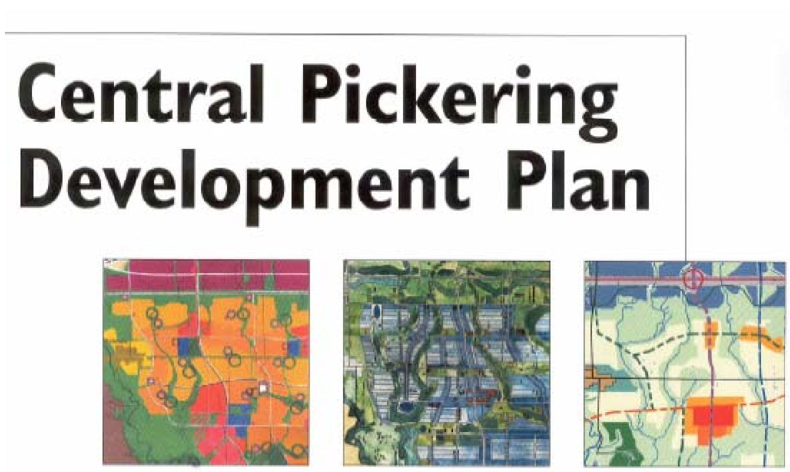
A Review and Critical Analysis of Hydrogeological Aspects of the Proposed Central Pickering Development Plan

Final Report



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Executive Summary

The Greater Toronto Area (GTA) is experiencing rapid urban development with serious questions raised concerning the environmental sustainability of this development and the potential long-term impacts on the quality and quantity of ground and surface water resources. The Proposed Central Pickering Development Plan (PCPDP) exemplifies these concerns. Most of the study area lies within the Duffins Creek watershed and has been the subject of debate for over two decades.

Duffins Creek and neighbouring watersheds have provided a major focus of research study at the University of Toronto since the early 1980s. The hydrogeological complexity of this region is well documented in the scientific literature but is amply demonstrated by the serious sub-surface conditions recently encountered along 16th Avenue in the neighbouring Rouge River catchment during sewer construction for the YDSS (York-Durham Sewer System). A particular concern is that the PCPDP study area supports three aquifers and numerous private wells, the majority located in the Middle Aquifer immediately beneath the Newmarket Till aquitard. This aquifer receives recharge via regional flow paths from the Oak Ridges Moraine to the north, but is also replenished locally via soil zone recharge within the PCPDP study area with subsequent leakage through the Newmarket Till. Replenishment rates are variable and sensitive to numerous factors including, but not limited to, the hydraulic properties of the Halton Till, a heterogeneous, clay-rich deposit that caps most of the study area. Locally, the Halton Till contains abundant gravel, sand and silt and supports an active groundwater flow system. It is impossible to reliably estimate potential impacts of any land use change on groundwater resources in the PCPDP study area without a full understanding of the Halton Till and how its hydrogeological properties vary across the area. Of notable concern within the PCPDP study area is that the aquifers are low storage systems which, contrary to popular belief, are significantly more sensitive to changing conditions than high storage systems such as the Oak Ridges Moraine aquifer. The sensitivity of the study area aquifers must be acknowledged when measures for mitigating potential impacts of urban development (quality and quantity) are designed.

Assessment of potential impacts on study area streams and wetlands is complicated by the hydrogeological conditions within the Duffins Creek watershed. Much of the flow originates as baseflow (discharging groundwater) from one or more of the three aquifers present. Relative contributions depend on the extent to which the streams incise the layer-cake, aquifer-aquitard system. While detailed flow analysis of isolated stretches of streams and rivers can begin to unravel the complexities of this interaction (something that has not been done) such analyses will shed little information on how the various contributions will change under altered land use conditions. A further complicating factor is that inflow of groundwater has a profound impact on stream quality in the PCPDP, and water quality in the contributing three aquifers is quite different, the shallow Upper Aquifer showing greatest anthropogenic impacts. In effect, it is impossible to reliably estimate potential impacts of land use change within the PCPDP study area on stream water quality and quantity without a detailed understanding of the aquifer system, its properties, and the nature of its hydraulic interaction with various stream reaches. Such studies are seriously lacking.

Recent hydrochemical studies at the University of Toronto confirm that urbanisation has severely impacted groundwater underlying more established parts of Toronto. Most problems stem from lawn, garden and parkland fertilizers/pesticides and the use of road de-icing chemicals. As evidenced in

2000 by the Walkerton events, bacteria may also represent a potential problem where recharge via the till cap (the Halton Till in the Toronto area as opposed to the Elma Till in Walkerton) is rapid. A properly planned and appropriately designed urban area (i.e. based on sound science and engineering) can prevent most potential problems associated with urban development. However, mitigation of potential impacts can be successfully achieved only if the properties and dynamics of the system (in 3-D space and time) are fully understood.

As it currently stands, the Proposed Central Pickering Development Plan (PCPDP) fails to appreciate the potential threats and issues; neither does it adequately identify the program of work required to ensure that the proposed development is environmentally sustainable and adequately protects the subsurface environment. The PCPDP is essentially "two-dimensional" in concept and ignores the complex hydrogeological system, the sensitive aquifers and the potential long-term impacts of urbanisation on the quality and quantity of water in local wells and the river system. In fact, the term "aquifer" is absent from the entire planning document. The water balance studies completed to date are similarly "two-dimensional", are severely limited in scope, and do nothing to reassure existing residents that their wells will be protected and that springs, streams and wetlands will not dry up seasonally or permanently. Proposed buffer zones (setbacks) can not be expected to protect streams and wetlands receiving groundwater along flow paths that can be several kilometres long.

If the protection of ground and surface water is to be guaranteed, there is a strong need to bring the planning process into line with modern hydrogeological thinking. Major progress in water resource protection has been made since the Walkerton tragedy, and planners would do well to heed the Commissioner of Inquiry, Justice O'Connor's recommendations including, most notably, his insistence that watershed-based source protection plans be developed that include groundwater flow models to describe the fate of contaminants in a watershed. Such models will, for example, allow the potential impacts of road de-icing chemicals on well and stream water quality to be determined, and can be used equally effectively to describe the potential impacts of recharge depletion on well water levels, stream flows and wetlands. It comes as no surprise that following the serious problems encountered during YDSS tunnel construction along 16th Avenue, groundwater flow models have become the preferred choice for evaluating potential impacts of dewatering for all future YDSS projects.

In conclusion, urban planning should no longer be seen as a two-dimensional exercise. In the interests of groundwater protection, the time has come to acknowledge groundwater flow dynamics and the extended time frames over which impacts of land use on groundwater can occur, and fully incorporate an understanding of the sub-surface into the deliberation/decision-making process. There are numerous ways that the potential impacts of urban development can be managed and reduced to environmentally acceptable levels. However, given the hydrogeological complexities of the PCPDP study area, none of these mitigation measures can be adequately evaluated without a 3-D numerical model of the aquifer system. From a hydrogeological standpoint, the PCPDP, as it currently exists, is unacceptable. The approach to urban design needs to be reconsidered. It is strongly recommended that the essentially "two-dimensional" planning approach promoted by the PCDCP be abandoned in favour of an iterative approach that fully utilises calibrated, 3-D groundwater flow models as an integral part of the planning process, to test and evaluate alternative land use configurations. Feedback from these models would be used to refine the land use plan until a satisfactory balance between development objectives and water resource protection objectives is achieved. While such an approach may require additional drilling to provide key input data, notably with respect to the Halton Till cover, the adoption of such a state-of-the-art, decision-making approach will ultimately ensure that development of the PCPDP lands can proceed in a safe, sustainable and environmentally responsible manner.

1. Introduction

The Greater Toronto Area (GTA), Metropolitan Toronto and Region of southern Ontario, shares a problem that is common to many cities throughout the world. It is undergoing explosive urban growth with serious questions being raised regarding the environmental sustainability of this development and the potential detrimental impact on groundwater resources and the environment as a whole. This report critically examines hydrogeological aspects of the "Proposed Central Pickering Development Plan" (PCPDP) (Planning Alliance Inc., 2005). The study area (Figure 1) lies predominantly within the Duffins Creek watershed, and has been the subject of planning debate for over two decades. The report is not designed to promote the position of any interested party or focus group and should be considered neither pro- nor against development. Its primary purpose is to summarise important scientific research findings published on the area during the past 30 years or more, and highlight issues requiring special attention during the planning process.

