Proposed Dolostone Quarry, Hamilton

Volume 2: Groundwater Flow Model

Prepared for
Lowndes Holdings Corp.

Submitted by
Gartner Lee Limited

June, 2005

Draft for Discussion

Gartner Lee

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Reference: **GLL 23-827**

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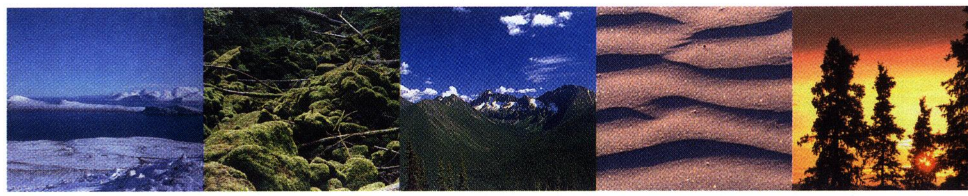

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1.0 Introduction

Lowndes Holdings Corp. proposes to develop a dolostone quarry on part of its Hamilton property, in the Geographic Township of East Flamborough (Figure 1). In September 2004, the Company applied for amendments to the former Town of Flamborough Official Plan and Zoning By-law, to enable licensing of a 154 ha (380 ac) site, comprising Part of Lot 1 and Lots 2 and 3, Concession 11. This application was accompanied by a Planning Report and a number of prescribed technical reports, including the *Preliminary Hydrogeological Assessment*, (Gartner Lee Limited, August 2004); and the John Emery Geotechnical Engineering Limited: *Geological Investigation*, (JEGEL, July 2004). The Company intends to file an 'Application For A Licence , under the Aggregate Resources Act', during 2005. One of the prescribed technical reports for that application is a "Hydrogeological Level 2 Report".

A regional groundwater flow model was developed as a component of the Level 2 Hydrogeological Assessment of the proposed dolostone quarry. The model was applied to simulate existing groundwater flow conditions in an extensive area that includes part of the Mountsberg Creek Subwatershed and the Flamboro Creek and Kilbride Creek subwatersheds within the Bronte Creek Watershed. The proposed dolostone quarry is located in the approximate centre of the modeled area (Figure 1).

The development of the groundwater flow model on a subwatershed scale was deemed appropriate for water resources planning, given the size and scope of the proposed development. This scale is also consistent with the Provincial Policy Statement under Section 3 of the Planning Act (2005) that considers the watershed as an 'ecologically meaningful scale for planning".

Model development involved the initial formulation of a conceptual model of the physical setting and groundwater flow, followed by data input, parameter selection and calibration of the numerical model. The groundwater model is used to predict the effects of quarry dewatering activities on groundwater levels and discharge to the existing wetlands and creeks, and to estimate the surface projection of the zone of influence for the quarry groundwater taking. The model also allows for the assessment of groundwater system responses to various quarry development scenarios and mitigation options.

The development of the conceptual and numerical models, and the results of model calibration and verification are the subject of this report. This report is referred to as 'Volume 2' of a set of three reports that encompass the Hydrogeological Level 2 Report. The application of the model to predict the potential impact of quarry dewatering operations is described in Sections 5 and 6 of this report and summarized in the main report (Volume 1). Volume 3 contains the field data, testing methodologies and results.

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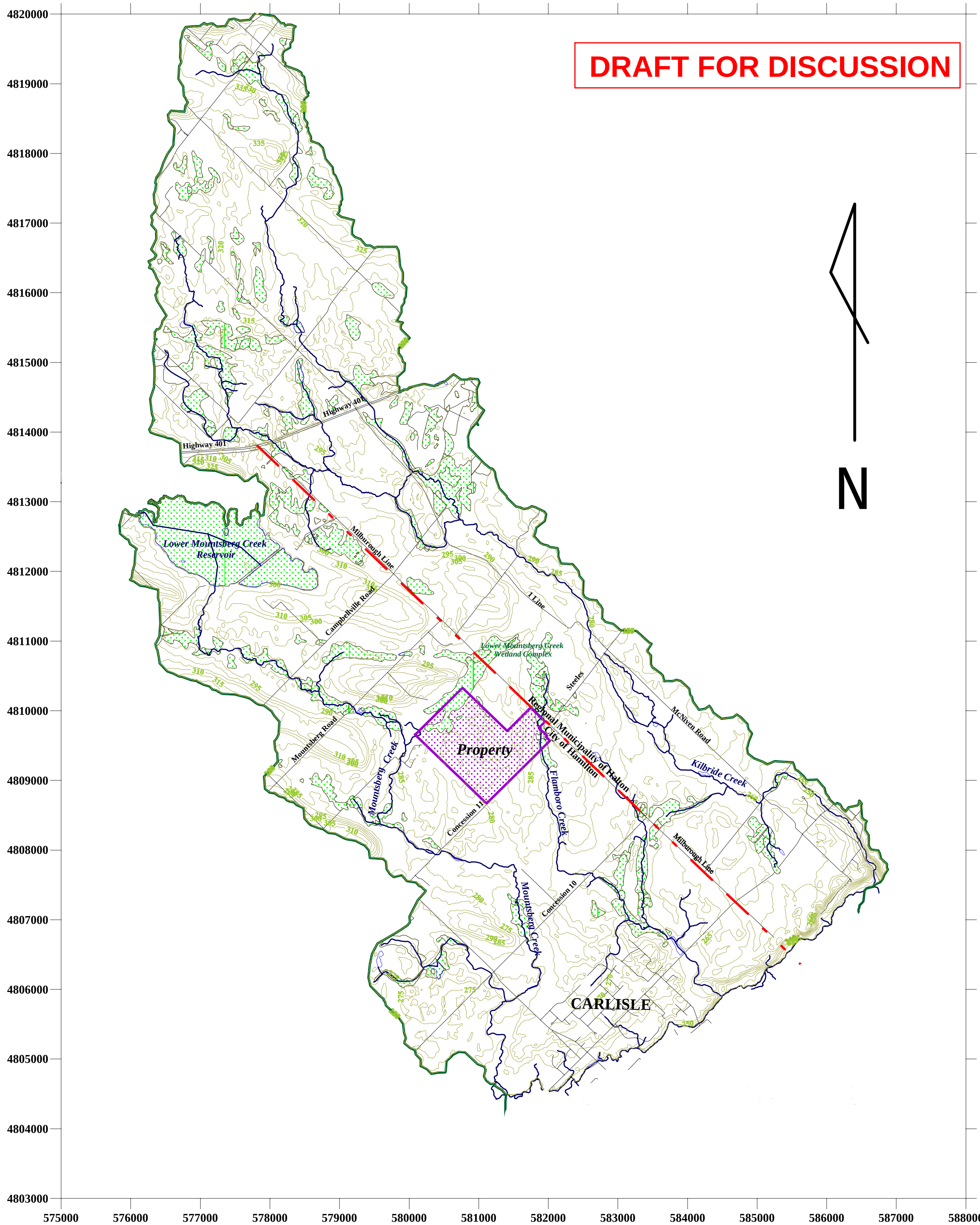


Legend

- Surface Drainage Features
- Water Bodies
- Wetlands
- Active Model Domain
- Property Boundary
- Roads

SOURCE: Base mapping produced by Gartner Lee Limited under license with the Ministry of Natural Resources, Queen's Printer 1997 - Reproduced 2004.

PROPOSED DOLOSTONE QUARRY	Figure 1
ACTIVE MODEL DOMAIN	
Project # 23827, Hydrogeological Modeling Investigation	
Gartner Lee Limited	
	Scale 1:80,000

2.0 Conceptual Model

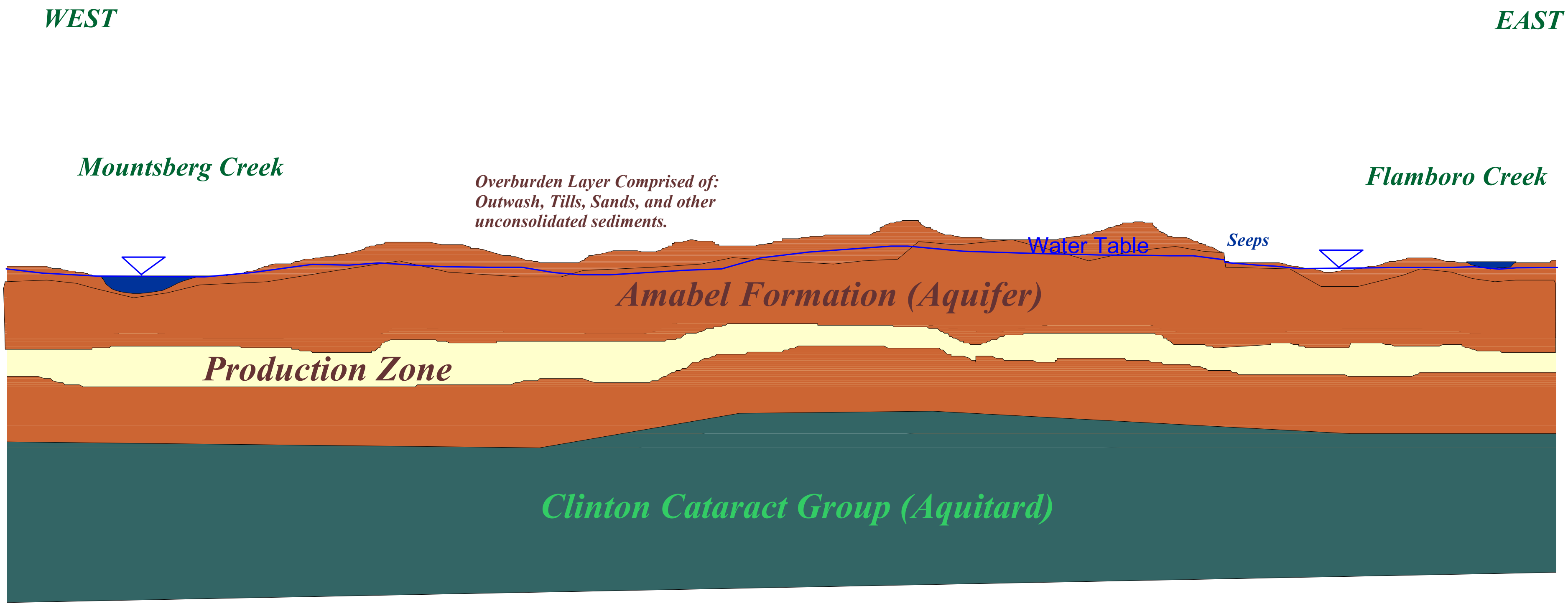
The initial step in the construction of the groundwater model is to develop a thorough understanding of the physical setting (topography, hydrology, geology and hydrogeology) and the various factors that govern groundwater flow within the watershed. This understanding, referred to as a conceptual model of the study area, considers:

1) the overburden and bedrock stratigraphy;
2) the geometry and continuity of the major water bearing geologic formations (aquifers and aquitards);
3) the physical conditions along the boundaries of the groundwater flow system;
4) the initial or ambient condition (historic and current groundwater levels and surface water flows);
5) the hydrogeologic properties of the major geologic units; and,
6) the rates of groundwater recharge and discharge.

The understanding of the physical setting of the study area was developed through a desktop assessment of available information, which was locally supplemented by field investigation. Specifically, the overburden and bedrock stratigraphy and geometry were used to create the stratigraphic layers employed in the model. Variations in the hydrogeologic properties of the layers and zones within the layers govern the magnitude of recharge and also control the movement of groundwater within and across the layers. Groundwater is discharged to streams and wetlands within the study area, and is extracted via residential and municipal water takings.

Information on groundwater levels was used to establish regional and local patterns of groundwater flow, and subsequently the extent of the area modeled and the conditions along the boundaries of the model. Water budget analysis was used to calculate initial estimates of natural recharge and the analysis of surface water flow (i.e., baseflow) and the compilation of the water takings provided an initial estimate of the discharge. These initial estimates were refined as additional field derived information was collected and again during model calibration.

Figure 2, a conceptual model of the study area in cross section, depicts the major stratigraphic units that comprise the groundwater domain. A summary description of the physical setting as defined in the conceptual model domain is presented in the following sections, whereas a more complete description of the study area is provided in the main report (Volume 1) and the supporting appendices (Volume 3).



DRAFT FOR DISCUSSION

PROPOSED DOLOSTONE QUARRY	Figure 2
CONCEPTUAL MODEL OF THE GROUNDWATER DOMAIN	
Project # 23827, Hydrogeological Modeling Investigation	
Gartner Lee Limited	Scale NTS

:07/07/05:\ N:\Projects\2003\23827\2005\WIP\Data Interpretation\2005 Model Report\Figures\Figure 2.srf

2.1 Information Sources

As noted, an understanding of the physical setting was developed through a review of available information including topographic maps and survey plans, Ministry of the Environment (MOE) water well records and existing geology/hydrogeology mapping and reports on the site and the vicinity. This was followed by the preparation of a series of base maps including a topographic surface map, a map depicting the major hydrologic features (streams, surface water bodies and wetlands), and a map showing the locations of MOE Water Well Records (WWR) as generated from the UTM co-ordinates provided in the WWR.

The MOE WWR database used for this groundwater study contains a total of 3,294 well records. The WWR data, however, are known to contain some information of uncertain quality so a quality control procedure was implemented to filter the WWR data prior to use. Of the total number of wells, 2,378 wells (72%) have acceptable quality assurance (QA) qualifiers (< or = 6) for both location coordinates and elevation, and were considered to be usable. The remaining 916 wells (28% of the total) have no location coordinates. Of the total usable geologic well records, 2,002 wells (84%) identify the depth at which bedrock was encountered, and were used to construct the overburden thickness and bedrock surface elevation maps presented in this study. The locations of the usable wells are shown in Figure 3. Approximately 28 water well records were identified as penetrating through the Amabel Formation within the model domain.

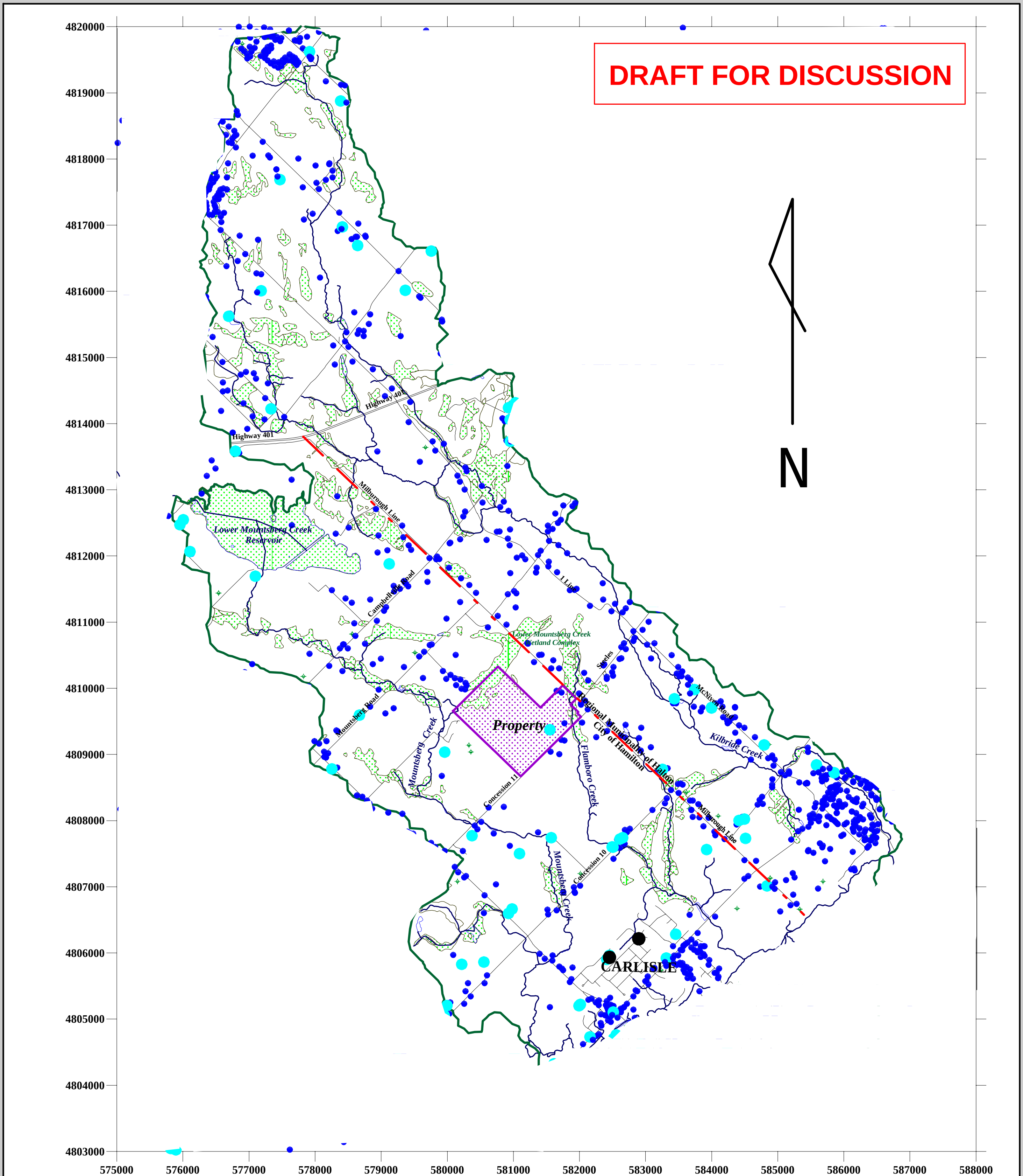
The field investigations completed on the subject property were undertaken to refine the understanding of the geology and hydrogeology developed from the background review. These investigations involved borehole drilling and well installation, hydrogeologic testing including pumping tests and discrete interval packer testing, and surface water flow and groundwater level measurements. This information was in turn used to generate surface elevation maps for the dominant aquifer and aquitard.

The reference section at the end of this report lists the published maps and reports that were considered in the review. A listing of the MOE WWR is provided in Appendix A. The field investigations are described in full in Volume 1 of this report and its supporting appendices (Volume 3).

2.2 Location and Topography

The property is bounded by residential development to the north, residential development and agricultural land (horse farm) to the west, forest to the east and Concession Road 11 to the south. Components of the Lower Mountsberg Creek Wetland Complex are located in the northern portion of the site and in the southeast portion of the site adjacent to Flamboro Creek. The Lower Mountsberg Creek Wetland Complex has been designated a Provincially Significant Wetland (PSW) by the MNR. The balance of the property is cultivated land separated by treed hedgerows.

The subject property is fairly hummocky, with rolling hills encompassing the majority of the site, except within the wetland boundaries. A dugout pond is found near the southern property line, with a pond elevation of 280.7 mASL. The ground elevation on the southern part of the property, closest to Concession 11, is about 281.5 mASL and rises to about 294.2 mASL in the center portion of the property, sloping downward to the north to an elevation of approximately 285 mASL in the wetland.



Legend

- Surface Drainage Features
- Water Bodies
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- Active Model Domain
- Property Boundary
- Roads
- MOE Water Well

SOURCE: Base mapping produced by Gartner Lee Limited under license with the Ministry of Natural Resources, Queen's Printer 1997 - Reproduced 2004.

PTTW (in Igpm)

- 0 to 10
- 11 to 50
- 51 to 100
- 101 to 200
- 201 to 9376

PROPOSED DOLOSTONE QUARRY

Figure 3

WATER WELL DISTRIBUTION INCLUDING WELLS WITH PTTW

Project # 23827, Hydrogeological Modeling Investigation

Gartner Lee Limited

Scale 1:80,000

:07/07/05:\ N:\Projects\2003\23827\2005\WIP\Data Interpretation\2005 Model Report\Figures\Figure 3.srf

2.3 Drainage Features

The various surface water features in the study area are shown in Figure 1. One of the primary features is the Lower Mountsberg Creek Wetland Complex, which is developed in topographically low areas adjacent to Mountsberg Creek and Flamboro Creek. The wetlands directly overlie the bedrock and demonstrate a discrete connection to the bedrock water table. The organic soils within the wetland areas are about 1 m to 2 m thick.

Flamboro Creek, which crosses the southeast corner of the property, drains towards the south. A tributary of Mountsberg Creek drains the wetland complex in the northern portion of the site and connects to Mountsberg Creek about 250 m northeast of the site. Kilbride Creek flows from the north of the study area to the south east of Flamboro Creek. Kilbride Creek, Flamboro Creek and Mountsberg Creek all connect to Bronte Creek over 3 km to the south of the property.

The hydrological flow stations (HYDAT) for this subwatershed exhibit flow fluctuations that range in the 300 to 16,000 liters per second (lps) range. The average annual flow for the Mountsberg Creek is approximately 670 lps. We are using 595 in Volume 1 The daily and annual average flow hydrographs for the subwatershed are presented in graphs provided in Appendix G, Volume 3.

2.4 Water Budget

The closest meteorological station with detailed coverage is located in the City of Hamilton. The mean annual precipitation as recorded at this station for the 55 years of meteorological data (from 1935 to 1990) is 849 mm per year. The total annual precipitation varies from 735 mm to 964 mm during 13 out of 20 years. This range is equivalent to a variation of one standard deviation of annual precipitation about the mean value.

The mean annual evapotranspiration is estimated to be 511 mm, based on assumed soil moisture storage of 100 mm. The mean annual water surplus is calculated to be 338 mm. The annual water surplus ranges from 257 mm to 439 mm during 13 out of 20 years. Page break? Part of this water will end up as surface runoff to local surface water features and the balance will infiltrate through the soil profile and recharge groundwater.

The water budget for the quarry will vary from that under the predevelopment condition. Specifically, with development, all soils and plants, and their associated evapotranspiration, will be removed within the quarry. The open excavation will therefore receive the full amount of available precipitation (849 mm).

An estimate of the volume of water surplus from direct precipitation is presented in the following table. This value was used to establish a recharge distribution throughout the model study area in the model calibration and values were adjusted slightly during the calibration process.

Table 1. Water Surplus Summary

	Total Precip. (mm)	Evapotranspiration (mm)	Surplus In Surounding Lands (mm)
JAN	59.3	0	59
FEB	56.1	0	56
MAR	67.4	0	67
APR	72.8	33	40
MAY	74.3	77	-3
JUN	71.7	105	-33
JUL	53.4	89	-36
AUG	74.0	84	-10
SEP	73.9	75	-1
OCT	72.7	39	34
NOV	91.2	10	81
DEC	82.6	0	83
YEAR	849	511	338

2.5 Geology

2.5.1 Surficial Geology and Overburden Thickness

The site is located in the Flamborough Plain physiographic region, described as a limestone plain with little overburden, scattered drumlins and numerous swamps (Chapman & Putnam, 1984). The overburden consists of either glacial till or sand and gravel. Organic deposits occur in the northern portion of the site, shale and dolomite outcropping along the western boundary and outwash gravel deposits in the southern portion.

The till is identified as the Wentworth Till (Karrow 1987). This till unit is present as surface cover over much of the area and forms the core of the drumlin hills within the subwatershed. It also forms the hummocky topography of the Galt and Paris moraines west of the study area. The Wentworth Till is a sandy till, which according to Karrow (1968) is made up of 49% sand, 18% clay and 33% silt. Older tills may underlie the Port Stanley Till at depth.

The overburden varies in thickness from 0.0 m to 7.9 m, and averages about 2.4 m (JEGEL, 2004). The Aggregate Resources Inventory Papers (ARIP,1984) shows the site to be located in the Selected Bedrock Resource Area 1, which encompasses the entire extent of the Amabel Formation covered by less than 25 feet (8 m) of drift.

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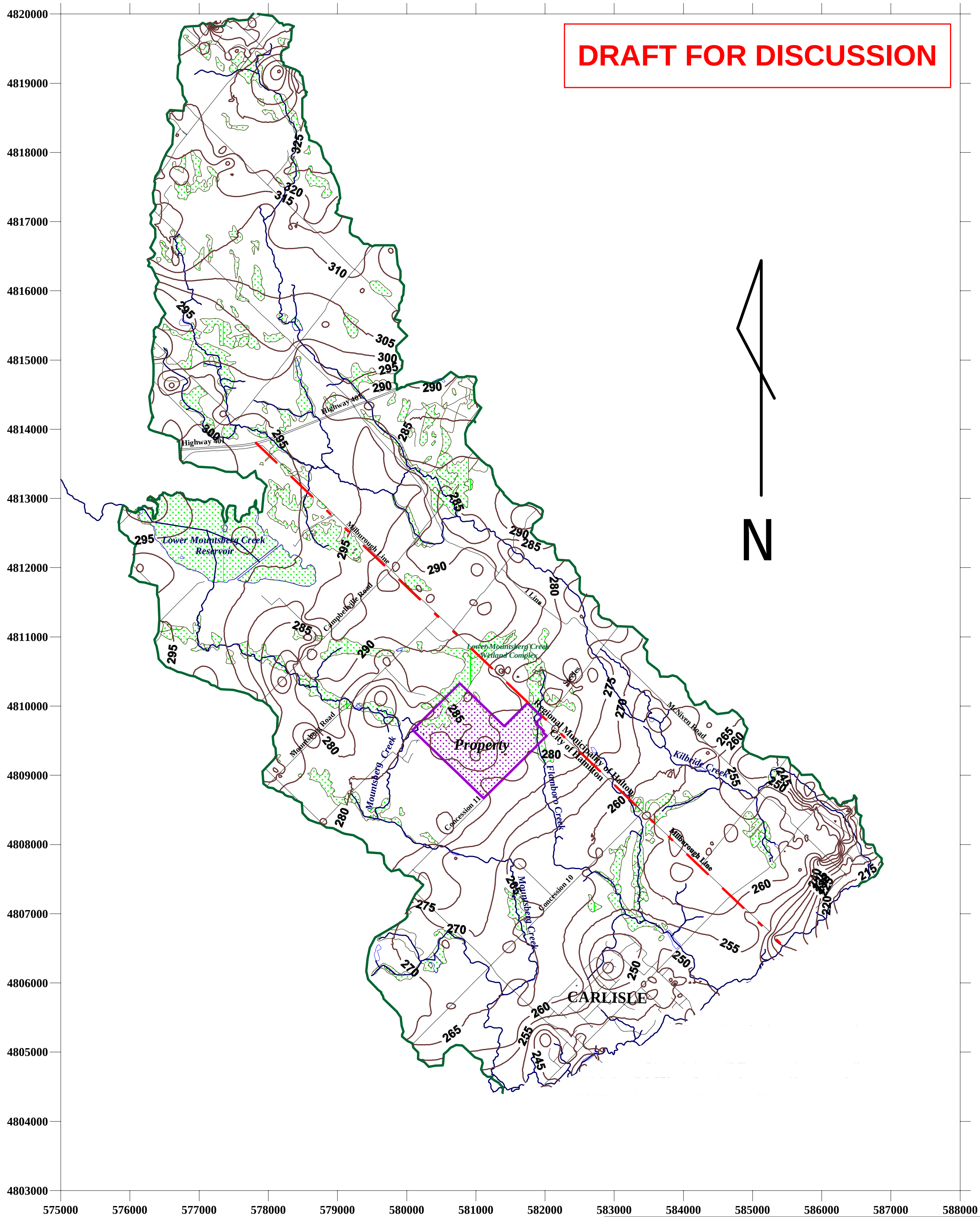
2.5.2 Bedrock Geology and Topography

The dominant bedrock unit, the Amabel Formation, is according to Telford (1979), approximately 30 m thick. From boreholes advanced on the property, the Amabel Formation is 27 m and 40 m thick, averaging 32.6 m (JEGEL, 2004). The Amabel Formation is underlain by the Reynales Formation a crystalline dolostone with calcareous shale, which averages about 2 m in thickness.. The Reynales Formation marks the transition between the carbonates of the Amabel Formation and the underlying Clinton Cataract Group that is comprised of the Cabot Head Shale, the Manitoulin Formation and the Whirlpool Formation.

Bedrock topography mapping on a regional scale is presented as Figure 4 and on a site scale in Figure 5. Figure 4 was prepared using the listed depths in the MOE WWR for the top of the uppermost bedrock unit and converting these depths to an elevation. Figure 5 was prepared using the geologic logs for boreholes installed on site.

On a regional basis, the bedrock surface slopes gently to the southwest at a rate of about 2 to 3 m/km. Land surface topography and the present-day drainage features closely follow the bedrock topography. Interpreted bedrock valleys identified based on bedrock topography, are also shown in Figure 4. The bedrock surface on a site scale (Figure 5) is generally consistent with the regional interpretation (Figure 4).

