Economic implications of increasing nitrate in groundwater due to climate change, Prince Edward Island, Canada

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Abstract

Prince Edward Island is a small, dominantly rural province in eastern Canada, relying completely on a productive but highly vulnerable aquifer for drinking water. The economy of the Province is dominated by agriculture, and contamination by nitrate is one of the most serious threats to groundwater quality. Currently, contamination of groundwater by nitrate affects 5% of domestic wells across the Province, and more than 10% of wells in more intensively cultivated watersheds. With the Province=s small land base, competition between agricultural productivity and the need to protect water quality poses difficult challenges. Under current land use practices, our research team is predicting that GW nitrate levels will increase by over 10% by the year 2050. Furthermore, when potential adaptations to climate change by the agricultural sector are considered, this increase could triple. Such changes could be expected to result in nearly doubling the proportion of wells exceeding the nitrate guideline. The potential economic and public health consequences of climate change highlight the need for aggressive actions to control nitrate leaching to groundwater.

1 Introduction

Prince Edward Island is Canada's smallest province and depends entirely on groundwater (GW) as a source of potable water. Agriculture dominates both the economy and the landscape of the Province, and the close juxtaposition of a large rural population and intensive agricultural activity, have created problems associated with gradually increasing nitrate levels in GW, affecting private domestic wells in many areas, and to lesser extent, some municipal wells. It is important to note that elevated nitrate levels in GW discharge (base-flow) to fresh water streams are believed to be a major source of nutrient loading, and associated eutrophication of the Island's many estuarine areas, with detrimental effects on the fisheries and tourism sectors. Due to the complexity of these phenomena it would be difficult to attempt to quantifying the economic impact on these sectors. Water supply infrastructure has evolved with little consideration of future climatic conditions, including the potential impact of climate change on water quality. Here we document the state of water supply infrastructure in the province, assess the current impact of nitrate contamination on drinking water supplies, and discuss the potential future consequences of climate change with respect to nitrate contamination of drinking water supplies.

1.1 General Setting

Prince Edward Island is located in the Gulf of Saint Lawrence in eastern Canada. The land area of the province is a mere 5684km^2, and in spite of a population of a little under 140,000, the Province has the highest population density in the country (24 people/km^2 (Info PEI, 2005), with 55% of residents living in rural settings. The actual farm population has declined dramatically, and now makes up less than 10% of the rural population compared to more than 60% in the 1930's. Primary resource industries, particularly agriculture, as well as the associated food processing sector are the principle engines of the local economy and agricultural products account for about 2/3 of the Province's exports.

The Province's topography is characterized by gently undulating to flat terrain, with a maximum elevation of 152m above sea level. The coastline is indented with numerous estuaries and fresh water rivers are typically short. Climate is humid-continental, with long, fairly cold winters and warm summers. Mean annual precipitation is in the range of 1078mm, 75% of which falls as rain, the remainder falling as snow. The mean annual temperature is 5.1 C and monthly mean temperatures range from minus 8.6 C in January, to 18.4 C in July.

The geology of PEI is dominated by an essentially flat lying sequence of continental red beds, Upper Pennsylvanian to Middle Permian in age. These sequences consist of conglomerate, sandstone and siltstones typically well fractured at shallow depths and covered by a thin layer of permeable glacial till, and rarer glacio-fluvial and glacio-marine deposits (Prest, 1973). The sandstone bedrock formations are the only significant aquifers, and the combination of thin cover and highly permeable nature of these formations make these aquifers highly productive, very responsive to individual recharge events, and highly vulnerable to contamination. The geometry of individual GW flow systems is controlled by topography and the boundaries of these systems mimic local surface watershed boundaries. Groundwater and surface water (SW) resources are closely linked with GW discharge (base flow) accounting for two thirds of annual stream flow, and during dry periods, nearly all stream flow is derived from base flow. As a consequence of these factors, watersheds are typically the defining unit for the study of both GW and SW resources.

