



Numerical Hydrogeological Modeling Report for Expansion Feasibility of the Ruby Road Waste Disposal Site

prepared for

THE CORPORATION OF THE TOWNSHIP OF BONNECHERE VALLEY

Reference No.: 07-1219-001

January 15, 2009

Cambium Environmental Inc.

Box 325, Unit 2, 2085 Whittington Drive, Peterborough, Ontario, K9J 6X4

Telephone: (705) 742.7900 (866) 217.7900

Facsimile: (705) 742.7907

www.cambium-env.com

NOTE: *This report refers to the samples as received.*

The practice of this Company in issuing reports of this nature is to require the recipient not to publish the report or any part thereof without the written consent of Cambium Environmental Inc.



EXECUTIVE SUMMARY

In support of a proposed capacity expansion at the Ruby Road Waste Disposal Site, Cambium Environmental Inc. numerically modeled the hydrogeologic conditions at the subject property using the Visual MODFLOW software package. The calibrated model was tested for sensitivity to variations in values associated with recharge, dispersion, hydraulic conductivity, effective porosity, and specific storage before simulating conservative scenarios for the proposed expanded waste disposal fill areas.

The sensitivity analysis indicated that the following parameters had very little or no effect on the model predictions: recharge, effective porosity, and specific storage. Therefore, the original values used for these parameters were used for subsequent model simulations. The hydraulic conductivity used in the models was 1×10^{-3} metres per second for the overburden material and 6.7×10^{-5} metres per second for the bedrock material, which was a greater a value than what was determined in the field using slug tests. However, the sensitivity analysis completed indicated a more conservative plume with the greater hydraulic conductivity within the bedrock; therefore, the greater conductivity was used for subsequent model simulations. Similarly, a dispersion value of 25 metres was used which is the maximum value that would be reasonable for the circumstances modeled.

A homogenous constant concentration was used for the entire waste disposal area footprint. Typical leachate concentrations from Table 1 of the *Guidance Manual for Landfill Sites Receiving Municipal Waste* (Ontario Ministry of Environment and Energy, 1993) were used in conjunction with typical leachate concentrations for other municipal waste disposal sites of a similar size to the proposed expansion were used to determine the constant concentrations used for this particular model. This approach is believed to be very conservative and sufficiently precautionary.

Based on the calibrated flow and transport models, and the model simulations, it can be concluded that the proposed expanded waste disposal area is feasible. The contaminant plumes simulated have indicated that in the predicted plume concentrations will not pass the property limit at values greater than the Reasonable Use Criteria prescribed by the Ontario Ministry of the Environment. It is believed the actual contaminant plume will exhibit concentrations much less than the Reasonable Use Criteria should the plume reach the property line at all.

CAMBIUM ENVIRONMENTAL INC.

Christine Teixeira, P.Eng.
Project Engineer

John Desbiens, P.Eng.
President



TABLE OF CONTENTS

1.0	OBJECTIVES	1
2.0	METHODOLOGY.....	1
3.0	SITE DESCRIPTION	2
4.0	DIMENSIONALITY AND DOMAIN.....	2
5.0	CALIBRATED FLOW MODEL	3
5.1	BOUNDARY CONDITIONS	3
5.1.1	Constant Head	3
5.1.2	Recharge.....	3
5.2	PROPERTIES	4
5.2.1	Conductivity.....	4
5.2.2	Storage Properties	4
5.2.3	Initial Heads	5
5.3	OBSERVATION WELLS.....	5
5.4	FLOW PATTERNS.....	6
5.5	MODEL RUN SETTINGS	6
5.6	CALIBRATION RESULTS	6
6.0	TRANSPORT MODEL.....	7
6.1	PROPERTIES	8
6.1.1	Initial Concentration	8
6.1.2	Dispersion	8
6.2	BOUNDARY CONDITIONS	9
6.2.1	Constant Concentration	9
6.3	MODEL RUN SETTINGS	10
6.4	SENSITIVITY ANALYSIS	10
6.4.1	Recharge.....	11
6.4.2	Dispersion	11
6.4.3	Hydraulic Conductivity	11
6.4.4	Effective Porosity	12
6.4.5	Specific Storage.....	12
6.4.6	Sensitivity Analysis Results	12
7.0	MODEL SIMULATIONS	13
7.1	EXPANDED FOOTPRINT	13



8.0 CONCLUSIONS..... 14

LIST OF FIGURES

Figure 1	Plan View of Model Domain
Figure 2	Cross-section View of Model Domain
Figure 3	Boundary Conditions
Figure 4	Final Flow Model Calibration Graph
Figure 5	Calibrated Equipotential Lines
Figure 6	Initial Chloride Plume (Layer 2)
Figure 7	Initial Chloride Plume (Layer 3)
Figure 8	Increased Recharge Sensitivity Analysis (Layer 2)
Figure 9	Increased Recharge Sensitivity Analysis (Layer 3)
Figure 10	Decreased Recharge Sensitivity Analysis (Layer 2)
Figure 11	Decreased Recharge Sensitivity Analysis (Layer 3)
Figure 12	Decreased Dispersion Sensitivity Analysis (Layer 2)
Figure 13	Decreased Dispersion Sensitivity Analysis (Layer 3)
Figure 14	Increased Hydraulic Conductivity Sensitivity Analysis (Layer 2)
Figure 15	Increased Hydraulic Conductivity Sensitivity Analysis (Layer 3)
Figure 16	Decreased Hydraulic Conductivity Sensitivity Analysis (Layer 2)
Figure 17	Decreased Hydraulic Conductivity Sensitivity Analysis (Layer 3)
Figure 18	Increased Effective Porosity Sensitivity Analysis (Layer 2)
Figure 19	Increased Effective Porosity Sensitivity Analysis (Layer 3)
Figure 20	Decreased Effective Porosity Sensitivity Analysis (Layer 2)
Figure 21	Decreased Effective Porosity Sensitivity Analysis (Layer 3)
Figure 22	Increased Specific Storage Sensitivity Analysis (Layer 2)
Figure 23	Increased Specific Storage Sensitivity Analysis (Layer 3)
Figure 24	Decreased Specific Storage Sensitivity Analysis (Layer 2)
Figure 25	Decreased Specific Storage Sensitivity Analysis (Layer 3)
Figure 26	Proposed Expansion Chloride Plume (Layer 2)
Figure 27	Proposed Expansion Chloride Plume (Layer 3)
Figure 28	Proposed Expansion Alkalinity Plume (Layer 2)
Figure 29	Proposed Expansion Alkalinity Plume (Layer 3)
Figure 30	Proposed Expansion Hardness Plume (Layer 2)
Figure 31	Proposed Expansion Hardness Plume (Layer 3)



LIST OF TABLES

Table 1	Constant Head Boundary Values.....	3
Table 2	Slug Test Results	4
Table 3	Initial Head Values	5
Table 4	Initial (Background) Concentrations of Modeled Parameters	8
Table 5	Contaminant Concentration Values Summary.....	10
Table 6	Summary of Sensitivity Analysis	12
Table 7	Calibrated Contaminant Concentration Plume Summary	14

LIST OF APPENDICIES

Appendix A:	Pre-screening Mass-balance Calculations
-------------	---



1.0 OBJECTIVES

In consideration of an expansion of the capacity at the Ruby Road Waste Disposal Site (WDS), it has been determined that modeling the groundwater regime would greatly benefit a comprehensive evaluation of the feasibility of the proposed capacity expansion. Visual MODFLOW was used to develop a numerical hydrogeological model to determine the extent of the leachate contaminant attenuation zone required for the proposed WDS expansion. The leachate contaminant plume simulations are used to determine if the expected leachate contaminant plume will extend beyond the property boundary such that concentrations of contaminants would or would not exceed the Ministry of the Environment (MOE) Reasonable Use Criteria (RUC) as defined by MOE Guideline B-7 where the plume is extending beyond the property line. The aforementioned guideline establishes the basis for determining the "reasonable use" of groundwater on property adjacent to sources of contaminants and for determining the levels of contaminant discharges considered acceptable by the Ministry. The numerical model was established based on the site groundwater conditions determined from the available well logs, site conditions, and well observation data collected over the past four (4) years.

The groundwater model was constructed using Visual MODFLOW, a graphical pre- and post-processor for the MODFLOW, MODPATH and RT3D numerical codes. MODFLOW and MODPATH were developed by the United States Geological Survey to simulate three-dimensional groundwater flow and advection transport in complex geological settings under a variety of boundary conditions and hydrogeological stresses. For this model, RT3D v2.5 was used. RT3D is a program for simulating reactive multi-species transport in three-dimensional groundwater aquifers and was first developed by P.T. Clement in 1997 for the Battelle Memorial Institute, Pacific Northwest National Laboratory, and was subsequently released into public domain and quickly became an accepted standard for reactive transport modeling.

2.0 METHODOLOGY

In an effort to understand the groundwater flow and plume contamination at the site, a calibrated flow model as defined by the USGS Guidelines for Evaluating Ground-Water Flow Models (2004) was used; meaning that the model was calibrated to match the field measurements at the site. Most model parameters were sourced from literature (Freeze and Cherry, 1979 and Johnston, 1967); however, the soil information obtained from various borehole logs, field investigations such as slug tests, and the site history were all used to determine which values were most representative for the site and should be used.

Once the calibrated flow model was completed and verified to be an accurate representation of the flow regime, a transport model was completed using four (4) distinct contaminants. Sensitivity analysis was completed to ensure the most reasonably conservative model was being used. The transport model was then used to generate various simulations to determine the potential contaminant attenuation zone requirements and to ensure that the

proposed Ruby Road WDS capacity expansion is not anticipated to produce leachate concentrations in the groundwater regime that are greater than the RUC when migrating past the property boundary.

3.0 SITE DESCRIPTION

The property on which the potential expansion to the Ruby Road waste disposal site would be situated is an approximately 32.4 hectare (80 acre) property (site) that is legally described as Lot 27, Concession 9 in the geographic township of South Algona, in the amalgamated Township of Bonnechere Valley, County of Renfrew. The proposed expansion is to occur at a WDS that is currently operating as a waste transfer station and was initially a sand and gravel pit. The surrounding landscape is described as vacant, rural, coniferous forest with pasture land to the south and west. The geologic stratigraphy at the site consists of silty sand, and sand and gravel, overlaying fractured granite.

4.0 DIMENSIONALITY AND DOMAIN

The constructed model domain covers an area of approximately 146 hectares (ha). The boundaries of the model were chosen so that the delineation of the contaminant plume would not be affected. The model consists of 78 rows and 65 columns. This grid spacing is considered appropriate and sufficient to provide the model resolution required for accurate prediction of groundwater quantity, elevation, and flow directions. The area selected for modeling is presented on the plan view (Figure 1) and on the cross-section view (Figure 2).

Vertically, the model is divided into 8 layers for a total of 40,560 grid blocks (=78x65x8). The numerous layers were used to create high vertical discretization in an effort to limit numerical dispersion and to better represent the plume. Layer One (1) represents the overburden and Layers Two (2) through Eight (8) represent the bedrock. The model domain includes the ground surface (approximately 217 metres above sea level assumed maximum elevation) to a minimum subsurface elevation ensuring all groundwater flow patterns could be included (approximately 120 metres above sea level).

The ground surface topography was derived from Ontario Base Mapping (OBM), topographical surveys completed on-site by Cambium Environmental, and topographic contours provided by First Base Solutions. All borehole and monitoring well data were raised 115 metres to relate to the OBM/topographic survey elevations. The elevation values were imported into MODFLOW and interpolated using the Natural Neighbours Method. The bedrock surface elevation was obtained from borehole logs, imported into MODFLOW and interpolated using the Inverse Distance Method.



5.0 CALIBRATED FLOW MODEL

5.1 BOUNDARY CONDITIONS

MODFLOW requires every model to have an appropriate set of boundary conditions to represent the system's relationship with surrounding systems (watersheds). Boundary conditions describe the exchange of flow between the model and external watersheds. MODFLOW requires a minimum of one (1) boundary condition to be applied to a minimum of one (1) active cell to run.

Two (2) boundary conditions were considered when creating the calibrated flow model: constant head and recharge boundaries. Figure 3 illustrates the boundary conditions applied to the models.

5.1.1 CONSTANT HEAD

Constant head boundaries, or specified head boundaries, are defined by MODFLOW to be fixed groundwater elevation values in a selected grid cell or cells regardless of the system conditions in the surrounding grid cells, thus acting as an infinite source or sink of water entering or leaving the system. As these boundaries are unchanging, regardless of the stresses imposed by nearby cells, the boundaries have been set at distances that are a sufficient distance from the area of interest.

In the calibrated flow model, constant head boundaries were used at the east and west extents of the model domain. Constant head boundary values were derived from a combination of the monitoring well groundwater elevations obtained in 2008, and calibration data obtained from multiple runs of the model which varied the constant head boundaries. The calibration data was used to adjust the input parameters within reasonable limits to produce simulation results that best matched measured groundwater elevation values on the property. Calibration results are discussed in Section 5.6 and values assigned to the constant head boundaries are presented in Table 1.

Table 1 Constant Head Boundary Values

Boundary Location	Constant Head Boundary Elevation (m)
West limit of model domain	210 to 215, north to south
East limit of model domain	160

5.1.2 RECHARGE

Recharge boundaries are used by MODFLOW to simulate surficially distributed recharge to the groundwater system. Recharge boundaries can also be used to simulate the effects of artificial recharge, seepage from a pond, and overland flow from impermeable surfaces such as bedrock outcrops.



A recharge boundary was used in the calibrated flow model to represent the annual recharge rate in the Bonnechere Valley region. The representative value used (175 mm/year) was obtained from the USGS Report 2005-5284 *Estimation of Shallow Ground-Water Recharge in the Great Lakes Basin*.

5.2 PROPERTIES

5.2.1 CONDUCTIVITY

Hydraulic conductivities can be assigned to individual cells or groups of cells to represent different geological stratigraphy and the characteristics of those stratigraphies. Values can also be entered to represent the three (3) dimensions of the cell. Conductivity values can be obtained through field or lab tests or can be obtained from literature.

The hydraulic conductivity for the overburden material used for the calibrated flow model was obtained from literature (Freeze and Cherry, 1979) in combination with determining the soil types from the borehole logs. It was determined that the majority of the site overburden is a fine to medium sand with some gravel and very few fines. Although there are some areas of sand layered with silty sand that may have a hydraulic conductivity less than that of clean sand, a hydraulic conductivity of 0.001 m/s was used.

The bedrock at the site was determined to be fractured granite. Slug tests were completed in May and June 2008 on monitoring wells MW4-08, MW5-08, and MW6-08, which are screened in the bedrock. The results are shown in Table 2.

Table 2 *Slug Test Results*

Monitoring Well	Hydraulic Conductivity (m/s)
MW4-08	4.3×10^{-7}
MW5-08	7.6×10^{-6}
MW6-08	1.2×10^{-5}
Average	6.7×10^{-6}

As a result of the slug tests, a hydraulic conductivity of 6.7×10^{-6} m/s was chosen as the representative value for the bedrock material.

5.2.2 STORAGE PROPERTIES

MODFLOW defines specific storage, specific yield, effective porosity, and total porosity as the following:

- *Specific Storage (SS)* is defined as the volume of water that a unit volume of aquifer releases from storage under a unit decline in hydraulic head due to aquifer compaction and water expansion.

- *Specific Yield (S_y)* is defined as the volume of water that an unconfined aquifer releases from storage per unit surface area per unit decline in the water table. MODFLOW uses S_s and S_y depending on the layer type assigned by the user, whether it is confined (S_s) or unconfined (S_y).
- *Effective Porosity* is the pore space through which flow actually occurs that is used by MODPATH to determine the average linear groundwater velocities for use within time-dependant capture zones and time markers along pathlines.
- *Total Porosity* is the percentage of the rock or soil that is void of material that is used by RT3D to determine the chemical reaction coefficients and for calculating the average linear groundwater flow velocity in the particle tracking solution schemes.

Storage properties for the calibrated flow model overburden were obtained from literature based on the soil types found at the Site. S_s was left as the MODFLOW default of 1.0×10^{-5} and S_y was determined to be 0.21 (Johnson, 1967) which is the average S_y determined for fine sand. Effective porosity and total porosity were set to the same value for sand, which was determined to be 0.3 (Freeze and Cherry, 1979).

5.2.3 INITIAL HEADS

Initial head values are required by MODFLOW to begin solving the flow simulation and can reduce the required run time significantly.

Initial heads for the calibrated flow model were determined and set based on the groundwater elevations observed in July 2008 at the onsite monitoring wells. Table 3 lists the July 2008 groundwater elevations.

Table 3 Initial Head Values

Monitoring Well	Groundwater Elevation (July 2008) in metres above sea level
BH1	187.56
BR1	187.52
BH2	189.68
BH3	188.56
MW4-08	200.05
MW5-08	188.80
MW6-08	204.56

5.3 OBSERVATION WELLS

Calibration data was entered by assigning values to observation wells within the flow model. This allowed MODFLOW to compare simulated (calculated) heads with the observed heads at designated locations. This procedure also enabled calibration statistics and time series graphs to be produced.



The flow model observation wells were located based on the actual monitoring well locations and groundwater elevations for July 2008 were used as calibration data. Table 3 presents the monitoring well groundwater elevations used.

5.4 FLOW PATTERNS

The MODPATH program was developed to calculate three-dimensional particle tracking pathlines from steady-state and transient flow simulation outputs obtained using MODFLOW. Particles can be added to the model to determine the flow path of the groundwater, but only by advection. No dispersion is simulated.

Particles were simulated in the calibrated flow model to show the pathlines of the leachate movement. The particles were therefore placed in the layers that are within the water table. Ten (10) particles were placed in each layer within the water table at the eastern edge of the proposed waste footprint.

5.5 MODEL RUN SETTINGS

MODFLOW has a series of settings that can be changed with the model engine to customize the model run. They are as follows: time steps, initial heads, solver, recharge, layers, rewetting, anisotropy, surface water leakage, output control, and list file options.

For the calibrated model, most settings were left as default. The PCG (Preconditioned Conjugate-Gradient) was the solver used. The PCG solver uses the preconditioned conjugate-gradient method to solve the simultaneous equations produced by the model. Convergence of the solver is determined using both the head-change and residual criteria.

The PCG solver works on a two-tier approach to a solution at one time step: with inner and outer iterations. Outer iterations are used to vary the preconditioned parameter matrix in an approach toward the solution. An outer iteration is where the hydrogeologic parameters of the flow system are updated (i.e. transmissivity, saturated thickness, storativity) in the preconditioned set of matrices. The inner iterations continue until the user-defined maximum number of inner iterations are executed, or the final convergence criteria are met. The outer iterations continue until the final convergence criteria are met on the first inner iteration after an update (Schlumberger, 2008).

5.6 CALIBRATION RESULTS

Calibration results obtained from the observation wells were used to determine if the model adequately simulated documented conditions. The calibration data can indicate whether the input parameters should be adjusted, within reasonable limits, to produce the results that best simulate real life conditions.

A calculated versus observed head graph was used to determine if the model was reproducing the measured values obtained in the field as shown in Figure 4, the final calibration graph. Final calibration showed the maximum residual to be 2.179 metres, meaning all of the calculated heads values were within 2.179 metres of the observed head values. The Residual Mean, the average residual value, was only 0.917 metres, meaning the average difference between calculated and observed head values was 0.917 metres. The Normalized Root Mean Squared (RMS) value was 7.6% and the Correlation Coefficient was 0.99.

The Normalized RMS value is the Root Mean Squared error divided by the maximum difference in the observed concentration values. This value is expressed as a percentage and is a more representative measure of fit than the standard RMS, as it accounts for the scale of the potential range of data values. A Normalized RMS value below 10% means the model is considered to be calibrated.

The Correlation Coefficient is calculated as the covariance between the calculated results and the observed results at selected data points divided by the product of their standard deviations. The value range is from -1.0 to 1.0. The Correlation Coefficient determines whether the two ranges of data move together, meaning large values of one data set are associated with large values of the other data set (1.0), whether small values of one data set are associated with large values of the other data set (-1.0) or whether the values in both sets are unrelated (0).

The calibration data indicates that the calibrated flow model is considered to sufficiently simulate the actual groundwater flow conditions at the site to meet the objectives of the modeling. Figure 5 presents the final calibrated equipotential lines generated by the model. The groundwater flow at the site in the calibrated flow model is towards the east, with a horizontal hydraulic gradient of approximately 0.04.

6.0 TRANSPORT MODEL

The calibrated flow model was used as a base model for transport modeling. The RT3D v 2.5 modular was used to simulate various contaminant transports to determine if the contaminants would reach the property boundaries at concentrations greater than the RUC. RT3D is a program for simulating reactive multi-species transport in three-dimensional groundwater aquifers.

Pre-screening mass-balance calculations (Appendix A) was used to identify the parameters for which there was the greatest possibility that the concentrations at the downgradient property limit would exceed RUC. Chloride was included in this set of most probable of RUC exceedance since it is considered a conservative tracer and usually marks the advancement of the leachate plume. To determine which other parameters to model, the ratio of the concentration at the downgradient property boundary (C_T) to the RUC value was calculated. The parameters with a ratio close to or above 0.5 were selected for transport modeling since these parameters indicated a downgradient concentration at the property boundary using the mass balance calculations closest to their respective RUC values.



Consequently, the four (4) parameters modeled were chloride, alkalinity, hardness, and sulphate. The following sections summarize the input parameters used.

6.1 PROPERTIES

6.1.1 INITIAL CONCENTRATION

Initial concentrations for transport models can be used similarly to initial heads for the flow model, although they are not necessary. In the case of modeling landfill leachate, initial concentrations are best used to represent the background concentrations of the parameters to be modeled, as most components of leachate are also found in the natural environment.

Measured groundwater quality data for the Site was used to provide the initial/background concentrations of the parameters to be modeled. A total of eight (8) data sets were used in this calculation. Since monitoring wells MW4, MW5, and MW6 are located in the area south of the existing site and no waste has been placed in this area, the water quality data from these wells was used to represent background groundwater quality. However, since there was only one (1) set of data available for these wells to date, water quality from monitoring well BH2 (the background location for the existing waste disposal site) was also used in the background calculations. Table 4 presents the initial concentrations used.

Table 4 Initial (Background) Concentrations of Modeled Parameters

Parameter	Background Concentration (mg/L)
Chloride	2.1
Alkalinity	185
Hardness	188
Sulphate	6.5

6.1.2 DISPERSION

Dispersion is defined by MODFLOW to be a physical process that tends to 'spread' the contaminant mass in three-dimensions along the advective path of the plume, and also acts to reduce the solute concentration. Dispersion is caused by the tortuosity of the flowpaths of the groundwater as it travels through the interconnected pores of the soil.

MODFLOW sets the default dispersion value to 10 metres, and the ratio of horizontal to longitudinal dispersivity for each layer to 0.1 and the ratio of vertical to longitudinal dispersivity for each layer to 0.01. It was decided to use a precautionary dispersion value of 25 metres for all parameters modeled.

6.2 BOUNDARY CONDITIONS

Similar to the flow model, the transport model required a minimum of one (1) transport boundary condition in order to run. Concentration boundary conditions allow MODFLOW to calculate a solution of the governing equation for mass transport; therefore a constant concentration boundary condition was used for the calibrated transport model.

6.2.1 CONSTANT CONCENTRATION

The constant concentration is used by MODFLOW as a contaminant source providing solute mass to the model domain in the form of a known concentration and must be located in the water table. This particular transport boundary essentially represents a constant source of contamination located in the surface of the water table. Although this does not represent the real field conditions of a source located above the water table at surface and contamination entering the water table through infiltration, it does serve as a precautionary approach such that the entire waste disposal area will be homogeneously represented by a chosen conservative concentration of a given contaminant. A conservative concentration is understood to be a concentration greater than would reasonably be expected for a landfill in the Township of Bonnechere Valley diverting problematic materials that contribute to leachate strength. Additionally, this method further exhibits a precautionary approach as the waste will actually be emplaced at decreasing depths from the centre of the waste disposal area and therefore decreasing parameter concentrations in leachate will infiltrate nearer the toe of the waste mound (i.e. greatest concentrations infiltrated in areas of greatest depth), whereas the model represents only the conservative concentration across the entire waste disposal area.

