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(59)

REPORT ON

MINISTRY OF TRANSPORTATION ONTARIO GROUNDWATER OPTIMIZATION ASSESSMENT OF PROPOSED HIGHWAY 416 CONSTRUCTION ON LYNWOOD SUBDIVISION AND BRUCE PIT EAST POND NEPEAN, ONTARIO

Submitted to:

Ministry of Transportation Ontario
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February 1995

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February 2, 1995

941-1129C

Ministry of Transportation Ontario
Planning and Design Section
355 Counter Street
Postal Bag 4000
Kingston, Ontario
K7L 5A3

Attention: Mr. B. Ruck, P. Eng.

RE: MINISTRY OF TRANSPORTATION ONTARIO
GROUNDWATER OPTIMIZATION ASSESSMENT OF
PROPOSED HIGHWAY 416 CONSTRUCTION ON LYNWOOD SUBDIVISION AND
BRUCE PIT EAST POND, NEPEAN, ONTARIO

Dear Sirs:

Please find enclosed 6 copies of the above noted report. The purpose of this study was to define the most practical and cost-effective mitigation strategy to deal with potential depressurization groundwater flows associated with the Highway 416 cut near Baseline Road. The cut will allow the highway to underpass the railway line near Baseline Road.

The digital computer modelling evaluation indicated that the long-term groundwater flows and impacts would not be substantially different than those observed during the dewatering for the pull-back sewer. The mitigation options evaluated with the digital model to deal with these potential impacts were a cut-off wall, a pumping/recharge well system and a combination of the two. The results of the digital analysis demonstrated that each of the mitigation options could be applied to the situation, however, the cut-off wall is indicated to be more practical in that the pumping recharge system would require a complex, multi pumping/recharge well system.

The economic analysis that followed the digital evaluation ultimately defined the cut-off wall to be more cost-effective due to the general unreliability of predicting long-term operation and maintenance costs for the pumping/recharge well system.

The most practical and cost predictable option to mitigate the depressurization impacts of the proposed Highway 416 cut based on the above analysis is the full 400 metre cut-off wall around the total cut with contingencies, if required, based on low capacity bedrock recharge wells, bedrock grouting, an outlet control structure on the East Pond or a combination of the above.

We trust this report, which details the above general results, is adequate for your requirements, however, do not hesitate to contact the undersigned should you have further questions.

Yours truly,

GOLDER ASSOCIATES LTD.

R.D. Sinclair, P. Eng.
Senior Hydrogeologist/Environmental Engineer

A.F. Chevrier, P. Eng.
Associate

RDS:AFC:cr
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TABLE OF CONTENTS

1.0 INTRODUCTION

Long-term planning by the Ontario Ministry of Transportation (MTO) for a highway link between Highway 401 (MacDonald Cartier Highway) and Highway 417 (the Queensway) at Ottawa has been finalized by the design and on-going construction of Highway 416. Just south of the Highways 416 and 417 interchange, the Highway 416 alignment requires a deep cut into the native soil materials in order that Highway 416 underpasses both a railway line and Baseline and Richmond Roads, major arterial roads (See Key Plan, Figure 1). The deep soil cut associated with this underpass construction will intersect local water bearing sand and sand and gravel which could require both temporary and long-term groundwater depressurization systems depending on ultimate mitigation options.

Golder Associates Ltd. (GAL) has been retained by MTO to assess the potential impact of these works on both local structure foundations within the Lynwood subdivision and the surface and groundwater resources within the adjacent Bruce Pit and to provide recommendations to the most practical and cost-effective mitigation options. Previous GAL studies for MTO have defined that significant impacts to both the Lynwood subdivision and Bruce Pit pond are likely and that a cut-off wall and/or system of recharge wells or a combination of the two were the most effective mitigation options. The objective of this study is to define the most practical and cost-effective mitigation option or combination of options in order that MTO will be able to adequately schedule the design and construction requirements for any mitigation option into the present overall Highway 416 construction program.

The background information that precipitated this study is presented in the following section, namely 2.0 BACKGROUND.

2.0 BACKGROUND

The final planning phases for the Highway 416 route into Ottawa were completed in the 1980's. Since the early 1980's, there have been many different studies concerning the Bruce Pit area, all of which deal with a wide variety of topics. The NCC for example, commissioned a study in 1983 (NCC, Bruce Pit Section, Development Plan, 1984) and this study included an evaluation of potential impact of the proposed Highway 416 on the water quality and levels of the Bruce Pit Ponds. MTO has conducted several geotechnical studies at or adjacent to the Bruce Pit and Lynwood sites as well as a number of environmental studies. The earlier environmental studies focused on the characterization and handling of solid wastes previously buried on the Bruce Pit site below the proposed Highway 416 alignment. The most recent GAL report assessed both impact and mitigation options for depressurization systems proposed as integral parts of the Highway 416 construction. The above reports are listed below and are followed by a brief overview of pertinent results and conclusions.

Ministry of Transportation Ontario (MTO)

"Preliminary Investigation for Proposed Highway 416, Century Road to Highway 417", 1984, MTO Report 31G5-138 MTO, "Foundation Investigation Report for Cedarview Road/Highway 416 Underpass", WP121-87-06, District 9, Ottawa, July, 1991.

"Foundation Investigation Report for Cedarview Road/Highway 416 Underpass, W.P. 121-87-06, Site 3-544, District 9, Ottawa", July 1991.

Golder Associates Ltd. (GAL) (for MTO)

"Preliminary Geotechnical and Groundwater Study, Proposed Highway 416, Cedarview Road Corridor near the Lynwood Subdivision, W.P. 146-74-00-3, District 9 (Ottawa), Nepean, Ontario", March 1989.

"Geotechnical and Groundwater Study, Proposed Highway 416, Cedarview Road Corridor near the Lynwood Subdivision, W.P. 146-74-00-3, District 9 (Ottawa), Nepean, Ontario", January 1990.

"Geotechnical Investigation, Proposed Diaphragm Wall and Slope Cut, Highway 416, District 9 (Ottawa), Nepean, Ontario W.P. 126-87-01(A)", August, 1990.

"Engineering Study, Proposed Cut and Railway Underpass, Highway 416, District 9 (Ottawa), Nepean, Ontario, W.P. 121-89-00", August, 1990.

"Additional Subsurface Investigation, Geotechnical and Groundwater Study, Proposed Highway 416, Cedarview Road Corridor, Lynwood Subdivision Area, W.P. 416-74-00-3A, District 9 (Ottawa)", May, 1991.

"Pump Test, Geotechnical and Groundwater Study, Proposed Highway 416, Cedarview Road Corridor Lynwood Subdivision Area, WP. 146-74-00-3 District 9 (Ottawa) Nepean, Ontario", June, 1991.

"Groundwater Level and Precise Settlement Monitoring, Proposed Highway 416, Lynwood Subdivision, W.P. 121-87-00, District 9 (Ottawa)", December, 1992 (ongoing).

"Groundwater Impact Assessment of Proposed Highway 416 Construction, Bruce Pit, Nepean, Ontario, W.P. 121-87-00, District 9, Ottawa, Ontario", February, 1995.

Acres International (for MTO)

"Foundation Investigation for Bridge Structure, Proposed Highway 416 and CNR Subway, District No. 9, Ottawa, W.P. 126-87-01, Site 3-544", February 1990.

Golder Associates Ltd. (for City of Nepean)

"Subsurface Investigation, Proposed Storm Sewers, Lynwood Subdivision, Nepean, Ontario", July 1990.

Golder Associates Ltd. (for Regional Municipality of Ottawa-Carleton)

"Geotechnical Investigation, Proposed Bell's Corners Pull-Back Sewer, Phases I and II, Nepean, Ontario", December, 1993.

Conestoga Rovers and Associates (CRA) (for MTO)

"Bruce Pit, Abandoned Landfill Site Investigation, Study Design", April, 1988

"Abandoned Landfill Site Investigation, Bruce Pit, Ottawa, Ontario", January, 1989

"Addendum 1, On-Site Waste Material Relocation, Bruce Pit, Nepean, Ontario", April, 1991

Ecoplans Limited (for MTO)

"Environmental Assessment of Highway 416, Century Road to Highway 417, Volume 1: Appendix A, Supplementary Report C, Bruce Pit: Former Landfill Site", December 1986

Gartner Lee Limited (GLL) (for MTO)

"Environmental Monitoring Report for Bruce Pit, 1992 - 1993," March 1994

National Capital Commission (NCC)

Corush Larocque and Sunderland and Partners Ltd. "Bruce Pit Sector - Development Plan", February 1984

The previous studies documented above provided a significant data base in terms of defining the local site conditions at and adjacent to the Lynwood subdivision and the Bruce Pit. The many geotechnical reports provided significant subsurface information in terms of defining local hydrogeologic conditions.

For example, the 1991 Golder Associates pump test report concluded that the long-term piezometric depressurization required adjacent to the rail underpass could be expected to influence groundwater levels locally during both construction and over the long-term. That report also indicated that the long-term groundwater flow rates and associated piezometric lowering especially within the Lynwood subdivision would be best defined during the early phases of construction depressurization.

In terms of the environmental studies, the 1989 CRA reports concluded that the solid waste buried within the Bruce Pit sand deposits had not adversely impacted either the local surface or groundwater. As well, that study concluded that the buried solid waste would be optimally handled by excavating and moving all such wastes to an on-site, environmentally sound solid waste repository.

The waste repository was constructed at the Bruce Pit site as located on Figure 2, the Site Plan. The 1992 and 1993 surface and groundwater monitoring of this repository by GLL has demonstrated no significant surface or groundwater impacts. One monitor, OW8-90 did demonstrate an increasing trend for conductivity, hardness and dissolved organic carbon through to 1993 (GLL, 93) however the most recent data collected by GAL during 1994 has shown significant reductions in both conductivity and hardness while dissolved organic carbon was not monitored.

Also, it should be noted that the 1984 NCC Bruce Pit development plan concluded that the proposed 416 Highway would not significantly impact on the surface and groundwater regimes of the Bruce Pit based mainly on the small area loss of the drainage basin for the proposed Highway 416 footprint. It would appear however, that the long-term depressurization requirements and related groundwater flows associated with the proposed underpass were undefined at that time.

In terms of assessing and predicting the local groundwater impacts of the proposed depressurization system for the Highway 416 section near the underpass structure with a relatively high degree of confidence, the local groundwater data collected as a result of the pull-back sewer depressurization system provided the first high capacity aquifer assessment data. Prior to the depressurization and groundwater pumping flows associated with pull-back sewer construction, the assessment and prediction of future impacts was based on point source data at many boreholes and one low capacity pump test. This data was sufficient to show that there should be concern for impacts within both the Lynwood subdivision and the Bruce Pit pond, however the necessary degree or scope of contingency planning for the Bruce Pit pond was less definitive than typically desired due to the broad range of possible depressurization flowrates. The relatively broad range of permeabilities in the sand and gravel deposits would facilitate only a similarly broad range of estimated flows. The groundwater data from the pull-back sewer depressurization flowrates remedied much of this uncertainty and facilitated the use of digital groundwater models to further refine predictions.

The above reports and general pull-back sewer groundwater data provided a basis for the development of the Scope of Work/Work Program as presented in the following section.

3.0 SCOPE OF WORK/WORK PROGRAM

3.1 Scope of Work

The Scope of Work for the work program of this study resulted from the meeting of October 7, 1994 between GAL and MTO representatives during which the overall local groundwater impacts of the pull-back sewer depressurization and general mitigation requirements for the future underpass depressurization were discussed. The specific Scope of Work resulting from this meeting are as follows:

(1) Define the approximate future depressurization flowrate for the Highway 416 underpass area based on the present data base with no provision for mitigation options.

(2) Define the impacts and effectiveness of the full range of individual and combinations of cut-off curtain/wall and recharge wells to mitigate potential groundwater impacts of the proposed 400 metre length of Highway 416 depressurization system on both the Lynwood subdivision and the Bruce Pit pond.

(3) Define the relative capital and operating costs of the above range of individual and combinations of mitigation options for a 50 year life-cycle.

(4) Define the most practical and cost effective mitigation option or combination of options for the long-term mitigation of groundwater impacts associated with the Highway 416 underpass structure.

3.2 Work Program

The Work Program developed by GAL to effectively deal with the above Scope of Work is as follows:

(1) Describe and quantify the hydrogeologic parameters which describe the general conceptual model of the local groundwater flow system.

(2) Quantify the approximate impacts of the pull-back sewer depressurization flowrates on the local groundwater flow systems.

(3) Define the most appropriate digital groundwater modelling system or systems to facilitate predictive modelling of potential future groundwater impacts of Highway 416 construction as well as the general effectiveness of mitigation strategies.

(4) Using the overall data base but especially the pull-back sewer depressurization hydraulic data, calibrate the appropriate digital groundwater model.

(5) Conduct a series of predictive modelling exercises to provide quantitative estimates of relative effectiveness of the range of mitigation strategies over the full length of depressurization system, some 400 metres in length.

(6) Based on the above predictive modelling exercise, define the components and associated capital and operating costs based on a 50 year life cycle using standardized actuarial procedures.

(7) Provide clear and concise conclusions to MTO with respect to the most practical and cost-effective mitigation option.

The above Work Program is developed through the main body of this report.

4.0 GENERAL PHYSICAL ENVIRONMENT

4.1 Introduction

Much of the information defined in this chapter of the report has been exerpted from another, closely associated report namely, "Groundwater Impact Assessment of Proposed Highway 416 Construction on Bruce Pit, Nepean, Ontario (GAL, December 1994). This information has been included with this report to facilitate a more "stand-alone" report, however the reader is strongly advised to be aware of the details of the above report as well as other reports defined earlier in order to better comprehend the direction and evaluation of this report. Also, the general groundwater effects of the pull-back sewer depressurization system are discussed in this report, the detailed data base is presented in an ongoing study, namely "Groundwater Level and Precise Settlement Monitoring, Proposed Highway 416, Lynwood Subdivision, Nepean, Ontario (GAL 1992, ongoing).

4.2 Physiography

The Bruce Pit area is within the Ottawa Clay Plains region. The Bruce Pit is a granular upland within this larger, extensive clay plain region with a maximum elevation of approximately 100 metres above sea level (ASL) while the bottom drainage basin, the Bruce Pit Pond, is at approximately elevations 87 metres (ASL). Local drainage is generally poorly developed due to the presence of extensive granular surface deposits and associated high infiltration potential. Surface drainage has been developed from the Bruce Pit into Graham Creek, a tributary of the Ottawa River. The underlying bedrock is reported to be composed of dolostone of the Oxford formation. Only the West Pond, a much smaller pond than the East Pond within the Bruce Pit area, has been infilled with blast shot rock to allow for the Highway 416 corridor to be raised to design grades.

Meteorologic conditions for the area indicate average monthly temperatures, average annual precipitation and annual lake evaporation are minus 15.4 to plus 14.9 degrees centigrade, 879 millimetres and 611 millimetres respectively.

4.3 Bedrock and Surficial Geology

4.3.1 Bedrock Geology

The bedrock underlying the site is composed of dolostone of the Oxford formation. Bedrock core information from the area during the many geotechnical evaluations indicate thin to thickly bedded dolostone with some sandstone layers and shale partings, as well as some horizontal jointing demonstrating weathering features. Bedrock outcrops of Oxford formation are indicated on bedrock mapping to be present approximately half a kilometre to the north-west and one kilometre to the south-west. The Oxford formation is underlain by the sandstone and sandy dolostone of the March formation.

4.3.2 Surficial Geology

The surficial geology of the site is variable in terms of both lateral and vertical extent. Laterally, the surficial sands which blanket most of the southern part of the study area abut a cap of mainly marine clay to the north, towards the rail underpass. The approximate boundary of the sands and clays based on the many boreholes in the area is presented on Figure 2, the Site Plan.

The borehole data demonstrate that the sand deposits are composed of fine to coarse, interlayered sands which thin and ultimately pinch out to the north and west as presented on Figure 3, Subsurface Profile. The limit of these sands below the clay is also shown on the Site Plan, Figure 2. It is the clays below the Lynwood subdivision that are potentially susceptible to consolidation effects associated with the possible depressurization impacts within the underlying sands. These sands have been determined to be in excess of 22 metres thick near the east end of the ponds. More recent borehole data obtained by GAL during November 1994 has demonstrated the presence of a coarse granular deposit under the Highway 416 corridor between the Bruce Pit and the proposed depressurization area.

Glacial till underlies much of the sand deposits with thicknesses of approximately 6 metres defined near the Cedarview bridge crossing, just north of the former West Pond and east of the East Pond. Some boreholes indicate that the till has been eroded or possibly not deposited as sand is found directly overlying the dolostone bedrock in some areas.

4.4 Surface Water Hydrology

A detailed evaluation of the local surface water hydrology for the Bruce Pit area was outside of the scope of work for the present work program. Some general estimate of the local surface water hydrology would assist however in the evaluation of the potential impact of groundwater depressurization flows.

The present surface water evaluation is based on previous reports (GAL, December 1994) as outlined in Section 4.1, Introduction.

The meteorologic and sub basin characteristics for the Bruce Pit water basin are as follows:

Meteorologic

Average annual precipitation (rain and snow)	879 millimetres
Average annual snowfall	2270 millimetres
Average annual snowfall water equivalent	227 millimetres
Average annual lake evaporation/transportation	611 millimetres

Sub Basin and Pond Characteristics

Sub Basin Area (after NCC, 1984)	125 hectares
East Pond Area	6.7 hectares
East Pond Volume	25,000 cubic metres
Average Net Inflow per year (Precipitation-Evapotranspiration)	335,000 cubic metres
Average Net Inflow per day	920 cubic metres
Number of Pond Turnovers per year	4.5

The above information indicates that the shallow ponds have a significant inflow water that is equivalent to approximately 4 to 5 pond volumes. This inflow volume is composed of both groundwater and surface water; the earlier NCC Bruce Pit Sector Report (1984) indicates that run-off including snow melt was the major pond inflow source with groundwater inflows being a more minor source. Recent observations reinforce the above statements with little outflow observed at the beaver dam during the winter or during dry weather. The dam has, however, been observed to be overtopped during and following storm events.

