Final Report

WELLFIELD PROTECTION STUDY

Village of Perth Andover

JURY CONSULTING SERVICES

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May 26, 2003

File: 1024-0

Village of Perth Andover
1131 West Riverside Drive
Perth-Andover, New Brunswick, E7H 5G5

Attn: Mr Danny Dion

RE: Wellfield Protection Study for the Village of Perth-Andover N.B.

Dear Mr Dion

Jury Consulting Services (JCS) is pleased to submit the following report for the Wellfield Protection Study (WPS) completed for the Village of Perth-Andover NB. We are pleased to submit 10 copies of this report and we thank you for the opportunity to work with you on this project.

We trust this report is sufficient for your requirements at this time. If you have any questions or wish to comment, please feel free to contact the undersigned.

Yours Truly,

JURY CONSULTING SERVICES

Arthur Jury, P.Geo.

President

REGISTERED PROFESSIONAL GEOSCIENTIST
Province of New Brunswick
#M5350
Arthur W. Jury
Signature
May 26, 2003
Date
Province du Nouveau-Brunswick
GEOSCIENTIFIQUE IMMATRICULÉ

Wellfield Protection Study

Prepared for

Village of Perth Andover, N.B.

May 2003

JURY CONSULTING SERVICES

Fredericton, New Brunswick

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

APPENDIXES

1.0 INTRODUCTION

Jury Consulting Services has completed a Wellfield Protection Study for the Village of Perth-Andover. This Wellfield Protection Study forms the basis for the development of a policy to protect and maintain the Village's water supply. The village currently utilizes two production wells, located on both sides of the Saint John River. The Andover well located on the west side of the river serves as the main water supply source, while on the opposite side of the river the Perth well is used as a back up well during peak demand periods.

The Perth-Andover wells are constructed with screened intervals at depth in buried fluvial gravel deposits of the Saint John River. The static water level in the fluvial deposits lies within 5m of ground surface at elevation similar to the adjacent Saint John River.

The Wellfield Protection Area was delineated using the computer software program Visual MODFLOW 3.0 (Version 180), which is a three-dimensional groundwater flow and wellfield analysis tool. The computer model created with this tool was used to estimate the size and shape of the capture zones around the two municipal wellfields. Protection Area Zones were then developed around each well, which correspond to zones established in the New Brunswick Department of Environment and Local Government – *Wellfield Protected Area Designation Order-Clean Water Act*. The three protection zones established around each well include:

Zone	Possible Contaminant	Travel Time to Well
A	Bacterial	0-100 Days
B	Petroleum	100 days to 5 years
C	Persistent Hazardous Chemical	5 years to 25 years

Within the proposed protection areas of Perth and Andover wellfields, land uses are primarily restricted to residential uses. Only a few commercial, industrial, institutional, and agricultural land uses are present. The main risks within the wellfield protection areas include underground petroleum storage tanks, fertilizer/pesticide use, and gravel pit activity.

In order to reduce the risk of well contamination from existing high-risk uses, we propose following recommendations proposed in the previous WPS. These recommendations include the following:

- implement a UST monitoring program with an eventual replacement of USTs within the wellfields;
- regulate pesticide and fertilizer storage within the WPA; and
- prohibit quarry activity within Protection Zone 1.
- Pass a resolution of council to designate the wellfield protection area under the *Wellfield Protected Area Designation Order-Clean Water Act*

To minimize future risks to groundwater quality, it is recommended that the Village:

- incorporate the Wellfield Protection Area into Municipal Plan;
- implement a public education program;
- implement a well monitoring and maintenance program;
- implement transportation of dangerous goods awareness program; and
- control use of other wells or exploratory holes.

2.0 WELLFIELD DESCRIPTION

2.1 Wellfield Setting

The Village of Perth-Andover (Population 1,908) is located in northwestern New Brunswick approximately 200 km north of Fredericton. The Village lies on both sides of the Saint John River with Perth located on the east bank of the river and Andover on the west bank. The water supply in the Village is derived from two production wells located on opposite sides of the Saint John River. The Andover well serves as the main water supply source for the Village while the Perth well is used as a back up well during peak demand.

The Perth well was drilled in 1957 to a total depth of 20m with a reported yield of 72 l/sec (950 igm). The well is located immediately adjacent to the banks of the Saint John River and it is anticipated that the well draws a large percentage of its yield from the river.

The Andover well was drilled in 1987 to a total depth of 32.9m. This well is screened in the lower medium grained sand and coarse gravel layer between 27.4m and 32.0m. A solid 254mm diameter steel casing extends from the screen to surface. The well was reported to have been pump tested at 31.9 l/sec (421 igpm) for 72 hours which resulted in a total drawdown of 0.5m in the pumping well and 0.2 m and 0.1 m respectively in nearby monitoring wells located at distances of 3.7m and 105.7m, respectively.

2.2 Physiographic and Geological Setting

The Village of Perth-Andover is located within a physiographic division known as the Chaleur Uplands of northwestern New Brunswick. Locally in the Perth-Andover area, the Chaleur Uplands comprises a slightly undulating peneplain, varying in elevation between 70m and 320m above sea level. The highest elevations are to the east where numerous streams have eroded valleys in the resistive sandstones.

The geology of the bedrock in Perth-Andover consists of Upper Ordovician, Silurian and Lower Devonian (390-445 million year old) sedimentary rocks units. The oldest of these are part of the Aroostook-Metapedia Carbonate Belt (Ayrton et al 1969). This unit, which is also known as the Metapedia Basin (Fyffe et al 1981), is composed of an argillaceous limestone of the Metapedia Group. Two north-northeast trending faults pass through the Perth-Andover area near the Saint John River and separate the Metapedia Group sedimentary rocks from the younger Silurian calcareous sandstones of the Perham Group and the non-calcareous sandstone and siltstone of the Lower Devonian Wapske Formation. The Wapske Formation is comprised of massive sedimentary beds of thinly laminated siltstone and sandstones that are more resistant to erosion than the Metapedia Group. All bedrock in the highland areas around the Village is overlain by a thin veneer of Quaternary-Wisconsin aged (10,000 year old) glacial derived till.

Extensive deltas of sand and gravel were deposited by melt water as an ice front retreated from the Perth-Andover area some 10,000 years ago (Rampton and Paradis 1981). These glaciofluvial deposits are restricted to the Saint John River valley, which follows a course underlain by the easily eroded fractured limestone of the Metapedia Group, along its faulted contact with Silurian and Devonian sandstones. These sand and gravel deposits can reach depths of greater than 30m. These gravel deposits are very permeable and were utilized for the construction of the municipal water supply wells. Surface deposits of the sand and gravel have previously been quarried in various areas of the Village and various tests on the deposits indicate a high percentage of fines exist in the upper 0-7 metres of the deposits. The municipal wells, however, have screens that are placed in cleaner gravels between 20-32 metres from surface.

2.3 Hydrogeological Setting

The locations of Perth Andover's two production wells are shown on Figures 2 1 and 2-2 respectively. The static water level within the gravel deposits is within 5m of ground surface at an elevation similar to the adjacent Saint John River. Groundwater levels can be expected to fluctuate with the level of river.

The stratigraphy at the two production wells consists of sand and gravel deposits of up to 7m in thickness overlying an intermediate silty sand and gravel (silty sand) stratum. Cleaner medium grained sand to coarse gravel underlies the silty sand. This is the principal gravel deposit that is used for water supply for the Village. The lower gravel deposits are bounded by the calcareous argillite (siltstone or slate) bedrock of the Metapedia Group on the west side of the river and massive laminated siltstones and sandstone beds on the east.

It is anticipated the sand and gravel deposits that form the Perth-Andover aquifer decrease in fines content with depth. This would correlate with the historic development of the river. High water flow velocities would be expected in a young Saint John River as glaciers retreated over 10,000 years ago, depositing coarse clean gravel at the bedrock surface as fines were carried away down river. Decreasing water velocities would then be expected over time as river outwash and gravels inundated the valley from the highlands, increasing elevations of the riverbed and decreasing its gradient. Increased fines content would be expected in these higher elevation sediments as the velocity of the river was reduced.

The lower gravel aquifer used for the water supply is found between 27.4 and 32.0 m in the Andover well and 18-20 m in the Perth well. Slug testing and grain size analysis have previously been completed of this unit in the Perth Andover area (Geocon 1990). Hydraulic conductivity values for this unit range from 10^{-2} cm/s to almost 10 cm/s as obtained by using different methods (pump tests, slug tests and grain size analysis. Various tests completed in these investigations are displayed in Table 1.

