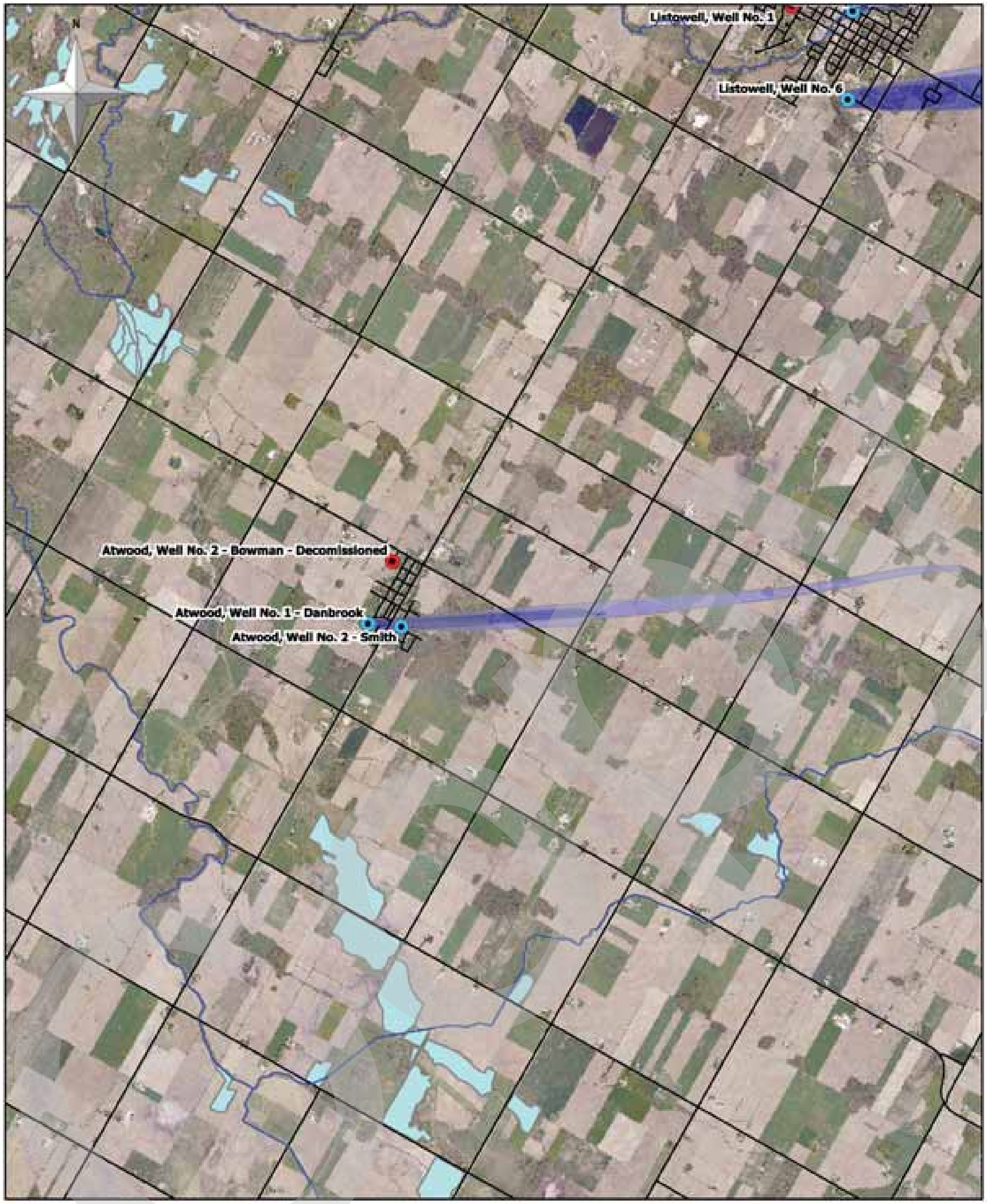
Figure 4-1-6-C

WHPA - Palmerston



DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

Ausable Bayfield & Maitland Valley Source Protection Region

ABMV WHPA
Areas : ZoneName
Zone A
Zone B
Zone C
Zone D
Zone E
Rivers
Lines
Wetlands NAD83
Areas
Municipal Wells - ABCA MVCA
Points : Active
No
Yes

0 1000 m

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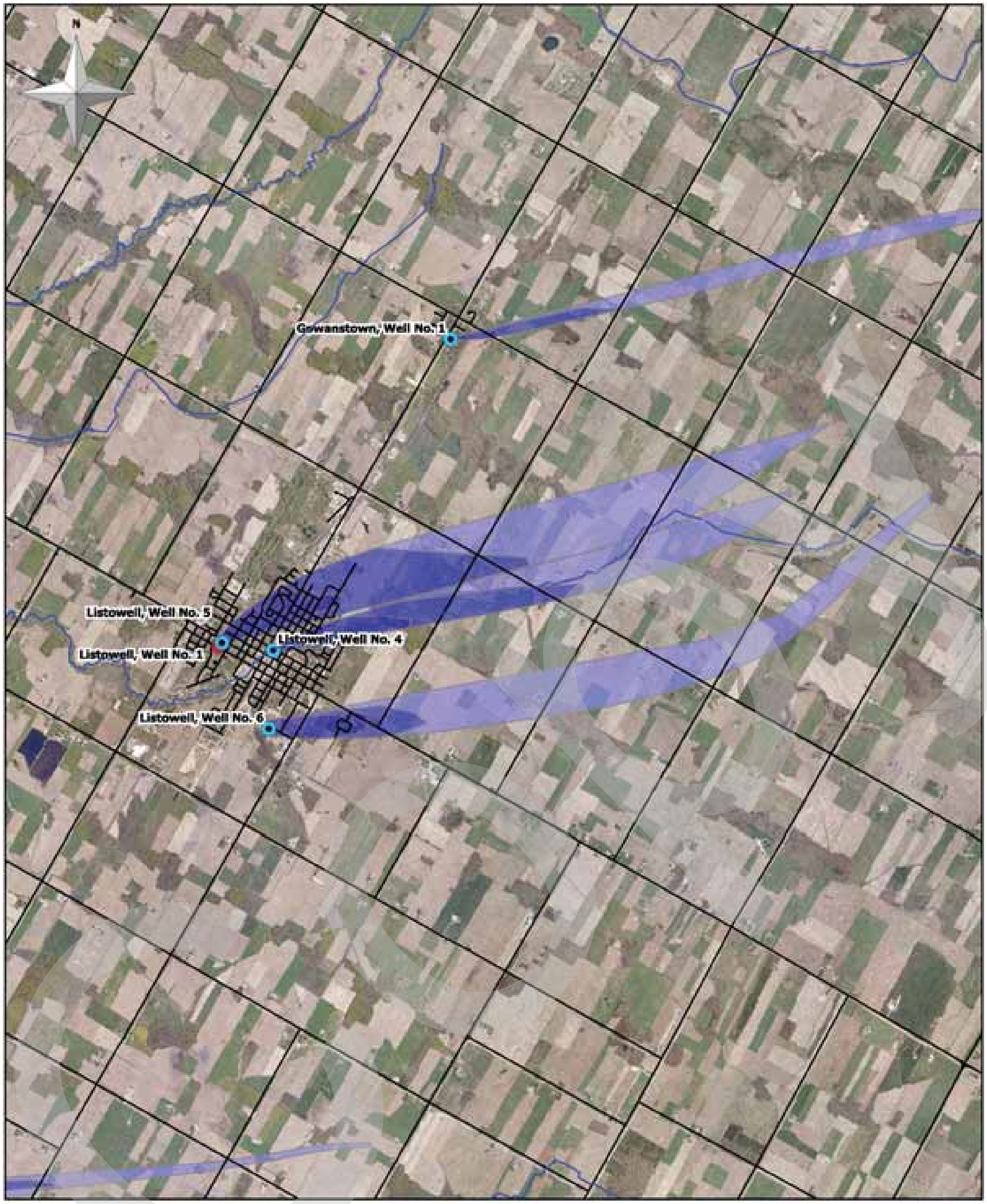
B.M. Ross and Associates Ltd.

Figure 4-1-7-A

WHPA - Atwood



ABMV WHPA
Areas : ZoneName
Zone A
Zone B
Zone C
Zone D
Zone E
Rivers
Lines
Wetlands NAD83
Areas
Municipal Wells - ABCA MVCA
Points : Active
No
Yes

0 1000 m

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

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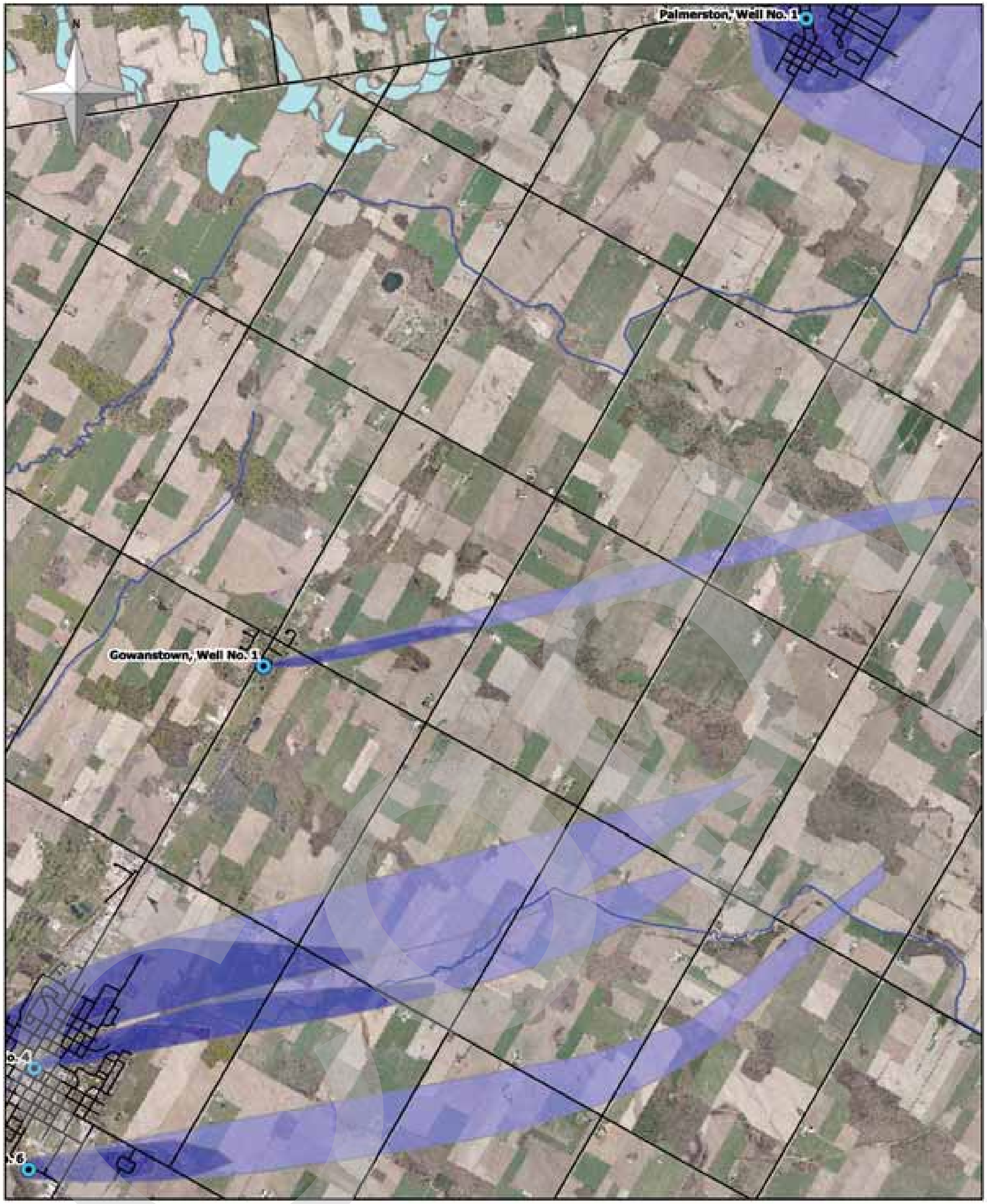
Figure 4-1-7-B

WHPA - Listowel



ABMV WHPA
Areas : ZoneName
Zone A
Zone B
Zone C
Zone D
Zone E
Rivers
Lines
Wetlands NAD83
Areas
Municipal Wells - ABCA MVCA
Points : Active
No
Yes

0 1000 m

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

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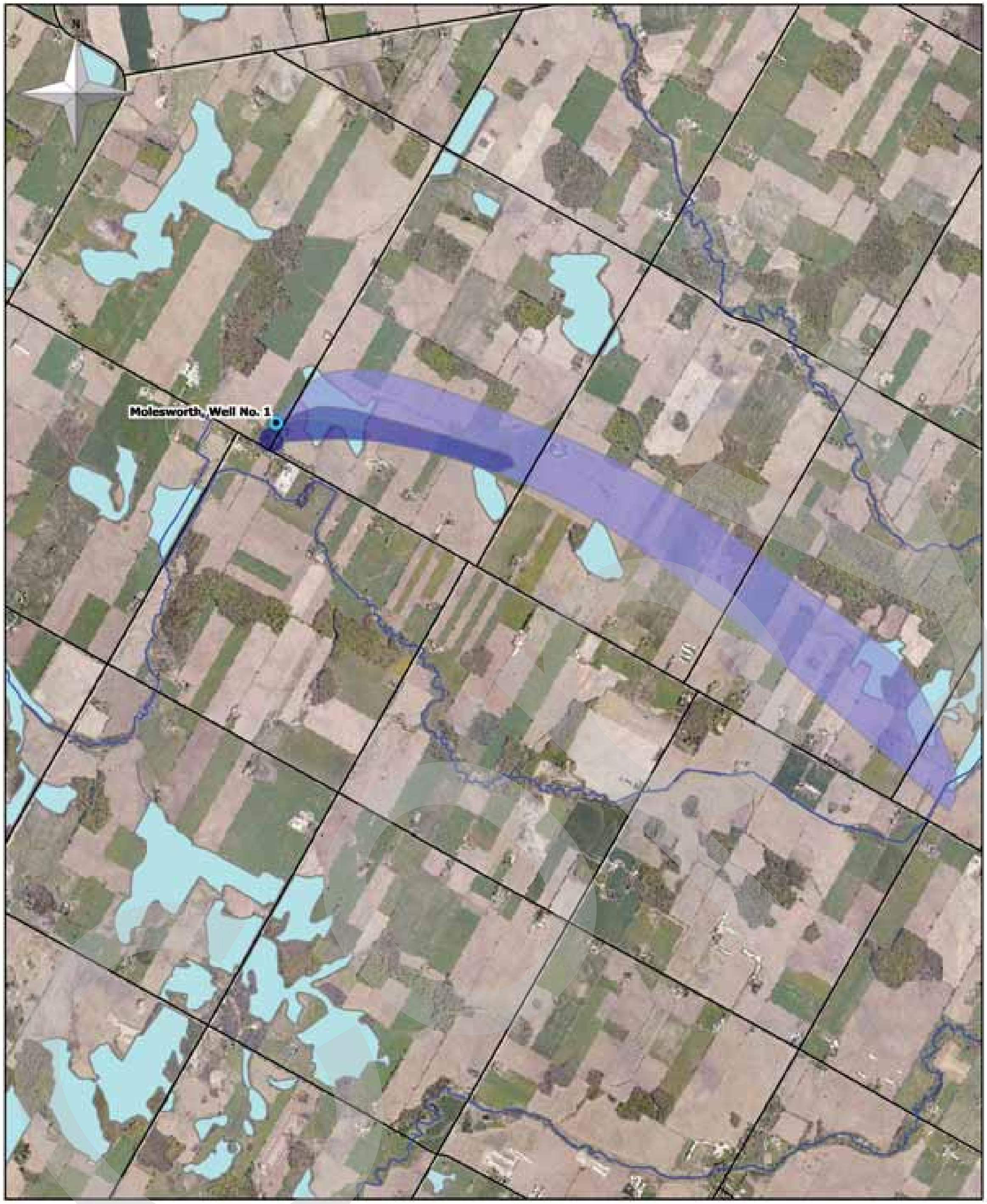
Figure 4-1-7-C

WHPA - Gowanstown



ABMV WHPA
Areas : ZoneName
Zone A
Zone B
Zone C
Zone D
Zone E
Rivers
Lines
Wetlands NAD83
Areas
Municipal Wells - ABCA MVCA
Points : Active
No
Yes

0 1000 m

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

Ausable Bayfield & Maitland Valley Source Protection Region

Study Team
Waterloo Numerical Modelling Corp.
International Water Consultants Ltd.
B.M. Ross and Associates Ltd.