Agricultural land use accounts for 46% of the province's land mass, followed by forest cover of approximately 40%. The remaining lands are occupied by residential, industrial/commercial and institutional land uses. In some watersheds however, as much as 75% of land use is devoted to agriculture, 80% of which is under intensive row crop production, primarily in a potato rotation system. It is these intensively cultivated areas where contamination of GW by nitrate is most severe.

1.2 OBJECTIVES

Groundwater resource management and the development of associated water supply infrastructure have evolved on the basis of historical circumstances and practices, with little thought to potential future conditions, including those related to climate change. Against this background, we attempt here to:

- characterize water supply infrastructure in terms of the status of groundwater sources in relation to nitrate levels, water use patterns and the physical characteristics and financial value of water supply infrastructure in the Province;

- estimate the current financial impact of nitrate contamination on existing water users; and

- discuss the potential financial impact of increased frequency or extent of nitrate contamination of GW under potential future climatic conditions.

1.3 Methods

Data and observations relating to existing GW nitrate concentrations in the Province are drawn from the Province's water quality data-bases, comprised dominantly of analyses of waters from private domestic wells, and from previous works (Young *et al*., 2002, Somers *et al*, 1999). Information on water well characteristics are derived from departmental data bases, while water-use figures are based on information assembled by Environment Canada (2001), and personal communication with water-utilities individual authorities. The economic valuation of water supply infrastructure is based on information from the Island Regulatory and Appeals Commission (the body responsible for regulation of financial aspects of water, wastewater and other utilities in the province) or individual water supply utilities. Assessment of the economic impact of future nitrate levels is based on scenarios presented by Vigneault *et al*., (2007). More detailed information on the sources of information and methods of aggregation of data are described in detail by Somers et al., (2007). It should be noted that the evaluation undertaken in this work is intended to provide only a first approximation of the current state and value (in Canadian dollars) of water supply infrastructure in PEI, and its potential vulnerability to changes in the extent of nitrate contamination as a result of climate change.

2 Results

2.1 Characterization of water supply

Source Water Quality Groundwater is typically of a Ca-Mg-HCO_3^- type, slightly alkaline with moderately high hardness and TDS (Somers *et al*., 1999). Locally in areas immediately adjacent to the coast, salt water intrusion may result in Na-Cl type waters, and more rarely in the distal end of longer groundwater flow systems, Na-HCO_3 type waters may be encountered. Groundwater nitrate concentrations in most regions of the Province are significantly above natural background levels averaging 3.8 mg/L NO_3-N. However nitrate levels are not evenly distributed geographically (Figure 1), with relatively pristine watersheds having mean nitrate concentrations of less than 2 mg/L, whereas mean concentrations are in excess of 5 mg/L in those watersheds with intensive agricultural activities. In a study conducted in the Wilmot watershed (Figure 1), Savard *et al.* (2007) found as many as 20% of wells sampled had NO_3-N concentrations exceeding the 10 mg/L drinking water guideline.

