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Towards Achieving Clean Water Goals:

An Evaluation of California's Mandatory Minimum Penalty Enforcement Program

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Victor Rigor Vasquez

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ABSTRACT OF THE DISSERTATION

Towards Achieving Clean Water Goals:

An Evaluation of California's Mandatory Minimum Penalty Enforcement Program

by

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An effective environmental regulatory policy requires an effective monitoring and enforcement strategy implemented by the regulatory agency. To achieve effective deterrence to prevent or reduce violations of environmental regulations, enforcement actions must have severity, and violation costs must be greater than the economic benefits realized by violators. In addition, effective deterrence also requires certainty that violations will be detected and sanctioned and that enforcement actions will be taken swiftly. The magnitude of environmental monetary penalties may take into consideration factors such as the degree of environmental damage, frequency of violations, and the culpability of the violator. Mandatory minimum penalties (MMPs) are a form of monetary penalties that require regulatory agencies to issue a set fixed dollar amount per violation, often through expedited administrative procedures; thus increasing certainty and celerity of enforcement actions but at the same time removing discretion from regulatory agencies to tailor the penalty amount to the violation. In California starting in 2000, an MMP of $3,000 has been issued to violating facilities for each violation of effluent limitations contained in National Pollutant Discharge Elimination System (NPDES) permits issued pursuant to the US Clean Water Act of 1972. The MMP enforcement program, however, includes provisions that provide relief from further MMP enforcement if a violator is implementing required corrective actions to prevent future violations.

In this dissertation, three preliminary investigations were conducted to evaluate California's MMP enforcement program to quantitatively estimate its impact on the number of NPDES effluent limitation violations and on improvements in water quality. Analysis was conducted using linear regression models and detailed data collected and assembled from the 2000-2011 NPDES and MMP enforcement program public record. Preliminary results suggest that the MMP enforcement program has resulted in modest decreases in the number of violations across the state and in measurable improvements in effluent quality discharged to San Francisco Bay and the Sacramento-San Joaquin Delta; however improvements in receiving water quality may not be observable due to other pollution inputs and fate and transport processes. The preliminary results suggest that mandatory penalties are effective in promoting compliance and achieving reductions in pollution and that the effects are due to both facility-specific effects as well as enhancement of the regulatory agency's enforcement reputation. However, because violations continue despite the MMP enforcement program, the results may also suggest that the MMP enforcement program could be optimized to achieve larger effects. Building on the initial work reported here, further analysis of the detailed data set assembled for this dissertation using other methods can provide additional insights into the effects of the MMP enforcement program on NPDES effluent limitation violations and on water quality.

Disclaimer: *The views and opinions expressed in this dissertation are solely those of the author and do not necessarily reflect the official policy or position of the State of California, the California Environmental Protection Agency, the California State Water Resources Control Board, the California regional water quality control boards, or the University of California. All data and information used in this dissertation are part of the public record.*

The dissertation of Victor Rigor Vasquez is approved

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DEDICATION

I dedicate this dissertation

to the memory of my father, Corsino, and to my mother, Aurora.

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LIST OF ABBREVIATIONS

ACL	Administrative Civil Liability
BOD	Biochemical oxygen demand
CDO	Cease and desist order
CEDEN	California Environmental Data Exchange Network
CIWQS	California Integrated Water Quality System
CN	Cyanide
Cu	Copper
CWA	Clean Water Act
CWEA	Clean Water Enforcement and Pollution Prevention Act
ERS	Electronic Reporting System
ESMR	Electronic Self-Monitoring Report
ICIS	Integrated Compliance Information System
MMP	Mandatory minimum penalty
NPDES	National Pollutant Discharge Elimination System
PCS	Permit Compliance System
RWQCB	Regional Water Quality Control Board
SFBRWQCB	San Francisco Bay Regional Water Quality Control Board
SWRCB	State Water Resources Control Board
TC	Total coliform
TSO	Time schedule order
TSS	Total suspended solids
USEPA	United States Environmental Protection Agency
WQI	Water quality index

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Lastly and most importantly, thanks be to God for this wonderful world.

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Olson, T. M.; Gonzalez, A. C.; Vasquez, V. R. (2001). Gas chromatography analyses for trihalomethanes: An experiment illustrating important sources of disinfection by-products in water treatment. *Journal of Chemical Education* 78, no. 9: 1231.

Vasquez, V.R., Chao, J.T., Olson, TM. (1999). Deposition of model polyelectrolyte-coated colloids in porous media. *Proc. 217th ACS National Meeting, Anaheim, March 1999*

Stroeve, P., Pettit, C. D., Vasquez, V., Kim, I., & Berry, A. M. (1998). Surface active behavior of hopanoid lipids: bacteriohopanetetrol and phenylacetate monoester bacteriohopanetetrol. *Langmuir*, *14*(15), 4261-4265.

Stroeve, P., Vasquez, V., Coelho, M. A., & Rabolt, J. F. (1996). Gas transfer in supported films made by molecular self-assembly of ionic polymers. *Thin Solid Films*, 284, 708-712.

CHAPTER ONE

Introduction

1. The Clean Water Act

To address growing public frustration with the deterioration of water quality, growing concerns with the impacts of nutrients and toxic pollutant discharges, and increased interest in environmental protection (Metcalf & Eddy et al, 1991; Copeland, 2010), the US Congress passed the Water Pollution Control Act Amendments of 1972, commonly referred to as the Clean Water Act (CWA). The CWA completely revised the previous Water Pollution Control Act of 1948 and its 1965 amendments (Copeland, 2010). The CWA established an ultimate goal of eliminating pollution discharges to waters of the US (i.e., navigable surface waters and their tributaries) by 1985 and established an interim goal of achieving "fishable" and "swimmable" water quality, i.e., water quality sufficient to allow intended beneficial uses of a water body (Metcalf & Eddy et al, 1991; Copeland, 2010; USEPA 2010). Unlike previous water pollution control laws which required industrial and municipal dischargers to meet effluent requirements based alone on water quality standards for the surface water bodies that receive discharges, the CWA added requirements for technology-based treatment standards which required industrial and municipal dischargers to install certain waste treatment technology to meet nationwide uniform treatment levels (USEPA, 2010). The CWA also targeted toxicity in surface waters and allowed narrative water quality standards that prohibited the presence of "toxic pollutants in toxic amounts" in surface waters (USEPA, 2010; Gaba, 1984).

The CWA identified three categories of pollutants to be eliminated from discharges, namely, (1) conventional pollutants such as biochemical oxygen demand (BOD) and total suspended solids (TSS), (2) nonconventional pollutants such as ammonia and chlorine, and (3) toxic pollutants such as metals and organic pesticides. The CWA required all municipal dischargers discharging to surface waters to install treatment technology to meet secondary treatment standards and authorized grants until 1990, and loans since 1989, to assist municipalities in upgrading wastewater treatment facilities (Copeland, 2010). The CWA, and subsequent amendments in 1977 and 1987, required industrial point source dischargers nationwide to treat discharges with progressively improved technology by installing best practicable control technology (BPT) by July 1, 1977, best conventional pollutant control technology (BCT) by July 1, 1984, and best available technology (BAT) or better by March 31, 1989 (Rechtschaffen, 2003; Copeland, 2010; USEPA, 2010). BPT applied to all three types of pollutants, BCT applied to conventional pollutants, and BAT applied to nonconventional pollutants and toxic pollutants (USEPA, 2010).

The CWA authorized the US Environmental Protection Agency (USEPA), itself only created in 1970 under President Nixon to implement other environmental laws, to implement the requirements of the CWA (USEPA, 2010). The USEPA established a permit system under the National Pollutant Discharge Elimination System (NPDES), and all discharges to surface waters were required to be covered under an NPDES permit. The components of NPDES permits are illustrated in Figure 1.1. Discharges must comply with technology-based effluent requirements (secondary treatment, BPT, BCT or BPT) and water-quality-based effluent limitations, for the control of nonconventional and toxic pollutants, which are specified in NPDES permits (USEPA, 2010; Copeland, 2010). NPDES permits also included effluent and receiving water monitoring requirements which specified the sampling locations, monitoring frequencies, sampling type, and sample analytical method (USEPA, 2010). An example of technology-based and water quality-based effluent limitations contained in an NPDES permit is shown in Figure 1.2a; an example of monitoring requirements is shown in Figure 1.2b. NPDES permits are typically issued as individual permits for a specific facility; however, a general permit may be issued to a group of facilities within the same industrial category (USEPA, 2010).

The CWA also authorized the USEPA to take enforcement actions against municipal and industrial dischargers who violate the requirements of NPDES permits (Copeland, 2010). The USEPA may issue compliance orders, assess administrative civil penalties, take a civil judicial action, or pursue criminal prosecution against dischargers who violate NPDES permit requirements (USEPA, 2010; Copeland, 2010). When determining the appropriate level of enforcement action to take, the USEPA takes into consideration the duration and severity of the violation, the economic benefit gained by the discharger from the violation, the discharging facility's compliance history, the discharger's culpability, and the deterrent effect of the possible enforcement action (USEPA, 2010).

The CWA has generally been deemed to be a success at improving the water quality of the nation's surface waters (Andreen, 2004) although its ultimate goal of eliminating pollutant discharges still has to be achieved. Numerous case studies on individual water bodies and a comprehensive evaluation funded by the USEPA in the 1990s indicated that the regulation of municipal and industrial point sources has resulted in a 95% decrease in BOD discharges to surface waters and improved dissolved oxygen levels in most of the stream reaches evaluated since implementation of the CWA (Andreen, 2004).

While improvements in water quality have been achieved, and while stormwater discharges and non-point source discharges have been identified as other major sources of pollutants that need to be addressed, municipal and industrial point sources continue to be a major source of pollutants, especially of nonconventional and toxic pollutants, discharged to surface waters (Andreen, 2004; Lyon and Stein, 2009). Violations of NPDES permits by municipal and industrial discharges continue, and therefore require an effective and consistent enforcement program (Andreen, 2004). The remainder of this chapter and this dissertation focus on the effectiveness of enforcement actions at achieving pollution reductions from municipal and industrial point sources.

2. Environmental enforcement: purpose, theory, and other considerations

An effective environmental policy requires an effective monitoring and enforcement strategy implemented by the regulatory agency (Laplante and Rilstone, 1996; Rousseau, 2009; Gray and Shimshack, 2011). Table 1.1 shows the annual number of enforcement actions taken under the CWA from 2001-2008 nationwide and the subset of these actions which included monetary penalties. While regulatory agencies can take non-monetary enforcement actions, such as cessation orders and clean-up orders, the majority of the available literature focus on the effectiveness of inspections (Magat and Viscusi, 1990; Earnhart, 2004a and 2004b) and monetary penalties (Rousseau, 2009; Gray and Shimshack, 2011). A main focus of the literature on inspections and monetary penalties is on evaluations of the effectiveness of these enforcement actions in deterring future environmental violations (Rouseau, 2009; Gray and Shimshack, 2011; Kadambe and Segerson, 1998); however, monetary actions may also have as objectives recovering the costs associated with environmental damage and obtaining justice and retribution (Rousseau, 2009).

The basic economic model for monetary penalties asserts that a rational, profit-maximizing firm will choose to violate environmental regulations at a level which minimizes TC, the sum of compliance costs and violation costs (Rousseau, 2009), as given by the following model equation:

$$\min_v TC = \min_v \{C(v) + pV(v)\} \quad \text{(Equation 1.1)}$$

Compliance costs *C* are those costs incurred by a firm to prevent the occurrence of violations and decrease as the magnitude of violations *v* increases. Violation costs *V* are those costs incurred by a firm as a result of having violations (e.g., costs for corrective actions, regulatory penalties), and increase as the magnitude of violations *v* increase, moderated by the probability *p* that violations will be sanctioned (Rousseau, 2009). If all detected violations result in a penalty, then the probability *p* accounts for the probability that a violation will be detected, otherwise, *p* accounts for both the probability that a violation will be detected and that a penalty will be assessed by regulatory agency for the violation (Rousseau, 2009). According to this economic model, a firm will choose to always comply with regulations if the cost to ensure compliance, and thus avoid all violations, is less than or equal to the violation costs of having at least one violation (Rouseau, 2009). However, if compliance costs and violation costs vary depending on the magnitude of violations, then a firm will choose to violate regulations at a level which balances increasing violation costs with increasing compliance costs (Rouseau, 2009).

The magnitude of environmental monetary penalties (i.e., violation costs) is determined by three categories of factors that may or should be considered by the regulatory agency, namely:

(1) the nature of the violation, e.g., degree of environmental damage, frequency of violations, extent to which the violation could have been avoided, economic gains realized by the violator, and costs of corrective actions incurred by firm (Rousseau, 2009);

(2) characteristics of the violator, e.g., culpability, likelihood of repeating violations, ability to pay (Rousseau, 2009); and

(3) the objectives of the regulatory agency in assessing the penalty (e.g., retribution, deterrence).

The regulatory agency may also consider, and may try to recover, the costs it incurs in pursuing monetary penalties, such as legal and administrative costs (Rousseau, 2009).

Deterrence is the primary objective of environmental enforcement actions (Silberman, 2000). Regulatory agencies seek both specific and general deterrence. Specific deterrence aims to return the violator into compliance and deter the violator from committing further violations (Silberman, 2000; Rouseau, 2009). General deterrence aims to deter other would-be violators by communicating the consequences of violations as well as the benefits of compliance (Rousseau, 2009). To achieve effective deterrence, enforcement actions should have severity and violation costs greater than the economic benefits realized by violators (Silberman, 2000; Weber and Crew, 2000; Rousseau, 2009). In addition, effective deterrence also requires certainty that violations will be detected and sanctioned and that enforcement actions will be taken swiftly (Silberman, 2000; Weber and Crew, 2000).

Several empirical studies have investigated the effectiveness of enforcement actions and the factors that determine their effectiveness. Magat and Viscusi (1990) found that the number of violations decreased and the effluent quality improved at paper and pulp mills in the US in response to inspections. LaPlante and Rilstone (1994) found that violations decreased and effluent quality improved in response to inspections and the threat of inspections. Weber and Crew (2000) found that the occurrence of oil spills into coastal waters from ships decreased with the severity of penalties and the swiftness that the penalty was assessed by the US Coast Guard. Shimshack and Ward (2005) found that statewide violation rates at paper and pulp mills declined by 31% to 75% in different states, which they attribute to an enhancement of the regulatory agency's reputation for taking enforcement actions. Earnhart (2004a, 2004b) found that the effluent quality from wastewater treatment plants in Kansas improved in response to actual, and the probability of, inspections and enforcement actions carried out by regulatory agencies. Earnhart also found that frequency of inspections are positively correlated with per capita income and educational level of a community and negatively correlated with unemployment rates in a community (2004a). Earnhart (2004b) further found that facility specific factors significantly determine wastewater treatment plant performance, i.e., that facilities with larger flow capacities have higher BOD emissions than smaller facilities and that facilities with "equivalent to secondary" treatment processes underperform facilities with standard secondary treatment processes, and consequently, suggests that regulatory agencies may want to re-evaluate regulations and policies in light of these factors. Adrison (2007) found that penalties against municipal and non-municipal discharging facilities reduce violations at a specific facility within one year after a penalty is levied against a facility and that penalties issued to other facilities result in a reduction of violations at all facilities as a result of enhancement of the regulatory agency's enforcement reputation. Adrison (2007) also found that the frequency of enforcement action, and not necessarily the amount of the penalty, leads to specific deterrence.

Other studies identified factors that may result in deviations from the enforcement economic model given in Equation 1.1. Heyes (1996) found that uniformly increasing penalties may not result in higher compliance and may act as a disincentive to corrective actions by violators; however, regulatory agencies may achieve greater general deterrence by issuing penalties that are less than the maximum penalty levels allowed by law. Oljaca et al (1998) found that facilities that have had a history of water pollution violations in Georgia tended to be levied higher penalties, suggesting that interactions between regulated parties and regulatory agencies significantly affect penalty size. Epple and Visscher (1984) found that regulatory agencies exercise discretion in taking enforcement, due to the agency's enforcement objectives or to resource constraints, which therefore affects the probability that violations will be detected and sanctioned. These studies illustrate the impact that a regulatory agency's decisions to take enforcement actions, and how much, has on the effectiveness of regulatory enforcement in reducing violations and consequently improving the environment.

3. Implementation of the CWA and NPDES program in California

3.1. State Water Resources Control Board and Regional Water Quality Control Boards

As authorized under the CWA, implementation of the NPDES program in California for point source discharges has been delegated by the USEPA to the State Water Resources Control Board (SWRCB) and the nine Regional Water Quality Control Boards (RWQCB). The RWQCB boundaries are defined by California's major watersheds and each RWQCB is formed from portions of several counties (Figure 1.4). Each RWQCB is semiautonomous and sets water quality policy for surface water and groundwater within their respective boundaries through the NPDES program and other state programs. Each RWQCB is made up of nine part-time governor-appointed board members who are supported by civil servants consisting of engineers, scientists, geologists, and administrative personnel. Two of the geographically larger RWQCBs (Region 5 and Region 6) are further sub-divided to smaller sub-regions for administrative purposes but are responsive to the same group of board members. The SWRCB is composed of five full-time governor-appointed board members and has both water rights and water quality functions. Although the RWQCBs are semiautonomous, the SWRCB sets statewide water quality policy through legislation that it sponsors and through policies and regulations that it adopts, which the RWQCBs must comply with. The SWRCB also has an appellate function through which RWQCB actions and decisions may be appealed by affected parties.

Because of California's large land area and population, the various RWQCBs are hydrogeologically and demographically diverse. The average demographics within each RWQCB reflect the uneven distribution of the population, industries and wealth across California, as shown in Table 1.2. The geographically smaller, highly-urbanized coastal RWQCBs (R2, R4, R8 and R9) contain over 70 percent of the state population, have median household incomes higher than the state average, have a higher percentage of the workforce in manufacturing, and have 25% or higher of their population with a college degree. Most inland RWQCBs (R5F, R5R, R5S, R6LT, R6V, and R7) have a higher percentage of rural population, and have higher unemployment and poverty rates (except for R6LT). In terms of water supply, the northern regions have greater precipitation and less of the population; hence, water is transported south to the farms of the San Joaquin Valley (R5F) and to the two thirds of the state population that live in the southern coastal regions (R4, R8, R9).

The regulatory activities of the RWQCBs also vary significantly. The main pollutants of concern within each RWQCB range from sediment to trash, and main sources of pollutants range from urban runoff to silviculture (SWRCB, 2012). As shown in Figure 1.4, the San Francisco Bay region (R2) has approximately twice as many wastewater treatment plants and twice as many major wastewater treatment plants than the Los Angeles region (R4) although the Los Angeles region has a 40% higher population, which indicates a greater degree of consolidation of wastewater treatment in the Los Angeles region. The Sacramento region (R5S) has twice as many wastewater treatment facilities and more major wastewater treatment facilities than the San Diego region (R9) although both have similar populations, which again reflects the numerous wastewater treatment facilities serving small communities in the geographically larger Sacramento region. RWQCBs R2, R4 and R5S have 60 or more industrial facilities which may be sources of toxic pollutant discharges to surface waters. The different RWQCBs also face unique environmental challenges – protection of the Sacramento-San Joaquin Delta in RWQCBs R5F, R5R and R5S; protection of Lake Tahoe in RWQCB R6LT, salvaging the Salton Sea in RWQCB R7, protecting endangered species habitats in RWQCBs R1, R2, and R5R; and protecting marine coastal waters for ecological, fishing and recreational uses in RWQCBs R3, R4, R8 and R9.

3.2. Enforcement activities of the SWRCB and RWQCBs

The SWRCB and RWQCBs are authorized by the California Water Code to take enforcement actions to promote and ensure compliance with NPDES permits and other regulations to protect public health and the environment (SWRCB, 2010). It is the policy of SWRCB and RWQCBs that its enforcement actions are fair, firm and consistent (SWRCB, 2010). Enforcement actions are progressive in severity and a non-compliant facility may initially be issued a notice of violation and escalate to cessation orders and monetary penalties (Sato and SWRCB, 2010).

Cessation orders include Cease and Desist Orders (CDO) and Time Schedule Orders (TSOs), which are similar enforcement actions authorized by different sections of the California Water Code. CDOs and TSOs prescribe a time schedule to complete corrective actions to correct and prevent future violations (SWRCB, 2010). The corrective actions are typically identified by the violating party and reviewed and formalized in the CDO or TSO by the RWQCBs. Because corrective actions often require construction of new treatment unit processes or treatment facilities, CDOs and TSOs may allow facilities up to five years to implement corrective actions.

Monetary penalties are issued through Administrative Civil Liability (ACL) Orders or Complaints. The RWQCBs are primarily responsible for issuing ACLs, with oversight provided by the SWRCB through implementing regulations and policies and an appeals process. The RWQCBs have discretion when setting penalty amounts assessed through “discretionary ACLs”, and penalties can be a maximum of $10,000 per day of violation plus up to $10 per gallon discharged, as authorized by the California Water Code. When issuing discretionary ACLs, the RWQCBs must recover any economic benefit realized by the violator and take a variety of factors into consideration (e.g., culpability, corrective actions taken, ability to pay, environmental damage). Violators who are issued ACLs have a right to a quasi-judicial hearing before the RWQCB or may waive the hearing and pay the penalty (SWRCB, 2010).

4. Mandatory Minimum Penalties in California

In response to the documented failure by the RWQCBs to carry out enforcement actions to address thousands of violations of NPDES permits across the state (Jahagirdar and Coyne, 2003), the California legislature enacted the 1999 Clean Water Enforcement and Pollution Prevention Act (CWEA), which amended the California Water Code to authorize mandatory minimum penalties in the state’s NPDES program. Mandatory minimum penalties (MMPs) are a form of monetary penalties that require regulatory agencies to issue a set fixed dollar amount per violation, often through expedited administrative procedures. Coyne and Metzger (2004) state that the lack of enforcement continues as the key problem in achieving water quality improvements in the nation’s waters, and they advocated instituting mandatory minimum penalties as a way to ensure that regulatory agencies consistently address violations with monetary penalties that are taken seriously by polluters and also stand up against court challenges.

As a result of the 1999 CWEA, beginning in January 2000, the SWRCB and RWQCBs are mandated to issue ACLs to assess a mandatory minimum penalty (MMP) of $3,000 for each instance of serious violation of effluent limitations in NPDES permits and for each chronic violation after the third violation in a six month period (Sato and SWRCB, 2009; SWRCB, 2010). Effluent violations exceeding effluent limitations for conventional and non-conventional pollutant constituents by 40% and 20%, respectively, are considered serious violations (SWRCB, 2010). Chronic violations include non-serious effluent violations and reporting violations; however, reporting violations constitute less than 10 percent of chronic violations and are not considered further in this dissertation (SWRCB, 2011).

In contrast to penalties issued through discretionary ACLs, MMP ACLs only require the determination of an effluent violation and the RWQCB may not consider factors such as culpability or severity of environmental damage. However, the MMP enforcement program includes several avenues that provide varying limited levels of relief from MMP liability, such as allowing small disadvantaged communities to apply the MMP amount towards the costs of corrective actions or allowing a violator to apply up to 50% of its MMP liability to an environmental project that benefits the local community (Sato and SWRCB, 2009). Additionally, a discharger that has been issued a CDO or TSO for effluent violations of specific effluent constituents is shielded from further MMPs for subsequent effluent violations of that constituent so long as the discharger is in compliance with the CDO or TSO (SWRCB, 2010).