4.5 Groundwater Hydrology

4.5.1 Borehole Data

The surficial geology of the Bruce Pit area is characterized by a thick sequence of interlayered fine to coarse sands underlying and flanking both the pond and Lynwood subdivision. The sands and gravel deposits demonstrate hydraulic conductivity values which range from $1x10^{-1}$ to $1x10^{-4}$ centimetres per second based on both rising head and grain size data. These sands pinch out to the north and west against low permeability marine clays. Below the Lynwood subdivision the sands grade finer and thinner to the west and pinch out within about 100 to 150 metres of Cedarview Road. Where present, the glacial till deposit forms a relatively low permeability barrier over the bedrock surface. The range of hydraulic conductivities for the till based on grain size distribution demonstrate all values in the $1x10^{-4}$ to $2x10^{-6}$ centimetres per second range with exception to 1 value of $1x10^{-3}$ centimetres per second.

The significance of the bedrock formation in terms of the overall local groundwater hydrology is generally defined and indicates much lower permeabilities than the surficial sands and gravels. The bedrock core data that have been obtained generally indicate sound bedrock with core recoveries at or near 100 percent. The associated pressure packer testing indicated generally low, horizontal permeability with no water take in many of the 1.5 metre test zones and with higher water takes in the order of only 0.4 to 0.5 litres per second (6 to 7 Imperial gallons per minute). The range of mainly horizontal hydraulic conductivities defined by packer testing for the bedrock formations at boreholes 89-2 and 89-6 was 2.0×10^{-3} to less than 1×10^{-6} centimetres per second. Furthermore, the vertical permeability of horizontally layered bedrock is typically several times less than the horizontal permeability, especially below the upper weathered or fractured zone. As a consequence, even the higher permeabilities in the bedrock are one to as much as to two orders of magnitude less permeable than the overlying sands. The hydraulic conductivity results from packer tests for bedrock boreholes at the Bruce Pit site are presented in the associated GAL report, defined in section 4.1.

The piezometric levels in the bedrock are several metres below that of the surficial sands and indicate a potential for downward groundwater flow from the sands into the bedrock. If this potential vertical downward groundwater flow was significant, it would be expected that the pond levels would decline, especially over the winter and as well, the water levels in the sands should demonstrate a gradient away from the ponds. Neither of the above conditions have been observed and in conjunction with the packer test results, generally indicates that the bedrock is not significantly interacting hydraulically with the surficial sand aquifer. More recent bedrock core and packer test data has demonstrated similar hydraulic conductivities. As well, bedrock excavation north and west of the cut near Baseline and Richmond Roads are essentially dry.

4.5.2 Pull-Back Sewer Depressurization Data

The Bell's Corners pull-back sewer is a 900 millimetres diameter concrete pipe with an invert elevation near 80 metres ASL or some 7 metres below the general groundwater level. In the area of excavation, local materials graded from silty clay to coarse sands and gravels from north to south. The contractor for the pull-back sewer, Peter Kiewit Sons Construction Ltd. with Griffin Groundwater Management Ltd. sub-contracted to lower water levels in the sand and gravels to below invert levels so that all excavation and pipe laying could be conducted in essentially dry conditions.

The depressurization system developed by Griffin used 2 stages of wellpoints connected to headers and vacuum pumps. At the outset of depressurization in early August 1994, the system included a single line of wellpoints at ground surface and one vacuum pump while at the end of construction, the system included two rows of wellpoints along each side of the excavation connected to three vacuum pumps. The final few weeks of pumping had few changes to mechanical system with relatively steady flowrates measured at approximately 2600 cubic metres per day (400 Imperial gallons per minute) by GAL staff.

The drawdown data associated with this latter period of depressurization indicated water level declines of approximately 7 metres within the excavation, 2.5 metres below the Lynwood subdivision and 0.7 metres adjacent to the north-east corner of the East Pond at GAL borehole 93-2. The fact that the proposed Highway 416 alignment and related depressurization system is closer to Lynwood subdivision, was in similar sands and gravels to the pull-back sewer excavation and that the cut depressurization would be up to 9 metres, indicated that at least similar and potentially more significant hydraulic impacts could be expected for the cut. It could be expected that Lynwood subdivision would have more serious drawdown effects due to the closer proximity to the Highway 416 depressurization system than the pull-back sewer.

The pull-back sewer data also showed that the East Pond would be impacted by the long-term effects of continuous depressurization but that the hydraulic connection would not be direct. The coarse sand and gravel deposits which underlie the pond and extend toward the depressurization zone appear to be separated by a sequence of finer sands. If these coarser materials had been directly hydraulically connected to the pond bottom sediments, the potential impacts on pond water levels would have been much more severe. As it was, during the maximum drawdown of approximately 0.7 metres below the pond, the fluid level of the pond declined steadily at approximately 6 millimetres per day. It should be noted that this decline also included evapotranspiration however declines were still significant into October when evapotranspiration is greatly reduced. The potential impacts of long-term depressurization on the East Pond fluid level, especially during the winter when no recharge will occur, could be expected to be significant and losses are estimated to be in the range of 260 to 460 cubic metres per day (40 to 60 Imperial gallons per minute) or 0.4 to 0.6 metres decline respectively over 100 winter days based on the current data.

The fact that the source of most of the pull-back sewer flowrates is not well defined adds further uncertainty as to possible drawdown effects beyond the present monitoring system. Other data for example, indicates that the sand and gravel potentially extends to the east beneath other subdivisions and below the clays to the east of the Queensway-Carleton Hospital. There is potential for long-term impacts in these eastern areas similar to those which could occur in the Lynwood area. The final mitigation strategy for the underpass depressurization system should focus on the maintenance of the status quo if possible in order to deal with potential impacts beyond the current monitoring system.

5.0 DIGITAL COMPUTER ANALYSIS

In this section, the focus of analysis is directed at the evaluation of individual and combined effectiveness of the two primary mitigation options, namely the cut-off wall and the pumping recharge well system to minimize potential hydraulic impacts of the depressurization systems associated with the Highway 416 cut near the Bruce Pit and Lynwood subdivision areas. Currently, the most practical methodology to assess a variety of individual and combined hydraulic mitigation options such as a cut-off wall or recharge well system is to utilize digital computer techniques.

Based on the fact that the long-term steady state impacts were of prime importance and there was only a single aquifer system (sand and gravel), a steady-state, two-dimensional digital model in the plane was chosen for analytical purposes. Flowpath is a commercially available model commonly utilized for similar hydraulic groundwater analysis by Golder Associates Ltd. and it was this model which was chosen for this analysis. A general description of the Flowpath model is presented in the following section.

5.1 Flowpath Model

Flowpath (version 5) is a steady-state, two-dimensional, horizontal aquifer simulation model. Flowpath has been developed under license by Waterloo Hydrogeologic Software. The model utilizes a finite difference mathematical technique to solve the steady-state groundwater flow equation. The model facilitates significant variability of aquifer conditions including hydraulic conductivities, porosities, aquifer thickness as well as vertical leakage and recharge rates. Boundary conditions can also be variable and can include constant head, constant flow and no-flow systems. Furthermore, the model facilitates both pumping and recharge wells as well as constant head wells and drainage wells.

In terms of the problem at hand, the Flowpath model would allow variable configurations of hydraulic conductivities to simulate the cut-off wall as well as complex recharge well pumping well and drain systems combinations to simulate the Highway 416 depressurization systems with adjacent recharge wells. The conceptual groundwater model and Flowpath model configuration for the Bruce Pit and Lynwood area are presented in the following sections.

5.2 Conceptual Groundwater Model

The primary concept of the groundwater model in the Bruce Pit and Lynwood subdivision areas is that of a confined, artesian aquifer. It is low permeability clay over the sand and gravel that predominate in the high drawdown areas around the Highway 416 cut. It is understood that the aquifer system is unconfined to the south and east around and beyond the Bruce Pit pond, however, the drawdown in these areas is relatively low such that the unconfined condition does not materially comprise the analysis. These areas to the south and east are beyond the current monitoring system but would appear to include significant areas and thicknesses of saturated sands. It is these areas which are theorized to furnish the bulk of the water to the groundwater flow system. Excess water is theorized to leave the system through the surface discharge pathway from the Bruce Pit Pond.

To the north and west, the geologic information demonstrates that the sand and gravel deposits pinch out with mainly clay deposits continuing in these directions. This low permeability, mainly clay formation especially to the north, forms an effective hydraulic barrier which prevents drainage of the sand and gravel deposits through to the northern lowland area.

To the south-west, the hydraulic characteristics of the aquifer and associated boundaries are relatively undefined, however, the more approximate interpretation of hydraulic conditions away from main drawdown areas have a generally lower sensitivity on the modelling process.

The Flowpath model assessment of the various cut-off wall and recharge well systems mitigation options, based on the above conceptual model, is presented in the following section.

5.3 Flowpath Model Assessment

5.3.1 Model Configuration and Calibration

Two general configurations of the Flowpath model were applied to the groundwater flow system in the Bruce Pit and Lynwood subdivision areas and are presented in Appendix A; Flowpath Model Parameter Configurations, namely boundary conditions and hydraulic conductivities, are presented as BC1 and BC2. The initial model configuration developed, namely BC1, included a slightly leaky aquifer condition west of the Lynwood subdivision and a constant head condition through the Bruce Pit pond. The second model configuration, namely BC2, included a no flow boundary condition west of the Lynwood subdivision and a constant head boundary south of the Bruce Pit pond. This latter configuration was conducted to evaluate drawdown conditions below the pond area as requested by MTO.

The aquifer is represented by the range of thicknesses from the boreholes and as generally defined in Figure 3, Subsurface profile Cross-Section A-A. The porosity for all sand and gravel deposits was incorporated as a constant 25 percent. The zones of hydraulic conductivity following the calibration assessment discussed below ranged from 1 to 35 metres per day ($1.2x10^{-3}$ to $4.0x10^{-2}$ centimetres per second), respectively. Hydraulic conductivity values in this range are quite typical of those estimated from rising head tests and grain size curves as well as the single, low capacity pump test.

The calibration curves Figures BC1-1 and BC2-1 developed for the model as presented in Appendix A, as noted earlier were based on the observed hydraulic head data from the pull-back sewer depressurization which indicated drawdowns within the excavation proper, within the Lynwood subdivision and at the north-east corner of the Bruce Pit pond of approximately 7.0, 2.5 and 0.7 metres, respectively for a measured flowrate of approximately 2600 cubic metres per day (400 Imperial gallons per minute). There are two calibration curves as there was some difficulty to produce observed drawdowns within the Lynwood subdivision due to the apparent complexity of the local boundary conditions to the west and possibly north of the subdivision. The drawdown within the excavation and near the north-east corner of the pond were however, reasonably matched.

5.3.2 Digital Model Assessment of Mitigation Options

As noted earlier, the primary mitigation options proposed to deal with generally predicted depressurization effects within the Lynwood subdivision, at the Bruce Pit pond and likely beyond included individual and combinations of cut-off wall lengths and recharge well systems. The various scenarios of mitigation options included the following:

- no mitigation options (no cut-off wall or recharge wells)

- variable cut-off wall length (100, 200, 300 and 400 metres)

- combinations - 100 metres of wall, 300 metres of recharge wells; 200 metres of wall, 200 metres of recharge wells; 300 metres of wall, 100 metres of recharge wells.

The results of the above simulations are presented in Appendix A and are summarized on Table 1, Summary of Flowpath Modelling Results.

These results demonstrate that without any mitigation, the long term flows to the depressurization system for the Highway 416 cut would be quite similar to those measured for the pull-back sewer construction and in the order of 2400 to 2500 cubic metres per day (360 to 380 Imperial gallons per minute). The predicted drawdown effects at the Lynwood subdivision, in the order of 1.0 to 6.0 metres (BC1-2) are reasonable considering that the proposed highway cut is to be relatively closer to the subdivision than the pull-back sewer. The drawdowns below the pond for the no mitigation option indicate that the pond would go dry or be severely impacted during dry weather periods but especially during the non recharge periods of the winter.

For the cut-off wall alone, both model configurations evaluated produced very similar results with flows to the drain ranging from 2070 to 2100 cubic metres per day (310 to 315 Imperial gallons per minute) for 100 metres of cut-off wall to 600 to 1000 cubic metres per day (100 to 150 Imperial gallons per minute) for 300 metres of cut-off wall. For the full 400 metre length of cut-off, the flow to the drains can not be evaluated and should be assumed to equal the leakage factor through and under the wall. Present data suggest this flow should be small and likely less than 325 cubic metres per day (50 Imperial gallons per minute).

The above data demonstrate that, as would be expected, increasing the length of cut-off wall reduces flows to the proposed sub-drain system as well as drawdown impacts in the Lynwood subdivision and below the Bruce Pit pond. However, even with 300 metres of cut-off wall, the projected flows to the remaining 100 metres of drain are in the order of 610 to 1000 cubic metres per day (100 to 150 Imperial gallons per minute). Furthermore, these values are likely underestimated as there is no inclusion for leakage flows through or under the wall and the fact that recent drilling has defined very permeable sand and gravel connected to nearly all of the proposed Highway 416 subdrain system. These are significant factors in terms of assessing the ultimate practicalities of any mitigation options.

The last mitigation scenario assessed through the digital simulations was that which included combinations of both cut-off wall and recharge wells. This scenario was based on essentially eliminating drawdown impacts in the subdivision through varying lengths of cut-off wall and recharge wells through the full 400 metre length of underdrain system. The recharge flow rates presented in Table 1 ranged from 2700 cubic metres per day (410 Imperial gallons per minute for no cut-off wall to 330 cubic metres per day (50 Imperial gallons per minute) for a 300 metre length of cut-off wall. It should be noted that drawdown is predicted below the Bruce Pit pond for all of the above scenarios such that long-term impact on pond water levels can be expected. Furthermore, as noted earlier, the additional impacts of leakage through and under the wall as well as the recently defined, highly permeable sands and gravels below the highway 416 cut would tend to increase both recharge rates and impacts on the Bruce Pit pond.

Also, it should be noted that other scenarios for the combined cut-off wall and recharge wells system were conducted for wells within the lower permeability deposits within the subdivision. This option, however, was found to have limited effectiveness for controlling drawdown effects within the Lynwood subdivision and was not evaluated further.

The above digital simulations provided the necessary information to assess the capital and long-term operating costs associated with the various combinations of cut-off wall and recharge wells and this economic assessment is presented in the following section.

6.0 ECONOMIC EVALUATION OF CUT-OFF WALL ALTERNATIVES

A life cycle costing was carried out for the cut-off wall and recharge well option assuming two alternative sources of recharge water (RMOC and groundwater) as well as two possible unit costs for the wall construction.

In Scenario 1, it was assumed that Regional Municipality of Ottawa-Carleton (RMOC) water would be used to recharge the wells in the subdivision. Based on a discussion with RMOC staff, a 1995 water cost of $0.50 per cubic metre was used which is the cost of water to industrial users within the RMOC, exclusive of the sewer surcharge costs. For Scenarios 2 and 2a, the water for recharging was assumed to be obtained from nearby groundwater sources, primarily the sand and gravel overburden but possibly within the rock at or in the vicinity of the proposed Highway 416 cut. The amount of groundwater recharge for each of these options was obtained from the groundwater modelling described in Section 5 of this report.

To assess the sensitivity of the cost evaluation to the initial (capital) construction cost of the cut-off wall, Scenario 2 assumes that the construction cost of the cut-off wall will be about $108 per square metre (about $10 per square foot), while Scenario 2a assumes a somewhat greater cost of $129 per square metre (about $12 per square foot). The above cut-off wall costs were based on discussions with a local specialist contractor and agree with previous costs for similar projects. The lower wall cost assumes that the excavation for the cut-off wall is carried out within loose to compact soils using a modified hydraulic excavator, that the depth of the excavation is less than about 20 metres, and that the cut-off wall material consists of either a mixture of imported sand and gravel and bentonite (mixed on site with a pug mill or on a wide pad constructed of native sand and gravel), or a mixture of cement and bentonite. The higher wall cost assumes, in addition to the above factors, a somewhat slower rate of excavation through dense deposits, should they exist at this site.

The cost factors that were included in the analysis for the wall options are as follows:

- construction of the cut-off wall

- design and inspection of the cut-off wall, inclusive of additional subsurface investigation effort

- the potential savings in groundwater lowering during construction as a result of the reduction in the amount of water that would otherwise enter the excavation

- the installation of water supply wells (Scenarios 2 and 2a only), recharge wells, pumps, and underground pipes to provide recharge to both the subdivision and the Bruce Pit pond

- the operation and maintenance of the recharge wells and pumps for both the subdivision and the Bruce Pit pond

- the replacement of the pumps for both the subdivision and the pond at regular intervals during the project life

- the supply costs for RMOC water to recharge the wells in the subdivision (Scenario 1 only)

In terms of the above cost components, the capital and operating costs for the recharge and pumping wells as well as piping and valving are addressed in the following paragraphs. For Scenario 1, all recharge water has been assumed to be from the RMOC communal water supply system although there are some environmental concerns for such a long-term program. It has been assumed that all pertinent RMOC piping requirements such as back-flow preventers, shut-off valves and minimum 150 millimetre diameter piping would apply to the overall systems as would other factors such as frost protection. It has been assumed that a single recharge well would be able to handle 330 cubic metres per day (50 Imperial gallons per minute) over the long-term and that, with all plumbing, each well would cost near $10,000. The cost of 150 millimetre diameter pipeline to form a header to connect each recharge well has been estimated at $150 per metre of length. The capital costs for between 2 and 8 recharge wells and 100 to 450 metres of pipeline ranges from approximately $35,000 to $150,000. A minimum of 2 recharge wells has also been assumed to allow some redundancy.

For the Bruce Pit pond, the costs for 3 bedrock recharge wells, electrical connections, controls and a short piping system has been estimated at $50,000.

The operation and maintenance costs have been estimated at between $2,000 and $10,000 per year for the recharge well system and $3,000 for the pond recharge system.

For Scenarios 2 and 2A, all costs with exception to the cut-off wall remain the same. It has been assumed that recharge and pumping wells will have a long-term capacity the same as Scenario 1 or 330 cubic metres per day (50 Imperial gallons per minute). The cost of both completed recharge and pumping wells has been estimated to be $10,000 each with pipeline costs also at $150 per metre for 150 millimetre diameter pressure water pipe. Based on these unit costs, the capital cost for 8 recharge and pumping wells and 450 metres of pipeline would be approximately $230,000 while 2 recharge and pumping wells with 100 metres of pipeline would be approximately $55,000. Power for 8 pumping wells requiring 3.75 kilowatts (5 horsepower) per pump would cost approximately $15,000 per year based on electrical costs of $0.05 per kilowatt hour. For mechanical systems of this complexity, daily maintenance checks would not be unreasonable however, even if weekly maintenance checks by a private firm at $150 per visitation, these costs would be approximately $8,000 per year. The regular maintenance costs for cleaning recharge wells and redeveloping of pumping wells is estimated at $1,000 per well or $16,000 per year. The total estimated operation and maintenance cost for the most complex system is approximately $40,000 per year with less complex options proportionately less costly.

