An Assessment of the Impact of Charging for Provincial Water Use Permits

STEVEN RENZETTI AND DIANE DUPONT
Department of Economics, Brock University
St. Catharines, Ontario

La croissance de la population et des revenus de même que le réchauffement de la planète contribuent à la préoccupation grandissante au sujet de la disponibilité des réserves d'eau potable au Canada. Alors que certaines provinces ont déjà introduit des frais pour les permis nécessaires au retrait direct de l'eau, d'autres distribuent ces permis gratuitement. L'article évalue les effets probables de l'introduction d'un prix pour les permis d'eau basé sur la quantité d'eau utilisée et les coûts de production des principaux secteurs consommateurs d'eau en Ontario. Ces effets sont mesurés à l'aide d'une analyse numérique basée sur des modèles économétriques de l'utilisation de l'eau. L'analyse indique qu'en imposant des frais pour les permis de retrait de l'eau le gouvernement peut encourager la conservation de l'eau et générer de nouveaux revenus tout en augmentant très peu les coûts de l'industrie.

Population and income growth and global warming have contributed to a growing concern regarding the availability of potable water supplies in Canada. While a number of provinces have already introduced fees for the permits required for direct water withdrawals, others give these permits away *gratis*. The paper assesses the likely impacts of introducing a charge for water permits upon the water use and production costs of the major water-using sectors in Ontario. These impacts are quantified by using a numerical analysis based upon econometric models of water use. The analysis indicates that by charging for water withdrawal permits the government can encourage water conservation and bring in new revenues, while doing relatively little to raise the industry's costs.

INTRODUCTION

The regulation of fresh water use is primarily a provincial responsibility under the Canadian constitution (Percy 1988). Almost all provinces require major water-users such as thermal electric generating facilities, municipal water utilities, mines, and manufacturing plants to obtain a licence or permit before they may withdraw water from the natural environment. In addition, a number of provinces require that a fee be paid for this licence or permit. Despite the fact that a number of provinces levy charges for the permits needed to withdraw water, there has been no systematic analysis of the various impacts of these charges upon water-users. As a result, it is not known whether these charges encourage water conservation and/or raise water-users' costs.

In order to consider these issues, this paper examines the potential impacts of a two-part charge for water permits in Ontario. Under current regulations, these permits are available free of charge to individuals and corporations that directly withdraw water from streams, rivers, lakes and groundwater sources (Ontario: Ministry of Environment 1990). In our study, the first part of the two-part charge is an annual permit fee, while the second part is a volumetric charge based on the quantity of water withdrawn. The merits of introducing a charge for a water permit (which we will subsequently call a Provincial Water Use Charge, or PWC) are its potential to improve the efficiency of water allocation, to improve water quality, to increase government revenues, and to improve the government's knowledge base regarding water use. The major possible drawback of the charge is its potential to raise water-users' costs.

In order to assess the impact of a PWC upon water use, firms' costs of operation, and government revenues a numerical simulation analysis is conducted with data collected from the province of Ontario in 1991.[1] Results demonstrate that the introduction of the PWC for the right to withdraw water will encourage water conservation and bring in new revenues to the government while having relatively small impacts on water-users' production costs. In our sensitivity analysis we use a range of values for a PWC. For example, the volumetric charge ranges from \$0.000 to \$0.005/m^3 on water intake, while the annual fee for each water user ranges from \$0 to \$2,500. As a result of these charges, the predicted decreases in non-hydroelectric water intake range between 1.21 percent and 8.27 percent.[2] Depending upon the particular combination of charges used, the introduction of a PWC would also lead to one-time increases in water-users' costs ranging between 0.01 percent and 0.22 percent and a net increase in government revenues of between \$15.6 and \$126.2 million.[3]

The next section provides information on current and forecasted water use in Ontario and the regulatory framework governing water use in that province. The third section examines the potential impacts of introducing a charge for water permits, while the fourth section describes the numerical simulations that are used to assess the impacts of such a charge. The fifth section presents the principal findings of the simulations, and the final section provides conclusions. The Appendix contains a detailed description of the simulation methodology.

Background

The province of Ontario is blessed with an apparent abundance of freshwater. Indeed, there was a time when these supplies were thought to be without limit. That perception, and the policies and regulations that followed from it, influenced the types of technologies that were adopted in industrial facilities, the ways in which cities were developed and the means by which human waste, industrial by-products and other residuals from modern society were disposed. The assumption of limitless freshwater supplies is no longer valid. The combination of population growth, rising incomes, urban development, global warming, and environmental pollution implies that the gap between reliable supplies of potable water and demands for freshwater is shrinking. On the supply side, the potential impact of global climate change on the Great Lakes basin is particularly worrisome. According to a recent report (Farid, Jackson and Clark 1997) which summarizes the available studies on this topic:

> Great Lakes' water levels will decrease due to increased evapotranspiration because of higher temperatures and decreased runoff. Runoff to the Great Lakes will decrease by 23 to 51 percent. Overall the Great Lakes will drop by a half metre to one metre (ibid., p. 74).

Furthermore, a recent Environment Canada report concludes that, "the average level of the Great Lakes could decline to record lows by the latter part of the 21st century" (Canada. Environment Canada 1997).

On the demand side, there is evidence of rapidly growing withdrawals in the Great Lakes basin. The Great Lakes Commission estimated that water withdrawals in the Great Lakes basin were 30,798 million cubic metres in 1992 (Vandierendonck 1995, Table 23). [4] This level of water use represents an increase of 50 percent over the level of withdrawals recorded in 1981 (Pearse Bertrand and MacLaren, 1985, Table 4.6).[5] These figures regarding rates of change of water use do not indicate how the level of demand for freshwater compares to the reliable supply in the Great Lakes basin. The Royal Commission on Federal Water Policy estimated that reliable annual flows of surface water into the Great Lakes were 75,780 million m^3/year. If it is assumed that, first, Farid, Jackson and Clark's (1997) forecast regarding the decrease in reliable inflows is accurate and second, that growth rates in water withdrawals continue at the pace set during the 1980s, then water withdrawals in the Great Lakes basin will equal reliable inflows early in the next century. As one reviewer notes, the bulk of these withdrawals remain in the Great Lakes basin, and once the water is returned to the environment, it becomes available for subsequent use. At each round of use, however, it can be expected that some proportion of water is lost to the Great Lakes basin — what is referred to as "water consumption" — due to evaporation or incorporation into final products. This possibility means that there is a pressing need to examine the regulations and practices governing water withdrawals in order to determine whether they promote sustainable and efficient water use.

