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An Assessment of groundwater use in thirteen counties in southern Ontario

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MANAGEMENT PERSPECTIVE

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EC Priority/Issue:	This work contributes to Sub-objective 3.6 of the Great Lakes 2000 program, Prevent or Mitigate Climate Impacts. This work began in fiscal year 1994/1995 and will be completed in fiscal year 1999/2000. This paper is the second publication resulting from this collaborative research initiative.
Current Status:	The Grand River watershed is a large and nationally significant watershed and is situated in southwestern Ontario. Surface water drainage from the watershed enters Lake Erie at Port Maitland. The population of the watershed is located at some distance from the Great Lakes and is largely dependent on groundwater as a water supply relative to conditions elsewhere in southern Ontario. Shifting patterns of water availability due to climate change and variability, and rapid population growth, may impact the sustainable development of the groundwater resources of the watershed and the integrity of the Grand River ecosystem. Characterization and numerical modelling procedures are being developed to estimate the impacts of climate change on the groundwater resources of the watershed. These results will also be used to formulate a water management strategy that seeks an optimal balance of ground and surface water development subject to constraints on the maintenance of the aquatic ecosystem.
Next Steps:	Continuing research will focus on relating groundwater use to ground and surface water conditions within the watershed and on estimating climate and water use impacts on the sustainability of groundwater resources.

ABSTRACT

An assessment of groundwater use within and surrounding the Grand River watershed is being carried out as part of a study of the potential impacts of climate change and variability on the groundwater resources of the region. Groundwater use, measured in terms of total annual water withdrawal, is estimated for each of the 171 census subdivisions which form the 13 counties within the study area. The average rate of groundwater use for the area is 22.4 mm/yr with local rates as high as 586 mm/yr. Non-municipal groundwater use associated with water taking permits accounts for 70 percent of the total use. The highest rates of groundwater use are significant relative to recharge and therefore groundwater withdrawals should be represented in climate change impacts analyses. Groundwater supply limitations resulting from inadequate well yield and poor water quality are also estimated and are related to the geology of the region.

An Assessment of Groundwater Use in Thirteen Counties in Southern Ontario

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Abstract

An assessment of groundwater use within and surrounding the Grand River watershed is being carried out as part of a study of the potential impacts of climate change and variability on the groundwater resources of the region. Groundwater use, measured in terms of total annual water withdrawal, is estimated for each of the 171 census subdivisions which form the 13 counties within the study area. The average rate of groundwater use for the area is 22.4 mm/yr with local rates as high as 586 mm/yr. Non-municipal groundwater use associated with water taking permits accounts for 70 percent of the total use. The highest rates of groundwater use are significant relative to recharge and therefore groundwater withdrawals should be represented in climate change impacts analyses. Groundwater supply limitations resulting from inadequate well yield and poor water quality are also estimated and are related to the geology of the region.

Introduction

Environment Canada is conducting a study of the potential impacts of climate change and variability on groundwater resources within and surrounding the Grand River watershed in southern Ontario. Understanding rates and patterns of groundwater use within the area is critical to estimating anthropogenic impacts on the groundwater resource and to measuring the impacts of climate change relative to water supply. This paper presents estimates of groundwater use and supply limitations for the study area shown in Figure 1, which includes Brant, Dufferin, Elgin, Grey, Middlesex, Oxford, Perth, and Wellington Counties and the Regional Municipalities of Haldimand-Norfolk, Halton, Hamilton-Wentworth, Niagara, and Waterloo. The region extends 240 km from east to west and 260 km for north to south and has a land area of 28,000 km^2.

Estimation of Groundwater Use

Groundwater use was estimated for each of the 171 Statistics Canada census subdivisions shown in Figure 1. These subdivisions are classified, largely by population, as cities, towns, villages, townships, and Indian Reserves. The data used to form the estimates were drawn from the Municipal Water Use Database (MUD) maintained by Environment Canada, water taking permits (WTP) and water well construction records maintained by the Ontario Ministry of the Environment (MOE), and census of population and agriculture information maintained by Statistics Canada. A consistent set of data were collected for 1991 and that year was selected as the reference for all subsequent calculations.