Also, the complete recharge and pumping well systems has been scheduled for replacement after 17 and 34 year periods as these reflect reasonable life periods for such systems.

The present value costs for each of the cut-off wall options are provided in Table B-1 to B-3 inclusive in Appendix B. The present values were based on a 50 year project life, an inflation rate of 5 percent and an interest rate of 9 percent.

The Scenario 1 costing indicates that the present value cost of the cut-off wall decreases with an increase in the length of the cut-off wall, due in large part to the annual cost of RMOC water to provide recharge to the subdivision. The present value costs range from about $11.3 M for no cut-off to about $1.6M for a 400 metre long cut-off wall.

The Scenario 2 and 2a costing does not indicate an unequivocal advantage for any of the wall length options. For Scenario 2, the present value costs range from about $1.5M for the 300 and 400 metre long walls to about $1.7M for the 100 metre long wall option. For Scenario 2a, the present values range from about $1.5M to $1.8M (exclusive of the contingency for the 400 metre long wall option). It is noted that the overall cost for the shorter wall options are very dependent on and sensitive to the annual operating and maintenance costs (electrical power, periodic maintenance, etc.). For instance, if the cost for electrical power increases above the escalation rate of 5 percent annually assumed in the analysis, the long-term cost advantage for the longer wall options would become much more evident.

In comparing Scenario 1 with Scenarios 2 and 2a, it is evident that there is a significant cost advantage to using groundwater sources to recharge the subdivision and the pond for cut-off wall lengths of 300 metres or less, and likely a small cost advantage for the 400 metre long cut-off wall option. Also, it should be understood that there are environmental concerns related to water quality that have not been factored into the economic analysis of the recharge wells. For example, a chemical spill along the completed Highway 416 could require the pumping/recharge system to be shut down. The above assumes that the sand and gravel below the future highway cut would be the only practical source of significant quantities of recharge water.

It should be emphasized that the costing is also highly dependent on the amount of leakage that occurs through the completed wall, since leakage through the wall affects the amount of recharge required in the subdivision and the pond. The cost estimates provided assume that the overall hydraulic conductivity of the cut-off wall will be in the order of 1×10^{-6} centimetres per second, which has previously been shown to be achievable using good construction techniques and materials, under the supervision of qualified personnel.

7.0 CONCLUSIONS

- The present geologic information demonstrates that the Lynwood subdivision and Bruce Pit area are underlain by sand and gravel sequences that are hydraulically connected.

- The pull-back sewer depressurization data collected during the summer/fall of 1994 confirmed and quantified this hydraulic connection with measured pumping flows of approximately 2600 cubic metres per day (400 Imperial gallons per minute) producing drawdowns in the sewer excavation, below the Lynwood subdivision and adjacent to the Bruce Pit pond of 7, 2.5, and 0.7 metres respectively.

- The pull-back sewer groundwater data demonstrated that a relatively significant impact to both the Lynwood subdivision and Bruce Pit pond could be expected from the proposed Highway 416 depressurization system and that the overall scale of impact would likely be somewhat greater than that observed during the pull-back sewer construction.

- The pull-back sewer construction produced groundwater impact data that facilitated digital computer predictions of future groundwater impact by the proposed Highway 416 cut to be estimated.

- The primary mitigation options to control potential groundwater impacts on the Lynwood subdivision and Bruce Pit pond were a low permeability cut-off wall, a system of recharge wells or a combination of these two options applied over the 400 metre length of the highway depressurization system.

- The optimum individual or combination of primary mitigation options was evaluated using Flowpath, a steady-state, commercially available finite difference groundwater model.

- The Flowpath computer modelling demonstrated that without any mitigation, long-term flows to the Highway 416 depressurization system would be similar to the 2400 cubic metres per day (400 Imperial gallons per minute) measured for the pull-back sewer and are estimated to be in the order of 2350 to 2500 cubic metres per day (360 to 380 Imperial gallons per minute).

- The digital simulations demonstrated that extending the cut-off wall through the Highway 416 depressurization system would reduce both flows and adjacent groundwater impacts however, flows in the order of 670 to 1000 cubic metres per day (100 to 150 Imperial gallons per minute) to the areas were still predicted with the 300 metre cut-off wall in place within the 400 metre length of depressurization system cut.

- The actual flow to drains and recharge wells can be expected to be somewhat higher than predicted due to the fact that no leakage through or under any of the cut-off wall options is included in the estimates and that recent borehole data has demonstrated highly permeable sand and gravel deposits below nearly all of the proposed Highway 416 cut.

- The life cycle costing demonstrated that the use of RMOC water would not be cost effective for even the lowest of recharge rates evaluated.

- The life cycle costing demonstrated that there is not a highly significant difference in cost between the cut-off wall and recharge well options when groundwater at no cost is utilized.

- The local sand and gravel deposits below the proposed roadway cut would be the only practical source of groundwater for all but the lowest recharge flow rates and this source has potentially significant quality concerns in terms of recharge associated with such factors as road salt on a chemical spill entering the groundwater adjacent to the highway.

- Options including pumping and recharge wells using groundwater have significant operation and maintenance costs which could be potentially quite unreliable over a 50 year life cycle.

- The most practical and feasible attractive mitigation option for the proposed Highway 416 depressurization system is the full, 400 metre length of cut-off wall.

- As a contingency, to deal with possible leakage losses through and under the wall, a few bedrock wells adjacent to both the Lynwood subdivision and the Bruce Pit East Pond may be practical sources of recharge water if required while bedrock grouting may also be a possible option if flow through the bedrock is defined.

GOLDER ASSOCIATES LTD.

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Senior Hydrogeologist/Environmental Engineer

A.F. Chevrier, P.Eng.
Associate

RDS:AFC:cj:cr
RCR18

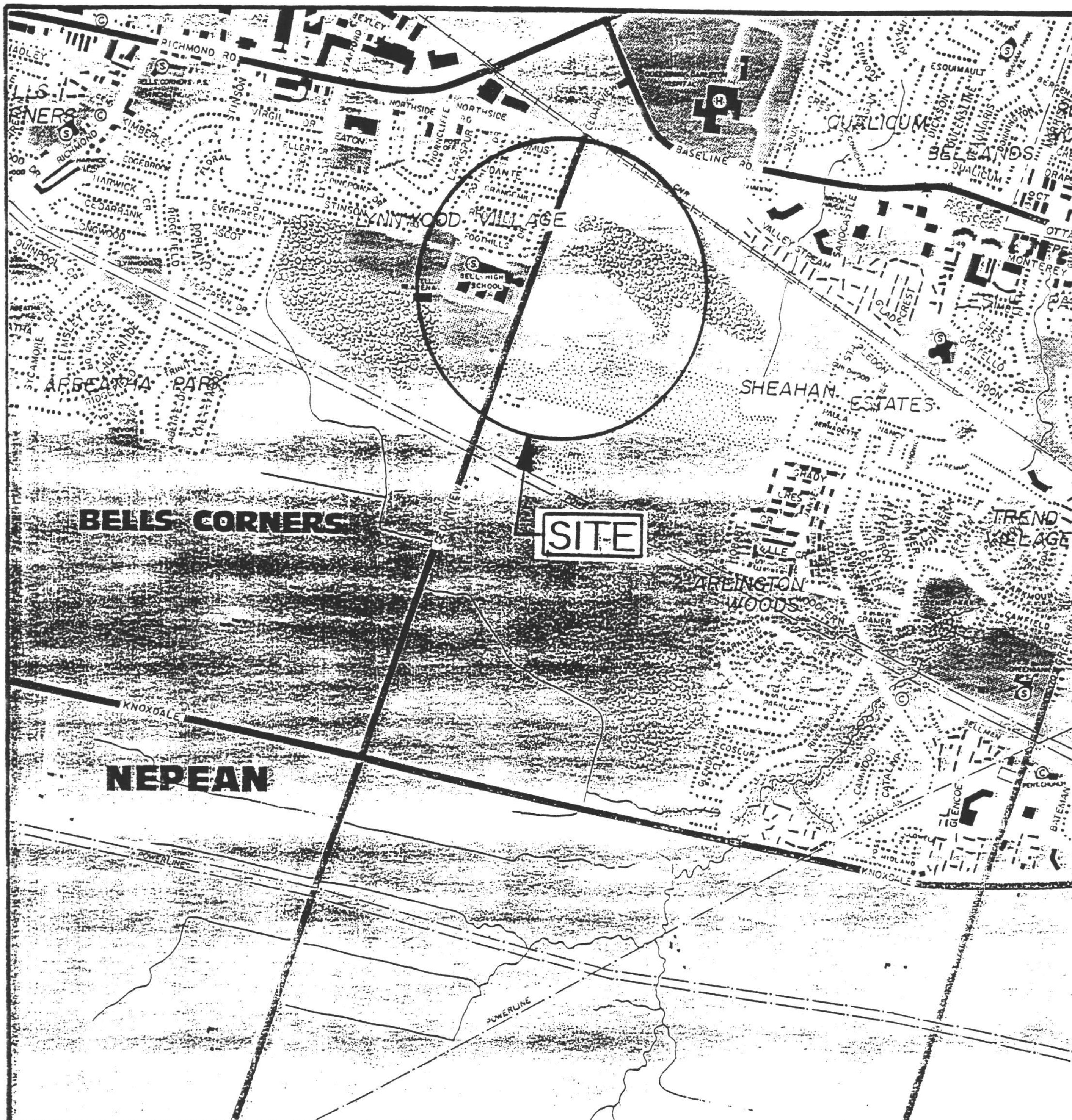
TABLE 1
SUMMARY OF FLOW PATH MODELLING RESULTS

Scenario Description	Scenario Identification	Flow to Drains (m^3/day (gallon/minute)	Recharge Flow (m^3/day (gallon/minute)	APPROXIMATE DRAWDOWN (metres)			
				Under Subdivision		Under Pond	
				Minimum	Maximum	Minimum	Maximum
Sewer Pumping Calibration	BC1 - 1 BC2 - 1	2700 (400) 2700 (400)	--- ---	0.5 4.0	4.5 6.0	--- 0.2	--- 0.5
No Cut-off Wall and No Recharge Wells	BC1 - 2 BC2 - 2	2550 (380) 2400 (360)	--- ---	1.0 4.0	6.0 6.0	--- 0.2	--- 1.2
100 metre Cut-Off Wall and No Recharge Wells	BC1 - 3 BC2 - 3	2100 (315) 2050 (310)	--- ---	1.0 3.0	3.0 4.5	--- 0.2	--- 1.0
200 metre Cut-off Wall and No Recharge Wells	BC1 - 4 BC2 - 4	1600 (240) 1550 (230)	--- ---	0.5 2.0	3.0 3.0	--- 0.2	--- 0.8
300 metre Cut-off Wall and No Recharge Wells	BC1 - 5 BC2 - 5	1000 (150) 670 (100)	--- ---	0.5 0	1.0 0.5	--- 0.2	--- 0.3
No Cutoff Wall but Recharge Wells on West Side	BC1 - 6 BC2 - 6	5000 (750)	2700 (400)	0 0	0.5 0.2	--- 0.2	--- 0.75
100 metre Cut-off Wall and Recharge Wells on West Side	BC1 - 7 BC2 - 7	4300 (650)	2400 (360)	0 0	0 0	--- 0.2	--- 0.5
200 metre Cut-off Wall and Recharge Wells on West Side	BC1 - 8 BC2 - 8	2600 (390)	1300 (195)	0 0	0 0.2	--- 0.2	--- 0.5
300 metre Cut-off Wall and Recharge Wells on West Side	BC1 - 9 BC2 - 9	720 (110)	330 (50)	0 0	0 0	--- 0.2	--- 0.4

Notes: BC1 - Boundary Condition One
BC2 - Boundary Condition Two

KEY PLAN

FIGURE 1



SCALE 1 : 18,500

SPECIAL NOTE
THIS DRAWING IS TO BE READ IN CONJUNCTION WITH ACCOMPANYING REPORT

Date APR. 7, 1994
Project 941-1129C

Golder Associates

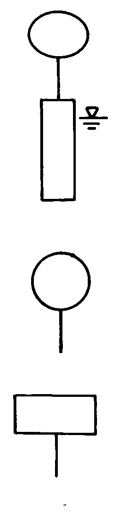
Drawn SL
Chkd. RDO


SITE PLAN
WP-121-87-00
FIGURE 2
LEGEND
BOREHOLE LOCATION IN PLAN BY GOLDER ASSOCIATES LTD REPORT No 931-2138 (WP-121-87-00)
BOREHOLE LOCATION IN PLAN, INVESTIGATIONS BY GOLDER ASSOCIATES LTD, REPORT Nos 901-2410 (WP 146-74-00-3A) 901-2256 (WP 126-87-01(A)) 901-2115 (WP 146-74-00-3) 891-2208 (WP 146-74-00-3) 881-2294 (WP 146-74-00-3)
BOREHOLE LOCATION IN PLAN, INVESTIGATIONS BY MINISTRY OF TRANSPORTATION (WP 146-74-00) (WP 121-87-06)
BOREHOLE LOCATION IN PLAN, INVESTIGATION BY ACRES INTERNATIONAL LTD (WP 126-87-01)
BOREHOLE LOCATION IN PLAN INVESTIGATION BY CONESTOGA ROVER AND ASSOCIATES LTD
BOREHOLE LOCATION IN PLAN, INVESTIGATION BY GOLDER ASSOCIATES LTD FOR THE CITY OF NEPEAN REPORT No 891-2615
MONITORING WELL LOCATION IN PLAN, INVESTIGATION BY CONESTOGA ROVER AND ASSOCIATES LTD
MONITORING WELL LOCATION IN PLAN, PREVIOUS INVESTIGATION BY GOLDER ASSOCIATES LTD (FOR R.W. CONNELLY ASSOCIATES)
INFERRED CLAY - SAND CONTACT (CLAY TO NORTH AND SAND TO SOUTH)
CLAY OVER SAND BOUNDARY (SAND PINCHES OUT TO NORTH AND UNDER CLAY TO SOUTH)
APPROXIMATE AREA OF BEDROCK DEPRESSURIZATION
APPROXIMATE AREA OF SAND DEPRESSURIZATION
SECTION LOCATION IN PLAN, FOR SUBSURFACE PROFILE, SECTION A-A SEE FIGURE 3
H ZONES OF HIGH HYDRAULIC CONDUCTIVITY (>1x10⁻² cm/sec)
POND BOTTOM PIT (PBP) LOCATION IN PLAN
APPROXIMATE LOCATION OF PULL-BACK SEWER (SUMMER/FALL, 1994)
SURFACE SAMPLING POINT (SSP-I)
SCALE
1 2000
SPECIAL NOTE
THIS DRAWING IS TO BE READ IN CONJUNCTION WITH ACCOMPANYING REPORT
BASELINE ROAD
RICHMOND ROAD
CN RAIL LINE
CEDARVIEW ROAD
PROPOSED HWY 416
(SAND PINCHES OUT TO NORTH)
(SAND BELOW CLAY)
CLAY
SAND
BELL HIGH SCHOOL
EAST POND
WEST POND
BRUCE PIT
PERMANENT WATER LEVEL AND PRECIPITATION MONITORING STATION
RELOCATED WASTE DISPOSAL AREA
NOTE MONITORING WELLS OW6A-90 AND OW6B-90 LOCATED 25 METRES SOUTH OF THE RELOCATED WASTE DISPOSAL AREA
EN DEVELOPPEMENT
BROUSSAILLE ET ARBRES DISPERSÉS
FEB 01 1995
941-1129-C
Golder Associates

SUBSURFACE PROFILE SECTION A-A

FIGURE 3

LEGEND



SPECIAL NOTE
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Date FEB. 1, 1995
Project 941-1129C

