MAXIMUM CONTAMINANT LEVEL REGULATION

AND ITS VIOLATION:

AN ECONOMETRIC ANALYSIS OF

DRINKING WATER SYSTEMS IN ARIZONA

by

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STATEMENT BY AUTHOR

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ABSTRACT

Whereas a large number of empirical studies have been devoted to analyzing environmental compliance (EC) by firms, less attention has been paid to EC by Public Water Systems (PWS). To address this gap in the literature, this thesis uses data on Maximum Contaminants Levels (MCLs) compliance of 971 PWS in Arizona. Four measures of MCL compliance are employed: an event of MCL violation, repeated MCL violation, and numbers of MCL violations within two and three years after the highest enforcement action. Using Probit and Count data models, we find that both publicly and privately owned systems are more likely to violate MCL regulations than mixed-owned systems; larger systems and systems serving to communities have a higher likelihood of violating MCL regulation; systems serving to communities violate more frequently than others; higher level of enforcement is ineffective for MCL compliance; and the level of enforcement action is determined by the compliance history of a PWS.

CHAPTER ONE

INTRODUCTION

Water pollution is a serious public health risk. For instance, excessive nitrate concentrations in water supplies is the cause of 'blue-baby' syndrome, and can cause still-birth in both humans and live stock.[1] Thus, water quality is an issue of state as well as federal attention and involvement. The Safe Drinking Water Act (SDWA), passed in 1974, authorized the United States Environmental Protection Agency (EPA) to set standards for drinking water quality. These standards, known as Maximum Contaminant Levels (MCLs) are maximum permissible levels of naturally occurring and human-made contaminants that can be present in drinking water and are harmful to health (SDWA 1974). The MCLs are set based on extensive empirical research and evidence on the most common contaminants in water, their health consequences, and best available cost effective technologies to treat water and make it safe for consumption.

According to the U.S. Census Bureau, Arizona had a population of about 5.8 million in 2004, a 12% increase since the year 2000 (USCB 2004). Drinking water for this increasingly growing population is provided by Public Water Systems (PWS) in the state. The EPA defines a public water system as, "[a] system for the provision to the public of water for human consumption through pipes or other constructed conveyances, if such system has at least fifteen service connections or regularly serves at least twenty-five individuals" (USEPA 2005). In Arizona, more than 5 million people receive drinking water from a regulated PWS (ADEQ 2004). The remaining, which amounts to

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[1] (U.S. EPA Maximum Contaminant Level and Arizona Aquifer Water Quality Standard for nitrate is 10 mg/L as N)

about 10% of the state's entire population, gets their supply of drinking water from private wells.

There is growing concern about the operations of water systems responsible for providing safe drinking water to people. Drinking water can get contaminated through perforation of chemicals and bacteria in the soil or as a result of exposure to pollutants in the air. Regardless of the manner of pollution, if consumed, contaminated water can be perilous to human health. In Arizona, the Arizona Department of Environmental Quality (ADEQ) monitors water systems in accordance with the provisions of the SDWA of 1974 and amendments made to the act in 1986 and 1996. It is the state agency responsible for ensuring that the quality of water supplied by the PWS is safe for consumption. It also ensures that the level of contaminants present in the water is lower than the maximum permissible limits specified by the EPA.

States and EPA provide technical assistance to water suppliers and can take legal action against systems that fail to provide water that meets state and EPA standards (USEPA 1999). However, mere presence of laws and regulations does not necessarily guarantee that they will be adhered to. An effective monitoring and enforcement strategy is essential to ensure the success of any regulatory mechanism.

Currently at ADEQ, PWS are inspected and monitored at regular intervals. Enforcement actions are taken against systems found to be in violation of MCL regulations. The inspection and enforcement activities undertaken by ADEQ are described in Chapter Three. The enforcement actions, however, follow the event of occurrence of a violation, which indicates that the water delivered from the violating system that entered the water supply was contaminated and might have been consumed by individuals. This is a potential health hazard that could cause water-borne illnesses.

It is estimated that each year between 7 and 30 million people in the U.S. are affected by gastrointestinal illnesses from consumption of contaminated drinking water (Gelt 1998). Hence arises the need for a monitoring mechanism by ADEQ that is preemptive, effective, and ensures the delivery of safe drinking water. For ADEQ to be able to accomplish these objectives, it would require a clear identification of water systems that are more likely to violate MCLs regulations. Having this knowledge will enable ADEQ to monitor identified PWSs at regular intervals in a timely fashion. It will also allow ADEQ to devote its limited resources for the inspection of those systems that have a higher probability of violating MCL regulations instead of randomly inspecting each of the hundreds of water systems operating in the state. To the best of our knowledge there have not been many studies that have attempted to identify and analyze the characteristics of PWSs that violate MCLs regulations. Thus, one of the main objectives of this thesis is to empirically identify PWSs in Arizona and their associated characteristics that are often in non-compliance of EPA regulations. In this case, our main variable of interest (dependent variable) is the occurrence of a MCL violation by a PWS. Since this variable is binary (dichotomous) in nature, we estimate a Probit Model that allows the estimation of probability of MCL violation by an individual PWS (see Chapter Four for model specifications and estimations).

A monitoring agency is required to best utilize the available resources in order to focus on PWSs that are more likely to violate repeatedly. Hence, prioritization of monitoring activities is a primary concern. Along with a focused monitoring effort, regulators also need to determine the level of punitive action/penalties that would discourage PWS from being negligent of adhering to the specified MCL levels.

The level of enforcement action/penalties is not uniform for all violating PWS. One of the few studies done on the relationship between a firm and regulatory agencies suggests that repeat offenders are fined more heavily (Harrington 1998). A similar study by Oljaca, Keeler and Dorfman, on the paper and pulp industry confirms that firm size and type of ownership has a strong influence on the level of penalties. They found that very small firms receive lower fines, but there was not much difference between fines for very large and medium sized firms. In addition, the penalties levied on private companies for water quality violations are influenced by the seriousness of violation and violation history (Oljaca, Keeler and Dorfman 1998).

Using econometric techniques for analyzing repeated violation (count) data, this study attempts to determine characteristics of those systems that are pre-disposed/likely to default on the MCL regulations and hence require frequent monitoring efforts. This study also examines the role of the violation history of a PWS in determining the level of enforcement action taken against it.

Specifically, the principal objectives of this thesis are to (1) determine the characteristics of water systems that are more likely to violate MCL regulations and quantify their effects on the probability of non-compliance; (2) examine the determinants of repeated violations and examine effectiveness of monitoring and enforcement activities; and (3) study the determinants of level of enforcement actions against a violating system by regulatory agencies.

The remainder of this thesis is organized as follows. Chapter Two provides a brief review of related literature on environmental quality compliance and regulations. Chapter Three discusses MCL regulations and their monitoring mechanisms. Chapter Four contains the discussion of empirical models and estimations. The description of data and variables is provided in Chapter Five. Chapter Six provides a discussion of empirical results. Finally, conclusions, policy implications, limitations of study, and areas of future research are provided in Chapter Seven.

CHAPTER TWO

LITERATURE REVIEW

Contrary to prevalent belief, concerns of drinking water quality are not restricted to under-developed or developing nations. Since there are diverse aspects of the effects of environmental quality on human life, the literature available is abundant. Studies on water quality range from source of water pollution to effects of certain pollutants on human health. However, there are few studies that are directly relevant for this study. In this section, we review the relevant literature.

Many factors affect the compliance of environmental regulations. Studies suggest that firms' awareness of regulations play a profound role on the level of compliance with regulations. Botelho, Pinto and Rodriguez (2005) show that a firm's level of information regarding the legal obligations has an extremely important effect on its decision to comply. An important finding of their study was that larger firms that were in operation for a shorter period of time were less likely to comply with environmental regulations than older firms that are smaller in size. Concurrent with this realization, the monitoring agencies directed greater efforts towards larger and younger firms (Botelho, Pinto and Rodriguez 2005). In contrast, our study presumes that all regulated firms in Arizona are aware of MCL regulations as well as their legal obligations.

The role of information on the extent of compliance has been emphasized by Winter and May (2001). Winter and May (2001) find that firms' willingness to comply is insufficient unless they are knowledgeable about the rules and have the technical and financial resources to comply. They hypothesize that one of the motivations for compliance is called calculated motivation that comprises of the likelihood of detection of violation, likelihood of fine, and the cost of compliance. Their results show that the cost of environmental compliance has a negative effect on compliance. Although they found that compliance is greater by firms that believe that the likelihood of detection of their violation is high, they could not establish any effect of likelihood of being fined once a violation was detected. The importance of enforcement mechanisms is noteworthy in cases where firms' perception of being penalized affects the level of compliance in the future.

A study done in Puerto Rico aimed at identifying determinants of compliance with drinking water standards by small community systems located in environmental justice communities (Guerrero-Preston et al. 2004). The results indicated that during the study period there was an 11% increase in compliance and a 6% decrease in the non-compliant systems that had installed treatment equipment. This study suggested implementation of an effective public policy to ensure that small drinking water systems in Puerto Rico comply with existing regulations. They suggested utilization of system specific determinants to develop assistance procedures within an appropriate strategic plan framework. Although one of the learning objectives of this study was to recognize differences in compliance with drinking water quality standards considering the source of water, population served, drinking water system's capacity and the neighborhood characteristics, it focused on small water systems serving water to communities. Our study expands the categories of water systems to both large and small, and attempts to identify those characteristics of any water system that make it more prone to be non-compliant.

Researchers have also used Bayesian networks for modeling of drinking water quality violations. Pike (2004) used probabilistic Bayesian network modeling to examine the causes of violations in water treatment systems. He replicated the type of model to predict violations designed by expert treatment system operators. However, it was found that the model did not make accurate predictions implying that experts at times make inaccurate quantitative estimates that could lead to violations. One of his recommendations was to combine the expertise of operators with compliance history of water systems to construct a Bayesian model that can precisely predict violations. Using Bayesian framework Pike found that system characteristics and operator decisions (coagulant dosing and filter backwash frequency) are the most important determinants of the probability of violation. Unlike Pike, this study employs discrete choice and count data models to examine the determinants of MCL violations by PWSs in Arizona.