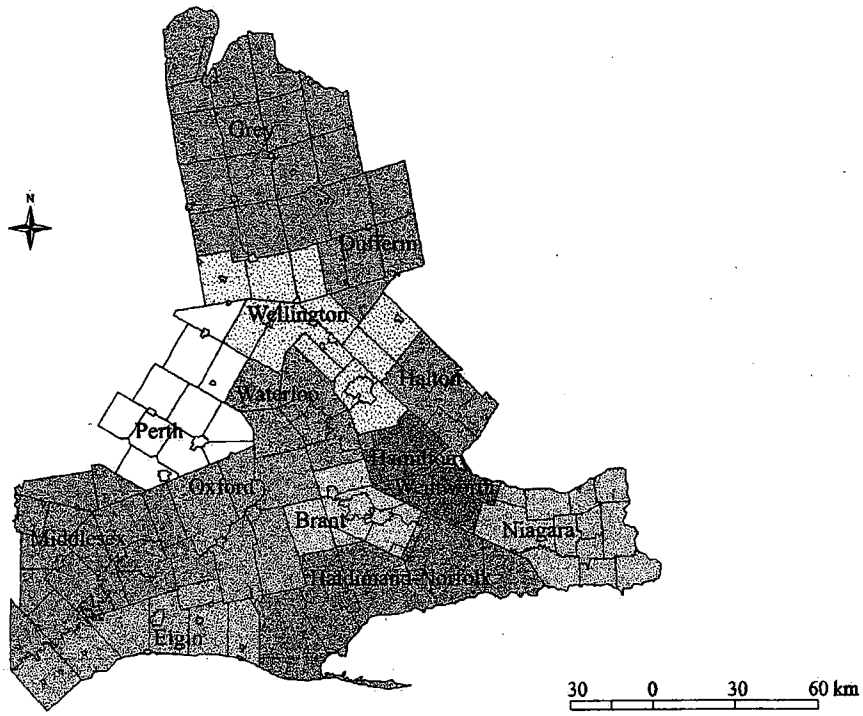

Figure 1. Thirteen counties and 171 census subdivisions in southern Ontario

The MUD was designed to provide access to data describing municipal water use for municipalities with populations of greater than 1000 and was used in this study to estimate the amount of water used in villages, towns, and cities. The MUD lists average daily volumes for the population in a municipality which is either served exclusively by municipal groundwater wells, or is served by a combination of ground and surface water. MUD does not account for individual water users that are independent of the municipal system.

Townships and Indian Reserves, most villages, and portions of towns and cities not serviced by municipal supplies were assumed to draw their water from private groundwater wells. Water use was estimated for private wells by assuming an average rate of 159L/day/person (Southam et. al., 1997). Similarly, water use rates for cattle, pigs, and chickens of 47, 10, and 0.4 L/day/head, respectively, were used (Southam et. al., 1997). Population and livestock data were taken from the 1991 census (Statistics Canada, 1991).

WTP databases from the Central, West-central and Southwestern offices of the MOE were used to estimate the amount of groundwater being taken from point sources. Water uses such as commercial, industrial, irrigation, municipal, public, or recreational are indicated on the water taking permits. All water taking permits that were valid in 1991 were considered in this study with the exception of permits for municipal wells, which are accounted for in the MUD. One principal limitation of the WTP data is that the data only specify how much water is permitted to be pumped, not how water much is actually pumped.

Table 1 summaries the estimated rates of groundwater use by county and sector. The overall average rate of groundwater use for the study area was determined by averaging the total volumes of groundwater use for each of the 13 counties and is estimated to be 22.4 mm/yr.

Table 1. Groundwater withdrawal rates by county and sector in mm/yr.

