City of Ottawa

Groundwater Flow and Contaminant Transport Model: Village of Greely and Surrounding Area

Final

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REPORT TO

CITY OF OTTAWA

ON

GROUNDWATER FLOW AND CONTAMINANT TRANSPORT MODEL: VILLAGE OF GREELY AND SURROUNDING AREA

PREPARED BY

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GLOSSARY OF TERMS

.dat	File extension for ASCII text data files
.mdb	File extension for Microsoft Access ™ files
.shp	File extension for ESRI ArcView feature files
.xls	File extension for Microsoft Excel ™ files
ArcView	ESRI geographic information system
bgs	Below Ground Surface
Data Dictionary	Compendium of datasets detailing source and nature of data
DTM	Digital Terrain Model
GIS	Geographic Information System
JW	Jacques Whitford
krig	Method of interpolation where values are exact at input data points
LEACHM	Public domain unsaturated zone infiltration and chemical fate and transport model
masl	Meters above Sea Level
MODFLOW	Public domain saturated zone groundwater flow model
MOE	Ministry of the Environment
PIN	Property Identification Number
QA/QC	Quality Assurance/Quality Control
RMS	Root Mean Square
UTM	Universal Transverse Mercator

1.0 INTRODUCTION

This report is submitted to the City of Ottawa (City) as a draft of the results of the modelling of groundwater flow and contaminant transport within and surrounding the Village of Greely. This work was executed in accordance with JW proposal number ONO030539 dated July 21, 2003. This model was required for three reasons:

- To support ongoing monitoring of the cumulative development pressures and related groundwater impacts within the Village of Greely and surrounding areas (hereafter referred to as the study area) necessitate an additional degree of diligence, to assure protection of human health,
- Provincial requirements for assessment of wellhead protection[1] and planning have been established which require verification through comparison to model results, and
- A greater understanding of the hydrogeological complexity and functioning of the area is required to support the review and approval of development.

The preliminary objectives of this model were as follows:

- To replicate observed groundwater flow and contaminant transport behavior within the study area, and
- To support planning through testing of future use scenarios.

For analysis of future use scenarios, the contaminant of concern is nitrate, and reference is made to the Ontario Drinking Water Standard (ODWS). Note that nitrate is also a good indicator of the potential presence of other contaminants of concern. Recognising that the return on the time and resources invested in this type of project is a function of how readily the model can continue to be utilised to assist decision making into the near future, the following guiding principles were adhered to:

- Duplication of effort was avoided wherever possible: as hydrogeological reports and wellhead protection plans were prepared for proposed developments, the information was added to the model to support calibration and improve accuracy, and
- The model user interface and training on delivery must be sufficiently user friendly to provide City staff or their delegates (i.e., RVCA, which provides review of hydrogeological assessments for the area of concern for the City) with a sufficient degree of comfort in its use.

[1] Ontario Ministry of Environment Terms of Reference – Hydrogeological Study to Examine Groundwater Sources Potentially Under Direct Influence of Surface Water, PIB 4167e, October, 2001.

2.0 SCOPE OF WORK AND METHODOLOGY

2.1 Scope of Work

The scope of work for the modelling effort was as follows:

- Design of the groundwater flow and contaminant transport model through execution of the following tasks;
  - Definition of model objectives, opportunities and constraints, and available data,
  - Selection of the modelling components to include numerical models, databases and model output mapping environments (GIS), and
  - Definition of model development, calibration, sensitivity analysis and validation scenarios.
- Development of the model through execution of the following tasks;
  - Collection, QA/QC, and formatting of source data covering physical factors (overburden depth, type, saturation, bedrock type, water table elevation, bedrock water elevation, background aquifer chemistry (overburden vs. bedrock aquifers), and land use) and anthropogenic factors (lot size, subdivision age, private well depth, roadway size/location),
  - Preparation of input files,
  - Model verification (using existing data sources),
  - Model calibration (using new field data as required),
  - Sensitivity analysis, and
  - Model validation.
- Implementation of the model through execution of the following tasks:
  - Collecting 'what if?' scenarios from City staff during a half-day workshop, including description of the model and results of design and development efforts,
  - Analysis of 'what if? scenarios,
  - Preparation of draft report outlining design, development and implementation results and including the model user guide,
  - Collection of comments, and
  - Preparation and delivery of final report in hard copy, and model with data in soft copy.

2.2 Methodology

The three phases and their constituent tasks were executed sequentially according to the methodologies described below. An overall systems engineering process was used to define the phases and tasks: such a process follows a define requirements – map requirements to functions – design – development – verification – validation stepwise approach.

2.2.1 Task 0: Project Management

Project management responsibility was borne by Mr. Wilson throughout this undertaking, covering coordination between staff, liaison and regular updating with the City, and QA/QC.

2.2.2 Phase 1: Model Design

Model design took the project from problem definition through conceptualisation to selection of the modelling components and analysis scenarios. The area of interest for the model is shown in Figure 2, covering all of the Village of Greely and extending into the surrounding area based on the continuity of hydrostratigraphic units (application of boundary conditions). The challenge in establishing the area of interest is highlighted in Figure 1, which shows the influence of bedrock highlighting the fact that a three-way flow divide exists below the Village. Hydraulic boundaries form as a result of hydrologic conditions, notably at groundwater divides, although these features are not permanent, and may shift their location or magnitude (of flux or head). Extreme care was taken in specifying hydraulic boundary conditions.

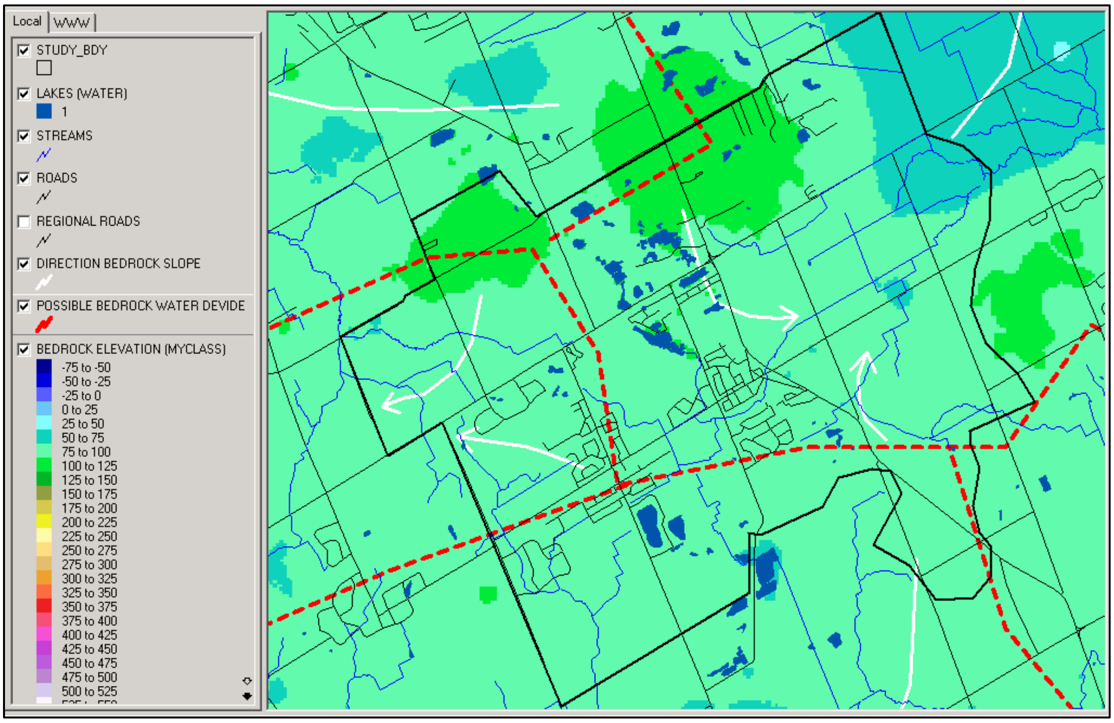


FIGURE 1. INFLUENCE OF BEDROCK

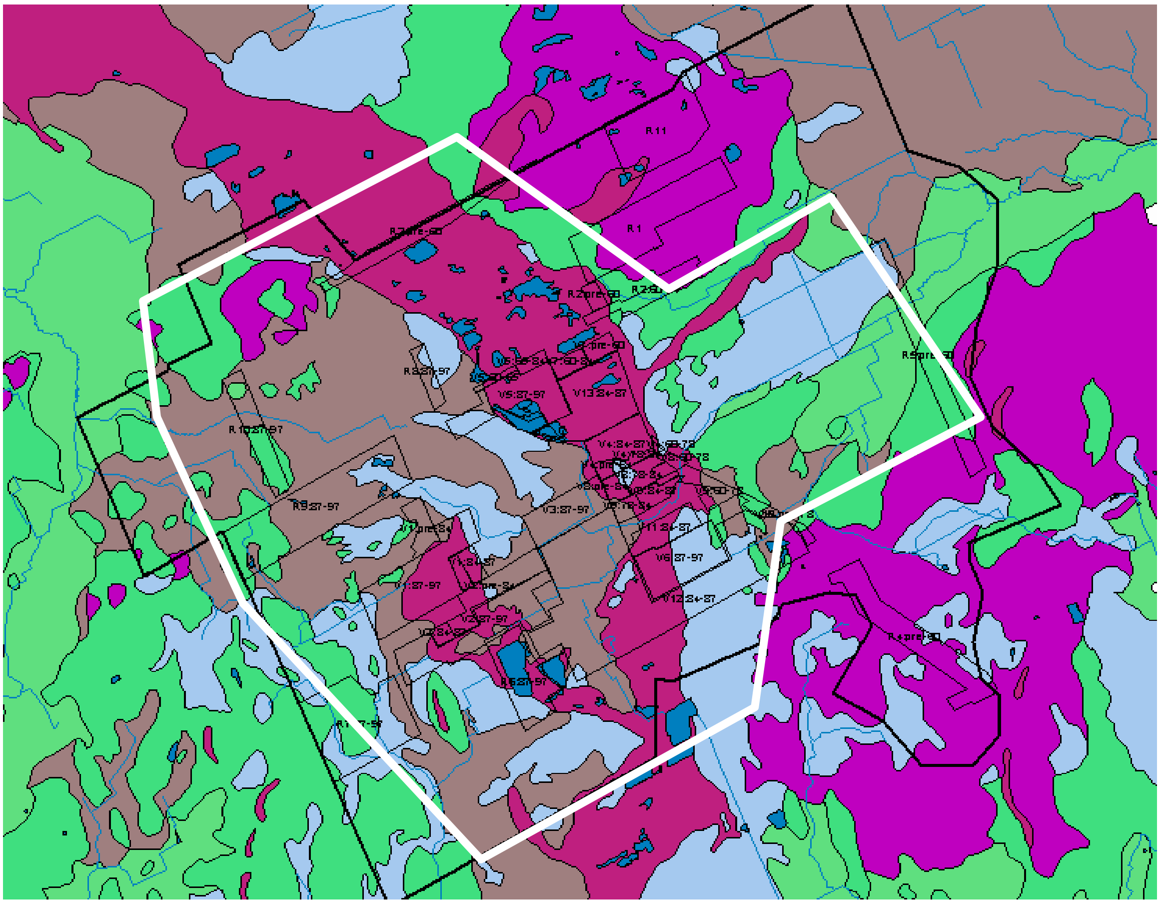


FIGURE 2. AREA OF INTEREST

Task 1.1: Definition of model objectives, opportunities and constraints, and available data

The preliminary objectives outlined in Section 1.0 were confirmed as part of this task, once the opportunities, constraints and available data had been defined. An examination of opportunities and constraints is a critical up front step, involving consideration of previous and current work undertaken in the area of interest that could potentially impact this study. The listing of such work is as follows:

Opportunities:	Completion Date
Shields Creek Subwatershed Study	March, 2004
Existing Conditions Reports[2]	June, 2002/January, 2003

[2] Including the drainage study previously completed by Stantec

Interim Groundwater Study Report #1	June, 2002
Interim Groundwater Study Report #2[3]	January, 2003
Detailed Analysis of Greely Area Groundwater Sampling	June, 2003
Greely Land Use Study	not known
Peer Review of Shadow Ridge	July, 2003

Constraints:

There are physical and budgetary constraints for this project. Physically, the major constraint was availability of data – data for model design, data for model calibration, data for scenario generation and analysis. From a budgetary perspective, it is unreasonable to assume that sufficient funds would be available to address all of the data gaps – this would also be unreasonable from a time to completion perspective. Therefore, a best value approach was needed; maximum gains for minimum costs. Section 5 outlines in detail the project risk elements and mitigation measures undertaken. There are also constraints associated with the capabilities of the existing groundwater modeling software packages to adequately represent the complexities of any given hydrogeological system, particularly in regard to unsaturated zone-groundwater interaction. These constraints were addressed by careful scoping of modeling approaches at the outset, and review at various stages throughout the project.

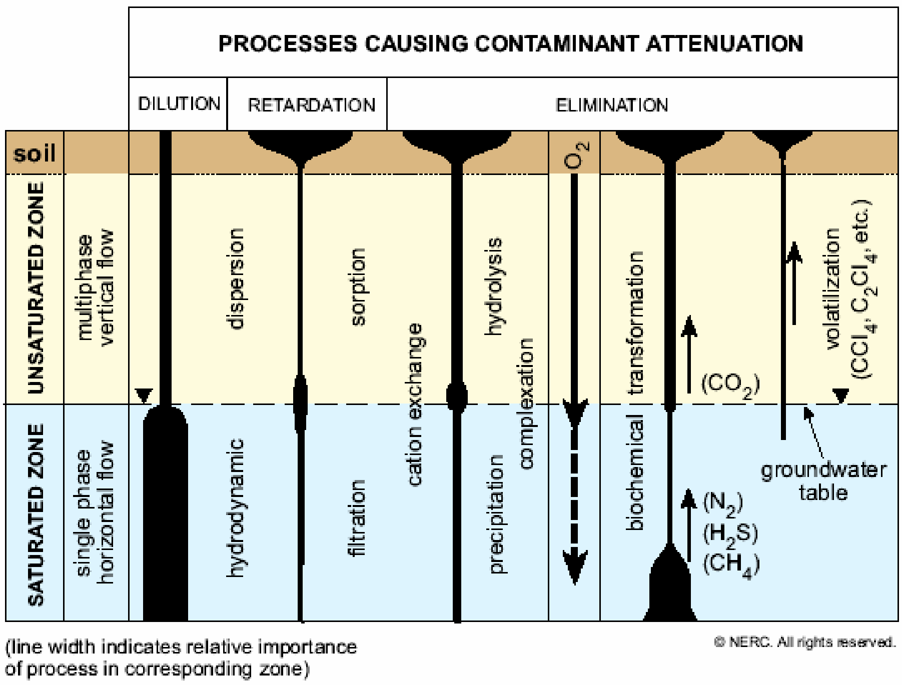


FIGURE 3. UNSATURATED AND SATURATED ZONES: CONSIDERATIONS

[3] Includes the reviewed background hydrogeological investigation reports

Task 1.2: Selection of the modelling components

This task required the modelling components to be selected. The overall modelling system of necessity is composed from a number of components, primarily driven by the fact that no one validated model can address all three physical domains: surface, unsaturated subsurface and saturated subsurface. Treatment of the unsaturated zone was the greatest technical challenge of this assignment. As shown in Figure 3, the importance of differing processes varies significantly by zone. This fact is often ignored, invalidating subsequent results. Section 5 further addresses the technical challenge of the unsaturated zone as a risk element, and describes the mitigation measures undertaken.

The behaviour of nitrate in each of these zones varies significantly. For that reason, JW employed a rigorous methodology for model selection, based on the US ASTM guidance document *RBCA Fate and Transport Models: Compendium and Selection Guidance (1999).* The selection process considered both institutional (e.g., preference of the City, degree of peer validation, consistency with existing information management tools such as the coupled Access database and ArcView GIS used for previous Greely work, data requirements, etc.) and physical (e.g., chemical and physical processes addressed – advection, dispersion, diffusion, equilibrium partitioning, biodegredation) factors, covering both analytical and numerical models.

Task 1.3: Definition of model development, calibration, sensitivity analysis and validation scenarios

The scenarios needed to support model development, calibration, sensitivity analysis and validation were defined in Phase 1, such that any gaps in available data for the scenarios could be addressed as part of Phase 2. This task also served to define the modelling regimes: Steady-state or dynamic? Present or future conditions? Average annual, seasonal, or daily? It also served to fix the data management process, the last step of the design phase.

2.2.3 Phase 2: Model Development

Task 2.1: Collection, QA/QC, and formatting of source data

At the outset of this task, JW set up the Data Dictionary for the project. A data dictionary is a listing of all files and data sets used throughout all phases, defining the data source, extent, nature, location, and usage history. A data dictionary is an excellent quality control tool, helping to prevent duplication of effort in preparing source data and prevent introduction of errors as data sets are formatted and processed. A listing of the contents of the data dictionary is contained in Appendix 3.

The data management platform used was the Wells database, populated during previous work by the Team, and a new Microsoft Access® database driving the unsaturated zone model. The utility associated with use of this data source cannot be overstated – the savings in person days associated with not having to prepare this source from scratch is significant. With delivery of the modelling toolbox, this advantage will be available to those performing future work within the study area, such as wellhead protection area plans.

The field work needed to address data gaps was not required, as additional background reports were provided by the City. Data gaps were also filled from the opportunities identified previously, as available. In order to prepare for the modelling effort, it was necessary to add hydraulic conductivity and other parameter information to the database (rainfall, infiltration, contaminant loading). Horizontal hydraulic conductivities of shallow and deep aquifers were obtained by referencing background reports of slug and pumping tests utilising existing wells in the study area. The spatial distribution of nitrate and soil organic content in unsaturated zone soils in the study area was not completely known – again reference to background reports and to published literature values were used to fill this data gap. Other information such as annual rainfall was obtained from existing data sources.

These data collection efforts completed the establishment of the baseline conditions for the area of interest, upon which all subsequent tasks relied.

Task 2.2: Preparation of input files

Having completed data collection, model selection and scenario definition, all necessary input files were prepared within the data management system, with source data residing either within the Access databases or within ArcView (as vector- or grid-based data as needed) as required. In addition, an Excel spreadsheet was set up as a link between Access and both ArcView and the unsaturated zone model (LEACHM), such that calculations representing the mixing of infiltrated precipitation and septic outflow could be performed.

Task 2.3: Model verification

Model verification is a distinct phase of the overall systems engineering process, wherein the modelling system is tested to ensure its calculations are correct. Verification is commonly confused with validation, wherein a modelling system is tested to ensure it meets its requirements. Verification involves calculating the outputs of each model component independently of the model, and comparing the results to the model results to flag any inconsistencies for subsequent troubleshooting and correction.