The interpreted bottom of the Amabel Formation on a regional scale, constructed using the MOE WWR data, is presented as Figure 6, and on a site scale, using the borehole data collected onsite, as Figure 7.



Legend

- Surface Drainage Features
- Water Bodies
- Wetlands
- Active Model Domain
- Property Boundary
- Roads
- Elevation Contours (mASL)

SOURCE: Base mapping produced by Gartner Lee Limited under license with the Ministry of Natural Resources, Queen's Printer 1997 - Reproduced 2004.

PROPOSED DOLOSTONE QUARRY	Figure 4
INTERPRETED TOP OF AMABEL FORMATION REGIONAL SCALE	
Project # 23827, Hydrogeological Modeling Investigation	
Gartner Lee Limited	
	Scale 1:80,000

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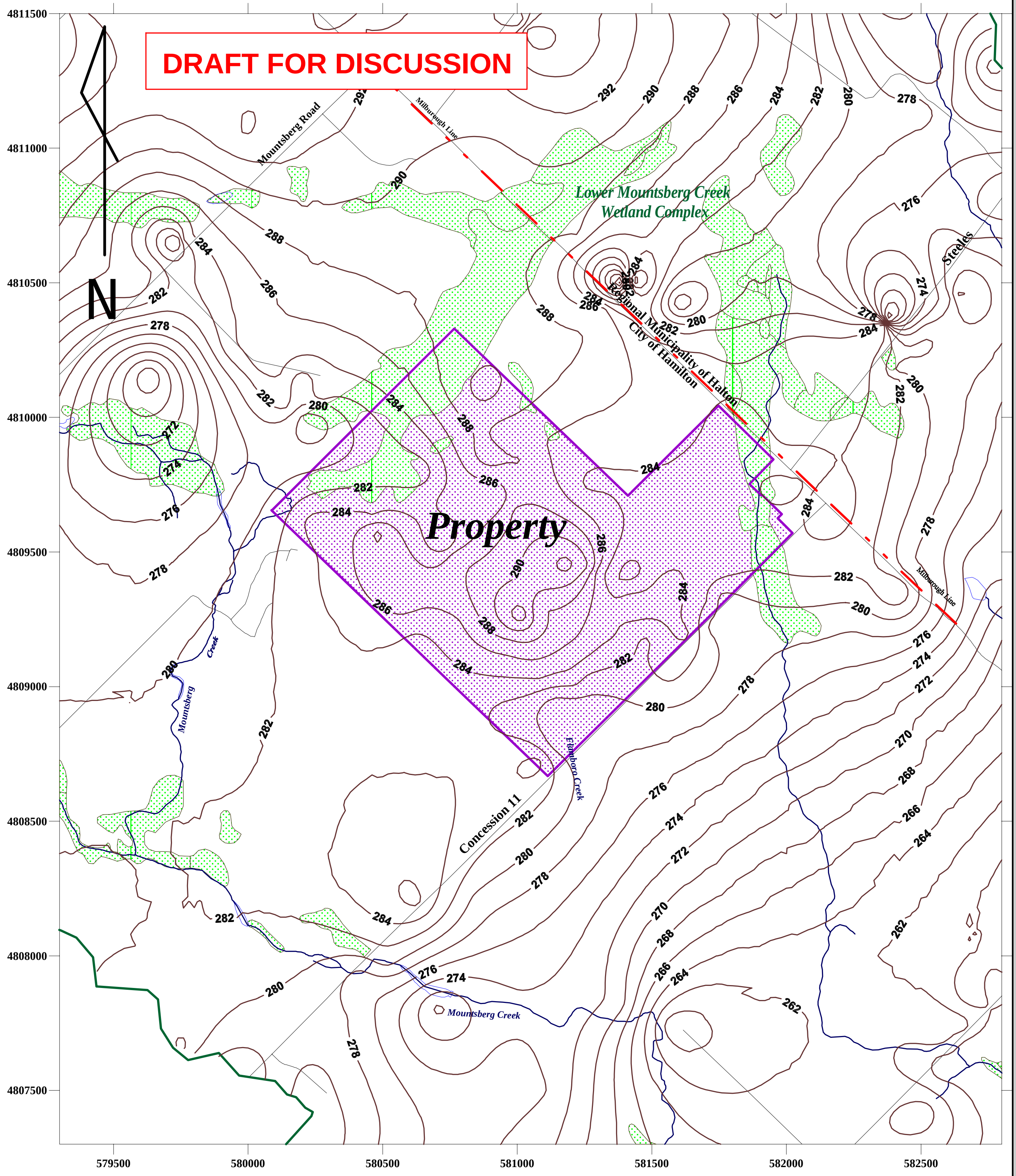

Legend

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SOURCE: Base mapping produced by Gartner Lee Limited under license with the Ministry of Natural Resources, Queen's Printer 1997 - Reproduced 2004.

PROPOSED DOLOSTONE QUARRY	Figure 5

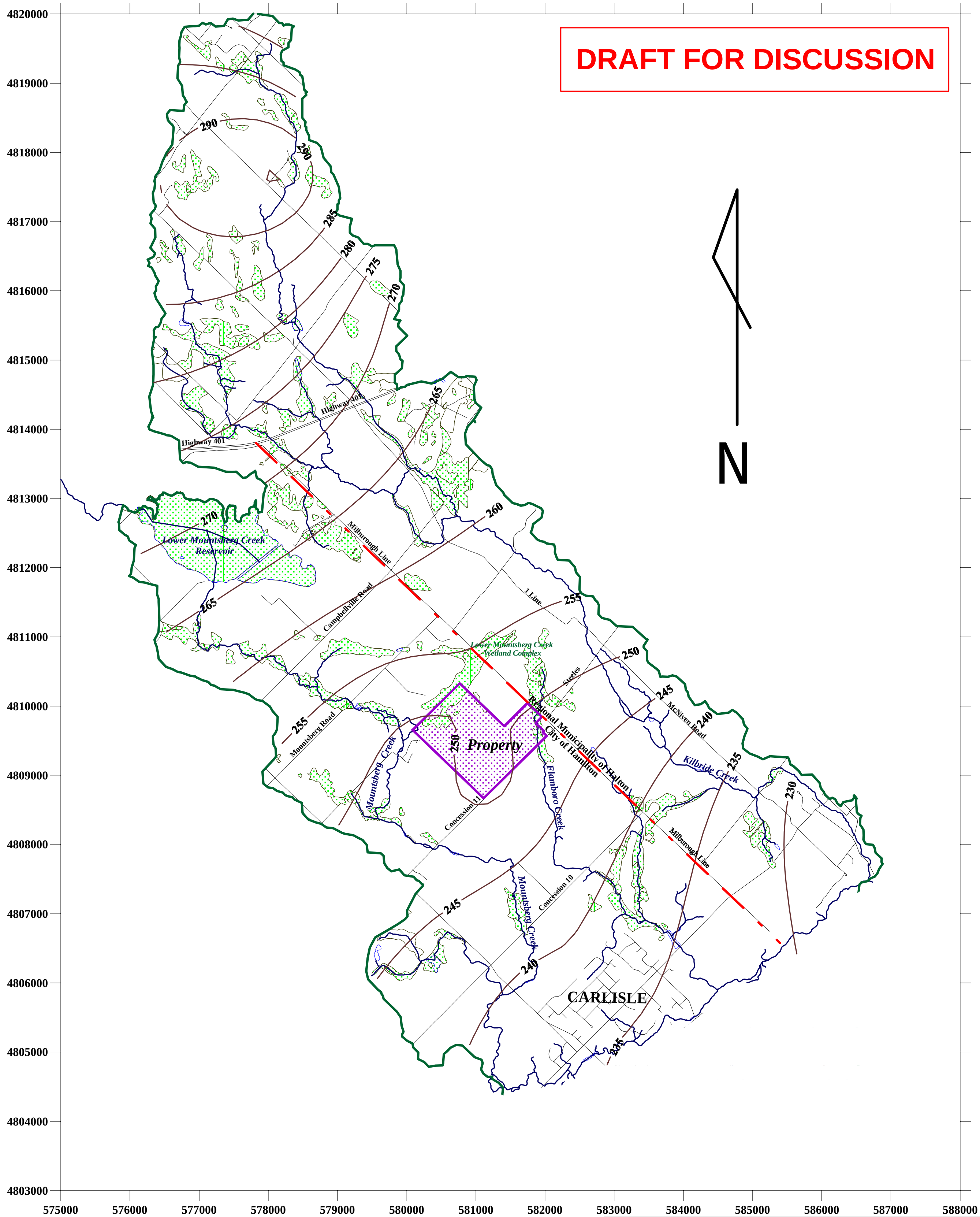
INTERPRETED TOP OF AMABEL FORMATION - SITE SCALE

Project # 23827, Hydrogeological Modeling Investigation

Gartner Lee Limited

Scale 1:20,000

:07/07/05:\ N:\Projects\2003\23827\2005\WIP\Data Interpretation\2005 Model Report\Figures\Figure 5.srf



Legend

- Surface Drainage Features
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- Active Model Domain
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- Elevation Contours (mASL)

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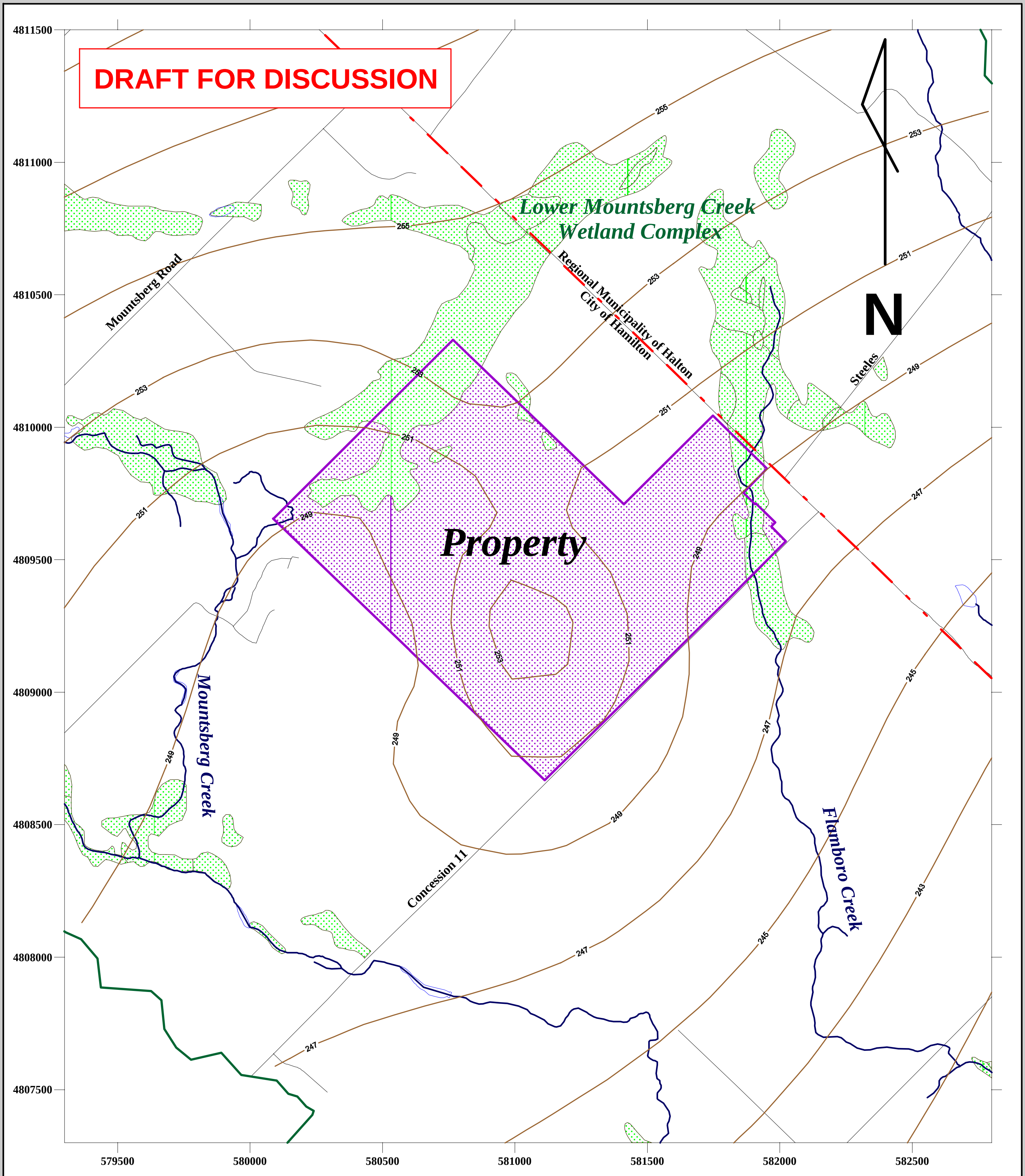
PROPOSED DOLOSTONE QUARRY	Figure 6
INTERPRETED BOTTOM OF AMABEL FORMATION - REGIONAL SCALE	
Project # 23827, Hydrogeological Modeling Investigation	
Gartner Lee Limited	Scale 1:80,000

:07/07/05:\ N:\Projects\2003\23827\2005\WIP\Data Interpretation\2005 Model Report\Figures\Figure 6.srf



Legend

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- Property Boundary
- Roads
- Interpreted Elevation Contours (mASL)

SOURCE: Base mapping produced by Gartner Lee Limited under license with the Ministry of Natural Resources, Queen's Printer 1997 - Reproduced 2004.

PROPOSED DOLOSTONE QUARRY | **Figure 7**

INTERPRETED BOTTOM OF AMABEL FORMATION - SITE SCALE

Project # 23827, Hydrogeological Modeling Investigation

Gartner Lee Limited

Scale 1:20,000

:07/07/05:\ N:\Projects\2003\23827\2005\WIP\Data Interpretation\2005 Model Report\Figures\Figure 7.srf

2.6 Hydrogeology

2.6.1 Overburden

Materials of varying hydraulic conductivity including lacustrine and outwash sands, ice contact gravel and glacial till, are fairly continuous across the study area. Till is the surface cover over much of the area and forms the core of the drumlin hills within the subwatershed. Discontinuous lenses of sand and gravel can occur within the till unit but are not significant from a regional flow perspective.

Where the till is at surface, the groundwater recharge potential is reduced, except in areas of hummocky topography where storm water runoff accumulates and, over time, infiltrates and recharges the groundwater system.

Glacial outwash and kame deposits occur in the southeastern part of the study area in the vicinity of Carlisle. Where present at surface, these deposits have a high groundwater recharge potential. The thicker, more continuous sand and gravel deposits have aquifer potential and represent a water supply source for some residences.

From a modeling perspective, the primary function of the overburden is to control precipitation infiltration or groundwater recharge and surface water runoff. The fine-grained soils (till, silt and clay) act to retard infiltration and promote surface runoff. Within the upland areas, the coarse-grained sediments (gravel and sand) and the bedrock where close to the surface, tend to reduce runoff and promote infiltration. In the topographically low areas these same materials are associated with groundwater discharge.

2.6.2 Bedrock

The Amabel Formation is a regionally significant aquifer extending from Niagara Falls to the Bruce Peninsula. This unit is capable of satisfying residential water supply requirements and in some cases more demanding municipal requirements. The thickness of the Amabel Formation ranges from 27 m in the eastern part of the study area to over 40 m in the west.

The permeability of the aquifer is due primarily to the dissolution of dolomite along fractures and bedding planes. Fracture patterns can be highly variable and, therefore, hydraulic conductivity can vary widely.

The hydraulic conductivity of the Amabel Formation ranges from 1×10^{-8} m/s to as high as 1×10^{-2} m/s depending on location and depth. The upper portion of the rock exhibited a hydraulic conductivity in the 1×10^{-6} m/s range, while the lower portion of the Amabel exhibited a hydraulic conductivity in the 1×10^{-7}

m/s range. Also from available packer testing, a zone of higher permeability rock was encountered in some boreholes about mid way through the Amabel Formation (i.e., 15 m to 25 m depth). The geometric mean of the hydraulic conductivity values through this zone, referred to as the “productive zone”, is 2 x 10^{-4} m/s.

Where the bedrock is at or close to surface, connectivity between the Amabel Formation and the local streams, tributaries, and wetlands is evident. The level of connectivity is variable and can range from a very strong connection to a very subtle connection with little dependence on groundwater originating from this formation.

The bedrock formations that comprise the Clinton Cataract Group have a low hydraulic conductivity and as such act as an aquitard unit relative to the Amabel Formation. .

2.6.3 Regional Groundwater Flow

Groundwater flow is for the most part under unconfined conditions. Upward hydraulic gradients and discharge conditions are prevalent through out the watershed in the low-lying areas, whereas downward gradients and recharge conditions are evident at topographic highs.

A potentiometric surface mapping for the Amabel Formation was prepared using static water level data from the MOE WWR database. The 2,378 “usable” well records were filtered to identify wells with high quality ground elevations. The recorded land surface elevations were compared against the Digital Elevation Model (DEM),calculated for a 100 m grid spacing, and those wells that showed a >10 m deviation from the DEM were rejected. The DEM referenced wells were then filtered to identify a subset of wells where the recorded bottom of the well is at a depth of less than 20 m below ground surface (bgs) [Note: The 20 m depth in the study area represents the approximate ‘midway’ depth of the Amabel Formation]. This resulted in 1,781 higher quality records.

Figure 8, ‘Calibration Targets with Interpreted Groundwater Contours’, was constructed using the static water levels at the time of well installation for this subset of WWR. Figure 9 is a potentiometric surface map prepared using groundwater level measurements taken at the deeper bedrock wells installed on site. The contoured surfaces presented in the figures were generated using kriging, a widely accepted interpolation method (see Davis, 1973).

The pattern of groundwater flow exhibited in Figure 8 and Figure 9 is consistent with the groundwater gradient map from Turner (1978) and shows that groundwater flow follows a general north-to-south trend. The regional trends and water levels depicted in Figure 8 were used to determine a reasonable limit for the model extent.

3.0 Numerical Model Development

Groundwater levels (also referred to as aquifer potentials or hydraulic heads) within the study area are controlled by the stratigraphy, the magnitude and spatial variation of hydraulic conductivity, and the rate and distribution of groundwater recharge and discharge. The groundwater flow model developed for this study incorporates this information and solves a mass-balance equation to determine aquifer potentials at all points within the study area. The resultant aquifer potentials can then be interpreted using Darcy's Law to determine the rates and direction of groundwater flow.

3.1 Groundwater Flow Theory

The general mass balance equation for steady-state groundwater flow can be stated as:

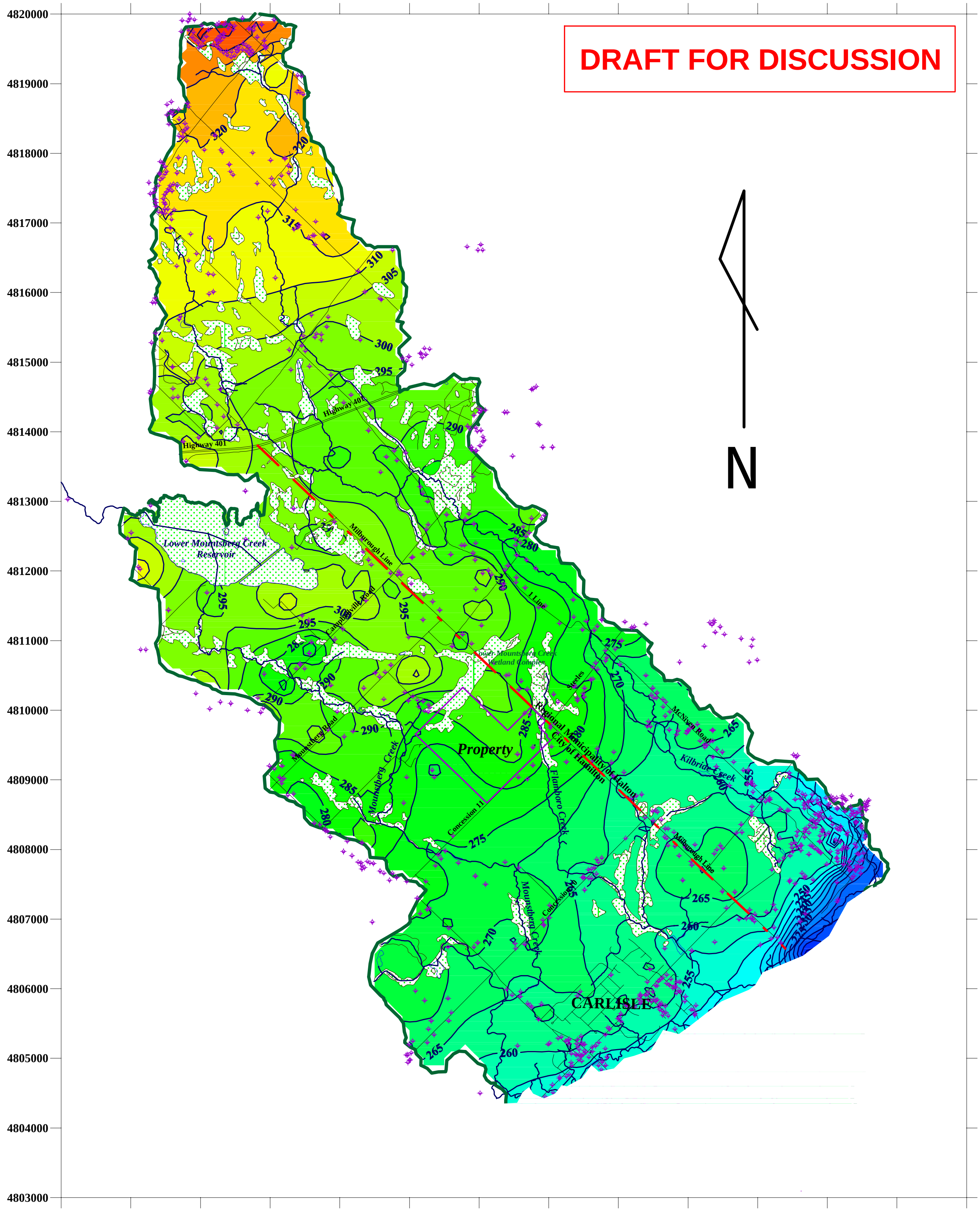
Sum of Boundary Inflows + Sum of All Internal Sources of Water = Sum of Boundary Outflows

Mathematically, the equation of mass balance in an unconfined aquifer with recharge, discharge, and leakage from below can be written as (Bear, 1979):

$$\frac{\partial}{\partial x}(h-b)\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}(h-b)\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{K'}{B'}(H_o-h)+N-W=0 \qquad (1)$$

Where:

	K_{xx}	=	hydraulic conductivity in the x direction (equivalent to model East);
	K_{yy}	=	hydraulic conductivity in the y direction (equivalent to model North);
	h	=	hydraulic head or aquifer potential;
	b	=	elevation of the unit bottom;
	K'	=	vertical hydraulic conductivity of an underlying confining unit;
	B'	=	thickness of the confining unit;
	H_o	=	head in the aquifer underlying the confining unit;
	N	=	a general source term representing the rate of groundwater recharge; and
	W	=	a general sink term representing the rate of groundwater discharge.



Legend

- Surface Drainage Features
- Water Bodies
- Wetlands
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- Property Boundary
- Roads
- Interpreted Grountwater Contours (mASL)

SOURCE: Base mapping produced by Gartner Lee Limited under license with the Ministry of Natural Resources, Queen's Printer 1997 - Reproduced 2004.

195 205 215 225 235 245 255 265 275 285 295 305 315 325 335

Groundwater Elevation Distribution (masl)

Water Balance

Total In	Total out
Recharge = 39, 383 cubic Metres/day	Drains = 869 cubic Metres/day
Rivers = 68,796 cubic metres/day	Rivers = 99,007 cubic metres/day
	Evapotranspiration (wetlands) = 9175 cubic metres/day
	(percent discrepency between in and out = 0.36%)

PROPOSED DOLOSTONE QUARRY — **Figure 8**

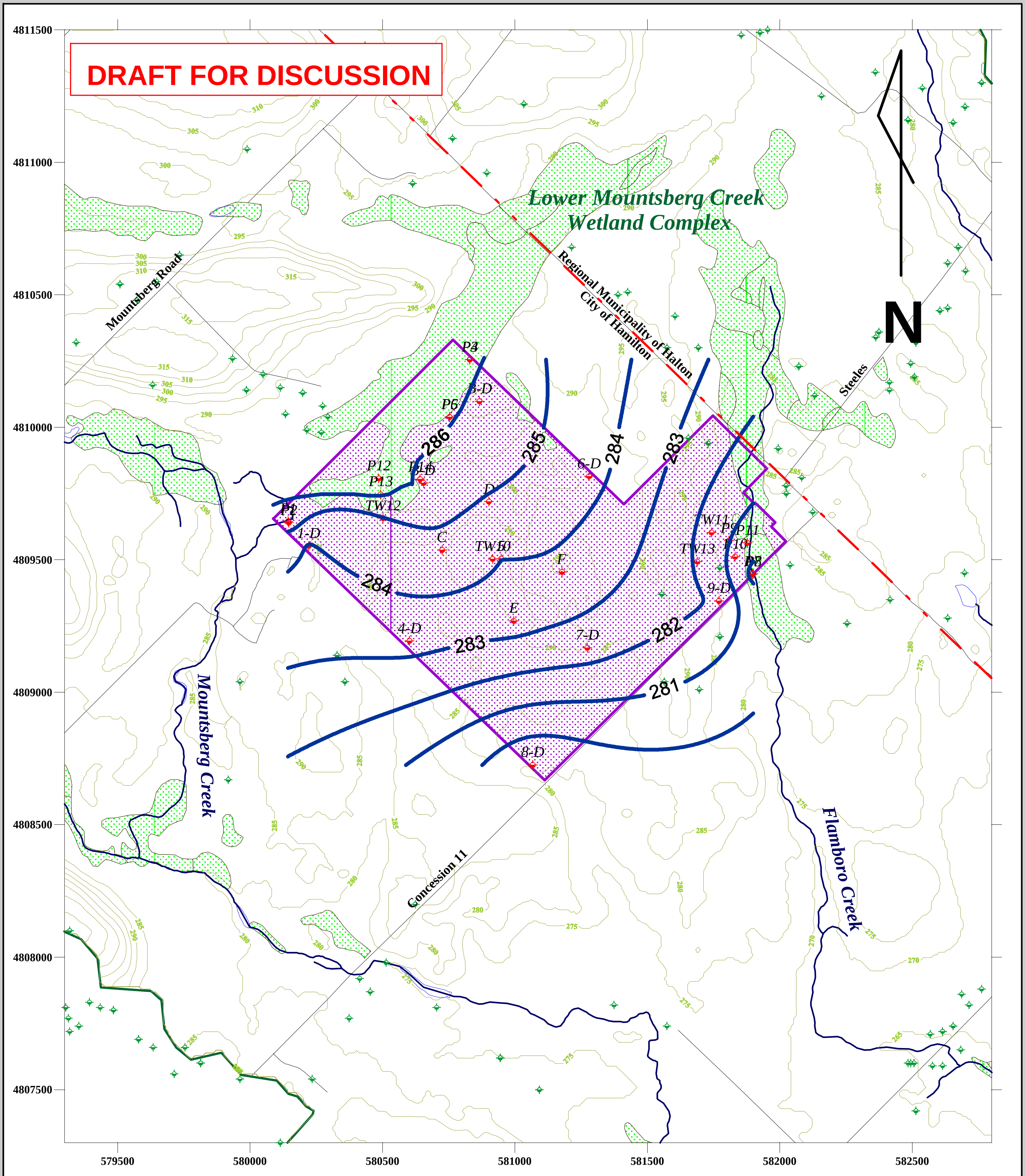
CALIBRATION TARGETS WITH INTERPRETED GROUNDWATER CONTOURS

Project # 23827, Hydrogeological Modeling Investigation

Gartner Lee Limited

Scale 1:80,000

:07/07/05:\ N:\Projects\2003\23827\2005\Data Interpretation\2005 Model Report\Figures\Figure 8.srf



Legend

- Surface Drainage Features
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- Groundwater Contours (mASL)

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PROPOSED DOLOSTONE QUARRY | **Figure 9**

CALIBRATION TARGETS WITH INTERPRETED GROUNDWATER CONTOURS - SITE SCALE

Project # 23827, Hydrogeological Modeling Investigation

Gartner Lee Limited

Scale 1:20,000

:07/07/05:\ N:\Projects\2003\23827\2005\WIP\Data Interpretation\2005 Model Report\Figures\Figure 9.srf

Similar equations can be written for each aquifer in a layered sequence of aquifers and confining units. When an aquifer layer is confined, the saturated thickness term (h-b) is replaced by the total thickness of the aquifer (B). The product of hydraulic conductivity and the aquifer thickness is referred to as the aquifer transmissivity.