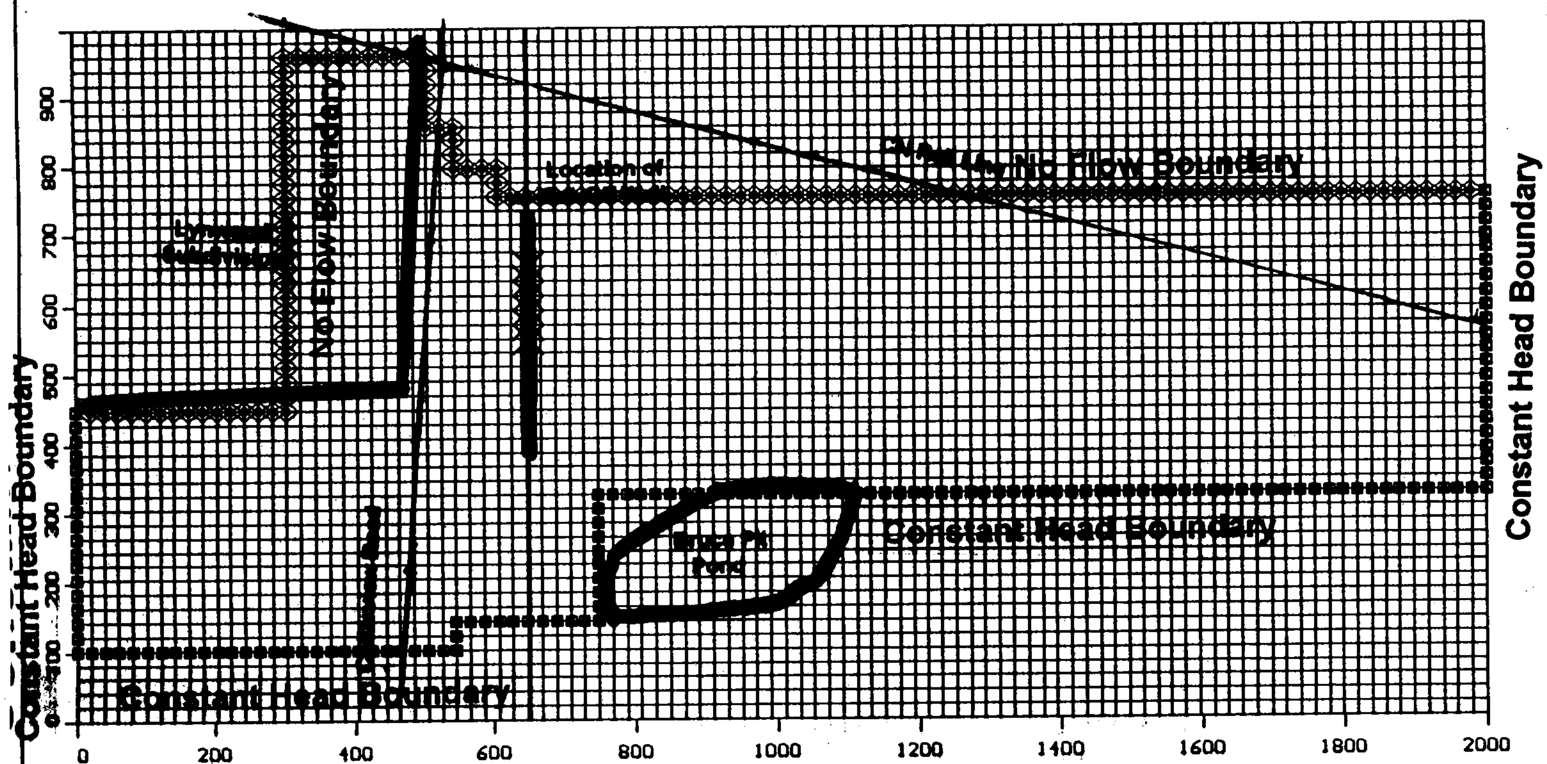
Golder Associates

Drawn SL
Chkd

APPENDIX A

FLOWPATH MODELLING RESULTS

HIGHWAY 416
NEAR LYNWOOD SUBDIVISION
NEPEAN, ONTARIO



FLOWPATH 5.03

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hydrogeologic
software

Model Dimensions

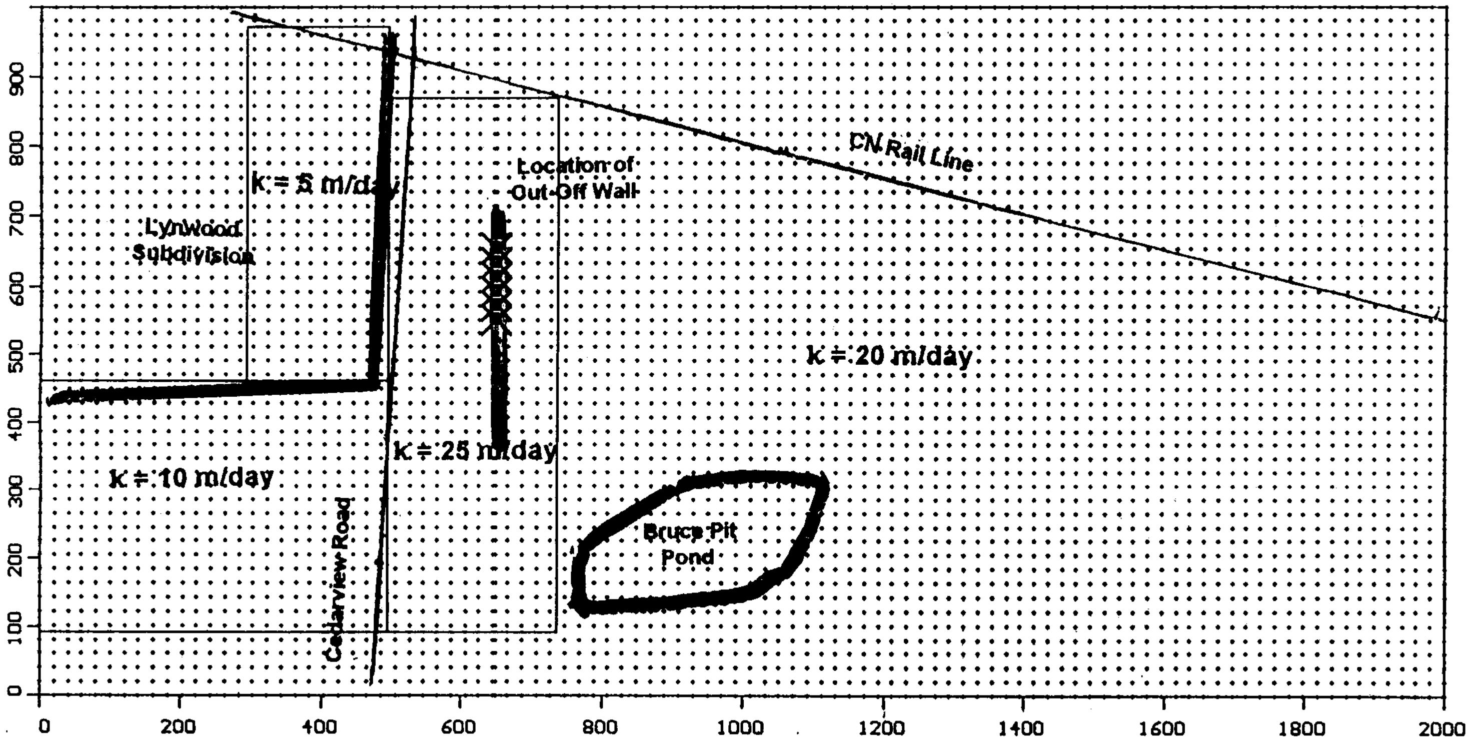
No. rows	:	50
No. columns	:	101
No. pumps	:	6
No. injct	:	0
No. const. heads	:	149
No. const. flux	:	133
No. river nodes	:	0
No. drain nodes	:	0

Units : [m][day]

Data Set : BRUCE

FLOWPATH MODELING RESULTS

BC1 (Boundary Conditions)



FLOWPATH 5.03

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Model Dimensions

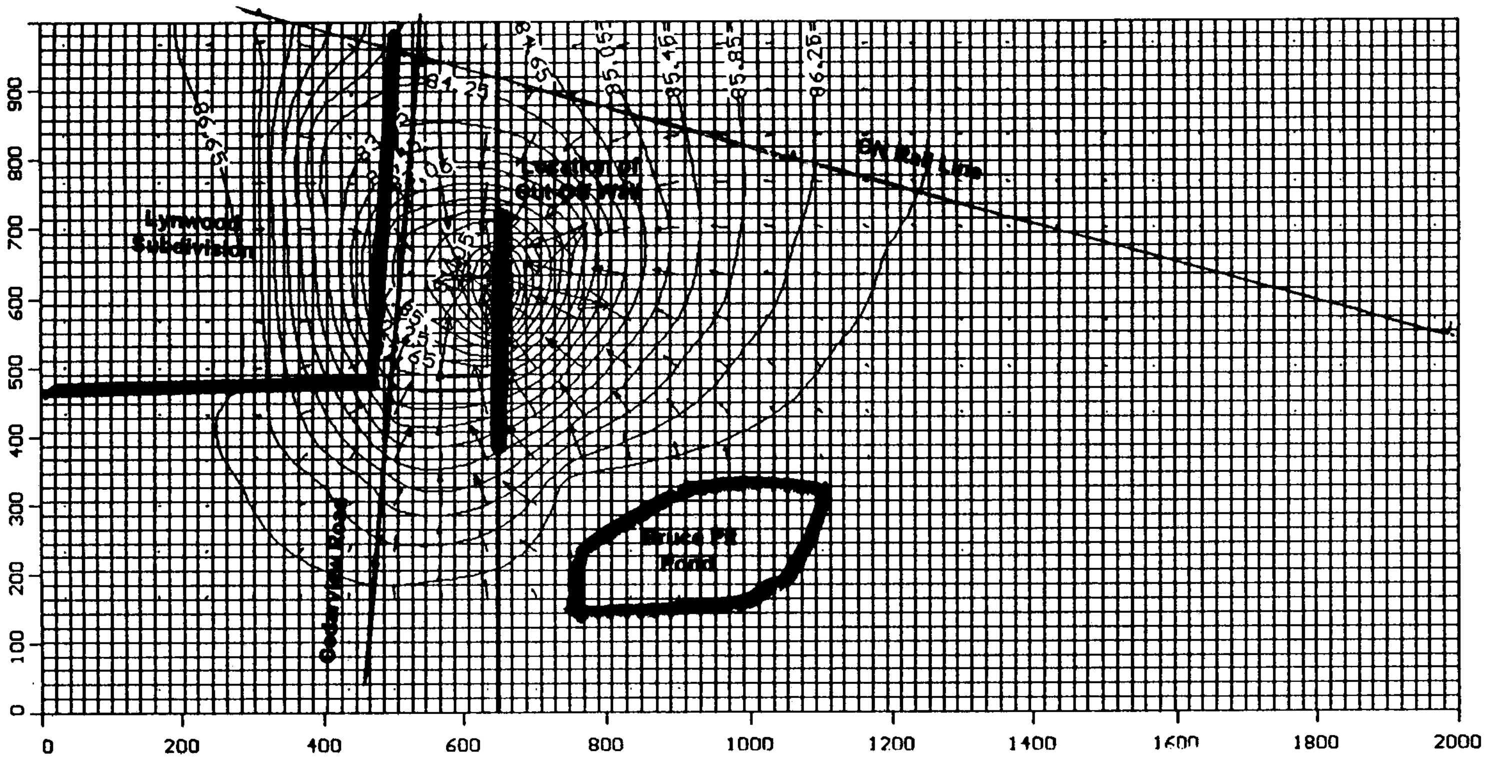
No. rows	: 50
No. columns	: 101
No. pumps	: 6
No. injct	: 0
No. const. heads	: 149
No. const. flux	: 133
No. river nodes	: 0
No. drain nodes	: 0

Units : [m][day]

Data Set : BRUCE

FLOWPATH MODELING RESULTS

BC1 (Hydraulic Conductivities)



FLOWPATH 5.03

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Model Dimensions

No. rows	:	50
No. columns	:	101
No. pumps	:	6
No. injct	:	0
No. const. heads	:	149
No. const. flux	:	133
No. river nodes	:	0
No. drain nodes	:	0

Hydraulic Heads (m)

Min :	78.646
Max :	87.000

Velocities (m/d)

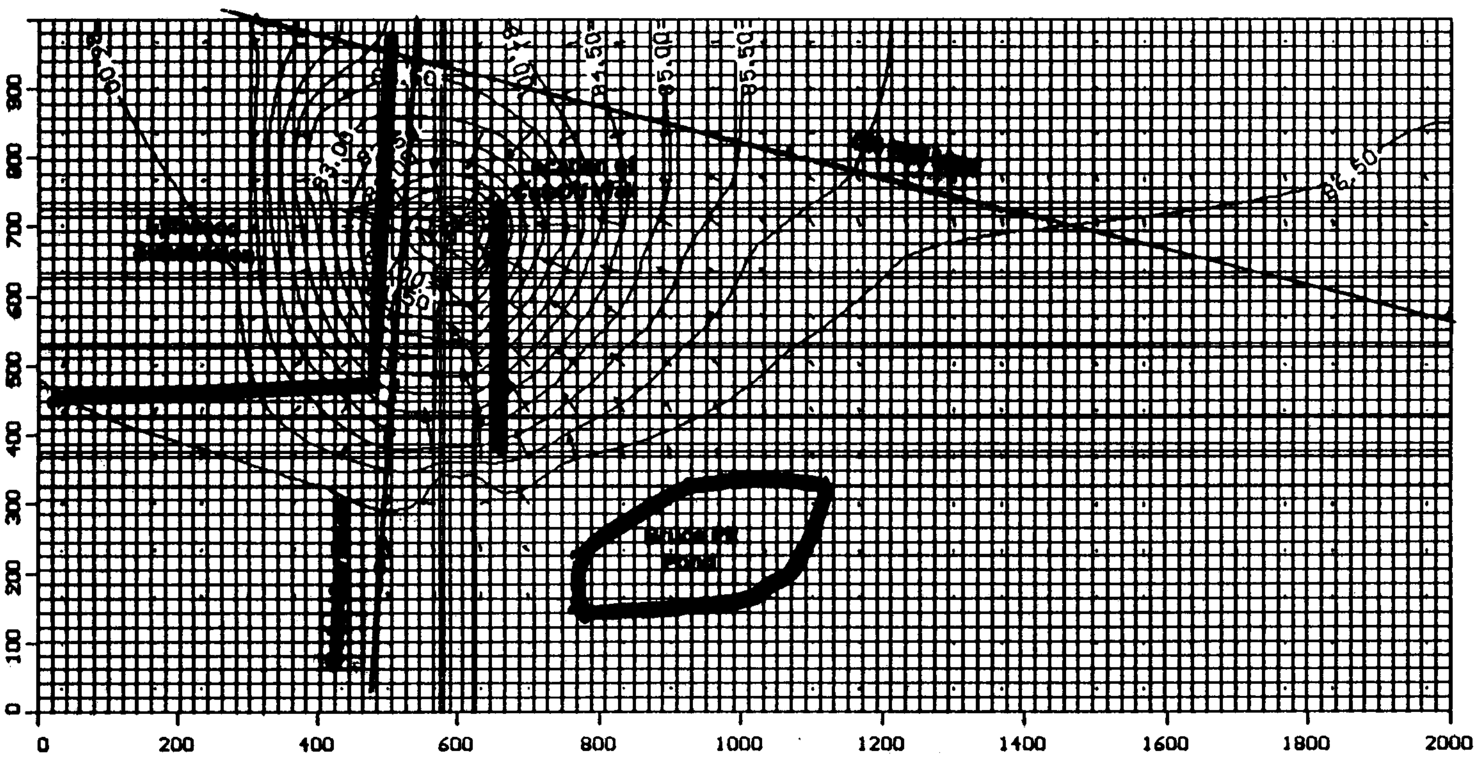
Min :	0.000
Max :	4.690
Avg :	0.292

Units : [m][day]

Data Set : BRUCE

FLOWPATH MODELING RESULTS

BC1-1



FLOWPATH 5.03

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hydrogeologic
software

Model Dimensions

No. rows	: 56
No. columns	: 103
No. pumps	: 1
No. injct	: 0
No. const. heads	: 189
No. const. flux	: 142
No. river nodes	: 0
No. drain nodes	: 0

Hydraulic Heads (m)

Min :	79.000
Max :	87.000

Velocities (m/d)

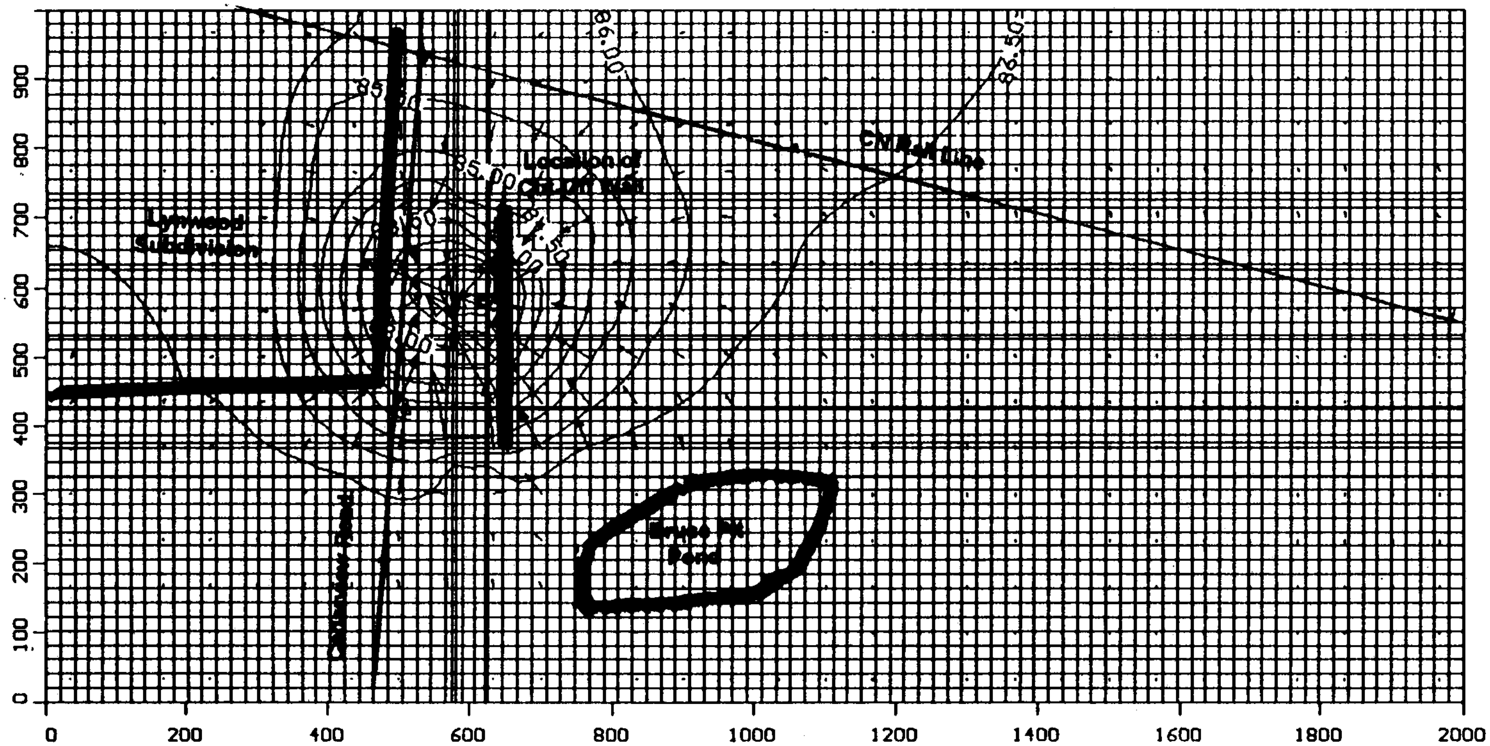
Min :	0.000
Max :	5.818
Avg :	0.314

Units : [m][day]

Data Set : BRUC100

FLOWPATH MODELING RESULTS

BC1-2



FLOWPATH 5.03

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Model Dimensions

No. rows : 56
No. columns : 103
No. pumps : 1
No. injct : 0
No. const. heads : 179
No. const. flux : 142
No. river nodes : 0
No. drain nodes : 0