There is a vast literature examining various contaminants and pollutants found in drinking water and their adverse effects on human health and the environment. The EPA releases a drinking water Candidate Contaminant List (CCL) every five years. This is a list of all the contaminants that are currently unregulated but are potentially harmful. A study by the National Research Council suggests identification of contaminants to monitor and focus upon. It recommended the adoption of a two-step approach to the EPA. The first step is the preparation of an initial Preliminary Candidate Contaminant List (PCCL) and the second step is to prioritize the contaminants to be listed in the CCL based on evaluation of health effects of each of the contaminant on the PCCL by "[u]sing more information in conjunction with a quantitative screening tool and expert judgment" (CGER 1999). The study also identified nine main drinking water contaminant categories to be evaluated for inclusion in future CCLs. Although this study provided a guideline for identification of main contaminants to focus regulation efforts, it does not specifically identify water systems that are more likely to be in violation of the contaminants listed in the CCLs.

Ownership of water systems has been one of the most debated topics in water economics literature. Some argue that privately owned water systems are less likely to violate water quality regulations than publicly owned water systems, while others disagree. The purpose of our study is different from most other studies dealing with the type of ownership debate. This is so because most studies that compare public and private water systems try to determine the type of ownership that is more profitable. We do not recommend one type of ownership over the other. Instead, we examine the historical trend of compliance actions of water systems to estimate the effect of type of ownership, if any, on compliance activity of the system. A similar study by Menard and Saussier (2000) used the regression model for water systems in France and concluded that there is no difference between privately and publicly owned systems with regard to compliance with water quality regulations.

There is a considerable literature examining the effectiveness of enforcement actions on the compliance activity of a firm. Kambhu (1989) analyzes the relationship between regulatory standards, penalties, enforcement efforts and compliance with regulatory standards. He demonstrates that raising a regulatory standard can lead to a decline in the level of compliance. As a result, instead of complying with the new regulations, a firm's compliance level can fall below the initial level. He also suggests that if the fine and enforcement resources are not raised, raising regulatory standards cannot induce compliance above some level.

In an influential study, Nowell and Shogren (1994) confirm that if a firm can contest the enforcement of an environmental regulation, neither increasing the probability nor severity of the fine will guarantee a reduction in a firm's illegally dumped waste. They conclude that, "lowering the cost of legal disposal will unambiguously decrease illegal dumping." The study by Gray and Deily (1996) on the Steel industry suggests that increased monitoring efforts lead to higher compliance with regulations and higher level of compliance leads to less enforcement.

A similar study by Dion, Lanoie and Laplante (1998) on the paper and pulp industry in Canada also found interesting results. They found that past compliance history explains enforcement activity and more visible firms can have higher inspections, but fewer penalties. They also observed that monitoring is concentrated where damages are largest. With regards to inspections, they found that more local employment causes more inspections and areas with higher unemployment have lower enforcements.

We examine the effectiveness of ADEQ's enforcement actions on compliance of MCLs regulations by PWSs in Arizona. The basic idea is to examine the determinants of repeated MCL violations where one of the causal variables is enforcement action. For this purpose, we estimate count data models (both poisson and negative binomial models). In order to examine the role of the violation history of a PWS in determining the level of enforcement action taken against it, we estimate an Ordered Probit model, where the dependent variable is the highest enforcement action taken by the ADEQ, and one of the its explanatory variables the number of MCL violations before the highest enforcement action was taken.

CHAPTER THREE

MCL REGULATIONS AND MONITORING MECHANISMS

3.1 MCL Regulations

The EPA determines national drinking water standards through a three-step process (USEPA 2005). The first step is the identification and study of contaminants that occur in drinking water frequently and in quantities that are perilous to human health. Once the potential contaminants are identified, the second step involves the determination of a Maximum Contaminant Level Goal (MCLG). The Office of Enforcement and Compliance Assurance defines MCLG as "[t]he maximum level of a contaminant that is associated with no adverse health effects from drinking water containing that contaminant over a lifetime. For chemicals believed to cause cancer, the MCLGs are set at zero. MCLGs are not enforceable, but are ideal, health-based goals that are set in the National Primary Drinking Water Standards developed by the EPA. MCLs are set as close to MCLGs as possible, considering costs and technology" (GEI 2004). There is no adverse risk to health if the contaminant level in the water is below the specified MCLG. The third step is establishing the MCL, which is set as close to its respective MCLG as feasible. Feasibility is defined by the SDWA as "[t]he level that may be achieved with the use of the best technology, treatment techniques, and other means which the EPA finds (after examination for efficiency under field conditions), are available, taking cost into consideration" (USEPA 2005). Another method adopted by the EPA is the treatment technique (TT) method, which prescribes a treatment plan for cases where it is not feasible to set the MCLs for technical or economic reasons. TTs were enforced by the

EPA for the Surface Water Treatment rule for disinfection and filtration and the Lead and Copper Rule for optimized corrosion control (USEPA 2005).

Once the EPA establishes the national standards for drinking water quality, the role of the state agency comes into effect. In Arizona, the Arizona Department of Environmental Quality (ADEQ) is responsible for the monitoring and enforcement of the MCL regulations determined by the EPA. The ADEQ was established in 1985 with the purpose of administrating environmental protection programs in Arizona (ADEQ 2004). It has four main divisions: air quality, water quality, tank programs and waste programs. Among the various core responsibilities of the water quality division are monitoring the violations of Arizona water quality laws. When a PWS violates MCL regulations, ADEQ's Water Quality Enforcement Unit is authorized to take enforcement action against them (A.R.S. §49-354). An exception is Maricopa County, where the Health Department of the county assumes this function. Violation histories of PWSs located in Maricopa County are also included in our study.

3.1.1. Inspection and Self-Reporting

According to the state law, the PWSs in Arizona are required to conduct the sampling and testing of their water systems to be in compliance with the MCL regulations specified by the EPA. All PWSs are supposed to monitor for the specified contaminants and the points of entry during the assigned year (ADEQ 1998). If a PWS is found to be in violation of the MCL regulations, then the enforcement mechanisms are initiated as described in the following section.

3.1.2. Self-reporting

Self-reporting is done for testing the level of lead, copper and bacterial contaminants. The procedure of self-reporting involves submitting samples of water from the water systems to testing laboratories. The laboratories are certified by, and the reports of the sample tests are sent directly to the ADEQ. However, for many water systems, it was getting increasingly harder to stay in compliance due to the inability of abiding by the monitoring regulations and self-reporting at the prescribed frequency. One of the suspected reasons was the lack of available funds to smaller utilities. Hence, the ADEQ formulated the Monitoring Assistance Program (MAP), discussed below.

3.2 Monitoring Assistance Program

The Monitoring Assistance Program (MAP) serves the purpose of providing monitoring assistance to PWSs (ARS § 49-360). According to the Capacity Development Report issued by the ADEQ, "[T]he Monitoring Assistance Program (MAP) provides for the collection, transportation, analysis, and reporting of baseline volatile organic contaminants (VOCs), synthetic organic contaminants (SOCs), and inorganic contaminants (IOCs) for regulated public water systems serving 10,000 persons or less. The public water systems are still responsible for collecting, analyzing, and reporting asbestos, lead, copper, nitrate, nitrite, microbiological (total coliform) and radiochemical. The program was initially developed to fill in substantial data gaps in the sampling and analysis of small water systems thereby bringing them into compliance with the Safe Drinking Water Act Monitoring and Reporting Requirements," (ADEQ 2001b). It is mandatory for small water systems (serving 10,000 people or less) and optional for larger systems. As part of the MAP, ADEQ contracts with private sector entities for sampling and transporting samples from a PWS to the testing facility/laboratory. The laboratories are approved by ADEQ and they report the results directly to the authorities.

3.3 Enforcement

This section examines the enforcement actions used by the ADEQ Drinking Water Compliance and Enforcement Unit (DWCEU) as specified in the Capacity Development Report (ADEQ 2001a). There are five types of enforcement mechanisms used by the ADEQ. They are discussed in the order of their severity of violations and consequences.

3.3.1 Compliance Assistance

This is an informal mechanism of enforcement of PWSs that have been found to be in minor non-compliance/deficiencies. By providing compliance assistance, the DWCEU helps the PWS to correct the minor deficiencies before they become a major case of violations. As part of compliance assistance, the ADEQ has developed a Compliance Assistance Package. All the forms and information is posted on the ADEQ website which allows a PWS to track its level of compliance with drinking water quality rules.

3.3.2 Notice of Opportunity to Correct (NOC)

If a deficiency is found in the PWS during a routine inspection or a sanitary survey then a NOC is issued. Sanitary survey is defined as an on-site review of the water sources, facilities, equipment, operation and maintenance of a public water system to evaluate the adequacy of those elements for producing and distributing safe drinking water. The NOC is a written record of the violation that may allow an inspector to provide advice of how the PWS can correct the deficiencies.[2] A period of 30 days is provided to the PWS to become compliant with the regulation.

3.3.3 Notice of Violation (NOV)

Of a higher level of significance is the notice of violation. The NOV is an informal enforcement document that includes the nature of violation, citation of authority resulting in violation, the time frame to correct the violation, an offer to discuss the violation and a statement detailing the consequence if the PWS fails to be in compliance with the regulation within 120 days.