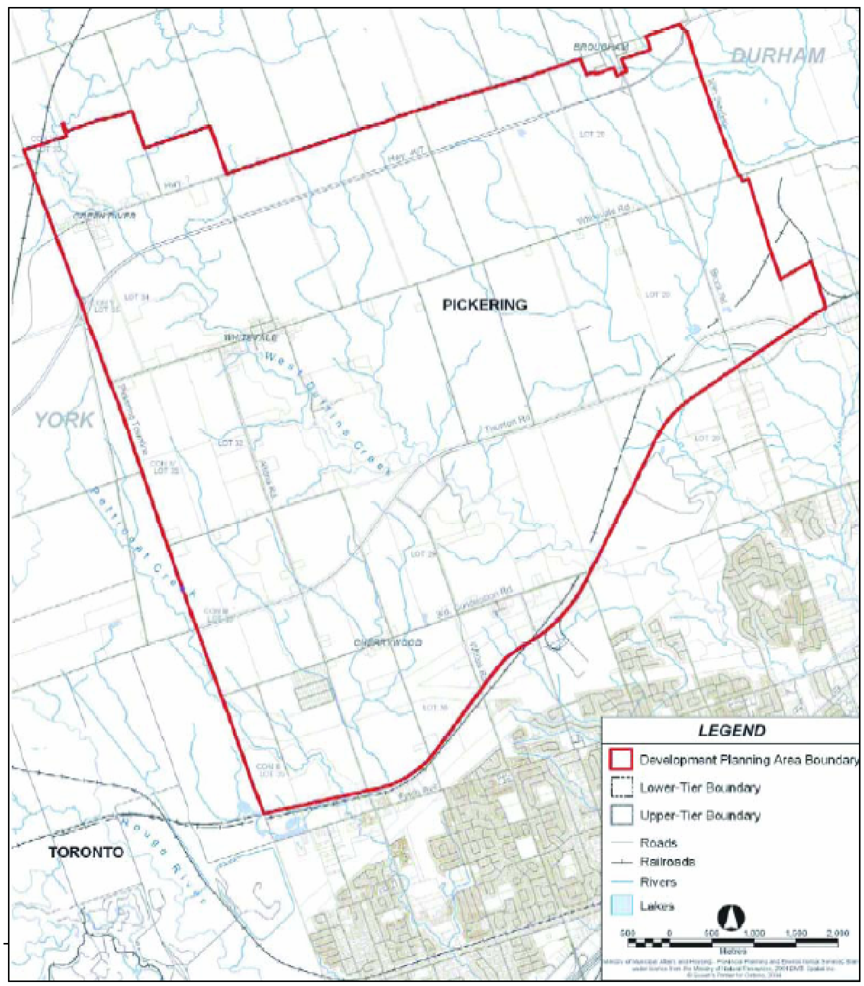


Figure 1. Development Planning Area (from Planning Alliance Inc., 2005).

Following this brief introduction, the review is divided into four main parts. The first part (Section 2) provides an overview of the hydrogeology of the study area and draws attention to issues of broad relevance to the proposed development. The second and third parts (Sections 3 and 4) deal respectively with potential water quantity and water quality concerns, and Section 5 provides a concluding discussion and recommendation. References are provided in Section 6.

2. Hydrogeology of the Study Area

The hydrogeology of the Duffins Creek watershed is complex (Gerber and Howard, 2002) and has been the subject of considerable study for thirty or more years, notably by the Ontario Ministry of the Environment and the University of Toronto. During the early 1990s, parts of the study area were investigated intensively during the Interim Waste Authority's (IWA) search for a new GTA landfill (IWA Limited, 1994a-e), and in the mid-1990s, the Geological Survey Canada conducted a stream flow survey (Hinton, 1996) as part of its study of the Oak Ridges Moraine aquifer.

The earliest systematic hydrogeological work in the Duffins Creek and Rouge River watersheds was carried out in the 1970s by the Ontario Ministry of Environment (Sibul *et al*. 1977; Ostry,1979) and identified as many as 14 aquifers in the two basins. Four of these (originally named Green River, Greenwood, and the Upper and Lower Brougham Aquifers) occur beneath the PCPDP study site. During the 1980s, Howard (1985) and Howard and Beck (1986) demonstrated:

- that all 14 aquifers are regionally interconnected to form a single, integrated groundwater flow system that extends from the Oak Ridges Moraine to Lake Ontario,
- that the Halton Till, a regionally extensive near surface deposit and long regarded as relatively "tight" or "impermeable" and a protective cover for the underlying aquifers, readily transmits groundwater vertically and in some cases horizontally, and
- that over a third of the Duffins Creek / Rouge River well waters were contaminated by anthropogenic activity, with aquifers well to the south of the Oak Ridges Moraine just as impacted, if not more so, than the Moraine aquifer itself. Elevated nitrate and chloride were the major concerns.

These three important findings spawned 20 years of follow-up research at the University of Toronto.

The first series of studies responded to the water quality issues and focussed on wells and springs throughout the GTA. The work reconfirmed the "leaky" nature of the Halton Till cover and demonstrated widespread contamination of shallow groundwater with road salt as the primary source (Pilon and Howard, 1987; Eyles and Howard, 1988). This surprised many since the common assumption at that time was that the majority of salt applied to roads each winter is flushed into storm drains the following spring and conveyed directly to urban streams and Lake Ontario (i.e. impacts on groundwater were thought to be minimal). Evidence clearly points to the contrary. Concentrations of chloride measured throughout the GTA range from around 400 mg/L in shallow springs along the Scarborough Bluffs (Eyles and Howard, 1988) to about 13,000 mg/L in shallow sub-surface waters near urban highways

(Howard and Beck, 1993). By comparison, sea water contains 19,000 mg/L. A study of 23 springs in the GTA by Williams *et al.* (1999) showed concentrations of chloride as high as 1,400 mg/L. Background levels in Ontario are typically <20 mg/L.

To investigate this issue further, a catchment road salt budget was carried out on the urbanised Highland Creek catchment in the east end of Toronto over a period of two years (Howard and Haynes, 1993). It demonstrated that less than 50% of the salt applied each year is removed from the catchment annually by storm sewers, the majority entering the shallow subsurface to the potential detriment of groundwater quality (Howard *et al.*, 1993).

Recognising that road salt is not the only source of contamination in a large urban region, the research program was further expanded in the mid-1990s with a chemical audit performed for all historical and current sources of potential contamination in a 700 km^2 region of the Greater Toronto Area (GTA) (Howard *et al.*, 1996; Howard and Livingstone, 1997). It revealed the potential for landfills, septic systems, underground storage tanks and chemical fertilizers to contribute to contaminant loadings in an urban area (Howard and Livingstone, 2000).

During the 1990s considerable research was also conducted on the role aquitards (sediments that are less permeable than those that form water-supply aquifers) exert on regional flow systems, water budgets and transport of contaminants. For example, while there was now general recognition that “tills leak” and “large urban areas potentially contaminate”, there was a serious need to:

- quantify the till leakage rates in the context of the regional aquifer systems,
- quantify the potential chemical impacts in terms of dilution capabilities, flow rates and travel times, and
- develop means of incorporating policies for groundwater protection into the urban planning process.

Much of this work was conducted on the Oak Ridges Moraine aquifer and in the Duffins Creek watershed and involved drilling, test pumping, water level monitoring, isotopic analysis, and the development of several regional 3-dimensional groundwater flow system models, one of which (Gerber and Howard, 2002) focused in detail on the Duffins Creek watershed. The results have been widely published in peer-reviewed books and journals (Gerber and Howard, 1996; Howard and Gerber, 1997; Gerber and Howard, 1997; Gerber and Howard, 2000; Gerber *et al*., 2000; Gerber and Howard, 2002). In the context of the Duffins Creek watershed and the PCPDP study area, key findings and their implications for potential development are as follows:

1. **The Aquifers.** The watershed is underlain by 3 aquifers (these days commonly referred to as the Upper, Middle and Lower Aquifers) separated by two regionally extensive aquitards (Figure 2). All 3 aquifers are present in the PCPDP study area, although the Middle Aquifer tends to be the preferred groundwater resource. The Upper and Middle Aquifers receive recharge locally (i.e. as recharge through the soil zone from above), but also receive water from the Oak Ridges Moraine via long, sometimes deep, flow paths. In all likelihood, the Lower Aquifer receives most of its recharge via similar flow paths from the Oak Ridges Moraine. Travel along these paths (Figure 3) can take thousands of years. The key to responsible long-term

management of study area aquifers is a prior understanding of the sources of recharge, spatially and over time, and a particular knowledge of the relative contributions of recharge received both locally and regionally. It should also be recognised that compared to the large, high storage and therefore resilient Oak Ridges Moraine aquifer, PCPDP study area aquifers are relatively low storage systems that are significantly more susceptible to changing conditions. It is important that this susceptibility or "sensitivity" be acknowledged when measures for mitigating potential impacts of urban development (quality and quantity) are designed.