The MMP enforcement program in California is only the second such state program under NPDES. The state of New Jersey implemented an MMP program in 1991 which required the assessment of a minimum penalty of $1000 for each serious violation or $5,000 for each violation that causes the violator to be a “significant noncomplier” as defined by the USEPA

(NJAC, 2010). Assessments of the New Jersey program indicate that MMPs have been effective – enforcement actions increased by 57% during the first year and violations subsequently decreased by 76% over the next eight years (Coyne and Metzger, 2004). Early assessments of the effectiveness of the MMP enforcement program in California cited reductions in numbers of violations across the state and an increase in the number of enforcement actions and penalty amounts issued (Jahagirdar and Coyne, 2003; Coyne and Metzger, 2004). Since 2005, the SWRCB has prepared an annual Enforcement Report which includes assessments of the MMP enforcement program in terms of number of violations subject to MMPs during the year, number of MMP enforcement actions taken, amount of civil penalties levied, number of facilities that have had violations subject to MMPs during the year, and the percentage of violations subject to MMPs within each RWQCB that have not been assessed the required MMP through an enforcement action. However, no long-term evaluation of California's MMP enforcement program has been conducted by the SWRCB or has been found in the enforcement literature.

MMPs presented both the regulated facilities in California and the SWRCB/RWQCBs with a new legal mechanism for improving water quality. The MMPS also presented the SWRCB/RWQCBs and the regulated facilities with programmatic challenges to equitably assess MMP amounts and evaluate effectiveness. Through 2011, California's experience with MMPs have resulted in the issuance of over 1,400 MMP enforcement actions to address thousands of effluent violations at hundreds of facilities across the state.

5. Dissertation Objectives

The objective of this dissertation is to provide an initial quantitative assessment of the effectiveness of California's MMP enforcement program in achieving clean water goals. The twelve year MMP enforcement program record (through 2011) provides a significant amount of data regarding mandatory penalties in environmental enforcement, and a second the contribution of this dissertation is the collection and assembling of this data. Early assessments and annual evaluations of California's MMP enforcement program have been limited to tallies of violations, the number of enforcement actions taken, and amount of penalties assessed, but do not explicitly link the number of violations to MMP enforcement actions nor quantify the effectiveness of MMPs in reducing violations or improving environmental quality. This dissertation quantitatively estimated the correlations between violations and enforcement actions and investigated correlations between effluent concentrations and enforcement actions. Additionally, this dissertation provides a preliminary assessment of the possible impact on water quality resulting from MMP enforcement actions. A goal of this dissertation is to develop the data set and propose a method to quantitatively estimate the impact of enforcement actions on levels of pollution. This dissertation consists of three investigations presented in the next three chapters, as follows:

Chapter Two: Evaluation of the correlation between number of NPDES effluent violations and enforcement actions under California's MMP enforcement program.

Chapter Three: Evaluation of correlations between effluent quality trends and enforcement actions under California's MMP enforcement program.

Chapter Four: Evaluation of correlations between effluent quality trends and enforcement actions under California's MMP enforcement program and impacts on water quality in the Sacramento-San Joaquin Delta

These studies contribute to the empirical literature regarding the effectiveness of enforcement actions in general, and specifically mandatory penalties, in achieving clean environment goals.

Table 1.1. Formal administrative enforcement actions under the CWA nationwide, 2001-2008. *(Adapted from Gray and Shimshack, 2011)*

	2001	2002	2003	2004	2005	2006	2007	2008
All enforcement actions	685	891	830	888	946	664	613	601
Subset with fines	376	495	553	675	763	577	511	489
Median fine (when assessed)	$3,000	$2,000	$2,100	$2,000	$3,000	$3,500	$3,000	$3,000

Table 1.2. Population demographics of RWQCB regions. *(Calculated from 2010 US Census data)*

RWQCB	Total Population (millions)	Median household income ($K)	Poverty (%)	Unem-ployment (%)	Bachelor's degree (%)	Manufac-turing employment (%)	Urban (%)	Rural (%)	Foreign-born (%)
R1	0.8	53.1	9.9	10.1	26.4	8.0	69.9	30.1	12.0
R2	6.5	84.4	7.3	8.6	42.6	11.6	98.0	2.0	31.3
R3	1.6	64.5	9.8	9.3	28.5	7.7	87.7	12.3	22.3
R4	10.5	62.2	13.1	9.7	28.0	11.5	99.2	0.8	35.0
R5F	2.8	48.7	18.6	12.9	15.1	7.2	85.2	14.8	22.0
R5R	0.6	45.4	13.4	12.9	20.2	6.3	63.4	36.6	7.9
R5S	4.3	60.9	11.0	12.2	24.3	7.8	87.7	12.3	17.7
R6LT	0.1	53.1	8.7	9.9	24.2	3.4	44.0	56.0	10.6
R6V	1.0	53.7	14.7	13.4	15.5	9.1	83.6	16.4	14.1
R7	0.8	49.1	15.1	13.3	17.8	4.0	81.0	19.0	24.0
R8	5.7	68.1	10.6	10.9	25.5	12.6	98.4	1.6	27.7
R9	4.0	72.6	8.7	8.9	34.6	9.5	96.5	3.5	21.9
California	37.3	61.6	10.8	10.1	30.2	10.2	95.0	5.0	27.2
US	308.7	52.8	10.5	8.7	28.2	10.8	80.7	19.3	12.8

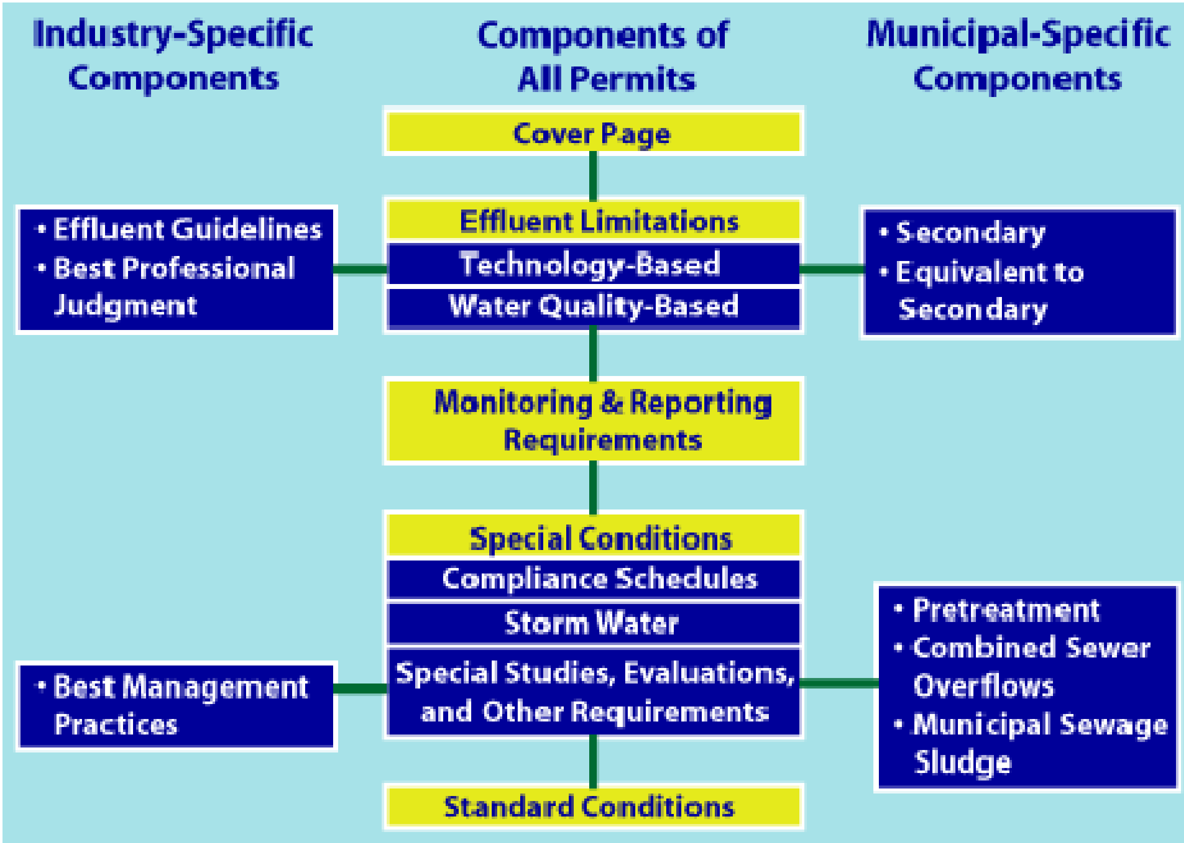


Figure 1.1. Components of NPDES permits. *(Source: USEPA Water Quality Standards Academy website, http://water.epa.gov/learn/training/standardsacademy/permit_page6.cfm, accessed March 23, 2014)*

1. The discharge of effluent from EWPCF, VMWRP, and BSWRP, as monitored at monitoring stations M-001, M-002 and M-003, respectively, shall maintain compliance with the following effluent limitations:

Table 7a. Effluent Limitations based on Secondary Treatment Standards

Constituent	Units	Effluent Limitations					
		Max Daily	Average Monthly	Average Weekly	Instantaneous		6 Month Median
					Min	Max	
CBOD 5-day 20°C *	mg/l		25	40			
	lbs/day		9.0 E+03	1.4 E+04			
	%	The average monthly percent removal shall not be less than 85 percent.					
Total Suspended Solids *	mg/l		30	45			
	lbs/day		1.1 E+04	1.6 E+04			
	%	The average monthly percent removal shall not be less than 85 percent.					
pH	pH units				6.0	9.0	

* $CBOD_5$ and total suspended solids mass emission rate effluent limitations apply to the sum of individual mass emission rates from EWPCF, VMWRP and BSWRP based on the effluent flowrate and concentrations measured at each treatment plant facility.

2. The discharge of effluent from the Discharger's Facilities to Outfall 001, as monitored at Monitoring Location M-004, shall maintain compliance with the following effluent limitations:

Table 7b. Effluent Limitations based on the 2001 California Ocean Plan

Constituent	Units	Effluent Limitations					
		Max Daily	Average Monthly	Average Weekly	Instantaneous		6 Month Median
					Min	Max	
Oil and Grease	mg/l		25	40		75	
	lbs/day		9.0 E+03	1.4 E+04		2.7 E+04	
Settleable Solids	ml/l		1.0	1.5		3.0	
Turbidity	NTU		75	100		225	
Chronic Toxicity	TUc	145					

Figure 1.2a. Example of technology-based and water quality-based effluent limitations contained in NPDES permits. *(Source: Order No. R9-2005-0219, RWQCB, San Diego Region)*

IV. EFFLUENT MONITORING REQUIREMENTS

Sample Type and Frequency

The Discharger shall monitor secondary effluent at monitoring location M-001, M-002, M-003, and M-004 as follows (Endnotes are located at the end of the MRP starting on page E-20):

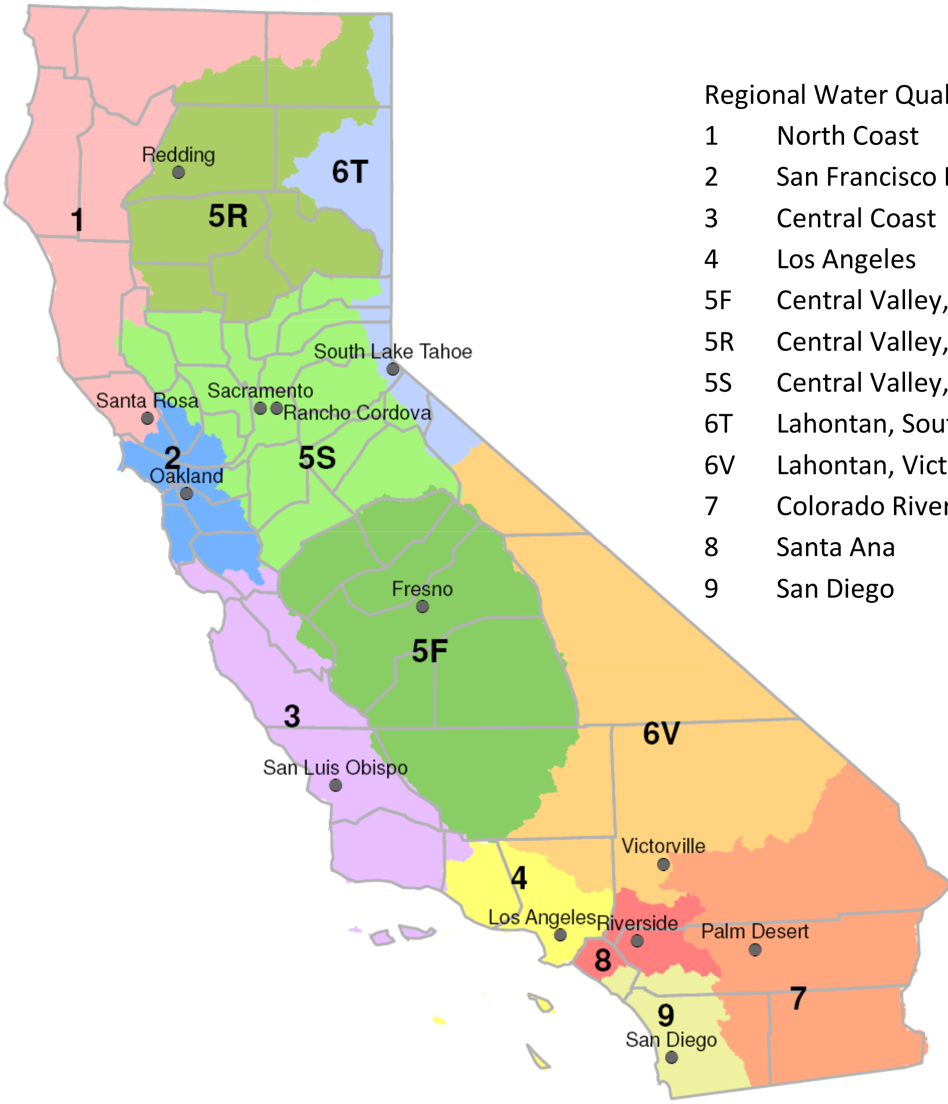
Table 3a. Effluent Monitoring at M-001, M-002 and M-003

Parameter	Units	Sample Type [1]	Minimum Sampling Frequency
Flow [14]	MGD	recorder / totalizer	continuous
$CBOD_5$	mg/L	24 hr composite	three days per week[2]
BOD_5	mg/L	24 hr composite	monthly
TSS	mg/L	24 hr composite	daily [2]
pH	pH Units	grab	daily [2]

Table 3b. Effluent Monitoring M-004

Parameter	Units	Sample Type [1]	Minimum Sampling Frequency
Settleable Solids	mL/L	grab	weekly
Turbidity	NTU	24 hr composite	weekly [3]
Dissolved Oxygen	mg/L	grab	weekly
Temperature	° F	grab	weekly
arsenic	µg/L	24 hr composite	quarterly [3, 4]
cadmium	µg/L	24 hr composite	quarterly [3, 4]
chromium (VI)	µg/L	24 hr composite	quarterly [3, 4, 6]
copper	µg/L	24 hr composite	quarterly [3, 4]
lead	µg/L	24 hr composite	quarterly [3, 4]
mercury	µg/L	24 hr composite	quarterly [3, 4]

Figure 1.2b. Example of monitoring requirements contained in NPDES permits. *(Source: Order No. R9-2005-0219, RWQCB, San Diego Region)*



Regional Water Quality Control Boards

1	North Coast
2	San Francisco Bay
3	Central Coast
4	Los Angeles
5F	Central Valley, Fresno
5R	Central Valley, Redding
5S	Central Valley, Sacramento
6T	Lahontan, South Lake Tahoe
6V	Lahontan, Victorville
7	Colorado River
8	Santa Ana
9	San Diego

Figure 1.3. Map of Regional Water Quality Control Board regions, showing county lines and office locations. The State Water Resources Control Board office is located in Sacramento.

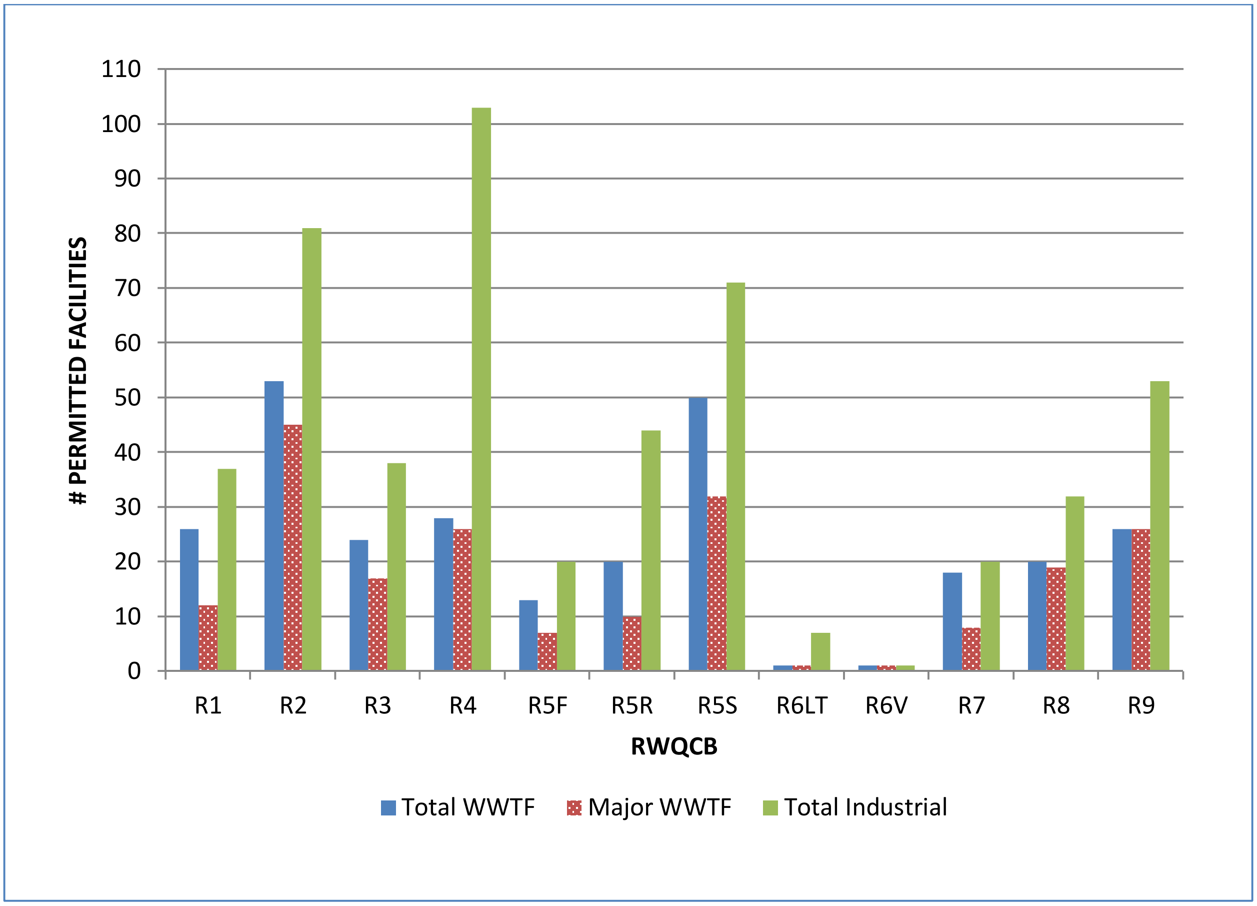


Figure 1.4. Number of wastewater treatment facilities, major wastewater treatment facilities (> 1 MGD capacity), and industrial facilities regulated under NPDES permits in each RWQCB region.

6. References

Adrison V. (2007). Estimating the Effect of Penalties on Regulatory Compliance. PhD. Dissertation, Georgia State University.

Andreen, WL. (2003). Water Quality Today-Has the Clean Water Act Been a Success. *Ala. L. Rev.*, *55*, 537.

Burian, S. J., Nix, S. J., Pitt, R. E., & Durrans, S. R. (2000). Urban wastewater management in the United States: Past, present, and future. *Journal of Urban Technology*, *7*(3), 33-62.

California State Water Resources Control Board (SWRCB). (May 2010). Water Quality Enforcement Policy.

California State Water Resources Control Board (SWRCB). (June 2011). 2010 Annual Enforcement Report.

California State Water Resources Control Board (SWRCB). (March 2012). Resource Alignment Evaluation Report.

Copeland, C. (2010). Clean Water Act: a summary of the law. Congressional Research Service, Library of Congress.

Coyne, W &Metzger, L. (May 2004). Mandatory Minimum Penalties, An Effective Tool for enforcement of Clean Water Laws. TexPIRG Education Fund, Austin, Texas.

Earnhart, D. (2004a). Panel data analysis of regulatory factors shaping environmental performance. *Review of Economics and Statistics*, *86*(1), 391-401.

Earnhart, D. (2004b). Regulatory factors shaping environmental performance at publicly-owned treatment plants. *Journal of Environmental Economics and Management*, *48*(1), 655-681.

Epple, D., & Visscher, M. (1984). Environmental pollution: Modeling occurrence, detection, and deterrence. *JL & Econ.*, 27, 29.

Gaba, J. M. (1984). Regulation of Toxic Pollutants Under the Clean Water Act: NPDES Toxics Control Strategies. *J. Air L. & Com*., 50, 761.

Gray, W. B., & Shimshack, J. P. (2011). The effectiveness of environmental monitoring and enforcement: A review of the empirical evidence. *Review of Environmental Economics and Policy*, 5(1), 3-24.

Harford, J. D. (1991). Measurement error and state-dependent pollution control enforcement. Journal of Environmental Economics and Management, 21(1), 67-81.

Heyes, A. G. (1996). Cutting environmental penalties to protect the environment. Journal of Public Economics, 60(2), 251-265.

Jahagirdar, S., & Coyne, W. (2003). Leaking Enforcement. Analyzing the Effectiveness of the 1999 Clean Water Enforcement and Pollution Prevention Act. Environment California Research and Policy Center, Los Angeles, California.

Kadambe, S., & Segerson, K. (1998). On the role of fines as an environmental enforcement tool. *Journal of Environmental Planning and Management*, *41*(2), 217-226.

Laplante, B., & Rilstone, P. (1996). Environmental inspections and emissions of the pulp and paper industry in Quebec. *Journal of Environmental Economics and Management*, *31*(1), 19-36.

Lyon, G. S., & Stein, E. D. (2009). How effective has the Clean Water Act been at reducing pollutant mass emissions to the Southern California Bight over the past 35 years?. *Environmental Monitoring and Assessment*, *154*(1-4), 413-426.

Magat, W. A., & Viscusi, W. K. (1990). Effectiveness of the EPA's regulatory enforcement: The case of industrial effluent standards. *JL & econ.*, *33*, 331.

Metcalf & Eddy. (1991). *Wastewater Engineering: Treatment, Disposal, and Reuse*. G. Tchobanoglou, & F. L. Burton (Eds.). McGraw-Hill.