Task 2.4: Model calibration

Perhaps the most critical task within model development, calibration is a process of adjusting model calibration constants in order to match model outputs to real world results. The hydrologic/hydrogeologic chain from precipitation through surface losses (runoff, evapotranspiration), infiltration and recharge to groundwater flow requires estimation of parameters based on physical data that offer an adjustment range.

Calibration was be assisted greatly by the geostatistical modelling work completed as part of the Detailed Analysis study. Deviations between observed and expected nitrate concentrations as described in that study and the outputs of the model were examined in detail, such that the sources of error could be uncovered and corrected.

Task 2.5: Sensitivity analysis

The sensitivity analysis is a process whereby the variation in model outputs as a function of variation in model inputs is assessed, such that the significance of input parameters can be determined. This is accomplished by varying the input parameters of the sensitivity analysis scenario through their range of potential values, and recording the change in outputs (e.g., varying the amount of infiltration from zero up to a theoretical maximum percentage of precipitation, and recording the resultant change to water levels, flows, and contaminant transport).

Task 2.6: Model validation

The final task of model development is validation, wherein the ability of the modelling system to achieve the objectives preliminarily defined in Section 1.0 and confirmed as part of Task 1.1 was assessed.

Based on feedback from the City, the validation scenario is an expected future conditions build-out impact assessment, demonstrating which sector-areas are under the greatest threat. Results, including GIS-based maps generated on overlays of planning information (i.e., present and planned subdivision boundaries, lots, etc.), are shown within the results of Section 3.

2.2.4 Phase 3: Implementation

Task 3.1: Collecting ‘what if?’ scenarios / half-day workshop

With the validated modelling system near completed, a presentation and workshop was held at the City. The results of the first two phases were described, followed by a guided session aimed at defining the future conditions scenario that was modelled and is described in this report.

Initial recommendations for additional scenarios, based on feedback from the City, were as follows:

- *Nitrate Impacts to Sensitive Environments.* One scenario of interest is prediction of when nitrates can be expected, through leaching and horizontal and vertical transport, to reach the nearest sensitive environments, as define in the ongoing Shields Creek Subwatershed Study.
- *Current Nitrate Levels, Dissipation over Time.* Another scenario of interest is to predict how current nitrate levels would reduce over time under the assumption that anthropogenic loadings were to cease.
- *Effect of Implementing Tertiary Nitrate Removal Systems.* A useful scenario for examining the benefit of requiring nitrate treatment as a condition of approval, this analysis would compare resulting nitrate levels with and without such systems, and would include a cost-benefit result summary including costs for available treatment systems.
- *Optimisation of Septic Design for At-Risk Subdivisions.* This scenario would examine the necessary reduction in septic-based nitrate loading required to bring at-risk subdivisions out of risk.
- *Optimisation of Area Monitoring Programs.* The final potential scenario is an examination of the expected future use conditions for key monitoring frequencies and locations: how often should monitoring occur (i.e., what is the rate of change of nitrate levels?)? where should monitoring occur (i.e., is it sufficient to monitor in high-risk areas, or is greater spatial coverage necessary given the geospatial variation in concentrations?
- *Back-Calculation of Optimal Lot Size*. This scenario would involve an iterative analysis of the expected future build-out by increasing lot sizes (and thereby decreasing lot density and nitrate loading) to a point where a target sub-surface nitrate level is met. This target should reflect a level where public health is adequately protected, and may not be as high as the ODWS of 10 mg/L.

Task 3.2: Analysis of ‘what if? Scenarios

Three ‘what if?’ scenarios were modelled by the Team and are presented in this final report, complete with results maps and descriptions: #1 current conditions (calibration scenario), #2 future build-out conditions (where all current applications are assumed built), and #3 future full build-out conditions (where in addition to #2, all remaining land available for development within the Village is assumed built).

Task 3.3: Preparation of draft report and user guide

The results of all phases of work less Tasks 3.4 and 3.5 were laid out in the final draft report, dated November 11, 2003. The User Guide for the modelling system was not included with the draft, but has subsequently been completed and forms part of this final report at Appendix 5 – JW intends to deliver both the work results and the modelling system to the City, for ongoing use.

Task 3.4: Collection of comments

City staff was afforded the opportunity to submit comments on the final draft report during this task, which were addressed within this final report.

Task 3.5: Preparation and delivery of final report

This final report is being delivered to the City in twenty hard copies and electronically. Ten hard copies include a CD, loaded with the soft copy of the report and with the complete modelling system, to include the data management platform (the Wells Access database, ArcView maps and shapefiles, and all modelling components) and the final User Guide.

3.0 RESULTS

3.1 Phase 1: Model Design

3.1.1 Confirmation of Objectives and Available Data

The final model objectives were confirmed after the project initiation meeting held with City staff on July 30, 2003, as follows:

- To replicate observed groundwater flow and nitrate transport behavior within the study area, and
- To support planning through testing of future land use scenarios.

Opportunities were confirmed, with data being added to the previous JW work through completion of the Shadow Ridge Peer Review (and the associated review of relevant reports – refer to the Data Dictionary completed under Phase 2 for details – a listing of the Data Dictionary is given in Appendix 3), and delivery of the Stantec and TSH surface water modelling data.

The surface water modelling data did not include information outside of the dendritic system modelled, i.e., overland areas were not characterised (for soil type, SCS curve number, or similar hydrologic ratings), and so could not improve the density of data available on surficial soils. The opportunity map resulting is shown in Figure 4.

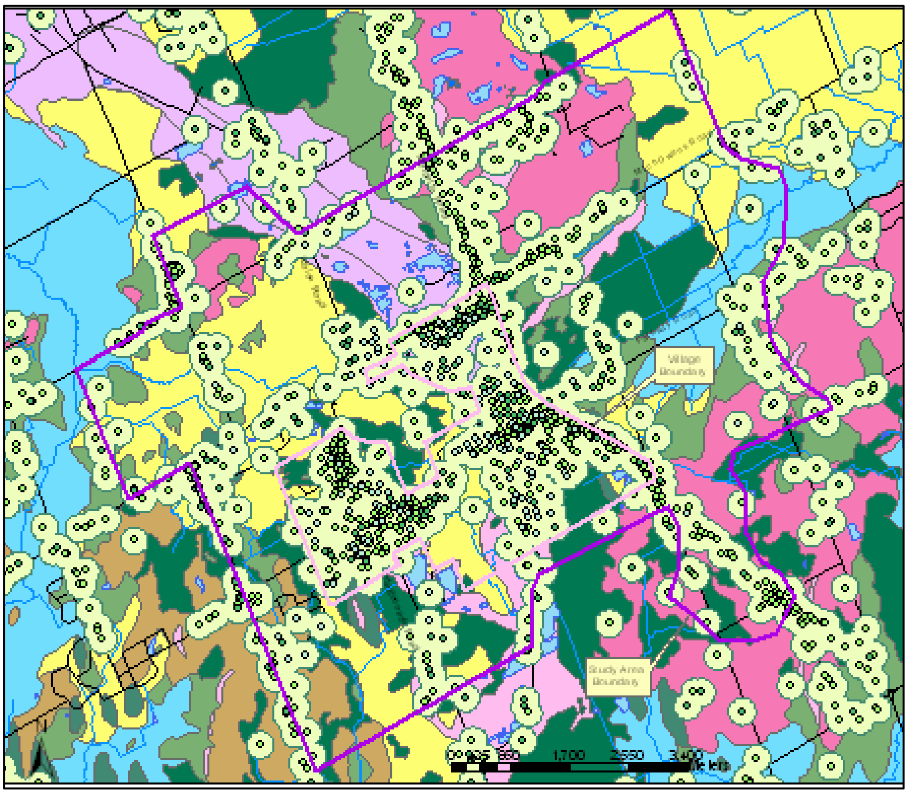


FIGURE 4. MODEL OPPORTUNITIES

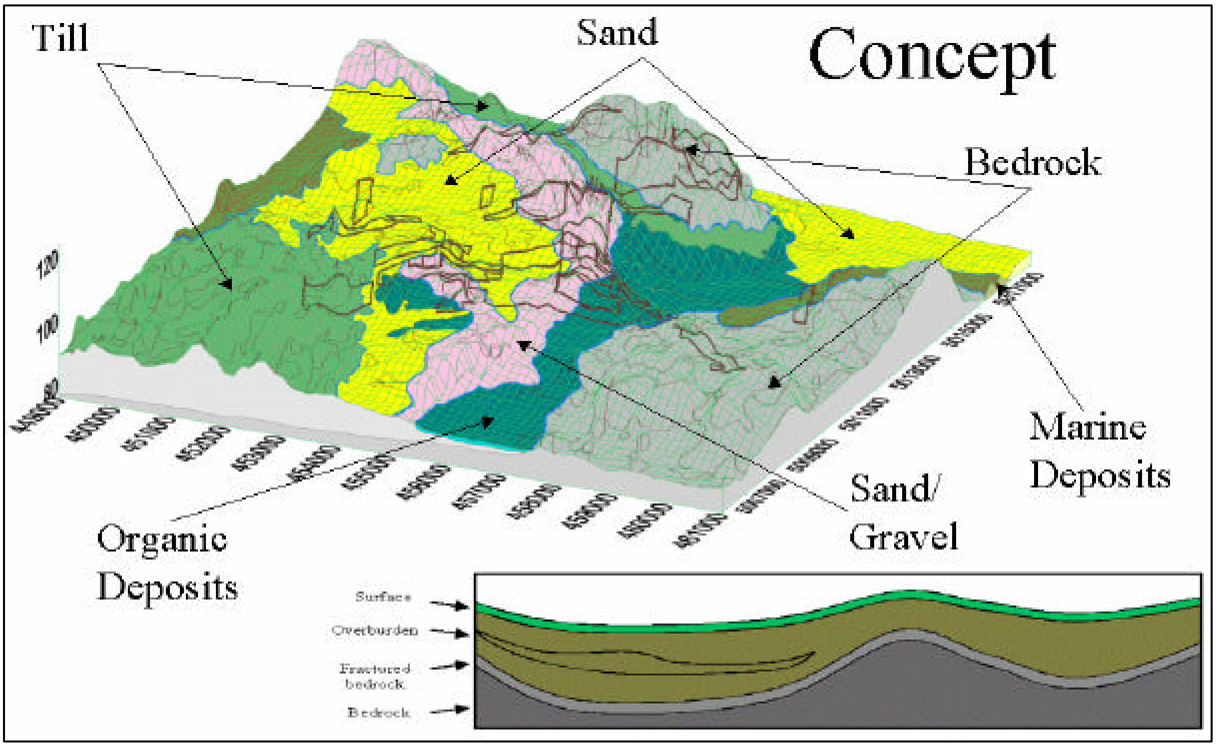
From a constraints perspective, the two of greatest import are data availability, and model suitability for predicting fate and transport in the unsaturated zone. With respect to the former, the opportunity map in Figure 4 demonstrated the need to 'plug the hole' between the northern and western sections of the Village through review of additional reports – see Phase 2 for details.

The final step of the design phase was to establish the data management process. As indicated in Section 2.2.3, the process used was similar to that employed for previous studies: a coupled Access database and ArcView GIS system, with the addition of a user interface for the LEACHM model coded directly into the database. Several Excel files were also required to provide computation to permit the LEACHM outputs to be used as MODFLOW inputs.

3.1.2 Conceptual Model

Prior to selecting the modelling components, the conceptual model of the study area, as developed under previous work, was confirmed. This aids in determining whether the available data is sufficient to characterise the conceptual model components. Figure 5 shows the conceptual model for the study area (see also Appendix 1 Figure 3 which includes an actual cross-section from the saturated zone model), with a simplified surficial geology draped over the surface. The x-scale represents latitude values (UTM NAD83 Zone 18 projection), the y-scale longitude, and the z-scale elevation above sea level (m). Note that the vertical scale is highly exaggerated – the area is actually quite flat.

FIGURE 5. CONCEPTUAL MODEL



A representational cross-section is also shown, indicating the broad layers present: surface material (represented to be from 0 – 2 m bgs, governed by the unsaturated zone model LEACHM), and sub-surface overburden, fractured bedrock and bedrock (from 2 m bgs down to 0 masl, with layers varying in thickness, governed by the saturated zone model MODFLOW). While not visible in this depiction, the vertical and horizontal extents of the various overburden materials varies across the study area, and includes clay/silty clay materials in a number of areas. This is described in greater detail in Section 3.2.

The general water balance was also considered at this stage. From previous work, the area is known to receive approximately 960 mm/yr of precipitation. The average evapotranspiration is in the range of 405 mm/yr, with the remaining 555 mm/yr contributing to surface runoff (majority) and recharge. For the unsaturated zone modelling, the Meteorological Survey of Canada daily precipitation record for 2002 was used (871 mm/yr as recorded at the Ottawa Airport). Estimates of recharge vary – values between 50 – 150 mm/yr are reasonable.

3.1.3 General Modelling Assumptions and Limitations

Any model represents a compromise solution to the real world, as it cannot be formulated in its full complexity. In doing so, a number of assumptions and simplifications have to be made – key assumptions made as part of this modelling effort are as follows:

- Model layers representing the differing stratigraphic layers are homogenous, i.e., their properties do not vary in space – this assumption can be a significant source of error, particularly in the presence of fractured media.
- All septic systems and water wells are properly constructed, such that they do not lead to higher levels of nitrate release than the default (for the former) or to preferential contaminant pathways to well source aquifers (for the latter).
- Models represent 'steady state' conditions, i.e., it is assumed that the inputs to a given scenario represent the time-averaged constant values for that scenario.
- The current conditions are in a steady-state, i.e., keeping all conditions as they are now, no changes to groundwater flow and nitrate fate/transport will occur.

Both of the models employed, while well suited to their use, have limitations that are of significance for this exercise, as follows:

- LEACHM:
  - The maximum recommended depth for simulation is 2 m.
  - Properties cannot vary horizontally (i.e., each surface unit requires a separate input file)

- MODFLOW:
  - Confined and unconfined aquifers cannot be simulated together
  - Perched aquifers cannot be simulated (i.e., model domain must be saturated)
  - Fractured flow cannot be simulated

See Section 5 for a more complete discussion of these issues.

3.1.4 Selection of Modelling Components

The model selection matrix is detailed in Appendix 2. The selection process considered these factors:

- Applicability: Eliminate models that do not meet technical requirements (e.g., surface attentuation models without biodegredation), then score remainder from 1-10 based on: somewhat matches (1), matches (5) or perfectly matches (10) unsaturated zone problem;
- Ease of Use: Score 1-10 based on: input data requirements (format, amount), platform (hardware and software), inclusion of parameter estimation, and output data useability; and
- Cost: For each group (unsaturated zone, saturated zone), highest cost = 1, lowest cost = 10, and in-between = portion therein).

The final selection was the LEACHM model for the unsaturated zone and MODFLOW for the saturated zone. Both models are DOS-based, built to reflect well-established physical processes. The LEACHM model does not have a Windows-based user interface, while a number of interfaces exist for MODFLOW, including GMS, PMWin and Visual MODFLOW. The lack of a Windows user interface for LEACHM does present challenges to users who are not familiar with DOS – to overcome this, an easy to use interface was coded into the Access database (LeachM_Input.mdb) designed as part of the data management toolbox.

While knowledge of LEACHM's validity is not as widespread as MODFLOW, it is used broadly and has been validated. It is used extensively by Health Canada for prediction of pesticide leaching, and has been applied to nitrate leaching problems on numerous occasions (for example, refer to *Mahmood, B. 2003. Sustainable Management of Effluent Irrigated Land Treatment System: Forecasting with the LEACHM Model.* Available at http://www.asae.org/imis/StaticContent/3/Sept03/SustainableFinal.pdf). The US ASTM guidance document *RBCA Fate and Transport Models: Compendium and Selection Guidance (1999)* compared a number of unsaturated zone models including LEACHM, and found it suitable for nitrate leaching applications.

3.1.5 Definition of Design/Development Scenarios

The scenarios required to support the design and development phases are based on current conditions as they were during the rural servicing investigation in October, 2002. Based on a current conditions scenario, the broad scenario regimes to consider are:

- Steady-state or dynamic: dynamic simulations offer the advantage of demonstrating the time-varying responses of physical systems to time-varying inputs, however this must be supported by time-series input data. Given the fact that there is no available time-series sub-surface data, a steady-state simulation must be performed. This implies that all inputs and outputs within a given scenario are constant – results must be interpreted accordingly.
- Average annual, seasonal, or daily inputs: given the above, consideration must be given to the appropriate time period over which to average input values. Different physical processes have different characteristic time and length scales – such scales are shorter for surface processes than sub-surface processes.

For the unsaturated zone modelling, seasonal fluctuations in ground temperatures have significant influence on the infiltration of precipitation and the amount of evapotranspiration (i.e., less precipitation will infiltrate when the ground is frozen). Therefore, the LEACHM modelling used daily inputs for temperature and precipitation – the data for 2002 as recorded at the Ottawa International Airport was used (repeated until outputs remained constant), and is reflected in the SoilCalcs.xls file.

For the saturated zone modelling, seasonal fluctuations cannot be represented due to the lack of seasonal input data. The primary source of water table data is MOE well records. These records are for wells completed throughout the year – water table contours derived from them therefore represent conditions averaged over the time frame for which the records are available (the 1500 records within the study area span the period 1947 – 1998). This source was further augmented with the background report well data compiled as part of previous work, which added 69 wells spanning the period 1986 – 2003. These records also provided groundwater chemistry data, to which is added the sampling data collected in October, 2002 from 222 residential wells. Calculations performed on well records are handled in two companion Excel files to the main Access database: Gr_Bd_El.xls for bedrock elevations and Gr_LayerThickness.xls for overburden layer thicknesses. For details on all data sources, see the Data Dictionary in Appendix 3.

