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ABSTRACT

This paper analyses the costs and benefits of controlling groundwater pollution from nitrogen fertilizer. The Village of Hensall, where nitrate concentrations have been observed above 10 mg/l in recent years, was selected as the study site. The CREAMS simulation model was used to estimate the effect of reducing nitrogen fertilizer on nitrate leaching and consequently on nitrate groundwater pollution. Estimates of the value of groundwater were obtained from the literature and used to calculate the off-farm cost of groundwater contamination. This procedure resulted in a wide range of values for the benefits of reducing nitrate pollution. Estimated annual benefits of improved groundwater quality ranged from less than $1000.00 to more than $30,000.00 for the village. The off-farm benefits of nitrate groundwater pollution abatement outweigh the cost of using bottled water and in this case the on-farm cost of reducing nitrogen fertilizer. Placing a tax on nitrogen fertilizer would reduce the level of nitrogen applications, but the farm cost of compliance to a nitrogen tax policy is substantially higher than the compliance cost under a regulatory policy.

INTRODUCTION

Groundwater pollution has been identified as an important environmental issue in Canada (Neufeld, 1987). In 1981, 6.2 million Canadians, or 25 percent of the population, used groundwater as their major water supply. In Ontario, approximately two million people, or 23 percent of the population, use groundwater (Conservation Council, 1987). Evidence of nitrate groundwater pollution above 10 mg/l nitrate nitrogen[1] continues to mount (Gillham, 1978; Gillham, 1988; Agriculture Canada, 1992). A recent study (Agriculture Canada, 1992) sampled approximately 1,300 domestic farm wells in Ontario for agricultural groundwater pollution. The study found that 13% of all wells tested had nitrate-N concentrations above the provincial drinking water standard.

Nitrogen fertilizer used in agriculture has been linked to groundwater pollution (U.S.D.A., 1987). Nitrogen found in groundwater originates from many sources but agriculture is considered to be a major source (U.S.D.A., 1987; Conservation Council, 1987). The main adverse effect of nitrate groundwater pollution are its consequences for human health. High concentrations of nitrate in drinking water can cause methaemoglobinaemia and form carcinogenic N-nitroso compounds (Fraser and Chilvers, 1981).

The level of nitrate concentration in groundwater is influenced by factors such as climate, soil, land use and agricultural practices. Computer simulation models can take into account these factors and estimate the rate of nitrate leaching. The CREAMS[2] model is used in this study to simulate the impact of changing farm nitrogen applications on the rate of nitrate leaching and consequently on the concentration of nitrate in groundwater. Published estimates of the value of groundwater and

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1 Nitrate polluted drinking water at concentrations above 10 mg/l nitrate nitrogen are considered to represent a health hazard to children (Health and Welfare Canada, 1989; U.S. Environmental Protection Agency, 1986).

2 The CREAMS (Chemical, Run-off, and Erosion from Agricultural Management Systems) model was developed by the USDA to simulate the effect of different agricultural management practices on water pollution.

human health risks from exposure to nitrate in drinking water are used to calculate the off-farm cost of nitrate groundwater pollution. We also compare farmers' compliance costs under a nitrogen tax to a simple regulatory policy.

THE HENSALL CASE STUDY

The Village of Hensall is located 65 kilometres north of the City of London in southwestern Ontario (Figure 1). It was selected as a case study because of its well documented nitrate pollution problem. The necessary data to run the CREAMS model and to perform a cost-benefit analysis is available from previous studies. Hensall's pollution problem has been documented by the Ministry of the Environment (1983) and Gartner Lee Limited (1988). The King Street well, which was the main groundwater source until 1982, exhibited levels of nitrate pollution above 10 mg/l nitrate nitrogen (Figure 2). Corn prices increased up to 1983 and then declined (Ontario Ministry of Agriculture and Food, 1989). This may account for the initial increase in nitrate concentration in the King Street well and the decline after 1983. After 1982, the York Street well became the main water source and King Street well was used as a secondary source. The York Street well has also started to exhibit higher levels of nitrate pollution (Figure 2). As a further precaution the Public Utilities Commission drilled a deeper well in 1984 and also informed consumers of the high levels of nitrate in their drinking water.

MEASURING THE COSTS OF NITRATE POLLUTION

Three approaches to estimation of the cost of human health risks have been used in the literature. The simplest approach treats the value of a human life as the present value of lifetime average earnings. The second approach uses income differentials among occupations considered to involve different levels of mortality risk. If a wage premium is observed for more risky occupations,

Figure 1. Farms East of the Village of Hensall and Their Level of Nitrogen Application (kg/ha), in 1987 (Gartner Lee Limited, 1988).