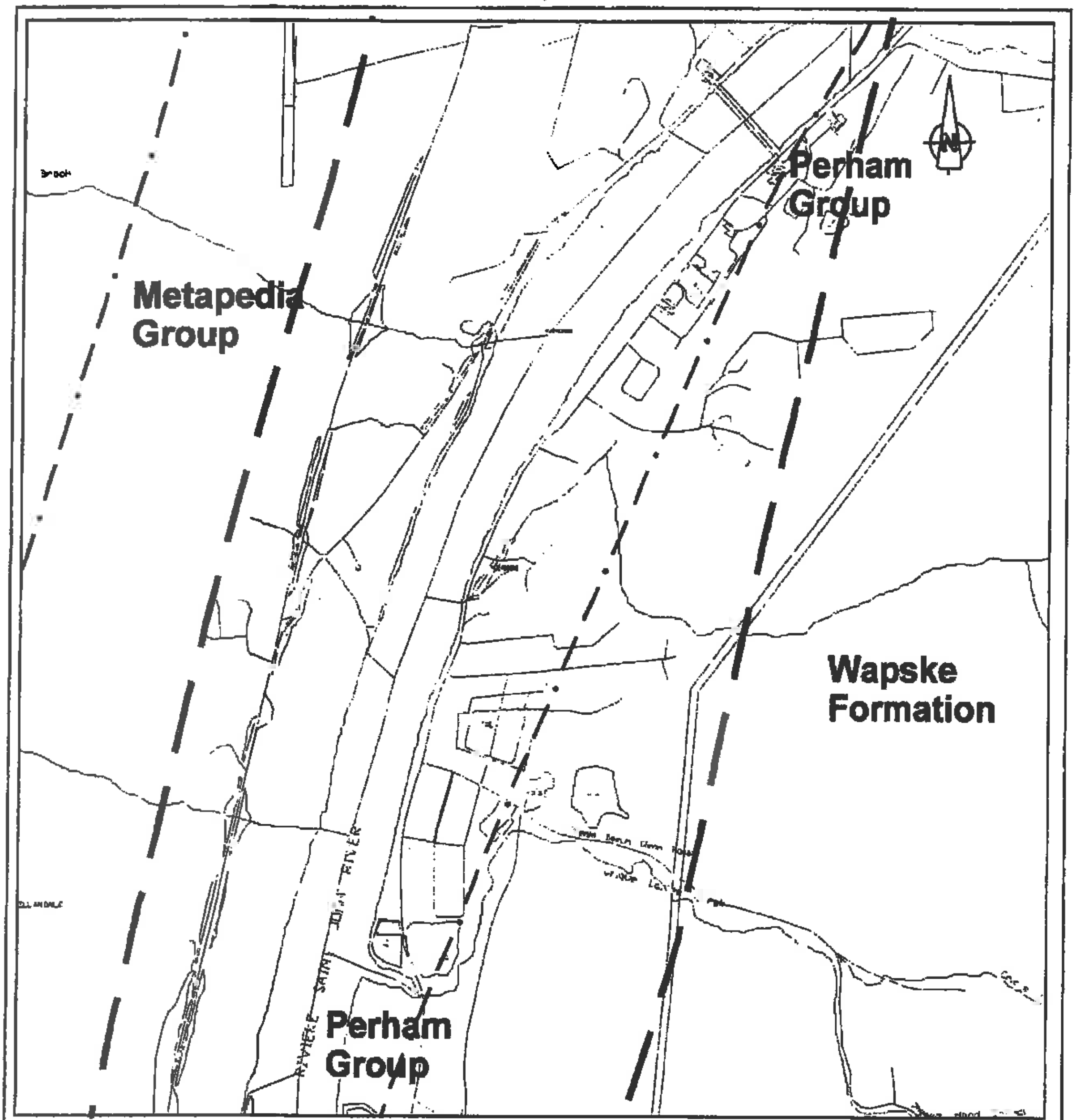
TABLE 1

HYDRAULIC CONDUCTIVITIES

Intermediate Silty Sand And Gravel	**Hydraulic Conductivity (K) Cm/Sec**
Subsurface Surveys 1989	2.0×10^{-4} to 3.5×10^{-2}
Gradation (Geocon 1990)	1.0×10^{-4} to 1.0×10^{-2}
Lower Sand And Gravel	
Modified Pump Test (WMS Associates 1987)	1.5×10^{-1} to 6.0×10^{-1}
Piezometer Response Log time (Geocon 1990)	1.0×10^{-2} to 1.0×10^{-1}
Piezometer Response Groundwater Rise (Geocon 1990)	1.0×10^{0} to 1.0×10^{-1}
Estimate from gradation	6.0×10^{-1} to 6.0×10^{0}
Lab testing	1.5×10^{-1} to 8.0×10^{-1}

2.4 Climate

The climate in the Perth-Andover region can be described as humid continental characterized by long, cold winters, cool summers, and no dry season. The average temperature in the region is 4.2 °C. The extreme annual maximum and minimum temperature recorded over the period 1941 -1970 was 37.2°C and-43.9°C respectively. The annual mean total precipitation over this period was 1030mm.



