1-1-2008

Water resource management in the southern Ontario region : water market simulations under scarcity conditions

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WATER RESOURCE MANAGEMENT IN THE SOUTHERN ONTARIO REGION

WATER MARKET SIMULATIONS UNDER SCARCITY CONDITIONS

by
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A thesis presented to Ryerson University
in partial fulfillment of the requirements for the degree of

Master of Applied Science
in the Program of
Environmental Applied Science & Management

Toronto, Ontario, Canada, 2008

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Abstract

Water Resource Management in the Southern Ontario Region, Water Market Simulations Under Scarcity Conditions

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Water resource scarcity is a increasingly important issue in many parts of the world. Population pressures, climatic changes, and general resource mismanagement are placing increasing strain on water supplies that provide for ecosystems and economies alike.

This thesis addresses the issue of water resource management with an investigation of free market principles to effectively manage end-use demand. A water market is designed for the Southern Ontario region, which consists of a large central population with extensive water use related to industrial, residential and agricultural users alike. A comparison to a traditional centralized utility model is used to measure market dynamics and overall efficacy.

The results indicate that a free market system produces economic advantages to a utility model while still demonstrating an ability to reduce demand. The model also suggests that the inclusion of certain end-use functions, such as agriculture, must be examined carefully for a free-market model implementation.

Acknowledgements

To Professor Paul Missios for his support and encouragement throughout this process. His advice has helped shape and improve this thesis to what it is today.

To my wife Jennifer and son Jackson, who are the reason that I pursue my dreams.

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Introduction

Central to the livelihood of any individual, community or economy is the access to reliable sources of water. Whether used as an input for agriculture and industry or for general purposes such as drinking, cleaning and transportation, the scarcity of water would quickly inhibit the smooth functioning of any human ecosystem, regardless of scale. In addition, water serves as a critical element in all natural ecosystems, making its value truly universal. As such, it is no surprise that we value water resources as being so critical to our well-being, either directly or tacitly. As with all resources, however, successful management with a view towards long-term sustainability and stability is paramount.

Currently, there are a number of issues, local and global, that have the potential for creating water scarcity for a number of population and economic centres around the world. Increased population and economic consumption of water resources can put a strain on a water resource base that may be more or less fixed. Multiple examples of increased scarcity currently exist all over the world. In China, the Yellow River, which contains 2% of the available national water supply and serves 10% of the Chinese population, is experiencing chronic shortages that are drastically affecting rural water supply[1]. In California, a combination of reduced snowfall in the mountains, depleted aquifers, unprecedented drought conditions for the Colorado river, and relentless population growth are causing urban and agricultural shortages that have put scarcity front and centre in the political landscape[2]. Even in Canada, which is considered to be one of the most water wealthy nations on Earth, has issues of water scarcity. In Alberta and Saskatchewan, increased immigration and economic prosperity are leading experts to predict chronic shortages that will exceed the severe conditions not seen since the dustbowl era of the 1930's[3].

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[1] "Chronic Water Shortages Hit Rural Chinese Hard," Yellow River: A Journey Through China, narr. Robert Gifford, National Public Radio, 12 Dec. 2007.
[2] "California Grapples with Water Shortage," Nation, narr. Ina Jaffe, National Public Radio, 15 Oct. 2007.
[3] Schindler, D.W., and Donahue, W.F. "An Impending Water Crisis in Canada's Western Prairie Provinces," Proceedings of the National Academy of Sciences, 25 Feb. 2006, 1. <www.pnas.org_cgi_doi_10.1073_pnas.0601568103>.

In addition, there are potentially negative effects on water resources for many areas due to climate change. The IPCC in its Fourth Assessment Report, Working Group II (AR4 – WGII) provides evidence that glacial melt and changes in precipitation patterns will have effects on water access for many regions[4]. The potential combination of increasing demand and shrinking supply of a regional water resource can create scarcity issues that, if left unmanaged, will produce significant strain.

Avoiding, or at least mitigating, the negative impacts of water scarcity requires that the water resource is managed efficiently and effectively. Water management, on a macro scale, involves affecting the allocation or resources among users in such a way as to provide for the requirements of the system. In practice, a number of strategies can be used for large scale water resource management. These include direct regulation, water banks, price manipulation and water markets. Of these strategies, water markets alone represent a true free market approach to resource management. The question remains, however, whether a free market approach to managing a resource as critical as water can be successful.

In order to answer this question, this thesis will investigate the feasability of a water market versus current practice in one of the most user diverse regions in Canada; Southern Ontario. The Southern Ontario region comprises the largest population centre in Canada as well as one of the largest industrial and agricultural bases in the country. This makes it a truly heterogeneous market for water.

Previous studies of water markets have focused on the value of water in terms of its in-site value and costs of extraction. Additionally, valuing water has been proposed by Ewers (2004a) to be a function of its contribution to end use production, as it relates to agricultural water use. Building on the work investigating water valuation was a review of water markets themselves,

[4] Kundzewicz, Z.W., L.J. Mata, N.W. Arnell, P. Döll, P. Kabat, B. Jiménez, K.A. Miller, T. Oki, Z. Sen and I.A. Shiklomanov, 2007: Freshwater resources and their management. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 176-180.

specifically Yoskowitz (1997) examination of the Rio Grande spot market. Recently, work has occurred in a Canadian context with the Mahan *et al* (2002) study of a potential water market in southern Alberta. Each of these studies provide a valuable context for which this thesis seeks to expand current ideas concerning water management.

Water management analysis (both review and simulation) has typically been limited to single sectors or water sources. This allows specific aspects of water management to be examined in isolation, whether it is groundwater price analysis as in Moncur and Pollock (1988), agriculture small market scenarios with Ewers, or surface water market review with Yoskowitz. This thesis will eliminate those restrictions and investigate the potential for a water market where there are multiple user groups, regions, water sources, and pre-existing pricing schemes.

In order to accurately simulate a water market in the Southern Ontario region, a thorough review of literature concerning water markets and water valuation is required. Next, water consumption and pricing data for the municipalities of Toronto, Peel, Durham, Halton, Hamilton, and Niagara are collected to accurately portray residential and industrial water use. For agricultural use, direct consumption data are unavailable. Therefore, crop data, weather history and generally accepted crop-hydrological principles are combined to estimate agricultural water requirements. Price data are then collected using published utility rates for residential and industrial use and derived for agricultural use using published crop sales data. Pricing and usage data are then combined to determine the demand curves for each user of water in the study area.

In addition, the general rules of the market and the scarcity scenarios that will be applied to Southern Ontario water resources will be described. With market definition, scarcity scenarios and demand curves are all clearly identified, such that a simulation of both market and non-market models can occur, with a comparison of how each performs with respect to each other and each scarcity scenario. The results of the simulation are then analyzed at the user, municipality and aggregate level for each scarcity scenario to determine the potential benefits of a free market approach versus the current water management system.

Literary Review

Initial studies of water pricing models focused on groundwater only, such as Moncur and Pollock (1988). In their analysis, a pricing model derived from marginal costs of extraction and the in-situ[5] value was used in comparison to the current practice of average cost pricing derived from conventional accounting principles. It was found that most water utilities appeared to be artificially suppressing water prices below their calculated *in situ* and extraction cost values[6]. Calculating the price of water based on marginal extraction costs and the in-situ value would result in a sharp jump in price. This was due mainly to the perceived future costs of extraction that would result from an ever-increasing need to switch to more expensive sources of water due to scarcity, and the decreasing efficiency of extraction from current resources as they became depleted. The authors conclude that these findings indicate that a policy of meeting water demand simply by augmenting supply may be incorrect. Instead, the large price increases attributable to what the authors call a *scarcity rent* resulting from expected future extraction costs create the need for tighter water demand management policies. The primary tool for implementing a policy for demand management would be the augmentation of price.

Ewers (2004b), in the second of three studies, reinforces these findings with an application of the Hotelling Valuation Principle (HVP), originally developed for the valuation of oil reserves, to value municipal groundwater reserves. The valuation is based on using the current above ground value of water for a particular source to estimate the value of that source's reserves. According to HVP, the reserve price[7] of water should be equal to the above ground price net of extraction costs. The *in situ* value versus the above ground value is then used to determine whether optimal extraction rates (through the definition of HVP) exist for sites identified in the essay. The targets of this

[5] *In situ* refers to the amount of a given resource not yet extracted that is considered recoverable. *In situ value* refers to the value of resources not yet extracted.
[6] Moncur, James E.T., and Richard L. Pollock, "Scarcity Rents for Water: A Valuation and Pricing Model," Land Economics Feb. 1988: 64, 1. 68-69.
[7] Also known as "shadow price", "user cost", and "scarcity rent"

analysis are municipal water utilities that have available data for determining above ground water valuation (through share price) and measurable extraction rates. The key question that this essay attempts to answer is whether HVP is an accurate tool to determine the value of *in situ* values.

The available data set that is used to test HVP's validity for water resource valuation consists of 19 publicly-traded water utilities. The stock valuation, income statement expenses, and extraction history are the primary sources of data used to test HVP. Stock valuation is used to estimate *in situ* values of reserves, whilst the income statement and extraction history are used in formulating both above ground water values and extraction costs. Frequently, water utilities operate in a sole-source environment, effectively making them monopolies in a given region. Both perfect competition and monopolistic scenarios are tested, covering both extremes of the competitive spectrum.

Miller & Upton (1985) use a common formulation of HVP for oil resources, which is used by Ewers as the litmus test to determine if the same principles for oil can apply to the valuation of water. The formula then is used to evaluate whether HVP hold up for water resources is as follows:

$$V/R = \alpha + \beta(p - c)$$ where,

V is the discounted present value of profits
R is the total of ground water reserves available
p is the market price for groundwater
c is the marginal cost of extraction
β is the comparison of increase in prices versus increase in the interest rate over time
α is the intercept

Essentially, the assumption that HVP makes is that the value of reserves as a function of volume should be equivalent to the present value of extracted resources. In other words, the growth in price should be directly offset by the interest rate, creating a β value of 1. If $\beta<1$, resource prices are rising less than the interest rate. This will undervalue the reserves as the firm owner will perceive that a specific unit quantity of a resource currently extracted has a greater value than that same quantity in the future, discounted to present value. Therefore, in the case of water, this thesis tests whether the HVP applies and that the β value is in fact equal to 1. Data were taken from an online database of publicly traded companies for 9 water utilities. There is currently no market available to determine a price for water such as the one that exists for other commodities such as oil. Therefore, Ewers proposes using a formulation of total revenues and total acre-feet of water extracted to determine revenue per acre-foot, which is then used as the spot price.

The results indicate that HVP does not apply for the valuation of water reserves as $\beta<1$ in all cases, except when considering a short-run scenario where the reserve has less than a 5 year expected lifetime. The conclusion that can be drawn from this analysis was that HVP is not applicable for water resources. The author has reasoned that this may be a function of how water itself is valued, specifically that the future production of ground water is less than the current value of production. This reinforces the findings Moncur and Pollock (1988) and suggests that they method in which water is valued is not in line with current accepted economic principles of resource valuation.

Further analysis on pricing has also been done by Schuck (1999), which examines pricing models on what is termed a conjunctive use system. Schuck refers to a conjunctive use system as one in which surface water and groundwater resources can be exploited interchangeably. This thesis deviates from much of the earlier (and current) work with regards to water valuation, as it considers both surface and groundwater. A conjunctive use system is defined as a dual use system where groundwater is pumped to replace surface water under drought conditions and surface water is redistributed to the aquifer under wet conditions (groundwater recharge). Schuck develops a theoretical model to optimize water system pricing for an agricultural community that relies on both surface water and groundwater in a supply-based model. Based in Kern County, California, the model has the objective to maximize the benefit of users and water agency under relevant supply constraints, similar to many of the studies examined. The benefits of the agency are defined as maintenance of financial obligations, aquifer stability and meeting customer demand. The benefits of the users are defined as profits for commercial and agricultural customers and consumer surplus for residential users.

The water agency's system in this case is subjected to wet season and drought conditions, which greatly affect the supply of surface water. The demand for surface water is defined as grower use and aquifer recharge (in wet years only), whereas the demand for groundwater is defined as direct grower extraction plus water agency extraction (in drought years). The total system maintains balance through groundwater pumping or recharge under the corresponding wet or dry seasons. The costs associated with water delivery, pumping or recharge costs, and scarcity account for the major inputs of the pricing optimization exercise.

Schuck makes a number of assumptions in order to perform the pricing optimization exercise. First, the optimization occurs over a multi-year period, in order to account for alternating wet, dry and normal rainfall seasons. Also, it's important to note that groundwater pumping and recharge are mutually exclusive events in any given year. An important assumption, and one that deviates from normal practice in most cases, is the agency's ability to completely regulate groundwater usage. Water legislation and water rights normally give the landowner the right to use water drawn from on property wells at their sole discretion so long as it does not adversely affect other users of that system. The model also assumes perfect information regarding users of the water agency for surface water and groundwater.

In performing an optimization for water prices in a conjunctive use system, Schuck concluded that a water district must reflect the following in order for the optimization to be accurate:

1) Substitutability between sources: This includes the technical substitutability through delivery systems, and a comparable quality of groundwater to surface water, such that both are considered sufficiently homogenous.

2) Marginal cost of pumping/recharging
3) Scarcity value of the surface water: Most pricing mechanisms in practice today do not take into account the availability of surface water in a given year when determining price.
4) *In situ* value of groundwater: Related to the supply and quality of groundwater available to users in any given period.

Optimizing the price of water for a supply based system shifts consumption away from drought periods to high supply periods for low-value uses of water (ie. Fallowing). Furthermore, it was found that linking the price of surface water to groundwater based on the available supply of each allowed the district to shift usage to groundwater use in times of scarcity. In extreme cases of scarcity, a subsidy for groundwater could result in order to encourage a heavy preference of users to avoid surface water consumption. Conversely, in high-supply periods of surface water, aquifer recharge[8] is performed, with recharge costs affixed to the price of groundwater, thereby providing an incentive to users to avoid groundwater extraction in favour of surface water consumption. This lowers groundwater usage, allowing aquifer stability objectives to be met.

Although the mechanisms that Schuck used to develop his optimization do not involve water markets in the sense they will be discussed in this thesis, manipulation of consumer demand was clearly demonstrated. It is a valuable result to demonstrate that water usage shows the properties of substitutability and price elasticity, providing additional avenues for which a proposed water market can investigate in order to achieve its goals.

The consistent theme with many of the studies concerning the valuation of water resources is that the current practice employed by many water utilities does not take supply side factors in to consideration. The resulting effect is an undervaluation of water price, specifically in the case of groundwater, or a rigid price that does not reflect the current availability of water to a given system.

[8] Aquifer recharge refers to the practice of pumping surface water resources into the aquifer in order to increase groundwater reserves.

Study of water markets must first begin with the criteria that constitute an effective market mechanism. Howe, Schumeier and Shaw (1986) began much of the work concerning the theoretical foundations of water markets. In their thesis, they established six primary criteria upon which an effective water market is based.

First there must be flexibility in the existing water supplies. This allows water to be shifted from one user or application to another. Not all water in the system needs to be flexible, but a tradable margin must exist in order for the market to function. Second, security of tenure for established users should exist. Guaranteed continuity of use will ensure that users of the water will invest and maintain water-using systems and markets. Third, the opportunity cost of the resource must be apparent to the user. Having strict limitations on the amount of use, or a competitive market where multiple users attempt to acquire a shared resource will make this cost explicit. Fourth, the predictability of the outcome of the process is required. Many users fear water markets because they cannot anticipate how extensive the reallocation might be in practice. Fifth, the perception of fairness in the process must exist for all participants. This includes the equality of compensation for all users as well as those that are injured at points of diversion or return flows. Sixth, a socially responsible water allocation process must be able to reflect values that may not be considered by individual users. Socially responsible water allocation generally refers to factors considered non-market values, resulting in allocations that would benefit the common good. Water quality, in-stream flow requirements for recreational and ecological purposes may generate increased value in terms of the public good, but not to the individual user. In order to create these allocations, market restrictions, incentives or other mechanisms designed to reinforce socially responsible behaviours may need to be imposed.

Simpson (1992) adds to the theoretical foundations of effective water markets with four additional criteria. First, well-defined rights for water must exist, including a title on record. This eliminates possibility of dispute over ownership of the right. Second, a system of water measurement must be fully established in order to ensure that market participants are receiving correct entitlements for tradable water. Third, an administrative body must exist to oversee the market such that any transaction in water rights is sanctioned by the relevant government jurisdiction. Fourth, physical delivery of the commodity to the buyer must be easy. The best market allocation systems function where infrastructure is in place to all for smooth delivery.

Going beyond the theory behind effective water markets, work has also been conducted on analyzing existing and potential markets. Yoskowitz (1997) analyzed the current spot water market that exists along the Rio Grande River in Texas. Specifically, transactions occurring between participants were studied in detail to determine what factors were statistically significant in determining price.

Yoskowitz begins by a general review of Texas surface water laws, which make provisions for priority rights of all users in the system. Prior Appropriation rights exist in Texas water laws that give priority rights to users who have a historical claim to usage. Therefore, land owners with the earliest established claim to water rights, based upon date of title of land, get their full appropriation of water. In times of scarcity, newer claimants to water rights may not receive all or any of their allocation, as priority users receive their fully allocated amounts first. The Texas spot water market was created, in part, to overcome the clear economic inefficiencies that exist under the Prior Appropriation rights system.

With an understanding of the regulatory and legal constraints governing the current spot water market in Texas, Yoskowitz performs a statistical analysis of the market's participants and the transactions that occur to determine what factors, if any, are affecting spot market prices for water. In order to accomplish this, multivariate regression is used on the transaction data available. By using multivariate regression, the following key questions were addressed:

- Examine/explain variations in price/acre-foot (AF) for given individual variables
- Test for a convergence in the price/AF of various water user groups. (Mining vs Irrigators, Municipalities)

- Provide explanations for the existence of price differentials that currently exist in the spot water market, even for transactions with similar variable sets.

Data for the analysis were available from the Rio Grande Watermaster Office (RGW), which records all transactions that occur in the water market. For the period of 1991 to 1996, 926 observations are available. Each observation contains six data points, constituting the variables used in the multivariate regression analysis. The variables used are as follows:

- PRICE: The dependent variable used in the analysis
- SEA: Dummy variable - Denotes time of year of transaction (Season). A value of 1 denotes that the transaction occurred during the high demand period April-September, The value 0 denotes the transaction occurred in the low demand period October-March
- USE: Three dummy variables, with a value of 1 denoting the usage profile of the buyer – Municipal (MUN) (0,1), Mining (MIN) (0,1), Irrigation (0,1)
- LOCATION: Dummy variable – Denotes if the buyer is located North (1) or South (0) of Eagle pass
- ARMS: Qualitative variable detailing the closeness of association of the parties involved in the transaction. Arms length (0), not at arms length (1)
- ACRE FEET (AF): Amount of water purchased in acre-feet (AF).
- β: Solved to determine each variables contribution to price

Using the data available and all six variables, three models each using multivariate regression are performed. The first model, labeled the ordinary model, uses an ordinary least squares regression to estimate the price function for the spot water market. Two iterations of the regression are run under this model. The first uses all available transaction data, while the second iteration removes observations where no sale price was observed. No sale price was observed in 88 instances, most likely the result of water transfers between close associates (ie. relatives, neighbours, etc.). Note that all further variations on the regression model are based upon the 2nd iteration. The basic model is formulated as follows, with the USE variable set as Irrigation unless otherwise denoted by the variables MIN=1 or MUN=1 in the model:

$$PRICE = \beta_0 + \beta_1 ARMS + \beta_2 LOC + \beta_3 MIN + \beta_4 MUN + \beta_5 AF + \beta_6 SEA$$

With the basic model, only 43% of the variation is explained through the regression analysis. Therefore, a more sensitive model is developed to better explain the variation in price due to the observed variables. This model, labeled the transformed model, contains three more iterations of the basic regression model. The third iteration of the regression model logarithmically transforms the dependent variable PRICE to better illustrate the effect any change in the independent variables have on the model. In addition, a fourth iteration is developed that tests the elasticity of price with respect to volume (AF). This iteration logarithmically transforms both PRICE and AF. Finally, a fifth iteration is developed that tests the relationship between ARMS and AF, as well as LOC and AF. The reason for this is that both ARMS and LOC are assumed to interact with AF in a way that is non-additive to the price/AF of water. Therefore, the fifth iteration of the model also includes the terms β7ARMS*AF and β8LOC*AF.

For each of the five iterations of the regression model, different variables were found to be statistically insignificant:

2nd iteration: AF, SEA insignificant

3rd iteration: AF, LOC insignificant

4th iteration: LOC insignificant

5th iteration: AF insignificant

In order to again more accurately determine the effects of the statistically significant variables under each regression model, the insignificant variables are removed from the equation. This model, labeled the Restricted model, focuses only on statistically significant variables.

Using the Transformed and Restricted models, Yoskowitz is able to explain 60% of the variable PRICE through the regression of the other five variables. Of the independent variables LOC, SEA, USE, and ARMS were found to be statistically significant. Yoskowitz is able to demonstrate, that under market conditions, the price of water is subject to non-regulatory factors.

Further analysis regarding water markets involved impact based analysis, specifically comparing alternate types of water institutions and their ability to achieve desired conservation goals. O'Connor (1999) for example, performed a comparison of a water bank versus a water market in meeting the stated goal of maintaining minimum in-stream flow along the Snake River Basin (Colorado). The minimum in-stream flow requirement is for riparian uses, including recreational and ecological concerns.

A water bank is a centralized institution controlled by the water authority that purchases water for storage purposes so that it can be used in later years and/or released back into the system to maintain minimum in-stream flow requirements. The central administrative body sets prices, and trade of water rights between users is not permitted. Conversely, the water market involves pricing set by supply and demand forces, with users trading water rights amongst each other.

The primary user of water in this study is agricultural use, which has been modeled in detail using crop data, hydrological data, and geographical detailing (storage capacity of the system, flow rates, etc.). The focus of the comparison is each system's ability to transfer water from the user base back to in stream flow. The analysis is performed under short run conditions, using one growing season. O'Connor divides the basin under study into distinct regions. Each region is assigned rights for flow water and storage. Since the water used in agriculture is not wholly consumptive, return flows available are detailed, including which region's outflow is another region's inflow. Using these data, the usage of water is optimized for each individual region.

Both models are run under dry, normal and wet season scenarios to determine their effectiveness under all possible levels of scarcity. In general, it is found that the water market scenario, which allows trade between individual users in a given region, are able to meet the in-stream flow requirements of the whole system more consistently. The in-stream flow requirements are met under the water bank scenario only when the bank prices are relatively high. Furthermore, during wet years, the bank is overpaying users for their water rights, which is economically inefficient. Conversely, with the water market system, low value producers sold their water rights to high value producers, maximizing the economic performance of the system and simultaneously lowering overall usage to meet in-stream flow requirements.

In addition to the conclusions noted above, O'Connor further examined water markets by comparing a consumptive versus diversionary rights market to determine which is more efficient in meeting the goals of maintained in-stream flow requirements. Both diversionary and consumptive markets behave in similar manners with the difference being that in a diversionary market the holder of the water right can transfer the entire right to another eligible user. Under a consumptive rights market, a right holder can only transfer the portion of water actually used by the holder. In other words, the right holder cannot market water that returns to the system naturally through usage. This distinction becomes important in cases where use of the water is not wholly consumptive, such as in agriculture.

The assumptions and models follow the same definitions in the previous study, although the focus with this model is on dry years only. Not surprisingly, both diversionary and consumptive use models show improvement over the base case scenario in which no market exists. Greater benefit is shown under a consumptive use market, however, as it prevents users from trading more water than is actually consumed, mitigating losses to the system due to users having differing consumptive values. O'Connor also concludes that the major drawback in a consumptive use market is unfortunately the high information requirements.

By comparing water banks to water markets and then the differing elements of a water market itself, O'Connor demonstrates the increased efficiencies a water market system can potentially have. The efficiencies may be ecological or economic as demonstrated by O'Connor.

Additional analysis of the specific elements of water markets includes the effect of tradable permits in a river-based surface water market, and their effect on localized availability and quality to users along the system. Weber (1999) examines the mechanisms needed to optimize the allocation of consumptive water rights along a river system. Since a tradable permit system can often allow for downstream users to transfer rights to upstream users by way of acquiesced early diversion, intermediate users may be affected. This third party effect could result from intermediate users not being able to meet their water requirements or having a lowered quality of product, as flow rate is reduced in their vicinity. Weber demonstrates that purchasing water from an upstream seller, increases both water flow and water quality at the buyer's point of diversion, something that cannot be said for the purchase of downstream rights. This effectively divides the market into two segments, upstream and downstream for each location. Using Nash equilibrium, Weber demonstrates that it is optimal to use location-specific pricing for each user.

Though optimal, it is conceded that there are drawbacks to this solution. Users must be able to recognize that there are asymmetric benefits from purchasing upstream versus downstream rights. This creates a high information requirement, since the benefit associated with upstream versus downstream diversion must be measured at each specific site. Each user is also required to have perfect information, to avoid increased transaction costs. Weber suggests a double auction format for the market to combat this. In the double auction initial allocations are grandfathered to each of the participants who then buy and sell from each other in a central organized market. Each participant must outbid the others in order to retain its initial allocation. The largest obstacle in creating this market is the legal manner in which water is currently allocated to each user. Prior appropriation rights law, which governs many areas that water markets have been studied in, protects from third-party injury. Under the market proposed, injury would apply as users may have to alter their water portfolios based upon the actions of other users.

Further analysis on the benefits of water markets can be found with Mahan *et al* (2002), with an examination of a market's effect in a Canadian setting. Using Southern Alberta as the setting, Mahan *et al* experimented with the welfare effects of an intra and inter-regional water market, with the goal of mitigating economic loss to the system under normal and scarcity conditions.

This thesis covers the Oldman and Bow River basins, which cover the area of Calgary and east. The Bow and Oldman rivers flow eastward towards Saskatchewan and merge into the South Saskatchewan river, just west of the border. The base case used to determine the economic effects of the water markets applied is the current reality, which is a complete absence of any water market in the region. The analysis and effects occur over the short run period, covering one full growing season (May to September). The mechanics used in the model are based upon the current hydrological system in existence, so that the market functions in a way that does not require additional diversions or infrastructure to be considered practical. Historical in-stream flows and hydrological data are used to determine a normal hydrological season as well as scarcity scenarios. Minimum flow rate constraints are also used to mimic the current requirements of specific users such as recreation and ecological functions. Minimum outflow rates are also used to stay within the legislated requirements of the provinces of Saskatchewan and Alberta, which require a minimum inflow from the South Saskatchewan River into Saskatchewan. As with previous studies, markets are assumed to be perfectly competitive, with water demand and supply considered deterministic. Using a short-run model as Mahan *et al* do, this assumption is realistic.

Users of the system are grouped into 16 activity nodes. Nodes are grouped geographically, into groups that share a common diversionary source from the system. Users are also categorized into distinct groups including urban, industrial, hydropower and agricultural. Each user group has a calculated or estimated consumptive rate for water. Consumptive rates are important as each user returns a proportion of water used back into the system. For the purposes of this study, hydropower usage is deemed consumptive since water is stored for the growing season for power generation purposes. Estimations are based upon best available data. Trading between users and groups is defined under two distinct models. Under an intra-regional market, trading is allowed within each node, but not between nodes. Under an inter-regional market, this restriction is removed.

Using historical hydrological data, Mahan *et al* perform three scenarios for the Southern Alberta market under normal, surplus and scarcity conditions. A scarcity condition is defined as a 25% effective precipitation level for the growing season, whilst a surplus condition is defined as a 75% precipitation level. The base case is defined as a 50% effective participation level. Under each condition (normal and scarcity), the base case, an intra-regional market, and an inter-regional market are applied.

The results of this analysis showed a material economic improvement under the market scenarios when compared to the base case. Comparing Scenario 3, the inter-regional market, to the base case, improvement was shown under all three water availability conditions. Under a scarcity condition, total economic improvement from the inter-regional market over the base case was found to be 14.8%. Under normal and surplus conditions, economic improvement was calculated at 6.3% and 2.6% respectively. Differences between inter-regional and intra-regional markets were negligible, with inter-regional markets showing little or no economic improvement over intra-regional markets. Mahan *et al* presume that the negligible improvement demonstrated in scenario 3 over scenario 2 is attributed to the high diversity of individual users under each activity node. Essentially, there exist sufficient market participants in each individual node such that economic efficiency can be fully or near fully maximized by trade within a node, creating little incentive to trade outside any particular node. If the nodes were more homogenous, Mahan *et al* predict that a more distinctive result between scenario 2 and 3 may exist. Given the results shown over scenario 1 by both market scenarios, Mahan *et al* demonstrate the potential positive economic effects that instituting a water market can have, especially under scarcity conditions that can exist in Alberta.