Figure 4-1-7-D

WHPA - Molesworth

Appendix C
North Huron Groundwater Model Figures

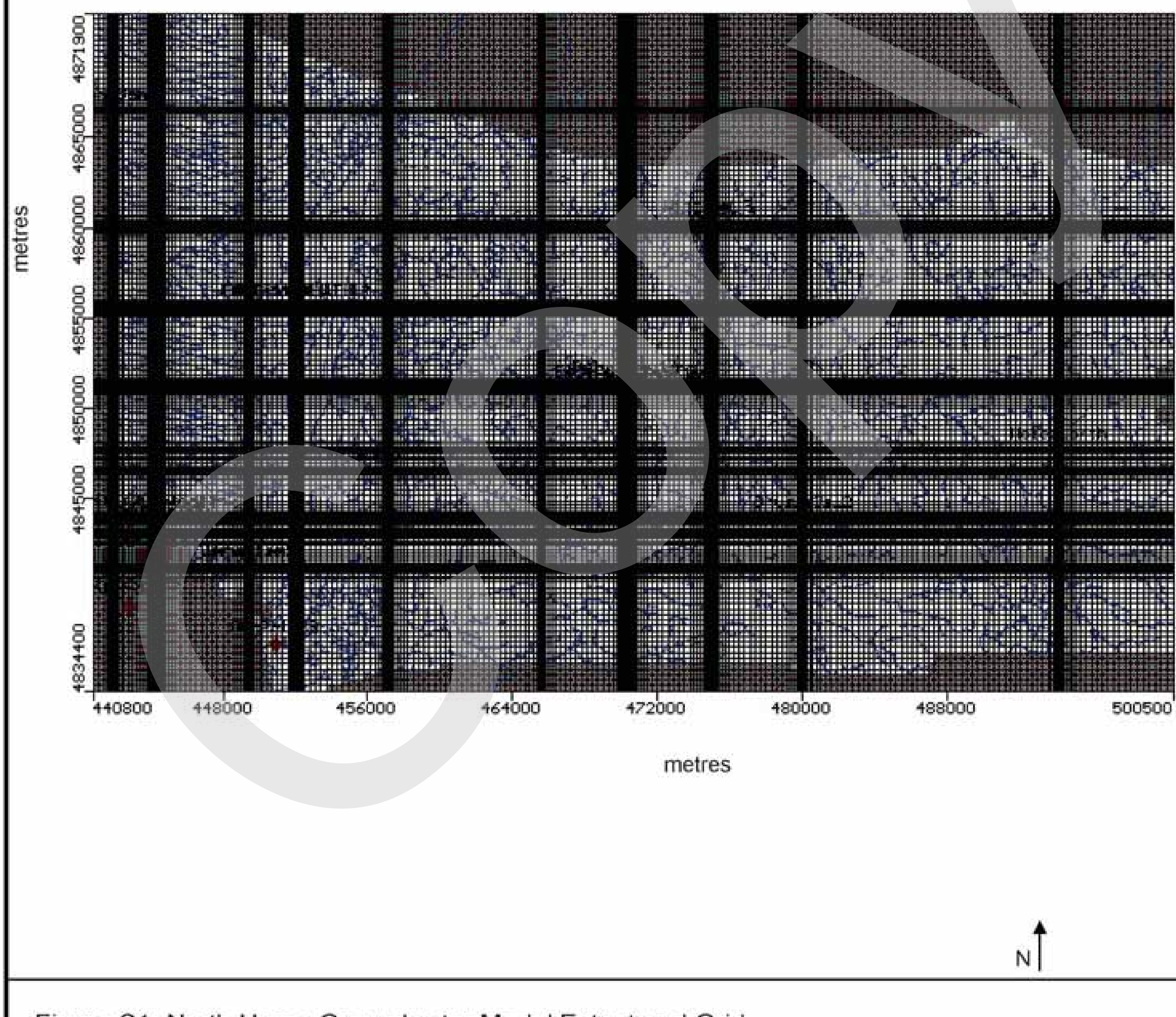


Figure C1: North Huron Groundwater Model Extent and Grid

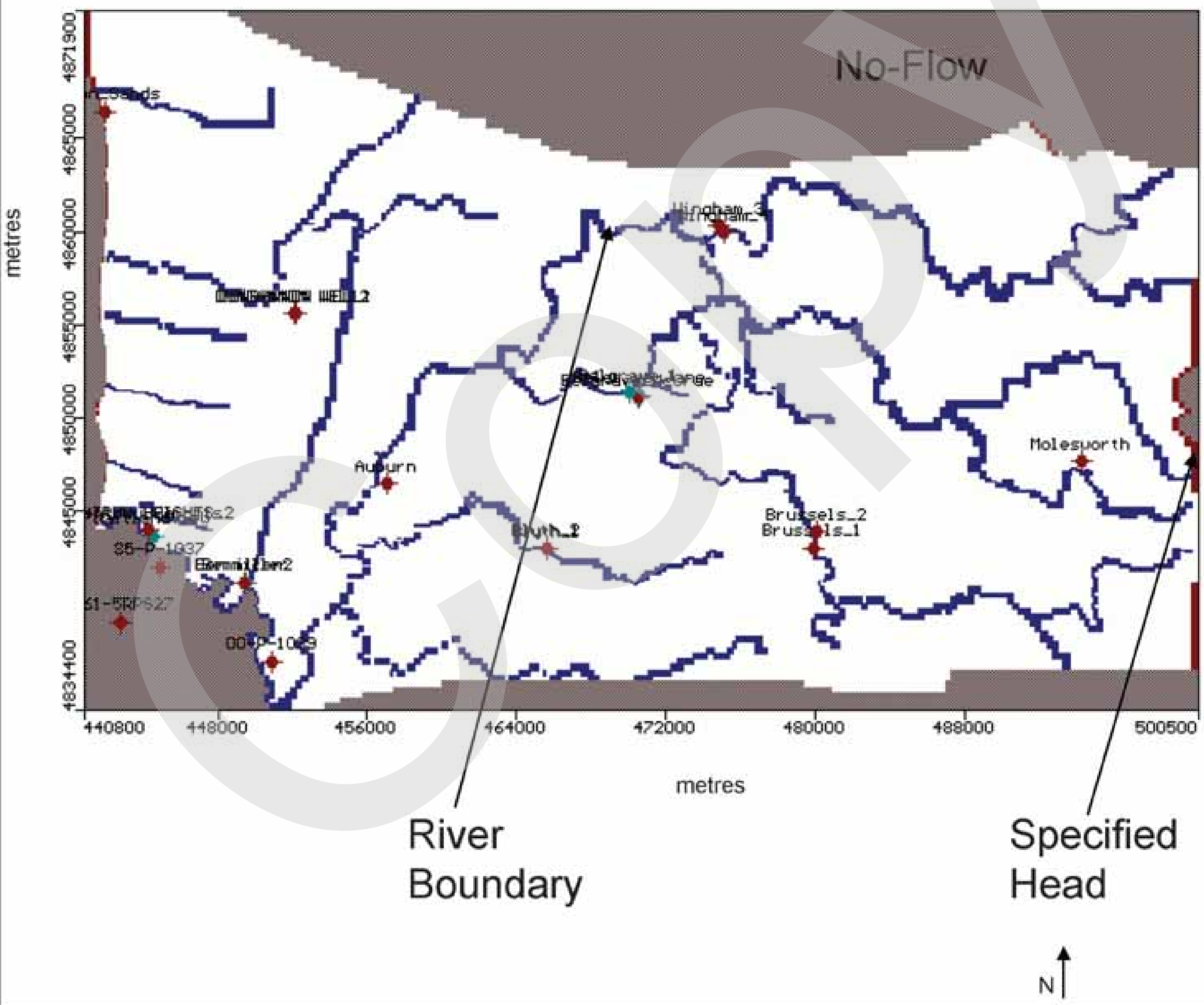


Figure C2: North Huron Groundwater Model Flow Boundaries

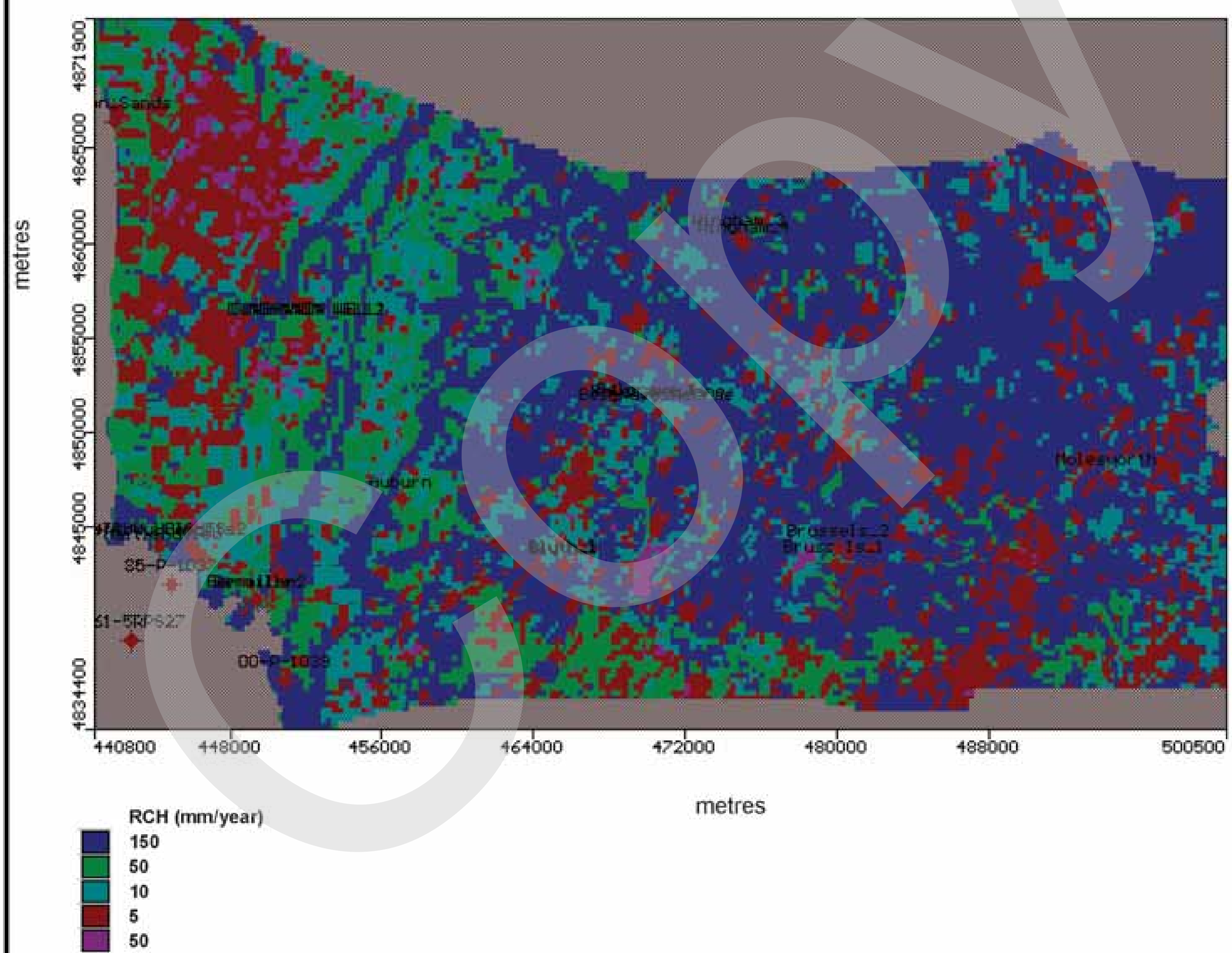
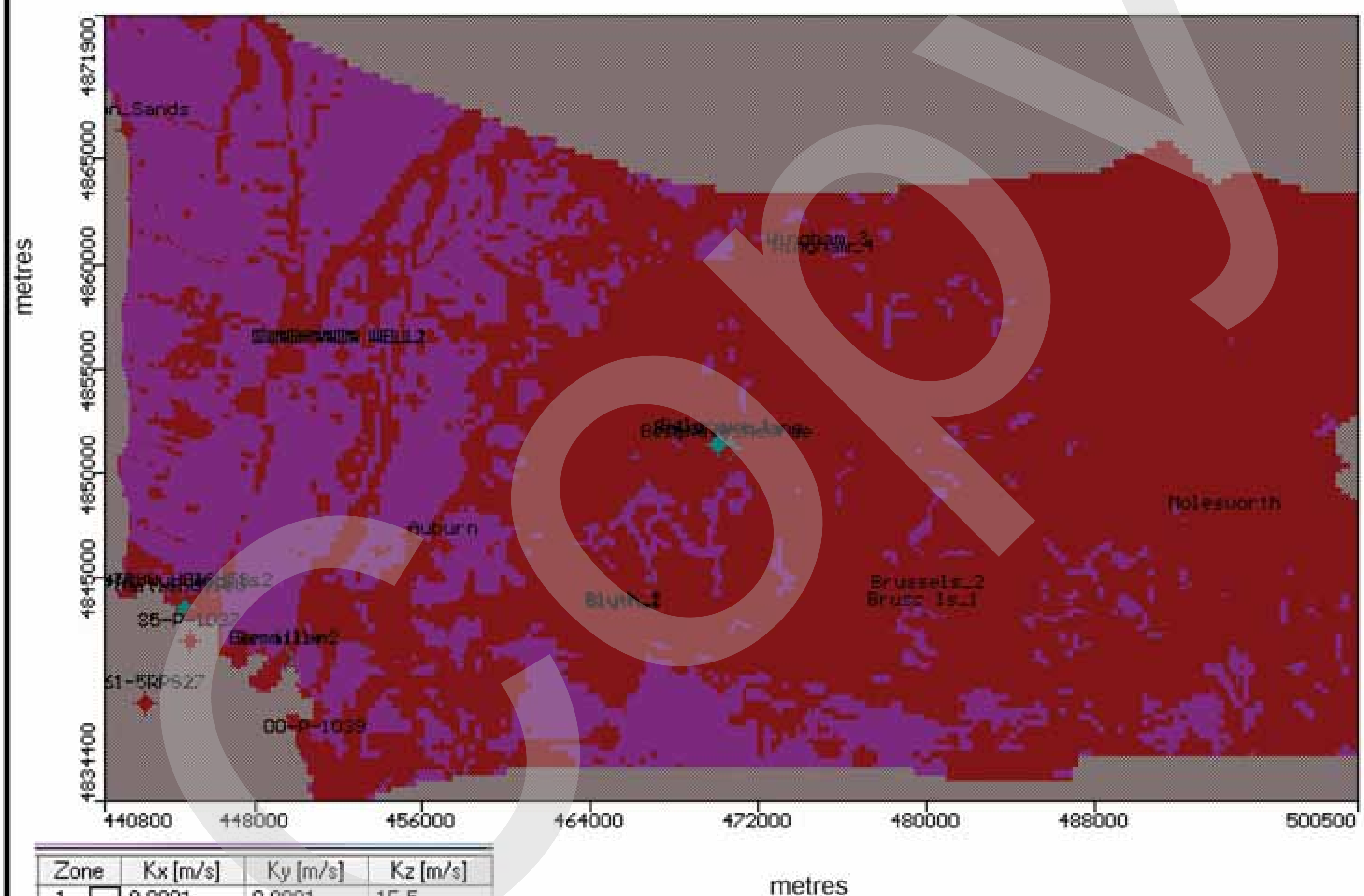
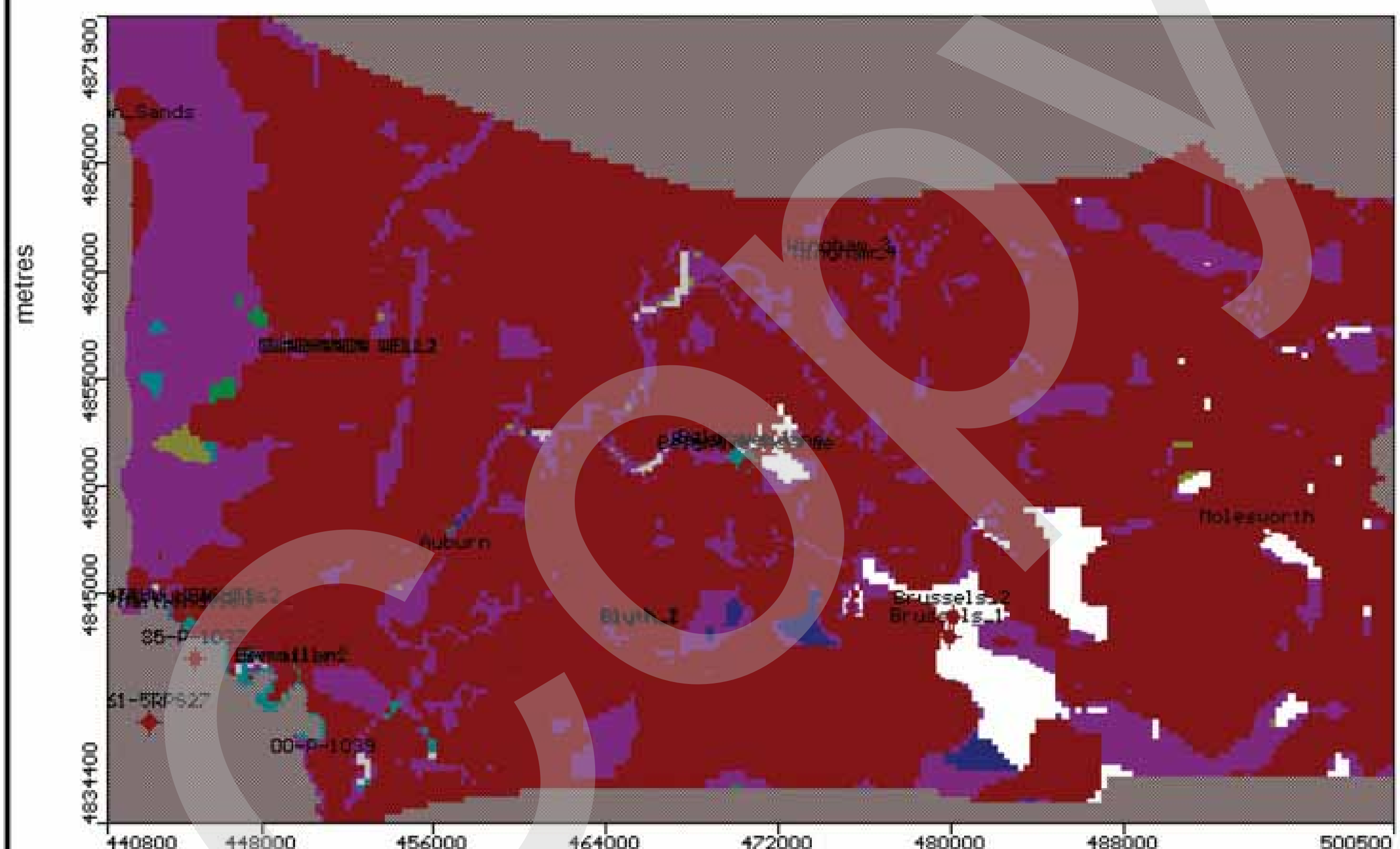


Figure C3: North Huron Groundwater Model Recharge



Zone		Kx [m/s]	Ky [m/s]	Kz [m/s]
1		0.0001	0.0001	1E-5
2		2E-5	2E-5	2E-6
3		0.0001	0.0001	1E-5
4		0.0005	0.0005	5E-5
5		0.0001	0.0001	1E-5
6		1E-5	1E-5	1E-6
7		0.0001	0.0001	1E-5
8		1E-6	1E-6	1E-7

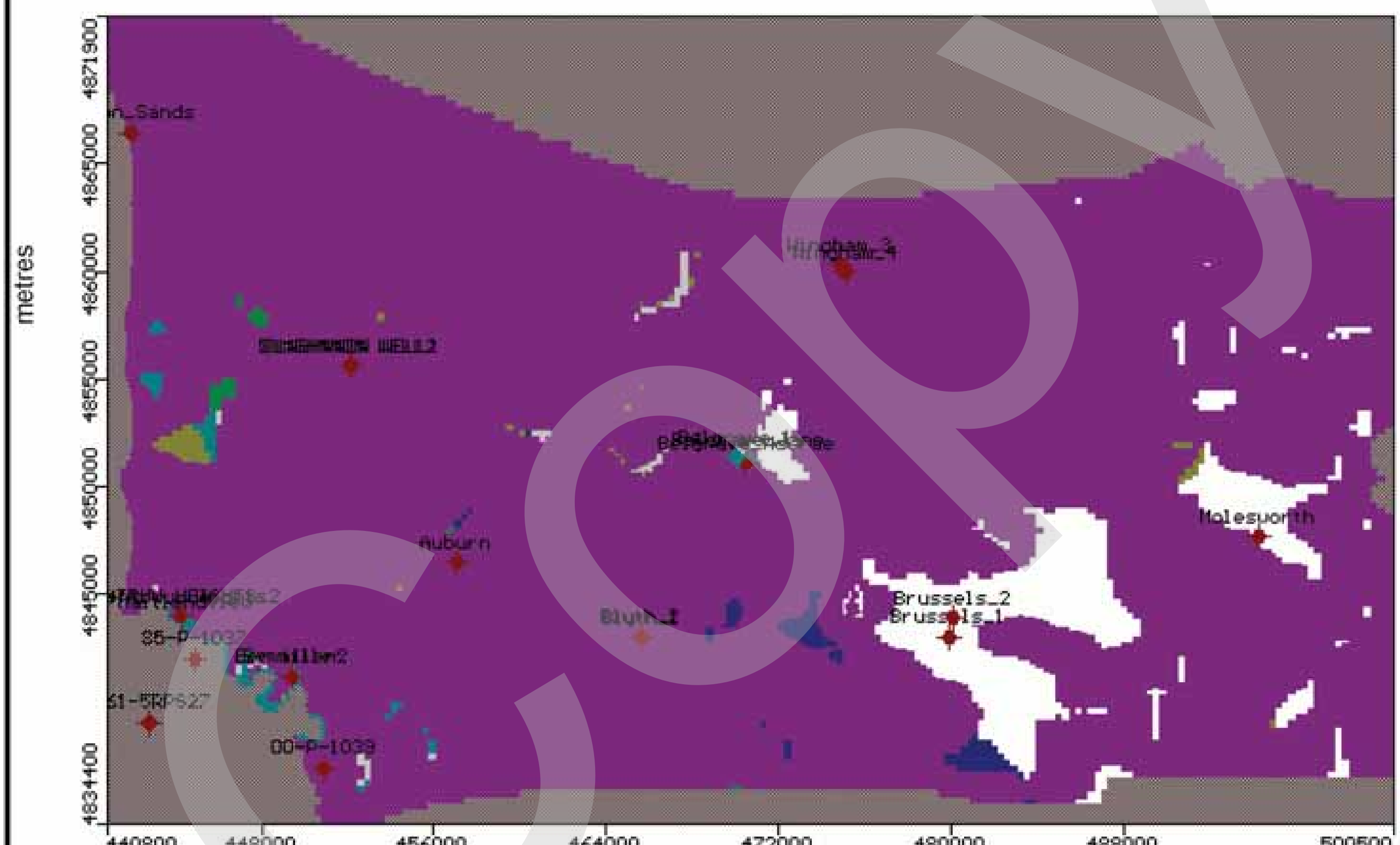
Figure C4: North Huron Groundwater Model Hydraulic Conductivity Layer 1



Zone		Kx [m/s]	Ky [m/s]	Kz [m/s]
1		0.0001	0.0001	1E-5
2		2E-5	2E-5	2E-6
3		0.0001	0.0001	1E-5
4		0.0005	0.0005	5E-5
5		0.0001	0.0001	1E-5
6		1E-5	1E-5	1E-6
7		0.0001	0.0001	1E-5
8		1E-6	1E-6	1E-7

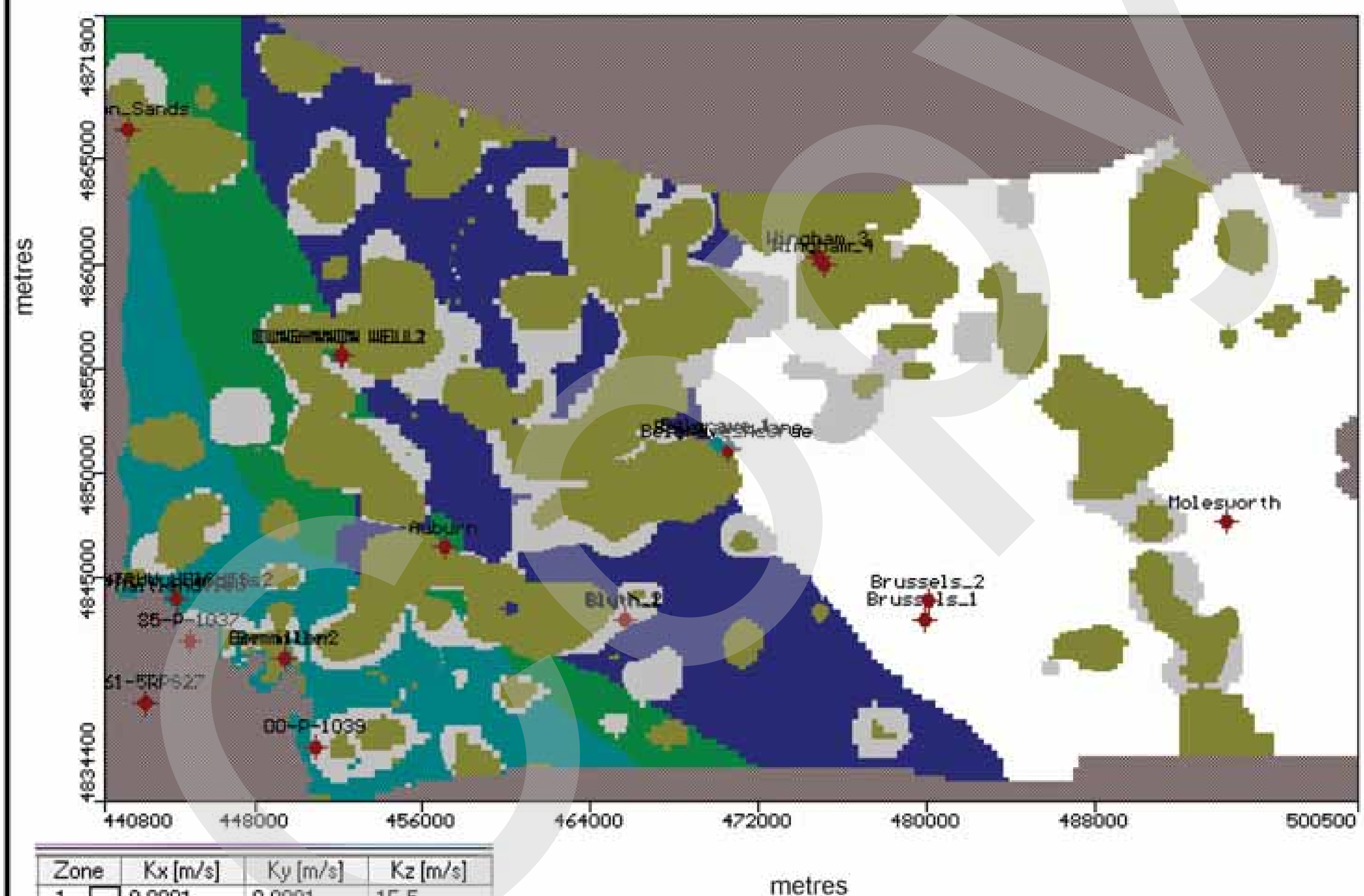
N

Figure C5: North Huron Groundwater Model Hydraulic Conductivity Layer 2



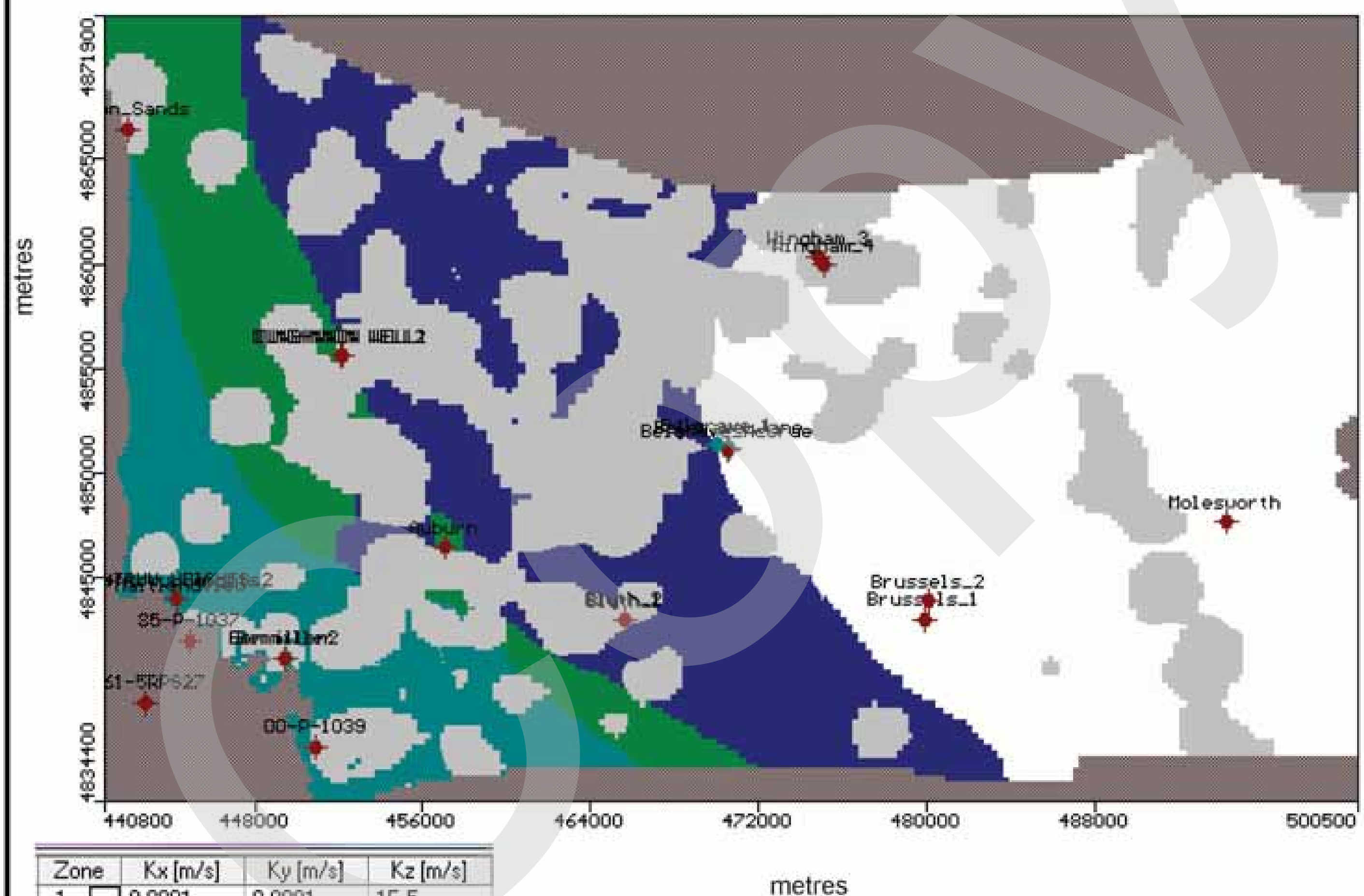
Zone		Kx [m/s]	Ky [m/s]	Kz [m/s]
1		0.0001	0.0001	1E-5
2		2E-5	2E-5	2E-6
3		0.0001	0.0001	1E-5
4		0.0005	0.0005	5E-5
5		0.0001	0.0001	1E-5
6		1E-5	1E-5	1E-6
7		0.0001	0.0001	1E-5
8		1E-6	1E-6	1E-7

Figure C6: North Huron Groundwater Model Hydraulic Conductivity Layer 3



Zone		Kx [m/s]	Ky [m/s]	Kz [m/s]
1		0.0001	0.0001	1E-5
2		2E-5	2E-5	2E-6
3		0.0001	0.0001	1E-5
4		0.0005	0.0005	5E-5
5		0.0001	0.0001	1E-5
6		1E-5	1E-5	1E-6
7		0.0001	0.0001	1E-5
8		1E-6	1E-6	1E-7

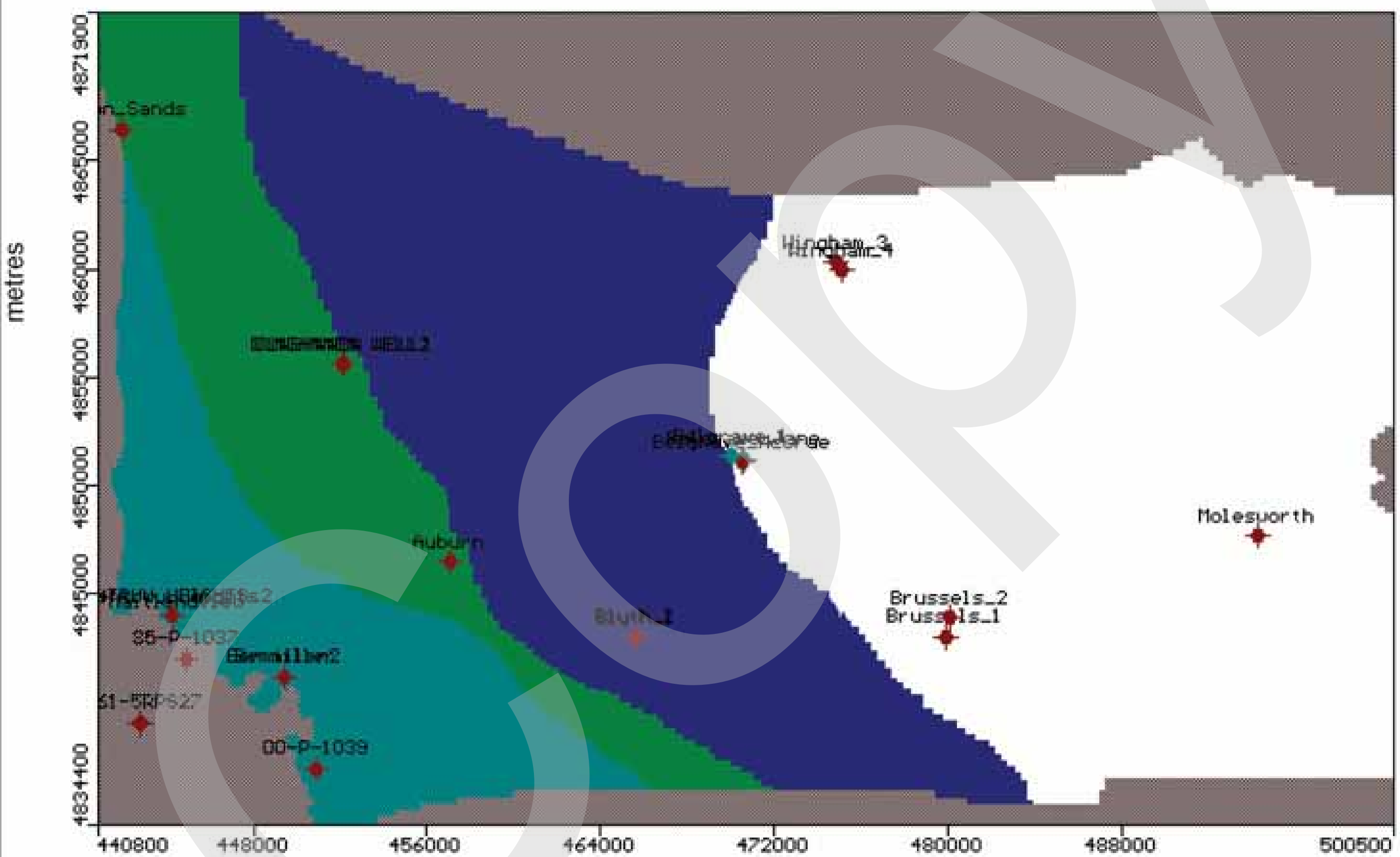
Figure C7: North Huron Groundwater Model Hydraulic Conductivity Layer 4