It might be argued that Ontario still possesses abundant supplies of freshwater and a province-wide charge for water permits would induce firms to substitute costly labour and capital in order to conserve on a resource whose opportunity cost is effectively zero. This position can be addressed in several ways. First, there are already numerous instances of conflicts over water resources in the southern parts of the Great Lakes basin. Most frequently, these have occurred in areas such as the Grand River basin or the area surrounding Metropolitan Toronto where urban growth has come into conflict with rural and agricultural demands for water supplies. Indeed, it was observed 25 years ago that, "in the more developed parts of the province, water supplies are neither costless to acquire, nor can they be had without effect on other uses" (Campbell *et al.* 1974, p. 500). Thus, there is an opportunity cost to water use in much of southern Ontario.

Second, it must be recognized that the decisions being made today regarding the design of, and amount of water, to be used in manufacturing facilities, electrical power plants, and municipal water-supply systems will determine water use for decades to come.[6] These investment decisions may not consider the possibility of growing future water scarcity because there are currently few, if any, signals of impending scarcity. The problem for policy-makers, then, is to weigh the net benefits of a PWC introduced today against the net benefits of retrofitting and redesigning water-using capital stocks some time in the near future. Finally, if it is believed that the opportunity costs of water use differ by region, the PWC can be designed to reflect differing regional supply-demand balances. For example, one simulation done in this paper examines the impact of a PWC that is designed to have a positive volumetric charge only in the southern Great Lakes basin (where water conflicts are more common) and a volumetric charge of zero for the rest of the province.

Regulatory Framework in Ontario

Any major direct withdrawal of surface water or groundwater in Ontario may be made only after the provincial government has granted a permit to allow that withdrawal. Direct water withdrawals occur for a number of reasons. For example, firms and farms withdraw water in order to apply it in some production process; water utilities withdraw water for the purpose of delivering it to households, institutions, and firms connected to the system; and Ontario Hydro facilities (thermal and hydroelectric) withdraw water in order to produce electricity. It should be noted that many firms, mining operations, and farms rely on both self-supplied water and publicly supplied water. Table 1 provides the most recent data available on water withdrawals and the expenditures related to these water withdrawals in Ontario.

The water permit system was established in Ontario in the early 1960s to replace the riparian doctrine[7] that governed water use up until that time. The purpose of the original legislation was "to promote efficient development and beneficial use of surface and groundwater" (*Ontario Water Resources Act*, R.S.O. 1990, section 1). Permits are issued on a first-come, first-serve basis at the discretion of the government with little analysis of the relative benefits associated with the proposed use (Percy 1988). No fee is levied for the application for a permit nor for the use of the water resource itself. Water permits may not be traded after they have been issued. While permits provide water users the opportunity to withdraw a specified quantity of water, conflicts between permit-holders can occur during periods of reduced lake levels or stream flows or falling groundwater levels when not all permitted withdrawals can be met. The *Ontario Water Resources Act* provides significant discretionary power to the administrators of the permit system in determining whether a shortage of water exists and how water withdrawals are to be reduced in the event of a shortage.

TABLE 1
Ontario Water Withdrawals and Expenditures, 1991

Sector	*Water Withdrawals*	*Expenditures*
Manufacturing	9,592	203,546
Ontario Hydro (Thermal)	63,154	9,620
Agriculture (Crop)	293	36,315
Agriculture (Livestock)	168	6,150
Mining	233	41,137
Municipal Water Utilities	4,543	407,542
TOTALS	77,983	704,312

Notes:

1. Water withdrawals are measured in thousands of cubic metres per day.
2. Expenditures represent expenditures on water intake and treatment prior to use and are measured in thousands of 1991 dollars (Renzetti and Dupont 1997).
3. The totals do not include water withdrawals by the hydroelectric division of Ontario Hydro (see endnote 2).

Source: Data are from Tate and Scharf (1995).

The permit system to allocate water resources in Ontario may be criticized on several grounds. First, because no fee is charged for a water permit, the system of regulating water use fails to extract any of the economic rents that are associated with using water.[8] This situation stands in contrast to established policies concerning other natural resources such as timber, fish or aggregates where users must pay a fee to acquire the right to harvest or use the resource. Second, the permit system provides only limited and poorly defined property rights to permit-holders. An important shortcoming in this regard concerns the lack of security of withdrawals during times of conflicts, especially during drought periods.

Finally, the existing permit system does little to ensure the efficient allocation of water resources. In the first place, water rights are not allocated according to the relative net benefits of proposed water use nor are they allocated with a clear understanding of the opportunity cost of the proposed water use. Moreover, if there are changes in the relative values of alternative allocations of water, permits cannot be traded after being issued. According to the Ontario government's own guidelines, the goal of its water quantity management program is not to obtain an efficient allocation of water resources. Rather, the goal is "to ensure the fair sharing of the available supply of water to protect both withdrawal and in-place uses of water" (Ontario Ministry of Environment and Energy 1994).

Assessment of the Provincial Water Use Charge

As indicated in the introduction, a number of provinces (including British Columbia, Manitoba, Saskatchewan, and Nova Scotia) currently have in place a charge or set of charges on direct water withdrawals.[9] Furthermore, the governments of Saskatchewan, Ontario, and Newfoundland have shown a renewed interest in the value and allocation of water resources (Saskatchewan Water Corporation 1998; Watershed Planning Implementation Project Management Committee 1997; ADI Nolan Davis 1996). Unfortunately, there is relatively little analysis of province-wide water-use charges to be found in the literature.[10] The paper by Tate and Rivers (1990) is an exception. In that paper, the authors consider the impact of introducing a province-wide charge on self-supplied water intake. Their analysis, however, does not consider the impacts on electricity prices or on water users' costs.

The introduction of a province-wide water-use charge is anticipated to have a variety of impacts. The first is to effect the efficient allocation of water, since prices play the important role of informing users of the opportunity costs associated with using any productive resource. If users of a resource such as water do not know the opportunity costs of their decisions, then it is not possible to conclude in general that the benefits of their water use exceed the costs. Thus, to the extent that a PWC can be designed to reflect these costs, then users of water will possess more information regarding the consequences of their actions and will be capable of making efficient decisions.

The price of any resource is an influential factor in the decision to use other inputs as well. Thus, the fact that water permits are underpriced (or not priced at all) can be expected to distort not only decisions with respect to water use but also decisions regarding other inputs as well. For example, this type of distortion can extend to decisions related to the desired level of investment and the preferred form of technology. In this way, the impact of the inefficient price of the resource becomes embedded in the stock of industrial capital and in the design of municipal water utility systems (Tate, Renzetti and Shaw 1992; Renzetti 1999).