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Fault

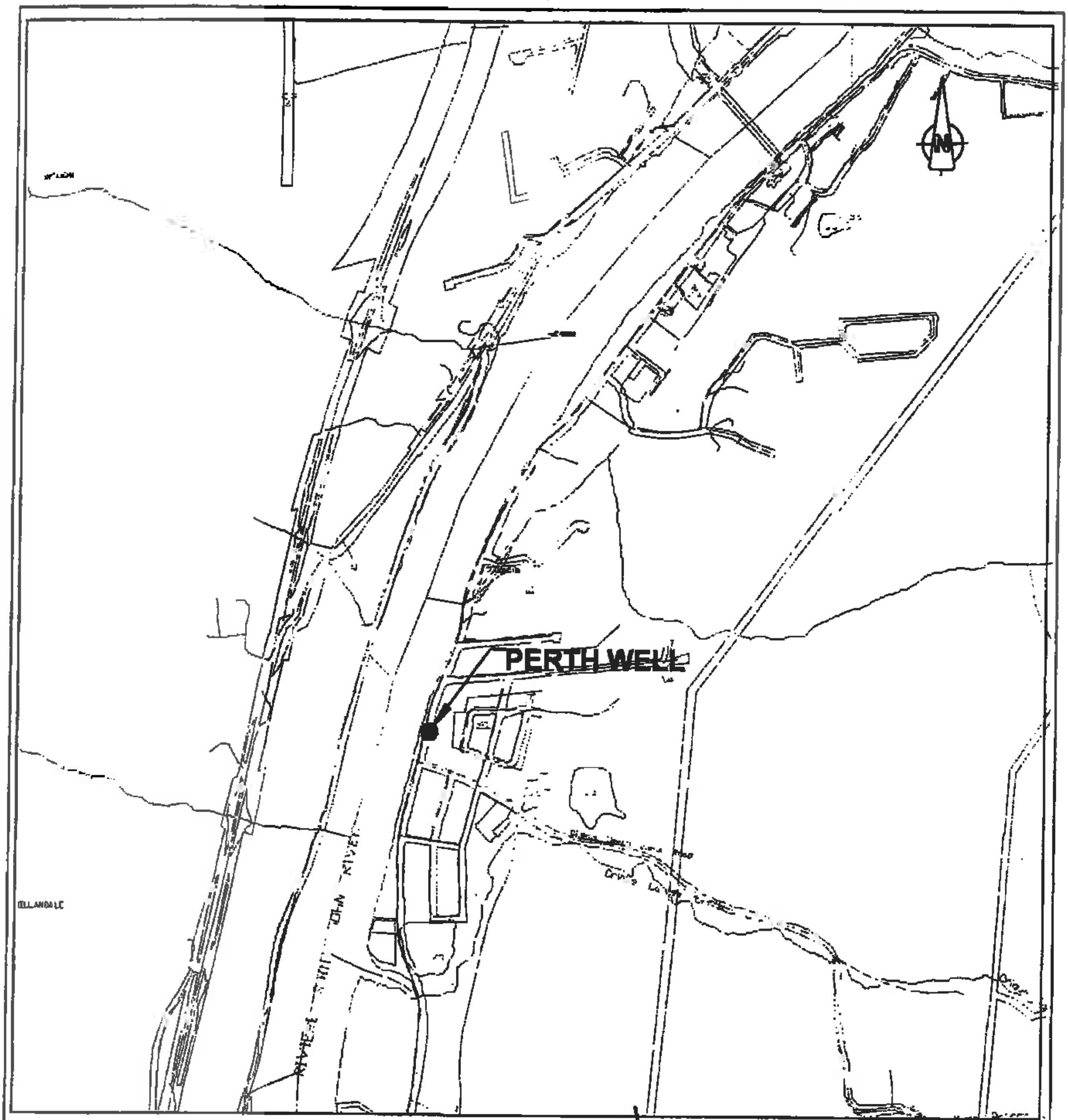
Geologic Boundary

Jury Consulting Services

GEOLOGY

Perth-Andover, NB

DATE	PROJECT#	FIGURE #
March 2003	1024	1



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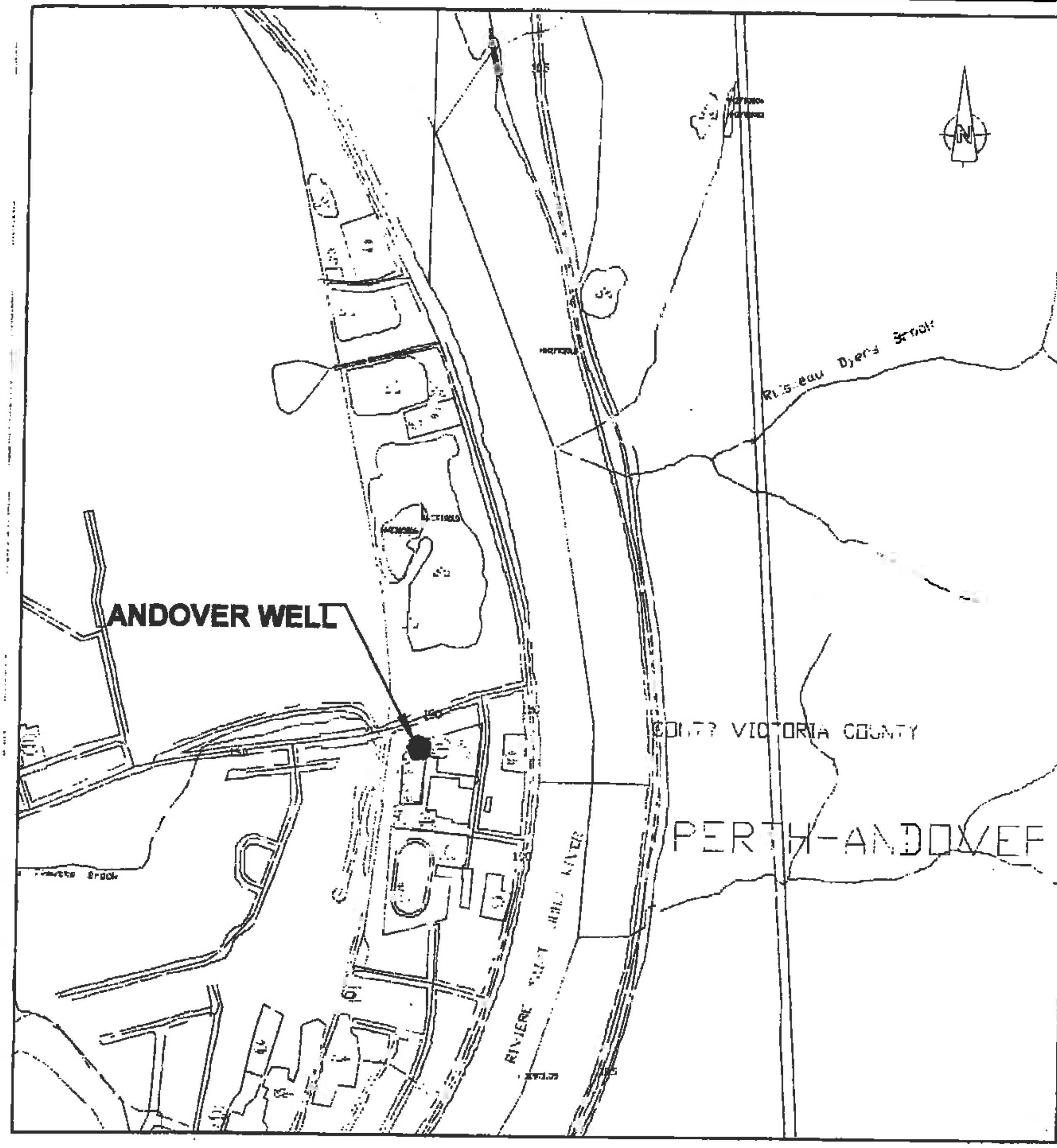
● Protection Well

Jury Consulting Services

Well Location

Perth-Andover NB

DATE	PROJECT#	FIGURE#
March 2003	1024	2



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● **Production Well**

Jury Consulting Services

Andover Production Well Location

Perth-Andover NB

DATE	PROJECT#	FIGURE#
March 2003	1024	3

3.0 GROUNDWATER MODELLING

The goal of computer modeling in a Wellfield Protection Study is to reproduce the natural groundwater flow characteristics around a production well on a computer using a specialized groundwater flow software program. For the current Wellfield Protection Study the software chosen to model the groundwater flow characteristics is Visual MODFLOW (Ver. 3.0.0.180). This software, developed by Waterloo Hydrogeologic Inc, uses known mathematical flow equations to develop a three dimensional graphical capture zone around the production well and allow the user to investigate groundwater movement and travel times both around the well and the surrounding area. Visual MODFLOW is a three-dimensional finite element model that simulates particle transport, steady state groundwater flow and/or contaminant transport in a porous media. The software illustrates groundwater movement by the graphical display of both groundwater directional arrows and by tracing imaginary particles placed in the modelled area by the user.

The delineation of the groundwater protection zone requires an understanding of the actual hydrological and hydrogeological processes affecting the area within and surrounding the wellfield. These processes are either measured or estimated to provide input for the model. The input parameters for Visual MODFLOW include aquifer thickness, hydraulic conductivity, stratigraphy, recharge, porosity, pumping rates of each well in the wellfield, and geodetic elevations. When possible, known or measured data and information was utilized for input into the model. A review of pump test results, precipitation records, granular aggregate and geological reports was completed and incorporated into the development of the model. Also, information included in the previous well head protection study (PDL 1996) was provided by the New Brunswick Department of Environment and Local Government (NBDELG). This document was reviewed and much of the wellfield data and input parameters were utilized when possible.

Groundwater path lines and travel times were calculated using the particle tracking method. The path lines were used to delineate the wellfield protected areas. A water balance developed for the wellfields was based on the mass balance of groundwater entering and leaving the model domain.

3.1 Groundwater Modelling Methodology

Groundwater modelling is a tool used to estimate the size and shape of the capture zones and zones of influence of a pumping well or wellfield. The technique involves the development and calibration of a numerical simulation of the groundwater flow system under non-pumping conditions. A conceptual model is first developed to understand the anticipated groundwater flow system for the model area. This conceptual model uses available information on the wellfield, surrounding topography, environmental conditions, geological and hydrological data sources to estimate the existing groundwater flow conditions.

Using the conceptual model as a general guide, data is entered into the software and a static groundwater model is developed that mimics the anticipated groundwater flow developed in the conceptual model. Once the conceptual model is modeled in the software, adjustments to the parameters are made to ensure the mathematical calculations of the changes in groundwater head values have reached a tolerance value set by the user. This "convergence" in the changes in groundwater head values ensures the modeled flow system makes sense with the data and parameters utilized in the model.

With a converged static groundwater flow model developed the municipal production wells are then added to the modelled area and water is withdrawn in the modeled domain at the maximum pumping rate of the wells. Additional minor adjustments are made to ensure convergence and to ensure modelled groundwater drawdown at the wellfield is consistent with measured pump test data. The model is then run over a 25 year time frame at the maximum rate of the production wells and the results predict the response to long term pumping. In order to visualize the groundwater flow conditions and to estimate the time period it takes to enter the well, imaginary particles are placed within the model domain. These particles are then traced by the mathematical groundwater flow equations and displayed in a graphical format to predict the area around the well in which groundwater is captured at the modeled pumping rate of the wells. This "Capture Zone" around the well is then broken down into time related segments that correspond to the required protection areas of the Wellfield Protection Study.

3.2 Conceptual Model

The conceptual model developed for the Perth Andover Wellfield Protection Study model was relatively simple. The Saint John River runs north south through the Village and topography rises rapidly on each side of the river from approximately 75 m above sea level at the river to elevations greater than 320 m in the hills to the east of the Village. Groundwater would be expected to recharge in the higher elevations and flow downwards into the bedrock, flow through the rock pores and fractures until it discharges into either the numerous streams in the area or ultimately to the Saint John River.

Bedrock in the area ranges from the argillaceous limestone of the Metapedia Group west of the river to the massive fine-grained laminated siltstone and sandstones of the Wapske Formation to the east. While these sediment types characteristically have extremely low permeability values it is anticipated both units are highly fractured due to the close proximity of a major fault that extends north south through the area, in the approximate area of the Saint John River. Highly fractured sediments of this type generally exhibit a primary groundwater flow through the fractures, which is similar to a homogeneous media. The recharge / runoff ratio would also likely be low due to relatively large increases in elevation on either side of the river.

Municipal production wells for the Village of Perth-Andover are located in gravel deposits that make up the bed and banks of the Saint John River. These gravel deposits are described in detail in the New Brunswick Department of Natural Resources-Granular Aggregate Resources (Open File Reports 81-2 and 80-6). These deposits have also been quarried in various areas within the Village limits. The usable surface expression of these deposits has been described as being 5-7m in thickness and containing a high percentage of fines. During construction of the two production wells these gravel deposits were found to extend to depths of at least 20 metres in the Perth well and 32 m in the Andover well where screens are placed in clean coarse gravel. As described in Section 2.3, it is anticipated these gravel deposits decrease in fines with depth. As a result, the permeability of the gravels would also be expected to increase with depth.