Zone		Kx [m/s]	Ky [m/s]	Kz [m/s]
1		0.0001	0.0001	1E-5
2		2E-5	2E-5	2E-6
3		0.0001	0.0001	1E-5
4		0.0005	0.0005	5E-5
5		0.0001	0.0001	1E-5
6		1E-5	1E-5	1E-6
7		0.0001	0.0001	1E-5
8		1E-6	1E-6	1E-7

N

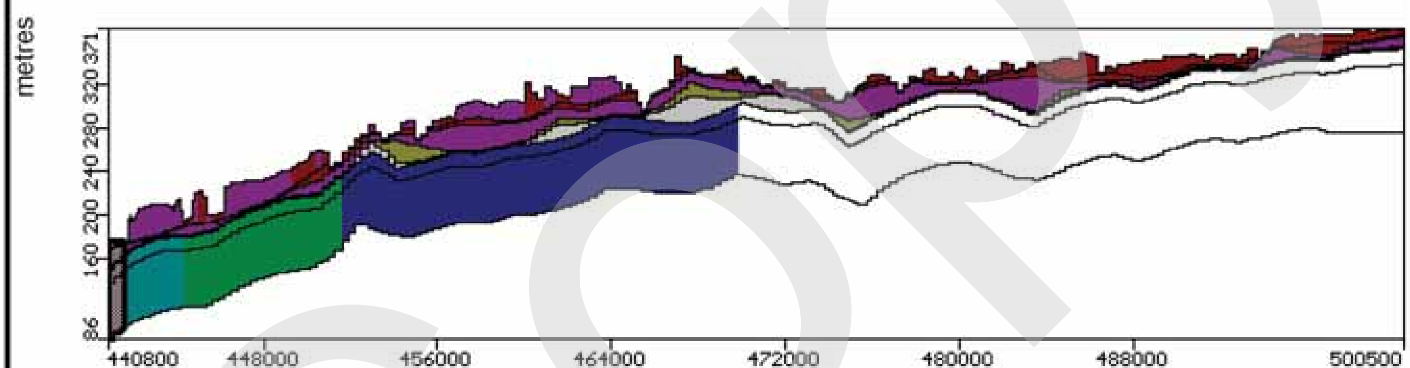
Figure C8: North Huron Groundwater Model Hydraulic Conductivity Layer 5



Zone	Kx [m/s]	Ky [m/s]	Kz [m/s]
1	0.0001	0.0001	1E-5
2	2E-5	2E-5	2E-6
3	0.0001	0.0001	1E-5
4	0.0005	0.0005	5E-5
5	0.0001	0.0001	1E-5
6	1E-5	1E-5	1E-6
7	0.0001	0.0001	1E-5
8	1E-6	1E-6	1E-7

N

Figure C9: North Huron Groundwater Model Hydraulic Conductivity Bedrock layers



metres

Zone		Kx [m/s]	Ky [m/s]	Kz [m/s]
1		0.0001	0.0001	1E-5
2		2E-5	2E-5	2E-6
3		0.0001	0.0001	1E-5
4		0.0005	0.0005	5E-5
5		0.0001	0.0001	1E-5
6		1E-5	1E-5	1E-6
7		0.0001	0.0001	1E-5
8		1E-6	1E-6	1E-7

N

Figure C10: North Huron Groundwater Model Typical Cross-Section

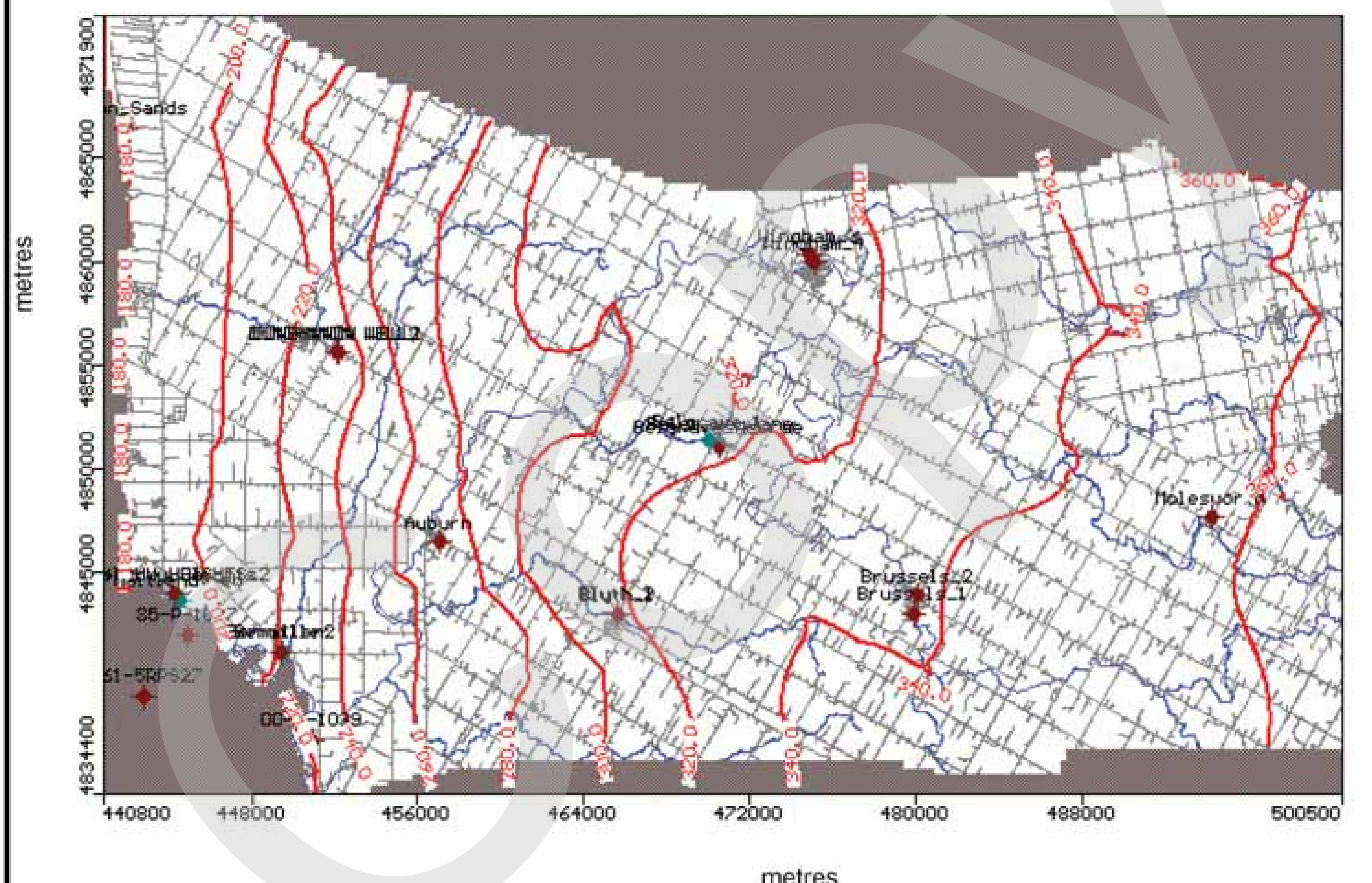


Figure C11: North Huron Groundwater Model Bedrock Water Levels (mamsl)

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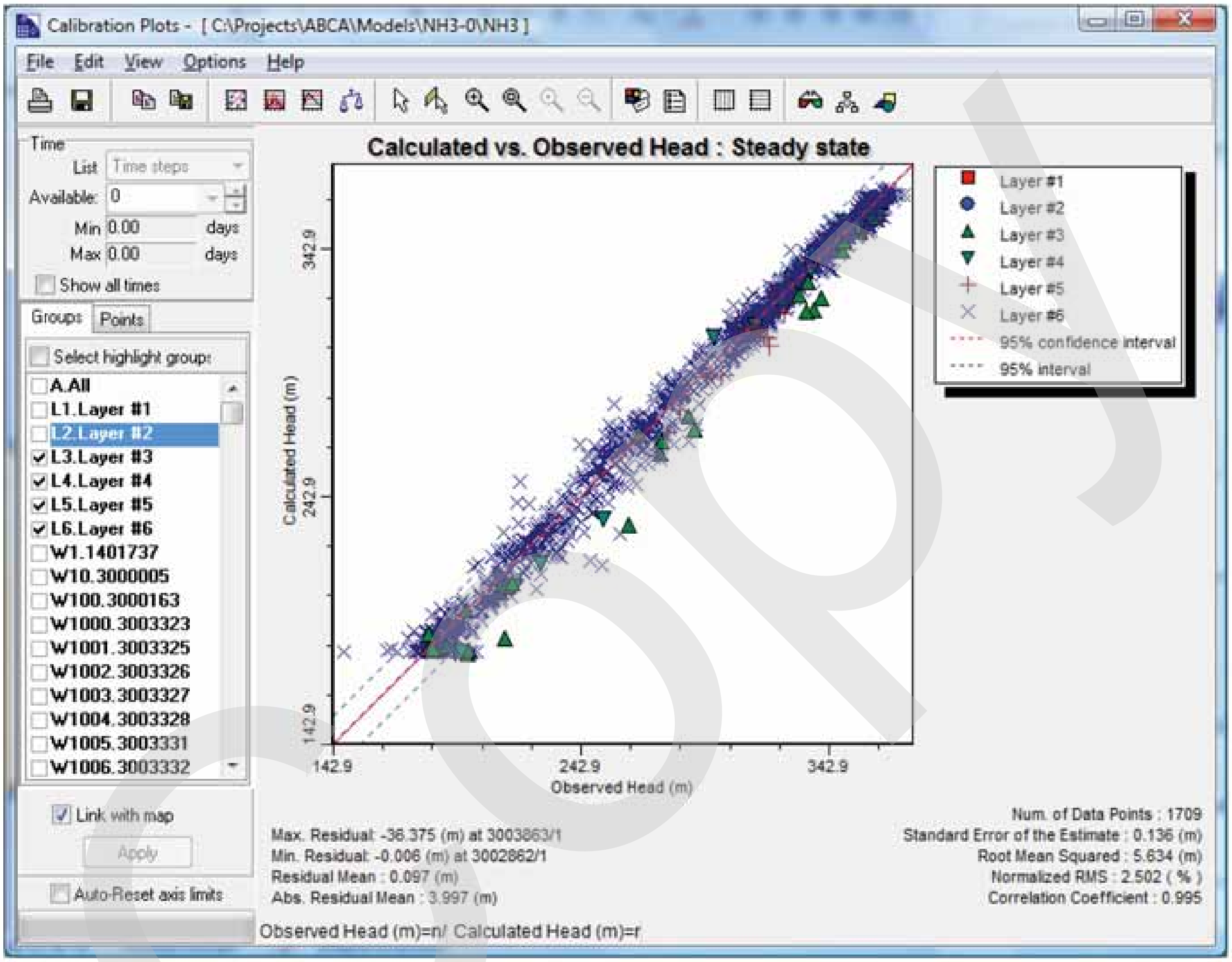