Ewers (2004a), in the first of three studies, uses Water District 21 the San Luis Valley (South Central Colorado) as the study area for a pragmatic examination of how water can be valued based upon the output goods (agricultural products) that it contributes to. Specifically, the economic benefit of optimal cropping patterns and the mitigation of economic impact from water shortages are examined. Both of these concepts are directly related to the price of material inputs. (i.e. water) Unlike O'Connor, ecological impacts are not considered in this scenario.

The first decision was the geographic location for the analysis as mentioned above. A smaller market with a homogenous firm base was used to allow for easy transfer of water between firms. For the purposes of a water market designed to encompass a large geographic area with a variety of firms, transfer of materials becomes an additional variable that can affect equilibrium price, logistical possibilities and resource equality. For the purposes of this study though, using a small market with a homogenous firm base allows this factor to be ignored. Furthermore, a limited number of different crop types exist in this region (Potato, Barley, Alfalfa, and Hay). This allows the author to easily optimize total market values as there are a limited number of products available to produce, and hence substitute. In addition, each firm has a homogenous crop with no mixing of output product. The separate irrigation ditches that comprise the agricultural infrastructure of the district represent the firms in this model. There are 74 firms in the district.

A smaller market was also used because a geographic area with limited water supply helps accentuate water's value as a material input. Water scarcity allows for a clear illustration of how water valuation can be calculated. By keeping the supply of water at a finite, and in some cases insufficient level, firms are required to make a decision about what goods to produce, whether to produce at all, or whether to sell their water to the market. In situations of water abundance, or effectively an infinite short-run supply, the price of water may be artificially suppressed. It is also important to note that the author does not focus on water conservation whatsoever and makes the assumption that the firms will use all available water.

The region chosen also has little or no regulation regarding the valuation mechanics and transport of water within the given market. This allows the model to ignore regulatory and transfer costs, making the valuation model less complex and allowing the focus to remain on the valuation of water.

Ewers also establishes other key parameters that simplify the water market model to better test impacts such as limited water supply and crop substitution. A prior appropriation model for individual firms, a "first in time, first in right" approach governs the method of water rights and access to material inputs. The basic principle is that in times of scarcity, those with "last in right" or "junior" water right holders lose their access to water first.

The supply of water is also governed by a short-run supply model time frame of one year. This allows rigidity of the model in terms of crop optimization by fixing the supply of water. With each season, the supply of water to a region can vary greatly depending on environmental factors. Eliminating this variability allows the optimization model to remain static, with known water supplies at the beginning of the year and crop choice to remain fixed for the duration of the model.

Before determining a water market model for the agricultural sector in the study area, a crop allocation model was designed and employed to ensure the most efficient use of resources. To set a realistic crop allocation model in the short-run, Ewers has established a number of constraints. Six constraints are employed in the model, four dealing with minimums/limits on product output volumes and two outlining land and water constraints.

Crop allocation constraints in the model dictate lower and upper bounds for each crop in terms of production volume. These were designed by Ewers to account for real life circumstances where there are physical, contractual and tertiary market considerations affecting what is produced. Without these limitations, the optimal market scenario would be to produce the most profitable crop in 100% of the available land. The total land available for farming is also limited to 75% of total available acreage. This is designed to reflect the reality of agricultural practice that requires land to be left "fallow" to maximize long-term land use maximization. The key constraint affecting the model is the amount of water made available to the system. This was set at the 1998 water supply level.

After determining overall parameters and model constraints for the crop allocation model, data were collected from local and state sources to determine optimal cropping patterns. Data collected were the following:

1) Water Appropriation Dates of all firms
2) Available water supply for 1998.
3) Net Irrigation Requirements (NIR) for each crop type in the model
4) Cost per acre for each crop type
5) Average production value for each crop type, including price, yield, acres harvested, etc.

Applying the data to the crop allocation model under the parameters and constraints noted above, an optimal cropping pattern can be determined for the District. The results of this essentially dictate that products with the highest profit/acre foot are maximized, while products with the lowest profit/acre foot are minimized, subject to the model's constraints. For District 21, each firm is allocated a particular crop type to produce, making the model mathematically and geographically demonstrable.

Having determined the optimal cropping pattern and hence profit/acre foot for each firm within the district, along with the amount of water required to do so (based on the NIR values), the profit per unit of water can be determined. This is determined by calculating acres of a crop per firm over the amount of water required to produce said product.

With the knowledge of optimal cropping patterns and hence profit/unit of water available. A water market can be modeled. To model this market, the author creates a fictitious situation in which total water available does not meet current market requirements for 100% production (80% of capacity in this case). The parameters regarding water appropriation rights then apply, leaving those with "junior" rights without the required material inputs to produce their product. Knowing the profit/acre foot of each firm, the relative supply and demand curves for all firms in the model can then be determined, with those lacking water representing the demand curve. Using these data, a clearing price that will determine the value at which those with water will sell their supply to those needing it, in place of producing the product can be determined.

With the water market modeled under a water resource constraint, a number of results occur:

1) Firms with prior appropriation rights have the ability to sell water to those lacking it. The decision to sell is based upon the clearing price per acre-foot of water versus the profit/acre-foot of producing their designated crop. Firms who produce crops with lower-than-clearing-price product will make the decision to sell.
2) Firms with "junior" rights are required to either purchase water from sellers or do nothing. The decision to buy is again based upon the clearing price per acre-foot of water versus the profit/acre-foot of producing their designated crop. In this situation, firms who produce crops with values higher than the clearing price will choose to buy.
3) Under this scenario, there is inevitable loss to the district as production is lost from firms unable to produce product due to lack of water rights and the ability to purchase at a cost-effective price; or firms that decide not to produce product and opt to sell their water in the market.
4) When compared to a "no water market" situation under a water constraint scenario to the "water market" scenario, overall value increase is realized. This is due to the optimization to produce higher value crops and let lower value crops go fallow until such time as water becomes abundant.

Ewers concedes that there may be issues in the transportation of water to one firm from another due to limits on the physical delivery of water. For example, a downstream water rights owner who delivers water to an upstream firm. Essentially, this becomes an issue of market size parameters as further disaggregating can alleviate these issues using a smaller geographic base for the market.

In general, the previous work discussed has taken one particular aspect of water management in isolation or with other variables largely fixed or ignored. The value in this approach is that it allows the analysis to focus on one particular feature of water management or pricing in order to gain a full understanding of the element in question. For example, earlier works of Moncur and Pollock focused purely on pricing, largely ignoring the application of price on a heterogeneous user group. This work was continued by Ewers with investigation of *in situ* reserve valuation, absent of above ground market dynamics. Research concerning markets themselves has been shown to focus on specific elements of a market such as system guidelines (Howe, Schumeier and Shaw, 1986), and transaction analysis (Yoskowitz, 1997). Full market simulation has occurred as demonstrated by Ewers; however, in this instance the user group was homogeneous, consisting of agricultural users in a controlled setting. Recent work has expanded the complexity of water market analysis, with Mahan *et al* (2002) using the Southern Alberta region as the case study for a water market simulation. In this system however, the physical flow of water is linear, originating from two surface water sources, the Bow and Oldman rivers.

This thesis will attempt to simulate a water market under extremely heterogeneous conditions. This will be done in terms of geographic area (Southern Ontario), resource end use (Grain growers, fruit growers, vegetable growers, 3 types of industrial usage, residential usage), and source (includes surface water and groundwater). In addition, 4 separate scenarios containing separate degrees of water scarcity, ranging from no scarcity to 60% scarcity, will test both the effectiveness and robustness of the water market model. Therefore, this thesis will serve as an extension of previous study of water management by examining water markets at a macroeconomic scale in order to determine the efficacy of a free market model in a typical urban/rural mixed environment.

The next section will focus on the different data requirements and techniques used to collect, derive, and analyze water use in order to prepare for a market simulation. Following this, the market parameters and methodology are described. Finally, the market simulation will be run and results will be discussed at the individual, group and aggregate level.

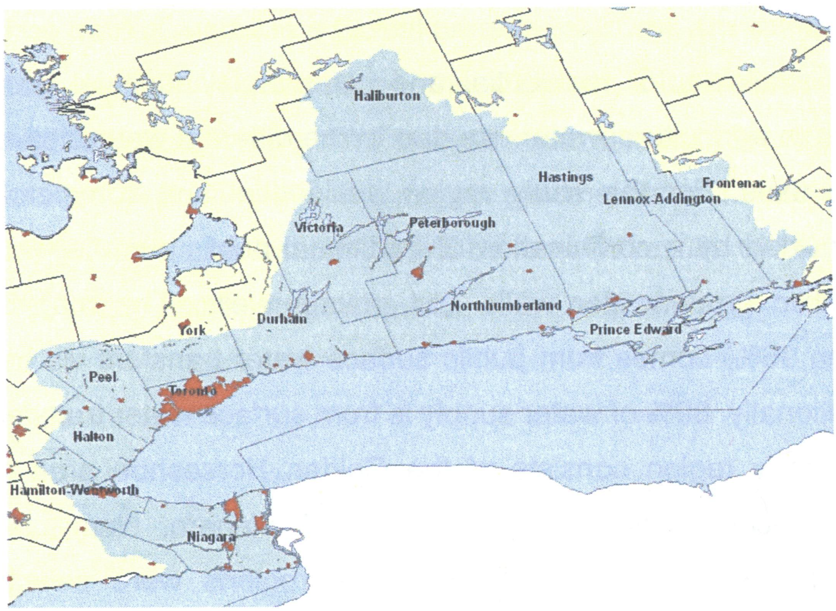
Data Sources

Data available for residential and commercial/industrial water use are separated from agricultural water use due to the different water delivery systems each group uses. For the study region, residential and commercial/industrial water is provided by a combination of traditional public surface water pumping stations, public groundwater wells and private wells. The majority of water (greater than 98%) comes from public surface water transfers via the municipal utilities[9]. Nationally, 89% of water supply is from surface water transfers[10].

The study region consists of the Golden Horseshoe area of Southern Ontario, specifically containing the regions of Niagara, Hamilton-Wentworth, Halton, Peel, Toronto, and Durham. These regions were selected for two reasons. First, they consist of a wide variety of water end-user types, including dense residential, commercial, industrial, large scale agriculture and rural communities. Additionally, the majority of each region is within the Lake Ontario Drainage Basin, which is depicted in green in Figure 1. With the majority of surface and groundwater draining into the basin, it is assumed that all users of water within the regions of the study area ultimately share a common resource, allowing them to be placed within a single water market for the purposes of this thesis.

[9] Calculated from the 2004 update for the Muncipal Water Use Database available from Environment Canada. <http://www.ec.gc.ca/water/en/manage/use/e_data.htm>
[10] "2004 Municipal Water Use Report," Environment Canada. <http://www.ec.gc.ca/water/en/info/pubs/sss/e_mun2001.pdf>

Figure 1: Lake Ontario Drainage Basin



Water consumption data are provided by Municipal Water Use Database: 2004, a national survey of water utilities beginning in 2001. The data are obtained via detailed survey sent to each municipal and regional water authority. Responses were collected and deposited into an online database available by direct download. Responses were updated as new data is available, with data are recent as 2004. The data set itself is divided into individual cities and/or municipalities and includes average daily flow for all areas included in this study. Also included in the survey are details concerning the usage profiles of the study area in terms of user group. The usage profiles consist of three categories: Residential, Commerical/Industrial and System Loss. For the purposes of this thesis, these categories have been renamed Residential, Industrial and System Losses.

Consumption data are reported as Average Daily Flow (ADF), which is the daily average for each reporting area as a function of total annual consumption. Seasonal variations in residential and industrial use are ignored for the market since no reliable assumptions concerning demand variation in the study area have been found.

For the study area, surface water withdrawals are primarily made from Lake Ontario. Other surface water withdrawals are made from local rivers along the study area to a small degree. However, even in these exceptional cases, all flows are ultimately inbound to Lake Ontario. For the purposes of this study, all surface water withdrawals are assumed to be directly from the lake.

Residential use is defined by water withdrawals made by users deemed "Residential" through zoning information and regional utility classification. Essentially, users who are on a residential utility payment scheme and inhabit land zoned "residential" are classified as such.

Industrial/Commercial users have been amalgamated due to lack of diversification in the base data set. The same rules have been applied for the base data set to correctly identify this user group. In order to account for the varying utility of water to different commercial and industrial users groups, total usage has been subdivided into three distinct groups. These groups are identified as "high-value users (HVU)", "medium value users (MVU)", and "low value users (LVU)". This division is an attempt to accurately quantify the criticality of water inputs to the underlying revenue stream subsequently generated by the end users. Using a qualitative example, HVUs would include industrial processes such as bottling, distillation and other water intensive processes where there is no economically viable substitute available. In addition, HVUs require water as an intrinsic part of the manufacturing process such that reductions in availability result in a direct reduction in production. Conversely, LVU can be identified as commercial or industrial users that have little or no direct requirement for water in the production of their good or service. Qualitative examples of LVUs are retail operations, service-based industries, and industrial processes requiring little or no water as a direct or indirect input. MVUs are an attempt to capture processes that fall in between the two extremes, where water is a secondary input, or primary input with alternative inputs available.

For all regions in the analysis HVUs, MVUs, and LVUs are allocated equal weighting, each receiving one-third of total water available. Information on the approximate share by region for each user group is unavailable at this time. It is recommended for future study that greater resources be applied to reflect a more accurate industrial representation of users for regional level analysis.

The third "user" defined in the municipal water database is labeled "System Loss" and signifies extracted water lost in the preparation and distribution to end-users. Sources of system lost include inefficiencies in the initial extraction process and leakage existing in the distribution network. While system losses are a valuable metric in determining potential efficiency improvements in the water distribution system, they are discounted for the purposes of the market design. It is also assumed that no efficiency improvements will occur during the market cycle in this analysis, eliminating a potential non-market source of water and fixing capacity.

Annual reporting required by the government of Ontario for all regional and municipal water authorities was also used to cross-reference and validate data collected in the online database. The annual reporting requirement focuses mainly on water quality and public maintenance issues, but does contain gross usage statistics for many of the surface water pumping stations and public groundwater wells included in this study. When discrepancies exist between the online database and annual reporting data, the online database is used given that its focus is specifically on water use statistics rather than other non-use related issues found in the annual compliance reporting.

Large sections of all but one region (Toronto) in the model contain significant amounts of agricultural land. Irrigation techniques in the southern Ontario area primarily consist of two water delivery mechanisms. For agricultural land that is significantly close to surface water sources including Lake Ontario and various river systems, a direct surface water irrigation approach is viable. This system consists of irrigation channels and reservoirs used by agriculture to supply fields directly via crop water delivery mechanisms. The alternative irrigation method consists of groundwater supply delivered through private well systems. A private well is normally owned by a single farm or a collaboration of geographically concentrated farms for common use. As with surface water irrigation, final delivery of water is via a crop water delivery system.

Crop water delivery systems can vary by crop and location, but typically include sprinkler and drip irrigation delivery methods. Though irrigation methods can vary from farm to farm, technological levels in the study area are considered advanced. Therefore, in line with more efficient irrigation systems, an irrigation efficiency ratio of 90% is used. This translates into 90% of irrigated water used reaching the desired crops for beneficial use, with 10% considered "System Loss"[11].

Due to the nature of the water delivery systems of agriculture land use in the area, direct metering of water use is an impractical notion. This results into a lack of direct water use measurement available for the study area. In order to derive agricultural water use to a level useful for the market model, however, a region and crop level data set is required. To accomplish this, water use by region and crop are calculated using a series of formulae and data based upon weather, crop sales, crop acreage, biological crop data and solar irradiance.

To derive agricultural water use, the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) provides crop data detailing total acreage and production by crop. OMAFRA updates these data on an annual basis, with 2004 data available for this thesis. Data are available for all commercially grown crops in the region with harvest dates occurring within the given calendar year. The following table illustrates crop production by region for all crops in 2004.

Table 1: Durham Horticulture and Field Crop Statistics

Crop Type	Harvested Area (acres)	Marketed Production ('000 kgs)	Marketed Yield/acre ('000 kg/lb)	Average Price ($/kg)	Market Value ($'000)
Apples	1,138	12,130	10.66	0.41	5,028.0
Grapes					
Peaches					
Strawberries	196	400	2.04	2.43	970.0
Cabbage	200	2,966	14.83	0.21	621.0
Carrots	26	382	14.69	0.15	58.0
Onions	18	257	14.29	0.24	62.0
White Beans	1,100	408	0.37	0.46	0.9

[11] Brouwer, C., Heibloem, M., Prins, K. Irrigation Scheduling. 1989, Food & Agricultural Organization, 27 April 2007. <http://www.fao.org/docrep/T7202E/t7202e00.HTM>. Annex I.

Potato	200	1,361	6.80	0.22	295.0
Tomato	69	2,131	30.89	0.14	296.0
Tobacco	70	80	1.15	4.96	398.0
Green Beans					
Peppers	15	112	7.50	0.65	74.0
Sweet Corn	450	2,123	4.72	0.13	285.0

Crop Type	Harvested Area (acres)	Yield (bu/ac)	Marketed Production ('000 bu)	Marketed Production ('000 tonnes)	Average Price ($/tonne)	Market Value ($'000)
Barley	8,500	61	519	11.3	102	1,153
Canola	9,100	36	324	7.3	192	1,402
Fodder Corn	5,200	15	77	69.9	23.4	1,636
Grain Corn	40,500	120	4,878	123.9	107	13,257
Hay	70,900	2.8	197.4	179.1	112.2	20,095
Mixed Grain	6,700	68	456	8.3	100	830
Oats	4,400	82	362	5.6	138	773
Soybeans	43,100	34	1,476	40.2	232	9,326
Spring Wheat	1,100	39	43	1.2	156	187
Winter Wheat	22,800	69	1,584	43.1	139	5,991

Table 2: Peel Horticulture and Field Crop Statistics

Crop Type	Harvested Area (acres)	Marketed Production ('000 kgs)	Marketed Yield/acre ('000 kg/lb)	Average Price ($/kg)	Market Value ($'000)
Apples	242	2,590	10.70	0.41	1,074.0
Grapes					
Peaches					
Strawberries	79	179	2.27	2.41	433.0
Cabbage					
Carrots					
Onions					
White Beans	100	45	0.45	0.02	0.1
Potato	150	1,225	8.16	0.22	265.0
Tomato	28	889	31.75	0.14	121.0
Tobacco					
Green Beans					
Peppers					
Sweet Corn	109	522	4.79	0.14	72.0

Crop Type	Harvested Area (acres)	Yield (bu/ac)	Marketed Production ('000 bu)	Marketed Production ('000 tonnes)	Average Price ($/tonne)	Market Value ($'000)
Barley	4,100	62	255	5.6	102	571
Canola	300	45	14	0.3	192	58
Fodder Corn	2,600	22	56	50.8	23.4	1,189
Grain Corn	6,200	118	734	18.6	107	1,990
Hay	41,000	2.6	108	98	112.2	10,996
Mixed Grain	800	59	48	0.9	100	90
Oats	500	61	30	0.5	138	69
Soybeans	15,300	37	571	15.5	232	3,596
Spring Wheat	1,100	39	43	1.2	156	187
Winter Wheat	5,200	67	350	9.5	139	1,321

Table 3: Halton Horticulture and Field Crop Statistics

Crop Type	Harvested Area (acres)	Marketed Production ('000 kgs)	Marketed Yield/acre ('000 kg/lb)	Average Price ($/kg)	Market Value ($'000)
Apples	271	2,901	10.71	0.42	1,215.0
Grapes					
Peaches					
Strawberries	125	272	2.18	2.42	658.0
Cabbage	102	1,481	14.51	0.22	320.0
Carrots					
Onions					
White Beans	700	227	0.32	0.22	0.5
Potato					
Tomato	47	1,492	31.75	0.14	204.0
Tobacco					
Green Beans	98	280	2.86	0.41	116.0
Peppers					
Sweet Corn	250	1,225	4.90	0.14	170.0

Crop Type	Harvested Area (acres)	Yield (bu/ac)	Marketed Production ('000 bu)	Marketed Production ('000 tonnes)	Average Price ($/tonne)	Market Value ($'000)
Barley	400	61	24	0.5	102	51
Canola	100	41	4	0.1	192	19
Fodder Corn	500	23	11.7	10.7	23.4	250
Grain Corn	12,500	112	1,398	35.5	107	3,799
Hay	8,600	2.3	19.4	17.6	112.2	1,975

Mixed Grain	1,500	62	93	1.7	100	170
Oats					138	0
Soybeans	22,700	33	740	20.1	232	4,663
Spring Wheat	300	33	10	0.3	156	47
Winter Wheat	7,300	60	435	11.8	139	1,640

Table 4: Hamilton Horticulture and Field Crop Statistics

Crop Type	Harvested Area (acres)	Marketed Production ('000 kgs)	Marketed Yield/acre ('000 kg/lb)	Average Price ($/kg)	Market Value ($'000)
Apples	560	5,995	10.70	0.42	2,537.0
Grapes	699	2,590	3.71	0.89	2,296.0
Peaches	17	65	3.82	1.17	76.0
Strawberries	94	209	2.22	2.43	508.0
Cabbage	364	5,449	14.97	0.22	1,177.0
Carrots					
Onions					
White Beans					
Potato	1200	8,437	7.03	0.22	1,827.0
Tomato	155	5,006	32.30	0.13	673.0
Tobacco					
Green Beans	251	706	2.81	0.42	296.0
Peppers	80	606	7.57	0.67	405.0
Sweet Corn	578	2,727	4.72	0.14	385.0

Crop Type	Harvested Area (acres)	Yield (bu/ac)	Marketed Productio n ('000 bu)	Marketed Production ('000 tonnes)	Average Price ($/tonne)	Market Value ($'000)
Barley	700	46	32	0.7	102	71
Canola					192	0
Fodder Corn	300	18	5.3	4.8	23.4	112
Grain Corn	17,100	115	1,959	49.8	107	5,329
Hay	19,500	2.8	54.6	49.5	112.2	5,554
Mixed Grain	600	72	43	0.8	100	80
Oats	1,900	61	115	1.8	138	248
Soybeans	27,500	32	892	24.3	232	5,638
Spring Wheat	200	51	10	0.3	156	47
Winter Wheat	7,300	56	411	11.2	139	1,557

Table 5: Niagara Horticulture and Field Crop Statistics

Crop Type	Harvested Area (acres)	Marketed Production ('000 kgs)	Marketed Yield/acre ('000 kg/lb)	Average Price ($/kg)	Market Value ($'000)
Apples	770	8,313	10.80	0.42	3,482.0
Grapes	13,740	51,043	3.71	0.90	45,800.0
Peaches	4,923	21,125	4.29	1.13	23,938.0
Strawberries	130	289	2.22	2.43	701.0
Cabbage	72	1,068	14.83	0.21	226.0
Carrots					
Onions					
White Beans					
Potato					
Tomato	112	3,577	31.93	0.13	481.0
Tobacco					
Green Beans					
Peppers	24	181	7.56	0.65	118.0
Sweet Corn	281	1,345	4.79	0.14	190.0

Crop Type	Harvested Area (acres)	Yield (bu/ac)	Marketed Production ('000 bu)	Marketed Production ('000 tonnes)	Average Price ($/tonne)	Market Value ($'000)
Barley	100	51	5	0.1	102	10
Canola					192	0
Fodder Corn	4,800	15	73.9	67	23.4	1,568
Grain Corn	15,900	112	1,776	45.1	107	4,826
Hay	41,700	2.1	87.4	79.3	112.2	8,897
Mixed Grain	600	55	33	0.6	100	60
Oats	500	60	30	0.5	138	69
Soybeans	60,000	38	2,277	62	232	14,384
Spring Wheat	100	50	5	0.1	156	16
Winter Wheat	11,800	47	553	15	139	2,085

All of the crops grown in the study regions have been grouped into three distinct categories. This has been done in order to simplify the market processes and get a larger market size for agricultural water segment to better display the market model's function. Crops are grouped into categories sharing similar properties to create homogeneity as much as possible. Initially, field crops are separated from horticultural crops as shown in Tables 1-5, referred to as

"Grains". Horticultural crops are then subdivided into "Fruits" and "Vegetables" to provided further specification. The reclassification of each crop group and characteristics that comprise each group are shown below.

Table 6: Crop Grouping Summary

Category	Crop Type	Crop Names	Average Value	Growing Cycle
Fruits	Horticulture	Apples Grapes Peaches Strawberries*	>$0.40 / kg	~180 days
Vegetables	Horticulture	Cabbage Carrots Green Beans Onions Peppers Potato Sweet Corn Tobacco** Tomato White Beans	<$0.40 / kg	~120-150 days
Grains	Field Crop	Barley Canola Fodder Corn Grain Corn Hay Mixed Grain Oats Soybean Wheat	~$0.10 / kg	~150 days

*Strawberries have a 90 day growth cycle

**Tobacco is valued at ~$5.00/kg, but does not occur in significant quantities in the study area

Crop Types follow those provided by OMAFRA for categorizing agricultural products. Average price is also provided by OMAFRA farm statistics. Growing cycles were obtained from the Farmer's Administration Organization (FAO), which is an international body dealing with agricultural matters. For the purposes of this analysis, crop type and price served as the primary drivers for the categorizations used. Crop value are considered constant and do not factor in any crop specific price fluctuations, such as what is currently occurring in corn and field crops due to biofuel demand in North America[12].

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[12] Wiggins, Jenny. "Rising Biofuel Demand Pushes Up Crop Prices", <u>Financial Times</u> 19 July 2006.

Given a complete set of agricultural production levels for the entire study region, a comprehensive account of water use can be derived. Irrigation water use for a given area is the sum of each individual crop group's water requirement less the sum of water made available through natural processes such as rainfall. Net Irrigation requirements (NIR) for each crop can be summarized as follows: (source, FAO)

(1) $NIR_C = (R_e - ET_C)$, where;

NIR_C = Net Irrigation Requirements, for crop (C),
R_e = Effective Rainfall,
ET_C = Evapotranspiration for crop (C)

Total or gross irrigation requirements (GIR) can be determined based upon net irrigation requirements and the efficiency of the irrigation techniques and technology being used. As mentioned earlier, it is assumed that high efficiency irrigation methods are being used, resulting in 90% irrigation efficiency.

The evapotranspiration rate (ET) is the combination of two bio-chemical processes occurring for a given crop that determines the rate of water use and dissipation over time. Evaporation is the process of liquid water conversion to water vapour by means of interaction with sunlight occurring on the soil surface, canopy or water body. This is important for determining irrigation requirements, as a percentage of water received to the crop surface will be lost to evaporation before it can be beneficially exploited by the crop. Factors affecting evaporation rates are many, including wind speed, ground cover provided by plant species (i.e. crop ground cover), temperature, humidity, and sunlight intensity (irradiance)[13].

The other process affecting evapotranspiration rate is the amount of transpiration occurring. Transpiration accounts for the movement of water within

[13] Allen, Richard G., Pereira, Luis S., Raes, Dirk, Smith, Martin. "Crop Evapotranspiration – Guidelines for computing crop water requirements" FAO Irrigation and drainage paper 56. 1998, Food & Agricultural Organization. 27 April 2007. <http://www.fao.org/docrep/X0490E/X0490E00.htm>, Chapter 1.

a plant and the subsequent loss of water as vapour through stomata in its leaves. As with evaporation, transpiration rates are affected by wind speed, sunlight intensity, temperature, humidity. Plant type, size and surface and subsurface soil conditions also affect transpiration[14].

Evapotranspiration is normally expressed as mm*day^{-1} and can be considered the rate of loss of water over a given surface area. As one hectare of land contains 10,000m^2 and 1 mm is equal to 0.001 m, a loss of 1 mm of water corresponds to a loss of 10 m^3 of water per hectare. In other words, 1 mm day^{-1} is equivalent to 10 m^3 ha^{-1} day^{-1}. Evapotranspiration can also be expressed in energy form as energy received per unit area. The energy refers to the energy or heat required to vaporize free water. This energy, known as the latent heat of vaporization (*L*), is a function of the water temperature. For example, at 20°C, *L* is about 2.45 MJ kg^{-1}. In other words, 2.45 MJ are needed to vaporize 1 kg or 0.001 m^3 of water. Hence, an energy input of 2.45 MJ per m^2 is able to vaporize 0.001 m or 1 mm of water, and therefore 1 mm of water is equivalent to 2.45 MJ m^{-2}. For this thesis, both of these equivalencies will be used.