3.2 Phase 2: Model Development

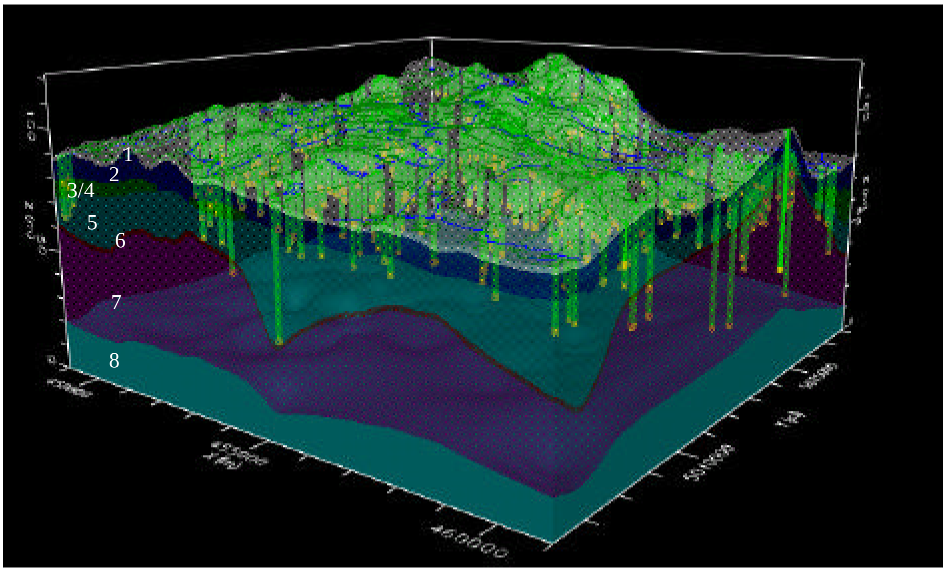
3.2.1 Vertical and Horizontal Discretization

Representations of the surface in the unsaturated zone, and of the subsurface in the saturated zone, were prepared based on available agricultural soil, surface water, surficial geology, and hydrogeologic information. The hydrogeological characterisation for the study area has been detailed in the previous work undertaken, and will not be repeated herein. For the preparation of the LEACHM units, discretization was determined from reference to property data provided by the City (for built up areas) and to agricultural soils – built up areas were kept as the sector-units defined in previous work, while new areas were outlined from current development applications. Areas that have not yet been developed were left as being characterised by the existing soils. Figure 9 in Appendix 1 shows all of the final LEACHM units.

Within the saturated zone, vertical discretization made use of eight layers (see Figure 6), as follows:

- Layer 1: set aside for LEACHM (unsaturated)
- Layers 2 –5: overburden, split into sand/organic material (Layer 2), clay/silty clay (Layers 3 and 4), and sand/gravel (Layer 5)
- Layers 6 – 8: bedrock, split into fractured bedrock (Layer 6) and unfractured bedrock (Layers 7 and 8).

FIGURE 6. VERTICAL DISCRETI-ZATION IN MODFLOW



The physical properties of all of the layers are outlined in Appendix 4 – Hydrogeological Framework.

3.2.2 Processing of Source Data/Preparation of Input Files

The steps in preparing input files for both models were as follows:

- LEACHM input files
  1. collect agricultural soil data for study area [ON Soil Names_Full table]
  2. compare agricultural soil data to previously collected surficial geology data [New_Surfge.shp]
  3. derive initial surface zones (LEACHM units) from soil data and sector-areas [Leach_Base.shp derived from New_Surfge.shp and Sector_Ages.shp files]
  4. calculate zone soil properties [Leach_Soils table defining percent clay, silt, organic content and bulk density (Bulk Density = 1.49 - (%Clay x 0.2)[4]), processed in SoilCalcs.xls file to derive proportionally weighted zone percents, and entered in Leach_Units table]
  5. calculate zone input recharge properties [taking a default of 1000 L/property/d with the number of properties calculated from a PIN count or for new developments from the expression (zone area (m^2) – road area[5] / 1 or ½ acre in m^2), calculate daily septage per unit area per day (mm) using a query and the expression (zone septage volume (L) / zone area (m^2)), and then calculate daily input recharge as daily precipitation plus daily septage].
  6. derive final surface zones (LEACHM units) from soil data and sector-areas including all proposed developments as supplied by the City during the workshop [Leach_Base.shp as carried to the Leach_Units.shp file]
  7. in ArcView, prepare grid file from vector zones file [leach_gr as derived from Leach_Units.shp] for tabulation of areas and calculation of zone slopes using the 'calculate slope' function of the Spatial Analysis package [derived from greely_UTM.dat DTM file, results carried back to Leach_Units table]
  8. preparation of LEACHM input file for each zone (unit) by replacing the default segment and precipitation properties with the appropriate values from the Leach_Units table and SoilCalcs.xls calculations.

The final surface zones (units) used are depicted in Figure 7.

[4] As derived from Visual MODFLOW V.3.1. User Manual pg. 115 Soil Hydraulic Properties table.

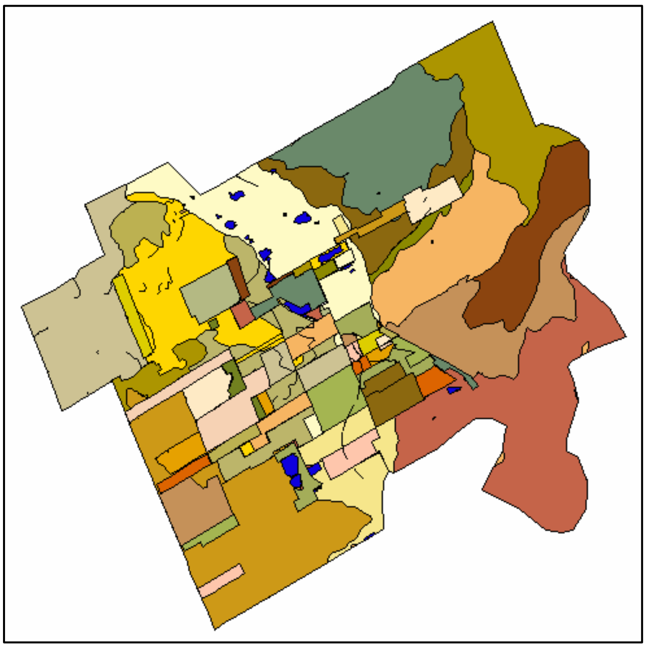


FIGURE 7. LEACHM UNITS

See also Appendix 1 Figure 10 for the Study Area Sectors.

- Visual MODFLOW input files:
  1. selection of the model domain and grid dimensions: domain had to cover area of interest as shown in Figure 2; this was then maximised to match the extent of available data, and to reduce the influence of interpolation errors from preparing surfaces
  2. preparation of surface using DTM model by kriging elevation points to the model grid (80 columns x 80 rows ranging from latitude 449000 – 461000 and longitude 5006100 – 5018100 at 150 m spacing) and importing into Visual MODFLOW
  3. preparation of bedrock elevation using grid output from kriged bedrock elevations [Greely-Model.mdb table MOE Well Records as processed through the SelWel_TerminateBedrock_Hydro query] imported into Visual MODFLOW
  4. division of depth between surface and bedrock into four layers in model, representing overburden: top layer set to 2 m and not further defined (as this layer is accounted for in the LEACHM model), layers 2 – 5 representing differing thicknesses of sand/organic material (layer 2), clay/silty clay (layers 3 and 4, split to ease the hydraulic conductivity gradient) and sand/gravel (layer 5)
  5. layers 2 – 5 thicknesses determined by kriging thicknesses of deposits from MOE and background well records [SelWel_TerminateBedrock_Hydro query imported into Gr_LayerThickness.xls file and used to calculate layer thicknesses at each well record point for subsequent kriging to the model grid and importing into Visual MODFLOW – see Figure 8 for the derived clay/silty clay layer areas where the thickness is 1 m+, and Appendix 1 Figure 2 for the deposits thickness]

[5] Defaults for road area were derived from an analysis of existing subdivisions within and outside the village: values are 10% for outside village and 15% for inside village subdivisions.

6. head and observation wells data as extracted from the Wells database [Greely_Model.mdb] and made available in the Wells_for_Input.mdb database, imported into Visual MODFLOW [separate groups covering MOE overburden wells, MOE bedrock wells, background report well chemistry, and sampling program well chemistry]
7. initial heads by cell imported from the kriged water table elevations file
8. boundary conditions were assigned in Visual MODFLOW, as options for automatically importing were restricted to time series data, not physical data

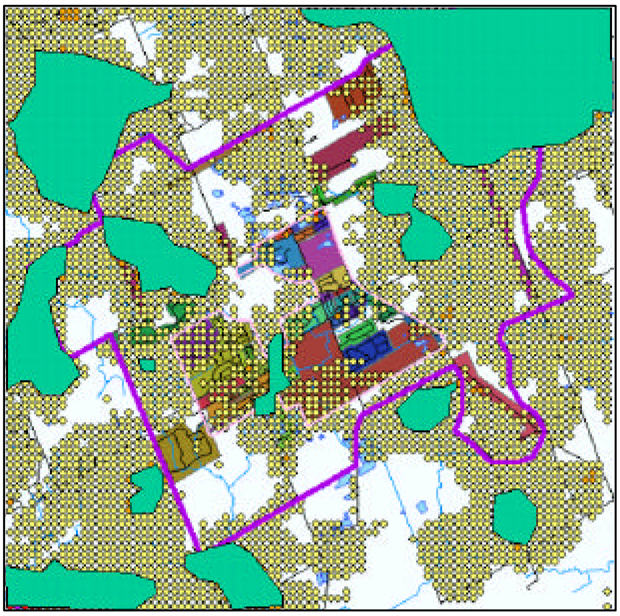


FIGURE 8. CLAY/SILTY CLAY LAYER EXTENT

3.2.3 Model Verification and Sensitivity Analysis

With completion of input file preparation, the LEACHM model was complete. For Visual MODFLOW, a number of additional steps were required to build the model from the input data, as follows:

Assign boundary conditions:

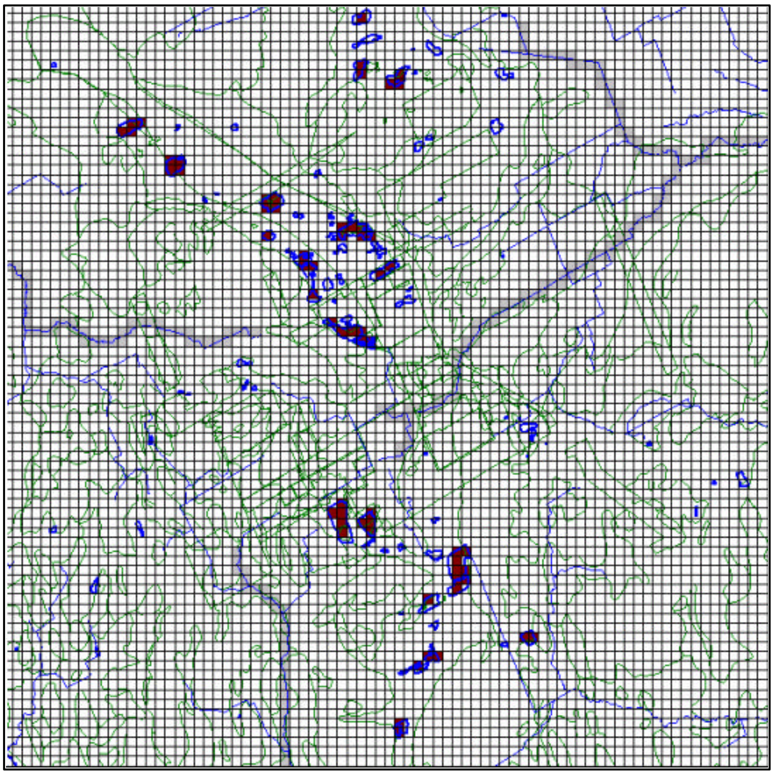
1. Surface water bodies: surface water bodies consist of lakes/ponds and streams. For the former, constant heads were assigned to those cells with a majority of their area occupied by a lake/pond at the level of the cell as determined from the kriged DTM. For the latter, given the fact that a steady state simulation was being conducted, only the annual average baseflow portion of streamflow was represented through assignment of drain boundaries along the significant stream courses.
2. Model extents: while it is always preferable to bound saturated zone models by known hydraulic boundaries (such as major rivers or lakes), this model domain would have had to extent out to the Rideau, Ottawa and St. Lawrence rivers, far beyond the area of interest, to accomplish that. The accepted approach of assigning constant heads matching kriged water table elevations around the model domain periphery was therefore used.

3. Recharge: arguably the most critical boundary for this modelling exercise, the recharge boundary represents the infiltrated precipitation plus septic outflow that drives the model, which in this case is taken from the output of the LEACHM modelling. It represents the mixture of ‘clean’ infiltration from precipitation mixed with septage. Recharge magnitude (defined in units of mm/yr) is often used as a calibration parameter for MODFLOW simulations, and is commonly cited as being poorly representational of known physical conditions. The benefit of using LEACHM to define both the spatial variation and quality of recharge is therefore large. Recharge was assigned to layer 2, reflecting its property as the leach output of the LEACHM model.

Table 1. LEACHM Segment (Layer) Properties

Soil segment no.	Soil retentivity parameters		Bulk density	Match K(h) curve at:			Dispers-ivity	For Addiscott flow option:	
	AEV	BCAM		K	Matric potential	using		Field capacity	Mobile/imm-obile threshold
	kPa		kg/dm^3	mm/d	kPa	P	mm	KPa	kPa
1	-4.89	5.54	1.37	1	-20	1	200	-5	-200

FIGURE 9. SATURATED ZONE MODEL BOUNDARY CONDITIONS



Conduct initial LEACHM model runs to test physical attributes:

1. verification of the LEACHM model commenced with initial runs using default values for nutrient chemistry equilibrium constants and segment (layer) starting values for ammonia and nitrate [Particle density: Clay 2.65, silt and sand 2.65, organic matter 1.10; see Table 1 for further values]

2. Nitrogen Pools: Urea - 0, NH_4 - 1, NO_3 - 1, and Residue Manure - 0 mg N/kg dry soil
3. adjustment of default values to reflect current conditions

Conduct initial MODFLOW model runs to test physical attributes:

1. verification of the MODFLOW model commenced with initial runs using a recharge of 300 mm/yr (typical of the area averaged LEACHM output)
2. compare resultant equipotential surface to water table elevations from kriged MOE well records; adjust (downwards) and repeat until providing best visual match (reached at a recharge of 143 mm/yr)

The variables most significantly influencing model output uncovered as part of this process were as follows:

- For LEACHM:
  1. for calibration: soil native organic content, ammonia and nitrate, and precipitation
  2. for scenarios: septic outfall quantity and quality (with zone area / number of properties defines overall infiltration quantity and quality)

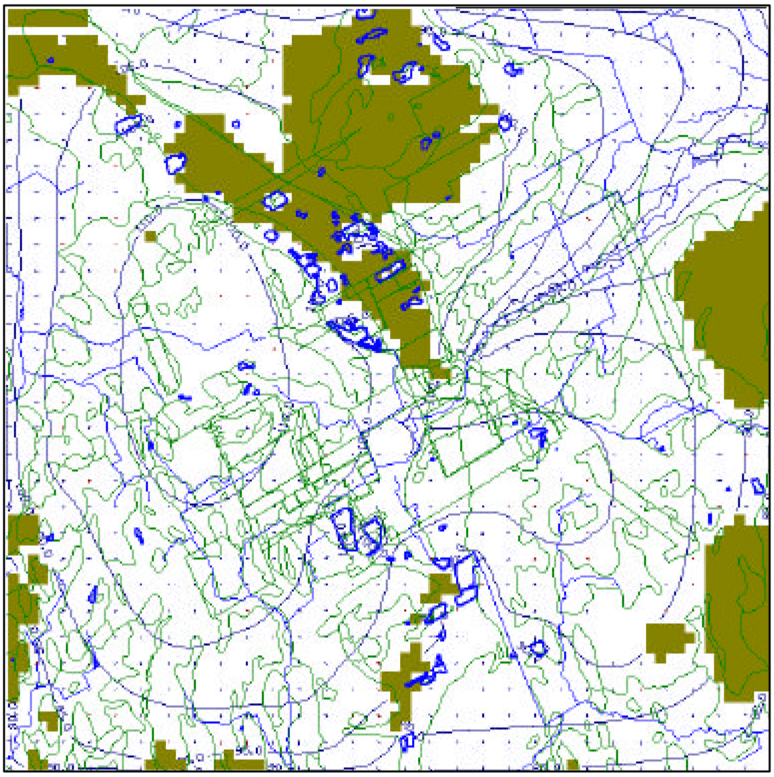


FIGURE 10. MODEL OUTPUT – WATER TABLE CONTOURS

- For MODFLOW:
  1. for calibration: layer hydraulic properties
  2. for scenarios: recharge quantity and quality

Figure 10 shows the resulting output from Visual MODLFOW of the water table contours and depiction of dry cells (i.e., cells above the water table). Note the close match to the water table contours produced under previous work. The RMS error for this match is approximately 15%. – this match was checked and was not exceeded for any of the scenarios modelled.

3.2.4 Model Calibration and Validation

Model calibration is an iterative process, executed as depicted in Figure 11.

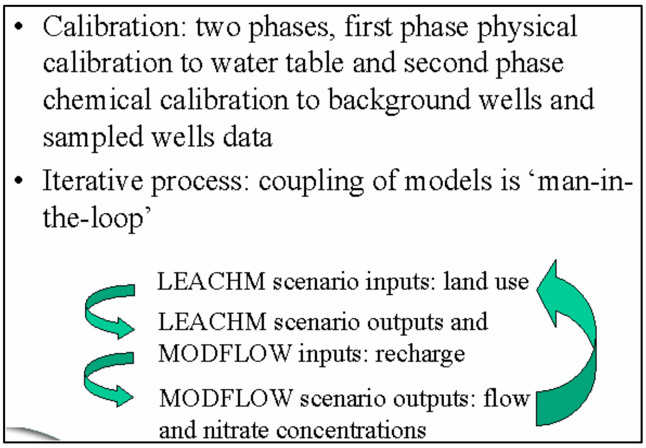


FIGURE 11. MODEL CALIBRATION PROCESS

The LEACHM outputs collected in the database for each unit consisted of a maximum and final value for the concentration of nitrate in the leach, and the annual amount of vertical 'loss' through the bottom segment, which corresponds to the amount of recharge for that unit. During the workshop with the City, it was recognised that an over-reliance on averaged values of nitrate concentration over the various units would not satisfactorily identify the potential for higher values. For instance, in examining the LEACHM output files, periods of prolonged low precipitation show increased concentrations of nitrate in the leach, as less 'clean' infiltration is available to dilute septic outflow. It was therefore decided after the workshop to run both the average and maximum LEACHM output values for scenarios #1 and #2 as inputs to Visual MODFLOW – these have been represented as the 'current/future – average' and 'current/future – peak' sub-scenarios of the three scenarios (current, future and future-full build out) analysed to date, and presented in Section 3.3.