Figure C12 North Huron Groundwater Model Calibration Plot

Appendix D
Zurich Groundwater Model Figures

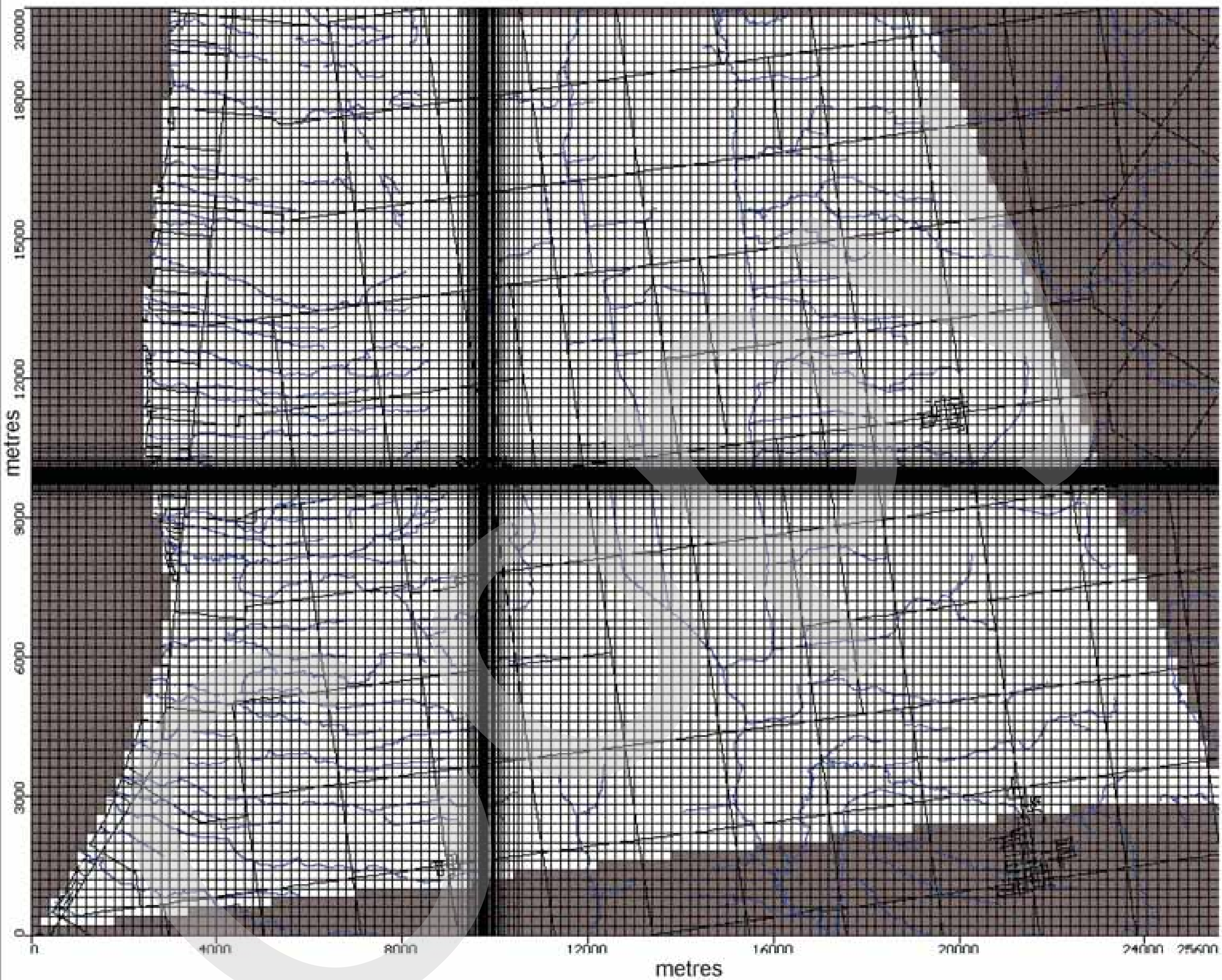


Figure D1: Zurich Groundwater Model Extent and Grid

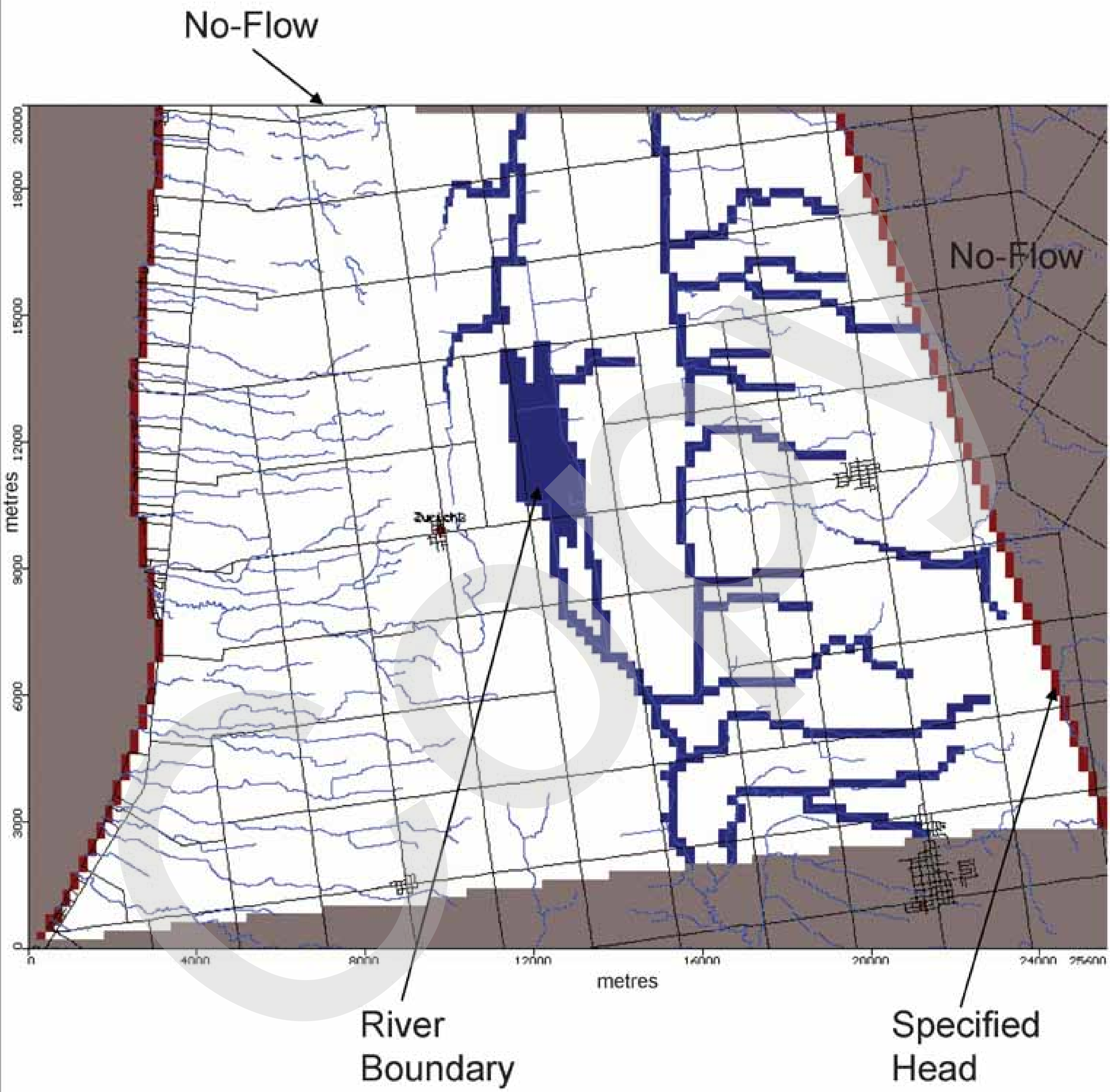


Figure D2: Zurich Groundwater Model Boundaries

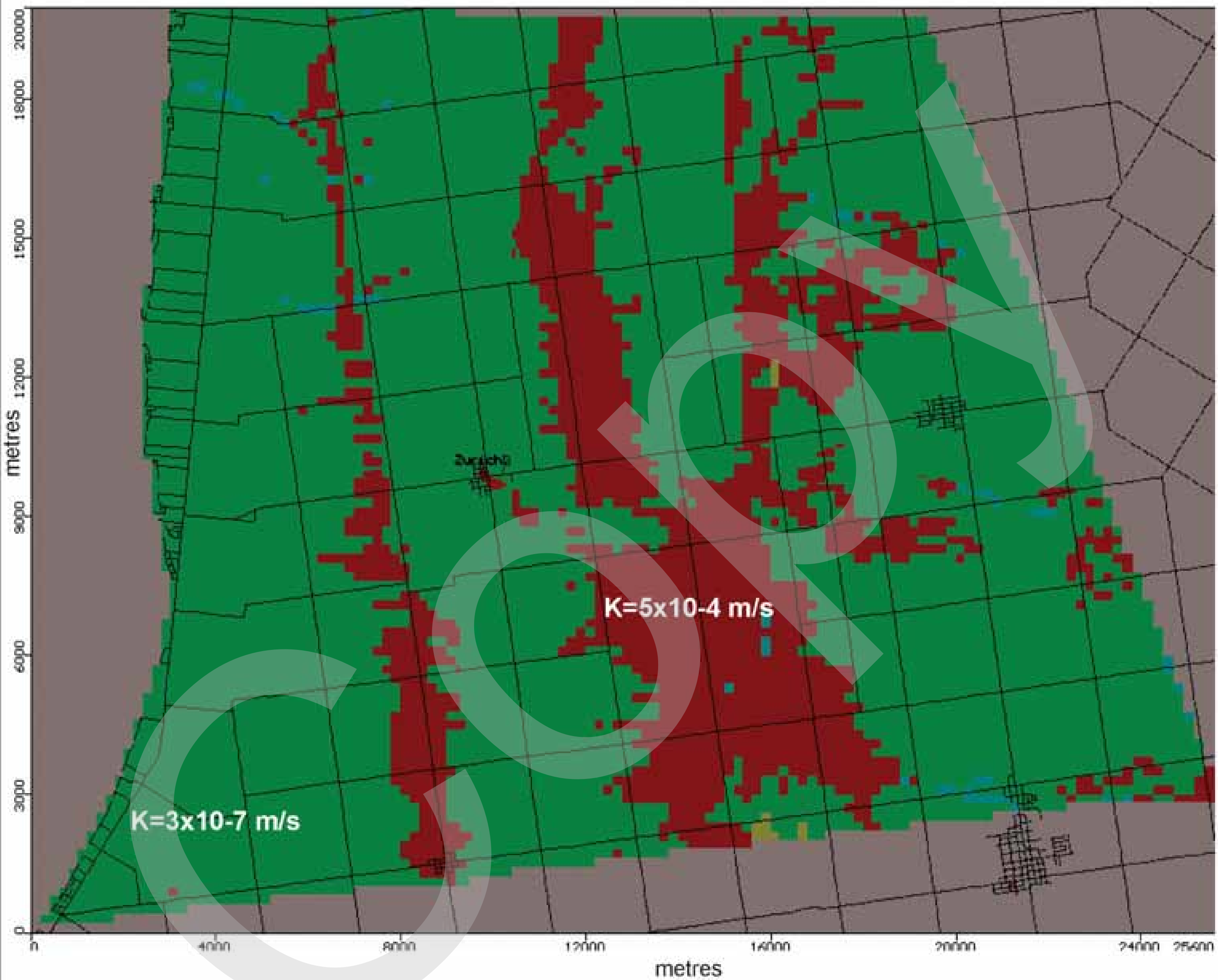


Figure D3: Zurich Groundwater Model Hydraulic Conductivity Layer 1

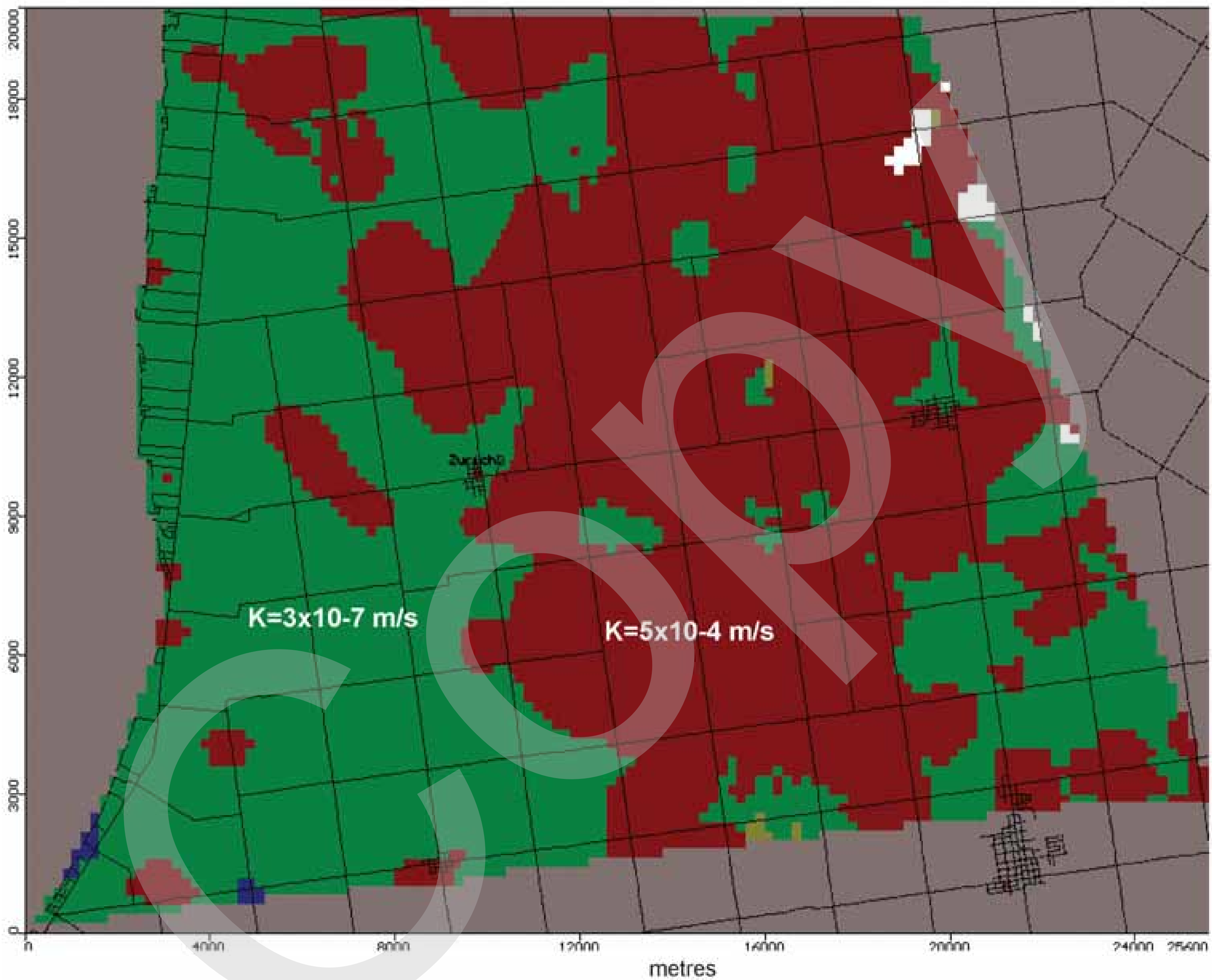


Figure D4 Zurich Groundwater Model Hydraulic Conductivity Layer 2

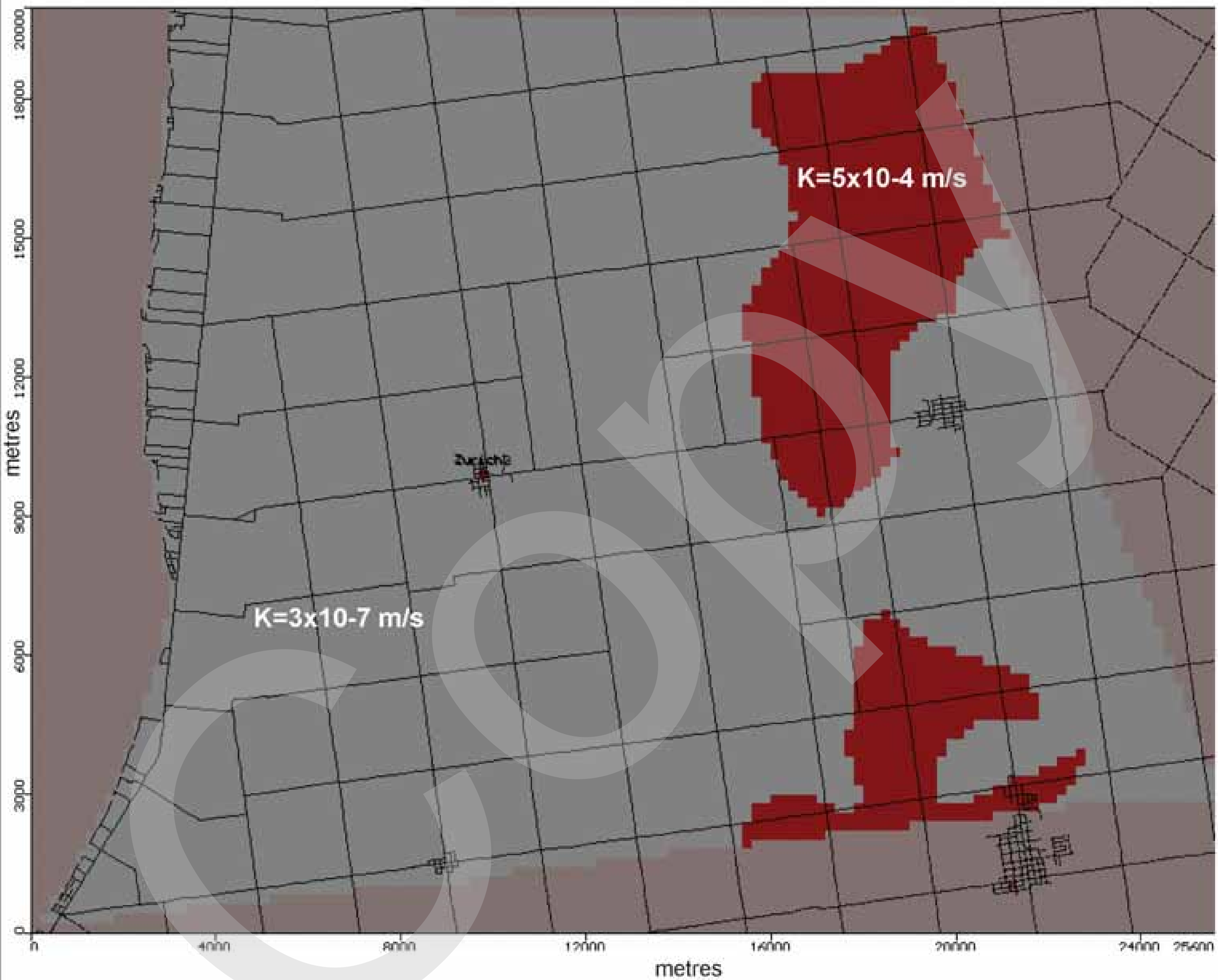


Figure D5: Zurich Groundwater Model Hydraulic Conductivity Layer 3

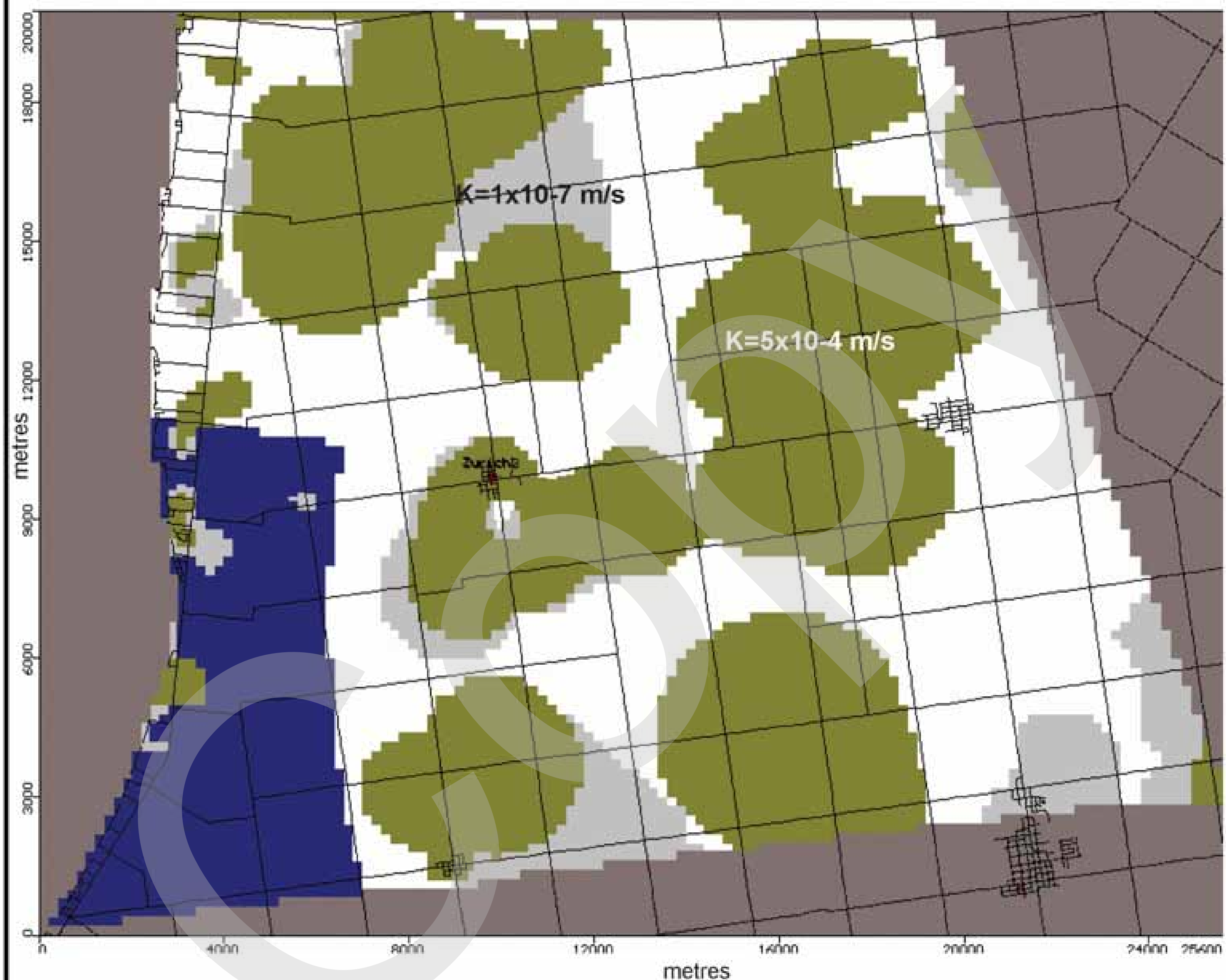


Figure D6: Zurich Groundwater Model Hydraulic Conductivity Layer 4

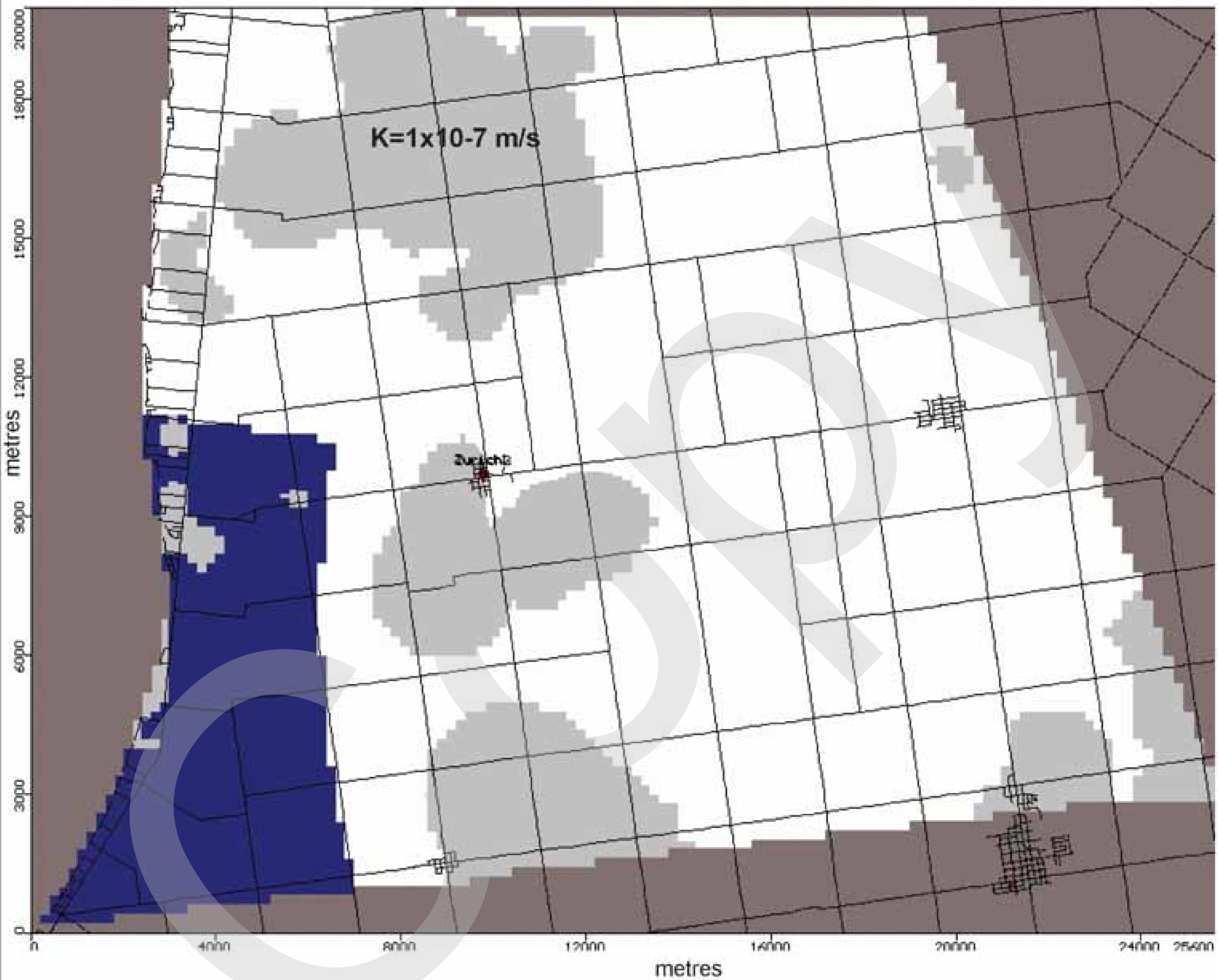


Figure D7: Zurich Groundwater Model Hydraulic Conductivity Layer 5

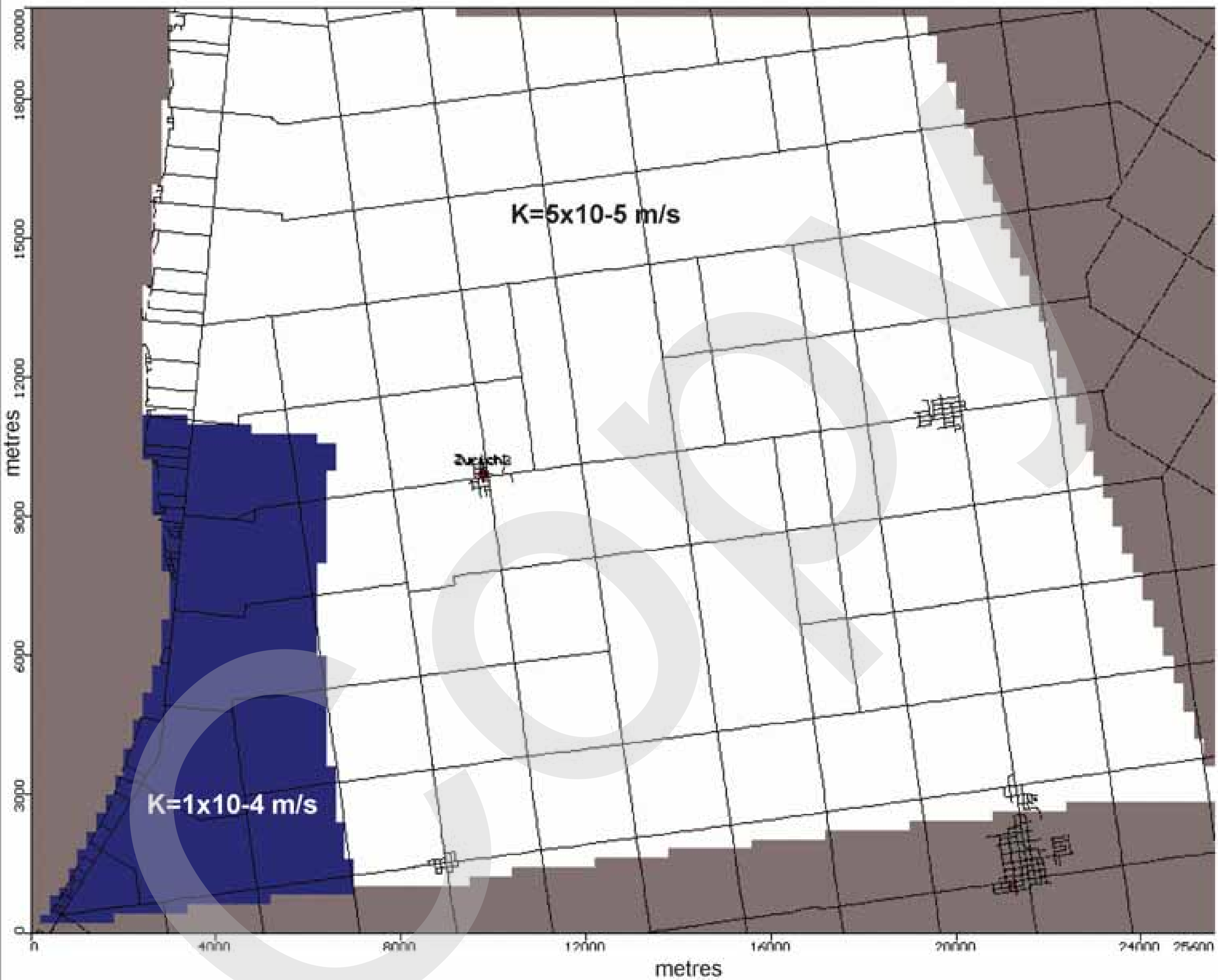


Figure D8: Zurich Groundwater Model Hydraulic Conductivity, Bedrock Layers

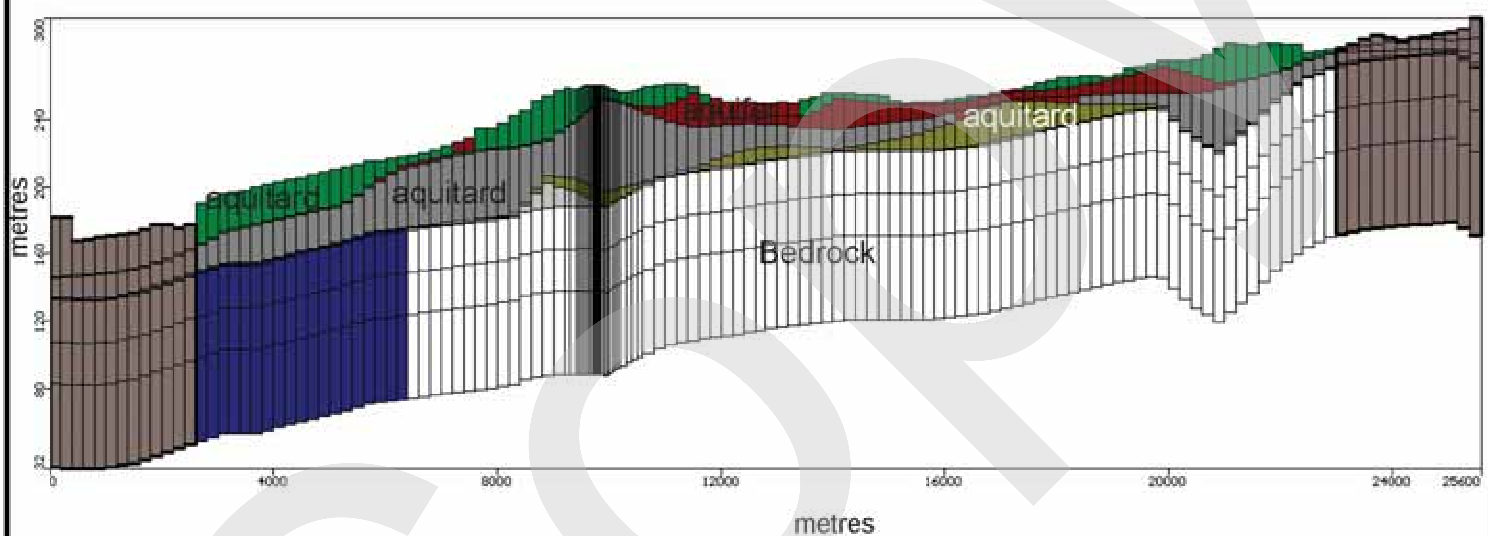


Figure D9: Zurich Groundwater Model Typical Cross-Section

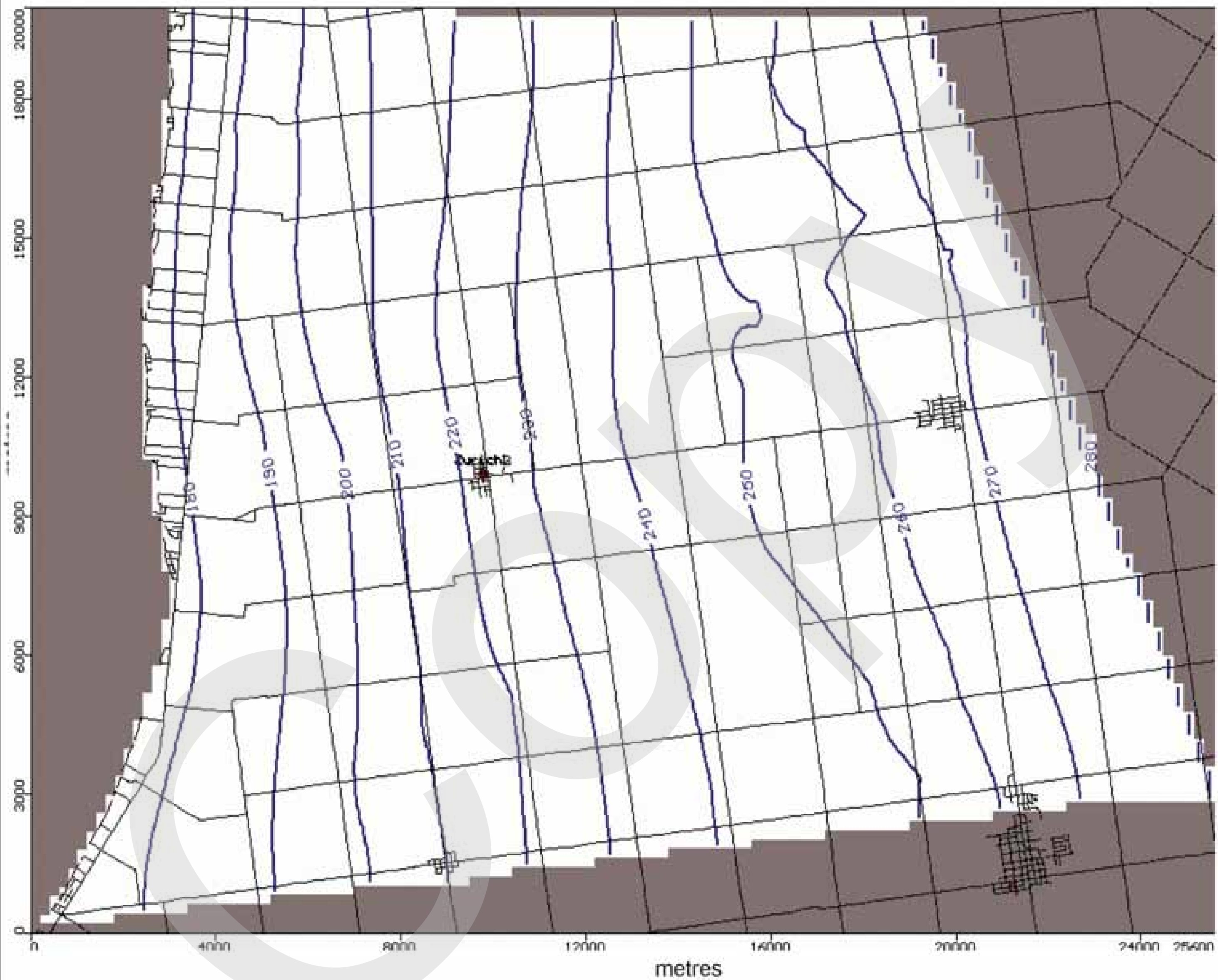
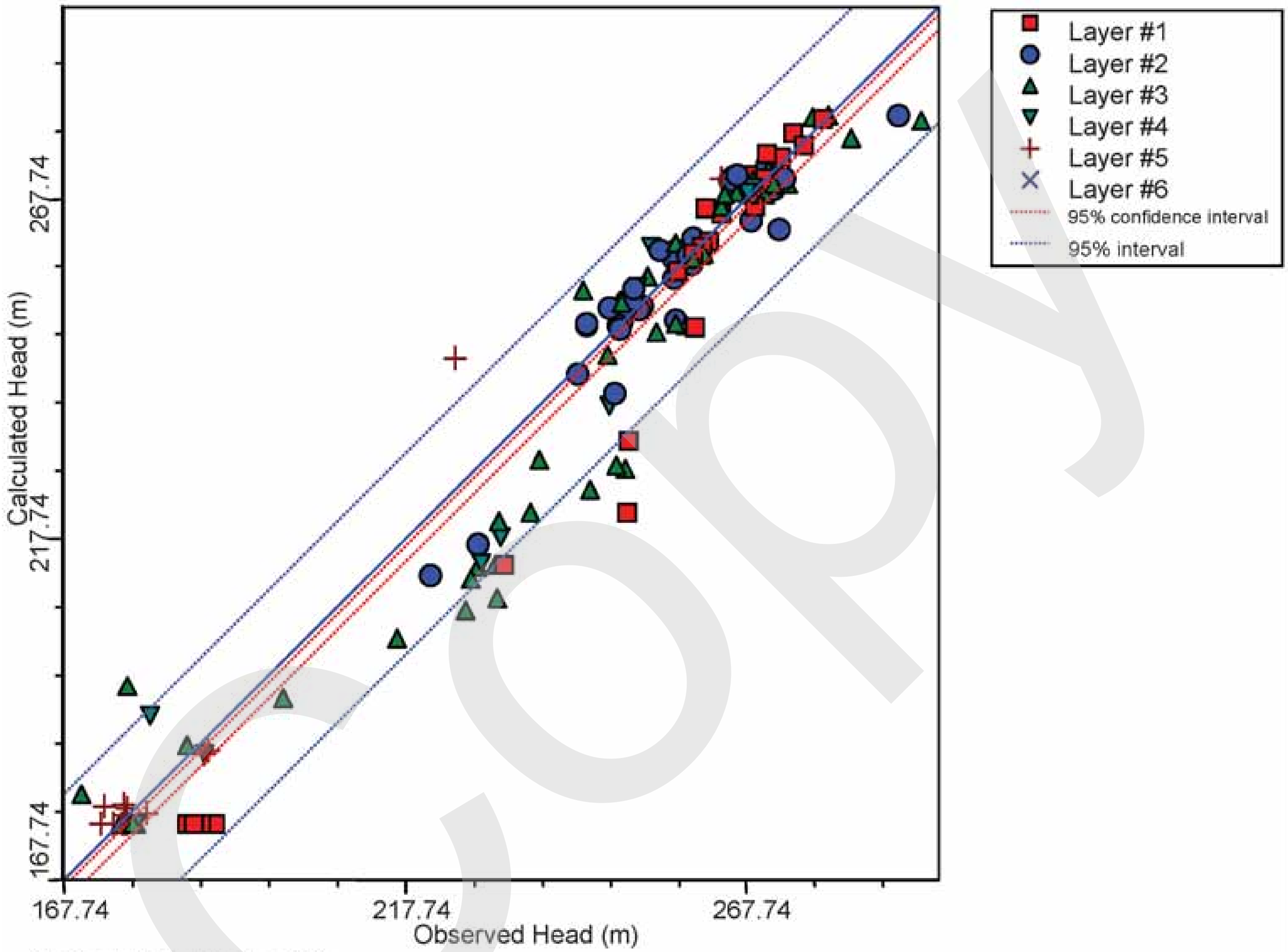


Figure D10: Zurich Groundwater Model Calculated Bedrock Water Levels, in metres

Calculated vs Observed Head Residuals



Num. of Data Points : 147
Residual Mean : -2.16 (m)
Abs. Residual Mean : 5.13 (m)
Root Mean Squared : 7.76 (m)
Normalized RMS : 6.30 (%)