Under normal static (non-pumping) conditions groundwater discharges from the bedrock into overlying gravel deposits prior to moving upwards to discharge to the Saint John River. Pumping of the production wells would be expected to reverse this normal discharge condition near the well. A slow downward migration velocity of the groundwater would be expected in this area as the natural upward migration is reversed. Alternately an increased upward velocity would be expected in the bedrock below the gravels. The following is a simplified figure illustrating the conceptual model described above.

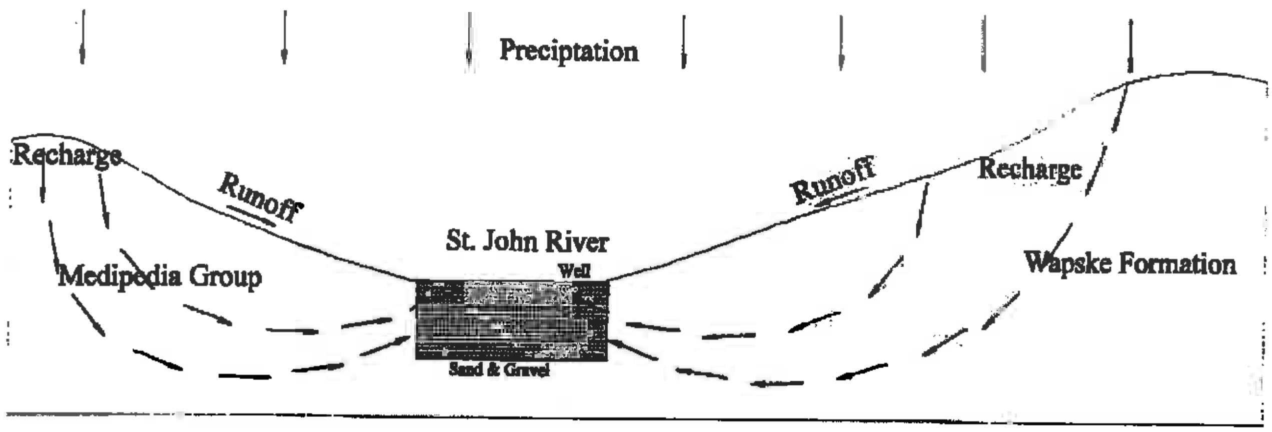

Figure 4
Conceptual Model

This conceptual visualization of the groundwater flow conditions in the Perth-Andover area was used as a base for the set up of the computer model in the Visual MODFLOW software.

3.3 Computer Modelling

The above conceptual model was used to develop a working numerical model of the anticipated groundwater flow. This model was developed using the Saint John River as the primary fixed flow boundary. The model was built around a backdrop of an aerial photograph of the Village imported from scanned imagery of 1:10000 orthographic mapping. Surface features including roads, streams, houses, topographic elevations etc. were also imported from various files supplied by the NBDELG.

The model assumed separate stratigraphic layers with increasing permeability with depth were present in the gravel deposits. The fractured argillaceous limestone of the Perham Group, west of the river, was assumed to be more highly fractured than the massive laminated sediments of the non-calcareous Wapske Formation to the east. These rock formations were given slightly different permeability's in the numerical model area.

When possible, actual information was used in the numerical model. Assumptions, however, had to be made for many input parameters for the model. These assumptions were normally obtained from various sources of literature and texts on groundwater flow, and wellfield protection. The following assumptions were made in the numerical model:

- The groundwater recharge rate, after run-off, evaporation and plant transpiration, was assumed approximately 20% of the average annual precipitation. This value was applied constant across the flow domain.
- The hydraulic conductivity of the gravel aquifer was assumed to range between 1.0×10^{-3} cm/s in the surface gravels to 1.0×10^{0} cm/s in the lower gravels were the well screens are installed.
- The effective porosity, storativity, and specific yield parameter values for all units were chosen from the literature.
- The hydraulic conductivity for the surface sediments and the fractured bedrock was chosen to be representative of homogeneous fracture flow with a vertical permeability 10 times less than horizontal.

The model grid for the both the Perth and Andover models was comprised of numerous rows and columns spread across a distance, which encompasses the local watershed area around the two production wells. The models also included vertical layers of varying thickness spanning an elevation difference from sea level to the local surface elevations of the area. The grid for the both models was established using coordinates derived from both the New Brunswick Grid System that was supplied by NBDELG and a simpler model grid based on the distance from the X,Y origin. The Perth model was comprised of 39 rows, 41 columns and 5 layers of varying thickness whereas the Andover model was comprised of 33 rows, 33 columns and 4 layers. Coordinate minimum and maximum values for both models are included in Table 2. Figures illustrating the grid setup are included in Appendix 1

(Figures A1-1 and A1-3).

Table 2
Model and World Coordinates (m)

Model	Coordinate	X(Min)	Y(Min)	X(Max)	Y(Max)
Perth	Model	0	0	3530	3770
	World	2406160	7523330	2409690	7527100
Andover	Model	0	0	3660	3540
	World	2406200	7527070	2409860	7530610

The modelled simulations for the Perth and Andover wellfields are based on pumping rates of 32.0 and 37.9 l/sec (420 & 500 igpm) respectively while the actual pumping rate for the wellfields are 26.5 l/sec and 19.0 l/sec (350 & 250 igpm) respectively. The total yield may periodically increase to 30.0 l/see each during peak pumping or fire fighting requirements. Simulations were conducted at these yields to optimize capture zones for the wells.

3.4 Model Calibration

The numerical model was first calibrated to produce the anticipated static groundwater flow conditions over the model. The simulated static groundwater flow conditions (without production wells running) are shown in Appendix 1. Groundwater recharges the bedrock at the edges of the model and flows downwards from the higher elevated areas to the low-lying areas. Streams in the model area also remove some of the groundwater but generally, groundwater flow is towards the Saint John River.

The calibrated static flow model was then used as a starting point to further calibrate the model to actual observed conditions recorded in the reported pump test completed on the Andover well. This well was reported to have been pump tested at 31.9 l/sec (421 igpm) for 72 hours which resulted in a total drawdown of 0.5m in the pumping well and 0.2 m and 0.1 m respectively in nearby monitoring wells located at distances of 3.7m and 105.7m, respectively. This information was incorporated in the model and model parameters adjusted to match these results a closely as possible. These adjustments were also used for the Perth model as no pump test data was found that applied to this production well, which was constructed in 1957.

The calibrated Hydrogeological input parameters selected for the calibrated flow model are given in Table 3

TABLE 3 Calibrated Model Input	
Model Parameter (Symbol - Units)	Selected Value
K (cm/s) Metapedia/Perham Group	Kxy -1.0×10^{-4}, Kz -1.0×10^{-5}
K (cm/s) Wapske Formation	Kxy -8.5×10^{-5}, Kz -8.5×10^{-6}
K (cm/s) Surface Gravel 0-7m Depth	Kxy -1.0×10^{-3}, Kz -1.0×10^{-4}
K (cm/s) Middle Gravel (Andover) 7-28m Depth	Kxy -1.0×10^{-2}, Kz -1.0×10^{-3}
K (cm/s) Lower Gravel (Well Screen)	Kxy -1.0×10^{0}, Kz -1.0×10^{-1}
Storativity (Ss)	0.155-0.200
Specific Yield (Sy)	0.01-0.25
Effective Porosity (n, - unit less)	10%-30%
Total Porosity (n, - unit less)	25%-35%
Groundwater Recharge (R - mm/yr)	20%
Surface Elevation (m. above sea level)	74m-280m
Aquifer Bottom Elevation (m above sea level)	0 m
Pumping Rate Perth Well (m^3/day)	3273
Pumping Rate Well #2 (m^3/day)	2765

3.5 Model Sensitivity Analysis

Once the calibrated numerical model was developed and tested, a sensitivity analysis was completed to test the effects on the model to changes in critical variables. The sensitivity analyses were completed with the production wells operational. The most critical variables in the model were found to be the following:

- Hydraulic conductivity, particularly the gravel deposit that hosts the main aquifer.
- The size and shape of the lower gravel deposit.
- Recharge parameter.

A sensitivity analysis of the hydraulic conductivities assigned to the bedrock was completed. A decrease in the hydraulic conductivity of the bedrock resulted in water levels exceeding the surface of the model at approximately 2-5 times the calibrated value. Alternately increasing the conductivity value for the upper layer resulted in a decreasing head values and hydraulic gradient of the model domain. This reduction of hydraulic gradient became almost flat and level with the elevation of the Saint John River when the increased conductivity value approached 10 times the calibrated parameter value.

A sensitivity analysis of the conductivities assigned to the gravel deposits was also completed. A decrease in the hydraulic conductivity of the gravel resulted in reducing the drawdown in the production wells. Alternately increasing the conductivity value resulted in a decreasing head values in the wells. In addition, the size of the lower gravel deposit was altered to inspect the effects on the model results. Similar changes were noted in drawdown in the wells with decreased drawdown noted when the size of the deposit is increased, and a greater drawdown in the well noted when the deposit size is decreased. None of the conductivity changes in the gravel deposits resulted in any noticeable head value changes in the bedrock areas of the model.