3.3.4 Consent Order

If a violation identified cannot be corrected by the PWS in the time frame of 120 days as specified in the NOC, then an agreement can be reached between the PWS and the DWCEU wherein the PWS can provide a time period in which it would be able to

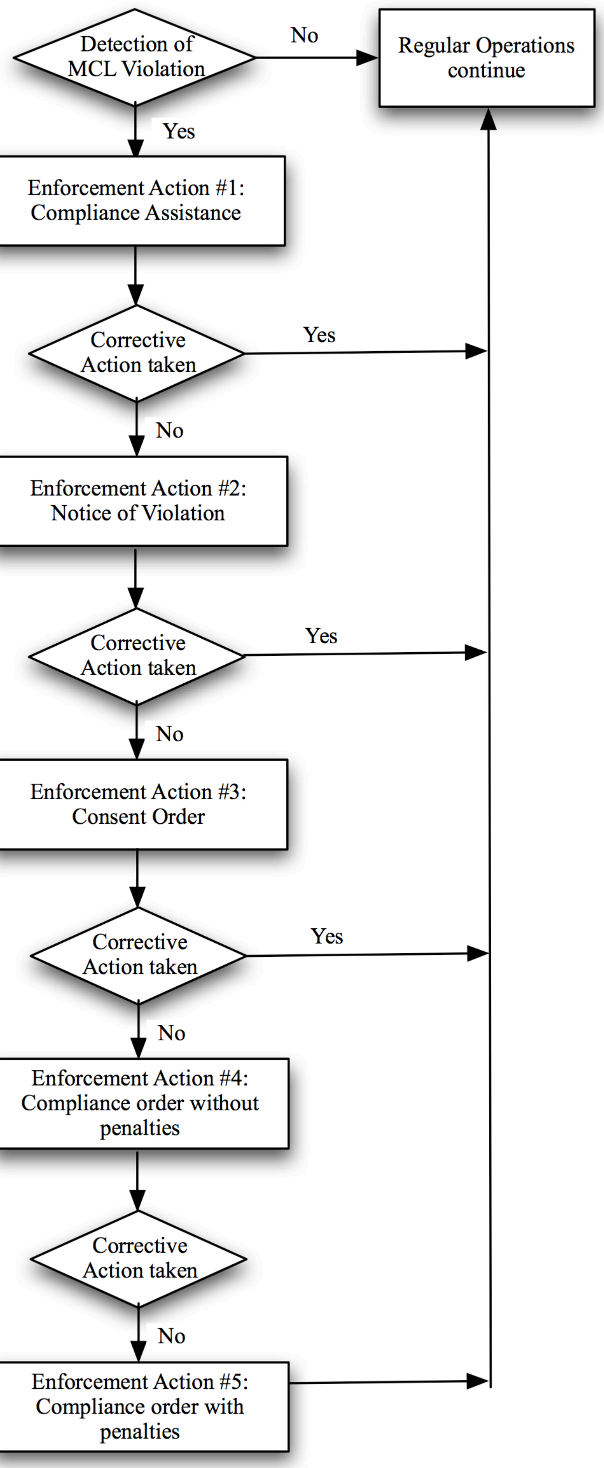
[2] A Notice of Opportunity to Correct (NOC) is authorized pursuant to Title 41, Article 1, Section 1009(E) of the Arizona Revised Statutes.

achieve compliance. The PWS might have to incur monetary penalties in lieu of a consent order by the regulating authority.

3.3.5 Compliance Order

For those PWSs that fail to achieve compliance with the state laws on water quality even after repeated warnings and opportunities to comply, the DWCEU issues a compliance order. It specifies the unresolved violation, a corrective action and the time frame to incorporate the specified measures. A PWS in recurrent non-compliance that has been issued the compliance order might have to pay a monetary fine as specified by ADEQ.

Figure 1: Levels of Enforcement Actions



CHAPTER FOUR

MODELS AND METHODS

As mentioned in Chapter One, this thesis aims to address three main issues relating to violation of MCLs regulations by PWSs in Arizona. The first objective of this thesis is to determine typical characteristics of PWSs that are more likely to violate MCLs (Probability of Non-Compliance Model). The second is to estimate the determinants of repeated violations and examine the effectiveness of monitoring and enforcement activities (Determinants of Repeated Violations: Count Data Model). The third objective is to study the determinants of level of enforcement actions against a violating system (Determinants of Enforcement Level). In the following, we discuss corresponding empirical models and their estimation.

4.1 Probability of Non-Compliance Model

Our main variable of interest (dependent variable) is the occurrence of a MCL violation by a public water system. "Probabilities are required to fall between zero and one, so a linear regression model is not appropriate to the modeling of probabilities since for extreme values of the independent variables, the predicted value of the dependent variable will be either less than zero or greater than one, which is impossible for a probability[3]." Since this variable is binary (dichotomous) in nature, we cannot use a linear regression model and instead an appropriate probability model is a Probit Regression Model.

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[3] http://elsa.berkeley.edu/sst/max.like.html (Last Accessed June 19, 2006)

The probit model estimates the ‘Probability of Default’ by a water system. Default is defined as the occurrence of violation of an MCL regulation. The approach of the Probit model is to assume that there is an underlying response variable Y_i^* defined as

(1) $$Y_i^* = X_i\beta + \varepsilon$$
$$\varepsilon \sim N(0,1)$$

where X_i is a set of independent or explanatory variables, ε is the stochastic disturbance term that follows a normal distribution, and Y_i^* is the latent variable, which in fact, is not observed. Instead, what is observed is Y_i.

(2) $$Y_i = \begin{Bmatrix} 1 \ when \ Y_i^* > 0 \\ 0 \ when \ Y_i^* = 0 \end{Bmatrix}$$

Y_i is defined as the occurrence or lack thereof of an event. That is, it tells us whether a violation of an MCL regulation has taken place:

(2a) $$Y_i = \begin{Bmatrix} 1 \ if \ MCL \ Violation \ occurs \\ 0 \ if \ no \ Violation \ occurs \end{Bmatrix}$$

Thus the empirical model for MCL violation to be estimated is specified as follows:

(3) $$violation(Y=1) = \beta_0 + \beta_1 population + \beta_2 watersource + \beta_3 urban + \beta_5 private + \beta_6 publicly + \beta_7 community + \beta_8 population * private + \beta_9 population * publicly$$

where violation (Y=1) is defined as above. *Population* represents the number of people served by a water system, *Watersource* indicates whether the source of water delivered is ground water or other, *Urban* represents the location (urban or non-urban) of the PWS well and the variable *Community* gives information about the type of people served by a

PWS (community or non-community).

The model in (3) is estimated by a maximum likelihood estimation procedure (MLE). The MLE procedure uses the cumulative density function (CDF) of the normal distribution.

4.2 Determinants of Repeated Violation

4.2.1 Poisson and Negative Binomial Model

In the binary model discussed in the previous section, the dependent variable takes the integer value equal to one if an MCL violation has occurred once or more in the in database during 1993 to 2005. That is, it takes the value 1 irrespective of the number of times a particular system has violated MCL regulations. As a result, the Probit model estimates the probability of occurrence of MCL violation by a PWS.

In the count data models, we examine the total number of violations by a PWS after the highest enforcement action against it. However, this method can give rise to inconsistencies in the study period for each system. For example, if the highest enforcement action for a system was imposed in year 2000, and the study period is till 2003, then it could be argued that another system that received highest level of enforcement action in 1995 was studied for a longer time period and hence the higher number of repeated violations was due to the inconsistency in study period rather than the compliance actions or characteristics of a system.

In order to make the study period consistent/symmetric for all the systems in this study, the dependent variable is modeled as the number of violations within two and three years following the highest enforcement level action against a water system. We estimate separate models in which the dependent variable is defined in three different ways: (i) the total number of MCL violations (between 1993 to 2004) by a system after the most severe enforcement action taken against it, (ii) the number of MCL violations within two years after highest enforcement action, (iii) the number of MCL violations within three years after highest enforcement action. The dependent variable is defined in three different ways since we attempt to study the effect of enforcement action on repeated violations by a water system. The reason for including definitions (ii) and (iii) is so that all systems are given a consistent study period after the highest enforcement action against them.

Since the dependent variable in all three cases is the number of violations, it takes integer values greater than or equal to zero. Thus the number of violation is a count data and for count dependent variables, the suitable probability model is a Poisson regression model or a Negative Binomial (NegBin) Model. OLS regression is not the appropriate method for estimating a count model, since a linear model might not provide the best fit over all values of the explanatory variables (Wooldridge 2003).

Let y_i denote the number of MCL violations, by a water system. The empirical specification of this "count" variable assumes that it is random and, in a given time interval, has a Poisson distribution with probability density,

$$\Pr(y_i = n_i) = \frac{e^{-\lambda_i}\lambda_i^{n_i}}{n_i!}, n_i = 0,1,2,..., \quad (4)$$

where n_i is the realized value of the random variable. This is a one-parameter distribution with mean and variance of y_i equal to λ_i. To incorporate a set of explanatory variables X_i into the analysis and to ensure non-negativity of the mean y_i, the parameter λ_i is specified such that,

$$E[y_i \mid X_i] = \lambda_i = \exp(x_i'\beta) = \exp(\beta_1 + \beta_2 x_{2i} + ...\beta_k x_{ki}). \quad (5)$$

The Poisson Regression model is estimated by using the maximum likelihood estimation procedure. The implicit assumption in the Poisson model is that the variance of y_i equals its mean or the data are equally dispersed. The violation of this assumption in the Poisson regression model has similar qualitative consequences as the failure of the assumption of homoskedasticity in the linear regression model (Cameron and Trivedi 2005). A simple regression based procedure is used for testing the null hypothesis that the variance of y_i is equal to its mean. The test statistic is given by:

$$z_i = \frac{(y_i - \hat{\lambda}_i)^2 - y_i}{\hat{\lambda}_i \sqrt{2}} \tag{6}$$

where $\hat{\lambda}_i$ is the predicted value from the regression. If this test were statistically significant, it would imply that the Poisson regression model is inappropriate, and a negative binomial model could be a better alternative.