Figure D11: Zurich Groundwater Model Calibration Plot of Head Residuals

Appendix E
Clinton Groundwater Model Figures

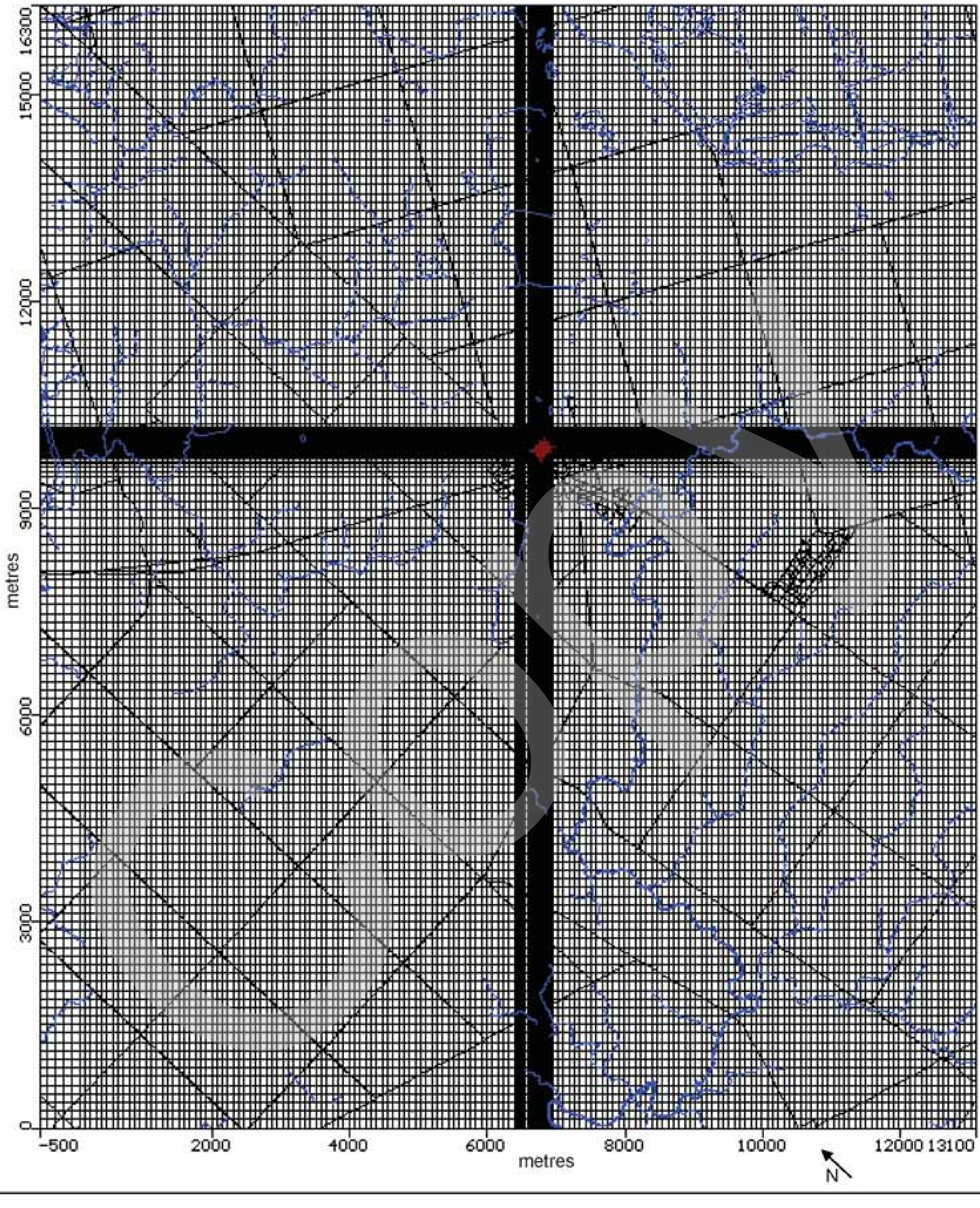


Figure E1: Clinton Groundwater Model Extent and Grid

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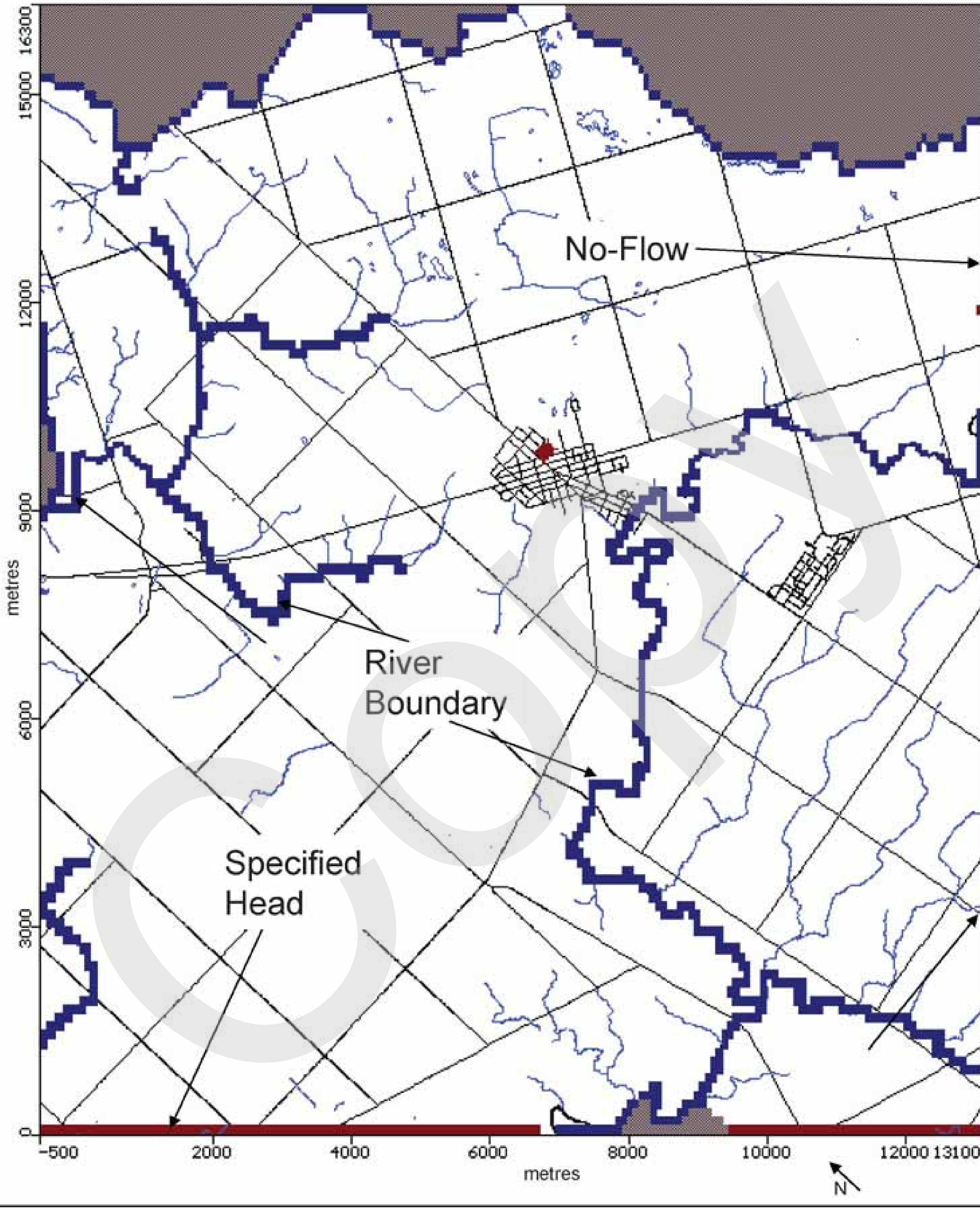

Figure E2: Clinton Groundwater Model Boundaries, Overburden

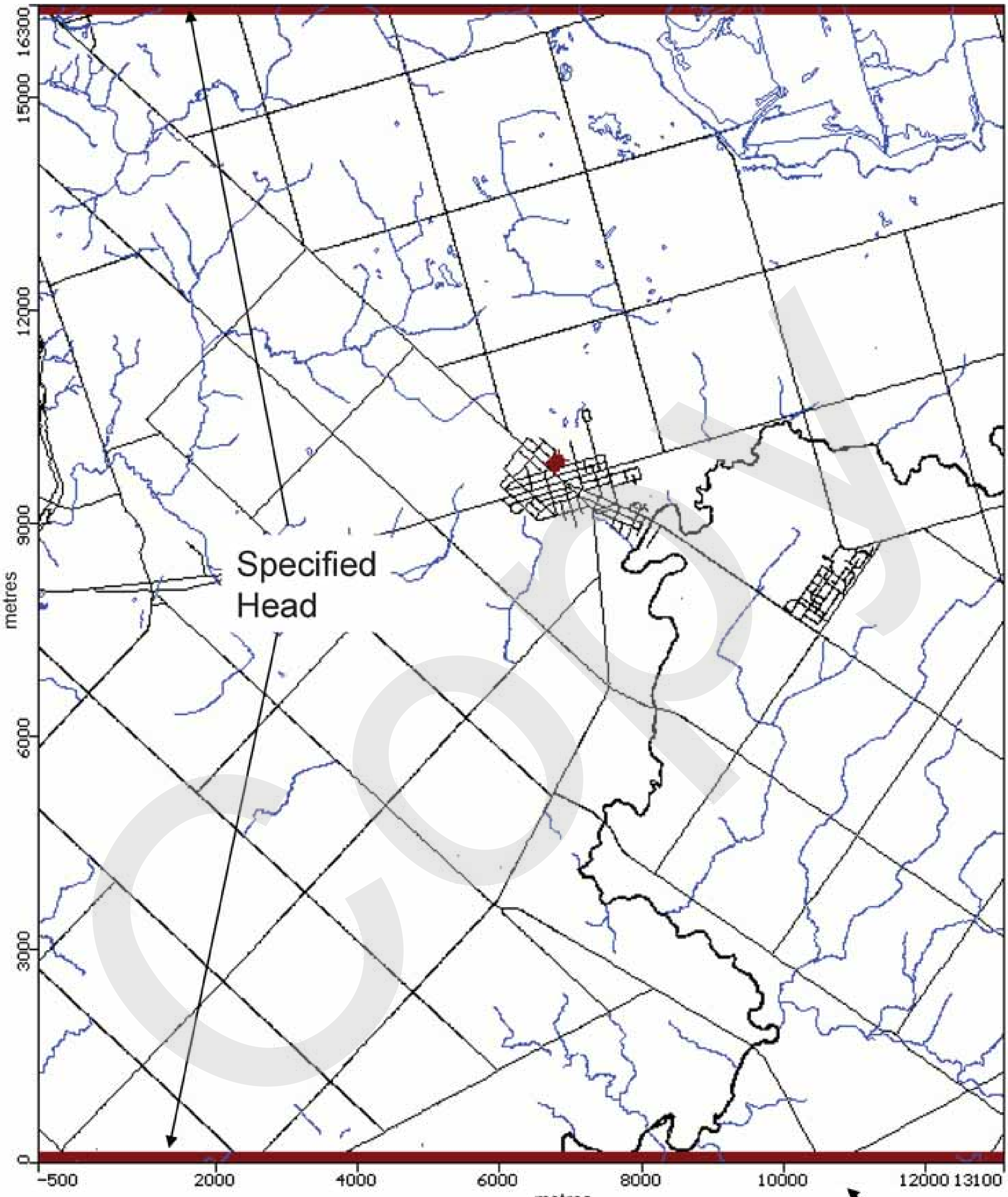

Figure E3: Clinton Groundwater Model Boundaries, Bedrock

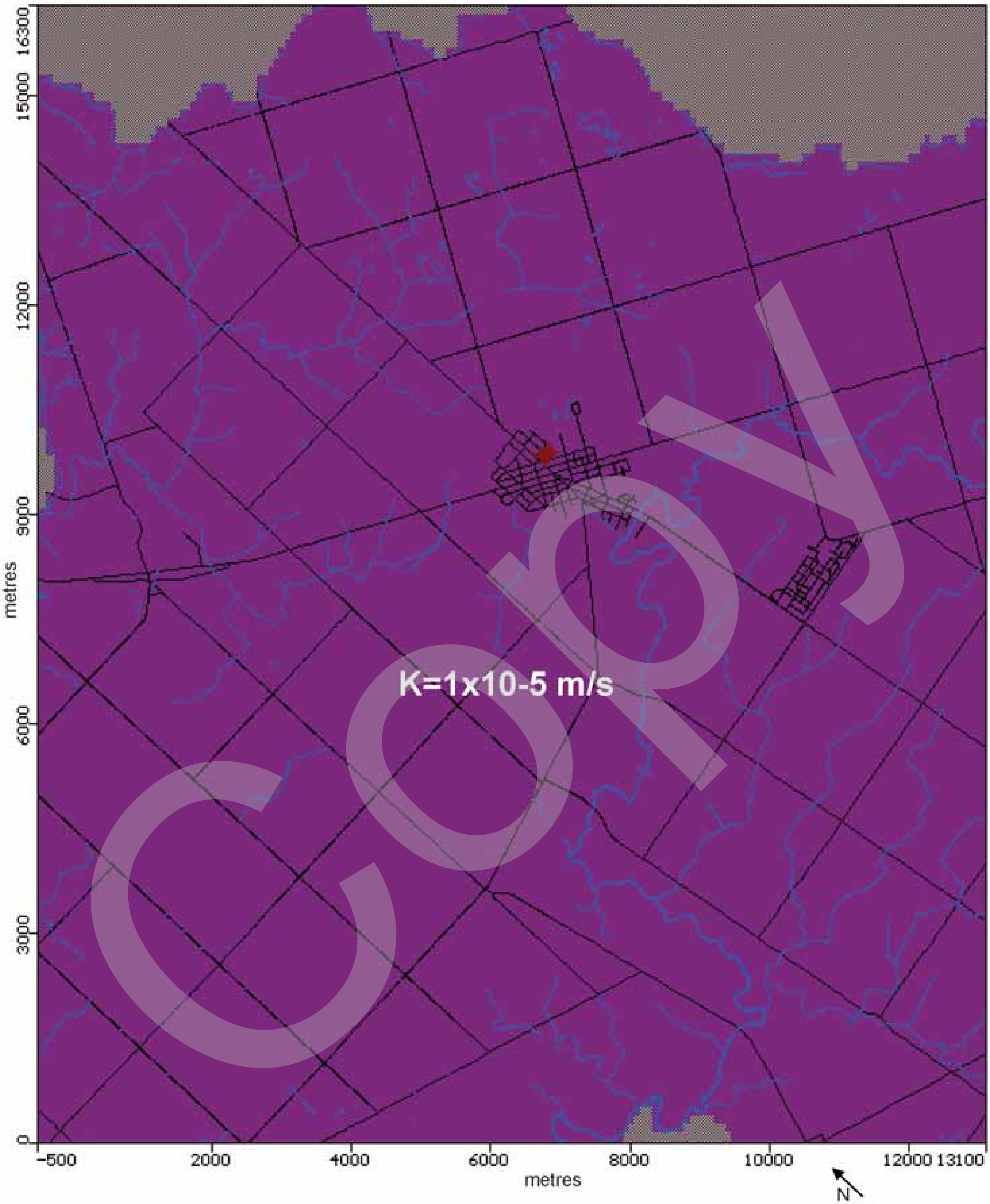

Figure E4: Clinton Groundwater Model Hydraulic Conductivity Layer 1

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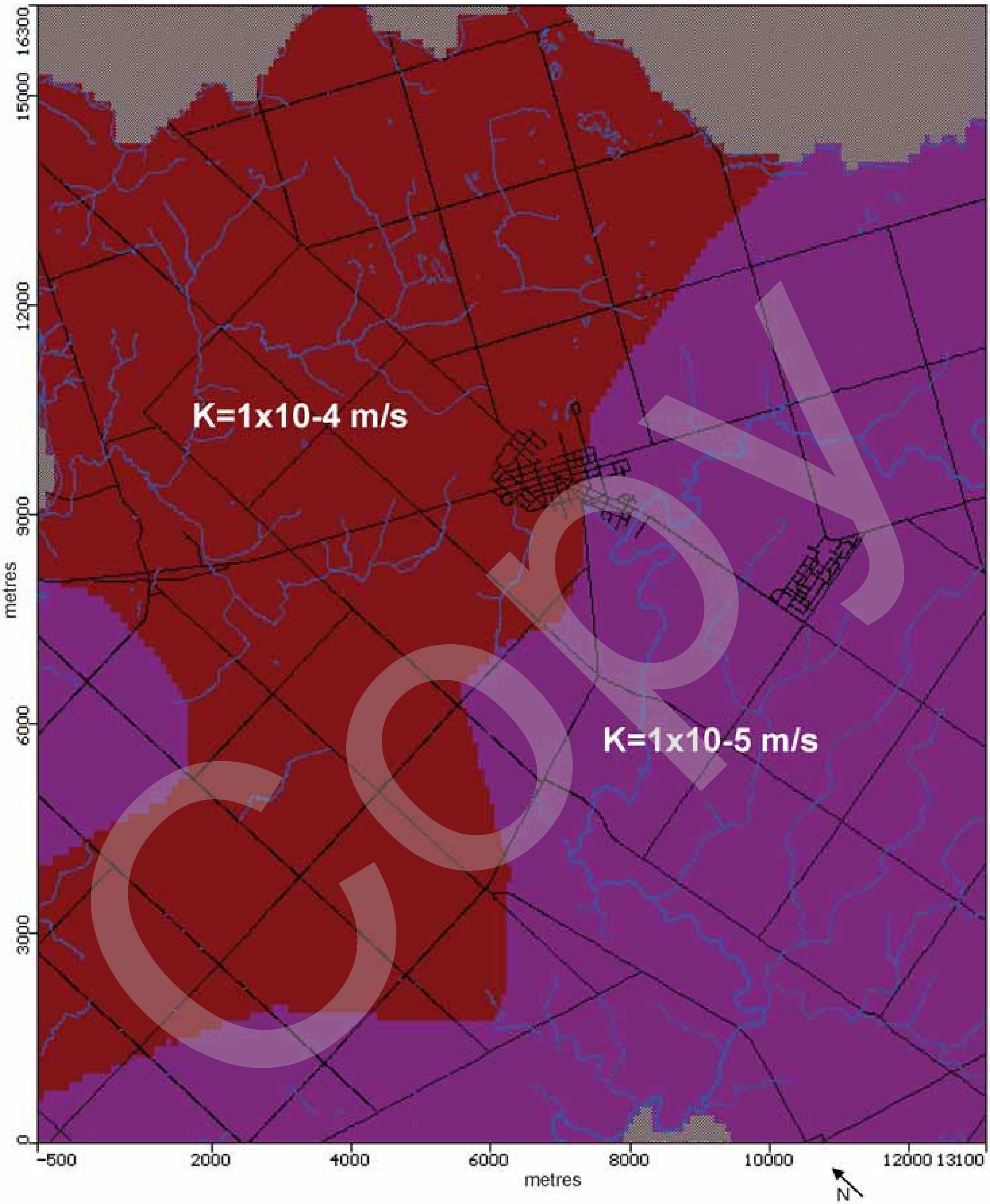


Figure E5: Clinton Groundwater Model Hydraulic Conductivity Layer 2

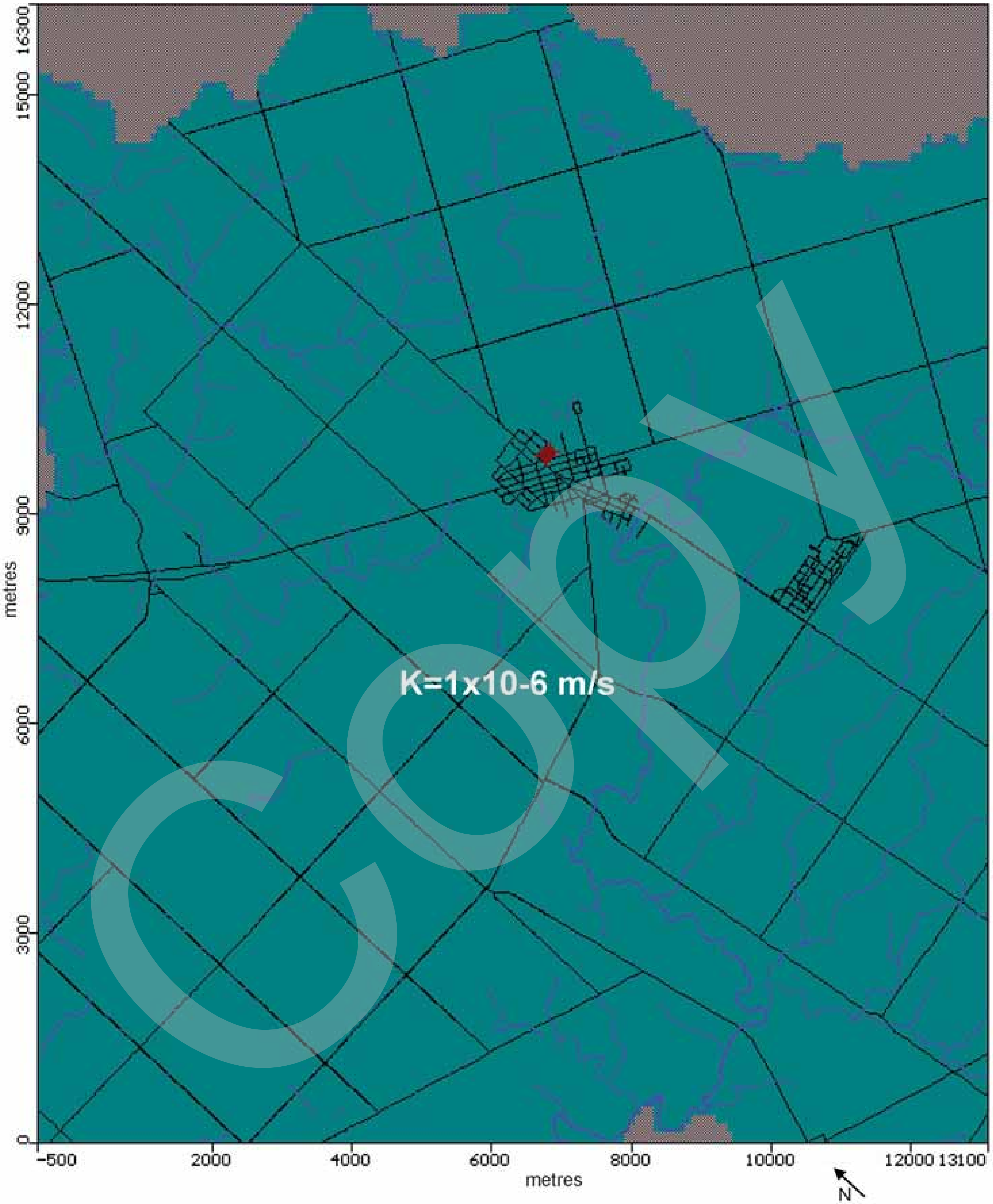


Figure E6: Clinton Groundwater Model Hydraulic Conductivity Layer 3

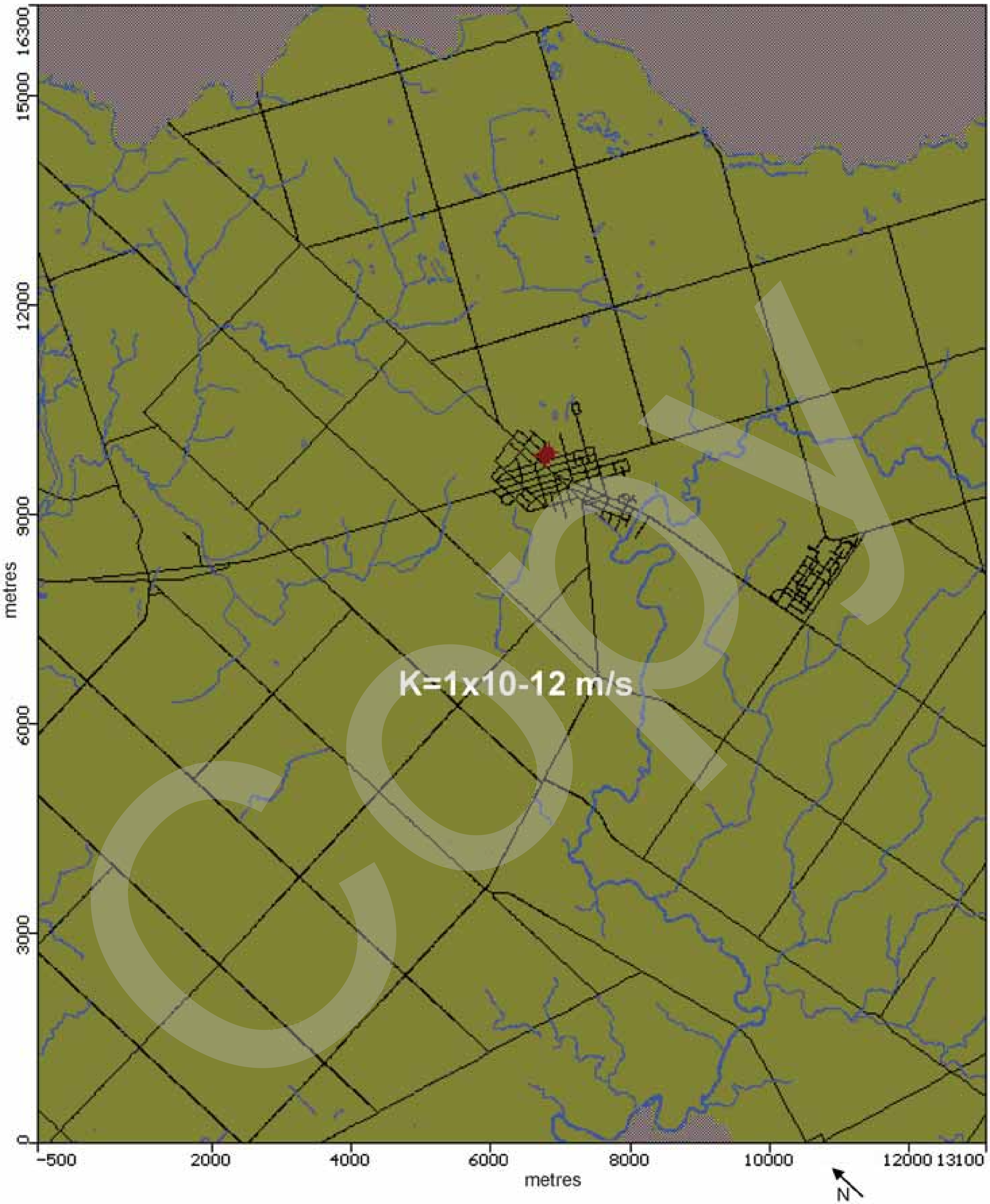


Figure E7: Clinton Groundwater Model Hydraulic Conductivity Layer 4 (Dundee)