Recharge rates were found to have only an effect on the model when modified to reasonable limits of change. When the calibrated recharge rate of 200 mm was reduced to 150 mm/yr the groundwater head values decreased by approximately 10 m. Conversely, increasing the calibrated recharge parameter by 50 mm/yr resulted in an increase of approximately 10m in model head values.

3.6 Wellfield Capture Zone

As previously mentioned, the delineation of protection areas for wellfield protection studies is determined based on the type of potential contaminant and the time it would take to affect the water withdrawn at the production well. Generally, the travel times coincide with either a response time for remedial measures to be designed and implemented, or to allow sufficient time for natural attenuation or retardation of contaminants to occur within the geological formations prior to entering the production wells. Visual- MODFLOW provides for the simulation of forward and reverse particle tracking of hypothetical groundwater particles. Tracing these hypothetical particles result in a visual representation of how groundwater is flowing within the model domain. The model calculates not only the direction of groundwater flow but also the rate at which it is flowing at any given time, so protection zones can be determined based on travel times of these particles in the study area. Simulated particle travel times used for development of the protection zones for both the Perth and Andover production wells are included in Appendix 1 (A1-2 and A1-4). These zones were then superimposed on land use mapping to produce the three protection zone areas around the two wells.

3.7 *Model Groundwater Mass Balance*

A mass balance evaluation was completed of the Perth and Andover models to determine the flow of groundwater into and out of the model from the various input parameter areas. Mass balance calculations are completed by Visual MODFLOW during the individual model runs and can be used to investigate areas where water is being added (IN) or removed (OUT) from the model. Mass balance calculations completed during steady state static and pumping well operation model runs are included in Table 4.

Table 4

Model Mass Balance (m^3/day)

	Andover Well			Perth Well		
	Static	**Operational**	**Difference**	**Static**	**Operational**	**Difference**
IN:						
Wells	0.00	0.00	0.00	0.00	0.00	0.00
Recharge	7101.43	7101.43	0.00	7287.73	7287.73	0.00
Stream Leakage	1159.74	1155.46	4.28	3672.58	3662.36	10.21
River Leakage	387.78	954.66	-566.88	229.93	430.94	-201.02
Total In	8648.95	9211.56	-562.61	11190.24	11381.04	-190.81
OUT:						
Wells	0.00	2765.00	-2765.00	0.00	3273.00	-3273.00
Recharge	0.00	0.00	0.00	0.00	0.00	0.00
Stream Leakage	4993.94	4921.16	72.78	5893.48	5637.80	255.68
River Leakage	3659.44	1530.18	2129.26	5295.12	2468.33	2826.79
Total Out	8653.38	9216.35	-562.96	11188.60	11379.13	-190.53
IN - OUT	-4.43	-4.79	0.36	1.63	1.91	-0.27
% Discrepancy	-0.05	-0.05		0.01	0.02	-0.01

The primary parameter adding water into the model domain in both static and operational models is through recharge from precipitation. Stream leakage and river leakage were also identified as adding water to the model in areas where water level and or stream bed elevations were above the calculated groundwater levels within the model. The primary parameter removing water from the model domain was from well operation.

The stream leakage into the model domain was relatively unaffected by well operation in the Perth and Andover models changing only between 4.28 and 10.21 m^3/d during operation of the Andover and Perth wells respectively. The stream leakage out of the model (i.e. discharge) increased marginally between 72.78 and 255.68 m^3/d during operation of the wells.

River leakage into the model from the Saint John River also showed an increase between 190.81 and 566.61 m^3/d during operation of the Perth and Andover wells respectively. Alternately well operation resulted in a decrease of groundwater discharge to the Saint John River between 2129.26 and 2826.79 m^3/d during operation of the Andover and Perth well respectively.

4.0 MODELLING RESULTS

Calibrated results of the computer models closely represent the conceptual model developed for the area. As expected, the static model results shows groundwater recharging the aquifer in the higher elevations with groundwater flow moving downwards into bedrock and migrating towards the Saint John River. Groundwater discharges to the gravel deposits located in the river valley and moves upward to discharge to the river. Graphical results of the modelling are included in Appendix 1.

Model results during the operation of the wells show similar results to the static flow conditions however, in areas of the well influence, groundwater was noted flowing downwards and in many areas recharging the aquifer as groundwater flowed out of the river and streams in the area of the well capture zone. Capture zones developed by the computer modelling identify the zones of groundwater movement, which will ultimately reach the wells after continuous pumping at the designated pumping rates.

4.1 Protection Area Zones

The wellfield capture zones were used to designate Wellfield Protection Area Zones (Zones A, B and C) around both Perth and Andover wells. The PAZ's were designed to match the three zones outlined in the NBDELG Wellfield Protected Area Designation Order. The three PAZ's developed around both the Perth and Andover wells are included in Appendix 1 (Figures A1-7 and A1-8). Both wellfields are similar in shape as each well is receiving water from the sand and gravel aquifer, the Saint John River, and the bedrock. The wellfields for each well extend approximately 1.0 km both up and down the river. Groundwater in these areas is captured in the continuous operation of the production wells.

For both the Perth and the Andover wells three capture zones were identified:

- Zone A - Bacterial Potential Hazard Area – 100 days groundwater travel time to the well in sand and gravel deposits, which corresponds to the length of time harmful bacteria can physically survive in a groundwater system. This area is located immediately adjacent to the well.
- Zone B - Petroleum Potential Hazard Area - 100 days to 5 years reflects the area in which hydrocarbon usage (gasoline, fuel oils, diesel, etc.) must be restricted as these substances require much longer to degrade or be removed once released.
- Zone C - Hazardous Chemical Potential Area – 5 to 25 years corresponds to substances, which are the most resistant to natural attenuation or removal from the system. This area has been outlined as the 5 year

- 25 year groundwater travel time and reflects the time period which would be required to remove, reduce or remediate these chemicals if released into the groundwater system.

4.2 High Risk Land Use

A review of the previously completed Wellfield Protection Study (Porter Dillon Ltd 1996) was completed to identify the properties that were classified as high risk around the two production wells. These properties were then investigated with respect to the zones developed in this current study to reclassify them as possible risks to the aquifer.

In the previous 1996 WPS, there were nine high-risk properties around the Andover well and two high-risk properties around the Perth well. For reference, copies of two figures from the previous 1996 WPS report are included in Appendix II. These figures detail the location and associated risk the properties pose to the aquifer. High-risk properties identified on these figures around the Perth and Andover wells are included in Table 5 and 6 respectively.

TABLE 5

FORMER PERTH HIGH RISK PROPERTIES

Property	PID#	Land Use	Potential Risk
Quickmart*	65044950	Commercial	Petroleum Storage
Hospital	65045171	Institutional	Petroleum Storage

* Denotes Property is still considered a possible high risk to the aquifer.

The two former high-risk Perth properties include the Quickmart and the Hospital. Of these two only the Quickmart, which contains a petroleum UST, is still considered a high risk treat to the aquifer. This property is within the Protection Area Zone 1, which does not permit the use of an Underground Storage Tank. The Hospital property was determined to be just outside the limits of the Protection Area Zone 3 and groundwater would therefore require greater than 25 years to reach the well screen from this property.

TABLE 6 FORMER ANDOVER HIGH RISK PROPERTIES			
Property	**PID#**	**Land Use**	**Potential Risk**
Andover Irving*	65047235	Commercial	Petroleum Storage
McAsphalt*	6509947	Industrial	Petroleum Storage
Gravel Pit*	65008922	Industrial	Water Table Exposure
High School*	65049090	Institutional	Petroleum Storage
Cemetery	65049082	Institutional	Biological Contamination
Cemetery	65050312	Institutional	Biological Contamination
Well house*	65049090	Institutional	Petroleum Storage
Nissan's Farm*	65049462	Agricultural	Pesticides / Fertilizers
Former Dump Site*	65099616 & 65099608	Vacant	Unknown Refuse Disposal
* Denotes Property is still considered a possible high risk to the aquifer.			

Of the nine former high risk properties around the Andover well seven remain high risk after evaluation under the current WPS. The other two properties are cemeteries, which are within 200 metres of the well. These two properties are a potential biological hazard to the aquifer, however model results indicate downward vertical groundwater flow in the area would require greater than 100 days to reach the well screen. It should be noted that while the cemeteries are primarily a biological concern, a persistent chemical concern also exists from embalming fluids used prior to burials. As a result these locations are still considered a concern as apposed to a direct hazard.

5.0 Recommendation Review

The review of recommendations presented in the previous 1996 WPS was completed to determine if changes are required based on the results of the three dimensional modelling. All but two of the recommendations from the 1996 WPS where found to still apply to the properties investigated in the current WPS.