For the chemical calibration, the procedure was to minimise the residual between observed and predicted concentrations of nitrate at the sampled locations, with the residual being represented as the square toot of the sum of the squares (RMS). This is shown pictorially in Figure 12, where the concentration contours for nitrate generated from the lab results at the sampled locations are shown on the left, and the concentrations of nitrate within layer 6 of the current – peak model are shown on the right. Note that 1/3 of the wells in the study area terminate in overburden – the calculation is independent of the layer shown, as model results are 3-D. It is important to consider statistical variation in sample results when conducting this comparison: as is highlighted in the left portion of Figure 12 (and as was explained in detail in the Detailed Analysis report), high values of nitrate were measured in close proximity to low values. MODFLOW simulations will not give evidence of such rapid geospatial variation, as the simplifications of model design cannot replicate preferential flow paths, faulty wells, or other potential causes of high geospatial variation.

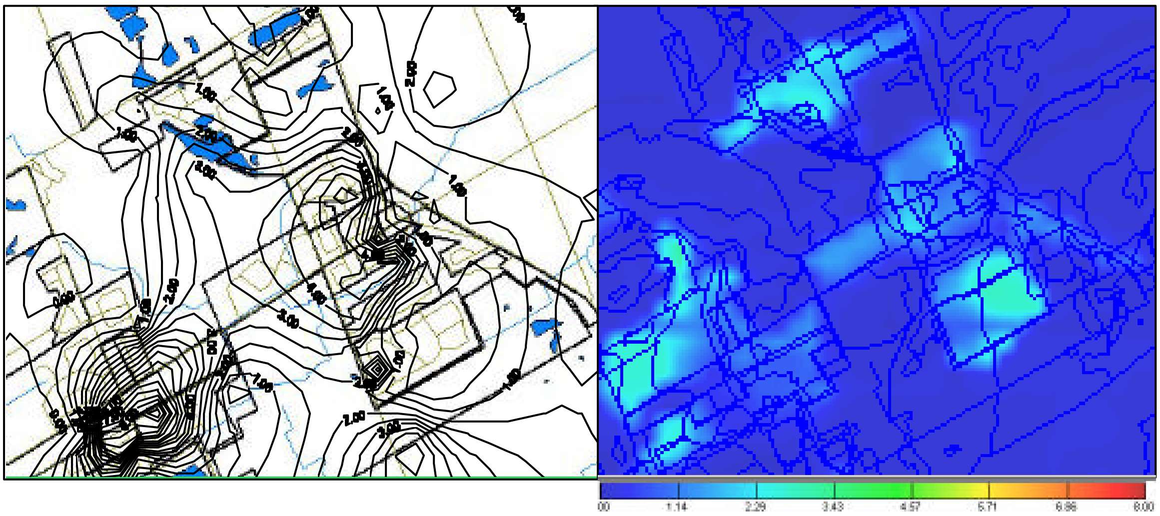


FIGURE 12. MODEL CALIBRATION – CHEMICAL COMPARISON (MG/L)

3.3 Phase 3: Model Implementation

3.3.1 Workshop

An afternoon workshop was held at the City on October 21, where the results of Phases 1 and 2 were presented, and scenarios for analysis were discussed. At that time, the listing of proposed developments required to be represented under the future build-out scenario (Scenario #2) was provided, as described in Table 2.

Table 2. Proposed Developments – Greely and Surrounding Area

Number	Subdivision Name	Leach Unit
Applications within the Village Boundary		
1	Thunderbird Cove	V20:00+
2	Sunset Lakes South 11	V21:00+
3	Shadow Ridge Estates	V17:00+
4a,b	Apple Orchard	V14:00+,R15:00+
5	Greelyhall Estates	V19:00+
6	Stanley Park (Phase 3)	V13:00+
Imminent Applications		
7	Meadowbrook Estates	V18:00+
Current Applications Outside of the Village Boundary		
8	Woodstream (Phases 2 and 3)	R21:00+, R24:00+
9	Susset Lakes South 59	R23:00+
10	Creekside Estates	R16:00+
11	Emerald Links (Phase 2)	R17:00+
12	Deermeadow	R14:00+

Table 2. Proposed Developments – Greely and Surrounding Area		
Number	**Subdivision Name**	**Leach Unit**
13	Moore Estates (Phase 2)	R12:00+
14	Thuderbird Cove (Phase 4)	R22:00+
15	Albion Sun Vista Mobile Home Park (Phase 2)	R20:00+
16	Commercial Gas/Car Wash	Part of 10
17	Emerald Creek	R19:00+
18	Adams Country Estates	R13:00+

3.3.2 Scenarios #1 and #2

The first two scenarios modelled are the current conditions scenario (#1), and the expected future build out scenario (#2), where all current and imminent applications are assumed to have been developed, to 1 acre lots outside the village and to ½ acre lots within the village. Review Section 3.2.2 for details on how the input values were calculated. The current and future build-out scenarios (#1, #2) are tabulated in Table 3.

Table 3. Unit Properties for Current and Future Build-Out Scenarios[6]					
Unit ID	**Area (m^2)**	**Properties (Current)**	**Properties (Future)**	**Area per Property (Current)**	**Area per Property (Future)**
1	6696929	74	74	90499.04	90499.04
10	3709553	12	12	309129.4	309129.4
11	1414041	3	3	471346.8	471346.8
12	3682806	8	8	460350.7	460350.7
13	4135727	42	42	98469.69	98469.69
14	6179815	22	22	280900.7	280900.7
15	1895492	8	8	236936.5	236936.5
16	331666.5	6	6	55277.75	55277.75
2	3414144	38	38	89845.9	89845.9
3	2870282	2	2	1435141	1435141
4	3519350	7	7	502764.3	502764.3
5	4850177	57	57	85090.81	85090.81
6	1962063	38	38	51633.23	51633.23
7	366735.2	0	0	0	0
8	4200515	41	41	102451.6	102451.6
9	779237.9	0	0	0	0
R10:87-97	338799.1	11	11	30799.92	30799.92
R12:00+	470752.4	24	24	19614.69	19614.69
R13:00+	177720.9	0	43	0	4133.045
R14:00+	190203	0	46	0	4134.848
R15:00+	206845.8	0	50	0	4136.916
R16:00+	343554.2	0	83	0	4139.207

[6] To promote consistency, the number of properties for future developments was calculated based on the unit area – road area / 1 or ½ acre (1 for outside the village)

Table 3. Unit Properties for Current and Future Build-Out Scenarios[6]					
Unit ID	**Area (m^2)**	**Properties (Current)**	**Properties (Future)**	**Area per Property (Current)**	**Area per Property (Future)**
R17:00+	451137.8	0	109	0	4138.878
R18:00+	23775.38	1	1	23775.38	23775.38
R19:00+	711478.1	0	172	0	4136.5
R2:60-84	249047.1	43	43	5791.792	5791.792
R2:pre-60	57060.9	14	14	4075.779	4075.779
R20:00+	128387	0	31	0	4141.517
R21:00+	65976.67	0	16	0	4123.542
R22:00+	234781.8	0	57	0	4118.979
R23:00+	390510.6	0	95	0	4110.638
R24:00+	316212.5	0	77	0	4106.656
R6:87-97	297192.2	48	48	6191.504	6191.504
R7:87-97	1022341	116	116	8813.286	8813.286
R8:87-97	133142.1	7	7	19020.3	19020.3
R9:87-97	687702.8	123	123	5591.079	5591.079
V1:84-87	77864.36	23	23	3385.407	3385.407
V1:87-97	870178.8	263	263	3308.665	3308.665
V1:pre-84	205062.6	80	80	2563.283	2563.283
V10:pre-78	98073.43	19	19	5161.759	5161.759
V11:84-87	237159.4	86	86	2757.667	2757.667
V13:00+	92723.97	1	42	92723.97	2207.714
V14:00+	212195.2	0	97	0	2187.58
V16:00+	508793	12	233	42399.42	2183.66
V17:00+	427362.4	0	196	0	2180.42
V18:00+	763783.9	1	349	763783.9	2188.493
V19:00+	229432.4	0	105	0	2185.07
V2:84-87	46361.98	21	21	2207.714	2207.714
V2:87-97	683542.1	234	234	2921.12	2921.12
V2:pre-84	339987.9	102	102	3333.214	3333.214
V20:00+	22586.61	0	10	0	2258.661
V21:00+	42795.68	0	20	0	2139.784
V3:87-97	407747.7	77	77	5295.424	5295.424
V4:60-78	4755.075	3	3	1585.025	1585.025
V4:78-84	7726.997	4	4	1931.749	1931.749
V4:84-87	305513.6	104	104	2937.631	2937.631
V4:pre-84	49333.91	17	17	2901.994	2901.994
V5:60-65	29719.22	16	16	1857.451	1857.451
V5:65-84	51117.06	22	22	2323.503	2323.503
V5:87-97	560504.5	205	205	2734.168	2734.168
V6:87-97	552183.1	180	180	3067.684	3067.684
V7:60-84	83808.2	42	42	1995.433	1995.433
V7:pre-60	77864.36	40	40	1946.609	1946.609
V8:60-78	38040.6	7	7	5434.372	5434.372
V8:78-84	114121.8	34	34	3356.524	3356.524
V8:pre-60	32096.76	12	12	2674.73	2674.73

Table 3. Unit Properties for Current and Future Build-Out Scenarios[6]					
Unit ID	**Area (m^2)**	**Properties (Current)**	**Properties (Future)**	**Area per Property (Current)**	**Area per Property (Future)**
V8:pre-84	73703.66	29	29	2541.506	2541.506
V9:60-78	155728.7	66	66	2359.526	2359.526
V9:78-84	76675.59	27	27	2839.836	2839.836
V9:84-87	95695.89	29	29	3299.858	3299.858
V9:pre-60	17831.53	7	7	2547.362	2547.362

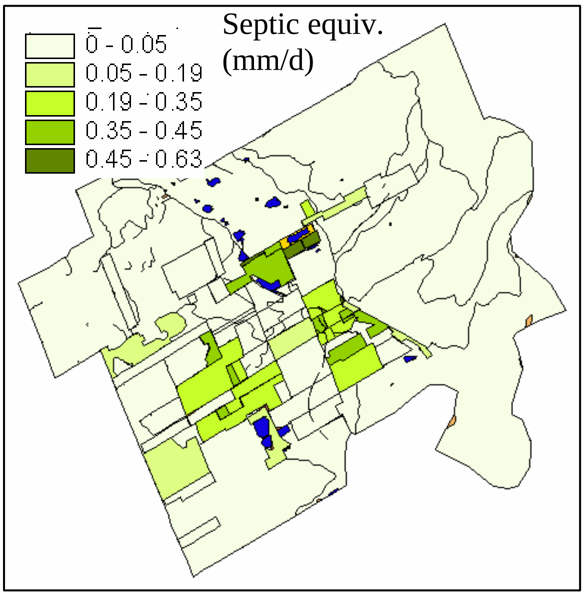
The tabulated LEACHM results for Scenarios #1 and #2 are given in Table 4. Recall that both final concentrations (steady state or averaged) and peak concentrations of nitrate were tabulated and rendered as inputs to MODFLOW.

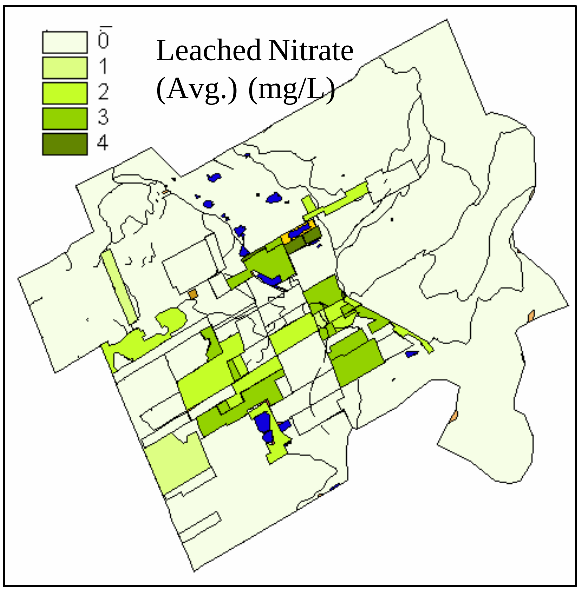
Table 4. LEACHM Results for Scenarios #1 and #2 (mm/yr and mg/L)								
Unit Id	**Scenario**	**Final Recharge**	**Final Nitrate**	**Peak Nitrate**	**Scenario**	**Final Recharge**	**Final Nitrate**	**Peak Nitrate**
1	Current	376.8	0	0.47	Future	376.8	0	0.47
10	Current	377.3	0	0.47	Future	377.3	0	0.47
11	Current	377.3	0	0.47	Future	377.3	0	0.47
12	Current	376.8	0	0.47	Future	376.8	0	0.47
13	Current	375.8	0	0.47	Future	375.8	0	0.47
14	Current	376.3	0	0.47	Future	376.3	0	0.47
15	Current	376.8	0	0.47	Future	376.8	0	0.47
16	Current	373.7	0	0.47	Future	373.7	0	0.47
2	Current	376.3	0	0.47	Future	376.3	0	0.47
3	Current	378.7	0	0.47	Future	378.7	0	0.47
4	Current	376.8	0	0.47	Future	376.8	0	0.47
5	Current	371.6	0	0.47	Future	371.6	0	0.47
6	Current	373.6	0	0.47	Future	373.6	0	0.47
7	Current	372.1	0	0.47	Future	372.1	0	0.47
8	Current	371.1	0	0.47	Future	371.1	0	0.47
9	Current	374.1	0	0.47	Future	374.1	0	0.47
R108797	Current	564.4	0.888	2.67	Future	564.4	0.888	2.67
R1200+c	Current	281.7	0	4.27	Future	601.6	1.64	4.32
R1300+c	Current	372.7	0	0.47	Future	628	2.13	5.63
R1400+c	Current	374.8	0	0.47	Future	631.7	2.14	5.63
R1500+c	Current	375.8	0	0.47	Future	632.3	2.14	5.63
R1600+c	Current	374.5	0	0.47	Future	631.2	2.14	5.63
R1700+c	Current	377.2	0	0.47	Future	634.5	2.14	5.62
R1900+c	Current	377.6	0	0.47	Future	635	2.14	5.61
R26084	Current	606.3	1.65	4.32	Future	606.3	1.65	4.32
R2pr60	Current	631.4	2.14	5.62	Future	631.4	2.14	5.62
R2000+c	Current	377.5	0	0.47	Future	634.9	2.15	5.65
R2100+c	Current	377.6	0	0.47	Future	635	2.15	5.64
R2200+c	Current	377.6	0	0.47	Future	635	2.15	5.64
R2300+c	Current	377.4	0	0.47	Future	634.7	2.15	5.64
R2400+c	Current	377.6	0	0.47	Future	635.2	2.15	5.66

Table 4. LEACHM Results for Scenarios #1 and #2 (mm/yr and mg/L)								
Unit Id	**Scenario**	**Final Recharge**	**Final Nitrate**	**Peak Nitrate**	**Scenario**	**Final Recharge**	**Final Nitrate**	**Peak Nitrate**
R68797	Current	605.4	1.63	4.16	Future	605.4	1.63	4.16
R78797	Current	586.6	1.33	3.18	Future	586.6	1.33	3.18
R88797	Current	285.5	0	4.36	Future	285.5	0	4.36
R98797	Current	608.3	1.65	4.32	Future	608.3	1.65	4.32
V18487	Current	645.2	2.44	6.54	Future	645.2	2.44	6.54
V18797	Current	654.7	2.49	6.64	Future	654.7	2.49	6.64
V1pr84	Current	682.9	2.98	7.96	Future	682.9	2.98	7.96
V10pr78	Current	616.6	1.81	4.76	Future	616.6	1.81	4.76
V118487	Current	671	2.83	7.6	Future	671	2.83	7.6
V1300+c	Current	377.9	0	0.47	Future	708.1	3.34	8.9
V1400+c	Current	376.8	0	0.47	Future	706.3	3.34	8.97
V1600+c	Current	377.7	0	0.47	Future	707.7	3.34	8.96
V1700+c	Current	377.7	0	0.47	Future	707.7	3.34	8.9
V1800+c	Current	377	0	0.47	Future	706.6	3.34	8.9
V1900+c	Current	376	0	0.47	Future	704.9	3.34	8.96
V28487	Current	704.8	3.32	8.85	Future	704.8	3.32	8.85
V28797	Current	666.1	2.71	7.25	Future	666.1	2.71	7.25
V2pr84	Current	654	2.48	6.6	Future	654	2.48	6.6
V2000+c	Current	375.9	0	0.47	Future	704.7	3.34	8.9
V2100+c	Current	378.4	0	0.47	Future	708.9	3.34	8.9
V38797	Current	614.9	1.78	4.67	Future	614.9	1.78	4.67
V46078	Current	760.2	4.18	11.1	Future	760.2	4.18	11.1
V47884	Current	721	3.66	9.85	Future	721	3.66	9.85
V48487	Current	658.3	2.69	7.25	Future	658.3	2.69	7.25
V4pr84	Current	664.8	2.73	7.36	Future	664.8	2.73	7.36
V56065	Current	733.7	3.76	9.98	Future	733.7	3.76	9.98
V56584	Current	693.7	3.19	8.53	Future	693.7	3.19	8.53
V58797	Current	672.1	2.85	7.63	Future	672.1	2.85	7.63
V68797	Current	659.6	2.62	7.04	Future	659.6	2.62	7.04
V76084	Current	713.4	3.56	9.5	Future	713.4	3.56	9.5
V7pr60	Current	715.5	3.63	9.67	Future	715.5	3.63	9.67
V86078	Current	608.2	1.74	4.58	Future	608.2	1.74	4.58
V87884	Current	650.6	2.46	6.55	Future	650.6	2.46	6.55
V8pr60	Current	670.3	2.89	7.73	Future	670.3	2.89	7.73
V8pr84	Current	682.3	2.99	8.05	Future	682.3	2.99	8.05
V96078	Current	690.7	3.16	8.45	Future	690.7	3.16	8.45
V97884	Current	666.4	2.76	7.4	Future	666.4	2.76	7.4
V98487	Current	649.9	2.49	6.63	Future	649.9	2.49	6.63
V9pr60	Current	676.8	2.98	8.01	Future	676.8	2.98	8.01

Figures 13A-C provides a visual representation of both the LEACHM input (Table 3 – Figure A) and output (Table 4 – Figures B(Average) and C(Peak)) values.