The Negative binomial distribution is given by the following:

$$\Pr(y \mid x) = \frac{\Gamma(y + \alpha^{-1})}{y!\Gamma(\alpha^{-1})} \left(\frac{\alpha^{-1}}{\alpha^{-1} + \lambda} \right)^{\alpha^{-1}} \left(\frac{\lambda}{\alpha^{-1} + \lambda} \right)^{y} \tag{7}$$

$$f(k; r, p) = \frac{\Gamma(r + k)}{k!\Gamma(r)} p^r (1 - p)^k$$

k=0, 1, 2,….(Γ is the gamma function)

Since the negative binomial distribution has one additional parameter than the Poisson model, the second parameter can be used to adjust the variance independently of the mean.[4] We use the NegBin distribution to estimate the number of violation as a function of enforcement actions and characteristics of a water system:

$$Number\_Violations = f\begin{pmatrix} Highest\ Enforcement\ Action,\ Type\ of\ Ownership,\ Location, \\ Type\ of\ Server,\ Population\ Served \end{pmatrix} \quad (8)$$

The model to be estimated is given by (9).

$$\begin{aligned} Number\_Viol\_After = \beta_0 + \beta_1 highest\_enf\_act + \beta_2 population + +\beta_3 watersource + \beta_4 urban + \\ \beta_5 private + \beta_6 publicly + \beta_7 community + \beta_8 population * private + \beta_{19} population * publicly \end{aligned} \quad (9)$$

As in the three specifications mentioned above, we model *Number_Violations* as the total number of violations, number of violations within two years and number of violations within three years after the highest enforcement action taken against a PWS by ADEQ as opposed to the total number of violations. This is done so as to estimate the effectiveness of monitoring and enforcement actions and to observe if higher levels of enforcement actions can lead to reduction in number of repeat violations.

[4] http://en.wikipedia.org/wiki/Negative_binomial_distribution (Accessed June 8, 2006).

4.3 Determinants of Enforcement Level

Enforcement actions can be associated with the number of violations by a PWS. The variable *Highest_Enf_Act* is the highest level of enforcement action taken against a PWS. It takes a non-negative integer values. However, the integer values are ordinal, that is, of significance is not the actual value taken by the variable, but the order (Wooldridge 2003). For ordinal variables, the ordering of the values conveys information but the magnitude of the values does not. For example, 3 is higher than 2, 2 is higher than 1 and so on.

We model the highest level of enforcement action taken against a system as a function of the number of violations before the highest level of enforcement and other characteristics of a PWS, including type of ownership, type of server, number of people served and location of water system wells. In this model, we include the number of violations before highest level of enforcement action so as to study whether previous compliance history of a PWS has any effect on level of enforcement action taken against it. Since the dependent variable is an ordinal variable, we estimate an Ordered Probit model.

The ordered probit model is an extension of the probit model. In this estimation, the level of enforcement action is the ordered response. As is the case with probit model, the errors in the ordered probit model follow the normal distribution. Consider a dependent variable *Y* that takes values 0, 1, 2,….. (for purpose of this study, the dependent variable is *Highest_Enf_Act* that takes the values 0, 1, 2, 3, 4, depending on the highest level of enforcement action taken against a violating water system). The ordered probit model, like the probit, is based on the assumption that Y_i^* is linearly dependent on the set of explanatory variables X_i such that,

$$Y_i^* = X_i\beta + \varepsilon_i \qquad (10)$$

Where, Y_i^* is the latent variable, which is not observed. Instead, what is observed is Y_i.

$$Y_i = \begin{cases} 0 \text{ if } -\infty < Y_i^* < k_1 \\ 1 \text{ if } k_1 < Y_i^* < k_2 \\ . \\ . \\ J \text{ if } k_{J-1} < Y_i^* < -\infty \end{cases} \qquad (11)$$

The parameters k_i=1,….., *J-1*, are cut-points or threshold parameters (Daykin and Moffatt 2002).

Employing the ordered probit model, we attempt to estimate the following model:

$$Highest\_Enf\_Act = f\begin{pmatrix} Num\_Viol\_Before, population, \\ watersource, location, \\ type\ of\ ownership,\ type\ of\ server \end{pmatrix} \qquad (12)$$

The model to be estimated is given by (13).

$$\begin{aligned} &Highest\_Enf\_Act = \beta_0 + \beta_1 Num\_Viol\_Before + \beta_2 population + +\beta_3 watersource + \\ &\beta_4 urban + \beta_5 private + \beta_6 publicly + \beta_7 community + +\beta_8 population * private + \\ &\beta_9 population * publicly \end{aligned} \qquad (13)$$

We estimate equation (13) by the MLE procedure.

CHAPTER FIVE

DATA

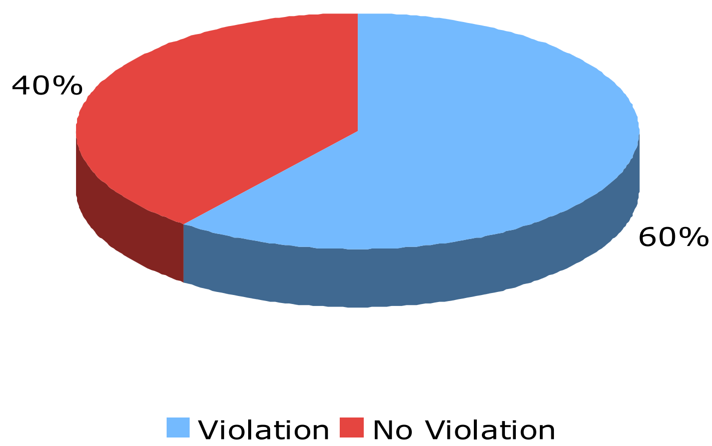
5.1 MCL Violations

The Arizona Department of Environmental Quality (ADEQ) carries out the inspection and enforcement activities of regulated drinking water systems in Arizona. The ADEQ reports MCL violations by water systems to the Environmental Protection Agency (EPA). This information is stored in the Safe Drinking Water Information System (SDWIS) database maintained by the EPA.

The stated objectives of this thesis are accomplished by using a unique dataset on PWS in Arizona. The dataset is cross-sectional and has system level data of PWSs. Information regarding the date of violation and enforcement actions is also available. A total of 971 PWSs were considered for this study. Each observation in the dataset is recognized by a PWS's unique identification number (SYSID). Corresponding to each observation, information on each system's characteristics, like number of people serviced by each system (population), type of server (Community or otherwise), source of water provided (watersource), ownership type (public, private or mixed) and the location of wells (urban or non-urban), is available. In addition, the data also provides particulars of the enforcement actions taken by ADEQ against the defaulting systems.

Figure 2 shows the distribution of PWS according to whether they have violated MCL regulation at least once. As we can see, 60% of PWS violated MCL regulation at least once.

Figure 2: Percentage of Systems by Occurrence of Violation



5.2 Explanatory Variables

Drinking water systems can be differentiated on the basis of their inherent characteristics. These characteristics include Population served, Type of Server, Source of water, Location and Type of Ownership.

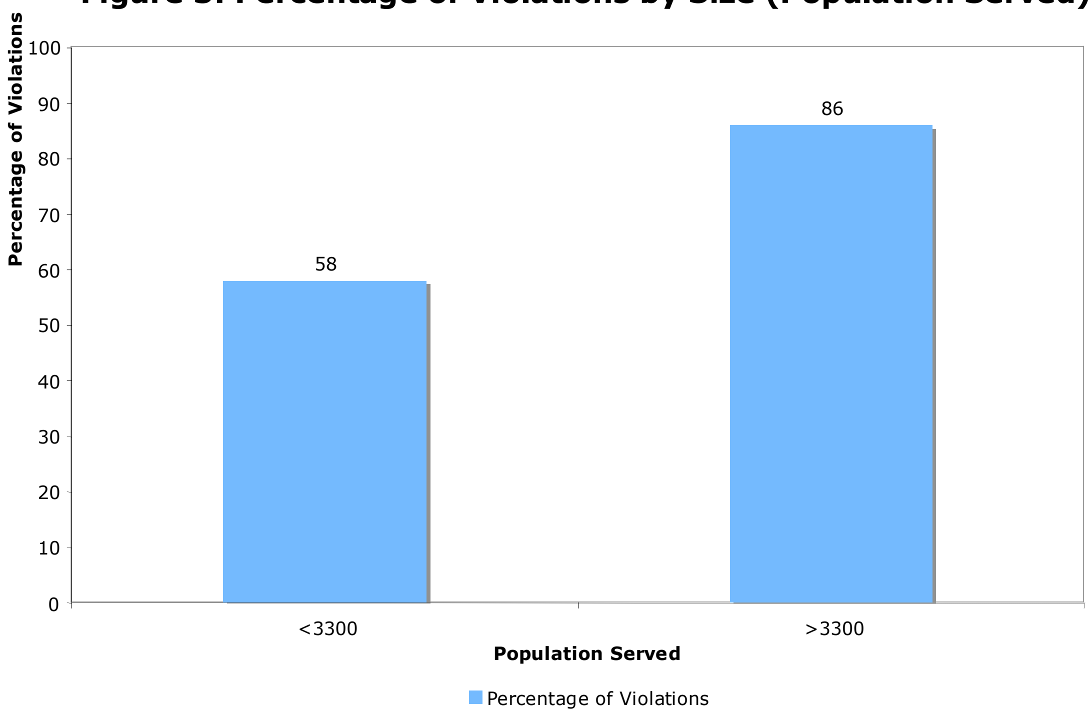
5.2.1 Population Served (*Population*) by a PWS

The variable *Population* defines the number of people a served by a PWS. We include it as one of our explanatory variables in order to test the significance of the size of a PWS in determining its compliance behavior.. The number of people served/receiving drinking water from a PWS is a measure of the size of a system. The larger the population served, the bigger the size of the PWS.

MCL regulations are updated regularly and as more contaminants and their permissible levels in drinking water are identified, water systems are provided a time frame to accommodate the new rules. It has been argued that larger firms are more financially able to make and absorb necessary pollution control expenditures without risk of bankruptcy or layoffs (Oljaca, Keeler and Dorfman 1998). And such may not be the case for smaller systems, as they may not have access to funds for upgrading their operating facilities.