New Jersey Administrative Code, Section 7:14, Water Pollution Control Act, October 5, 2010.

Olds, D. M., Unkovic, J. C., & Lewin, J. L. (1978). Thoughts on the Role of Penalties in the Enforcement of the Clean Air and Clean Water Acts. Duq. L. Rev., 17, 1.

Oljaca, N., Keeler, A. G., & Dorfman, J. (1998). Penalty functions for environmental violations: evidence from water quality enforcement. *Journal of Regulatory Economics*, *14*(3), 255-264.

Rechtschaffen, C. (2003). Enforcing the Clean Water Act in the Twenty-First Century: Harnessing the Power of the Public Spotlight. *Ala. L. Rev.*, *55*, 775.

Rousseau, S. (2009). Empirical analysis of sanctions for environmental offenses. *International Review of Environmental and Resource Economics*, *3*(3), 161-194.

Sato, R. and California State Water Resources Control Board (SWRCB). (October 2009). Deconstructing Enforcement, A Primer on Water Quality Enforcement.

Shimshack, J. P., & Ward, M. B. (2005). Regulator reputation, enforcement, and environmental compliance. *Journal of Environmental Economics and Management*, *50*(3), 519-540.

Shimshack, J. P., & Ward, M. B. (2008). Enforcement and over-compliance. Journal of Environmental Economics and Management, 55(1), 90-105.

Silberman, J. D. (2000). TITLE: Does Environmental Deterrence Work? Evidence and Experience Say Yes, But We Need to Understand How and Why.*Environmental Law Reporter NEWS & ANALYSIS*.

USEPA, Office of Wastewater Management, Water Permits Division, State and Regional Branch. (September 2010). NPDES Permit Writer's Manual. EPA-833-K-10-001.

Weber, J. M., & Crew Jr, R. E. (2000). Deterrence theory and marine oil spills: Do coast guard civil penalties deter pollution? *Journal of Environmental Management*, *58*(3), 161-168.

CHAPTER TWO

Evaluation of the correlation between number of NPDES effluent violations and enforcement actions under California's MMP enforcement program

1. Introduction

1.1. Background

Under the National Pollutant Discharge Elimination System (NPDES), a regulatory program was created to control water pollution from point source facilities that discharge pollutants into surface waters (i.e., waters of the United States) (Copeland, 2010). NPDES was established by the US Environmental Protection Agency (USEPA) in 1972 as authorized by the Clean Water Act (CWA) to regulate discharges from municipal wastewater treatment plants and industrial facilities through the issuance of facility-specific NPDES permits. Discharging facilities must ensure that their effluent quality meets technology-based and water quality-based effluent limitations established in NPDES permits. The NPDES permits also establish a self-monitoring program which requires facilities to monitor their effluent discharges to demonstrate compliance with the effluent limitations. Despite the goals of NPDES, non-compliance with NPDES permits by the regulated facilities is a common occurrence, and effluent discharged to receiving waters often exceed the effluent limitations of NPDES permits (Coyne and Metzger, 2004; Andreen, 2004).

The USEPA has mostly delegated the implementation of the NPDES program to individual state governments (Copeland, 2010). In California, the NPDES program is implemented by the State Water Resources Control Board (SWRCB) and the nine Regional Water Quality Control Boards (RWQCBs). Because of California's large land area and population, the various RWQCBs are hydrogeologically and demographically diverse. For example, the smaller, highly urbanized coastal RWQCBs contain over 70 percent of the state population and have higher median household incomes and levels of college degree attainment than the larger inland RWQCBs. The RWQCBs also have different water quality challenges and varying numbers of wastewater treatment facilities and industrial facilities.

An effective environmental policy requires an effective monitoring and enforcement strategy implemented by the regulatory agency (Laplante and Rilstone, 1996; Rousseau, 2009; Gray and Shimshack, 2011). The SWRCB and RWQCBs have statutory authority under the California Water Code to issue administrative civil liabilities (ACLs), i.e., monetary penalties, for violations of permits and regulations within the NPDES program as well as other regulatory programs implemented by the RWQCB (e.g., underground storage tanks, discharges to land). The ACLs issued by the RWQCBs are typically discretionary, and a range of factors (e.g., culpability, corrective actions taken, ability to pay, environmental damage) are taken into consideration by the RWQCB in the determining the amount of the penalties, and when they will be assessed, subject to maximum allowed penalties established in the California Water Code for each day of violation and for each gallon of polluted wastes discharged (SWRCB, 2010).

In response to the documented failure by the RWQCBs to carry out enforcement actions to address thousands of violations of NPDES permits across the state, the California legislature enacted the 1999 Clean Water Enforcement and Pollution Prevention Act (CWEA), which amended the California Water Code, (Jahagirdar and Coyne, 2003). Beginning in January 2000, the California legislature has mandated the RWQCBs to issue a mandatory minimum penalty (MMP) of $3,000 for each instance of serious violation of effluent limitations in NPDES permits and for each chronic effluent violation after the third violation, whether serious or chronic, that occurs within a six-month period. MMP ACLs only require the determination of an effluent violation to assess the minimum mandated penalty, and the RWQCB may not consider other factors such as culpability or severity of environmental damage as it can under a discretionary ACL. The goal of MMPs is to increase compliance by regulated dischargers with their NPDES permits (Jahagirdar and Coyne, 2003). MMPs presented both the regulated facilities in California and the SWRCB/RWQCBs with a new legal mechanism aimed towards improving water quality. The MMPS also presented the SWRCB/RWQCBs and the regulated facilities with programmatic challenges to equitably assess MMP amounts and evaluate effectiveness.

The CWEA statutes that authorized MMPs included provisions that exempted certain effluent limitation violations from MMP. One provision allowed RWQCBs to exempt violations from MMP if the violation is for an effluent constituent that is covered by a cease and desist order (CDO) or a time schedule order (TSO) (SWRCB, 2010). CDOs and TSOs are non-monetary enforcement actions that require violating facilities to take corrective actions to prevent future violations for one or more effluent limitation. Because corrective actions often required construction of new treatment unit processes or upgrades of entire wastewater treatment plants, CDOs and TSOs allowed facilities up to five years to implement corrective actions during which time additional violations are exempted from additional MMP.

California's MMP enforcement program continued to evolve since it was first implemented. Notably, in 2006, the SWRCB formed the Office of Enforcement to ensure that firm, fair and consistent enforcement actions were taken when violations occur (Sato and SWRCB, 2009) In 2008, the SWRCB launched an MMP enforcement initiative to address a significant backlog of violations subject to MMP that have not been assessed an MMP (SWRCB, 2009). In 2010, the SWRCB adopted a new Enforcement Policy which included a provision requiring an 18-month time limit to assess MMPs after discovery of a violation (SWRB, 2010).

The effectiveness of MMPs in water pollution control has not been well studied; however, many studies have investigated the effectiveness of enforcement actions with variable penalty amounts such those assessed under discretionary ACLs. Coyne and Metzger (2004) state that the lack of enforcement in NPDES nationwide continues as the key problem in achieving water quality improvements in the nation's waters, and they advocate instituting mandatory minimum penalties as a way to ensure that violations are consistently addressed by penalties that are at the same time taken seriously by polluters and stand up against court challenges. New Jersey began implementing an MMP program for NPDES violations in 1991 and is the only other state that issues mandatory penalties for water pollution control; results from that program indicate that MMPs have been effective – enforcement actions increased by 57% during the first year and violations subsequently decreased by 76% over the next eight years (Coyne and Metzger, 2004).

Results from investigations of the effectiveness of variable penalty amounts suggest that certain features of MMP enforcement programs may promote compliance and improve the environment. In a study of enforcement actions against paper pulp plants nationwide, Shimshack and Ward (2005) found that the probability that a facility will have a violation decreases by 31% to 75% if the regulatory agency issued a penalty to any facility during the previous year; this result is attributed to general deterrence resulting from an enhancement of the regulatory agency's enforcement reputation. Since MMPs must be assessed, the probability of penalties is increased and is expected to similarly enhance the regulatory agency's enforcement reputation and result in fewer violations. In contrast to Shimshack and Ward (2005), Adrison (2007) found that the deterrence effect of penalties on municipal and industrial facilities is economically small and recommended that regulators impose more frequent and severe penalties to increase the probability of compliance by facilities. Again, issuance of MMPs are expected to increase the frequency of penalties, if not also the penalty amount, and therefore, also expected to reduce violations. Weber and Crew (2000) found that the volume of oil spills into marine waters decreased in response to the swiftness and severity of penalties assessed by the US Coast Guard; therefore, MMPs have the potential to achieve faster issuance of penalties compared to discretionary penalties because RWQCBS need only to have evidence of a violation to issue MMPs and are not required to consider other factors. Weber and Crew (2000) also recommended that penalty schedules with a constant penalty amount per liter of oil spilled, similar to MMPs for each violation, are preferable to existing US Coast Guard penalty schedules that effectively reduce the per liter penalty as volume of oil spilled increased. On the other hand, Oljaca et al (1998) provide empirical evidence from water quality enforcement indicating that the seriousness of a violation, the compliance history of the polluter, and the size of the polluting company are important considerations when determining the severity of penalty amount levied by regulatory agencies. Consequently, the lack of ability to levy more stringent penalties for repeat offenders or relative to environmental damage may be the downside of MMPs.

1.2. Current study

Early assessments of the effectiveness of the MMP enforcement program in California cited reductions in numbers of violations across the state and an increase in the number of enforcement actions and penalty amounts issued (Jahagirdar and Coyne, 2003; Metzger and Coyne, 2004). The SWRCB also prepares annual Reports to the Legislature and Annual Enforcement Reports which include assessments of the MMP enforcement program in terms of number of facilities that have had violations subject to MMPs during the year, the number of MMP enforcement actions taken by each RWQCB, and the percentage of violations subject to MMPs within each RWQCB that have not been assessed the required MMP (SWRCB, 2003;

SWRCB, 2011). However, no long-term evaluation of California's MMP enforcement program has been conducted by the SWRCB or has been found in the enforcement literature.

The objective of this investigation is to evaluate the effectiveness of California's MMP enforcement program in achieving clean water goals by quantitatively estimating the correlation between number of violations and number of MMP enforcement actions. The main contribution of this investigation is in the preliminary analyses performed on the unique data set collected and assembled from the NPDES and MMP enforcement program public record. Because of the diversity found within California (e.g., geographic, demographic, economic), the data collected for the current investigation also provide an opportunity to evaluate mandatory minimum penalties as implemented in a larger and more complex state and organizational structure, in order to provide greater insight to the effectiveness of mandatory penalties if applied across the US, and contribute to the empirical literature about enforcement actions. Follow-up research will provide additional insights and conclusions regarding the effectiveness of the MMP enforcement program.

2. Data and Methods

2.1.1. Data Source

This study analyzes the relationship between the number of violations that are subject to MMPs, as the dependent variable, and two types of enforcement actions (i.e., penalties and cease and desist orders), as the independent variables, using data obtained from the California Integrated Water Quality System (CIWQS) database. Since 2005, the RWQCBs enter violation data and enforcement action data into CIWQS; prior to 2005, data was entered in an earlier database that has since been migrated into CIWQS. The SWRCB maintains the CIWQS database and the CIWQS Internet web site[1] which provides a database portal that allows access to CIWQS data to the public. The CIWQS website database portal includes several query interfaces (e.g., for violations reports and enforcement reports) and allows users to customize queries such as by specifying date ranges, geographical areas, and regulatory program (i.e., NPDES program for this study). The query reports often have additional hyperlinks that allow the user to look at details of the tabulated data. For example, if the violations report counts five violations for a facility, the user can click on a hyperlink to look at the details of those five violations.

The CIWQS database is a living database, and data contained in CIWQS may be updated and is subject to data entry errors. Because of data quality assurance issues, errors or deficiencies are regularly encountered in CIWQS data entries (SWRCB, 2008). For example, although a violation that is subject to MMP must be flagged as such by putting a check mark in an appropriate data entry field, an MMP violation may inadvertently not be flagged as a violation subject to MMP due to data entry errors or because the violation data was not correctly migrated from the previous database. Because there are errors in the database, it was necessary to determine ways to validate the data obtained from CIWQS in order to increase the accuracy of the analysis in this study. In addition, entries can be added, removed or modified at any time; therefore, query results may change depending on when the query was done. For example, if data for the number of MMP violations for Facility A were obtained today for year 2009, and after today some violations for Facility A were challenged during enforcement negotiations and proven not to be violations, those changes would not be captured unless a new violations query

[1] http://www.swrcb.ca.gov/water_issues/programs/ciwqs/publicreports.shtml

was made. The procedures for obtaining and validating data are described further below for the three types of data used.

2.1.2. Violations data

Violations data are entered in CIWQS by RWQCB staff after a violation has been detected, for example, after staff review of self-monitoring reports or after inspections. Violations data entries include information about the date of occurrence, type of violation (e.g., effluent violation, late report violation, permit condition violation), the constituent and sample result for effluent violations, and whether the violation is subject to MMPs. A listing of all violations for a specific RWQCB region and each year can be obtained from the Interactive Violation Reports query by specifying the RWQCB region and date range. The number of effluent violations for each year from 1995 to 2011 was obtained for preliminary data analysis discussed below.

The CIWQS web site has a Mandatory Minimum Penalty (MMP) Report query interface which gives tabulated results listing the regulated facilities that have violations that are subject to MMP and the number of MMP violations for each facility. A master spreadsheet of facilities with MMP violations and the number of MMP violations for each facility was prepared in Excel for this study using CIWQS MMP Report query results for each year from 2000 through 2011. The year for each query was added to the master MMP violations spreadsheet to allow further data analyses based on calendar year. The MMP violations report includes a count of violations that would normally be subject to MMP but are exempted, a count of MMP violations that have been assessed penalties already, and a count of MMP violations that are still pending penalty assessment. For this study, the counts of MMP violations include those violations that have either been assessed a penalty or are pending penalty assessment, and do not include exempted violations; this is consistent with the manner that MMP violations are tabulated in the query results.   A separate count of the number of violations exempt from MMP was also maintained. The pivot table function in Excel was used to generate summary tallies of violations, such as number of MMP violations for each RWQCB for each year. The number of MMP violations and number violations exempt from MMP for each RWQCB office for each year is provided in Tables 2.1 and 2.2, respectively, using results from CIWQS queries conducted in the evening of April 1, 2013.

A limited validation of the MMP Reports query results can be accomplished by using the Interactive Violation Reports query from the CIWQS web site to obtain a broader list of violations which includes all violations. Validation of MMP Report query results may be necessary if the number of MMP violations for a given year for a RWQCB office was particularly smaller (or is zero) or greater than in other years. All violations for a specific RWQCB region and each year were obtained from the Interactive Violation Reports, and the list was reviewed in detail if necessary to validate the MMP Report results to identify effluent violations that should be subject to MMP but were not flagged as subject in the MMP Report. While earlier MMP Report queries required some data validation, the query results obtained on April 1, 2013 did not.

2.1.3.   Administrative Civil Liability (ACL) data

Administrative civil liability (ACL) enforcement actions are entered in CIWQS by RWQCB staff. ACL data entries include information about the facility, the effective dates of the enforcement action, the status of the action (e.g., active or historical), the liability dollar amount, the violations being addressed by the action, etc. The CIWQS web site has an Administrative Civil Liability (ACL) Report query interface which gives tabulated results listing the number of

ACLs issued by each RWQCB office during a specified date range in the NPDES program. From the query results, a listing of the actual ACL enforcement actions for a RWQCB office can be obtained, which includes more detailed information about the specific ACL actions.
A master spreadsheet in Excel of all ACL actions that address MMP violations was prepared for each RWQCB office for this study using CIWQS query results. While the listing of actual ACL enforcement actions from the CIWQS query results includes a field that identifies whether or not a specific ACL action addressed MMP violations, the field entry was not always accurate and it was determined that some ACL actions were identified as not addressing MMP violations when they actually did and vice versa. Therefore, it was necessary to evaluate each ACL action to validate whether or not the ACL action actually addressed MMP violations.

Validation of ACL action data was accomplished using two approaches. In the first approach, a list of ACL actions was obtained using another CIWQS query interface, i.e., the Enforcement Action Report query which identifies all enforcement actions, but the query can be specified to identify only enforcement actions that are ACL actions issued under the NPDES program. The Enforcement Action Report query results include a title field that provides a short description of the enforcement action. In many instances, an ACL action that was identified as not addressing MMP violations in the ACL report query results had a title description in the Enforcement Action query results that clearly indicated the ACL action addressed MMP violations; in those instances, the master spreadsheet entry for an ACL action was corrected. The second approach for ACL action validation required reviewing the actual ACL action document (available as a PDF or Word document through the RWQCB websites for most ACL actions) and determining if the ACL action was issued to address MMP violations. This second approach was utilized only for a those ACL actions that could not be validated otherwise. For some RWQCB offices that had a large number of ACL actions, all ACL actions that were identified from the ACL Reports query as not addressing MMP violations were validated while only a sample (e.g., one out of every four) of the ACL actions that were initially identified as addressing MMP violations were validated to determine if actually correctly identified and the rest were assumed to also be correctly identified.

After validation of the ACL actions, the pivot table function in Excel was used to tally number of ACL actions for each year using the master spreadsheet of validated ACL actions for each RWQCB office. A summary of the number of ACL actions that address MMP violations for each RWQCB office for each calendar year, using results from CIWQS queries conducted in October and November 2012, is provided in Table 2.3.

The Enforcement Action Report query was also used to obtain a list of ACL actions under the NPDES for the years 1995-1999. This data set was used for preliminary data analysis as discussed below.

2.1.4. Cease and Desist Orders and Time Schedule Orders

Cease and Desist Orders (CDO) and Time Schedule Orders (TSO) enforcement actions are entered in CIWQS by RWQCB staff. CDO/TSO data entries include information about the facility, the effective dates of the enforcement action, and the status of the action (e.g., active or historical), etc. The CIWQS website Enforcement Report query was used to obtain a list of all CDOs and TSOs issued under the NPDES program. The CIWQS query results obtained in September 2012 yielded 553 CDOs and 232 TSOs issued by all the RWQCB offices combined under the NPDES program. One master Excel spreadsheet was prepared containing all the CDOs issued by all of the RWQCB offices, and a separate master Excel spread sheet was prepared containing all the TSOs issued by all of the RWQCB offices. However, the CIWQS results from the query did not always include the end date for CDOs and TSOs; over half of the CDOs did not have a recorded end date and about a third of the TSOs did not have an end date. Because CDOs and TSOs could only be in effect for five years pursuant to the California Water Code, an artificial end date equal to five years from the start date was assigned to those CDOs and TSOs that did not have an end date, for purposes of the analysis in this study; however, it is possible that actual effective periods could be less than or greater than five years. A summary of the number of CDO and TSO enforcement actions for each RWQCB for each calendar year, using results from CIWQS queries conducted in October and November 2012, is provided in Table 2.4

All CDOs and TSOs issued under the NPDES program that were in effect at least part of the time in 2000 or later have the potential to exempt violations from MMPs and must be retained for part of the analysis in this study. CDOs and TSOs issued in 2000 or later were retained in their respective master spreadsheets. Also CDOs and TSOs, with actual or assumed end dates that were in 2000 or later were also retained. Given the assumption that CDOs and TSOs remained in effect for five years, those CDOs and TSOs issued from 1995 to 1999 but did not have an end date in CIWQS were also retained in the master Excel spreadsheets.

For the statistical analysis in this study, discussed further in Section 2.3, the effect of CDOs and TSOs on the number of MMP violations was considered in two approaches, which required two types of tallies. In the first approach, the effect of CDOs and TSOs is assumed to be limited to the year of issuance; therefore, the number of CDOs and TSOs issued each year by each RWQCB office was tallied. In the second approach, the effect of CDOs and TSOs is assumed to extend to the entire period that the CDO or TSO was in effect; therefore, the number of CDOs and TSOs that were in effect for a given year for each RWQCB was tallied. For the first approach, only CDOs and TSOs issued after 2000 were tallied. For the second approach, CDOs and TSOs that may have been issued prior to the year 2000 but remained in effect post-2000 were included in the tally for the year 2000 and later.

2.2. Preliminary data analysis

2.2.1. Effluent and violations frequencies before and after MMP enforcement program

To do a preliminary assessment as to whether the implementation of the MMP program caused changes in the occurrence of effluent violations and the issuance of ACL enforcement actions, CIWQS data obtained from the Interactive Violations Report query and the Enforcement Action Report query were obtained for the years 1995-2011. The violations data were summed for the years 1995-1999, 2000-2004, 2005-2009, and 2010-2011. The ACL data was analyzed to calculate the annual average number of ACLs issued for the years 1995-1999, 2000-2007, and 2008-2011, which would also provide information about the MMP enforcement initiative that was initiated in 2008 to reduce the number of backlogged violations requiring MMP.

2.2.2. Time series plots of violations and ACLs

For each RWQCB region, the number of effluent violations subject to MMP and the number of ACLs issued by RWQCB were plotted for each year for the period 2000-2011.

2.3. Statistical analysis and modeling

2.3.1. General approach

In this study, the relationship between the number of violations subject to MMPs and the two types of enforcement actions (i.e., ACLs and CDOs/TSOs) is analyzed using linear regression models implemented using the R programming language (R Development Core Team, 2008). Several linear regression models were proposed, and compared with each other. The number of MMP violations was the dependent variable modeled against several expressions of the number of ACLs and CDOs/TSOs as the independent explanatory variables, as discussed in more detail below. As previously discussed above, annual tallies of MMP violations, ACLs and CDOs/TSOs for each of the twelve RWQCB offices serve as the raw data for the dependent and explanatory model variables. Gray and Shimshack (2011) identified interrelated challenges when attempting to measure the effects of environmental enforcement, namely, omission of explanatory variables from the model, inability to observe how discharging facilities actually responded to enforcement actions, and apparent reverse causality (e.g., such as when a facility with frequent violations receives enforcement actions more frequently, which may appear as the enforcement actions causing the violations).

Given the diverse characteristics apparent between the different RWQCB offices (e.g., demographic and geographic diversity), it would be highly instructive to conduct linear regression models specific to each RWQCB office and then compare the results between offices in order to more accurately identify those regional characteristics that are significant in determining number of violations. However, because there are only 12 years for which data are available, the data set for each RWQCB office would be limited (N=12) and not sufficient to do statistical analysis. Consequently, in order to have a larger data set for linear regression analysis, the twelve years of data available for the twelve RWQCB offices were combined to increase the possible sample observations to N=144. This is a common approach; for example, Weber and Crew (2000) pooled the number of oil spills that occurred over five years within 46 US Coast Guard Ports/Offices to obtain a sample set of N=230.