Hydraulic Heads (m)

Min : 81.000
Max : 87.000

Velocities (m/d)

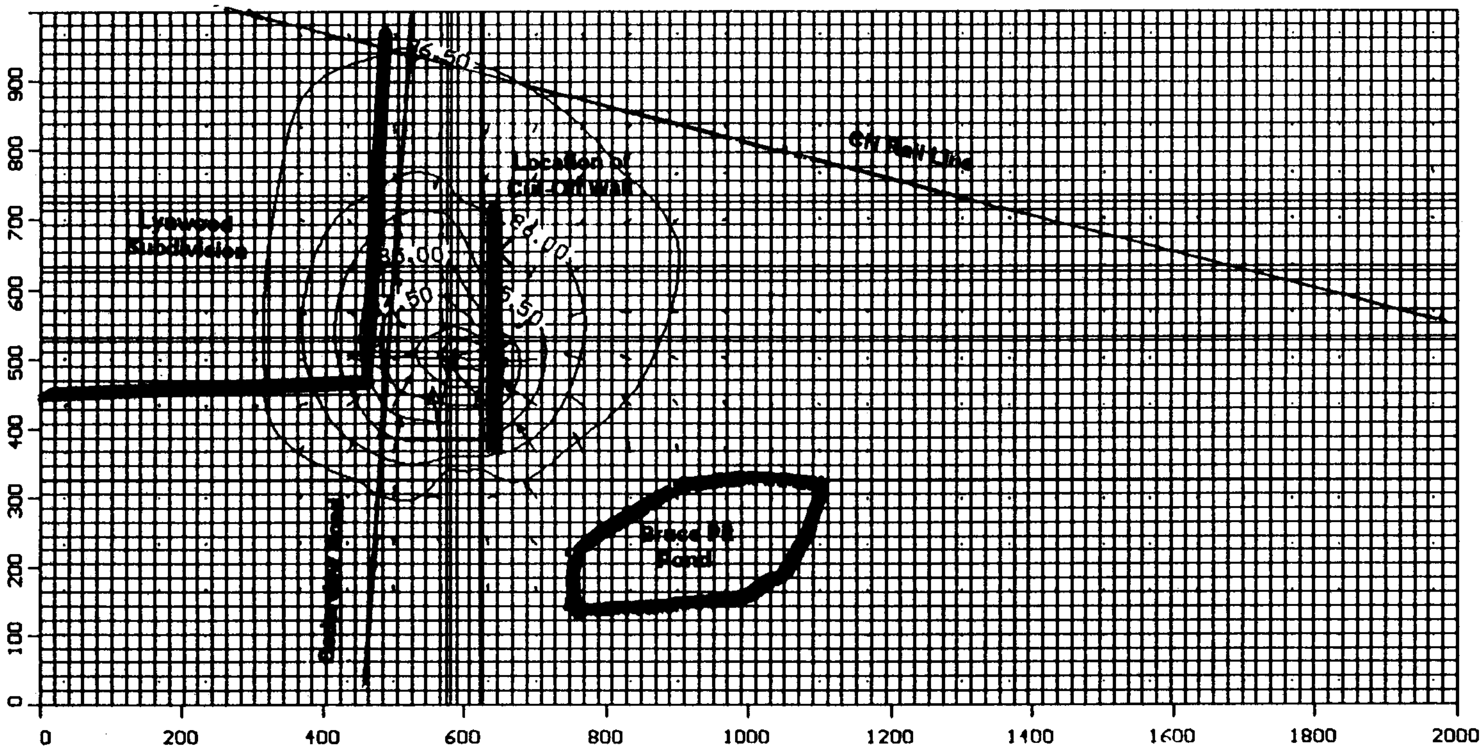
Min : 0.000
Max : 3.744
Avg : 0.201

Units : [m][day]

Data Set : BRUCE1

FLOWPATH MODELING RESULTS

BC1-3



FLOWPATH 5.03

Model Dimensions

No. rows : 54
No. columns : 103
No. pumps : 1
No. injct : 0
No. const. heads : 169
No. const. flux : 142
No. river nodes : 0
No. drain nodes : 0

Hydraulic Heads (m)

Min : 83.000
Max : 87.000

Velocities (m/d)

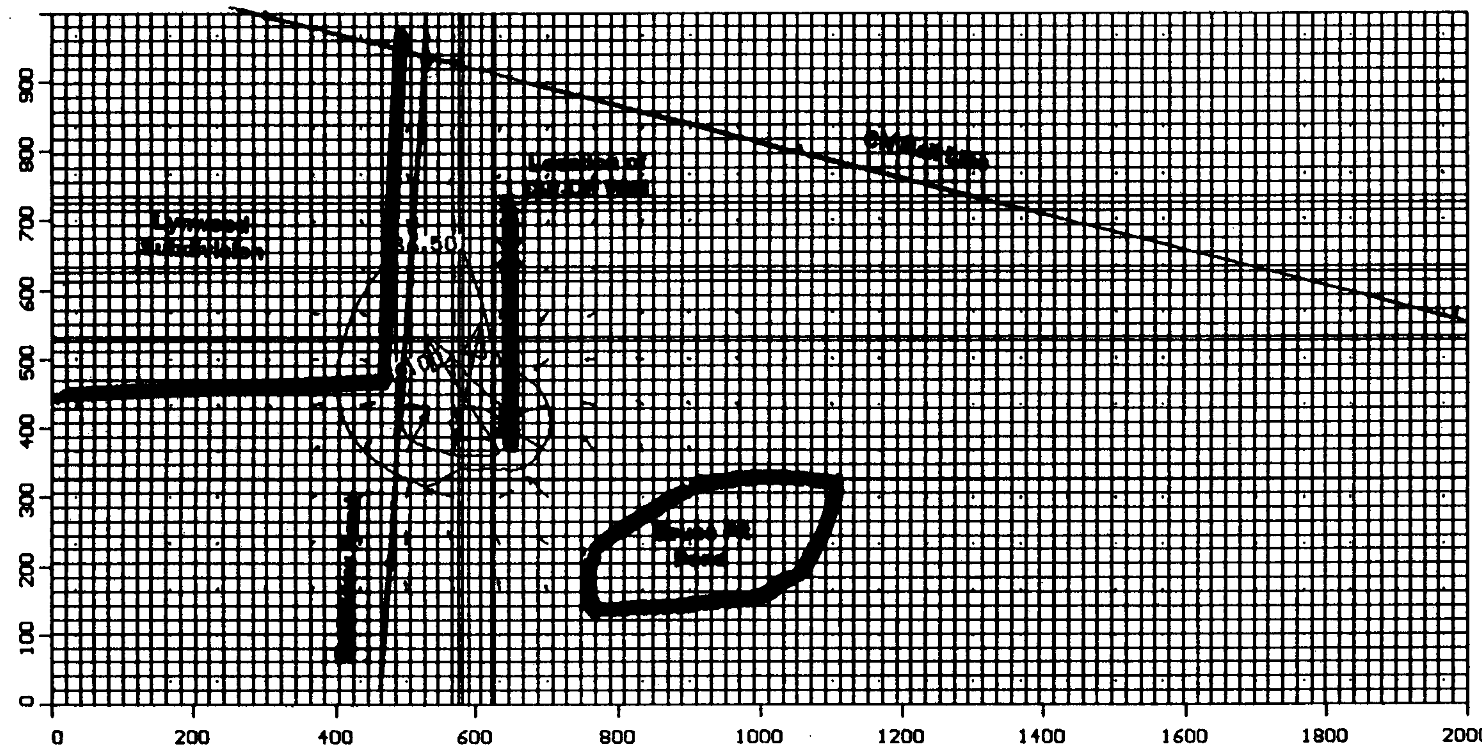
Min : 0.000
Max : 4.544
Avg : 0.125

Units : [m][day]

Data Set : BRUCE2

FLOWPATH MODELING RESULTS

BC1-4



FLOWPATH 5.03

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Model Dimensions

No. rows	: 54
No. columns	: 103
No. pumps	: 1
No. injct	: 0
No. const. heads	: 159
No. const. flux	: 142
No. river nodes	: 0
No. drain nodes	: 0

Hydraulic Heads (m)

Min :	85.000
Max :	87.000

Velocities (m/d)

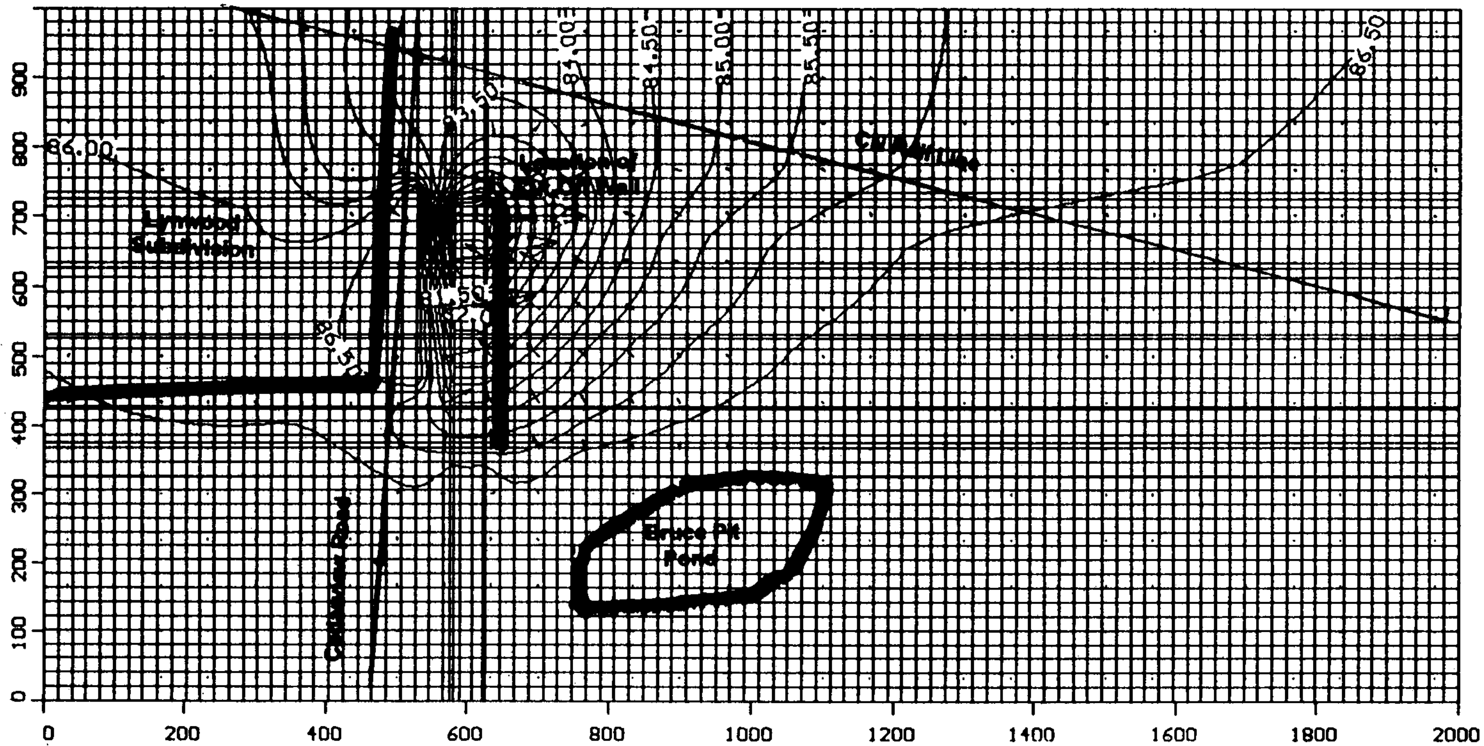
Min :	0.000
Max :	2.053
Avg :	0.044

Units : [m][day]

Data Set : BRUCE3

FLOWPATH MODELING RESULTS

BC1-5



FLOWPATH 5.03

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Model Dimensions

No. rows	:	56
No. columns	:	103
No. pumps	:	1
No. injct	:	0
No. const. heads	:	204
No. const. flux	:	142
No. river nodes	:	0
No. drain nodes	:	0

Hydraulic Heads (m)

Min :	79.000
Max :	87.000

Velocities (m/d)

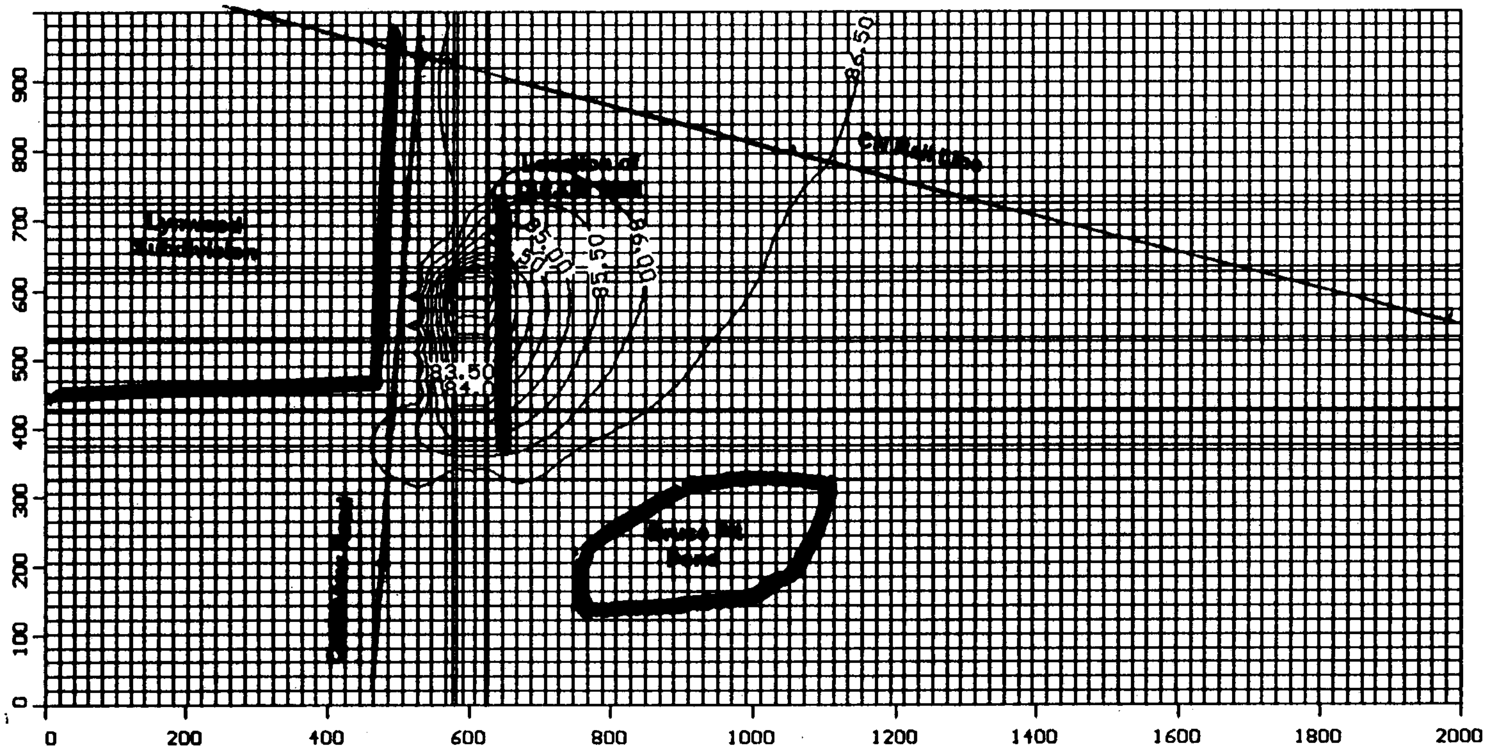
Min :	0.000
Max :	14.653
Avg :	0.356

Units : [m][day]

Data Set : CUTOE1

FLOWPATH MODELING RESULTS

BC1-6



FLOWPATH 5.03

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hydrogeologic
software

Model Dimensions

No. rows	:	56
No. columns	:	103
No. pumps	:	1
No. injct	:	0
No. const. heads	:	190
No. const. flux	:	142
No. river nodes	:	0
No. drain nodes	:	0

Hydraulic Heads (m)

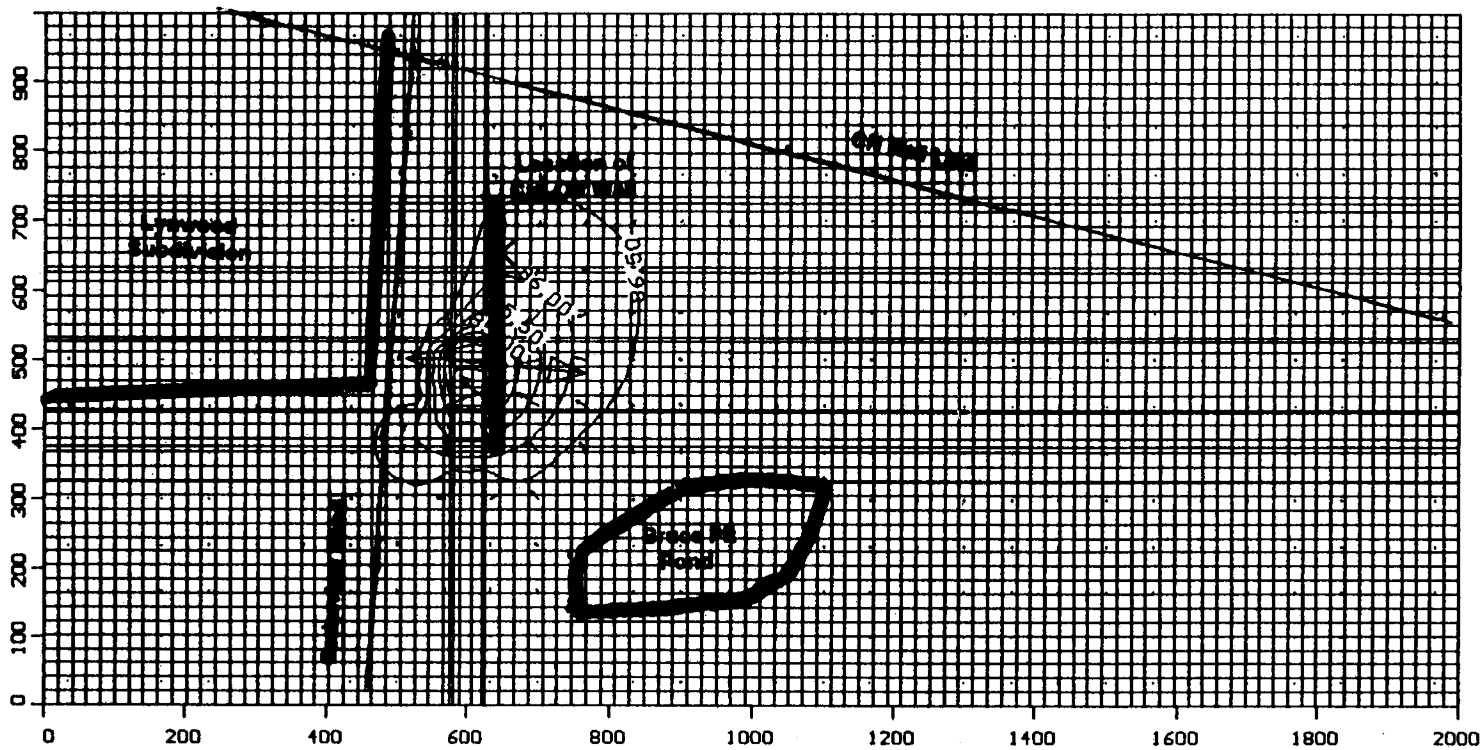
Min :	81.000
Max :	87.000

Units : [m][day]