It is experimentally difficult to determine the amount water loss attributed to evaporation or transpiration separately, so for practical purposes, each process is combined into the single mechanism of evapotranspiration to determine a plant's water requirements.

There are a number of formulaic and empirical methods to determine evapotranspiration rates for given crops in given soil condition, each with benefits and drawbacks. For this analysis, a formulaic approach is used that relies on temperature, solar intensity and crop type to determine a base ET rate from which individual crop ET rates can be derived. The base evapotranspiration rate can be expressed in the form of the Hargreaves ET_O equation:

(2) $ET_O = 0.0023\,(T_{mean} + 17.8)(T_{max} - T_{min})^{0.5}\,R_a$, where;

[14] *ibid*

ET_O = the base evapotranspiration rate for standard grass crop expressed in mm * day^{-1};

T_{mean} = Mean temperature expressed in °C

T_{max} = Observed maximum daily temperature expressed in °C

T_{min} = Observed daily minimum temperature expressed in °C

R_a = extraterrestrial radiation expressed in mm day^{-1}

Temperature data are available from the Canadian national weather office in the form of monthly daily, maximum and minimum temperature readings. Daily temperatures for each month are averaged over a 30-year historical dataset to provide a monthly temperature average.

Table 7: Regional Temperature Statistics

Region: Durham Climate ID: 6155878	Latitude: 43° 52.200' N Longitude: 78° 49.800' W Elevation: 83.80 m

Temperature (°C)	*J*	*F*	*M*	**A**	**M**	**J**	**J**	**A**	**S**	O	N	D
Mean	*-5.3*	*-4.4*	*0.1*	**6.3**	**12.3**	**17.2**	**20.3**	**19.6**	**15.5**	*9.2*	*4.0*	*-2.0*
Max	*-1.4*	*-0.6*	*4.1*	**10.5**	**17.0**	**21.9**	**25.0**	**24.0**	**19.7**	*13.1*	*7.2*	*1.5*
Min	*-9.2*	*-8.2*	*-3.8*	**2.0**	**7.6**	**12.4**	**15.5**	**15.2**	**11.2**	*5.2*	*0.7*	*-5.4*

Region: Peel, Toronto Climate ID: 6158733	Latitude: 43° 40.800' N Longitude: 79° 37.800' W Elevation: 173.40 m

Temperature (°C)	*J*	*F*	*M*	**A**	**M**	**J**	**J**	**A**	**S**	O	N	D
Mean	*-6.3*	*-5.4*	*-0.4*	**6.3**	**12.9**	**17.8**	**20.8**	**19.9**	**15.3**	*8.9*	*3.2*	*-2.9*
Max	*-2.1*	*-1.1*	*4.1*	**11.5**	**18.8**	**23.7**	**26.8**	**25.6**	**21.0**	*13.9*	*7.0*	*0.9*
Min	*-10.5*	*-9.7*	*-5.0*	**1.0**	**6.9**	**11.9**	**14.8**	**14.0**	**9.6**	*3.9*	*-0.7*	*-6.7*

Region: Halton Climate ID: 615N745	Latitude: 43° 28.800' N Longitude: 79° 37.800' W Elevation: 86.90 m

Temperature (°C)	*J*	*F*	*M*	**A**	**M**	**J**	**J**	**A**	**S**	O	N	D
Mean	*-4.9*	*-4.2*	*0.1*	**6.2**	**12.1**	**17.5**	**20.7**	**20.0**	**15.5**	*9.3*	*3.9*	*-1.8*
Max	*-0.6*	*0.2*	*4.7*	**11.2**	**17.6**	**23.0**	**26.2**	**25.1**	**20.8**	*14.0*	*8.0*	*2.3*
Min	*-9.2*	*-8.7*	*-4.4*	**1.2**	**6.6**	**12.0**	**15.3**	**14.9**	**10.2**	*4.5*	*-0.1*	*-5.9*

Region: Hamilton	Latitude: 43° 10.200' N											
Climate ID: 6153194	Longitude: 79° 55.800' W											
	Elevation: 237.70 m											
Temperature (°C)	*J*	*F*	*M*	**A**	**M**	**J**	**J**	**A**	**S**	O	N	D
Mean	*-6.0*	*-5.2*	*-0.3*	**6.3**	**12.9**	**18.0**	**20.8**	**19.8**	**15.5**	*9.1*	*3.3*	*-2.7*
Max	*-2.2*	*-1.2*	*4.0*	**11.2**	**18.5**	**23.7**	**26.3**	**25.1**	**20.7**	*13.8*	*7.0*	*0.9*
Min	*-9.7*	*-9.1*	*-4.5*	**1.2**	**7.3**	**12.4**	**15.1**	**14.5**	**10.2**	*4.4*	*-0.4*	*-6.2*

Region: Niagara	Latitude: 43° 7.800' N											
Climate ID: 6135638	Longitude: 79° 4.800' W											
	Elevation: 182.90 m											
Temperature (°C)	*J*	*F*	*M*	**A**	**M**	**J**	**J**	**A**	**S**	O	N	D
Mean	*-4.5*	*-4.1*	*1.0*	**7.3**	**14.0**	**19.1**	**22.3**	**21.4**	**16.9**	*10.6*	*4.7*	*-1.4*
Max	*-1.0*	*-0.5*	*5.1*	**12.2**	**19.3**	**24.2**	**27.2**	**26.0**	**21.3**	*14.7*	*8.0*	*1.9*
Min	*-7.9*	*-7.7*	*-3.2*	**2.4**	**8.6**	**13.9**	**17.2**	**16.7**	**12.5**	*6.4*	*1.3*	*-4.7*

Extraterrestrial radiation (R_a) is normally available through publicly available information for many geographic locations. Alternatively, it can be derived using the following formula, provided by the Food and Agriculture Organization of the United Nations (FAO):

(3) $R_s = 0.7\ R_a - b$, where;

R_s = Solar radiation, expressed in MJ m^{-2} day^{-1};
R_a = Extraterrestrial radiation, expressed in MJ m^{-2} day^{-1};
b = Empirical constant of 4 MJ m^{-2} day^{-1}

Natural Resources Canada provides an average level of solar radiation of 14 MJ m^{-2} day^{-1} for most of the southern portions of Canada where major population centers are located. Given solar radiation and the empirical constant b, which accounts for cloud cover, extraterrestrial radiation can be derived. Solving for R_a, a value of 25.71 MJ m^{-2} day^{-1} is obtained. This can be converted to an evapotranspiration compatible metric, given that 1 MJ m^{-2} day^{-1} is equivalent to 0.408 mm day^{-1}. Using this conversion rate, Ra is calculated at 10.49 mm day^{-1}.

Given the relatively small geographic size of the study area, it is assumed that a single value for solar radiation, and hence extraterrestrial radiation is sufficient. Furthermore, there is a relationship between temperature and radiation levels that is not taken into account. A more accurate reflection of solar radiation levels can be derived through direct measurement, however, this is outside the scope of the analysis.

Using solar radiation and regional temperature measurements over the past 30 years, the base evapotranspiration provided in equation 2 can be calculated for each region.

(2) $ET_O = 0.0023\,(T_{mean} + 17.8)(T_{max} - T_{min})^{0.5}\,R_a$

Table 8: Base Evapotranspiration Rates by Region

ET_O (mm * day^{-1})	April	May	June	July	Aug.	Sept.
Region: Durham	*1.70*	*2.23*	*2.60*	*2.83*	*2.68*	*2.34*
Region: Peel, Toronto	*1.88*	*2.56*	*2.95*	*3.23*	*3.10*	*2.70*
Region: Halton	*1.83*	*2.39*	*2.83*	*3.07*	*2.91*	*2.62*
Region: Hamilton	*1.84*	*2.48*	*2.90*	*3.12*	*2.95*	*2.60*
Region: Niagara	*1.90*	*2.51*	*2.86*	*3.06*	*2.88*	*2.48*

Using base evapotranspiration rates calculated in Table 8, crop specific ET rates can be derived. To calculate crop specific evapotranspiration rates (ET_c), the following formula is used:

(4) $ET_C = ET_0 * K_C$, where;

ET_C = Evapotranspiration rate for each individual crop, expressed in mm day^{-1};
ET_0 = Base Evapotranspiration rate, expressed in mm day^{-1};
K_C = Crop coefficient for each individual crop

As stated previously, crops were amalgamated into 3 distinct crop groupings. Each grouping contains crops sharing similar characteristics of growing time, crop co-efficients, yield and plant characteristics. Crop specific evapotranspiration rates are applied to the group as a whole for the purposes of this analysis.

Crop groups have simply been labeled as fruits, vegetables, and grains. For each group, an average crop co-efficient has been calculated for each stage of crop growth. Each crop group has also been assigned growth stage lengths divided into initial, mid, and end stages. The exception to this is with grain crops, as the majority, with the exception of winter wheat, does not have a discernable initial stage requiring a unique crop coefficient. For each group, the crop co-efficient is calculated by applying the length of the growth stage, in days, to the crop co-efficient for that stage. Each weighted stage-level co-efficient is then amalgamated into an average crop coefficient for the entire growing season. The results are presented below.

Table 9: Crop Co-Efficient by Crop Group

	Initial Growing Period (Days)	$K_{C\ INI}$	Mid Growing Period (days)	$K_{C\ MID}$	End Growing Period (days)	$K_{C\ END}$	**Total Growing Period (days)**	**Average K_C**
Fruit	30	0.65	100	1.00	50	0.90	**180**	**0.91**
Vegetable	30	0.65	80	1.10	30	1.00	**140**	**0.98**
Grain			105	0.95	35	0.40	**135**	**0.83**

Using equation (4), each crop group specific evapotranspiration rate (ET_C) is calculated for all months and regions of the analysis. The results are presented in Table 10. Using an average crop coefficient across time and crop type creates two potential smoothing functions, eliminating water demand peaks during summer months, and moving all individual crop water requirements to a central average. Water demand peaks are somewhat reinforced through higher base evpaotranspiration rates in hotter months; however, the peaks are lower than they would be otherwise. This is compensated by a higher than normal water requirement in the initial and end months for crops. Unfortunately, for the study area, the early spring months have a relative abundance of naturally occurring water through increased rainfall and lower temperatures, masking the higher crop requirements present via crop coefficient smoothing. This is primarily due to the fact that the amount of water available for crops exceeds the crop requirements despite the increased demand through K_C smoothing. This cannot be said for the summer months when evapotranspiration rates become elevated, exceeding available water occurring naturally. Therefore, irrigation requirements for the system may be potentially understated as smoothing effects are generally recognized in time periods where there is downward pressure on actual water requirements due to the use of an average crop coefficient.

Table 10: Crop Group Evapotranspiration Rates

Durham	April	May	June	July	Aug.	Sept.
ET_O (mm * day^{-1})	*1.7*	*2.2*	*2.6*	*2.8*	*2.7*	*2.3*
ET_C (mm * day^{-1})						
Fruit	1.5	2.0	2.4	2.6	2.4	2.1
Vegetable	1.7	2.2	2.6	2.8	2.6	2.3
Grain	1.4	1.8	2.2	2.3	2.2	1.9

Toronto, Peel	April	May	June	July	Aug.	Sept.
ET_O (mm * day^{-1})	*1.9*	*2.6*	*3.0*	*3.2*	*3.1*	*2.7*
ET_C (mm * day^{-1})						
Fruit	1.7	2.3	2.7	2.9	2.8	2.5
Vegetable	1.9	2.5	2.9	3.2	3.0	2.6
Grain	1.6	2.1	2.4	2.7	2.6	2.2

Halton	April	May	June	July	Aug.	Sept.
ET_O (mm * day^{-1})	*1.8*	*2.4*	*2.8*	*3.1*	*2.9*	*2.6*
ET_C (mm * day^{-1})						
Fruit	1.7	2.2	2.6	2.8	2.7	2.4
Vegetable	1.8	2.4	2.8	3.0	2.9	2.6
Grain	1.5	2.0	2.3	2.5	2.4	2.2

Hamilton	April	May	June	July	Aug.	Sept.
ET_O (mm * day^{-1})	*1.8*	*2.5*	*2.9*	*3.1*	*3.0*	*2.6*
ET_C (mm * day^{-1})						
Fruit	1.7	2.3	2.7	2.8	2.7	2.4
Vegetable	1.8	2.4	2.9	3.1	2.9	2.6
Grain	1.5	2.1	2.4	2.6	2.4	2.2

Niagara	April	May	June	July	Aug.	Sept.
ET_O (mm * day^{-1})	*1.9*	*2.5*	*2.9*	*3.1*	*2.9*	*2.5*
ET_C (mm * day^{-1})						
Fruit	1.7	2.3	2.6	2.8	2.6	2.3
Vegetable	1.9	2.5	2.8	3.0	2.8	2.4
Grain	1.6	2.1	2.4	2.5	2.4	2.1

With crop groupings and evapotranspiration rates now available, each crop group's monthly water requirement can be calculated. Evapotranspiration rates are a function of the water lost due to evaporation and transpiration processes in a given day. Therefore, daily rates can be extrapolated to monthly rates in a straightforward manner. Table 11 provides the monthly and season total water requirements for each crop grouping on a per acre basis. Therefore, the values can be interpreted as the depth of water (in mm) that is required to blanket each acre of crop area in order to satisfy water demands for the specified time period.

Table 11: Crop Group Water Requirements

Durham	April	May	June	July	Aug.	Sept.	Season
Fruits	46.48	63.09	71.37	80.28	75.85	64.23	401.29
Vegetables	49.96	67.80	76.70	86.28	81.51	69.03	431.27
Grains	42.10	57.14	64.64	72.72	68.70	58.18	363.48

Peel, Toronto	April	May	June	July	Aug.	Sept.	Season
Fruits	51.66	72.40	80.90	91.41	87.78	73.94	458.09
Vegetables	55.52	77.81	86.95	98.24	94.33	79.46	492.30
Grains	46.80	65.58	73.28	82.80	79.51	66.97	414.93

Halton	April	May	June	July	Aug.	Sept.	Season
Fruits	50.21	67.79	77.45	86.89	82.53	71.73	436.61
Vegetables	53.96	72.86	83.24	93.38	88.69	77.08	469.22
Grains	45.48	61.41	70.16	78.71	74.75	64.97	395.47

Hamilton	April	May	June	July	Aug.	Sept.	Season
Fruits	50.42	70.24	79.62	88.31	83.69	71.39	443.66
Vegetables	54.18	75.48	85.56	94.91	89.94	76.72	476.79
Grains	45.67	63.62	72.11	79.99	75.80	64.66	401.85

Niagara	April	May	June	July	Aug.	Sept.	Season
Fruits	51.98	71.11	78.35	86.69	81.72	68.10	437.95
Vegetables	55.87	76.42	84.20	93.16	87.83	73.19	470.66
Grains	47.09	64.41	70.96	78.52	74.02	61.68	396.69

*** All units in millimeters (mm)**

The necessary water required for each crop group is provided through a mix of naturally occurring sources via rain and human induced sources via irrigation. To determine what the irrigation requirement is, rainfall must be accounted for, as stated in equation (1).

(1) $NIR_C = (R_e - ET_C)$

The Canadian Weather Office provides 30 year averaged precipitation data as part of the same data set used in temperature calculations. These data can be used to calculate regional precipitation levels for all regions in the study area. Like irrigation, however, precipitation (rainfall) is not 100% efficient in delivery of water to the crop for use. A key factor in reduced water delivery to a crop through rainfall is in the surface and sub-surface saturation of water levels such that excess water provided is not available for use by the plant. This occurs primarily through extreme precipitation events, where excess water delivered becomes runoff before being utilized by the crop. The amount of rainfall that can be used by the crop is labeled "effective rainfall" (R_e). The most accurate way of calculating effective rainfall for a given farm or irrigation area is through direct measurement. In direct measurement, both spatial and volumetric intensity can be measured to determine effective rainfall over the measurement period. While this method is highly accurate, it is most useful when used it is site specific, involving management at the farm or community level.

For an analysis involving multiple regions and time periods, an approximation is required. Using a fixed amount of time for an observation period (ie. 1 month), the effective rainfall can be approximated given the volume of rainfall over the observed period. The United States Bureau of Reclamation

(USBR) has provided a guideline to calculating effective rainfall under these circumstances[15]. The underlying assumption is that over a fixed period of time, a greater total volume of rainfall correlates positively with the probability of extreme rainfall and hence, saturation events. The USBR table is provided below.

Table 12: Effective Rainfall Reference Table (in inches)

Rainfall (R)	Effective Rainfall (R_e)
$R < 1$	$R_e = 0.95R$
$1 < R < 2$	$R_e = 0.95 + 0.9(R-1)$
$2 < R < 3$	$R_e = 1.85 + 0.82(R-2)$
$3 < R < 4$	$R_e = 2.67 + 0.65(R-3)$
$4 < R < 5$	$R_e = 3.32 + 0.45(R-4)$
$5 < R < 6$	$R_e = 3.77 + 0.25(R-5)$
$R > 6$	$R_e = 4.02 + 0.05(R-6)$

Using the 30-year average rainfall rates for all regions of the study area in Table 13, effective rainfall for each area can be calculated. Note that rainfall data were accumulated from the same weather stations used for temperature data in this analysis.

Table 13: 30-Year Historical Rainfall Rates by Region

Effective Rainfall in millimeters (mm)

	April	May	June	July	Aug.	Sept.
Durham	65.28	66.59	71.43	60.52	72.43	75.42
Peel, Toronto	61.42	64.78	66.18	66.34	70.03	68.66
Halton	60.77	62.98	63.80	65.11	69.25	69.31
Hamilton	68.99	67.33	72.82	74.51	70.68	71.65
Niagara	67.24	68.01	75.16	67.16	71.33	80.17

Effective Rainfall in inches (in)

	April	May	June	July	Aug.	Sept.
Durham	2.57	2.62	2.81	2.38	2.85	2.97
Peel, Toronto	2.42	2.55	2.61	2.61	2.76	2.70
Halton	2.39	2.48	2.51	2.56	2.73	2.73

[15] Brower, Al. ET Toolbox Evapotranspiration Toolbox for the Middle Rio Grande, A Water Resources Decision Support Tool. 1 May 2008, US Beareau of Reclamation, 31. <http://www.usbr.gov/pmts/rivers/awards/ettoolbox.pdf>

Hamilton	2.72	2.65	2.87	2.93	2.78	2.82
Niagara	2.65	2.68	2.96	2.64	2.81	3.16

With effective rainfall for each region available, net irrigation requirements (NIR) for each crop group, time period, and region can be calculated. These values, found in Table 14, represent the amount of irrigated water required by each crop group before irrigation efficiency issues are considered. As with the crop water requirements presented in Table 14, these values determine the depth of water (in mm) that needs to blanket each acre of crop area in order to meet water requirements not satisfied through natural processes. In instances where the value is negative, rainfall provides more than enough water for the given months to meet water requirements. It is assumed that no significant water storage capabilities are in use for agriculture for this thesis so that no excess water is carried forward for use in subsequent months. For months where excess rainwater exists, net irrigation requirements are assumed to be 0.

Table 14: Crop Group Net Irrigation Requirements (NIR)

Durham	April	May	June	July	Aug.	Sept.	Season
Fruits	-18.79	-3.50	-0.06	19.76	3.41	-11.19	23.17
Vegetables	-15.32	1.21	5.27	25.76	9.08	-6.40	41.32
Grains	-23.17	-9.44	-6.78	12.20	-3.73	-17.25	12.20

Peel, Toronto	April	May	June	July	Aug.	Sept.	Season
Fruits	-9.76	7.61	14.73	25.07	17.75	5.27	70.43
Vegetables	-5.90	13.02	20.77	31.90	24.31	10.80	100.79
Grains	-14.63	0.79	7.10	16.46	9.48	-1.69	33.83

Halton	April	May	June	July	Aug.	Sept.	Season
Fruits	-10.56	4.81	13.65	21.78	13.28	2.41	55.94
Vegetables	-6.81	9.88	19.44	28.27	19.45	7.77	84.80
Grains	-15.29	-1.57	6.36	13.59	5.51	-4.35	25.46

Hamilton	April	May	June	July	Aug.	Sept.	Season
Fruits	-18.57	2.91	6.79	13.80	13.01	-0.27	36.51
Vegetables	-14.80	8.16	12.74	20.39	19.26	5.07	65.61
Grains	-23.32	-3.71	-0.71	5.48	5.12	-6.99	10.60

Niagara	April	May	June	July	Aug.	Sept.	Season
Fruits	-15.26	3.10	3.18	19.53	10.40	-12.07	36.20
Vegetables	-11.38	8.41	9.04	26.00	16.50	-6.98	59.94
Grains	-20.16	-3.60	-4.20	11.36	2.69	-18.48	14.05

*** All units in millimitres (mm)**

To determine water requirements for each crop group and region at an aggregate level, spatial considerations need to be factored in. Evapotranspiration rates, and hence, net irrigation requirements are calculated in the form of a rate, specifically mm day^{-1}. To derive overall agricultural water use within the system, these rates must be applied to the acreage available for each crop. Using the crop statistics provided in Tables 1-5, aggregate net irrigation requirements can be derived using the formula:

(5) $ANIR_C = NIR_C \times V \times a_C$, where;

$ANIR_C$ = Aggregate Net Irrigation Requirement, for crop (C)
NIR_C = Net Irrigation Requirement, for crop (C)
V = volumetric constant of 4046.94 L/acre
a_C = Total acreage, for crop (C)

The volumetric constant (V), is derived from the earlier stated notion that 1 mm day^{-1} is equivalent to 10 m^3 ha^{-1} day^{-1}. Removing the time component from each term due to the fact that values have been converted from a rate to a monthly total, an equivalency of 1mm to 10 m^3 ha^{-1} remains. Since 1 hectare equals 10,000m^2 , a 1mm volume covering that area equates to 10m^3 of total volume (10,000m^2 x 0.001m). There are 1,000L per cubic metre, therefore each 1mm of NIR is equivalent to 10,000L of water. Converting units from hectares to acres by dividing by 2.471, the resulting volume of 4,046.94 L/acre results. Restated, every millimetre of irrigation required is equivalent to 4,046.94 litres of water per acre of crop.

It is assumed that irrigation efficiency for all regions in the subject area is 90%. Therefore, aggregated net irrigation requirements must be divided by the irrigation efficiency to determine aggregated gross irrigation requirements.

(6) $GIR_C = ANIR_C / IE$, where;

GIR_C = Gross Irrigation Requirement, for crop (C)
$ANIR_C$ = Aggregate Net Irrigation Requirement, for crop (C)
IE = Irrigation Efficiency, expressed as a percentage

Gross Irrigation Requirements (GIR) are presented in Table 15.

Table 15: Crop Group Gross Irrigation Requirements (GIR)

Durham	April	May	June	July	Aug.	Sept.	Season
Fruits	-	-	-	19.76	3.41	-	23.17
Vegetables	-	1.21	5.27	25.76	9.08	-	41.32
Grains	-	-	-	12.20	-	-	12.20

Peel, Toronto	April	May	June	July	Aug.	Sept.	Season
Fruits	-	7.61	14.73	25.07	17.75	5.27	70.43
Vegetables	-	13.02	20.77	31.90	24.31	10.80	100.79
Grains	-	0.79	7.10	16.46	9.48	-	33.83

Halton	April	May	June	July	Aug.	Sept.	Season
Fruits	-	4.81	13.65	21.78	13.28	2.41	55.94
Vegetables	-	9.88	19.44	28.27	19.45	7.77	84.80
Grains	-	-	6.36	13.59	5.51	-	25.46

Hamilton	April	May	June	July	Aug.	Sept.	Season
Fruits	-	2.91	6.79	13.80	13.01	-	36.51
Vegetables	-	8.16	12.74	20.39	19.26	5.07	65.61
Grains	-	-	-	5.48	5.12	-	10.60

Niagara	April	May	June	July	Aug.	Sept.	Season
Fruits	-	3.10	3.18	19.53	10.40	-	36.20
Vegetables	-	8.41	9.04	26.00	16.50	-	59.94
Grains	-	-	-	11.36	2.69	-	14.05

*** All units in millions of litres (ML)**

Using residential, commercial/industrial, agricultural and system loss data, a comprehensive record of water consumption for the April to September time period is generated for all regions within the study. A summary of water consumption is provided in Appendix A.

Information concerning the price of water is similar to the consumption data in that it is readily available for municipal use activities and must be derived for agricultural activities.

For commercial / industrial and residential use, user costs can be directly obtained from utility data available publicly for each region. The rates are applied at a cost per m^3 and in some cases contain block pricing with discounts for high volume use. For this study, the first pricing tier is used, as per user volume is unknown. Prices are further divided into two parts, water use fees and sewer surcharges. Water use fees are designed to cover the costs of pumping and delivery to the user network, while sewer surcharges cover the cost of transportation back to the network, filtration and cleaning, and eventual delivery to the distribution system. For regions where the sewer surcharges are not specifically identified, it is assumed that it is 50% of overall price. Price differentiation can also occur between residential and commercial / industrial uses. Residential rates are not consistently lower or higher than commercial / industrial for all regions, with a variability of no more than 15.5% in any instance. All utility rates are presented in Table 16.

Table 16: Regional Utility Rates

	Published Rate		**Sewer Surchage (already incl. in totals)**		**Base Rate (Gross Rate less Surcharge)**	
($\$/m^3$)	Residential	Commercial	Residential	Commercial	Residential	Commercial
Durham	$ 1.49	$ 1.29	$ 0.93	$ 0.82	$ 0.56	$ 0.48
Halton	$ 1.62	$ 1.68	$ 0.79	$ 0.79	$ 0.84	$ 0.89
Hamilton	$ 1.70	$ 1.70	$ 0.85	$ 0.85	$ 0.85	$ 0.85
Niagara	$ 1.46	$ 1.46	$ 0.88	$ 0.88	$ 0.58	$ 0.58
Peel	$ 0.95	$ 1.06	$ 0.45	$ 0.56	$ 0.50	$ 0.50
Toronto	$ 1.42	$ 1.47	$ 0.66	$ 0.67	$ 0.76	$ 0.80

Source: http://www.ec.gc.ca/water/en/manage/use/e_mun.htm. Accessed May 2, 2007.

Agricultural water use is largely un-metered, providing no published consumption price for current use. Most farmers have access to irrigation systems, private, or shared wells for agriculture practices. Though these systems do have costs associated with their construction and use, there is no easily discernable way to determine what these costs are at a regional level. Therefore, in order to determine a price point for agricultural water use, a potential maximum cost for each crop group must be derived using water consumption rates and sales statistics for all crops.

Using gross irrigation requirements and production yields for each crop grouping; a water efficiency rate can be derived. This rate, expressed in kg/L, denotes the mass of a crop grouping produced per litre of water input. The efficiency is applied to the gross irrigation requirement to correctly identify the amount of irrigated water needed by the system and not the amount of irrigated water needed by the crop itself. With water efficiencies expressed in kg/L and crop sales prices known in $/kg, crop pricing expressed in $/L can be derived. Assuming a generous net profit margin for crops of 20%, profit expressed in $/L is available[16]. If it is assumed that agriculture can pay for water up to the point of 0% profit margin, then the users choke price for water if a price were attached for growers would equal the profit per litre[17]. Efficiencies and crop pricing per litre for each crop group and region are provided in Table 17.

[16] Actual operating profit margins can vary between farm size, location and crop type.
[17] Choke price refers to the maximum price the user is willing to pay for water while maintaining a unit revenue greater than zero.