Table 5 shows the contaminant concentrations used for the proposed expanded footprint model in comparison to the average of the greatest 25% of historical concentrations for other waste disposal sites of similar size and waste composition, the maximum historical concentration at the existing Ruby Road waste disposal site, and typical leachate concentrations as per Table 1 of the *Guidance Manual for Landfill Sites Receiving Municipal Waste* (MOEE, 1993). Table 5 shows that the final constant concentration values used are 25% greater than the average of the greatest 25% concentrations for other waste disposal sites of similar size and waste composition and are greater than the maximum historical concentration at the existing Ruby Road waste disposal site, with the exception of sulphate. The final constant concentration values used are also within or greater than the typical leachate concentrations as per Table 1 of the *Guidance Manual for Landfill Sites Receiving Municipal Waste* (MOEE, 1993). It should be noted that for these typical leachate values in Table 1 of the *Guidance Manual*, it is not known the size of the sites or the age or composition of the waste at the sites these values were obtained from. This approach is believed to be very conservative and sufficiently precautionary.

Table 5 Contaminant Concentration Values Summary

Contaminant	Average of the Greatest 25% of Concentrations for Similar Sites (mg/L) ¹	Maximum Concentration Observed at Existing Ruby Road Site(mg/L) ²	Typical Leachate Concentration (mg/L) ³	Value Used for Proposed Expanded Footprint Simulations (mg/L) ⁴
Chloride	300	42	20 – 2500	375
Alkalinity	860	494	300 - 2000	1075
Hardness	900	625	400 – 2000	1115
Sulphate	110	130	1 - 300	140

- Notes: 1. Values obtained from sites of similar size and waste composition. The average of the greatest 25% of historical concentrations was used.
2. Maximum historical value from monitoring well BH-1 at the existing Ruby Road waste disposal site.
3. From Table 1 in Guidance Manual for Landfill Sites Receiving Municipal Waste (MOEE, 1993).
4. Calculated as 25% greater than the value obtained in Note 1.

Since the sulphate constant concentration of 140 mg/L is less than the RUC value for this parameter of 253 mg/L, this parameter was not modeled.

6.3 MODEL RUN SETTINGS

Similar to the MODFLOW flow model, the transport model RT3D v2.5 has a number of settings that can be altered. Most settings were left as the default settings, except where noted. The run settings are: solution methods, output/time steps, assign initial concentrations, and view/convert initial concentrations.

For this transport model, implicit GCG Solver, Upstream Finite Difference Solution method was selected. This means that all terms in the governing equation are represented with implicit-in-time weighted finite-difference approximations as opposed to explicit-in-time weighted finite-difference approximations. Individual Output times were selected to correlate with the number of years the model was being run and the maximum number of transport steps was increased to one million.

6.4 SENSITIVITY ANALYSIS

Sensitivity analysis is used to evaluate the model input parameters and to determine the effect of the parameters on the model output. Sensitivity analysis can also be used to determine if the model is reasonably precautionary; while remaining a reasonably representative model for the specific circumstances. A manual approach is to run the model multiple times and adjust each input parameter by a standard amount, review the results, and determine the most appropriate values to achieve model calibration.

As some of the input parameters were derived from literature values for the model, it was decided to assess the sensitivity of the transport model to determine which flow input parameters would have the most effect on the model output and therefore the accuracy of the contaminant plume simulations. The chloride plume at the

breakthrough time (25 years) was used to conduct sensitivity analysis on the following input parameters: hydraulic conductivity, recharge, dispersion, specific storage, and effective porosity. Total porosity was not analyzed, as the model was run using the effective porosity only. All input parameters were both increased and decreased.

The distance from the east property boundary that the concentration in the plume was equal to the RUC value and the maximum concentration generated by the model at the property boundary were the metrics used to determine the effect of input parameter changes for precautionary outputs while remaining reasonably representative of site conditions. The plume travels within the top two (2) layers of the bedrock; Figure 6 illustrates the calibrated chloride plume for comparison in layer 2 (the top layer of bedrock) and Figure 7 illustrates the chloride plume in layer 3 (the second layer of bedrock). Each input parameter analyzed is summarized below.

6.4.1 RECHARGE

The recharge value could potentially affect the amount of infiltration and therefore the quantity of contaminant infiltrating into the groundwater; the more infiltration, the greater the quantity of contaminant. The recharge value was therefore increased from the originally selected representative value of 175 mm/year (see 5.1.2) to a precautionary value of 740 mm/year, which is the 2005 annual total precipitation recorded at the recently established station in Eganville (Eganville 2; Climate ID: 6102252) as obtained from Environment Canada. The recharge value was then decreased to 0 mm/year to determine the change to the chloride plume. Numerical results are displayed in Table 6 and the resultant contaminant plumes are displayed in Figure 8, Figure 9, Figure 10, and Figure 11.

6.4.2 DISPERSION

As the dispersion value affects both the concentration and the travel distance of the contaminant, it was decided to assess the effects on the chloride plume. As dispersion decreases, the plume size decreases while concentrations increase and so for the sensitivity analysis the dispersion value was decreased to the default value of 10 metres. As the initial dispersion value of 25 metres is considered to already be precautionary and would simulate the plume's furthest reasonably possible travel distance, a greater dispersion value was not analysed. Numerical results are displayed in Table 6 and the resultant contaminant plume is displayed in Figure 12 and Figure 13.

6.4.3 HYDRAULIC CONDUCTIVITY

The actual hydraulic conductivity values for the bedrock aquifer were determined from slug tests performed at the site (Section 5.2.1), nonetheless the effects that varied conductivities would have on the flow model and therefore the contaminant plume travel were analysed. The conductivity value of the bedrock layers was increased and decreased by one order of magnitude. Numerical results are presented in Table 6 and the resultant contaminant plumes are displayed in Figure 14, Figure 15, Figure 16, and Figure 17.

6.4.4 EFFECTIVE POROSITY

The effective porosity is a representation of the pore space through which flow actually occurs, and is used by the model to determine the average linear groundwater velocities for use in time-dependant capture zones and time markers along pathlines. The reasonable effective porosity value of 0.3 was determined from literature (Freeze and Cherry, 1979) based on the soil (0 to 0.3) and bedrock (0 to 0.1) type at the site; however the effects that different effective porosities would have on the flow model and therefore the contaminant plume travel were analysed. Total porosity was not analyzed since the model was run using effective porosity only. The effective porosity value was increased to 0.4 and decreased to 0.2. Numerical results are presented in Table 6 and the resultant contaminant plumes are displayed in Figure 18 and Figure 19, Figure 20, and Figure 21.

6.4.5 SPECIFIC STORAGE

The specific storage is the volume of water that a unit volume of aquifer releases from storage under a unit decline in hydraulic head due to aquifer compaction and water expansion. A representative specific storage value of 1.0×10^{-5} was used, which is the MODFLOW default value; therefore, it was decided to examine the effects that different specific storage values would have on the flow model and therefore the contaminant plume travel. The specific storage value was increased and decreased by an order of magnitude (i.e. 1.0×10^{-4} and 1.0×10^{-6}). Numerical results are presented in Table 6 and the resultant contaminant plumes are displayed in Figure 22, Figure 23, Figure 24, and Figure 25.

6.4.6 SENSITIVITY ANALYSIS RESULTS

Table 6 Summary of Sensitivity Analysis

Parameter	Initial Value in Original Model	Value Used for Sensitivity Analysis	RUC Distance ¹	Max. Conc. Calculated at Property Boundary ²
Original Model	N/A	N/A	118 m	105 mg/L
Recharge Increased	175 mm/year	740 mm/year	122 m	100 mg/L
Recharge Decreased	175 mm/year	0 mm/year	117 m	107 mg/L
Dispersion Decreased	25 metres	10 metres	158 m	59 mg/L
Conductivity Increased	6.7×10^{-6} m/s	6.7×10^{-5} m/s	91 m	115 mg/L
Conductivity Decreased	6.7×10^{-6} m/s	6.7×10^{-7} m/s	191 m	103 mg/L
Effective Porosity Increased	0.3	0.4	117 m	105 mg/L
Effective Porosity Decreased	0.3	0.2	117 m	105 mg/L
Specific Storage Increased	1.0×10^{-5}	1.0×10^{-4}	117 m	105 mg/L
Specific Storage Decreased	1.0×10^{-5}	1.0×10^{-6}	117 m	105 mg/L

Notes: 1. Distance from (i.e. west of) property boundary where the concentration in the plume equals the RUC value (m). Both layers 2 and 3 (top 2 layers of bedrock) were assessed and the layer in which the plume traveled further in was used in the 'RUC Distance' column.

2. Both layers 2 and 3 (top 2 layers of bedrock) were assessed and the layer with the greater concentration at the property boundary was used in the 'Max. Conc. Calculated at Property Boundary' column.



The following parameters had very little or no effect on the model predictions: recharge, effective porosity, and specific storage. Therefore, the original representative values that had been used for these parameters were used for subsequent model simulations.

When the dispersion value was decreased, a smaller plume resulted. Therefore, to provide a precautionary model, the dispersion value of 25 metres was used for subsequent model simulations.

Although the increased conductivity model indicated that the plume and the RUC concentration would extend slightly further than the original model suggesting a more precautionary model, the head values did not calibrate as well. The calibration normalized RMS value was 7.6% as indicated in Section 5.6, and the normalized RMS was 12.0% for the increased conductivity model. Therefore, it is believed the original model is a better representation of the Ruby Road waste disposal site. However, in order to provide a more precautionary model, a hydraulic conductivity of 6.7×10^{-5} m/s was used for subsequent model simulations.

The sensitivity analysis provided confidence that the model is appropriate for the specific circumstances and that any bias that results from the model inputs is biased towards a precautionary approach. Therefore, the model as described above was used to produce the multiple model simulations described below.

7.0 MODEL SIMULATIONS

7.1 EXPANDED FOOTPRINT

In order to simulate the proposed expansion, the constant concentration boundary was used in the entire proposed waste fill area. As indicated in Section 6.2.1, the following concentrations were used:

- Chloride: 375 mg/L.
- Alkalinity: 1075 mg/L.
- Hardness: 1115 mg/L.

The contaminant plume did not cross the property line at concentration values greater than the RUC for any of the three (3) contaminants modeled. The results obtained from the expanded footprint simulations are summarized in Table 7 and the contaminant plumes are shown in Figure 26 and Figure 27 for chloride, Figure 28 and Figure 29 for alkalinity, and Figure 30 and Figure 31 for hardness.



Table 7 Calibrated Contaminant Concentration Plume Summary

Contaminant	RUC Value	RUC Distance ¹	Max. Conc. Calculated at Property Boundary ²
Chloride	126 mg/L	105 m	108 mg/L
Alkalinity	342 mg/L	94 m	311 mg/L
Hardness	344 mg/L	85 m	323 mg/L

Notes: 1. Distance from (i.e. west of) property boundary where the concentration in the plume equals the RUC value (m). Both layers 2 and 3 (top 2 layers of bedrock) were assessed and the layer in which the plume traveled further in was used in the 'RUC Distance' column.

2. Both layers 2 and 3 (top 2 layers of bedrock) were assessed and the layer with the greater concentration at the property boundary was used in the 'Max. Conc. Calculated at Property Boundary' column.

Under these extreme conditions, the modeled plume concentrations are less than RUC at the property boundary for all parameters modeled. The breakthrough time for this expanded footprint is approximately 25 years (from the time landfilling began); therefore, the concentrations would be expected to increase minimally beyond the 25 year time period. It is also believed that the plumes simulated thus far have been very conservative and are showing the worst case scenario. Section 8.0 provides a summary of assumption details that support the opinion that this is an ultra-conservative model scenario.

8.0 CONCLUSIONS

Based on the calibrated flow and transport models and the model simulations, it can be concluded that groundwater regime will adequately assimilate the leachate infiltration from the proposed expanded waste disposal area. The contaminant plumes simulated with a precautionary model thus far have indicated that the plume concentrations at the property limit will be sufficiently less than the RUC value. It is believed the actual contaminant plume will be at concentrations less than those modeled and much less than the RUC when it reaches the property line.

The modeling of the leachate plumes generated from a proposed waste disposal area at the Ruby Road waste disposal site should be considered very conservative and sufficient precautionary for the following reasons:

1. A sensitivity analysis was completed for all input parameters (hydraulic conductivity, recharge, dispersion, porosity, and specific storage) to determine the values that yielded the most conservative result (i.e. the largest leachate plume) while remaining representative of site conditions, which were then used as in the input parameter values in the model.
2. The modeling was conducted without including any chemical retardation processes such as sorption and reaction, thereby making the predictions conservative by nature.
3. A constant concentration scenario was used which represents a homogeneous contaminant concentration applied directly to the water table. This effectively ignores any attenuation that would occur in the migration of the leachate through the sand overburden material to the water table.



4. The source constant concentrations used in the proposed waste disposal site are 25% greater than the average of the greatest 25% concentrations for other waste disposal sites of similar size and waste composition and are greater than the maximum historical concentration at the existing Ruby Road waste disposal site. These concentrations were applied directly to the water table over the entire area of the proposed waste disposal area. It is believed that this is not a realistic approach as the leachate generated beneath the depth of waste at the toe of the slope will be much less than that near the centre of the waste mound; still, this method is only one more way the model is hyper-conservative.



REFERENCES

Cambium Environmental Inc. March 24, 2008. *2007 Annual Report, Ruby Road Waste Disposal Site.*

Freeze, R. Allan and Cherry, Joan A. 1979. *Groundwater.* Prentice-Hall, Inc., Englewood Cliffs, N.J.

Johnson, A.I. 1967. *Specific yield — compilation of specific yields for various materials.* U.S. Geological Survey Water Supply Paper 1662-D, 74 p.

Neff, B.P., Piggott, A.R., and Sheets, R.A. 2005. *Estimation of Shallow Ground-Water Recharge in the Great Lakes Basin.* U.S. Geological Survey Scientific Investigations Report 2005-5284.

Ontario Ministry of the Environment. June 2006. *Technical Support Document for Ontario Drinking Water Standards, Objectives and Guidelines.*

Ontario Ministry of the Environment. May 1998. *Landfill Standards, A Guideline on the Regulatory and Approval Requirements for New or Expanding Landfill Sites.*

Ontario Ministry of the Environment. April 1994. *Incorporation of the Reasonable Use Concept into MOEE Groundwater Management Activities.*

Ontario Ministry of Environment and Energy. November 1993. *Guidance Manual for Landfill Sites Receiving Municipal Waste.*

Schlumberger Water Services. 2008. *Visual MODFLOW v.4.3 User's Manual.*



ABBREVIATIONS & TERMS

Abbreviations

RFP	Request For Proposal
MOE	Ontario Ministry of the Environment
MNR	Ontario Ministry of Natural Resources
PCofA	Provisional Certificate Of Approval
EPA	Environmental Protection Act
EAA	Environmental Assessment Act
MW	monitor well
amsl	above mean sea level
kg	kilogram
mm	millimetres
m	metres
km	kilometres
ha	hectare
m³	cubic metres
m²	square metres
mg/l	milligrams per litre
µS	microSiemens
ODWS	Ontario Drinking Water Standards
PWQO	Provincial Water Quality Objectives
TOC	Total Organic Carbon
VOC	Volatile Organic Compounds
BTU	British Thermal Unit
°C	temperature in degrees Celsius
N/A	not available
%	percent
cfm	cubic feet per minute
ppmdv	part per million by dry volume
ppmv	part per million by volume
ppm	part per million
min	minimum
max	maximum

Elements

Cd	Cadmium
Hg	Mercury
Pb	Lead



Compounds

CO	Carbon Monoxide	NO_x	Nitrogen Oxides
CO₂	Carbon Dioxide	N₂O	Nitrous Oxide
CH₄	Methane	PCDDs	Polychlorinated Dibenzodioxins
HCl	Hydrogen Chloride	PCDFs	Polychlorinated Dibenzofurans
TPM	Total Particulate Matter	SO₂	Sulphur Dioxide
PM2.5	Particulate Matter Diameter <=2.5 µm	VOCs	Volatile organic compounds

Glossary of Terms

Active Face/Area

The portion of the landfill facility where waste is currently being deposited, spread and/or compacted prior to the placement of cover material.

Adverse Environmental Impact

Any direct or indirect undesirable effect on the environment resulting from an emission or discharge which is caused or likely to be caused by human activity.

Annual Report

Report documenting the results of water quality, environmental quality, and operations monitoring for the year, or for a period as prescribed in the Certificate of Approval.

Approved Design and Operations Plan

The design of a landfill site and its facilities which have been submitted along with the application documents for which formal MOE approval has been issued through the Certificate of Approval.

Approved Site or Facility

A landfill site/facility for which there is an existing and current Certificate of Approval.

Aquifer

A geologic unit (soil or rock) that contains sufficient saturated permeable material to yield measurable quantities of water to wells and springs.

Attenuation

Natural process through which the concentrations of landfill generated contaminants are reduced to safe levels.

Borehole

Is a hole drilled for soil sampling purposes.

Buffer Area

An area of land situated within the peripheral area surrounding an active filling area, but limited in extent to the property boundary, assigned to provide space for remedial measures, contaminant control measures, and for the reduction or elimination of adverse environmental impact caused by migrating contaminants.

Certificate of Approval

The license or permit issued by the MOE for the operation of a landfill site. Issued to the owner of the site with conditions of compliance stated therein.

Contaminant

A compound, element or physical parameter, usually resulting from human activity, or found at elevated concentrations, that have or may have a harmful effect on public health or the environment.

Contaminant Migration Path

Route by which a contaminant will move from the site into adjacent properties or the natural environment. Usually a route that offers the least resistance to movement.



Contamination Attenuation Zone

The zone beneath the surface, located beyond the landfill site boundary, where contaminants will be naturally attenuated to predetermined levels. Also, see Reasonable Use Policy.

Contingency Plan

A documented plan detailing a co-ordinated course of action to be followed to control and remediate occurrences such as a fire, explosion, or release of contaminants in an uncontrolled manner that could threaten the environment and public health.

Cover Material

Material approved by the MOE that is used to cover compacted solid waste. Usually, a soil with suitable characteristics for specific end-use.

Site Development Plan and Operations Report

Development and Operations Plan or Report is a document detailing the planned sequence of activities through the landfill site's active life, the control systems, site facilities and monitoring systems, that are necessary. This document is required for obtaining a Certificate of Approval.

Design Capacity

The maximum amount of waste that is planned to be disposed of at a landfill site.

Detection Limit

Concentration under which a parameter cannot be quantitatively measured.

EAA or EA Act

Environmental Assessment Act, Revised Statutes of Ontario, 1990. One of the primary acts of legislation intended to protect, conserve and wisely manage Ontario's environment through regulating planning and development.

EPA

Environmental Protection Act, Revised Status of Ontario, 1990. EPA is another of the primary pieces of Provincial legislation governing the protection of the natural environment of the Province.

Evapotranspiration

The evaporation of all water from soil, snow, ice, vegetation and other surfaces, including the water absorbed by plants, that is released to the atmosphere as vapour.

Fill Area

The area of a landfill site designed and designated for the disposal of waste.

Final Cover

Soil material or soil in combination with synthetic membranes, overlain by vegetation in a planned landscape, placed over a waste cell that has reached the end of its active life.

Groundwater

Subsurface water that occurs beneath the water table in soils and rocks that are fully saturated.

Hydraulic Conductivity

The rate of flow of water through a cross-section under a specific hydraulic gradient. It is a property of the geologic formation and the fluid, in hydrogeologic applications where the fluid is water. (Units of m/day or cm/s).

Hydraulic Gradient

The head drop per unit distance in the direction of flow, the driving force for groundwater flow.

Hydrogeology

The study of subsurface waters and related geologic aspects of surface waters.

Impermeable Fill

Soil material that is placed as filling material that is sufficiently cohesive and fine grained to impede and restrict the flow of water through it.

In situ Testing

Testing done on-site, in the field, of material or naturally occurring substances in their original state.



Landfill Gas

Combustible gas (primarily methane and carbon dioxide) generated by the decomposition of organic waste materials.

Landfill Site

A parcel of land where solid waste is disposed of in or on land for the purposes of waste management.

Leachate

Water or other liquid that has been contaminated by dissolved or suspended particles due to contact with solid waste.

Leachate Breakout

Location where leachate comes to the ground surfaces; a seep of spring.

Limit of Filling

The outermost limit at which waste has been disposed of, or approved or proposed for disposal at a landfill.

MOE

Ontario Ministry of the Environment.

Monitoring

Regular or spontaneous procedures used to methodically inspect and collect data on the performance of a landfill site relating to environmental quality (i.e. air, leachate, gas, ground or surface water, unsaturated soils, etc.).

Monitoring Well

Is the constructed unit of casing and screen installed in a borehole.

Multi-Level Monitoring Well

More than one monitoring well installed at a given test well location.

Native Soil

Soil material occurring naturally in the ground at a location.

Natural Attenuation

Where contaminants are reduced to acceptable concentration levels by natural mechanisms (dilution, absorption onto the soil matrix, etc.), biological action, and chemical interaction.

Occupational Health and Safety Act

The primary act of legislation enacted by Ontario Ministry of Labour to regulate and control the safety in the workplace, also Occupational Health and Safety Act, Revised Statutes of Ontario, 1990.

Odour Control

Minimizing or eliminating the nuisance and undesirable impact of objectionable or unpleasant odours arising from waste disposal operations.

Open Burning

Burning any matter whereby the resultant combustion products are emitted directly to the atmosphere without passing through an adequate stack, duct, or chimney.

Operations Plan

A document detailing the waste disposal operations in a planned, and if necessary, a staged manner, that ensure compliance with regulatory provisions concerning the operations of a landfill site.

Operator (Site Operator)/Attendant

The individual or organization who, through ownership or under contract, manages and operates a landfill site for the purpose of waste disposal.

Owner

A person, persons, organization or municipal authority who own a landfill facility or part of a landfill facility, and in whose name the Certificate of Approval for the site is issued.



Percolation

The movement of infiltrating water through soil.

Permeability

Often used interchangeable with hydraulic conductivity, but not strictly correct. Permeability is a property of the porous media only. Dependent upon media properties that affect flow, diameter, sphericity, roundness and packing of the grains.

Piezometer

A well that intersects a confined aquifer.

Provisional Certificate of Approval (Provisional C of A)

Same as Certificate of Approval.

Reasonable Use Policy

A policy developed by the Ministry to stipulate limits to the level of groundwater quality impairment that may be permitted to occur at site property boundaries, to allow the reasonable use of adjacent properties or land without adversely affecting public health and the environment.

Recharge Zone

An area where precipitation or surface run-off infiltrates into the ground and then, through natural percolation enters an aquifer.

Recycling

Sorting, collecting or processing waste materials that can be used as a substitute for the raw materials in a process or activity for the production of (the same or other) goods. For example, the "Blue Box" system, in-plant scrap handling, or raw material recovery systems. Recycling is also the marketing of products made from recycled or recycled materials.

Reduction (of waste or component of 3Rs program)

Those actions, practices or processes which result in the production or generation of less waste.

Remedial Action

Corrective action taken to clean-up or remedy a spill, an uncontrolled discharge of a contaminant, or a breach in a facility or its operations, in order to minimize the consequent threat to public health and the environment.

Representative Sample

A small portion of soil, water, etc. which can be subjected to testing and analysis, that is expected to yield results that will reliably represent the identical characteristics of the source of the material or of a larger body of material.

Reuse (component of 3Rs program)

The use of an item again in its original form, for a similar purpose as originally intended, or to fulfil a different function.

Run-off

The part of precipitation (rain water, snow melt) that flows overland and does not infiltrate the surface material (soil or rock).