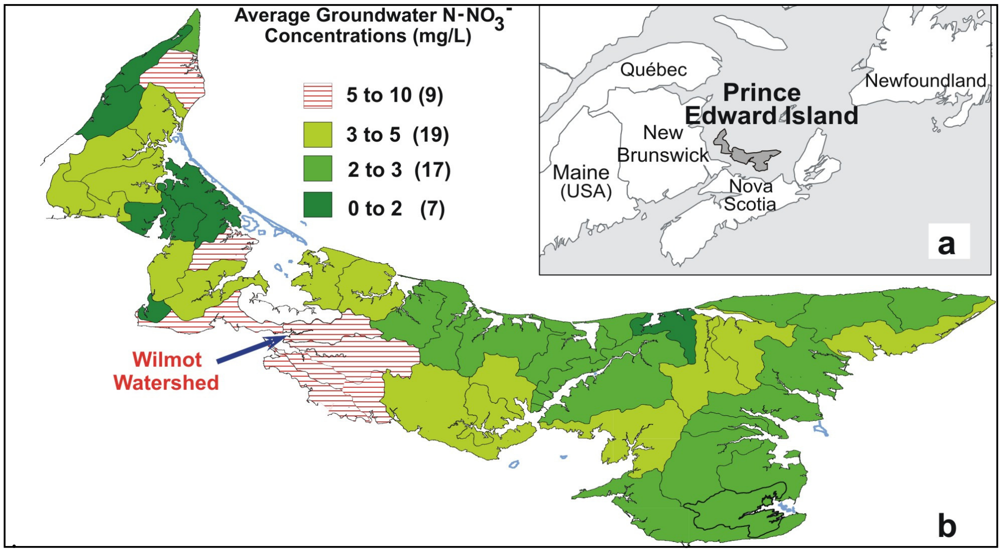

Figure 1. (a) Location of Prince Edward Island in eastern North America. (b) Distribution of watersheds in the Province with shading illustrating average nitrate-concentrations for domestic wells. The Wilmot watershed belongs to a class which is particularly at risk, as reflected by their high average GW nitrate concentrations (data from PEI-EEF).

At the same time, it is important to note that within any given watershed, there is a broad range of nitrate concentrations, and even in heavily impacted regions of the province, nitrate concentrations reflecting essentially pristine conditions are observed in some wells (see figure 3). Finally there is evidence to suggest that nitrate levels are continuing to rise in both GW and fresh SW fed by GW (Somers *et al*., 1999, Young *et al*., 2002).

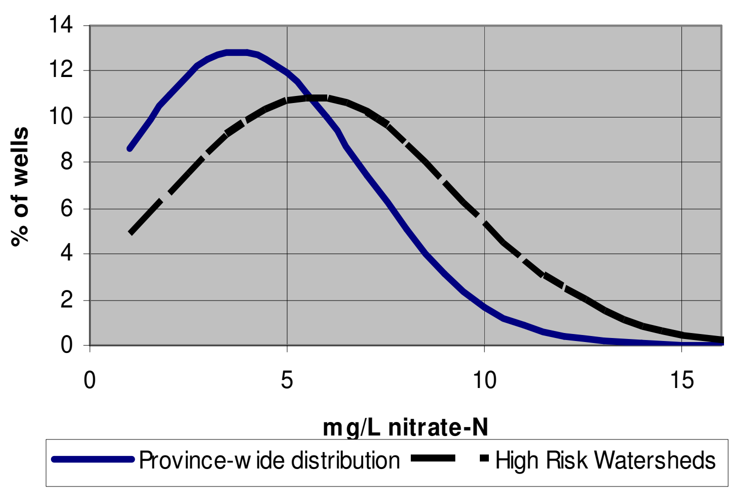

Figure 2. Distribution of nitrate-N concentrations in private wells for the Province as a whole, and for intensively cultivated watersheds.

There are an estimated 21,000 to 25,000 wells in operation in PEI, the vast majority being private domestic wells serving about 55% of the population (Young *et al.*, 2002). Municipal water supply systems serve the remaining population and consist of 12 municipal water utilities collectively supplied by 18 municipal well fields and 59 municipal wells.

Virtually all wells in the Province, whether they are for private, industrial or municipal use, are of simple “open hole” construction (i.e., no well screens or gravel packs are used), and with the exception of well diameter and pumping rates, there are no significant differences in construction between private domestic wells and municipal or industrial wells. Well construction standards require a minimum of 12m of casing with mandatory grouting of casing and pitless well completion, although some older wells are completed in well pits and may have as little as 6m of casing. In some other instances as much as 30m of casing has been installed, usually in response to site specific water quality problems. Table 1 summarizes the principle characteristics of domestic and municipal/industrial wells in the Province.

Table 1. Principle characteristics of water wells in Prince Edward Island.