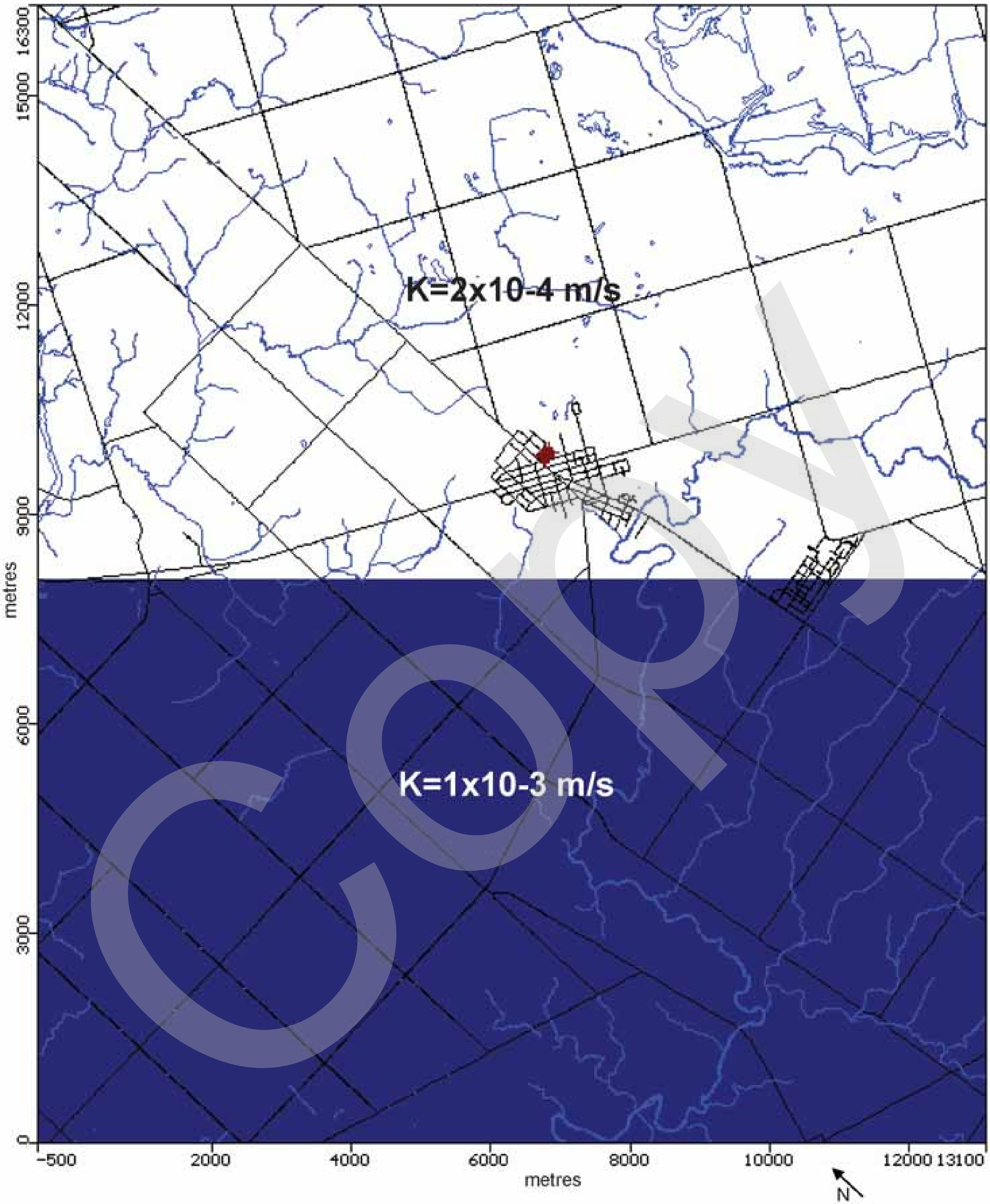


Figure E8: Clinton Groundwater Model Hydraulic Conductivity Layer 5-7 (Lucas)

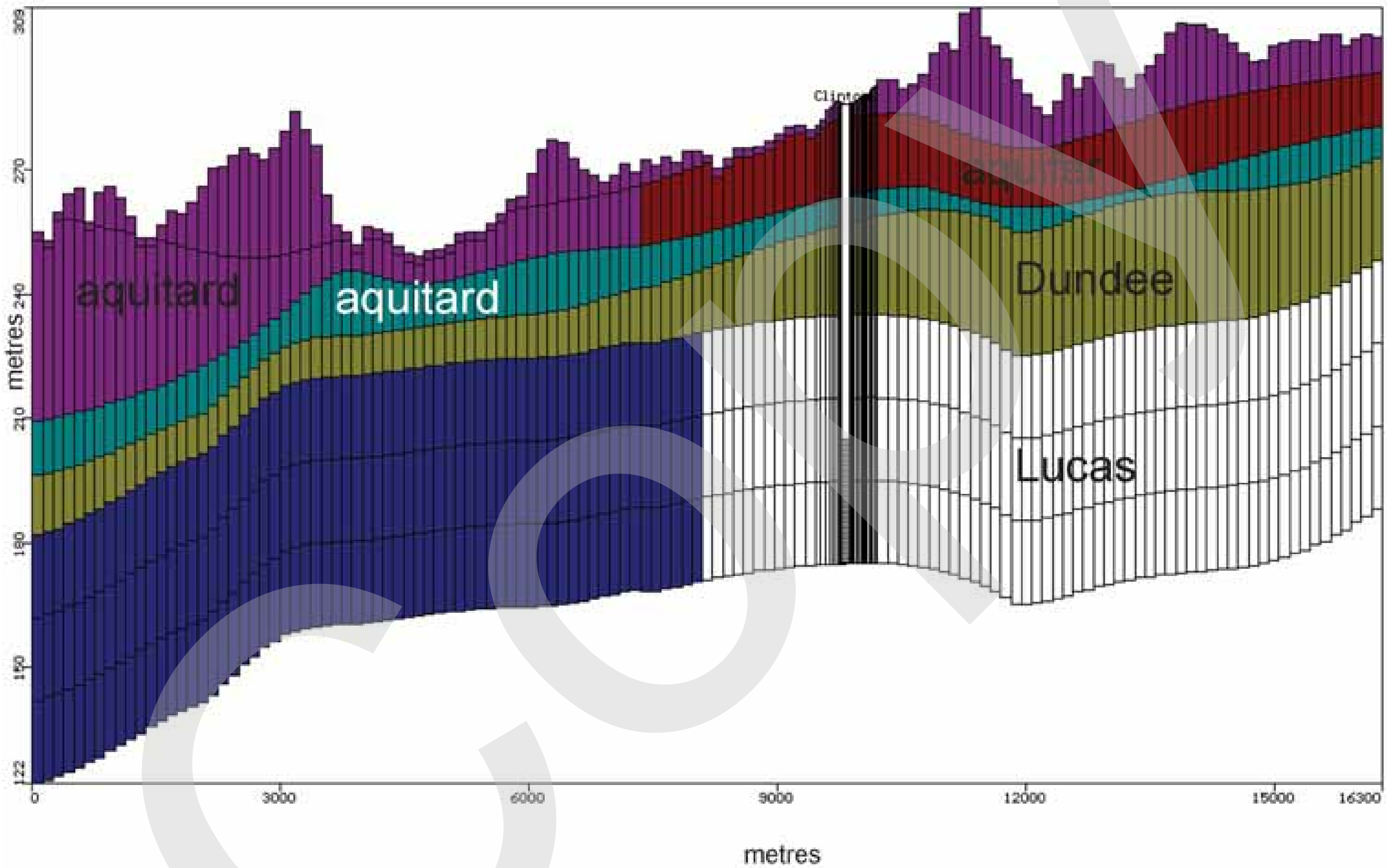


Figure E9: Clinton Groundwater Model Typical Cross-Section

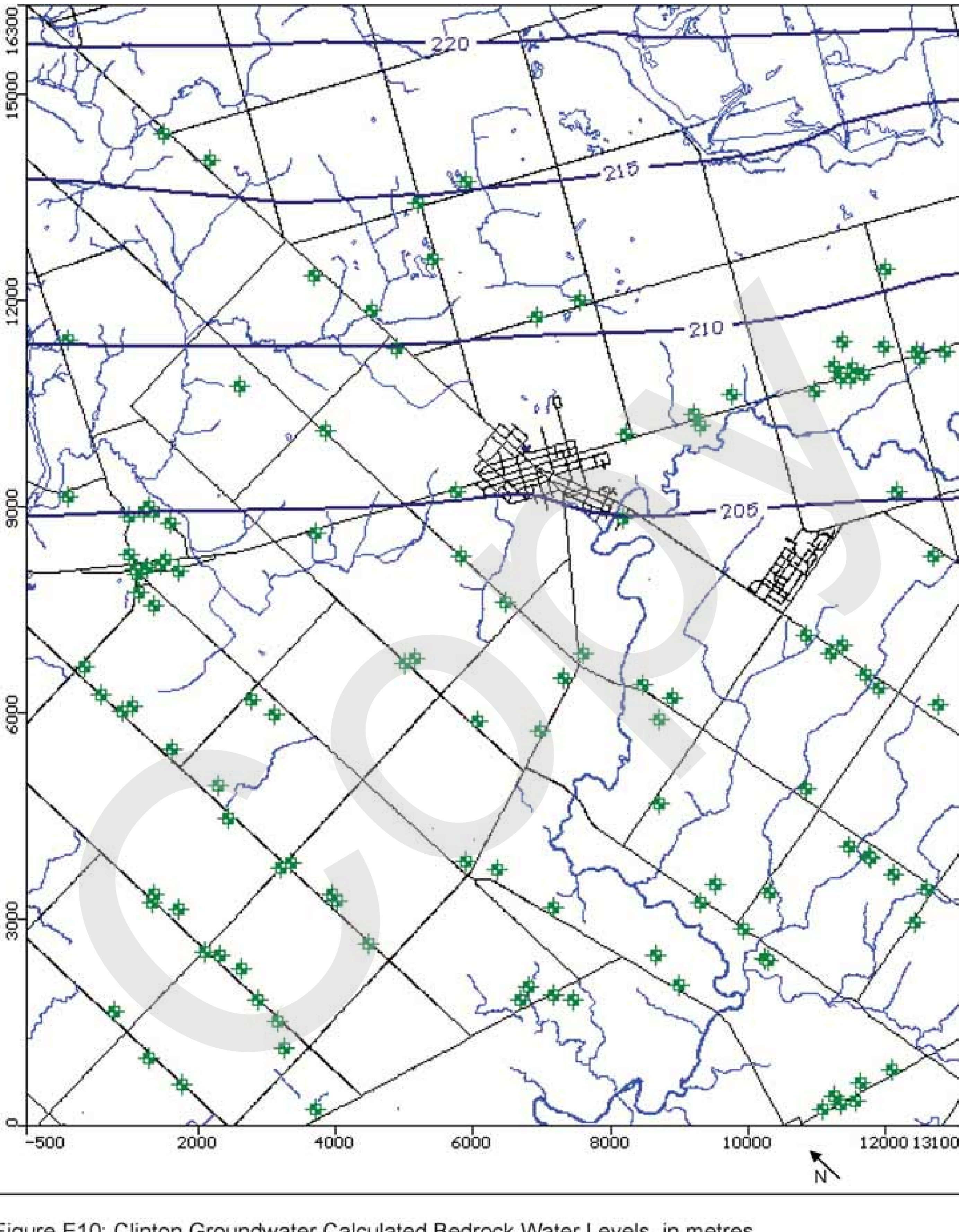
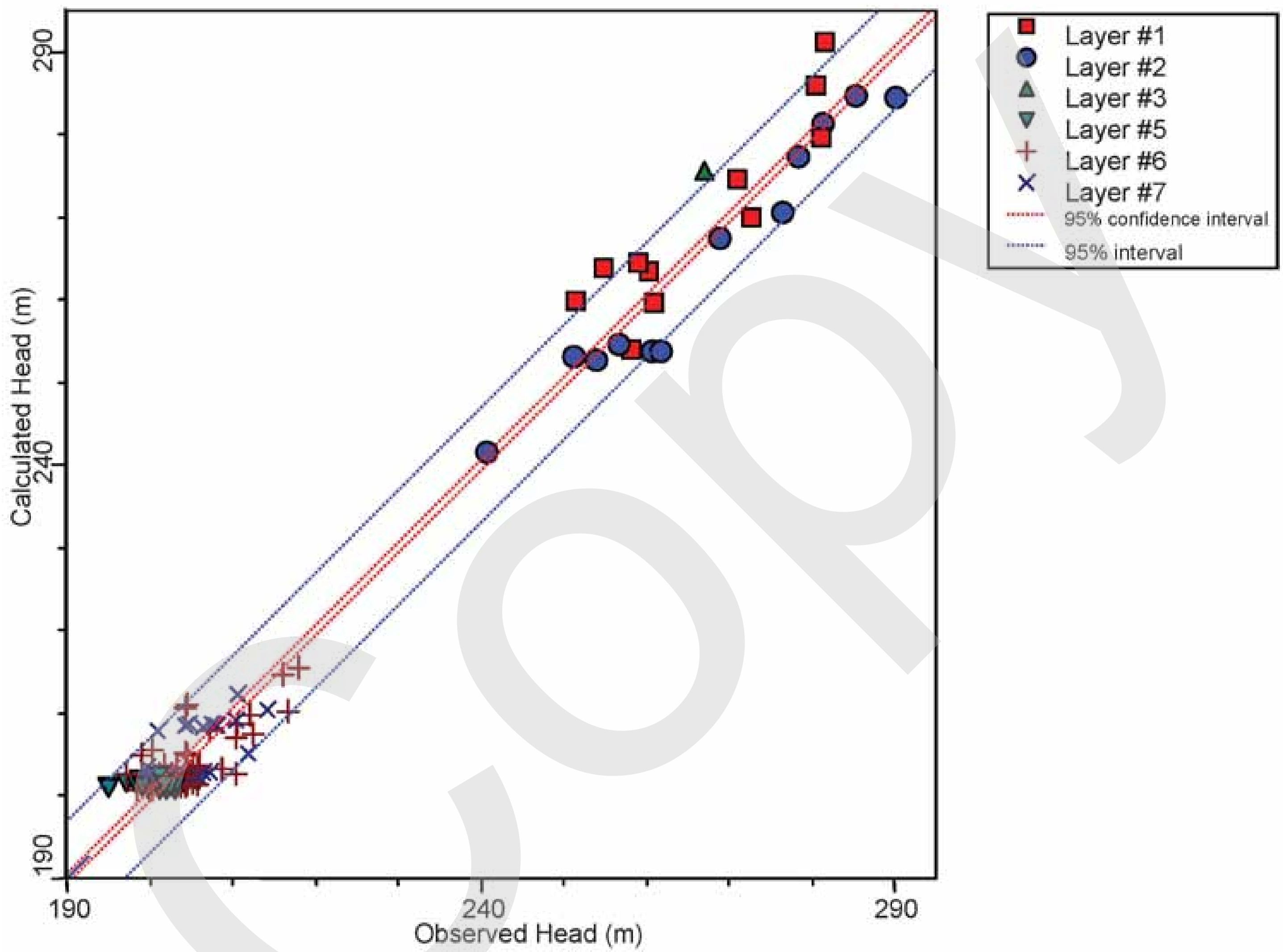


Figure E10: Clinton Groundwater Calculated Bedrock Water Levels, in metres

Calculated vs Observed Head Residuals



Num. of Data Points : 123
Residual Mean : 0.02 (m)
Root Mean Squared : 3.53 (m)
Normalized RMS : 3.70 (%)
Abs. Residual Mean: 2.70 (m)
Correlation Coefficient : 0.99

Figure E11: Clinton Groundwater Model Calibration Plot of Head Residuals

Appendix F
Brucefield Groundwater Model Figures

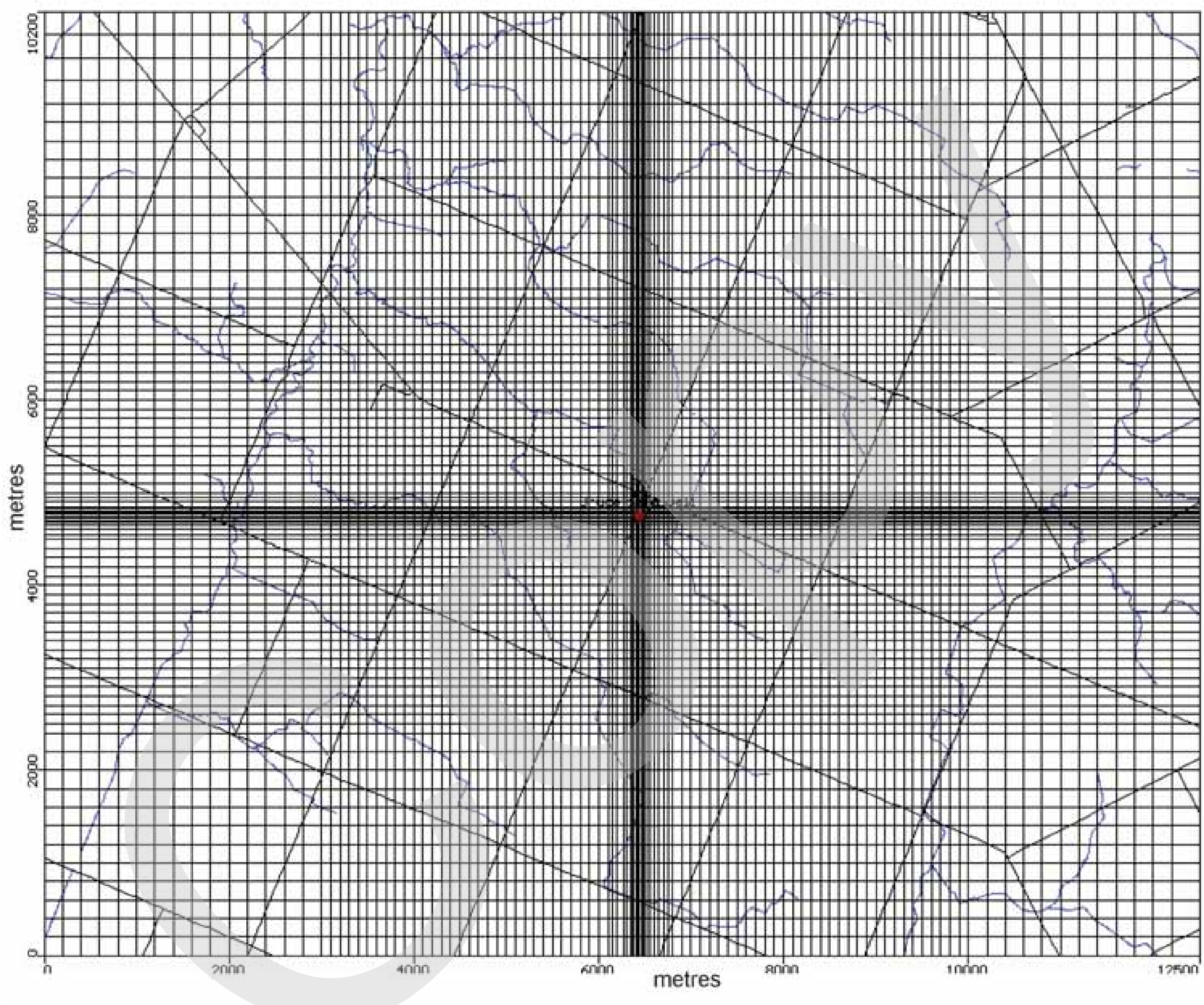


Figure F1: Brucefield Groundwater Model Extent and Grid

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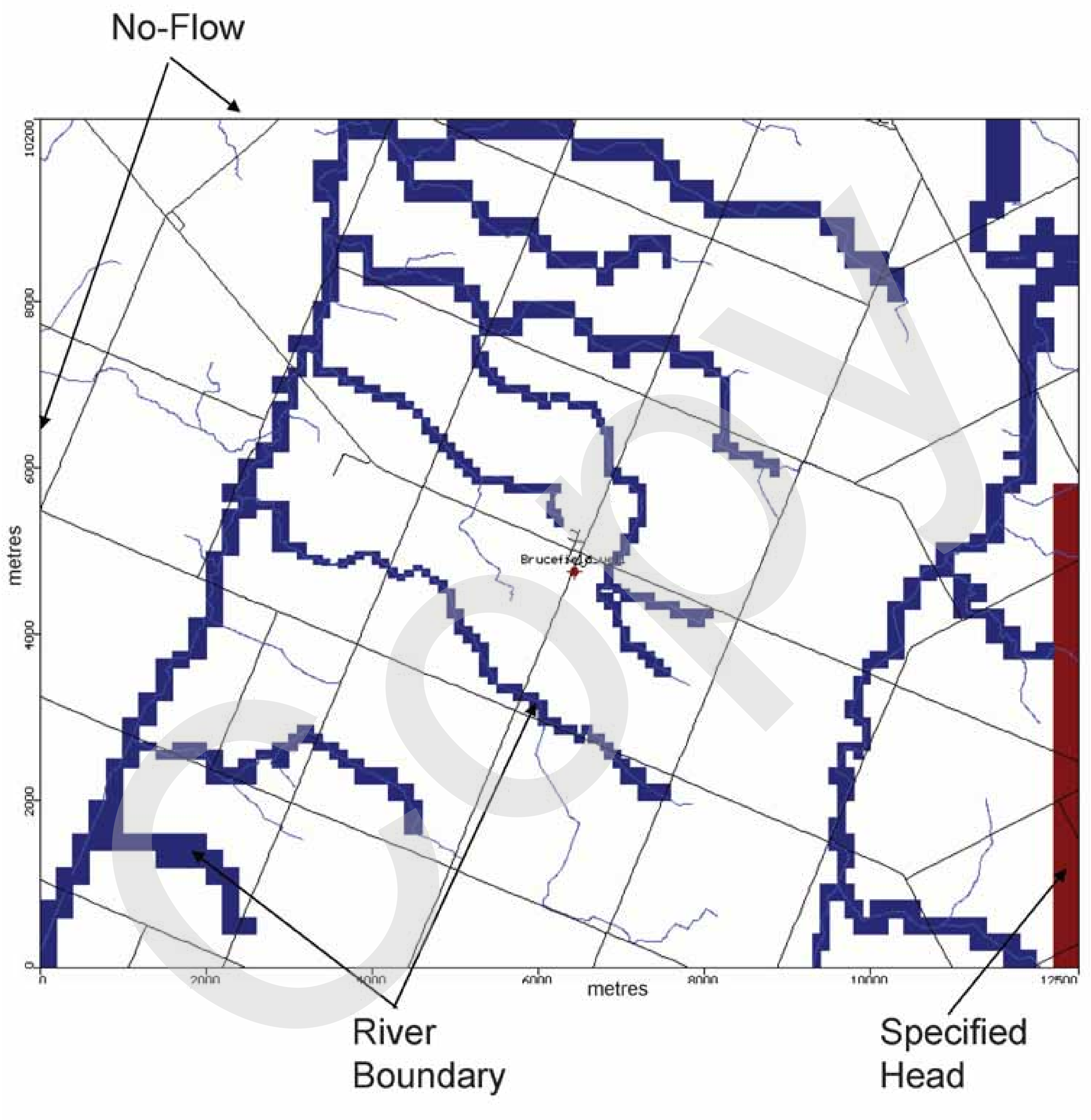