Saturated Zone

The zone of a subsurface soil where all voids are filled with water.

Sedimentation

The deposition of fine grained soil in an undesirable location, caused by the scouring, erosion and transportation of earth materials by surface run-off.

Sensitive Land Use

A land use where humans or the natural environment may experience an adverse environmental impact.

Settlement

The subsidence of the top surface and underlying waste of a landfill or waste cell as a result of densification under its own weight.

Site Capacity

The maximum amount of waste that is planned to be disposed (design capacity) or that has been disposed of at a landfill site.



Site Closure

The planned and approved cessation or termination of landfilling activities at a landfill site upon reaching its site capacity.

Site Life

The period of time from its inception through active period of waste disposal, to the time when a landfill site reaches its' site capacity, when it ceases to receive any further waste, including and up to closure.

Solid Waste

Any waste matter that cannot be characterized by its physical properties as a liquid waste product.

Solid Waste Disposal Site or Facility

A site or facility such as a landfill site where solid waste is disposed of.

Source Separation

The separation of various wastes at their point of generation for the purposes of recycling or further processing.

Standpipe

A monitoring well which intersects the water table aquifer.

Stormwater

Run-off that occurs as a direct result of a storm event or thaw.

Stormwater Detention

Control of stormwater by the construction of impoundments of structures for the purpose of regulating stormwater flows during high intensity rainfall events, that would otherwise transport excessive amounts of sediment, cause soil erosion or cause flooding.

Stratigraphy

The geologic sub-structuring, usually layered with different distribution, deposition and age.

Surface Run-off (Drainage)

See Run-off.

Surface Water

Water that occurs at the earth's surface (ponds, streams, rivers, lakes, oceans).

Sub-Soil

Soil horizons below the topsoil.

Test hole

Is a hole drilled for soil sampling purposes.

Topsoil

The uppermost layer of the soil containing appreciable organic materials in mineral soils. Adequate fertility to support plant growth.

Unsaturated Zone

(also vadose zone) - The zone in a porous sub-soil, where the voids are not completely water-filled, but contain some air-filled voids. Limited above by the land surface and below by the water-table.

Vector

A disease carrier and transmitter; usually an insect or rodent.

V.O.C.

Volatile organic compounds are those compounds which will readily volatilize (convert from liquid to gas phase) at conditions normally found in the environment.

Waste

Ashes, garbage, refuse, domestic waste, industrial waste, or municipal refuse and other used products as are designated or interpreted by the provisions of the Environmental Protection Act.



Waste Disposal Site (Facility)

Any land or land covered by water upon, into, in or through which, or building or structure in which, waste is deposited or processed and any machinery or equipment or operation required for the treatment or disposal of waste.

Waste Management System

All facilities, equipment and operations for the complete management of waste, including the collection, handling, transportation, storage, processing and disposal thereof, and may include one or more waste disposal sites.

Water Table

The water level attained in a monitoring well which screens the surficial unconfined aquifer.

Water Balance

Amounts of water to various components in a system so that water entering the system equals the amount of water contained within and discharged out of a system.

Water Level

The level of water in a well.

Well Casing

The pipe that is used to construct a well.

Well Screen

A filtering device used to keep sediment from entering a well.

Wetlands

Areas where water is at, near or above the land surface long enough to be capable of supporting aquatic or hydrolytic vegetation, and which have soils indicative of wet conditions.



UNITS OF MEASUREMENT AND CONVERSIONS

Length

1 metre (m)	=	3.28 feet
1 millimetre (mm)	=	0.039 inches
1 kilometre (km)	=	0.621 miles

Area

1 hectare (ha)	=	2.47 acres
1 square metre (m ²)	=	10.76 square feet

Volume

1 cubic metre(m ³)	=	35.29 cubic feet
1 litre(L)	=	0.220 gallons

Mass

1 metric ton (tonne)	=	1.10 Imperial tons
1 kilogram (kg)	=	2.20 lbs
pound (lb)	=	453.6 g
gram (g)	=	---
milligrams (mg)	=	1 x 10 ⁻³ g
microgram (µg)	=	1 x 10 ⁻⁶ g
nanogram (ng)	=	1 x 10 ⁻⁹ g
kilogram (kg)	=	1000 g
pictogram (pg)	=	1 x 10 ¹² g
metric tonne (t)	=	1000 kg
kilotonne (kt)	=	1 x 10 ⁶ kg



QUALIFICATIONS AND LIMITATIONS

Limited Warranty

In performing work on behalf of a client, Cambium Environmental relies on its client to provide instructions on the scope of its retainer and, on that basis, Cambium Environmental determines the precise nature of the work to be performed. Cambium Environmental undertakes all work in accordance with applicable accepted industry practices and standards. Unless required under local laws, other than as expressly stated herein, no other warranties or conditions, either expressed or implied, are made regarding the services, work or reports provided.

Reliance on Materials and Information

The findings and results presented in reports prepared by Cambium Environmental are based on the materials and information provided by the client to Cambium Environmental and on the facts, conditions and circumstances encountered by Cambium Environmental during the performance of the work requested by the client. In formulating its findings and results into a report, Cambium Environmental assumes that the information and materials provided by the client or obtained by Cambium Environmental from the client or otherwise are factual, accurate and represent a true depiction of the circumstances that exist. Cambium Environmental relies on its client to inform Cambium Environmental if there are changes to any such information and materials. Cambium Environmental does not review, analyze or attempt to verify the accuracy or completeness of the information or materials provided, or circumstances encountered, other than in accordance with applicable accepted industry practice. Cambium Environmental will not be responsible for matters arising from incomplete, incorrect or misleading information or from facts or circumstances that are not fully disclosed to or that are concealed from Cambium Environmental during the provision of services, work or reports.

Facts, conditions, information and circumstances may vary with time and locations and Cambium Environmental's work is based on a review of such matters as they existed at the particular time and location indicated in its reports. No assurance is made by Cambium Environmental that the facts, conditions, information, circumstances or any underlying assumptions made by Cambium Environmental in connection with the work performed will not change after the work is completed and a report is submitted. If any such changes occur or additional information is obtained, Cambium Environmental should be advised and requested to consider if the changes or additional information affect its findings or results.

When preparing reports, Cambium Environmental considers applicable legislation, regulations, governmental guidelines and policies to the extent they are within its knowledge, but Cambium Environmental is not qualified to advise with respect to legal matters. The presentation of information regarding applicable legislation, regulations, governmental guidelines and policies is for information only and is not intended to and should not be interpreted as constituting a legal opinion concerning the work completed or conditions outlined in a report. All legal matters should be reviewed and considered by an appropriately qualified legal practitioner.

Site Assessments

A site assessment is created using data and information collected during the investigation of a site and based on conditions encountered at the time and particular locations at which fieldwork is conducted. The information, sample results and data collected represent the conditions only at the specific times at which and at those specific locations from which the information, samples and data were obtained and the information, sample results and data may vary at other locations and times. To the extent that Cambium Environmental's work or report considers any locations or times other than those from which information, sample results and data was specifically received, the work or report is based on a reasonable extrapolation from such information, sample results and data but the actual conditions encountered may vary from those extrapolations.

Only conditions at the site and locations chosen for study by the client are evaluated; no adjacent or other properties are evaluated unless specifically requested by the client. Any physical or other aspects of the site chosen for study by the client, or any other matter not specifically addressed in a report prepared by Cambium Environmental, are beyond the scope of the work performed by Cambium Environmental and such matters have not been investigated or addressed.

No Reliance

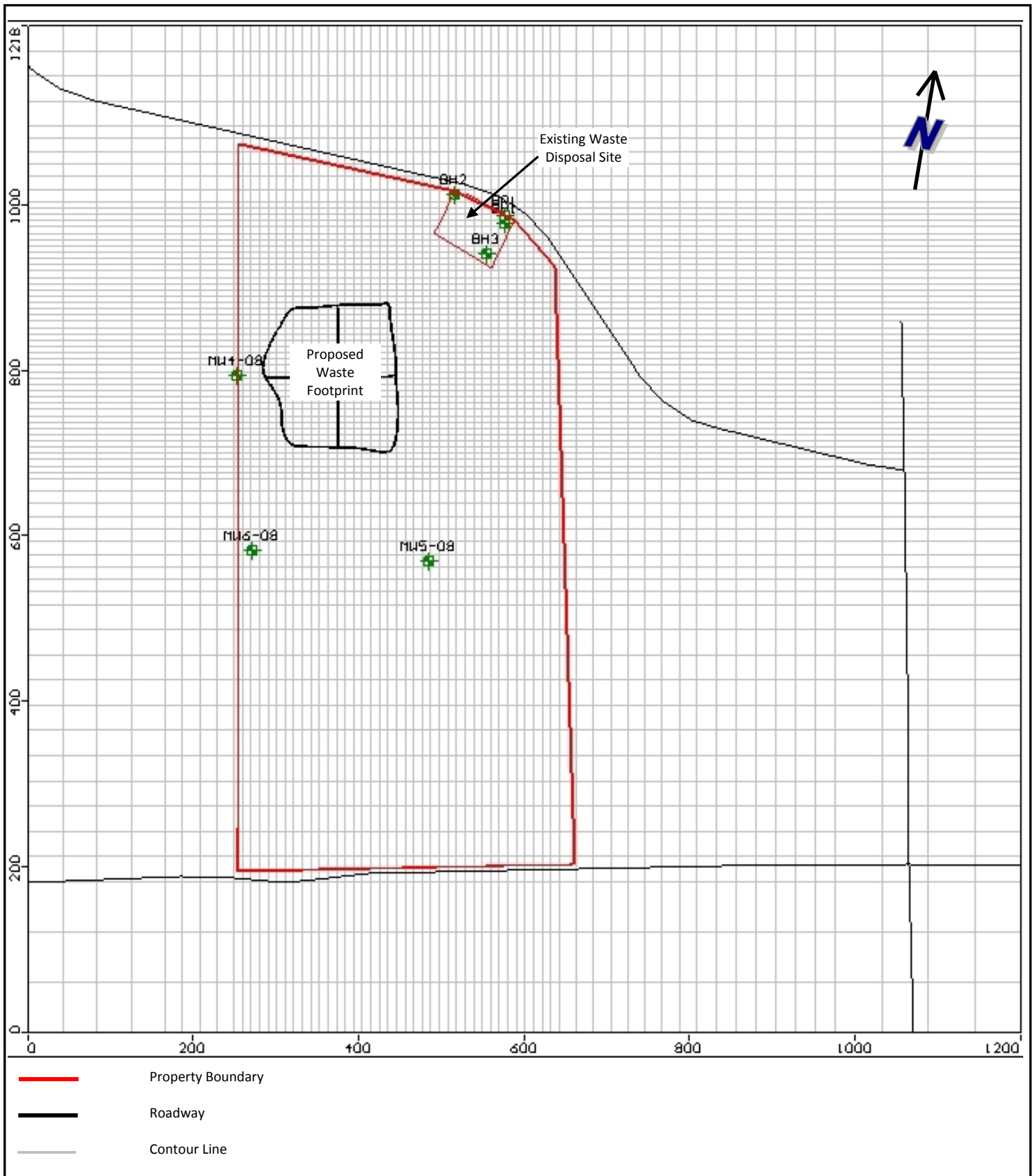
Cambium Environmental's services, work and reports are provided solely for the exclusive use of the client which has retained the services of Cambium Environmental and to which its reports are addressed. Cambium Environmental is not responsible for the use of its work or reports by any other party, or for the reliance on, or for any decision which is made by any party using the services or work performed by or a report prepared by Cambium Environmental without Cambium Environmental's express written consent. Any party that relies on services or work performed by Cambium Environmental or a report prepared by Cambium Environmental without Cambium Environmental's express written consent, does so at its own risk. No report of Cambium Environmental may be disclosed or referred to in any public document without Cambium Environmental's express prior written consent. Cambium Environmental specifically disclaims any liability or responsibility to any such party for any loss, damage, expense, fine, penalty or other such thing which may arise or result from the use of any information, recommendation or other matter arising from the services, work or reports provided by Cambium Environmental.

Limitation of Liability

Cambium Environmental is not responsible for any lost revenues, lost profits, cost of capital, or any special, indirect, consequential or punitive damages suffered by the client or any other party in reliance on any Cambium Environmental work or report. Cambium Environmental's total liability and responsibility to the client or any other person for any and all losses, costs, expenses, damages, claims, causes of action or other liability whatsoever which do or may result or arise from or be in relation to Cambium Environmental's services, work (or failure to perform services or work) or reports shall be limited to the invoiced charges for the work performed by Cambium Environmental.



Figures




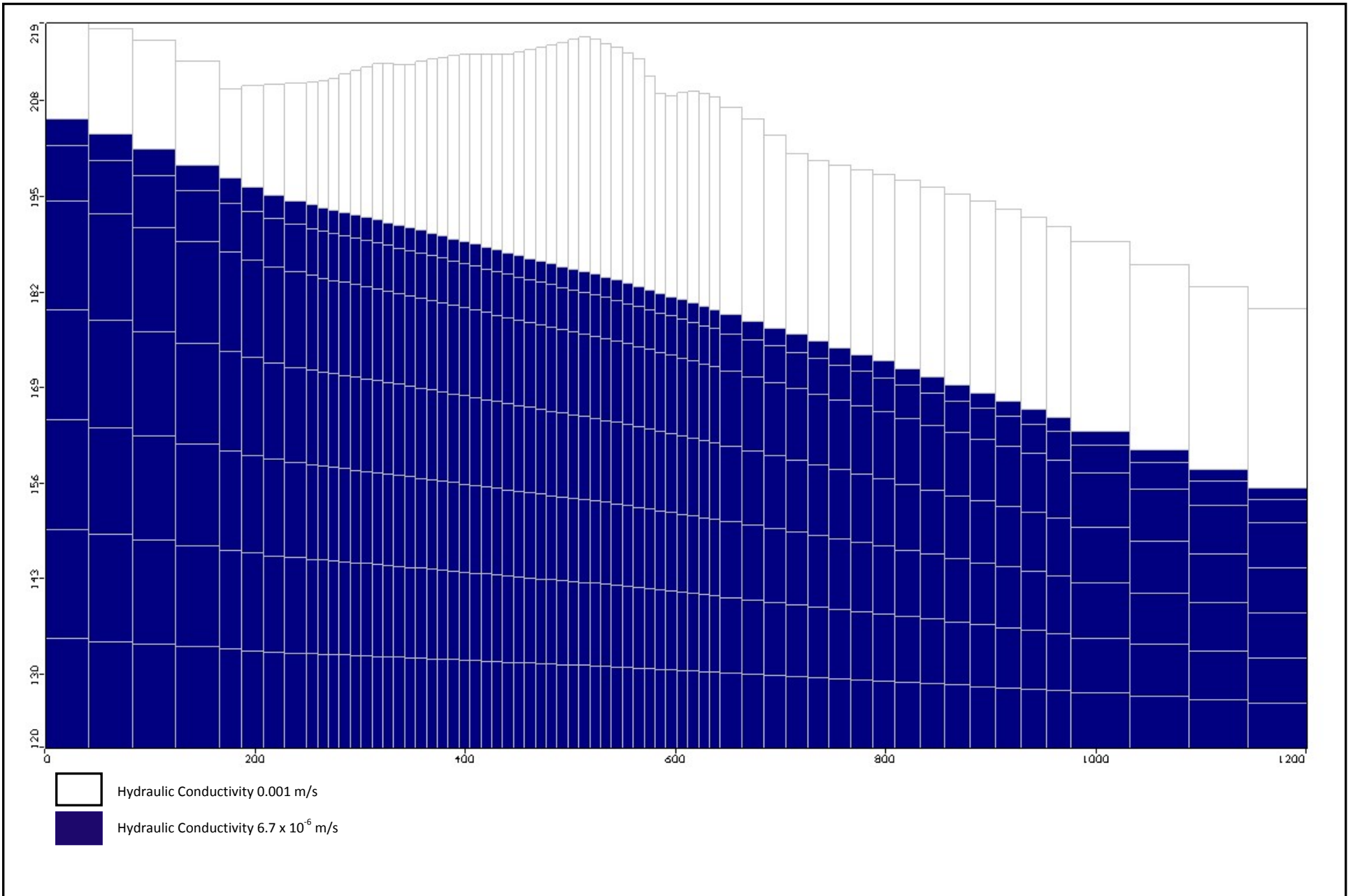
 <p>PO Box 325, 2085 Whittington Drive Peterborough, Ontario, K9J 6X4 Tel: 705-742-7900 Fax: 705-742-7907 www.cambium-env.com</p>	Created by:	Project No.:	<p align="center">PLAN VIEW OF MODEL DOMAIN</p> <p align="center">Numerical Hydrogeological Modeling Report for Expansion Feasibility of the Ruby Road Waste Disposal Site</p>
	Checked by:	Scale:	
	Date:		
	CMT	07-1219-001	
	JPD	NTS	
	January 2009		

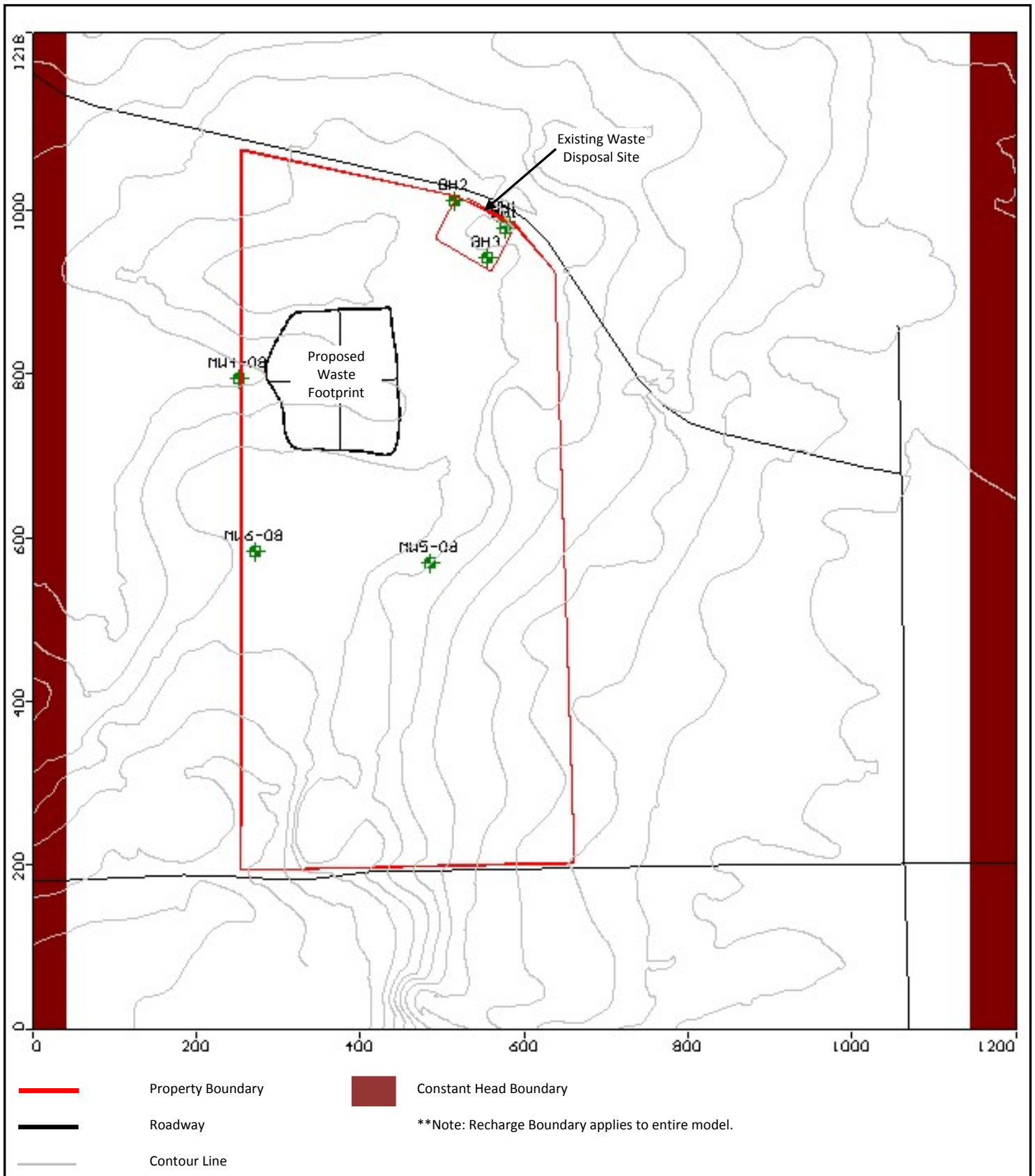
Figure No: **1**




PO Box 325, 2085 Whittington Drive
 Peterborough, Ontario, K9J 6X4
 Tel: 705-742-7900 Fax: 705-742-7907
www.cambium-env.com

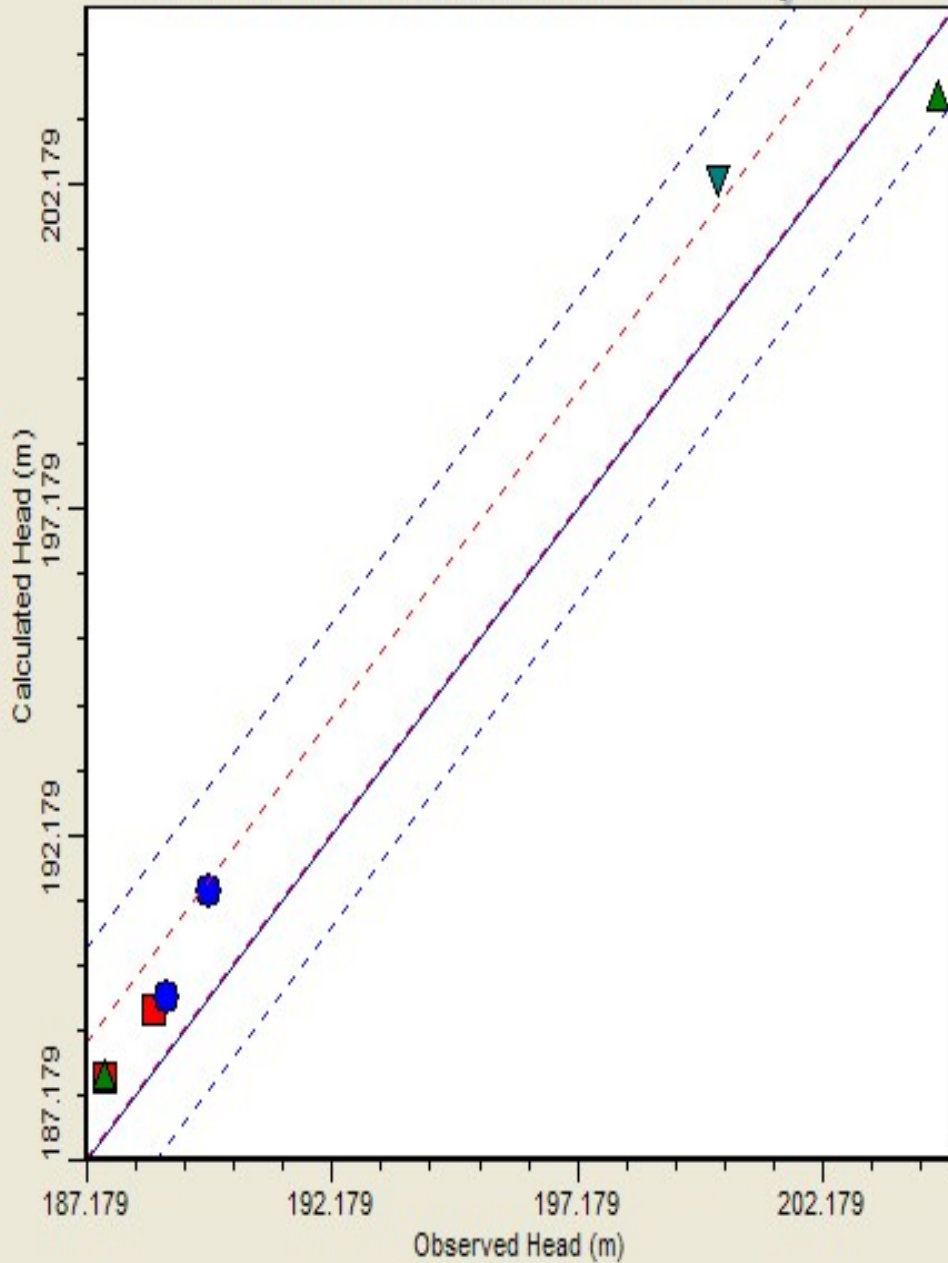
Created by:	CMT	Project No.:	07-1219-001
Checked by:	JPD	Scale:	NTS
Date:	January 2009		