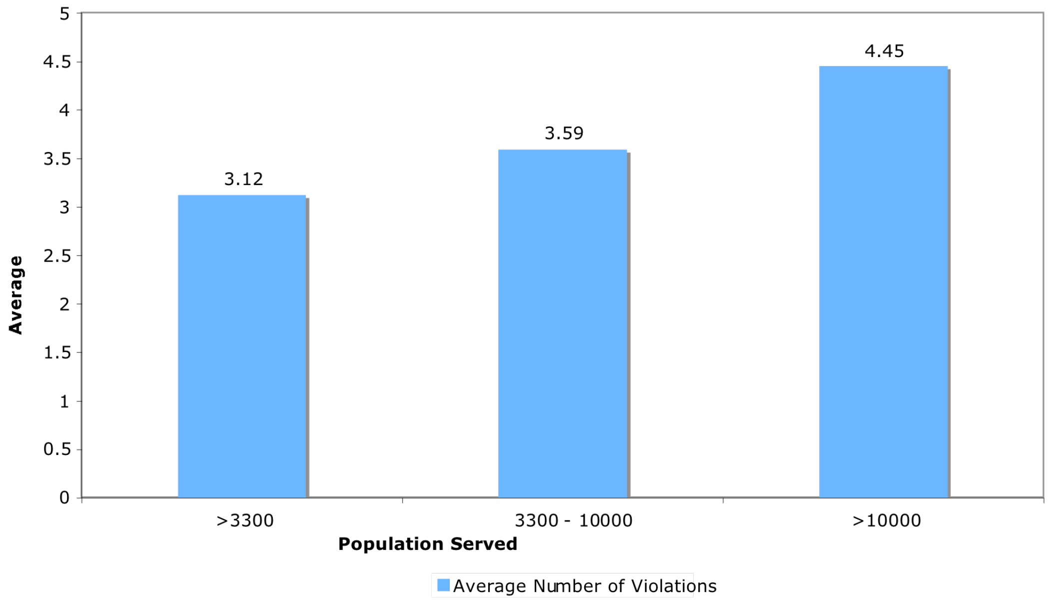
However, it should also be noted that larger water systems usually have either larger wells or greater number of wells than smaller systems. This can lead to complexities in management of the wells. Also, some wells can be more prone to having increased levels of naturally occurring contaminants and can be considered as a problematic well, which would require additional treatment procedures. A closer look at the data suggests that a higher percentage of larger PWSs have at least one or more MCL violations as compared to smaller systems (Figure 3).

Figure 3: Percentage of Violations by Size (Population Served)



A similar trend is also observed for the case of repeated violations, as seen in figure 5. The average number of violations of the groups depicting the systems serving a larger population is higher than the average number of violations of the groups serving to a smaller population. Hence we hypothesize that larger PWSs have a greater average number of repeated violations compared to smaller PWSs.

Figure 4: Distribution of Average Number of Violations by Population Served



5.2.2 Type of Server/Water System

By definition, public water systems have more than 15 service connections or serve at least 25 people regularly. They are further categorized based on the type of population they service to. A PWS can be either one of the following types:

(i) Community Water Systems (CO): Those water systems that serve the same people for at least 60 days of the year to communities. For example, residential homes and apartments.

(ii) Non-Community Water System: Water systems that serve people outside residential areas. There are two kinds of such systems:

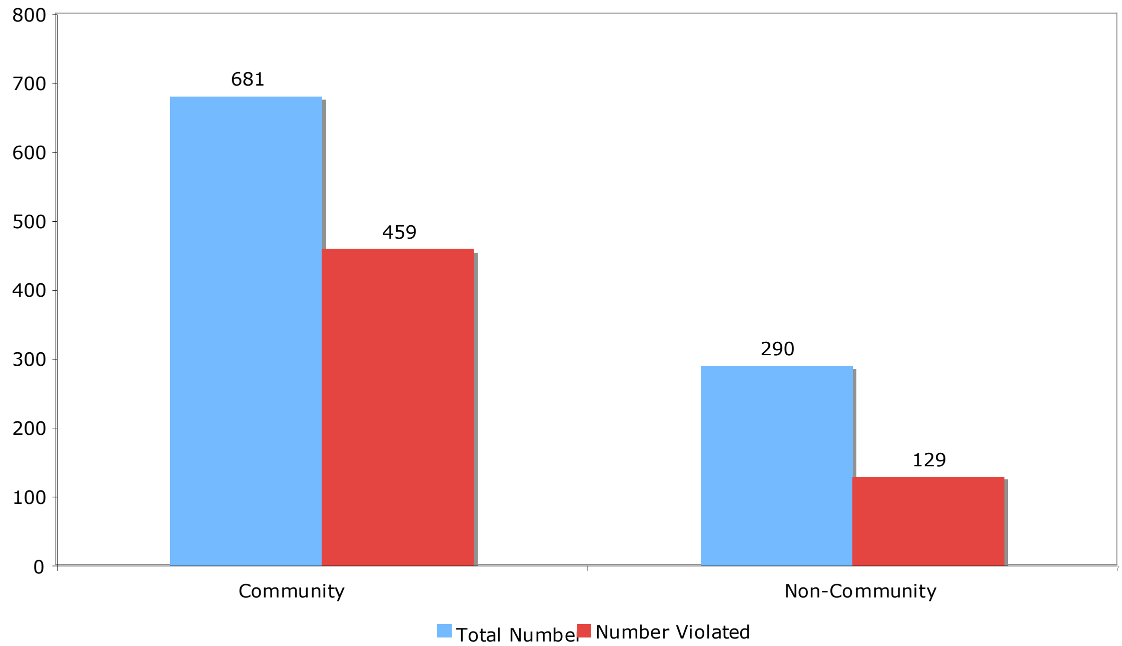
- Non-transient Non-community water system (NN): As the name suggests, these PWS do not serve water to residential communities, but they serve to the same people for a period greater than six months per year but not to a residential community. E.g. a school district with its water supply.

- Transient Non-community water system (TN): These systems do not serve the same people for more than six month in a year. E.g. Rest areas.

The variable *Community* indicates PWS serving to communities, and has been included in order to ascertain if difference in the kind of customers served, influences the level of compliance by a PWS. Depending on the statistical significance of the estimated coefficient, we can infer whether systems providing water to residential areas are more or less likely to be in violation than those serving to non-communities. This could be based on their cost-benefit analysis or age of the systems. As indicated above, a PWS servicing a school is a type of a non-community server. Although enforcement methods are not uniform and penalties of non-compliance are decided on a case to case basis, the penalties by defaulting systems providing drinking water to areas like schools or offices, might be of higher consequences and could be more severe since a violation would affect a larger number of people than if water is provided to a relatively smaller residential area. Hence, we postulate that community water systems have a higher likelihood of violation as compared to non-community systems.

Figure 5 shows the percentage of violations to total number of systems by the type of server: community or non-community. It suggests that 459 out of 681 systems (67%) serving water to communities have one or more violations in the study period. However, for non-community systems, 129 out of 290 systems (45%) have one or more MCL violations throughout the study period. From figure 5 we also observe that PWS serving to communities violate more than the PWS serving to non-communities..

Figure 5: Percentage of Violations to Total Number of Systems by Type of Server



5.2.3 Source of Water

The major sources of water delivered to consumers by a PWS are: groundwater, surface or purchased water/other. Groundwater means water under the surface of the earth regardless of the geologic structure in which it is standing or moving. Groundwater does not include water flowing in underground streams with ascertainable beds and banks (ARS § 45-101). Surface water is defined as the waters of all sources, flowing in streams, canyons, ravines or other natural channels, or in definite underground channels, whether perennial or intermittent, floodwater, wastewater or surplus water, and of lakes, ponds and springs on the surface (ARS § 45-101). Surface water, as it is defined, can be further exposed to contaminants in the environment when compared to groundwater.

A recent study by the EPA suggests that water pumped from wells generally contains less organic material than surface water and may not need to go through all of the treatments required. It also mentions that the quality of the water depends on local conditions (USEPA 1999). Another study with a similar conclusion suggests that people who get treated surface water in their homes are more vulnerable to parasites and contaminants from drinking water compared to those people for whom the source of tap water is groundwater (CSPI 2000).

It can be postulated that water systems whose major source of delivered water is groundwater may be less predisposed to violating MCL regulations as compared to systems treating and delivering surface or purchased water. A test of this hypothesis can facilitate understanding the effect of the source of water on the likelihood of violation by a PWS.

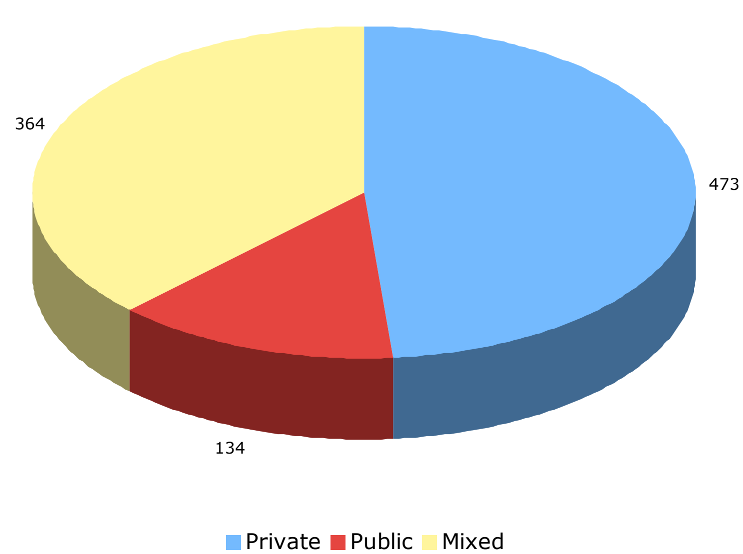
5.2.4 Type of Ownership of Water System

A PWS can be classified as having public, private or mixed ownership. Publicly owned water systems are owned and operated by the federal, state or local government. A privately owned water system in the state is defined as one that is owned by private entities and is registered with the Arizona Corporation Commission (ACC). Our dataset includes 473 private, 134 publicly and 364 systems with mixed ownership.