The above equation forms the basis of the mathematical model developed for the study area. This equation is solved using a numerical model code called MODFLOW developed by the USEPA (McDonald and Harbaugh, 1998), to determine the aquifer potentials once the required data on aquifer properties, recharge and discharge rates, and conditions along the study area boundaries have been specified. Numerical methods and computer techniques are needed to solve this equation because study area boundaries are irregular and aquifer properties, stratigraphy, and rates of recharge and discharge vary spatially within the study area.

3.2 Model Limitations

The modeling conducted for this study using the MODFLOW code simulated steady-state flow conditions only. Steady-state simulations are a simplification of the actual transient flow system. The various transient effects, such as daily or seasonal fluctuations in aquifer potentials, rates of precipitation and evapotranspiration and surface water level, are removed from the model and average values for each parameter have been applied. For example, precipitation and the water level in the Mountsberg Creek are represented using average annual values. The resulting steady-state model provides a good representation of average groundwater flow conditions over the course of the year.

All models are a simplification of the true physical system and as such, the predictions made by the model are framed within the nature of the simplifying assumptions used in model development. While there are certain inherent assumptions relating to the governing flow equations and the numerical methods employed in their solution, the most significant simplifying assumptions made in model development are related to the limited availability and uncertainty in the field data. Specifically, geologic systems tend to be complex due to the variable physical properties of rock and soil. Because the number of boreholes available to characterize a site is limited, there is generally some uncertainty regarding how representative the measured values are of average properties in the vicinity of the borehole and how the property values change between boreholes. Other uncertainties arise related to how well groundwater recharge and discharge rates can be measured or estimated. Data limitations can also affect the quality of the model calibration. Lack of data in critical areas of the model can reduce the number of unique parameter zones that can be represented and can lead to non-unique model calibrations.

Despite these limitations, groundwater models are a useful tool and provide insight into the factors that influence groundwater flow in a particular area. Particularly, models that are developed and calibrated for a specific site can be applied to predict the effects of induced changes to the natural water budget attributed to municipal water takings or quarry dewatering. The resultant modification to the natural water budget is a water balance, whereby water is redistributed between ecological function and human use. The extent to which this balance is modified will determine whether the effects are detrimental to the natural ecology of a watershed or if the balance of water use is sustainable within the watershed. In general, groundwater models can accurately simulate average water levels, gradients, and flow directions and are very useful tools in determining the balance of water within a given watershed.

It should be noted that predictions of flow paths and well capture zones, are less reliable since actual flow paths and capture zones can be significantly affected by small-scale variations in geology and aquifer properties that are not incorporated into the model.

3.3 Modeling Environment

In addition to MODFLOW, the USGS MODPATH code (Pollock, 1989) was used to simulate groundwater flow paths. This code uses the aquifer potentials determined by MODFLOW along with other data to determine groundwater time of travel for municipal well capture analyses.

The data management and presentation tool *Visual Modflow* (Waterloo Hydrogeologic Inc., Version 4.1) was used to pre-process the model input data and post-process model results. Most figures presented in this technical report were generated using *Arcview GIS software.*

4.0 Numerical Model Construction

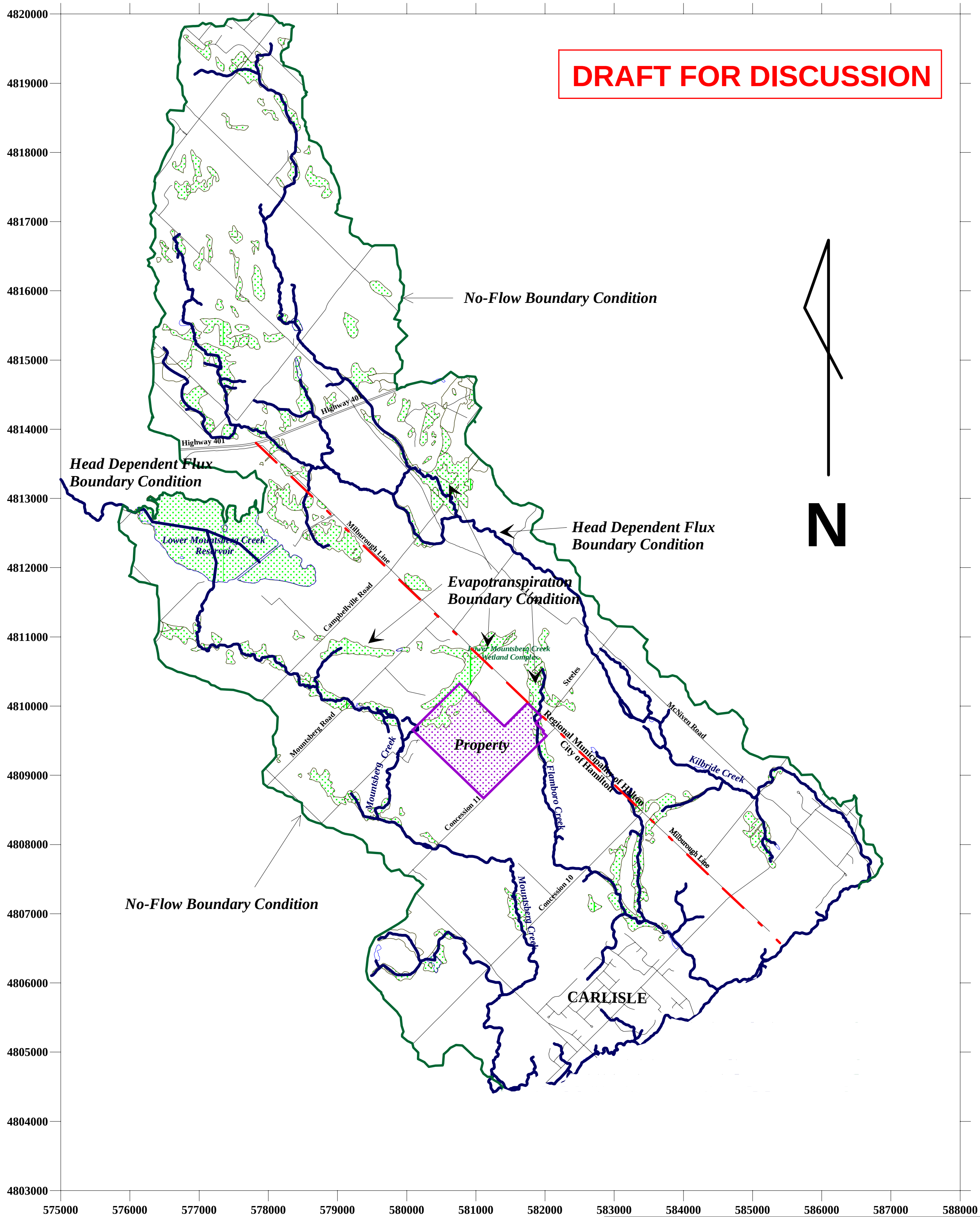
4.1 Model Setup

The groundwater model was constructed to retain the primary components of the conceptual model, such as stratigraphy, hydraulic boundaries, recharge distribution, confined and unconfined aquifers, and local stresses such as pumping wells. The active model domain extends from north of Highway 401, to just south of Carlisle. This encompasses the Mountsberg Creek subwatershed and portions of the Kilbride Creek and Flamboro Creek subwatersheds. Where possible, the perimeter boundary of the model coincided with natural physical boundaries such as rivers, lakes and watershed divides. This approach is important from a water balance perspective, and in particular when evaluating the groundwater inputs and outputs from an environmental perspective. Figure 10 illustrates the active model domain.

4.1.1 Model Grid

The model grid was designed to optimize grid resolution in the vicinity of the proposed development. The grid was oriented north to south and east to west consistent with the Universal Transverse Mercator co-ordinate system. Rotation or translation of the model grid was not applied due to the scale of the regional model as well as the prominent north orientation of this particular subwatershed.

Figure 11 illustrates the regional grid discretization and orientation. The model grid consists of 377 rows by 264 columns by four (4) layers. The total number of grid cells is 398,112.



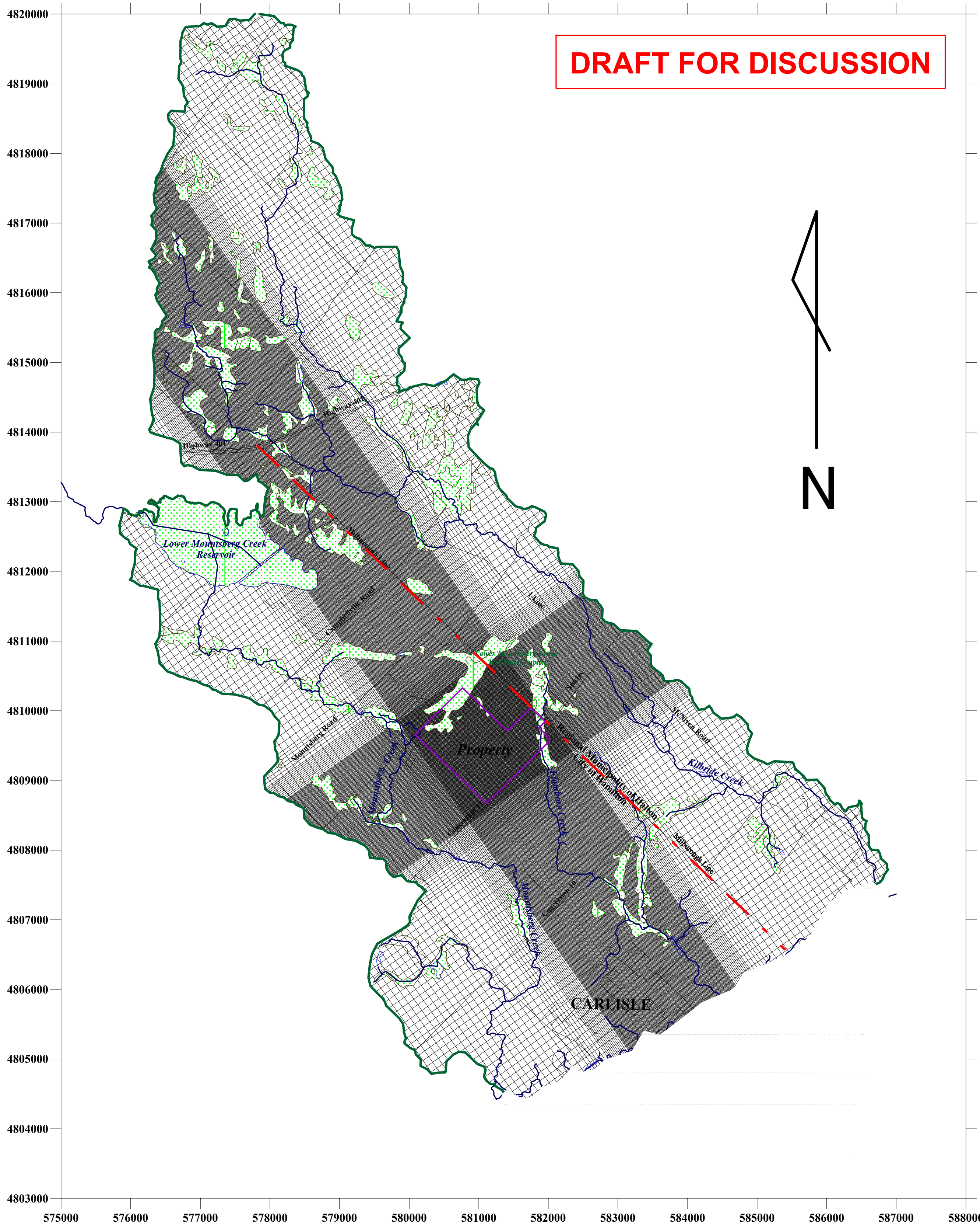
Legend

- Surface Drainage Features
- Water Bodies
- Wetlands
- Active Model Domain
- Property Boundary
- Roads
- Boundary Conditions

SOURCE: Base mapping produced by Gartner Lee Limited under license with the Ministry of Natural Resources, Queen's Printer 1997 - Reproduced 2004.

PROPOSED DOLOSTONE QUARRY	Figure 10
ACTIVE MODEL DOMAIN WITH BOUNDARY CONDITIONS	
Project # 23827, Hydrogeological Modeling Investigation	
Gartner Lee Limited	
	Scale 1:80,000

:07/07/05:\ N:\Projects\2003\23827\2005\WIP\Data Interpretation\2005 Model Report\Figures\Figure 10.srf



Legend

- Surface Drainage Features
- Water Bodies
- Wetlands
- Active Model Domain
- Property Boundary
- Roads
- Model Grid Distribution

SOURCE: Base mapping produced by Gartner Lee Limited under license with the Ministry of Natural Resources, Queen's Printer 1997 - Reproduced 2004.

PROPOSED DOLOSTONE QUARRY | **Figure 11**

MODEL FINITE DIFFERENCE GRID DISCRETIZATION AND ORIENTATION

Project # 23827, Hydrogeological Modeling Investigation

Gartner Lee Limited

Scale 1:80,000

:07/07/05:\ N:\Projects\2003\23827\2005\WIP\Data Interpretation\2005 Model Report\Figures\Figure 11.srf

4.1.2 Flow Boundaries

Internal boundaries in the model were designed to represent natural drainage features such as streams creeks and rivers. These features were represented with flux river boundaries, whereby water can be removed from the model but can also be added to the model domain. Applying this type of boundary is an appropriate measure since the boundary will add water to the model domain in the case, for example, of a loosing stream.

The Mountsberg Creek, Flamboro Creek and Kilbride Creek are the main streams within the model domain and are simulated as head-dependent recharge/discharge boundaries using the MODFOW River Package. This allows groundwater to flow into or out of the model depending on the hydraulic gradient at the applicable grid nodes in the model. Smaller streams are simulated as head-dependent drains using the MODFOW Drain Package. Under this condition, groundwater can only flow out of the model at rates dependent on the hydraulic gradient at the applicable grid nodes in the model. A summary of the input parameters for the MODFLOW River and Drain Packages is presented below.

Table 2. River Boundary Summary

Surface Water Body Type	MODFLOW Package Applied	Stream Bed Conductance (m^2/day)	River Width (m)	Surface Water Elevation (mASL)
Mountsberg Creek from Reservoir	River	1,000-2,000	3	ground surface elevation
Flamboro Creek	River	2,000-4,000	2	ground surface elevation
Lower Mountsberg Creek	River	2,000-4,000	6	ground surface elevation
Flamboro Creek, Steeles & Conc 11	River	170-2,200	5	ground surface elevation
Kilbride Creek and other Streams/Creeks	River/Drain	2,000-4,000	4	ground surface elevation

The head dependent flux (HDF) term for each grid cell is calculated as follows:

$$HDF = SBC \bullet RW \bullet RL(h_{SWE} - h_{WT}) \qquad (2)$$

Where:
- SBC = Stream bed conductance (hydraulic conductivity divided by bed thickness);
- RW = River bed width (specified in above table);
- RL = River length (calculated with Arcview);
- h_{SWE} = Surface water elevation (based on Digital Elevation Model); and,
- h_{WT} = Water table elevation in cell.

When the water table is above the specified surface water elevation, both the river and drain boundaries allow groundwater to discharge from the groundwater system. When the water table drops below the surface water elevation of a river boundary, water is allowed to recharge into the groundwater system. Under these conditions, the maximum difference in hydraulic head between the river and the water table has been set to 1 m. However, when the water table drops below the surface water elevation of a drain boundary, no flow is allowed to recharge into the groundwater system (i.e., flow is allowed from the aquifer to the drain only).

Cells within the active model domain can go “dry” during a simulation if the water table drops below the base of the layer. These cells are then treated internally by MODFLOW as inactive cells since they no longer contribute flow to the rest of the model area. The number of dry cells and their locations varied in each of the model simulations in response to changes in model input conditions

No-flow boundaries were applied to surface water divides that were assumed to approximate groundwater divides. Figure 10 illustrates the model boundary conditions.

4.1.3 Extraction Wells

The locations of residential water wells, larger capacity municipal wells and private wells exceeding a production rate of 50,000 L/day with MOE issued Permit To Take Water (PTTW) are shown in Figure 3. Information on these wells is provided in Appendix B, Volume 3. These groundwater takings were incorporated into the model. Most of the watershed wells and other permitted takings extract water from the Amabel Aquifer.

The Carlisle municipal wells were simulated using the USGS Modflows Well package. Permitted rates for the respective water takings were applied in the model.

4.1.4 Groundwater Infiltration or Recharge

Methodology for Determining Recharge: The key to the hydrologic cycle in any terrestrial environment is the influx of water into the system. In this case the driving factor is the fraction of precipitation that infiltrates the ground surface and enters the groundwater system – known simply as recharge. In most environments the majority of the precipitation is lost through evapotranspiration, while the surplus is partitioned into surface run-off and infiltration. Climate (particularly temperature), surficial geology, vegetation cover and ground slope govern the relative amount contributed to evapotranspiration, run-off and infiltration

Often groundwater models are set up using a set of arbitrary numbers to model the partitioning of precipitation into infiltration, evapotranspiration and run-off across the model domain, and these are frequently assumed to be constant across the study area. Due to the relative size of the model constructed for this project (approximately 2,000 km^2) a more detailed process was used in an attempt to more accurately model the variety of conditions occurring in the natural system.

Three steps have been used to produce an estimate of recharge. The first was to calculate the quantity of surplus water available for infiltration and run-off using the method developed by Thornthwaite and Mather (1957). Secondly, in order to partition the surplus water into run-off and infiltration, an infiltration coefficient, as outlined by the Ministry of the Environment (1995), was determined for the region relative to the Mountsberg Creek subwatershed. This infiltration partitioning distribution, in combination with the distribution of water surpluses given by the water surplus calculations, will produce a model of the spatial variability of groundwater recharge across the study area, from which the recharge distribution for the model domain can be applied. The third step involves the multiplication of the surplus grid with the infiltration grid to produce the groundwater recharge distribution grid for the model.

Water Surplus: A water balance was prepared using the method described in Thornthwaite and Mather (1957). This method is used to estimate the available water surplus within the defined study area and considers precipitation, temperature, latitude, soil type and vegetative cover. Surficial soil type and vegetative cover are represented in the Thornthwaite technique by a factor known as the Water Holding Capacity (WHC), which is measured in millimetres. The WHC provides a way of modeling the ability of fine-grained soils or those with deep-rooted vegetation to hold more water than coarser-grained soils or those with shallow-rooted vegetation or no cover at all.

Surficial geology and vegetation distributions are available for the study area, however temperature and precipitation data exist only for a number of discrete points in proximity to the area of interest. The calculation of water surplus was done using the monthly mean climate data for the climate station present in the vicinity of the study area. For each station and its surrounding area, the prevalent vegetation type and density of cover were combined with the predominant surficial soil type to give a Water Holding Capacity (WHC, in millimetres) for the area.

The Thornthwaite and Mather method assumes that water is lost to evapotranspiration in a non-linear fashion, that is, the actual evapotranspiration is somewhat less than the potential evapotranspiration. The calculation produces an annual water surplus for the station and the surrounding area.

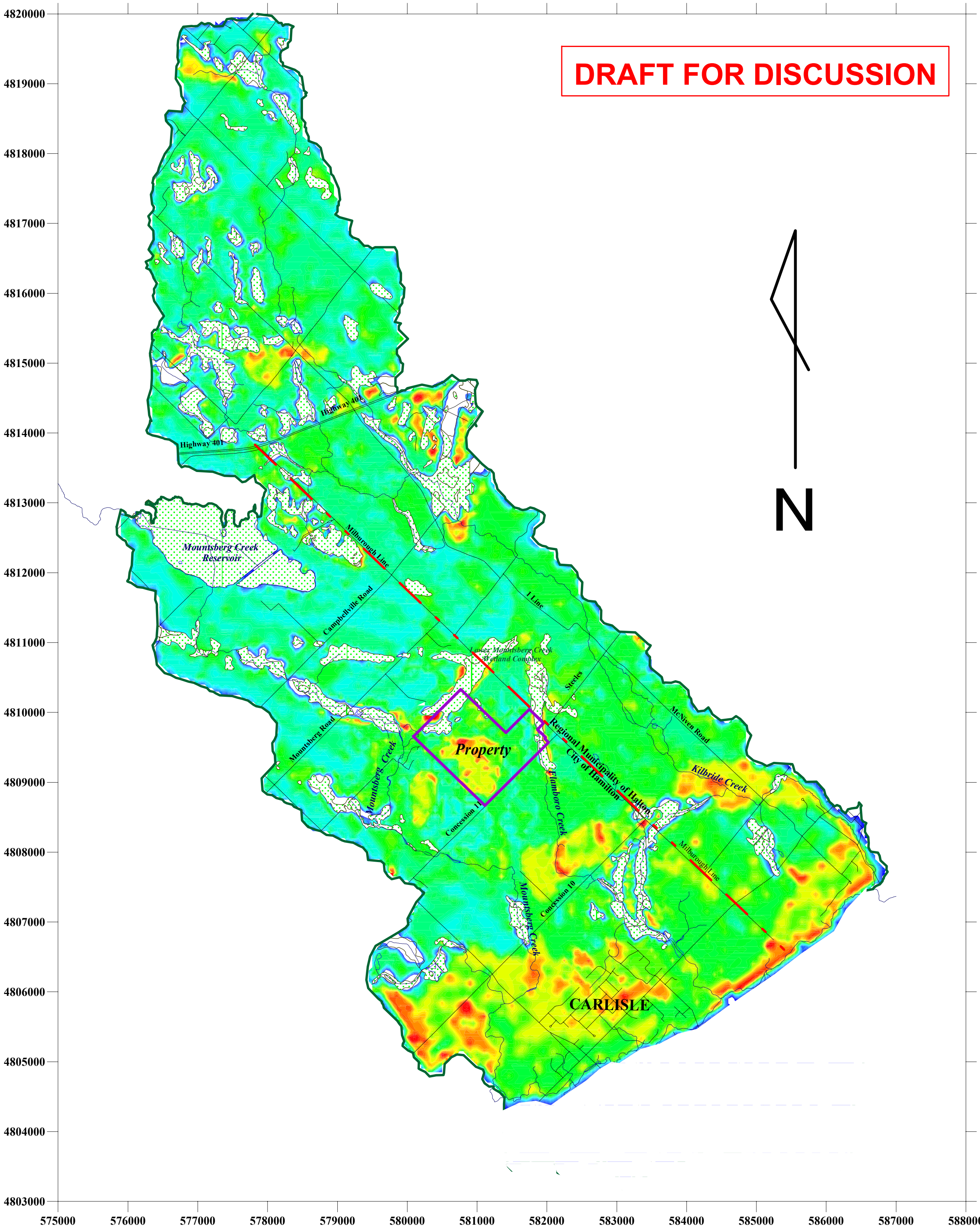
Vegetation Component: It may appear that the described approach is accounting for the affect of vegetation twice; that is, once in the calculation of water surplus (by Thornthwaite) and then again in the application of the Infiltration Factor. This, however, is not the case.

In the determination of the surplus (the partitioning of precipitation into surplus and evapotranspiration) increased vegetation cover decreases the amount of surplus water. Transpiration is the obvious and primary mechanism responsible for the decrease in water surplus when vegetative cover increases. Interception by foliage is also instrumental in enhancing the evaporative affect - interception prevents, or at least slows, precipitation reaching the ground surface, thus increasing exposure to the atmosphere and elevating the amount of evaporation that occurs.

Separate from influencing evapotranspiration, infiltration is affected by differing levels of vegetation cover. Water left over from precipitation after evapotranspiration has been accounted for and is directed either to surface runoff or to infiltration. Non-porous and sloped surfaces promote runoff, but the addition of vegetation to such a surface retards the ability of the water to runoff, and increases the contribution to infiltration. Plants interrupt and reduce the potential for surface flow and cause ponding, especially in the case of vegetation with extensive lateral root systems. Ponding, by extending residence time at the surface, increases the amount of water that percolates into the soil, removing it from the runoff component. Root systems are also responsible for improving the ability of water to infiltrate into the subsurface. Roots cause the formation of macropores, which develop into preferential flowpaths for vertical drainage, and can contribute a significant amount of recharge to the groundwater-system.

Infiltration Factor: The average annual water surplus can be partitioned between runoff and infiltration by the method given by the Ontario MOE (1995). In essence, this methodology derives infiltration coefficients based on soils, topography and vegetation. Coarser soils are more permeable than soils composed of finer grains, and thus lead to higher rates of infiltration. Sloped ground promotes run-off, and so retards infiltration. Shallow-rooted vegetation (particularly cultivated crops) allows less infiltration than do deep-rooted cover. These factors are added to produce a calculated infiltration coefficient within the range 0-1.0, which represents the fraction of surplus water, which permeates the soils at surface and enters the groundwater system as recharge. Because the study area is complex in terms of soil polygons, changes in slope, and changes in vegetative cover GIS (Arcview) is the tool of choice for this calculation.

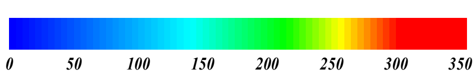
Recharge Distribution: The water surplus calculated using Thornthwaite and Mather method, is multiplied by the Infiltration factor in order to determine the amount of recharge (and, if desired, the amount of run-off) that results from precipitation. Generating the spatial distribution of groundwater recharge is then a matter of multiplying the distributions of both Infiltration factor and water surplus. Due to the complexity of carrying this process out for a large geographic area this task was performed using GIS programs. The final recharge distribution, as imported into Visual MODFLOW, is illustrated in Figure 12.



Legend

- Surface Drainage Features
- Water Bodies
- Wetlands
- Active Model Domain
- Property Boundary
- Roads

SOURCE: Base mapping produced by Gartner Lee Limited under license with the Ministry of Natural Resources, Queen's Printer 1997 - Reproduced 2004.



Groundwater Recharge Distribution (mm/yr)

PROPOSED DOLOSTONE QUARRY | **Figure 12**

GROUNDWATER RECHARGE DISTRIBUTION

Project # 23827, Hydrogeological Modeling Investigation

Gartner Lee Limited

Scale 1:80,000

:07/07/05:\ N:\Projects\2003\23827\2005\WIP\Data Interpretation\2005 Model Report\Figures\Figure 12.srf

4.1.5 Preparation of Model Layer Surfaces

The numerical model developed for the study area incorporated detailed information on the stratigraphy of the aquifers and aquitards. Four layers were used in the groundwater flow model to represent the flow units identified in the study area (see Figure 2). Model layers are discussed further in the next section. Preparation of the surfaces representing the tops and bottoms of each layer involved: (1) analyzing MOE WWR and site specific borehole logs; (2) identifying the top and bottom of each aquifer layer and aquitard; (3) interpolating the point elevation data to the finite-difference grid; (4) checking the generated surfaces; and, (5) correcting surfaces by slightly adjusting elevations, where required.

The layers are based on MOE WWR data, site-specific borehole data and the results of the packer testing performed on these boreholes. The following information was summarized for each well/borehole location: 1) land surface elevation; 2) the top of the Amabel Formation; 3) the top of the "production zone" within the Amabel aquifer; 4) the bottom of the "production zone"; and 5) the top of the lower shale unit that served as the base of the Amabel aquifer. The base of the Amabel Formation is indicated by the Reynales Formation, which is stratigraphically older than the Amabel Formation and averages about 2 m thick below the subject property and is about 3 m to 5 m thick in broader area.

4.1.6 Model Layers

The model incorporates four layers to simulate the hydrogeology (as shown in the conceptual model in Figure 2) for the region. The four layers are described as follows:

- Layer 1 (top layer) encompasses the overburden and the upper portion of the bedrock;
- Layer 2 represents the productive zone of the Amabel Formation (the intermediate bedrock aquifer, herein referred to as the Amabel production zone, found across much of area modeled);
- Layer 3 represents the lower Amabel Formation and the Reynales Formation, (units that exhibits a lower transmissivity compared to the productive zone within the Amabel Formation);
- Layer 4 represents the Unsubdivided Clinton Cataract Group (the lower shale bedrock aquitard, herein referred to as the Clinton Cataract Group Aquitard, present across the entire modeled area);

The ground surface contours for the model which are presented in Figure 1, were developed by applying the Digital Elevation Model (DEM) obtained from the MNR for the study area. The top of bedrock layer, presented in Figure 4, was developed using the top of the first bedrock unit encountered in the screened WWR. The layer contact surfaces are presented in Figures 13 and 14 for the productive zone. The surface contours were generated by kriging the contact elevations. Since MODFLOW requires each model layer to be continuous across the grid, these units do not pose any mathematical barriers.