CROSS SECTION VIEW OF MODEL DOMAIN
 Numerical Hydrogeological Modeling Report for Expansion
 Feasibility of the Ruby Road Waste Disposal Site



 <p>PO Box 325, 2085 Whittington Drive Peterborough, Ontario, K9J 6X4 Tel: 705-742-7900 Fax: 705-742-7907 www.cambium-env.com</p>	Created by:	Project No.:	<p align="center">BOUNDARY CONDITIONS</p> <p align="center">Numerical Hydrogeological Modeling Report for Expansion Feasibility of the Ruby Road Waste Disposal Site</p> <p align="right">Figure No: 3</p>
	CMT	07-1219-001	
	Checked by:	Scale:	
JPD	NTS	Date:	
	January 2009		

Calculated vs. Observed Head : Steady state



- Layer #6
- Layer #7
- ▲ Layer #8
- ▼ Layer #9
- - - 95% confidence interval
- · · 95% interval

Max. Residual: 2.179 (m) at MW4-08/A
 Min. Residual: 0.88 (m) at MW5-08/A
 Residual Mean : 0.917 (m)
 Abs. Residual Mean : 1.213 (m)

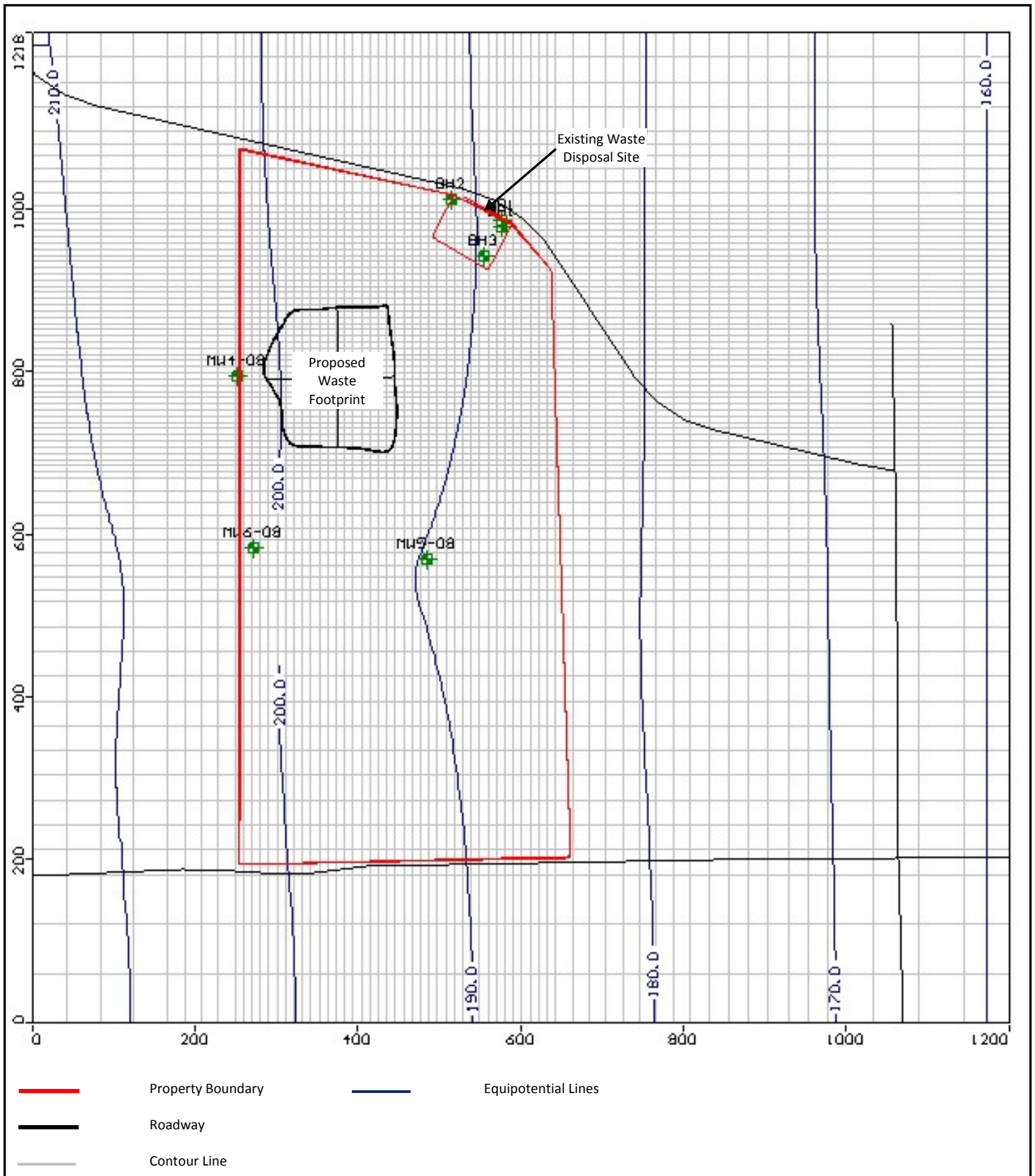
Num. of Data Points : 7
 Standard Error of the Estimate : 0.375 (m)
 Root Mean Squared : 1.297 (m)
 Normalized RMS : 7.611 (%)
 Correlation Coefficient : 0.99




PO Box 325, 2085 Whittington Drive
 Peterborough, Ontario, K9J 6X4
 Tel: 705-742-7900 Fax: 705-742-7907
 www.cambium-env.com

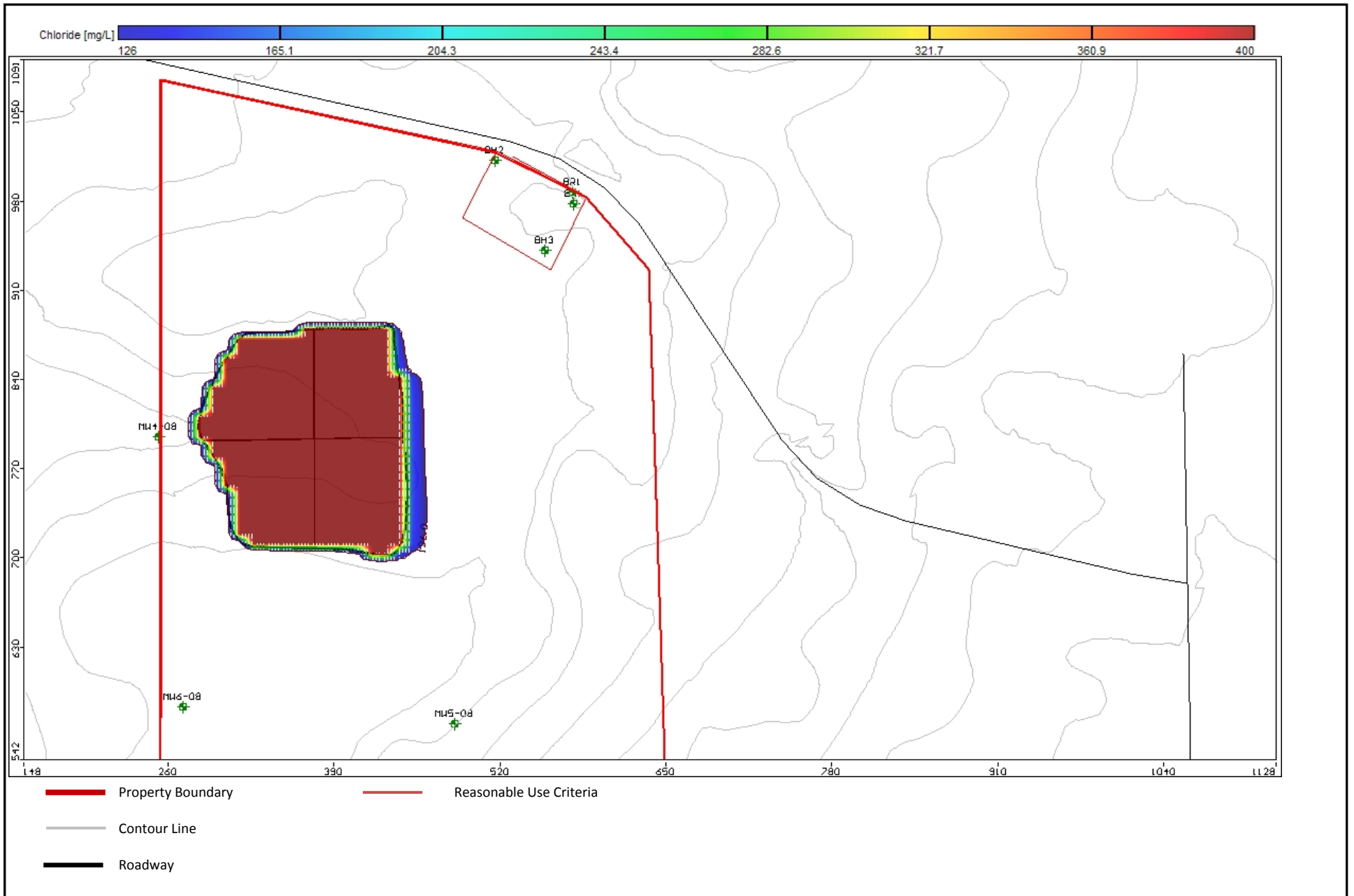
Created by:	CMT	Project No.:	07-1219-001
Checked by:	JPD	Scale:	NTS
Date:	January 2009		

FINAL FLOW MODEL CALIBRATION GRAPH
 Numerical Hydrogeological Modeling Report for
 Expansion Feasibility of the Ruby Road Waste
 Disposal Site



 <p>PO Box 325, 2085 Whittington Drive Peterborough, Ontario, K9J 6X4 Tel: 705-742-7900 Fax: 705-742-7907 www.cambium-env.com</p>	Created by:	Project No.:	<p>CALIBRATED EQUIPOTENTIAL LINES</p> <p>Numerical Hydrogeological Modeling Report for Expansion Feasibility of the Ruby Road Waste Disposal Site</p>
	Checked by:	Scale:	
	Date:		

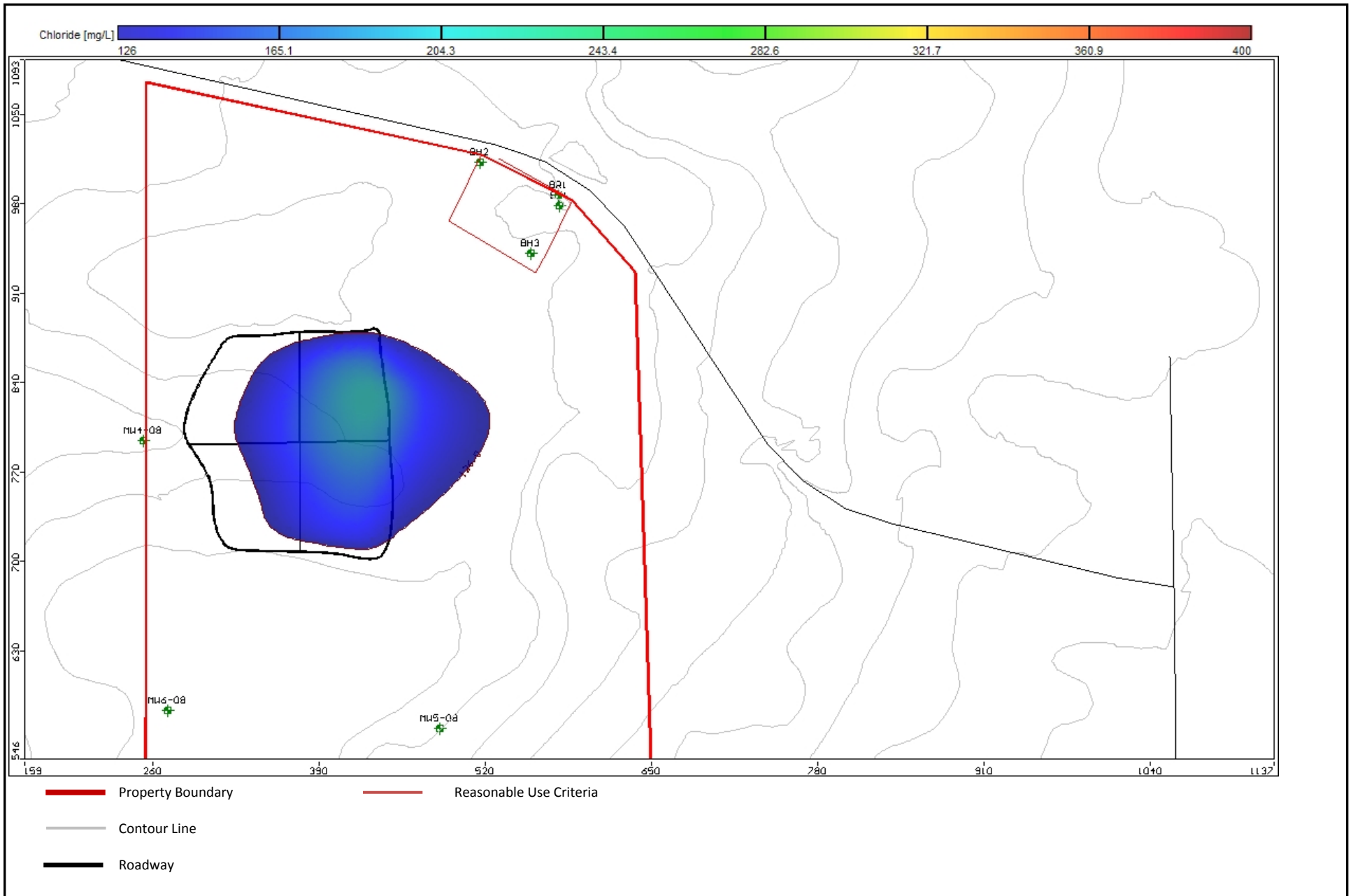
CMT
 JPD
 NTS
 January 2009
 07-1219-001
 NTS



PO Box 325, 2085 Whittington Drive
 Peterborough, Ontario, K9J 6X4
 Tel: 705-742-7900 Fax: 705-742-7907
 www.cambium-env.com

Created by:	CMT	Project No.:	07-1219-001
Checked by:	JPD	Scale:	NTS
Date:	January 2009		

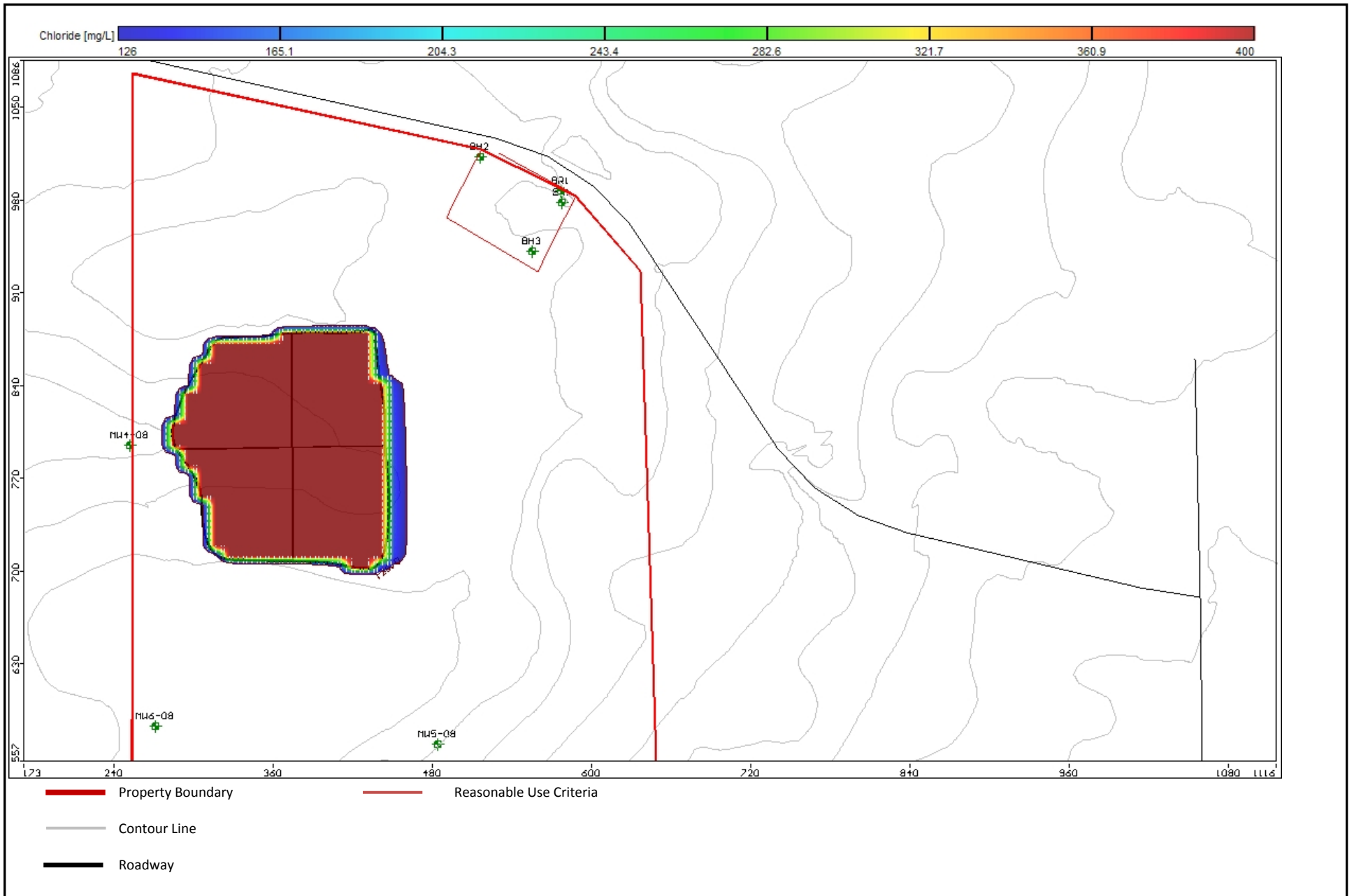
INITIAL CHLORIDE PLUME SENSITIVITY ANALYSIS (LAYER 2)
 Numerical Hydrogeological Modeling Report for Expansion
 Feasibility of the Ruby Road Waste Disposal Site



PO Box 325, 2085 Whittington Drive
Peterborough, Ontario, K9J 6X4
Tel: 705-742-7900 Fax: 705-742-7907
www.cambium-env.com

Created by:	CMT	Project No.:	07-1219-001
Checked by:	JPD	Scale:	NTS
Date:	January 2009		

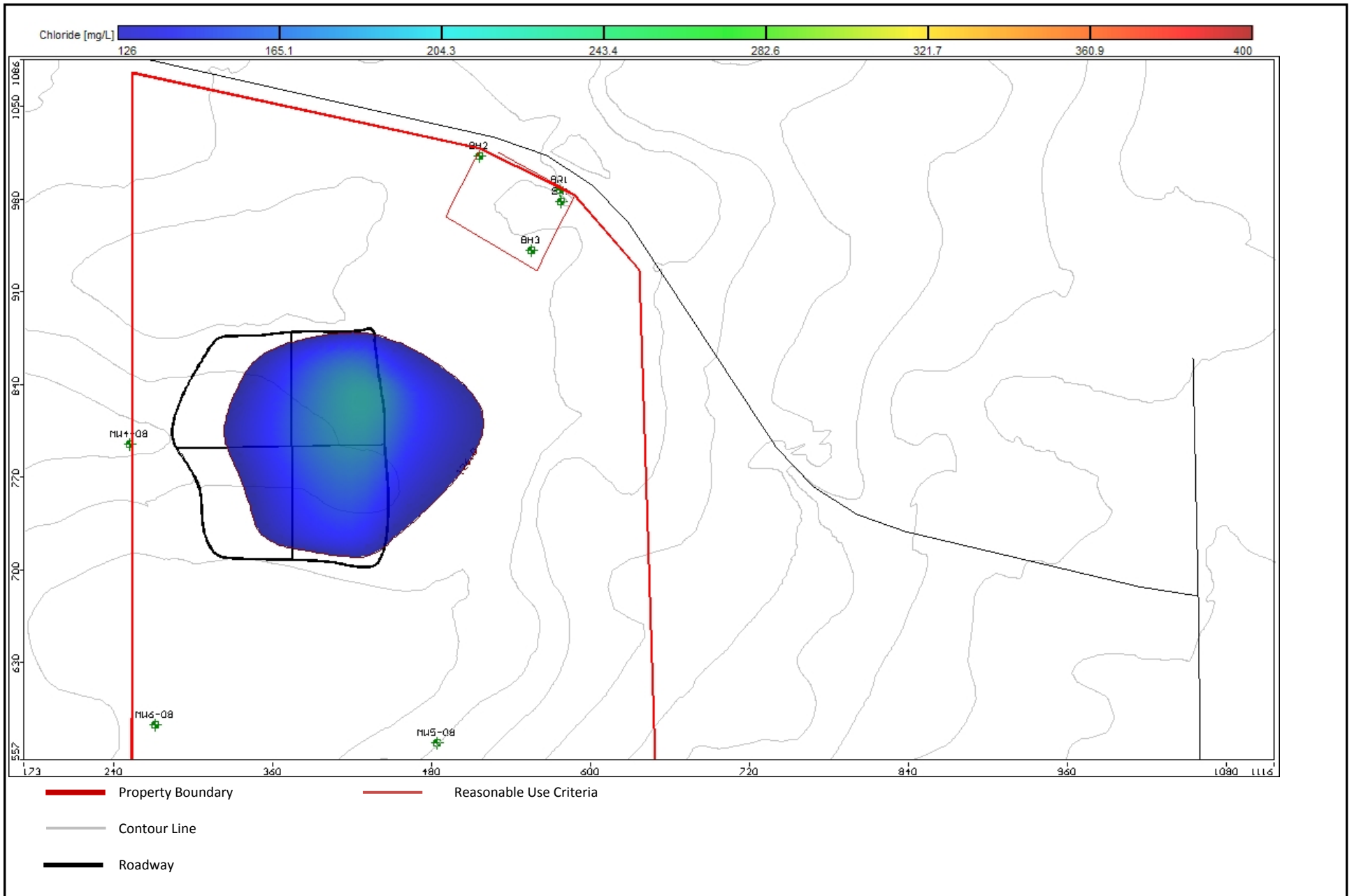
INITIAL CHLORIDE PLUME SENSITIVITY ANALYSIS (LAYER 3)
Numerical Hydrogeological Modeling Report for Expansion
Feasibility of the Ruby Road Waste Disposal Site



PO Box 325, 2085 Whittington Drive
Peterborough, Ontario, K9J 6X4
Tel: 705-742-7900 Fax: 705-742-7907
www.cambium-env.com

Created by:	CMT	Project No.:	07-1219-001
Checked by:	JPD	Scale:	NTS
Date:	January 2009		