County	Population	Municipal	Private	WTP	Livestock	Total
Brant	114,508	1.9	1.2	108.2	0.3	111.7
Dufferin	39,897	2.5	0.7	6.0	0.3	9.5
Elgin	75,423	0.6	0.9	15.4	0.3	17.2
Grey	84,071	0.8	0.5	1.5	0.4	3.3
Haldimand-Norfolk	99,186	1.6	1.1	1.7	0.3	4.7
Hamilton-Wentworth	451,665	0.1	2.2	29.1	0.4	31.9
Halton	313,136	9.3	1.1	21.8	0.3	32.6
Middlesex	375,131	1.3	0.8	6.8	0.6	9.4
Niagara	393,936	0.3	1.6	10.4	0.5	12.7
Oxford	92,888	6.2	1.0	27.6	0.9	35.7
Perth	69,976	4.0	0.7	1.1	1.2	7.0
Waterloo	377,762	38.0	1.7	59.5	1.3	100.5
Wellington	159,609	8.5	1.0	11.5	0.9	21.9
Average		4.6	1.0	15.8	0.6	22.4

Average rates of groundwater use for each of the 5 types of census subdivisions are listed in Table 2. Cities and villages use groundwater most intensely with average rates of 73 and 57 mm/yr, respectively. Towns use groundwater at an intermediate rate and Indian Reserves and townships have the lowest average use rates of 2 and 16 mm/yr, respectively.

Table 2. Groundwater withdrawal rates, population, and well densities by type of census subdivision.

Type of Census Subdivision	Average Groundwater Withdrawal Rate (mm/yr)	Population Density (people/km^2)	Well Density (wells/km^2)
Cities	73	976	4.4
Towns	28	539	3.9
Villages	57	544	21.8
Indian Reserves	2	27	4.4
Townships	16	18	2.8

Figure 2 shows total groundwater withdrawals for both municipal and private supplies. The highest withdrawal rates, rates greater than 200 mm/yr, occur inland away from the Great Lakes, often in cities (i.e., Kitchener, Waterloo, Guelph, Stratford, and Woodstock), and in towns (i.e., Ingersoll, Fergus, and Orangeville).

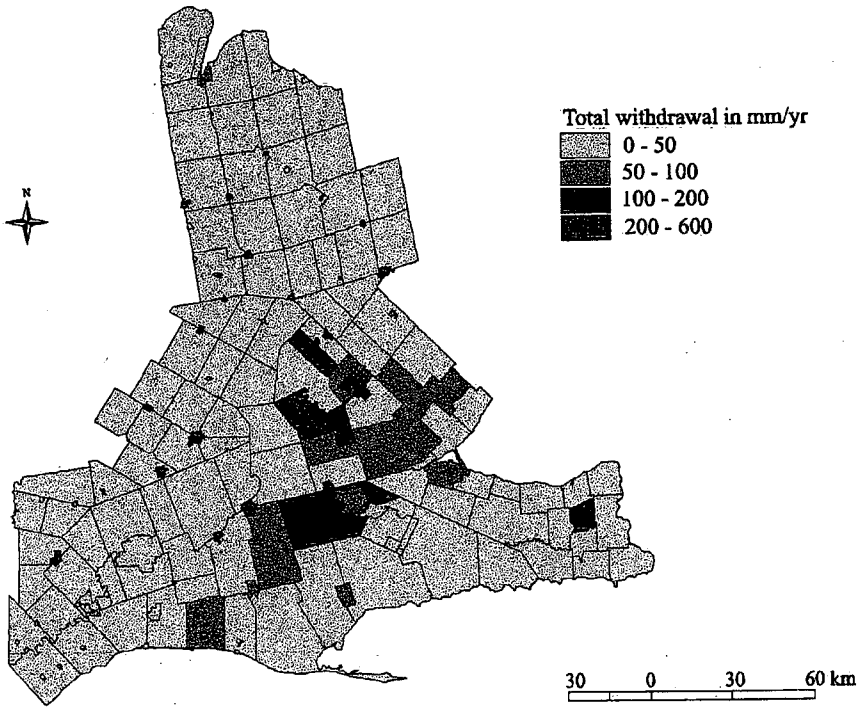

Figure 2. Total groundwater withdrawal rates in mm/yr.