It was mentioned above that MCL regulations are dynamic and are changed periodically based on new studies and findings. In order to implement the new levels into the treatment systems, the water utilities need to make financial investments for new infrastructure and water purification procedures. This expenditure can be transferred to customers by way of rate increases and the process for such changes take a long time, especially for private systems. Unless a system can afford to pay for the updated treatment facilities, they would not be able to achieve new levels of water quality, which could lead to an event of violation. Also of importance is the fact that management of water systems is a complex task and requires both financial availability and technical expertise.

As regards to type of ownership of PWS, 134 systems are publicly owned, 473 systems are owned privately and the remaining 364 systems have mixed ownership (Figure 6).

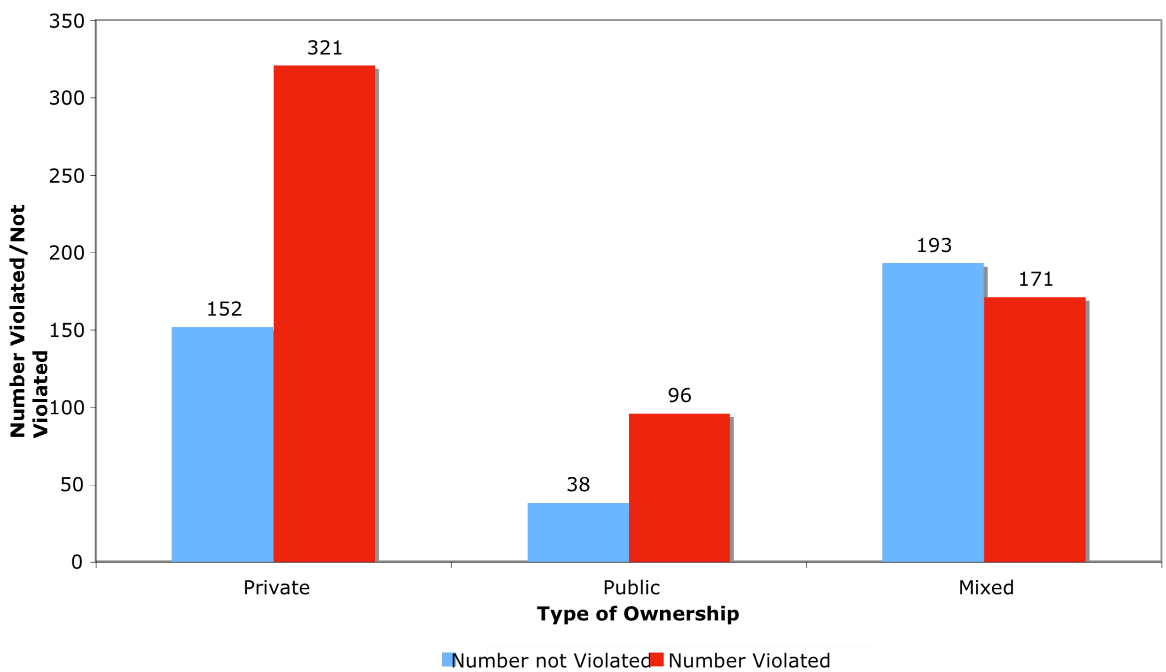
Figure 6: Distribution of Water Systems by Type of Ownership



As depicted in Figure 6, shows the distribution of PWS by its ownership type.

Figure 7 shows the distribution of MCL violation of PWS by ownership type. We observe from figure 7 that both publicly and privately owned PWS have a higher number of violations as compared to water systems with mixed ownership. This could be attributed to the fact that a mixed water system has the combination of expertise and better management from both publicly and privately owned systems. Thus, we hypothesize that both publicly and privately owned systems have a higher likelihood of violating MCL regulation than mixed-owned PWS.

Figure 7: Distribution of Occurence of Viola tion by Type of Ownership



5.2.5 Location of Source Water Wells

The variable *Urban* defines the location of source wells from which water is taken for treatment and distribution. A system well can either be located in urban or non-urban areas. An area is defined as urban or otherwise depending on land use classification. Based on Anderson land use codes, urban areas are classified as the following: urban or built-up land, residential, commercial and services, industrial, transportation, communication, utilities, industrial and commercial complexes, mixed urban or built-up land and other urban or built-up land. All other land-uses are classified as 'non-urban'.[5]

About 6 percent of urban wells and 1.5 percent of rural wells in the US contain levels of volatile organic compounds (VOC) in excess of drinking water criteria (USG 1999).[6] Hence, the systems located in urban areas would require additional treatment mechanisms to remove impurities and make the water potable. Unless proper methods are adopted, systems drawing water from wells located in urban areas might have a higher probability of violation as compared to wells located in non-urban locations.

5.2.6 Highest Enforcement Action

The highest level of enforcement action (denoted by *Highest_Enforcement_Action*) is an ordered variable that can take a discrete value of 0, 1, 2, 3 or 4 depending on the highest level of enforcement action taken by the ADEQ against a PWS in response to a violation of MCL regulations. More specifically, it is defined as:

$$Highest\_Enf\_Act = \begin{cases} = 0 \text{ when highest level of enforcement} = \text{Compliance Assistance} \\ = 1 \text{ when} \qquad = \text{Notice of Violation} \\ = 2 \text{ when} \qquad = \text{Consent Order} \\ = 3 \text{ when} \qquad = \text{Compliance Order (CO) without penalties} \\ = 4 \text{ when} \qquad = \text{CO with penalties} \end{cases}$$

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5 See Appendix 1 for Anderson Land-use codes.

6 Reported as 7% by Squillace et.al. (Squillace, 1999).

The highest enforcement action is included as one of the explanatory variables for the determination of repeat MCL regulation violation. The rationale is to test the effectiveness of enforcement action on compliance behavior of PWS.

Figure 8: Distribution of Number of Violations by Enforcement Action

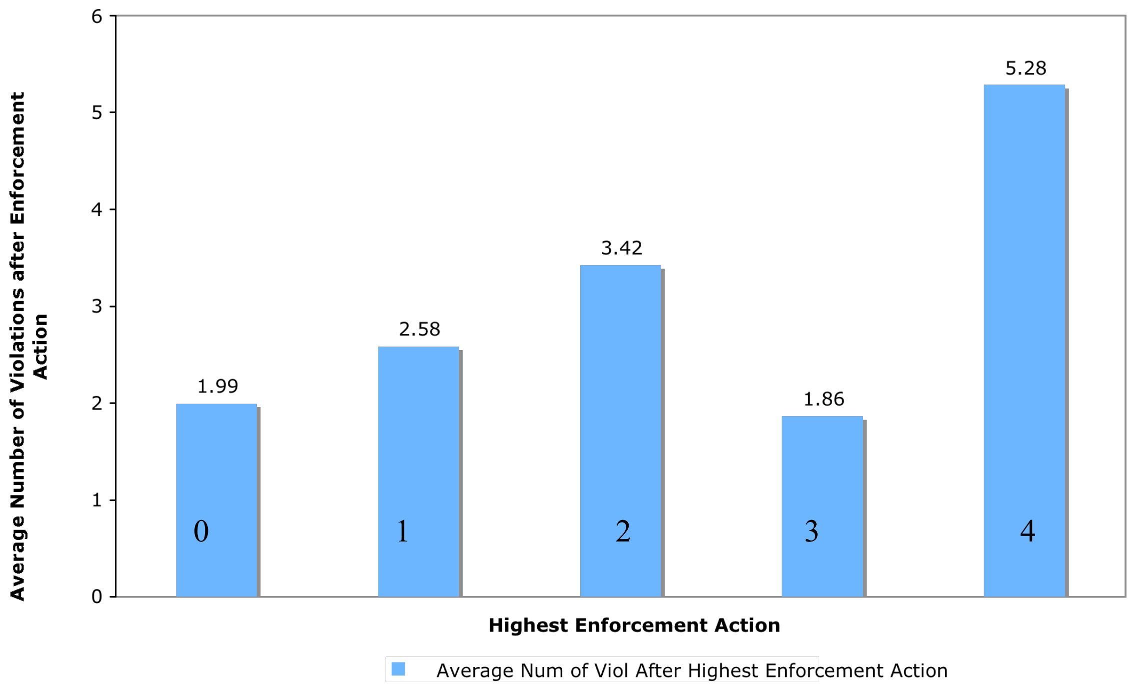

Figure 8 shows the distribution of number of violations by highest enforcement action taken against a PWS. It shows that with the exception of enforcement action level 3, systems having a higher level of enforcement action have a larger average number of violations compared to systems having a lower level of enforcement action taken against them.

Table 1 lists the variables, and their definition. Table 2 lists the summary statistics of the data variables. The mean of *Watersource* is 0.346, which indicates that 34.6% of the systems serve ground water to consumers. That is, the source of water delivered for

927 systems is groundwater and that of the remaining 44 systems is purchased or surface water. The mean of variable *Community* is .701, which shows that 70% of water systems in the study serve drinking water to communities. Hence, the total number of systems serving drinking water to residential areas is 681. The remaining 290 systems provide water to non-communities like offices, restaurants, schools etc. The mean of *Urban* is .346, implying that 34.6% of systems have source wells in urban areas. That is, most wells belonging to 336 systems are located in urban areas and wells for the remaining 635 systems are located in non-urban areas of the state.

Table 1: Variables and Definitions

VARIABLE NAME	DESCRIPTION	TYPE
Violation	={1, if Violation of MCL occurs; 0, if no Violation occurs}	Binary
Number of Violation	Number of violations following highest enforcement action	Count
COMMUNITY	={1, if PWS serves to Communities; 0, if not}	Binary
POPULATION	Population Served by each PWS	Continuous
PUBLICLY	={1, if owner of PWS is Municipal; 0, if not}	Binary
PRIVATE	={1, if PWS is privately owned; 0, if not}	Binary
SOURCE	={1, if source of water is Ground Water; 0, if source is surface/purchased}	Binary
URBAN	={1, if source well(s) located in urban area; 0, if source well(s) located in rural area}	Binary
HIGHEST_ENF_ACT	Order of enforcement action against violating system	Ordered

Table 2: Summary Statistics

Variables	Mean	Standard Dev	Min	Max
Violation	0.601	0.4890	0	1
Population	1.285	3.5445	.025	34
Watersource	0.955	0.2081	0	1
Urban	0.346	0.4760	0	1
Private	0.487	0.5000	0	1
Public	0.138	0.3451	0	1
Community	0.701	0.4579	0	1
Number of Violations after max Enforcement	2.531	4.7072	0	65
Highest Enforcement Actions	0.775	1.248	0	4
Population*Private	0.619	2.3914	0	34
Population *Public	0.512	2.7122	0	34

CHAPTER SIX

RESULTS AND FINDINGS

6.1 Probability of Non-Compliance Model

Table 3 presents the estimated results of the probit model. The dependent variable is a occurrence of MCL violation by a PWS. The explanatory variables are given in column 1, while their corresponding parameters estimates, standard errors, associated p-values, and calculated marginal effects are given in columns 2, 3, 4, and 5 respectively.