Table 17: Crop Efficiencies and Pricing[18]

Region/Crop	Yield Efficiency (kg/litre)	Crop Price Efficiency ($/litre)	Crop Profit Efficiency ($/litre)	Crop Profit Efficiency ($/m3)
Durham				
Fruits	0.0921	$ 0.0441	$ 0.0088	$ 8.82
Vegetables	0.0257	$ 0.0055	$ 0.0011	$ 1.09
Grains	0.0421	$ 0.0047	$ 0.0009	$ 0.94
Halton				
Fruits	0.0349	$ 0.0206	$ 0.0041	$ 4.13
Vegetables	0.0110	$ 0.0019	$ 0.0004	$ 0.38
Grains	0.0159	$ 0.0020	$ 0.0004	$ 0.41
Hamilton				
Fruits	0.0404	$ 0.0247	$ 0.0049	$ 4.94
Vegetables	0.0296	$ 0.0061	$ 0.0012	$ 1.23
Grains	0.0400	$ 0.0052	$ 0.0010	$ 1.04
Niagara				
Fruits	0.0254	$ 0.0233	$ 0.0047	$ 4.65
Vegetables	0.0468	$ 0.0077	$ 0.0015	$ 1.54
Grains	0.0315	$ 0.0037	$ 0.0007	$ 0.75
Peel				
Fruits	0.0290	$ 0.0158	$ 0.0032	$ 3.16
Vegetables	0.0153	$ 0.0026	$ 0.0005	$ 0.52
Grains	0.0171	$ 0.0017	$ 0.0003	$ 0.34

[18] Differences in yield efficiencies between identical crop types are due to environmental factors specific to each region, including rainfall and average temperature.

Methodology

The objective of the model is to simulate, economically, the effects on each region and user group under different water scarcity scenarios. For each scenario, there are two simulations. The first simulation is the "business as usual" model, which contains no market for the trading of water rights. Under this model, each user is allocated a percentage of the available water under a scarcity condition based upon their usage in the base case. The second simulation is the "water market" model, which contains provisions for the purchase and/or sale of water rights to other users. What follows is a description of each scenario and how both models are intend to function.

There are four scenarios that describe potential situations of water scarcity for the study region. The first scenario is the "base scenario", which uses current measured water use and applies each model to determine economic benefits and usage patterns. The other three scenarios can be described as "scarcity scenarios" with water availability of 80%, 60%, and 40% of current totals. These percentages were chosen to reflect both varying degrees of scarcity for comparison, and a realistic range of scarcity within the system. It is important to note that each scarcity scenario reflects the available supply of water for the end user, with system losses and positive feedback loops associated with drought conditions already discounted.

For each scenario, the business as usual case involves no trading or market mechanisms of any kind. This is contrasted against the market mechanisms described earlier. For the business as usual scenario, it is assumed each user consumes a proportionate amount of available water resources equal to their share from the base case. As an example, if residential user "A" used 35% of available water in for their region in the base scenario, then they will continue to use 35% of available water regardless of the total amount of water resources present.

In order to run each scenario and determine the economic outcomes that result, a water demand curve must be derived for each user. Demand curves are assumed to be linear and are based upon available consumption, pricing, and elasticity data. Consumption – price pairings are available for residential and commercial/industrial users via utility meter rates and usage readings. In the case of agriculture, however, price data were derived based upon crop sales price and crop water requirements at current production rates.

To determine each user's demand curve, we begin with the equation for linear demand, with the traditionally dependent variable of quantity on the right hand side of the equation:

(7) $P = a - bQ$, where;

Q = Quantity
P = Price
a = Choke price (y-intercept)
b =Slope of inverse demand

For residential and commercial / industrial users, sufficient data are available to determine demand curves directly. Elasticity (E) for water for both residential and commercial users has been investigated in previous studies, most notably McNeil and Tate (1991), and Tate, Renzetti & Shaw (1992). Mahan *et al* (2002) also used elasticity's for both residential and commercial water use in their study of Alberta water markets. The following table summarizes previous work on this subject. Elasticity values from McNeil and Tate (1991) were used for this analysis based upon the existence of both residential and commercial values for elasticity and additionally the existence of a min, max and mean value for industrial/commercial, which corresponds to the HVU, MVU, and LVU users respectively.

Table 18: Water Consumption Elasticities

	Min	Max	Mean
McNeil and Tate (1991) Residential	-0.10	-1.00	-0.25

Industrial/Commercial	**-0.05**	**-1.00**	**-0.50**
Tate, Renzetti, Shaw (1992) Industrial/Commercial	**-0.354**	**-1.202**	
Mahan, Horbulyk, Rowse Residential Industrial/Commercial			**-0.5** **-0.5**

Given that residential and commercial users have a known elasticity and a price quantity pairing, both intercepts and slopes of inverse demand can be derived.

To determine the slope of inverse demand, the given elasticity for each user is used. Inverse slope of demand is a function of the change in price versus the change in quantity, or:

(8) $b = \Delta P / \Delta Q$

Elasticity can also be expressed in terms of price and quantity. Elasticity, at any given point of the demand curve can be expressed as the percentage change in quantity corresponding to a percentage change in price at the given point of that curve. Mathematically, it is expressed as:

(9) $E = (\Delta Q/Q) / (\Delta P/P)$

(10) $E = (P/Q) * (\Delta Q/\Delta P)$

(11) $E / (\Delta Q/\Delta P) = P/Q$

(12) $E (\Delta P/\Delta Q) = P/Q$

(13) $\Delta P/\Delta Q = (P/Q) (1/E)$

* Note that E is expressed as an absolute value in this equation.

Substituting equation (8) into equation (13);

(14) $b = (P/Q) (1/E)$

From equation (14) all residential and commercial/industrial slopes of inverse demand can be calculated given the current price-usage combinations and assumed elasticities. The results are presented in Table 19.

To determine the choke price (x-intercept), a linear demand curve is assumed.

$$(7) \qquad P = a - bQ$$

This equation can be restated as:

$$(15) \qquad a = P + bQ$$

Substituting the values from known price quantity pairings and the inverse slope of demand derived from equation (14), choke prices are calculated. The results are presented in Table 19.

Rewriting equation (7) to the more traditional equation, with the quantity (Q) on the left hand side of the equation;

$$(16) \qquad Q = a/b - P(1/b)$$

Under equation (16), the y-intercept and slope of demand are derived. The y-intercept is a function of the x-intercept and slope of inverse demand (a/b), while the slope of demand is expressed as the inverse of the inverse slope of demand (1/b). Both the y-intercept and the slope of demand are expressed in Table 19.

For agricultural users, different data are available compared to residential and commercial/industrial users, preventing a straightforward calculation of demand curves. As with residential and commercial/industrial users, a linear demand curve, solving for price is assumed;

(7) $P = a - bQ$

Both the quantity demanded at zero price as well as the choke price is available for agricultural users. Setting the price equal to zero in (7), the inverse slope of demand is given by;

(17) $0 = a - bQ$

(18) $bQ = a$

(19) $b = a/Q$

At zero price, both the quantity and the value of the x-intercept are known, allowing calculation of the inverse slope of demand. To determine slope of the demand curve, the inverse of b is calculated. Demand curve data for agricultural users are shown in Table 19.

With all demand functions derived, the aggregate demand functions can be calculated. Due to the use of demand curves and the varying choke prices for each user and region, the aggregate demand function becomes a series of functions as users leave the market. At each known choke price, the user associated at that price will no longer be willing to purchase any water resources, effectively removing their demand from the market. The result is an aggregate demand curve with 39 separate linear curve segments reflecting the escalating number of users leaving the market as price increases. Therefore, for each segment of the curve, there exists a different x-intercept, y-intercept and slope. The resulting curve is depicted in Figure 2. For illustration, each line segment represents the aggregate demand curve for n number of participants at a given price. Note that each segment is only a true reflection of the market when all participants within the segment have choke prices above market price. The thickness of each segment represents the diminishing number of users willing to purchase water as the price rises beyond their respective choke point. As a choke price is reached, a user is removed from the market and a new line segment with n=current number of participants reflects the current aggregate demand. In the figure below, the overall demand curve is demonstrated as the rightmost section of all line segments at any given price point.

Figure 2: Graphical Representation of the Aggregate Demand Curve

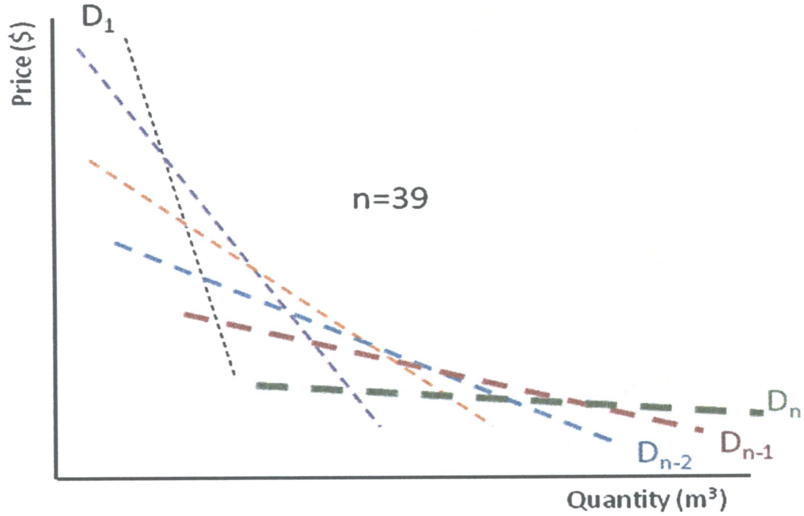


Table 19: Crop Demand Curve Statistics

	Elasticity	Slope of Inverse Demand	y-intercept (Choke Price)	x-intercept (m3)	Slope of Demand
Durham					
Residential	0.25	2.79E-07	7.45	26,720,695	3,586,670.43
High Value Industrial	0.05	6.94E-06	27.17	3,917,170	144,151.39
Mid Value Industrial	0.50	6.94E-07	3.88	5,595,957	1,441,513.91
Low Value Industrial	1.00	3.47E-07	2.59	7,461,276	2,883,027.82
Fruit		6.49E-05	8.82	135,990	15,416.31
Vegetables		2.86E-06	1.09	382,092	349,284.50
Grain		8.06E-08	0.94	11,641,920	12,400,327.70
Halton					
Residential	0.25	3.35E-07	8.11	24,205,524	2,985,203.72
High Value Industrial	0.05	1.18E-05	35.18	2,986,716	84,910.18
Mid Value Industrial	0.50	1.18E-06	5.03	4,266,737	849,101.79
Low Value Industrial	1.00	5.89E-07	3.35	5,688,982	1,698,203.58
Fruit		4.54E-05	4.13	90,797	22,007.79
Vegetables		8.90E-07	0.38	426,786	1,123,664.51
Grain		6.63E-08	0.41	6,169,907	15,089,485.51
Hamilton					
Residential	0.25	1.71E-07	8.51	49,797,091	5,851,597.03
High Value Industrial	0.05	4.12E-06	35.74	8,681,606	242,896.48
Mid Value Industrial	0.50	4.12E-07	5.11	12,402,294	2,428,964.81
Low Value Industrial	1.00	2.06E-07	3.40	16,536,392	4,857,929.61
Fruit		2.25E-05	4.94	219,422	44,439.60
Vegetables		1.58E-06	1.23	775,360	631,097.94
Grain		2.91E-07	1.04	3,579,772	3,438,208.39
Niagara					
Residential	0.25	2.48E-07	7.28	29,336,799	4,029,780.03
High Value Industrial	0.05	8.45E-06	30.58	3,619,863	118,389.02
Mid Value Industrial	0.50	8.45E-07	4.37	5,171,232	1,183,890.18
Low Value Industrial	1.00	4.22E-07	2.91	6,894,976	2,367,780.36
Fruit		1.46E-06	4.65	3,178,692	683,437.91
Vegetables		1.17E-05	1.54	131,808	85,582.75
Grain		8.71E-08	0.75	8,562,586	11,486,516.21
Peel					
Residential	0.25	8.54E-08	4.73	55,407,198	11,707,807.35
High Value Industrial	0.05	2.30E-06	22.22	9,659,670	434,644.51
Mid Value Industrial	0.50	2.30E-07	3.17	13,799,529	4,346,445.13
Low Value Industrial	1.00	1.15E-07	2.12	18,399,372	8,692,890.25
Fruit		3.31E-05	3.16	95,358	30,169.60
Vegetables		2.98E-06	0.52	175,388	335,744.66
Grain		2.92E-08	0.34	11,728,629	34,277,037.48
Toronto					
Residential	0.25	4.62E-08	7.10	153,740,061	21,644,384.26
High Value Industrial	0.05	3.83E-07	11.26	29,355,649	2,607,598.58
Mid Value Industrial	0.50	1.15E-07	4.41	38,289,978	8,691,995.27
Low Value Industrial	1.00	5.75E-08	2.94	51,053,303	17,383,990.53

Using the aggregate demand and user demand functions, the market simulation can be performed for each scarcity scenario. The functions by setting a price-quantity equilibrium sufficiently high to achieve two results. The first result is a demand for water sufficiently low such that consumption is within ecologically or technically constrained limitations. This includes issues of water availability, water delivery or aquatic habitat considerations. In this model, the limitations are artificially imposed; however, under other circumstances the limitations in supply could be driven through non-controllable factors such as drought or maximized resource utilization.

The second result is to create a system that minimizes losses associated with scarcity conditions. Essentially, this is a resource allocation problem whereby the most cost effective uses of water are maximized while lower yield utilization is eliminated. The buffering effect exists where users who can no longer afford to purchase water at the market price can instead sell their right to water to any other users at the market price to mitigate losses associated with foregoing production. At the same time, highly efficient uses of water can continue at 100% capacity by purchasing water so long as marginal revenues associated with incremental use exceed marginal costs.

To simulate these conditions and desired behaviours in an economic simulation requires certain assumptions and rules to determine how the system operates.

- Market simulation is for one growing season only
- Land-use changes will not occur during the season, users are relegated to a “consume or sell decision” tree
- Agricultural water use can be accurately metered to determine tradeable quantities
- Sales of water do not constitute a physical delivery of water resources. Rather, they constitute a payment “not to consume”
- Therefore, all users within the marketplace share a water resource that is physically connected for both groundwater and surface water

- Trading information is perfect and shared between all users
- Transaction and information costs are ignored
- Scarcity levels can be accurately predicted in advance of the trading season
- Current water management and delivery infrastructure is able to handle regional volume increases due to trading
- Consumptive use rates for individual users are considered equal throughout the region
- Changes in water use, and hence effluent can be managed by the current wastewater infrastructure
- Complete sale outcomes (when a user sells 100% of their allocation) will be observed as a general sellout of the user group. It is assumed that even in these circumstances, a small number of users would continue to consume their allocation
- Users within the market will act rationally

For each scenario, each user is allocated a fixed percentage of their normal usage based upon the overall system supply. This amount represents the number of "permits" that each user has available in the market. These permits can then be redeemed by using available water supply or sold in the marketplace for the clearing price.

The clearing price can be determined using the individual and aggregate demand functions of the market participants. The first step is to determine the proper aggregate demand function that applies. This is necessary as the aggregate demand function is in fact a series of separate functions relating to each user's choke price. To determine the appropriate aggregate demand function, each choke price is used as a minimum price point. For each minimum price point, a "use" or "not-use" condition will exist for each user. Given that a "not-use" condition indicates zero demand for a particular user, the total population in the model will transform into a series of positive or zero values for quantity demanded. Adding all non-zero values for quantity demanded provides a maximum demand for the entire market. The maximum demand is then matched with available supply to determine a "best fit" for the appropriate aggregate demand function. Stated another way, as individual users are unwilling to participate in the market as purchasers, their individual demand curves would be subtracted from the aggregate demand curve. When an aggregate demand curve that contains the appropriate number of users to reflect the available supply is reached, the remaining users use this demand curve to determine market equilibrium price and individual demand quantities.

Once the correct selection of users has been determined by matching the demand to available supply, a new aggregate demand function is calculated. Using non-zero demand curves only provides a new aggregate demand function with the appropriate x-intercept and slope for the market. Given that supply is fixed due to scarcity, price under the new aggregate demand can be derived. This price serves as the market-clearing price for which all water "permits" will be purchased or sold.

For each individual demand curve, the market-clearing price is included to determine the quantity demanded. Users with choke prices below the market-clearing price will demonstrate a negative value for quantity demanded, indicating a value below the x-axis. These values are set to zero in order to prevent "phantom supply" in the marketplace. Phantom supply can be defined as a participant's willingness to sell in excess of their available resources due to their position on the aggregate demand curve. Setting this user's quantity demanded value to zero effectively means that they will sell 100% of their available permits. Each user's individual demand is then compared against available individual supply. What results is a list of both purchase and sale listings for each user at the market-clearing price. There are four potential actions that may occur. First, a user may purchase additional "permits" from the market in order to meet their excess demand. Second, a user may sell a portion of their permits in the case of excess supply above demand. Third, for users where the price is sufficiently high compared to their demand function, a complete sale of all permits will occur, meaning that the user forgoes production. Finally, a user may forgo both the purchase and sale of permits, instead using all available water supplies in production without the purchase of additional permits.

There are two metrics that are used to determine the economic benefit associated with incorporating a market into the water management system. The first method is to calculate economic gain versus the non-market system for each scenario. This measures the mitigation associated with instituting a water market. The economic benefit for each participant is individually calculated and then aggregated to determine the total benefit to the system. Additionally, each user group is analyzed discretely so that the flow of benefits from one group to another can be generalized. Benefits are calculated separately for buyers and sellers since each group is performing a different task within the marketplace.

For buyers, economic benefit (or mitigation of loss) can be described as the difference between what they would have had to pay in a non-market situation versus what they are paying under a water market, to meet their optimal economic performance. Benefit is calculated as follows:

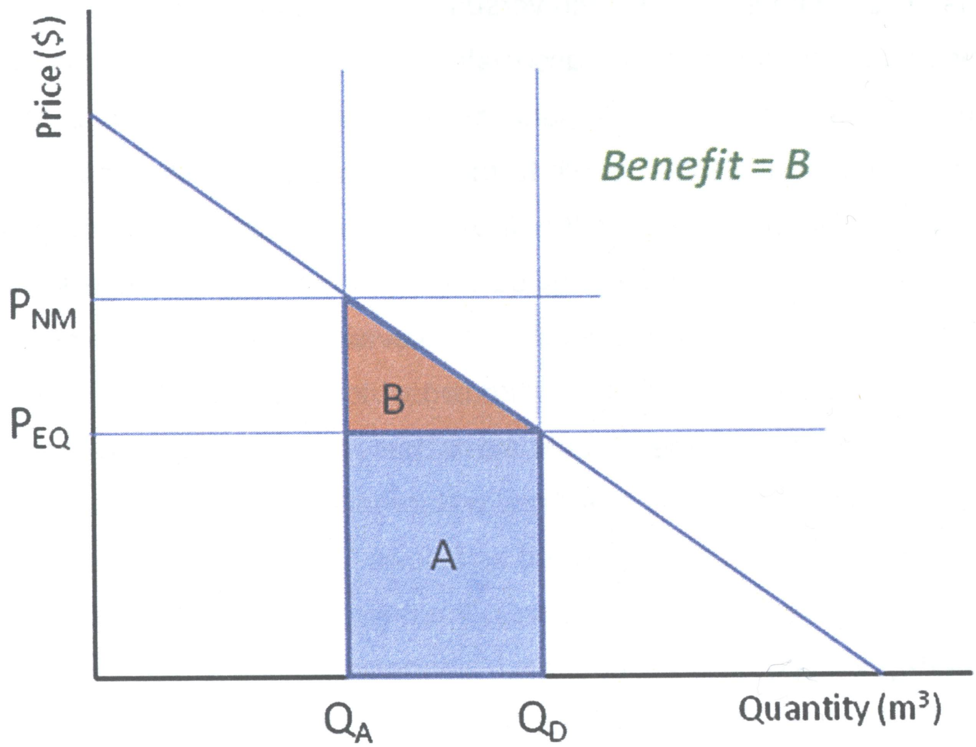
(20) $((P_{NM} - P_{EQ}) \times (Q_D - Q_A) / 2)$, where;

P_{NM} = Price if no market exists
P_{EQ} = Equilibrium price under a water market
Q_D = Quantity demanded by the participant
Q_A = Quantity allocated to the participant

The above equation describes the benefit to a net purchaser of water allowances under a market condition. The benefit is described as the total economic gain of the water purchased at the equilibrium price. Allocated water is not factored into overall benefit versus a non-market situation, since in either case the water is made available to the user. The non-market price reflects the price on the demand curve for the quantity that the individual user is demanding if an aggregated market did not exist. The equilibrium price reflects the cost of water allowances in the aggregate market.

Graphically, the net benefit for net purchasers in the market is shown below.

Figure 3: Graphical representation of net purchasers benefit



For sellers, the economic benefits can be described as the incremental revenue received above and beyond what would have been received if the water had been used directly. Primarily, this constitutes low value uses for water where the equilibrium price of the market exceeds the choke price for that user, though partial sale of allowances can also occur. Benefits are calculated as follows:

(21) $(P_{EQ}) \times (Q_A - Q_D) - [((P_{CP} - P_{NM}) \times (Q_A - Q_D)) / 2] - (Q_A - Q_D) \times (P_{NM})$, where;

P_{NM} = Price if no market exists

P_{EQ} = Equilibrium price under a water market

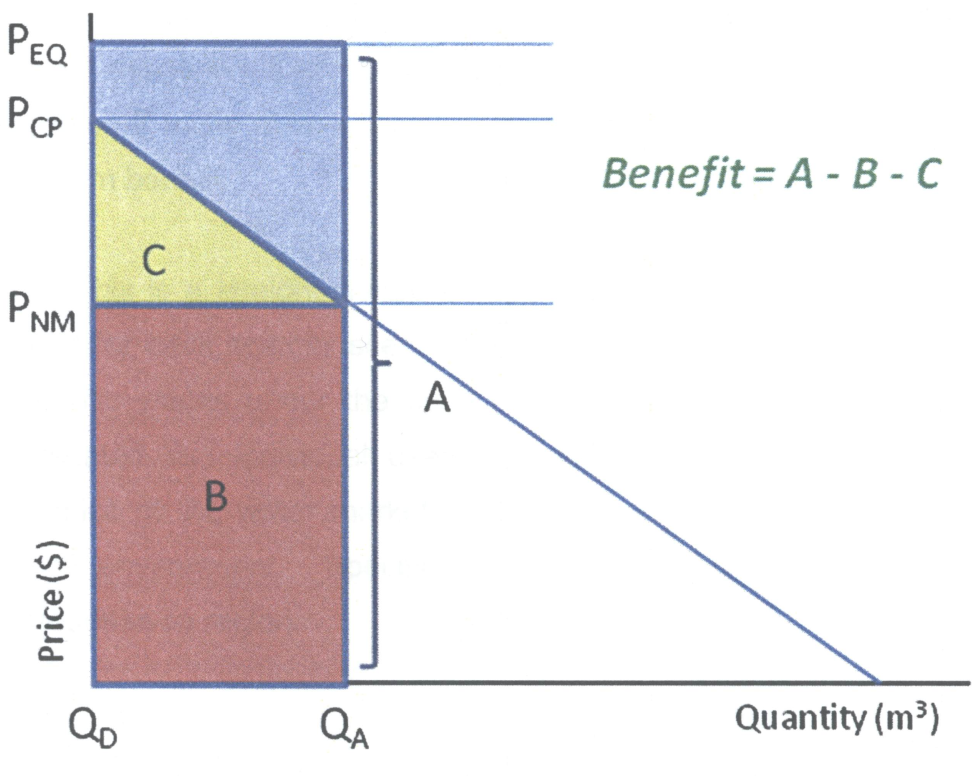
P_{CP} = Choke price for the participant

Q_A = Quantity allocated to the participant

Q_D = Quantity demanded by the participant

This equation provides a description of how a net seller views the marketplace with respect to the value they can receive for using the water themselves. The benefit to the user is in taking advantage of a high unit cost of water based upon demand from other users and scarcity conditions present. Essentially, the lower inelasticity user is leveraging the high inelasticity of demand present with other users to maintain optimum economic benefit of individual water supplies. It is important to note that a full sale of allowances does not necessarily constitute the cessation of economic activity for any particular user. This is especially true in instances of agricultural use where a natural alternative through rainwater is available. It can be assumed, however, that a full sale of allowances would result in at least a partially diminished production capacity. This relationship is demonstrated graphically below:

Figure 4: Graphical representation of net benefit for full allowance sellers

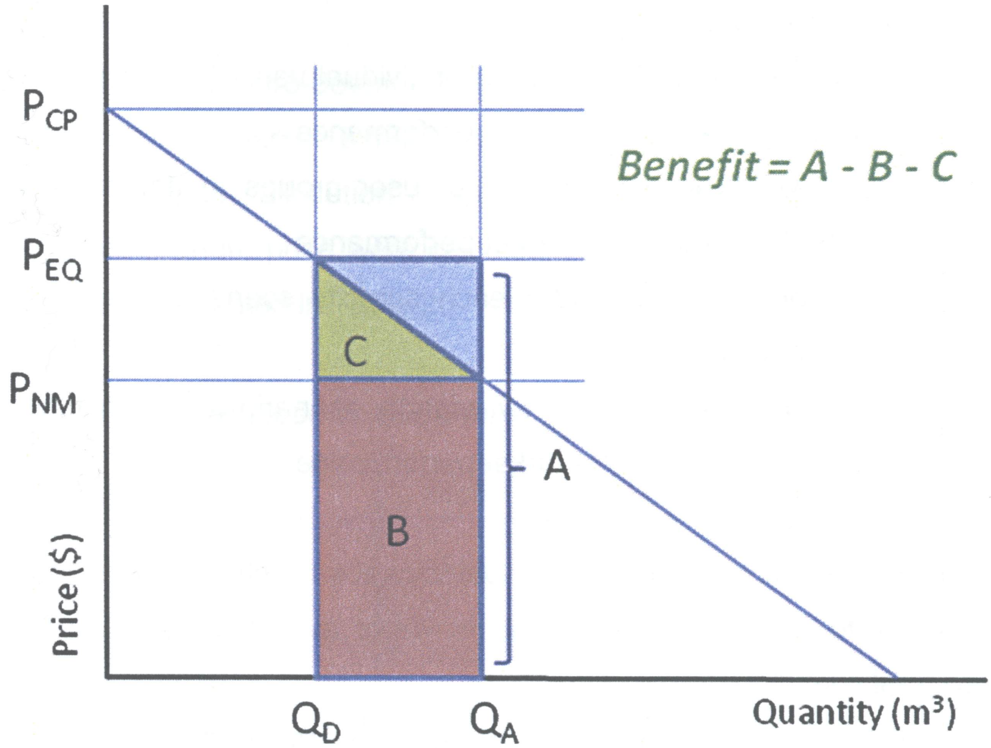


For users that participate in the market with a partial sale of allowances, a third equation is required. In this instance, optimum benefit is achieved through a mix of selling water allowances and using a portion of the allocation internally. This will occur in instances where the equilibrium price occurs somewhere between the choke price and the price attached to the allocated quantity in a no-market condition. The benefit in this case is calculated as follows:

$$(22)\quad (P_{EQ}) \times (Q_A - Q_D) - [((P_{EQ} - P_{NM}) \times (Q_A - Q_D)) / 2] - (Q_A - Q_D) \times (P_{NM})$$

Equation (22) accurately describes the benefits from the seller's perspective. The seller will use the water allocations provided so long as they provide more economic benefit per unit than can be received through participation in the water market. Once that threshold is crossed, the user will sell remaining credits at the equilibrium price, providing incremental revenue higher than what can be achieved by using the remaining allocation internally. This transition is demonstrated graphically below:

Figure 5: Graphical representation of benefit for partial allowance sellers



The second approach to quantifying the benefits of the water market is to calculate economic loss versus the no scarcity scenario to determine the overall level of mitigation that occurs under each scarcity scenario. This helps to determine if there is an optimal point at which instituting a market will provide maximum benefit.

This is a straightforward exercise where individual values under a water market for each scarcity scenario can be aggregated and matched against the economic values under the base case. In addition, this analysis can be dis-aggregated into individual users or user groups to determine the economic dynamics of the water market as the overall system moves to a more water scarce environment. Specifically, the analysis will consist of the following approaches by region:

- Individual user’s economic benefit under each scarcity scenario against the base case (no market)
- Allocation loss versus economic loss for individual users to determine an “optimal scarcity” for maximized market performance
- Allocation loss versus economic loss for user groups to determine an “optimal scarcity” for maximized market performance
- Aggregate economic benefit under each scarcity scenario against the base case (no market)
- Aggregate economic performance by scarcity scenario to determine an “optimal scarcity” for maximized market performance

These analyses will determine each participant’s reaction to the market and the overall performance of the market as water availability is subject to increasing levels of scarcity.

In addition, residential use will be monitored to determine the scarcity level at which it is affected. Residential use, at least in part, is considered essential for general quality of life, as its use is both economic and non-economic in nature (ie. drinking, cleaning, etc.).