Figure F2: Brucefield Groundwater Model Boundaries, Overburden

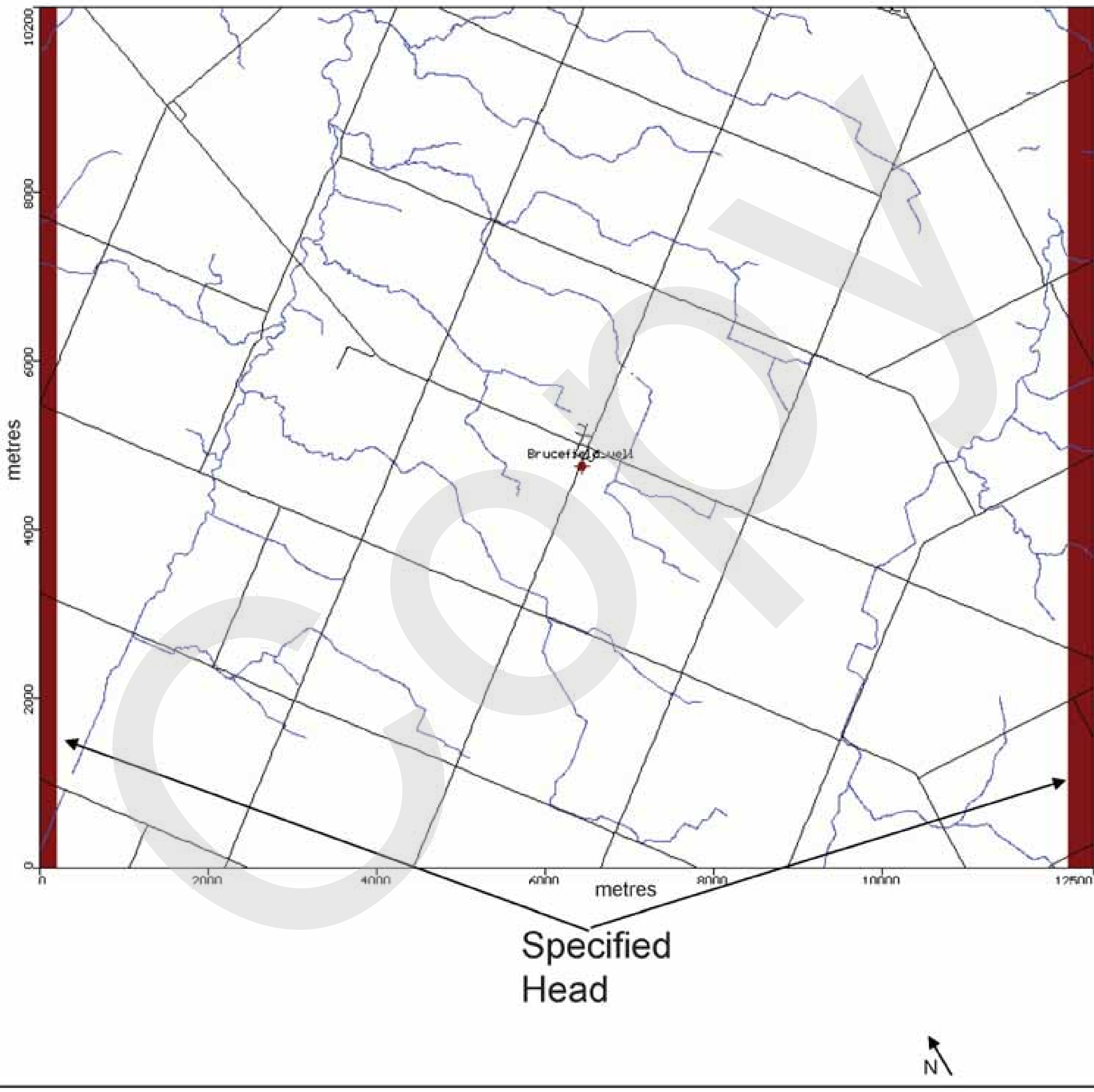

Figure F3: Brucefield Groundwater Model Boundaries, Bedrock

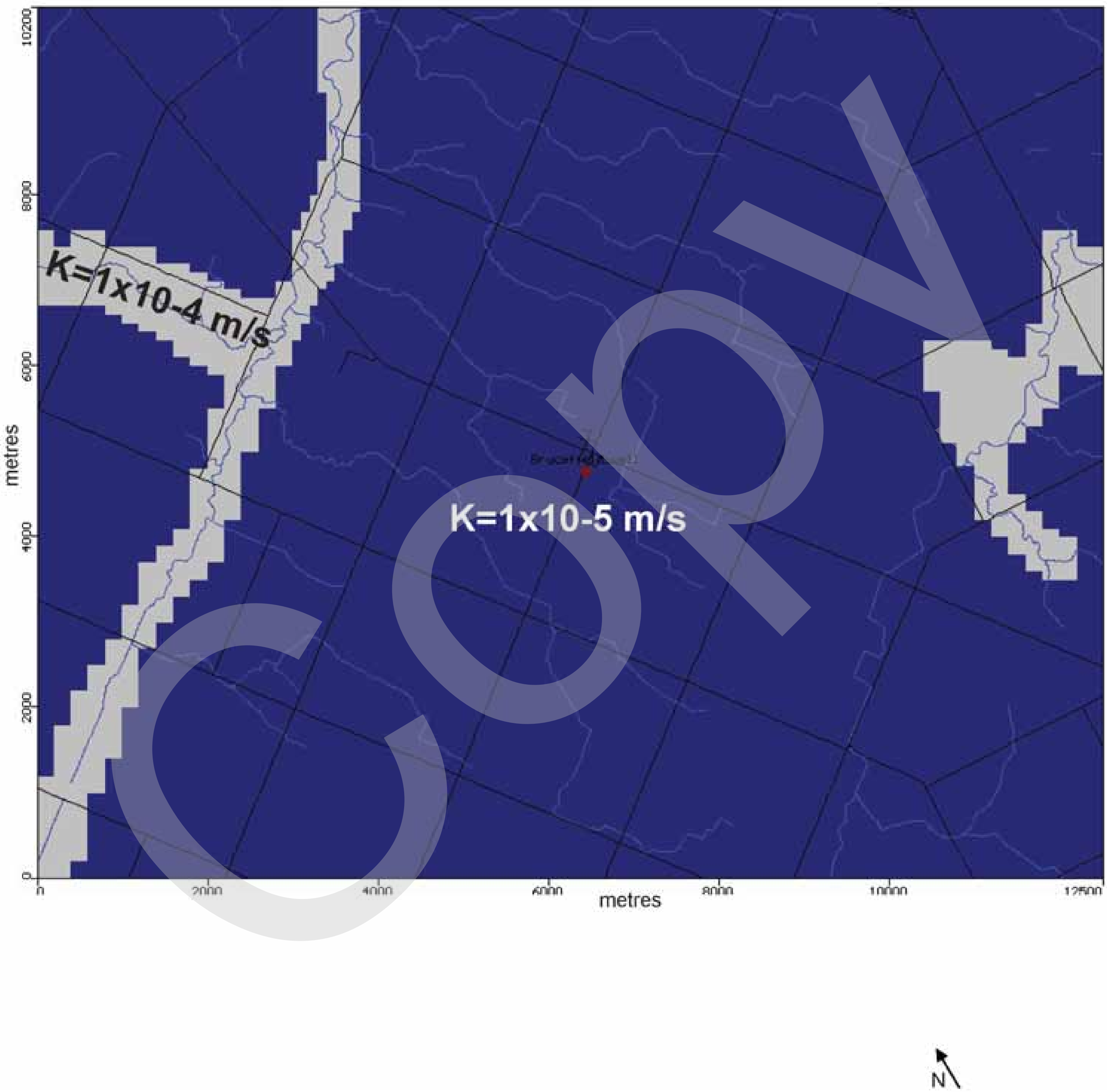

Figure F4: Brucefield Groundwater Model Hydraulic Conductivity Layer 1

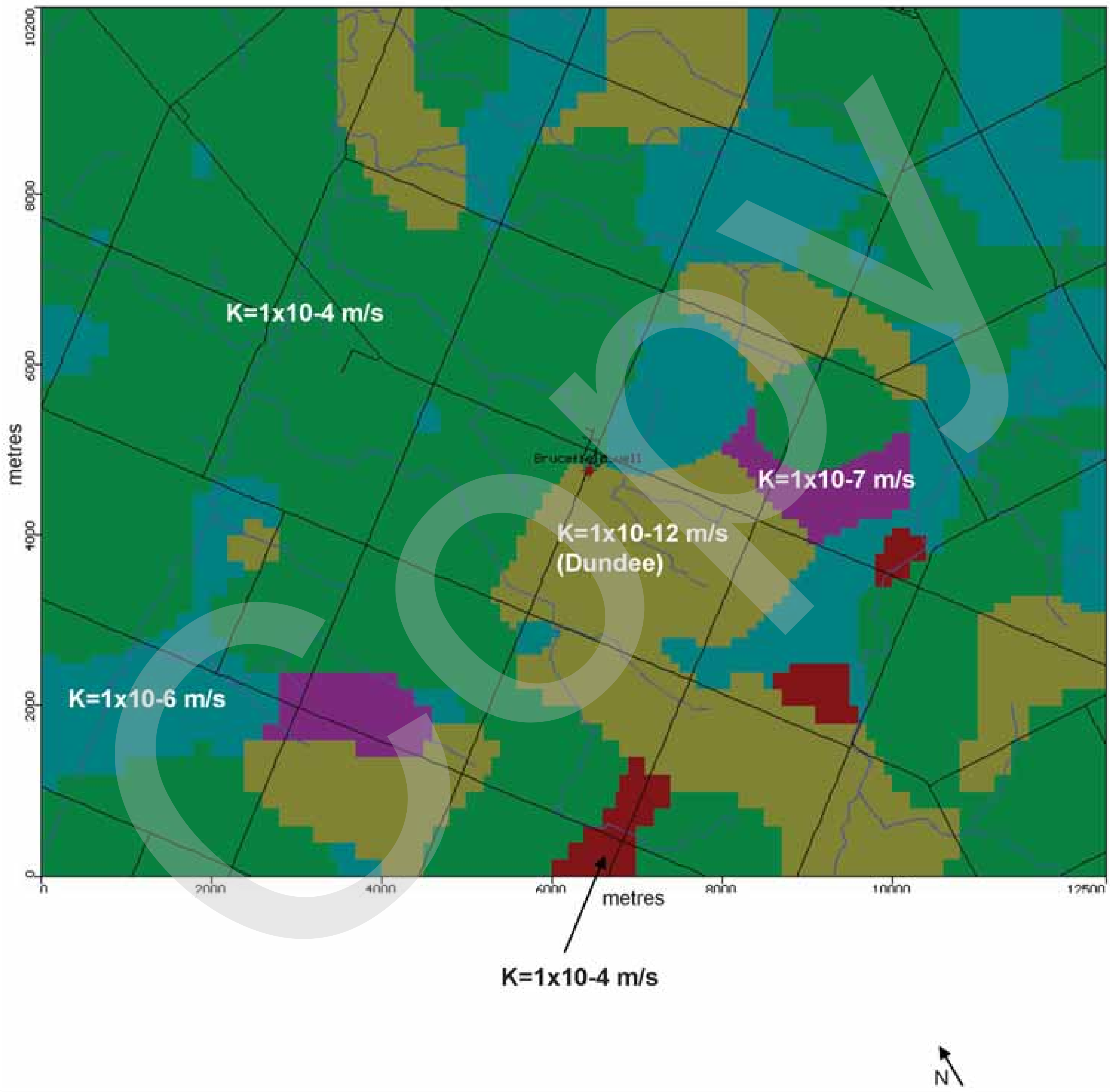

Figure F4: Brucefield Groundwater Model Hydraulic Conductivity Layer 2

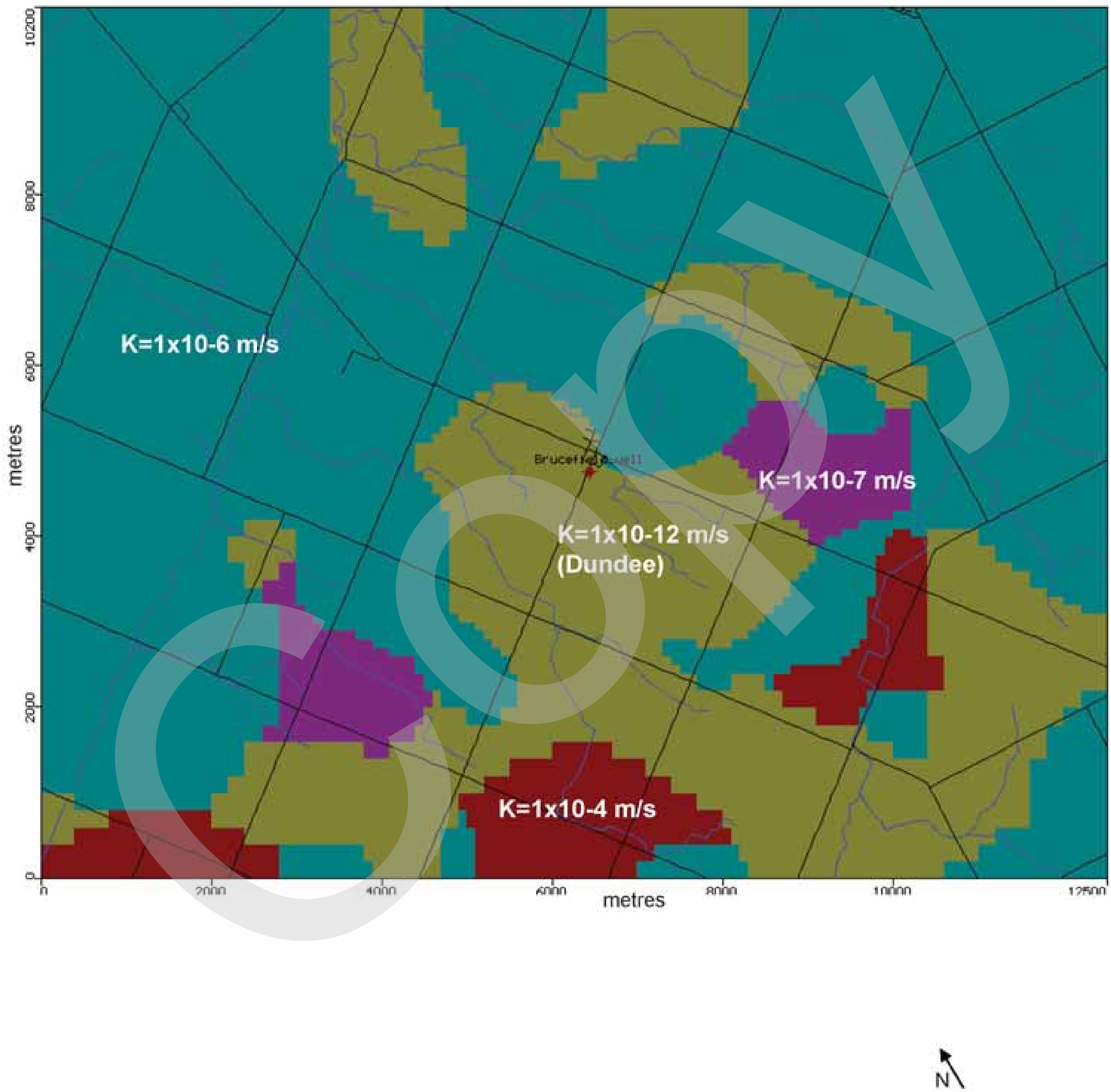

Figure F6: Brucefield Groundwater Model Hydraulic Conductivity Layer 3

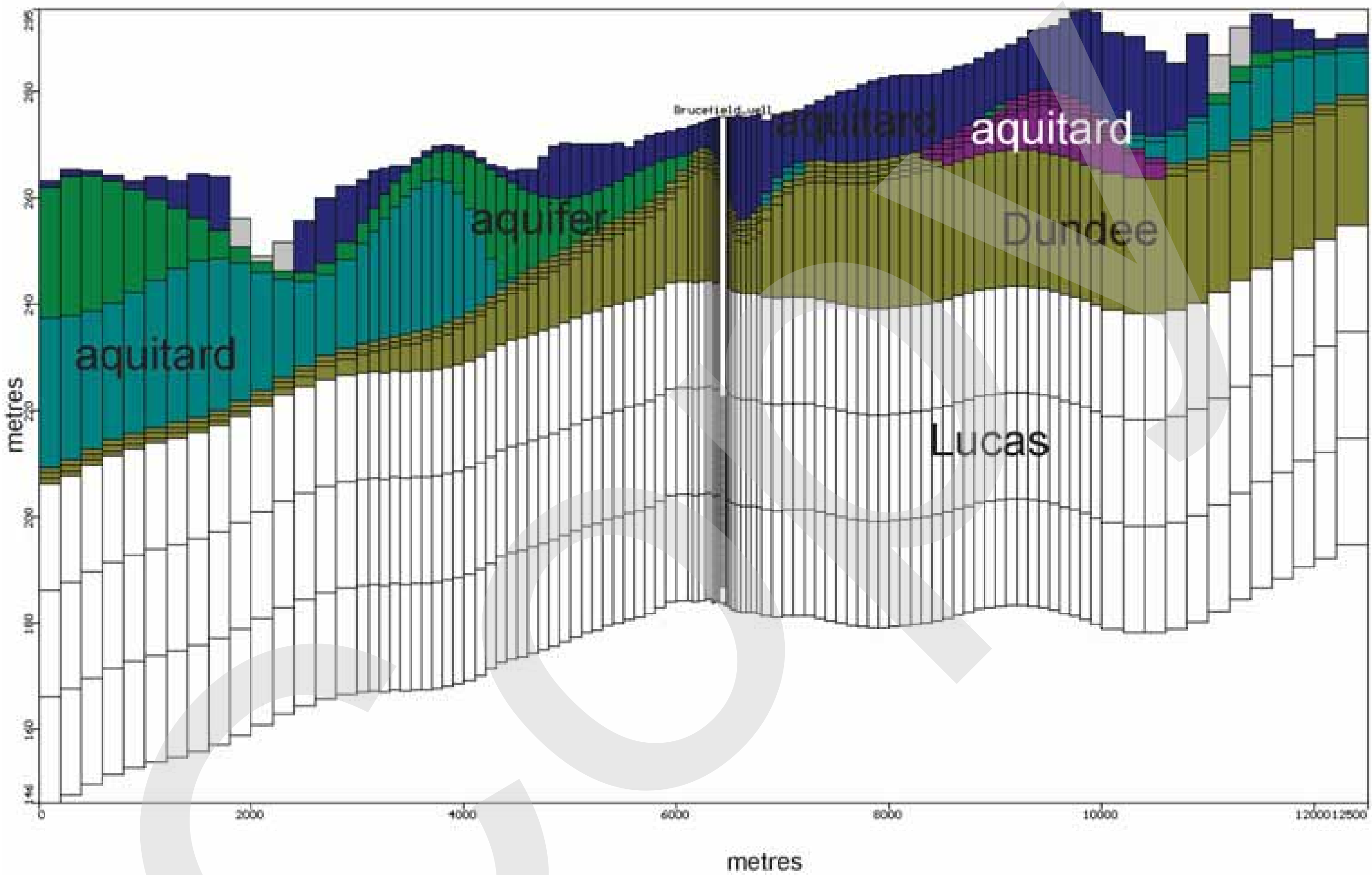

Figure F7: Brucefield Groundwater Model Typical Cross-Section

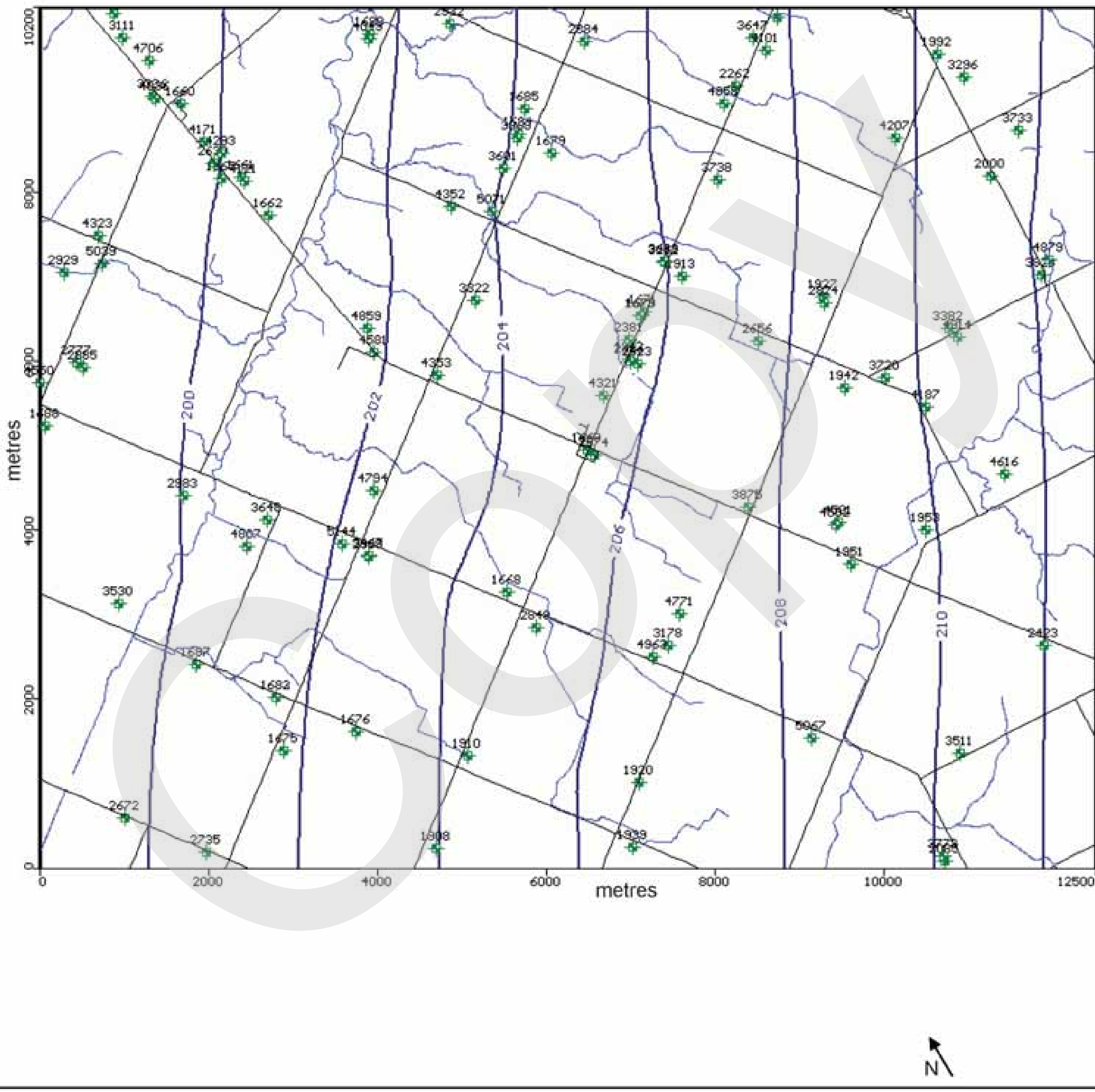

Figure F8: Brucefield Groundwater Model Calculated Bedrock Water Levels, in metres

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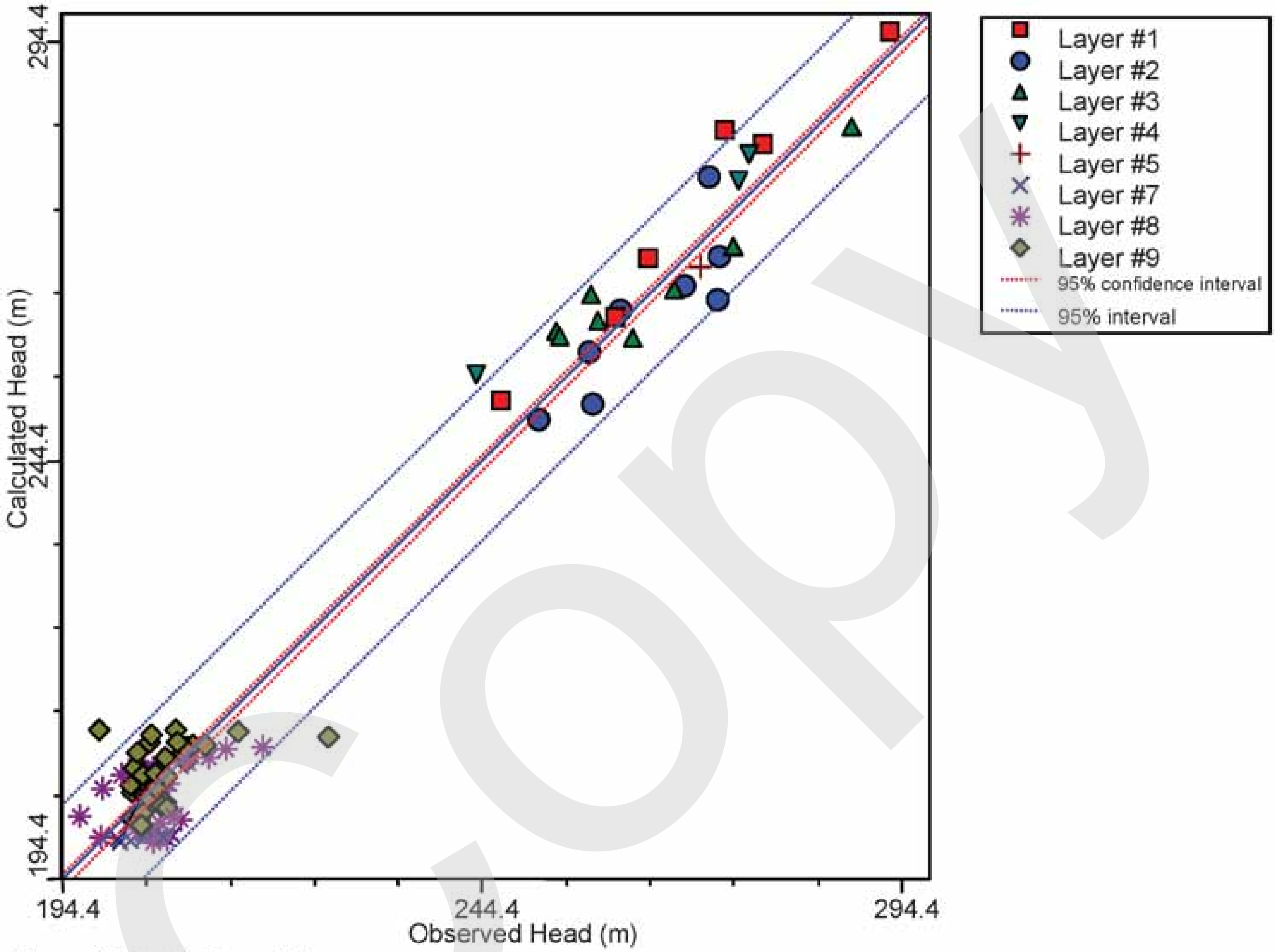
Calculated vs Observed Head Residuals



Num. of Data Points : 104
Residual Mean : -0.35 (m)
Abs. Residual Mean : 3.66 (m)
Root Mean Squared : 4.66 (m)
Normalized RMS : 4.83 (%)