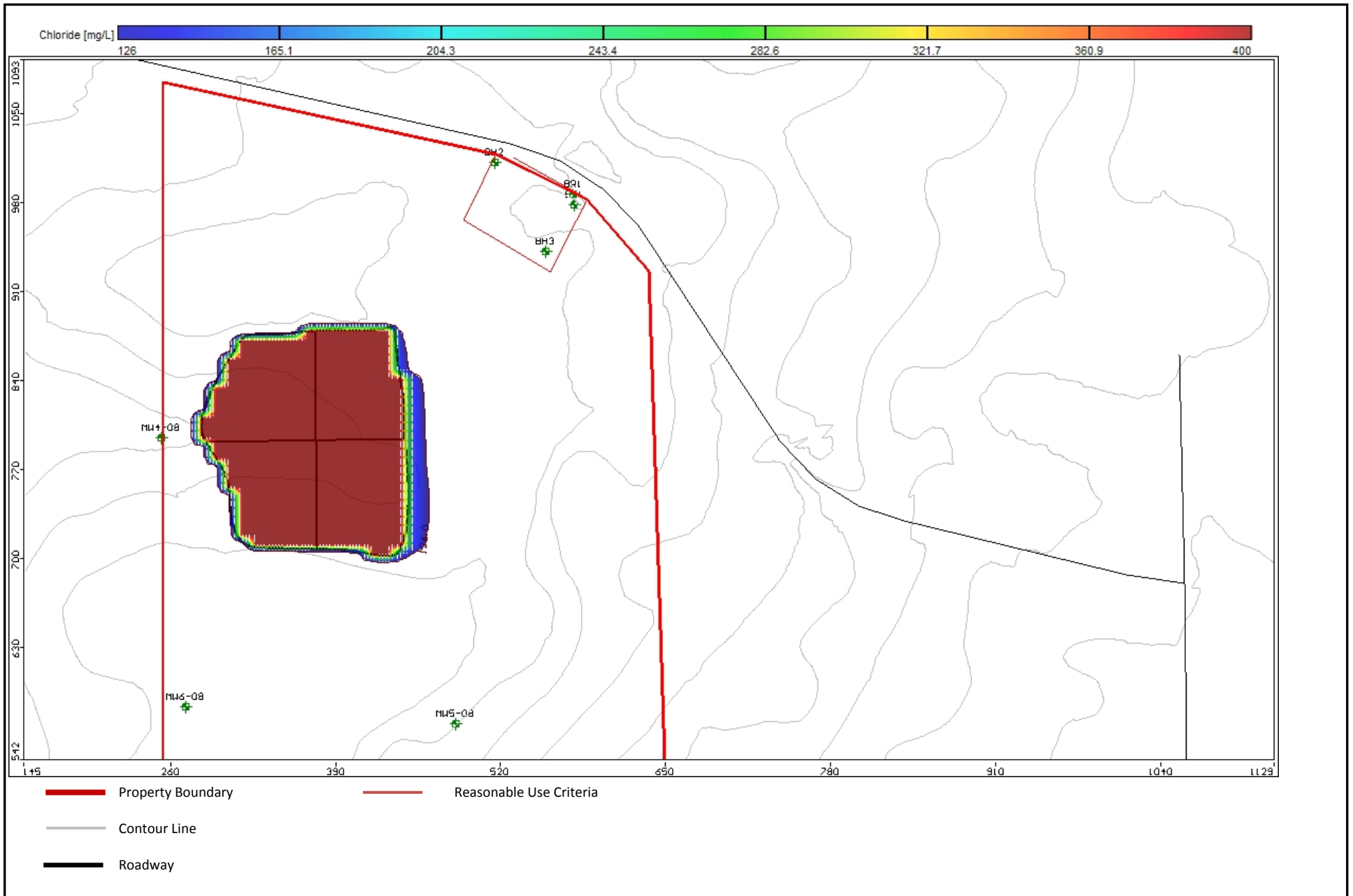
INCREASED RECHARGE SENSITIVITY ANALYSIS (LAYER 2)
Numerical Hydrogeological Modeling Report for Expansion
Feasibility of the Ruby Road Waste Disposal Site



PO Box 325, 2085 Whittington Drive
 Peterborough, Ontario, K9J 6X4
 Tel: 705-742-7900 Fax: 705-742-7907
 www.cambium-env.com

Created by:	CMT	Project No.:	07-1219-001
Checked by:	JPD	Scale:	NTS
Date:	January 2009		

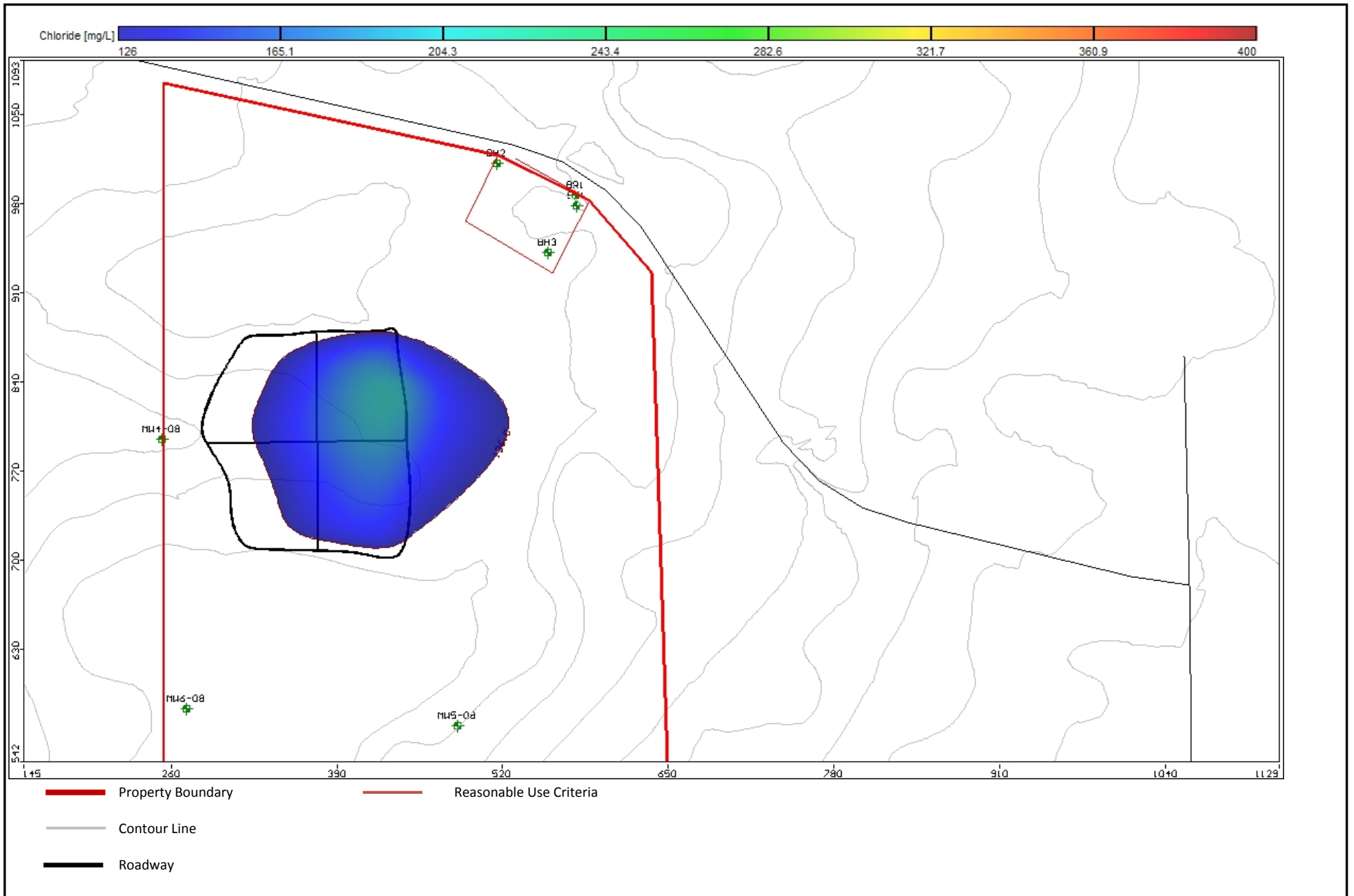
INCREASED RECHARGE SENSITIVITY ANALYSIS (LAYER 3)
 Numerical Hydrogeological Modeling Report for Expansion
 Feasibility of the Ruby Road Waste Disposal Site



PO Box 325, 2085 Whittington Drive
Peterborough, Ontario, K9J 6X4
Tel: 705-742-7900 Fax: 705-742-7907
www.cambium-env.com

Created by:	CMT	Project No.:	07-1219-001
Checked by:	JPD	Scale:	NTS
Date:	January 2009		

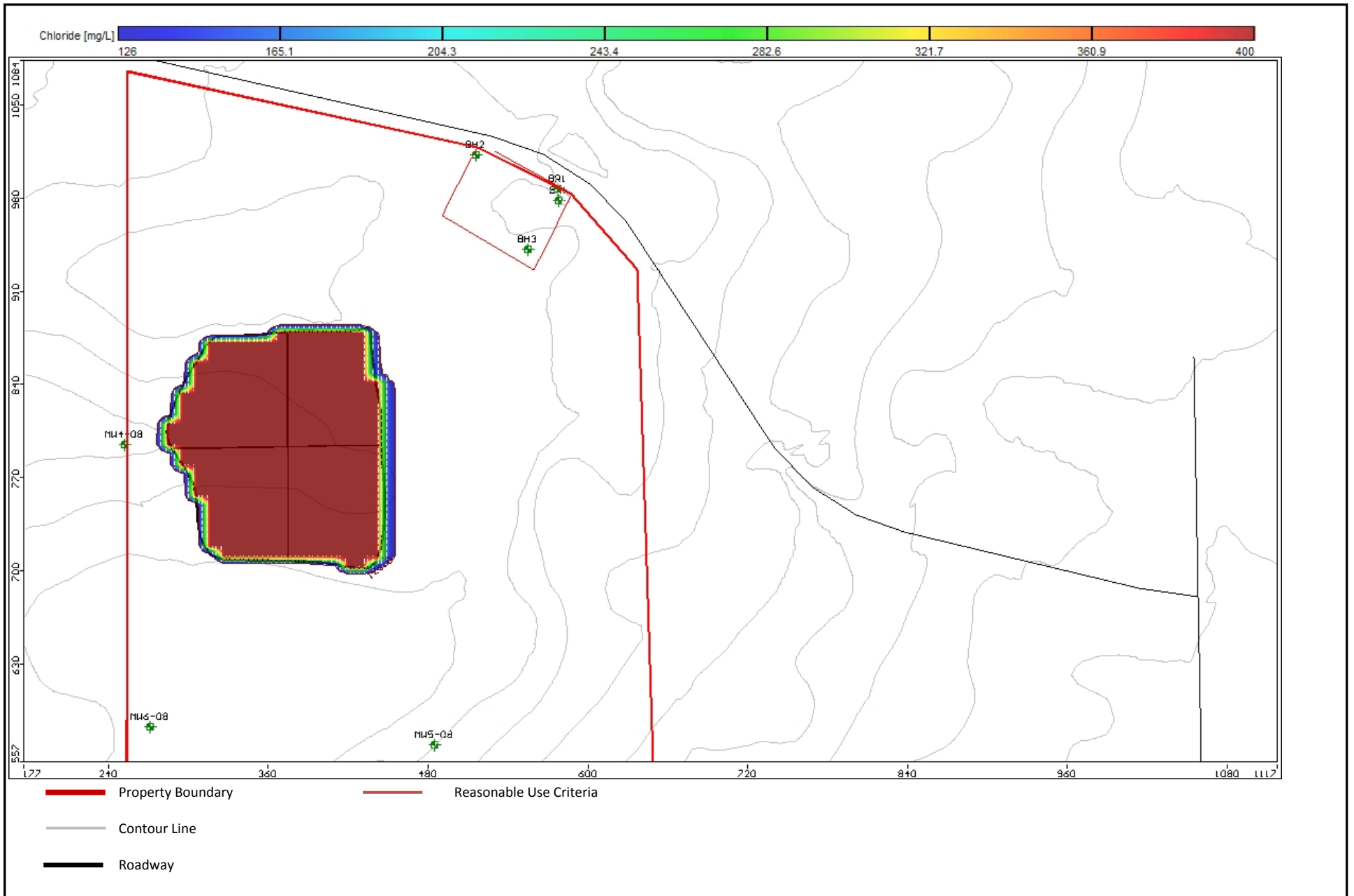
DECREASED RECHARGE SENSITIVITY ANALYSIS (LAYER 2)
Numerical Hydrogeological Modeling Report for Expansion
Feasibility of the Ruby Road Waste Disposal Site



PO Box 325, 2085 Whittington Drive
Peterborough, Ontario, K9J 6X4
Tel: 705-742-7900 Fax: 705-742-7907
www.cambium-env.com

Created by:	CMT	Project No.:	07-1219-001
Checked by:	JPD	Scale:	NTS
Date:	January 2009		

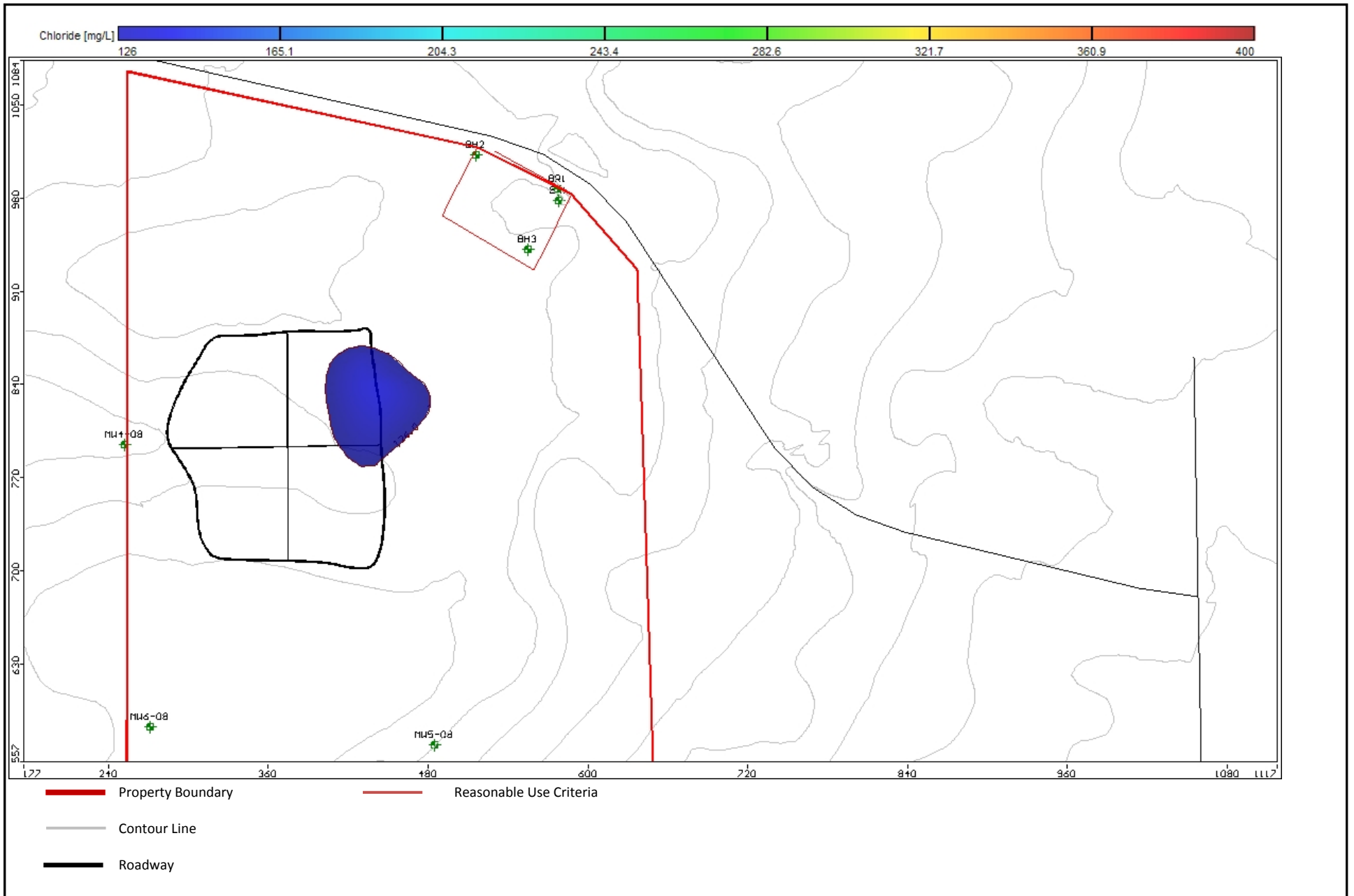
DECREASED RECHARGE SENSITIVITY ANALYSIS (LAYER 3)
Numerical Hydrogeological Modeling Report for Expansion
Feasibility of the Ruby Road Waste Disposal Site



PO Box 325, 2085 Whittington Drive
 Peterborough, Ontario, K9J 6X4
 Tel: 705-742-7900 Fax: 705-742-7907
 www.cambium-env.com

Created by:	CMT	Project No.:	07-1219-001
Checked by:	JPD	Scale:	NTS
Date:	January 2009		

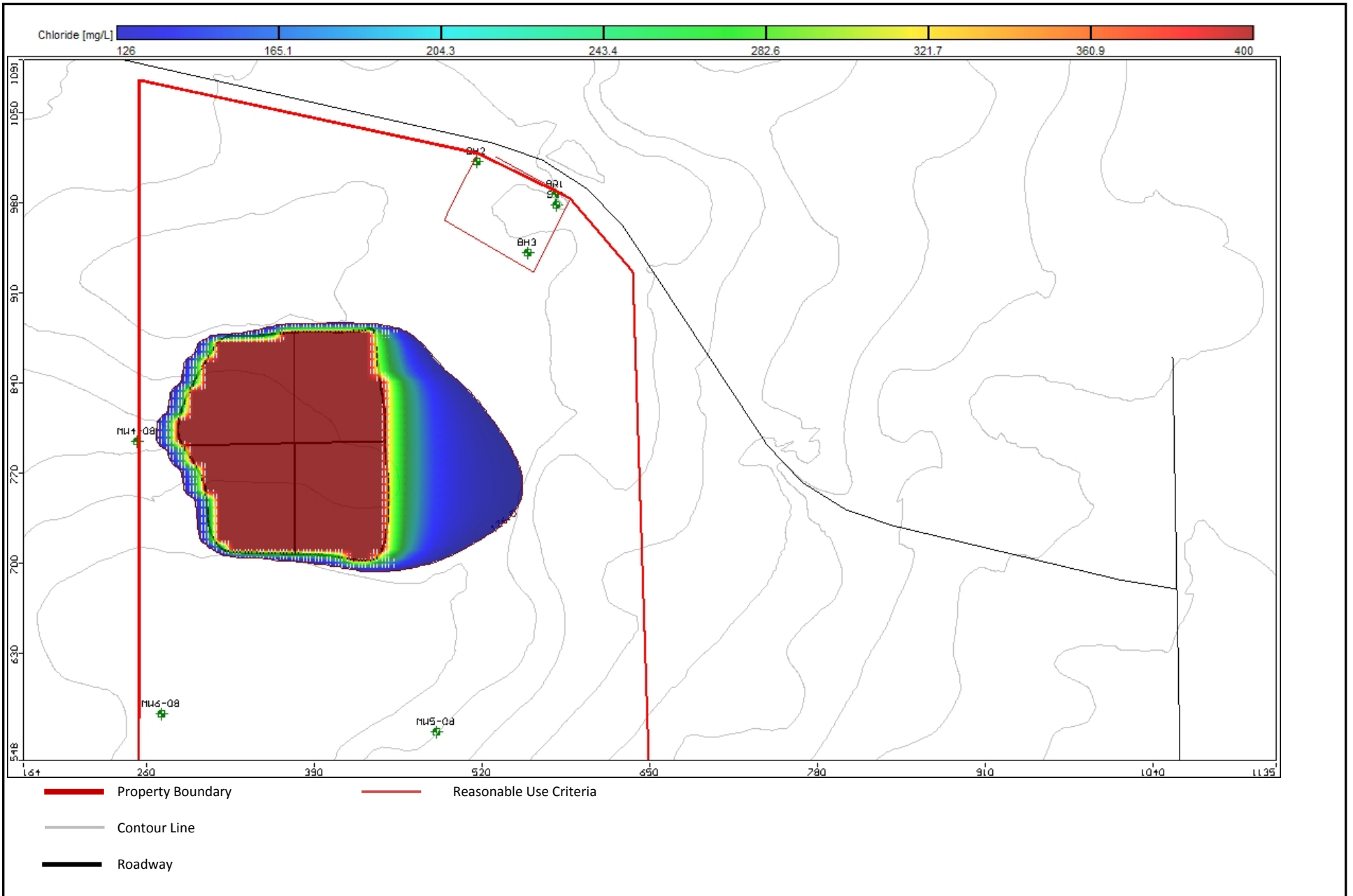
DECREASED DISPERSION SENSITIVITY ANALYSIS (LAYER 2)
 Numerical Hydrogeological Modeling Report for Expansion
 Feasibility of the Ruby Road Waste Disposal Site



PO Box 325, 2085 Whittington Drive
 Peterborough, Ontario, K9J 6X4
 Tel: 705-742-7900 Fax: 705-742-7907
 www.cambium-env.com

Created by:	CMT	Project No.:	07-1219-001
Checked by:	JPD	Scale:	NTS
Date:	January 2009		

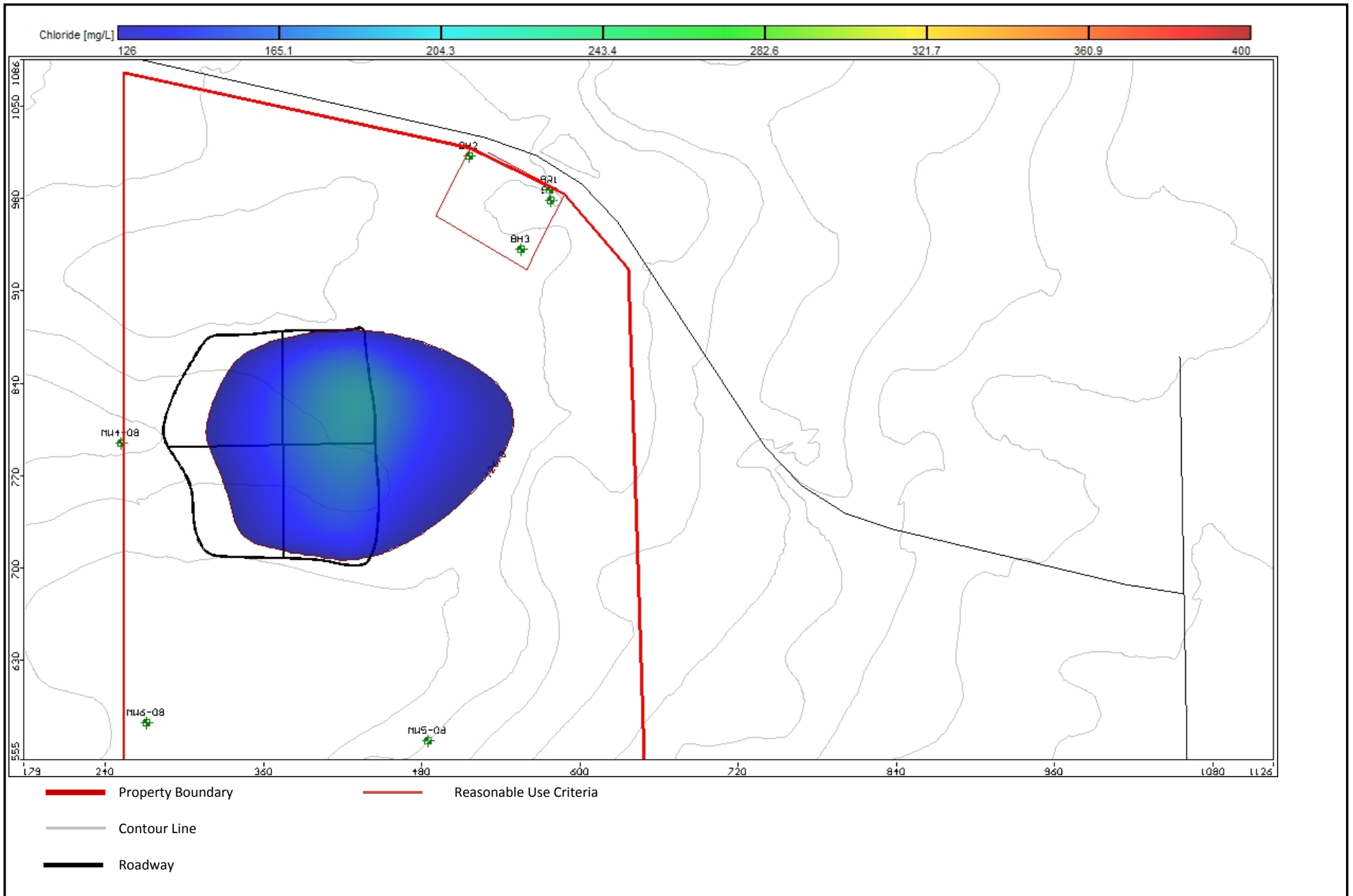
DECREASED DISPERSION SENSITIVITY ANALYSIS (LAYER 3)
 Numerical Hydrogeological Modeling Report for Expansion
 Feasibility of the Ruby Road Waste Disposal Site