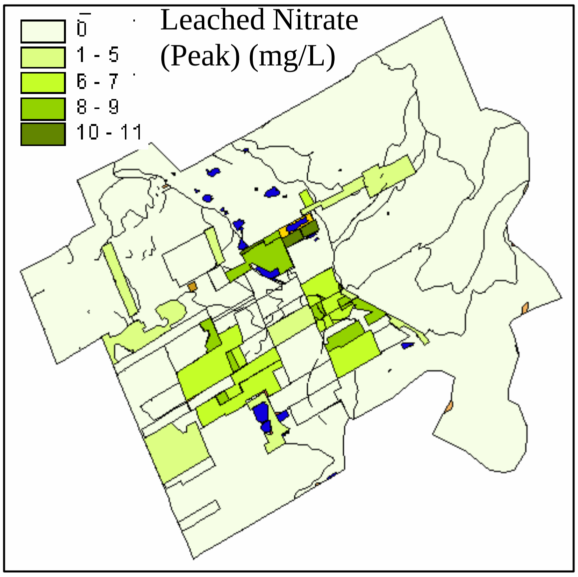
FIGURE 13A,B,C. CURRENT CONDITIONS - LEACHM INPUT AND OUTPUTS





For the current conditions scenario, the variation in inputs (Figure 13A) is strictly a function of the property density, as the septic outflow is set at the default 1000 L/property and 40 mg/L nitrate. The areas therefore with higher values tend to be older developed areas with smaller lot sizes.

For the LEACHM outputs, the calculated concentrations of leached nitrate vary from 0 to 4.18 mg/L for the averaged case, with the maximum peak at 11.1 mg/L, with both maximums occurring in sector-area V4:60-78.



For the MODFLOW results, full figures of the concentration plots (all with the same colour coded legend) for all analysed scenarios at Layers 2, 5 and 6, Row51 and Column 40 are given in Appendix 1, as follows:

Scenario	Layer/Cross-Section	Appendix 1 Figure
Current (Average)	Layer 2	Figure 4A
Current (Average)	Layer 5	Figure 4B

Current (Average)	Layer 6	Figure 4C
Current (Average)	Row 51	Figure 4D
Current (Average)	Column 40	Figure 4D
Current (Peak)	Layer 2	Figure 5A
Current (Peak)	Layer 5	Figure 5B
Current (Peak)	Layer 6	Figure 5C
Current (Peak)	Row 51	Figure 5D
Current (Peak)	Column 40	Figure 5D
Future (Average)	Layer 2	Figure 6A
Future (Average)	Layer 5	Figure 6B
Future (Average)	Layer 6	Figure 6C
Future (Average)	Row 51	Figure 6D
Future (Average)	Column 40	Figure 6D
Future (Peak)	Layer 2	Figure 7A
Future (Peak)	Layer 5	Figure 7B
Future (Peak)	Layer 6	Figure 7C
Future (Peak)	Row 51	Figure 7D
Future (Peak)	Column 40	Figure 7D
Future Full (Peak)	Layer 2	Figure 8A
Future Full (Peak)	Layer 5	Figure 8B
Future Full (Peak)	Layer 6	Figure 8C
Future Full (Peak)	Row 51	Figure 8D
Future Full (Peak)	Column 40	Figure 8D
Future Full (Average)	Layer 2	Figure 9A
Future Full (Average)	Layer 5	Figure 9B
Future Full (Average)	Layer 6	Figure 9C
Future Full (Average)	Row 51	Figure 9D
Future Full (Average)	Column 40	Figure 9D

Given the importance of the location and depth of residential water wells, a tabulation of well counts that terminate in either overburden (typically Layers 5) or bedrock (Layers 6-8) has been added to all B and C figures, such that the risks posed by the presence of the various predicted concentrations of nitrate can be considered. None of the MOE wells in the database are dug wells, and so no tabulation is given for Layer 2. As an example of interpreting this information, refer to Appendix 1 Figures 5B/C – the shading in sector V1:87-97 (found by referring to the Key or to Appendix 1 Figure 10) which is in the most westerly portion of the village shows nitrate concentrations up to 3.5 mg/L in Layer 5 and 2.5 mg/L in Layer 6, and the tabulation indicates that there are no wells terminating in Layer 5 and 25 terminating in Layers 6-8.

In general, the MODFLOW results confirm several observations made in earlier investigations. Nitrate concentrations range from zero to over 9 mg/L. Concentrations drop off as depth increases, however this reduction varies geospatially, driven by the magnitude of the recharge and the groundwater flow. Near-surface (Layer 2) values exhibit similar values and variations to the LEACHM inputs, as is expected; looking at subsequent layers, areas coincident with deeper bedrock show nitrate values dropping off more than areas coincident with shallower bedrock, as a result of the greater travel distances and subsequent dilution/dispersion. For example, looking at Appendix 1 Figures 5B and 5C, the reduction in nitrate levels from Layer 5 to 6 are more marked in the central portion of eastern Greely (sectors V4, V8) than in the southern portion of eastern Greely (sector V6) – this is consistent with the results from the sampling program and subsequent geostatistical investigation completed under the Detailed Analysis work. A view of this effect is further enhanced with the D figure cross-sections, where Layer 5 has been highlighted on each image to highlight where nitrate is being transported into the bedrock below (see for example Appendix 1 Figure 5D, reproduced as Figure 14A below, where for Row 51 the nitrate is transported into bedrock from the eastern-most source, while the neighbouring source to the west is not – this coincides with the area of the western village where some of the highest levels of nitrate were collected during the sampling program).

Selected results have been used to highlight key features through the remainder of this section.

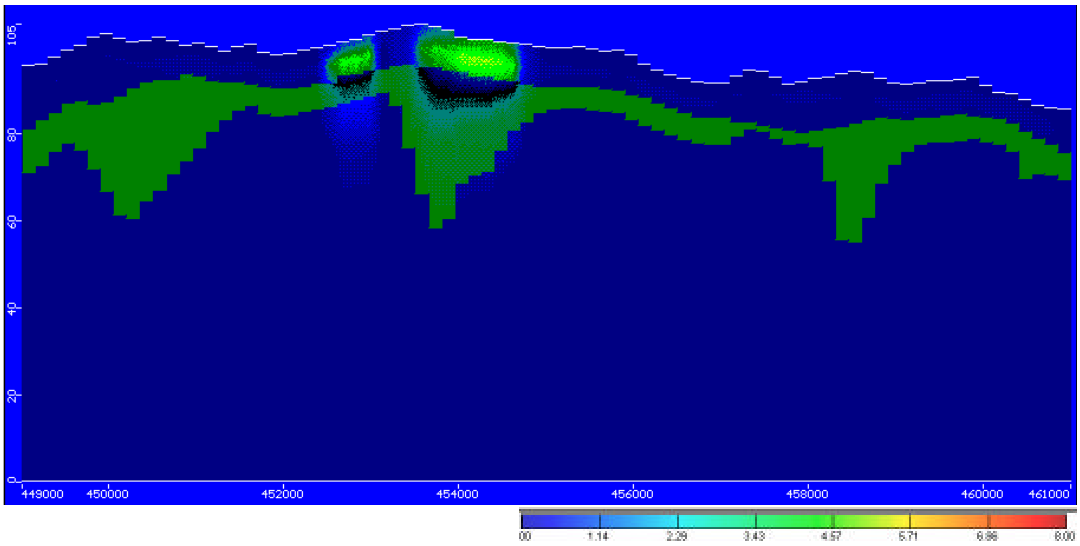
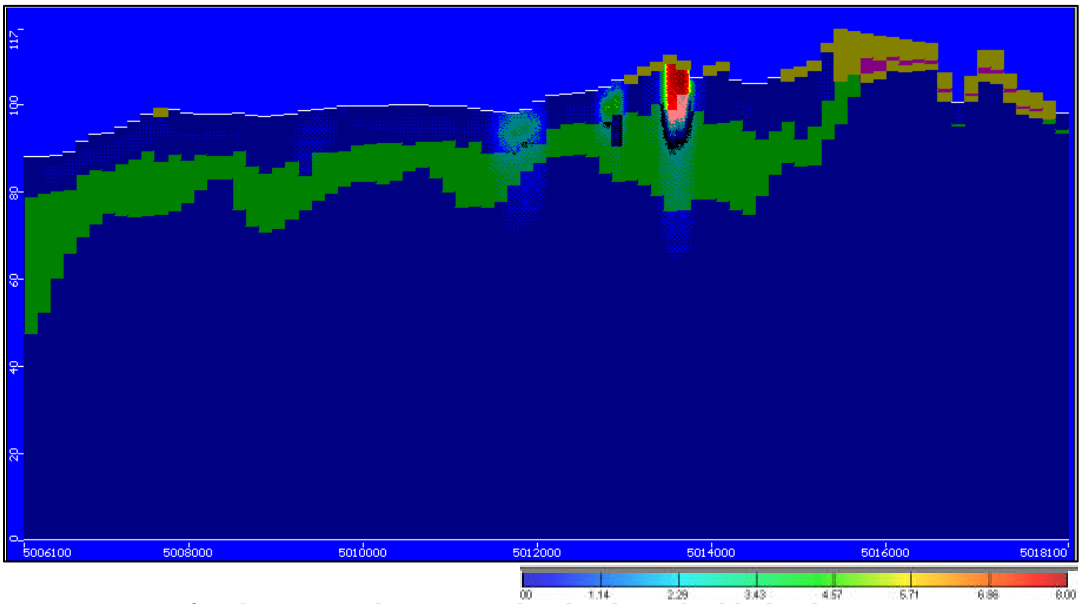


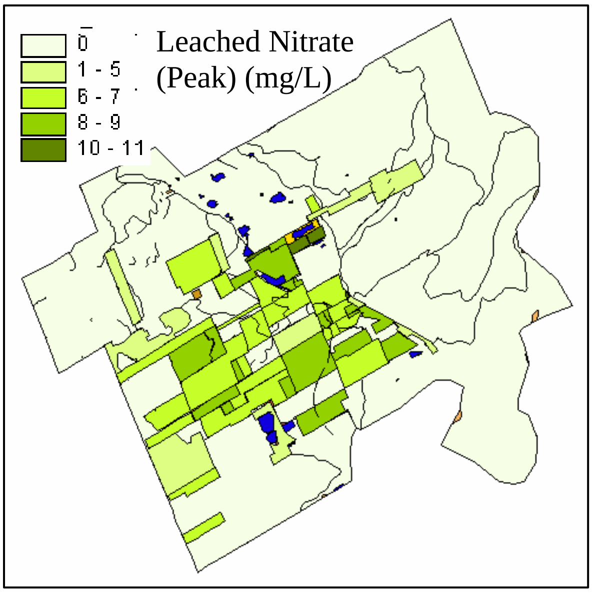
FIGURE 14A,B. CURRENT (PEAK) CONDITIONS - MODFLOW OUTPUTS

Cross-section view of Row 51 – lowest overburden layer highlighted in green.



Cross section view of Column 40 – lowest overburden layer highlighted in green.

Figure 14B highlights the importance of interpreting results in light of model characteristics – the area of high nitrate shown is beneath dry surface cells – as a result, dilution is constrained more severely than would occur in the real world, resulting in high values being maintained for a greater depth that elsewhere. For this case, the area is coincident with relatively deep bedrock, such that bedrock levels are low (this is also consistent with sampling results for this area, sector V7.



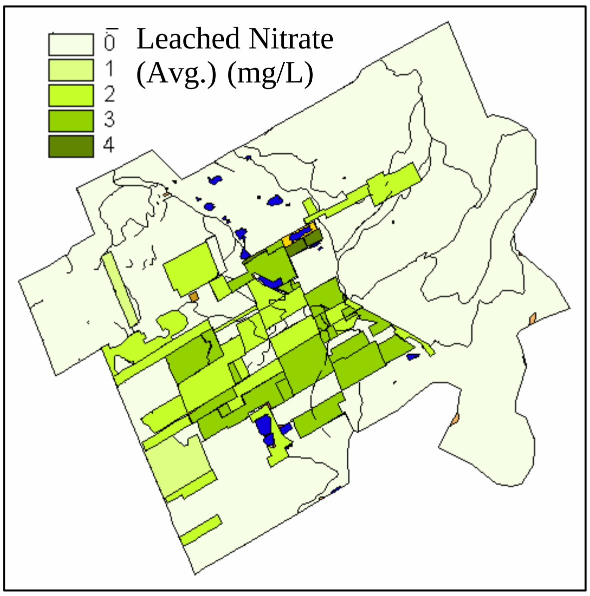


FIGURE 15A,B. FUTURE CONDITIONS - LEACHM OUTPUTS

Looking now at scenario #2, future build-out conditions, the area experiencing nitrate leach concentrations near or above 8 mg/L (Figures 15A) has increased significantly. The breadth of nitrate impact across the village is significantly greater. In the MODFLOW results, the proportion of the village showing values at half the ODWS for nitrate (5 mg/L) or greater is over 50%. The gradual radial flow out from the village centre is evident when looking at Appendix 1 Figures 7B and 7C.

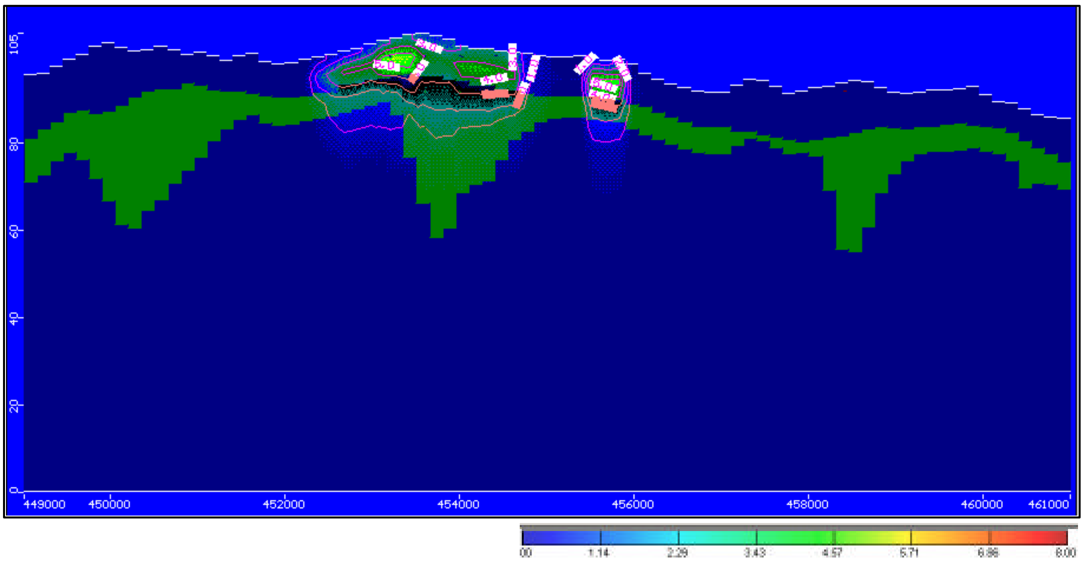
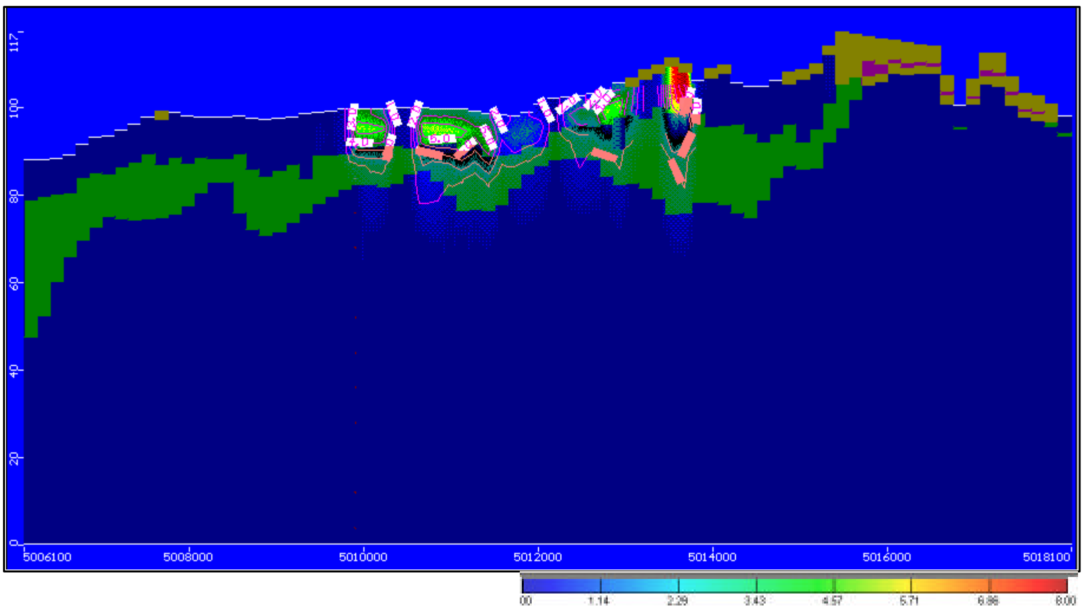


FIGURE 16A,B. FUTURE CONDITIONS - MODFLOW OUTPUTS

Cross-section view of Row 51 – lowest overburden layer highlighted in green.



Cross-section view of Column 40 – lowest overburden layer highlighted in green.

In examining Figure 16A, and Appendix 1 Figure 7C, concerns with bedrock nitrate contamination emerge over new predicted impacts in the western and southern portions of the village, in addition to the zones of concern already identified. The bedrock layer (C) plots show themselves to be particularly useful in highlighting areas where problems may arise.

3.3.3 Scenario #3 – Future Peak with Full Build Out

As a worst-case scenario, scenario #3 adds to scenario #2 (future build out) by assuming that all remaining developable land within the village not set aside for parks is developed to ½ acre lots. These results are shown in Appendix 1 Figures 8A-D (peak) and Figures 9A-D (average) – note that for this scenario, average plots follow peak plots. With the additional assumed development, the areas of concern from Appendix 1 Figure 7C are added to along the southern portio n of the village. Under this scenario, the model predicts levels of impact roughly equal to those within the western portion of the village, which leads to the prediction that under such a scenario, the potential for encountering nitrate levels near to or in excess of 10 mg/ in residential water supplies is significant, as was the case for the sampling program. The overage case does however show that such incidents would be on an exception basis, not on a general basis. The protection afforded to the older portions of the village, and to northern portions, due to deeper overburden, clearly show up on the figures.

3.3.4 Preparation of Draft and Final Report

Having completed the runs for scenarios #1, #2 and #3, a draft report was prepared to described the details of model design and development and facilitate discussions with City staff. City comments were collected and were addressed in production of this final report. Having run three scenarios, two remain, to be exercised at the City's discretion and reported as addendums to this report.