A second impact of the PWC has to do with distributional issues. By allowing industry, public utilities, and farming operations free access to water resources, a provincial government is undertaking an implicit and poorly understood redistribution of wealth. This is because, by failing to capture some of the economic value created by the application of water in production processes, a government *de facto* allows that value to be directed toward those individuals and groups which have gained access to the use of freshwater resources.[11] This is reinforced by the fact that some water-users return water to the basin in a degraded state, thereby imposing costs upon other users.

It seems reasonable to argue that, as the owner of a scarce and productive natural resource, the Crown is entitled to share in the economic value created by the application of water in industrial processes. This has certainly been the position taken by provincial governments with respect to the use of other natural resources, e.g., forests. As indicated above, a number of other provincial governments already levy some type of charge for direct water withdrawals.

By the same token, it would seem fair to expect users to pay a reasonable fee in order to secure the use of a natural resource that contributes to their profitability. This point is reinforced by the observation that the provincial government provides infrastructure (such as dams and flood protection) and services (such as water quality and hydrologic information) that increase the value of water to users.

A third potential effect of the PWC is its impact upon water quality. By reducing water use, a charge for water permits may also have a beneficial impact on water quality. In many industrial applications of water, the total quantity of pollutants emitted depends on the quantity of water used. For example, in cases where water must be chemically treated prior to it being used in a manufacturing process, lowered water intake would translate into fewer polluting inputs being used and, as a result, fewer pollutants being released into the environment. This need to treat water prior to its use is the case for the production of photographic film, some food and beverage products, and also the provision of potable water by municipal water utilities.

A fourth beneficial aspect of the introduction of a PWC is the potential that it has to contribute to the collection of information about the state of the water resource. A number of authors have criticized: (a) the limited amount of water-use data that is collected by the federal and provincial governments, and (b) that water resource allocation decisions have been made on the basis of incomplete hydrologic knowledge (Brooks and Peters 1988; Vandierendonck 1996; Zachariah 1999). One of the benefits of a water permit system that includes a fee based on the volume of water withdrawn is that permit-holders are required to record and report their water use. This set of data would provide the government with a comprehensive and up-to-date picture of aggregate and regional water withdrawals. This type of information would be particularly valuable for modelling the use of groundwater resources on a watershed basis.

A final beneficial effect of a PWC may be in the area of revenue generation. The current system of permit issuance generates no revenue in Ontario. By way of contrast, the fees from water-use permits earned the British Columbia government $264 million in 1996-97 (British Columbia Ministry of Finance 1998). As the results of the numerical simulations indicate below, the PWC has the potential to generate revenue for the Ontario government that approaches the level of revenues in British Columbia. These revenues could be used to reduce distorting taxes or to support water-related programs (such as wetlands preservation, flood control, and pollution reduction).

The introduction of a charge for water permits does not come without costs. For example, such a charge may increase the costs to water-users. Whether costs increase will depend on a variety of factors, including the ability of users to substitute away from water use, water's share in total costs, and the ability of users to pass on higher costs in the form of either lower wages or higher output prices. However, to the extent that Ontario firms' costs rise and those of their competitors in other provinces or other countries do not, the PWC has the potential to affect adversely the competitiveness of Ontario firms.

The argument that the PWC might adversely affect competitiveness, however, should be interpreted with caution. As is the case in Ontario, most self-supplied water use in Canada is available freely or at very low cost. If water's value to society exceeds the price paid by water-users, then those users are receiving an implicit subsidy. Furthermore, this subsidy provides water-users with an artificial advantage over their competitors in other jurisdictions where charges more closely reflect the value of water. In this light, the introduction of a charge for a water permit would not imply a reduction in competitiveness but rather the removal of an inefficient and distortionary subsidy.

A second type of cost associated with the introduction of the PWC has to do with its administration. There is already a bureaucratic structure within the Ontario government that is responsible for the administration of the water permit system. The introduction of a set of fees for those permits would require an expansion of that administrative structure. Fortin (Ecologistics 1989) considers a similar water-use charge and suggests that the cost of expanding the existing water permit system would be approximately $5-6 million annually. There would also be costs imposed on those water-users who do not currently measure their water.

A final comment regarding the PWC is in order. It can be argued that, in itself, a PWC does not constitute a water conservation strategy. In order to be fully effective, the charge would be complemented with other programs to promote a set of goals which could include water conservation, improved water quality, wetlands preservation, and flood management. These programs would include education, research, improved integration of land-use and water-use regulations, etc.

A separate line of reasoning would argue that if the water permit system were to be reformed, a preferable route would be to make the permits tradeable. This would then allow a permit's price to be determined by market forces rather than by government decree. In theory, a competitive market would ensure that water permits are allocated efficiently and that the price of a permit reflects its value to society (Campbell *et al.* 1974). There are, however, a number of concerns surrounding the implementation of tradeable water permits. First, Canadian governments have little experience implementing and administering markets for tradeable permits. Second, even in jurisdictions such as the United States, where tradeable permits have been implemented to regulate air pollution, recent research indicates that the presence of non-competitive market structures and high transactions costs have led to smaller efficiency gains than were anticipated (Stavins 1997). In addition, Zilberman, Chakravorty and Shah (1997) simulate the transition from a "first-come, first-capture" allocation rule to a tradeable water-rights market and find that this transition may reduce welfare if transactions and information costs are sufficiently high. Finally, the preceding point regarding the importance of having a competitive market in which permits are to be traded is particularly important to the case of Ontario. This is because direct water withdrawals in Ontario are dominated by a small number of very large thermal power generating stations and manufacturing facilities. This indicates that the market for water permits would be non-competitive and that the political process of designing markets may be open to influence from large water-users.

A final conclusion regarding the relative merits of the introduction of a PWC will clearly depend upon a variety of factors. One of these is its impact upon the economy. We turn next to an analysis of the quantifiable impacts upon water use and water-users of the introduction of such a charge in Ontario.