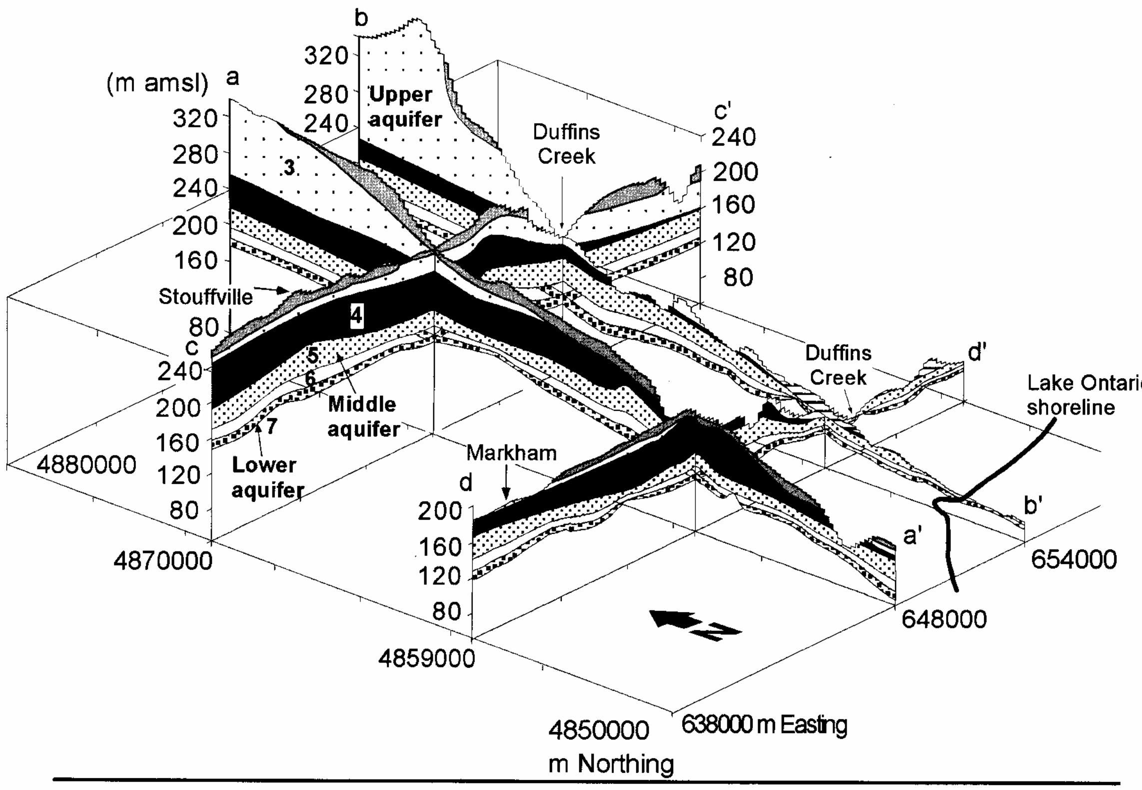
2. **The Halton Till.** The PCPDP study area is draped by the Halton Till, a depositional product of the most recent glacial advance (about 13,300 years before present (BP)). It forms a low relief plane with undulating streamlined hills (drumlins) and, except in the north-west corner where clay-rich "Lake Markham" sediments were deposited during a pause in the glacier's retreat, forms the uppermost geological unit, typically 10m or so thick. As such, the Halton Till has a significant influence on local recharge to the underlying aquifers. The Halton Till's reputation as a protective cover for underlying aquifers has long passed. Despite the significant presence of clay material, the Halton Till is heterogeneous and in places contains abundant gravel, sand and silt. Locally, it supports an active groundwater flow system which allows rapid recharge to the underlying Upper Aquifer. The hydraulic conductivity (permeability) of the Halton Till ranges over four orders of magnitude from about 10^{-9} m/s to around 10^{-5} m/s (Gerber and Howard, 2000). While the geometric mean is about $4x10^{-7}$ ms^{-1}, the adoption of such a value as "representative" of the PCPDP study area, could lead to a serious miscalculation of sub-surface fluxes. Estimates of recharge through the Halton Till plain generally range from 125 to 200 mm/a (IWA, 1994e; Gerber, 1994) (approximately 50% of the recharge rate along the Oak Ridges Moraine). In sandier areas, recharge rates may well be above this range while in areas where the till is poorly permeable, recharge rates may be significantly lower. Where the Halton Till is overlain by Lake Markham deposits, recharge to the Upper Aquifer is likely to be 50mm/a or less.

3. **The Newmarket Till** (also known as Northern Till). The regional groundwater flow system is largely controlled by vertical leakage from the Upper to the Middle Aquifer through the Newmarket Till aquitard (Gerber and Howard, 2002). In the PCPDP study area, vertical leakage through the Newmarket Till to the underlying Middle Aquifer (the primary groundwater resource) likely averages 30 to 40 mm/a but will be locally variable depending on variations in the till's permeability and the vertical gradients of potentiometric head. Flow velocities through the Newmarket Till are typically in the order of 1m per year (i.e. relatively high) downwards, which has important implications for the fate of any contaminants released to the shallow, Upper Aquifer.

4. **The Creeks.** Analysis of flow in the creeks is complicated by the complex hydrogeological conditions within the Duffins Creek watershed. Groundwater flow simulations using numerical models demonstrate that contrary to popular belief, headwater springs that discharge above 275 masl (metres above sea level) (one of

the commonly accepted planning boundaries for the Oak Ridges Moraine) are not the primary source of baseflow in the system (Gerber and Howard, 2002). While 60% of the baseflow may ultimately have originated as recharge on the Oak Ridges Moraine, the majority of this water enters below the 275 masl contour, and suggests that the goal of protecting the quality of water discharging to Duffins Creek is as much, if not more, about preventing contamination of groundwater off the moraine (to the south) as it is about protecting groundwater on the moraine. The development of adequate protection measures also requires that the source of the baseflow be known. For example, while 75 to 80% of baseflow discharge within the Duffins Creek watershed is derived from the Upper Aquifer, 20-25% is contributed by deeper aquifers. This means that any prediction of potential impacts of reduced recharge within the PCPDP study area on local streams must recognise the relative contributions of each aquifer to the stream, how this changes along the stream reach, and how changes to aquifer recharge (soil zone recharge or "groundwater infiltration") are likely to affect each of these contributions. In the PCPDP study area, the situation is especially complicated by the fact that some stream reaches are contained within the Newmarket Till aquitard and receive most of their local baseflow from the Upper Aquifer, while other stream reaches penetrate the Newmarket Till entirely (generating high vertical gradients across the Till), and acquire significant contributions of flow from the Middle and Lower Aquifers (Figure 4). Over-simplified analysis of stream flows can lead to a distorted interpretation of stream baseflow conditions and the potential impacts of urbanisation.

5. **Contaminant Travel Times.** Throughout the Duffins Creek watershed, groundwater flow velocities within aquifers are slow (typically less than 100 m per year) meaning contaminant impacts can take decades or centuries to materialise (Gerber and Howard, 2002; Howard and Livingstone, 2000). This is not a problem when predicting future impacts in areas which, historically, have been essentially pristine. However, in areas with a prior history of contaminant release (e.g. septic tanks, old landfills, old underground storage tanks or road salt application (all characteristics of the PCPDP study area and surrounding groundwater catchment), the quality of groundwater, as observed in wells or receiving streams, is unlikely to be a true representation of the long-term, steady state condition since contaminant plumes have only just embarked upon their slow journey. All rivers in the GTA can anticipate a significant increase in salinity in future years simply due to road salt that has already accumulated in the system and has yet to be released as baseflow (Howard *et al*., 1993). The implications for urban planning purposes are important. In evaluating potential impacts of future land use change on water quality in the study area, due consideration must be given to water quality degradation that can be anticipated but is yet to be observed at monitoring stations. While, the well owner in Whitevale may be convinced that future degradation of his/her water quality as a result of future development will be within acceptable limits, he/she also needs to be forewarned of the deterioration that might reasonably be expected as a result of impacted water already in the system e.g. as a result of historical salt application along Highway 7, Highway 407 and other major roads.



Late Wisconsinan	Model Layer
Lake Iroquois	1,2
Halton Till	1,2
Mackinaw Interstadial/Oak Ridges Complex (**Upper aquifer**) Glaciofluvial and glaciolacustrine with sand and gravel outwash	3
Northern/Newmarket till (23 000 – 18 000 BP)	4
Middle Wisconsinan	
Thorncliffe Fm. (**Middle aquifer**) Deltaic sand and lacustrine silt and clay interbedded with diamict (<50 000 BP)	5
Early Wisconsinan	
Sunnybrook Diamict	6
Scarborough Fm. (**Lower Aquifer**) Deltaic sands and glaciolacustrine silt and clay (~70 000 BP)	7

Figure 2. Three aquifers (Upper, Middle and Lower) (layers 3, 5 and 7) are separated by aquitards (layers 4 and 6). The Upper Aquifer is locally confined by a third aquitard (layers1,2) (predominantly by layer 2, the Halton Till). Section a-a' passes north to south directly through the PCPDP study area; section b-b' passes just to the east of the study area (from Gerber and Howard, 2000).