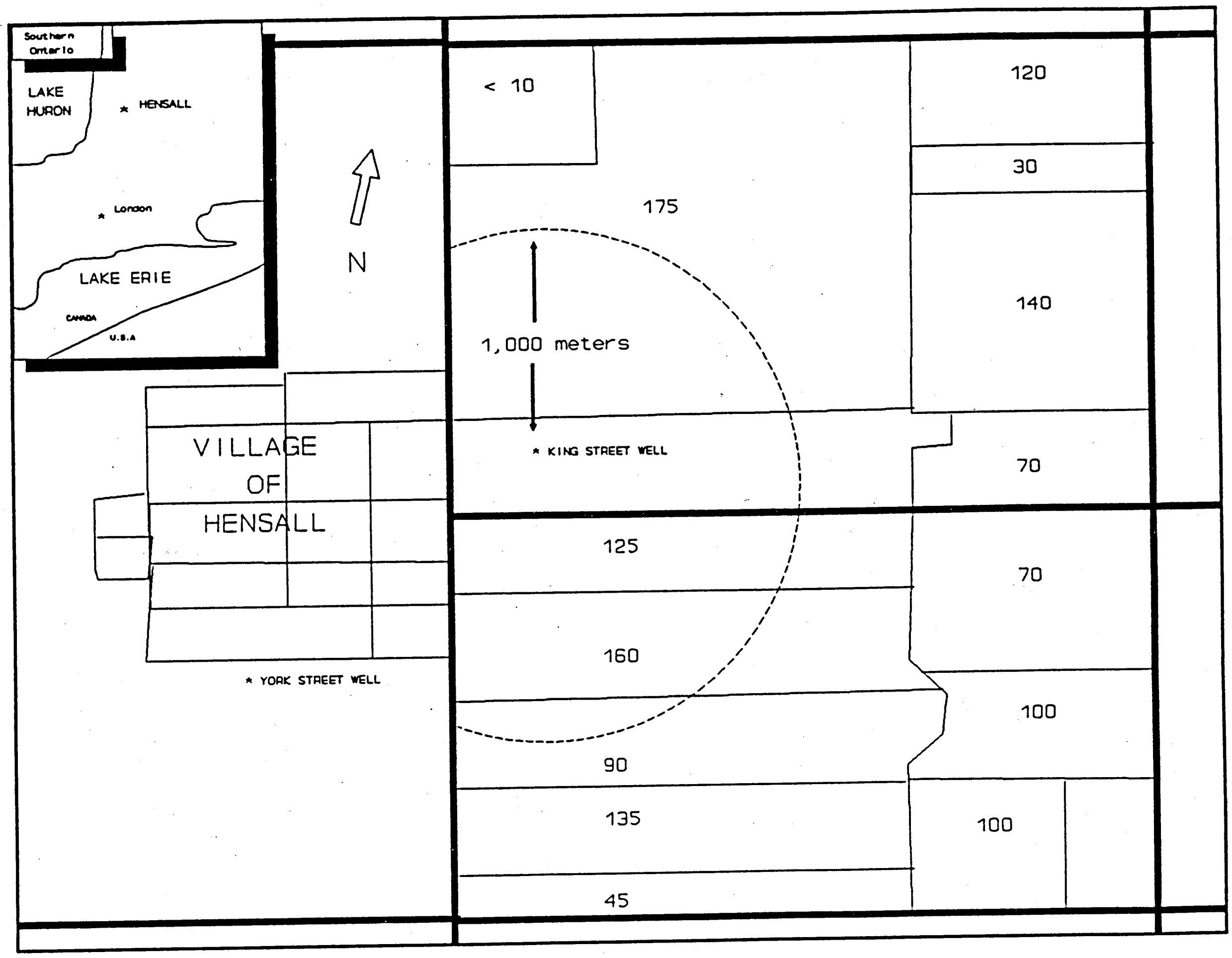