4.0 DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

4.1 Discussion

In reviewing the results of the modelling, the predictions do not indicate an immediate threat to public health through private well water quality. They do reinforce the degree of concern raised by the results from the sampling program, and indicate that such results can be expected to be repeated in identified high risk areas with increased development. This warrants ongoing monitoring and analysis of the situation, and extra care in reviewing and approving development applications.

The results also demonstrate the fact that deeper wells have a lower likelihood of encountering nitrate levels of concern; however, the assimilative capacity of the overburden aquifers is reduced and will be further reduced with additional development. Existing users (approximately 1/3 of which have been shown to draw from sources above bedrock) must be protected along with ensuring that future users have a safe supply of water.

4.2 Conclusions

The results outlined in the modelling report lead to the following conclusions.

Model Development

A modelling system has been developed to conceptually represent the physical characteristics of groundwater flow and contaminant transport within the Village of Greely and the surrounding area. The modelling system consists of a 1D numerical unsaturated zone model (LEACHM) and a 3D numerical saturated zone model (MODFLOW). Both the LEACHM and MODFLOW models are public domain DOS models, however the pre- and post-processor for MODFLOW used for this work was Visual MODFLOW Pro 3.1, available from Waterloo Hydrogeologic Inc. in Waterloo, Ontario.

Summary of Results

Three scenarios were built and analysed. For the scenarios, both average and peak conditions were examined, where average conditions make use of the final (steady-state) nitrate concentrations in the predicted leach output as inputs into MODFLOW and peak conditions make use of the highest nitrate concentration observed. When looking at general modeled impacts, the key figures to examine are therefore Appendix 1 Figures 4-9C, representing MODFLOW outputs of nitrate concentrations in Layer 6 (the uppermost bedrock layer). The scenario descriptions and a summary of results is as follows:

- Scenario #1 – Current Conditions: For the average case, areas of Layer 6 showing visible nitrate levels correspond to sectors V1, V2, V5, V6 and V11, with values up to approximately 1 mg/L. For the LEACHM outputs, the calculated concentrations of leached nitrate vary from 0 to 4.18 mg/L for the averaged case, with the maximum peak at 11.1 mg/L. The MODFLOW results show nitrate concentrations ranging from zero to over 9 mg/L - concentrations drop off as depth increases, however this reduction varies geospatially, driven by the magnitude of the recharge and the groundwater flow. Near-surface (Layer 2) values exhibit similar values and variations to the LEACHM inputs, as is expected; looking at subsequent layers, areas coincident with deeper bedrock show nitrate values dropping off more than areas coincident with shallower bedrock, as a result of the greater travel distances and subsequent dilution/dispersion.

- Scenario #2 – Future Build Out: In the MODFLOW results, for the average case, the visible nitrate levels again have values up to approximately 1 mg/L with some areas slightly higher, and now there are additional (to scenario #1) areas of Layer 6 showing visible nitrate levels corresponding to sector V17, and V1/V2 areas have expanded. The proportion of the village showing values at half the ODWS for nitrate (5 mg/L) or greater is over 50% for peak conditions. For the LEACHM outputs, the area experiencing nitrate leach concentrations at or above 8 mg/L has increased significantly. The breadth of nitrate impact across the village is significantly greater.
- Scenario #3 – Future Full Build Out: Again in the MODFLOW results, for the average case, the visible nitrate levels have values near 1 mg/L, and with the additional assumed development, the areas of concern are added to along the southern portion of the village where the model predicts levels of impact roughly equal to those within the western portion of the village (western section of unit 1). The protection afforded to the older portions of the village, and to northern portions, due to deeper overburden, clearly shows up on the figures.

Model Limitations and Interpretation

Interpretation of the modelling results must always make reference to the assumptions made as part of the effort and to the limitations inherent in an idealised mathematical representation of a real world system, in particular:

- A numerical model by necessity requires the smoothing of real world conditions, both physical features and contaminant mass transport conditions, such that calibration to real world conditions necessitates use of values averaged both in space and in time.
- Previous work in estimating the statistical variability of sampled parameters should be used to provide a necessary interpretation factor in using results from this modelling system.

Potential for Statistical Variation

The potential for statistical variation in groundwater nitrate concentrations has been identified in previous work (Detailed Analysis). Such variation can be the result of a number of causes, such as the presence of non-homogeneous conditions in the sub-surface such as bedrock fractures or from water leakage around well casings. While not demonstrating immediate health concerns (i.e., no saturated zone simulations generated nitrate concentrations above 10 mg/L), results do give cause for concern, particularly in areas where contaminant transport into bedrock is clearly indicated. In fact, those areas where bedrock concentrations match or exceed those of scenario #1 (current conditions) can be reasonably expected to lead to instances where private water supply wells drawing from the aquifer under future build-out conditions significantly exceed average nitrate concentrations. This is supported by the sampling program results (see Appendix 1 Figure 10) and results of recent residential sampling conducted as part of hydrogeological investigations, where values up to and exceeding 10 mg/L have been found.

4.3 Recommendations

Hydrogeological and Terrain Analysis reports are required for proposed developments on private services to ensure that groundwater quantity and quality (and its current and proposed future users) will not be adversely affected. In light of the above conclusions, the critical importance of conducting complete and thoroughly diligent hydrogeological assessments for all developments within the Village of Greely cannot be overly stressed. Guidance[7] and procedures[8,9] for such assessments have been provided by the MOE, as has the supporting document *MOEE Hydrological Technical Information Requirements for Land Development Applications (April, 1995)* - consistent and thorough application of these procedures is recommended. The consultant preparing these assessments is responsible for ensuring that the Provincial requirements are being met. Any deviations from these requirements must be fully justified.

Based on previous investigations and the results and conclusions of this study, all Hydrogeological and Terrain Analysis reports for proposed developments within the Greely area will include satisfaction of the recommendations below as part of ensuring that the Provincial requirements are met.

<u>Minimum Requirements for Aquifer Characterisation and Background Nitrate Levels</u>

1. Groundwater flow directions and gradients must be determined for all aquifers below the proposed subdivision, i.e., the bedrock aquifer and shallow/receiving (overburden) aquifer (if present). This will require the installation of a sufficient number of screened monitoring wells completed in the receiving aquifer, in addition to the required test wells - the number of such wells will be at least three but more will typically be required based on the size and shape of the development. The determination of static water levels will

[7] Guideline D-5. Planning for Sewage and Water Services. Director, Environmental Planning and Analysis Branch, Ontario Ministry of the Environment. Last Revision: August, 1996.
[8] Procedure D-5-5. Technical Guideline for Private Wells: Water Supply Assessment. Director, Environmental Planning and Analysis Branch, Ontario Ministry of the Environment. Last Revision: August, 1996.
[9] Procedure D-5-4. Technical Guideline for Individual On-Site Sewage Systems: Water Quality Impact Risk Assessment. Director, Environmental Planning and Analysis Branch, Ontario Ministry of the Environment. Last Revision: August, 1996.

require more than one set of measurements, such that the wells have stabilised and variability can be assessed.

2. Consultants must predict the impact of proposed on-site sewage systems on water quality within the proposed development. This prediction must make use of data from nearby residential developments where available, i.e., where there are wells in nearby established developments and on-site sewage systems are used in the existing development(s) and are also to be used in the proposed development, sufficient well water samples must be obtained and analysed [see Section 4.4.1 of Procedure D-5-5] to make this impact prediction. Note that this effort may be combined with efforts aimed at establishing background nitrate-nitrogen concentrations (see item #4 below).

3. Recognising the fact that shallow and/or unconfined aquifers are susceptible to contamination from sources located at or near the ground surface, reports must address the risk of contamination (including contamination from septic system outflow) and recommend measures which will reduce that risk [see Section 4.4.1 of Procedure D-5-5]. This is of particular importance given the fact that in many areas the contact aquifer within the Village demonstrates hydraulic connection between the overburden and bedrock aquifer. There may be cases where the local groundwater (i.e., from the development under review) will discharge directly to surface water – in these cases, the impact on the water body must be addressed and include discussion with the Conservation Authority and the City.

4. Land uses within a minimum of 500 m of the site must be described. Where wells exist on or adjacent to the site, a survey and sampling and analysis of representative well water must be performed and reported [see Section 4.6 of Procedure D-5-5]. For all hydrogeological assessments, representative well water must include both overburden and bedrock well water samples, if available within 500 m of the site, and in addition to on-site wells (see item #1) must include wells that are hydraulically up-gradient, as determined through either a site-specific calculation of hydraulic gradient (preferred), or through use of the groundwater modelling results from this report. Sufficient samples of groundwater from the receiving aquifer are to be analysed for total nitrogen species in order to establish the background nitrate-nitrogen concentrations [see Section 5.1 of Procedure D-5-4].

Minimum Requirements for Prediction of Nitrate Concentrations in the Receiving Aquifer

5. For developments with lot sizes less than 1 ha, the guide states in Section 5.5 that the potential for isolation be examined. This report (and the previous sampling) has identified the fact that the bedrock aquifer is for the most part not isolated, and so all assessments within the Village must complete Step Three: Contaminant Attenuation Considerations.

6. The available Moisture Surplus (precipitation minus actual evapotranspiration) used in the dilution calculation is to be either 350 mm/yr or a site-specific value obtained from Environment Canada (EC), who can provide detailed water budgets. A Moisture Surplus value obtained from a detailed EC water budget for another site in Ottawa may be used provided that the soil conditions can be demonstrated to be similar. The Moisture Surplus must be multiplied by the sum of the factors found in Table 2 (Infiltration Factors) of the supporting document *MOEE Hydrological Technical Information Requirements for Land Development Applications (April, 1995)* in order to obtain the groundwater recharge to be used in the nitrate dilution calculations. The groundwater recharge must be based on post-development conditions and must make allowance for impervious areas such as rooftops and paved areas. Only areas that can actually contribute to dilution will be used, i.e., areas that are outside of the groundwater flow path cannot be included, as they will not contribute to the recharge.

5.0 RISK ELEMENTS AND MITIGATION

As identified in the proposal and defined throughout the course of this project, there are a number of areas where significant risks were posed (defining risk as factors that threaten either the cost, schedule, or satisfaction of requirements of the project) that threatened project completion. Details on the risk elements and mitigation measures taken in response are provided below.

5.1 Model Calibration: Sufficiency of Site-Specific Data

The area of interest for the model encompasses a broad range of physical conditions: surficial geology ranges from high permeability gravels through sands to bedrock outcrops, drift thickness varies from near zero to over 25m, and land uses range from wetlands and fallow agricultural land through to new residential developments. For this reason, information on the chemical loading (in this case nitrate), fate and transport had to be obtained with sufficient density to characterise the area of interest.

JW mitigated the risk posed by an insufficient density of data through use of new data generated through the course of this assignment, as listed in Section 3.1 and as relayed by the City.

5.2 Modelling the Unsaturated Zone: Variability of Transport/Leaching

In order to complete the modelling of contaminant (nitrate) transport, the behaviour of nitrate from its sources (primarily septic systems, but also from agriculture and natural sources) through the unsaturated zone (primarily in multiphase vertical transport) into and through the saturated zone (primarily in horizontal transport) had to be defined. JW recognises the shortcomings of typical modelling efforts in addressing the unsaturated zone, and applied the latest available expertise to mitigate this risk.

As a mitigative approach, JW used the selected data management platform (the coupled Access database/ArcView GIS mentioned in Section 3.2.2 and used for the Detailed Analysis work previously completed) to 'host' the unsaturated zone analytical model. The vector-based surface data (contaminant sources) provided the inputs to the unsaturated zone calculation, which specific to the scenario output the values for formulation of the grid-based inputs for the saturated zone numerical model.

The risks associated with the variability of nitrate leaching and transport were further reduced ideally by using small time steps (during which model calculations are made to simulate the effect of stresses on the system) to obtain accurate iterative solutions.

5.3 Degree of Representativeness: Ultimate Model Accuracy

From a technical standpoint, the most significant model limitation for the physical system described is the inability to simulate fractured flow. The modelling system designed in this project makes two attempts to compensate for this: firstly, through use of an upper bedrock layer (Layer #6) with greater hydraulic conductivity that bedrock layers beneath it, and secondly, by referring to estimates of what the statistical likelihood of contaminant concentrations exceeding averaged conditions is (as represented by the sector nitrate concentration standard deviations from the previous Detailed Analysis work). The layer must still however be represented as homogenous. It is therefore necessary to interpret resulting groundwater flow and contaminant transport behaviour as an averaged condition, where the lesser flows of areas with below average fracturing and the greater flows of areas with above average fracturing are smoothed.

The most significant practical limitation of the modelling system is the inability to simulate malfunctioning septic systems and water wells. For the former, systems that have been improperly constructed or poorly maintained may result in the release of septic outflow with higher concentrations of nitrate that used in the simulations, while for the latter, wells that have cracked casings or other flaws may be introducing preferential contaminant pathways that are affecting the quality of water within some residences.

From the City's perspective, the utility of this exercise ultimately rests with the accuracy with which the model will be able to predict future use scenarios, in support of land use decision making within and around the Village of Greely.

6.0 CLOSURE

This report has been prepared for the sole benefit of the City of Ottawa. The report may not be relied upon by any other person or entity without the express written consent of Jacques Whitford and the City. Any use that a third party makes of this report, or any reliance on decisions made based on it, are the responsibility of such third parties. Jacques Whitford accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions taken based on this report.

The information and conclusions contained in this report are based upon work undertaken by trained professionals and technical staff in accordance with generally accepted engineering and scientific practices current at the time the work was performed. The conclusions and recommendations resented in this report should not be construed as legal advice.

Should additional information become available, Jacques Whitford requests that this information be brought to our attention so that we may re-assess the conclusions presented herein.

We would like to thank you for the opportunity to submit this report. Should you require any further information or clarification, please do not hesitate to contact the undersigned.

Yours truly,

JACQUES WHITFORD ENVIRONMENT LIMITED

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APPENDIX 1

11 X 17 FIGURES 1-11

APPENDIX 2

MODEL SELECTION MATRIX

MODEL SELECTION MATRIX
Phase 1 Task 1.2

Fate & Transport Pathway	Name of Model/ Algorithm	Model Description/ Process Simulations	Type of Code/ Algorithm	Model Outputs	Features/ Characteristics/ Use Conditions/ Limitations	Computer Needs	References/ Sources	Cost	Applicability/ Ease of Use/ Cost/Final Score[10]
Soil to Ground-water	LEACH	Calculates soil leaching partitioning factor and an attenuation factor for mixing with groundwater specifically developed for use with hydrocarbon fractions. Has linear equilibrium partitioning, no biodegradation and well-mixed dispersion in groundwater.	1D Analytical – Linear	Leachin g factor	Assumes constant concentration in subsurface soils, linear equilibrium partitioning, steady-state leaching from the soil to groundwater, no biodegradation, and well-mixed dispersion of leachate in groundwater. Relatively simple and very conservative. Commonly used for Tier 1.	386/486 with math coprocessor, 4 MB RAM, 2.5 MB free disk space, and DOS 3.0 or higher	ASTM,1995; ASTM RBCA, SSG		5/5/10=6.7
Soil Attenuation	SAM	SAM = Soil Attenuation Model. A modification of the LEACH model to provide a more rigorous characterization of soil to groundwater process with dilution, evapotranspiration, sorption, biodegradation time average factor.	1D Analytical - Exponential	Leaching factor with biodegradation/ time-average factor	Augments the LEACH model to characterize critical input parameters and more accurately simulate rainfall infiltration and leachate migration. Applicable to analysis of porous media soils impacted by either organic and inorganic constituents in the absence of NAPLs. Can predict groundwater concentration given affected soil value or calculate a SSTL given a groundwater exposure limit	386/486 with math coprocessor, 4 MB RAM, 2.5 MB free disk space, and DOS 3.0 or higher	J. A. Connor et al, 1996; TNRCC	SAM is included in RNA Tool Kit , US 495 Http://www.gsi-net.com/Software/Florida.htm	8/5/1=4.7
Vadose/ Unsaturat-ed Zone Transport	VADSAT	Contaminant transport through unsaturated soil using compartmental approach with different models to describe source zone, vadose zone above the source, and vadose zone between source and groundwater.	1D Analytical - Exponential	Contaminant transfer to groundwater, volatilization losses	Homogenous/uniform soil conditions below source, hydraulic conductivity calculated as a function of constant moisture content, assumes source has uniform concentration, does not consider water table fluctuations. Considers finite-mass source zone, pseudo steady-state volatilization , diffusive vapor transport from source to ground surface, leaching from source zone	IBM 486 or compatible, 10 MB RAM, 8 MB free disk space, Windows 3.1	Scientific Software Group	US 425 Environmental Systems & Technologies Inc	8/5/3=5.3
Leaching-Vadose Zone	VLEACH	Describes movement of volatile organic constituents within and between three phases: solute dissolved in groundwater, gas in the vapor phase, adsorbed compound in the solid phase.	1D Numerical Finite Difference	Equilibrium distribution of constituent mass between liquid, gas, and sorbed phases. Area-weighted groundwater impact	Assumes vadose zone is in a steady-state condition with respect to water movement. Assumes moisture profile within vadose zone is constant. Assumes homogenous soil conditions within polygon. Does not incorporate biodegradation. Does not account for nonaqueous phase liquids.	Intel 8086, 80286, 80386, 80486, 256Kb RAM, DOS 2.0 or higher,	Ravi, V. and J.A. Johnson, 1997; Center for Subsurface Modeling	Free http://www.waterloohydrogeologic.com/free_downloads.htm	5/5/10=6.7

[10] Applicability Score: Eliminate models that do not meet technical requirements (e.g., surface attentuation models without biodegredation), then score remainder 1-10 based on: somewhat matches (1), matches (5) or perfectly matches (10) unsaturated zone problem

Fate & Transport Pathway	Name of Model/ Algorithm	Model Description/ Process Simulations	Type of Code/ Algorithm	Model Outputs	Features/ Characteristics/ Use Conditions/ Limitations	Computer Needs	References/ Sources	Cost	Applicability/ Ease of Use/ Cost/Final Score[10]
		Leaching is simulated in a number of distinct, user-defined polygons vertically divided into a series of user-defined cells.		for modeled area.		CGA board, math coprocessor	Support (CSMoS); Scientific Software Group		