Characteristics	**Domestics Wells**	**Municipal Wells**
Rock type	Sandstone	Sandstone
Type of well	Open hole	Open hole
Depths	25 to 50 m	75 to 100 m
Yields	33 to 66 m^3/day	650 to 3300 m^3/day

Information provided by Water Management Division of PEI-FEE.

With exception of two cities (Charlottetown and Summerside), municipal well fields are located quite close to the area being serviced and generally there are no extensive water transmission mains connecting sources of supply and municipal water distribution systems. The size and nature of storage facilities depend principally on system size and whether or not the system provides fire flows. In all cases, storage capacity, in relation to average daily demand is low, and aside from fire protection purposes, storage is used to buffer short term peaks in water demand. Natural GW quality is such that treatment is not required (Fleury, 2003), although in most cases municipal water is chlorinated, primarily for the purpose of distribution system maintenance. There are no water treatment plants in the traditional sense. For private wells point of entry devices are used to treat for hardness, iron & manganese, nitrate and barium.

Beginning in 2005, municipal water utilities have been required to develop well field protection plans on the basis of protective zones defined by “time of travel” to the well or well field. Because of the persistence of nitrate in GW, there is an expectation that these well field protection strategies will include measures such as nutrient management planning within a 25-year travel-time zone. At this point, it is too early to determine how effective these measures will be in reducing the impact of nitrate leaching from agricultural lands to GW.

Average per capita residential water use for PEI is 218 L/day (Environment Canada 2004), significantly below the Canadian average of 335 L/day for the same period. The greater part of water demand in PEI is for domestic use (Figure 3). When additional demand associated with tourism is factored in, residential water use is estimated to be 11,875,000m^3/year. Commercial/industrial supplies collectively use approximately

4,124,500m^3/year and when combined with the industrial demand met by municipal water supplies, total industrial/commercial water use is estimated to be 8,665,100m^3/year. The greatest proportion of this industrial water use is by the food processing sector, and typical large food processing plants use a daily average GW quantity ranging between 2 and 8 million L/day (Info PEI, 2005).

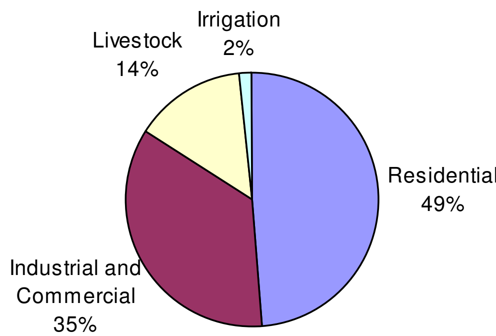

Figure 3 Distribution of water use by sector on Prince Edward Island.

The context of enquiry pursued here poses some difficulties in establishing a meaningful valuation of municipal water supply infrastructure. First, only some of the components that make up water systems may be vulnerable to the impact of nitrate contamination (i.e. sources of supply, treatment facilities), yet information on the value of individual system components is difficult to obtain. Secondly, the value of infrastructure can be measured several ways; original construction costs, "book values" or replacement costs. Book values have been used here, as they take into account the aggregate value over the remaining useful life of individual system components. Based on this approach, the overall "book value" of municipal systems in the Province is estimated to be in the order of $65 million, with almost ¾ of this being associated with the Province's two largest water utilities serving the Cities of Charlottetown and Summerside. Replacement costs for municipal infrastructure is much more difficult to assess, and is beyond the scope of this work, requiring detailed case by case evaluation. Nonetheless, rough estimates for two utilities would suggest that replacement costs could be in the vicinity of 3 times the "book value".

The valuation of private wells is somewhat simpler and can be based on typical construction costs, prorated to account for the useful life of a typical domestic well, with a resulting estimate in the range of $45 million. Combining the value of municipal and private supplies as derived in this manner suggests a "first order" estimate of the financial investment in water supply infrastructure in the Province at approximately $100 million, with municipal water supply systems accounting for approximately 65% of this total.