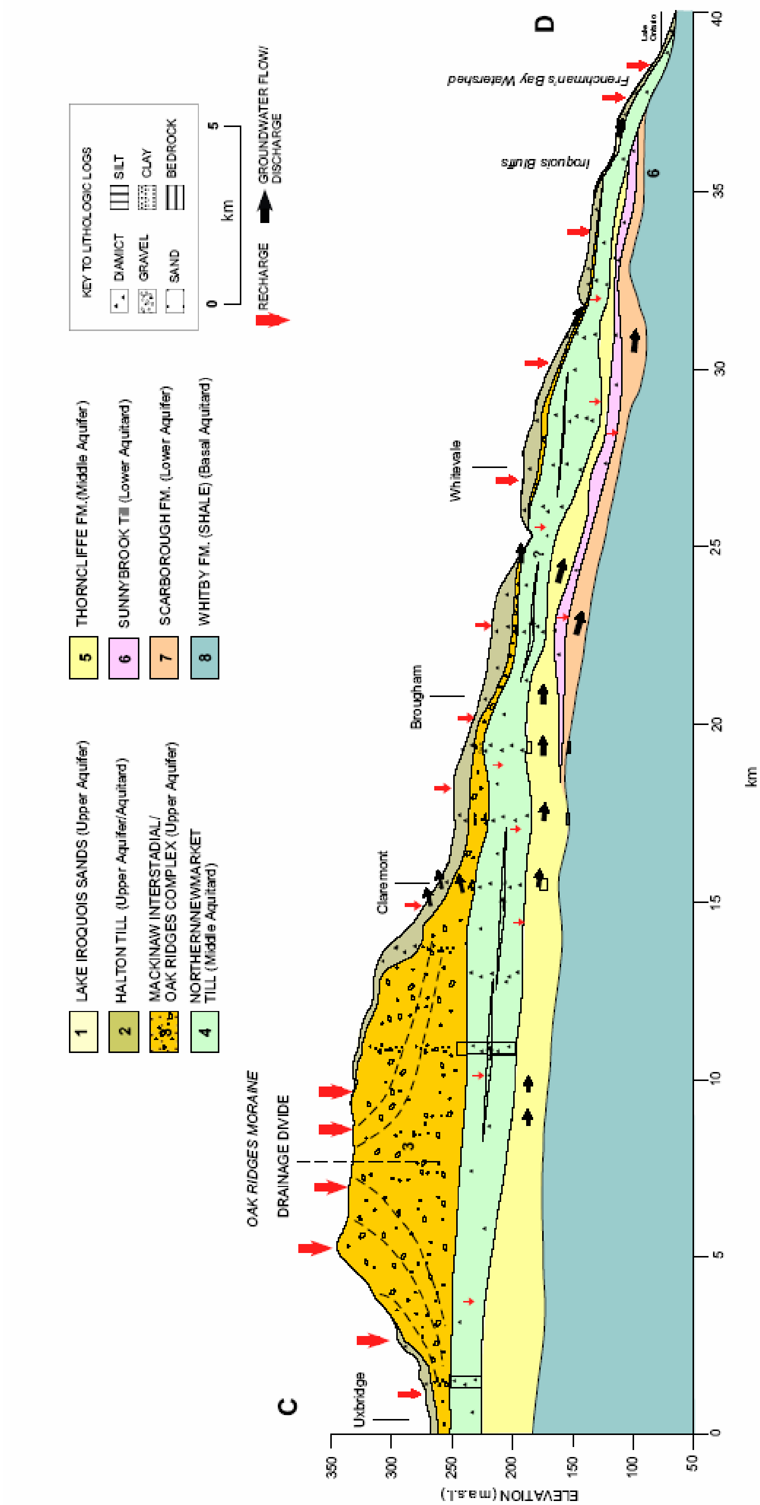


Figure 3. North-east to south-west illustrative section showing recharge areas (red arrows) and regional groundwater flows (black arrows). Note that recharge takes place via the Halton Till plain and is not simply confined to the Oak Ridges Moraine.

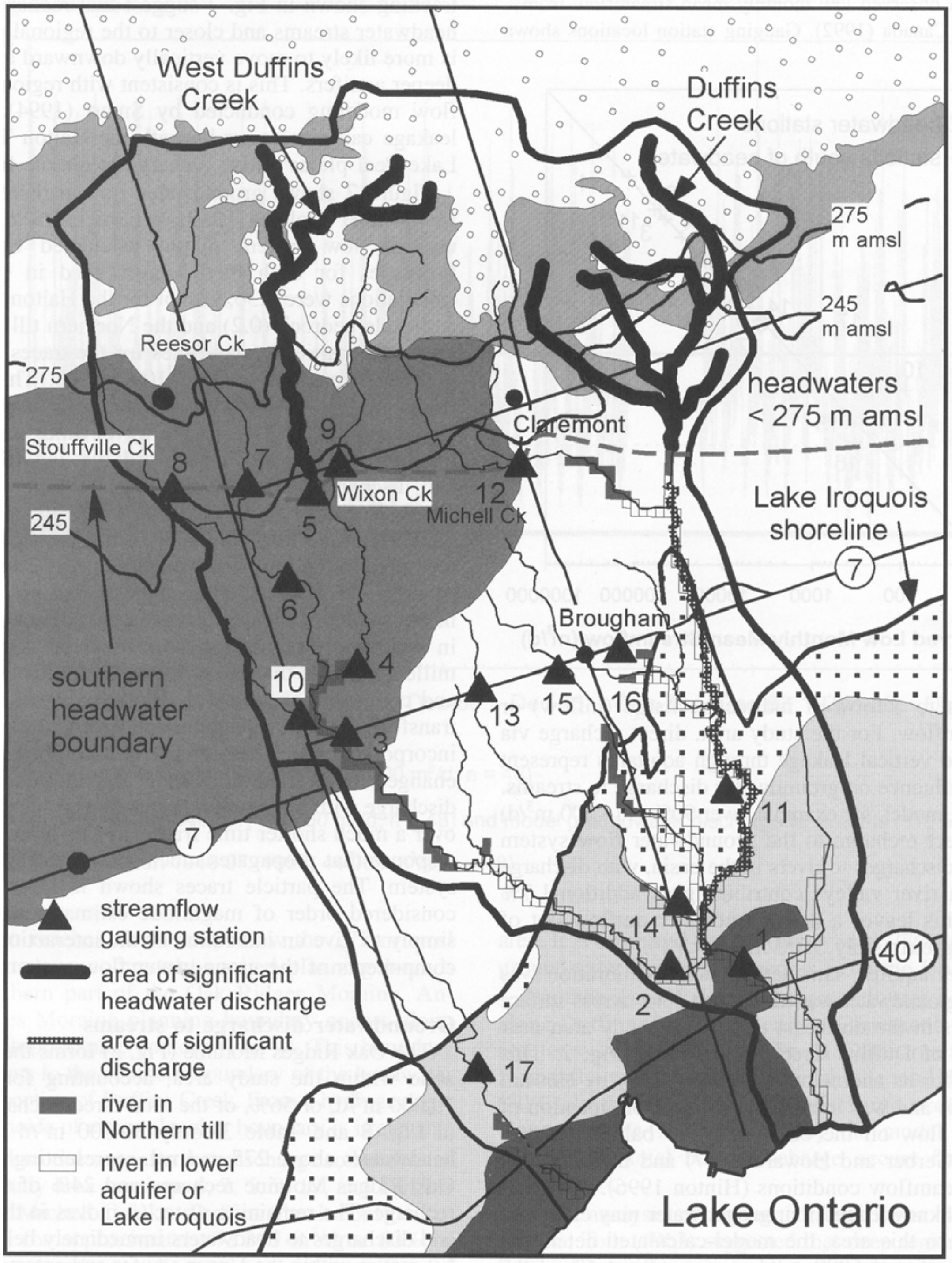


Figure 4. The Duffins Creek watershed showing the relationship between streams and the local hydrogeology (from Gerber and Howard, 2002). PCPDP study area streams receive groundwater as baseflow discharge from all three aquifers. Relative amounts depend on whether the rivers sit within the Halton Till, the Newmarket Till or fully penetrate the Newmarket Till to draw water from the Middle and Lower Aquifers.