Simulation Analysis

Overview of Methodology

There are two types of impacts associated with the introduction of a charge for water permits. The direct impact results in an increase in the price of direct water withdrawals for self-supplied firms, municipal water utilities, and Ontario Hydro.[12] Two different indirect impacts result. First, assuming that water utilities pass on some portion of the PWC to end users, municipal water-users will face higher prices for publicly supplied water. Second, electricity users (both firms and households) will face higher electricity prices if Ontario Hydro chooses to increase the price of electricity in response to the introduction of the PWC. Thus, the predicted change in water use is a function of the percentage change in input prices that confront each user and the sensitivity of those users to input price changes (see equation A-1 in the Appendix). Having calculated the expected changes in input usage, the simulations then calculate the associated changes in production costs that firms will experience. These cost changes are functions of water and electricity's cost shares and price elasticities, as well as the structure of markets in which firms operate (see equation A-5 in the Appendix).

The simulations adopt a method of analysis that lies between a partial equilibrium model and a general equilibrium model. Given the paucity of detailed data available for describing the role of water in the economy, a general equilibrium model that considers the interactions of all of the economy's markets when assessing the impact of a PWC is not possible. A more detailed description of the methodology is presented in the Appendix.

It is assumed that the charge for a water permit has two parts: an annual fee and a charge based on the annual quantity of water withdrawn from the environment. The annual fee generates revenue to cover administration and program costs. The principle role for the volumetric charge is to encourage water conservation.

The Effect of the PWC upon Water Withdrawals

The introduction of the PWC raises the average cost of self-supplied water intake. It will also raise the operating costs of municipal water utilities and Ontario Hydro and, as a result, will lead to an increase in the price of publicly supplied water intake and an increase in the price of electricity. In all but one of the numerical simulations, electricity users are also assumed to experience an increase in the price of electricity due to the PWC.[13]

In most of the numerical simulations, water-users face a possible total of three price increases: an increase in the price of self-supplied water, an increase in the price of publicly-supplied water, and an increase in the price of electricity. The impact of these various price changes upon self-supplied water intake depends upon a number of factors. These include the responsiveness of both self- and publicly supplied water demands and electricity demands to their own prices and on the relationship between water intake and electricity. These demand elasticities are estimated from observed responses to variations in water intake costs for two-digit SIC manufacturing sectors, the mining industry, Ontario Hydro's thermal generating facilities, municipal water utilities and households.[14] Demand elasticities differ across these sectors due to differences in production technologies, the uses to which water is put, and the ability of firms to recirculate water. Another important factor is the level of water and electricity unit/average costs facing users prior to the introduction of the charge. Different industries have different unit costs of self-supplied water and electricity and, as a result, a given charge level (for example, \$0.001/cubic metre) will imply different percentage increases in unit costs for different industries. (Data and parameter values used in this analysis are available from the authors upon request.)

With the exception of Ontario Hydro and the municipal water utility sectors, it is assumed that the PWC does not lead to changes in the level of output produced. Two reasons support this assumption. First, recent research (Caves 1990) indicates that the principle determinant of output level for most Ontario industries is the price received for output (which is largely determined in world markets), rather than input costs. Second, water expenditures form a very small share of total production costs. Preliminary simulations showed the impact of the PWC on costs (and, hence, output decisions) to be small.

In contrast, it is expected that output levels for Ontario Hydro and the water utilities will fall slightly after they increase their prices. This means that their responses to the PWC will be a combination of a substitution effect (decreased water intake since it is more expensive) and an output effect (decreased water intake because the firms are producing less output).

The Impact of the PWC upon Costs

There are several factors that determine the PWC's impact on users' costs. The first is the sensitivity of the user's water and electricity demands to prices. In general, the larger the price elasticity of demand, the larger will be the reduction in input use and, as a result, the smaller will be the increase in costs. The second factor is the share in total costs accounted for by water and electricity use. As the cost share grows, then a given increase in the input's price will have a greater impact upon the user's total costs. The third factor concerns the structure of output markets for water-users. If water-users exist in a market environment which allows them to pass on some portion of the increase in their input costs (to consumers in the form of higher prices or to input suppliers in the form of lower input prices), then this will reduce the final burden of the PWC-related price increase upon the water-user.

The Impact of the PWC upon Government Revenue

The revenue from the PWC is composed of the annual payment for the water permit and payments that stem from the volume of water withdrawn. In order to calculate the change in government revenues due to the introduction of the PWC, three components must be deducted from this amount. The first relates to the costs of administering the PWC, which are estimated to be approximately $5 million (Ecologistics 1989). The second relates to a decrease in corporate income taxes. This results from firms being able to claim PWC-related payments as deductions against taxable corporate income. [15] The third component to be deducted is the amount of $105 million that is already being paid to the Province of Ontario by Ontario Hydro's hydroelectric division for its use of water. Thus, revenues are defined as the increase in government revenues from the water permit charges once the decrease in corporate income taxes, the administration costs, and the revenues already collected from Ontario Hydro's hydroelectric division have been taken into account.

Simulation Results

For the purposes of this study the following values were chosen. The annual fee ranged from zero to either $300 (for farms) or $2,500 (for firms and utilities).[16] The volumetric charge on self-supplied water intake varied between zero and $0.005 per cubic metre. With respect to the particular values chosen for the charge, there are no data available to indicate the opportunity cost of water use in Ontario and we have not attempted to calculate that value.[17] In the absence of such data we chose values for the volumetric and annual charges that are comparable to charges in use in other provinces.

The results of five simulations are reported here and shown in Table 2. The first four simulations model the impact of the PWC as it is applied to the entire province and allow us to do a sensitivity analysis of water use, firms' costs, and government revenues to different levels of the two components of the PWC. It should be noted that Simulation 2 uses the same values and parameters as Simulation 1. However, Simulation 2 is the only simulation that assumes that Ontario Hydro does not pass on higher water costs in the form of higher electricity prices.

The final simulation considers the implications of a PWC defined to differ across regions of Ontario. This is done to allow the PWC to reflect differing regional supply-demand patterns across the province. Specifically, Simulation 5 reproduces Simulation 1 but sets the volumetric charge in the northern region (essentially all of Ontario outside the Great lakes basin) to zero for all users. Water users in the northern region pay only the annual permit fee. The indirect effects of the PWC are still felt in the north as it is assumed that any change in electricity prices occurs uniformly across the province.

Table 2 summarizes the major results of the simulations. The first column provides the values for the components of the PWC. The second column measures the estimated average percentage change in total self-supplied provincial water intake. The third column indicates the estimated average percentage change in costs for Ontario industry, water utilities, and households. Finally, the fourth column indicates the estimated revenue collected from the PWC.