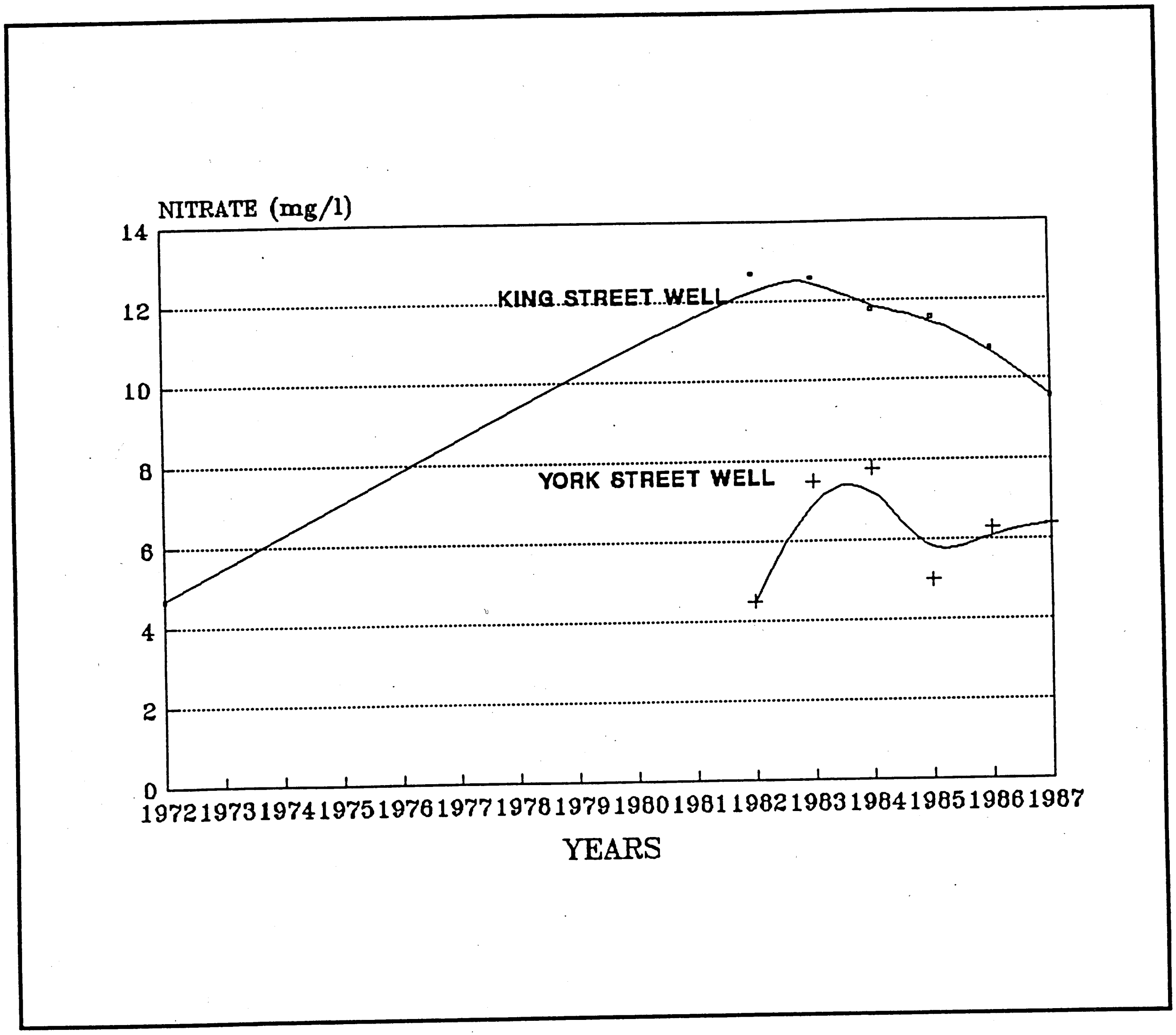