2.2 Current financial impact of nitrate contamination

As noted in the introduction, while the full economic impact of GW nitrate contamination can be measured in terms of drinking water impacts, the fisheries and tourism sectors, and other ecological effects, here we discuss only the relative costs of nitrate contamination on drinking water supplies, based on the current situation.

Owners of private well with elevated nitrate levels are generally faced with two options: replacement/reconstruction of the well with additional casing to avoid shallower, high nitrate water, or the installation of a treatment device for the removal of nitrate. While in some areas it is increasingly difficult to tap lower nitrate GW through well reconstruction or new wells, with current prices, typical replacement costs are in the order of $3,000, assuming that the original pumping equipment can be re-installed. In cases where homeowners opt to install water treatment (generally ion-exchange), costs are in the vicinity of $1,500. Based on departmental records over the past 5 years, an average of 133 private wells per year will have nitrate levels in excess of the drinking water guideline. While there is no way of tracking what proportion of homeowners chose to address this situation, if for the sake of illustration it is assumed that all these homeowners acted to reduce problem nitrate levels, this scenario would generate a net cost of $200,000 to $400,000 per year depending on the manner selected to reduce nitrate levels.

While the greatest burden of GW nitrate contamination has fallen on the shoulders of private well owners, municipal water utilities have also been affected. Three municipalities have experienced cases where GW-nitrate concentrations in one or more of their production wells have exceeded the health guideline (see Figure 4). However to date, municipal authorities have dealt with the issue through relocation of the well fields (Borden-Carleton), reconstruction of wells with additional casing (Victoria) or blending of water with wells with lower nitrate contamination (Wilmot well field serving Summerside).

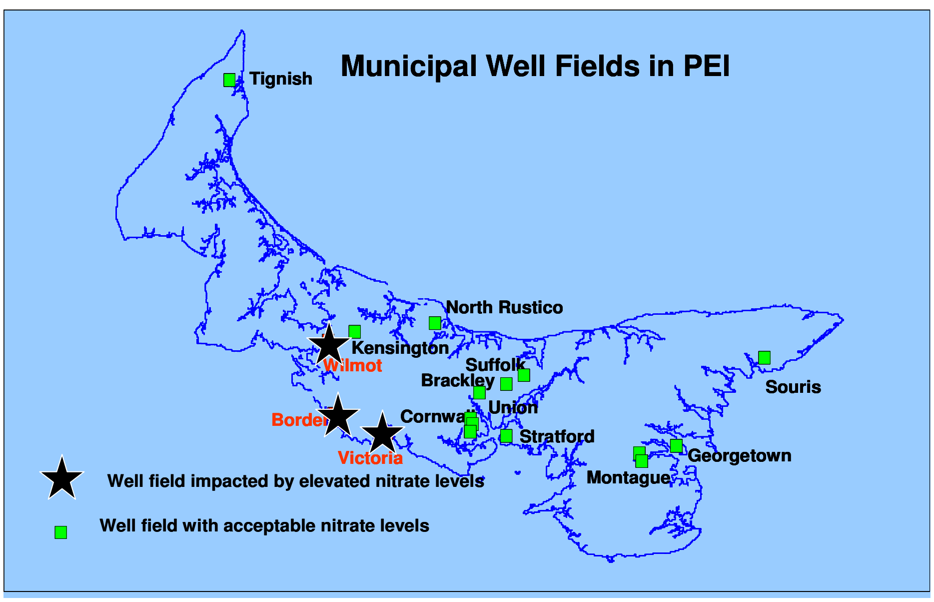

Figure 4. Municipal water supply utilities in PEI, with well fields impacted by elevated nitrate levels indicated by stars.

The fact that to date, water treatment has not been employed may be in part due to the lack of experience in water treatment technologies and the absence of existing water treatment plants that can be modified or upgraded to accommodate treatment, and concerns over additional costs that could be associated with constructing water treatment facilities, complete with storage reservoirs, auxiliary pumping equipment etc.