Results derived from the WTP data alone are shown in Figure 3 and indicate that the largest private consumers of groundwater are farmers using water for irrigation in Waterloo and, in particular, in Oakland Township located southwest of Brantford. Oakland Township has the highest withdrawal rate encountered in the study at 586 mm/yr where this rate is due to pumping from several irrigation wells. Other large private users include quarries and industries in the Kitchener-Waterloo area, followed by industrial and commercial uses in Pilkington Township and in Thorold. The volume of water taken through water taking permits, excluding municipal water use, accounts for 70 percent of all groundwater taken.

Analysis of Groundwater Resource Development

The water well construction records may be used to assess patterns of groundwater resource development. Approximately 84,000 records spanning a 50 year period were obtained for the study area. These records have been organized within a formal database and have been used to perform a range of hydrogeological characterization tasks. A geographical information system was used to classify each of the well locations according to census subdivision such that the well record data can be compared to the other forms of data used in this study.

Table 2 indicates that towns and cities have well densities of approximately 4 wells/km^2 despite having population densities of 539 and 976 people/km^2, respectively. This suggests that these types of subdivisions generally have access to municipal water supplies where these supplies are obtained from a few high yield wells. Townships have the lowest population and well densities

with 18 people/km^2 and 2.8 wells/km^2. The highest well density of 22 wells/km^2 corresponds to villages with a substantial population density and largely private wells.

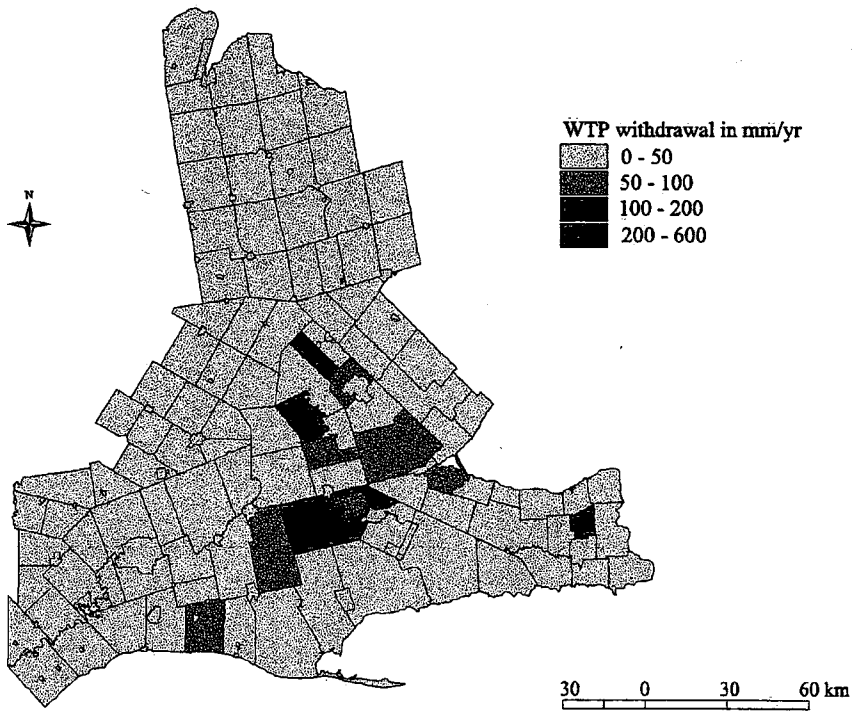

Figure 3. Groundwater withdrawal rates due to water taking permits (WTP) in mm/yr.

Figure 4 is a plot of well density as a function of population density for the five types of census subdivisions. There is a consistent increase in well density with increasing population density for townships, Indian reserves, and a minority of villages. The slope of the trend line shown in the figure suggests linear proportionality among well and population densities for these types of census subdivisions. Demographic data suggests that in 1991 an average household consisted of 2.7 individuals and therefore it is expected that private wells in rural areas serve 2.7 people. The intercept of the trend line indicates that there is approximately one well for each ten people. Thus, it is estimated that roughly one-fourth of existing wells are present in the database.