PO Box 325, 2085 Whittington Drive
 Peterborough, Ontario, K9J 6X4
 Tel: 705-742-7900 Fax: 705-742-7907
 www.cambium-env.com

Created by:	CMT	Project No.:	07-1219-001
Checked by:	JPD	Scale:	NTS
Date:	January 2009		

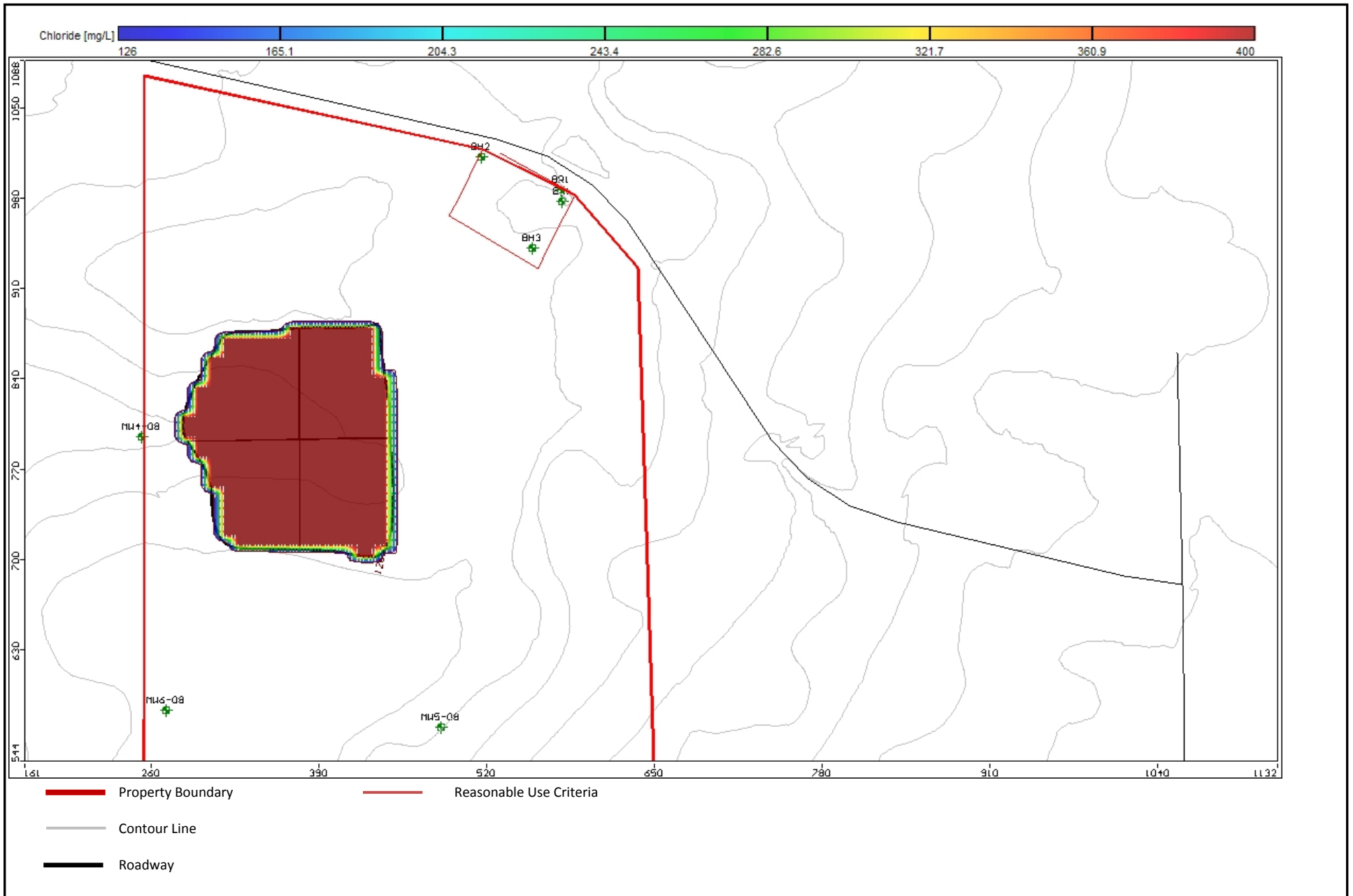
INCREASED CONDUCTIVITY SENSITIVITY ANALYSIS (LAYER 2)
 Numerical Hydrogeological Modeling Report for Expansion
 Feasibility of the Ruby Road Waste Disposal Site



PO Box 325, 2085 Whittington Drive
 Peterborough, Ontario, K9J 6X4
 Tel: 705-742-7900 Fax: 705-742-7907
 www.cambium-env.com

Created by:	CMT	Project No.:	07-1219-001
Checked by:	JPD	Scale:	NTS
Date:	January 2009		

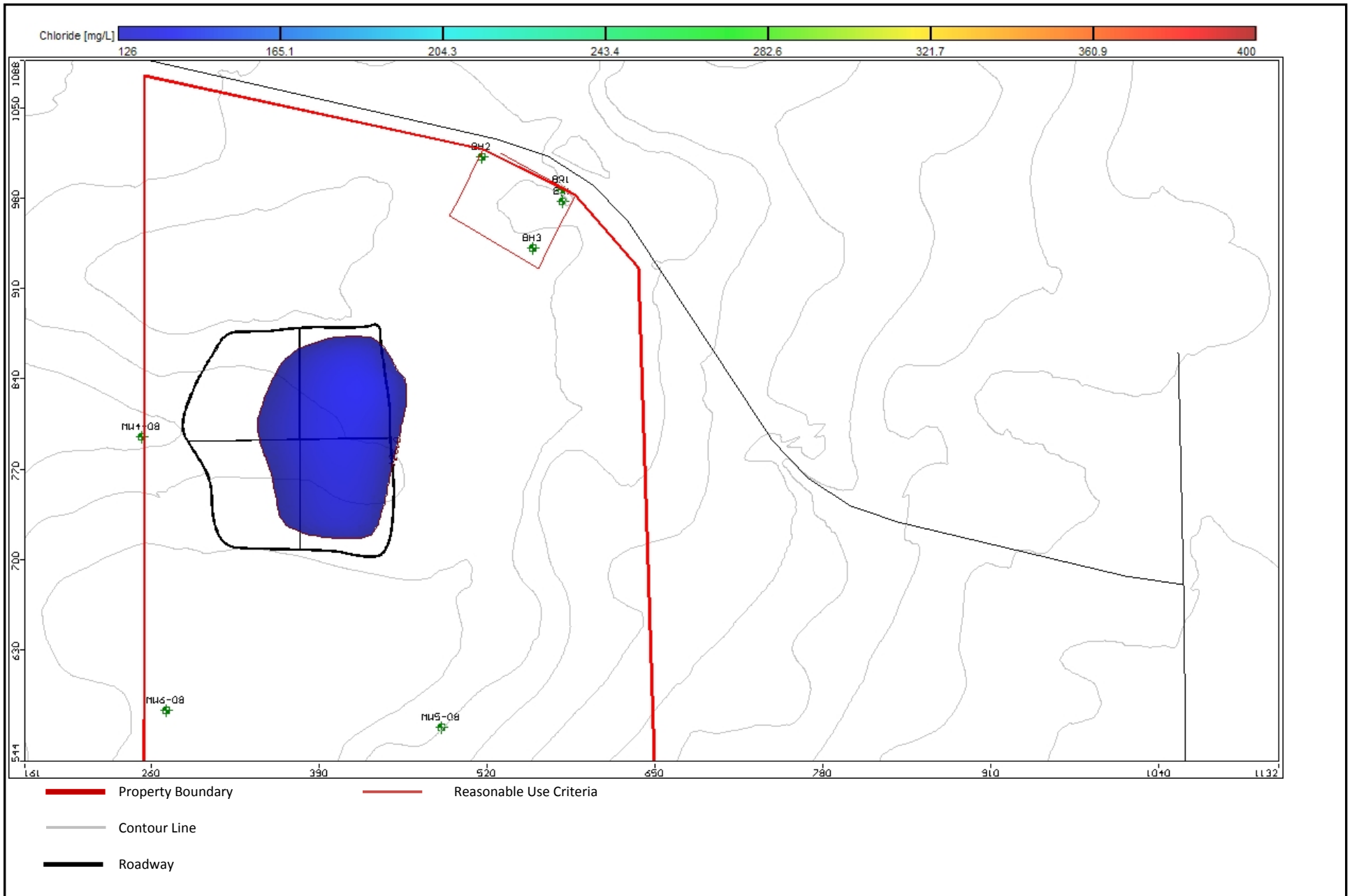
INCREASED CONDUCTIVITY SENSITIVITY ANALYSIS (LAYER 3)
 Numerical Hydrogeological Modeling Report for Expansion
 Feasibility of the Ruby Road Waste Disposal Site



PO Box 325, 2085 Whittington Drive
 Peterborough, Ontario, K9J 6X4
 Tel: 705-742-7900 Fax: 705-742-7907
 www.cambium-env.com

Created by:	CMT	Project No.:	07-1219-001
Checked by:	JPD	Scale:	NTS
Date:	January 2009		

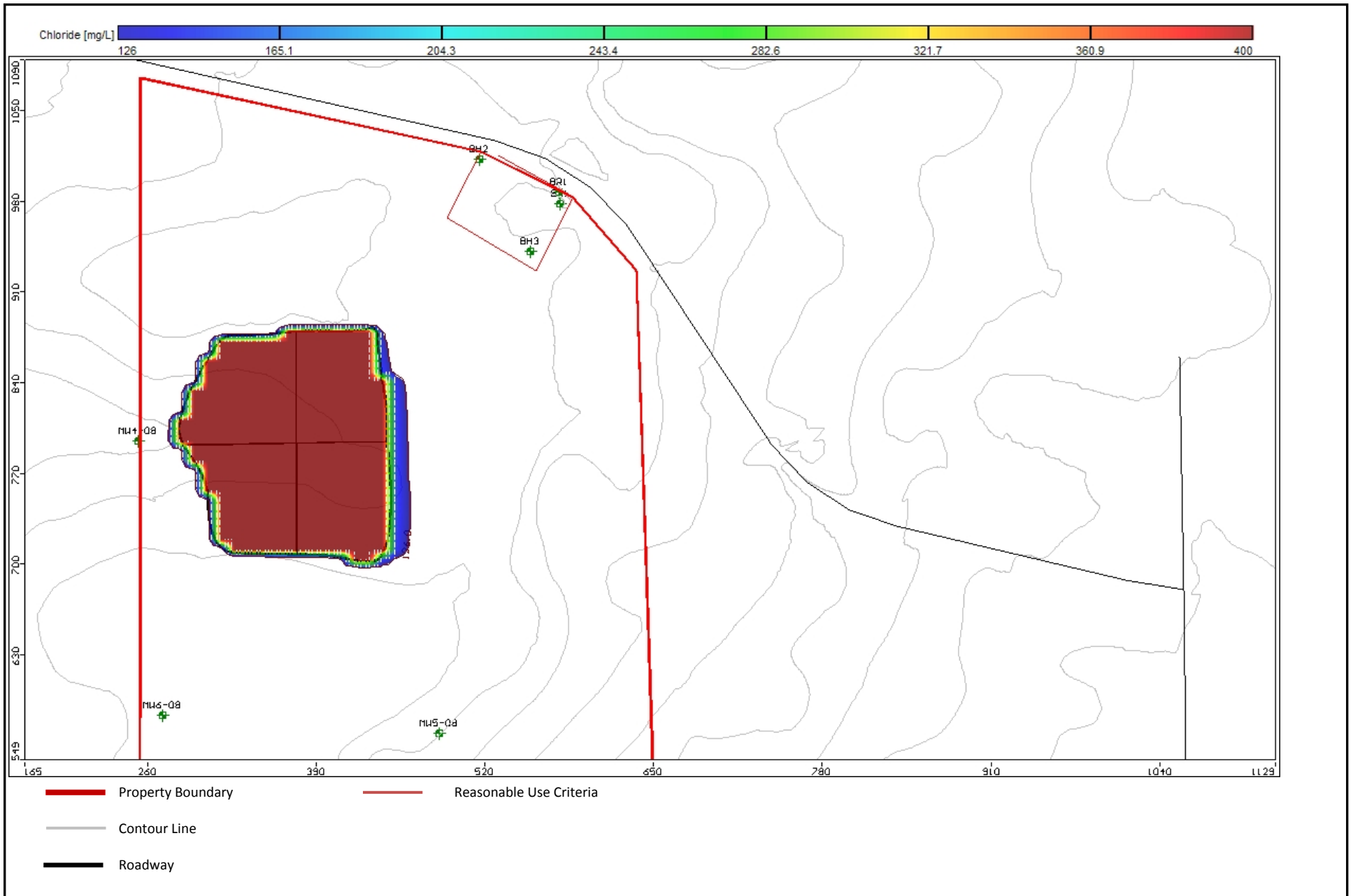
DECREASED CONDUCTIVITY SENSITIVITY ANALYSIS (LAYER 2)
 Numerical Hydrogeological Modeling Report for Expansion
 Feasibility of the Ruby Road Waste Disposal Site



PO Box 325, 2085 Whittington Drive
 Peterborough, Ontario, K9J 6X4
 Tel: 705-742-7900 Fax: 705-742-7907
 www.cambium-env.com

Created by:	CMT	Project No.:	07-1219-001
Checked by:	JPD	Scale:	NTS
Date:	January 2009		

DECREASED CONDUCTIVITY SENSITIVITY ANALYSIS (LAYER 3)
 Numerical Hydrogeological Modeling Report for Expansion
 Feasibility of the Ruby Road Waste Disposal Site

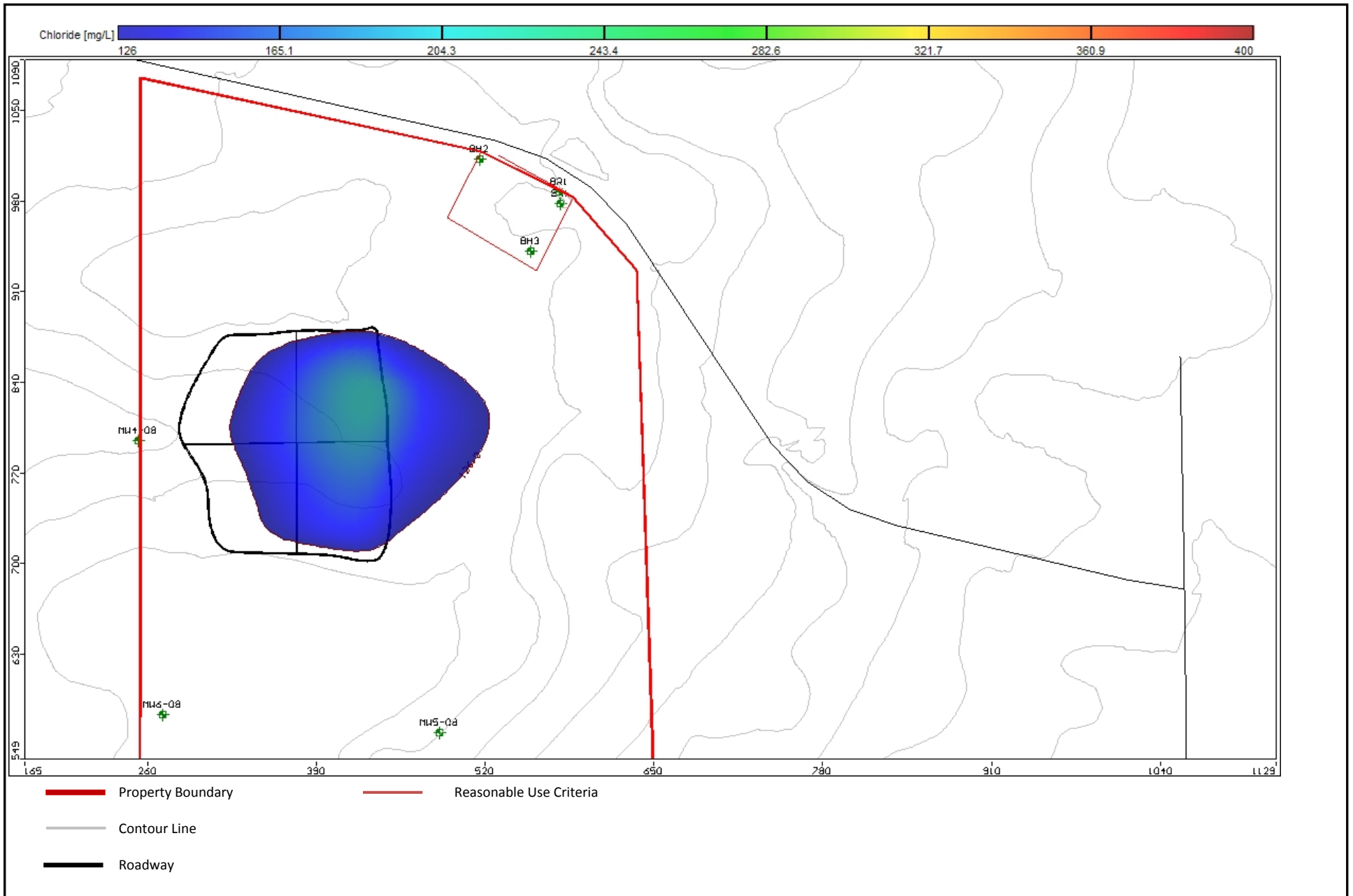


PO Box 325, 2085 Whittington Drive
Peterborough, Ontario, K9J 6X4
Tel: 705-742-7900 Fax: 705-742-7907
www.cambium-env.com

Created by:	CMT	Project No.:	07-1219-001
Checked by:	JPD	Scale:	NTS
Date:	January 2009		

INCREASED EFFECTIVE POROSITY SENSITIVITY ANALYSIS (LAYER 2)
Numerical Hydrogeological Modeling Report for Expansion
Feasibility of the Ruby Road Waste Disposal Site

Figure No: **18**

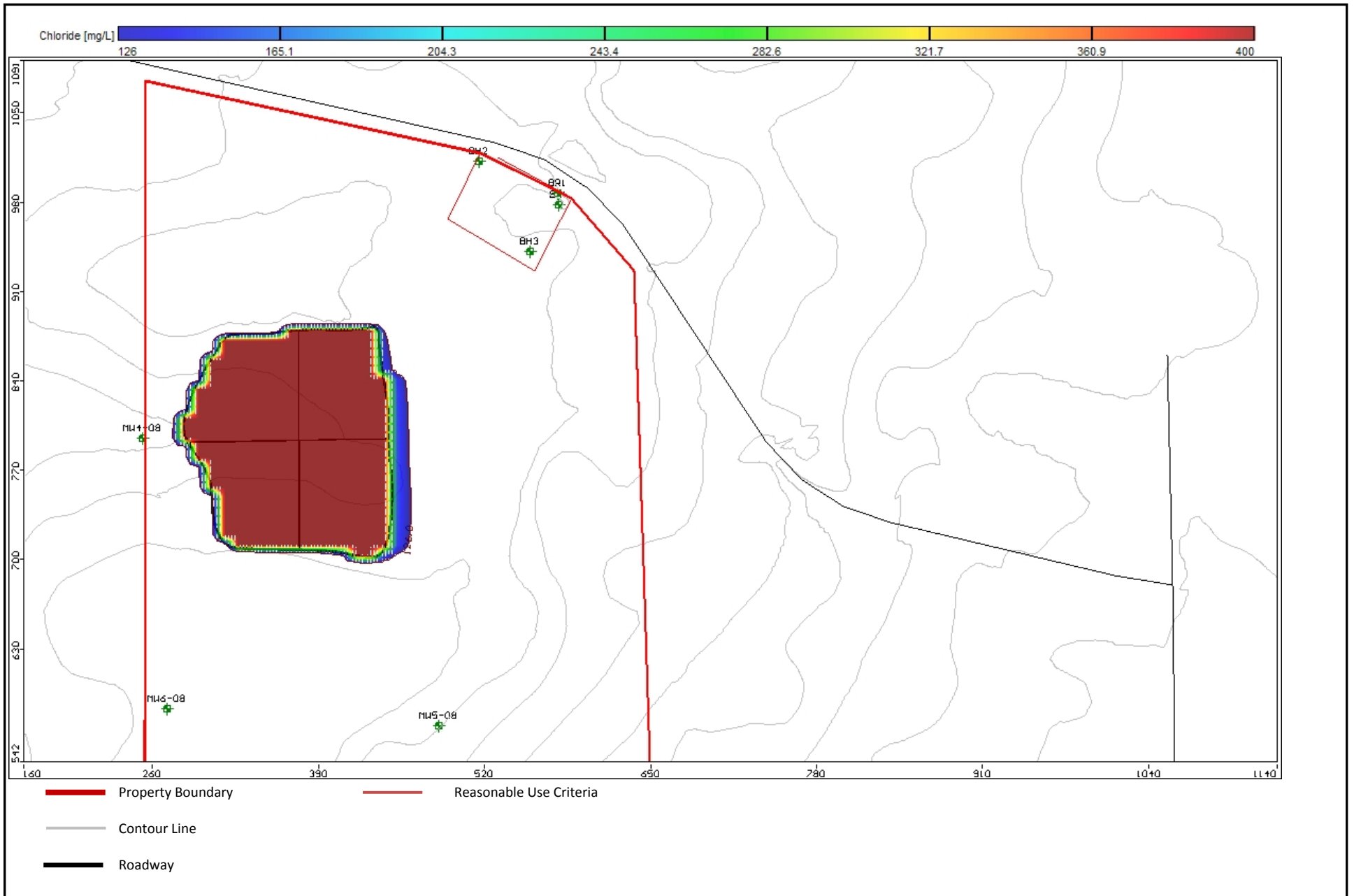


PO Box 325, 2085 Whittington Drive
Peterborough, Ontario, K9J 6X4
Tel: 705-742-7900 Fax: 705-742-7907
www.cambium-env.com

Created by:	CMT	Project No.:	07-1219-001
Checked by:	JPD	Scale:	NTS
Date:	January 2009		

INCREASED EFFECTIVE POROSITY SENSITIVITY ANALYSIS (LAYER 3)
Numerical Hydrogeological Modeling Report for Expansion
Feasibility of the Ruby Road Waste Disposal Site