There are several interesting results in Table 2. The first result is that the province-wide reductions in non-hydroelectric water intake range from 1.2 percent (when only an annual fee is charged) to 8.3 percent (when the volumetric fee is set at its highest level). These responses are smaller than those predicted in Tate and Rivers (1990) because they use higher PWC charge levels and their assumed elasticities of water demand are larger. In addition, they do not take into account any cross-price effects between water and electricity. The second result is that increases in cost range from a high of 0.22 percent (corresponding to the components of the PWC being set at their highest levels) to a low of 0.01

TABLE 2
Simulation Results

Sim.	*Parameter Values*	*% Change Intake Quantity*	*% Change Costs*	*Government Revenue*[e]
1	**t**=0.003[a] **A**=2500/300[b]	- 5.44	0.10	88.42
2	**t**=0.003 **A**=2500/300 **(electricity prices kept constant)**[c]	- 5.18	0.03	88.59
3	**t**=0 **A**=2500/300	- 1.21	0.01	15.56
4	**t**=0.005 **A**=2500/300	- 8.27	0.22	126.23
5	**t**=0.003 (South)[d] **t**=0 (North) **A**=2500/300 (all)	-4.82 South -0.01 North	0.15 South 0.02 North	75.56 South 13.72 North

Notes:
[a] The symbol **t** represents the volumetric charge on water intake (measured in 1991 Canadian dollars per cubic metre).
[b] The symbol **A** represents the annual permit fee (measured in 1991 Canadian dollars).
[c] All simulations other than Simulation 2 allow electricity prices to adjust to the introduction of the PWC.
[d] South refers to the southern portion of Ontario and is defined according to Ontario Ministry of Natural Resources secondary watersheds definitions. North refers to the remainder of the province.
[e] Revenues are in millions of 1991 dollars.

percent (when only an annual fee is used). There are two reasons for the PWC's relatively small impact on costs. The first reason is that most water-using sectors are found to be able to reduce water use to some degree in response to the PWC. The second reason is that water intake tends to account for a very small share of total costs.

The third result is that the revenues that the PWC generates vary significantly across the simulations. Total revenues range from $15 million when only an annual licence fee is charged to $126 million when the components of the PWC are set at their highest values. (In each simulation, the government would also collect $105 million from Ontario Hydro's hydroelectric generation plants as it did prior to the introduction of the PWC.) Thus, gross revenues across the simulations would range between a low of $120.6 million to a high of $231.2. Interestingly, this latter figure is close to the revenue of $264 million collected from water permits by the British Columbia government in 1996-97 (British Columbia Ministry of Finance 1998).

There are also some interesting differences among the simulations. First, by comparing

Simulations 3 and 4, the impact of an increase in the volumetric fee can be observed. The intake-related charge rises from $0.00/m^3 in Simulation 3 to $0.005/m^3 in Simulation 4. The increase in the volumetric charge leads to significantly larger reductions in water use (8.27 percent versus 1.21 percent). It also leads to larger increases in costs (0.22 percent versus 0.01 percent) and higher revenues ($42.23 million versus $20.53 million).

Second, the significance of the assumption regarding whether Ontario Hydro raises its prices in response to the PWC may be examined by comparing Simulations 1 and 2. Simulation 2 indicates that if Ontario Hydro does not pass on its cost increase in the form of higher electricity prices, then there is a smaller degree of water conservation. This arises for two reasons. First, water demands respond only to an increase in the price of water. In addition, Ontario Hydro does not reduce its water use to the same extent since its output has not fallen. There is also a smaller increase in costs for Ontario firms because they only face a single price increase.

Third, the impact of designing the PWC to have only an annual fee can be seen in a comparison of Simulations 1 and 3. In the latter case, only an annual fee is used and the result is very little water conservation, little increase in costs and relatively little revenue generated. The small decrease in water intake is due to the small increase in the price of electricity caused by the annual fee.

Another type of simulation result concerns the impact of a PWC that is set at different levels for different geographic areas of the province. Not surprisingly, a regionally differentiated PWC leads to regionally differentiated impacts as shown in the last row of Table 2. Water-users in the south respond as they do in Simulation 1 — by reducing water intake and experiencing small increases in costs. Water-users in the north experience only small increases in electricity prices. As a result, they demonstrate very small reductions in water intake and experience equally small increases in costs.

The preceding discussion concerns the aggregate impacts of introducing a charge for water permits. However, these results may obscure important differences in the impact of the PWC across sectors of the Ontario economy. In order to demonstrate this, Table 3 reports the sectoral impacts of the PWC using the parameter values of Simulation 1.

It is clear from Table 3 that there are substantial differences in the impact of the PWC across sectors. It is particularly interesting to examine the impact of the PWC on Ontario Hydro, the province's largest user of water. The thermal generating division of Ontario Hydro experiences both the largest drop in water intake and also the largest net increase in costs. These results are largely due to the combined effects of the extremely low unit cost for intake water that Ontario Hydro enjoyed prior to the PWC and the assumption that Ontario Hydro's price elasticity of water intake demand is quite small (-0.01). With respect to the former, Ontario Hydro's thermal generating facilities have an average cost of intake of only $0.0004 per cubic metre compared to an average cost of $0.058 per cubic metre for the manufacturing sector (Tate and Scharf 1995). This difference implies that a given level of the volumetric charge represents a much larger percentage change in average water intake costs for Ontario Hydro's thermal facilities than it does for most manufacturing plants. The thermal-generating division of Ontario Hydro also makes the largest single contribution to total revenues.

The manufacturing and mining sectors also display fairly large reductions in the quantities of water intake, but this leads them to have quite small increases in cost. Finally, the agricultural sector is modeled to be quite insensitive to the unit cost of water intake. As a result, it displays small decreases in the quantity of water withdrawn and has relatively large increases in costs. It also makes quite large contributions to total revenues relative to its size in the Ontario economy. This is primarily because there are a large number of self-supplied farm operators in Ontario and each of these would have to pay the annual permit fee.

TABLE 3
Sectoral Impacts of the PWC under Simulation 1

Sector	*% Change Intake Quantity*	*% Change Costs*	*Government Revenue*[a]
Manufacturing	- 7.04	0.08	10.10
Ontario Hydro (Thermal Generation)	- 10.67	1.50	56.73
Agriculture (Crop)	- 0.27	0.28	7.77
Agriculture (Livestock)	- 1.27	0.39	7.93
Mining	- 10.40	0.08	0.29
Municipal Water Utilities	- 2.30	0.53	5.59

Note: [a] Revenue is measured in millions of 1991 Canadian dollars.