Fate & Transport Pathway	Name of Model/ Algorithm	Model Description/ Process Simulations	Type of Code/ Algorithm	Model Outputs	Features/ Characteristics/ Use Conditions/ Limitations	Computer Needs	References/ Sources	Cost	Applicability/ Ease of Use/ Cost/Final Score[10]
Leaching-Vadose Zone	LEACHM	LEACHM = Leaching Estimation And Chemistry Model. LEACHM is a model to simulate soil water and solute transport under a wide range of laboratory and field conditions. It describes the water regime and the chemistry and transport of solutes in unsaturated or partially saturated soils to a depth of about two metres.	1D Numerical Finite Difference	The detailed output (.OUT) file . This consists of several separate tables: 1) A table of profile water retentivity and hydraulic conductivity data. 2) A cumulative mass balance summary for the whole profile. 3) Profile chemical contents, water contents, potentials and fluxes. 4) Plant growth, chemical uptake and transpiration details. **The summary (.SUM) file** The summary file (unit 12) contains one record per print. Each record contains cumulative time, cumulative (rain + irrigation), actual transpiration and evaporation, chemical fluxes at four depths in the profile, water fluxes at these depths and at the surface, and water and chemical contents in each of four profile layers. These data are the sum of chemical contents through one or more segments and are defined in the input data file.	LEACHM is intended primarily as a model for simulating water and chemical transport in soil profiles. It can be applied to laboratory columns as well as natural soils. Three variants of the model describe pesticides, nutrients (N and P), and salinity. The model can be run with a minimum of commonly measured data, but more detailed data can be included if available. It has graphical interfaces, menu-driven file preparation utilities, GIS integration and crop growth modelling have been developed by several individuals and institutions.			http://www.scieng.flinders.edu.au/cpes/people/hutson_j/leachweb.html FREE	8/5/10=7.7

Fate & Transport Pathway	Name of Model/ Algorithm	Model Description/ Process Simulations	Type of Code/ Algorithm	Model Outputs	Features/ Characteristics/ Use Conditions/ Limitations	Computer Needs	References/ Sources	Cost	Applicability/ Ease of Use/ Cost/Final Score[10]
Leaching-Vadose Zone	PEARL GeoPEARL	PEARL=Pesticide Emission Assessment at Regional and Local scales. PEARL is used to evaluate the leaching of pesticides to the groundwater in support to the European and Dutch pesticide registration procedures. GeoPEARL is in its final stage of development. A recent study has shown that it is insufficient to base pesticide registration and policy evaluation on pesticide properties alone. It was concluded that spatial variation of soil properties should be included in pesticide leaching assessments. The spatially distributed model GeoPEARL has been developed to meet this requirement. The model is the next step in the growing demand for tailor-made decisions in pesticide registration, in an agricultural environment facing the challenges of sustainability. The model is in the final stage of development and will be launched by the end of 2003.	PEARL is a one-dimensional, dynamic, multi-layer model that describes the fate of a pesticide and relevant transformation products in the soil-plant system. The model is linked with the Soil Water Atmosphere Plant (SWAP) model .		Graphical User Interface for Windows 95/98/NT. All data are stored in a relational database. Both the Dutch standard scenario and the European standard scenarios as suggested by the FOCUS modeling working group can be accessed through the User Interface.	Windows 95/98/NT/2000/XP, 64 Mb RAM, 30 Mb for installation, and around 40 Mb for output	The model is a joint product of Alterra Green World research and the National Institute of Public Health and the Environment. http://www.pearl.alterra.nl	see link for details: http://www.alterra-research.nl/pls/portal30/docs/folder/pearl/pearl/home2.htm	3/5/5=4.3
Ground-water Transport	MODFLOW	Saturated, steady-state or transient flow for single or multiple aquifers, commonly used for Tiers 2 or 3.	2D or 3D Numerical Finite Difference	Hydraulic head	Assumes saturated zone can be heterogeneous and anisotropic, confined or unconfined aquifer system. Limited to groundwater flow. Commonly used for Tiers 2 or 3.	Intel 80286, DOS 3.0 or higher, 640 Kb RAM, 500 Kb free disk space, math coprocessor	McDonald, M. and Harbaugh, A., 1988; IGWMC, USGS	Free http://www.waterloohydrogeologic.com/free_downloads.htm	8/1/10=6.3

Fate & Transport Pathway	Name of Model/ Algorithm	Model Description/ Process Simulations	Type of Code/ Algorithm	Model Outputs	Features/ Characteristics/ Use Conditions/ Limitations	Computer Needs	References/ Sources	Cost	Applicability/ Ease of Use/ Cost/Final Score[10]
	PLASM	Saturated, steady-state or transient flow for single or multiple aquifers.	2D or 3D Numerical Finite Difference	Hydraulic head	Assumes saturated zone can be heterogeneous and anisotropic, confined or unconfined aquifer system. Limited to groundwater flow. Does not consider advection, diffusion, or dispersion. Commonly used for Tiers 2 or 3.	Intel 80i86, DOS 2.1or higher, 640 Kb RAM, 1.5 MB free disk space, math coprocessor	Prickett, T. and Lonnquist, C., 1971; IGWMC	$US 150	3/3/9=5
	MT3D	Mass Transport in the saturated zone, steady -state or transient flow for single or multiple aquifers.	3D Numerical – Finite Difference	Simulates changes in concentration	Assumes saturated zone can be heterogeneous and anisotropic, confined or unconfined aquifer system Handles a variety of discretization schemes and boundary conditions. Commonly used for Tiers 2 or 3.	386/486 with math coprocessor, 2 MB RAM, DOS 3.0 or higher	Zheng, C., 1990; IGWMC, Scientific Software Group	Free http://www.waterloohydrogeologic.com/free_downloads.htm	-
	MODPATH	Semi-analytical Particle Tracking Scheme for steadystate	3D Numerical Finite Difference	Computes 3D path lines	Assumes saturated zone can be heterogeneous and anisotropic confined or unconfined aquifer system. Can handle multiple release times for particles and can draw true cross-section grids displaying spatial data. Superimposes particle tracks on flow field typically generated using another model.	Requires 386/486 with math coprocessor, 4MB RAM 5MB free disk space, DOS 3.0 or higher	Pollock, D. W. 1989; IGWMC, Scientific Software Group, USGS	Free http://www.waterloohydrogeologic.com/free_downloads.htm	-

Fate & Transport Pathway	Name of Model/ Algorithm	Model Description/ Process Simulations	Type of Code/ Algorithm	Model Outputs	Features/ Characteristics/ Use Conditions/ Limitations	Computer Needs	References/ Sources	Cost	Applicability/ Ease of Use/ Cost/Final Score[10]
	GMS	GMS integrates and simplifies the process of groundwater flow and transport modeling by bringing together all of the tools needed to complete a successful study. GMS provides a comprehensive graphical environment for numerical modeling, tools for site characterization, model conceptualization, mesh and grid generation, geostatistics, and sophisticated tools for graphical visualization.	3D Numerical Finite Difference and Finite Element	Hydraulic head Contaminant Transport Output in several graphical formats including GIS	Several types of models are supported by GMS. The current version of GMS provides a complete interface for the codes FEMWATER, MODFLOW2000, MODPATH, MT3D, RT3D, ART3D, SEAM 3D, NUFT, UTCHEM, FACT and SEEP2D. The parameter estimation codes PEST and UCODE are also supported. Stochastic modeling -Two types of analysis are currently supported: probabilistic threshold analysis and probabilistic capture zone delineation. GMS can read/write for this type of data are: ArcGIS Shapefiles USGS DLG files CAD DXF files Georeferenced or regular TIFF files Georeferenced or regular JPEG files	PC version runs under Windows® 98/NT/2000/X P. Pentium w/16MB RAM required.	The Department of Defense, in partnership with the Department of Energy, the U.S. Environmental Protection Agency, the U.S. Nuclear Regulatory Commission and 20 academic partners, has developed the Groundwater Modeling System. Registration or assistance is only provided to DoD/USEPA /DoE/NRC users. Other interested parties should contact Environmental Modeling Systems Incorporated (EMS-I).	http://www.ems-i.com/GMS/GMS_Pricing/gms_pricing.html US $2500 MODFLOW: Map+Sub+Grid +Geostat+ModF packages (basic package) Expensive compared other models	9/7/1=5.7

Fate & Transport Pathway	Name of Model/ Algorithm	Model Description/ Process Simulations	Type of Code/ Algorithm	Model Outputs	Features/ Characteristics/ Use Conditions/ Limitations	Computer Needs	References/ Sources	Cost	Applicability/ Ease of Use/ Cost/Final Score[10]
N/A	PEST	PEST is a Module for GMS. PEST is a general purpose parameter estimation utility. More complex parameterizations are possible. Yet PEST can indicate where further complexity is non-sustainable, given the current dataset.	Use of nonlinear parameter estimation techniques for model calibration and/or data interpre-tation.	Calibration results or success/failure of auto calibration process	The PEST interface in GMS can be used to perform parameter estimation for MODFLOW. Setting up a PEST run takes only a few simple steps. The parameter zones can be assigned directly to the cells or using GIS feature objects in the conceptual model. A unique feature of the GMS PEST interface is that it supports both head and flux observations.		http://www.parameter-estimation.com/index.html		-
N/A	Visual PEST	Parameter Estimation Software for Automated Calibration of Groundwater Models	PEST2000 is the latest version of PEST	Calibration results or success/failure of auto calibration process	PEST is now used extensively for automated model calibration and data interpretation in groundwater and surface water hydrology, geophysics, geotechnical, mechanical and mining engineering, as well as many other fields	PC or UNIX Workstation.	http://www.parameter-estimation.com/index.html	US 595 http://www.scisoftware.com/products/visual_pest_prices/visual_pest_prices.html	-
Groundwater Transport	Visual MODFLOW PRO	Comprehensive GUI based pre and post processor for USGS MODFLOW 2000 by Waterloo Hydrogeologic. Software also includes MT3D and MODPATH	GUI for USGS MODFLOW 2000 (numerical finite difference 3-D)	Hydraulic head Contaminant Transport Output in popular graphical formats.	It does not support unsaturated zone simulation. Supports Win-PEST (not included in the package price?) Interactive display of model solution convergence for on-the-fly modification of solver settings Batch processing of multiple simulations for sensitivity analyses Advanced 3-D visualization and animation of model input data and simulation results Supports importing Shape, DXF, DWG, BMP files Support for MS Access Database. Most Popular Tool for GW Modelling.	Windows Platforms: Pentium-class processor running Windows 9x, ME, NT, or 2000 or XP 300 MB RAM 800x600 w/ High Color (min.) 150 MB disk space	http://www.waterloohydrogeologic.com/software/visual_modflow_pro/visual_modflow_pro_prod_details.htm#hardware	US$ $1995 (Full Price) We may qualify for the upgrade price (US $1295 or US$395 depending on the version we currently own) http://www.waterloohydrogeologic.com/software/visual_modflow_pro/visual_modflow_pro_pricing.htm	8/7/4=6.3

Fate & Transport Pathway	Name of Model/ Algorithm	Model Description/ Process Simulations	Type of Code/ Algorithm	Model Outputs	Features/ Characteristics/ Use Conditions/ Limitations	Computer Needs	References/ Sources	Cost	Applicability/ Ease of Use/ Cost/Final Score[10]
Groundwater Transport Saturated and unsaturated	Visual MODFLOW-SURFACT	MODFLOW-SURFACT is a powerful three-dimensional finite-difference flow and transport program for saturated and unsaturated flow problems.	GUI for USGS MODFLOW –SURFACT (numerical finite difference 3-D)	Hydraulic heads Contaminant transport Data files and popular graphical formats.	-Simulating multiple water tables - Simulating surface water infiltration through the vadose zone to the water table -First-order decay or biochemical degradation in soil and/or water -includes new Newton Raphson linearization package with backtracking (NRB1) -will simulate unsaturated flow includes fractured flow and dual porosity	Windows Platforms: Pentium-class processor running Windows 9x, ME, NT, or 2000 or XP 300 MB RAM 800x600 w/ High Color (min.) 150 MB disk space		http://www.waterloohydrogeologic.com/software/modflow_surfact/modflow_surfact_pricing.htm US$ 2995 (advanced transport)	
Ground-water Transport Saturated and Un-saturated	MS-VMS	Sophisticated, comprehensive subsurface flow and contaminant transport model, MODFLOW-SURFACT provides efficient simulations of complex subsurface conditions	GUI for USGS MODFLOW-SURFACT (numerical finite difference 3-D)	Hydraulic heads Contaminant transport Data files and popular graphical formats.	MS-VMS provides several tools for grid refinement, cut-out (zoom) model construction, calibration statistics, model sensitivities, model restart, and graphical model manipulation, along with display of calibration and results statistics, hydrographs and breakthrough curves.	Pentium CPU 16 MB extended memory (recommended) Microsoft Windows 3.1 / 95 / 98 / NT, or later		http://www.scisoftware.com/products/modflow_surfact_prices/modflow_surfact_prices.html US$ 2975 (advanced transport)	9/6/2=6
Ground-water Transport	Ground-water Vistas	Developed by the author of ModelCad, GV is a model-independent graphical design system for MODFLOW MODPATH (both steady-state and transient versions), MT3DMS, MODFLOWT, MODFLOW-SURFACT, MODFLOW2000, GFLOW, RT3D, PATH3D, SEAWAT and PEST, the model-independent calibration software. The combination of PEST and GV's automatic sensitivity analysis make GV a powerful calibration tool.	GUI for USGS MODFLOW (numerical finite difference 3-D)	Hydraulic heads Contaminant transport Data files and popular graphical formats.	Automatic Calibration procedure and supports PEST ASP and UCODE model-independent calibration software Support for SEAWAT: Simulation of Three-Dimensional Variable-Density Ground-Water Flow First modeling environment for the MODFLOW family of models that allows for the quantification of uncertainty	Windows Platforms Pentium-class processor running Windows 9x, ME, NT, or 2000 or XP 128 MB RAM 1024x768 w/ High Color (min.) 100 MB disk space		http://www.groundwater-vistas.com/html/groundwater_vistas_prices.html US $ 1445	8/6/3=5.7

Fate & Transport Pathway	Name of Model/ Algorithm	Model Description/ Process Simulations	Type of Code/ Algorithm	Model Outputs	Features/ Characteristics/ Use Conditions/ Limitations	Computer Needs	References/ Sources	Cost	Applicability/ Ease of Use/ Cost/Final Score[10]
Ground-water Transport	Processing MOFLOW PRO 7.0	A professional graphical preprocessor and postprocessor 3D finite-difference ground-water models MODFLOW-88, MODFLOW-96, and MODFLOW 2000 Solute transport models MT3D, MT3DMS, RT3D and MOC3D Particle tracking model PMPATH Inverse models UCODE and PEST-ASP for automatic parameter estimation.	GUI for USGS MODFLOW (numerical finite difference 3-D)	Hydraulic heads Contaminant transport Data files and popular graphical formats.	Supports and includes MODFLOW-88/96/2000, MT3D,MT3DMS, RT3D 2.5, MOC3D, PMPATH, UCODE, and PEST-ASP Supports Streamflow-Routing Package, Horizontal-Flow Barrier Package, Reservoir Package, and Time-Variant Specified Head Package Supports various equation solvers including Direct Solution Package, Link-Algebraic Multigrid Package, Strongly Implicit Procedure Package, and Preconditioned Conjugate-Gradient Package 2 Generate heterogeneously-distributed parameter fields for stochastic simulation.	Version 7.0 64 MB RAM 128 MB disk space Windows 95/98/Me/NT4 .0/2000/XP		http://www.civiltools.com/apppages/cart.asp US$ 1195	8/5/4=5.7
Groundwater Transport	PMWIN	Integrated graphical simulation system for the 3D models MODFLOW, MT3D, MT3DMS, MO C3D, PMPATH 99 and inverse models PEST and UCODE. (Includes all above-mentioned models.		Hydraulic heads Contaminant transport Data files and popular graphical formats.	PMWIN comes with a professional graphical user-interface, the supported models and programs and several other useful modeling tools. It can import DXF- and raster graphics and handle models with up to 1,000 stress periods, 80 layers and 250,000 cells in each model layer. The modeling tools include a *Presentation tool*, a *Result Extractor*, a *Field Interpolator*, a *Field Generator*, a *Water Budget Calculator* and a *Graph Viewer.* Software is developed by a university professor in South Africa. Quality and extent of software support is not fully known. Not sure what version is included in the book and number of supported USGS MODFLOW packages (drain, stream, and etc.,) in the GUI.	http://www.environmental-center.com/publications/springer/3540677445.htm http://www.ground-water-models.com/products/pmwin_prices/pmwin_prices.html	Cost of the software varies widely.	Processing Modflow for Windows (PMWIN) is included in the book "3D-Groundwater Modeling with PMWIN" Retail price of the book + CD is US$149. US$695 for base Package and add-on extra	8/5/5=6

List of models http://eco.wiz.uni-kassel.de/model_db/models.html

APPENDIX 3

DATA DICTIONARY

Data Dictionary

Data element number	Data element name	Data element description	Related data elements	Data element type	Source of the data element
1	Chloride_Average_By_Sector	Table in Wells Database (project 50505). Data about average level of Chloride in taken water samples by sector. Fields: Sector; AgeRange; Parameter; AvgValue	Nitrate_Average_By_Sector	Table	Lab analysis.
2	Nitrate_Average_By_Sector	Table in Wells Database (project 50505). Data about average level of Nitrate in taken water samples by sector.	Chloride_Average_By_Sector. Fields: Sector;AgeRange;Parameter;AvgValue	Table	Lab analysis.
3	Parameters	Table in Wells Database (project 50505). List of parameters of water quality to be analysed in lab. Field: Parameter	WellsWaterQuality	Table	
4	PIN_Age	Table in Wells Database (project 50505). Holds info abot Age range of surveyed wells. Fields: PIN, Age, AgeRange		Table	
5	Site Reports	Table in Wells Database (project 50505). Fields:ReportID; Title; Date; Location; Author	Test_Pits_Wells	Table	Hard copies of the reports.
6	StatValues	Table that holds water quality statistical data. Fields: RecID; Parameter; MinValue; MaxValue; AvgValue; MedianValue; StDevValue; SkewValue; NumericRecords; Sector	WellsWaterQuality	Table	Wells database utility for calculating statistical data.
7	StatValues_June25_2003	Table that holds water quality (Nitrate and Chloride only) statictical data. Fields: Sector; AgeRange; Parameter; AvgValue;		Table	Wells database utility for calculating statistical data.
8	Test_Pits_Wells	Table with data extracted from hard copies of the reports listed in SiteReports table. Fields: TPWID; ReportID; Type; Layer1; Depth1; Layer2; Depth2; Layer3; Depth3; Layer4; Depth4; Layer5; Depth5; Bedrock; Depth_to_Bedrock; X; Y	SiteReports	Table	Data exracted from hard copies of the reports listed in SiteReports table

9	Wells_Survey	Table with data collected while surveying wells. Fields: PIN; Sector; Project_N; Well_N; AgeRange; Identifier; Date; Investigator; Owner; Addr_Num; Addr_Modifier; Rd_Name; Rd_Type; City; Province; PostalCode; E_mail; Phone; Wellhead_location; Easting; Northing; Contact_Method_Email; Contact_Method_Phone; Contact_Method_Fax; Fax_N; Dug_well; Drilled_well; Year_drilled; Well_record_available; Quantity_problems; Quantity_problems_describe; Quality_problems; Quality_problems_describe; Water_treatment; Water_treatment_describe; Had_drilled_well_before; Reason_for_abandonment; Type_pump_distrib_system; Original_owner; Wellhead_accessibility; Source_of_well_data; Well_depth; Well_diameter; Rock_Overburden; Static_level; Water_found; Driller; Prim_Alternate; Water_Sample_Taken_Y_N; Dublicate_Y_N; Parameters_GGP_SIP; Environmental_Parameters; Pumping_Test_Conducted_Y_N; Duration; Temperature; Conductivity; pH; Hydrogeology		Table	Data collected while wells survey.
10	WellsWaterQuality	Table holds water quality analysis results. Fields: TPW_ID; Date; Begining_End; Alkalinity; Ammonia; Calcium; Chloride; Colour; DOC; E_Coli; Faecal_Streptococci; Fluoride; Hardness; Heterotrophic_Plate_Count; Hydrogen_Sulphide; Iron; Magnesium; Manganese; Nitrate; Nitrite; Phenols; Potassium; Sodium; Sulphate; Tannin_Lignin; TDS; TKN; Turbidity; TotalPhosphorus; TotalColiforms; pH; Conductivity		Table	Water analyze lab results.
11	WellsWaterQualityMetals	Table holds water quality metals analysis results. Fields: RecID; TPW_ID; Aluminum; Antimony; Arsenic; Barium; Beryllium; Boron; Cadmiun; Calcium; Chromium; Cobalt; Copper; Iron; Lead; Magnesium; Manganese; Molybdenum; Nickel; Potassium; Selenium; Silver; Sodium; Thallium; Vanadium; Zinc; Mercury; Uranium		Table	Water analyze lab results.
12	WellsWaterQualityPAHs	Table holds water quality analysis results. Fields: RecID; TPW_ID; Acenaphthalene; Acenaphthene; Anthracene; Benzo_a_anthracene; Benzo_a_pyrene; Benzo_b_fluoranthene; Benzo_k_fluoranthene; Benzo_g_h_l_perylene; Chrysene; Dibenzo_a_h_anthracene; Fluoranthene; Fluorene; Indeno_1_2_3_c_d_pyrene; Napthalene; Phenanthrene; Pyrene.		Table	Water analyze lab results.