2.3.2. Description of Model Variables

The proposed linear regression models have the form:

$$y = \alpha + \Sigma\beta_i X_i + \varepsilon \qquad \text{(Equation 2.1)}$$

where y is the dependent variable, α is the model intercept, β_i is the regression coefficient for independent variable X_i, and ε is the error term. The model variables used in the linear regression models are summarized and defined in Table 2.5 with descriptive statistics. The dependent variable VIOS consist of the number of violations subject to MMP for each year for each RWQCB office. The independent variable VIOS_EXMPT would show if the number of violations that are subject to MMP is affected by the number of violations that are exempted from MMP by CDOs and TSOs. The 12 RWQCB offices comprise the independent variable REGION, which is treated as a factor variable with 12 levels in the linear regressions. The years 2000-2011 for which data are available are treated as a factor variable called YEAR. The variable REGION captures differences in overall level of violations among the 12 RWQCB offices; the variable YEAR captures time trends that are common to all RWQCB offices. The remaining independent variables are based on the number of ACLs and CDOs/TSOs and are discussed below.

This study attempts to determine whether the issuance of civil penalties affects the number of violations that are subject to MMPs; however, the effects of an ACL action may not be evident in the year that the penalty is levied (Gray and Shimshack, 2011). Therefore, the number of ACLs issued by each RWQCB office for a particular year and additional ACL related variables were considered for linear regression analysis. The number of ACLs issued in a given year for each region was lagged by zero, one, three, and five years and assigned to the independent variables ACL0YRLAG, ACL1YRLAG, ACL1YRLAG, and ACL5YRLAG. This group of independent variables is referred to as the ACL_ISS variables in the remainder of this study.

While an ACL is required by the California Water Code to be issued for all violations that are subject to MMPs, the actual issuance of the ACL action for a given violation is usually delayed by several months to a few years for various reasons. Therefore, this study also considered the effect that the probability that a facility with a violation will be issued an ACL has on the number of violations. The independent variable PROB1YR is calculated as the number of ACL enforcement actions issued by a RWQCB office in a given year, divided by the number of facilities that had at least one MMP violation in the previous year within that RWQCB region, which assumes that issuance of ACL enforcement actions are delayed by one year. Another independent variable, PROB2YR, was calculated which assumes that issuance of ACL enforcement actions are delayed by 2 years. The additional independent variables PROB1YRLAG1YR and PROB2YRLAG1YR are the values of the variables PROB1YR and PROB2YR lagged by one year to test if the effects of probabilities on reducing violations are themselves delayed. This group of independent variables is referred to as the PROB variables in the remainder of this study.

As discussed in the introduction section, CDOs and TSOs are enforcement actions that are in one way punitive but also provide a shield to a violating discharger that limits future ACLs for future MMP violations. As discussed in Section 2.1.4, since CDOs and TSOs have an effective period lasting up to five years pursuant to the California Water Code, CDOs and TSOs were tallied in two ways. The total number of CDOs and TSOs issued in a given year by each RWQCB office is the independent variable CDOTSO_ISS0YRLAG. The total number of CDOs and TSOs that were in effect each calendar year for each RWQCB office, regardless of actual year of issuance, is the independent variable CDOTSO_EFF0YRLAG. Similar to the ACL enforcement actions, the effects of a CDO or TSO enforcement action may not be evident in the year that the action is issued; therefore, additional CDO/TSO related variables were considered for linear regression analysis. The number of CDOs/TSOs issued, or that were in effect, in a given year for each region were lagged by one, three and five years and assigned to the independent variables CDOTSO_ISS1YRLAG, CDOTSO_ISS 3YRLAG, CDOTSO_ISS5YRLAG, CDOTSO_EFF1YRLAG, CDOTSO_EFF3YRLAG, and CDOTSO_EFF5YRLAG. The group of variables related to the number of CDOs/TSOs issued is referred to as the CDOTSO_ISS variables for the remainder of this study and the group of variables related to the number of CDOs/TSOs in effect is referred to as the CDOTSO_EFF variables.

2.3.3. Description of regression models

Several linear regression models were run with all or a subset of the independent variables listed in Table 2.5. Because the value of the variable VIOS, the number of violations per year, ranged from 0 to over 1300, the natural log of VIOS was determined to provide better modeling results; and therefore, the model results are conditional on observing violations, i.e., VIOS cannot be zero because the natural log would not be defined. The Base Model only considers the natural log of the dependent variable VIOS as a function of the factor variables REGION and YEAR.

Model 1A, shown as Equation 2.2 below, is the "full" model and incorporates all of the variables listed in Table 2.5.

Full Model (Model 1A):

$$Log(VIOS) = \alpha\, REGION + \beta\, YEAR + \gamma\, VIOS\_EXMPT + [\, \delta_1 ACL\_0YRLAG + \delta_2 ACL\_1YRLAG + \delta_3 ACL\_3YRLAG + \delta_4 ACL\_5YRLAG] + [\, \lambda_1 PROB\_1YR + \lambda_2 PROB\_2YR\,] + [\, \lambda_3 PROB\_1YR\_1YRLAG + \lambda_4 PROB\_2YR\_LAG1YR\,] + [\, \zeta_1 CDOTSO\_ISS\_0YRLAG + \zeta_2 CDOTSO\_ISS\_1YRLAG + \zeta_3 CDOTSO\_ISS\_3YRLAG + \zeta_4 CDOTSO\_ISS\_5YRLAG\,] + [\, \eta_1 CDOTSO\_EFF\_0YRLAG + \eta_2 CDOTSO\_EFF\_1YRLAG\,] + [\, \eta_3 CDOTSO\_EFF\_3YRLAG + \eta_4 CDOTSO\_EFF\_5YRLAG\,] + \varepsilon \quad \text{(Equation 2.2)}$$

Model 1A allows for all the independent variables to affect the linear regression analysis results; however, the linear regression model coefficients and standard errors would indicate the relative importance between related variables (e.g., ACL0YRLAG vs. ACL1YRLAG). Because the probability variables (i.e., PROB1YR, PROB2YR, PROB1YRLAG1YR, and PROB2YRLAG1YR) are not defined for years 2010 and 2011, the full model (Model 1A) linear regression only considered data from years 2000-2009, which reduces the data set.

To evaluate the sensitivity of the linear regression models to the variables included in the models, other models where VIOS was the dependent variable were fitted to determine how groups of related variables affect the linear regression analysis. Model 1B excludes the variables related to ACLs (i.e., ACL0YRLAG, ACL1YRLAG, ACL3YRLAG, ACL5YRLAG) from the full model (Model 1A). Model 1C excludes the variables related to CDOs and TSOs issued (i.e., CDOTSO_ISS) from the full model. Model 1D excludes the variables related to CDOs and TSOs that are in effect (i.e., CDOTSO_EFF) from the full model. Model 1E is the full model with the variable VIOS_EXMPT excluded. Model 2A is the full model with the variables related to probability excluded (i.e., PROB variables).

Finally, a separate linear regression was conducted with VIOS_EXMPT as the dependent variable and REGION, YEAR and the variables related to CDOs and TSOs as the independent variables. Because CDOs and TSOs exempt violations from MMP, this analysis is expected to show if VIOS_EXMPT and the variables related to CDOs and TSOs are correlated as well as provide insight to how the provision allowing exemption from MMP via CDOs and TSOs was applied in the different RWQCB offices.

3. Results

3.1. Effluent and violation frequencies before and after MMP enforcement program

As shown in Table 2.6, in all the RWQCB regions, except in RWQCB R5R and R6B, the number of violations during the five-year period 2000-2004 after implementation of the MMP enforcement program increased, by as much as a factor of ten, compared to the preceding five-year period 1995-1999. In the subsequent five-year period 2005-2009, the number of violations remained much higher than during the period 1995-1999. At the same time, as shown in Table 2.7, the annual average number of ACL enforcement actions was significantly higher at each RWQCB region after implementation of the MMP enforcement program. These results may seem contradictory; however, it is consistent with observations by other researchers that increased enforcement activity also increased detection of violations (Epple and Visscher, 1984; Weber and Crew, 2000). Early on after implementation of the MMP enforcement program, a number of improvements to the SWRCB and RWQCB enforcement program were recommended to help SWRCB and RWQCB staff identify and track violations and enforcement actions (SWRCB, 2003). Among the recommendations that have been implemented include the development of NPDES permit templates to increase the enforceability of permits and the development of improved databases such as CIWQS. In addition, the SWRCB developed extensive guidance to facilitate the counting of effluent violations and the determination of MMP amounts to assess; see for example "SB 709 and SB 2165 Questions and Answers" (SWRCB, 2001). The SWRCB and RWQCBs underwent significant operational changes after implementation of the MMP enforcement program such that the period prior to 2000 can be characterized as encompassing a different and distinct enforcement paradigm. For this reason, it is appropriate that the linear regression modeling, discussed below, only included data since the MMP enforcement program started and using the year 2000 as the baseline.

3.2. Time series plots of violations and ACLs

The time series plots of effluent violations and MMP ACLs are shown in the 12 charts in Figure 2.1. There were large variations in the patterns of ACLs and effluent violations between regions. The plots for RWQCB R2, R3 and R8 show a decreasing effluent violation trend as well as ACLs issued during all or most years during the period 2000-2011.

3.3. Linear regression models

3.3.1. General results

The linear regression coefficients for the different variables for the Base Model and Model 1A are given in Table 2.8. The coefficients for Models 1B-1E and Model 2A are given in Table 2.9. For each linear regression model, the intercept reflects the effects of the reference value of the factor variables REGION and YEAR on the model. The reference values for the factor variables REGION and YEAR are RWQCB office Region 1 and year 2000, respectively. The choice for using RWQCB Region 1 as the base value for REGION is arbitrary since there is no reason to choose one RQWCB office over another. The choice of year 2000 as the base value for YEAR is not so arbitrary since it can be expected that violations would decrease in future years. Nevertheless, the coefficients of the other factor values for REGION and YEAR are relative to the base values for those variables. In Tables 2.8 and 2.9, the row for the model intercept is labeled as "Region 1", which also reflects the effect of base year 2000; a separate row for base year 2000 is not obtained from the modeling results.

The significance code in the column next to the coefficient estimate column for each model indicates the statistical significance of the coefficient relative to the standard deviation. An "a" indicates a p-value of 0.001 or less, a "b" indicates significance p-value of 0.001 to 0.01, a "c" indicates a p-value between 0.01 and 0.05, a "d" indicates significance p-value between 0.05 and 0.10, and a blank indicates significance p-value greater than 0.10. In the discussion below, a p-value of less than 0.1 is considered statistically significant.

3.3.2. Base Model Results

The Base Model fitted the dependent variable VIOS as only a function of the factor variables REGION and YEAR. The Base Model coefficient results in Table 2.8 indicate that in the absence of information about other independent variables in the linear regression model, the coefficients for variable REGION for RWQCB Region 4 and Region 5S, with p-values less than 0.01, suggest that these regions have more MMP violations than the reference region, Region 1. The coefficients for RWQCB Region 3, Region 5R, Region 6T, Region 6V, Region 7, Region 8, and Region 9, with p-values at least less than 0.1, suggest that these regions have fewer violations than the reference region. The reasons for these differences between RWQCB regions may be due to the demographic and economic differences between the regions, as discussed in the Chapter 1, or due to the effects of ACLs and CDOs/TSOs, which are considered in the full model (Model 1A) and other models, discussed below.

For the Base Model coefficient results in Table 2.8, none of the years from 2001 through 2011 under the factor variable YEAR were statistically significant; however, it is interesting to note some observations about the sign and magnitude of the coefficients. Again, these observations are made in the absence of information about other independent variables in the linear regression model. The coefficients for the years 2001-2003 were negative, indicating fewer MMP violations relative to the base year 2000, with the coefficient for 2001 being most negative. The coefficients for the years 2004 through 2008 were positive, indicating there were more MMP violations in these years relative to year 2000, and these years coincide with the years during which many fewer ACLs were issued in RWQCB Regions 2, 4, 5S, and 9 which are also the regions that account for most of the MMP violations statewide. The coefficient for year 2009 is negative, which is interesting because it follows year 2008 when the State Water Board initiated the MMP initiative, as discussed in the Introduction section. The coefficients for years 2010 and 2011 are again positive, indicating more violations relative to year 2000, but still fewer than during years 2004-2008.

3.3.3. Full Model (Model 1A) and Other regression models

3.3.3.1. Effect of ACL enforcement action variables

The model coefficients in for Models 1A-1E and Model 2A in Tables 2.8 and 2.9 suggest that ACLs do reduce the number of MMP violations as indicated by the negative values of the coefficients for the variables ACL0YR LAG, ACL1YRLAG, ACL3YRLAG, and ACL5YRLAG, although the magnitude of the coefficients for these variables are small. Because the dependent variable was the natural log of the number of violations, i.e., log(VIOS), the coefficients of the ACL variables approximately indicate the percentage by which the number of violations is reduced. The coefficients for ACL0YRLAG in Models 1A, 1C and 1E ranged from

-0.018 to - 0.019 and were statistically significant with p-values at least less than 0.1. These suggest that the number of total violations in a given year is reduced by about 1.8% to 1.9% for each ACL enforcement taken during the year. The coefficients for ACL3YRLAG in Models 1A, 1D and 1E ranged from -0.033 to - 0.039 and were statistically significant with p-values at least less than 0.1. These suggest that the number of total violations in a given year is reduced by about 3.3% to 3.9% for each ACL enforcement taken three years prior. The coefficients for the variable ACL5YRLAG in Models 1A, 1C, 1D, 1E and 2A ranged from -0.036 to -0.059 and were statistically significant with p-values at least less than 0.05. This indicates that the number of total violations in a given year is reduced by about 3.6% to 5.9% for each ACL enforcement taken five years prior. The coefficients for the ACL variables suggest that discharging facilities that have MMP violations and are issued an ACL likely do respond to the penalties but may take three to five years to show a detectable response. Furthermore, the reduction effect may be observable the year that the ACL action is issued and the reduction effect appears to increase in subsequent years. The lagged reduction effect may be due to corrective actions taken by violating facilities that received the ACL actions as well as pro-active actions taken by other facilities to avoid violations and possible enforcement actions.

3.3.3.2. Effect of probability variables

The model coefficient results indicate that discharging facilities may also respond to a perceived probability that a penalty will be issued for a violation and the timing of the penalty. Recall that the variable PROB1YR is the number of facilities that received an ACL in the following year divided by the number of facilities that experienced violations in a given year, and the variable PROB2YR is the number of facilities that received an ACL in the second following year divided by the number of facilities that experienced violations in a given year The coefficients for PROB1YR ranged from -0.911 to -1.129 in Models 1A -1E and were statistically significant with p-values of at least less than 0.01. These suggest that discharging facilities responded by reducing violations in subsequent years when ACL penalties are issued quickly the following year. Similarly, the coefficients for PROB2YR ranged from -0.318 to -0.425 and were statistically significant with p-values of at least less than 0.1. On the other hand, the coefficients for the variable PROB2YRLAG1YR were positive and statistically significant with p-values at least less than 0.05, which indicate that ACL penalties that are issued two years after the violation occurred appear to have a lagged effect of increasing the occurrence of violations. The coefficients for PROB1YR and PROB2YRLAG1YR suggest that the issuance of penalties appear to be most effective when issued closer in time to when the violations occurred. The effects of the probability variables are not likely auto-correlated with the ACL variables because the ACL variable lagged one year (ACL1YRLAG) was not significant in Models 1A-1E, and the coefficients of the ACL variables did not vary much between Model 1A and 2A when the probability variables were excluded. The effect of the probability variables are hypothetical because, in order for discharging facilities to respond to the probability of being issued an ACL in a given year, it would require knowledge of how many ACLs will be issued the following years. Nevertheless, the negative coefficients for PROB1YR and the positive coefficients for PROB2YRLAG1YR suggest that the issuance of ACL penalties appear to be most effective when issued closer in time to when violations occurred.

3.3.3.3. Effect of CDO/TSO variables

The models considered the effects of total number of CDOs and TSOs issued in one year and the effect of cumulative total of CDOs and TSOs that are in effect in a given year on the number of MMP violations. The coefficients for the variable CDOTSO_ISS1YRLAG in

Models 1A, 1E and 2A were -0.090, -0.090, and -0.077and were statistically significant with p-values at least less than 0.1. These coefficients indicate that the number of violations decreased by about 7.7% to 9.0% if a CDO or TSO had been issued during the previous year. The coefficient for the variable CDOTSO_ISS5YRLAG in Model 1D was +0.076 and statistically significant with a p-value less than 0.05. This may indicate that if a CDO or TSO remained in effect five years after being issued, it is possible that the prescribed corrective action has not been completed and that perhaps other violations unrelated to the CDO or TSO but related to the corrective action also begin to occur. This may happen, for example, if a CDO was issued to address effluent violations for biological oxygen demand (BOD), and if corrective actions to a wastewater treatment plant's secondary treatment unit to address BOD are not completed, then other effluent constituents that depend on secondary treatment may also become affected over time and result in additional violations. As discussed in the section below, because the coefficients for the variable VIOS_EXMPT indicate that exempted violations appeared to neither increase nor decrease the number of MMP violations, the coefficient results for the variable group CDOTSO_ISS suggest that the issuance of CDOs and TSOs appear to have a deterrent effect which results in fewer MMP violations during the year following issuance of the CDO or TSO, which is reasonable since CDOs and TSOs are enforcement actions that require discharging facilities to take action to reduce their violations.

Among the variables in the group CDTSO_EFF, only CDOTSO_EFF3YRLAG had a statistically significant coefficient in Models 1A, 1B, 1C, 1E and 2A. The positive sign of the CTOTSO_EFF3YRLAG coefficient indicates that this variable appears to result in an increase in MMP violations of about 4% to 6.7%, which is not expected, especially because the coefficient for this variable indicated that this variable also increased the number of violations that are exempted from MMP, as discussed in the next section and shown in Table 2.10. These results again may indicate that corrective actions prescribed by the CDO or TSO are not completed timely, and other effluent constituents that depend on the corrective action may also become affected over time and result in additional violations. These contradictory results regarding CDOs and TSOs may require further analysis.

3.3.3.4. Effect of exempted violations

The models considered how the number of violations that are exempted from MMPs through a CDO or TSO affected the number of MMP violations. It could be expected that exempting violations from MMP would reduce the number of MMP violations. However, the model coefficients in Tables 2.8 and 2.9 for VIOS_EXMPT are very nearly zero and not statistically significant, and indicate that exempted violations neither increase nor decrease the number of violations that are subject to MMP. The coefficients for Model 1E, when VIOS_EXMPT was excluded from the model, were very nearly unchanged from those for Model 1A. These indicate that the effect of VIOS_EXEMPT on the number of violations that are subject to MMP is negligible.

The relationship between the number of exempted violations, as the dependent variable, to the variables REGION, YEAR and the variable groups CDOTSO_ISS and CDOTSO_EFF was analyzed in a separate linear regression model; the coefficient results for this model are given in Table 2.10. The coefficients indicate that RWQCB Region 3, Region 5S, Region 6T, Region 6V and Region 9 had statistically significantly more exempted violations relative to reference region, Region 1. It is also interesting to note that the coefficient for the years 2003 through 2011 were negative, indicating fewer exempted violation relative to year 2000, although only year 2004 had a statistically significant coefficient. Amongst the coefficients for the

CDOTSO_ISS and CDOTSO_EFF variables, only CDOTSO_EFF3YRLAG and CDOTSO_EFF had statistically significant coefficients. The positive value of the coefficient for CDOTSO_EFF3YRLAG is expected since the more CDOs and TSOs that were in effect during a given year, the greater the potential that violations that occur would be exempted. The negative value of the coefficient for CDOTSO_EFF5YR may reflect the completion of compliance projects which typically must be completed within five years of issuance of a CDO or TSO; as compliance projects are completed, the number of violations that occur and must be exempted decrease.

3.3.3.5. Effect of the REGION variable

The coefficients for the different RWQCB offices under the variable REGION changed magnitude and sign from the Base Model coefficients as the different variable groups (VIOS_EXMPT, ACL_ISS, PROB, CDTSO_ISS, and CDOTSO_EFF) were included in Models 1A-1E and Model 2A. As shown in Table 2.8, the coefficient for REGION2 became 1.522 in the full model (Model 1A) from -0.290 in the Base Model, which suggests that the coefficient for REGION2 in the Base Model should have been positive (indicating that REGION2 increases MMP violations) had RWQCB Region 2 not issued ACLs and CDOs/TSOs. Similar conclusions can be made for REGION3, REGION4, REGION5F, REGION7, REGION8, and REGION9 whose coefficients became less negative, became positive, or, became more positive. However, the coefficient for REGION5R became more negative and the coefficient for REGION5S became less positive, which may be due to interactions between the ACL_ISS variables, the CDTSO_ISS variables and CDOTSO_EFF variables in the full model. The coefficient for REGION6T became less negative while the coefficient for REGION6V became more negative; however, comparing these results to the Base Model coefficients may not be meaningful since most of the data for RWQCB Region 6T and Region 6V were excluded by the R statistical software from the linear regression analysis due to undefined values for the probability variables.

3.3.3.6. Effect of the YEAR variable

With a few exceptions, the coefficients for the factor variables YEAR2001-YEAR 2011 were all not significant in Models 1A-1E and Model 2A. The coefficients for YEAR2008, however, were positive and significant in Models 1A, 1E and 2A. These may indicate the effect of the 2008 MMP initiative to reduce the backlog of violations that required an MMP assessment. The increased number of MMP ACLs issued beginning in 2008 may have also resulted in more in-depth reviews of self-monitoring reports by the RWQCBs, which in turn identified more violations. The coefficient for YEAR2006 was also positive and significant and may reflect the creation of the SWRCB's Office of Enforcement, whose function was to ensure that firm, fair and consistent enforcement actions are taken by the RWQCBs when violation occur (Sato and SWRCB, 2010). The coefficient for YEAR2003 in Model 1C was negative and significant, which may reflect an overall deterrence trend during the fourth year of the MMP enforcement program. The exceptions are noteworthy because they indicate an effect that are not explained by the explanatory variables in the models, and therefore may be due to specific circumstances unique to certain years.

4. Discussion and Recommendations

The linear regressions suggest that the issuance of ACLs results in decreases in MMP violations, even when CDOs and TSOs are issued to provide relief from penalties. The statistically significant negative model coefficients for the ACL variables suggest that ACLs result in fewer MMP violations in the year the ACLs are issued and the reduction effects continue and increase three to five years after ACLs are issued. The statistically significant negative coefficient for the variable PROB1YRLAG also suggests that the issuance of ACLs have a deterrent effect when ACLs are issued within a year of occurrence of the violations. The statistically significant negative coefficient for CDOTSO_ISS1YRLAG suggests that the issuance of CDOs and TSOs also provide a deterrent to the occurrence of MMP violations. The nearly-zero and statistically not significant coefficient for VIOS_EXMPT indicates that exempted violations do not result in an increase or decrease in MMP violations; however, in real terms, the exempted violations provide relief from further penalties to communities in the state that are diligently working towards corrective actions requiring significant treatment facility upgrades to prevent future violations. The results of this study, though preliminary, suggest that the issuance of ACLs, with provisions to issue CDOs and TSOs to provide relief to some communities, is an effective government policy which results in a reduction in the occurrence of environmental violations and should be continued. The results indicate that the increased enforcement activity as a result of the MMP program correlate with decreases in numbers of effluent violations, which can be attributed to an enhancement of the reputations of the SWRCB and RWQCBs to take enforcement actions against violations.