3. Potential Water Quantity Issues

A pre-and post development water budget for the PCPDP study area has been provided recently by Clarifica (2005) using an in-house approach that is not well documented and does not appear to have received peer review in the scientific literature. The methodology, while simple in concept (i.e. using a lumped analysis approach) is difficult to follow, and the sources of key input data are unclear. The models are calibrated using overland runoff estimates only (not using groundwater discharge), and in several cases the calibration is poor (see the Urfe catchment (1999) calibration, for example, on page C-5 of the Clarifica report). Moreover, the results are not intuitively correct. For example, in all the study area catchments for which development is proposed, the reduction in soil zone infiltration (ranging from 4.4% to 27%) is significantly less than both the anticipated total imperviousness (ranging from 11% to 40%) and directly connected imperviousness (ranging from 8% to 30%). If this is explained by runoff from imperviousness that is not "directly connected", subsequently infiltrating in adjacent vegetated areas as "indirect recharge", it begs the question as to whether such additional recharge be sustained everywhere within the catchment, particularly given the heterogeneity of the Halton Till.

Concerns over such details aside, the primary problem with the Clarifica report is that it is two-dimensional and fails to address the major issue which is <u>how</u>, and <u>over what time-frame</u> will the flow system change? Soil zone infiltration may well be reduced by less than 10% when averaged over the entire study area, but as indicated by Table 8 of the Clarifica report, the Brougham, Whitevale and Ganatsekiagon watersheds can expect reductions in soil zone infiltration of 27%, 14.3% and 11.9%, respectively. In total, soil zone infiltration will be reduced by well over half a billion litres of water per year. The Clarifica report makes the unsupported assumption that there is a linear relationship between groundwater infiltration and baseflow along the entire length of the creeks, and suggests that for the Urfe, West Duffins, Ganatsekiagon and Whitevale Creeks, at least, average baseflow contributions will remain above the 25% threshold required for trout production. The questions that really need to be addressed by the water budget studies include, amongst many:

1. to what extent do heterogeneities in the Halton Till affect the distribution of recharge across the watersheds?
2. what proportion of soil zone recharge contributes to aquifer recharge and how much moves relatively quickly through the shallow subsurface to enter streams and wetlands?
3. by how much will these proportions change following development?
4. to what extent will recharge to each of the three aquifers underlying the study area be lowered as a result of reduced infiltration?
5. by how much will water levels drop in the large number of water wells operating in the study area?
6. over what time frame will water levels drop and will some areas be impacted more seriously than others?
7. which and how many groundwater-fed wetlands will become dry as a result of reduced infiltration?
8. over what time frame will these wetlands dry up?

9. for those groundwater-fed wetlands that remain, what changes can be expected, and over what time frame will these changes occur?
10. to what extent will natural overland runoff to area wetlands be affected recognising that runoff from large parts of the study area will be managed as storm water?
11. to what extent will spring flows be affected....and which springs will dry up?
12. which stream reaches will dry up permanently..... and which will dry up only during the summer months?
13. are the proposed buffer zones (setbacks) of, for example, 30m, 50m and 120m scientifically justified and appropriate from the perspective of potential impacts on surface water features?
14. how can groundwater seepage/discharge areas be adequately protected by buffer zones (a key "Natural Heritage System" objective – see page 31 of the PCPDP (Planning Alliance Inc., 2005)) given that groundwater flow paths to those seepage/discharge areas range up to 10 km or more?
15. recognising that runoff will increase by as much as 200% and will therefore become a much larger constituent of stream flow, along which stream reaches, and at what times of the year will baseflow contributions to total stream flow approach or fall below the 25% trout production threshold?

These questions (and similar questions) need to be addressed in a scientifically defensible manner before alternative urban design plans are debated, and <u>before</u> population targets are set and land uses are assigned (including land uses such as "agricultural lands" and "linkages"). For example, recognising the heterogeneous nature of the Halton Till cover, there remains a risk that key recharge areas are paved while less important recharge areas are preserved. Clarifica's analyses may prove to be perfectly reasonable and justified, but the scope of work completed to date is simply insufficient to provide the answers required. Three important steps need to be taken:

1. **Environmental Objectives**. Realistic and measurable environmental objectives need to be agreed. Zero change is never an option as any land use change will create impacts, some negative, others positive. The challenge is to set objectives that are measurable and meaningful in the context of the study area and the needs of the living environment and residents. For example, recognising the area's wetlands, the well users, and the aesthetic as well as environmental benefits of local streams, the "25% trout production threshold" for baseflow is not an appropriate measure of acceptability. What about well owners who may have to lower their pumps and anticipate higher pumping costs? What about residents who find their local stream reduces to a trickle in the summer months? Instead of planning according to "standards of practice" e.g. by establishing largely arbitrary buffer zones or setbacks, appropriate "standards of environmental performance" need to be established e.g. "stream flows during summer months should not be lowered by more than 10% for 95% of the stream reach", and/or mean groundwater levels should not be lowered by over 0.5 m, <u>and plan in order to meet those specific objectives</u>.

2. **Data.** Adequate hydrogeological data need to be collected, notably, but not limited to the regional variability of the characteristically heterogeneous Halton Till and the

gradients of potentiometric head that influence flow within this important unit. Although parts of the study area are well studied as a result of landfill site investigations, many areas are less well understood.

3. **Impact Assessment through Modelling.** Potential impacts of urbanisation on surface and sub-surface flows in the area must be investigated with one or more groundwater flow system models, and urban design options should be developed iteratively using feedback from these models until a satisfactory balance between development objectives and water quantity protection objectives is achieved. Groundwater models were explicitly identified by Justice Dennis O'Connor in Part 2 of the Walkerton Inquiry Report (O'Connor, 2002b) as a necessary element for source water protection. The technology is well advanced, the sub-surface knowledge base is generally good and there is no reason why hydrogeological models should not be an integral component of the planning process, especially in areas underlain by important and sensitive aquifers.

4. Potential Water Quality Issues

A common concern associated with urbanisation is the potential introduction of contaminants that can seriously degrade drinking water quality (Howard and Gelo, 2002; Howard, 2002; Howard and Israfilov, 2002; Howard, 2006, in press). The most severe impacts are usually caused by point sources such as:

- leaks from underground storage tanks containing solvents, brines, gasoline and heating fuels,
- municipal waste disposal (landfilling) (Howard *et al*., 1996),
- industrial discharges, leaks and spills (Nazari *et al*., 1993; Burston *et al*., 1993),
- stockpiles of raw materials and industrial wastes,
- spillages during road and rail transport of chemicals.

However, while point sources can cause severe degradation of water quality on a local scale, non-point sources can render large areas of the aquifer unpotable by simply elevating solute concentrations and bacterial counts to levels that may just marginally exceed drinking water quality standards. Distributed and line sources (i.e. non-point sources) include:

- effluent from latrines and cesspits (Foster *et al*., 1999, Morris *et al*.,1997),
- leaking sewers and septic tanks (Eiswirth and Hotzl, 1997; Robertson *et al.*, 1991)
- oil and chemical pipelines,
- lawn, garden and parkland fertilizers and pesticides (Kolpin *et al*., 1997; Flipse *et al*., 1984; Morton *et al*., 1988),
- road de-icing chemicals (Nysten and Suokko, 1998; Howard and Haynes, 1993; Howard and Beck, 1993; Thunqvist, 2004),
- oil and grease and rubber from motorized vehicles,
- wet and dry deposition from smoke stacks.

In terms of the PCPDP study area and the currently proposed land uses, most problems potentially stem from lawn, garden and parkland fertilizers/pesticides, the use of road de-icing chemicals, and runoff from roads and highways containing oil grease and rubber. Shopping plazas are an especially serious potential source of groundwater contamination by road salt. As evidenced at Walkerton (O'Connor, 2002a), bacteria may be a problem where recharge via the till cap is rapid. Other potential risks include spills from industrial premises and the enhanced mobilization of contaminants already present in the system (e.g. septic tank effluent, and landfill leachate from the Brock West Landfill which occurs along the southern boundary of the PCPDP study area) due to changes in the hydrological system such as a lowering of the regional water table.

A properly planned and appropriately designed urban area (i.e. based on sound science) can prevent the majority of, if not all hydrological (including hydrogeological) impacts of urban development. However, mitigation of potential impacts can be successfully achieved only if the dynamics of the hydrological system (in 3-D space and time) are fully understood. As it stands, the Proposed Central Pickering Development Plan (Planning Alliance Inc. 2005) does not show an adequate awareness of the potential threats and issues; neither does it show an appreciation for the program of work required to ensure that any development that takes place is environmentally sustainable and adequately protects the subsurface environment. Warning signs include the following:

The Planning Goals. The goals of the Proposed Central Pickering Development Plan (page 20 of the plan) are commendable but, as explained on page 7 of the plan, are simply "ideals" which may be unachievable. Objectives, on the other hand are described as "ends, actions or situations that are capable of attainment or measurement", and in effect represent the meaningful criteria by which the plans should be evaluated. For what it is worth, the only "goal" of the plan that relates to the subsurface is described under "Natural Heritage", and the goal for this element is "to protect, maintain and enhance the natural features, functions, and systems intended to sustain a viable and permanent natural ecosystem".