Table 3: Determinant of MCL Violation (Probit Model)

VARIABLE	COEFFICIENT	STD. ERROR	P-VALUE	MARGINAL EFFECTS
Intercept	**-0.5317***	0.2192	0.0153	**-0.1889**
Population	**0.2498***	0.1115	0.025	**0.0887**
Watersource	0.1383	0.2028	0.4954	0.0491
Urban	0.4535	0.09	0.6145	0.0161
Private	**0.4522***	0.1039	<.0001	**0.1606**
Publicly	**0.5324***	0.1585	0.0008	**0.1891**
Community	**0.3998***	0.0965	<.0001	**0.142**
Population*Private	**-0.1871****	0.1147	0.1028	**-0.0665**
Population *Publicly	-0.1765	0.1167	0.1303	-0.0627
Log-likelihood Ratio	95.044			

Note: * significant at 5% level of significance, ** significant at 10% level of significance.

From Table 3 we can infer the following: first, the larger PWS have a higher likelihood of violating MCL regulation than the smaller ones; second, both privately and publicly owned PWSs have higher likelihood of being in non-compliance of MCL regulation than the mixed-owned PWSs; third, publicly owned PWS have higher probability of violating MCL regulations (marginal effect is 0.1891) than privately owned PWSs (with marginal effect of 0.1606); fourth, privately owned large PWSs have less likely to violate MCL regulation as compared to privately owned smaller PWSs; and fifth, PWSs serving to communities have higher likelihood of violating MCL regulation as compared to PWSs serving to non-communities.

One possible explanation of why PWS serving to communities are more likely to violate MCL regulation as compared to PWS serving to non-communities is that, the consequences of non-compliance by systems providing drinking water to schools or offices could be more severe since it would affect a larger number of people than a relatively smaller residential area.

The variable *Watersource* indicating the source of water is statistically insignificant. This implies that given our sample data, the source of water delivered (surface or groundwater) is not indicative of whether or not a particular PWS will be in violation of MCL regulations. That is, two water systems that have similar characteristics but different sources of water will have the same probability of violation, irrespective of the source. In other words, all other characteristics being the same, the effect of different sources of water delivered does not affect the probability of violation.

The variable *Urban*, is also not significant. Thus, we conclude that the location (urban or non-urban) of a water system does not affect the likelihood of violation.

6.2 Determinants of Repeated Violation

In order to study the determinants of repeated violations by PWSs, both the Poisson and Negative Binomial models are estimated. First, we statistically test for the suitability of Poisson model. As discussed earlier, Poisson model implicitly assumes equality of its mean and variance. Therefore, it is important to test the validity of this assumption for our data. Deviance test statistics show that Poisson models are not appropriate for our data. Therefore, we estimate negative binomial models that do not assume equality of mean and variance. However, we estimate both Poisson and Negative binomial models and results of both models are presented here.

As discussed in Chapter 4, in order to make the study period consistent/symmetric for all the systems in this study, the dependent variable is modeled with three separate specifications. Also, each of the Poisson and Negative Binomial models was estimated using two specifications: with and without the interaction terms.

Table 4 shows the results of the Poisson model, where the dependent variable is the total number of violations following the highest enforcement action. For both specification I and II (with and without interaction terms), the coefficient of variable *highest_enf_act* is positive and statistically significant. This implies that applying a higher level of enforcement action can increase the total number of repeated violations by PWS. The variable *Population* is positive and significant only in the model without interaction terms. The ownership variables are both positive and significant at 95% CI, meaning that both publicly and privately owned water systems have a greater average number of violations compared to water systems with mixed ownership. The variable

Community is significant at 90% CI and has a positive sign. Hence, water systems serving to communities have a larger average number of violations compared to water systems serving to non-communities.

Table 4: Results of Poisson (Count) Model: Dependent Variable (Number of Violations Following Highest Enforcement Action)

POISSON MODEL				
	Specification I		Specification II	
Variables	Coefficient	S.E.	Coefficient	S.E.
Intercept	**0.2897***	**0.139**	**0.2762***	**0.1362**
Highest_Enf_Act	**0.2475***	**0.0176**	**0.2482***	**0.0174**
Population	0.0029	0.0346	**0.0253***	**0.0051**
Watersource	0.0899	0.1152	0.0909	0.1142
Urban	-0.0124	0.0553	-0.0114	0.0553
Private	**0.1320***	**0.0732**	**0.1462***	**0.0687**
Publicly	**0.4613***	**0.0915**	**0.4801***	**0.0837**
Community	**0.1225****	**0.0741**	**0.1192****	**0.0737**
Population*Private	0.0225	0.0355		
Population*Publicly	0.0232	0.0351		
Deviance (Value/DF)	3.95		3.94	
Log Likelihood Value	29.21		28.97	

Note: * Significant at 5% level of significance, ** Significant at 10% level of significance.

Table 5 shows the results of the Poisson model where the dependent variable is the number of violations by a water system within two years of highest enforcement action against it by ADEQ. The variable *Highest_Enf_Act* is positive and significant at 90% CI. In the previous model (Table 4), it was significant at 95% CI. The variables *Population* and *Private* are only significant for the specification without interaction terms. *Publicly* is positive and significant at 90% CI, indicating that publicly owned water systems have higher numbers of repeated violations as compared to mixed-owned water systems. The variable *Community* is only significant in specification I. According to this model, water systems that are publicly owned, serve water to communities have greater number of repeated violation compared to water systems having mixed ownership and those serving to non-communities.

Table 5: Results of Poisson (Count) Model: Dependent Variable (Number of Violations within two years of Highest Enforcement Action)

POISSON MODEL				
	Specification I		**Specification II**	
Variables	**Coefficient**	**S.E.**	**Coefficient**	**S.E.**
Intercept	**0.7094***	**0.2539**	**-0.7562***	**0.2491**
Highest_Enf_Act	**0.0572****	**0.0343**	**0.0590****	**0.034**
Population	-0.0747	0.0774	**0.0232***	**0.0085**
Watersource	0.152	0.2183	0.1507	0.2164
Urban	0.0917	0.0918	0.0945	0.0916
Private	0.1779	0.1234	**0.2392***	**0.1149**
Publicly	**0.2888****	**0.1598**	**0.3551***	**0.1447**
Community	**0.210****	**0.1271**	0.1964	0.1265
Population*Private	0.0996	0.0783		
Population*Publicly	0.0993	0.078		
Deviance (Value/DF)	2.091		2.0877	
Log Likelihood Value	-567.208		-568.3282	

Note: * Significant at 5% level of significance, ** Significant at 10% level of significance.

The effect of highest level of enforcement action is same as the previous model. That is, systems that receive a higher level of enforcement action or penalty have more number of violations in the two years following date of highest enforcement than those that receive a lower level of enforcement action by ADEQ.

Table 6 presents the results of the Poisson model where the dependent variable is number of violations within three years of highest level of enforcement action against a water system. Consistent with the results of the previous Poisson models, the variable

Highest_Enf_Act is positive and significant.

Table 6: Results of Poisson (Count) Model: Dependent Variable (Number of Violations within three years of Highest Enforcement Action)

POISSON MODEL				
	Specification I		**Specification II**	
Variables	**Coefficient**	**S.E.**	**Coefficient**	**S.E.**
Intercept	**-0.5214***	**0.2183**	**-0.5224***	**0.2137**
Highest_Enf_Act	**0.0828***	**0.0296**	**0.0802***	**0.0294**
Population	-0.0542	0.0169	**0.0249***	**0.0073**
Watersource	0.0955	0.183	0.0667	0.1814
Urban	0.0313	0.0813	0.0277	0.0813
Private	0.1094	0.1091	**0.1827****	**0.1017**
Publicly	**0.4246***	**0.1372**	**0.4328***	**0.1253**
Community	**0.3591***	**0.1156**	**0.3379***	**0.1151**
Population*Private	0.0894	0.0627		
Population*Publicly	0.0732	0.0626		
Deviance (Value/DF)	2.495		2.492	
Log Likelihood Value	-551.207		-552.917	

Note: * Significant at 5% level of significance, ** Significant at 10% level of significance.

Population is not significant in the specification including interaction terms. The variable *Private* is positive and significant only in specification II. The other ownership variable *Publicly* is positive and significant in both the specifications. This implies that both publicly and privately owned water systems have a higher average number of violations than systems with mixed ownership. Another result that is consistent throughout the three Poisson models is that the variable *Community* is positive and significant. Irrespective of the definition of the dependent variable, the results from tables 4, 5, and 6 show that water systems serving water to communities have larger number of repeated violations in the three years following the date of highest enforcement action than non-community water systems.

In summary, results in tables 4-6 show that enforcement action increases the MCL non-compliance instead of decreasing it, which goes against the sole objective of enforcement and monitoring mechanism. In other words, ADEQ's enforcement policy is ineffective in terms of enforcing water quality compliance by PWS in Arizona.

Table 7 presents the results of Negative binomial model where the dependent variable is the number of violation after the highest enforcement action has taken place against a PWS by the ADEQ. The explanatory variables are same as in the Poisson regression models. The main result from that we can infer from this table is that enforcement action increases the non-compliance of MCL regulation instead of decreasing it. This validates the result that we obtained in the Poisson model. Although this result is surprising given the fact that enforcement and monitoring policy exist in order to enhance water quality compliance by PWS in Arizona, it is not quite unexpected given the distribution of violation of MCL in figure 8.