13	WellsWaterQualityPesticides	Table holds water quality analysis results. Fields:TPW_ID; Aldrin; Alpha; Beta_BHC; ppDDD; ppDDE; ppDDT; Delta_BHC; Dieldrin; Endosulfan_I; Endosulfan_II; Endosufan_Sulfate; Endrin; Endrin_aldehyde; Gamma_BHC_Lindane; Heptachlor; Heptachlor_epoxide; Methoxychlor; Decachlorobiphenyl;		Table	Water analyze lab results.
14	WellsWaterQualityTPH	Table holds water quality analysis results. Fields: RecID; TPW_ID; TotalPetrHydrocarb_Gas_Diesel; TotalPetrHydrocarb_HeavyOil.		Table	Water analyze lab results.
15	WellsWaterQualityVOCs	Table holds water quality analysis results. Fields: TPW_ID; Benzene; Bromdichloromethane; Bromoform; Bromomethane; Carbon_Tetrachloride; Chlorobenzene; Cloroethane; Chloroform; Chloromethane; Dibromochloromethane; 1_2_Dibromoethane; m_Dichlorobenzene; o_Dichlorobenzene; p_Dichlorobenzene; 1_1_Dichloroethane; 1_2_Dichloroethane; 1_1_Dichloroethylene; c_1_2_Dichloroethylene; t_1_2_Dichloroethylene; 1_2_Dichloropropane; c_1_3_Dichloropropene; t_1_3_Dichloropropene; Ethylbenzene; Methylene_Chloride; Styrene; 1_1_2_2_Tetrachloroethane; Tetrachloroethylene; Toluene; 1_1_1_Trichloroethane; 1_1_2_Trichloroethane; Trichloroethylene; Trichlorofluoromethane; 1_3_5; Trimethylbenzene; Vinyl Chloride; Xylenes; 1_2_Dichlorobenzene; 1_4_Dichlorobenzene; Dichloromethane; Monochlorobenzene; Trihalomethanes.		Table	Water analyze lab results.
16	SelectedWells_Hydro	Geological information from MOE well records. Fields: Well ID; Easting; Northing; Layer One Depth (m); Formmat1_1; Formmat2_1; Formmat3_1; Layer Two Depth (m); Formmat1_2; Formmat2_2; Formmat3_2; Layer Three Depth(m); Formmat1_3; Formmat2_3; Hydrogeology_Desc; Bedrock/Overburden; Comments; Drift_Thickness_Band.		Table	MOE Records; Reports listed in SiteReports.
17	SelectedWells	Query. Wells info selected using Easting and Northing.		Query	MOE well records table
18	Wells_Stat	Query. Wells info combined with water quality data.		Query	SelectedWells_Hydro, WellsWaterQuality tables.

19	Potential_Contaminant_Sources	Table lists Potential Contaminants. Fields: ID; Location; Type; Potential Source.		Table	Visual survey of Greely and surrounding area, and review of City HLUI (Historical Land Use Inventory) database
20	SIP_GGP_Prim_Environ_Standards_MDLs	Table: Summary info abour the laboratory method detection limits (MDLs) and ODWS criteria (either as a Maximum Allowable Concentration (MAC), Interim Maximum Allowable Concentration (IMAC) or Aesthetic Objective (AO)) for the SIP, GGP and environmental parameters).	Additional_Env_Standards_MDLs	Table	ODWS
21	Additional_Env_Standards_MDLs	Table: Summary info about additional environmental standards and MDLs.	SIP_GGP_Prim_Environ_Standards_MDLs	Table	
22	Sector_Ages_Count	ArcView shape file, part of Greely_Categ.mxd project file. Displays Sector Area Impact Categories.		Shape File	P:\2003\60000\62726\Database\WellStat.mdb - Sector_Ages_Areas table
23	Sector_Ages_Count	Table holds info about sector ages, sector areas and number of properties belonged to each sector.		Table	City data and database utilities.
24	New_roads	Shape file. Used for displaying roads on ArcView maps.		Shape File	
25	New_streams	Shape file. Used for displaying streams on ArcView maps.		Shape File	
26	New_lakes	Shape file. Used for displaying lakes on ArcView maps.		Shape File	
27	PIN	Shape file. Used for displaying property locations on several ArcView maps.		Shape File	City data.
28	New_drift	ArcView shape file, part of Greely_Drift.mxd project file. Used for displaying Drift Thickness.		Shape File	
29	SelWel_HyGe	ArcView shape file, part of Greely_Drift.mxd project file. Used for displaying Well Depth Bands.		Shape File	P:\2003\60000\62726\Database\WellStat.mdb - SelectedWells_Hydro table

30	New_surfge	ArcView shape file, part of Greely_Anls.mxd project file. Used for displaying Surficial Geology.		Shape File	
31	Res_Sec_Ag e	ArcView shape file. Used for displaying Nitrate Concentrations in SpPrResSectorFig1A_BackgroundNitrate .mxd project file, and for displaying Chloride Concentration in SpPrResSectorFig2A_BackgroundChloride .mxd project file, and also for displaying Ammonia average concentration in SpPrRes_Bio.mxd project file.		Shape File	Res_Sec_Age shape file is located in P:\2002\50000\50505\X_GIS\8.1Maps. Stats_Ammonia, Stats_Ecoli, and Stats_TotCol tables in P:\2002\50000\50505\X_GIS\8.1Maps\Stats_Master.mdb were used as source of data.
32	Potential Contaminant Sources	ArcView shape file. Used for displaying Potential Contaminant Sources in Shields_SpPgMaster.mxd project file.		Shape File	City data, lab analysis results
36	parcel_edges	ArcView shape file. Used for displaying property boundaries.		Shape File	City data.
37	Res_Sur_Qu	ArcView shape file. Used for displaying sampled locations and Chloride concentration in SpPrRes_Bio.mxd project file		Shape File	The source of data for the shape file is WellsSur_QuSIPGGP table in P:\2002\50000\50505\X_GIS\8.1Maps\Stats_Master.mdb
38	MS Excell SectorCorrel worksheet in WatQu_Loc_Wells.xls file	Correlation Analysis of dependence of water quality on various factors.		Worksheet	

39	MS Excel DriftCorrel worksheet in WatQu_Loc_Wells.xls file.	Correlation Analysis of dependence of water quality on various factors.		Worksheet	
40	MS Excel Drift_Correl_Regression.xls file.	The multiple regression procedures are applied to data collected while working on Greely area groundwater sampling program.		Worksheet	
41	SelectedWells_Hydro file in Greely_Anls.mxd GIS file.	ArcView XY Data Source file. The file is used for displaying MOE Well locations in Greely_Anls.mxd project file.		GIS file	SelectedWells_Hydro table in P:\2003\60000\62726\Database\WellStat.mdb database.
43	Greely/Shields Creek Stormwater And Drainage Study.	Stantec Sonsulting Ltd. Final Report.	Data and Parameter files used by Modelling software. (record 44)	Document	
44	Data and Parameter files used by Modelling software.	Set of input, output and parameter files used by the modelling applications. Received from Stantec Consulting Ltd. (400-1505 Laperriere Avenue Ottawa ON K1R 6K7)	Greely/Shields Creek Stormwater And Drainage Study. Final report. (record 43)	Data File	OTTHYMO Model, SWMHMO Model, HEC-2 Model
45	Set of input, output files used by a modelling application.	Set of input, output files used by the modelling application. Received from TSH Associates (240 Terence Matthews Crescent Ottawa, Ontario K2M 2C4)	Frequency Curves.xls file located in P:\2003\60000\62904\Data\CD_1\TSH Ottawa Information folder. Also set of files located in P:\2003\60000\62904\Data\CD_1\TSH Ottawa Information\Interim Future Conditions folder.	Data File	QHM Model

47	Set of input, output files used by a modelling application.	Set of input, output files used by the modelling application. Received from TSH Associates (240 Terence Matthews Crescent Ottawa, Ontario K2M 2C4)	Frequency Curves.xls file located in P:\2003\60000\62904\Data\CD_1\TSH Ottawa Information folder. Also set of files located in P:\2003\60000\62904\Data\CD_1\TSH Ottawa Information\Future Conditions folder.	Data File	QHM Model
48	Set of input, output files used by a modelling application.	Set of input, output files used by the modelling application. Received from TSH Associates (240 Terence Matthews Crescent Ottawa, Ontario K2M 2C4)	Set of files located in P:\2003\60000\62904\Data\CD_2\TSH Modelling\Existing Conditions; ...\Future Conditions; ...\Interim Future Conditions; ...\Ultimate Buildout Conditions folders.	Data File	QHM Model
49	Set of input, output files used by a modelling application.	Set of input, output files used by the modelling application. Received from TSH Associates (240 Terence Matthews Crescent Ottawa, Ontario K2M 2C4)	Set of files located in P:\2003\60000\62904\Data\CD_2\TSH Modelling\Existing Conditions; ...\Future Conditions; ...\Interim Future Conditions; ...\Ultimate Buildout Conditions folders.	Data File	QHM Model

50	Set of input, output files used by a modelling application.	Set of input, output files used by the modelling application. Received from TSH Associates (240 Terence Matthews Crescent Ottawa, Ontario K2M 2C4)	Set of files located in P:\2003\60000\62904\Data\CD_2\TSH Modelling\Existing Conditions; ...\Future Conditions; ...\Interim Future Conditions; ...\Ultimate Buildout Conditions folders.	Data File	QHM Model
51	Set of input, output files used by a modelling application.	Set of input, output files used by the modelling application. Received from TSH Associates (240 Terence Matthews Crescent Ottawa, Ontario K2M 2C4)	Set of files located in P:\2003\60000\62904\Data\CD_2\TSH Modelling\Existing Conditions; ...\Future Conditions; ...\Interim Future Conditions; ...\Ultimate Buildout Conditions folders.	Data File	QHM Model
52	Leach_Unit	ArcView shape file, part of LeachM.mxd project file. Displays units used in Modflow modelling software.		Shape File	
53	Greely_Model.mdb	Contains set of tables which are used as source of data for displaying Data Coverage (Fig.1) and Deposits Thickness (Fig. 2) in ModellingData.mxd file.	ModellingData.mxd	Database	
54	Gr_Bd_El.xls	Used in modelling process.		Worksheet	
55	Gr_LayerThickness.xls	Used in modelling process.		Worksheet	
56	SoilCalcs.xls	Contains key data of the modelling.		Worksheet	Modflow output files, Greely_Model.mdb, LeachM_Input.mdb

57	Leach_Soils, Leach_Units, ResultsFrom OutputFiles, Dom_Soils, Greely Ag Soil Types, Sls%Mix, SlsCoun, unit_slp, unit_val	Tables in LeachM_Input.mdb with data used in calculation and modelling process.		Table	
58	1-16, R, R00+, V00+, V1, V2, V3, V4, V5, V6, V7, V8, V9, V10, V11, V12	Folders with Modflow input and output files.		Data File	

APPENDIX 4

HYDROGEOLOGICAL FRAMEWORK

HYDROGEOLOGICAL FRAMEWORK

Feature	Purpose	Source	Model Conceptualization	Comment
Aquifer	Define the aquifers hydro-stratigraphically	Water well Records	The primary aquifer in the Greeley area consists of the upper portion of the fractured bedrock and lower portion of the overburden. This aquifer system known as the Contact Zone aquifer. This aquifer system is represented in the model as unconfined water table aquifer.	A review of water well records and consultant hydrogeological reports indicate that a majority (?) of water wells in the Greely area obtain water from the Contact Zone Aquifer.
Aquifer extents and connectivity	Distribution of aquifer units	Water well records, NR Canada, and other consultant reports	Horizontal and vertical distribution of different hydro-stratigraphic units in the Greely area are represented by six (6) units, eight (8) layers as follows: Layer 1: Topsoil Layer 2: Sand/Organic deposits Layer 3/4: Clay/Silty Clay Layer 5: Sand/Gravel Layer 6: Fractured bedrock Layer 7/8: Bedrock It is assumed that the first two (2) metres of the bedrock is fractured and represented as a distinct unit (layer 6).	Horizontal and vertical distributions of different hydro-stratigraphic units were interpreted from the water well records. The hydraulic connectivity between different hydro-stratigraphic units was interpreted based on the lithologic composition of adjoining units. The hydraulic connectivity between upper fractured bedrock (layer 6) and lower portion of the overburden (layer 5) is difficult to map with available data sources. The fracturing of bedrock units intersected by a well is inconsistently reported in water well records. Reports by Charron (1978), Bélanger and Harrison (1980), and Brandon (1960) support the interpretation that the first few metres of the bedrock is generally fractured from weathering.
Groundwater elevation	Define groundwater elevations	Water well records	The Greeley area hydrostratigraphy is largely unconfined. Most of the Greeley area will be represented in the model by a water table based on the MOE data from Greely Area wells sampled in 2002/2003.	A review of water well records and consultant hydrogeological reports indicate the presence of discontinuous layers of clay and silty clay in the overburden. The existence of artesian conditions is not fully known in the Greely area. It is assumed that the nitrate fate and transport in these clastic deposits is hydrogeologically more significant than simulating local-scale piezometric elevations.

Feature	Purpose	Source	Model Conceptualization	Comment
Horizontal Hydraulic Conductivity	Define the hydraulic conductivity	Literature and other consultant reports	Horizontal hydraulic conductivity values inferred from the literature and consultant reports and assigned to all fully saturated units. Following conductivity values are in (cm/s) Layer 2: Sand /Organic deposits ($1x10^{-3}$- $1x10^{-4}$/$1x10^{-5}$) Layer 3: Clay/Silty clay ($1x10^{-7}$- $1x10^{-9}$) Layer 4: Sand /Gravel ($1x10^{-3}$) Layer 5: Fractured bedrock ($1x10^{-3}$ - $1x10^{-5}$) Layer 6: Bedrock ($1x10^{-5}$ - $1x10^{-7}$)	
Specific Yield	Define the aquifer yield	Literature and other consultant reports	Specific Yield (SY) is known as the storage term for an unconfined aquifer. It is assumed that the specific yield of the hydro-stratigraphic units within the contact zone aquifer is equal to their effective porosity.	For sand and gravel aquifers, specific yield is generally equal to the effective porosity (Freeze and Cheery, 1979)
Vertical Hydraulic Conductivity	Define the vertical hydraulic conductivity	Literature and other consultant reports	Vertical hydraulic conductivity values were assumed to be one-tenth of the horizontal hydraulic conductivity for saturated layers (layers 2 through 6) Layer 2: Sand /Organic deposits ($1x10^{-4}$- $1x10^{-5}$/$1x10^{-6}$) Layer 3: Clay/Silty clay ($1x10^{-8}$- $1x10^{-10}$) Layer 4: Sand /Gravel ($1x10^{-4}$) Layer 5: Fractured bedrock ($1x10^{-4}$ - $1x10^{-6}$) Layer 6: Bedrock ($1x10^{-6}$ - $1x10^{-8}$)	Most sedimentary rocks such as limestone and sandstone have a directional quality to their overall structure. The horizontal conductivity is taken in the direction of the structural features, such as stratification, and vertical conductivity is taken at right angles to the stratification. Vertical hydraulic conductivities for bedrock can be as high as their horizontal hydraulic conductivities (Freeze and Cherry, 1979).

Feature	Purpose	Source	Model Conceptualization	Comment
Porosity	Define the water bearing capacity of aquifer units	Johnson and Morris, 1962 Norton and Knapp (1977) Croff and others (1985)	Porosity and effective porosity values inferred from the literature and assigned to all five saturated layers. Spatial distribution of the porosity within each unit was further interpolated to match the compositional changes. Layer 2: Sand /Organic deposits (40%/ne 35%)/(70%/ne 65%) Layer 3: Clay/Silty Clay (45%/ne 40%) Layer 4: Sand /Gravel (35%/ne 30%) Layer 5: Fractured bedrock (20%/ne 5%-10%) Layer 6: Bedrock (10%/ne 0.5 %-1.0%)	Porosity can range from near zero to 70 % in the Greeley area.

APPENDIX 5

DRAFT MODELLING SYSTEM USER GUIDE

USER GUIDE

APPENDIX 6

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