5. Conclusion

The preliminary results of this initial investigation provide supporting empirical evidence suggesting that mandatory minimum penalties result in a decrease in the number of effluent limitation violations by dischargers to surface waters. The results indicate a delayed effect by three to five years in response to the mandatory penalties levied; however, facilities may respond more quickly if the enforcement agency appears to issue MMPs swiftly. Provisions in enforcement programs that exempt some violations, such as through cease and desist orders, provide needed relief to certain communities working towards corrective action to prevent future violations, yet still allow the overall enforcement program to achieve the goal of reducing violations. Overall, the results suggest that the MMP enforcement program appears to have enhanced the regulatory agencies' enforcement reputation. Follow-up research will provide additional insights and conclusions regarding the effectiveness of the MMP enforcement program.

Table 2.1. Number of violations subject to MMP within each RWQCB region, 2000-2011.

Region	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Total
1	195	218	129	136	194	211	168	175	456	162	128	77	2249
2	323	285	155	123	169	122	201	140	105	34	65	85	1807
3	160	122	80	49	92	63	97	89	64	76	92	95	1079
4	800	985	1160	1320	377	491	982	755	827	745	688	733	9863
5F	69	31	270	222	126	130	164	160	176	97	44	35	1524
5R	35	7	14	17	33	14	35	38	7	92	90	96	478
5S	298	352	551	336	617	879	1073	1204	471	366	1049	899	8095
6T	0	0	0	0	0	0	0	0	26	98	21	29	174
6V	0	0	1	2	2	0	102	22	37	0	12	20	198
7	60	48	96	135	81	89	166	171	153	26	72	75	1172
8	318	147	63	39	99	170	157	93	121	30	57	33	1327
9	26	29	18	17	414	65	95	107	108	1	4	5	889
California	2284	2224	2537	2396	2204	2234	3240	2954	2551	1727	2322	2182	28855

Table 2.2. Number of violations exempted from MMP, 2000-2011.

Region	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Total
1	0	10	16	4	1	1	0	1	3	6	16	14	72
2	6	54	12	0	0	19	2	3	6	4	19	7	132
3	8	31	30	1	4	0	22	72	1	8	3	1	181
4	1	0	2	0	2	0	3	15	33	6	1	1	64
5F	0	11	0	0	0	2	2	2	7	0	6	4	34
5R	3	8	19	16	0	2	6	10	7	1	0	2	74
5S	27	30	74	250	465	1016	983	354	1049	1699	1597	1570	9114
6T	0	0	0	0	0	0	0	0	0	1	0	0	1
6V	0	0	0	0	1	0	0	0	0	11	17	33	62
7	0	0	14	94	7	14	2	1	12	90	172	102	508
8	0	1	0	0	7	11	3	2	1	1	0	1	27
9	16	10	4	28	50	16	5	10	0	0	0	0	139
California	**61**	**155**	**171**	**393**	**537**	**1081**	**1028**	**470**	**1119**	**1827**	**1831**	**1735**	**10408**

Table 2.3. Administrative Civil Liability (ACL) actions issued to address MMP violations, 2000-2011.

Region	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Total
1	2	0	4	2	2	17	8	15	14	8	4	10	86
2	19	33	20	31	22	10	9	14	38	39	9	30	274
3	8	8	6	8	7	7	5	0	11	11	3	5	79
4	11	26	35	18	30	9	9	6	98	40	93	56	431
5F	1	1	0	0	2	1	1	0	15	5	0	1	27
5R	3	3	1	2	3	4	0	2	8	9	4	14	53
5S	9	13	7	2	10	5	3	5	51	38	31	39	213
6T	0	0	0	0	0	0	1	0	0	0	0	1	2
6V	0	0	0	0	0	0	3	0	1	0	1	0	5
7	8	8	5	3	8	3	3	8	9	5	8	11	79
8	11	13	8	18	19	5	5	6	7	1	3	6	102
9	9	7	7	4	15	5	0	2	6	7	1	2	65
SWRCB											1	1	2
California	**81**	**112**	**93**	**88**	**118**	**66**	**47**	**58**	**258**	**163**	**158**	**176**	**1418**

Table 2.4. Cease and Desist Order and Time Schedule Orders, 2000-2011.

Region	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Total
1	1	4	2	5	6	5	4	1	2	0	3	1	34
2	0	1	1	2	0	2	0	6	7	6	2	2	29
3	0	1	0	0	0	0	0	1	0	0	1	1	4
4	10	1	3	10	7	7	4	7	4	1	3	6	63
5F	3	2	0	0	0	2	0	0	2	0	3	7	19
5R	0	0	1	3	7	1	2	2	0	2	10	4	32
5S	2	1	18	11	5	12	7	14	17	9	12	7	115
6T	0	0	0	0	0	0	0	0	0	0	0	0	0
6V	0	0	0	0	0	0	0	0	1	1	2	0	4
7	2	2	1	3	1	0	0	0	3	19	4	3	38
8	1	2	0	0	3	0	0	1	0	2	0	0	9
9	2	0	0	2	0	0	0	0	0	2	0	2	8
California	**21**	**14**	**26**	**36**	**29**	**29**	**17**	**32**	**36**	**42**	**40**	**33**	**355**

Table 2.5. Model variable definitions and descriptive statistics

Variable	Variable type	Definition	Mean Value	Standard Deviation	Minimum Value	Maximum Value
YEAR	factor	Calendar year violations occurred	------	------	------	------
REGION	factor	One of the 12 RWQCB offices	------	------	------	------
VIOS	integer	Number of violations subject to mandatory minimum penalties in each RWQCB during a calendar year	201.5	284	0	1320
VIOS_EXMPT	integer	Number of violations exempted from mandatory minimum penalties for each RWQCB during the calendar year	72.3	274	0	1699
ACL0YRLAG	integer	Number of ACL actions issued by each RWQCB office during the calendar year	9	14.7	0	98
ACL1YRLAG	integer	Number of ACL actions issued by each RWQCB office during the calendar year one year prior	7.8	14	0	98
ACL3YRLAG	integer	Number of ACL actions issued by each RWQCB office during calendar year three years prior	5.7	11.2	0	98
ACL5YRLAG	integer	Number of ACL actions issued by each RWQCB office during the calendar year five years prior	3.6	6.6	0	33
PROB1YR	number	Number of ACL actions issued by an RWQCB office in the following calendar year divided by the number of facilities that had at least one violation during the current calendar year under the jurisdiction of an RWQCB office	0.53	0.5	0	3
PROB2YR	number	Number of ACL actions issued by an RWQCB office in the calendar year two years forward divided by the number of facilities that had at least one violation during the current calendar year under the jurisdiction of an RWQCB office	0.55	0.56	0	3

Table 2.5. Model variable definitions and descriptive statistics *(continued)*

Variable	Variable type	Definition	Mean Value	Standard Deviation	Minimum Value	Maximum Value
PROB2YRLAG1YR	number	The corresponding value of PROB2YR lagged by one year	0.5	0.55	0	3
CDOTSO_ISS	integer	Number of CDO or TSO actions issued by each RWQCB office during the calendar year	2.5	3.7	0	19
CDOTSO_ISS1YRLAG	integer	Number of CDO or TSO actions issued by each RWQCB office during the calendar year one year prior	2.2	3.7	0	19
CDOTSO_ISS3YRLAG	integer	Number of CDO or TSO actions issued by each RWQCB office during the calendar year three years prior	1.7	3.2	0	18
CDOTSO_ISS5YRLAG	integer	Number of CDO or TSO actions issued by each RWQCB office during the calendar year five years prior	1.2	2.7	0	18
CDOTSO_EFF	integer	Number of CDO or TSO actions that were in effect during the calendar year	14.3	14.5	0	71
CDOTSO_EFF1YRLAG	integer	Number of CDO or TSO actions that were in effect during the calendar year one year prior	13	14.3	0	71
CDOTSO_EFF3YRLAG	integer	Number of CDO or TSO actions that were in effect during the calendar year three years prior	10.5	13.3	0	71
CDOTSO_EFF5YRLAG	integer	Number of CDO or TSO actions that were in effect during the calendar year five years prior	8	11.4	0	51

Table 2.6. Effluent violations before and after implementation of MMP enforcement program.

Region	1995-99	2000-04	2005-09	2010-2011
1	169	1113	1217	285
2	242	1642	1092	287
3	552	789	727	249
4	926	6985	4315	1477
5F	103	823	730	111
5R	357	261	376	255
5S	336	3618	8553	5280
6T	9	11	132	60
6V	18	15	190	94
7	97	783	963	496
8	217	1029	693	121
9	517	1303	772	79
California	**3543**	**18372**	**19760**	**8794**

Table 2.7. ACLs issued before and after implementation of MMP enforcement program in 2000.

Region	Total ACLs 1995-1999	Total ACLs 2000-2011	1995-1999 # ACLs Yearly Average	2000-2007 # ACLs Yearly Average	2008-2011 # ACLS Yearly Average
1	7	86	1.4	6.3	9.0
2	31	274	6.2	19.8	29.0
3	5	79	1.0	6.1	7.5
4	13	431	2.6	18.0	71.8
5F	2	27	0.4	0.8	5.3
5R	3	53	0.6	2.3	8.8
5S	12	213	2.4	6.8	39.8
6T	1	2	0.2	0.1	0.3
6V	1	5	0.2	0.4	0.5
7	8	79	1.6	5.8	8.3
8	19	102	3.8	10.6	4.3
9	6	65	1.2	6.1	4.0
SWRCB	0	2			1.0
TOTALS	108	1418	23.3	93.0	143.3

Table 2.8. Base Model and Full Model Linear Regression Results

Variable	MODEL Base		MODEL 1A	
	Coefficient Estimate	Signif. code	Coefficient Estimate	Signif. code
REGION1 (Intercept)	4.987	a	4.889	a
REGION2	-0.290		1.522	b
REGION3	-0.691	d	-0.096	
REGION4	1.515	a	3.085	a
REGION5F	-0.509		-0.232	
REGION5R	-1.826	a	-2.051	a
REGION5S	1.253	b	1.105	c
REGION6T	-3.362	a	-2.742	a
REGION6V	-2.606	a	-4.953	a
REGION7	-0.691	d	-0.259	
REGION8	-0.677	d	0.208	
REGION9	-1.858	a	-1.031	c
YEAR2001	-0.267		0.064	
YEAR2002	-0.102		0.189	
YEAR2003	-0.032		-0.530	
YEAR2004	0.425		-0.108	
YEAR2005	0.127		0.055	
YEAR2006	0.627		0.718	
YEAR2007	0.377		0.638	
YEAR2008	0.547		0.896	d
YEAR2009	-0.103		0.367	
YEAR2010	0.166		-----	
YEAR2011	0.131		-----	
VIOS_EXMPT			0.000	
ACL0YRLAG			-0.019	d
ACL1YRLAG			-0.002	
ACL3YRLAG			-0.039	c
ACL5YRLAG			-0.047	b
PROB1YR			-1.129	a
PROB2YR			-0.339	d
PROB1YRLAG1YR			-0.097	
PROB2YRLAG1YR			0.873	c
CDOTSO_ISS0YRLAG			-0.054	
CDOTSO_ISS1YRLAG			-0.090	c
CDOTSO_ISS3YRLAG			-0.063	
CDOTSO_ISS5YRLAG			0.001	
CDOTSO_EFF0YRLAG		d	0.032	
CDOTSO_EFF1YRLAG			-0.014	
CDOTSO_EFF3YRLAG			0.067	b
CDOTSO_EFF5YRLAG			-0.010	
Adjusted R-squared	0.673		0.684	
DF	121		68	

Signif. codes: 0 ‘a’ 0.001 ‘b’ 0.01 ‘c’ 0.05 ‘d’ 0.1 ‘ ’ 1

Table 2.9. Models 1B-1E and Model 2A Linear Regression Results

Variable	MODEL 1B		MODEL 1C		MODEL 1D	
	Coefficient Estimate	Signif. code	Coefficient Estimate	Signif. code	Coefficient Estimate	Signif. code
REGION1 (Intercept)	5.312	a	5.354	a	5.622	a
REGION2	0.022		1.346	c	1.033	c
REGION3	-0.687		-0.140		-0.679	d
REGION4	1.796	a	2.575	a	2.617	a
REGION5F	-0.442		-0.282		-0.692	d
REGION5R	-2.106	a	-1.973	a	-2.151	a
REGION5S	1.024	c	1.260	b	1.296	b
REGION6T	-2.889	a	-2.755	a	-3.378	a
REGION6V	-5.361	a	-5.344	a	-5.622	a
REGION7	-0.583		-0.312		-0.508	
REGION8	-0.458		0.131		-0.235	
REGION9	-1.343	b	-0.921	c	-1.096	b
YEAR2001	0.197		-0.189		-0.375	
YEAR2002	0.285		-0.095		-0.207	
YEAR2003	-0.484		-1.147	c	-0.046	
YEAR2004	-0.257		-0.717		0.197	
YEAR2005	-0.097		-0.481		-0.078	
YEAR2006	0.472		0.232		0.672	
YEAR2007	0.217		0.155		0.580	
YEAR2008	0.319		0.316		0.507	
YEAR2009	-0.154		-0.176		0.126	
YEAR2010	-----		-----		-----	
YEAR2011	-----		-----		-----	
VIOS_EXMPT	0.001		-0.001		0.001	
ACL0YRLAG	-----		-0.018	d	-0.015	
ACL1YRLAG	-----		0.001		-0.001	
ACL3YRLAG	-----		-0.028		-0.033	d
ACL5YRLAG	-----		-0.051	b	-0.036	c
PROB1YR	-1.061	b	-0.918	b	-0.911	b
PROB2YR	-0.294		-0.318	d	-0.425	c
PROB1YRLAG1YR	-0.047		-0.016		0.058	
PROB2YRLAG1YR	0.940	c	0.736	c	0.757	c
CDOTSO_ISS0YRLAG	-0.046		-----		-0.043	
CDOTSO_ISS1YRLAG	-0.073		-----		-0.044	
CDOTSO_ISS3YRLAG	-0.045		-----		0.015	
CDOTSO_ISS5YRLAG	0.024		-----		0.076	c
CDOTSO_EFF0YRLAG	0.025		-0.005		-----	
CDOTSO_EFF1YRLAG	-0.030		-0.009		-----	
CDOTSO_EFF3YRLAG	0.051	c	0.064	b	-----	
CDOTSO_EFF5YRLAG	-0.021		-0.011		-----	
Adjusted R-squared	0.741		0.700		0.715	
DF	72		72		72	

Signif. codes: 0 ‘a’ 0.001 ‘b’ 0.01 ‘c’ 0.05 ‘d’ 0.1 ‘ ’ 1

Table 2.9. Models 1B-1E and Model 2A Linear Regression Results (continued)

Variable	MODEL 1E Coefficient Estimate	MODEL 1E Signif. code	MODEL 2A Coefficient Estimate	MODEL 2A Signif. code
REGION1 (Intercept)	4.921	a	4.177	a
REGION2	1.500	b	0.706	
REGION3	-0.131		-0.158	
REGION4	3.075	a	2.838	a
REGION5F	-0.260		-0.118	
REGION5R	-2.060	a	-1.834	a
REGION5S	1.090	c	1.152	d
REGION6T	-2.782	a	-2.831	a
REGION6V	-4.983	a	-2.067	a
REGION7	-0.275		-0.367	
REGION8	0.185		-0.188	
REGION9	-1.033	c	-1.843	a
YEAR2001	0.068		-0.079	
YEAR2002	0.190		0.116	
YEAR2003	-0.522		-0.114	
YEAR2004	-0.103		0.461	
YEAR2005	0.076		0.360	
YEAR2006	0.742		0.971	d
YEAR2007	0.661		0.715	
YEAR2008	0.906	d	1.133	c
YEAR2009	0.369		0.506	
YEAR2010	-----		0.614	
YEAR2011	-----		0.585	
VIOS_EXMPT	-----		0.000	
ACL0YRLAG	-0.019	d	-0.011	
ACL1YRLAG	-0.002		-0.001	
ACL3YRLAG	-0.039	c	-0.015	
ACL5YRLAG	-0.046	b	-0.059	b
PROB1YR	-1.129	a	-----	
PROB2YR	-0.340	d	-----	
PROB1YRLAG1YR	-0.094		-----	
PROB2YRLAG1YR	0.873	c	-----	
CDOTSO_ISS0YRLAG	-0.054		-0.045	
CDOTSO_ISS1YRLAG	-0.090	c	-0.077	d
CDOTSO_ISS3YRLAG	-0.063		-0.078	
CDOTSO_ISS5YRLAG	0.007		-0.082	
CDOTSO_EFF0YRLAG	0.031		0.034	
CDOTSO_EFF1YRLAG	-0.015		0.000	
CDOTSO_EFF3YRLAG	0.066	b	0.040	d
CDOTSO_EFF5YRLAG	-0.012		0.018	
Adjusted R-squared	0.679		0.931	
DF	69		108	

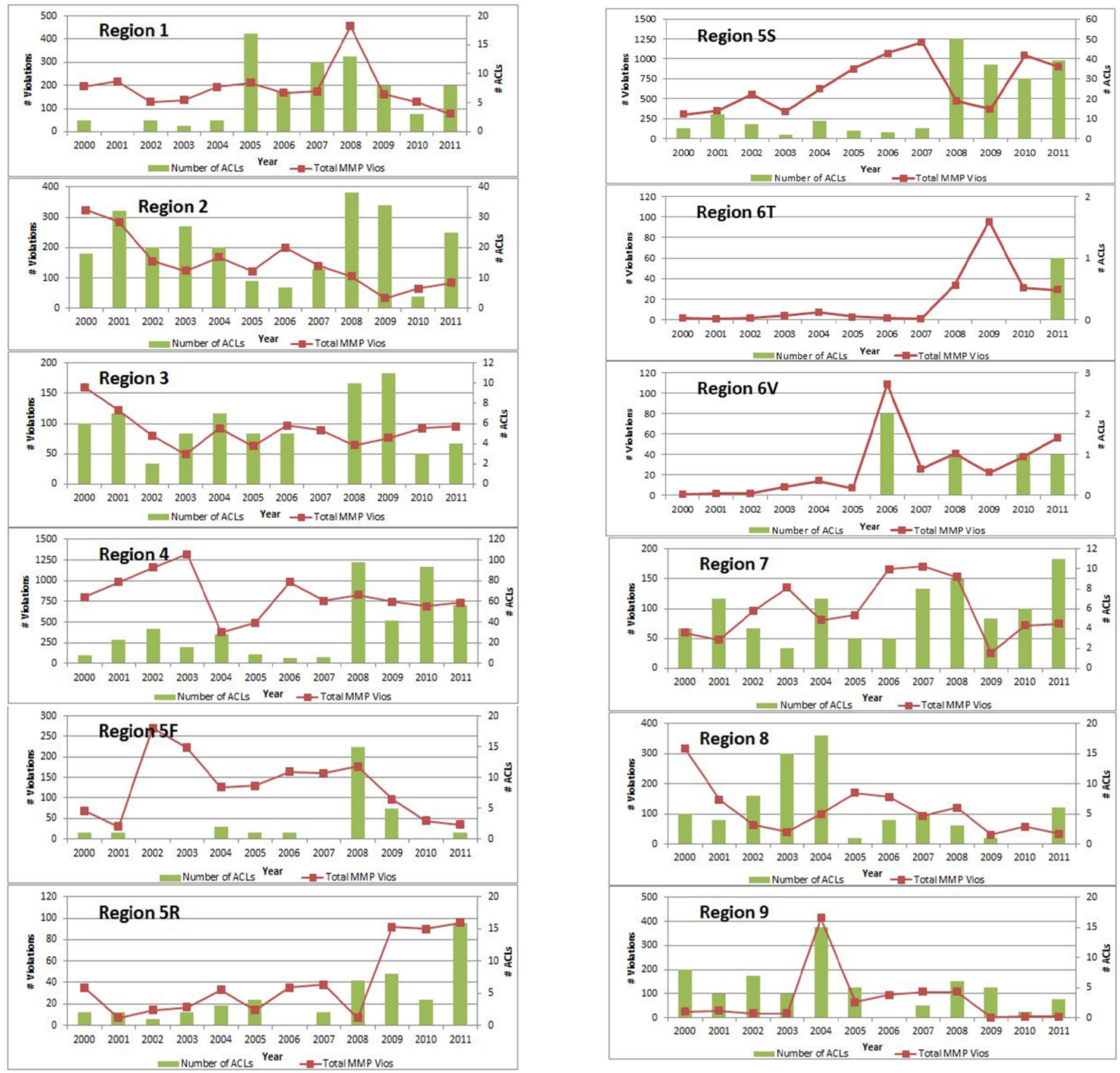
Signif. codes: 0 ‘a’ 0.001 ‘b’ 0.01 ‘c’ 0.05 ‘d’ 0.1 ‘ ’ 1

Table 2.10. Exempt Violations Linear Regression Results

Variable	Coefficient Estimate	Signif. Code
REGION1(Intercept)	0.604	
REGION2	1.036	d
REGION3	1.775	b
REGION4	-0.601	
REGION5F	1.024	
REGION5R	0.685	
REGION5S	2.125	b
REGION6T	0.431	
REGION6V	2.648	b
REGION7	2.151	a
REGION8	0.617	
REGION9	1.405	c
YEAR2001	0.236	
YEAR2002	0.187	
YEAR2003	-2.118	d
YEAR2004	-2.384	c
YEAR2005	-0.491	
YEAR2006	-0.757	
YEAR2007	-0.845	
YEAR2008	-0.914	
YEAR2009	-1.034	
YEAR2010	-0.494	
YEAR2011	-1.121	
CDOTSO_ISS0YRLAG	0.080	
CDOTSO_ISS1YRLAG	0.047	
CDOTSO_ISS3YRLAG	-0.051	
CDOTSO_ISS5YRLAG	-0.015	
CDOTSO_EFF0YRLAG	-0.001	
CDOTSO_EFF1YRLAG	0.023	
CDOTSO_EFF3YRLAG	0.113	b
CDOTSO_EFF5YRLAG	-0.070	c
Adjusted R-squared	0.651	
DF	69	

Signif. codes: 0 ‘a’ 0.001 ‘b’ 0.01 ‘c’ 0.05 ‘d’ 0.1 ‘ ’ 1

Figure 2.1. Time series plots of number of MMP violations and ACLs in each RWQCB



6. References

Adrison V. (2007). Estimating the Effect of Penalties on Regulatory Compliance. PhD. Dissertation, Georgia State University.

Andreen, WL. (2003). Water Quality Today-Has the Clean Water Act Been a Success. *Ala. L. Rev.*, *55*, 537.

California State Water Resources Control Board (SWRCB). (April 17, 2001). SB 709 and SB 2165 Questions and Answers.

California State Water Resources Control Board (SWRCB). (January 2003). Report to the Legislature, Enforcement Activities of the Regional Water Quality Control Boards, 2002.

California State Water Resources Control Board (SWRCB). 2008 Panel Quality Assurance presentation. http://www.swrcb.ca.gov/water_issues/programs/ciwqs/docs/panel/quality_assurance.ppt accessed 4-7-2013

California State Water Resources Control Board (SWRCB). (May 2009). Report of the Statewide Initiative on Mandatory Minimum Penalty Enforcement.

California State Water Resources Control Board (SWRCB). (May 2010). Water Quality Enforcement Policy.