Results

Using the pre-determined scarcity levels of 80%, 60% and 40%, a comprehensive market simulation was conducted. Under each scenario, the change in water allocation, water demand, individual equilibrium price and market equilibrium price were calculated to determine overall performance. The results are presented in Table 20.

Table 20: Market Results Summary

Summary Table	No Scarcity	20% Scarcity	40% Scarcity	60% Scarcity
Water Available (m^3)	477,655,512	382,124,410	286,593,307	191,062,205
No Market				
Overall Value	$ 2,063,705,600	$ 1,926,699,789	$ 1,711,867,460	$ 1,397,977,841
Change in Value from Normal Conditions	*n/a*	$ (137,005,811)	$ (351,838,140)	$ (665,727,759)
Value Retention Ratio	***n/a***	***1.17***	***1.38***	***1.69***
Market				
Market Price	$ 0.99	$ 1.84	$ 2.76	$ 4.01
Overall Value	$ 2,103,995,612	$ 2,010,423,849	$ 1,868,047,361	$ 1,638,968,758
Change in Value from Normal Conditions	n/a	$ (93,571,763)	$ (235,948,251)	$ (465,026,854)
Benefit vs No-Market	$ 40,290,012	$ 83,724,060	$ 156,179,901	$ 240,990,917
Transaction Volume (m^3)	44,333,298	46,190,882	59,921,488	62,668,182
# of Sellers	16	22	25	27
Value Retention Ratio	***n/a***	***1.19***	***1.48***	***1.95***
Benefit Ratio	***2.0%***	***4.3%***	***9.1%***	***17.2%***
Activity Ratio	***9.3%***	***12.1%***	***20.9%***	***32.8%***

The results are presented for both no market and market situations for all scarcity scenarios. Overall value, the benefit of having a market over no market, and value retention are shown. The value retention ratio refers to the value of water relative to the total availability of water compared to the base case and is expressed as:

Value Retention Ratio = $(V_n/V_0)/(W_n/W_0)$, where;

V_n = Water Value under scarcity scenario n

V_0 = Water Value under the base case

W_n = Water Allowance Volume under scarcity scenario n

W_0 = Water Allowance Volume under the base case

Expressed differently, the value retention ratio is the efficiency that the market (or non-market) system has in retaining value. A value retention ratio greater than 1 indicates that the system retains value under the scarcity condition at a rate greater than the lost amount. Alternatively, a value retention ratio less than 1 indicates that the system is inefficient and is losing value at a rate greater than the loss of water volume (as a percentage).

In all three scarcity scenarios, the value retention ratio remains strongly positive for both the market and non-market scenarios. This indicates that even under non-market conditions, efficiencies can be gained as uneconomic users of water within a user group curtail use. This has the effect of shifting overall use in each individual demand curve to higher value/unit users of water.

In all three scenarios, the market condition also produces a value retention ratio greater than the non-market condition. This difference is small at first, but grows substantially under the 60% scarcity scenario, shown below.

Table 21: Value Retention Summary

	20% Scarcity	40% Scarcity	60% Scarcity
Value Retention Ratio - No Market	1.17	1.38	1.69
Value Retention Ratio - Market	1.19	1.48	1.95
Market Improvement over No Market	2.35%	7.03%	14.99%

The primary driver for the increased performance of the market concerning value retention is the ability for water use to shift both upward and between individual demand curves depending on the optimal economic condition available. For example, Peel region mid-value industrial use can shift to the most optimal mid-industrial use within Peel region, thereby retaining a certain level of value retention efficiency. In a market example, however, Toronto high-value industrial water use may prove to be more economic than the highest possible Peel mid-value industrial use, providing an incremental benefit that only a market condition can accommodate. In this example, while using the available water allocation for Peel mid-value water use is by no means uneconomic, it is simply less economic than selling it to a higher value user, if that option is to exist.

The benefit ratio is a measure of the benefit of the market design over a non-market design and is expressed as a percentage of overall market value. The ratio is determined as:

Benefit Ratio = (Market Value – No Market Value) / No Market Value

This ratio is closely related to the value retention ratio and specifically the difference between non-market and market value retention differences. The main purpose of the benefit ratio is to determine the degree of improvement under a market system for each scarcity scenario. It has been assumed that there exists both perfect information and zero transaction costs for this model. Both these assumptions serve to improve the calculated efficiency of the market as transactions are completed at a level that receives the theoretical maximum benefit (via a theoretically accurate equilibrium price) and at no cost to all parties. The benefit ratio therefore may serve as an indication of the "degree of benefit" under a given scarcity and the resulting decision of whether the market provides a benefit substantial enough to warrant implementation. The decision on what percentage of overall market value constitutes a fair measure of anticipated transaction costs is not introduced at this point. For example, if we assume a general reduction in benefits to the market of 5% of total market value due to a combination of market inefficiencies and transaction costs, a market application would not be the optimal solution in both the control and 20% scarcity scenarios. The exact amount in benefit loss due to these two assumptions is unknown at this point; however using 5% does not seem to constitute an unreasonable assumption for the purposes of this analysis. In a real world application of this model, such factors would need to be considered when determining the ideal point for the system to convert to a market based approach.

The activity ratio is described as the number allowances traded under any given market scenario taken as a percentage of overall available allowances. Each unit of water allowance is equivalent to 1 m^3 of water.

Activity Ratio = Total Traded Allowances / Total Allowances

The activity ratio provides insight into total market volume. Larger volumes of water traded would indicate a perceived benefit in either acquiring or selling water allowances. This in turn serves as an indication of the degree of disequilibrium that is present in the system prior to trading under each scarcity scenario. Alternatively stated, the activity ratio provides a measure of the amount of activity required to put the water allowances into a state of economic equilibrium.

Not surprisingly, the activity ratio increases with scarcity. This is expected due to the both the shrinking availability of water allowances (the denominator) and the increasingly attractive equilibrium price for water allowances as scarcity increases, prompting greater sales incentive to marginal or uneconomic users of water given the market conditions present.

In addition to running three scarcity scenarios, the summary table above provides results for the market condition under a no scarcity, or "control" scenario. This is done in an effort to determine initial market equilibrium; a scenario containing zero water scarcity (100% allocation) is run to determine any movements in water between the users. In effect, any movements prior to the scarcity condition would indicate that prices are currently in disequilibrium. Users that would immediately sell their water under no scarcity condition can be said to have a portion or all of their water as currently undervalued in association with its end use when compared to what the overall market is offering. Conversely, users that are buying additional water resources under a market with no scarcity condition perceive a higher value associated with their water end use in comparison to the market price. Under a no scarcity scenario, it is expected that the water market including agricultural users could potentially lower overall water unit prices to the system. This is primarily due to additional supply being made available to all users from a previously excluded source. If the additional source, in this case agricultural users, attaches a value to water lower than current rates, there is the potential for additional water to be supplied to the market at a discount. The results of the creation of a full water market under no scarcity condition are shown below in tables 22, 23, and 24.

Table 22: Monetary Benefit of a Water Market vs No Market – No Scarcity

Sceanrio: No Scarcity	Durham	Halton	Hamilton	Niagara	Peel	Toronto	All Regions
Residential	$ 455,906.24	$ 603,570.87	$ 1,500,786.61	$ 445,477.30	$ 9,039.06	$ 2,045,992.45	$ 5,060,772.53
High Value Industrial	$ 6,846.49	$ 20,166.31	$ 62,296.80	$ 13,087.47	$ 1,142.45	$ 303,664.57	$ 407,204.10
Mid Value Industrial	$ 68,464.87	$ 201,663.10	$ 622,968.03	$ 130,874.69	$ 11,424.53	$ 1,012,215.25	$ 2,047,610.46
Low Value Industrial	$ 136,929.75	$ 403,326.19	$ 1,245,936.06	$ 261,749.37	$ 22,849.07	$ 2,024,430.49	$ 4,095,220.93
Fruit	$ 7,490.73	$ 10,693.50	$ 21,593.02	$ 332,079.76	$ 14,659.29		$ 386,516.30
Vegetables	$ 169,715.95	$ 339,673.25	$ 306,647.98	$ 41,584.32	$ 127,086.57		$ 984,708.07
Grain	$ 6,011,599.73	$ 4,820,864.44	$ 1,670,611.79	$ 5,249,479.78	$ 9,555,423.66		$ 27,307,979.41
All Users	$ 6,856,953.76	$ 6,399,957.66	$ 5,430,840.30	$ 6,474,332.69	$ 9,741,624.63	$ 5,386,302.76	$ 40,290,011.80

Table 23: Overall Value of the Water Market – No Scarcity

Scenario: No Scarcity	Durham	Halton	Hamilton	Niagara	Peel	Toronto	All Regions
Residential	$ 97,791,838.76	$ 96,684,748.57	$ 209,043,353.40	$ 104,827,892.89	$ 125,872,030.69	$ 535,490,907.69	$ 1,169,710,772.01
High Value Industrial	$ 53,152,544.84	$ 52,487,602.22	$ 155,030,958.57	$ 55,282,934.83	$ 107,128,510.41	$ 163,972,014.91	$ 587,054,565.77
Mid Value Industrial	$ 10,161,326.66	$ 10,307,600.27	$ 30,482,833.00	$ 10,718,723.81	$ 19,794,141.31	$ 80,114,098.60	$ 161,578,723.65
Low Value Industrial	$ 8,254,039.38	$ 8,703,894.48	$ 25,784,491.17	$ 8,888,590.57	$ 15,248,214.04	$ 66,519,858.81	$ 133,399,088.46
Fruit	$ 607,290.73	$ 197,993.50	$ 563,293.02	$ 7,724,179.76	$ 165,359.29	$ -	$ 9,258,116.30
Vegetables	$ 378,705.95	$ 420,723.25	$ 782,947.98	$ 143,084.32	$ 172,896.57	$ -	$ 1,898,358.07
Grain	$ 11,476,547.73	$ 6,082,264.44	$ 3,534,193.79	$ 8,440,955.78	$ 11,562,025.66	$ -	$ 41,095,987.41
All Users	$ 181,822,294.05	$ 174,884,826.73	$ 425,222,070.94	$ 196,026,361.97	$ 279,943,177.97	$ 846,096,880.01	$ 2,103,995,611.68

Table 24: Movement of water under a Water Market – No Scarcity

Scenario: No Scarcity	Durham	Halton	Hamilton	Niagara	Peel	Toronto	All Regions
Residential	1,808,416.67	1,898,305.57	4,190,942.26	1,894,822.17	(460,059.89)	9,411,083.55	18,743,510.33
High Value Industrial	44,428.16	58,520.51	173,963.64	55,667.09	31,513.84	1,258,439.76	1,622,533.00
Mid Value Industrial	444,281.60	585,205.08	1,739,636.41	556,670.92	315,138.41	4,194,799.19	7,835,731.61
Low Value Industrial	888,563.20	1,170,410.17	3,479,272.82	1,113,341.84	630,276.82	8,389,598.38	15,671,463.23
Fruit	(15,197.33)	(21,695.17)	(43,808.34)	(673,729.77)	(29,741.04)	-	(784,171.65)
Vegetables	(382,091.53)	(426,785.68)	(775,360.50)	(131,807.81)	(175,387.93)	-	(1,891,433.45)
Grain	(11,641,919.61)	(6,169,907.13)	(3,579,771.85)	(8,562,586.15)	(11,728,629.24)	-	(41,682,813.99)
All Users	(8,853,518.84)	(2,905,946.66)	5,184,874.43	(5,747,621.70)	(11,416,889.03)	23,253,920.88	(485,180.92)

Even under conditions absent of scarcity, there is a movement of water from low value uses to higher value uses as the market corrects. Essentially, the observable trend is a movement from agricultural use to non-agricultural use, in particular to low value industrial and residential uses. This demonstrates that under current conditions the value of water as an input into agricultural processes is significantly lower than its value as a component of non-agricultural processes, based upon cost and revenue factors alone. The primary driver for this is the large amount of irrigated water required for food production coupled with the comparatively low sale value of crops on a revenue per unit of water basis. A number of factors could potentially explain this relationship, including:

1. The current separation of agricultural and municipal water use that has been waived for the purposes of this analysis. Most agricultural water use is not covered under municipal water utility fee structures. This could potentially create a de-coupling of any existing price trends between the two uses. Integrating all uses under a single market would create an opportunity for re-distribution of resources and without the proper controls, cause a large shift in overall water use away from agricultural use until the resulting price jumps were accounted for in crop prices.
2. The reduced management controls and decentralization of a large proportion of agricultural water use. Many agricultural operations use private wells, irrigation, or limited shared system access between other farms within close proximity. Therefore, cost pressures and controls on pricing do not exist as in a municipal system. This is strongly related to the factor described in the previous point.
3. The post-consumption costs associated with water treatment. Agricultural users do not have direct sewage treatment costs associated with water use when not included in the municipal systems, creating a lower initial cost point upon which water-related production revenues are based.

The first scarcity scenario is one in which 80% of normal water supply is available. Even under moderate scarcity, a large movement of water takes place, as demonstrated in Table 25, and reinforced in Tables 26, and 27.

Table 25: Monetary Benefit of a Water Market vs No Market – 20% Scarcity

80% Water Availability	Durham	Halton	Hamilton	Niagara	Peel	Toronto	
Residential	$ 1,265,030.02	$ 1,731,134.45	$ 4,365,364.27	$ 1,221,728.33	$ 112,153.72	$ 5,532,029.14	$ 14,227,439.92
High Value Industrial	$ 1,543,668.01	$ 1,811,923.05	$ 5,399,672.15	$ 1,750,416.56	$ 2,585,755.60	$ 3,271,930.74	$ 16,363,366.12
Mid Value Industrial	$ 671.16	$ 107,365.97	$ 355,041.74	$ 22,806.28	$ 282,425.16	$ 198,369.00	$ 966,679.29
Low Value Industrial	$ 120,659.52	$ 23,932.17	$ 97,435.42	$ 10,665.56	$ 1,422,859.53	$ 55,677.85	$ 1,731,230.05
Fruit	$ 46.75	$ 11,380.74	$ 16,228.42	$ 284,165.83	$ 22,084.56		$ 333,906.29
Vegetables	$ 362,454.92	$ 551,142.74	$ 685,394.74	$ 96,804.14	$ 214,490.23		$ 1,910,286.77
Grain	$ 11,910,256.36	$ 7,881,600.19	$ 3,486,443.24	$ 9,554,799.70	$ 15,358,051.83		$ 48,191,151.32
	$ 15,202,786.73	$ 12,118,479.30	$ 14,405,579.97	$ 12,941,386.40	$ 19,997,820.64	$ 9,058,006.72	$ 83,724,059.76

Table 26: Overall Value of the Water Market – 20% Scarcity

80% Water Availability	Durham	Halton	Hamilton	Niagara	Peel	Toronto	
Residential	$ 93,449,104.18	$ 93,070,268.88	$ 201,958,249.46	$ 99,948,641.94	$ 114,227,932.79	$ 509,283,923.28	$ 1,111,938,120.53
High Value Industrial	$ 52,978,006.58	$ 52,384,793.11	$ 154,736,859.92	$ 55,139,589.60	$ 106,602,243.55	$ 160,814,738.89	$ 582,656,231.66
Mid Value Industrial	$ 8,496,975.36	$ 9,279,509.24	$ 27,541,846.46	$ 9,285,271.55	$ 17,417,833.44	$ 69,589,845.20	$ 141,611,281.26
Low Value Industrial	$ 6,299,789.85	$ 6,647,712.41	$ 19,902,518.09	$ 6,435,680.37	$ 13,884,974.65	$ 48,034,347.11	$ 101,205,022.47
Fruit	$ 575,854.75	$ 191,188.74	$ 536,260.42	$ 7,380,581.83	$ 114,277.38	$ -	$ 8,798,163.11
Vegetables	$ 563,085.32	$ 628,950.74	$ 1,142,642.74	$ 194,244.14	$ 258,467.83	$ -	$ 2,787,390.77
Grain	$ 17,156,606.44	$ 9,092,544.19	$ 5,275,481.96	$ 12,618,616.66	$ 17,284,389.75	$ -	$ 61,427,639.00
	$ 179,519,422.47	$ 171,294,967.31	$ 411,093,859.04	$ 191,002,626.10	$ 269,790,119.39	$ 787,722,854.48	$ 2,010,423,848.79

Table 27: Movement of water under a Water Market – 20% Scarcity

80% Water Availability	Durham	Halton	Hamilton	Niagara	Peel	Toronto	
Residential	3,012,389.67	3,214,899.37	7,147,636.34	3,137,928.12	(1,620,539.48)	15,474,971.04	30,367,285.06
High Value Industrial	667,116.02	554,708.41	1,619,605.73	643,785.83	1,499,256.14	4,130,830.90	9,115,303.03
Mid Value Industrial	(43,988.21)	427,000.31	1,313,304.15	232,379.55	(1,566,872.97)	1,856,998.86	2,218,821.69
Low Value Industrial	(834,104.01)	285,102.43	972,969.05	(224,738.55)	(4,973,683.09)	(1,391,332.62)	(6,165,786.80)
Fruit	(1,200.53)	(22,381.46)	(37,978.53)	(623,233.02)	(36,504.31)	-	(721,297.86)
Vegetables	(305,673.22)	(341,428.54)	(620,288.40)	(105,446.25)	(140,310.34)	-	(1,513,146.76)
Grain	(9,313,535.69)	(4,935,925.71)	(2,863,817.48)	(6,850,068.92)	(9,382,903.39)	-	(33,346,251.19)
	(6,818,995.97)	(818,025.19)	7,531,430.85	(3,789,393.24)	(16,221,557.46)	20,071,468.17	(45,072.83)

With a reduced water supply of 20%, there is a more pronounced movement of water from low value uses to high value uses when compared to the zero scarcity scenario. In addition to the movement of agricultural water use to non-agricultural water use, there is a net sale of water from low industrial uses and large gains in residential and high value industrial use. The exception to this is Peel region, where all users, except high value industrial are net sellers. Overall, three economic groups remain net purchasers of water allowances under the market; residential, high value industrial, and mid value industrial. Also note that although the number of sellers increased from 16 to 22 users (41% of total to 56% of total), total sales of water allowances increased by only 1.86MM allowances, or 4.1%. This is due to the lower per user allowance levels under the scarcity condition. What is observed is that the lack of allowances that grain, agriculture, and to some extent fruit provide the market in the control scenario is accommodated by increased sales of allowances from low value industrial users. Therefore, the allowances required by the highest value users in order to maintain optimal economic output can no longer be satisfied through cheap water from agriculture and must therefore jump to the next lowest value users. The change in perceived value of the sellers between low value agriculture and low value industry is significant, and must be considered as one of the primary drivers for the significant jump in equilibrium price from $0.99 to $1.84, an increase of 86.8%.

Economic benefits of the market over a non-market solution have doubled from the control scenario to $83.7MM with a retained total value of approximately $2.01 billion for all water allowances. It is important to note that of a total benefit of over $80MM, 57.5% is allocated to the sale of water allowances by grain agriculture users and 2.2% to vegetable agriculture. This is lower than the control scenario, where grain producers accounted for approximately 67% of the total benefit.

The next scarcity scenario is one in which there is 40% scarcity, or 60% of total water available compared to normal. The previous trends observed in the 20% scarcity scenario continue, with a few exceptions such as Halton region, which converts from a net seller to a net buyer and mid-value industrial users, who switch to net sellers of water allowances.

Table 28: Monetary Benefit of a Water Market vs No Market – 40% Scarcity

60% Water Availability	Durham	Halton	Hamilton	Niagara	Peel	Toronto	
Residential	$ 2,238,375.93	$ 3,180,028.49	$ 8,144,253.26	$ 2,132,670.62	$ 512,505.93	$ 9,496,935.31	$ 25,704,769.54
High Value Industrial	$ 5,695,284.40	$ 6,442,065.60	$ 19,162,596.28	$ 6,337,648.61	$ 9,954,367.54	$ 9,000,056.07	$ 56,592,018.50
Mid Value Industrial	$ 131,776.78	$ 28,306.37	$ 114,323.96	$ 10,946.61	$ 1,576,986.37	$ 56,151.62	$ 1,918,491.72
Low Value Industrial	$ 1,246,751.30	$ 143,981.31	$ 339,731.22	$ 610,982.80	$ 5,286,199.39	$ 4,271,590.64	$ 11,899,236.67
Fruit	$ 4,590.31	$ 13,472.90	$ 13,580.20	$ 274,566.82	$ 33,602.11		$ 339,812.33
Vegetables	$ 456,455.50	$ 637,852.47	$ 882,410.49	$ 132,759.67	$ 251,623.95		$ 2,361,102.08
Grain	$ 14,666,022.95	$ 9,145,897.82	$ 4,355,793.36	$ 11,482,298.59	$ 17,714,457.61		$ 57,364,470.34
	$ 24,439,257.16	$ 19,591,604.97	$ 33,012,688.78	$ 20,981,873.72	$ 35,329,742.91	$ 22,824,733.64	$ 156,179,901.17

Table 29: Overall Value of the Water Market – 40% Scarcity

60% Water Availability	Durham	Halton	Hamilton	Niagara	Peel	Toronto	
Residential	$ 85,905,459.77	$ 86,791,655.94	$ 189,650,910.90	$ 91,473,029.75	$ 96,168,379.57	$ 463,760,493.77	$ 1,013,749,929.69
High Value Industrial	$ 52,674,820.98	$ 52,206,206.26	$ 154,225,989.26	$ 54,890,588.57	$ 105,688,079.93	$ 155,330,321.84	$ 575,016,006.82
Mid Value Industrial	$ 7,083,298.41	$ 7,493,640.67	$ 29,135,624.45	$ 7,239,088.27	$ 15,596,865.88	$ 43,512,541.78	$ 110,061,059.45
Low Value Industrial	$ 6,170,745.79	$ 5,003,794.19	$ 14,693,650.55	$ 5,730,916.48	$ 15,216,947.37	$ 42,504,592.70	$ 89,320,647.08
Fruit	$ 541,218.95	$ 170,804.90	$ 468,608.20	$ 6,483,930.82	$ 160,190.11	$ -	$ 7,824,752.98
Vegetables	$ 632,007.10	$ 705,934.47	$ 1,282,502.49	$ 218,019.67	$ 290,104.35	$ -	$ 3,128,568.08
Grain	$ 19,256,579.27	$ 10,205,473.82	$ 5,921,202.24	$ 14,163,138.43	$ 19,400,003.29	$ -	$ 68,946,397.06
	$ 172,264,130.26	$ 162,577,510.24	$ 395,378,488.09	$ 180,198,711.98	$ 252,520,570.50	$ 705,107,950.09	$ 1,868,047,361.15

Table 30: Movement of water under a Water Market – 40% Scarcity

60% Water Availability	Durham	Halton	Hamilton	Niagara	Peel	Toronto	
Residential	4,007,072.93	4,357,300.29	9,762,877.47	4,145,887.95	(3,464,194.18)	20,275,863.34	39,084,807.80
High Value Industrial	1,281,392.34	1,045,941.63	3,051,074.30	1,224,996.32	2,941,636.02	6,851,063.19	16,396,103.80
Mid Value Industrial	(616,373.37)	219,248.67	745,236.70	(160,994.30)	(3,702,508.54)	(987,997.62)	(4,503,388.46)
Low Value Industrial	(2,238,382.80)	(699,299.06)	(1,816,805.09)	(1,700,983.88)	(5,519,811.45)	(12,186,655.92)	(24,161,938.19)
Fruit	11,896.69	(24,351.95)	(34,741.87)	(612,616.31)	(45,028.04)	-	(704,841.48)
Vegetables	(229,254.92)	(256,071.41)	(465,216.30)	(79,084.68)	(105,232.76)	-	(1,134,860.07)
Grain	(6,985,151.76)	(3,701,944.28)	(2,147,863.11)	(5,137,551.69)	(7,037,177.55)	-	(25,009,688.40)
	(4,768,800.89)	940,823.89	9,094,562.10	(2,320,346.59)	(16,932,316.50)	13,952,272.99	(33,804.99)

The water scarcity in this scenario is significant, causing a large re-allocation of allowances to maximize optimal economic value for the entire system. Although the number of sellers in the marketplace increases by only 3, from 22 to 25, the total number of allowances sold increases by 29.7%, from 46.1MM to 59.9MM allowances. The primary increase comes from two sources, low-value industrial and mid-value industrial users, who are now selling significantly larger portions of their water allowances, and in some cases converting from a net buyer to a net seller of allowances. Movement within these user groups is provided in Table 31 below.

Table 31: Low and Mid Value Industrial Allowance Transactions

	Net Transaction Changes from 20% Scarcity (ML)	**% of Total Allowances Sold**
Mid-Value Industrial	**(5.95)**	**14.2%**
Durham	(0.57)	27.5%
Halton*	(0.21)	-
Hamilton*	(0.57)	-
Niagara	(0.39)	7.8%
Peel	(2.14)	67.1%
Toronto	(2.84)	6.5%

Low-Value Industrial	**(18.0)**	**76.0%**
Durham	(1.40)	100.0%
Halton	(0.98)	41.0%
Hamilton	(2.79)	36.6%
Niagara	(1.48)	82.2%
Peel	(0.55)	100.0%
Toronto	(10.80)	79.6%

*Users still purchased allowances, though less of them than in the 20% scarcity scenario

Only two mid value industrial users remain net purchasers of water and all low value industrial users are now selling all or a portion of their water allowances. The introduction of mid value industrial sales of water allowances combined with the increasingly large share of sales from low value industrial water allowances continues to create upward pressure on the equilibrium price of water. Under the 60% scarcity scenario, the equilibrium price has increased to $2.76/m^3, an increase of $0.91 over the 20% scarcity scenario. This represents an increase of 49.7% over the 20% scarcity scenario and an increase of 180.6% over the control scenario equilibrium price.

Benefits of the market scenario over a non-market scenario have increased 86.5% to $156.2MM. The primary beneficiaries of this increased benefit are high value industrial users and low value industrial users. High value industrial users, through allowance purchases, are able to maintain water use at 88.2% of pre-scarcity levels, while low value industrial users are able to sell allowances at a price that allows for a substantial benefit over using the water directly. Overall, the market has a benefit ratio of 9.1%, which under the previous assumption of transaction and imperfect information costs at 5% of total water value, makes the market economically viable at the 40% scarcity level.

The final scenario is one in which there is a 60% scarcity of water, signifying a severe shortage in water resources. Strain on the entire system is substantial at this point, with many users forced into dramatically lowered use or a complete sale of their water allowances.