CONCLUSIONS

There is a growing interest in the use of economic instruments to promote the efficient use of natural resources. At the same time, a number of provinces already have in place a system of charges for the permits needed to make use of freshwater resources. Despite the existence of these regulatory frameworks, there has been relatively little analysis of the merits of these charges or of the impacts of these charges on water use and water-users. The purpose of this paper has been to assess this type of charge and to simulate the impact of its introduction in Ontario, one of the provinces that does not currently charge for direct water withdrawals.

The qualitative analysis of the merits and drawbacks of a province-wide water charge highlights the potential for a number of beneficial impacts. These include encouraging efficient water use, improving water quality and providing government with new revenues and improved information regarding water use. Conversely, there are some concerns regarding the potential adverse effects of such a charge. These could include reduced international competitiveness and premature reduction of water withdrawals.

The numerical simulations for Ontario demonstrate that the Provincial Water Use Charge has the potential to encourage water conservation and to bring in new revenues to the government while having small but discernible impacts on production costs. Beyond this general conclusion, a number of more specific conclusions regarding the simulated impacts of the PWC are possible.

First, a PWC will temporarily offset growth in water withdrawals. Direct water withdrawals grew at an approximate annual rate of 4 percent over the period 1981 to 1992 in the Great Lakes basin. However, the simulations show that the maximum reduction in annual non-hydroelectric water intake is 8 percent when the intake charge is $0.005 per cubic metre. If this growth rate persists, then the PWC would offset approximately two years' growth in non-hydroelectric water withdrawals. As long as the population and income continue to grow, there would be the need for the PWC charge to increase over time in order to keep withdrawals in line with reliable inflows.

Second, a PWC defined to include only an annual licence fee will earn a limited amount of revenue for the government and provide little or no incentive to conserve on water withdrawals.

Third, the impact of the PWC depends in part on how Ontario Hydro responds. This is because the thermal generating facilities of Ontario Hydro are the largest users of water in the province and because an increase in Ontario Hydro costs can translate into an increase in electricity prices for all Ontario residents. If Ontario Hydro does not raise its prices in response to the PWC, then firms see only an increase in the price of water. As a result, there is less overall water conservation, a smaller percentage increase in costs for Ontario and slightly higher revenues.

Finally, the exercise of modeling the impact of the PWC upon water-users has demonstrated that there are significant gaps in our knowledge of water use in Canada. The biggest gaps occur predominantly with respect to thermal power and agricultural water-users' responsiveness to change in unit costs of water, and the opportunity cost of the water resources. Before any PWC could be established, it would be necessary to determine the value of water resources and use this information to set the appropriate levels for the volumetric charge and for the annual fee.

Notes

The authors would like to thank Kari Heinrichs and Andrew Gretzinger for providing invaluable research assistance. We would also like to thank the following: John Kinkead, Douglass Legg, Benoît Laplante, Lewis Soroka, and Tony Ward. In addition, we appreciate the comments of the participants of the Canadian Resource and Environmental Economics Study Group, the Canadian Economics Association meetings, and the Northeastern Agricultural and Resource Economists Association meetings. This research is based, in part, upon a project funded by the Ontario Ministry of Natural Resources. All opinions, errors, and omissions remain the sole responsibility of the authors.

[1]This is the most recent year for which there are complete data.

[2]Water use by Ontario Hydro's hydroelectric facilities dominates water use in Ontario. In 1991, recorded water use by these facilities was 1.50 billion cubic metres/day (20 times the total water withdrawals listed in Table 1).

[3]Total (or gross) government revenues from such a charge would include the water fee of $105 million already collected from Ontario Hydro (hydroelectric division), along with the net increase in revenues from firms and other utilities.

[4]The Inquiry on Federal Water Policy commissioned Environment Canada in 1985 to forecast water withdrawals until the year 2011. The "Low Estimate" and "High Estimate" forecasts for annual withdrawals from the Great Lakes basin in the year 2011 were 28,471 and 46,665 million cubic metres, respectively (Pearse, Bertrand and MacLaren 1985, Table 4.6). Based on available data, it appears that annual withdrawals in 1992 have already surpassed the lower estimate for annual withdrawals in 2011. Furthermore, if growth trends continue, the "high estimate" of annual water withdrawals for the year 2011 will be exceeded by the year 2002.

[5]Over the same period, real income per capita in Ontario rose approximately 20 percent and population grew 21 percent (Statistics Canada 1996).

[6]Since the inception of the permit system, it was common practice for the Ontario Ministry of Environment and Energy to issue water permits that contained expiration dates (at which time the permit holder was obliged to reapply to have the permit continue). Recently, however, the ministry began to issue open-ended permits with no expiration date (Ontario Ministry of Agriculture, Food and Rural Affairs, 1998).

[7]Riparian rights allocated the right to use the water to the owner of the land adjacent to the water.

[8]The exception to this last statement concerns a separate royalty paid by hydroelectric generating facilities in

Ontario for their water use. Ontario Hydro's facilities paid approximately $105 million under this royalty in 1991.

[9]Fees can be quite simple, as in the case of Manitoba's one-time payment when the licence is issued, or complicated, as the fee schedules found in British Columbia's regulations. In the latter case, fees depend upon the use to which the water is to be put, the characteristics and location of the agency or firm proposing the water withdrawal, and the quantity of water to be withdrawn (Driscoll and Kruger 1994).

[10]Brooks and Peters (1988) are critical of provinces' failure to make use of water-use fees as a means of encouraging conservation.

[11]In a recent *News Release* entitled, "Do you Need a Permit to take Water?" the province of Ontario indicated that, "The taking of water has not been a major issue for Ontario farmers. However, consider what might happen if water use was in short supply. Having a valid permit might be a highly valued commodity if a shortage should ever arise, since it protects the permit holder by establishing the holder's interest in water in terms of date and quantity" (Ontario Ministry of Agriculture, Food and Rural Affairs 1998).

[12]It is assumed that holders of water permits for very small water withdrawals (such as those needed for rural households or cottages) would be exempted from the charges discussed here. Under the regulations, these users are not required to hold permits for water withdrawals.

[13]Ontario Hydro's hydroelectric generating facilities already pay a rental fee to the Ontario government based on their installed capacity and on their production of electricity. However, Ontario Hydro's thermal power generating stations do not pay for their water intake. Under the introduction of a charge for water permits, it is assumed that the water rental fee paid by Ontario Hydro's hydroelectric division is replaced by a charge on its permits (which generates the equivalent amount of current revenue) and that the thermal electric division begins paying the PWC.