However, the availability of affordable, alternate sources of water cannot always be guaranteed, and indeed, the small Village of Victoria is now investigating water treatment for nitrate removal. The community owns a small water utility servicing fewer than 80 customers with peak flows in the range of $400m^3$/day. The system was originally supplied by 2 wells constructed in 1987, both 75m deep, and with 12m casing. At the time of commissioning, nitrate levels in the two wells were 3.9 and 4.2mg/ L, respectively. By 2002 nitrate levels in each well had climbed to concentrations of slightly over 10mg/L, and were replaced with new wells cased and grouted to depths of 30 and 36m at an estimated cost of $20,000. By late 2007, nitrate levels climbed to 8 and 13.3mg/L in the two replacement wells respectively. Given the existing land use in the area, there is no information to suggest a new well field location with potentially lower nitrate levels, and clearly, deeper casing may hold only temporary relief. In consequence, the community is now investigating water treatment by ion exchange devices. While design criteria have not been finalized, capital costs are expected to be around $50,000. If these capital costs, as well as expected annual operating costs, were fully recovered, they could represent a water rate increase of about 30% over current rates in the community.

The foregoing example is for a very small system, not typical of most municipal water supplies in the Province. It is therefore perhaps instructive to examine the approximate magnitude of costs that might be incurred to treat water for nitrate removal for more typical municipal systems. In the absence of local examples to draw from, general information was gathered from industry and government officials in other jurisdictions with the intent of deriving a rough estimate of treatment costs for a small utility (peak flow of $1000m^3$/day and a single well field, or moderately sized utility ($4500m^3$/day).

In both cases it was assumed that ion exchange would be the most cost effective treatment technology, and because most systems on PEI have limited storage capacity, it is further assumed that treatment plant size would be based on peak flows, rather than average daily flows. It was also assumed that there would be additional costs associated with building construction, plumbing and electrical work for the installation of nitrate treatment capability. With these assumptions, capital costs for a treatment plant with a capacity of $1000m^3$/day are estimated to be in the vicinity of $150,000. For a larger plant suitable for an intermediate sized utility, or a single well field for a larger supplier, capital costs might be expected to range anywhere from $500,000 to $1,500,000 depending on the specific nature of the system infrastructure (D. French, Kinetico Canada Inc., pers. comm. 2006; F. Lemieux, Health Canada, pers. comm. 2006). While these estimates show a very broad range of costs, it is important to recognize that actual costs will depend very heavily on the individual characteristics of the utility, and as such serve only as order of magnitude estimates. To put such costs in perspective the Charlottetown Water and Sewer Utility recently undertook a major well replacement program at two of their older well fields each with a capacity in the range of 4500 m^3/day. Costs for well construction and associated engineering for 5 wells totaled about $1.25 million (Walker, 2005, pers. comm.). Thus the costs of treating water for nitrate removal would be in the same general range as the costs of developing the source of supply in the first place, and the need for water treatment would essentially double the cost of securing water for distribution to the serviced area.

2.3 Impact of future nitrate contamination

Water supply infrastructure and to a large extent water management decisions in the Province, have evolved under existing climatic conditions, water demand scenarios and general design considerations, and in general, little consideration has been given to the potential water supply conditions associated with climate change. Recently Vigneault *et al* (2007) described potential increases in average nitrate concentrations in the Province over the next 4 decades. Under existing land-use practices with no consideration of climate change it is suggested that average GW nitrate levels in the Province will increase by 11%. When this effect is combined with the effects of climate change, including possible adaptations the agricultural community might adopt as a result of a warmer and longer growing season, GW nitrate levels are projected to increase by a full 32% (see also Savard *et al.*, this volume).