Table 32: Monetary Benefit of a Water Market vs No Market – 60% Scarcity

40% Water Availability	Durham	Halton	Hamilton	Niagara	Peel	Toronto	
Residential	$ 1,998,786.06	$ 3,374,084.81	$ 9,233,981.02	$ 1,780,845.19	$ 3,673,529.58	$ 7,272,741.22	$ 27,333,967.88
High Value Industrial	$ 11,830,533.34	$ 13,398,214.63	$ 39,856,839.08	$ 13,173,065.28	$ 20,649,150.07	$ 14,472,716.56	$ 113,380,518.96
Mid Value Industrial	$ 963,804.48	$ 44,918.03	$ 85,848.64	$ 385,571.56	$ 4,631,824.97	$ 2,642,688.74	$ 8,754,656.42
Low Value Industrial	$ 2,508,587.06	$ 1,132,415.85	$ 3,130,904.90	$ 1,916,074.06	$ 7,747,353.75	$ 13,959,515.80	$ 30,394,851.43
Fruit	$ 12,677.48	$ 36,255.35	$ 24,392.72	$ 508,323.98	$ 56,516.31		$ 638,165.84
Vegetables	$ 479,162.64	$ 632,738.51	$ 938,930.31	$ 146,474.02	$ 252,022.86		$ 2,449,328.34
Grain	$ 15,177,334.70	$ 9,089,904.07	$ 4,549,649.74	$ 11,692,772.02	$ 17,529,767.80		$ 58,039,428.32
	$ 32,970,885.77	$ 27,708,531.25	$ 57,820,546.41	$ 29,603,126.11	$ 54,540,165.34	$ 38,347,662.32	$ 240,990,917.20

Table 33: Overall Value of the Water Market – 60% Scarcity

40% Water Availability	Durham	Halton	Hamilton	Niagara	Peel	Toronto	
Residential	$ 70,693,679.11	$ 74,130,814.87	$ 164,833,127.28	$ 74,381,933.37	$ 74,156,804.90	$ 371,962,367.20	$ 830,158,726.73
High Value Industrial	$ 52,063,446.34	$ 51,846,085.35	$ 153,195,817.11	$ 54,388,477.26	$ 103,844,666.34	$ 144,270,979.07	$ 559,609,471.46
Mid Value Industrial	$ 5,984,347.88	$ 5,000,021.35	$ 14,721,217.37	$ 5,605,896.09	$ 14,757,293.50	$ 14,443,979.13	$ 60,512,755.32
Low Value Industrial	$ 5,984,347.88	$ 4,562,872.00	$ 13,263,083.25	$ 5,530,144.89	$ 14,757,293.50	$ 40,947,517.26	$ 85,045,258.78
Fruit	$ 654,241.32	$ 145,795.00	$ 371,080.72	$ 5,239,267.98	$ 152,964.31	$ -	$ 6,563,349.33
Vegetables	$ 612,916.24	$ 684,610.51	$ 1,243,762.31	$ 211,434.02	$ 281,341.26	$ -	$ 3,034,064.34
Grain	$ 18,674,901.42	$ 9,897,200.07	$ 5,742,342.22	$ 13,735,316.66	$ 18,813,993.08	$ -	$ 66,863,753.44
	$ 154,667,880.19	$ 146,267,399.14	$ 353,370,430.26	$ 159,092,470.27	$ 226,764,356.88	$ 571,624,842.66	$ 1,611,787,379.40

Table 34: Movement of water under a Water Market – 60% Scarcity

40% Water Availability	Durham	Halton	Hamilton	Niagara	Peel	Toronto	
Residential	3,786,551.69	4,488,280.42	10,395,531.34	3,788,512.74	(9,274,586.42)	17,743,393.45	30,927,683.21
High Value Industrial	1,846,828.55	1,508,406.31	4,400,246.80	1,766,095.28	4,236,753.42	8,687,811.59	22,446,141.95
Mid Value Industrial	(1,492,255.20)	(276,188.26)	(645,791.50)	(955,483.53)	(3,679,874.30)	(6,777,940.40)	(13,827,533.19)
Low Value Industrial	(1,492,255.20)	(1,137,796.40)	(3,307,278.48)	(1,378,995.28)	(3,679,874.30)	(10,210,660.68)	(21,206,860.34)
Fruit	19,770.69	(33,778.93)	(46,561.85)	(833,556.09)	(38,143.14)	-	(932,269.31)
Vegetables	(152,836.61)	(170,714.27)	(310,144.20)	(52,723.12)	(70,155.17)	-	(756,573.38)
Grain	(4,656,767.84)	(2,467,962.85)	(1,431,908.74)	(3,425,034.46)	(4,691,451.70)	-	(16,673,125.60)
	(2,140,963.93)	1,910,246.02	9,054,093.37	(1,091,184.47)	(17,197,331.61)	9,442,603.97	(22,536.66)

At this point, virtually all users are selling to either residential users or high industrial users. The exception to this is Peel region residential users, who are sellers of allowances and Durham region fruit producers, who are small buyers of allowances. To illustrate the dichotomy of the market under this scenario, Table 35 quantifies the percentage of allowances purchased (or sold) by each user. Users that have purchased over 100% of their pre-market allowance volume are highlighted in green. These users have more than doubled their water use through the market mechanism. Users who have sold greater than 50% of their allowances are shown in yellow, while users who have sold all allowances are shown in red.

Table 35: Percentage of Prescribed Allowances Purchased (Sold)

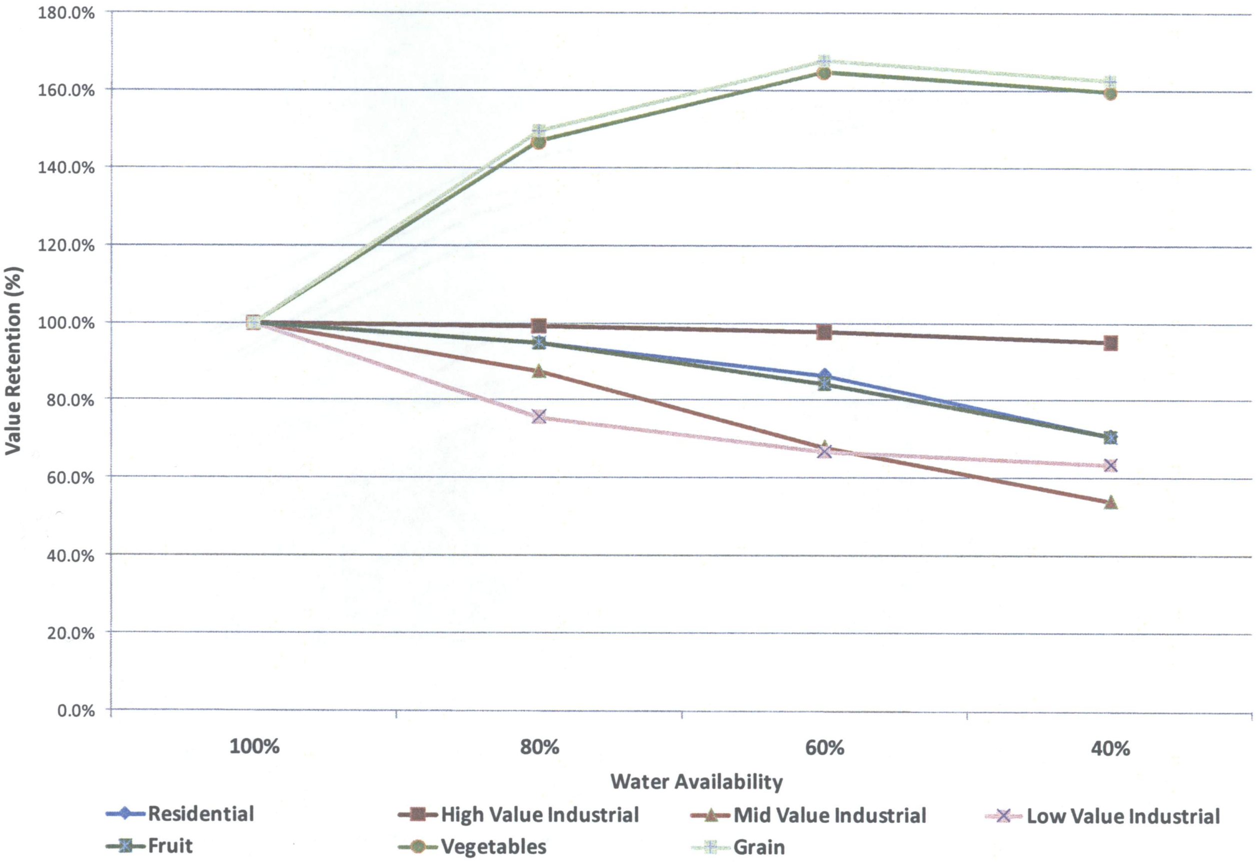
40% Water Availability	Durham	Halton	Hamilton	Niagara	Peel	Toronto	All Regions
Residential	44%	58%	65%	40%	-52%	36%	28%
High Value Industrial	124%	133%	133%	128%	115%	85%	106%
Mid Value Industrial	-100%	-24%	-20%	-69%	-100%	-66%	-65%
Low Value Industrial	-100%	-100%	-100%	-100%	-100%	-100%	-100%
Fruit	36%	-93%	-53%	-66%	-100%		-63%
Vegetables	-100%	-100%	-100%	-100%	-100%		-100%
Grain	-100%	-100%	-100%	-100%	-100%		-100%
All Users	-12%	14%	33%	-6%	-51%	12%	

At 60% scarcity, 3 entire user groups have sold all of their allowances, with two other groups selling almost two thirds of their allowances. Regionally, with the exception of Toronto, every region has at least half of their user groups selling all allowances. Most importantly, we have Peel region residential users selling over half of their allowances. As mentioned earlier, for the purposes of this analysis, a sale of more than 50% of a residential users allowance signifies a potentially negative impact to basic living standards and as such indicates a situation where the concept of fairness would need to be addressed.

Examining the market from a benefit perspective indicates that a scarcity level of 60% provides substantial benefits over a non-market application. Specifically, total benefits under the market compared to the no market condition are $241MM, giving a benefit ratio of 17.2%. Of the total benefit received, 47% is allocated to high value industrial users, up from 36.2% in the previous scenario. Effectively, all water resources are being diverted to residential and high value industrial use at this point, with compensation provided to the sellers at a rate of $4.01/m^3$.

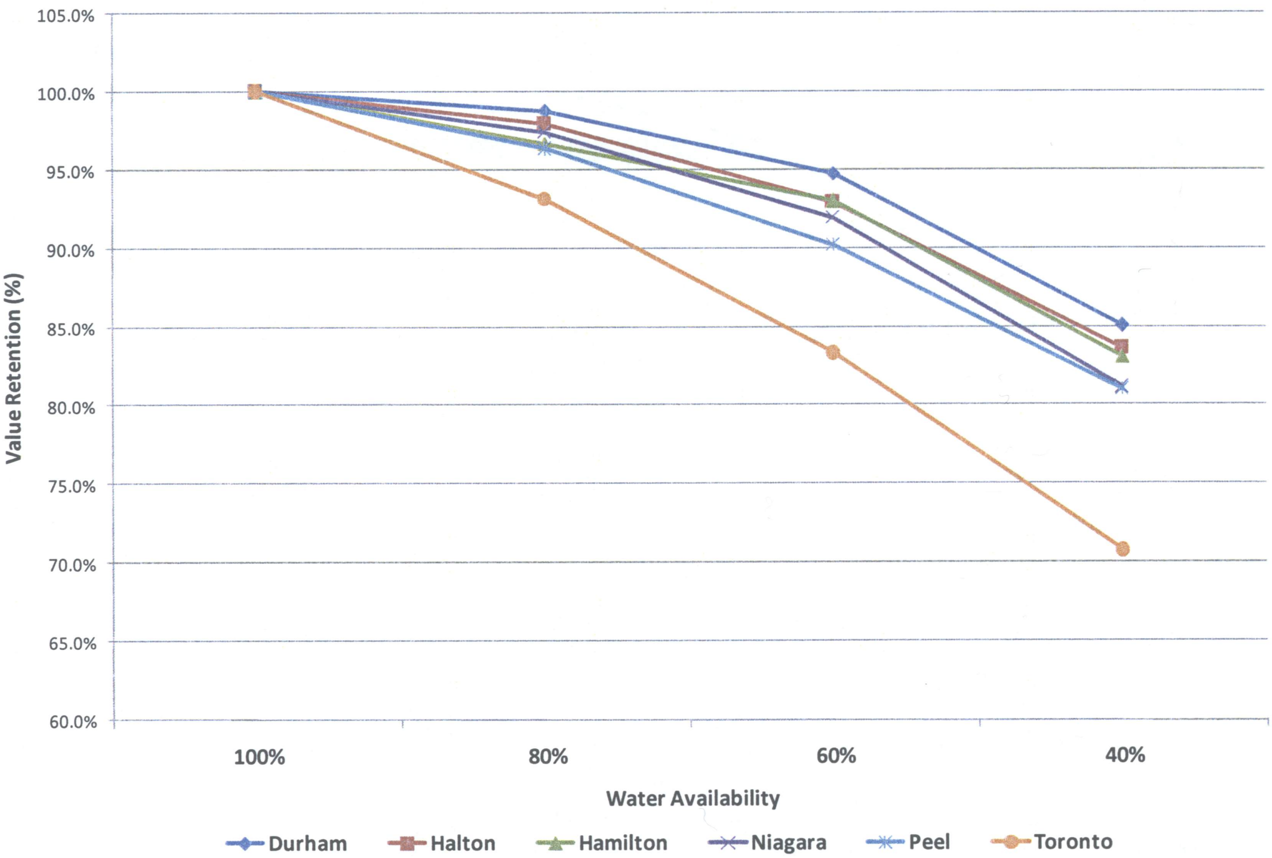
A more detailed look at the market constitutes an analysis of the regions themselves and the user groups across regions. Figures 5 and 6 demonstrate the performance of these groupings with respect to value retention.

Figure 6: Value Retention by User Group



At the user group level, there is a distinct value increase for agricultural users growing vegetables or grains. This gain in value is driven primarily from the disproportionally low value assigned to water by these users in the initial condition. Aside from vegetables and grains, all users see value loss to a certain extent. High-value industrial users retain up to 95.3% of their original water value due to the high value placed upon water and the subsequent purchasing of allowances to keep use near maximum. Other users (residential, fruits, low-value industrial and mid-value industrial) experience efficiencies in value retention, but to a lesser degree than vegetables, grains, or high-value industrial users.

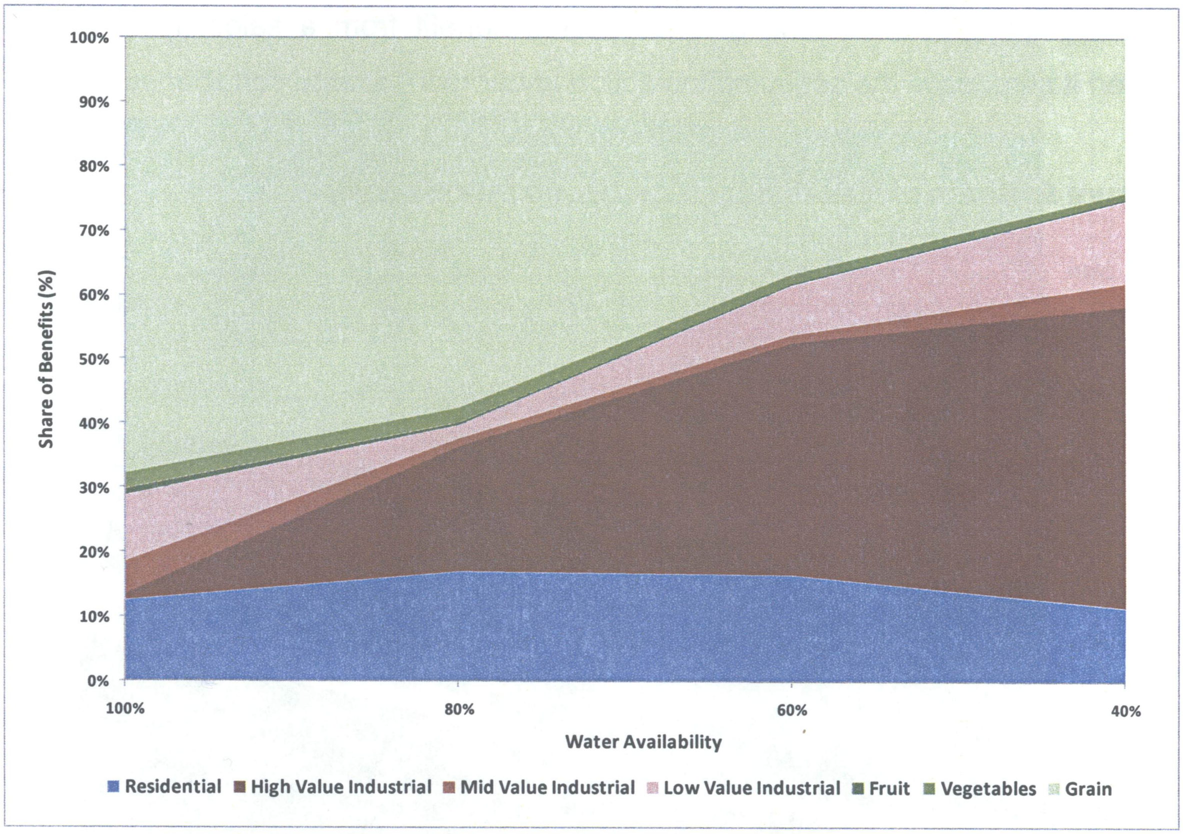
Figure 7: Value Retention by Region



The loss in value by region is more uniform than by user group, with the one exception being a higher than average value loss by Toronto. This is driven chiefly by the absence of agriculture in this region, which was previously shown to actually gain value under scarcity when subject to market conditions. However, even in the case of Toronto, over 70% of the original value is maintained, even in a scarcity scenario of 60% water loss (40% water availability).

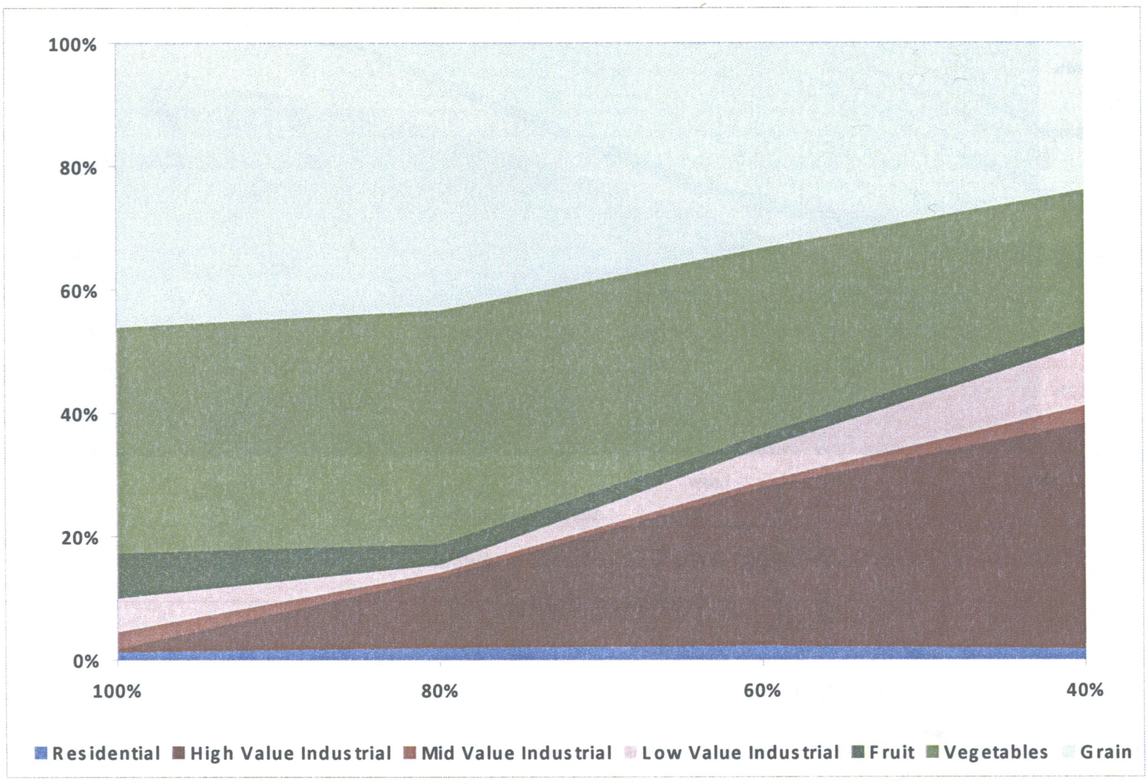
An examination of benefits at a user group level reveals the results presented below in Figure 7. Looking at the dispersion of benefits at the user group level, there is a clear transfer of benefit from agriculture to industrial uses as scarcity increases. In particular, grain production receives a large initial allocation of market benefits under the control scenario, whereas high value industrial use gains a large share of benefits under the 60% scarcity scenario.

Figure 8: Share of Benefits by User Group



For a true reflection of the share of the benefit received by each user with respect to their share of initial water allocation, refer to Figure 8. With the benefits represented in comparison to initial water allocations, the trend remains unchanged; however, the share of benefits is distributed differently among the user groups. Grain users continue to receive a large share of benefits relative to their allotment. In addition, both vegetable growers, and to a lesser extent fruit growers, receive a proportionately larger share of benefits in the initial condition. Off all users, mid-value industrial and residential users demonstrate the lowest proportional share of benefits throughout each scenario, although these are joined by fruit growers as scarcity increases. The primary reason can be attributed to the moderately elastic nature of demand for these users and the higher opportunity costs for forgoing water consumption as scarcity increases. For residential users, this translates into only moderate purchases of water in the scarcity scenarios compared to high value industrial. For mid-value industrial users, the margin on water allowance sales is lower than for other users as scarcity increases, creating a lower overall benefit from a sales action, even when it surpasses the consumption action under more scarce conditions.

Figure 9: Share of Benefits by User Group (normalized)



The share of benefits is consistent across each region as each scarcity scenario is modeled and is shown in Figure 10. The initial share of benefits does show a discrepancy among the volume of water each region controls, where Toronto has a disproportionably low share of benefits in relation to their overall market share of water allowances. This is shown in Figure 11.

Figure 10: Share of Benefits by Region

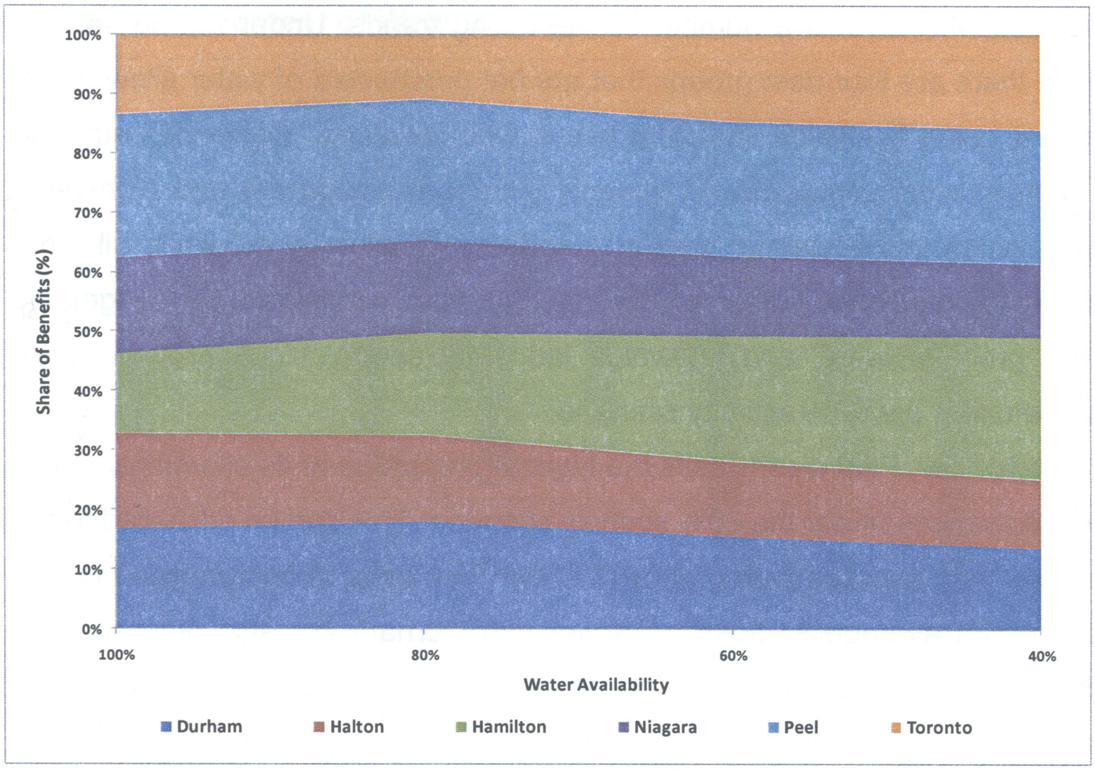
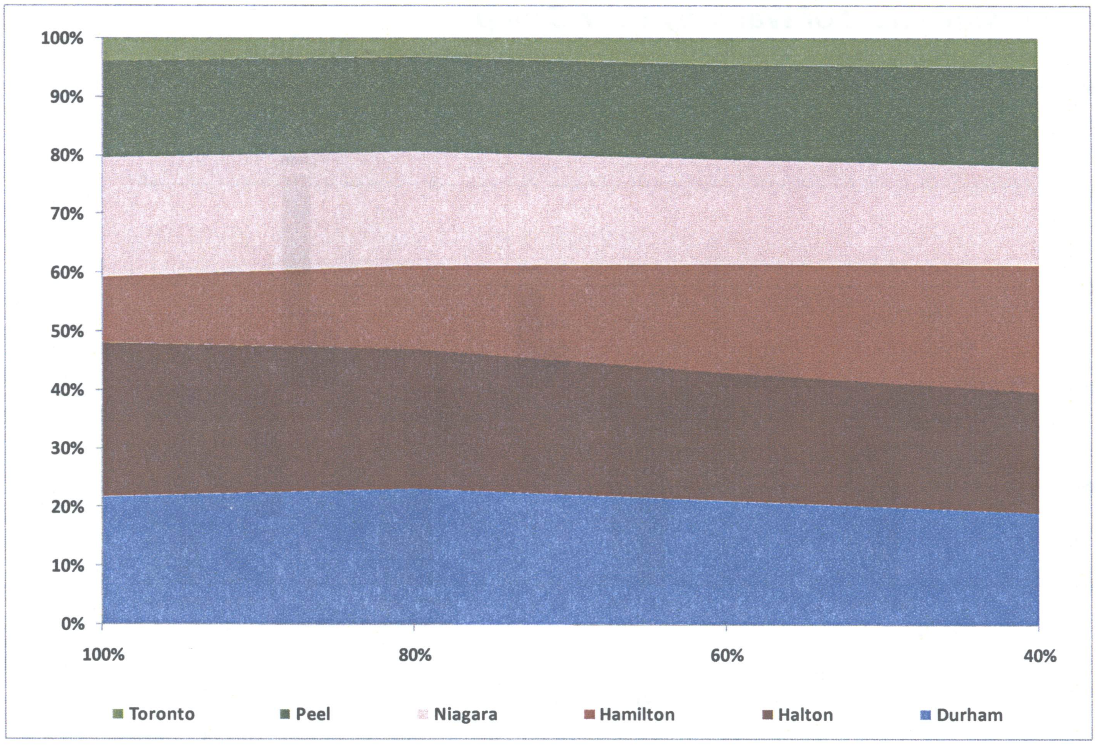


Figure 11: Share of Benefits by Region (normalized)



Reviewing the movement of water allowances themselves under each scarcity scenario reveals a number of interesting trends. Under the no scarcity condition there are four user groups that are net purchasers of water allowances, the largest being low-value industrial users, who purchase allowances equal to 30% of their initial allocation. As scarcity increases residential and high-value industrial users trend towards greater purchases of allowances, while all other users sell increasingly larger proportions of their allotment, with vegetable growers, grain growers, and low-value industrial selling 100% of their water allowance under the 60% scarcity scenario.

Regionally, Peel clearly sells the highest proportion of its allotment, selling 51% of allowances under the 60% scarcity scenario. This can be attributed to the initial lower than average selling price ($1.00/m^3$) of water in comparison to other regions, which average $1.50/m^3$. Niagara and Durham are also net sellers of allowances under each scarcity scenario; however, in both cases they are trending toward net purchases as scarcity increases.