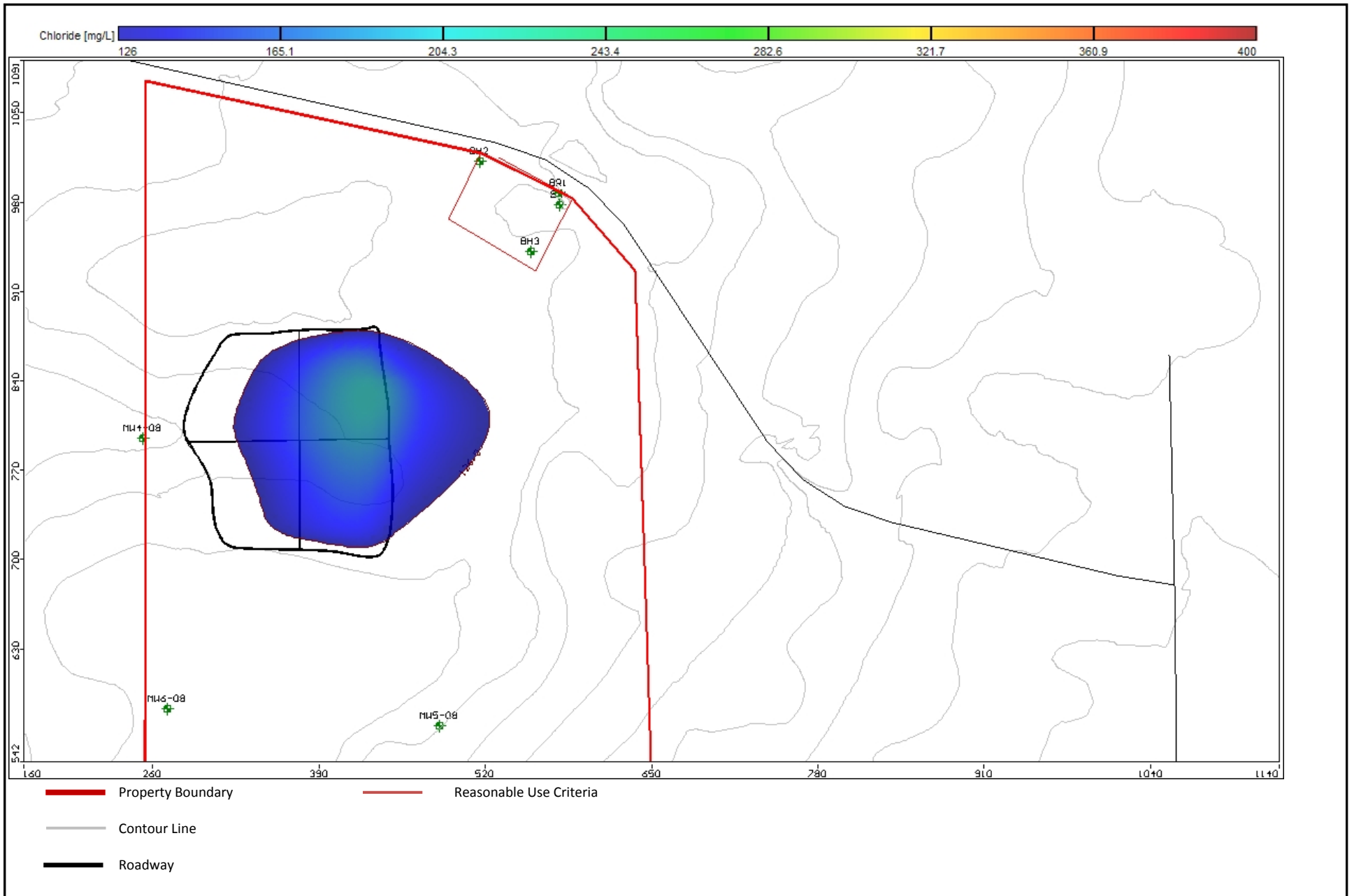
Figure No: **19**



PO Box 325, 2085 Whittington Drive
 Peterborough, Ontario, K9J 6X4
 Tel: 705-742-7900 Fax: 705-742-7907
 www.cambium-env.com

Created by:	CMT	Project No.:	07-1219-001
Checked by:	JPD	Scale:	NTS
Date:	January 2009		

DECREASED EFFECTIVE POROSITY SENSITIVITY ANALYSIS (LAYER 2)
 Numerical Hydrogeological Modeling Report for Expansion
 Feasibility of the Ruby Road Waste Disposal Site

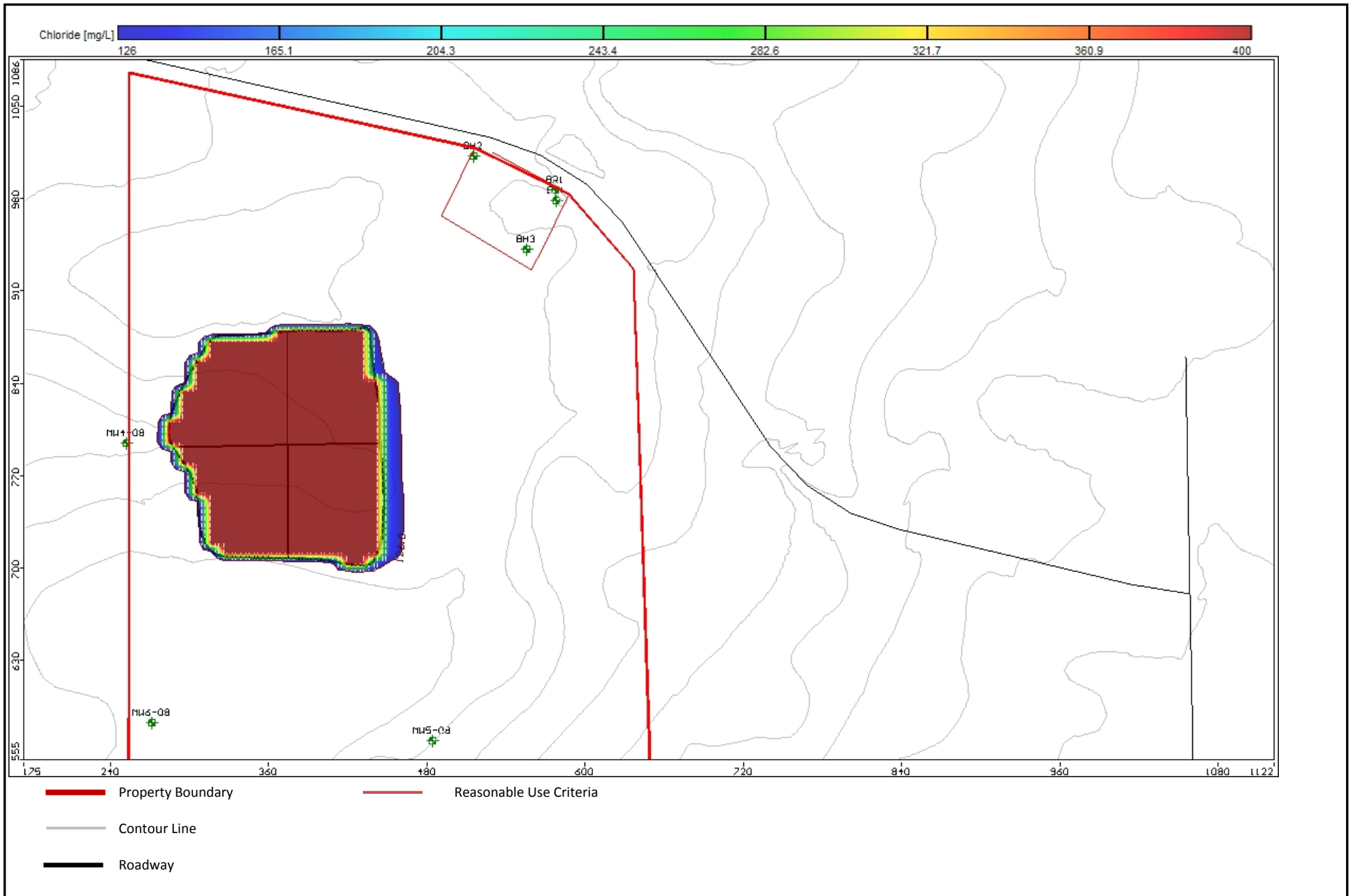


PO Box 325, 2085 Whittington Drive
Peterborough, Ontario, K9J 6X4
Tel: 705-742-7900 Fax: 705-742-7907
www.cambium-env.com

Created by:	CMT	Project No.:	07-1219-001
Checked by:	JPD	Scale:	NTS
Date:	January 2009		

DECREASED EFFECTIVE POROSITY SENSITIVITY ANALYSIS (LAYER 3)
Numerical Hydrogeological Modeling Report for Expansion
Feasibility of the Ruby Road Waste Disposal Site

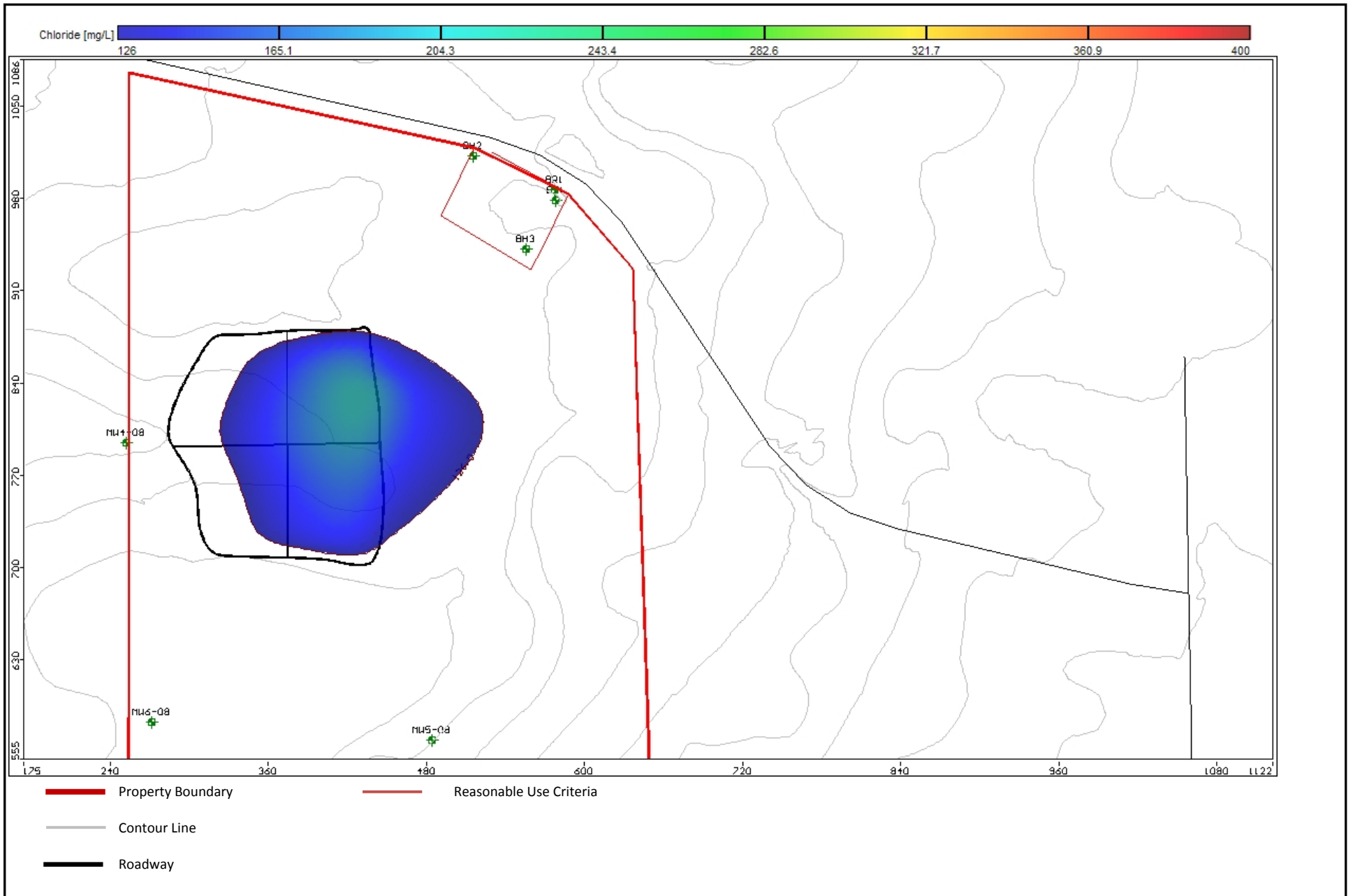
Figure No: **21**



PO Box 325, 2085 Whittington Drive
 Peterborough, Ontario, K9J 6X4
 Tel: 705-742-7900 Fax: 705-742-7907
 www.cambium-env.com

Created by:	CMT	Project No.:	07-1219-001
Checked by:	JPD	Scale:	NTS
Date:	January 2009		

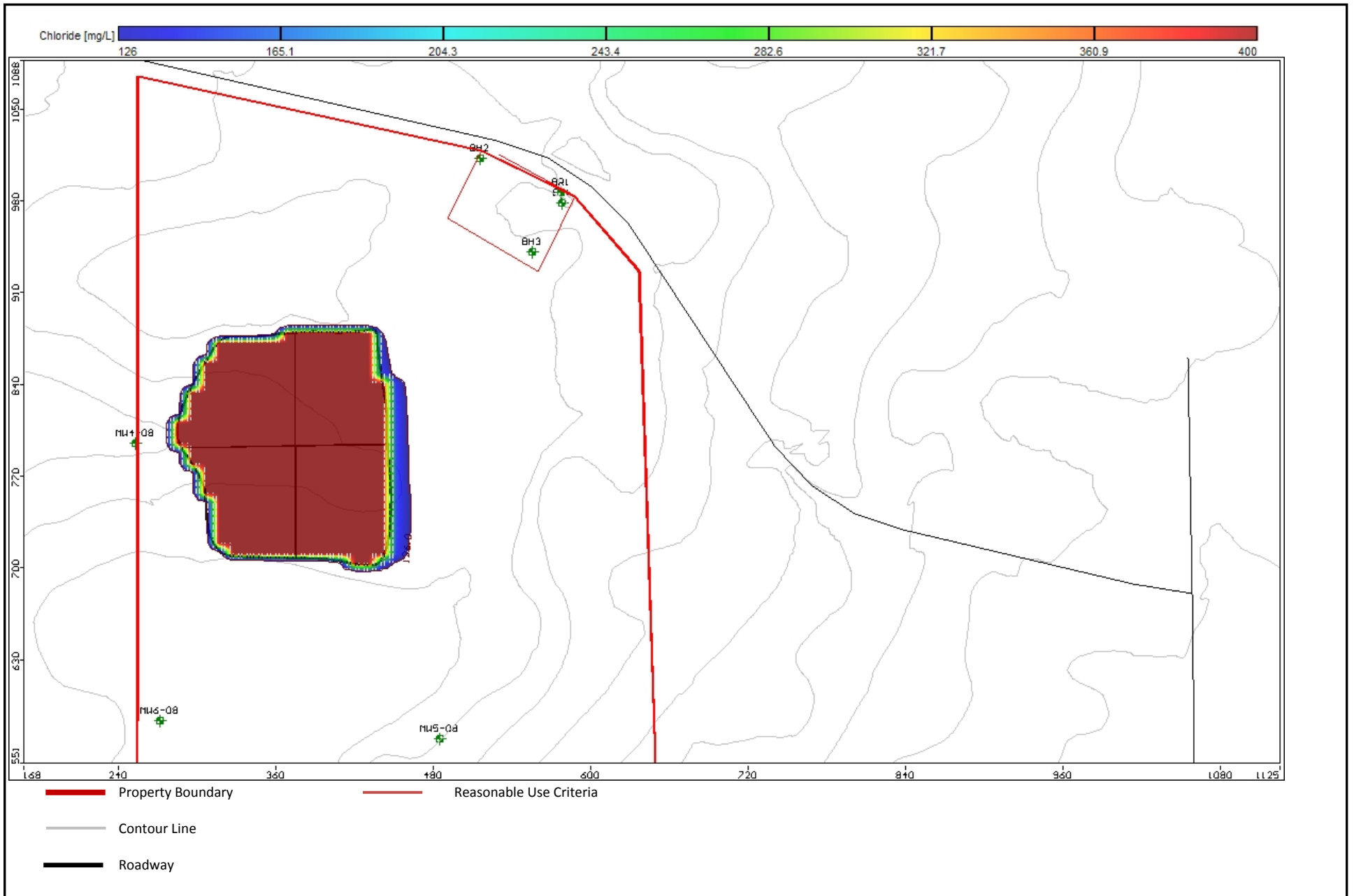
INCREASED SPECIFIC STORAGE SENSITIVITY ANALYSIS (LAYER 2)
 Numerical Hydrogeological Modeling Report for Expansion
 Feasibility of the Ruby Road Waste Disposal Site



PO Box 325, 2085 Whittington Drive
Peterborough, Ontario, K9J 6X4
Tel: 705-742-7900 Fax: 705-742-7907
www.cambium-env.com

Created by:	CMT	Project No.:	07-1219-001
Checked by:	JPD	Scale:	NTS
Date:	January 2009		

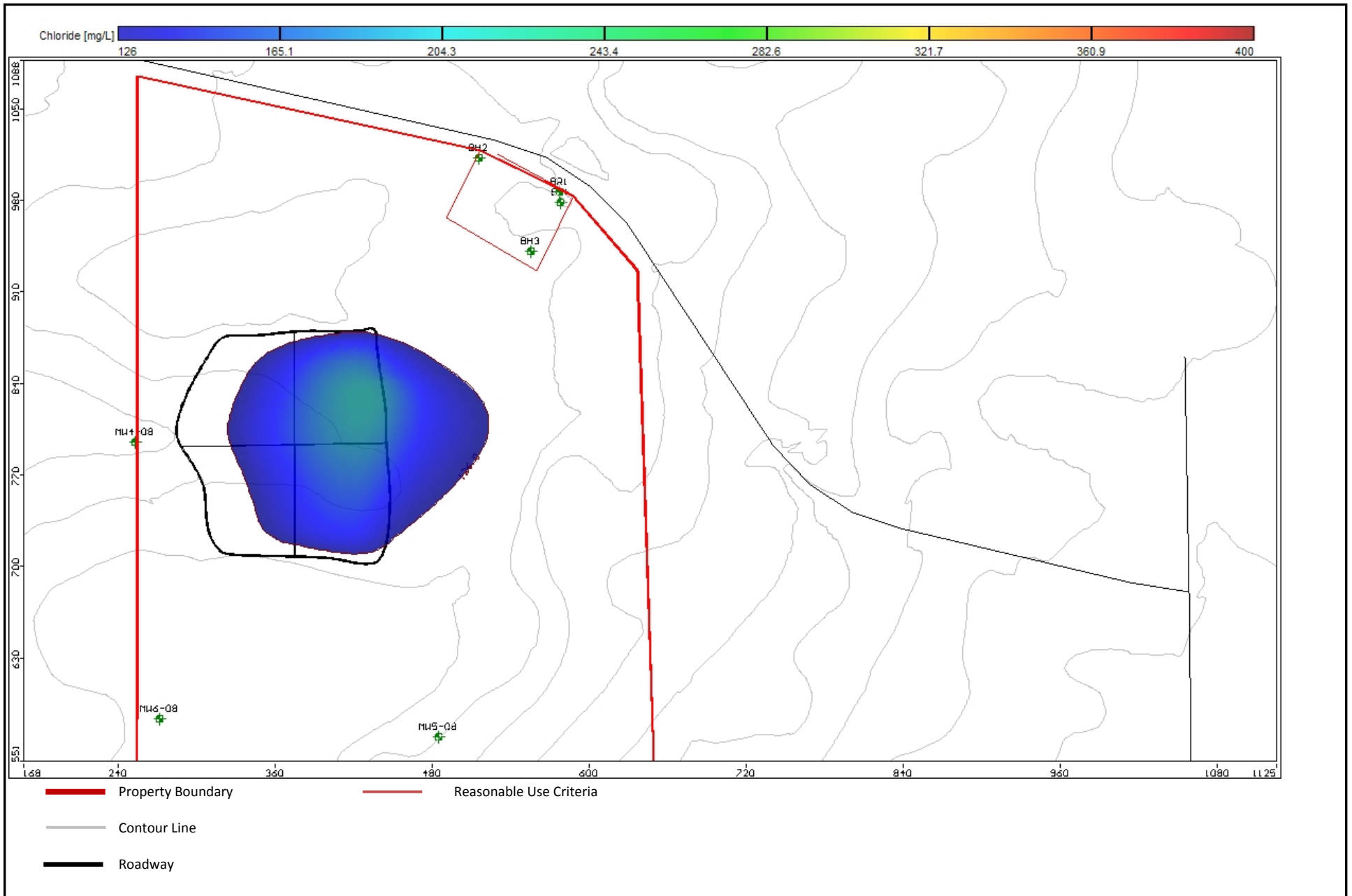
INCREASED SPECIFIC STORAGE SENSITIVITY ANALYSIS (LAYER 3)
Numerical Hydrogeological Modeling Report for Expansion
Feasibility of the Ruby Road Waste Disposal Site



PO Box 325, 2085 Whittington Drive
Peterborough, Ontario, K9J 6X4
Tel: 705-742-7900 Fax: 705-742-7907
www.cambium-env.com

Created by:	CMT	Project No.:	07-1219-001
Checked by:	JPD	Scale:	NTS
Date:	January 2009		

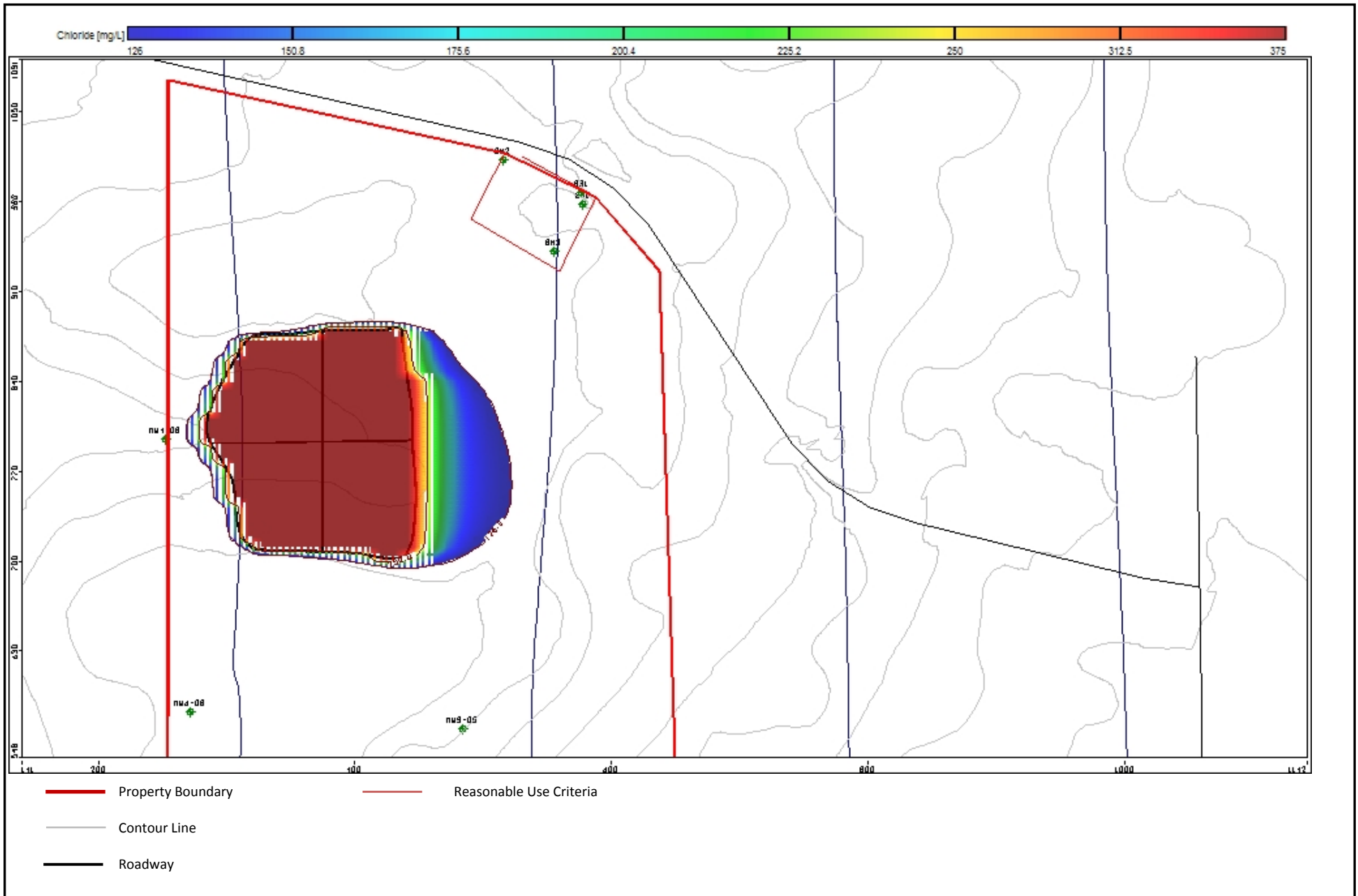
DECREASED SPECIFIC STORAGE SENSITIVITY ANALYSIS (LAYER 2)
Numerical Hydrogeological Modeling Report for Expansion
Feasibility of the Ruby Road Waste Disposal Site