Data Set : BRUCE11

FLOWPATH MODELING RESULTS

BC1-7



FLOWPATH 5.03

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Model Dimensions

No. rows	: 56
No. columns	: 103
No. pumps	: 1
No. injct	: 0
No. const. heads	: 180
No. const. flux	: 142
No. river nodes	: 0
No. drain nodes	: 0

Hydraulic Heads (m)

Min :	83.000
Max :	87.000

Velocities (m/d)

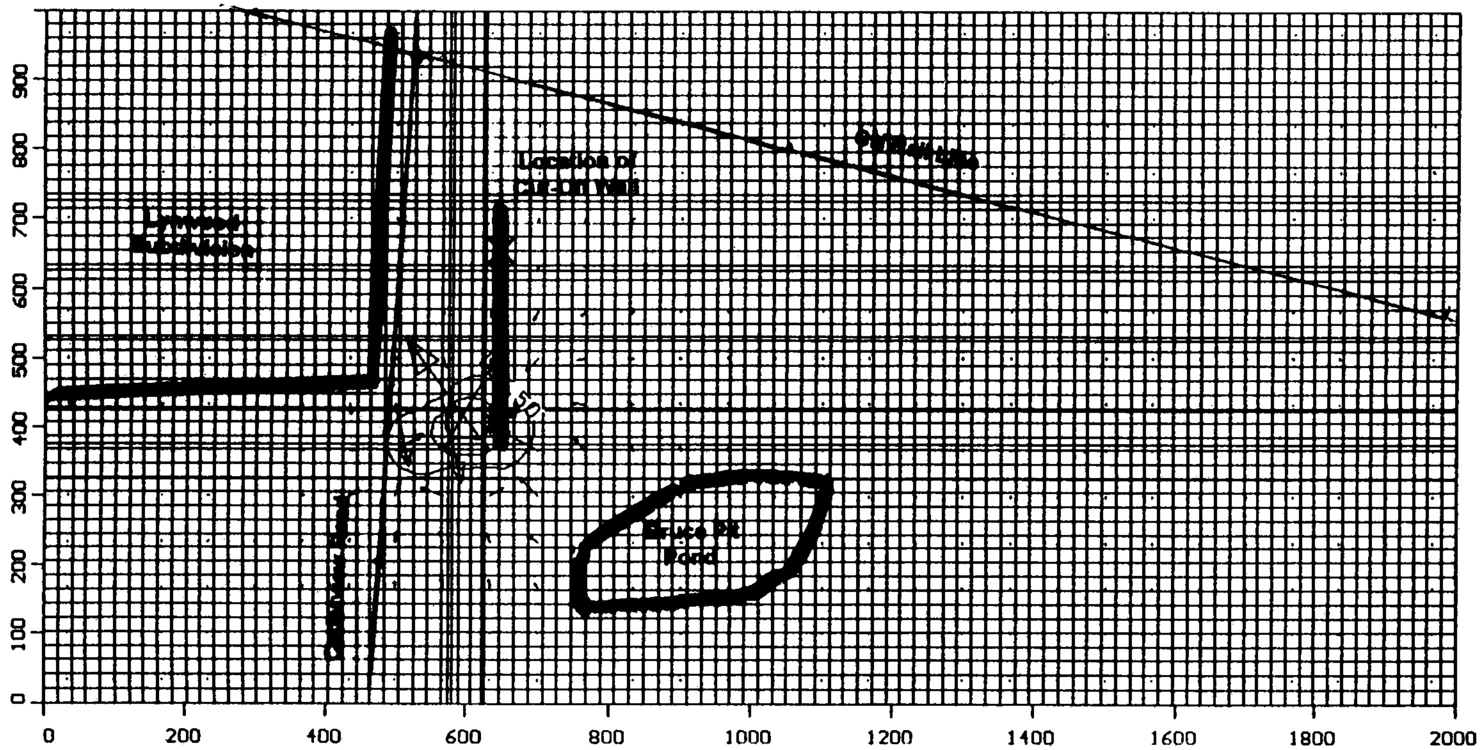
Min :	0.000
Max :	7.876
Avg :	0.121

Units : [m][day]

Data Set : BRUCE22

FLOWPATH MODELING RESULTS

BC1-8



FLOWPATH 5.03

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Model Dimensions

No. rows	: 56
No. columns	: 103
No. pumps	: 1
No. injct	: 0
No. const. heads	: 163
No. const. flux	: 142
No. river nodes	: 0
No. drain nodes	: 0

Hydraulic Heads (m)

Min :	85.000
Max :	87.000

Velocities (m/d)

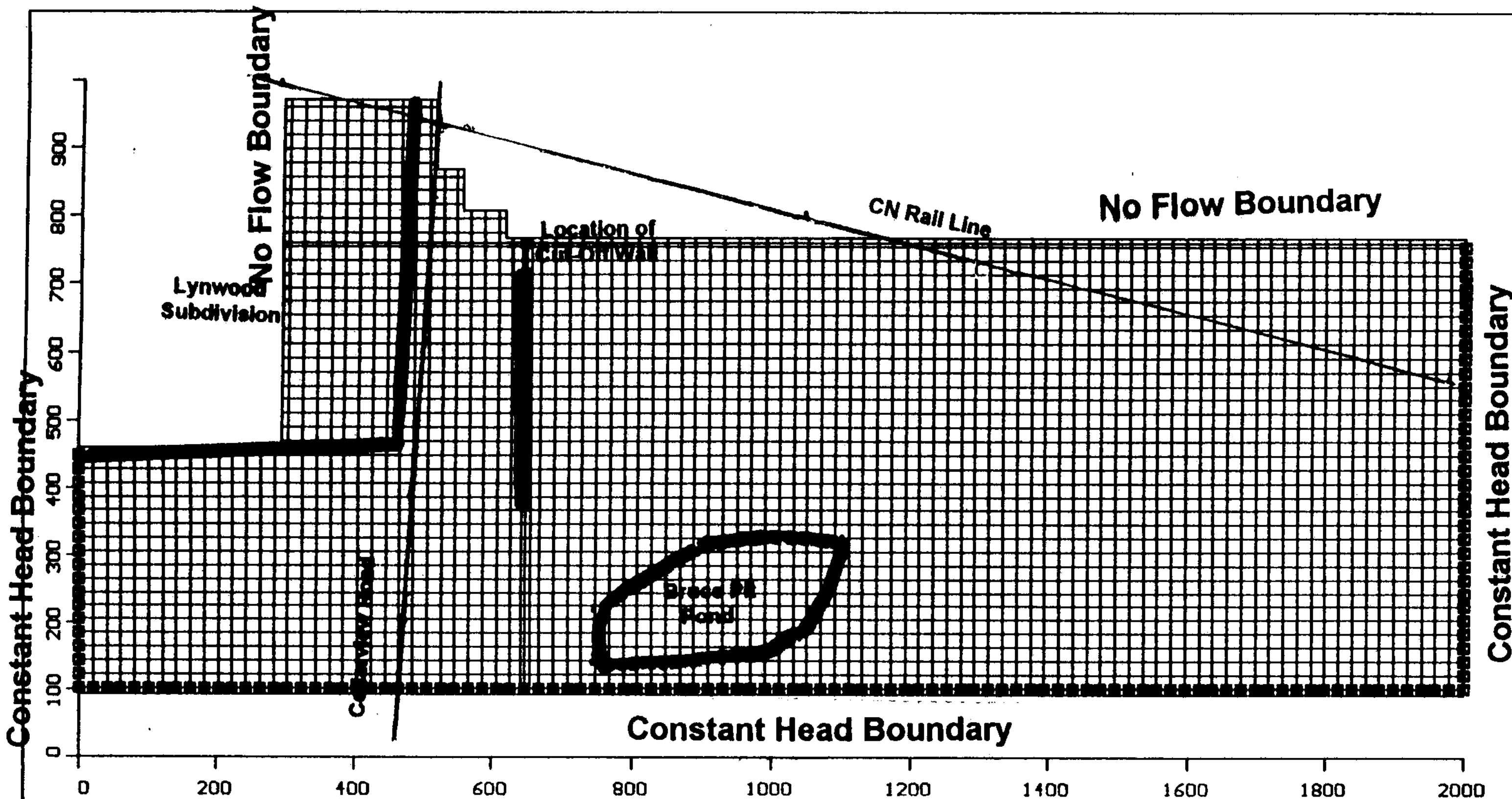
Min :	0.000
Max :	2.038
Avg :	0.036

Units : [m][day]

Data Set : BRUCE33

FLOWPATH MODELING RESULTS

BC1-9



FLOWPATH 5.03

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Model Dimensions

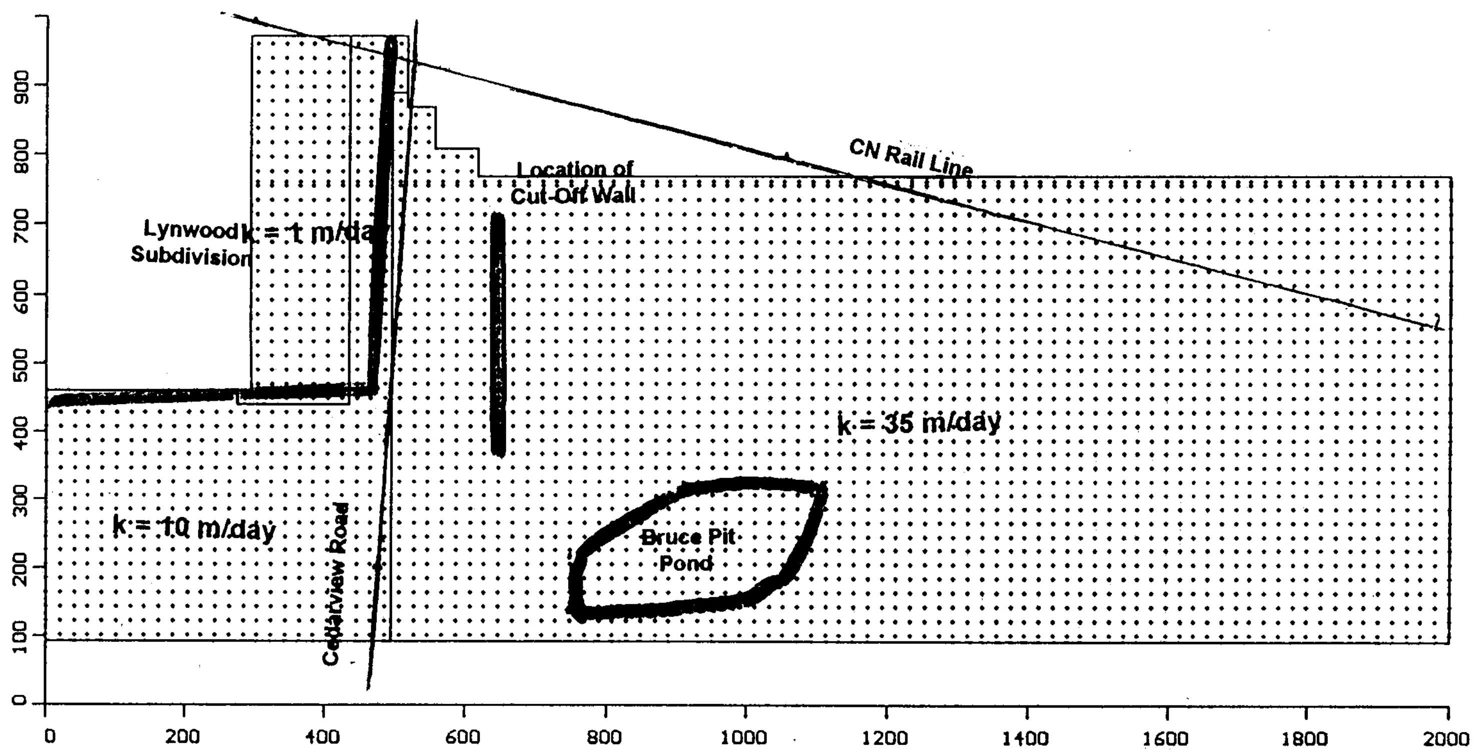
No. rows	:	51
No. columns	:	102
No. pumps	:	0
No. injct	:	0
No. const. heads	:	164
No. const. flux	:	0
No. river nodes	:	0
No. drain nodes	:	0

Units : [m][day]

Data Set : COW200

FLOWPATH MODELING RESULTS

BC2 (Boundary Conditions)



FLOWPATH 5.03

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Model Dimensions

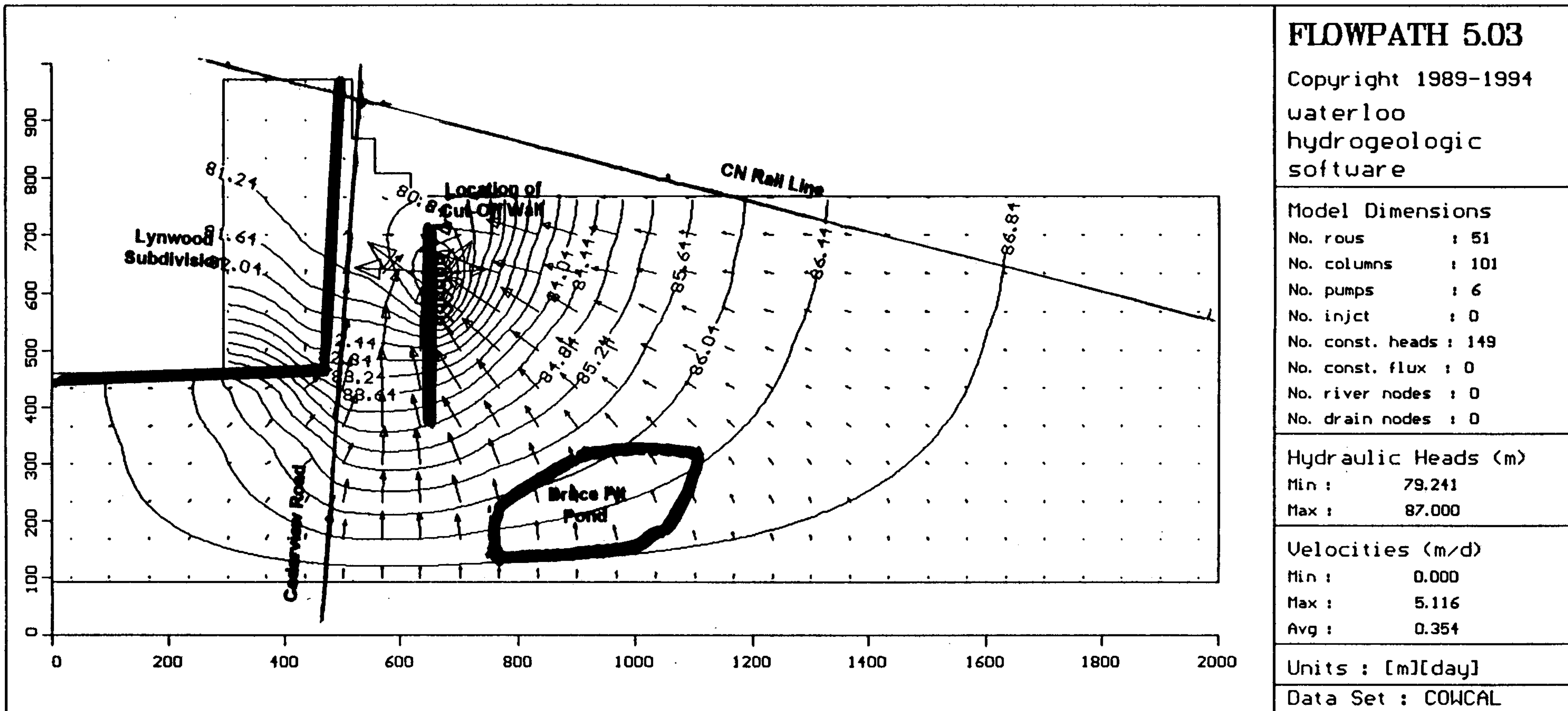
No. rows : 51
No. columns : 100
No. pumps : 0
No. injct : 0
No. const. heads : 164
No. const. flux : 0
No. river nodes : 0
No. drain nodes : 0

Units : [m][day]