Table 7: Results of Negative Binomial (Count) Model: Dependent Variable (Number of Violations Following Highest Enforcement Action)

NEGATIVE BINOMIAL MODEL				
	Specification I		Specification II	
Variables	**Coefficient**	**S.E.**	**Coefficient**	**S.E.**
Intercept	**0.5498***	**0.2669**	**0.535***	**0.2625**
Highest_Enf_Act	**0.2375***	**0.0413**	**0.2381***	**0.0411**
Population	-0.0019	0.0643	**0.0318***	**0.0132**
Watersource	-0.0961	0.2499	-0.0987	0.2471
Urban	-0.0163	0.1122	-0.0134	0.1121
Private	0.1202	0.1451	0.1419	0.1341
Publicly	**0.3062****	0.1861	**0.336****	**0.172**
Community	0.0613	0.1466	0.055	0.1459
Population*Private	0.034	0.0677		
Population*Publicly	0.0357	0.0662		
Deviance (Value/DF)	1.075		1.072	
Log Likelihood Value	544.89		544.75	

Note: * Significant at 5% level of significance, ** Significant at 10% level of significance.

Table 8 shows the results of the Negative Binomial model, where dependent variable the number of violations within two years of highest enforcement action. In this model, with the exception of the intercept term, none of the coefficients are significant in both specifications I and II (with and without interaction terms, respectively). On comparing the results in table 7 with that of in table 8, we note that in table 8 the explanatory variable, the highest enforcement action, is statistically insignificant and positive, while it was significant and positive in table 7. A careful reading of both tables tells us that at best enforcement action is ineffective when it comes to enforcing water quality compliance by PWS in Arizona.

Table 8: Results of Negative Binomial (Count) Model: Dependent Variable (Number of Violations within two years of Highest Enforcement Action)

NEGATIVE BINOMIAL MODEL				
	Specification I		**Specification II**	
Variables	**Coefficient**	**S.E.**	**Coefficient**	**S.E.**
Intercept	**-0.5969****	**0.3697**	**-0.6282****	**0.3647**
Highest_Enf_Act	0.0511	0.0565	0.052	0.0562
Population	-0.0745	0.0995	0.0254	0.0161
Watersource	0.0965	0.3357	0.0821	0.3334
Urban	0.0458	0.1462	0.0508	0.1462
Private	0.1571	0.1903	0.2264	0.1772
Publicly	0.2444	0.246	0.2957	0.2285
Community	0.1784	0.1947	0.1625	0.1943
Population*Private	0.1072	0.1027		
Population*Publicly	0.0995	0.1012		
Deviance (Value/DF)	0.8938		0.891	
Log Likelihood Value	-408.432		-409.0044	

Note: * Significant at 5% level of significance, ** Significant at 10% level of significance.

Table 9 shows the estimates of the Negative Binomial model, where the dependent variable is the number of violations within three years of highest enforcement action and results are similar to those we found in table 8. Only the coefficient of *Community* is significant in both specifications I and II, indicating that water systems serving to communities have higher number of violations than those serving to non-communities.

Table 9: Results of Negative Binomial (Count) Model: Dependent Variable (Number of Violations within three years of Highest Enforcement Action)

NEGATIVE BINOMIAL MODEL				
	Specification I		**Specification II**	
Variables	**Coefficient**	**S.E.**	**Coefficient**	**S.E.**
Intercept	-0.3883	0.3459	-0.3809	0.3394
Highest_Enf_Act	0.071	0.0538	0.069	0.0535
Population	-0.0542	0.0858	**0.0297****	**0.0156**
Watersource	0.0418	0.3159	-0.0012	0.3113
Urban	-0.0234	0.1387	-0.0177	0.1387
Private	0.0776	0.181	0.1564	0.1689
Publicly	0.337	0.2335	**0.3484****	**0.2152**
Community	**0.3207****	**0.1864**	**0.3006****	**0.1859**
Population*Private	0.0991	0.0891		
Population*Publicly	0.0767	0.0878		
Deviance (Value/DF)	0.9412		0.9381	
Log Likelihood Value	-321.413		-322.1428	

Note: * Significant at 5% level of significance, ** Significant at 10% level of significance.

5.3 Determinants of Level of Enforcement Actions

In Table 10, we present the results of estimated Ordered Probit model. In this case the dependent variable is level of the highest enforcement action taken against a MCL violating PWS in Arizona. The set of explanatory variables includes the number of times a PWS has violated MCL regulation in the period preceding the highest enforcement action.

Table 10: Results of Ordered Probit Model

ORDERED PROBIT MODEL				
	Specification I		**Specification II**	
Variables	**Coefficient**	**S.E.**	**Coefficient**	**S.E.**
Intercept	-0.1578	0.351	-0.31069	0.343
Num_Viol_Bef_Maxenf	**0.0219***	0.011	**0.0237***	0.011
Population	-0.1114	0.094	-0.0188	0.014
Watersource	-0.267	0.315	-0.181	0.309
Urban	-0.1512	0.143	-0.1438	0.142
Private	0.2209	0.186	0.2165	0.171
Publicly	-0.0273	0.238	0.2178	0.215
Community	0.0278	0.182	0.0283	0.181
Population*Private	0.0511	0.097		
Population*Publicly	0.1262	0.095		

Note: * Significant at 5% level of significance, ** Significant at 10% level of significance.

The results show that the number of violations before that maximum level of enforcement is positive and significant. There is a positive relationship between the level of enforcement action against a system and the compliance history of drinking water systems. This finding suggests that one of the most important factors that determine the level of enforcement action against a violating system by a regulatory agency is the compliance history of a water system.

None of the other variables in the model are significant. The reason for this result can be investigated for further work by better model specification, thereby, testing the interdependence between number of violations and level of enforcement actions.

CHAPTER SEVEN

CONCLUSIONS

This thesis examined compliance of MCL regulations by 971 PWS in Arizona. In particular we examined the determinants of MCL non-compliance, repeated MCL violation, and level of highest enforcement action taken by the ADEQ against a MCL violating PWS.

The results of the first model showed that the larger PWSs have a higher likelihood of violating MCL regulation than the smaller ones; both privately and publicly owned PWSs have higher likelihood of being in non-compliance of MCL regulation than the mixed-owned PWSs; publicly owned PWSs have higher probability of violating MCL regulations (marginal effect is 0.1891) than privately owned PWSs (with marginal effect of 0.1606); privately owned large PWSs have less likely to violate MCL regulation as compared to privately owned smaller PWSs; and PWSs serving to communities have higher likelihood of violating MCL regulation as compared to PWSs serving to non-communities.

With regards to probability of repeated violations, we modeled the different type of dependent count variables in order to look at the effect of level of enforcement action and system characteristics on the number of repeated violations by drinking water systems. Since the dependent variables in the models were count data, the Poisson and Negative Binomial models were used. Some results that were consistent from the Poisson models were that systems subjected to higher level of enforcement actions, publicly owned systems and those systems serving to communities had a higher average number of violations. However, the Poisson model was found to be unfit for our data due to the presence of dispersion in the model.

The alternative method was to employ the Negative Binomial model. Dissimilarities were observed between the results across three different estimations. Findings from the estimated models suggest that larger water systems have more number of violations than smaller systems. Ownership also plays an important role in determining the type of water systems least likely to violate repeatedly. It is seen from the data, that water systems with mixed ownership are less likely than publicly and privately owned systems to violation more number of times. Also, systems with higher level of enforcement actions have an increased average number of violations than systems with lower level of enforcement actions.

The finding of the determinants of enforcement action model indicates that the most important factor affecting the level of enforcement action by a regulatory agency is the compliance history of a water system. The larger the number of MCL violation by a PWS before the enforcement actions, the higher would be the level of enforcement action taken against the violating PWS.

Results from this study provide policy implications for regulatory and monitoring agencies to focus efforts on those systems that have higher likelihood of non-compliance and repeated violations. A more channeled effort in monitoring and enforcement actions could lead to improved compliance behavior of water systems and prevent consumption of contaminated water.

APPENDIX 1

The Anderson land use codes are described below and are adapted directly from documentation by U.S. Geological Survey, 1990. Land use and land cover digital data from 1:250,000- and 1:100,000-scale maps. Data User Guide 4. Reston, Virginia.

1. Urban or built-up land
    - 11 Residental
    - 12 Commercial and services
    - 13 Industrial
    - 14 Transportation, communication, utilities
    - 15 Industrial and commercial complexes
    - 16 Mixed urban or built-up land
    - 17 Other urban or built-up land

2. Agricultural land
    - 21 Cropland and pasture
    - 22 Orchards, groves, vineyards, nurseries and ornamental horticultural areas
    - 23 Confined feeding operations
    - 24 Other agricultural land

3. Rangeland
    - 31 Herbaceous rangeland
    - 32 Shrub and brush rangeland
    - 33 Mixed rangeland

4. Forest land
    - 41 Deciduous forest land
    - 42 Evergreen forest land
    - 43 Mixed forest land

5. Water
    - 51 Streams and canals
    - 52 Lakes
    - 53 Reservoirs
    - 54 Bays and estuaries

6. Wetland
    - 61 Forested wetland
    - 62 Nonforested wetland

7. Barren land
    - 71 Dry salt flats

- 72 Beaches
- 73 Sandy areas not beaches
- 74 Bare exposed rock
- 75 Strip mines, quarries, gravel pits
- 76 Transitional areas

8. Tundra
   - 81 Shrub and brush tundra
   - 82 Herbaceous tundra
   - 83 Bare ground
   - 84 Wet tundra
   - 85 Mixed tundra

9. Perennial snow or ice
   - 91 Perennial snowfields
   - 92 Glaciers

For our study, wells are either classified as URBAN (category 1. Urban and built-up lands) or NON-URBAN (all others).

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