Figure F9: Brucefield Groundwater Model Calibration Plot of Head Residuals

Appendix G
West Huron Groundwater Model Figures

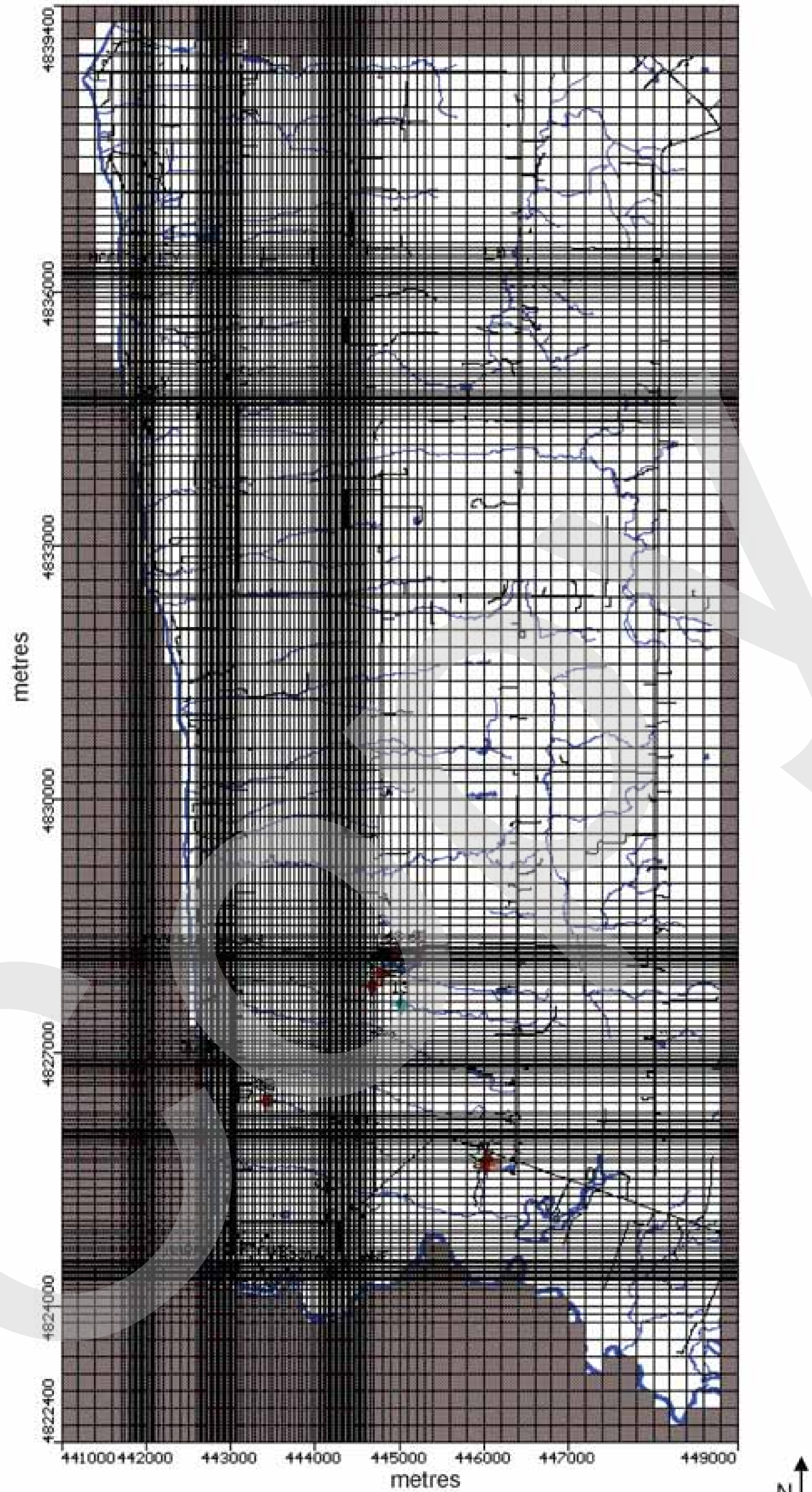


Figure G1: West Huron Groundwater Model Extent and Grid

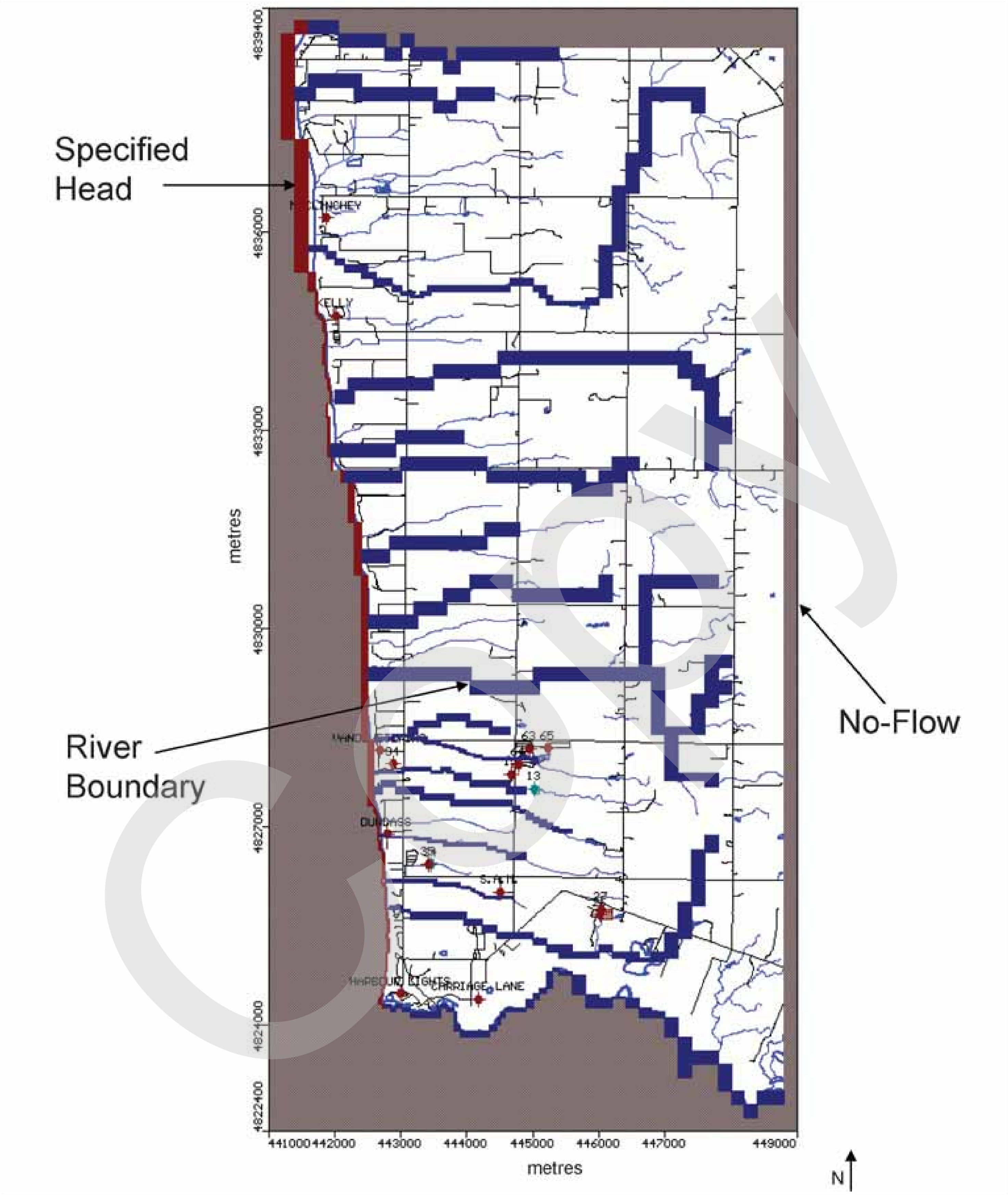


Figure G2: West Huron Groundwater Model Boundaries

Recharge Rates:

Green - 50 mm/yr

Red - 2 mm/yr (tile drained)

Blue - 50 mm/yr

White - 350 mm/yr

Teal - 200 mm/yr

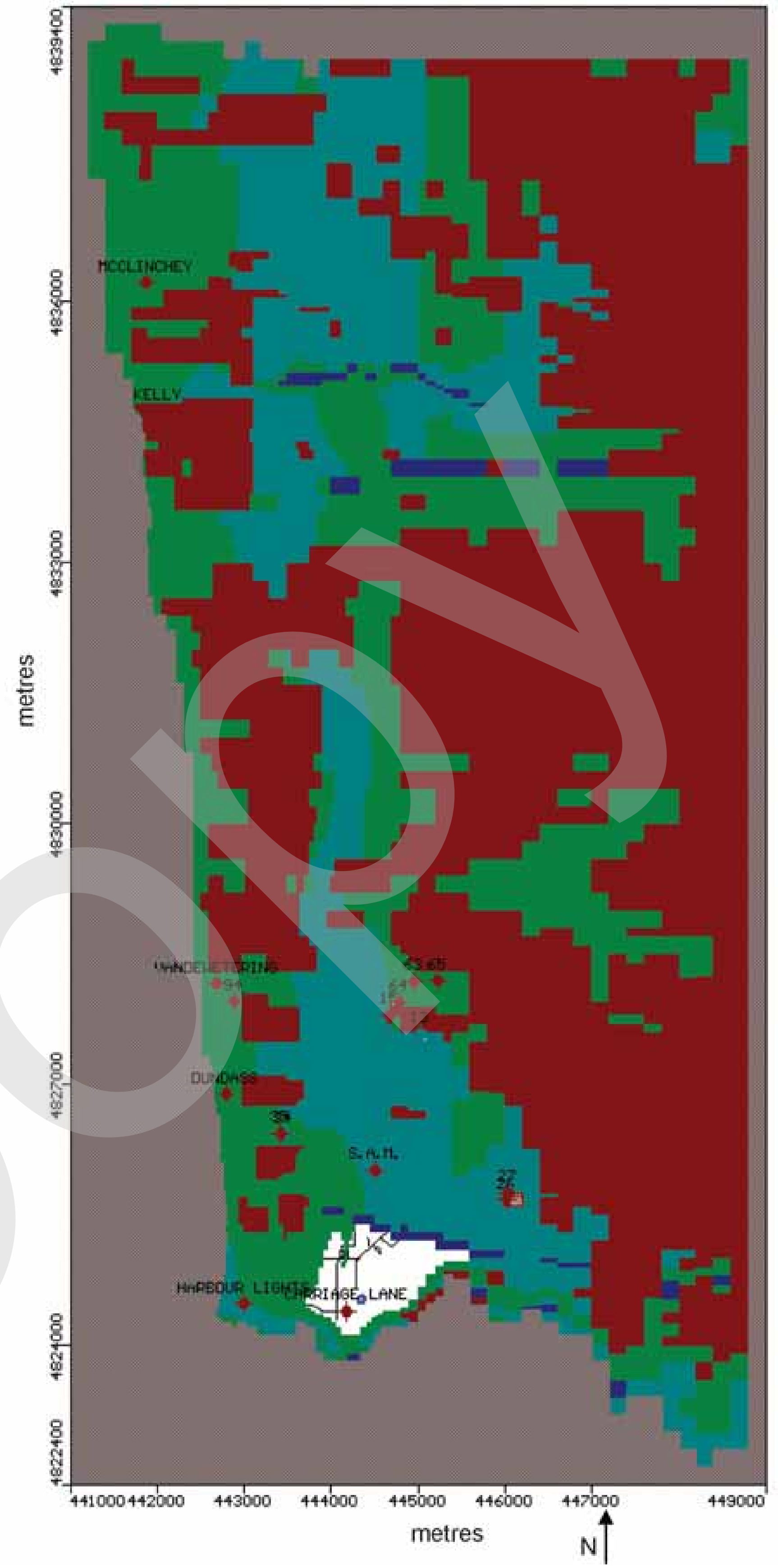


Figure G3: West Huron Groundwater Model Recharge Distribution

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Conductivity Values:

Light Grey (1e-6 m/s)
Dark Grey (1e-4 m/s)
Olive (5e-5 m/s)

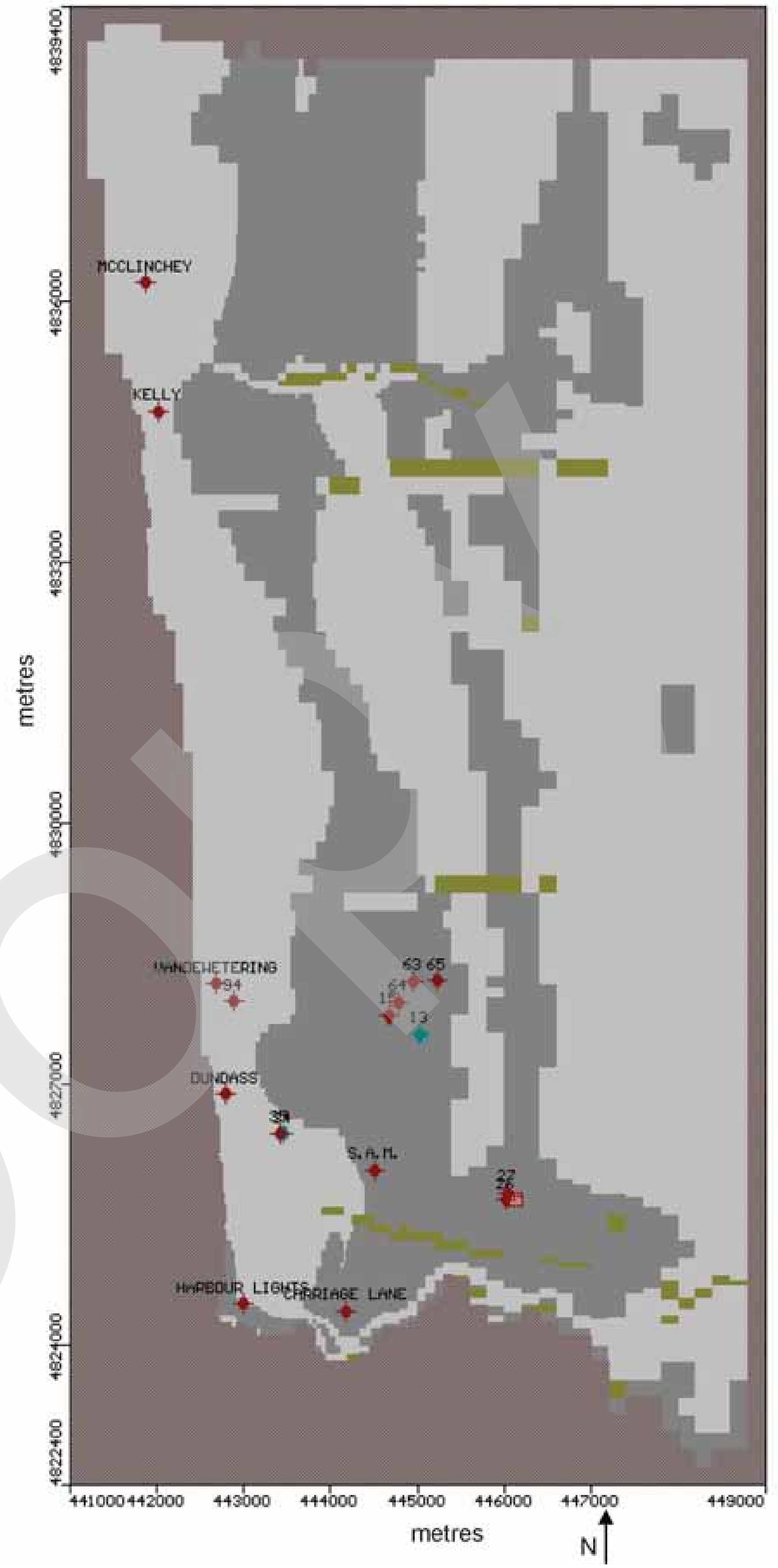

Figure G4: West Huron Groundwater Model Hydraulic Conductivity Layer 1

ABCA/MVCA Well Head Protection Area Delineation Project

WNMC
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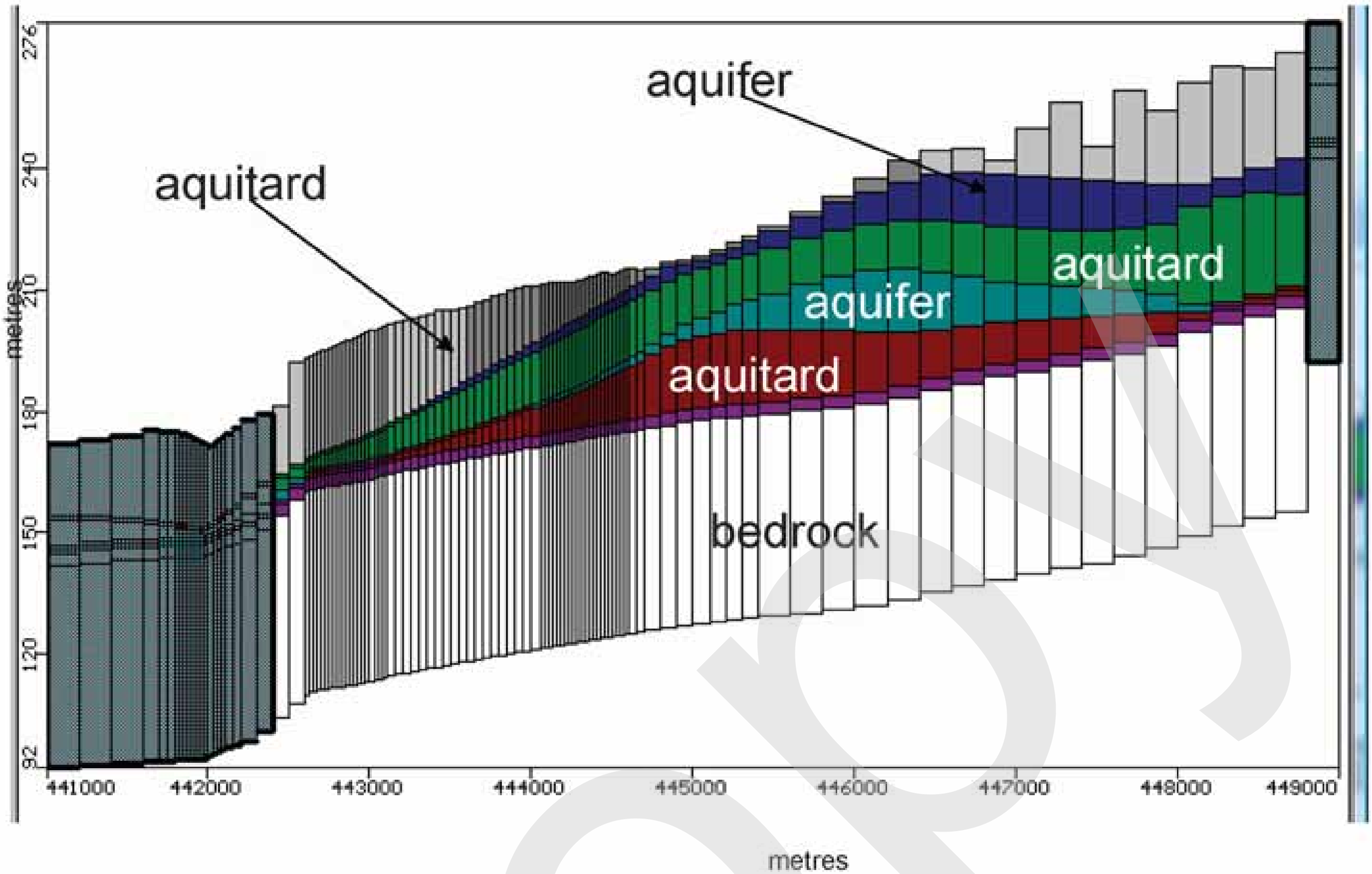

Zone		Kx [m/s]	Ky [m/s]	Kz [m/s]
1		2E-5	2E-5	2E-6
2		0.0001	0.0001	1E-5
3		5E-6	5E-6	5E-7
4		0.0001	0.0001	1E-5
5		5E-6	5E-6	5E-7
6		3E-5	3E-5	3E-6
7		5E-5	5E-5	5E-6
8		1E-6	1E-6	1E-7
9		0.0001	0.0001	1E-5

Figure G5: West Huron Groundwater Model Typical Cross-Section Showing Conductivity Values

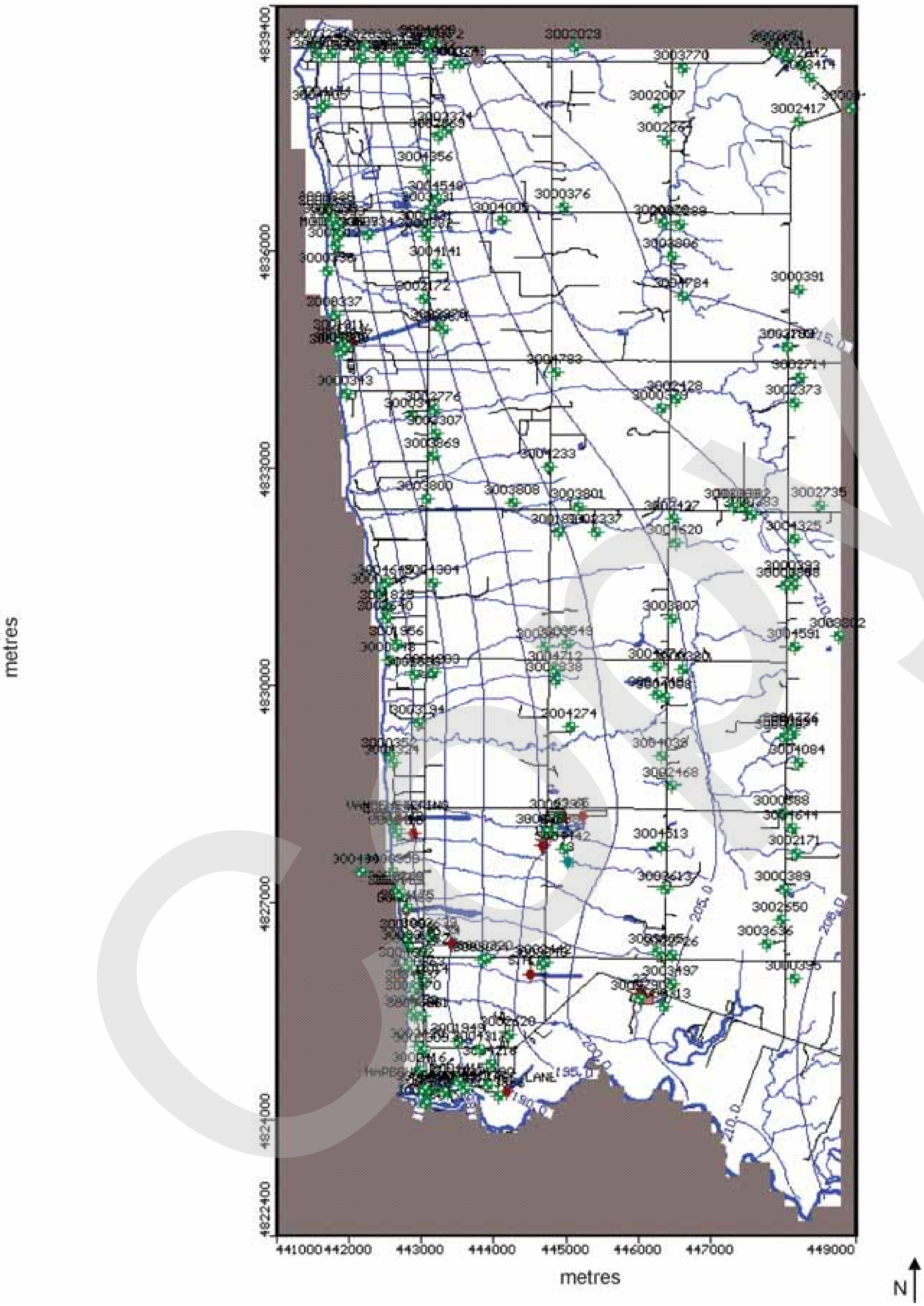

Figure G6: West Huron Groundwater Model Calculated Bedrock Water Levels, in metres

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Engineering & Environmental Consulting

Calculated vs Observed Head Residuals

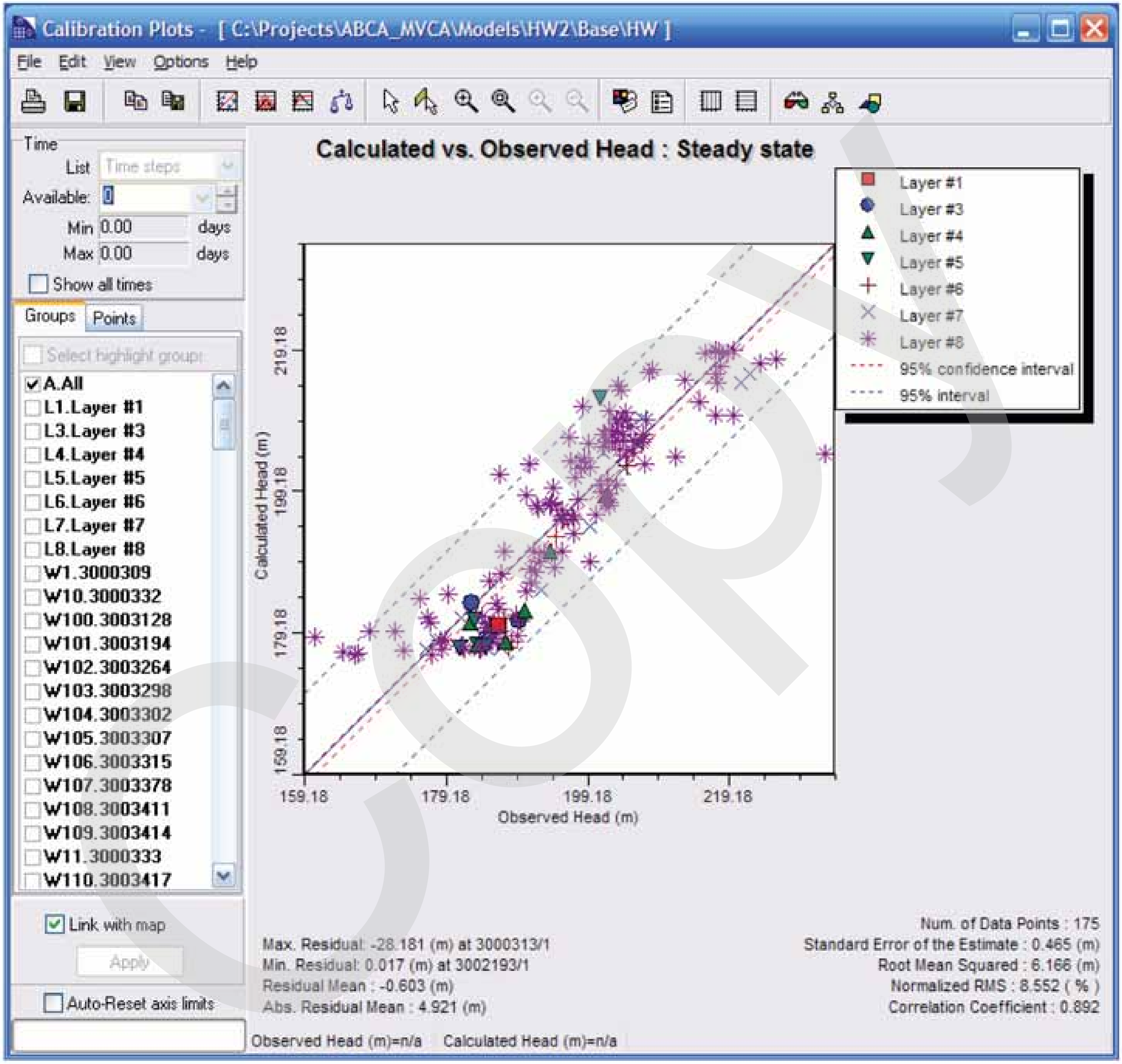

Figure G7: West Huron Groundwater Model Calibration Plot of Head Residuals