Figure 2. Historical Water Quality Trends in the Hensall Municipality Wells.



Source: Ministry of the Environment, 1983

Gartner Lee Limited, 1988

this value can be used to calculate the value that workers place on incremental changes in mortality risk. This can be extrapolated to an estimate of the value of life. Contingent valuation approaches use questionnaires or interviews to elicit willingness to pay to obtain a stipulated reduction in mortality risk or, alternatively, an improvement in environmental quality. The costs of contamination of groundwater by nitrate were calculated as the product of estimates of the value of a human life and the probability of mortality from consuming drinking water containing nitrate in concentrations in excess of current provincial standards.

The medical literature has not yet determined the exact correlation between nitrate ingestion and the risk of methaemoglobinaemia. Nevertheless, studies such as Super et al. (1981) provide an indication of the possible health risk. In the Super et al. study one infant out of 486 in a village in South Africa suffered methaemoglobinaemia. The infant population had been drinking well water that contained nitrate concentrations of 56 mg/l as nitrogen. The mortality rate for infants with methaemoglobinaemia has been 8% worldwide. If any deaths occurred in the Village of Hensall it would be a result of negligence since the symptoms of methaemoglobinaemia are easily recognizable by a physician, the treatment is simple and consumers in Hensall are aware of the pollution problem. However, assuming a mortality rate of 8% and a risk of 1/486 of contracting the illness, the risk of death for infants from exposure to nitrate polluted water in the range of 10 to 20 mg/l, would not exceed 0.08 deaths out of 486 or 16.5 deaths out of 100,000. This estimate of the risk of mortality is likely high for North America since no deaths due to methaemoglobinaemia have been reported since 1949 (Agriculture Canada, 1992). This risk level would give a worst case scenario. The population of the Village of Hensall was 1,155 in 1986 (Canadian Almanac and Directory, 1991). There were 14.6 live births per 1,000 population in Ontario in that year so one would expect around 17 births per year in the Village of Hensall. This estimate of mortality risk is used in conjunction with calculations of the present value of lifetime earnings to estimate annual health costs for the

Table 1: Lifetime Earnings Calculations and Estimated Annual Mortality Costs*

Annual Income	Discount Rate 2% Present Value	2% Mortality Costs	5% Present Value	5% Mortality Costs	10% Present Value	10% Mortality Costs
$25,000.00	$747,308.00	$2096.00	$447,001.00	$1254.00	$246,882.00	$693.00
$50,000.00	$1,494,616.00	$4192.00	$894,003.00	$2508.00	$493,764.00	$1385.00
$75,000.00	$2,241,924.00	$6289.00	$1,341,005.00	$3762.00	$740,646.00	$2078.00

* Present value calculated at birth for the assumed annual income earned from age 20 to age 65, inclusive, cost of health risk calculated as $17 \times \frac{16.5}{100,000} \times$ Present Value.

Hensall situation (Table 1). Depending on the discount rate and annual income assumed, the costs of nitrate contamination of groundwater obtained using this approach range from $693.00 to $6289.00 per year.

Wage risk studies examine willingness to accept compensation for exposure to risk associated with an occupation. It derives values from actual rather than proposed or expected behaviour and is therefore a market based approach. A summary of estimates of the value of life obtained from occupational risk studies is presented by OECD (1989). The estimated value of life ranged from $260,000 to $11 million, with a mean of $3 million. Using this mean value of $3 million, then the health costs of nitrate water pollution above 10 mg/l in the Village of Hensall will be $8,415[3] per year. The annual health costs would be $729.00 and $30,855.00 respectively for estimates of the value of a life of $260,000 and $11 million.

Using a Contingent Valuation approach, Hanley (1989) concluded that individuals in the United Kingdom were willing to pay £12.97 ($25.92 Cdn) per person, per year, for a guarantee that water supplies meet nitrate standards. For the 1,155 individuals in the Village of Hensall that would total approximately Cdn $29,938 per year. The estimated cost of nitrate pollution tends to be higher using the contingent valuation approach than it is with the other two approaches. This may be the result of several factors. First, individuals perception of the risk from nitrate pollution may be higher than the value obtained from epidemiological studies. In contingent valuation, it is the level perceived by individuals that matters. Second, individuals willingness to pay for a reduction in risk from nitrate pollution may be higher than what people are normally willing to pay for the same reduction in risk caused by another factor such as a car accident. This may be a result of a distinction between so-called voluntary and involuntary risks. Third, the uncertainty surrounding the health effects of nitrate pollution may cause individuals to be concerned about their own health, not just that

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3 (17x16.5/100,000)x$3 million

of their children.

Apart from the health value of an aquifer, economists have estimated bequest values[4] and option values.[5] Edwards (1988) reported that individuals households in Cape Cod, Massachusetts, would be willing to pay $1,623 annually to protect an aquifer from uncertain future nitrate contamination. This study attempted to only measure option value and bequest value. In Ontario, the average number of persons per household is 2.8 (Statistics Canada, 1987). Consequently based on Edwards (1988) study, the bequest and option value of nitrate safe groundwater would total around $669,487.49[6] per year in the Village of Hensall.