4.1.7 Model Parameters

The hydrogeologic characteristics of the overburden (Layer 1) were defined using estimated hydraulic conductivities based on the soil types shown in the surficial geology map. Initial estimates for the different soil types were based on ranges provided in Freeze and Cherry (1979) and refined during the process of calibrating the model.

Calibration of bedrock hydraulic conductivities was accomplished by first simulating pre-development conditions (i.e., no pumping) and comparing with Turner (1978) to ensure that the hydraulic conductivities and recharge rates selected, yielded a reasonable match to regional flow patterns. Next, a composite of the static water levels, as determined in the MOE WWR well database, was matched. This resulted in an initial definition of higher and lower permeability zones within the bedrock aquifer layers. Further adjustment of the hydraulic conductivities for the bedrock units was undertaken to better match observed hydraulic heads.

The hydraulic conductivities used for the regional model are summarized in Table 3 and shown Figure 15 and Figure 17. Figure 16 presents the location of the cross-section presented in Figure 17 for vertical hydraulic conductivity distributions. Anisotropy ratios were selected through the process of calibrating the model. No leakage is assumed to occur between the Amabel Aquifer and the underlying Clinton Cataract Group in the model.

Larger zones of higher hydraulic conductivity were placed in locations where bedrock valleys and existing rivers coincide. Aquifer test results from pumping tests conducted on site test wells in 2003/2004 were used to help refine and verify hydraulic conductivity values selected for the different zones identified in the bedrock formation.

The hydraulic conductivity values selected to represent the Amabel Aquifer in the Lowndes Quarry area were based on the results from: 1) discrete interval packer testing; 2) 72-hour formation pumping test; and, 3) 168-hour aquifer system pumping test. These pumping test results indicated hydraulic conductivities for the Amabel Formation range from 1×10^{-6} m/s in the shallow bedrock, to 1×10^{-2} m/s in the “productive zone”, to 1×10^{-8} m/s in the lower beds of the Amabel Formation. These hydraulic conductivities are considered representative of the Amabel in the model domain. Hydraulic conductivity values of 1×10^{-6} m/s and 1×10^{-8} m/s were applied to the upper and lower beds of the Amabel Formation (Layers 1 and 3), respectively.

A higher hydraulic conductivity of 4×10^{-4} m/s was applied to Layer 2 of the model in the southern and eastern portions of the model domain. This value was selected based on model calibration and is consistent with the 168-hour and the 72-hour pumping test conducted at TW11 and TW12 by Gartner Lee Limited (2004). Results of the pumping test indicated the productive zone (Layer 2) of the Amabel

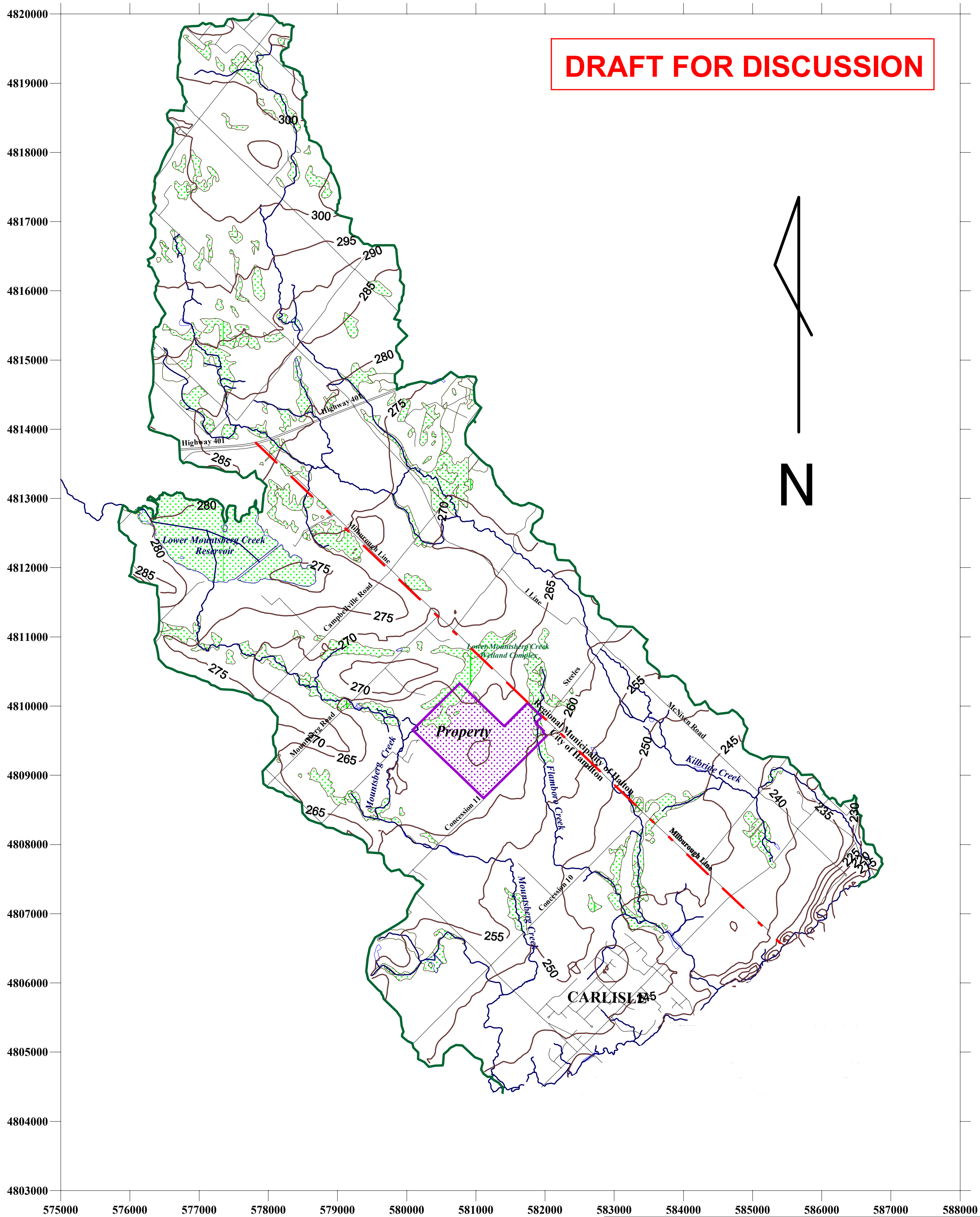
Aquifer is present at an elevation of approximately 260 mASL and 265 mASL. This zone has a transmissivity in the range of approximately 4.3 x 10^{-4} m^2/s to 1.3 x 10^{-3} m^2/s. Assuming the thickness of the productive zone is 5 m, the highest transmissivity converts to a hydraulic conductivity of 2.0 x 10^{-4} m/s.

Gartner Lee

Table 3: Parameters for the Calibrated Groundwater Flow Model

Layer 1 -- Overburden and Upper Amabel		Hydraulic Conductivity		Vertical Hydraulic Conductivity Anisotropy Ratios	Effective Porosity
Area Number	Surficial Geology	m/d	m/s	(-)	(-)
1	Wentworth Till	0.0864	1.00E-06	0.1	0.3
5	Glacial Lacustrine Sand	3.456	4.00E-05	0.1	0.3
6	Till	0.864	1.00E-05	0.1	0.3
7	Ice contact Gravel	34.56	4.00E-04	0.1	0.3
8	Bedrock	0.0432	5.00E-07	0.1	0.1
9	Till	6.048	7.00E-05	0.1	0.3
11	Organic Deposits	0.00864	1.00E-07	0.2	0.4

Layers 2 -4 -- Bedrock		Hydraulic Conductivity		Vertical Hydraulic Conductivity Anisotropy Ratios	Effective Porosity
Area Number	Layer Number -- Formation	m/d	m/s	(-)	(-)
12	Layer 2 -- Productive Zone	17.28	2.00E-04	0.1	0.1
10	Layer 3 -- Lower Amabel	0.00864	1.00E-07	0.1	0.1
2	Layer 4 -- Bedrock	0.00864	1.00E-07	0.1	0.1



Legend

- Surface Drainage Features
- Water Bodies
- Wetlands
- Active Model Domain
- Property Boundary
- Roads
- Elevation Contours (mASL)

SOURCE: Base mapping produced by Gartner Lee Limited under license with the Ministry of Natural Resources, Queen's Printer 1997 - Reproduced 2004.

PROPOSED DOLOSTONE QUARRY | **Figure 13**

INTERPRETED TOP OF PRODUCTION ZONE

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Gartner Lee Limited

Scale 1:80,000

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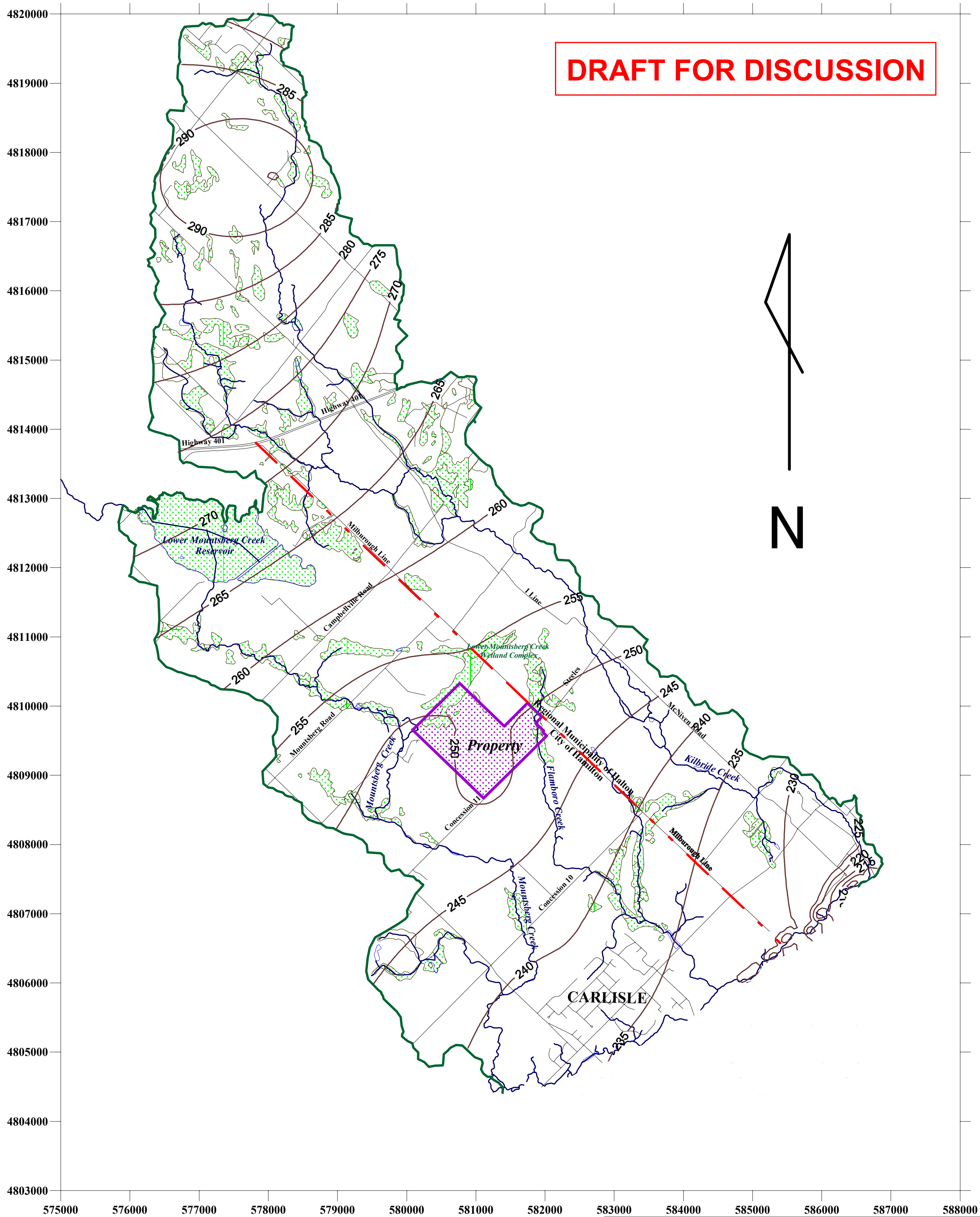


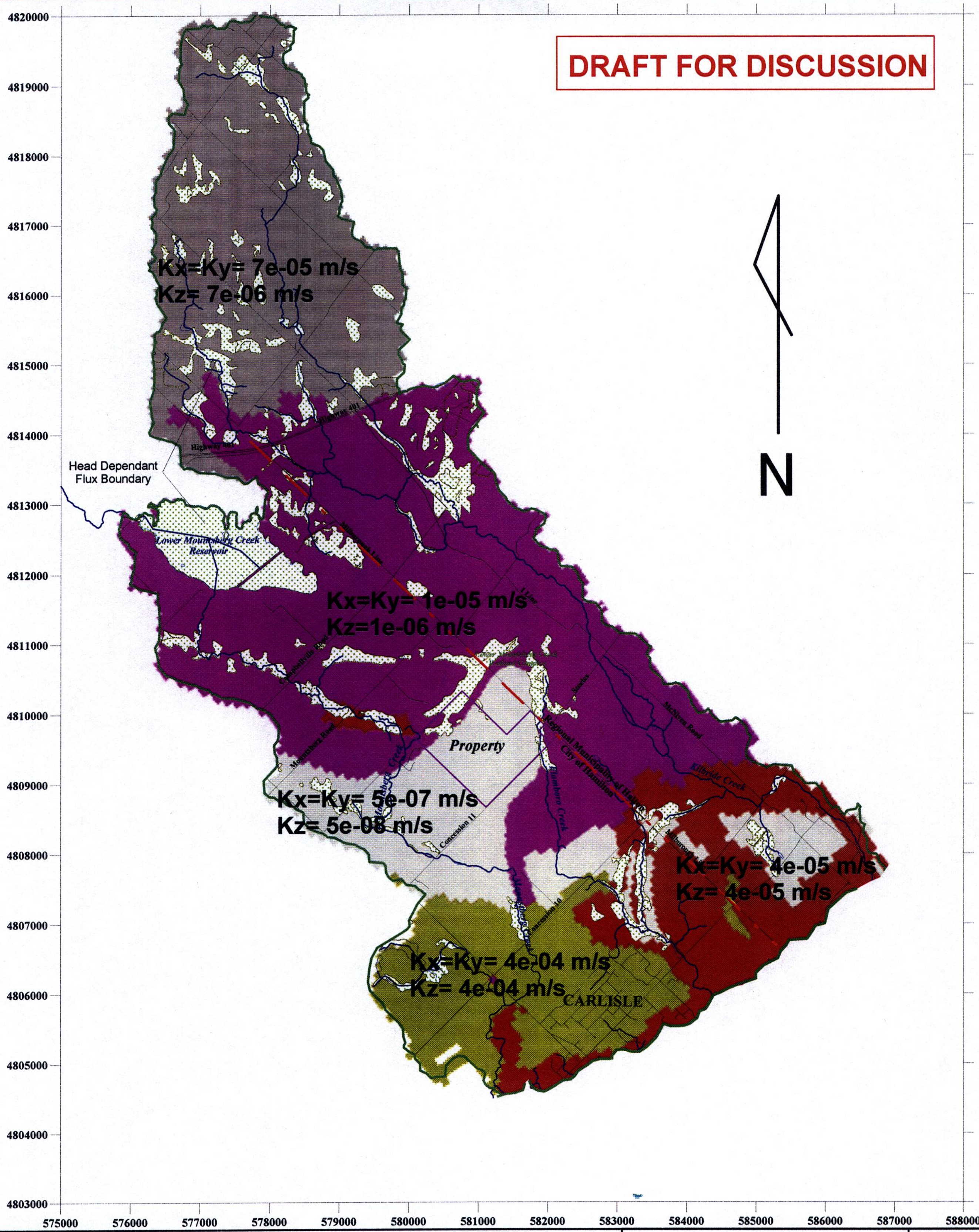
Legend

- Surface Drainage Features
- Water Bodies
- Wetlands
- Active Model Domain
- Property Boundary
- Roads
- Elevation Contours (mASL)

SOURCE: Base mapping produced by Gartner Lee Limited under license with the Ministry of Natural Resources, Queen's Printer 1997 - Reproduced 2004.

PROPOSED DOLOSTONE QUARRY	**Figure 14**
INTERPRETED BOTTOM OF PRODUCTION ZONE	
Project # 23827, Hydrogeological Modeling Investigation	
Gartner Lee Limited	
	Scale 1:80,000

:07/07/05:\ N:\Projects\2003\23827\2005\WIP\Data Interpretation\2005 Model Report\Figures\Figure 14.srf



Legend

- Surface Drainage Features
- Water Bodies
- Wetlands
- Active Model Domain
- Property Boundary
- Roads

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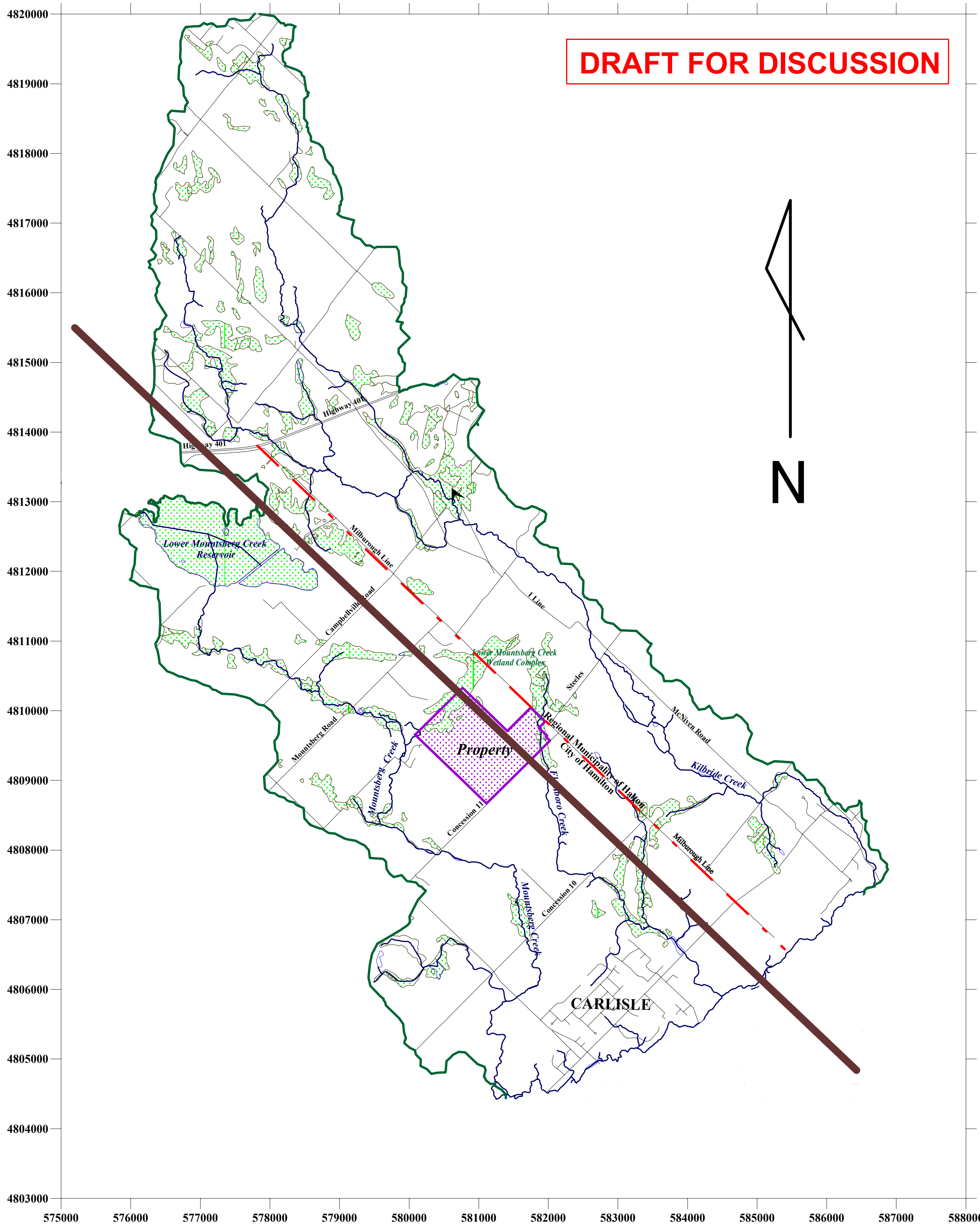
PROPOSED DOLOSTONE QUARRY	Figure 15
MODEL HYDRAULIC CONDUCTIVITY DISTRIBUTION	
Project # 23827, Hydrogeological Modeling Investigation	
Gartner Lee Limited	Scale 1:80,000



Legend

- Surface Drainage Features
- Water Bodies
- Wetlands
- Active Model Domain
- Property Boundary
- Roads
- Cross-section Location

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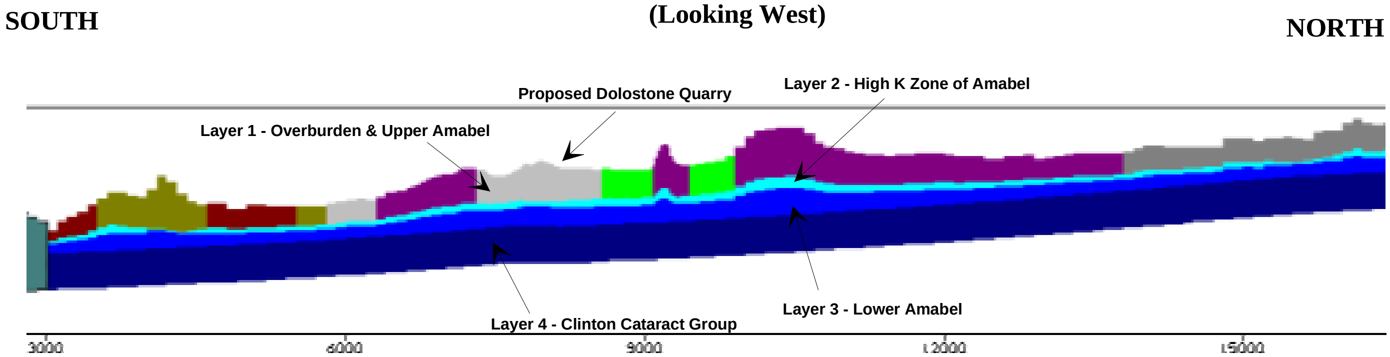
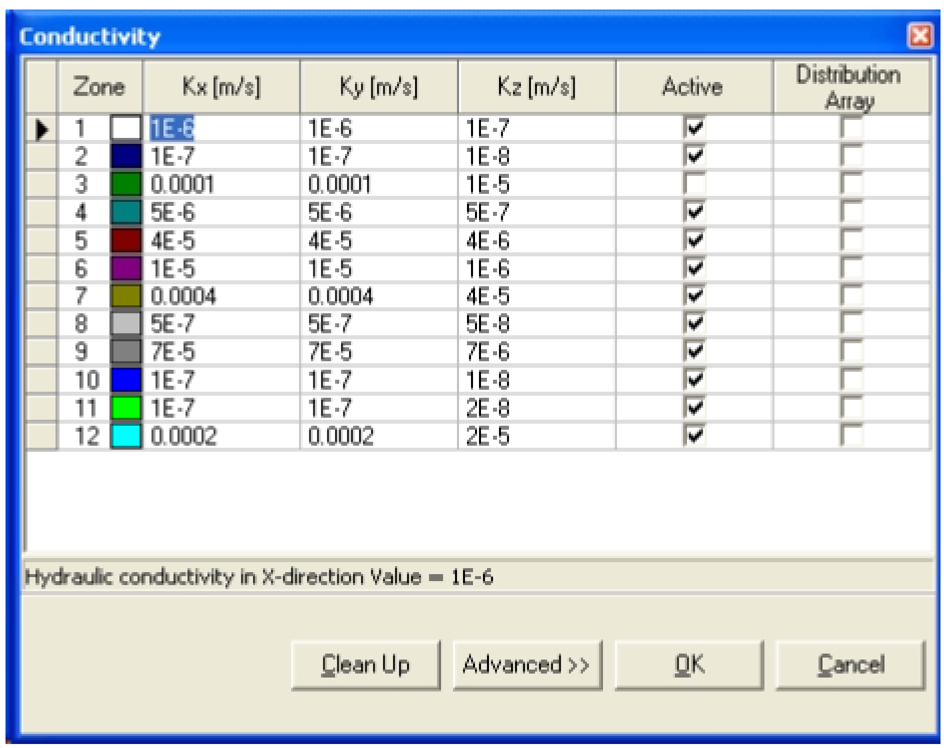
PROPOSED DOLOSTONE QUARRY	Figure 16
MODEL CROSS-SECTION LOCATION	
Project # 23827, Hydrogeological Modeling Investigation	
Gartner Lee Limited	
	Scale 1:80,000

:07/07/05:\ N:\Projects\2003\23827\2004\WIP\Data Interpretation\2005 Model Report\Figures\Figure 16.srf

DRAFT FOR DISCUSSION

North-South Cross-section
(Looking West)





Conductivity

	Zone	Kx [m/s]	Ky [m/s]	Kz [m/s]	Active	Distribution Array
▶	1	1E-6	1E-6	1E-7	☑	☐
	2	1E-7	1E-7	1E-8	☑	☐
	3	0.0001	0.0001	1E-5	☐	☐
	4	5E-6	5E-6	5E-7	☑	☐
	5	4E-5	4E-5	4E-6	☑	☐
	6	1E-5	1E-5	1E-6	☑	☐
	7	0.0004	0.0004	4E-5	☑	☐
	8	5E-7	5E-7	5E-8	☑	☐
	9	7E-5	7E-5	7E-6	☑	☐
	10	1E-7	1E-7	1E-8	☑	☐
	11	1E-7	1E-7	2E-8	☑	☐
	12	0.0002	0.0002	2E-5	☑	☐

Hydraulic conductivity in X-direction Value = 1E-6

Clean Up | Advanced >> | OK | Cancel

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PROPOSED DOLOSTONE QUARRY | **Figure 17**

VERTICAL HYDRAULIC CONDUCTIVITY DISTRIBUTION

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Gartner Lee Limited

Scale 1:20,000

4.2 Model Calibration

The model was calibrated to steady-state conditions by adjusting aquifer and aquitard properties until a reasonable match with observed groundwater levels and flow direction was achieved. The model calibration targets for water level along with the interpreted groundwater contours are illustrated in Figure 8 at the regional scale and Figure 9 at the site scale. Post-calibration sensitivity analyses were conducted by varying parameters within a reasonable range to demonstrate that the calibrated model parameters truly lie at a minimum point on the sensitivity curves.

4.2.1 Mountsberg Creek Subwatershed Water Budget

The model was calibrated to stream baseflow values obtained from HYDAT Station 02HB016 on Mountsberg Creek (near Carlisle). This involved a volumetric match to groundwater discharge to streams and rivers. This calibration target is particularly important when considering groundwater resources on a local watershed scale and potential impacts to ecological features such as cold-water fisheries.

The stream flow rates recorded more than 20% of the time were considered to be representative of the annual average stream baseflow. The baseflow at this gauging station follows:

Table 4. Baseflow Estimate

Steam Gauge Flow Station	Period of Record	Average Flow (m^3/s)	Baseflow (m^3/s)
Mountsberg Creek Down Stream from Carlisle 02HB016	1977 through 1985	1.447	0.67

* *1977-1985 record was simulated based on Mountsberg Creek Flow records*

The calibrated steady-state model simulated 0.69 m^3/s of groundwater discharge to Mountsberg Creek. This compares favorably with the observed baseflow estimated volumes of 0.67 m^3/s for HYDAT Station 02HB016. Stream flow stations were not identified for Kilbride Creek or Flamboro Creek in Environment Canada's HYDAT database version 2000-01 ©2002. Since the model simulates the estimated baseflow for Mountsberg Creek, and similar settings and assumptions are applied to both Kilbride and Flamboro Creeks, it is reasonable to assume the same level of accuracy is achieved with the model calibration to these two creeks as well.

4.2.2 Calibration to Regional Groundwater Heads

The model was calibrated using 860 MOE water well records and static water level data for monitoring wells installed on the property. The Root Mean Square or RMS was calculated as 4.717%. An RMS in the range of 10% is generally accepted by ASTM standards (ASTM, D5981-96). The calibration scatterplot and statistics are shown in Figure 18 and Figure 19. The simulated regional groundwater contours for the calibrated model are illustrated on Figure 20. The simulated groundwater contours for the site scale are presented in Figure 21. The calibrated target water levels for the regional and site scales are shown in Figure 8 and Figure 9, respectively.