One change is recommended to be made to the recommendations for the Hotel Dieu St. Joseph Hospital. This property, which has petroleum underground storage tanks (UST's), was previously inside the Protection Area Zone 3 in the 1996 WPS. However, the current WPS model has shown this location is actually located outside, but adjacent to the northern boundary of this zone. As a result removal of the UST's may not be necessary at this location as groundwater will take over 25 years to reach the well. Due to it's close proximity to the boundary of the Protection Area Zone 3 the Village may wish to initiate procedures to enable a long-term groundwater-monitoring program around the UST location as an added preventive measure.

The two cemeteries located near the river in Andover (PIDs 65049082, 65050312) adjacent to Trinity Anglican Church were found to be just outside Protection Zone 1. However, they remain very close to the boundary of this zone and are considered as a concern as opposed to a direct hazard. The Village may wish to take steps to ensue they are still no longer be used for burials.

6.0 Disclaimer

Jury Consulting Services ("JCS") prepared this Wellfield Protection Study report exclusively for the Village of Perth Andover, New Brunswick. This report was prepared by JCS for the sole benefit of the Village of Perth-Andover and any use which a third party makes of this report, or any reliance on or decisions made based on it, are the responsibilities of such third parties. JCS accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions taken based on information provided in this report. This report is based on information provided by others and/or obtained by JCS during the coarse of the study, and applies solely to site conditions existing at the time of the report preparation. The material in it reflects JCS's best judgement in light of the information available at the time of preparation. Although a reasonable investigation was conducted by JCS, this investigation was by no means exhaustive and cannot be construed as a certification of the absence of any information and/or contaminants from the properties within the Wellfield Protection Areas. Rather this report represents a reasonable review of available information, within an established work scope, work schedule and budgetary constraints. It is therefore possible that currently unrecognized information; contamination or potentially hazardous materials may exist within the Wellfield Protection Areas that may not have been identified as part of this study. Further review and updating of this report may be required as local site conditions, and the regulatory and planning frameworks, change over time.

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APPENDIX I

Model Results

ANDOVER

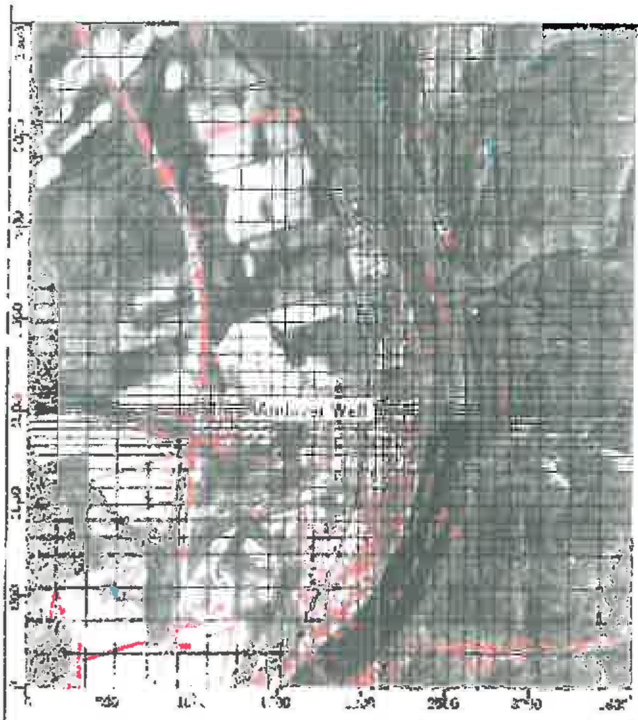


Figure A1-1 Model/Grid Setup

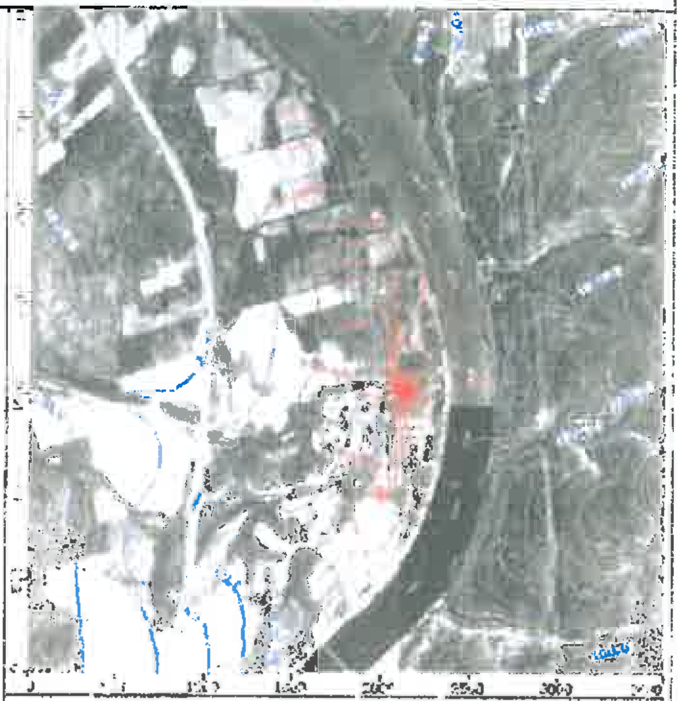


Figure A1-2 25 Year Pathline Trace (5 yr Markers)