While from a scientific perspective, average nitrate concentrations in an aquifer are certainly of interest, from a public health perspective, it is the percentage of wells with nitrate levels exceeding the drinking water guideline, that is the chief concern. Using predicted changes in average GW nitrate concentrations described above, and the observed statistical distribution of nitrate levels, it is possible to provide some insight into the corresponding percentage of wells that can be expected to exceed drinking water guidelines under each of these scenarios. Figure 5 summarizes the results of such an evaluation, and shows that even without the effects of climate change, under current land use the percentage of wells expected to exceed the drinking water threshold of 10 mg/L NO_3-N will increase by 20%.

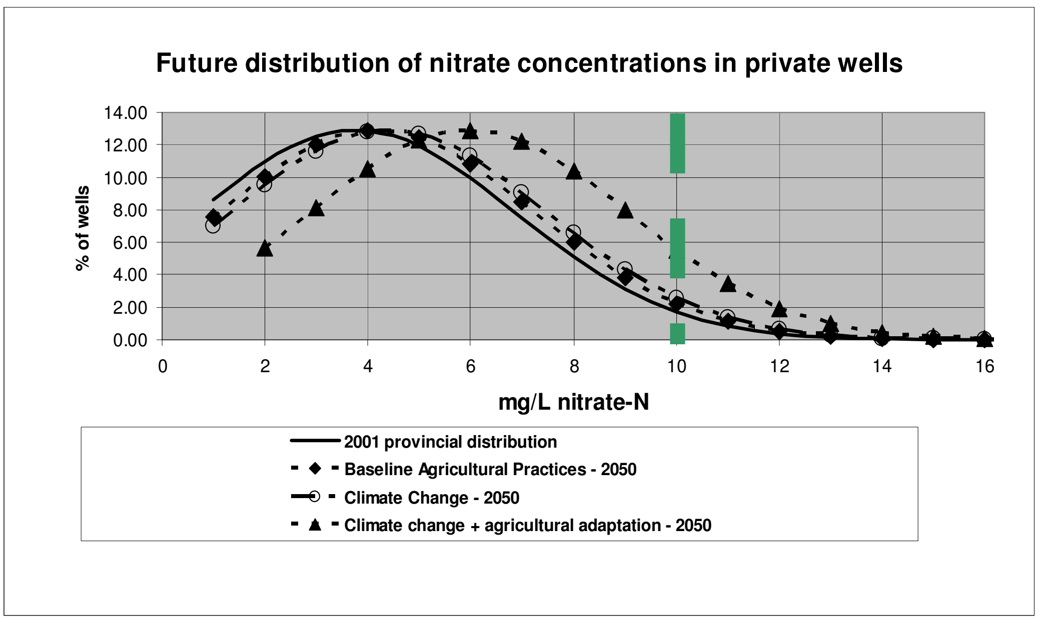

Figure 5. Projected distribution of nitrate concentrations in private wells with and without the effects of climate change, and projected adaptation of agriculture practices to climate change in 2050.

When the impact of climate change, including the effects of how the agricultural sector is expected to adapt to it are considered, the proportion of wells expected to exceed 10 mg/L NO3-N increases by approximately 70%. This assessment is based on a simple examination of the statistical distribution of nitrate contamination in private wells and cannot be applied in any useful manner to the comparatively small number of municipal water supplies.

A further, but still more intangible element to be considered is the cost associated with well field protection measures intended to preserve source water quality, including a reduction of nitrate losses from agricultural lands in sensitive water supply areas. Here the economic burden is not up-front capital costs borne by a water supply utility, but on-going opportunity costs associated with alteration to existing land use practices. At this point, it is not possible either to judge the effectiveness of these measures, or to quantify the financial burden of these measures.