California State Water Resources Control Board (SWRCB). (June 2011). 2010 Annual Enforcement Report.

California State Water Resources Control Board (SWRCB). (March 2012). Resource Alignment Evaluation Report.

Copeland, C. (2010). Clean Water Act: a summary of the law. Congressional Research Service, Library of Congress.

Coyne, W &Metzger, L. (May 2004). Mandatory Minimum Penalties, An Effective Tool for enforcement of Clean Water Laws. TexPIRG Education Fund, Austin, Texas.

Epple, D., & Visscher, M. (1984). Environmental pollution: Modeling occurrence, detection, and deterrence. JL & Econ., 27, 29.

Gray, W. B., & Shimshack, J. P. (2011). The effectiveness of environmental monitoring and enforcement: A review of the empirical evidence. Review of Environmental Economics and Policy, 5(1), 3-24.

Jahagirdar, S., & Coyne, W. (2003). Leaking Enforcement. Analyzing the Effectiveness of the 1999 Clean Water Enforcement and Pollution Prevention Act. Environment California Research and Policy Center, Los Angeles, California.

Laplante, B., & Rilstone, P. (1996). Environmental inspections and emissions of the pulp and paper industry in Quebec. *Journal of Environmental Economics and Management*, *31*(1), 19-36.

Oljaca, N., Keeler, A. G., & Dorfman, J. (1998). Penalty functions for environmental violations: evidence from water quality enforcement. *Journal of Regulatory Economics*, *14*(3), 255-264.

R Development Core Team. (2008). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

Sato, R. and California State Water Resources Control Board (SWRCB). (October 2009). Deconstructing Enforcement, A Primer on Water Quality Enforcement.

Shimshack, J. P., & Ward, M. B. (2005). Regulator reputation, enforcement, and environmental compliance. *Journal of Environmental Economics and Management*, *50*(3), 519-540.

Weber, J. M., & Crew Jr, R. E. (2000). Deterrence theory and marine oil spills: Do coast guard civil penalties deter pollution? *Journal of Environmental Management*, *58*(3), 161-168.

CHAPTER THREE

Evaluation of correlations between effluent quality trends and enforcement actions under California's MMP enforcement program

1. Introduction

1.1. Municipal Wastewater Treatment Facilities and the Clean Water Act

There are approximately 16,000 municipal wastewater treatment plants in the United States which now serve over 75 percent of the nation's population (USEPA, 2004). As the nation's urban population grew during the first half of the 20th century and as various industries developed, the goals of wastewater treatment facilities were to prevent human waste from reaching water supplies, remove suspended and floatable materials that interfered with navigable waters, treatment of biodegradable organics, and elimination of pathogenic organisms (Metcalf & Eddy et al, 1991; USEPA, 2004). However, wastewater treatment was mostly controlled by local jurisdictions, and consequently treatment objectives were not uniform (Metcalf & Eddy et al, 1991; USEPA, 2004). Despite the federal Water Pollution Control Act of 1948 and the 1965 amendments to provide planning, technical, research and financial assistance to protect water resources (Burian et al, 1990), many treatment facilities still discharged only partially treated wastewater until the 1960s (Metcalf & Eddy et al, 1991).

To address growing public frustration with the deterioration of water quality, growing concerns with the impacts of nutrient and toxic pollutant discharges, and increased interests in environmental protection (Metcalf & Eddy et al, 1991, Copeland, 1999), the Water Pollution Control Act of 1972, commonly referred to as the Clean Water Act, established an ultimate goal of eliminating pollution discharges, established an interim goal of achieving "fishable" and "swimmable" water quality, and required all municipal and industrial discharges to surface water to be treated (Metcalf & Eddy et al, 1991, Copeland, 1999).

The Clean Water Act required municipal wastewater treatment facilities to meet technology-based and water quality-based discharge requirements and established the National Pollutant Discharge Elimination System (NPDES) regulatory program under the USEPA (Copeland, 2004). The USEPA established technology-based standards for wastewater treatment plants as secondary treatment standards to remove conventional pollutants such as biochemical oxygen demand (BOD) and total suspended solids (TSS) (Metcalf & Eddy et al, 1991). Secondary-treatment standards set effluent limitations for BOD and TSS as maximum effluent concentrations allowable for discharge to surface waters, as summarized in Table 3.1, as well as a requirement to achieve 85% removal of these constituents from the influent (Metcalf & Eddy et al, 1991). Water quality-based effluent limitations set concentration and mass emission limitations for discharges based on the water quality standards that were necessary to maintain the beneficial uses of the surface water body that receive the discharges and the assimilative capacity of the water body. Water quality-based effluent limitations control for nutrients, pathogens, and toxic organic and inorganic constituents, such as metals and pesticides, to maintain ecological, drinking water, and recreational beneficial uses of surface water bodies. Technology-based and water quality-based effluent requirements are embodied in NPDES permits issued to discharging facilities. The Clean Water Act provided grants during its early years, and loans starting in 1987, to assist in upgrading wastewater treatment facilities to meet technology-based and water quality-based requirements (Copeland, 1999).

1.2. Wastewater Treatment Processes

The treatment sequence at most modern wastewater treatment facilities consist of preliminary treatment, primary treatment, biological treatment, secondary sedimentation, and disinfection. Nutrient removal and other advanced treatment processes are also implemented to meet NPDES permit requirements. A typical treatment sequence schematic is shown Figure 3.1. Preliminary treatment removes large debris that may cause operational problems and clogging (Metcalf & Eddy et al, 1991). Primary treatment is a physical process, typically by sedimentation, to remove smaller particles that contribute to TSS and BOD. Biological treatment, typically followed by secondary sedimentation, employs microbial populations to degrade organic material to further remove up to 90 percent of BOD and TSS and reduce effluent toxicity. Biological treatment also removes heavy metals such as cadmium, chromium and copper via metal adsorption to larger particles that settle out, however, biological treatment may also promote solubilization of metals and therefore higher metals concentration in the effluent (Goldstone et al, 1990). Disinfection, typically by chlorination and increasing by ultra-violet radiation, kills pathogens remaining in the effluent prior to discharge. Nutrient removal processes, such as denitrification or phosphorus precipitation, remove nitrogen and phosphorus compounds from effluents which may contribute to eutrophication and toxicity in surface water bodies or impact groundwater drinking water source (Metcalf and Eddy). Advanced treatment, such as membrane filtration or reverse osmosis, further remove organic and inorganic constituents to meet water quality standards for drinking water and ecological purposes for water bodies (USEPA, 2004). In addition to treatment process at wastewater treatment facilities, NPDES permits for facilities treating greater than 5 million gallons per day include pretreatment requirements to prevent industries from discharging pollutants to the sewer system that may interfere with the biological treatment processes at the wastewater treatment facility or which cannot be removed by the wastewater treatment facility and therefore ultimately contribute to pollution of surface water bodies (USEPA, 2010). Effluent concentrations of various constituents found at several wastewater treatment facilities with flow rates of 1 to 20 million gallons per day (MGD) in southern California are presented in Table 3.2 (Raco-Rands, 1995).

1.3. Enforcement and Literature Survey

The 1987 revisions to the Clean Water Act authorized the USEPA, and states that have been delegated NPDES authority, to issue enforcement actions for violations of NPDES permits, including civil monetary penalties (Copeland, 1999; Magat and Viscusi, 1990). Effective regulations require effective enforcement sanctions (Laplante and Rilstone, 1996; Shimshack and Ward, 2005). A number of studies have investigated the effectiveness of enforcement actions under the NPDES program as well as other factors that affect compliance at discharging facilities. Magat and Viscusi (1990) found that BOD mass emissions decline by 20 percent, and the number of BOD effluent violations similarly declined, at paper pulp mills across the US in the quarter following an inspection, where inspections are interpreted to proxy for further enforcement actions, and that the decreases were sustained long term. Shimshack and Ward (2005) found that BOD and TSS mass emission levels from paper pulp mills in the US decreased significantly in response to monetary penalties levied, as well as inspections conducted, during the preceding 12 months. Shimshack and Ward (2005) also found that statewide violation rates in different states declined by 31% to 75%, which they attribute to a response to the enhancement of the regulatory agency's reputation to take enforcement actions. Earnhart (2004a, 2004b) found that the BOD emission levels of wastewater treatment plants in Kansas improved in response to actual, and the probability of, inspections and enforcement actions carried out by both the USEPA and by the state. Earnhart also found that frequency of inspections are positively correlated with per capita income and educational level of a community and negatively correlated with unemployment rates in a community (2004a), and that facility specific factors – flow capacity and treatment technology – significantly determine wastewater treatment plant performance (2004b). Adrison (2007) found that penalties against municipal and non-municipal discharging facilities reduce violations at a specific facility within one year that a penalty is levied against a facility and that penalties issued to other facilities result in a reduction of violations at all facilities as a result of enhancement of the regulatory agency's enforcement reputation. Adrison (2007) recommended that regulatory agencies should increase the frequency and severity of penalties to achieve both specific deterrence and enforcement reputation enhancement.

1.4. Mandatory Minimum Penalties in California

In California, implementation of the NPDES program has been delegated by the USEPA to the State Water Resources Control Board (SWRCB) and the nine Regional Water Quality Control Boards (RWQCB). The California legislature enacted the 1999 Clean Water Enforcement and Pollution Prevent Act (CWEA), which amended the California Water Code, in response to the documented failure by the RWQCBs to carry out enforcement actions to address thousands of violations of NPDES permits across the state (Jahagirdar and Coyne, 2003). As a result of the 1999 CWEA, beginning in January 2000, the SWRCB and RWQCBs are mandated to issue a mandatory minimum penalty (MMP) of $3,000 for each instance of serious violation of effluent limitations in NPDES permits and for each chronic violation after the third violation in a six month period (Sato and SWRCB, 2009; SWRCB, 2010). Effluent violation exceeding effluent limitations for conventional and non-conventional pollutant constituents by 40% and

20% respectively are considered serious violations (SWRCB, 2010). Chronic violations include non-serious effluent violations and reporting violations. The goal of the MMP enforcement program is to increase compliance by regulated dischargers with their National Pollutant Discharge Elimination System (NPDES) permits (Jahagirdar and Coyne, 2003). To assess penalties from dischargers with violations subject to MMP, the State Water Board and the regional boards issue administrative civil liability complaints or orders (SWRCB, 2010).

The MMP enforcement program includes several avenues that provide varying limited levels of relief from MMP liability. First, municipal wastewater treatment facilities serving small communities with financial hardship may apply the entire penalty amount towards a corrective measure to achieve compliance within five years. Second, a wastewater treatment facility that has been issued a cease and desist order (CDO) or a time-schedule order (TSO) that contains interim effluent limitations that are less stringent than final NPDES permit effluent limitations are exempt from MMP liability so long as the facility complies with the interim limitation. Third, the operator of a wastewater treatment facility may apply up to 50% of its MMP liability to an environmental project that benefits the local community. (Sato and SWRCB, 2009, SWRCB, 2010)

Early assessments of the effectiveness of the MMP enforcement program cited reductions in numbers of violations across the state and an increase in the number of enforcement actions and penalty amounts issued (Jahagirdar and Coyne, 2003; Coyne and Metzger, 2004). However, by 2008, a significant backlog of MMP violations for which an MMP liability had not been assessed had accumulated at the different regional boards to varying degrees (SWRCB, 2009). To address the backlog, the State Water Board's Office of Enforcement launched an MMP backlog reduction initiative, which resulted in a significant jump in the number of ACLs issued since

2008 (SWRCB, 2009). Expedited payment letters have been issued by some regional boards in lieu of formal ACL complaints or orders in order to expedite the assessment of MMP liabilities. In 2010, the update of the State Water Board's water quality enforcement policy included a goal of assessing MMPs within 18 months of discovery of a violation to avoid further backlogs and to more swiftly take enforcement actions (SWRCB, 2010). The number of violations subject to MMP enforcement at wastewater treatment facilities and the number of MMP administrative civil liability enforcement actions at the different regional boards during the period 2000 to 2011 are tabulated in Table 3.3.

1.5. Objectives

The impact of the MMP program in California on the environment has not been quantified, based on a review of the enforcement literature. Although the SWRCB issues annual enforcement reports to assess the various enforcement activities of the SWRCB and regional boards, including the MMP program, these reports focus on tallies of the number of violations and enforcement actions (e.g., SWRCB, 2011). There have not been previous assessments of the effect of the MMP program on reducing pollution emissions. Therefore, the objective of this investigation is to determine if there is a correlation between the issuance of MMP ACLs and the levels of pollutants in the effluent discharged. This investigation will focus on discharges from wastewater treatment facilities. Unlike previous studies found in the literature, this investigation will consider conventional pollutants (e.g., BOD and TSS) as well as non-conventional pollutants (e.g., copper and cyanide) to determine if enforcement action effects vary with the treatment process for removal of the constituent from the effluent. The main contribution of this investigation is the preliminary analyses performed on the unique data set collected and assembled from the NPDES and MMP enforcement program public record. This study will contribute knowledge to the enforcement literature about the effectiveness of enforcement actions, particularly mandatory actions, on achieving facility-specific compliance, enhancement of regulatory agency enforcement reputation, and reducing levels of pollution emissions. Follow-up research using the data assembled for this investigation should provide additional insights and conclusions regarding the effectiveness of the MMP enforcement program.

2. Data and Methods

2.1. General Approach

This study analyzes the correlation between the quality of the effluent discharged by wastewater treatment facilities to surface waters under an NPDES permit and the enforcement actions taken by a regulatory agency. Monthly effluent concentration data for several discharging facilities were correlated with the occurrence of enforcement actions using linear regressions. The discharging facilities considered in this study are all located within the regulatory jurisdiction of the San Francisco Bay RWQCB (SFBRWQCB), shown in Figure 3.2. The primary reason for choosing the SFBRWQCB is the large number of MMP administrative civil liability (ACL) enforcement actions, 274 ACLs total, that were taken by the SFBRWQCB from 2000 to 2011 and the relatively constant annual rate that these ACLs were issued, averaging 23 enforcement actions per year. By considering discharging facilities contained within only one RWQCB region, variability that may exist due to the different regulatory priorities that each RWQCB office may have and the differences in organizational culture between RWQCB offices is eliminated. The SFBRWQCB region also offers a study area that is relatively economically, geographically and demographically homogeneous, which removes some of the variability associated with the funding, management and operation of the wastewater treatment plants, and public sentiment towards the environment. Wastewater treatment facilities were selected as the category of facility for this study because this category had the highest number of facilities within the SFBRWQCB. Limiting the facility type to one category removes much of the variability that would be observed due to differing management approaches and treatment technologies across different facility types.

2.2. Data

2.2.1. ACL and CDO/TSO enforcement action data

ACL enforcement action data were obtained from the California Integrated Water Quality System (CIWQS) database which contains a large range of information regarding discharging facilities and regulatory actions. The SWRCB maintains the CIWQS database and the CIWQS Internet website (http://www.swrcb.ca.gov/water_issues/programs/ciwqs/publicreports.shtml) which provides access to CIWQS data to the public. The CIWQS website database portal includes several query interfaces (e.g., facility reports and enforcement reports) and allows users to customize queries, such as by specifying date ranges, geographical areas, and regulatory programs (i.e., NPDES program for this study).

A CIWQS query identified 274 ACL enforcement actions for MMP violations issued by the SFBRWQCB between 2000 and 2011. The information available from CIWQS about each ACL enforcement action include the facility, type of facility (e.g., wastewater treatment), the effective dates of the enforcement action, the status of the action (e.g., active or historical), the penalty dollar amount, and the violations being addressed by the action. Of these ACL enforcement actions, 140 were issued to 46 wastewater treatment facilities, and these ACLs and facilities were initially considered for this study.

A CIWQS query also identified 39 CDOs and 4 TSOs issued by the SFBRWQCB that were effective for any part of the period 2000-2011. Of these 43 CDOs/TSOs, 23 were issued to 18 wastewater treatment facilities and these were considered for this study.

2.2.2. Effluent concentration data

Discharging facilities are required to monitor the quality of their effluent discharges at frequencies prescribed by their respective NPDES permits, and the monitoring results are required to be reported to the RWQCBs, typically in monthly reports. Effluent concentration data were obtained in electronic format from three different sources. Among the different RWQCBS, the SFBRWQCB pioneered the electronic submittal of monitoring data through its Electronic Reporting System (ERS), and consequently effluent concentration data are available in electronic format for many of the larger discharging facilities within the SFBRWQCB region beginning in 1998. The ERS was replaced starting in 2008 when the SWRCB and RWQCBs implemented electronic reporting through the Electronic Self-Monitoring Report (ESMR) module contained within CIWQS. Effluent data is also available in electronic format from the Permit Compliance System (PCS) and Integrated Compliance Information System (ICIS) databases maintained by the USEPA and which can be accessed through USEPA's Envirofacts website.

Monthly effluent concentration data for the period January 2000 through December 2011 were obtained for each facility selected for this study for four selected effluent constituents. The selection of the four effluent constituents and selection of facilities are described in the following sections. Additional effluent concentration data prior to 2000 were also obtained for some facilities for additional statistical analysis if the data were available. The effluent concentration data available from the ERS, ESMR and PCS/ICIS databases were often incomplete;

consequently, the entire series of monthly effluent concentration data for a given constituent and a given facility was often constructed using a combination of data obtained from two or all three of the databases. Even so doing, the monthly series could have missing values and these were filled in using averages of available data when there was no apparent pattern to the occurrence of missing values. For some facilities, significant portions of the monthly data series were missing, and it was necessary to eliminate those facilities from the study, as discussed below.

2.2.3. Selection of effluent constituents

The individual effluent violations associated with each of the 140 ACL enforcement actions for wastewater treatment plants were reviewed and the effluent constituent of each violation was identified. For each effluent constituent, a tally was made of the number of effluent violations for each effluent constituent, as shown in Table 3.4. For each effluent constituent, a tally was also made of the number of facilities that had at least one violation of a given effluent constituent, as also shown in Table 3.4. The information from these tallies guided the selection of four effluent constituents for this study. Biochemical oxygen demand (BOD), total suspended solids (TSS), cyanide (CN) and copper (Cu) were chosen for this study because a large number of the 46 wastewater treatment facilities that had ACLs had violations of one or more of each of these constituents and there were a large number of occurrences of violations of each of these constituents. Another consideration for the selection of the effluent constituents for this study was whether the monthly effluent concentration data can be obtained from the ERS, ESMR or PCS/ICIS databases because some constituents were not required to be monitored by some facilities or were monitored at less than monthly frequency. A further consideration in selecting the four constituents was the inclusion in the study of constituents that are subject to technology-based effluent standards as well as subject to water quality-based effluent standards.

2.2.4. Selection of facilities

A CIWQS query identified 86 wastewater treatment facilities with an NPDES permit within the SFBRWQCB region. Of these, 46 facilities were issued at least one of the 140 ACL enforcement actions that were issued to wastewater treatment plants. The number of ACL enforcement actions that were issued during the period 2000-2011 to each of these 46 facilities varied from seven ACLs to one ACL. For many of these 46 facilities, significant portions of the monthly effluent concentration data series were missing for one or more of the four selected constituents, and those facilities were excluded from the study for those constituents. Consequently, the number of facilities in the study for each of the four selected effluent constituents varied depending on the completeness of the monthly series; nevertheless, the facilities included in the study still represented a range of number of ACLs issued to a facility. One additional facility that had no ACLs issued to it but had fairly complete monthly series for each of the four selected constituents was also included in the study. In summary, the number of facilities included in the study for each of the selected constituents is as follows: BOD, 26 facilities; TSS, 30 facilities; Cu, 29 facilities; and CN, 32 facilities.

2.3. Preliminary data analysis

2.3.1. Comparison of pre- and post-MMP era effluent data

For each constituent, effluent concentration data was available for the years 1998-199 for several, but not all, of the facilities selected. To determine if effluent concentrations before the MMP period are higher than after the start of the MMP period, the two-year averages of the effluent concentrations for each facility for which data were available were calculated for the years 1998-1999, 2000-2001, 2002-2003, 2004-2005, 2006-2007, 2008-2009, and 2010-2011. A one-tailed paired t-test comparing the facility averages for 1998-1999 against subsequent two-year averages was conducted. The p-values for the probability that 1998-1999 averages are greater than subsequent two year averages are shown in Table 3.5.

2.3.2. Effluent concentration- time series

For each of the four study effluent constituents and for each facility, effluent concentration data were plotted against time, as shown in Figures 3.3a-3.3d. A regression line was also determined and included for each plot. The regression line slopes (i.e., the time coefficient) are tabulated in Table 3.6.

2.3.3. ACL and CDO/TSO frequency analysis

The total number of ACL enforcement actions issued for each facility during 2000-2011 was determined along with subtotals for the periods 2000-2003, 2004-2007, and 2008-2011. Similar totals and subtotals were also determined according to whether an ACL addressed violations for one of the four study effluent constituents. Because an ACL could address more than one constituent, a given ACL could be counted towards the tallies for up to all four study constituents, or towards none of the study constituents if the ACL address constituents other than the four selected for this study. Total number of CDOs/TSOs for each facility that was in effect for any part of the period 2000-2011 was also determined. These totals and subtotals are also included in Table 3.7.

2.4. Linear Regression Model

2.4.1. General Approach

Linear regression was used to investigate the possible effect of ACL enforcement actions through several regression models. The linear regression models have the form:

$$y = \alpha + \Sigma\beta_i X_i + \varepsilon \qquad \text{(Equation 3.1)}$$

where y is the dependent variable, α is the model intercept, β_i is the regression coefficient for explanatory variable X_i, and ε is the error term. The statistical analyses were conducted using the R computing software (R Development Core Team, 2008).

The regression models are based on the premise that effluent concentrations are affected by the issuance of ACL enforcement actions. The effect on a particular facility's effluent concentrations may be direct, if ACLs are issued directly to the particular facility, or indirect, if ACLs are issued to other facilities and a particular facility decides to improve its effluent concentration in order to avoid being issued an ACL. The effect of ACLs may also be delayed since facility improvements may take several years to implement. In addition, other factors may affect effluent concentrations, such as facility to facility variations, past facility performance, and whether or not a facility is also subject to a CDO/TSO enforcement action.

Four estimating model equations were used in this study, one for each of the four selected effluent constituents (i.e., for BOD, TSS, Cu and CN). The estimating equations have the form:

$$\log(EFF_{i\,t}) = \alpha + \beta_1\, TIME_t + \beta_2\, FACILITY_i + \beta_3 \log[\,EFF_{i\,(t-1)}\,] + \beta_4 \log[\,EFF_{i\,(t-12)}\,] + \beta_5\, CDOTSO_{i\,t} + \sum_{q=1}^{20} \theta_q\, ACLQ_{i\,t\,q} + \sum_{q=1}^{20} \rho_q\, ACLEFFQ_{i\,t\,q} + \sum_{y=1}^{5} \phi_y\, ACLY_{i\,t\,y} + \sum_{y=1}^{5} \gamma_y\, ACLEFFY_{i\,ty} + \varepsilon \qquad \text{(Equation 3.2)}$$

where $EFF_{i\,t}$ is the effluent concentration for BOD, TSS, CN or Cu.