4.2.3 Calibration Site Groundwater Heads

At the site scale, the model calibration goals were to reasonably match groundwater flow gradients, groundwater elevations and groundwater volumetric flux through the property. The distribution of monitors on the site provided sufficient coverage of water levels for the property. The standard error of the estimate at the site scale is 0.205 m and the RMS 14.31%. While this value appears high relative to the regional RMS of 4.717%, it reflects the scale of the calibration. The head difference is the key parameter in determining the RMS %. The smaller the head difference the more challenging it becomes to achieve 10% RMS. Site scale calibration often approaches or exceeds this 10% threshold, as is the case with this model. As discussed, modeling is an approximation of the natural system that must apply some simplification while still achieving parsimony. The most important calibration measure for a model of this nature is the volumetric flux through the aquifer system. If the volume of groundwater is reasonably simulated, the site scale elevations are generally acceptable even if they approach or slightly exceed the 10% RMS.

4.2.4 Calibration to Transient Groundwater Head

Further model calibration to transient groundwater responses was completed for the 168-hour pumping test completed in November/December 2004. The pumping rates and duration were inputted for the respective pumping wells, TW12 and TW13, utilized for this pumping test. The resulting groundwater drawdown for both the deep groundwater system and the shallow groundwater system in proximity to the wetland features were matched to within an acceptable degree of accuracy for the purposes of this study. Figure 22 illustrates the simulated drawdown results for the 168–hour pumping test at the end of pumping. The actual drawdown for the deep and shallow aquifer is shown in Figure 8 and Figure 9, respectively in the Volume 1 report.

The transient model calibration focused on the drawdown response of the groundwater system to a groundwater stress condition, namely the 168-hour pumping test. The level of drawdown and the zone of influence observed during the 168-hour pumping test (Figures 8 and 9, Volume 1 report) were compared to the simulated drawdown in the model (Figure 22). The simulated drawdown matched the observed drawdown to an acceptable degree.

In order to identify the level of stress imposed upon the groundwater flow regime it was necessary to simulate both the steady-state condition as well as the transient response of the groundwater system. As described in the pumping test section of the main report, there are very distinct responses observed for the deep groundwater monitors as well as the shallow mini-piezometers positioned within the wetland features. The models ability to reasonably match the pumping test scenario as well as the steady state scenario increases the level of confidence in the models predictions with respect to quarry dewatering influences on the natural groundwater and surface water system.

A comparison of recorded hydraulic head contours to modeled hydraulic head contours for the subwatershed was completed. To assess the accuracy of the model, the recorded hydraulic head at overburden/shallow bedrock zone wells was statistically compared to the hydraulic head simulated by the calibrated model.

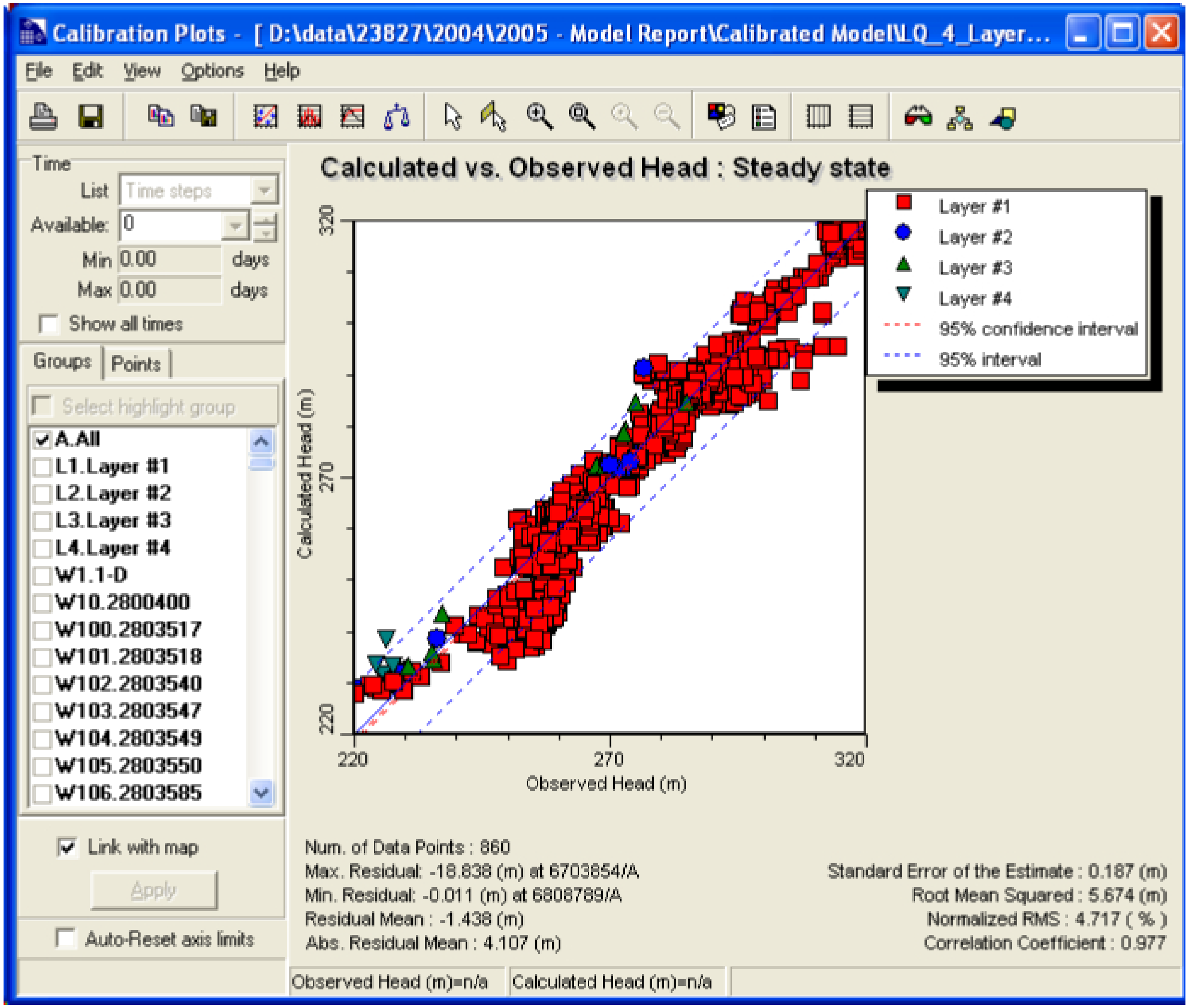
The groundwater model was calibrated to provide a reasonable match to recorded hydraulic head conditions during both non-pumping and pumping conditions. By making minor adjustments to bedrock permeability and groundwater recharge, the model was able to match the observed data on existing aquifer potentials and hydraulic gradients reasonably well. Calibration statistics used to assess the accuracy of the model are described below.

$$\text{Mean Error} = \frac{1}{n}\sum_{1}^{n}(h_O - h_m)_i \qquad (2)$$

$$\text{Mean Absolute Error} = \frac{1}{n}\sum_{1}^{n}\left|(h_O - h_m)_i\right| \qquad (3)$$

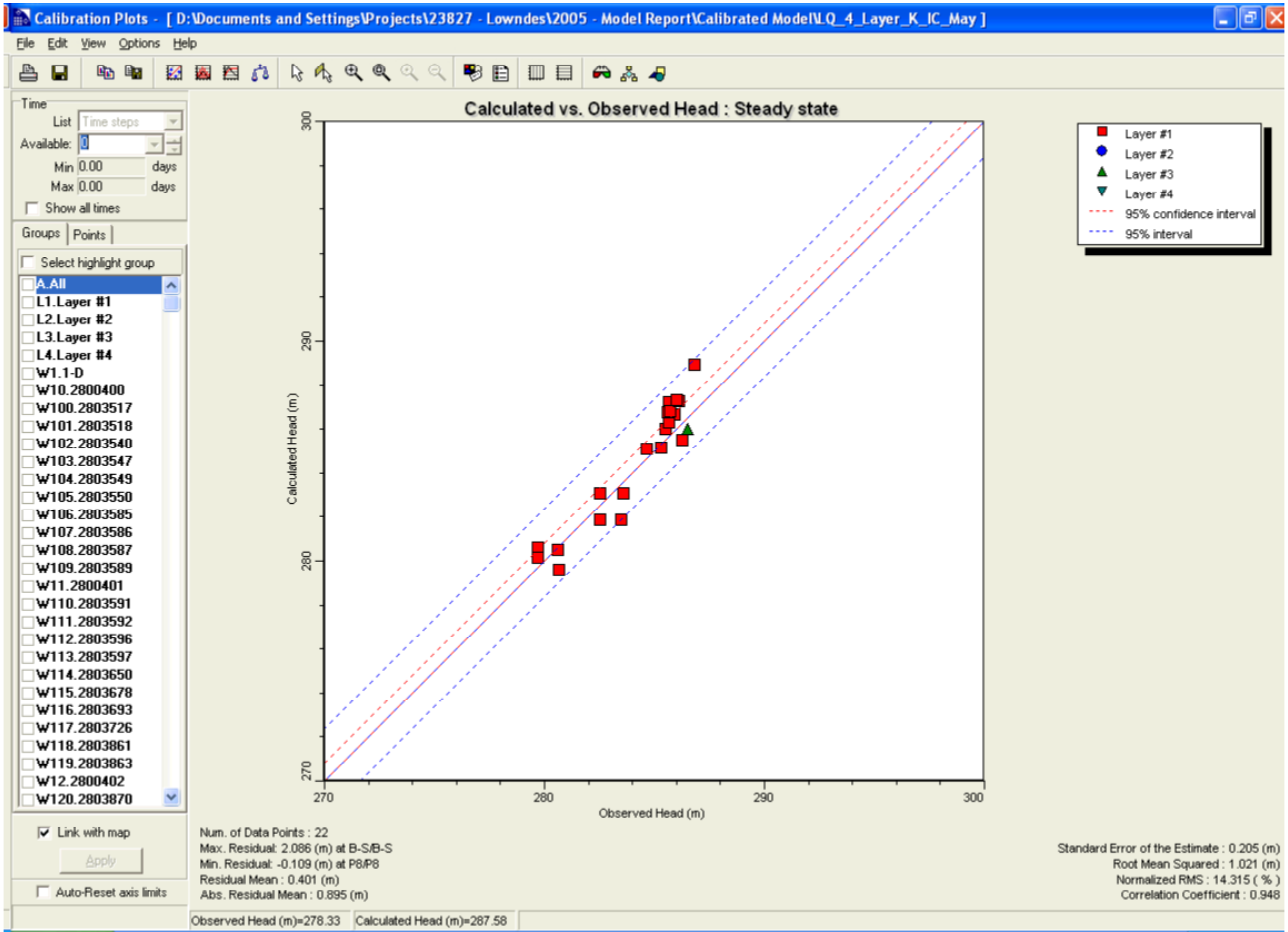
Where: h_o = Observed hydraulic head;
h_m = Simulated hydraulic head; and,
n = Number of wells.

The mean error provided the average difference between the observed values (h_0) and simulated values (h_m) and indicates whether the simulated values are higher (indicated by negative value) or lower (indicated by a positive value) than the observed values. The mean absolute error indicates the average difference between the observed and simulated values. Figure 18 and 19 presents the results of the statistical analysis and indicates the average error between static regional heads and simulated heads for the model.



DRAFT FOR DISCUSSION

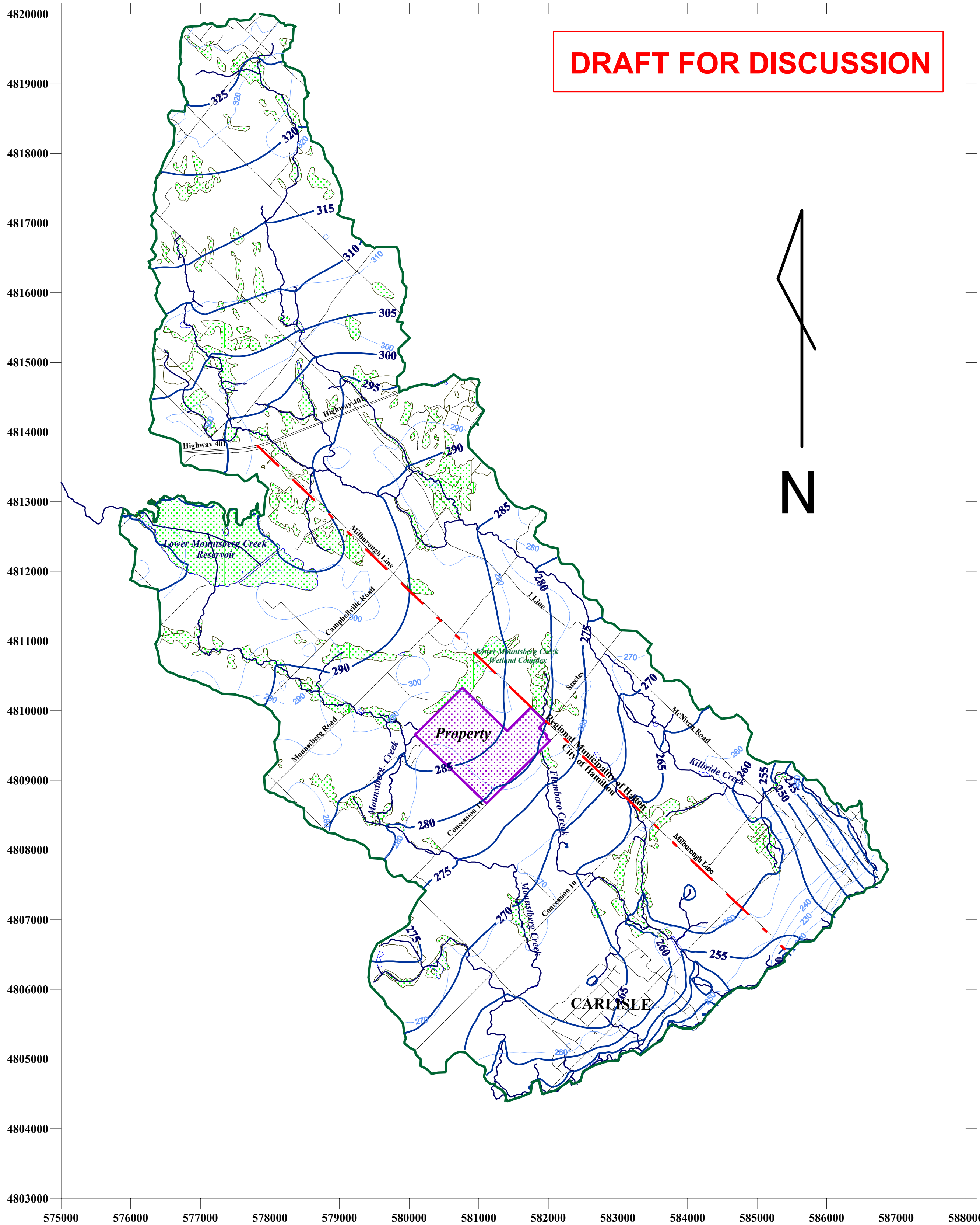
PROPOSED DOLOSTONE QUARRY	Figure 18
REGIONAL CALIBRATION STATISTICS	
Project # 23827, Hydrogeological Modeling Investigation	
Gartner Lee Limited	Scale NTS



DRAFT FOR DISCUSSION

PROPOSED DOLOSTONE QUARRY	Figure 19
SITE CALIBRATION STATISTICS	
Project # 23827, Hydrogeological Modeling Investigation	
Gartner Lee Limited	Scale NTS

:07/07/05:\ N:\Projects\2003\23827\2005\WIP\Data Interpretation\2005 Model Report\Figures\Figure 19.srf



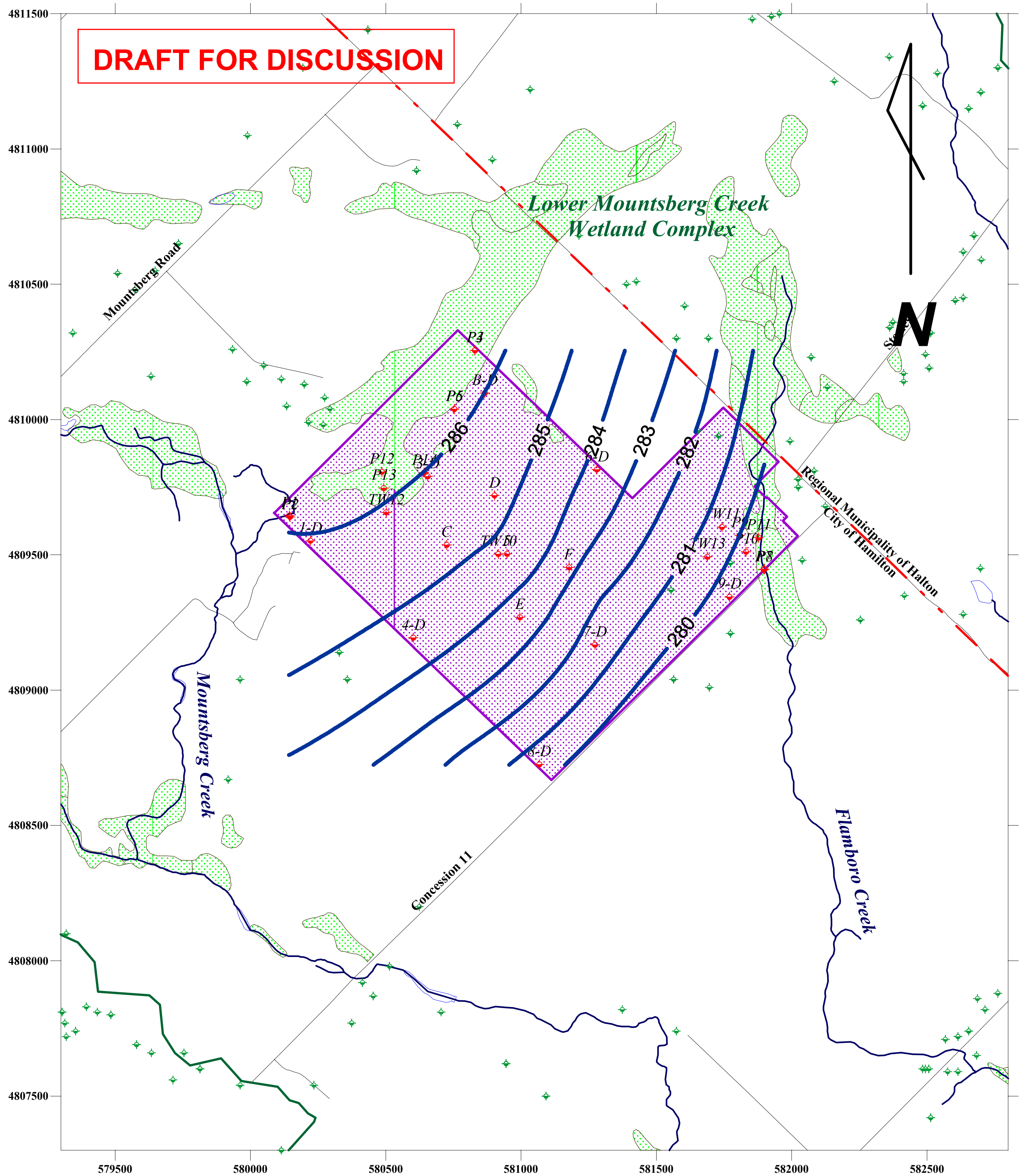
Legend

- Surface Drainage Features
- Water Bodies
- Wetlands
- Active Model Domain
- Property Boundary
- Roads
- Simulated Groundwater Contours (mASL)
- Interpreted Groundwater Contours (mASL)

SOURCE: Base mapping produced by Gartner Lee Limited under license with the Ministry of Natural Resources, Queen's Printer 1997 - Reproduced 2004.

PROPOSED DOLOSTONE QUARRY	Figure 20
SIMULATED GROUNDWATER CONTOURS REGIONAL SCALE - CALIBRATED MODEL	
Project # 23827, Hydrogeological Modeling Investigation	
Gartner Lee Limited	Scale 1:80,000

:07/07/05:\ N:\Projects\2003\23827\2005\WIP\Data Interpretation\2005 Model Report\Figures\Figure 20.srf



Legend

- Surface Drainage Features
- Water Bodies
- Wetlands
- Active Model Domain
- Property Boundary
- Roads
- Simulated Groundwater Contours (mASL)

SOURCE: Base mapping produced by Gartner Lee Limited under license with the Ministry of Natural Resources, Queen's Printer 1997 - Reproduced 2004.

PROPOSED DOLOSTONE QUARRY — **Figure 21**

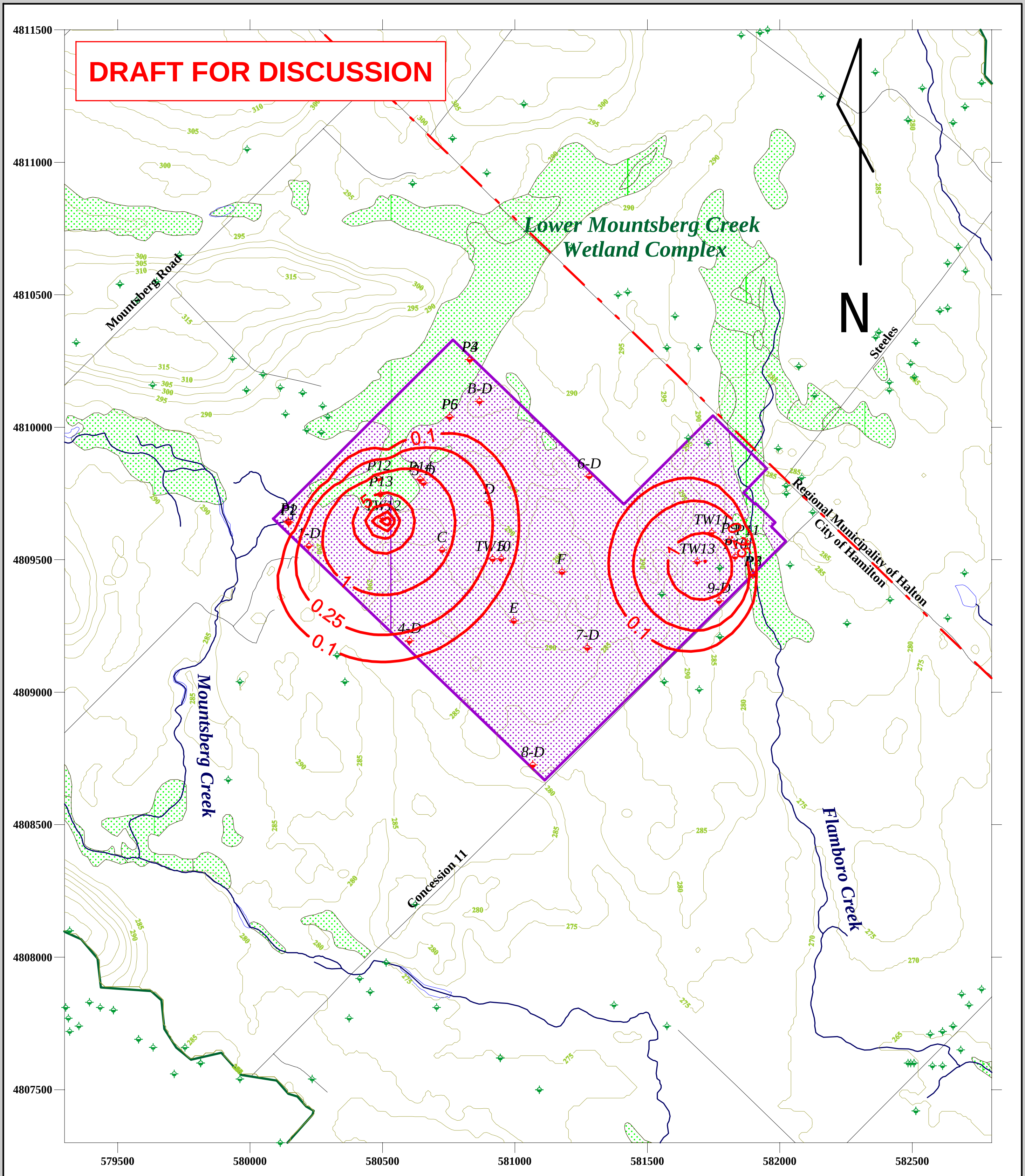
SIMULATED GROUNDWATER CONTOURS SITE SCALE - CALIBRATED MODEL

Project # 23827, Hydrogeological Modeling Investigation

Gartner Lee Limited

Scale 1:20,000

:07/07/05:\ N:\Projects\2003\23827\2005\WIP\Data Interpretation\2005 Model Report\Figures\Figure 21.srf



Legend

- Surface Drainage Features
- Water Bodies
- Wetlands
- Active Model Domain
- Property Boundary
- Roads
- Simulated Drawdown (m)

SOURCE: Base mapping produced by Gartner Lee Limited under license with the Ministry of Natural Resources, Queen's Printer 1997 - Reproduced 2004.

PROPOSED DOLOSTONE QUARRY

Figure 22

SIMULATED DRAWDOWN
168-HOUR PUMPING TEST

Project # 23827, Hydrogeological Modeling Investigation

Gartner Lee Limited

Scale 1:20,000

:07/07/05:\ N:\Projects\2003\23827\2005\WIP\Data Interpretation\2005 Model Report\Figures\Figure 22.srf

4.2.5 Model Mass Balance

The model mass balance is a representation of the numerical accuracy in which the mathematical solvers are solving the matrix equations under the specified solver parameters for a given simulation. The lower the mass balance error the more accurate the mathematical solution. A mass balance error of less that 4% or 5% is generally acceptable for a regional scale model. This ensures that the volume of water (mass) entering the model domain is reasonably close to the volume of water that leaves the model domain. This is an important parameter used to gauge the mathematical accuracy of the numerical solvers used to solve the set of equations that calculate groundwater levels and flow throughout the model domain.

The model convergence criteria were adjusted to ensure an acceptable mass balance was maintained through out all model simulations. The following table presents the model mass balance including all model inputs and outputs and a comparison between the two volumes.

Table 5. Mass Balance Error

Model Simulation		Mass % error
Steady-State Calibrated Model		-0.36%
Stage 1 1st Lift no Mitigation		0.23%
Stage 1 1st Lift with Mitigation		0.24%
Full Quarry No Mitigation		0.62%
Full Quarry with Mitigation		0.52%

4.3. Model Calibration Discussion

Numerous model simulations were completed as the modeling investigation progressed from a simplified two-layer representation to the present 4-layer representation of the groundwater flow system.

The model was calibrated to average annual steady-state conditions for both groundwater levels and base flow conditions observed at the only available HYDAT stream flow location. The calibrated model reasonably simulates the groundwater head distribution from the head to the toe of the modeled domain. The calibrated model also reasonably simulates the volume of groundwater moving though the model domain when compared to the available HYDAT station base flow estimate.

Lastly, the model was tested for its transient response to the 168-hour pumping test. The pumping schedule for the test was input into the model for a comparison between the models ability to recreate the response of the groundwater system to this level of stress. More importantly, the findings of the pumping test, in regard to the connectivity of the surface water features to the groundwater system must be incorporated into the numerical representation of the system in the model. The simulated pumping test demonstrates the models ability to reasonably match the observed stress conditions induced by the pumping test on both the groundwater system and the surface water features that are connected to the groundwater system.

5.0 Predictive Model Simulations for Proposed Quarry

A preliminary assessment of the influence of the proposed quarry development and associated dewatering was undertaken using the groundwater flow model. The key objectives of the modeling effort were to:

- estimate the potential effects of the proposed dolostone quarry on existing wetlands, streams and recharge areas;
- predict the potential influence of the quarry dewatering on residential supply wells in the vicinity of the quarry and on the Carlisle Municipal wells; and
- provide a tool for assisting in the design and evaluation of quarry development plans and possible mitigation measures.

The full details of the quarry development have not yet been finalized. However, to facilitate peer review and agency dialogue, it is intended that quarry development proceed as generally reflected in the 2004 Site Plan (Long, 2004). To enable initial modeling and predictive analysis, conceptual limits for quarry Stage 1 and full excavation have been conservatively established. These limits are shown in Figure 23. For the modeling proposed, Stage 1 will be excavated to an approximate elevation of 272 mASL and the Full Quarry to an approximate elevation of 249 mASL. The final development limits and excavation depths will be established through agency consultation and further analysis.