Data Set : COWO

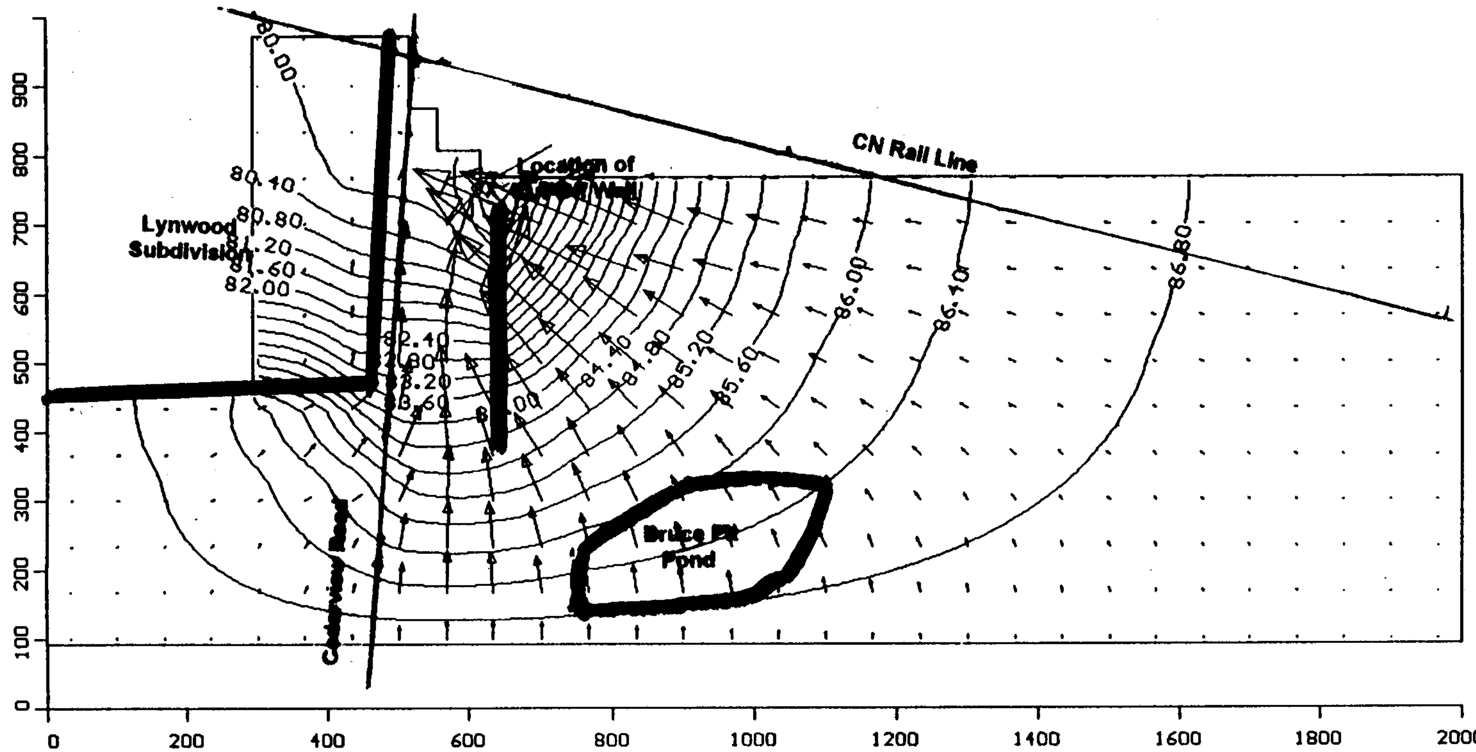
FLOWPATH MODELING RESULTS

BC2 (Hydraulic Conductivities)



FLOWPATH MODELING RESULTS

BC2-1



FLOWPATH 5.03

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Model Dimensions

No. rows	:	51
No. columns	:	100
No. pumps	:	0
No. injct	:	0
No. const. heads	:	164
No. const. flux	:	0
No. river nodes	:	0
No. drain nodes	:	0

Hydraulic Heads (m)

Min :	78.000
Max :	87.000

Velocities (m/d)

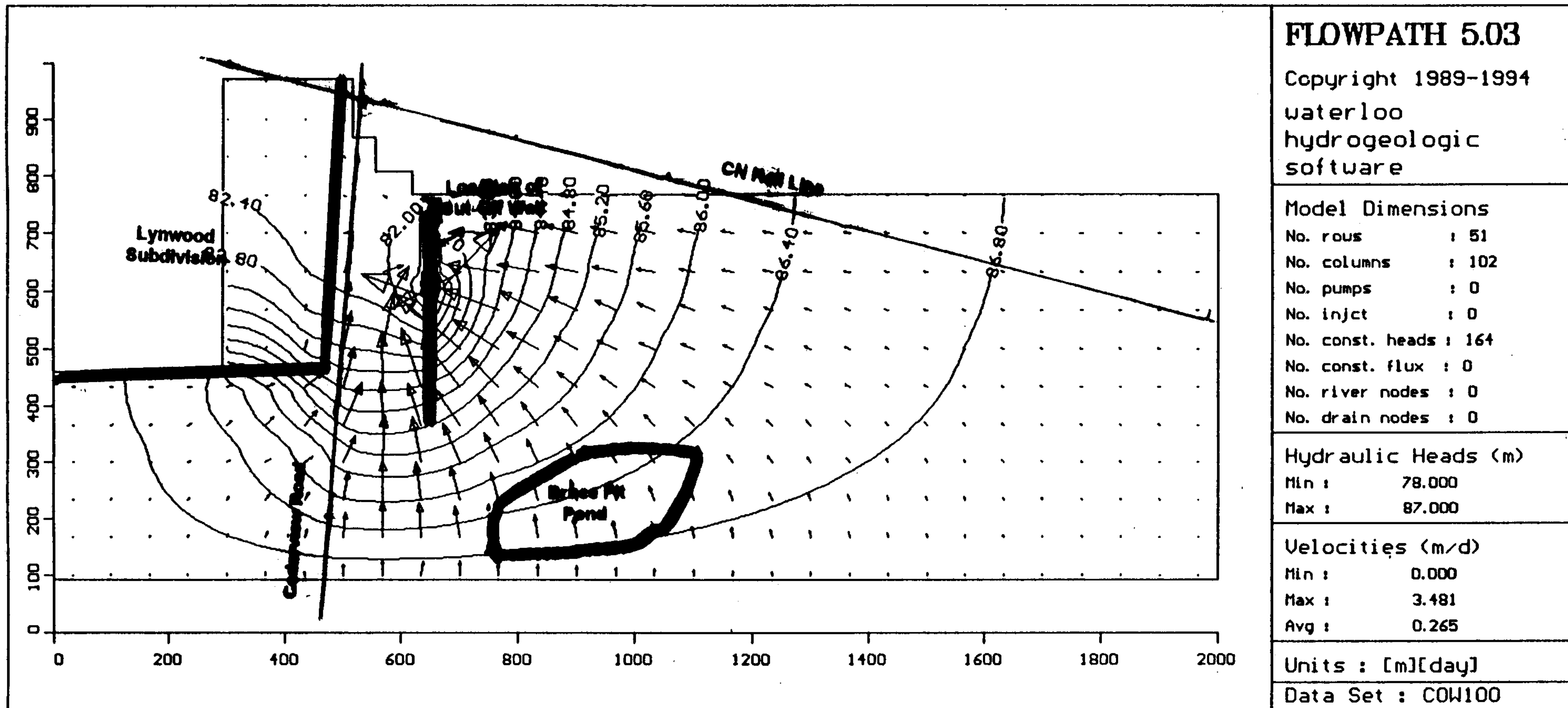
Min :	0.000
Max :	3.770
Avg :	0.362

Units : [m][day]

Data Set : COWO

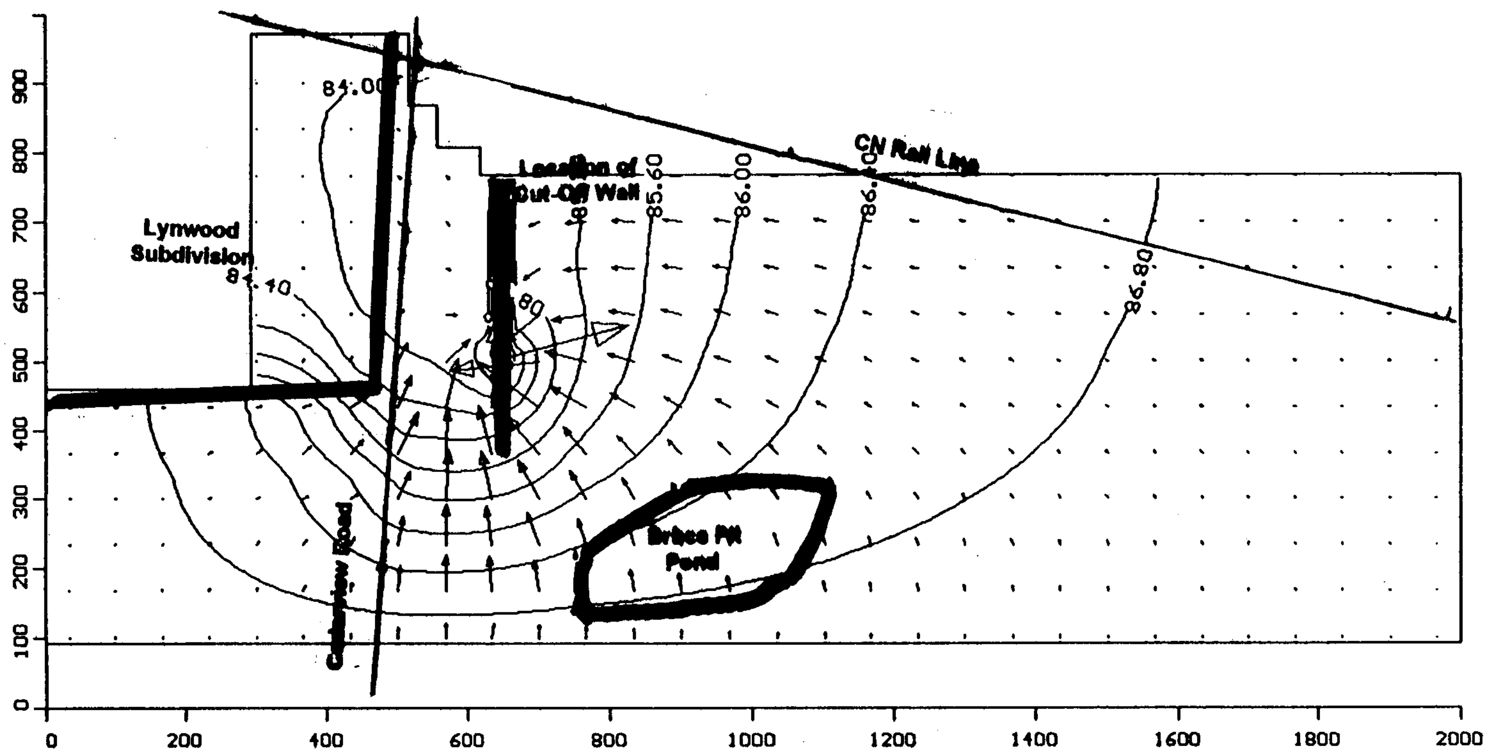
FLOWPATH MODELING RESULTS

BC2-2



FLOWPATH MODELING RESULTS

BC2-3



FLOWPATH 5.03

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Model Dimensions

No. rows	: 51
No. columns	: 102
No. pumps	: 0
No. injct	: 0
No. const. heads	: 164
No. const. flux	: 0
No. river nodes	: 0
No. drain nodes	: 0

Hydraulic Heads (m)

Min :	78.000
Max :	87.000

Velocities (m/d)

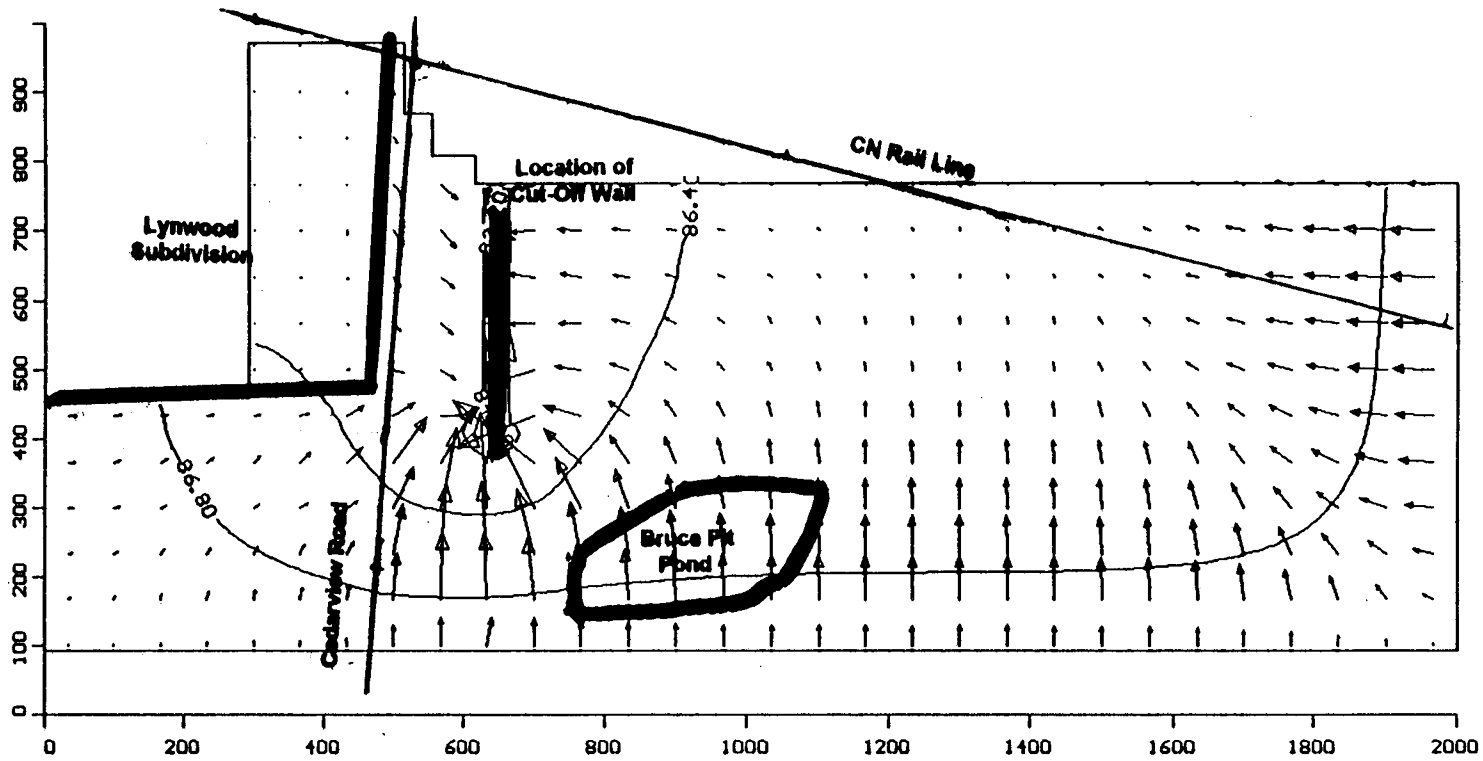
Min :	0.000
Max :	3.599
Avg :	0.181

Units : [m][day]

Data Set : COW200

FLOWPATH MODELING RESULTS

BC2-4



FLOWPATH 5.03

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Model Dimensions

No. rows	: 51
No. columns	: 102
No. pumps	: 0
No. injct	: 0
No. const. heads	: 166
No. const. flux	: 0
No. river nodes	: 0
No. drain nodes	: 0

Hydraulic Heads (m)

Min :	78.000
Max :	87.000

Velocities (m/d)

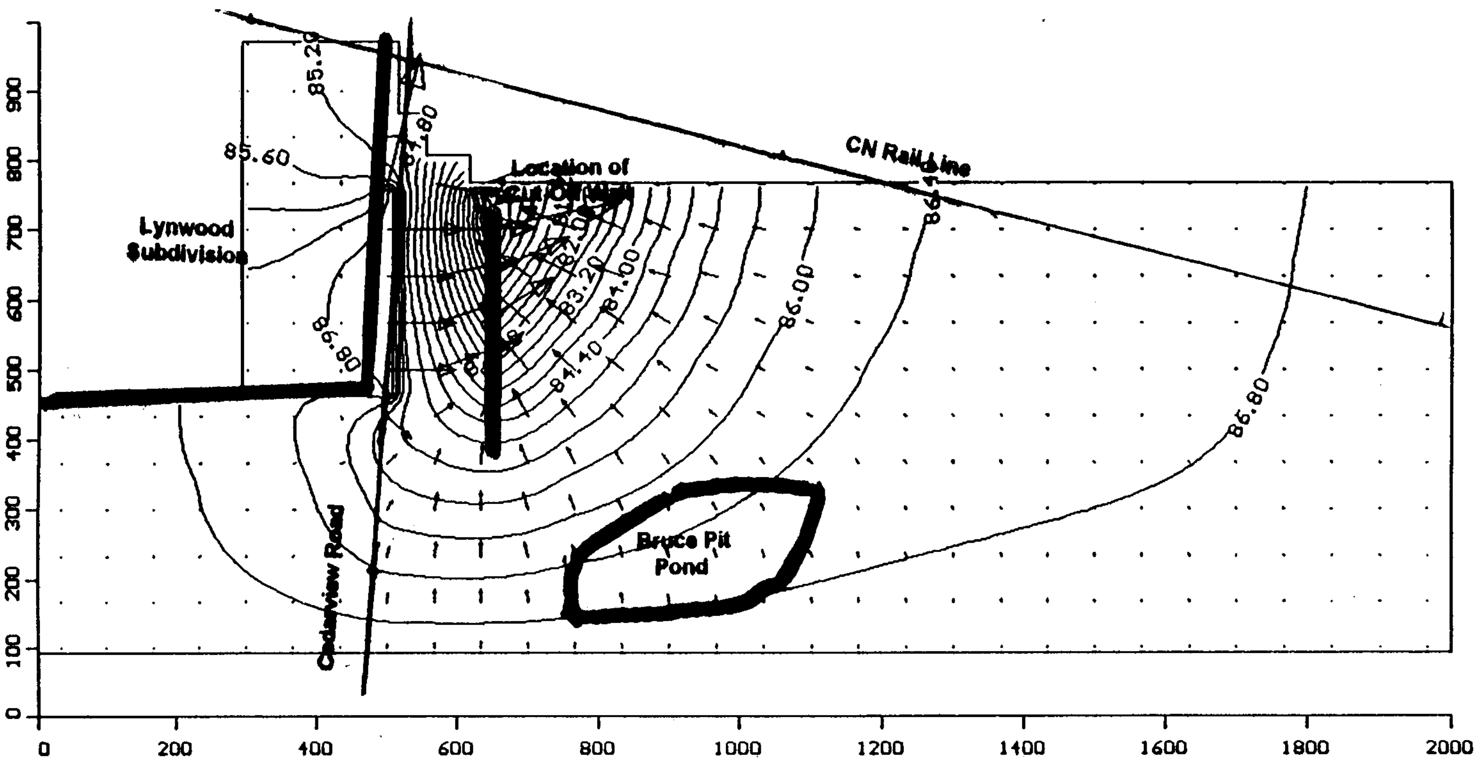
Min :	0.000
Max :	0.851
Avg :	0.092

Units : [m][day]