3 Discussion

We have described the general characteristics of water supply infrastructure in PEI, including source water characteristics with respect to nitrate, typical well and water system characteristics and the current impact of GW nitrate contamination on water users. In addition, we have discussed, in general terms, the potential impacts of future increasing nitrate levels, associated both with current land-use practices and with the possible impacts of climate change factored in. It is suggested that while the focus of much work has been on average GW nitrate concentrations, the percentage of wells exceeding the guideline for nitrate is a more important metric from both public health and economic perspectives. Furthermore, it is noted that because in these cases we are dealing with nitrate levels on the upper tail of the overall distribution of values, even a small change in average nitrate levels in a watershed can have quite a significant influence on the proportion of wells adversely effected and the corresponding financial impacts.

To date, the majority of costs associated with increased nitrate levels in GW have fallen principally on private well owners, and with the prospect of increased nitrate concentrations either as the result of current land use practices or more importantly as a result of adaptation to climate change, the economic impact on private well owners could be substantial. It is more difficult to speculate on the extent of future economic impacts for municipal utilities, and it is unrealistic to assume all water utilities are equally vulnerable to nitrate contamination. Thus any global estimates of economic impacts associated with a need for water treatment (nitrate removal) are unlikely to be realistic. Nonetheless, as average GW nitrate levels increase, so too does the probability that a larger number of municipal wells will be impacted, incurring, at the very least, costs associated with the exploration and development of progressively more scarce un-impacted GW sources. Failing this the prospect of establishing treatment facilities for nitrate removal could potentially double the cost of producing water for distribution. Finally, municipal utilities are potentially incurring real costs now, through the management of well-field protection measures designed among other things to reduce vulnerability of supplies to nitrate from agricultural activities. As noted earlier, it is impossible at this point to predict whether the current measures of conventional nutrient management practices on these lands will be sufficient to assure continued water quality, or if more stringent measures will be required.

Looking at the current economic impacts of GW nitrate contamination, as well as the potential effects associated with climate change, it is clear that immediate and substantial actions are required if the full impacts described above are to be avoided. While many sources of GW nitrate can be identified, given the dominant influence that agricultural activities have on current and future GW nitrate levels, adaptation of agricultural practices, particularly with respect to intensive row crop production, will need to be at the heart of these efforts.

4 Conclusions

Prince Edward Island's access to potable water depends entirely on the integrity of GW contained in a highly productive but vulnerable system of aquifers. With the Province's small land base and high population density, there are significant challenges in balancing the often competing needs for a financially healthy and productive agricultural sector on the one hand, and secure sources of GW on the other hand. Water supply infrastructures have been developed based on historical conditions of water availability and quality. The effects of progressive degradation of GW quality, in this case with respect to nitrate content, are already manifested in the proportion of private wells impacted by elevated nitrate levels and the associated economic burden placed on individual homeowners. In more recent years some municipal water sources have been impacted as well, and while to date, this has not generally resulted in widespread economic consequences, alternative sources of un-impacted GW will only become more scarce with time, and substantial investments in water treatment could be required, potentially doubling the cost of securing potable water for distribution.

More concerning is the fact that nitrate levels in many regions of the Province are likely to increase simply as a result of existing land use practices. When the potential impacts of climate change are considered as well, there is the probability of much greater financial hardship for water users of the Province in the future. All these factors underline the urgency of acting quickly and decisively to limit the further degradation of GW quality, and thereby reduce the associated economic consequences to the greatest extent possible. It is perhaps worth noting that while we have no direct control over the impact of CC on GW nitrate levels, we do have the opportunity to intervene with respect to how the agricultural sector responds to CC, and it is this component that represents the greatest potential impact on GW nitrate levels (Vigneault *et a.l*, 2007; Savard *et al.*, this volume) Fortunately the gravity of the situation has been gaining public attention, and there is now a general recognition of the need for change. Toward this end, the Province established a "Commission on Nitrates in Groundwater" with a mandate to report to the Premier of the Province on with recommendations for a strategy to reduce nitrate concentrations in groundwater and surface water. The success of these efforts will play a critical role in assuring continued access of safe drinking water of the Province's water users at an affordable cost.

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