The Natural Heritage System. The Natural Heritage System is described on pages 30 to 34 of the PCPDP. Ten key features of this system are listed including wetlands and streams/watercourses, but there is absolutely no mention of water in the subsurface. In fact, the word "aquifer" is absent from the entire "two-dimensional" planning document. Groundwater seepage/discharge areas manage to make the list of features, and on page 30 one of the future tasks is apparently "to define appropriate buffer zones for each identified feature". This raises serious concerns with regards to the protection of groundwater. By all accounts, the intention is to "protect" groundwater discharge/seepage zones, where the fresh groundwater emerges (apparently by a prescribed "buffer zone"), but pays little or no consideration to aquifer recharge areas where contaminants potentially enter the aquifer system. This makes little sense. Well owners in the area should be extremely disturbed.

Protection of Groundwater Quality. Page 53 of the PCPDP does suggest that protection of groundwater quality and quantity is an important objective (and note, not simply an idealistic "goal"). Indeed, maintenance of the natural hydrologic cycle and function of the watersheds is also described as an objective. However, the context of these statements is important. Both objectives are described explicitly as "in respect of servicing" (i.e. with regard to stormwater, water supply, wastewater and utility services). This incorrectly implies that management of stormwater will resolve all potential impacts from urbanisation – quality and quantity. If that were the case, springs in urban areas throughout the GTA would not show impacts (on quality and quantity) of urban development, something they clearly do. Stormwater management can partially resolve potential groundwater problems but are not a panacea, and in many cases will simply transfer such problems to receiving surface water bodies. A particular concern is that stormwater systems will not collect all urban sources of contamination including:

- the majority of fertilizers, pesticides and de-icing salts used by residents;
- the 50% or more of salt applied to roads that, by one means or another (spray, infiltration through cracks and crevices and recharge via roadside swales), manages to elude stormwater drains and reach the aquifer;
- urban runoff from imperviousness that is not "directly connected" (Clarifica, 2005).

Moreover, stormwater management will not resolve the potential problem of reduced aquifer recharge unless "recharge management" (artificial recharge) is adopted. Recharge management can be an effective solution to the problem of depleted recharge in urban areas, but is not without risk and can potentially introduce contaminants to the aquifer. It should only be practiced with a thorough prior understanding of subsurface hydrogeological conditions (including a comprehensive appreciation of the regionally variable characteristics of the Halton Till cover) and the potential sensitivity of receiving aquifers. Without such knowledge, it is impossible to identify the most appropriate sites for the installation of recharge management facilities and, related to that, where residential areas are most effectively sited.

As indicated, there are numerous ways that impacts of urban development on the hydrologic system can be managed and reduced to environmentally appropriate levels, but there are steps that must be taken if well users are to be reassured, and if potential damage is to be confined to acceptable limits. In some respects, these steps are not unlike those that need to be adopted from a water quantity perspective. They include:

1. **Problem Definition.** The first steps in finding a resolution to any problem are to acknowledge a problem may exist and define the potential scope of that problem. Until there is an acceptance that stormwater collection will not fully solve the potential impacts on groundwater quality and quantity, no solution will be forthcoming.

2. **Standards of Performance.** Realistic and measurable water quality objectives must be established – objectives that will safeguard both well users and receiving streams. As indicated above, zero change is an unrealistic option; however, small changes can often be accommodated without serious loss of hydrologic function. There is a precedent – the MOE Reasonable Use guidelines dictate what are acceptable water quality impacts at the property boundary adjacent to a landfill, and it is quite conceivable that a similar approach could be adopted for establishing water quality impacts associated with urban development.

3. **Impact Assessment and Contaminant Flow Modeling.** Contaminant loadings associated with any proposed land use change are not difficult to predict. The real

challenge is to convert those chemical loadings into water quality parameters (chemical concentrations) in time and 3-dimensional space and provide reassurance that groundwater quality will remain acceptable for all time. For example, it is relatively easy to estimate how much salt or nitrogen fertilizer might be used annually as a consequence of urbanisation. The difficulty lies in predicting the concentration of chloride, nitrate (or similar water quality parameter) that can be anticipated in a resident's well or at a receiving stream, 25 or 50 years from now, and providing assurance that such levels will be acceptable (i.e. meet the standards of performance established in 2. above). The only reliable means of determining the fate and potential impacts of contaminant releases in a catchment is to use groundwater flow models, a conclusion clearly drawn by Justice O'Connor in his recommendations for source water protection following the Walkerton Inquiry (O'Connor, 2002b). In the PCPDP study area, groundwater flow models would allow impacts to be predicted as a function of time and provide feedback that would allow refinement of the land use plan. Moreover, models would allow recharge facilities to be sited so as to maximise the use of sub-surface storage and minimise risks associated with potential chemical spills.

An example of the benefits of the modeling approach is shown in Figures 5, 6 and 7 (Howard and Maier, 2006, in press). Figure 5 shows the predicted long-term impacts of salt application in the Duffins Creek watershed prior to any development on the PCPDP lands. Contours shown represent predicted chloride concentrations in the Upper Aquifer when chemical steady state is reached. Figure 6 shows predicted long-term chloride concentrations following urban development, while Figure 7 demonstrates how chloride changes with time in 3 randomly selected observation wells. Models such as these can be developed for a whole range of land use scenarios and mitigation measures within the PCPDP study area, with adjustments made to the development plan until impacts fall within acceptable levels.

5. Concluding Discussion and Recommendation

The Greater Toronto Area, similar to many urban centres around the world, is experiencing rapid urban development with serious questions being raised concerning the environmental sustainability of this development and the potentially detrimental impacts on the quality and quantity of ground and surface water resources. Urban planning can no longer be regarded as a two-dimensional exercise. In the interests of groundwater protection, planners and legislators must be required to fully incorporate an understanding of the sub-surface into the deliberation/decision-making process. Where appropriate, they must acknowledge hydrogeological complexity, groundwater flow dynamics and the extended time frames over which impacts of land use on groundwater can occur.

The PCPDP study area lies well to the south of the Provincially recognised "Oak Ridges Moraine" (ORM) (as defined by the Oak Ridges Moraine Conservation Act, 2001) and, as such, is not directly affected by ORM legislation. Nevertheless, as well demonstrated in the scientific literature, the ORM is just one component of a complex multi-layered aquifer system that extends from beyond the shoreline of Lake Simcoe in the north to Lake Ontario in the south – a regional system that supplies wells and feeds wetlands and streams far beyond the

ORM boundary. From an environmental standpoint, the aquifer system within the PCPDP study area is as much, if not more, in need of management and protection as the ORM itself.