2.4.2. Description of Model Variables

2.4.2.1. Effluent concentrations

The variable $EFF_{i\,t}$ is the dependent variable and is the effluent concentration of facility i for one of the selected constituents. The explanatory variable $EFF_{i\,(t-1)}$ is the effluent concentration lagged by one month and accounts for the status of the wastewater treatment facility from the preceding month that may be persisting and impacting the effluent concentration at time t. The explanatory variable $EFF_{i\,(t-12)}$ is the effluent concentration lagged by 12 months and accounts for annual seasonal effects as well as the longer term performance of a facility (i.e., a well-operated facility would be expected to continue to perform well). Based on regression analyses not presented here, using the data for this study, the natural log transformation of the effluent variables were used in the estimating model equations because better model fits were obtained. In addition, natural log transformations are commonly used for statistical analysis of effluent data (USEPA, 1991). A summary of the descriptive statistics for these effluent concentration variables is provided in Tables 3.8a-3.8d.

2.4.2.2. ACL enforcement variables

The primary explanatory variables in this study are related to the occurrence of ACL enforcement actions issued to the various wastewater treatment facilities. The date of issuance of each of the ACLs are known; however, a contemporaneous effect on effluent concentration $EFF_{i\,t}$ at time t is not expected since any action taken by a facility to improve its effluent concentration typically occurs or is presumed to occur after an ACL is issued. However, it is not known how long after ACL issuance the effect on $EFF_{i\,t}$ is observable. Depending on the complexity or scope of upgrades needed to bring a facility's effluent discharge into compliance, it may take a year to over five years to complete facility upgrade projects. ACLs, CDOs and TSOs typically incorporate time schedules for completion of upgrades within five years of the issuance of the enforcement action. Some facilities that incur an MMP violation may anticipate the ACL issuance and may initiate upgrades prior to actual ACL issuance. For example if an MMP effluent violation occurred in Month 1 and the facility completes an upgrade by Month 15 which improves the effluent, however, the ACL was not issued until Month 12, it would appear that the effect on $EFF_{i\,t}$ occurred three months after ACL issuance.

To account for lagged effects that may occur anywhere from three months to five years after ACL issuance, serial lagged ACL-related dummy variables are utilized as explanatory variables in the estimating model equations. The variable $ACLQ_{i\,tq}$ is a series of dummy variables that are lagged by 1 to 20 quarters as indicated by the index q. The variable $ACLQ_{i\,t\,q}$ would have a value of 1 if an ACL was issued during any of the three months following the lag period. For example, if for the period Months 1-7, an ACL was issued to Facility A in Month 3 only, then at Month 7, $ACLQ_{A7(1)}$ would have a value of 0 since there were no ACLs issued during Months 4-6, and $ACLQ_{A7(2)}$ would have a value of 1, since Months 1-3 include the ACL issued in Month 3.

Recall that there are four estimating equations of the form of Equation 3.2, one for each of the four selected effluent constituents. The variable $ACLQ_{i\,tq}$ discussed above accounts for the impact of an ACL on the effluent concentration regardless of whether that ACL was issued to address effluent violations of the constituent for which the estimating equation is for. For example, for the estimating equation for the constituent BOD, the variable $ACLQ_{i\,tq}$ reflects ACLs that address BOD effluent violations as well as ACLs that do not. It is quite possible that ACLs that do not address BOD effluent violations could still contribute to a decrease in future

BOD effluent concentrations as a result of corrective actions taken by the operators of the wastewater treatment facility that result in overall improvement of the effluent discharged, such as when an old facility is entirely replaced by a modern facility. However, it is also possible that the effect of ACLs are limited to the constituent that the ACL was issued for, such as when only a specific unit process within the wastewater treatment sequence is upgraded. The number and frequency of constituent specific-ACLs were previously tabulated in Tables 3.8a-3.8d. To consider the latter situation, the dummy variable $ACLEFFQ_{i\,t\,q}$ reflects only ACLs that are issued for the effluent constituent that the estimating equation is for; all other aspects of how the value of $ACLEFFQ_{i\,t\,q}$ is determined are same as for the previous variable $ACLFQ_{i\,t\,q}$.

The variables $ACLY_{i\,t\,y}$ and $ACLEFFY_{i\,t\,y}$ are two additional explanatory variables that reflect ACL enforcement actions. The two previous variables discussed, $ACLFQ_{i\,t\,q}$ and $ACLEFFQ_{i\,t\,q}$, are lagged by quarters and reflect the occurrence of ACLs during the three months preceding the quarters lagged. The variables $ACLY_{i\,t\,y}$ and $ACLEFFY_{i\,t\,y}$ are analogous, but the lag periods are one to five year lags and the variables reflect the occurrence of ACLs during the 12 months preceding the lag period. For example, if for the period Months 1-25, an ACL was issued to Facility A in Month 15 only, then at Month 25, $ACLY_{A25(1)}$ would have a value of 1 since Months 13-24 include the ACL issued in Month 15, and $ACLY_{A25(2)}$ would have a value of 0, since there were no ACLs issued during Months 1-12. The variables $ACLY_{i\,t\,y}$ and $ACLEFFY_{i\,ty}$ are included in this study to investigate if the possible effects of ACLs on effluent concentrations extend further from the date of ACL issuance, by up to 12 months.

In applying the estimating model equations, Equation 3.2, to investigate the correlation between effluent concentration and ACL enforcement actions, the ACL-related variable series for $ACLFQ_{i\,t\,j}$, $ACLEFFQ_{i\,t\,j}$, $ACLY_{i\,t\,k}$ and $ACLEFFY_{i\,t\,k}$ are not included simultaneously but rather one at a time. A summary of the descriptive statistics for these ACL-related variables is provided in Tables 3.8a-3.8d.

2.4.2.3. Other explanatory variables

The variable *TIME* is a factor variable with 156 levels, with a value from 1 to 156, representing each month during the period 2000-2011. The *TIME* variable is included as a factor variable rather than a sequential numeric variable to serve the function of capturing month-specific effects and seasonal effects. Other studies have included similar time series variables for similar reasons (Magat and Viscusi, 1990).

The variable $FACILITY_i$ is a factor variable corresponding to each of the facilities included in the study. The $FACILITY_i$ factor variables are included to capture facility-specific effects on $EFF_{i\,t}$ that would otherwise be become attributed to other explanatory variables in the model. Other studies have found that it is necessary to capture facility specific effects due to differences across individual facilities (Earhart, 2004a). Nevertheless, the wastewater treatment facilities in this study are expected to be more similar to each other because of their location within the SFRWQCB region than if they were located in different regions of California and within different regional board jurisdictions.

The variable $CDOTSO_{i\,t}$ is a dummy variable included to account for effects on $EFF_{i\,t}$ due to CDOs and TSOs that may be in effect for a particular facility. The value of $CDOTSO_{i\,t}$ is 1 if at time *t* there is one or more CDO or TSO in effect for the facility corresponding to $EFF_{i\,t}$.' otherwise its value is 0. As stated earlier, there were 23 CDOs or TSOs that were issued to 18 of the wastewater treatment facilities in this study and that were in effect for at least some part of the period 2000-2011.

A summary of the descriptive statistics for these other explanatory variables is provided in Tables 3.8a-3.8d.

3. Results

3.1. Comparison of pre- and post- MMP era effluent data

As shown in Table 3.5, the one-tailed paired t-test results indicate that for BOD, Cu and CN, the two-year effluent concentration averages for 2006-2007 and later were significantly lower than the averages for 1998-1999, with p-values at least less than 0.1. For TSS, the averages for 2004-2005 and later were significantly lower than the averages for 1998-1999, with p-values at least less than 0.1.

3.2. Effluent time series

Figures 3.3a-3.3d show a decreasing effluent concentration time trend for more than half of the wastewater treatment facilities for the each of the constituents BOD, TSS, CN and Cu. In Tables 3.9a-3.9d, the coefficients of the time variable for each facility and for each effluent constituent are sorted from most negative to most positive along with the total number of ACLs and number of constituent-specific ACLs issued to each facility. For BOD, TSS and CN, the facilities with more negative time variable coefficients tended to correspond to facilities that also had more ACLs; however, there were also a number of facilities with positive time variable coefficients that had several ACLs. For BOD and CN, there is also a possible trend indicating that facilities that had constituent-specific ACLS also had the more negative time variable coefficients. However, there are no apparent trends for the time variable coefficient for Cu either with regards to total ACLs to constituent-specific ACLs. This analysis suggests that, if ACLs cause effluent concentrations to decrease over time, the effect of ACLs are likely facility-specific influences, as well as cross-facility influences. However, there may be other factors unrelated to ACLs that affect effluent concentration. The objectives of the linear regression models are to capture ACL effects on effluent concentrations and quantify those effects.

3.3. Linear Regression Model results

3.3.1. General model results

For each of the four selected effluent constituents, four model regressions were conducted. The basic model for the four model regressions includes the explanatory variables *TIME,* $FACILITY_i$, $CDOTSO_{i\,t}$, and the natural log of the lagged effluent variables $EFF_{i(t-1)}$ and $EFF_{i\,(t-12)}$. Model 1 includes the total ACL variable series $ACLQ_{i\,tq}$ lagged by quarters. Model 2 includes the constituent-specific ACL variable series $ACLEFFQ_{i\,t\,q}$ lagged by quarters. Model 3 includes the total ACL variable series $ACLY_{i\,ty}$ lagged by years. Model 4 includes the constituent-specific ACL variable series $ACLEFFQ_{i\,t\,y}$ lagged by years. The coefficients for the explanatory variables obtained from the linear regressions are given in Tables 3.10a – 3.10d. The statistical significance of the coefficients is indicated with the letters *a,b, c* or *d* alongside the coefficient results as explained in the table footnotes. The adjusted R-squared values were near 0.82 and 0.87 for BOD and TSS, respectively, for Models 1-4, indicating a relatively good fit for the linear regression. The adjusted R-squared values for CN and Cu were near 0.54 and 0.69, respectively, for Models 1-4. A review of the standard error of residuals for all constituents and regression models further indicate relatively good fit, although, there were some outliers.

Additional trial model regressions based on Models 1 and 2 were conducted by including only the first ten and then only the last ten variables of the ACL variables series lagged quarterly.

The results of these regressions did not significantly differ from the regressions using the full ACL variable series; consequently, these results are not presented here.

3.3.2. Effect of TIME variable

The regression results indicate that many of the *TIME* factor variables are significant. ANOVA analysis for Type II error indicates that the *TIME* factor variables, taken as a whole, are significant in the models for TSS, Cu, and CN but not for BOD. Plots of the regression coefficients for the *TIME* factor variables (Figures 3.4a-3.4d) from the regression equations for BOD, Cu and CN generally indicate that the coefficients are decreasing with time, becoming negative midway through the study period, and continuing to become more negative, suggesting that effluent concentrations began to generally decrease with time midway through the study period. This observation agrees qualitatively with the results of the comparisons of the two-year averages of effluent concentrations before and after initiation of the MMP program. The *TIME* variable coefficients may a suggest a general decreasing trend in response to ACLs or a trend in response to other factors not included in the model equation such as other regulatory actions taken by the SFRWQCB (e.g., permit updates, total maximum daily loads).

3.3.3. Effect of lagged effluent variables

As shown in Tables 3.10a-3.10d, the coefficients for the log of the 12-month lagged effluent $EFF_{i\,t-12}$ for all four effluent constituents for all Models 1-4 ranged from a low of 0.073 for Model 2 for BOD to a high of 0.145 for Model 4 for Cu, and all the $EFF_{i\,t-12}$ coefficients were significant with p-value less than 0.001. Because the dependent variable of the regression equations is the log of $EFF_{i\,t}$, coefficients indicate that the effect of the explanatory variable on the effluent concentration $EFF_{i\,t}$ is approximately equal the percentage of the explanatory variable equal to the value of the coefficient. The coefficients of the lagged variable $EFF_{i\,t\text{-}12}$ suggest that long-term past performance of the wastewater treatment facility may predict only a small part of current performance. This is in contrast to other studies which found that long-term past performance explained a large part of present performance with coefficients up to 0.98 for 12-month lagged effluent variables where the dependent variable was the absolute value of present effluent concentration (Magat and Viscusi, 1990, Laplante and Rilstone, 1996; Shimshack and Ward, 2005).

The lower coefficients for the 12-month lagged effluent concentration variable found in this study may be due to the inclusion of the 1-month lagged effluent concentration where as other studies did not include a 1-month lagged effluent variables. As shown in Tables 3.9a-3.9d, the coefficients for these variables ranged from a low value of 0.337 for Model 2 for CN to a high of 0.510 for Models 3 and 4 for BOD. The coefficients indicate that short-term wastewater treatment facility performance has a stronger influence on present performance than long-term performance. It is therefore possible that the 1-month lagged effluent variable in this study captured the impact which other studies that did not have a 1-month lagged effluent variable attributed to the 12-month lagged effluent variable.

3.3.4. Effect of CDOs and TSOs

As shown in Tables 3.10a-3.10d, the contemporaneous effect on the dependent variable $EFF_{i\,t}$ by the presence of CDOs and TSOs was significant with a p-value less than 0.05 for Models 2 and 4 for BOD and Models 3 and 4 for CN and marginally significant with a p-value less than 0.1 for Models 1 and 3 for BOD and Models 1 and 2 for CN. CDOs and TSOs were not significant for TSS or Cu. This may be attributable to the low numbers of CDOs and TSOs that were issued to wastewater treatment facilities in the SFBRWQCB region or perhaps the CDOs or

TSOs did not specifically address TSS or Cu. Nevertheless, the significant result indicates that CDOs and TSOs may result in a decrease in effluent concentrations.

3.3.5. Effect of ACLs on BOD effluent concentrations

As shown in Table 3.10a for BOD model results, the total ACL variable lagged 18 quarters had a coefficient of -0.056 and a p-value less than 0.05. This suggests that the monthly BOD effluent concentration of a facility at, for example, Month 61 is reduced by approximately 5.6% if an ACL had been issued to the facility during the three-month period from Month 7 to Month 9 (i.e., the 18th quarter, or three-month period, preceding Month 61), regardless of the effluent constituent addressed by the ACL. Similarly, as shown in Table 3.10a, the total ACL variable lagged five years had a coefficient of -0.027, which was marginally significant with a p-value less than 0.1. This suggests that the current monthly BOD effluent concentration of a facility at, again for example, Month 61 is reduced by approximately 2.7% if an ACL had been issued to the facility during the 12-month period from Month 1 to Month 12 (i.e., the fifth year, or 12-month period, preceding Month 61), regardless of the effluent constituent addressed by the ACL.

The results of the BOD regression models considering only the constituent-specific ACLs that addressed BOD are also shown in Table 3.10a. The coefficients for the constituent-specific ACL variables, whether lagged by quarters or by years, were not significant for BOD. This suggests that effluent BOD concentration decreased in response to the issuance of an ACL to a facility even if the ACL did not address BOD effluent violations. This may be due to the corrective actions taken by wastewater treatment facilities to address other types of effluent violations which may entail process adjustments or installation of new equipment (e.g., increasing primary treatment settling time to address TSS violations, or installing fine bubble aeration equipment during secondary treatment to facilitate nitrification for subsequent nitrogen removal by denitrification). These corrective actions may result in reductions in BOD effluent concentrations as an additional benefit in addition to reductions in the target constituent.

3.3.6. Effect of ACLs on TSS effluent concentrations

As shown in Table 3.10b for TSS model results, the total ACL variables lagged by 10, 11, 12,14,15, and 16 quarters had coefficients ranging from +0.045 to +0.070 that were significant or marginally significant, with p-values at least less than 0.1. This suggests that current monthly TSS effluent concentrations of a facility tended to increase by approximately 4.5% to 7.0% if an ACL was issued to the facility during the three-month period 10 to 16 quarters prior to the current month, regardless of the effluent constituent addressed by the ACL. Similarly, as shown in Table 3.10b, the total ACL variable lagged three and four years had coefficients of +0.052 and +0.046, respectively, which were significant with p-values less than 0.001. These suggest that the current monthly TSS effluent concentrations of a facility tended to increase by approximately 5.2% to 4.6% if an ACL had been issued to the facility during the 12-month period three to four years prior to the current month, regardless of the effluent constituent addressed by the ACL.

The results of the TSS regression models considering only the constituent-specific ACLs that addressed TSS are shown in Table 3.10b. The coefficient for the constituent-specific ACL variable lagged by nine quarters was -0.088, which was marginally significant with a p-value less than 0.1. This suggests that current monthly TSS effluent concentrations at a facility decreased by approximately 8.8% if an ACL which addressed TSS effluent violations was issued to the facility during the three-month period nine quarters prior to the current month. Similarly, as shown in Table 3.10b, the constituent-specific ACL variable lagged one year had a coefficient of -0.067, which was significant with a p-value less than 0.05. This suggests that current monthly TSS effluent concentrations of a facility are reduced by approximately 6.7% if an ACL which addressed TSS effluent violations was issued to the facility during the 12-month period prior to the current month.

The positive significant coefficients for the total ACL variables, whether lagged by quarters or by years, appear to conflict with the negative significant coefficients for the constituent-specific ACL variables, and thereby appearing to suggest that ACLs both increase and decrease TSS effluent concentration. However, it is notable that the negative significant coefficient for the constituent-specific ACL variables occurs at the nine-quarter lagged variable while the positive significant coefficients for the total ACL variables begin at the ten-quarter lagged variable. Similarly, the negative significant coefficient for the constituent-specific ACL variables occurs at the one-year lagged variable while the positive significant coefficients for the total ACL variables occur at the three-year and four-year lagged variables. It is possible that these results indicate that corrective measures for TSS at the wastewater treatment facility are implemented within a year or two after an ACL is issued; however, the corrective measures do not have a permanent effect and consequently TSS effluent concentration rebound and increase. TSS removal is mostly achieved by allowing solids to passively settle out of the wastewater stream during the primary treatment process early in the treatment chain while a constituent like BOD requires more complex adjustments to subsequent treatment processes and equipment.

It is also notable that, as shown in Tables 3.7a and 3.7b, while an almost equal number of BOD and TSS effluent violations occurred during the period 2000-2011, BOD constituent-specific ACLs were issued to only six facilities out of the 26 facilities represented in the BOD data while TSS constituent-specific ACLs were issued to 16 out of the 30 facilities represented in the TSS data. This further supports the conclusion regarding the BOD results stated in the previous section that improvements in BOD effluent concentration may result from corrective measures taken for effluent violations of other constituents.

3.3.7. Effect of ACLs on Cu effluent concentrations

As shown in Table 3.10c for Cu model results, the total ACL variables lagged by 12, 15, and 19 quarters had coefficients ranging from -0.049, -0.050, and -0.072 that were significant or marginally significant, with p-values at least less than 0.1. This suggests that current monthly Cu effluent concentrations of a facility tended to decrease by approximately 4.9% to 7.2% if an ACL was issued to the facility during the three-month period 12, 15, or 19 quarters prior to the current month, regardless of the effluent constituent addressed by the ACL. Similarly, as shown in Table 3.10c, the total ACL variable lagged two, three and four years had coefficients of -0.044, -0.046 and -0.036, respectively, which were significant with p-values at least less than 0.05. These suggest that the current monthly Cu effluent concentrations of a facility tended to decrease by approximately 3.6% to 4.6% if an ACL had been issued to the facility during the 12-month period two to four years prior to the current month, regardless of the effluent constituent addressed by the ACL.

The results of the Cu regression models considering only the constituent-specific ACLs that addressed Cu are shown in Table 3.10c. The coefficient for the constituent-specific ACL variable lagged by three, five, ten and 12 quarters were +0.277, -0.202, +0.168, and -0.145, respectively, which were significant or marginally significant with a p-value at least less than 0.1. These suggest that current monthly Cu effluent concentrations at a facility increased by approximately 27.2% and 16.8% if an ACL which addressed Cu effluent violations were issued to the facility during the three-month period three quarters and ten quarters prior to the current month. However, these also suggest that current monthly Cu effluent concentrations at a facility decreased by approximately 20.2% and 14.5% if an ACL which addressed Cu effluent violations were issued to the facility during the three-month period five quarters and 12 quarters prior to the current month. None of the coefficients for the constituent-specific ACL variables for Cu lagged by years were significant.

The alternating positive and negative significant coefficients for the constituent-specific ACL variables for Cu lagged by quarters suggest that Cu effluent concentrations may show a net increase of 1.7% three years after an ACL is issued to a facility to address Cu effluent violations although some interim reductions are achieved. However, the negative significant coefficients for the total ACL variables, both lagged by quarters or years, suggest that a permanent reduction in Cu effluent concentrations is achieved when an ACL is issued to a facility, regardless of the constituent addressed by the ACL. High removal rates of Cu in the influent to conventional treatment facilities have been reported and range from 86% to 93% (Goldstone et al, 1990; Nielsen and Hrudey, 1983). Cu removal is achieved both during primary sedimentation and the biological treatments phases of the wastewater treatment train, with more than half of the removal efficiency achieved during primary sedimentation (Goldstone et al, 1990; Nielsen and Hrudey, 1983; Ekster and Jenkins, 1996). Consequently, a treatment facility that upgrades its primary sedimentation unit to address TSS violations or upgrades its activated sludge process to address BOD violations, will also achieve a reduction in Cu effluent concentrations. Therefore, it is possible that corrective actions taken to reduce Cu effluent concentrations in response to issuance of constituent- specific ACL may not achieve permanent reduction, and may even result in a slight increase; however, permanent Cu effluent concentration reductions may be achieved as an additional benefit of corrective actions to address effluent violations for other constituents.

3.3.8. Effect of ACLs on CN effluent concentrations

As shown in Table 3.10d for CN model results, the total ACL variables lagged by 8 quarters had a coefficient of +0.111 that was significant, with a p-value less than 0.05. This suggests that the current monthly CN effluent concentrations of a facility tended to increase by approximately 11.1% if an ACL was issued to the facility during the three-month period 8 quarters prior to the current month, regardless of the effluent constituent addressed by the ACL. Similarly, as shown in Table 3.10d, the total ACL variable lagged one year had a coefficient of +0.053, which was marginally significant with a p-value less than 0.1. This suggests that current monthly TSS effluent concentrations of a facility tended to increase by approximately 5.3% if an ACL had been issued to the facility during the 12-month period prior to the current month, regardless of the effluent constituent addressed by the ACL.

The results of the CN regression models considering only the constituent-specific ACLs that addressed CN are shown in Table 3.10d. The coefficient for the constituent-specific ACL variable lagged by three quarters was -0.166, which was marginally significant with a p-value less than 0.1. This suggests that current monthly CN effluent concentrations at a facility decreased by approximately 16.6% if an ACL which addressed CN effluent violations was issued to the facility during the three-month period nine quarters prior to the current month. In addition, the constituent-specific ACL variable lagged 20 quarters had a coefficient of +0.166, which was marginally significant with a p-value less than 0.1. This suggests that current monthly CN effluent concentrations of a facility increase by approximately 16.6% if an ACL which addressed CN effluent violations was issued to the facility during the 3-month period prior to the current month. None of the coefficients for the constituent-specific ACL variables for CN lagged by years were significant.