PERTH

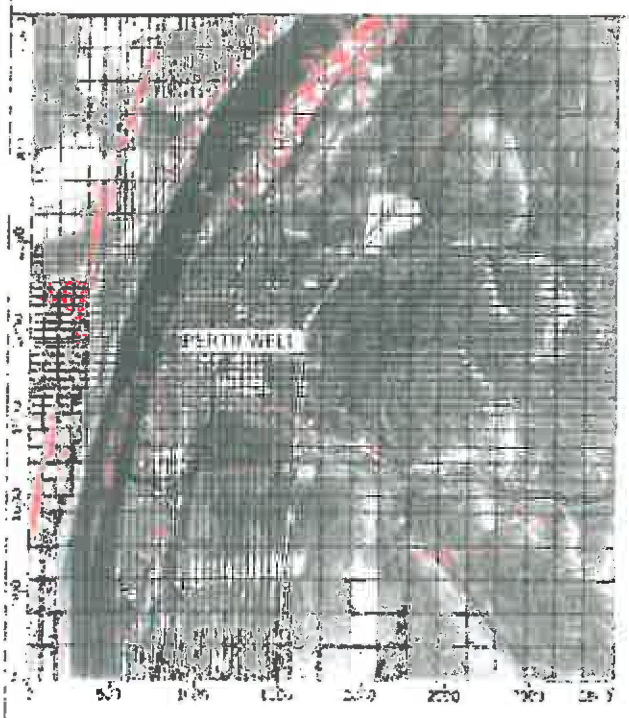


Figure A1-3 Model/Grid Setup

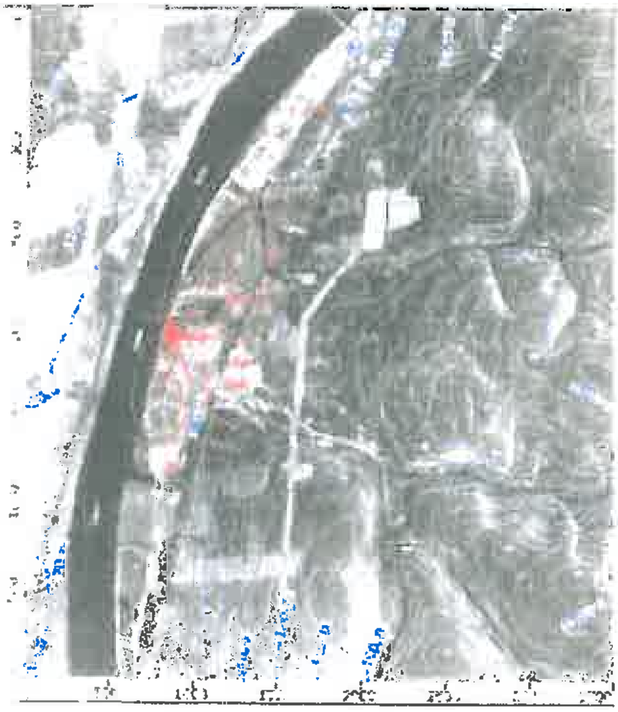
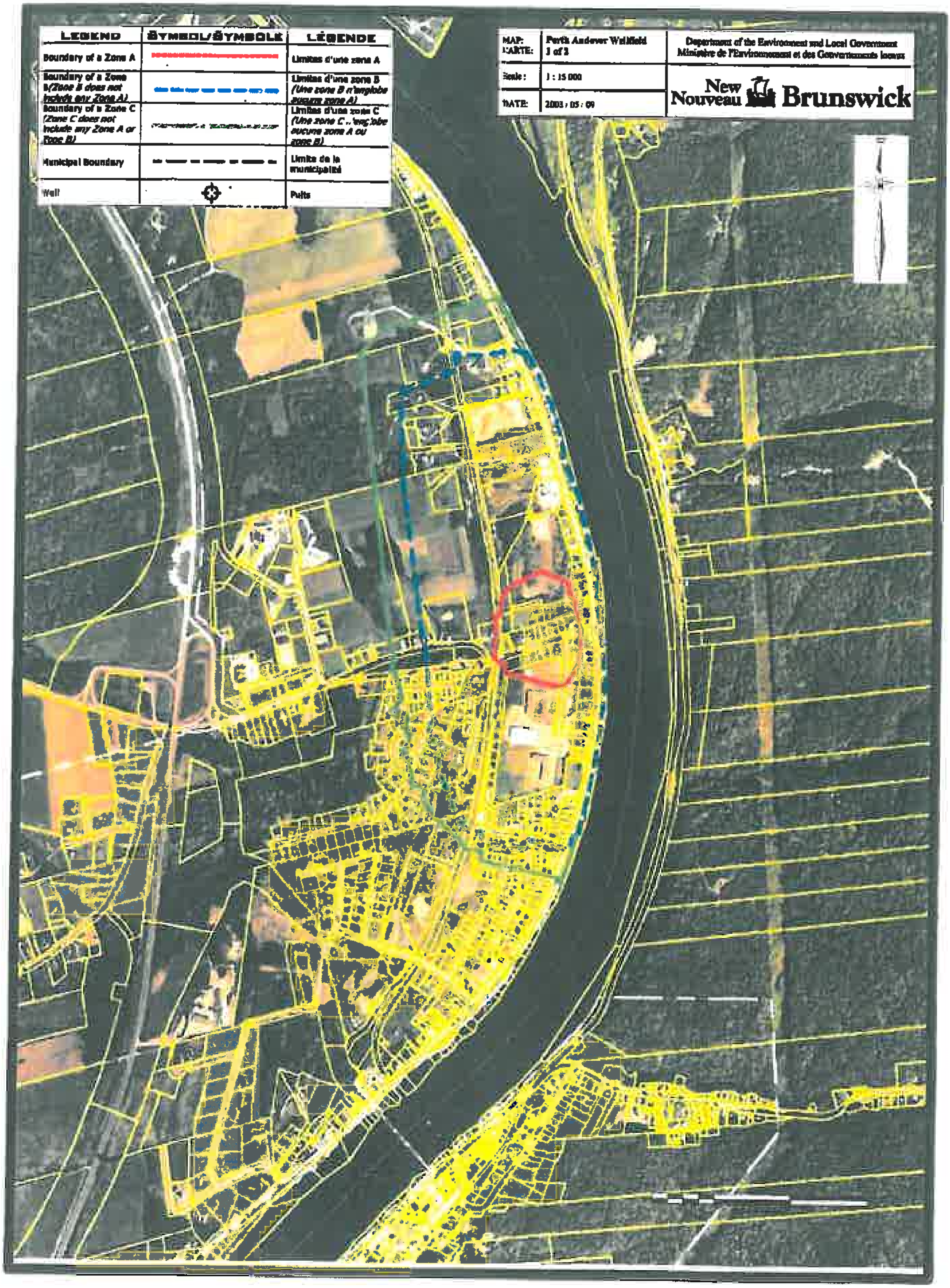
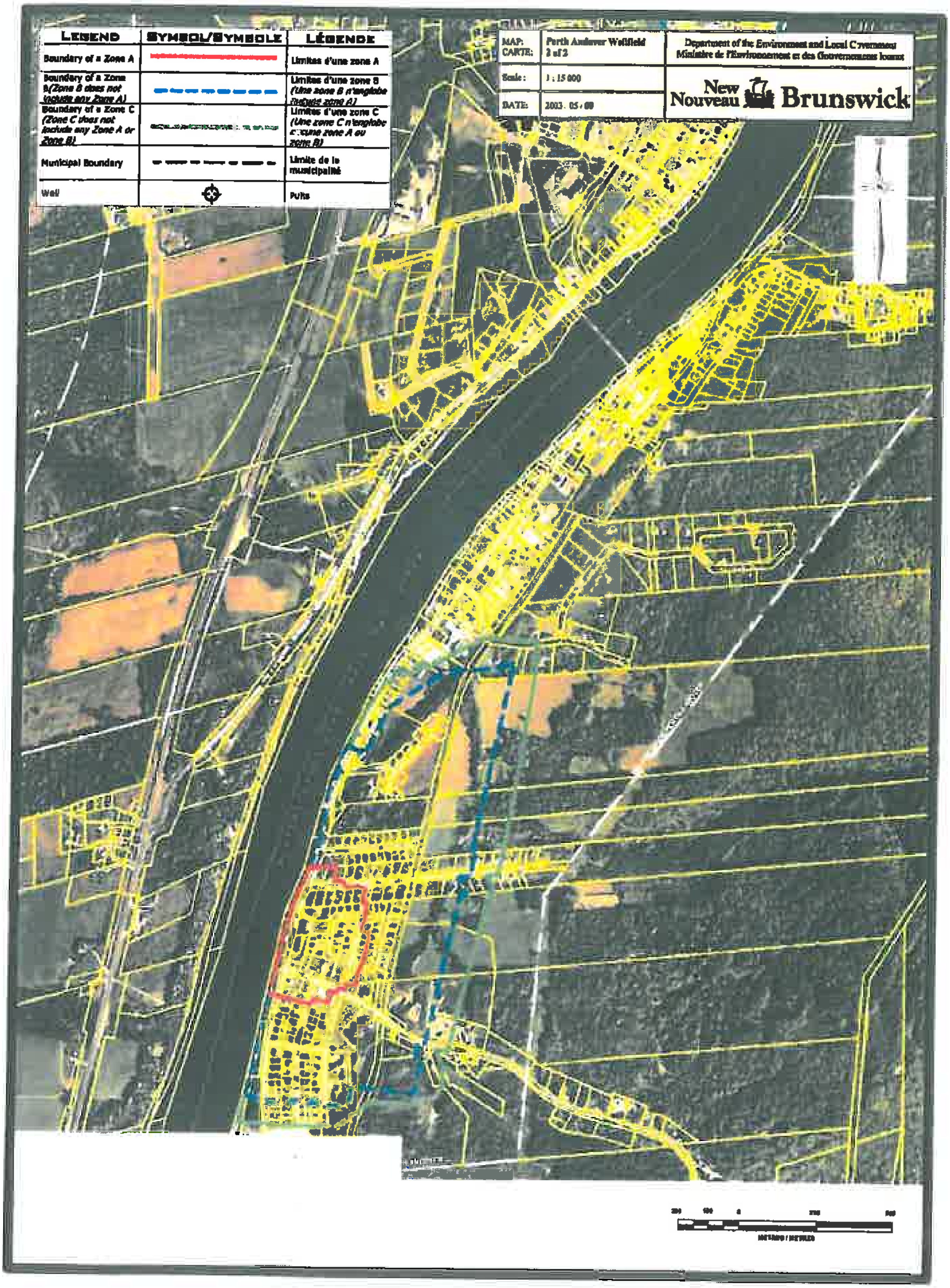


Figure A1-4 25 Year Path line Trace (5 yr Markers)



LEGEND
SYMBOL/SYMBOLE
LÉGENDE
Boundary of a Zone A
Limites d'une zone A
Boundary of a Zone B (Zone B does not include any Zone A)
Limites d'une zone B (Une zone B n'englobe aucune zone A)
Boundary of a Zone C (Zone C does not include any Zone A or Zone B)
Limites d'une zone C (Une zone C n'englobe aucune zone A ou zone B)
Municipal Boundary
Limite de la municipalité
Well
Puits
MAP: CARTE:
Perth Andover Wellfield
1 of 2
Scale: 1 : 15 000
DATE: 2003 / 05 / 09
Department of the Environment and Local Government
Ministère de l'Environnement et des Gouvernements locaux
New Nouveau Brunswick