The large discrepancy between health value and bequest and option values brings into doubt the validity of Edward's results. The main concern of nitrate groundwater pollution is its health effect and if individuals are only willing to pay $25.92 per year to reduce the present risk of nitrate ingestion, it is questionable that they would be willing to pay $579.64 per year to preserve an aquifer safe from nitrate pollution for future use and future generations. The high cost of nitrate pollution calculated in Edwards' study may be a result of several factors. First, there may have been double counting if individuals included their health costs with the bequest and option value. It may be very difficult for an individual to separate the bequest and option value from the health cost in a contingent valuation study. Second, this issue was discussed widely by the news media at the time of the survey and created the impression that nitrate pollution is of greater risk than it really is. Third, Edwards' study may have any one or several of the problems facing the contingent valuation studies, such as strategic biases, design bias and operational bias.

In summary, based on Hanley (1989) and Edwards (1988), the total annual cost of nitrate

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4 Individuals desire to preserve the aquifer for the benefits of future generations.

5 The desire to preserve the option of a clean aquifer for future use.

6 [$1,623*(1,155 individuals in the Village of Hensall/1.8 individuals per household)]

groundwater pollution above 10 mg/l in the Village of Hensall would be between $30,000 and $700,000 per year depending on whether bequest and option costs are included. Based on the lifetime earnings and wage-risk approaches, the annual costs ranged from $693.00 to $30,855.00.

These results create a quandary for the cost-benefit analyst. Depending on the technique employed, estimates of the cost of groundwater contamination can vary by a factor of 100. As we indicated above, we believe that there are reasons to question the values of life derived from the Contingent Valuation approach.[7] Similarly, the $260,000.00 value reported in one of the studies in the OECD survey seems low relative to the present value of lifetime earnings in Table 1. For a real discount rate of 5% and an estimated annual income of $50,000.00, the health costs reported in Table 1 amount to $2508.00. The mean values of health costs based on the OECD survey of wage-risk studies would be $8415.00 annually. We will use these values in our comparison of the costs and benefits of abatement.

ENVIRONMENTAL ANALYSIS

The CREAMS model (version 1.8) was used to predict the impact of changes in agricultural practices. The CREAMS model was chosen for the following reasons. First, CREAMS was specifically developed to analyze the effect of changes in agricultural production practices on chemical pollutants such as nitrogen. Second, CREAMS has been widely used in similar studies. Third, CREAMS is well supported. Environmental simulation models, such as CREAMS, are able to better predict relative changes in pollution levels than absolute values (Barfield et al., 1989). For this study, however, absolute pollution levels are already known. Therefore the main concern of this study is in predicting the relative effect that changes in agricultural practices will have on nitrate pollution

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7 See Fox (1992) and Cambridge Economics Inc. (1992) for a more in-depth assessment of Contingent Valuation.

levels.

Modelling

CREAMS was used to estimate the level of nitrogen in the surface run-off and the level of nitrate leached out of the rootzone. Based on interviews with Dr. Rudra and Dr. Dickinson[8], it was assumed that changes in nitrate leaching affect groundwater quality proportionally. For example, a 10% reduction in nitrate leaching will result in approximately a 10% reduction in nitrate groundwater pollution. Since the pollution levels in the King Street well were between 10-12 mg/l nitrate nitrogen, approximately a 16.67%[9] reduction in nitrate leaching is needed to reduce the pollution to a safe level of 10 mg/l nitrate nitrogen. The CREAMS model was used to identify agricultural practices that would result in a 16.67% reduction in nitrate leaching. Corn was assumed to be the only crop grown in the study site. Approximately 90% of the acreage within a 1,000 meter cone around the King Street well were planted to corn in 1987.

It was concluded that the major source of nitrate in the King Street well was unused residual nitrogenous fertilizer leaching from the soil (Ministry of the Environment, 1983; Gartner Lee Limited, 1988). Natural nitrate concentration in groundwater is commonly around 1.0 mg/l (Ministry of the Environment, 1983). Other sources of pollution, such as fertilizer and manure storage, feedlot run-off and septic tanks, were examined and not considered a major hazard to the groundwater in this area (Ministry of the Environment, 1983). Furthermore most of the households have sewer connections to the sewage treatment plant and would not be considered a threat.

Based on the field data and calculations, the Ministry of the Environment (1983) found that

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[8] R.P. Rudra, Associate Professor; W.T. Dickinson, Professor, School of Engineering, University of Guelph, Guelph, Ontario, Canada.

[9] ((12 mg/1-10 mg/1) (12 mg/1)*100