Groundwater Supply Limitations

The water well construction records also indicate the status of each well at completion. Two of the prescribed range of entries, namely wells abandoned at completion due to an inadequate well yield or poor water quality, may be used to estimate the distribution of groundwater supply limitations. Figure 5 shows the percentage of wells that were abandoned due to inadequate well yield. Of the 2470 wells that were abandoned for this reason, the highest percentage occur in the southwestern portion of the study area surrounding Ekfrid Township, an area which is characterized by thick clay deposits (Chapman and Putnam, 1984). The lowest percentage of

abandoned wells occurs in the north-central portion of the study area in an area characterized by thick and relatively permeable overburden deposits (Chapman and Putnam, 1984).

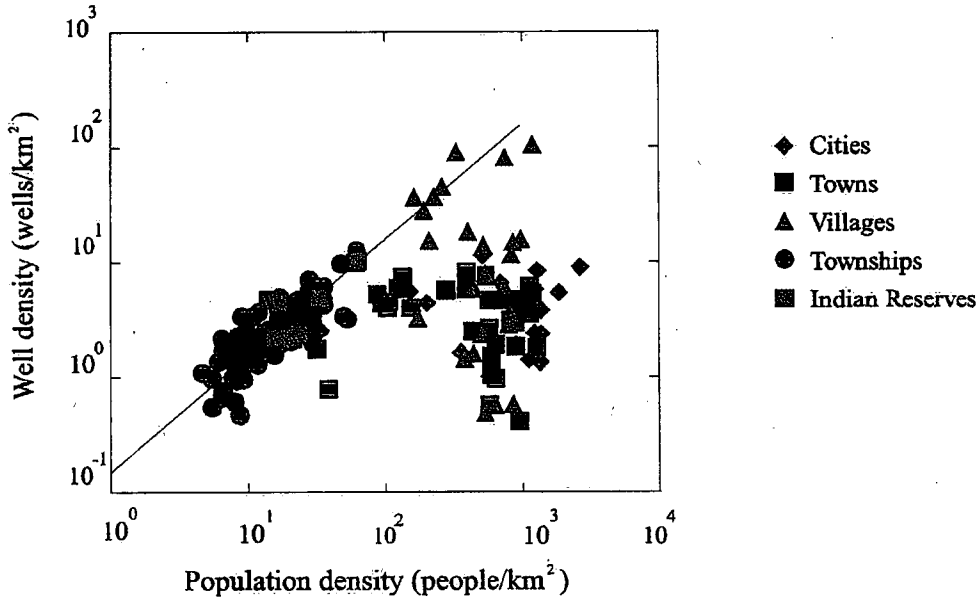

Figure 4. Well density versus population density for the 5 types of census subdivisions.