Figure 11: Movement of Water by User Group

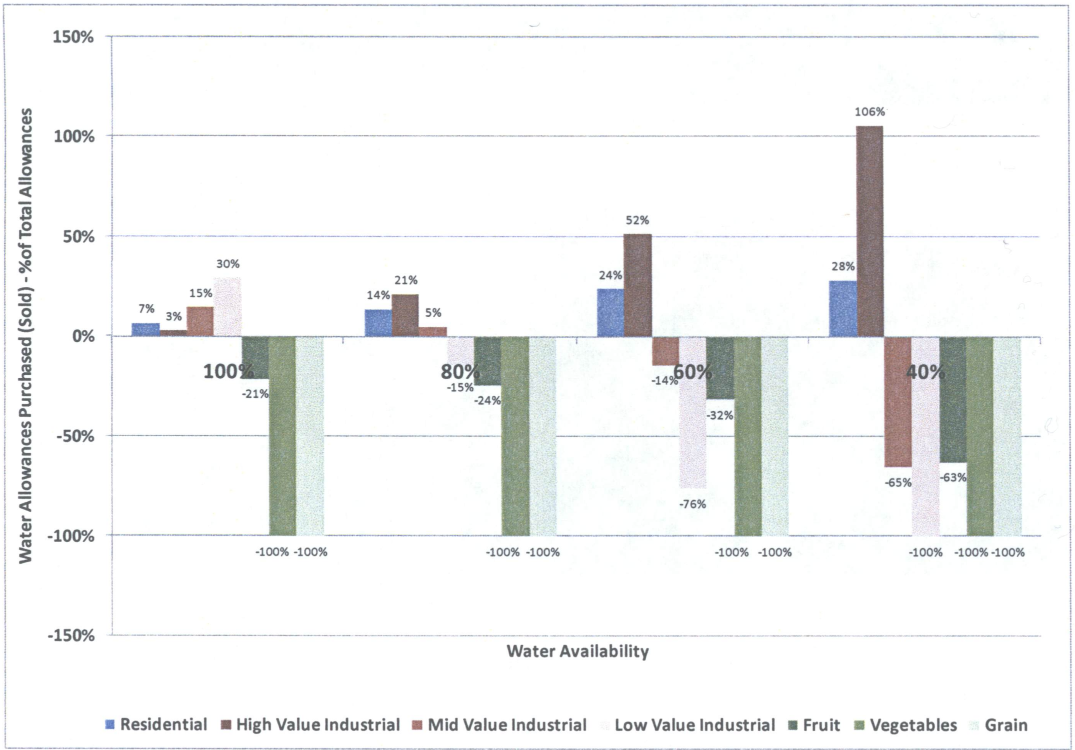
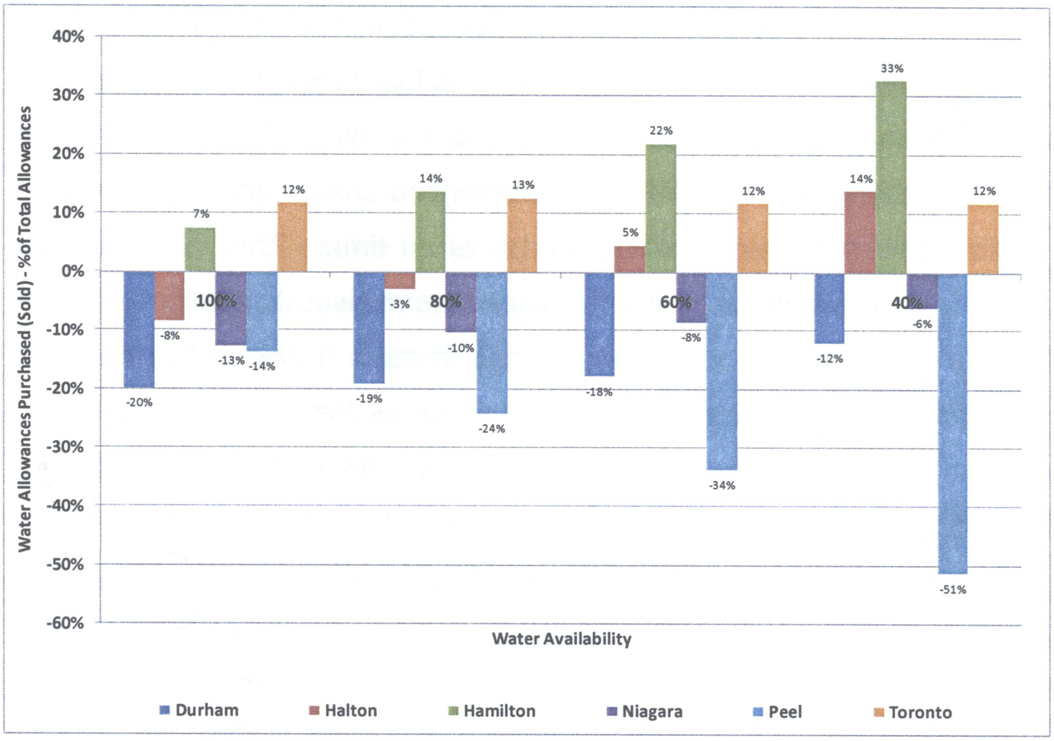


Figure 12: Movement of Water by Region



Conclusions

Overall, the implementation of the market model in contrast to a conventional approach presents some opportunities for economic benefit, even in instances where no water scarcity exists. Both a traditional approach and a market approach demonstrate positive value retention characteristics in that the value retention ratio remains greater than 1.0 at all times. This indicates that there is some built-in robustness with the users themselves to reallocate water more efficiently. However, as scarcity increases there is a divergence between the value retention ratio of the traditional model versus that of a market model, with a market model showing superior performance. This is in turn reflected by the benefit ratio, which shows benefits increasing as a percentage of value between the two models as scarcity increases. This is indicative of an improved allocation efficiency that allowance trading provides, particularly as water becomes scarce and higher value uses can become potentially constrained without the ability to purchase additional units. This effect can be indirectly demonstrated by examining the activity ratio, which shows an increasing percentage of allowances traded as scarcity increases, with more and more users finding greater benefit in selling their allowances than using it themselves as they may have done in less scarce conditions.

It is important to reiterate the role that agriculture has in providing benefit to the market. In its current state, water valuation for agricultural uses is considerably less than non-agricultural uses under the current model. However, this is demonstrative of how market forces can best re-allocate resources at a macro-scale, even when a large disparity in initial conditions may not exist. Indeed, under conditions of large scarcity, users that were initially purchasing significant quantities of allowances became sellers, indicating that allocation efficiencies are in fact working as intended under the market model.

In taking a system currently designed for all users and regions to operate autonomously and forcing them into a single market, price disparities are bound to exist. This discrepancy exists not only between heterogeneous user groups, but also among groups across distinct regional boundaries. In the model as designed, the creation of a market, particularly under scarcity conditions, created an equilibrium price that "priced out" many users within the market. This is a predictable result when instituting a market with a diverse base of participants that have substantially different end use designs for the material input; in this case water. This creates a trade-off between user equity and overall market efficiency. As was shown in previous studies, this problem can be avoided through exclusion of certain user groups within the marketplace. Primarily, this has been achieved by creating agriculture only, or alternatively non-agriculture type markets. For this thesis however, the primary design was overall market efficiency and not user equity, making an inclusive design more appropriate. In practice, the trade-off between user equity and market efficiency needs to be closely examined for market implementation. Potential approaches could include excluding users considered "essential services" and/or creating allocation and price rules that would influence certain users not to trade their allotments. Functionally, this might resemble a mix of free market allocation and a modified approach to the *a priori* rights allocations discussed in the literature. This is outside of the scope of this thesis, however, and would make interesting research for future study. Furthermore, any examination into alternate or hybrid approaches to address equity would be situational, depending on local/regional economic, political and environmental factors.

In addition, for this thesis, trading and economic benefit was modeled for a single growing season only. Long-run scenarios, which take into account price corrections in the output products of user groups and sustained scarcity issues, would prove useful in determining the lasting effects of a water market on each group with respect to their purchasing/selling behaviour.

Qualitatively speaking, the application of a market model to the Southern Ontario region creates substantial changes to the water use equilibrium condition. As stated, the primary driver is a move from low value agriculture to industrial uses, with a secondary driver of low-value industrial to high-value industrial uses. This relationship becomes increasingly more pronounced as scarcity increases. This serves as an important exercise in how to best deal with scarcity conditions, whether imposed through natural cycles of abundance versus drought or through artificial constraints imposed for a number of potential reasons including downstream flow rate requirements, political water sharing agreements, ecological water table requirements, etc. Ideally, the institution of a market would accomplish use reduction goals on a large scale to meet natural and/or artificial constraints while mitigating loss and/or maximizing benefit. The creation of a market in Southern Ontario, demonstrates that economic efficiencies can be maintained to a reasonable level in an environment of declining resources using proper reallocation of resources.

Appendix A: Regional Water Usage

Durham

Millions of Litres (ML)

Month	April	May	June	July	August	September	TOTAL
Days	30	31	30	31	31	30	
Residential	**3,504.4**	**3,621.2**	**3,504.4**	**3,621.2**	**3,621.2**	**3,504.4**	**21,376.6**
Industrial/Commercial	**1,834.7**	**1,895.9**	**1,834.7**	**1,895.9**	**1,895.9**	**1,834.7**	**11,191.9**
High Value Users	*611.6*	*632.0*	*611.6*	*632.0*	*632.0*	*611.6*	*3,730.6*
Medium Value Users	*611.6*	*632.0*	*611.6*	*632.0*	*632.0*	*611.6*	*3,730.6*
Low Value Users	*611.6*	*632.0*	*611.6*	*632.0*	*632.0*	*611.6*	*3,730.6*
System Loss	**776.7**	**802.6**	**776.7**	**802.6**	**802.6**	**776.7**	**4,737.9**
Agriculture	-	-	**50.9**	**12,009.2**	**99.9**	-	**12,160.0**
Fruit Crops	-	*(21.0)*	*(0.3)*	*118.5*	*17.5*	-	*136.0*
Vegetable Crops	-	-	*50.9*	*248.8*	*82.4*	-	*382.1*
Grain Crops	-	-	-	*11,641.9*	*(3,564.4)*	*N/A*	*11,641.9*
TOTAL	**5,339.1**	**5,517.1**	**5,390.0**	**17,526.3**	**5,616.9**	**5,339.1**	**44,728.5**

Halton

Millions of Litres (ML)

Month	A	M	J	J	A	S	TOTAL
Days	30	31	30	31	31	30	
Residential	**3,174.5**	**3,280.3**	**3,174.5**	**3,280.3**	**3,280.3**	**3,174.5**	**19,364.4**
Industrial/Commercial	**1,398.9**	**1,445.6**	**1,398.9**	**1,445.6**	**1,445.6**	**1,398.9**	**8,533.5**
High Value Users	*466.3*	*481.9*	*466.3*	*481.9*	*481.9*	*466.3*	*2,844.5*
Medium Value Users	*466.3*	*481.9*	*466.3*	*481.9*	*481.9*	*466.3*	*2,844.5*
Low Value Users	*466.3*	*481.9*	*466.3*	*481.9*	*481.9*	*466.3*	*2,844.5*
System Loss	**807.1**	**834.0**	**807.1**	**834.0**	**834.0**	**807.1**	**4,923.2**
Agriculture	-	**61.7**	**1,669.6**	**3,485.9**	**1,455.2**	**15.1**	**6,687.5**
Fruit Crops	-	*8.6*	*24.3*	*38.8*	*16.2*	*2.9*	*90.8*
Vegetable Crops	-	*53.2*	*104.6*	*152.2*	*104.7*	*12.2*	*426.8*
Grain Crops	-	*(381.6)*	*1,540.7*	*3,294.9*	*1,334.3*	*N/A*	*6,169.9*
TOTAL	**4,573.4**	**4,787.6**	**6,243.0**	**8,211.8**	**6,181.0**	**4,588.5**	**34,585.4**

Hamilton

Millions of Litres (ML)

Month	A	M	J	J	A	S	TOTAL
Days	30	31	30	31	31	30	
Residential	**6,530.8**	**6,748.5**	**6,530.8**	**6,748.5**	**6,748.5**	**6,530.8**	**39,837.7**
Industrial/Commercial	**4,066.3**	**4,201.9**	**4,066.3**	**4,201.9**	**4,201.9**	**4,066.3**	**24,804.6**
High Value Users	*1,355.4*	*1,400.6*	*1,355.4*	*1,400.6*	*1,400.6*	*1,355.4*	*8,268.2*
Medium Value Users	*1,355.4*	*1,400.6*	*1,355.4*	*1,400.6*	*1,400.6*	*1,355.4*	*8,268.2*
Low Value Users	*1,355.4*	*1,400.6*	*1,355.4*	*1,400.6*	*1,400.6*	*1,355.4*	*8,268.2*
System Loss	**1,725.1**	**1,782.6**	**1,725.1**	**1,782.6**	**1,782.6**	**1,725.1**	**10,523.2**
Agriculture	-	**114.3**	**192.4**	**2,175.5**	**2,032.5**	**18.9**	**4,574.6**
Fruit Crops	-	*17.9*	*41.8*	*85.0*	*74.6*	*(1.5)*	*219.4*
Vegetable Crops	-	*96.4*	*150.5*	*241.0*	*227.6*	*18.9*	*775.4*
Grain Crops	-	*(1,251.9)*	*(239.4)*	*1,849.5*	*1,730.3*	*N/A*	*3,579.8*
TOTAL	**10,597.1**	**11,064.6**	**10,789.5**	**13,125.8**	**12,982.8**	**10,616.0**	**69,175.8**

Niagara

Millions of Litres (ML)

Month	A	M	J	J	A	S	TOTAL
Days	30	31	30	31	31	30	
Residential	**3,847.4**	**3,975.7**	**3,847.4**	**3,975.7**	**3,975.7**	**3,847.4**	**23,469.4**
Industrial/Commercial	**1,695.5**	**1,752.0**	**1,695.5**	**1,752.0**	**1,752.0**	**1,695.5**	**10,342.5**
High Value Users	*565.2*	*584.0*	*565.2*	*584.0*	*584.0*	*565.2*	*3,447.5*
Medium Value Users	*565.2*	*584.0*	*565.2*	*584.0*	*584.0*	*565.2*	*3,447.5*
Low Value Users	*565.2*	*584.0*	*565.2*	*584.0*	*584.0*	*565.2*	*3,447.5*
System Loss	**978.2**	**1,010.8**	**978.2**	**1,010.8**	**1,010.8**	**978.2**	**5,966.8**
Agriculture	-	**291.0**	**300.0**	**8,695.5**	**2,586.6**	-	**11,873.1**
Fruit Crops	-	*272.5*	*280.1*	*1,717.7*	*908.4*	-	*3,178.7*
Vegetable Crops	-	*18.5*	*19.9*	*57.2*	*36.3*	-	*131.8*
Grain Crops	-	*(2,194.9)*	*(2,557.9)*	*6,920.6*	*1,642.0*	*N/A*	*8,562.6*
TOTAL	**5,542.9**	**6,018.7**	**5,842.9**	**14,423.2**	**8,314.3**	**5,542.9**	**45,685.0**

Peel

Millions of Litres (ML)

Month	A	M	J	J	A	S	TOTAL
Days	30	31	30	31	31	30	
Residential	**7,266.5**	**7,508.7**	**7,266.5**	**7,508.7**	**7,508.7**	**7,266.5**	**44,325.8**
Industrial/Commercial	**4,524.4**	**4,675.3**	**4,524.4**	**4,675.3**	**4,675.3**	**4,524.4**	**27,599.1**
High Value Users	*1,508.1*	*1,558.4*	*1,508.1*	*1,558.4*	*1,558.4*	*1,508.1*	*9,199.7*
Medium Value Users	*1,508.1*	*1,558.4*	*1,508.1*	*1,558.4*	*1,558.4*	*1,508.1*	*9,199.7*
Low Value Users	*1,508.1*	*1,558.4*	*1,508.1*	*1,558.4*	*1,558.4*	*1,508.1*	*9,199.7*
System Loss	**1,919.5**	**1,983.4**	**1,919.5**	**1,983.4**	**1,983.4**	**1,919.5**	**11,708.7**
Agriculture	-	**308.5**	**2,519.8**	**5,796.6**	**3,348.1**	**11.0**	**11,999.4**
Fruit Crops	-	*11.0*	*21.3*	*36.2*	*19.3*	*5.7*	*95.4*
Vegetable Crops	-	*22.7*	*36.1*	*55.5*	*42.3*	*5.3*	*175.4*
Grain Crops	-	*274.9*	*2,462.4*	*5,704.9*	*3,286.5*	*N/A*	*11,728.6*
TOTAL	**11,791.0**	**12,492.5**	**14,310.7**	**17,980.6**	**15,532.1**	**11,802.0**	**83,908.8**

Toronto

Millions of Litres (ML)

Month	A	M	J	J	A	S	TOTAL
Days	30	31	30	31	31	30	
Residential	**20,162.6**	**20,834.7**	**20,162.6**	**20,834.7**	**20,834.7**	**20,162.6**	**122,992.0**
Industrial/Commercial	**12,554.1**	**12,972.6**	**12,554.1**	**12,972.6**	**12,972.6**	**12,554.1**	**76,580.0**
High Value Users	*4,184.7*	*4,324.2*	*4,184.7*	*4,324.2*	*4,324.2*	*4,184.7*	*25,526.7*
Medium Value Users	*4,184.7*	*4,324.2*	*4,184.7*	*4,324.2*	*4,324.2*	*4,184.7*	*25,526.7*
Low Value Users	*4,184.7*	*4,324.2*	*4,184.7*	*4,324.2*	*4,324.2*	*4,184.7*	*25,526.7*
System Loss	**5,326.0**	**5,503.5**	**5,326.0**	**5,503.5**	**5,503.5**	**5,326.0**	**32,488.5**
Agriculture	-	-	-	-	-	-	-
Fruit Crops	-	-	-	-	-	-	-
Vegetable Crops	-	-	-	-	-	-	-
Grain Crops	-	-	-	-	-	-	-
TOTAL	**32,716.7**	**33,807.3**	**32,716.7**	**33,807.3**	**33,807.3**	**32,716.7**	**199,572.0**

Appendix B: Weather Data and Related Calculations

Region: Durham

	J	F	M	A	M	J	J	A	S	O	N	D
Mean	-5	-4	0	6	12	17	20	20	16	9	4	-2
Max	-1	-1	4	11	17	22	25	24	20	13	7	2
Min	-9	-8	-4	2	8	12	16	15	11	5	1	-5
ET Base (mm/day)				***1.7***	***2.2***	***2.6***	***2.8***	***2.7***	***2.3***			
Rain (mm)	32	30	47	70	75	81	67	83	88	66	74	47
Snow (cm)	39	23	16	3	0	0	0	0	0	0	6	32
Total (mm)	71	53	62	73	75	81	67	83	88	66	80	79
Days	31		31	30	31	30	31	31	30	31	30	31

Region: Peel, Toronto

	J	F	M	A	M	J	J	A	S	O	N	D
Mean	-6	-5	0	6	13	18	21	20	15	9	3	-3
Max	-2	-1	4	12	19	24	27	26	21	14	7	1
Min	-11	-10	-5	1	7	12	15	14	10	4	-1	-7
ET Base (mm/day)				***1.9***	***2.6***	***3.0***	***3.2***	***3.1***	***2.7***			
Rain (mm)	25	22	37	62	72	74	74	80	78	63	62	35
Snow (cm)	31	22	19	6	0	0	0	0	0	1	8	29
Total (mm)	52	43	57	68	73	74	74	80	78	64	69	61
Days	31		31	30	31	30	31	31	30	31	30	31

Region: Halton

	J	F	M	A	M	J	J	A	S	O	N	D
Mean	-5	-4	0	6	12	18	21	20	16	9	4	-2
Max	-1	0	5	11	18	23	26	25	21	14	8	2
Min	-9	-9	-4	1	7	12	15	15	10	5	0	-6
ET Base (mm/day)				***1.8***	***2.4***	***2.8***	***3.1***	***2.9***	***2.6***			
Rain (mm)	31	28	47	65	70	71	73	78	79	69	69	47
Snow (cm)	28	17	15	3	0	0	0	0	0	0	3	18
Total (mm)	59	44	62	68	70	71	73	78	79	69	72	65
Days	31		31	30	31	30	31	31	30	31	30	31

Region: Hamilton

	J	F	M	A	M	J	J	A	S	O	N	D
Mean	-6	-5	0	6	13	18	21	20	16	9	3	-3
Max	-2	-1	4	11	19	24	26	25	21	14	7	1
Min	-10	-9	-5	1	7	12	15	15	10	4	0	-6
ET Base (mm/day)				***1.8***	***2.5***	***2.9***	***3.1***	***3.0***	***2.6***			
Rain (mm)	30	26	49	70	75	84	87	81	82	72	68	44
Snow (cm)	43	35	26	9	1	0	0	0	0	1	11	37
Total (mm)	66	55	75	78	76	84	87	81	82	73	79	77
Days	31		31	30	31	30	31	31	30	31	30	31

Region: Niagara

	J	F	M	A	M	J	J	A	S	O	N	D
Mean	-5	-4	1	7	14	19	22	21	17	11	5	-1
Max	-1	-1	5	12	19	24	27	26	21	15	8	2
Min	-8	-8	-3	2	9	14	17	17	13	6	1	-5
ET Base (mm/day)				***1.9***	***2.5***	***2.9***	***3.1***	***2.9***	***2.5***			
Rain (mm)	27	29	56	68	76	88	75	82	95	84	79	51
Snow (cm)	42	39	20	7	1	0	0	0	0	1	12	40
Total (mm)	70	67	76	76	77	88	75	82	95	84	91	91
Days	31		31	30	31	30	31	31	30	31	30	31

*Data covers 30 years historical data, 1971-2000
Source: http://www.climate.weatheroffice.ec.gc.ca/climate_normals

Rs = 0.7 Ra - b

Rs = Solar Radiation
Ra = Extraterrestrial Radiation
b = 4 MJ m-2 day-1

Rs estimated at 14 MJ m-2 day -1
Source: http://atlas.nrcan.gc.ca/

Ra = 25.71
1 MJ m-2 day -1 is 0.408 mm day-1
Ra = 10.49 mm day-1

$ET_o = 0.0023(T_{mean} + 17.8)(T_{max} - T_{min})^{0.5} R_a$

Source: FAO *ET refers to Evapotranspiration
**ETo is the base evapotranspiration for standard grass crop to which a crop factor is applied

Rainfall Conversions to Inches

	A	M	J	J	A	S
Region: Durham	2.88	2.94	3.17	2.65	3.28	3.46
Region: Peel, Toronto	2.69	2.85	2.92	2.93	3.13	3.05
Region: Halton	2.66	2.77	2.81	2.87	3.09	3.09
Region: Hamilton	3.07	2.98	3.30	3.41	3.17	3.23
Region: Niagara	2.97	3.01	3.44	2.97	3.21	3.75

Effective Rainfall Formulae Source: US Bureau of Reclamation

R=Rainfall	Re=Effective Rainfall
R<1	0.95R
1<R<2	0.95R + 0.9(R-1)
2<R<3	1.85 + 0.82(R-2)
3<R<4	2.67 + 0.65(R-3)
4<R<5	3.32 + 0.45(R-4)
5<R<6	3.77 + 0.25(R-5)
R>6	4.02 + 0.05(R-6)

Effective Rainfall in Inches

	A	M	J	J	A	S
Region: Durham	2.57	2.62	2.81	2.38	2.85	2.97
Region: Peel, Toronto	2.42	2.55	2.61	2.61	2.76	2.70
Region: Halton	2.39	2.48	2.51	2.56	2.73	2.73
Region: Hamilton	2.72	2.65	2.87	2.93	2.78	2.82
Region: Niagara	2.65	2.68	2.96	2.64	2.81	3.16

Effective Rainfall in mm

	A	M	J	J	A	S
Region: Durham	65.28	66.59	71.43	60.52	72.43	75.42
Region: Peel, Toronto	61.42	64.78	66.18	66.34	70.03	68.66
Region: Halton	60.77	62.98	63.80	65.11	69.25	69.31
Region: Hamilton	68.99	67.33	72.82	74.51	70.68	71.65
Region: Niagara	67.24	68.01	75.16	67.16	71.33	80.17

Appendix C: Market Summary Calculations
No Scarcity (Control)

Applicable Choke Price -->	0.94	Q-intercept	Slope	Equilibrium Quantity	100%Q	Purchase/Sale	Actual Change	P(NM)	Benefit ($)	Market Value	Non-Market Value
Durham											
Residential	23,353,386.18	26,720,694.68	3,586,670.43	23,184,972.41	21,376,555.74	1,808,416.67	1,808,416.67	1.49	455,906.24	$ 97,791,838.76	$ 95,553,204.16
High Value Industrial	3,781,834.86	3,917,169.90	144,151.39	3,775,066.16	3,730,638.00	44,428.16	44,428.16	1.29	6,846.49	$ 53,152,544.84	$ 53,101,901.29
Mid Value Industrial	4,242,606.55	5,595,957.00	1,441,513.91	4,174,919.60	3,730,638.00	444,281.60	444,281.60	1.29	68,464.87	$ 10,161,326.66	$ 9,654,891.14
Low Value Industrial	4,754,575.10	7,461,276.00	2,883,027.82	4,619,201.20	3,730,638.00	888,563.20	888,563.20	1.29	136,929.75	$ 8,254,039.38	$ 7,241,168.36
Fruit	121,517.03	135,990.48	15,416.31	120,793.15	135,990.48	(15,197.33)	(15,197.33)	0.00	7,490.73	$ 607,290.73	$ 599,800.00
Vegetables	54,169.38	382,091.53	349,284.50	37,768.56	382,091.53	(344,322.97)	(382,091.53)	0.00	169,715.95	$ 378,705.95	$ 208,990.00
Grain	0.00	0.00	0.00	0.00	11,641,919.61	(11,641,919.61)	(11,641,919.61)	0.00	6,011,599.73	$ 11,476,547.73	$ 5,464,948.00
Halton											
Residential	21,402,896.69	24,205,524.38	2,985,203.72	21,262,725.07	19,364,419.50	1,898,305.57	1,898,305.57	1.62	603,570.87	$ 96,684,748.57	$ 94,209,837.31
High Value Industrial	2,906,998.51	2,986,715.55	84,910.18	2,903,011.51	2,844,491.00	58,520.51	58,520.51	1.67	20,166.31	$ 52,487,602.22	$ 52,409,746.68
Mid Value Industrial	3,469,566.05	4,266,736.50	849,101.79	3,429,696.08	2,844,491.00	585,205.08	585,205.08	1.68	201,663.10	$ 10,307,600.27	$ 9,529,044.85
Low Value Industrial	4,094,641.10	5,688,982.00	1,698,203.58	4,014,901.17	2,844,491.00	1,170,410.17	1,170,410.17	1.68	403,326.19	$ 8,703,894.48	$ 7,146,783.64
Fruit	70,135.34	90,797.13	22,007.79	69,101.95	90,797.13	(21,695.17)	(21,695.17)	0.00	10,693.50	$ 197,993.50	$ 187,300.00
Vegetables	0.00	0.00	0.00	0.00	426,785.68	(426,785.68)	(426,785.68)	0.00	339,673.25	$ 420,723.25	$ 81,050.00
Grain	0.00	0.00	0.00	0.00	6,169,907.13	(6,169,907.13)	(6,169,907.13)	0.00	4,820,864.44	$ 6,082,264.44	$ 1,261,400.00
Hamilton											
Residential	44,303,379.30	49,797,090.75	5,851,597.03	44,028,614.86	39,837,672.60	4,190,942.26	4,190,942.26	1.70	1,500,786.61	$ 209,043,353.40	$ 203,411,156.30
High Value Industrial	8,453,565.16	8,681,606.01	242,896.48	8,442,159.84	8,268,196.20	173,963.64	173,963.64	1.70	62,296.80	$ 155,030,958.57	$ 154,797,169.26
Mid Value Industrial	10,121,885.78	12,402,294.30	2,428,964.81	10,007,832.61	8,268,196.20	1,739,636.41	1,739,636.41	1.70	622,968.03	$ 30,482,833.00	$ 28,144,939.86
Low Value Industrial	11,975,575.35	16,536,392.40	4,857,929.61	11,747,469.02	8,268,196.20	3,479,272.82	3,479,272.82	1.70	1,245,936.06	$ 25,784,491.17	$ 21,108,704.90
Fruit	177,699.99	219,421.65	44,439.60	175,613.31	219,421.65	(43,808.34)	(43,808.34)	0.00	21,593.02	$ 563,293.02	$ 541,700.00
Vegetables	182,860.71	775,360.50	631,097.94	153,227.21	775,360.50	(622,133.28)	(775,360.50)	0.00	306,647.98	$ 782,947.98	$ 476,300.00
Grain	351,845.42	3,579,771.85	3,438,208.39	190,402.75	3,579,771.85	(3,389,369.11)	(3,579,771.85)	0.00	1,670,611.79	$ 3,534,193.79	$ 1,863,582.00
Niagara											
Residential	25,553,481.26	29,336,798.63	4,029,780.03	25,364,261.07	23,469,438.90	1,894,822.17	1,894,822.17	1.46	445,477.30	$ 104,827,892.89	$ 102,514,509.12
High Value Industrial	3,508,714.30	3,619,862.61	118,389.02	3,503,155.29	3,447,488.20	55,667.09	55,667.09	1.46	13,087.47	$ 55,282,934.83	$ 55,214,971.01
Mid Value Industrial	4,059,749.23	5,171,232.30	1,183,890.18	4,004,159.12	3,447,488.20	556,670.92	556,670.92	1.46	130,874.69	$ 10,718,723.81	$ 10,039,085.64
Low Value Industrial	4,672,010.26	6,894,976.40	2,367,780.36	4,560,830.04	3,447,488.20	1,113,341.84	1,113,341.84	1.46	261,749.37	$ 8,888,590.57	$ 7,529,314.23
Fruit	2,537,053.36	3,178,691.98	683,437.91	2,504,962.22	3,178,691.98	(673,729.77)	(673,729.77)	0.00	332,079.76	$ 7,724,179.76	$ 7,392,100.00
Vegetables	51,459.33	131,807.81	85,582.75	47,440.75	131,807.81	(84,367.06)	(131,807.81)	0.00	41,584.32	$ 143,084.32	$ 101,500.00
Grain	0.00	0.00	0.00	0.00	8,562,586.15	(8,562,586.15)	(8,562,586.15)	0.00	5,249,479.78	$ 8,440,955.78	$ 3,191,476.00
Peel											
Residential	44,415,444.26	55,407,198.29	11,707,807.35	43,865,698.74	44,325,758.63	(460,059.89)	(460,059.89)	0.95	9,039.06	$ 125,872,030.69	$ 125,862,991.63
High Value Industrial	9,251,608.53	9,659,670.04	434,644.51	9,231,199.59	9,199,685.75	31,513.84	31,513.84	1.06	1,142.45	$ 107,128,510.41	$ 107,096,301.76
Mid Value Industrial	9,718,913.51	13,799,528.63	4,346,445.13	9,514,824.16	9,199,685.75	315,138.41	315,138.41	1.06	11,424.53	$ 19,794,141.31	$ 19,472,054.87
Low Value Industrial	10,238,141.26	18,399,371.51	8,692,890.25	9,829,962.58	9,199,685.75	630,276.82	630,276.82	1.06	22,849.07	$ 15,248,214.04	$ 14,604,041.15
Fruit	67,033.42	95,357.84	30,169.60	65,616.79	95,357.84	(29,741.04)	(29,741.04)	0.00	14,659.29	$ 165,359.29	$ 150,700.00
Vegetables	0.00	0.00	0.00	0.00	175,387.93	(175,387.93)	(175,387.93)	0.00	127,086.57	$ 172,896.57	$ 45,810.00
Grain	0.00	0.00	0.00	0.00	11,728,629.24	(11,728,629.24)	(11,728,629.24)	0.00	9,555,423.66	$ 11,562,025.66	$ 2,006,602.00
Toronto											
Residential	133,419,454.73	153,740,061.38	21,644,384.26	132,403,132.65	122,992,049.10	9,411,083.55	9,411,083.55	1.42	2,045,992.45	$ 535,490,907.69	$ 524,167,514.85
High Value Industrial	26,907,532.46	29,355,649.46	2,607,598.58	26,785,091.46	25,526,651.70	1,258,439.76	1,258,439.76	1.47	303,664.57	$ 163,972,014.91	$ 162,427,786.54
Mid Value Industrial	30,129,587.55	38,289,977.55	8,691,995.27	29,721,450.89	25,526,651.70	4,194,799.19	4,194,799.19	1.47	1,012,215.25	$ 80,114,098.60	$ 74,966,670.71
Low Value Industrial	34,732,523.41	51,053,303.40	17,383,990.53	33,916,250.08	25,526,651.70	8,389,598.38	8,389,598.38	1.47	2,024,430.49	$ 66,519,858.81	$ 56,225,003.03
Total Market	483,081,845	591,577,360	115,563,411	477,655,512							
Equilibrium Price	0.99										