PO Box 325, 2085 Whittington Drive
 Peterborough, Ontario, K9J 6X4
 Tel: 705-742-7900 Fax: 705-742-7907
 www.cambium-env.com

Created by:	CMT	Project No.:	07-1219-001
Checked by:	JPD	Scale:	NTS
Date:	January 2009		

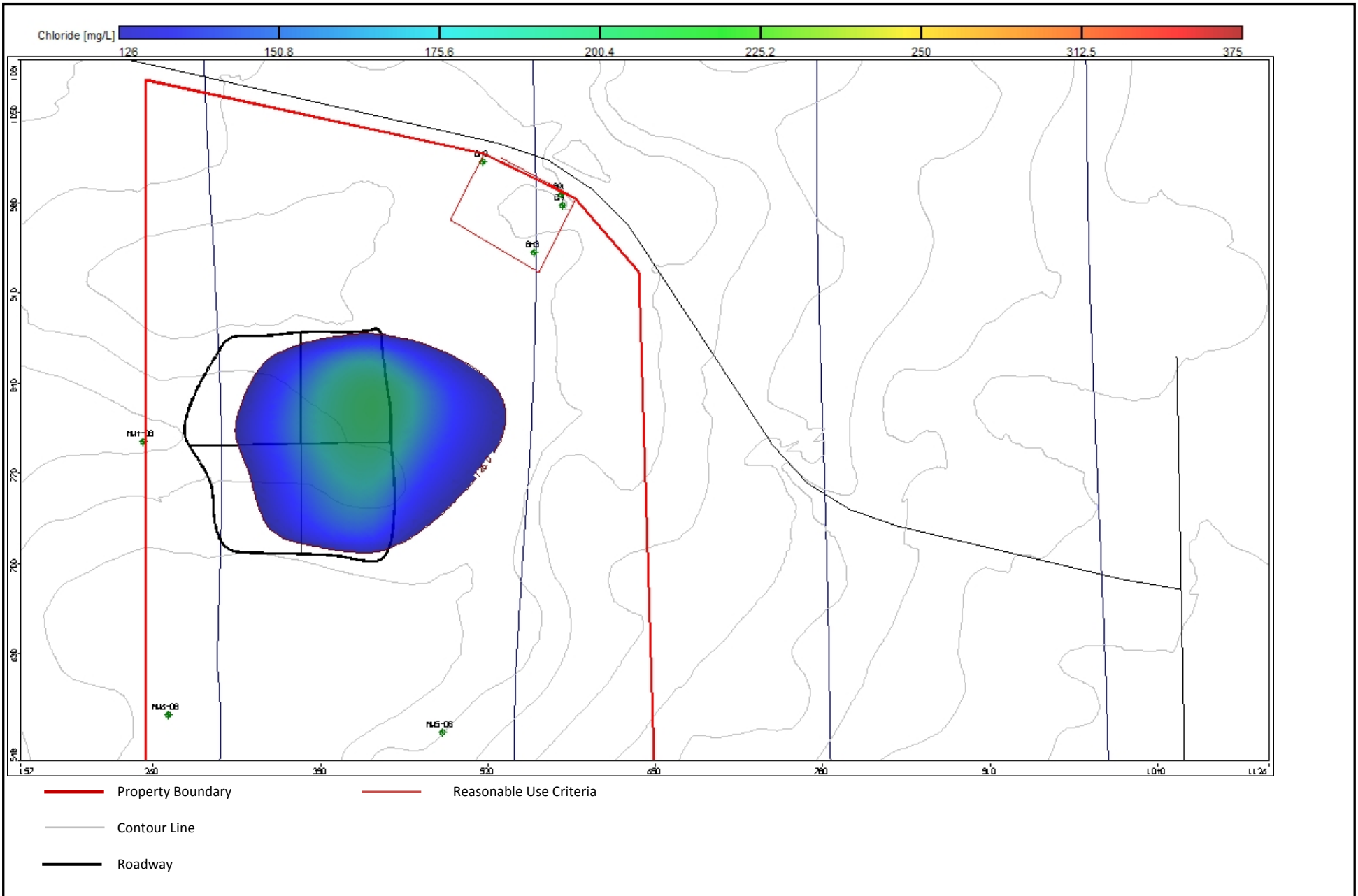
DECREASED SPECIFIC STORAGE SENSITIVITY ANALYSIS (LAYER 3)
 Numerical Hydrogeological Modeling Report for Expansion
 Feasibility of the Ruby Road Waste Disposal Site



PO Box 325, 2085 Whittington Drive
Peterborough, Ontario, K9J 6X4
Tel: 705-742-7900 Fax: 705-742-7907
www.cambium-env.com

Created by:	CMT	Project No.:	07-1219-001
Checked by:	JPD	Scale:	NTS
Date:	January 2009		

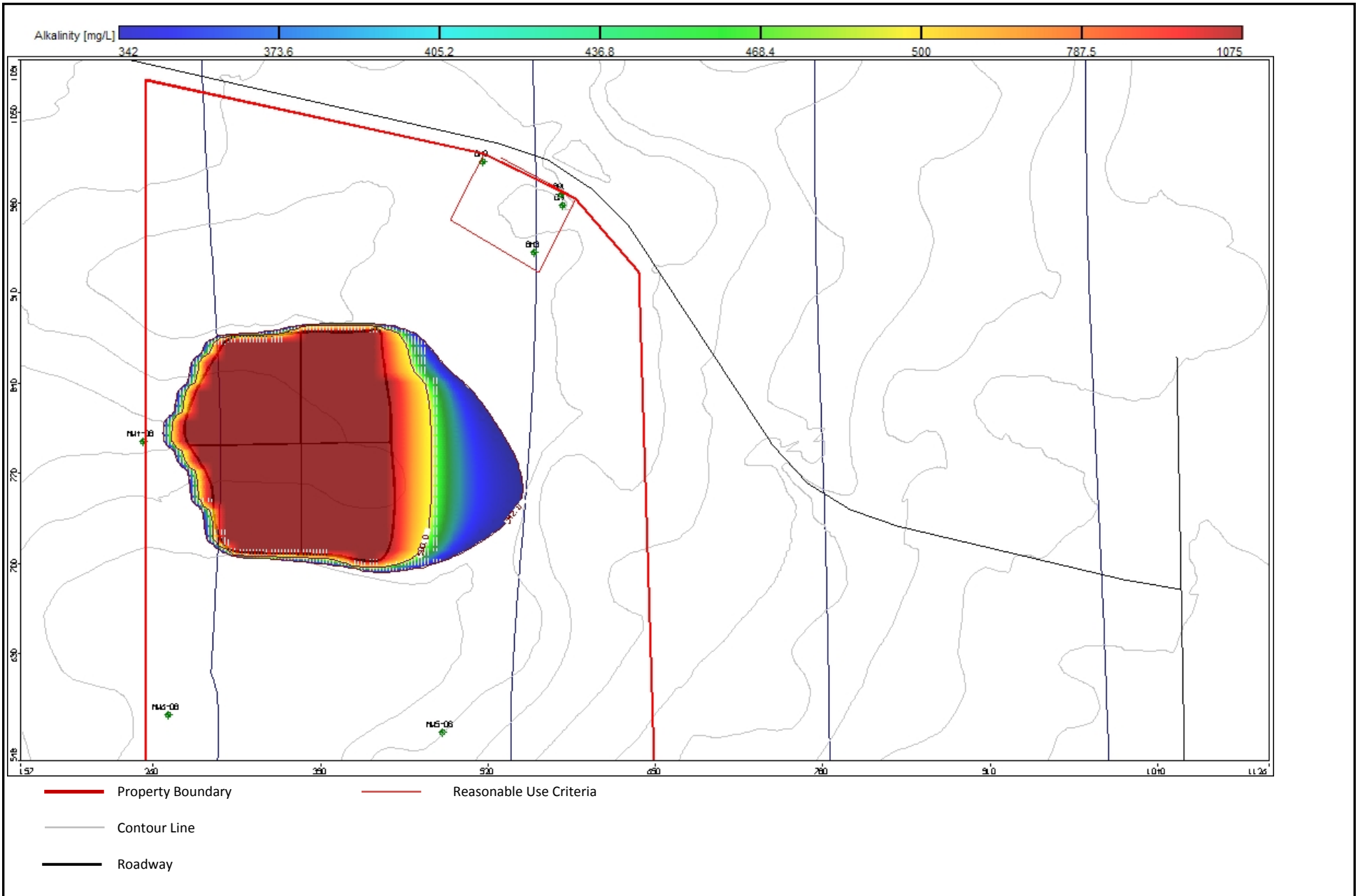
PROPOSED EXPANSION CHLORIDE PLUME (LAYER 2)
Numerical Hydrogeological Modeling Report for Expansion
Feasibility of the Ruby Road Waste Disposal Site



PO Box 325, 2085 Whittington Drive
Peterborough, Ontario, K9J 6X4
Tel: 705-742-7900 Fax: 705-742-7907
www.cambium-env.com

Created by:	CMT	Project No.:	07-1219-001
Checked by:	JPD	Scale:	NTS
Date:	January 2009		

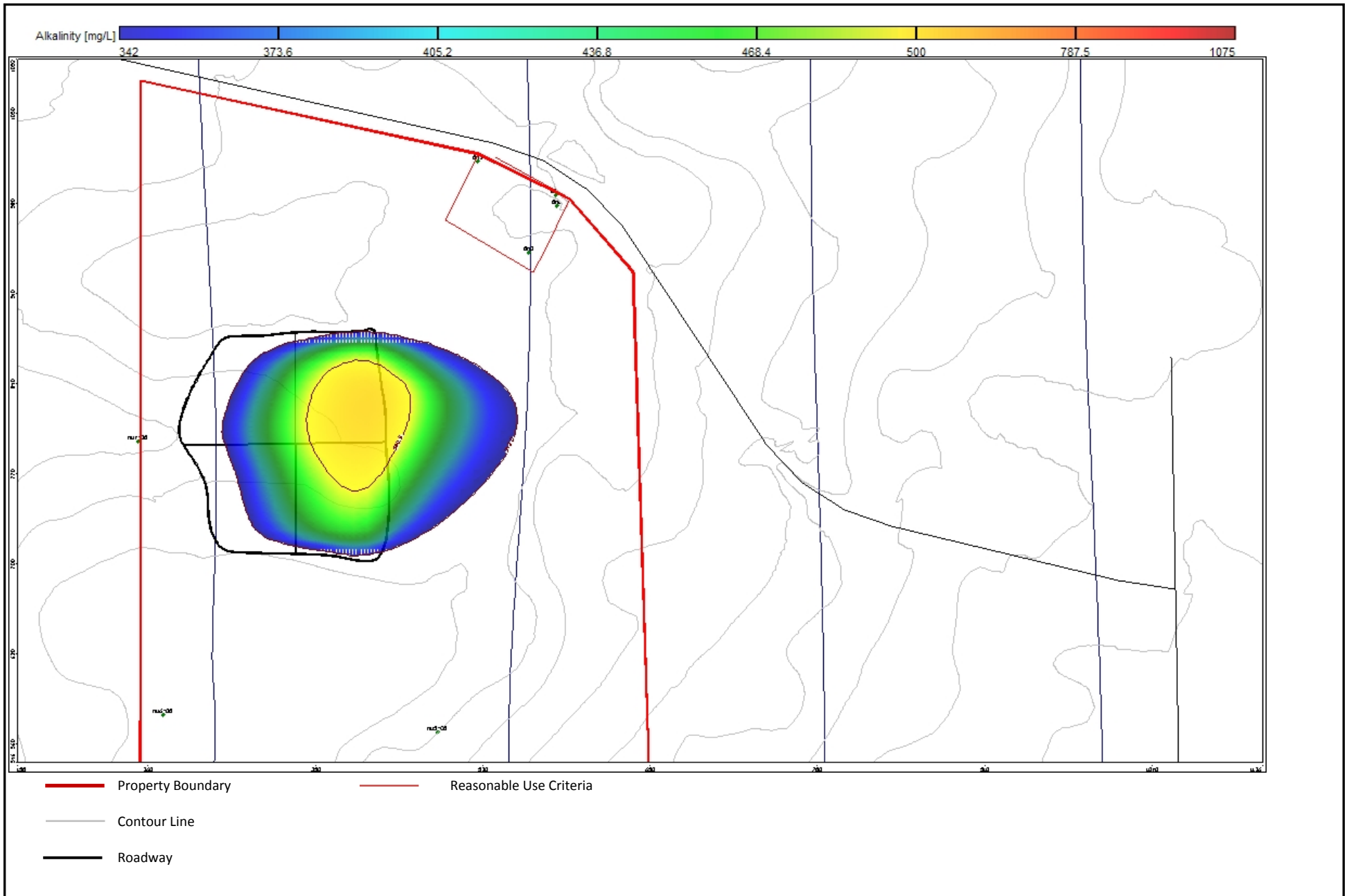
PROPOSED EXPANSION CHLORIDE PLUME (LAYER 3)
Numerical Hydrogeological Modeling Report for Expansion
Feasibility of the Ruby Road Waste Disposal Site



PO Box 325, 2085 Whittington Drive
 Peterborough, Ontario, K9J 6X4
 Tel: 705-742-7900 Fax: 705-742-7907
 www.cambium-env.com

Created by:	CMT	Project No.:	07-1219-001
Checked by:	JPD	Scale:	NTS
Date:	January 2009		

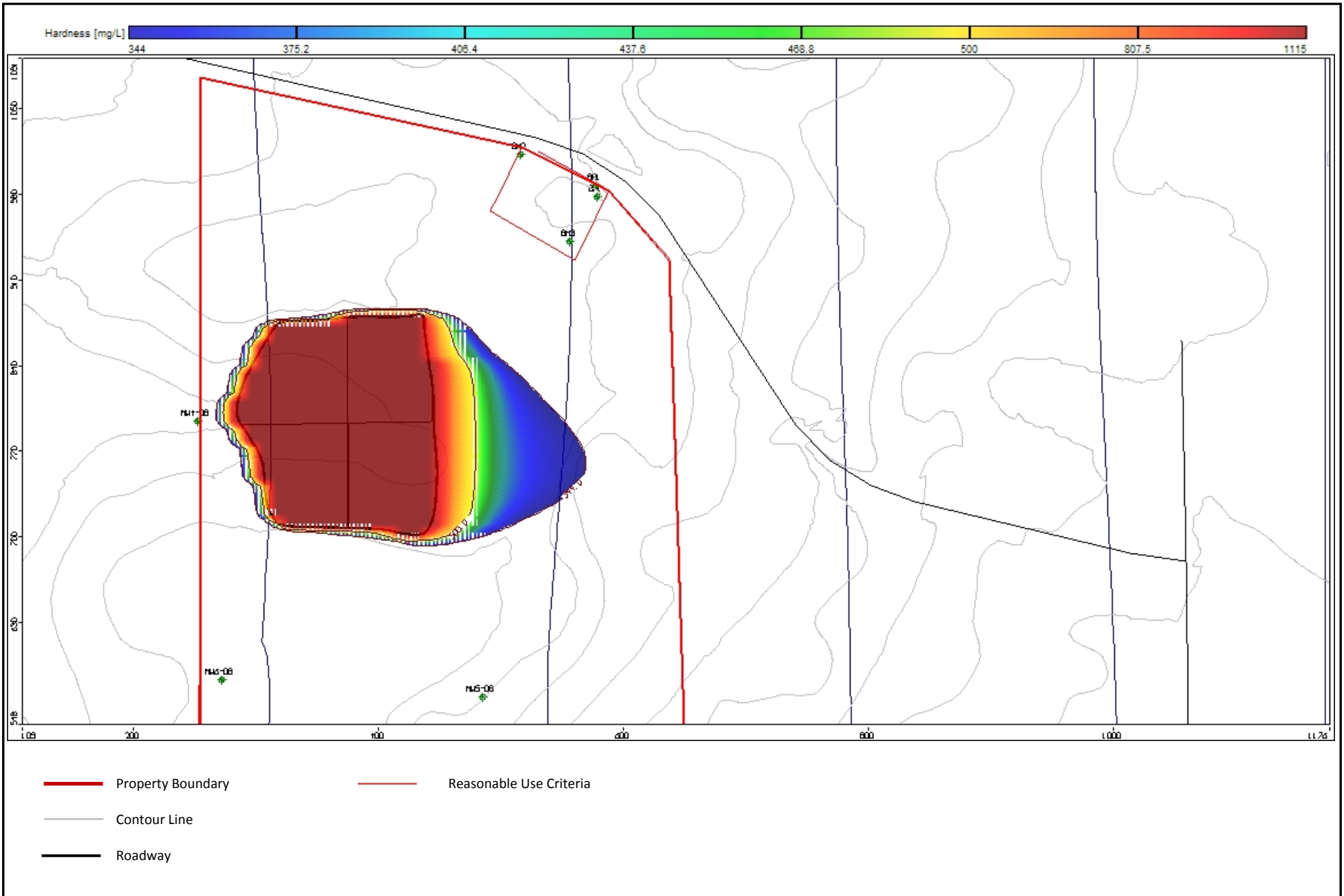
PROPOSED EXPANSION ALKALINITY PLUME (LAYER 2)
 Numerical Hydrogeological Modeling Report for Expansion
 Feasibility of the Ruby Road Waste Disposal Site



PO Box 325, 2085 Whittington Drive
 Peterborough, Ontario, K9J 6X4
 Tel: 705-742-7900 Fax: 705-742-7907
 www.cambium-env.com

Created by:	CMT	Project No.:	07-1219-001
Checked by:	JPD	Scale:	NTS
Date:	January 2009		

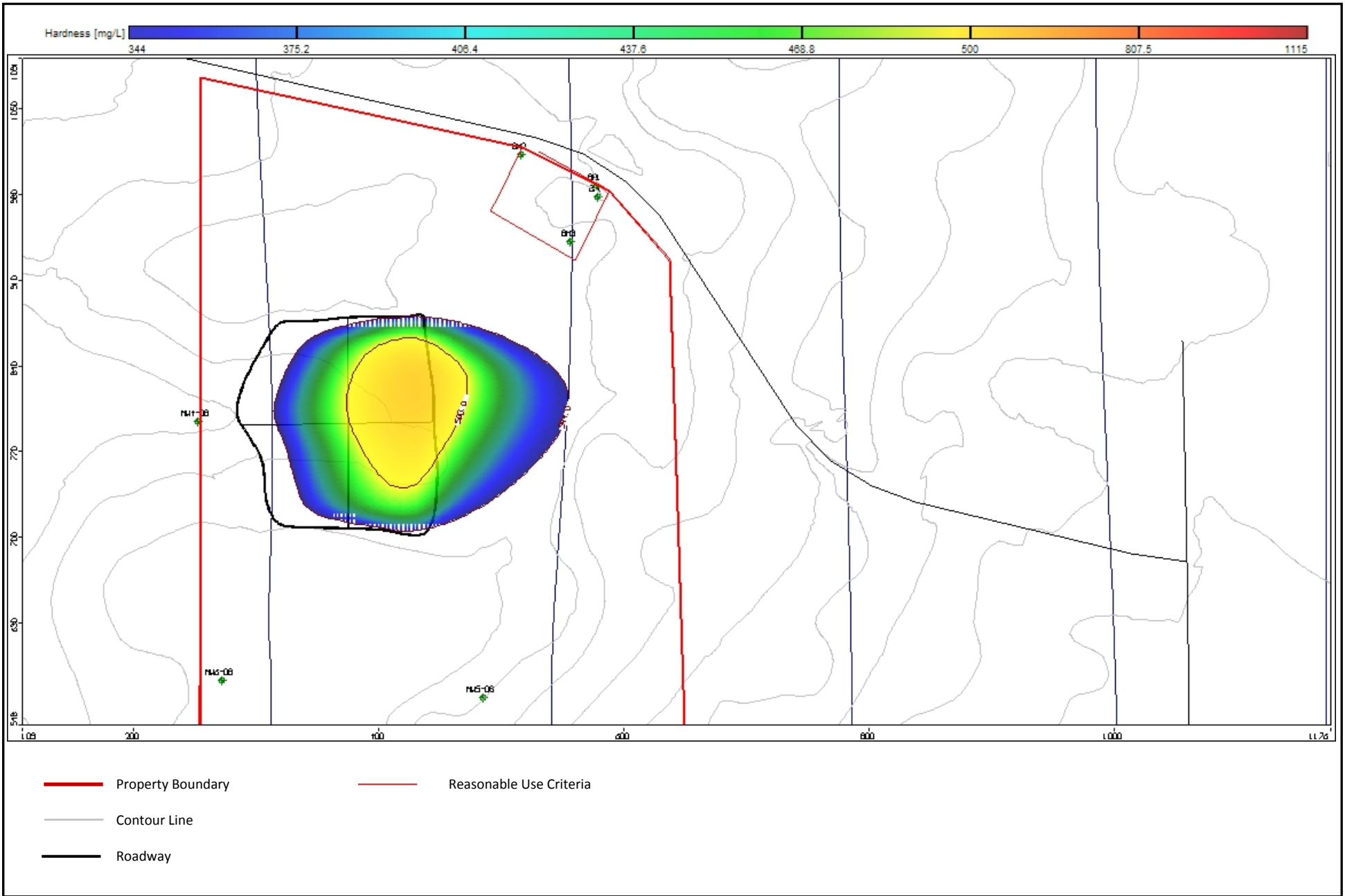
PROPOSED EXPANSION ALKALINITY PLUME (LAYER 3)
 Numerical Hydrogeological Modeling Report for Expansion
 Feasibility of the Ruby Road Waste Disposal Site



PO Box 325, 2085 Whittington Drive
Peterborough, Ontario, K9J 6X4
Tel: 705-742-7900 Fax: 705-742-7907
www.cambium-env.com

Created by:	CMT	Project No.:	07-1219-001
Checked by:	JPD	Scale:	NTS
Date:	January 2009		

PROPOSED EXPANSION HARDNESS PLUME (LAYER 2)
Numerical Hydrogeological Modeling Report for Expansion
Feasibility of the Ruby Road Waste Disposal Site



PO Box 325, 2085 Whittington Drive
Peterborough, Ontario, K9J 6X4
Tel: 705-742-7900 Fax: 705-742-7907
www.cambium-env.com

Created by:	CMT	Project No.:	07-1219-001
Checked by:	JPD	Scale:	NTS
Date:	January 2009		

PROPOSED EXPANSION HARDNESS PLUME (LAYER 3)
Numerical Hydrogeological Modeling Report for Expansion
Feasibility of the Ruby Road Waste Disposal Site



Appendix A

Pre-screening Mass-balance Calculations