[14]The values pertaining to manufacturing firms water use are taken from Renzetti (1992), while the values pertaining to residential household use are found in Renzetti (1998). Data on municipal and thermal use are found in Renzetti and Dupont (1997). In the case of Agriculture, the data needed to estimate price elasticities are not available. Estimates of price elasticity of intake water demand of 0.0 and –1.5 for livestock and crop operations, respectively, are taken from Ecologistics (1989).

[15]Personal communication with Douglass Legg, Ontario Ministry of Natural Resources, 17 April 1997.

[16]There are a large number of small-scale farm operators who directly withdraw water from nearby lakes and rivers. However, most other water-using sectors are characterized by a small number of large water-users. The annual fee was designed to reflect this difference in the composition of firms across sectors.

[17]Muller (1985) calculated the approximate value of water use in Canada. His estimates imply an average value of one cubic metre withdrawn from a lake or stream to range from $0.039 to $0.315 (in 1991 dollars).

References

ADI Nolan Davis and Gardner Pinfold Consulting Economists (1996), *Assessment of the Economic Value of Water and its Contribution to the Economy of Newfoundland*. Report prepared for the Department of Environment, Government of Newfoundland and Labrador.

British Columbia Ministry of Finance (1998), "1998 Budget Reports: Revenue by Source," www.fin.bc.ca/budget98/bgt_tbh5.htm

Brooks, D. and R. Peters (1988), *Water: The Potential for Demand Management* (Ottawa: Science Council of Canada).

Campbell, R., P.H. Pearse, A. Scott and M. Uzelac (1974), "Water Management in Ontario: An Economic Evaluation of Public Policy," *Osgoode Hall Law Journal* 12(3):475-526.

Canada. Environment Canada (1997), *Canada country study: adapting to climate variability and change in Ontario* http://www.ec.gc.ca/ccs_b_e.htm.

Canada. National Round Table on the Environment and the Economy (1996), *State of the Debate: Water and Wastewater Services in Canada* (Ottawa: Supply and Services Canada).

Canada. Task Force on Economic Instruments and Disincentives to Sound Environmental Practices (1994), *Final Report of the Task Force* (Ottawa: Environment Canada).

Caves, R. E. (1990), *Adjustment to International Compe-*

tition Short-Run Relations of Prices, Trade Flows, and Inputs in Canadian Manufacturing Industries (Ottawa: Economic Council of Canada).

Chambers, R.G. (1988), *Applied Production Analysis* (Cambridge: Cambridge University Press).

Dinar, A. and D. Zilberman, eds. (1991), *The Economics of Management of Water and Drainage in Agriculture* (Norwell, MA: Kluwer).

Driscoll, A. and B. Kruger (1994), *Regulating the Surface Waters of Canada: A Province by Province Analysis of Water Management Policies* (Toronto: Ministry of Natural Resources).

Dupont, D. P. and S. Renzetti (1996), "The Role of Water in the Canadian Manufacturing Industry," Department of Economics Discussion Paper 96-03 (St. Catharines: Brock University).

Ecologistics Limited (1989), *Provincial Water Use Charges - Their Role in Water Demand Management.* Paper prepared for the Conservation Authorities and Water Management Branch, Ontario Ministry of Natural Resources.

Farid, C., J. Jackson and K. Clark (1997), *The Fate of the Great Lakes: Sustaining or Draining the Sweetwater Seas?* (Toronto: Canadian Environmental Law Association and Great Lakes Unlimited).

Muller, R.A. (1985), "The Socioeconomic Value of Water in Canada," Research Report 5 for the Inquiry on Federal Water Policy, Ottawa.

Ontario Ministry of Agriculture, Food and Rural Affairs (1992), *Agricultural Statistics for Ontario, 1991* (Toronto: Ministry of Agriculture, Food and Rural Affairs).

____ (1998), "Do You Need a Permit to Take Water?" Simcoe Area News Release, April, www.gov.on.ca:80/OMAFRA/english/…duffs/common/press%20release/permit.htm

Ontario Ministry of Environment (1990), *The Permit to Take Water Program* (Toronto: Ministry of the Environment).

Ontario Ministry of Environment and Energy (1994), *Water Management-Guidelines and Procedures of the Ministry of Environment and Energy*, Guideline B-1 (Toronto: Ministry of Environment and Energy).

Ontario Hydro (1995), *Annual Report* (Toronto: Ontario Hydro).

Ontario Round Table on Environment and Economy (1992), *Restructuring for Sustainability* (Toronto: Queen's Printer).

Pearse, P.H., F. Bertrand and J.W. MacLaren (1985), *Currents of Change: Final Report of the Inquiry on Federal Water Policy* (Ottawa: Environment Canada).

Percy, M. (1988), *The Framework of Water Rights Legislation in Canada* (Calgary: The Canadian Institute of Resources Law).

Renzetti, S. (1992), "Estimating the Structure of Industrial Water Demands: The Case of Canadian Manufacturing," *Land Economics* 68(4): 396-404.

____ (1999), "Municipal Water Supply and Sewage Treatment: Costs, Prices and Distortions," *Canadian Journal of Economics* 32(2): 688-704.

Renzetti, S. and D. Dupont (1997), *An Economic Assessment of the Impact of Adopting a Provincial Water Use Charge*. Report prepared for the Lands and Natural Heritage Branch of the Ontario Ministry of Natural Resources.

Saskatchewan Water Corporation (1998), "Water Demand Management," Discussion Paper (Moose Jaw: Saskatchewan Water Corporation).

Statistics Canada (1991), *Census Overview of Canadian Agriculture 1971-1991*, Catalogue 93-348 (Ottawa: Statistics Canada).

____ (1993), *Manufacturing Industries of Canada: National and Provincial Areas, 1991-1992*, Catalogue 31-203 (Ottawa: Statistics Canada).

____ (1996), *Annual Demographic Statistics*, Catalogue 91-213-XPB (Ottawa: Statistics Canada).

Stavins, R.N. (1997), "Transactions Costs and Tradeable Permits," *Journal of Environmental Economics and Management* 29(2):133-49.

Tate, D.M., S. Renzetti and H.A. Shaw (1992), *Economic Instruments for Water Management: The Case for Industrial Water Pricing*, Social Sciences Series No.26 (Ottawa: Environment Canada, Economics and Conservation Branch).

Tate, D.M. and R. Rivers (1990), "Industrial Water Pricing for Ontario: Towards Realistic Pricing," in *Proceedings of the Symposium on International and Transboundary Water Resources Issues*, ed. J. FitzGibbon, pp. 463-74.