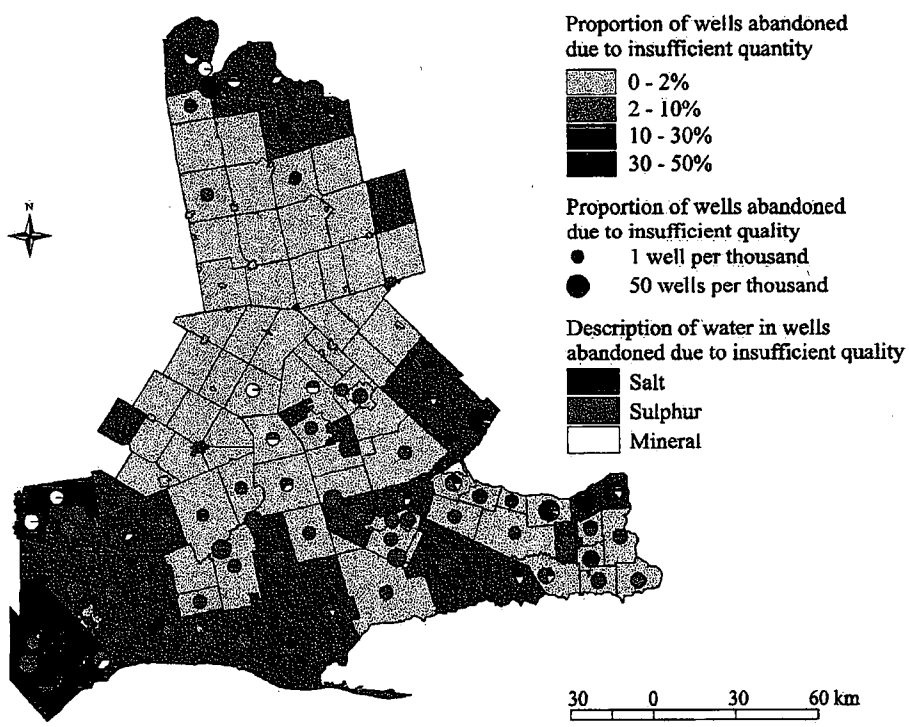

Figure 5. Wells abandoned due to inadequate well yield and poor water quality.

Figure 5 also shows indicates the distribution of wells that were abandoned due to poor water quality and summaries the corresponding descriptions of the water encountered in these wells. Of the 338 wells that were abandoned due to poor quality water, the largest number of wells were abandoned due to excessive levels of sulphur, followed by salt and mineralization. Few wells were abandoned due to poor water quality in the north-central portion of the study area, which again is characterized by thick and permeable overburden deposits. By contrast, the western limit of Lake Ontario, where overburden deposits are thin and where the bedrock is often shale, has the largest proportion of wells that were abandoned due to poor water quality.

The results shown in Figure 5 indicate a discernible spatial pattern among groundwater supply limitations. In many cases, elevated rates of inadequate well yield and poor water quality are coincident. This relation may suggest a groundwater flow regime with a minimal capacity for the recharge and transmission of groundwater and the displacement of naturally occurring sources of contamination. It is reasonable to conclude that it may be more difficult and costly to expand existing groundwater supplies as an adaptation to climate change in these areas.

Conclusions

The average rate of groundwater use for the study area is estimated to be 22.4 mm/yr with local rates as high as 586 mm/yr at the scale of a census subdivision. Annual groundwater recharge is estimated to be on the order of 160 mm/yr (Singer et al., 1997). Thus, the estimated rates of groundwater use are significant relative to recharge and groundwater use is an important component of the regional groundwater budget that should be addressed in climate change impacts analyses. Quantitative analyses will be required to determine the sustainability of the projected rates of groundwater use relative to climate change. These analyses should also address the concurrent impacts of climate change and population and industrial growth.

Analysis of water well construction data by census subdivision and relative to population provides a method of classifying water supply development, estimating the impacts of climate change on these supplies, and designing adaptation alternatives. For example, townships and Indian Reserves and a minority of villages are largely dependent on private wells. Economic constraints dictate that these wells are constructed to the minimum depth required to secure reliable a water supply. It is reasonable to conclude that these classes of subdivisions may have an elevated vulnerability to climate change. The minority of villages that are dependent on private wells have populations densities which are comparable to those of villages that have shared water supplies and therefore the installation of deeper, shared wells may be a reasonable adaptation strategy.

Groundwater supply limitations, specifically inadequate well yield and poor water quality, affect a meaningful proportion of wells in some subdivisions. These limitations are likely to have economic implications relative to the extension of existing groundwater supplies, and the development of new supplies, in response to climate change.

Approximately 70 percent of the estimated non-municipal groundwater use within the area may be attributed to water taking permits. These permits indicate only the allowable rates of

groundwater use and do not necessarily reflect actual use. As a result, the derivation of more precise estimates of groundwater use will require the resolution of uncertainties within the WTP data. Further, groundwater flow within the area is sufficiently dynamic that quantitative analyses will require the distribution of the annual rates of groundwater use on a daily basis.

Acknowledgements

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