80% Water Availability

Applicable Choke Price -->	1.54	Q-intercept	Slope	Equilibrium Quantity	80% Q	Purchase/Sale	Actual Change	P(NM)	Benefit ($)		Market Value
Durham											
Residential	21,196,787.50	26,720,694.68	3,586,670.43	20,113,634.26	17,101,244.59	3,012,389.67	3,012,389.67	2.68	1,265,030.02	$	93,449,104.18
High Value Industrial	3,695,159.29	3,917,169.90	144,151.39	3,651,626.42	2,984,510.40	667,116.02	667,116.02	6.47	1,543,668.01	$	52,978,006.58
Mid Value Industrial	3,375,850.86	5,595,957.00	1,441,513.91	2,940,522.19	2,984,510.40	(43,988.21)	(43,988.21)	1.81	671.16	$	8,496,975.36
Low Value Industrial	3,021,063.73	7,461,276.00	2,883,027.82	2,150,406.39	2,984,510.40	(834,104.01)	(834,104.01)	1.55	120,659.52	$	6,299,789.85
Fruit	112,247.49	135,990.48	15,416.31	107,591.85	108,792.38	(1,200.53)	(1,200.53)	1.76	46.75	$	575,854.75
Vegetables	0.00	0.00	0.00	0.00	305,673.22	(305,673.22)	(305,673.22)	0.22	362,454.92	$	563,085.32
Grain	0.00	0.00	0.00	0.00	9,313,535.69	(9,313,535.69)	(9,313,535.69)	0.19	11,910,256.36	$	17,156,606.44
Halton											
Residential	19,607,948.83	24,205,524.38	2,985,203.72	18,706,434.97	15,491,535.60	3,214,899.37	3,214,899.37	2.92	1,731,134.45	$	93,070,268.88
High Value Industrial	2,855,943.58	2,986,715.55	84,910.18	2,830,301.21	2,275,592.80	554,708.41	554,708.41	8.37	1,811,923.05	$	52,384,793.11
Mid Value Industrial	2,959,016.83	4,266,736.50	849,101.79	2,702,593.11	2,275,592.80	427,000.31	427,000.31	2.35	107,365.97	$	9,279,509.24
Low Value Industrial	3,073,542.66	5,688,982.00	1,698,203.58	2,560,695.23	2,275,592.80	285,102.43	285,102.43	2.01	23,932.17	$	6,647,712.41
Fruit	56,902.46	90,797.13	22,007.79	50,256.24	72,637.70	(22,381.46)	(22,381.46)	0.83	11,380.74	$	191,188.74
Vegetables	0.00	0.00	0.00	0.00	341,428.54	(341,428.54)	(341,428.54)	0.08	551,142.74	$	628,950.74
Grain	0.00	0.00	0.00	0.00	4,935,925.71	(4,935,925.71)	(4,935,925.71)	0.08	7,881,600.19	$	9,092,544.19
Hamilton											
Residential	40,784,922.09	49,797,090.75	5,851,597.03	39,017,774.42	31,870,138.08	7,147,636.34	7,147,636.34	3.06	4,365,364.27	$	201,958,249.46
High Value Industrial	8,307,515.99	8,681,606.01	242,896.48	8,234,162.69	6,614,556.96	1,619,605.73	1,619,605.73	8.51	5,399,672.15	$	154,736,859.92
Mid Value Industrial	8,661,394.10	12,402,294.30	2,428,964.81	7,927,861.11	6,614,556.96	1,313,304.15	1,313,304.15	2.38	355,041.74	$	27,541,846.46
Low Value Industrial	9,054,592.00	16,536,392.40	4,857,929.61	7,587,526.01	6,614,556.96	972,969.05	972,969.05	2.04	97,435.42	$	19,902,518.09
Fruit	150,979.28	219,421.65	44,439.60	137,558.79	175,537.32	(37,978.53)	(37,978.53)	0.99	16,228.42	$	536,260.42
Vegetables	0.00	0.00	0.00	0.00	620,288.40	(620,288.40)	(620,288.40)	0.25	685,394.74	$	1,142,642.74
Grain	0.00	0.00	0.00	0.00	2,863,817.48	(2,863,817.48)	(2,863,817.48)	0.21	3,486,443.24	$	5,275,481.96
Niagara											
Residential	23,130,448.96	29,336,798.63	4,029,780.03	21,913,479.24	18,775,551.12	3,137,928.12	3,137,928.12	2.62	1,221,728.33	$	99,948,641.94
High Value Industrial	3,437,529.17	3,619,862.61	118,389.02	3,401,776.39	2,757,990.56	643,785.83	643,785.83	7.28	1,750,416.56	$	55,139,589.60
Mid Value Industrial	3,347,897.93	5,171,232.30	1,183,890.18	2,990,370.11	2,757,990.56	232,379.55	232,379.55	2.04	22,806.28	$	9,285,271.55
Low Value Industrial	3,248,307.67	6,894,976.40	2,367,780.36	2,533,252.01	2,757,990.56	(224,738.55)	(224,738.55)	1.75	10,665.56	$	6,435,680.37
Fruit	2,126,114.77	3,178,691.98	683,437.91	1,919,720.57	2,542,953.58	(623,233.02)	(623,233.02)	0.93	284,165.83	$	7,380,581.83
Vegetables	0.00	0.00	0.00	0.00	105,446.25	(105,446.25)	(105,446.25)	0.31	96,804.14	$	194,244.14
Grain	0.00	0.00	0.00	0.00	6,850,068.92	(6,850,068.92)	(6,850,068.92)	0.15	9,554,799.70	$	12,618,616.66
Peel											
Residential	37,375,755.95	55,407,198.29	11,707,807.35	33,840,067.42	35,460,606.90	(1,620,539.48)	(1,620,539.48)	1.70	112,153.72	$	114,227,932.79
High Value Industrial	8,990,264.81	9,659,670.04	434,644.51	8,859,004.74	7,359,748.60	1,499,256.14	1,499,256.14	5.29	2,585,755.60	$	106,602,243.55
Mid Value Industrial	7,105,476.34	13,799,528.63	4,346,445.13	5,792,875.63	7,359,748.60	(1,566,872.97)	(1,566,872.97)	1.48	282,425.16	$	17,417,833.44
Low Value Industrial	5,011,266.92	18,399,371.51	8,692,890.25	2,386,065.51	7,359,748.60	(4,973,683.09)	(4,973,683.09)	1.27	1,422,859.53	$	13,884,974.65
Fruit	48,893.00	95,357.84	30,169.60	39,781.96	76,286.27	(36,504.31)	(36,504.31)	0.63	22,084.56	$	114,277.38
Vegetables	0.00	0.00	0.00	0.00	140,310.34	(140,310.34)	(140,310.34)	0.10	214,490.23	$	258,467.83
Grain	0.00	0.00	0.00	0.00	9,382,903.39	(9,382,903.39)	(9,382,903.39)	0.07	15,358,051.83	$	17,284,389.75
Toronto											
Residential	120,405,086.26	153,740,061.38	21,644,384.26	113,868,610.32	98,393,639.28	15,474,971.04	15,474,971.04	2.56	5,532,029.14	$	509,283,923.28
High Value Industrial	25,339,631.59	29,355,649.46	2,607,598.58	24,552,152.26	20,421,321.36	4,130,830.90	4,130,830.90	3.43	3,271,930.74	$	160,814,738.89
Mid Value Industrial	24,903,251.35	38,289,977.55	8,691,995.27	22,278,320.22	20,421,321.36	1,856,998.86	1,856,998.86	2.06	198,369.00	$	69,589,845.20
Low Value Industrial	24,279,850.99	51,053,303.40	17,383,990.53	19,029,988.74	20,421,321.36	(1,391,332.62)	(1,391,332.62)	1.76	55,677.85	$	48,034,347.11
	415,663,642	586,708,329	111,059,237	382,124,410							
Equilibrium Price	**1.84**										

60% Water Availability

Applicable Choke Price -->	2.59	Q-intercept	Slope	Equilibrium Quantity	60% Q	Purchase/Sale	Actual Change	P(NM)	Benefit ($)	Market Value	Non-Market Value
Durham											
Residential	17,438,391.61	26,720,694.68	3,586,670.43	16,833,006.38	12,825,933.44	4,007,072.93	4,007,072.93	3.87	2,238,375.93	$ 85,905,459.77	$ 72,620,435.16
High Value Industrial	3,544,106.10	3,917,169.90	144,151.39	3,519,775.14	2,238,382.80	1,281,392.34	1,281,392.34	11.65	5,695,284.40	$ 52,674,820.98	$ 43,447,010.15
Mid Value Industrial	1,865,319.00	5,595,957.00	1,441,513.91	1,622,009.43	2,238,382.80	(616,373.37)	(616,373.37)	2.33	131,776.78	$ 7,083,298.41	$ 6,951,521.62
Low Value Industrial	0.00	0.00	0.00	0.00	2,238,382.80	(2,238,382.80)	(2,238,382.80)	1.81	1,246,751.30	$ 6,170,745.79	$ 4,923,994.48
Fruit	96,093.06	135,990.48	15,416.31	93,490.98	81,594.29	11,896.69	11,896.69	3.53	4,590.31	$ 541,218.95	$ 503,832.00
Vegetables	0.00	0.00	0.00	0.00	229,254.92	(229,254.92)	(229,254.92)	0.44	456,455.50	$ 632,007.10	$ 175,551.60
Grain	0.00	0.00	0.00	0.00	6,985,151.76	(6,985,151.76)	(6,985,151.76)	0.38	14,666,022.95	$ 19,256,579.27	$ 4,590,556.32
Halton											
Residential	16,479,817.14	24,205,524.38	2,985,203.72	15,975,951.99	11,618,651.70	4,357,300.29	4,357,300.29	4.22	3,180,028.49	$ 86,791,655.94	$ 71,599,476.36
High Value Industrial	2,766,968.01	2,986,715.55	84,910.18	2,752,636.23	1,706,694.60	1,045,941.63	1,045,941.63	15.08	6,442,065.60	$ 52,206,206.26	$ 42,880,701.83
Mid Value Industrial	2,069,261.06	4,266,736.50	849,101.79	1,925,943.27	1,706,694.60	219,248.67	219,248.67	3.02	28,306.37	$ 7,493,640.67	$ 6,860,912.29
Low Value Industrial	1,294,031.13	5,688,982.00	1,698,203.58	1,007,395.54	1,706,694.60	(699,299.06)	(699,299.06)	2.35	143,981.31	$ 5,003,794.19	$ 4,859,812.87
Fruit	33,840.97	90,797.13	22,007.79	30,126.33	54,478.28	(24,351.95)	(24,351.95)	1.65	13,472.90	$ 170,804.90	$ 157,332.00
Vegetables	0.00	0.00	0.00	0.00	256,071.41	(256,071.41)	(256,071.41)	0.15	637,852.47	$ 705,934.47	$ 68,082.00
Grain	0.00	0.00	0.00	0.00	3,701,944.28	(3,701,944.28)	(3,701,944.28)	0.16	9,145,897.82	$ 10,205,473.82	$ 1,059,576.00
Hamilton											
Residential	34,653,157.63	49,797,090.75	5,851,597.03	33,665,481.03	23,902,603.56	9,762,877.47	9,762,877.47	4.43	8,144,253.26	$ 189,650,910.90	$ 154,592,478.78
High Value Industrial	8,052,989.92	8,681,606.01	242,896.48	8,011,992.02	4,960,917.72	3,051,074.30	3,051,074.30	15.32	19,162,596.28	$ 154,225,989.26	$ 126,652,229.39
Mid Value Industrial	6,116,133.38	12,402,294.30	2,428,964.81	5,706,154.42	4,960,917.72	745,236.70	745,236.70	3.06	114,323.96	$ 29,135,624.45	$ 20,264,356.70
Low Value Industrial	3,964,070.56	16,536,392.40	4,857,929.61	3,144,112.63	4,960,917.72	(1,816,805.09)	(1,816,805.09)	2.38	339,731.22	$ 14,693,650.55	$ 14,353,919.33
Fruit	104,411.97	219,421.65	44,439.60	96,911.12	131,652.99	(34,741.87)	(34,741.87)	1.98	13,580.20	$ 468,608.20	$ 455,028.00
Vegetables	0.00	0.00	0.00	0.00	465,216.30	(465,216.30)	(465,216.30)	0.49	882,410.49	$ 1,282,502.49	$ 400,092.00
Grain	0.00	0.00	0.00	0.00	2,147,863.11	(2,147,863.11)	(2,147,863.11)	0.42	4,355,793.36	$ 5,921,202.24	$ 1,565,408.88
Niagara											
Residential	18,907,727.91	29,336,798.63	4,029,780.03	18,227,551.29	14,081,663.34	4,145,887.95	4,145,887.95	3.79	2,132,670.62	$ 91,473,029.75	$ 77,911,026.93
High Value Industrial	3,313,471.83	3,619,862.61	118,389.02	3,293,489.24	2,068,492.92	1,224,996.32	1,224,996.32	13.10	6,337,648.61	$ 54,890,588.57	$ 45,175,885.37
Mid Value Industrial	2,107,324.52	5,171,232.30	1,183,890.18	1,907,498.62	2,068,492.92	(160,994.30)	(160,994.30)	2.62	10,946.61	$ 7,239,088.27	$ 7,228,141.66
Low Value Industrial	767,160.84	6,894,976.40	2,367,780.36	367,509.04	2,068,492.92	(1,700,983.88)	(1,700,983.88)	2.04	610,982.80	$ 5,730,916.48	$ 5,119,933.68
Fruit	1,409,954.68	3,178,691.98	683,437.91	1,294,598.88	1,907,215.19	(612,616.31)	(612,616.31)	1.86	274,566.82	$ 6,483,930.82	$ 6,209,364.00
Vegetables	0.00	0.00	0.00	0.00	79,084.68	(79,084.68)	(79,084.68)	0.62	132,759.67	$ 218,019.67	$ 85,260.00
Grain	0.00	0.00	0.00	0.00	5,137,551.69	(5,137,551.69)	(5,137,551.69)	0.30	11,482,298.59	$ 14,163,138.43	$ 2,680,839.84
Peel											
Residential	25,107,392.86	55,407,198.29	11,707,807.35	23,131,261.00	26,595,455.18	(3,464,194.18)	(3,464,194.18)	2.46	512,505.93	$ 96,168,379.57	$ 95,655,873.64
High Value Industrial	8,534,810.04	9,659,670.04	434,644.51	8,461,447.47	5,519,811.45	2,941,636.02	2,941,636.02	9.52	9,954,367.54	$ 105,688,079.93	$ 87,624,246.90
Mid Value Industrial	2,550,928.64	13,799,528.63	4,346,445.13	1,817,302.91	5,519,811.45	(3,702,508.54)	(3,702,508.54)	1.90	1,576,986.37	$ 15,596,865.88	$ 14,019,879.50
Low Value Industrial	0.00	0.00	0.00	0.00	5,519,811.45	(5,519,811.45)	(5,519,811.45)	1.48	5,286,199.39	$ 15,216,947.37	$ 9,930,747.98
Fruit	17,278.91	95,357.84	30,169.60	12,186.66	57,214.70	(45,028.04)	(45,028.04)	1.26	33,602.11	$ 160,190.11	$ 126,588.00
Vegetables	0.00	0.00	0.00	0.00	105,232.76	(105,232.76)	(105,232.76)	0.21	251,623.95	$ 290,104.35	$ 38,480.40
Grain	0.00	0.00	0.00	0.00	7,037,177.55	(7,037,177.55)	(7,037,177.55)	0.14	17,714,457.61	$ 19,400,003.29	$ 1,685,545.68
Toronto											
Residential	97,724,394.92	153,740,061.38	21,644,384.26	94,071,092.80	73,795,229.46	20,275,863.34	20,275,863.34	3.69	9,496,935.31	$ 463,760,493.77	$ 398,367,311.29
High Value Industrial	22,607,184.33	29,355,649.46	2,607,598.58	22,167,054.21	15,315,991.02	6,851,063.19	6,851,063.19	5.38	9,000,056.07	$ 155,330,321.84	$ 127,443,340.21
Mid Value Industrial	15,795,093.80	38,289,977.55	8,691,995.27	14,327,993.40	15,315,991.02	(987,997.62)	(987,997.62)	2.64	56,151.62	$ 43,512,541.78	$ 43,456,390.16
Low Value Industrial	6,063,535.90	51,053,303.40	17,383,990.53	3,129,335.10	15,315,991.02	(12,186,655.92)	(12,186,655.92)	2.06	4,271,590.64	$ 42,504,592.70	$ 38,233,002.06
Total Market	303,384,851	560,847,681	99,483,319	286,593,307							

40% Water Availability

Applicable Choke Price -->	3.88	Q-intercept	Slope	Equilibrium Quantity	40% Q	Purchase/Sale	Actual Change	P(NM)	Benefit ($)	Market Value	Non-Market Value
Durham											
Residential	12,797,240.08	26,720,694.68	3,586,670.43	12,337,173.98	8,550,622.30	3,786,551.69	3,786,551.69	5.07	1,998,786.06	$ 70,693,679.11	$ 53,509,794.33
High Value Industrial	3,357,574.20	3,917,169.90	144,151.39	3,339,083.75	1,492,255.20	1,846,828.55	1,846,828.55	16.82	11,830,533.34	$ 52,063,446.34	$ 32,826,629.89
Mid Value Industrial	0.00	0.00	0.00	0.00	1,492,255.20	(1,492,255.20)	(1,492,255.20)	2.85	963,804.48	$ 5,984,347.88	$ 5,020,543.39
Low Value Industrial	0.00	0.00	0.00	0.00	1,492,255.20	(1,492,255.20)	(1,492,255.20)	2.07	2,508,587.06	$ 5,984,347.88	$ 3,475,760.81
Fruit	76,144.35	135,990.48	15,416.31	74,166.88	54,396.19	19,770.69	19,770.69	5.29	12,677.48	$ 654,241.32	$ 641,563.84
Vegetables	0.00	0.00	0.00	0.00	152,836.61	(152,836.61)	(152,836.61)	0.66	479,162.64	$ 612,916.24	$ 133,753.60
Grain	0.00	0.00	0.00	0.00	4,656,767.84	(4,656,767.84)	(4,656,767.84)	0.56	15,177,334.70	$ 18,674,901.42	$ 3,497,566.72
						(2,140,963.93)					
Halton											
Residential	12,616,963.53	24,205,524.38	2,985,203.72	12,234,048.22	7,745,767.80	4,488,280.42	4,488,280.42	5.51	3,374,084.81	$ 74,130,814.87	$ 52,757,508.89
High Value Industrial	2,657,094.23	2,986,715.55	84,910.18	2,646,202.71	1,137,796.40	1,508,406.31	1,508,406.31	21.78	13,398,214.63	$ 51,846,085.35	$ 32,398,752.49
Mid Value Industrial	970,523.35	4,266,736.50	849,101.79	861,608.14	1,137,796.40	(276,188.26)	(276,188.26)	3.69	44,918.03	$ 5,000,021.35	$ 4,955,103.32
Low Value Industrial	0.00	0.00	0.00	0.00	1,137,796.40	(1,137,796.40)	(1,137,796.40)	2.68	1,132,415.85	$ 4,562,872.00	$ 3,430,456.15
Fruit	5,362.89	90,797.13	22,007.79	2,539.92	36,318.85	(33,778.93)	(33,778.93)	2.48	36,255.35	$ 145,795.00	$ 109,539.65
Vegetables	0.00	0.00	0.00	0.00	170,714.27	(170,714.27)	(170,714.27)	0.23	632,738.51	$ 684,610.51	$ 51,872.00
Grain	0.00	0.00	0.00	0.00	2,467,962.85	(2,467,962.85)	(2,467,962.85)	0.25	9,089,904.07	$ 9,897,200.07	$ 807,296.00
						1,910,246.02					
Hamilton											
Residential	27,081,191.07	49,797,090.75	5,851,597.03	26,330,600.38	15,935,069.04	10,395,531.34	10,395,531.34	5.79	9,233,981.02	$ 164,833,127.28	$ 113,910,247.53
High Value Industrial	7,738,681.87	8,681,606.01	242,896.48	7,707,525.28	3,307,278.48	4,400,246.80	4,400,246.80	22.13	39,856,839.08	$ 153,195,817.11	$ 95,692,795.54
Mid Value Industrial	2,973,052.92	12,402,294.30	2,428,964.81	2,661,486.98	3,307,278.48	(645,791.50)	(645,791.50)	3.74	85,848.64	$ 14,721,217.37	$ 14,635,368.73
Low Value Industrial	0.00	0.00	0.00	0.00	3,307,278.48	(3,307,278.48)	(3,307,278.48)	2.72	3,130,904.90	$ 13,263,083.25	$ 10,132,178.35
Fruit	46,907.13	219,421.65	44,439.60	41,206.82	87,768.66	(46,561.85)	(46,561.85)	2.96	24,392.72	$ 371,080.72	$ 346,688.00
Vegetables	0.00	0.00	0.00	0.00	310,144.20	(310,144.20)	(310,144.20)	0.74	938,930.31	$ 1,243,762.31	$ 304,832.00
Grain	0.00	0.00	0.00	0.00	1,431,908.74	(1,431,908.74)	(1,431,908.74)	0.62	4,549,649.74	$ 5,742,342.22	$ 1,192,692.48
						9,054,093.37					
Niagara											
Residential	13,693,192.55	29,336,798.63	4,029,780.03	13,176,288.30	9,387,775.56	3,788,512.74	3,788,512.74	4.95	1,780,845.19	$ 74,381,933.37	$ 57,408,125.10
High Value Industrial	3,160,276.44	3,619,862.61	118,389.02	3,145,090.56	1,378,995.28	1,766,095.28	1,766,095.28	18.93	13,173,065.28	$ 54,388,477.26	$ 34,132,891.17
Mid Value Industrial	575,370.63	5,171,232.30	1,183,890.18	423,511.75	1,378,995.28	(955,483.53)	(955,483.53)	3.20	385,571.56	$ 5,605,896.09	$ 5,220,324.53
Low Value Industrial	0.00	0.00	0.00	0.00	1,378,995.28	(1,378,995.28)	(1,378,995.28)	2.33	1,916,074.06	$ 5,530,144.89	$ 3,614,070.83
Fruit	525,586.02	3,178,691.98	683,437.91	437,920.70	1,271,476.79	(833,556.09)	(833,556.09)	2.79	508,323.98	$ 5,239,267.98	$ 4,730,944.00
Vegetables	0.00	0.00	0.00	0.00	52,723.12	(52,723.12)	(52,723.12)	0.92	146,474.02	$ 211,434.02	$ 64,960.00
Grain	0.00	0.00	0.00	0.00	3,425,034.46	(3,425,034.46)	(3,425,034.46)	0.45	11,692,772.02	$ 13,735,316.66	$ 2,042,544.64
						(1,091,184.47)					
Peel											
Residential	9,957,490.15	55,407,198.29	11,707,807.35	8,455,717.03	17,730,303.45	(9,274,586.42)	(9,274,586.42)	3.22	3,673,529.58	$ 74,156,804.90	$ 70,483,275.31
High Value Industrial	7,972,380.04	9,659,670.04	434,644.51	7,916,627.72	3,679,874.30	4,236,753.42	4,236,753.42	13.76	20,649,150.07	$ 103,844,666.34	$ 66,204,986.54
Mid Value Industrial	0.00	0.00	0.00	0.00	3,679,874.30	(3,679,874.30)	(3,679,874.30)	2.33	4,631,824.97	$ 14,757,293.50	$ 10,125,468.53
Low Value Industrial	0.00	0.00	0.00	0.00	3,679,874.30	(3,679,874.30)	(3,679,874.30)	1.69	7,747,353.75	$ 14,757,293.50	$ 7,009,939.75
Fruit	0.00	0.00	0.00	0.00	38,143.14	(38,143.14)	(38,143.14)	1.90	56,516.31	$ 152,964.31	$ 96,448.00
Vegetables	0.00	0.00	0.00	0.00	70,155.17	(70,155.17)	(70,155.17)	0.31	252,022.86	$ 281,341.26	$ 29,318.40
Grain	0.00	0.00	0.00	0.00	4,691,451.70	(4,691,451.70)	(4,691,451.70)	0.21	17,529,767.80	$ 18,813,993.08	$ 1,284,225.28
						(17,197,331.61)					
Toronto											
Residential	69,716,561.69	153,740,061.38	21,644,384.26	66,940,213.09	49,196,819.64	17,743,393.45	17,743,393.45	4.83	7,272,741.22	$ 371,962,367.20	$ 293,533,808.32
High Value Industrial	19,232,951.77	29,355,649.46	2,607,598.58	18,898,472.27	10,210,660.68	8,687,811.59	8,687,811.59	7.34	14,472,716.56	$ 144,270,979.07	$ 94,957,782.90
Mid Value Industrial	4,547,651.92	38,289,977.55	8,691,995.27	3,432,720.28	10,210,660.68	(6,777,940.40)	(6,777,940.40)	3.23	2,642,688.74	$ 41,625,357.51	$ 38,982,668.77
Low Value Industrial	0.00	0.00	0.00	0.00	10,210,660.68	(10,210,660.68)	(10,210,660.68)	2.35	13,959,515.80	$ 40,947,517.26	$ 26,988,001.46
						9,442,603.97					
Total Market	199,702,197	461,183,184	67,357,287	191,062,205							
Equilibrium Price	4.01										

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