Tate, D.M. and D.N. Scharf (1995), *Water Use in Canadian Industry, 1991* (Ottawa: Environment Canada, Water and Habitat Conservation Branch).

Vandierendonck, M. (1996), *Report to the Ontario Ministry of Natural Resources on Water Use in Ontario* (Waterloo: The Water Network, University of Waterloo).

Watershed Planning Implementation Project Management Committee (1997), *An Evaluation of Watershed Management in Ontario: Final Report* (Toronto: Ontario Ministry of Energy and the Environment).

Winfield, M. and G. Jenish (1996), *Ontario's Environment and the "Common Sense Revolution": A First Year Report* (Toronto: Canadian Institute for Environmental Law and Policy).

Zachariah, O. (1999), "Optimal Management of Groundwater Quantity and Quality: An Integrated Approach," PhD dissertation (Guelph: University of Guelph, Department of Agricultural Economics and Business).

Zilberman, D., U. Chakrovorty and F. Shah (1997), "Efficient Management of Water in Agriculture," in *Decentralization and Coordination of Water Resources Management*, ed. D. Parker and Y. Tsur (Boston: Kluwer Academic Press).

APPENDIX
METHODOLOGY AND ASSUMPTIONS

The purpose of this Appendix is to list the assumptions and describe the method used in conducting the numerical simulations.

1. The level of output for the manufacturing, mining, and agricultural sectors is assumed to remain constant throughout the simulations. The levels of output for Ontario Hydro and municipal water utilities, on the other hand, are assumed to change in response to the PWC.

2. Water-using firms are expected to respond to the introduction of the volumetric charge by reducing their water intake in the manner described below. However, there is assumed to be no behavioural response to the introduction of the annual fee (e.g., firms do not leave the province).

3. The water use and expenditure data come from a variety of sources. Data for the manufacturing, mining, and power-generating industries are from the 1991 Industrial Water Use Survey administered by Environment Canada (Tate and Scharf 1995). Data on water use in the agricultural sector are from the Ontario Ministry of Agriculture and Food (1992). Finally, data on municipal and residential water use are from Environment Canada's Municipal Water-Use Database (Vandierendonck 1996). Data on industrial output levels are from Statistics Canada (1991, 1992); Ontario Ministry of Agriculture and Food (1992); and Ontario Hydro (1995).

4. All price elasticities are assumed to be constant in the range of water and electricity prices considered. The values of the elasticities and all other parameters used in the simulations are available from the authors upon request.

5. For the sectors which are assumed to keep their output constant, the impact of the PWC on the demand for self-supplied intake water, publicly supplied intake water and electricity is described by the following equation:

$$\Delta Q_i = \eta_i \cdot \Delta p_i + \sum_{j \neq i} \eta_{ij} \cdot \Delta p_j \qquad \text{(A-1)}$$

Recall, that a firm which is both a self-supplier of water and a user of publicly supplied water may face three price increases upon the imposition of the PWC: an increase in the price of self-supplied water, an increase in the price of publicly supplied water, and an increase in the price of electricity. Thus, the total change in water demand by the i^{th} firm is shown in the equation above. In this equation above the subscripts i and j index three inputs: self-supplied intake water, publicly supplied intake water and electricity. The symbols η_i and η_{ij} measure the own and cross price elasticities of demand for input i. The symbol Δ indicates the *percentage change* in a variable.

In the cases where the sector's output level is not assumed to be fixed (Ontario Hydro and municipal water utilities), an additional term is required to represent how output changes and how that change induces a further change in the demand for self-supplied and publicly supplied intake water and electricity:

$$\Delta Q_i = \eta_i \cdot \Delta p_i + \sum_{j \neq i} \eta_{ij} \cdot \Delta p_j + \theta_i \cdot \Delta y \qquad \text{(A-2)}$$

where Δy is the percentage change in output and θ_i is the output elasticity of the i^{th} input. The expected change in output due to the PWC is related to the anticipated percentage change in the utility's output price ($\Delta\rho$) which is in turn related to the changes in input prices induced by the PWC. These relationships are expressed in the following two equations:

$$\Delta y = (S_R \cdot \eta_R + S_{NR} \cdot \eta_{NR}) \cdot \Delta\rho \qquad \text{(A-3)}$$

where Δy is y the percentage change in output and $\Delta\rho$ is the percentage change in the utility's price of output. The terms S_R and S_{NR} are the respective residential and non-residential shares in the utility's output. And, η_R and η_{NR} are the price elasticities of demand for residential and non-residential consumers of the utility's output.

The percentage change in output price, $\Delta\rho$, must be related back to the changes in the prices of self-supplied water and electricity as shown below.

$$\Delta\rho = \left[\left(\frac{1}{MC \cdot y}\right) \left\{ E_S \cdot \theta_S \cdot \Delta p_S + E_E \cdot \theta_E \cdot \Delta p_E \right\} \right] \qquad \text{(A-4)}$$

where $\Delta\rho$ is the percentage change in the price. MC is the marginal cost of output and y is the quantity of output. The variables E_S and E_E are the expenditures by the utility on self-supplied water and electricity respectively. The terms θ_S and θ_E are the output elasticities for self-supplied water and electricity. Finally, the Δp_S and Δp_E terms represent the percentage changes in the prices of self-supplied water and electricity. This equation implicitly assumes that the utilities are using marginal cost pricing and is from Chambers

(1988). The marginal cost estimates for Ontario Hydro and municipal water utilities are from Ontario Hydro (1995) and Renzetti (1999), respectively.

6. It is assumed that all firms choose inputs in order to minimize the cost of producing an exogenously determined level of output. Employing Sheppard's Lemma and some manipulation yields the following expression for the impacts of PWC on each industry's costs. The equation incorporates the approximate effects of three input prices changing simultaneously (the prices of self-supplied water, publicly supplied water, and electricity) and as well as the introduction of the annual fee:

$$\Delta C = (\sum_i S_i \cdot (1+\eta_i) + \sum_i \sum_{j \neq i} S_j \cdot \eta_{ij}) \cdot \Delta p_i + a \qquad \text{(A-5)}$$

where the i index includes self-supplied water, publicly supplied water, and electricity and the j index includes labour and capital. Further, S_i is the i^{th} cost share, η_i is the i^{th} output constant price elasticity of demand, η_{ij} is the output constant cross price elasticity of input j with respect to the price of input I, ΔC and Δp_i are the percentage change in cost and the i^{th} input price, respectively and *a* is the impact of the annual fee expressed as a percentage of total cost.