Four predictive simulations were undertaken. The initial two simulations were developed to illustrate the potential effects of quarry development without mitigation. Specifically, the effects of the first stage of quarry development (Stage 1 Quarry) without mitigation are presented in Section 5.1.1 and the results of the second simulation that addresses the effects of the Full Quarry are provided in Section 5.1.2. The remaining two simulations, examine the effect of recharging the water extracted from the quarry as a mitigation measure and are provided in Section 5.2. Section 5.2.1 introduces the preferred mitigation measure, a ‘Groundwater Recirculation System’ and Sections 5.2.2 and 5.2.3 examine the effects of mitigation during the Stage 1 Quarry and Full Quarry development, respectively.

5.1 Quarry - Simulation Results

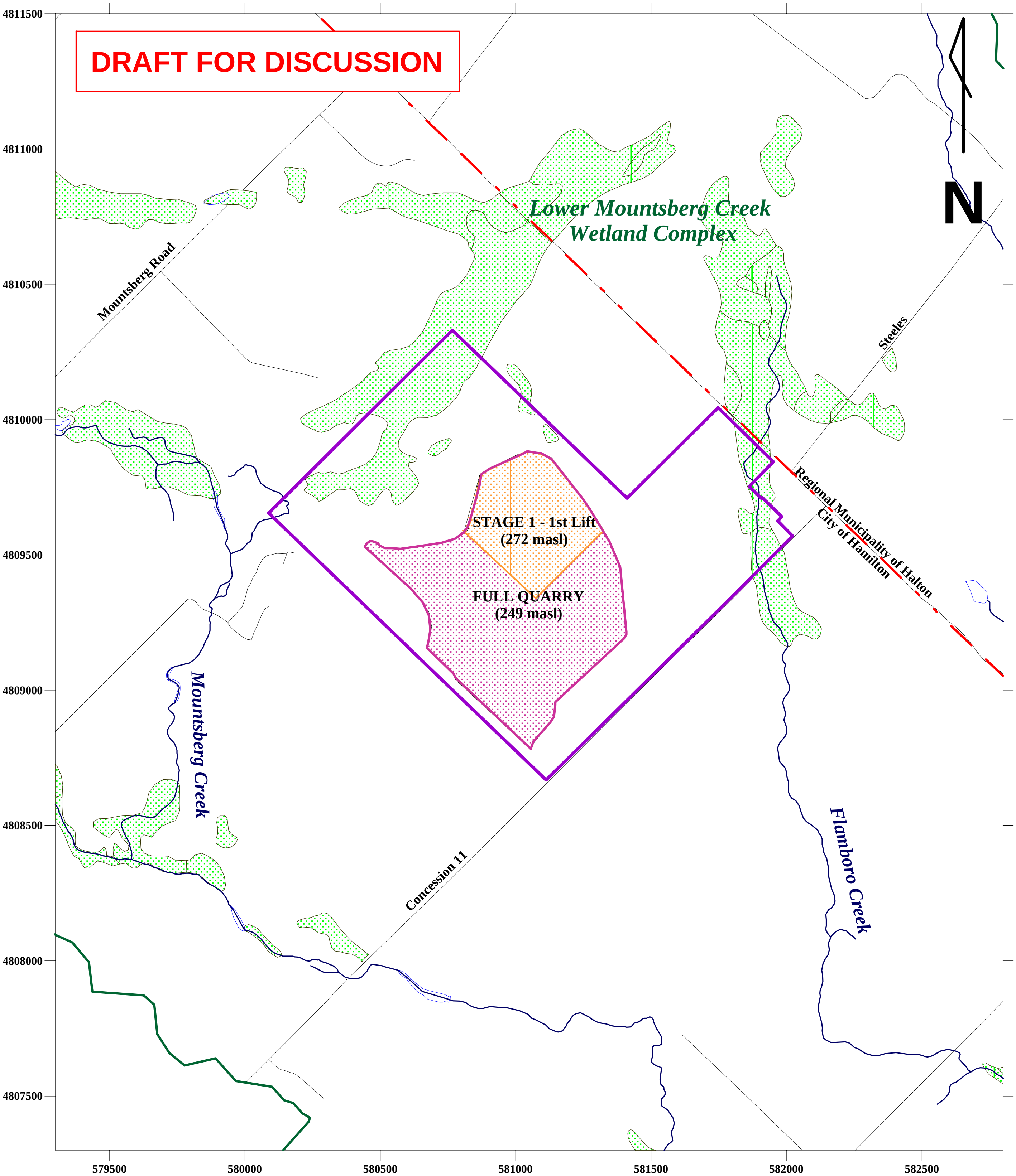
The results of the two preliminary simulations (Stage 1 Quarry and Full Quarry) are presented herein. These two simulations assume that no mitigation measures would be implemented during quarry excavation to counter the effects of quarry dewatering. As such, these are an unlikely scenario for development of this quarry but are provided to illustrate a 'worst case situation'. The results of the second set of preliminary simulations presented in Section 5.2 (again for the Stage 1 Quarry and Full Quarry), assume that the water extracted during quarry dewatering will be re-circulated and are therefore a more realistic depiction of the potential effects of quarry development.

5.1.1 Stage 1 Quarry

Stage 1 of quarry development for purposes of this preliminary predictive assessment will involve the excavation of the quarry within the footprint shown in Figure 23 to a depth of 272 mASL. Given, that the water table is within a few metres of ground surface, the quarry development will extend below the current water table requiring that dewatering be undertaken as the quarry operations progress. For purposes of the modeling effort, the water extracted during dewatering is to be released to Mountsberg Creek, and not re-circulated, as is the intended mode of operation. The potential effects of the un-mitigated Stage 1 Quarry on the Lower Mountsberg Creek Wetland Complex and on water wells used by local residents and the Community of Carlisle as a source of supply is described below.

Stage 1 Quarry Influence on Lower Mountsberg Creek Wetland Complex: Figure 24 and Figure 25 illustrates the zone of influence and drawdown in Amabel Formation from the Stage 1 Quarry dewatering operations, without mitigation, at a regional scale and site scale, respectively. The zone of influence extends beyond both wetlands in an elliptical shape with an 800 m radius along the long axis and 750 m radius along the short axis. The predicted volume of groundwater pumped from the Stage 1 dewatering operations is 23.0 lps or (300 igpm).

As simulated, Stage 1 Quarry dewatering without mitigation has the potential to reduce groundwater levels adjacent to, and beneath, the Lower Mountsberg Creek Wetland Complex in proximity to the property. The decrease in the groundwater level below the wetland would in turn result in a reduction in the groundwater flux to the wetland. The predicted reductions to the northerly (wetlands adjacent to Mountsberg Creek) and easterly (wetlands adjacent to Flamboro Creek) areas of the Lower Mountsberg Creek Wetland Complex are 28% and 29% respectively.



Legend

- Surface Drainage Features
- Water Bodies
- Wetlands
- Active Model Domain
- Property Boundary
- Roads
- Footprint - Stage 1 - 1st Lift
- Footprint - Full Quarry

SOURCE: Base mapping produced by Gartner Lee Limited under license with the Ministry of Natural Resources, Queen's Printer 1997 - Reproduced 2004.

PROPOSED DOLOSTONE QUARRY	Figure 23
FOOTPRINT OF PROPOSED DOLOSTONE QUARRY STAGE 1 AND FULL DEVELOPMENT	
Project # 23827, Hydrogeological Modeling Investigation	
Gartner Lee Limited	Scale 1:20,000

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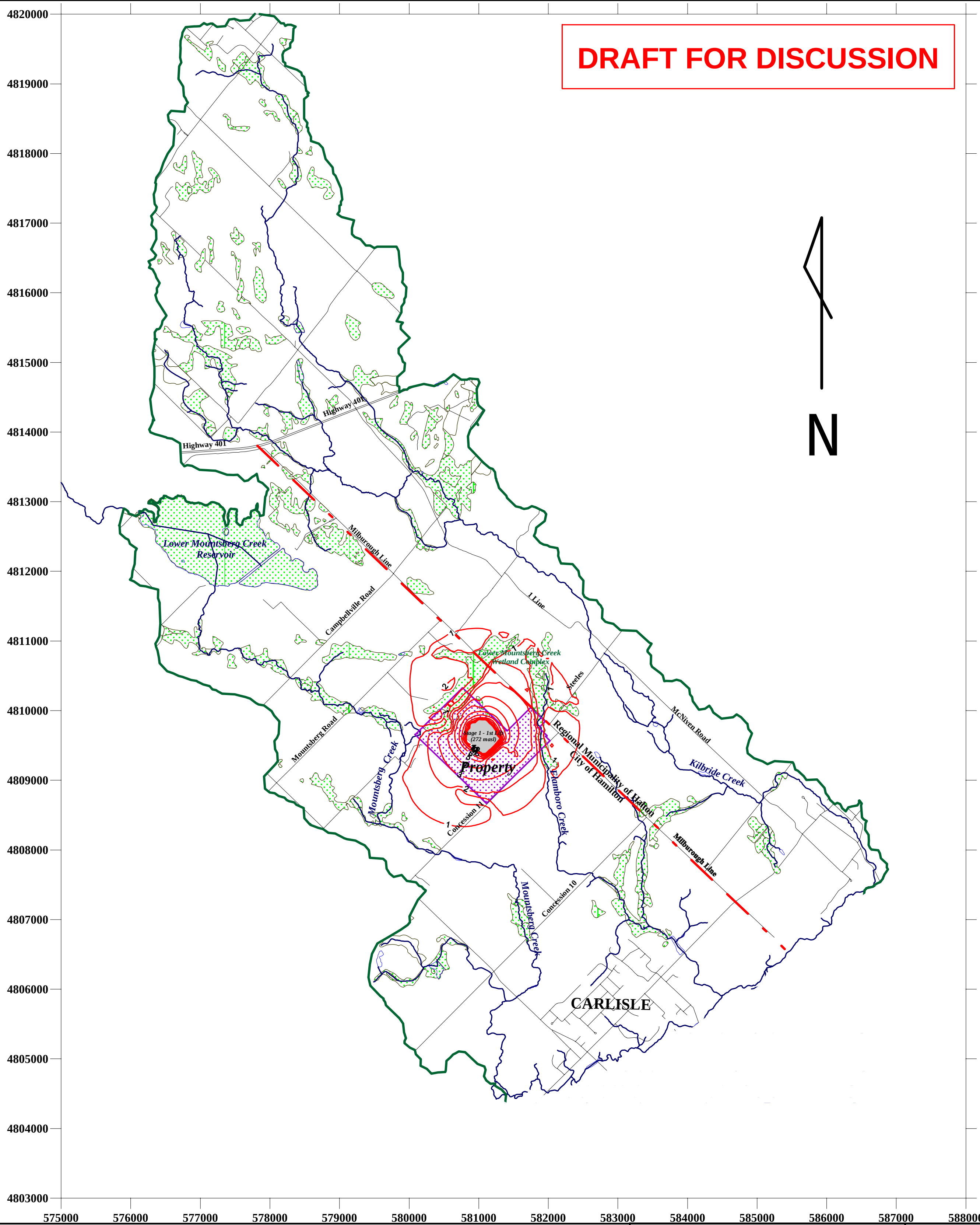

Legend

- Surface Drainage Features
- Water Bodies
- Wetlands
- Active Model Domain
- Property Boundary
- Roads
- Simulated Drawdown (m)
- Extraction Limits

SOURCE: Base mapping produced by Gartner Lee Limited under license with the Ministry of Natural Resources, Queen's Printer 1997 - Reproduced 2004.

NOTE:
Stage 1 - 1st Lift - Without mitigation
Quarry dewatering: 1988 m^3/d

PROPOSED DOLOSTONE QUARRY	Figure 24
SIMULATED DRAWDOWN - NO MITIGATION STAGE 1 - 1st LIFT (272 masl) - REGIONAL SCALE	
Project # 23827, Hydrogeological Modeling Investigation	
Gartner Lee Limited	Scale 1:80,000

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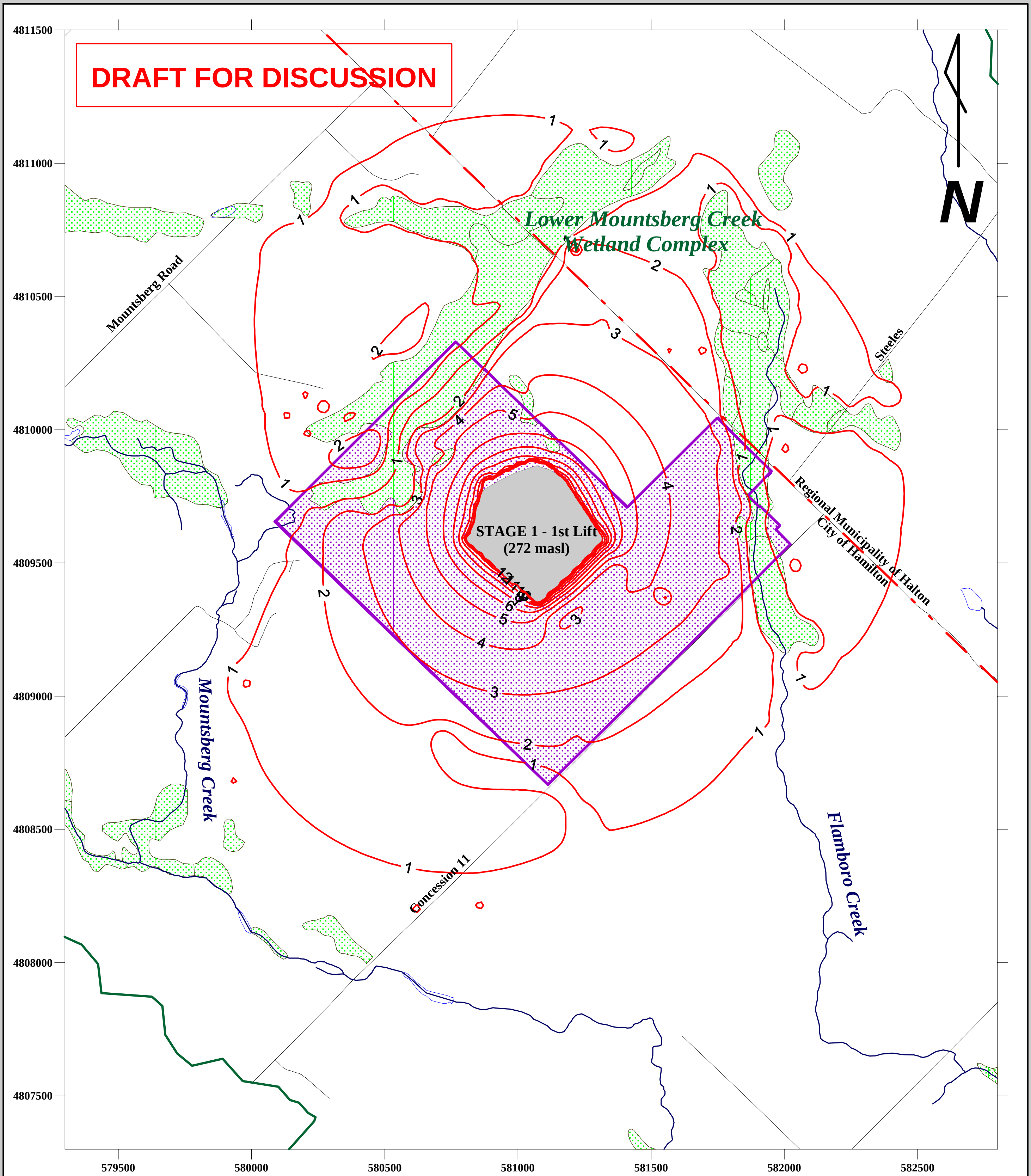

Legend

- Surface Drainage Features
- Water Bodies
- Wetlands
- Active Model Domain
- Property Boundary
- Roads
- Simulated Drawdown (m)
- Extraction Limit

SOURCE: Base mapping produced by Gartner Lee Limited under license with the Ministry of Natural Resources, Queen's Printer 1997 - Reproduced 2004.

NOTE:
Stage 1 - 1st Lift - Without Mitigation
Volume of Quarry Dewatering: 1988 m^3/d

PROPOSED DOLOSTONE QUARRY

Figure 25

SIMULATED DRAWDOWN - NO MITIGATION
STAGE 1 - 1st LIFT (272 masl) - SITE SCALE

Project # 23827, Hydrogeological Modeling Investigation

Gartner Lee Limited

Scale 1:20,000

:07/07/05:\ N:\Projects\2003\23827\2005\WIP\Data Interpretation\2005 Model Report\Figures\Figure 25.srf

Stage 1 Quarry Influence on Residential Water Wells:

Stage 1 Quarry dewatering without recirculation of the groundwater as a mitigation measure also has the potential to impact on domestic water supplies at the residential properties located along Milburough Line, northeast of the quarry. Based on the simulation, the predicted drawdown in the water table is up to 6 m in this area. The simulated drawdown to the south of Concession 11, downgradient from the quarry, is predicted to be on the order of 2 m from the pre-quarry development groundwater levels. The impact of this drawdown on individual wells located in these areas would depend on the depth of the well and pump setting, and the static water level at the wellhead. Specifically, shallow wells are more likely to experience an impact in the form of a reduction in well yield than deeper wells.

Water wells located to the north and west of the quarry property (north) and west of Mountsberg Creek) are less likely to experience an impact from the Stage 1 Quarry dewatering. The simulated groundwater drawdown is less than one (1) meter in this area. The limited groundwater drawdown observed is a function of two physical characteristics of the subwatershed. The first is the positive hydraulic boundary in Mountsberg Creek, and the second is related to the fact that this location is upgradient from the proposed quarry. Groundwater must first travel through this location before entering the quarry property where it would discharge into the quarry under gravity drainage. The continuous flow in Mountsberg Creek will mitigate the drawdown induced by the quarry dewatering.

Stage 1 Quarry Influence on Carlisle Municipal Wells:

The Community of Carlisle municipal wells are located approximately 3.5 km from the footprint of the proposed quarry (Stage 1). The groundwater flow trend through the subwatershed is from north to south passing the quarry and eventually passing the Carlisle wells on its way to the outlet of the subwatershed. Based on the model simulation, the predicted drawdown induced by the Stage 1 Quarry dewatering will extend approximately 1 km south of the quarry property, some 2.5 km distant from the nearest Carlisle municipal well. As such, the proposed quarry will not impact the yield and volume of supply of the Carlisle Municipal supply.

Particle tracking is commonly used to estimate the time a particle of water will take to enter a well intake. By tracking a particle of water backward from a well intake through the groundwater system, estimates can be made on the origin of the groundwater and the zone of influence of a well. Furthermore, particle tracking can estimate the distance groundwater will travel for a given period of time. Typically groundwater movement is slow and is measured in meters per day, month or even per year.

Included in the model predictions for this investigation was reverse particle tracking from the Carlisle municipal wells. Applying the permitted rates presented in the PTTW for the individual wells within the well field, the model predicts it would take about 20 years or more for a particle of water to pass the quarry and move to the intake of the Carlisle wells. The results for a 25-year ‘time of travel’ simulation are illustrated in Figure 26.

The model also demonstrates through particle tracking and the removal of particles at river boundaries that it is likely that surface water features that exist between the quarry property and the Carlisle wells will contribute water flowing to the wells. Water wells developed in a fractured rock environment commonly draw from surface water features and effectively “short-circuit” the groundwater flow path, reducing the distance (and time) over which the source water will travel to the wells.

5.1.2 Full Quarry Influence

The Full Quarry development for purposes of the model will involve the excavation of the quarry within the footprint shown in Figure 23 to a depth of 249 mASL. Again, this will result in a quarry excavation that extends below the water table, which will require that dewatering be undertaken. This will induce groundwater to flow into the quarry. It is again assumed that the extracted water would be discharged to Mountsberg Creek and not re-circulated which is the intended mode of operation. The potential effects of the un-mitigated Full Quarry development on the Lower Mountsberg Creek Wetland Complex and on water wells used by local residents and the Community of Carlisle as a source of supply is described below.

Full Quarry Influence on Local Wetlands:

Figure 27 and Figure 28 illustrate the simulation results for the Full Quarry dewatering operation, without mitigation, at a regional and site scale, respectively. The zone of influence extends beyond both areas of the MSW (Mountsberg Creek and Flamboro Creek) in an elliptical shape measuring 2,000 m in radius along the long axis and 1,500 m along the short axis. The simulated volume of groundwater pumped from the Full Quarry dewatering operation is predicted to be in the order of 114.5 lps or (1,512 igpm).

The predictive simulation of the un-mitigated Full Quarry dewatering influences demonstrate that there will be a marked lowering of the water table adjacent to, and beneath the Lower Mountsberg Creek Wetland Complex. This will result in a reduction in the available groundwater flux that sustains the wetland. The groundwater model predicts that the wetland in the vicinity of Mountsberg Creek will experience up to a 86.8% reduction in groundwater flux and that the wetland near Flamboro Creek will experience an 79% reduction in the groundwater flux.

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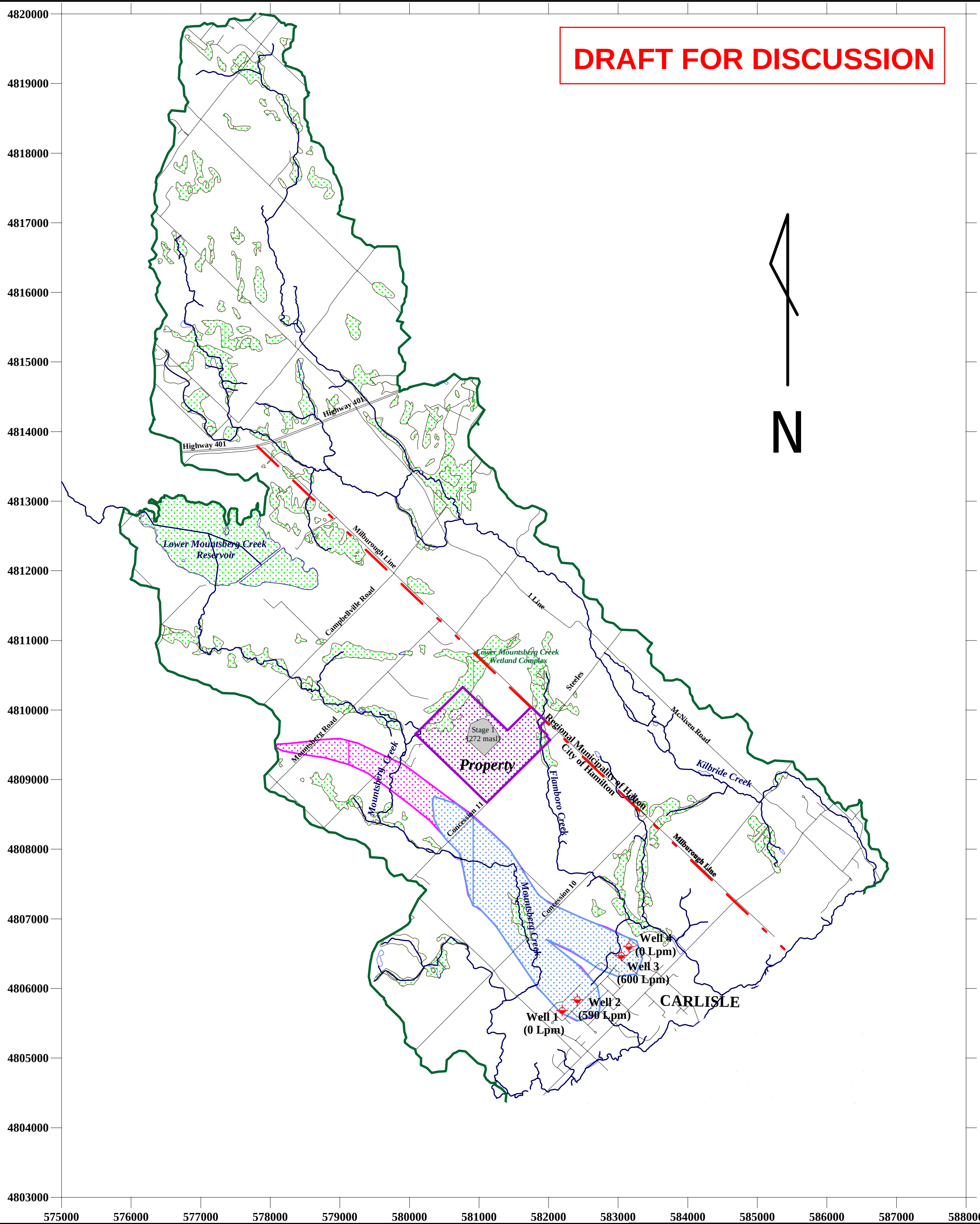


Legend

- Surface Drainage Features
- Water Bodies
- Wetlands
- Active Model Domain
- Property Boundary
- Roads
- Excavation Limit
- Capture Zone - 25 years of travel
- Capture Zone - Steady State

SOURCE: Base mapping produced by Gartner Lee Limited under license with the Ministry of Natural Resources, Queen's Printer 1997 - Reproduced 2004.