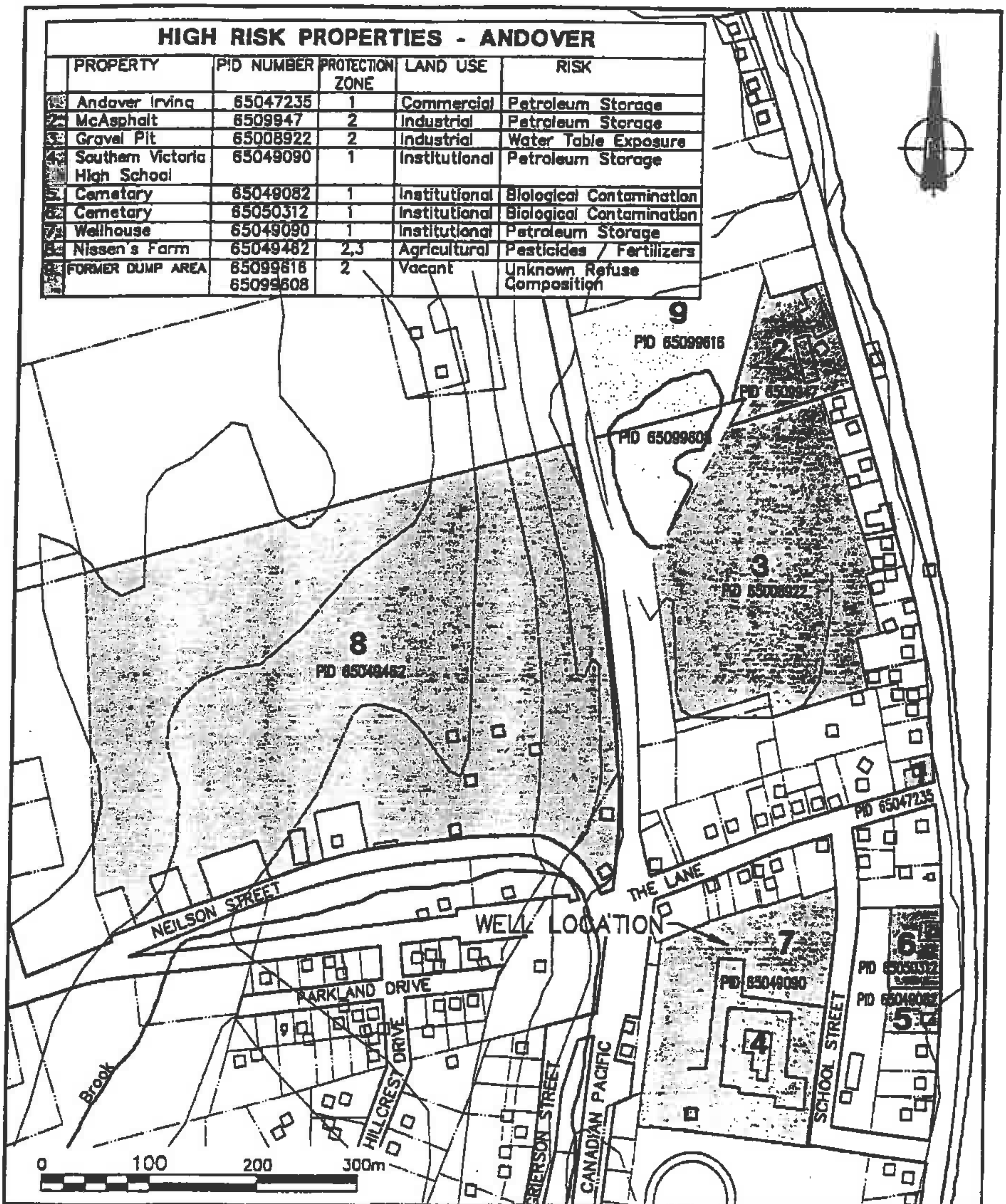
LEGEND
SYMBOL/SYMBOLE
LÉGENDE
Boundary of a Zone A
Limites d'une zone A
Boundary of a Zone B (Zone B does not include any Zone A)
Limites d'une zone B (Une zone B n'englobe aucune zone A)
Boundary of a Zone C (Zone C does not include any Zone A or Zone B)
Limites d'une zone C (Une zone C n'englobe aucune zone A ou zone B)
Municipal Boundary
Limite de la municipalité
Well
Puits
MAP: CARTE:
Perth Andover Wellfield
2 of 2
Scale:
1 : 15 000
DATE:
2003 . 05 . 09
Department of the Environment and Local Government
Ministère de l'Environnement et des Gouvernements locaux
New Nouveau Brunswick

APPENDIX II

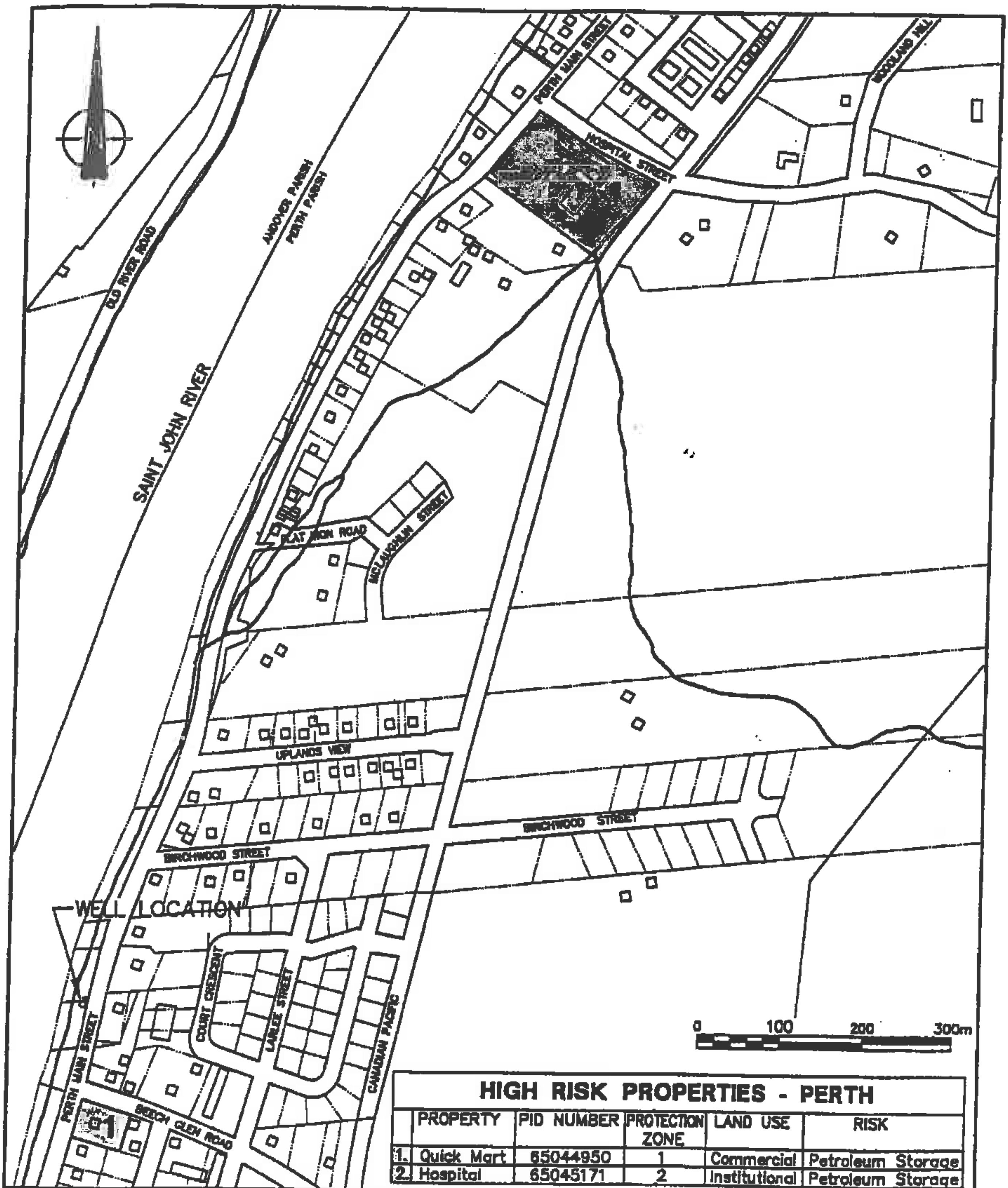
Former WPS (1996) High Risk Properties

HIGH RISK PROPERTIES - ANDOVER

	PROPERTY	PID NUMBER	PROTECTION ZONE	LAND USE	RISK
1	Andover Irving	65047235	1	Commercial	Petroleum Storage
2	McAsphalt	6509947	2	Industrial	Petroleum Storage
3	Gravel Pit	65008922	2	Industrial	Water Table Exposure
4	Southern Victoria High School	65049090	1	Institutional	Petroleum Storage
5	Cemetary	65049082	1	Institutional	Biological Contamination
6	Cemetary	65050312	1	Institutional	Biological Contamination
7	Wellhouse	65049090	1	Institutional	Petroleum Storage
8	Nissen's Farm	65049462	2,3	Agricultural	Pesticides / Fertilizers
9	FORMER DUMP AREA	65099616 65099608	2	Vacant	Unknown Refuse Composition



PORTER DILLON Consulting Engineers • Planners Environmental Scientists	TITLE: **HIGH RISK PROPERTIES - ANDOVER**	PROJECT No. **95-3102**
DATE **MARCH 1996**	PROJECT: **WELLFIELD PROTECTION STUDY VILLAGE OF PERTH ANDOVER, NEW BRUNSWICK**	FIGURE No. **3-1**



HIGH RISK PROPERTIES - PERTH

	PROPERTY	PID NUMBER	PROTECTION ZONE	LAND USE	RISK
1.	Quick Mart	65044950	1	Commercial	Petroleum Storage
2.	Hospital	65045171	2	Institutional	Petroleum Storage

PORTER DILLON
Consulting Engineers - Planners
Environmental Scientists

DATE MARCH 1996

TITLE
HIGH RISK PROPERTIES - PERTH

PROJECT
WELLFIELD PROTECTION STUDY
VILLAGE OF PERTH ANDOVER, NEW BRUNSWICK

PROJECT No.
95-3102

FIGURE No.
3-2