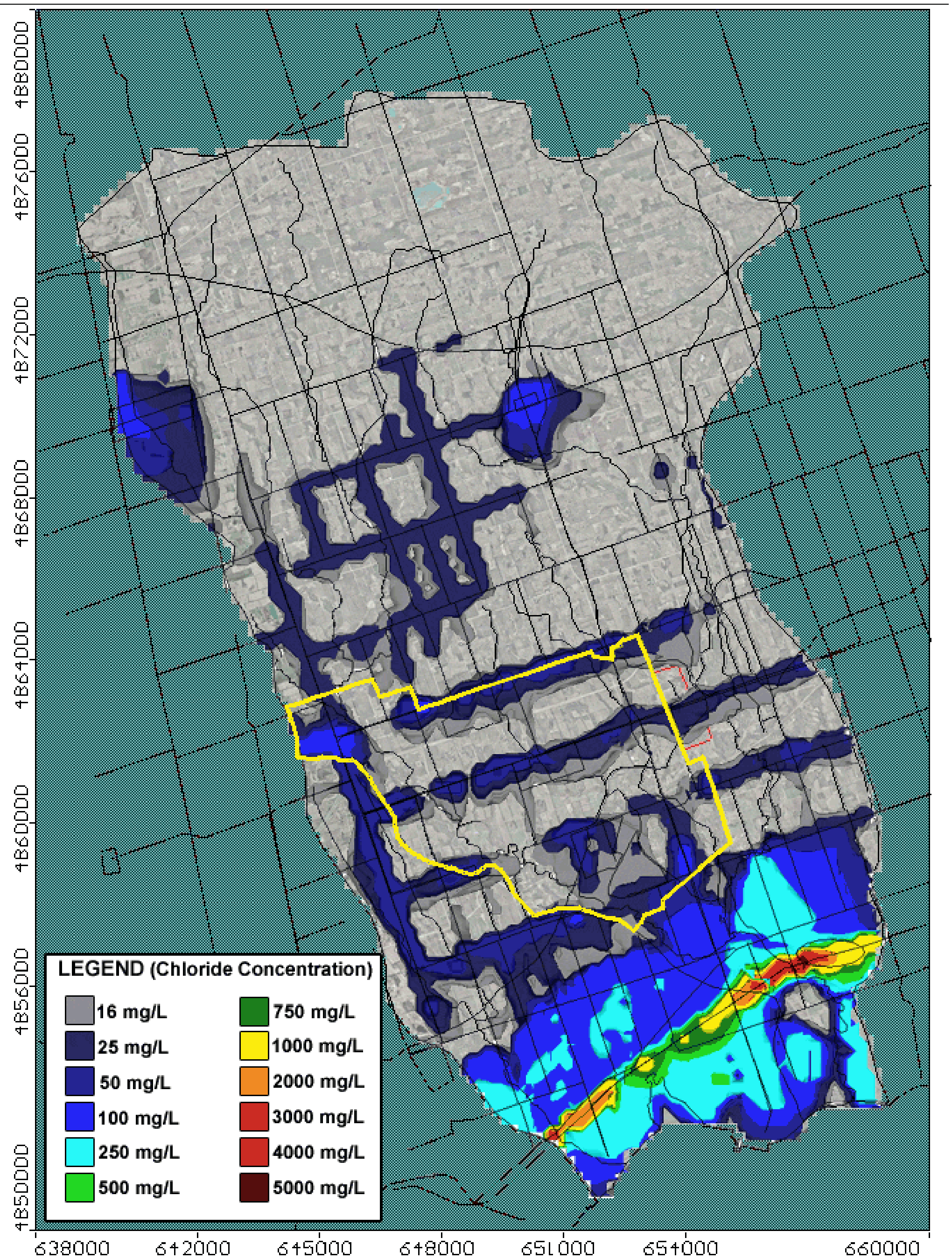


Figure 5. Long-term, steady state chloride concentrations in the Upper Aquifer as a result of road salt application, prior to urban development in the PCPDP study area (shown by yellow line). Predictions were generated using Modflow.

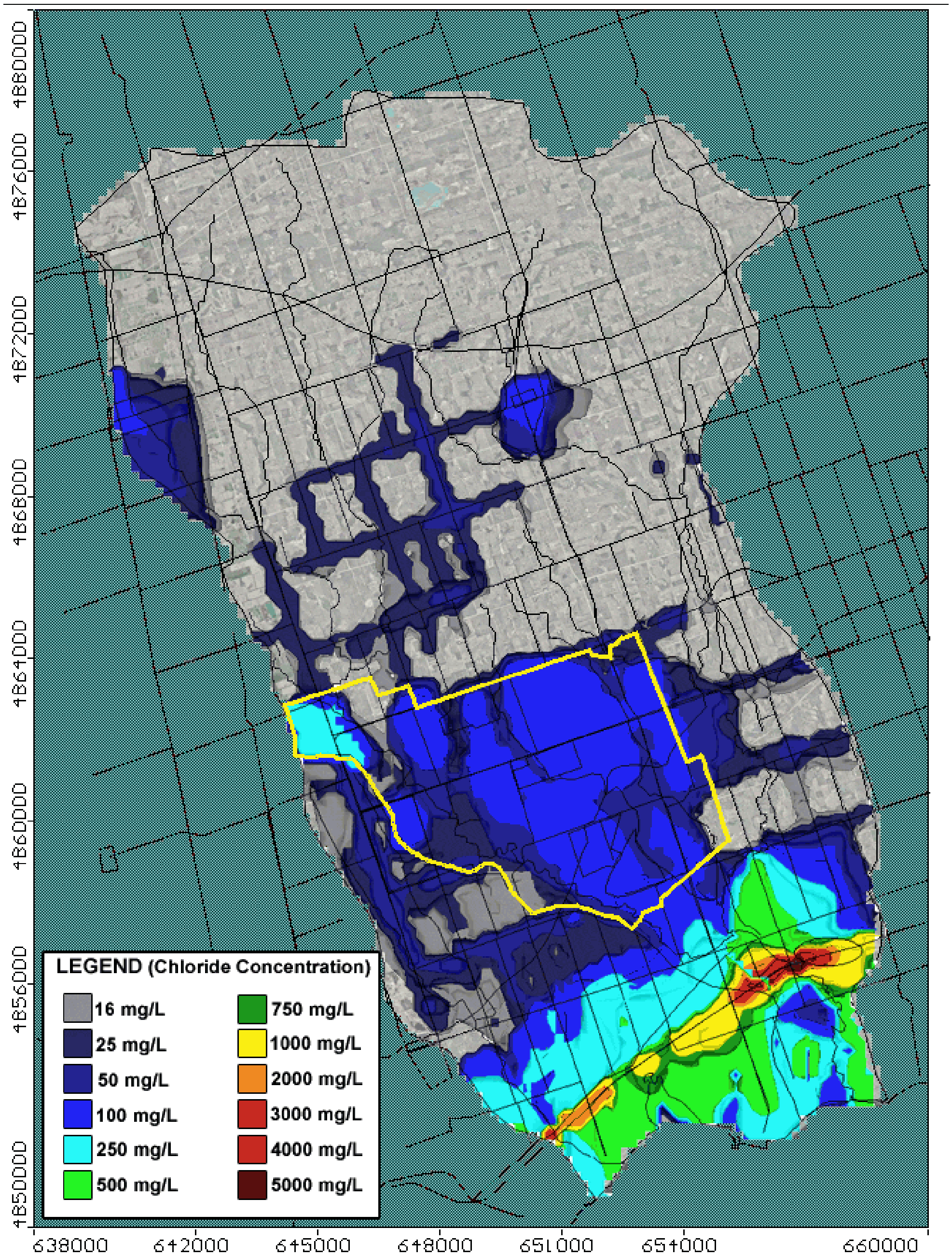


Figure 6. Long-term, steady state chloride concentrations in the Upper Aquifer as a result of road salt application following one scenario of development in PCPDP study area (shown by yellow line). Predictions were generated using Modflow.

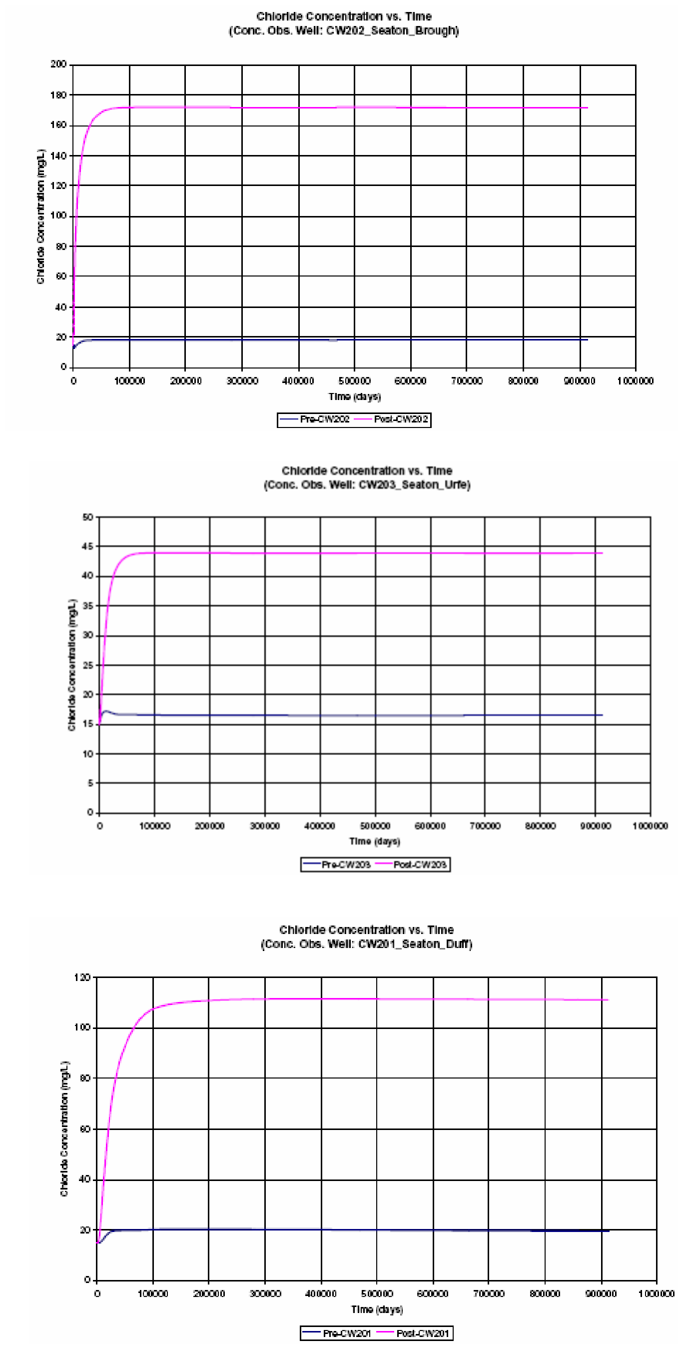


Figure 7. The change of chloride with time in 3 randomly selected, shallow observation wells within the PCPDP study area. The blue line shows the predicted change without development and the pink line shows the change following development. Predictions were generated using Modflow. Note that while the rates of degradation appear rapid, the changes do in fact occur over a period of several hundred years.