Data Set : COW300

FLOWPATH MODELING RESULTS

BC2-5



FLOWPATH 5.03	
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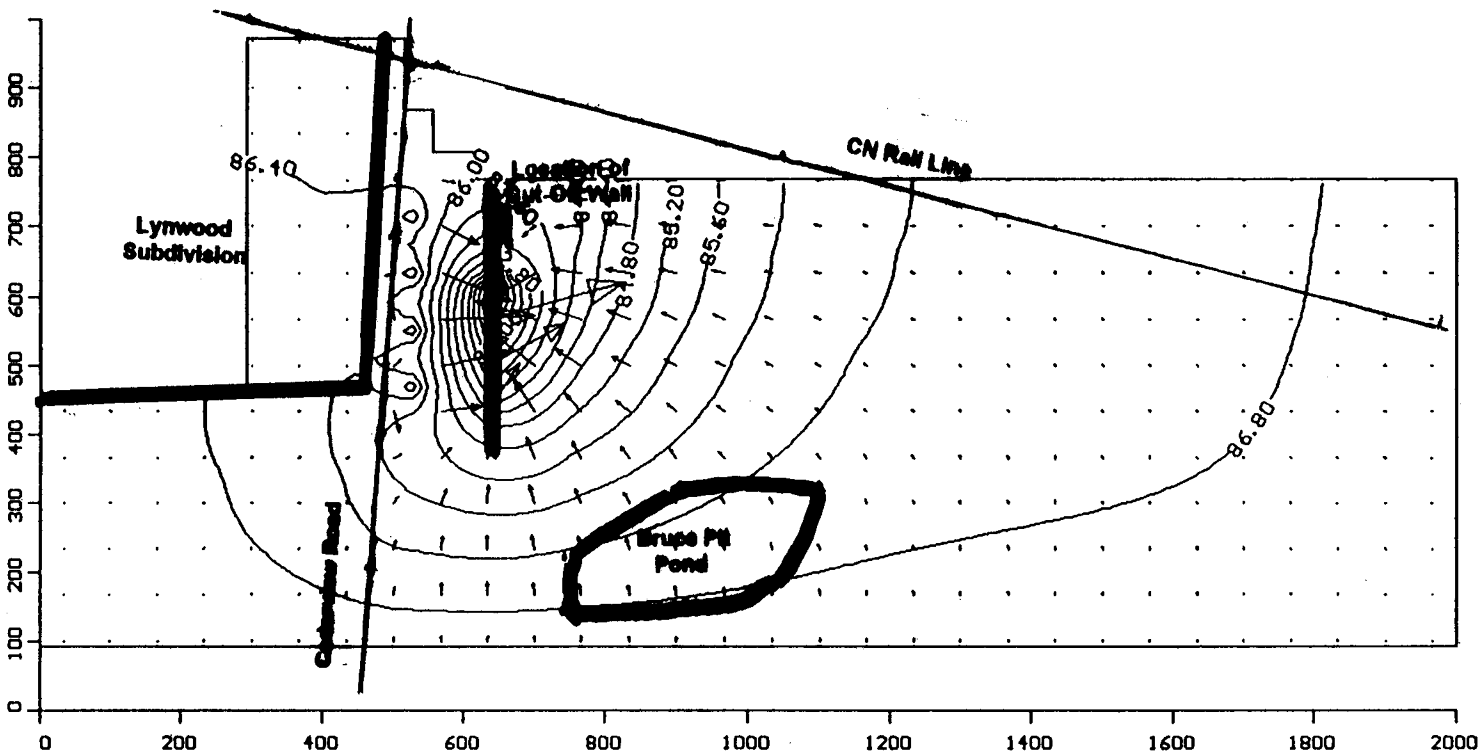
Model Dimensions	
No. rows	51
No. columns	100
No. pumps	0
No. injct	0
No. const. heads	179
No. const. flux	0
No. river nodes	0
No. drain nodes	0
Hydraulic Heads (m)	
Min :	78.000
Max :	87.000
Velocities (m/d)	
Min :	0.000
Max :	8.942
Avg :	0.455
Units : [m][day]	
Data Set : COWOP	

FLOWPATH MODELING RESULTS

BC2-6



FLOWPATH 5.03

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Model Dimensions

No. rows	: 51
No. columns	: 102
No. pumps	: 0
No. injct	: 0
No. const. heads	: 168
No. const. flux	: 0
No. river nodes	: 0
No. drain nodes	: 0

Hydraulic Heads (m)

Min :	78.000
Max :	87.000

Velocities (m/d)

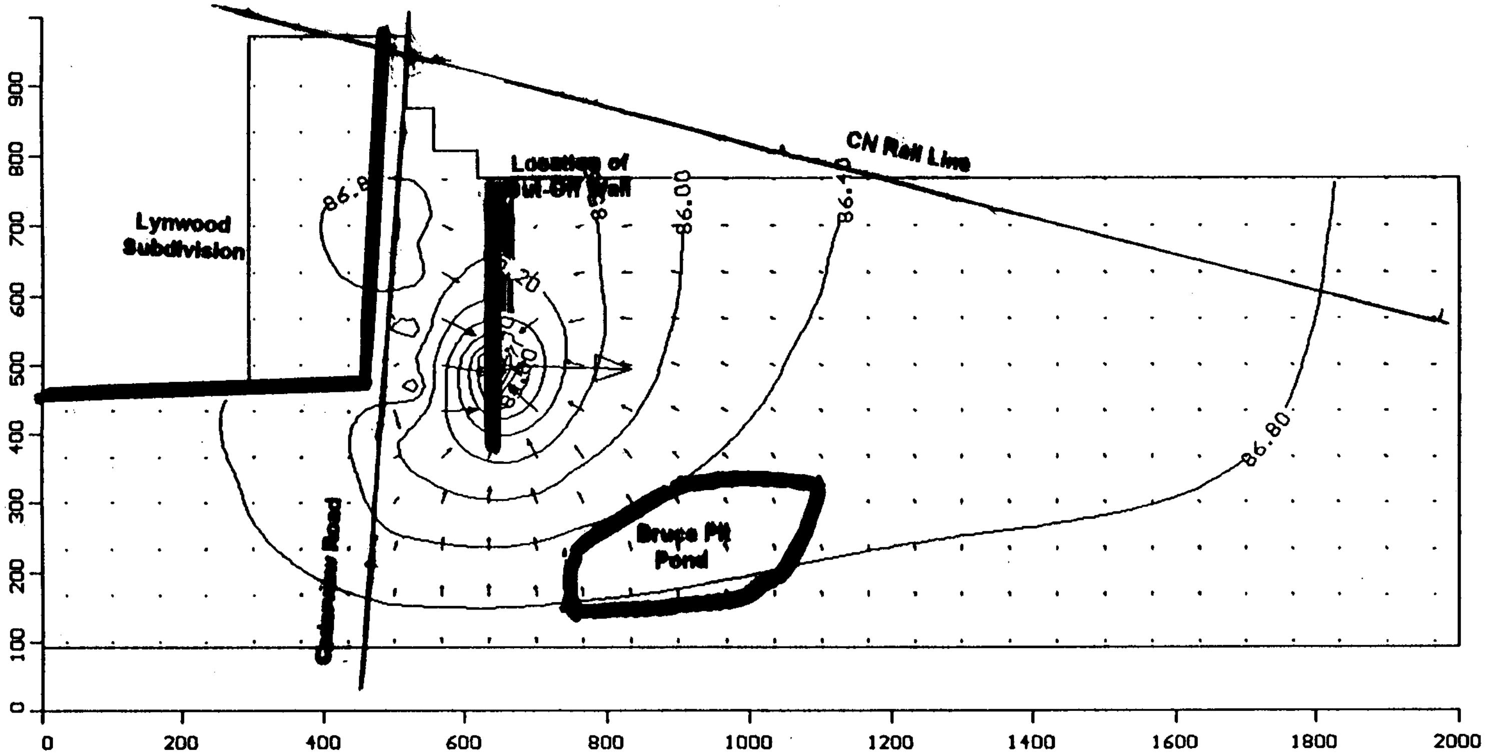
Min :	0.000
Max :	7.677
Avg :	0.287

Units : [m][day]

Data Set : COW100P

FLOWPATH MODELING RESULTS

BC2-7



FLOWPATH 5.03

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Model Dimensions

No. rows	: 51
No. columns	: 102
No. pumps	: 0
No. injct	: 0
No. const. heads	: 168
No. const. flux	: 0
No. river nodes	: 0
No. drain nodes	: 0

Hydraulic Heads (m)

Min :	78.000
Max :	87.000

Velocities (m/d)

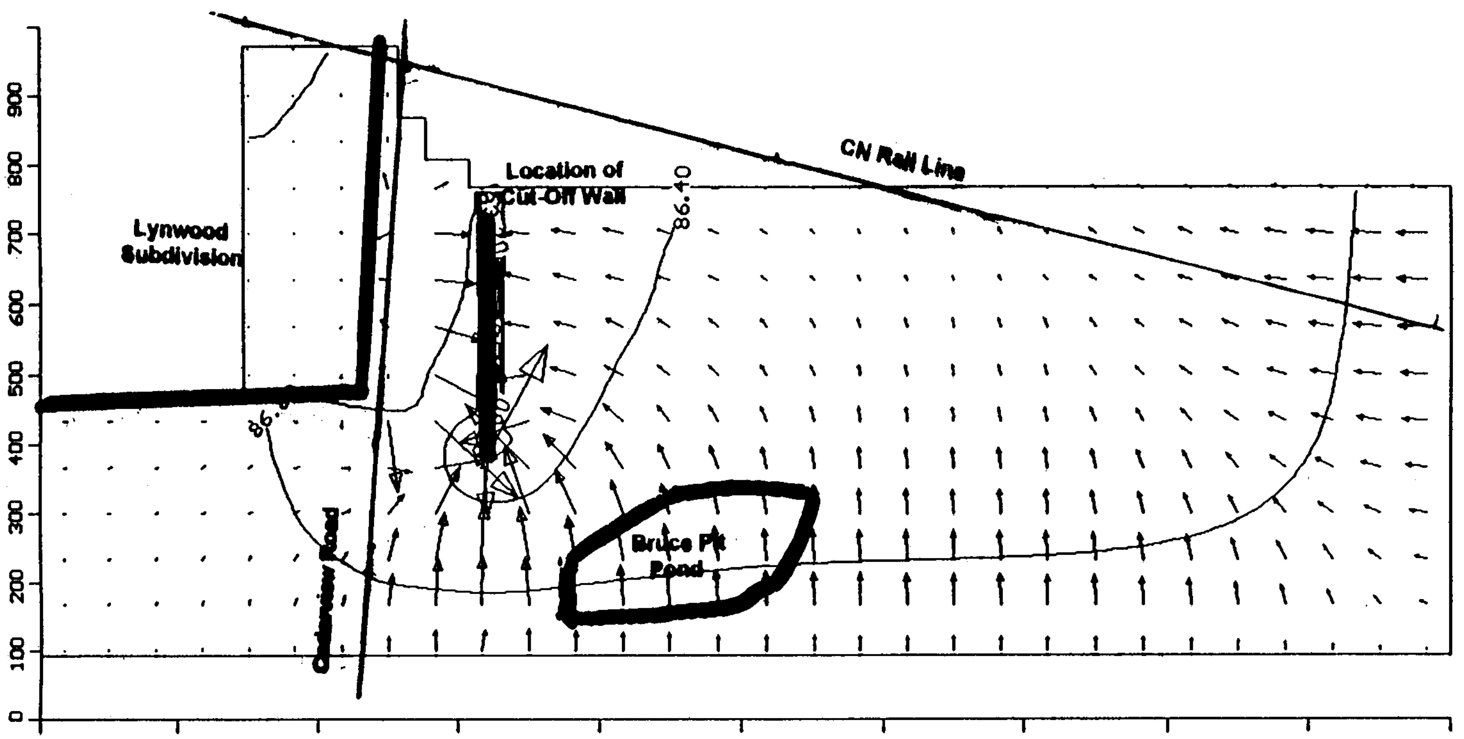
Min :	0.000
Max :	8.187
Avg :	0.189

Units : [m][day]

Data Set : COW200P

FLOWPATH MODELING RESULTS

BC2-8



FLOWPATH 5.03	
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Model Dimensions	
No. rows	51
No. columns	102
No. pumps	0
No. injct	0
No. const. heads	170
No. const. flux	0
No. river nodes	0
No. drain nodes	0
Hydraulic Heads (m)	
Min :	78.000
Max :	87.000
Velocities (m/d)	
Min :	0.000
Max :	0.940
Avg :	0.087
Units : [m][day]	
Data Set : COW300P	

FLOWPATH MODELING RESULTS

BC2-9

APPENDIX B

PRESENT VALUE COSTING OF CUT-OFF WALL OPTIONS

HIGHWAY 416
NEAR LYNWOOD SUBDIVISION
NEPEAN, ONTARIO

TABLE B-1

SCENARIO 1
RECHARGE TO SUBDIVISION WITH RMOC WATER
(CUT-OFF WALL COST OF $108/m^2)

	Alt #0 (no wall)	Alt #1 (100 m)	Alt #2 (200 m)	Alt #3 (300 m)	Alt #4 (400 m)
1.0 Capital Costs					
1.1 Cut-off wall	0	463	815	1,160	1,528
1.2 Inspection and design	0	50	88	120	151
1.3 Savings in well points	0	-27	-81	-135	-255
1.4 Recharge wells for subdivisions	150	125	80	45	35
1.5 Recharge & pumps for pond	50	50	50	50	(50*)
Sub Total	200	661	952	1,240	1,459 (50*)
2.0 O & M Costs					
2.1 Recharge wells for subdivision	10	10	6	2	1
2.2 Recharge and pumps for pond	3	3	3	3	(3*)
Sub Total	13	13	9	5	1 (3*)
Present Value	289	289	200	111	22 (67*)
3.0 Replacement Costs					
3.1 Recharge pumps for pond at 17 & 34 years	4	4	4	4	(4*)
Present Value	3	3	3	3	(3*)
4.0 Annual Water Costs	490	436	231	60	5
Present Value	10,878	9,679	5,128	1,332	111
TOTAL PRESENT VALUE (1000's)	$11,370	$10,632	$6,283	$2,686	$1,592 (120*)

* Contingency costs

TABLE B-2

SCENARIO 2
RECHARGE TO SUBDIVISION WITH GROUNDWATER
(CUT-OFF WALL COST OF $108/m^2)

	Alt #0 (no wall)	Alt #1 (100 m)	Alt #2 (200 m)	Alt #3 (300 m)	Alt #4 (400 m)
1.0 Capital Costs					
1.1 Cut-off wall	0	463	815	1,160	1,528
1.2 Inspection and design	0	50	88	120	151
1.3 Savings in well points	0	-27	-81	-135	-255
1.4 Recharge wells for subdivisions	230	190	120	65	55
1.5 Recharge & pumps for pond	50	50	50	50	(50*)
Sub Total	280	726	992	1260	1,479 (50*)
2.0 O & M Costs					
2.1 Recharge wells for subdivision	40	35	20	8	2
2.2 Recharge and pumps for pond	3	3	3	3	(3*)
Sub Total	43	38	23	11	2 (3*)
Present Value	955	844	511	244	45 (66*)
3.0 Replacement Costs					
3.1 Recharge well pumps for pond at 17 & 34 years	160	140	80	40	10
3.2 Recharge well pumps for pond at 17 & 34 years	30	30	30	30	(30*)
Sub Total	190	170	110	70	10 (30*)
Present Value	154	138	89	57	8 (24*)
TOTAL PRESENT VALUE (1000's)	$1,389	$1,708	$1,592	$1,561	$1,532 (140*)

* Contingency costs

TABLE B-3

SCENARIO 2A
RECHARGE TO SUBDIVISION WITH GROUNDWATER
(CUT-OFF WALL COST OF $129/m^2)

	Alt #0 (no wall)	Alt #1 (100 m)	Alt #2 (200 m)	Alt #3 (300 m)	Alt #4 (400 m)
1.0 Capital Costs					
1.1 Cut-off wall	0	546	973	1,400	1,841
1.2 Inspection	0	50	88	120	151
1.3 Savings in well points	0	-27	-81	135	-255
1.4 Recharge wells and pumps for subdivisions	230	190	120	65	55
1.5 Recharge & pumps for pond	50	50	50	50	(50*)
Sub Total	280	809	1150	1500	1,792 (50*)
2.0 O & M Costs					
2.1 Recharge wells for subdivision	40	35	20	8	2
2.2 Recharge and pumps for pond	3	3	3	3	(3*)
Sub Total	43	38	23	11	2 (3*)
Present Value	955	844	511	244	45 (66*)
3.0 Replacement Costs					
3.1 Recharge pumps for pond at 17 & 34 years	160	140	80	40	10
3.2 Recharge pumps for pond at 17 & 34 years	30	30	30	30	(30*)
Sub Total	190	170	110	70	10 (30*)
Present Value	154	138	89	57	8 (24*)
TOTAL PRESENT VALUE (1000's)	$1,389	$1,791	$1,750	$1,801	$1,845 (140*)

* Contingency costs

1) Capital Costs

Present value equals the estimated construction cost plus engineering and contingencies;

2) Annual operating and maintenance costs

$$PV = Ax \frac{1-\left(\frac{1+e}{1+i}\right)^{n}}{\left(\frac{1+i}{1+e}\right)-1}$$

3) Residual value

$$PV = P\left(\frac{1+e}{1+i}\right)^{n}$$

4) Present value of a cost in year n, based upon a given base year cost escalating annually at an escalation rate e and with an interest rate i.

$$PV = P\left(\frac{1+e}{1+i}\right)^{n}$$

Definitions:

PV = present value

Ax = annual sum

e = escalation rate (5% assumed)

i = interest rate (9% assumed)

P = principal sum (current cost)

n = number of years (50 years assumed)

5) The present value of any option equals = Capital cost + PV of O & M costs + PV of any equipment replacement costs - PV of equipment remaining at the end of the study period.