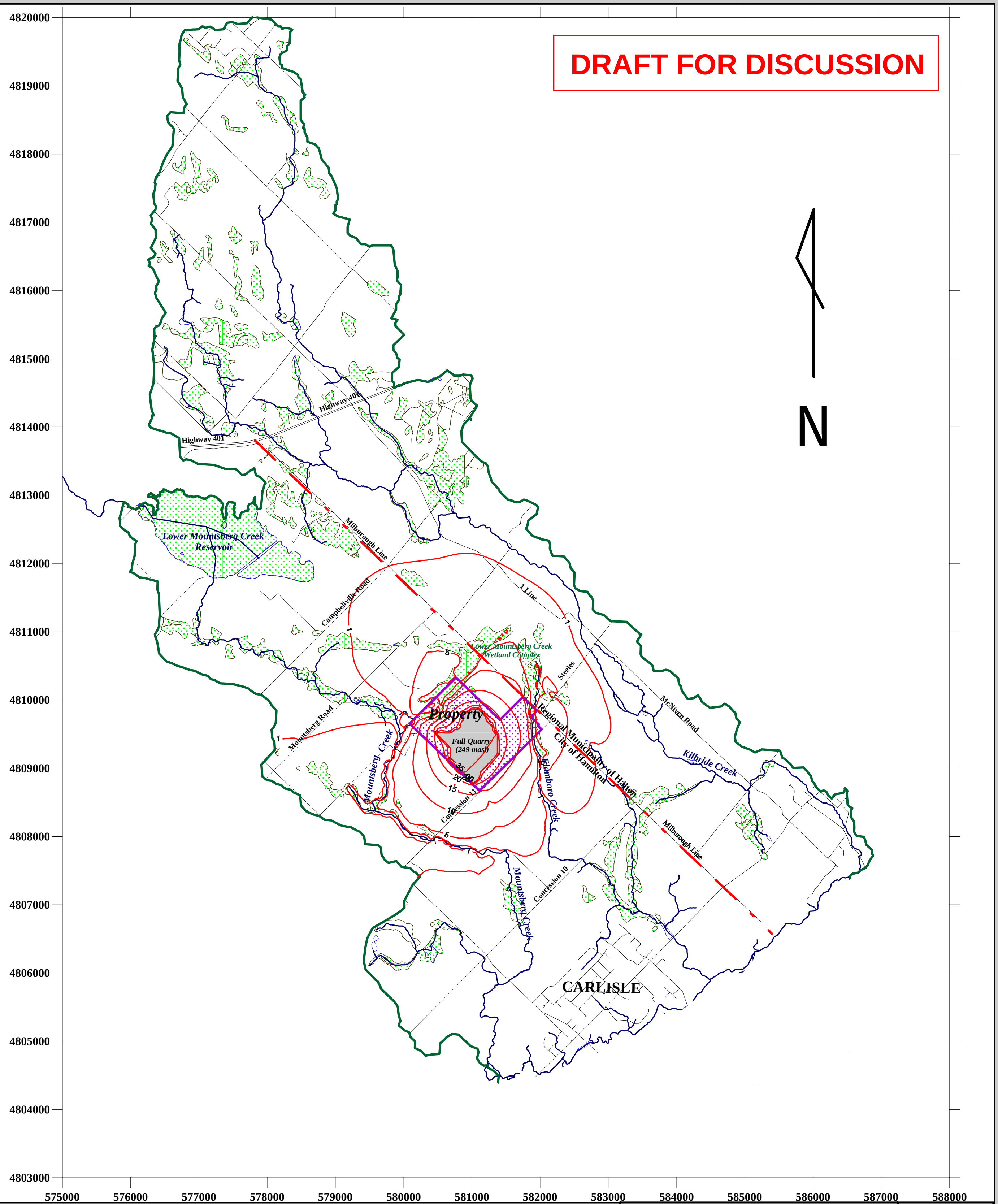
PROPOSED DOLOSTONE QUARRY | **Figure 26**

SIMULATED ZONE OF CAPTURE - STAGE 1
CARLISLE MUNICIPAL WELLS

Project # 23827, Hydrogeological Model Investigation

Gartner Lee Limited

Scale 1:80,000



Legend

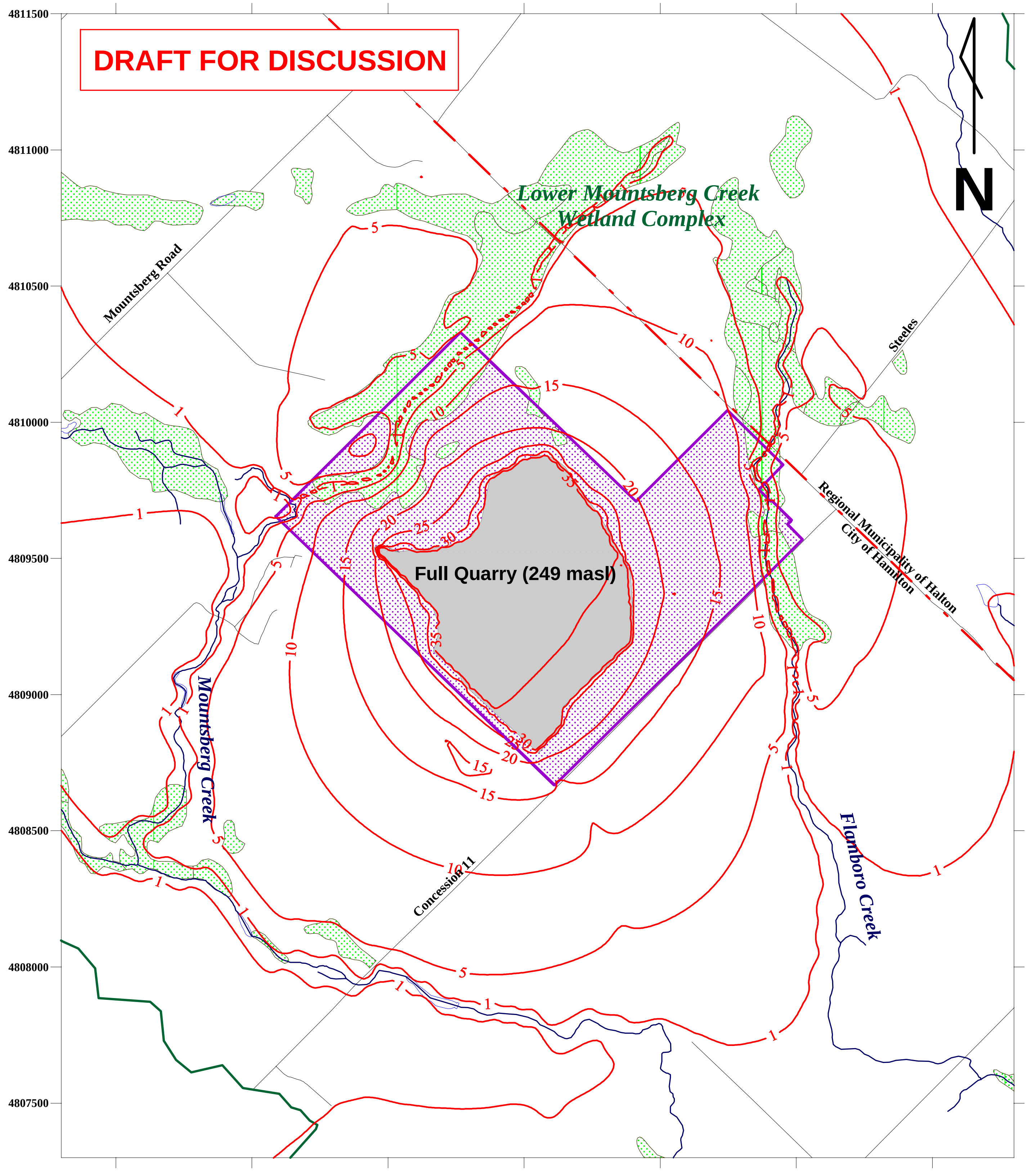
- Surface Drainage Features
- Water Bodies
- Wetlands
- Active Model Domain
- Property Boundary
- Roads
- Simulated Drawdown (m)
- Extraction Limit

SOURCE: Base mapping produced by Gartner Lee Limited under license with the Ministry of Natural Resources, Queen's Printer 1997 - Reproduced 2004.

NOTE:
Full Quarry - Without mitigation
Quarry dewatering: 9894 m^3/d

PROPOSED DOLOSTONE QUARRY	Figure 27
SIMULATED DRAWDOWN - NO MITIGATION FULL QUARRY (249 masl) - REGIONAL SCALE	
Project # 23827, Hydrogeological Modeling Investigation	
Gartner Lee Limited	
	Scale 1:80,000

:07/07/05:\ N:\Projects\2003\23827\2005\WIP\Data Interpretation\Level 2 Report\Figures\Figure 27.srf



Legend

- Surface Drainage Features
- Water Bodies
- Wetlands
- Active Model Domain
- Property Boundary
- Roads
- Simulated Drawdown (m)
- Extraction Limit

SOURCE: Base mapping produced by Gartner Lee Limited under license with the Ministry of Natural Resources, Queen's Printer 1997 - Reproduced 2004.

NOTE:
Full Quarry - No Mitigation
Quarry Dewatering = 9894 m^3/d

PROPOSED DOLOSTONE QUARRY	Figure 28
SIMULATED DRAWDOWN - NO MITIGATION FULL QUARRY (249 masl) - SITE SCALE	
Project # 23827, Hydrogeological Modeling Investigation	
Gartner Lee Limited	Scale 1:20,000

:07/07/05:\ N:\Projects\2003\23827\2005\WIP\Data Interpretation\2005 Model Report\Figures\Figure 28.srf

The model predicts that Mountsberg Creek could experience a change in the groundwater to surface water flux conditions. That is, the creek will loose surface water to the aquifer system. This is due to the fact that groundwater gradients will be directed toward the open quarry and water will tend to migrate toward the property at a greater rate than under present conditions. The predicted loss of creek water to the aquifer system will increase by 342% or about three times the current loss in the vicinity of the property. This would represent an increase in aquifer recharge from creek discharge by approximately 33 lps to 90 lps in the vicinity of the quarry. The flow in the creek at this location can range from 800 lps to several thousand lps.

Full Quarry Influence on Residential Water Wells:

Based on the predictive simulation, the dewatering required for the development of the Full Quarry, without mitigation will have an associated drawdown response in the area along Milburough Line, northeast of the quarry, of up to 10 m. The area south of Concession 11, down gradient from the quarry, is predicted to experience a drawdown of up to 15 m from the pre-development groundwater level. The impact on individual residential water supplies will depend on the location and depth of these wells. In some instances, this could result in a complete disruption of the residential supply.

The impact on the residential water wells to the north and west of Mountsberg Creek is not predicted to be as severe, with a simulated groundwater drawdown of between 1 m and 5 m in this area. As noted in Section 5.1.1, the positive hydraulic boundary created by flow in Mountsberg Creek, and the wells' locations upgradient from the quarry will mitigate the effects of quarry dewatering to some degree.

Full Quarry Influence on Carlisle Municipal Wells:

The Carlisle municipal water wells are located approximately 3.5 km from the footprint of the quarry. The cone of influence and associated drawdown in the groundwater levels is projected to extend approximately 1 km south of the quarry property or about 2.0 km distant from the nearest Carlisle Municipal well.

Applying reverse particle tracking from the Carlisle municipal wells, under the permitted rates in the PTTW, the model predicts it would take about 20 years or more for a particle of water to pass the quarry and be extracted at the intake of the Carlisle wells. Again, the surface water features that exist between the quarry property and the Carlisle wells will mitigate the drawdown effects and are likely to contribute a greater volume of water to the Carlisle supply wells than groundwater originating on the proposed quarry property.

Figure 26 presented earlier is a simulation that shows the Carlisle municipal wells capture area for a 25-year time of travel, at Stage 1 of the quarry development, without mitigation. Figure 29 illustrates the capture area for the 25-year time of travel with the full quarry present, without mitigation.

5.2 Quarry Simulations with Mitigation

5.2.1 Groundwater Re-circulation System (GRS)

As demonstrated in Section 5.1, the development of the proposed quarry, without mitigation has the potential to impact on the wetlands and various residential wells. These quarry dewatering effects can be mitigated through the recirculation of the extracted water. The underlying premise of this mitigation measure is that the groundwater and surface water collected within the quarry through the dewatering operations is used to maintain groundwater heads and flow between the footprint of the quarry area and adjacent wetland features and wells. This would involve discharging the extracted water into a perimeter trench excavated into the top of the bedrock where it would subsequently infiltrate and maintain water table elevations peripheral to the quarry. This mitigation measure is referred to herein as a ‘Groundwater Re-circulation System’ or GRS.

The goal of the GRS is to maintain the groundwater level in the general area and the groundwater flux balance in the wetlands at a pre-development condition. Provided the system operates as designed, the net water loss to the system would be limited to the volume of water lost to operations within the quarry itself. The balance of the extracted water would be re-circulated to the groundwater flow system. A significant portion of this water however would drain back to the quarry and again need to be extracted and re-circulated.

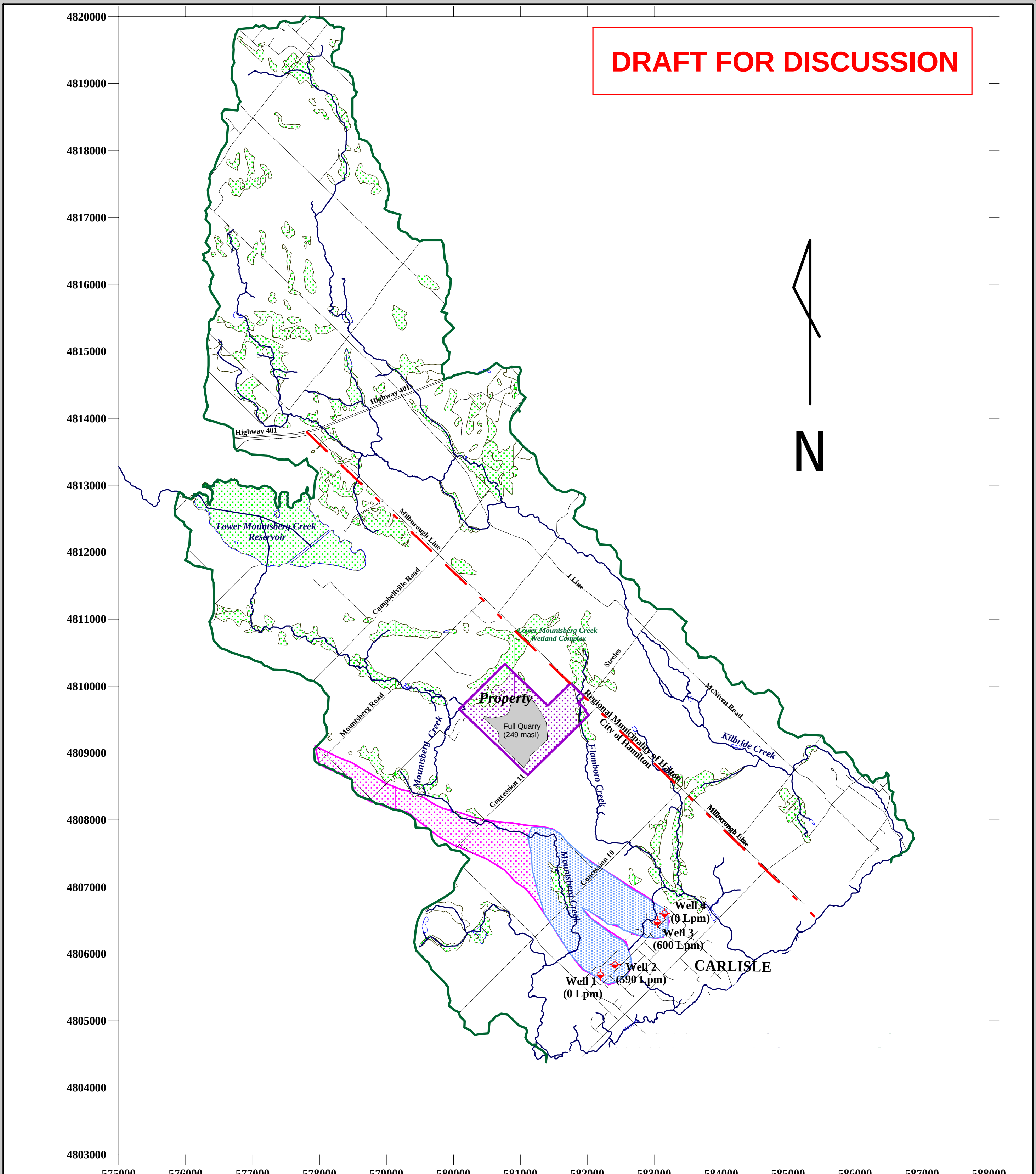
‘Zone budget’ is a module that is used in conjunction with MODFLOW to calculate the water balance or input/output water volumes for a defined area such as the quarry property or the Lower Mountsberg Creek Wetland Complex. A zone budget analysis was used to determine the pre and post water flux to the wetland in proximity to the quarry. As noted, the goal of the GRS is to achieve no net loss in the groundwater flux to the wetland features. This was assessed through an iterative approach, where a series of model simulations were undertaken to optimize the GRS configuration and evaluate the volumetric re-circulation rate required to achieve this goal of no net loss to the wetland.

One key finding in the GRS predictive simulations, was the necessity to accommodate the water loss through the hydraulically conductive zone encountered at mid-depth within the Amabel Formation. It was determined that it is necessary to maintain the groundwater flux to this high conductivity zone otherwise the drawdown cone would expand outward beyond the GRS trench into the wetlands. This was addressed in the simulation by creating a hydraulic connection between the GRS at surface and this higher conductivity zone. These hydraulic connections can be achieved by drilling conduits to depth along the axis of the GRS trench and allowing the water to drain to the higher conductive zone under gravity. [Note: These conduits are drilled boreholes and are not to be confused with injection wells.] This combination of a trench and drainage wells is shown schematically in Figure 30.

5.2.2 Stage 1 Quarry Mitigation

The resulting configuration of the GRS (trench and the conduits) for the Stage 1 Quarry, as determined through the optimization efforts, is shown in Figure 31, and 32. Based on these simulations, it was established that 43.12 lps (570 igpm) would be required to maintain the GRS. At this rate, only a relatively small volume of this water is required to maintain water levels and groundwater flux to the wetland features. Most of the water re-distributed to the subwatershed and some is re-circulated back to the quarry through the bedrock.

As depicted in Figure 31 and Figure 32, the cone of influence and associated drawdown are effectively contained within the GRS. Because the groundwater level along the outer perimeter of the GRS is maintained there is no net loss in the groundwater flux to the adjacent wetland features. The model simulation indicates the potential benefit of installing the GRS as part of the Stage 1 Quarry operations.



Legend

- Surface Drainage Features
- Water Bodies
- Wetlands
- Active Model Domain
- Property Boundary
- Roads
- Extraction Limits
- Capture Zone - 25 Years of Travel
- Capture Zone - Steady State

SOURCE: Base mapping produced by Gartner Lee Limited under license with the Ministry of Natural Resources, Queen's Printer 1997 - Reproduced 2004.

PROPOSED DOLOSTONE QUARRY | **Figure 29**

SIMULATED ZONE OF CAPTURE
FULL QUARRY - CARLISLE WELLS

Project # 23827, Hydrogeological Modeling Investigation

Gartner Lee Limited

Scale
1:80,000

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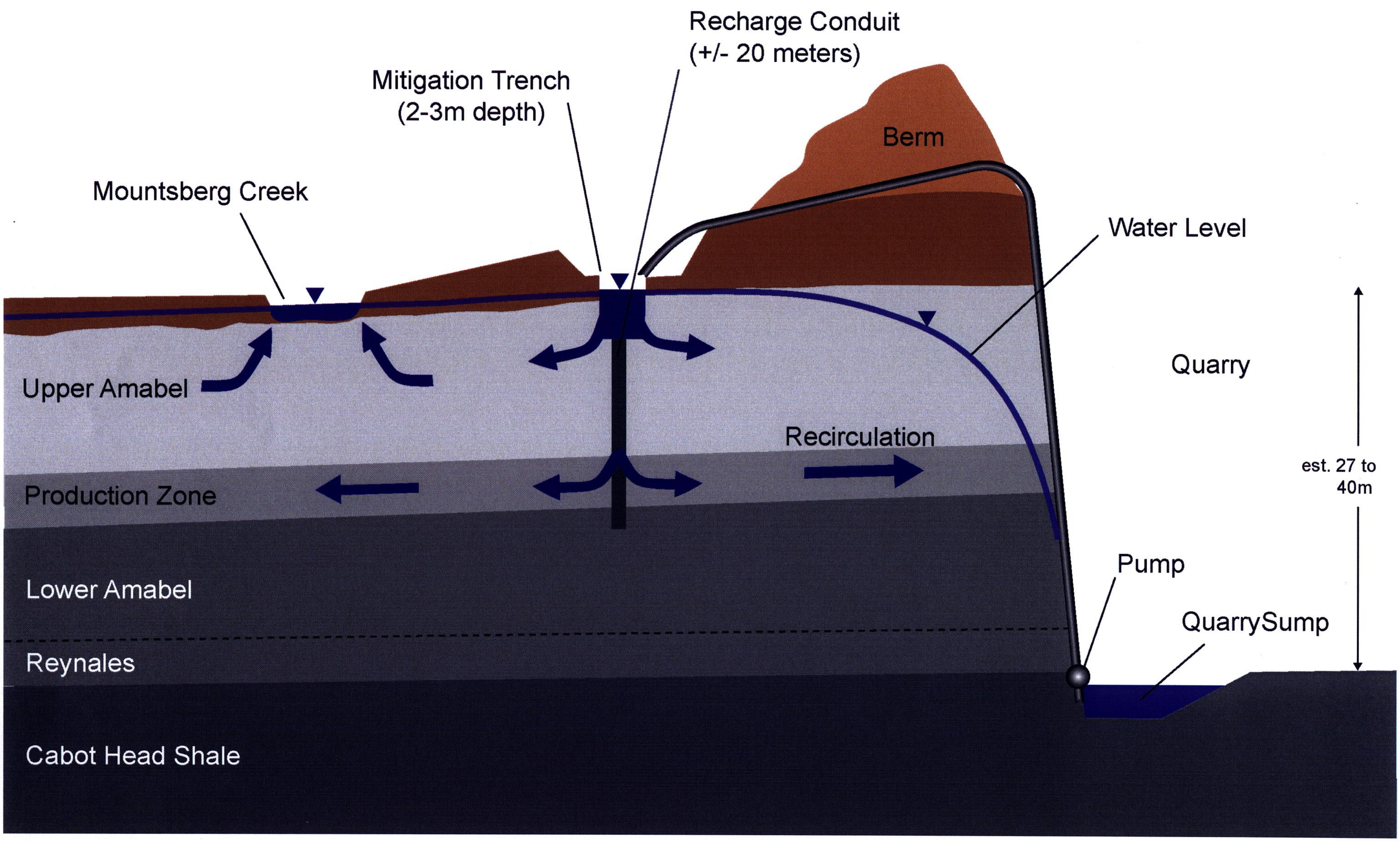

Not to Scale

Gartner Lee

Conceptual Mitigation System

DRAFT FOR DISCUSSION

FIGURE
30

Project 23-827

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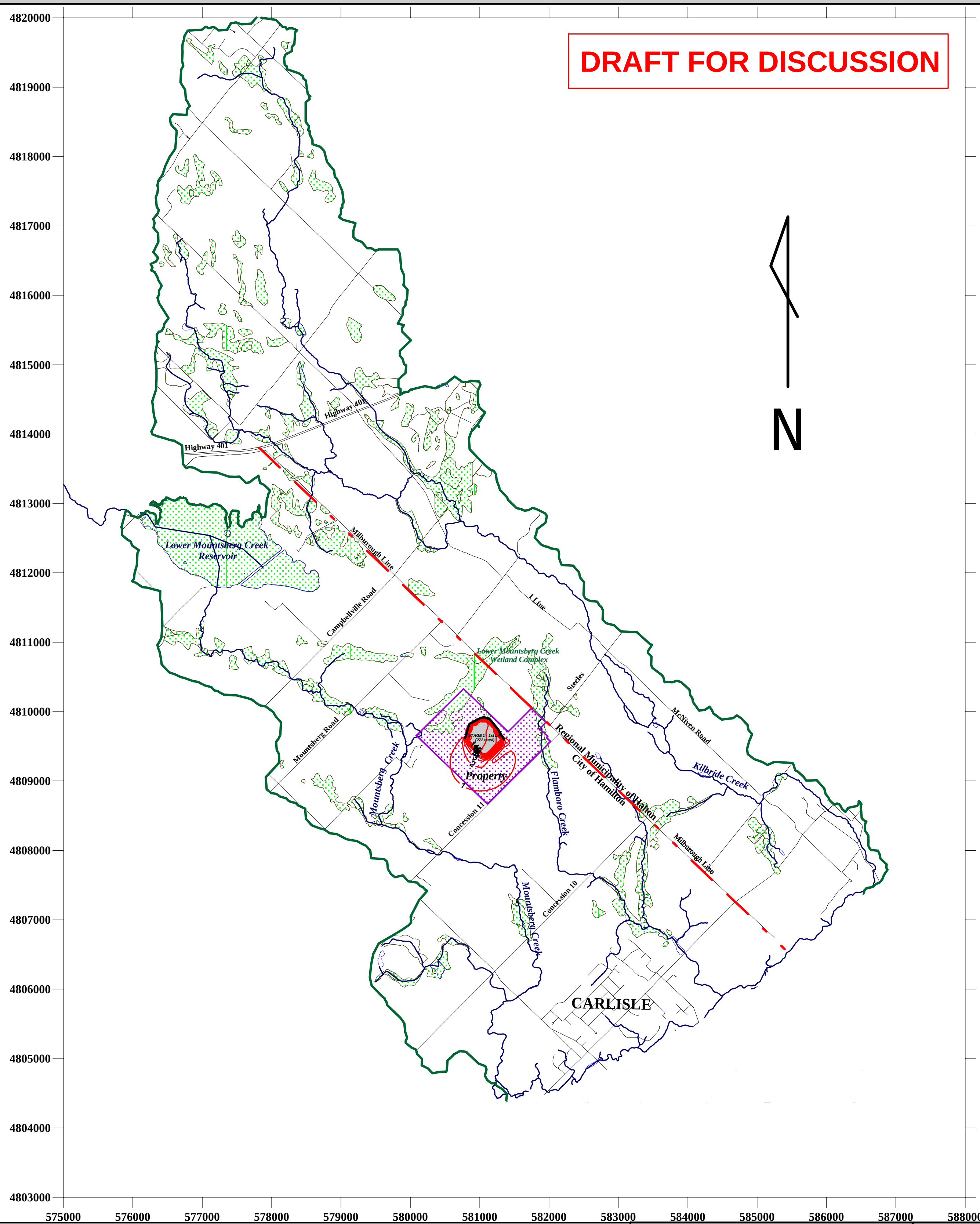

Legend

- Surface Drainage Features
- Water Bodies
- Wetlands
- Active Model Domain
- Property Boundary
- Roads
- Simulated Drawdown (m)
- Groundwater Recirculation System
- Extraction Limit

SOURCE: Base mapping produced by Gartner Lee Limited under license with the Ministry of Natural Resources, Queen's Printer 1997 - Reproduced 2004.

NOTE:
STAGE 1 1st Lift With Groundwater Recirculation System
Quarry Extraction = 4025 m^3/d
Water Delivered to Trench = 3726 m^3/d

PROPOSED DOLOSTONE QUARRY	Figure 31
SIMULATED DRAWDOWN - WITH MITIGATION STAGE 1 - 1st LIFT (272 masl) - REGIONAL SCALE	
Project # 23827, Hydrogeological Modeling Investigation	
Gartner Lee Limited	Scale 1:80,000

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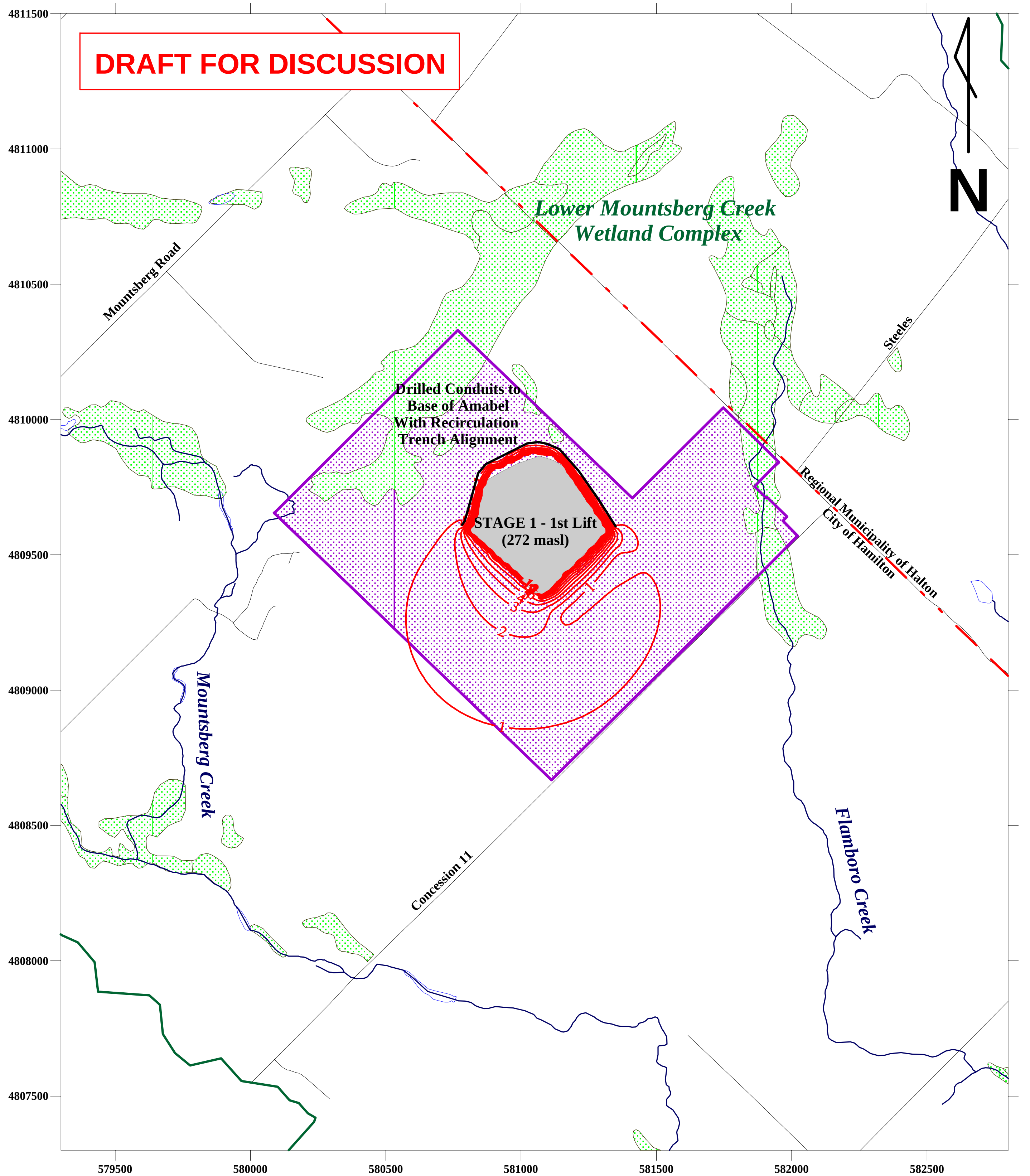


Legend

- Surface Drainage Features
- Water Bodies
- Wetlands
- Active Model Domain
- Property Boundary
- Roads
- Simulated Drawdown (m)
- Groundwater Recirculation System
- Extraction Limit

SOURCE: Base mapping produced by Gartner Lee Limited under license with the Ministry of Natural Resources, Queen's Printer 1997 - Reproduced 2004.