Hydrogeological Issues

The hydrogeology of the Duffins Creek watershed is complex (Gerber and Howard, 2002). The watershed supports three relatively “weak” aquifers separated by two regionally extensive aquitards. The uppermost aquifer is overlain by the Halton Till, a heterogeneous, clay-rich deposit that contains abundant gravel, sand and silt, and locally supports an active groundwater flow system. All of these units are present within the PCPDP study area, and the potential complexities of the aquifer system are amply demonstrated in the region by adverse, unanticipated sub-surface conditions recently encountered along16th Avenue in the neighbouring Rouge River catchment during sewer construction for the YDSS (York-Durham Sewer System). As clearly demonstrated by the YDSS project and the response of the Province to the severe problems encountered, impacts on the sub-surface can not be fully evaluated without a thorough understanding of local hydrogeological conditions. A particular concern within the PCPDP study area is that the aquifers are relatively low storage systems that are significantly more susceptible to changing conditions than high storage systems (e.g. the aquifer underlying the Oak Ridges Moraine). It is essential that the susceptibility or “sensitivity” of study area aquifers be acknowledged when measures for mitigating potential impacts of urban development (quality and quantity) are designed.

A particular concern is that the PCPDP study area supports numerous private wells, many within the Middle Aquifer that lies beneath the regionally extensive but leaky Newmarket Till (Northern Till) aquitard. This aquifer receives replenishment both regionally (as recharge via the Oak Ridges Moraine to the north) and locally (via recharge within the PCPDP study area and subsequent leakage via the Newmarket Till). Replenishment rates are regionally variable and depend on numerous factors including, but not limited to, the hydraulic properties of the Halton Till and its variability across the region. It is impossible to reliably estimate potential impacts of any land use change within the PCPDP study area without a comprehensive understanding of the Halton Till and how its hydrogeological characteristics vary across the area.

Streams and Wetlands

Assessment of potential impacts on study area streams and wetlands is complicated by the complex hydrogeological conditions within the Duffins Creek watershed. While part of the flow in local streams is due to overland runoff from the surrounding sub-watershed and is relatively easy to assess, much of the flow, especially during summer months enters as baseflow from one or more of the three aquifers present. Relative contributions depend on the degree to which the stream channel has penetrated the aquifer system, the hydraulic properties of each aquifer and the gradient of pressure that is acting at any one time. While detailed flow analysis of isolated stretches of streams and rivers can begin to unravel the complexity of this issue, such analyses shed little light on how various contributions will change under altered land use conditions. A further complicating factor is that inflow of groundwater in the PCPDP has a profound impact on stream quality, and water quality in the three aquifers is quite different, the shallow aquifer showing greatest anthropogenic impacts. In effect, it is impossible to reliably estimate potential impacts of land use change within the PCPDP study area on stream water quality and quantity without a full understanding of the aquifer system, its properties, and the nature of its hydraulic interaction with various stream reaches.

Limitations of the PCPDP

As it currently stands, the "Proposed Central Pickering Development Plan" (PCPDP) is two-dimensional and fails to appreciate the complex hydrogeological system, the sensitive aquifers (more sensitive than the Oak Ridges Moraine aquifer) and the potential long-term impacts of urbanisation on the quality and quantity of water in local wells and the river system. The water balance studies completed to date are severely limited in scope and there is nothing to reassure existing residents that their wells will be protected (with respect to both quality and quantity) and that streams will not be unduly impacted. Proposed buffer zones (setbacks) may provide some measure of protection for surface water bodies fed entirely by surface water runoff, but will not provide adequate protection for streams and wetlands receiving groundwater.

The Preferred Approach

Recent hydrogeological and hydrochemical studies at the University of Toronto confirm that urbanisation has severely impacted groundwater underlying more established parts of Toronto. Federal, Provincial and Municipal laws exist that may limit degradation from future development. However, it is not clear that the legislation - essentially a patchwork of statutes, policies, programs, regulations and guidelines - is sufficiently versatile to deal with the wide range of potential urban contaminants and the dynamics of groundwater flow within the complex, glacial aquifer system (Howard, 1997). If the protection of ground and surface water is to be guaranteed, there is a strong need to consolidate available legislation and bring it into line with modern hydrogeological thinking. In many respects, "modern hydrogeological thinking" is enshrined in Part 2 of the Report on the Walkerton Inquiry where Justice O'Connor describes a blueprint for groundwater resource protection in Ontario that requires source protection plans be developed for all watersheds in Ontario. He indicates that, at a minimum, plans should include:

- a water budget for the watershed, or a plan for developing a water budget where sufficient data are not yet available;
- the identification of all significant water withdrawals, including municipal intakes;
- land use maps for the watershed;
- the identification of wellhead areas;
- maps of areas of groundwater vulnerability that include characteristics such as depth to bedrock, depth to water table, the extent of aquifers, and recharge rates;
- the identification of all major point and non–point sources of contaminants in the watershed;
- a model that describes the fate of pollutants in the watershed;
- a program for identifying and properly decommissioning abandoned wells, excavations, quarries, and other shortcuts that can introduce contaminants into aquifers;
- the identification of areas where a significant direct threat exists to the safety of drinking water;

- the identification of significant knowledge gaps and or research needs to help target monitoring efforts.

Urban planners should acknowledge Justice O'Connor's important advice and act accordingly.

From a planner's perspective, groundwater protection is normally incorporated into the urban planning process by defining standards of practice i.e. explicit directions or guidelines which would, for example, exclude certain types of development and land use activity in specified areas e.g. in "buffer zones", and recharge areas of major aquifers. This type of approach is easy to administer and is readily incorporated into planning tools such as geographical information systems. However, the approach has little merit in southern Ontario where recharge is almost ubiquitous, and till cap heterogeneities and dynamic flow systems prevent "protection zones" from being defined with the necessary degree of confidence. Instead, a standards of performance approach is often more appropriate as it provides greater flexibility in urban design and encourages planning innovation. The standards of performance approach would designate limits for the degree of acceptable groundwater quality degradation, and may also, for example, require that total recharge (direct and indirect) be maintained at pre-development levels. Just as importantly, the standards of performance approach would put the onus on the proponent to perform the necessary sub-surface investigations and provide designs (including monitoring programs, mitigation measures and contingency plans) that would ensure environmental performance standards are met for all time.

The standards of performance approach is data demanding but is directly compatible with Justice O'Connor's recommendation that groundwater flow models be developed that "describe the fate of pollutants in the watershed". Such models can be used equally effectively to describe the potential impacts of recharge depletion on well water levels and stream flows and, as indicated, the potential impacts of road de-icing chemicals on well and stream water quality.

The Most Appropriate Plan of Action

Recognising:

1. the hydrogeological complexity of the study area,
2. the sensitivity of study area aquifers and receiving streams,
3. the severe limitations of the "Proposed Central Pickering Development Plan", and
4. the recommendations of Justice O'Connor following the Walkerton Inquiry,

the appropriate course of action is clearly apparent. While there are numerous ways that potential impacts of urban development on the hydrologic system can be managed and reduced to environmentally appropriate levels, none of these methods can be properly evaluated without a well calibrated numerical model of the aquifer system. Justice O'Connor was obviously convinced of the importance of aquifer modeling for resource protection purposes, and following the serious problems encountered during YDSS tunnel construction along 16th Avenue, aquifer models have become the preferred choice for evaluating potential impacts of dewatering for future YDSS projects. Aquifer modelling is no more a panacea for environmental protection in urban areas as storm water management; nevertheless, it is just as essential.

Recommendation

In terms of the PCPDP study area, it is strongly recommended that the essentially 2-dimensional planning approach be abandoned in favour of an iterative approach that fully utilises calibrated, 3-D groundwater flow models as an integral part of the planning process, to test and evaluate alternative land use configurations. Such an approach may require additional drilling to provide key input data, notably with respect to the Halton Till cover. Ultimately, however, adoption of such a state-of-the-art decision-making approach will ensure that development of the PCPDP lands can proceed in a safe, sustainable and environmentally responsible manner.

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