NOTE:
STAGE 1 1st Lift With Groundwater Recirculation System
Quarry Extraction = 4025 m^3/d
Water Delivered to Trench = 3726 m^3/d

PROPOSED DOLOSTONE QUARRY | **Figure 32**

SIMULATED DRAWDOWN - WITH MITIGATION
STAGE 1 - 1st LIFT (272 masl) - SITE SCALE

Project # 23827, Hydrogeological Modeling Investigation

Gartner Lee Limited

Scale
1:20,000

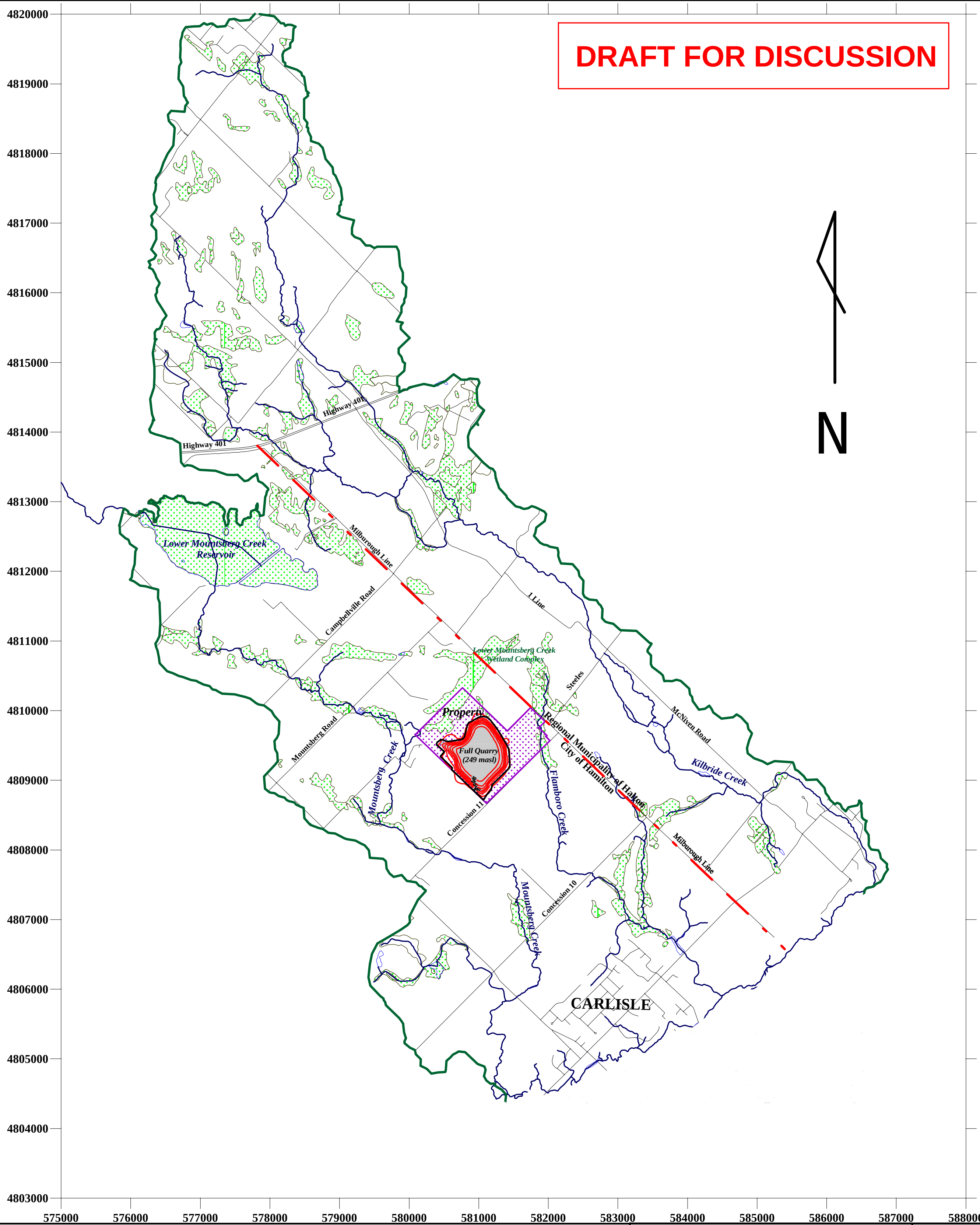
:07/07/05:\ N:\Projects\2003\23827\2005\WIP\Data Interpretation\2005 Model Report\Figures\Figure 32.srf

5.2.3 Full Quarry Mitigation

Additional simulations were undertaken to assess the effectiveness of using a perimeter GRS to mitigate the effects of the Full Quarry dewatering. The optimization efforts established that a GRS installed around the entire perimeter of the property would be required. .

The configuration of the GRS (trench and the conduits) for the Full Quarry and the resulting zone of influence and drawdown under the mitigating influence of the GRS at the regional and site scale, are shown in Figure 31, and 32, respectively. The volume of groundwater required to maintain the system as determined through the zone budget analysis, is on the order of 340 lps or (4,485 igpm). As depicted, the drawdown would be effectively contained within the GRS. Groundwater levels along the outer perimeter of the GRS are maintained resulting in no net losses to the adjacent wetland features.

Again, as with the Stage 1 Quarry 1 simulations, it should be noted that a relatively small quantity of the re-circulation water is required to maintain water levels and groundwater flux to the wetland features.



Legend

- Surface Drainage Features
- Water Bodies
- Wetlands
- Active Model Domain
- Property Boundary
- Roads
- Simulated Drawdown (m)
- Groundwater Recirculation System
- Extraction Limit

SOURCE: Base mapping produced by Gartner Lee Limited under license with the Ministry of Natural Resources, Queen's Printer 1997 - Reproduced 2004.

NOTE:
Full Quarry - With Groundwatre Recirculation System
Quarry dewatering: 29,274 m^3/d
Water delivered to Trench: 29,365 m^3/d

PROPOSED DOLOSTONE QUARRY

Figure 33

SIMULATED DRAWDOWN - WITH MITIGATION FULL QUARRY (249 masl) - REGIONAL SCALE

Project # 23827, Hydrogeological Modeling Investigation

Gartner Lee Limited

Scale 1:80,000

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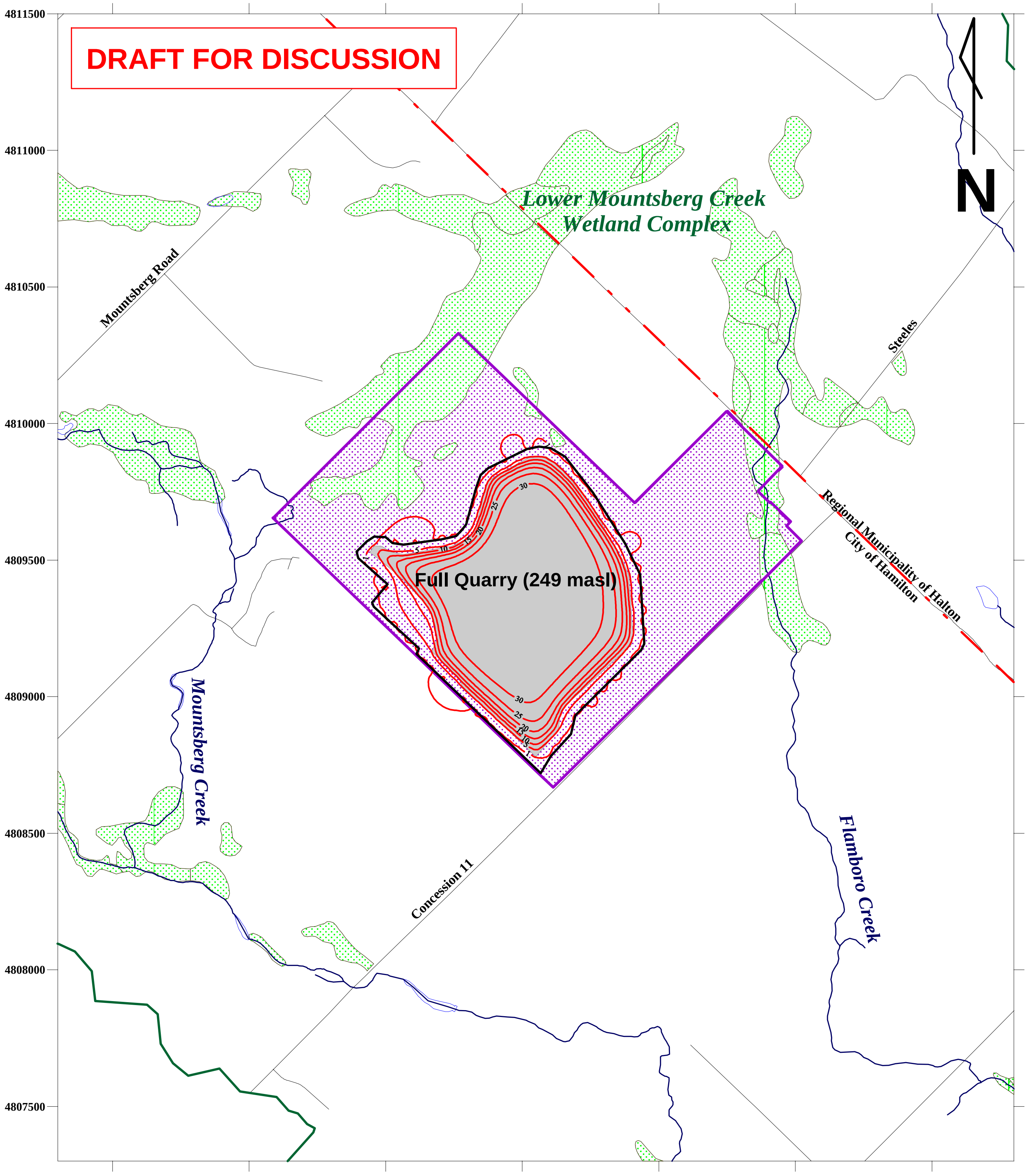

Legend

- Surface Drainage Features
- Water Bodies
- Wetlands
- Active Model Domain
- Property Boundary
- Roads
- Simulated Drawdown (m)
- Groundwater Recirculation System
- Extraction Limit

SOURCE: Base mapping produced by Gartner Lee Limited under license with the Ministry of Natural Resources, Queen's Printer 1997 - Reproduced 2004.

NOTES:
Full Quarry (249 masl) - With Groundwater Recirculation System
Quarry Dewatering = 29,274 m^3/d
Groundwater Recirculation System = 29,365 m^3/d

PROPOSED DOLOSTONE QUARRY	Figure 34
SIMULATED DRAWDOWN - WITH MITIGATION FULL QUARRY (249 masl) - SITE SCALE	
Project # 23827, Hydrogeological Modeling Investigation	
Gartner Lee Limited	Scale 1:20,000

:07/07/05:\ N:\Projects\2003\23827\2005\WIP\Data Interpretation\2005 Model Report\Figures\Figure 34.srf

6.0 Water Balance

The groundwater flow model was employed to establish a water balance for the subwatershed. The primary driving factors (water input and output) for any subwatershed water balance are: i) the recharge distribution throughout the given study area; ii) the surface water drainage network, including streams, rivers, creeks, and wetlands; and iii) existing water takings in both domestic water supply and Permits to Take Water for industry, commercial and municipal applications. The groundwater flow model accommodates these inputs.

Five water balances were completed. Specifically, a pre-quarry water balance to establish the 'baseline condition' and subsequent water balances to assess the effects of the Stage 1 Quarry and Full Quarry with and without mitigation. The results are presented in this Section.

6.1 Subwatershed Water Balance (Baseline)

The subwatershed water balance was first evaluated under pre-quarry conditions using the calibrated model. This water balance provides a baseline from which the influence of the quarry on the subwatershed water balance is evaluated. The water balance, which is a summary of the water inputs and water outputs for the subwatershed prior to quarry development, is provided in Table 6.

Table 6. Subwatershed Water Balance Pre-Quarry Development

Active Model Domain Water Balance Components				
A		**Water Input**	***Active Model Area (m^3/Year)***	***Lps***
	I	Groundwater Recharge	14,549,995	461.38
	II	River Leakage	22,526,705	714.32
		Total	**37,076,700**	1,175.69
B		**Water Outputs**	***Active Model Area (m^3/Year)***	***Lps***
	I	Rivers	32,658,010	1,035.58
	II	Water Wells (Domestic & PTTW)	890,600	28.24
	III	Drains (creeks)	180,310	5.72
	IV	Evapotranspiration (Wetlands)	3,347,780	106.16
		Total	**37,076,700**	1,175.69

The total volume of renewable groundwater available for natural and anthropogenic receptors for this study area is 37,076,700 m^3/yr (1,175 lps). This includes the volume of water infiltrating to the aquifer from precipitation, as well as surface water infiltration and recharge. This number does not account for the surface water flowing throughout the streams at any given point in time, after a rain event for example. The primary output (or water loss) for the subwatershed is the volume of water released to the network of streams, creeks and rivers, represented by drain and river drainage boundaries. This volume accounts for 88.5% of the total water available in the system. The next largest output (9.0%) is in the water uptake from wetlands (evapotranspiration). The third largest output (2.5%) is water uptake from domestic water use and PTTW throughout the subwatershed.

6.2 Subwatershed Water Balance (With Quarry Development)

The following is a listing of given assumptions and parameters that were used to develop the quarry water balance:

a) the surface area of the Stage 1 Quarry, as currently established, will cover 15 ha;

b) the developed area of the Full Quarry, as currently established, will cover 73 ha;

c) the annual production rate of stone proposed from the quarry is 3,000,000 tonnes;

d) it is estimated that about 50% of the product will be washed and will consist of coarse aggregate (1,2 million tonnes or 80%) and fine aggregate (0.3 million tones or 20%). The coarse aggregate will have an estimated water content of about 2% at the time it is shipped and the fine aggregate about 10%. The water loss for the coarse aggregate is estimated as 24,000 tonnes and 30,000 tonnes for the fine aggregate for a total of 54,000 m^3/yr);

e) other water losses include water used for dust suppression [assumed two trucks (10,000 L tanks) per day for four months of the year (50 m^3/yr)] and the water used in ancillary operations [assumed to include a water supply for a shop and office including 25 staff at 150 L/day per staff member for a 250-day working year (938 m^3/yr)];

f) the bulk of the precipitation that falls on the quarry will rapidly infiltrate the quarry floor due to blast induced fractures in the bedrock;

g) evaporation of precipitation within the quarry is assumed to be 20% of normal evaporation rates for the area (511 mm/yr x 0.2 =102 mm/yr within quarry);

h) pond evaporation rates for the quarry sump ponds is based on rates observed at Acton Quarry, 710 mm/year;

i) quarry sump pond area is expected to not exceed 3% of the quarry footprint at any given point during quarry development; and,

j) the productive zone identified in the Amabel Formation is present across the property and elsewhere within the local area.

The water balance is discussed from two perspectives: 1) the proposed quarry; and, 2) the subwatershed. The water balance of the quarry was initially completed based on assumptions on quarry operations and was then used as an input to analyze the water balance of the subwatershed and the overall disturbance to the subwatershed water balance from the quarry operation. Furthermore, for operational maintenance, it is important that a site-scale water balance be completed for the quarry apart from the watershed.

The quarry water balances for the Stage 1 Quarry and Full Quarry scenarios, under the above assumptions and given parameters, is discussed in detail in Volume 1. A summary is presented here.

- ***Stage 1 Quarry:*** The combined groundwater and surface water input for the Stage 1 Quarry is estimated as 852,974 m^3/yr (27.05 lps). The total water loss from the quarry was calculated to be 70,747 m^3/yr (2.24 lps). The volume of water to be extracted from the quarry during dewatering is estimated as 782,227 m^3/yr (24.80 lps).

- ***Full Quarry:*** The combined groundwater and surface water input for the Full Quarry is estimated as 4,076,562 m^3/yr (129.27 lps). The total water loss from the quarry was calculated to be 112,561 m^3/yr (3.58 lps). The volume of water to be extracted from the Full Quarry during dewatering is estimated as 3,964,001 m^3/yr (125.70 lps).

Subwatershed Water Balance (Stage 1 Quarry):

The water balance for the Stage 1 Quarry without mitigation is presented in Table 7.

Table 7. Un-mitigated Quarry Water Balance

Water Balance Components			*Stage 1 (m^3/year)*	*Full Quarry (m^3/year)*
A	**Water Input**			
I	Precipitation (849 mm average annual)		127,350	465,252
II	Groundwater inflow (from the model) or Dewatering Operations		725,624	3,611,310
		Total	**852,974**	**4,076,562**
B	**Water Loss** (1)			
I	Evaporation (Quarry Floor – 20% of 510mm/yr evaporation =		15,300	55,896
II	Evaporation (Pond Evaporation 710 mm/yr), from quarry sump ponds		459	1,677
III	Stone Shipments		54,000	54,000
IV	Dust Suppression		50	50
V	Ancillary Operations		938	938
		Total	**70,747**	**112,561**
C	**Water removed from quarry (i.e., water available for GRS trench or discharge to Mountsberg Creek)**			
	C = A – B		**782,227**	**3,964,001**
		Ips conversion	24.80	125.70

Note:

(1) Various components of a quarry operation such as the water adsorption in stone product shipped off site cannot be incorporated directly into the groundwater model and must be considered outside the model and subsequently added in the overall water balance analysis for the quarry for evaluation in the subwatershed context.

As indicated, the amount of water loss from the Stage 1 Quarry is estimated as 70,747 m^3/yr (2.24 lps). The water inputs/outputs for the un-mitigated Stage 1 Quarry condition calculated using the groundwater model are listed in Table 8.

Table 8. Un-mitigated Stage 1 Quarry Subwatershed Water Balance

Stage 1 Quarry Conditions – Subwatershed Water Balance Components				
A		**Water Input**	***Active Model Area (m^3/Year)***	***Lps***
	I	Groundwater Recharge	14,638,325	464.18
	II	River Leakage	22,669,055	718.83
		Total	**37,307,380**	**1,183.00**
B		**Water Outputs**	***Active Model Area (m^3/Year)***	***Lps***
	I	Rivers	32,196,285	1,020.94
	II	Water Wells (Domestic & PTTW)	890,600	28.24
	III	Drains (creeks)	136,123	4.32
	IV	Evapotranspiration (Wetlands)	3,263,100	103.47
	V	Quarry Dewatering Operations	725,624(1)	23.00
		Total	**37,211,732(2)**	1,179.97

Notes:

(1) The majority of this water is returned to the subwatershed through direct discharge to surface drainage features. The amount returned is estimated as 654,877 m^3/yr (20.80 lps), which means the subwatershed experiences a net loss from the quarry of about 70,747 m^3/yr (2.24 lps).

(2) The difference between the total input and output is due to mass balance error in the model simulations and represents about 0.26%, which is acceptable under ASTM standards for model applications.

The primary output for the subwatershed is still the network of streams, creeks and rivers, represented by drain and river drainage boundaries. Under the Stage 1 Quarry conditions this amount represents 86.6% of the total water available in the system. The next largest output (8.7%) is in the form of the water uptake from wetlands (evapotranspiration). The third largest (2.4%) form of water uptake is from domestic water use and PTTW through out the subwatershed. The quarry water uptake represents 0.19% of the subwatershed water balance and the water discharge to the subwatershed from the quarry represents 2.11% of the subwatershed water balance.

Subwatershed Water Balance (Full Quarry):

The volume of water loss from the Full Quarry without mitigation is estimated as 112,561 m^3/yr (3.57 lps). It is assumed that the majority of the water collected in the quarry would be discharged directly to local surface drainage features. The water inputs/outputs for the Full Quarry condition as calculated using the groundwater model, are presented in Table 9.

Table 9. Full Quarry Subwatershed Water Balance

Full Quarry Conditions – Subwatershed Water Balance Components			
A	**Water Input**	***Active Model Area (m^3/Year)***	***Lps***
I	Groundwater Recharge	14,638,325	479.17
II	River Leakage	24,136,355	765.36
	Total	**38,774,680**	1,229.53
B	**Water Outputs**	***Active Model Area (m^3/Year)***	***Lps***
I	Rivers	30,863,305	978.67
II	Water Wells (Domestic & PTTW)	890,600	28.24
III	Drains (creeks)	103,295	3.27
IV	Evapotranspiration (Wetlands)	3,088,265	97.93
V	Quarry Dewatering Operations	3,611,310(1)	114.51
	Total	**38,556,775(2)**	1,222.62

Notes:

(1) The majority of this water is returned to the subwatershed through direct discharge to surface drainage features. The amount returned is 3,498,749 m^3/yr (110.94 lps)., which means the subwatershed experiences a net loss from the quarry of about 112,561 m^3/yr (3.57 lps).

(2) The difference between the total input and output is due to mass balance error in the model simulations and represents about 0.56%, which is acceptable under ASTM standards for model applications.

Again, the primary output for the subwatershed is to the network of streams, creeks and rivers, represented by drain and river drainage boundaries. Under the Full Quarry condition this amount represents 79.9% of the total water available in the system. The next largest outputs are from water uptake from wetlands as evapotranspiration (8.0%) and water uptake is from domestic water use and PTTW (2.3%). The quarry water uptake represents 0.29% of the subwatershed water balance and the quarry discharge to the subwatershed represents 9.51% of the subwatershed water balance.

6.3 Quarry Effects - Predictive Simulations Discussion

The groundwater model was also employed to address specific questions regarding the influence of the proposed dewatering as the quarry advances through the sequential staging developed for the quarry operations. The focus of the first round of predictive simulations (which are provided in this report) is to promote dialogue with the City of Hamilton peer reviewer and the applicable agencies.

The unmitigated quarry development and the associated dewatering impacts will reduce groundwater levels adjacent to, and beneath, the wetlands in proximity to the property. This reduction in the water level will, in turn, result in a decrease in the volume of groundwater (flux) that discharges and sustains the wetland features, and will affect the baseflow in Mountsberg Creek and Flamboro Creek.

The simulated volume of groundwater pumped from the quarry during the Stage 1 Quarry dewatering operations is predicted to be about 27.0 lps (488 igpm). Figure 24 and Figure 25 illustrates the simulated zone of influence and the drawdown in the groundwater level from the Stage 1 dewatering operations, at a regional and site scale, respectively. The zone of influence per the 1 m contour extends through both wetlands with a radius of about 1,500 m in the longest axis (southwest to northeast).

The simulated volume of groundwater pumped from the Full Quarry during the dewatering operations is predicted to be about 129.26 lps (1,706 igpm). The simulated zone of influence and predicted drawdown in the groundwater level for full quarry development to a base elevation of 249 mASL is shown in Figure 27 (regional scale) and Figure 28 (site scale). As illustrated, the 1 m drawdown contour extends well beyond the Mountsberg Creek and Flamboro Creek wetlands with a radius of over 2,500 m in the longest axis (southwest to northeast).

The simulated groundwater drawdown to the north is buffered to some degree because of the positive hydraulic boundary namely Mountsberg Creek, and the fact that this area is upgradient of the quarry. Groundwater moves through this area prior entering the quarry property where it discharges into the quarry under gravity drainage. The continuous flow in Mountsberg Creek will act to recharge the bedrock reducing the drawdown induced from quarry dewatering.

Effects of Quarry Development on the Wetlands and Surface Water Balance:

'Zone budget' is a module that is used in conjunction with MODFLOW to calculate the water balance or volumes of inputs and outputs for given areas delineated within a model. For example, a particular zone can be applied to the quarry area, a second zone applied to the wetlands near Mountsberg Creek and a third applied to the wetlands near Flamboro Creek. A zone budget analysis was used to determine the pre and post water flux to the wetland features in proximity to the quarry. The results of this analysis are presented in Table 10.

Table 10. Predictive Groundwater Model Results for Quarry Configurations

Scenario	% Change in Groundwater Flux to Wetland		River Loss to Recharge (% change)	Predicted Flows (lps) Into Quarry[1]
	Wetlands near Mountsberg Creek	Wetlands near Flamboro Creek	Mountsberg Creek subwatershed	
Calibrated Base Case Model	0	0	0	n/a
Stage 1, 1st Lift (272 mASL)	28%	29%	18%	27.00
Full Quarry, final depth,(249 mASL)	86.8%	79%	342%	129.26

Notes:

(1) This value includes both the groundwater discharge and direct precipitation(14.75 lps) on the quarry.

The groundwater model predicts that as a result of the Stage 1 Quarry dewatering, the wetlands adjacent to Mountsberg Creek will experience up to a 28% decrease in the groundwater flux from dewatering. The wetlands adjacent to Flamboro Creek will experience up to a 29% decrease in the groundwater flux. The river loss to recharge in the Mountsberg Creek subwatershed is simulated as 18%.

The decreases in groundwater flux for the wetlands along Mountsberg Creek and Flamboro Creek respectively for the Full Quarry are estimated as 86.8% and 79%. The aquifer gain from river recharge for the reach of Mountsberg Creek directly adjacent to the quarry in the subwatershed is simulated as 342%.

Table 11. Predicted Flows Required to Mitigate Quarry Dewatering

Computer Simulation	Predicted Flows Extracted from Quarry	GRS Discharge Required to Maintain Water Levels
Stage 1, 1st Lift (272 mASL)	23.0 lps (303 igpm) (1)	
Stage 1, 1st Lift (272 mASL), with mitigation	46.58 lps (615 igpm) (1)	43.12 lps (570 igpm) (1)
Full Quarry, final depth (249 mASL)	114.51 lps (1,511 igpm) (1)	
Full Quarry, final depth (249 mASL) with mitigation	338.82 lps (4,472 igpm) (1)	339.87 lps (4,485 igpm)(1)

Note:

(1) These numbers reflect the full quarry footprint and do not account for the volume of water generated from direct precipitation over the quarry footprint. For a more detailed discussion on water balance including these volumes refer to the Volume I report.

7.0 Conclusions

The hydrogeological modeling investigation for this quarry development has provided a comprehensive analysis of the groundwater and surface water resources for the Mountsberg, Flamboro, and Kilbride Creek subwatersheds. The source water for the three subwatersheds that comprise the model domain has been reasonably accounted for in the water budget determined in the modeling investigation. The modeling investigation has considered the primary elements of water inputs and outputs for the system, including variable recharge distribution throughout the model domain, streams and creeks, wetlands, PTTW extraction from groundwater resources currently in the area, as well as domestic water takings represented by MOE WWR .

The model has achieved a high standard of data integration that provides a high level of prediction confidence for additional stresses that are proposed for these subwatersheds. The following are key conclusions obtained from this hydrogeological modeling investigation:

(1) The bedrock aquifer system and the surface water drainage features are connected, at times discretely throughout the subwatersheds;

(2) The groundwater system is governed by four specific hydrostratigraphic units throughout the model study area:

   i) Overburden and upper portion of the Amabel Formation;
   ii) The productive zone within the mid section of the Amabel Formation;
   iii) The deeper and tighter portion of the Amabel Formation and Reynales Formation; and
   iv) The Clinton Cataract Group;

(3) The wetland features are discretely connected to the groundwater system and represent a groundwater output for the subwatershed;

(4) The recommended Groundwater Recirculation System (GRS) comprises a perimeter trench, excavated into the bedrock; and conduits drilled along the trench axis, to provide a hydraulic connection to the productive zone, within the Amabel Formation;

(5) Water discharged to the GRS will recirculate into the quarry excavation;

(6) Stage 1 and Full quarry operations, without mitigation, would influence the existing groundwater regime; affect the water balance for the Lower Mountsberg Creek Wetland Complex; and could adversely affect local water supplies;

(7) With the recommended GRS in operation, these effects can be mitigated, so that the groundwater regime, wetland water balance and local water supplies are not adversely affected;

(8) The proposed quarry operations will not impact the quantity of water available for the Carlisle Municipal system; and

(9) The initial GRS should be installed prior to excavation of stage 1, monitored and, as necessary modified and expanded, as part of an adaptive management plan, for the life of the quarry operation.

8.0 Closing

The numerical model presented here demonstrates the complexities inherent in any groundwater/surface water system.

The many parameters that effect a groundwater system are difficult, if not impossible, to assess one at a time. A groundwater model assists the hydrogeologist in understanding the overall response and behavior of the system under a given set of stress conditions such as municipal water well pumping, and quarry dewatering in the presence of variable recharge and discharge conditions through out a given model domain

This groundwater flow model presented herein has identified the potential influence the proposed quarry will have on the surrounding groundwater and surface water flow regime under mitigated and un-mitigated scenarios and for stage 1 quarrying as well as for the completed quarry under active dewatering conditions.

Report Prepared By:

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