The negative significant coefficient for the constituent-specific ACL variable lagged three months and the positive significant coefficient for the constituent-specific ACL variable lagged 20 months suggest that an ACL that addresses CN effluent violations results in reduction of the pollutant in the effluent within three quarters of the constituent-specific ACL issuance; however, the reduction may not be permanent and effluent CN concentrations rebound within five years of ACL issuance. Furthermore, the positive significant coefficients for the total ACL variables lagged by eight quarter and by one year suggest that ACLs increase CN effluent concentrations in the first or second year after ACL issuance.

The apparent positive correlation between CN effluent concentrations and ACLs is unexpected based on a qualitative inspection of the effluent-time slopes shown in Figure 3.3d and Table 3.6d. Out of 32 facilities represented in the CN effluent data, 18 had negative effluent-time slopes, which suggest decreasing CN effluent concentrations at these facilities. Furthermore, 15 out the 32 facilities had been issued one or more constituent-specific ACLs for CN effluent violations. It should be noted that of the four constituents considered in this study, the CN effluent concentration data had the largest standard deviation from the mean concentration of the data set and was the only constituent that had a standard deviation greater than mean; this greater variability for CN has also been observed in other studies (Raco-Rands, 1995). This greater variability in the CN effluent data is reflected in the adjusted R-squared values near 0.54 for the four CN regression models, which were the lowest out of the four constituents in this study. Therefore, the positive correlation between CN effluent concentrations and ACLs may be partly explained by the greater variability in the data and in the model equations.

The CN in the influent entering wastewater treatment plants is typically associated with waste discharges from industrial sources to the municipal sewer system (Lordi et al, 1980; Wild et al, 1994). CN can be removed during the activated sludge phase of wastewater treatment (Lordi et al, 1980; Gaudy et al, 1982); however, reported removal rates range from 0% to 91% (average 62%) and vary significantly between plants depending on influent concentration (Wild, 1994; Lordi, 1980). In addition, CN in wastewater could negatively affect biological treatment processes and jeopardize the function of the treatment facility entirely (Wild, 1994). Therefore, unlike, BOD, TSS and even Cu, CN is not as effectively removed by a conventional wastewater treatment facility, and reducing CN effluent concentration by reducing or eliminating inputs of CN from industrial facilities through the NPDES pretreatment may be preferable and more effective. Control of CN sources is a different corrective measure than process changes or facility upgrades and may take much more effort and time. For example, from 1970 to 1977, out of 284 industrial dischargers in the Chicago area that had violations for CN discharges to the municipal sewer system, 37% remained out compliance (Lordi et al, 1980).

CN effluent concentrations have also been observed to be greater than the CN concentrations of the influent due to formation of CN during the chlorine disinfection phase of the treatment sequence (Zheng et al, 2004a, 2004b). As shown in Table 3.4, the effluent constituent that had the highest number of violations was total coliform (TC). While TC was not considered in the regression models in this study due to lack of complete effluent data for most facilities, ACLs were issued to many facilities for total coliform effluent violations (i.e., 47 ACLs addressed TC compared to 27 ACLs that addressed CN). Corrective actions for TC violations commonly involve adding chlorine disinfection to the treatment sequence or increasing the chlorine dose in an existing chlorine disinfection process, which may result in higher CN effluent concentrations.

Consequently, because CN source control is a less direct corrective measure for CN effluent violations and because corrective measures for total coliform may result in increasing CN effluent concentrations, the expected negative correlation between CN effluent concentrations and ACLs may not be observed.

4. Discussion and Recommendations

The results of the comparison of pre- and post- MMP era effluent concentration data, shown in Tables 3.5a-3.5d, indicate that effluent concentrations for the four constituents BOD, TSS, Cu and CN were not significantly different between the period 1998-1999 and during the early years of the MMP enforcement program. Although the 1998-1999 data were limited, these results suggest that effluent concentrations did not improve significantly until after the first four to six years after the MMP enforcement program started in 2000. This delay may be due to the time between the occurrence of effluent violations and the issuance of MMP ACLs as well as the time necessary to implement corrective actions at the wastewater treatment facilities.

The significant coefficients for the ACL variables obtained from the regression models for the four constituents are summarized in Table 3.11. The sign and magnitude of the coefficients indicate that the effect of ACLs on constituent effluent concentrations may vary depending on the constituent. For BOD and Cu, the coefficients suggest that an ACL issued to a facility, regardless of the constituents addressed by the ACL, result in a reduction in BOD or Cu effluent concentration, while constituent-specific ACLs do not affect BOD concentrations and may result in a slight increase in Cu concentrations long-term. For TSS, the coefficients suggest that constituent-specific ACLs may result in short-term reductions in TSS concentrations; however, long-term TSS concentrations seem to increase in response to other ACLs issued to a facility. For CN, constituent-specific ACLs may result in short-term reduction in CN concentrations but also result in long-term increases in CN concentrations, while other ACLs may result in increases in CN concentrations.

The results from the regression models in this study likely reflect the complexity of municipal wastewater composition and treatment processes. Unlike industrial facilities that directly discharge to surface waters and which have greater control over its raw wastewater stream and its treatment processes, municipal wastewater treatment facilities do not have the same level of direct control over the quantity and quality of the raw wastewater influent to the treatment facilities. Furthermore, municipal wastewater treatment facilities may be more effective at addressing conventional pollutants such as BOD and TSS, but less effective at removing specific metal and inorganic pollutants such as Cu and CN. Nevertheless, the results suggest that MMP ACL enforcement actions in general promote improvements in effluent concentrations, at least for a year or two after ACL issuance, if not longer.

As explained in the Results section, because of the logarithmic form of the regression estimating equations, the coefficients of the ACL variables in the regression models approximately indicate the percentage by which an ACL reduces effluent concentrations. Again for example, the coefficient for the total ACL variable lagged 5 years for BOD is -0.027 which indicates that the current BOD effluent concentration for a facility was reduced by approximately 2.7 percent if an ACL, regardless of the constituent addressed by the ACL, had been issued to the facility.

The approximate pollution reduction achieved as indicated by the ACL variable coefficients has been quantified as shown in Tables 3.12a-3.12d. For each constituent, the average effluent concentration for all the wastewater treatment facilities considered in this study was calculated for each year. The pollution reduction by which the average annual effluent concentrations had been reduced was calculated, taking into consideration the logarithmic form of the regression equations. By multiplying the pollution reduction by the average discharge flow rate of the wastewater treatment facilities, a mass emission rate, in units of lbs/day, was calculated for each year. As shown in Tables 3.12a and 3.12b, these calculations indicate that overall BOD and TSS emissions within the SFBRWQCB were reduced annually by 31 to 157 tons and 22 to 80 tons, respectively. Similar calculations, as shown in Tables 3.12c and3.12d, indicate that mass emission for Cu and CN were reduced annually by 37 to 359 lbs and 43 to 361 lbs, respectively. While these mass emission reductions are only a small fraction of total emissions, the reduction of several tons or pounds of pollutants annually offers the public a tangible measure of pollution reduction. Based on an MMP liability of $3,000 per effluent violation, the MMP amount assessed for each ton of pollution reduction and the MMP cost per million residents for each unit of pollution mass reduction were calculated, as shown in Tables 3.12a-3.12d. The MMP levied per ton of BOD or TSS pollution reduction range from under $200 to $13,500. The MMP levied per pound of Cu or CN pollution reduction range from under $100 to $5,700. For the approximate population of 7.15 million in the SFBRWQCB, the MMP cost of pollution reduction per million residents range from under $20 to almost $2,000 per ton of BOD and TSS and from under $10 to $800 per pound of Cu or CN. The true cost of pollution reduction, however, is much more and depends on the actual costs of corrective actions taken.

ACLs likely incentivize the managers of municipal wastewater treatment facilities to upgrade portions of facilities or entirely replace aging treatment facilities. However, if the effects of ACLs are short term (i.e., within two or three years), as indicated by the constituent-specific ACL coefficients for TSS, Cu and CN, then the results of this study suggest that issuance of ACLs more frequently as effluent violations occur, result in improvement in effluent concentrations for several constituents and not just for the constituent(s) specifically addressed by the ACL. As indicated by negative slopes of the effluent-time graphs (Figures 3.3a-3.3d and Table 3.6) and by the trend towards more negative coefficients for the TIME variable (Figures 3.4a-3.4d), effluent concentrations for BOD, TSS, Cu and CN have generally decreased during the period 2000-2011 when MMP ACLs have been issued. These trends likely reflect the reputation enhancement that a regulatory agency establishes, i.e., that enforcement actions will be taken when effluent violations occur. In this sense, the MMP enforcement program has achieved its purpose, although quantitatively the environmental end results may be smaller than may have been expected when the MMP enforcement program was legislated.

In May 2010, the SWRCB began implementation of a new Enforcement Policy which included expectations that regional boards will address effluent violations within 18 months that a violation becomes known (SWRCB, 2010). The SWRCB has also encouraged issuance of ACLs through expedited payment letters in order to streamline the process of issuing ACLs (SWRCB, 2010). Furthermore, beginning in 2012, changes to the California Water Code allow the time schedules for corrective actions under a CDO or TSO to be extended to 10 years, instead of five years, under certain conditions. The effects of these changes may not be evident for several more years. These changes may increase the certainty that an enforcement action will be taken swiftly and increase the effectiveness of MMP ACLs in promoting compliance and reducing effluent violations. However, it is possible that MMP ACL enforcement actions may become fairly routine expenditures for discharging facilities and lose their effectiveness. The time schedule extensions for corrective actions may also result in effluent quality deterioration until corrective actions are completed. The effects of these three changes may not be evident for several more years.

5. Conclusion

The preliminary results of this investigation show that the MMP enforcement program which began in 2000 in California has been effective at reducing pollution emissions from wastewater treatment plants. While effluent concentrations during the early years of the program were similar to those from the period prior to MMP program, linear regression models suggest that modest reductions in the concentrations of BOD, TSS, Cu and CN, on the order of 2% to 16%, have been achieved in the years following the issuance of MMP enforcement actions, and the reductions may be due both to facility-specific effects as well as enhancement of the regulatory agency's enforcement reputation. Approximate calculations indicate that pollution emissions in the SFBRWQCB region are reduced by several tons for BOD and TSS and by several hundred pounds for Cu and CN annually. This study also demonstrated that the effects of enforcement actions on effluent concentrations can vary between the four constituents considered. Because this study only considered facilities within one regional board jurisdiction, and one that is demographically and geographically homogeneous, the results of this study may be indicative of the effects of the MMP program statewide under similar frequencies of MMP ACL issuance. Follow-up research using the data assembled for this investigation will be conducted to provide additional insights and conclusions regarding the effectiveness of the MMP enforcement program on levels of pollution emissions.

Table 3.1. Secondary treatment standards for municipal wastewater treatment facilities *(Adapted from USEPA, 2010)*

Constituent	30-day average	7-day average
5-day biochemical oxygen demand (BOD)	30 mg/L	45 mg/L
Total suspended solids (TSS)	30 mg/L	45 mg/L
BOD and TSS removal	85%	
pH	6-9 s.u. (instantaneous)	

Table 3.2. Effluent concentrations at mid-sized municipal wastewater treatment facilities in Southern California
(*adapted from Raco-Rands, 1996*)

	Goleta		Santa Barbara		Carpinteria		Oxnard		Terminal Island		AWMA		SERRA		Oceanside		Encina		San Elijo		Escondido	
Constituent	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
Flow (MGD)	4.62	7	7.05	5	1.31	6	17.4	3	16.1	6	17.7	10	16.2	4	12.1	5	20.3	3	2.89	3	14.4	2
TSS (mg/L)	36.9	32	12.6	37	27	6	9.4	39	7	40	7.13	12	11.1	8	6.3	25	6.2	25	10.7	26	8.6	42
BOD (mg/L)	52.1	29	9.6	25	23	11	16.1	31	5	55	5.28b	9	5.3a	17	4.3b	24	24	22	25	29	6.2b	30
Nitrate-N (mg/L)	-	-	-	-	-	-	4.5	75	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ammonia-N (mg/L)	39.7	15	15.6	13	27.7	17	15	27	0.8	142	15.9	63	17	15	18.7	20	21.0c	18	23	21	26	30
Cyanide (ug/L)	<5	-	40	-	10	141	40	48	<5	-	<20	-	<20d	-	<20	-	22	169	nd	-	10	141
Toxicity (TU)	0.76	43	0.85	69	10	0	0.42	70	0.11	234	0	-	-	-	1.16	12	0.69	40	0.74	47	0.8	49
Arsenic (ug/L)	<5	-	<5	-	3.1	141	2.3	22	3	40	1.7	8	4	118	<10	-	5.9	72	1	200	<1.2	-
Cadmium (ug/L)	<1d	-	<5	-	<1	-	<4	-	<1	-	<1	-	<10	-	<3	-	30	41	5	200	<0.25	-
Chromium (ug/L)	<5	-	<10	-	5	141	<10	-	<1e	-	<1	-	<50e	-	<11	-	55	97	10	200	1	82
Copper (ug/L)	33	50	<10	-	<50	-	17.5	18	5	109	6	141	13	151	<10	-	59	102	18	55	12	37
Lead (ug/L)	<5	-	<2	-	<5	-	<10	-	<2	-	<1	-	<70	-	<70	-	97	41	nd	-	1.7	48
Mercury (ug/L)	<0.5	-	<0.2	-	<1	-	<0.5	-	<0.3d	-	<0.5	-	<0.6	-	<1	-	<0.1	-	nd	-	<0.5	-
Nickel (ug/L)	<50	-	<10	-	<10	-	22.2	20	<2	-	141	<40	-	<25	-	91	65	83	30	16	37	
Selenium (ug/L)	<5	-	<5	-	-	-	-	-	25	81	2.65	19	-	-	-	-	-	-	-	-	<4	-
Silver (ug/L)	<5	-	<10	-	<10	-	<4	-	<0.4	-	<1	-	<20	-	<10	-	47	98	15	86	<1	-
Zinc (ug/L)	<40	-	40	-	<50	-	17.5	37	44	13	35	77	75	34	14	123	141	58	60	36	97	30
DDT (ug/L)	<0.02	-	<0.02	-	0.04	0	<0.2d	-	nd	-	-	-	nd	-	<0.04	-	nd	-	nd	-	<0.1	-
PCB (ug/L)	<0.1	-	<0.5	-	<0.1	-	<0.8d	-	nd	-	-	-	nd	-	<0.1	-	nd	-	nd	-	<1	-

Table 3.3. Violations and Administrative Civil Liabilities during 2000-2011

Region	Effluent Violations	ACLs
1	5,529	49
2	2,020	118
3	2,757	50
4	5,234	31
5F	2,120	11
5R	872	36
5S	20,271	139
6T	225	1
6V	194	0
7	1,879	32
8	1,463	38
9	1,463	12
Total	44,027	517

Table 3.4. Facilities and effluent violations according to constituent

Constituent	# Violations of this constituent from all facilities	# Facilities with violation of this constituent
Total Coliform	405	27
Total Residual Chlorine	185	28
BOD	164	13
TSS	163	24
Settleable Solids	116	19
Ammonia	102	6
Cyanide	64	18
Zinc	48	6
pH	39	7
Copper	32	11
Selenium	20	1
Oil & Grease	16	8
Mercury	10	4
Nickel	5	4
Tributyltin	5	2
Turbidity	4	3
Acute Toxicity	2	2
Lead	2	1
Bis(2-ethylhexyl)phthalate	2	1
dibromochloromethane	1	1
metals	1	1
Sulfide	1	1
Dieldrin	1	1
Dioxin TCDD	1	1
Total Dissolved Solids	0	0
Flow	0	0
Fecal Coliform	0	0
Nitrate	0	0
Chronic Toxicity	0	0
Trihalomethanes	0	0

Tables 3.5a-3.5d. One-tailed t-test results comparing two-year effluent concentration averages

a. Biochemical Oxygen Demand (BOD)

Two-year period	# Facilities	Mean Effluent Concentration (mg/L)	Std. Dev. Effluent concentration	P(T<=t) one-tail
1998-1999	16	9.58	5.53	---
2000-2001	16	9.52	4.85	0.442866
2002-2003	16	8.99	4.53	0.205730
2004-2005	16	9.17	5.31	0.280708
2006-2007	16	8.27	4.57	0.044237
2008-2009	16	8.20	4.46	0.092152
2010-2011	16	7.71	3.89	0.030966

b. Total Suspended Solids (TSS)

Two-year period	# Facilities	Mean Effluent Concentration (mg/L)	Std. Dev. Effluent concentration	P(T<=t) one-tail
1998-1999	16	9.83	6.08	---
2000-2001	16	9.30	5.25	0.209464
2002-2003	16	8.81	4.60	0.180885
2004-2005	16	8.01	4.41	0.045615
2006-2007	16	8.25	4.91	0.064851
2008-2009	16	8.38	4.92	0.093228
2010-2011	16	8.14	5.08	0.084525

c. Copper (Cu)

Two-year period	# Facilities	Mean Effluent Concentration (ug/L)	Std. Dev. Effluent concentration	P(T<=t) one-tail
1998-1999	20	9.27	5.63	---
2000-2001	20	9.38	8.37	0.458795
2002-2003	20	8.82	7.56	0.312198
2004-2005	20	8.70	10.66	0.359778
2006-2007	20	6.54	2.39	0.013536
2008-2009	20	5.99	2.71	0.003492
2010-2011	20	5.33	2.25	0.000412

d. Cyanide (CN)

Two-year period	# Facilities	Mean Effluent Concentration (ug/L)	Std. Dev. Effluent concentration	P(T<=t) one-tail
1998-1999	20	6.19	3.15	---
2000-2001	20	6.69	3.14	0.149169
2002-2003	20	5.51	3.24	0.152991
2004-2005	20	5.32	4.61	0.199479
2006-2007	20	4.52	3.18	0.004971
2008-2009	20	3.61	3.40	0.002122
2010-2011	20	2.92	2.45	0.000029

Table 3.6. Concentration-time regression slopes

Facility	BOD	TSS	Copper (Cu)	Cyanide (CN)
American Canyon	---	---	0.002	-0.005
Benicia	-0.079	-0.034	-0.006	-0.037
Burlingame	-0.014	-0.047	-0.026	-0.02
Calera Creek	-0.006	-0.001	0.003	-0.03
Central Contra Costa	0.001	-0.007	0.003	-0.018
Central Marin	---	-0.019	0.011	-0.017
Delta Diablo	0.012	-0.019	-0.015	-0.047
Dublin	-0.043	-0.046	-0.316	-0.037
EBDA	-0.001	-0.037	-0.039	-0.003
EBMUD	-0.016	-0.004	-0.043	-0.007
FSSD	-0.01	0.000	-0.006	-0.009
Golden Eagle	0.012	-0.011	-0.029	-0.041
Livermore	---	---	---	0.031
Millbrae	---	0.066	-0.004	-0.004
Mt. View	-0.03	0.003	0.005	-0.02
North San Mateo	0.003	0.054	---	---
Palo Alto	0.016	-0.004	0.013	-0.015
Pinole	---	-0.015	0.01	-0.01
Rodeo	-0.104	-0.025	---	0.003
SAM	0.004	-0.012	---	---
San Jose - Santa Clara	-0.007	-0.006	-0.003	-0.028
San Mateo	-0.015	-0.006	---	-0.009
Sausalito	0.015	-0.031	0.007	-0.053
SBSA	-0.018	-0.015	-0.051	-0.039
SF Airport Industrial	-0.022	0.009	-0.038	-0.072
SF Airport Sanitary	-0.005	0.004	-0.049	-0.059
SF-SE NP&BS	0.003	0.007	-0.065	-0.041
Shell	-0.003	-0.005	-0.02	-0.013
Sonoma Valley	---	---	-0.026	-0.009
South SF - San Bruno	-0.066	-0.045	-0.014	-0.097
Sunnyvale	0.007	-0.003	0.009	-0.028
Tiburon	---	0.001	-0.088	-0.011
Vallejo	-0.07	-0.008	-0.001	-0.017
West County	---	---	-0.033	-0.02

Table 3.7. ACL and CDO/TSO frequencies by facility

FACILITY	# MMP ACLs Issued				# CDOs/TSOs 2000-2012
	2000-2012	2000-2003	2004-2007	2008-2012	
AMERICAN CANYON WWTP	3	0	1	2	0
BENICIA WWTP	7	4	2	1	0
BURLINGAME WWTP	5	4	1	0	0
CALERA CREEK WATER RECYCLING PLANT	4	1	1	2	1
CENTRAL CONTRA COSTA WWTP	0	0	0	0	0
CENTRAL MARIN SAN. AGCY. WWTP	4	4	0	0	0
DELTA DIABLO SD WWTP	2	1	1	0	0
DUBLIN SAN RAMON SD WWTP	1	0	1	0	0
EBDA COMMON OUTFALL	1	0	1	0	1
EBMUD WPCP	1	0	0	1	0
FSSD SUBREGIONAL WWTP	3	2	0	1	1
GOLDEN EAGLE REFINERY WWTP	3	1	1	1	0
LIVERMORE WWTP	1	1	0	0	0
MILLBRAE WWTP	2	0	0	2	0
MT. VIEW SANITARY DISTRICT WWTP	2	1	0	1	0
NORTH SAN MATEO COUNTY SANITATION	1	0	1	0	0
PALO ALTO REGIONAL WQCP	5	3	2	0	0
PINOLE WWTP	4	2	0	2	0
RODEO SANITARY DISTRICT WWTP	4	1	1	2	0
SAM WWTP	3	2	0	1	0
SAN JOSE/SANTA CLARA WPCP	1	1	0	0	0
SAN MATEO WWTP	3	2	1	0	1
SAUSALITO MARIN CITY STP	6	2	2	2	1
SBSA WWTP	3	0	0	3	0
SF Arprt Mel Leong TP-Industrl	3	1	2	0	1
SF ARPRT MEL LEONG TP-SANITARY WASTE	4	2	1	1	2
SF-SE WPCP, N-Point & Bayside	2	1	0	1	0
SHELL MARTINEZ REFINERY WWTP	4	1	1	2	0
SONOMA VALLEY COUNTY SD WWTP	7	3	1	3	0
SOUTH SAN FRANCISICO-SAN BRUNO WQCP	5	3	1	1	0
SUNNYVALE WPCP	5	2	1	2	0
TIBURON WWTP	1	0	0	1	1
VALLEJO SFCD WWTP	4	3	0	1	0
WEST COUNTY AGENCY OUTFALL	6	3	1	2	1

Table 3.8. Descriptive statistics for ACL-concentration regression model variables

		BOD [a]		TSS [a]		Copper (Cu) [b]		Cyanide (CN) [b]	
Variable	Variable type (units)	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
$EFF_{i\,t}$	*continuous (mg/L)* [a]*, (ug/L)* [b]	8.646	5.661	9.131	6.550	7.087	6.856	4.807	5.427
$EFF_{i\,(t-1\,month)}$	*continuous (mg/L)* [a]*, (ug/L)* [b]	8.648	5.663	9.128	6.553	7.098	6.873	4.810	5.432
$EFF_{i\,(t-12\,month)}$	*continuous (mg/L)* [a]*, (ug/L)* [b]	8.718	5.677	9.177	6.599	7.219	7.038	4.922	5.494
$CDOTSO_{i\,t}$	*0 or 1 dummy*	0.141	0.348	0.133	0.340	0.153	0.360	0.149	0.356
$ACLQ_{i\,t\,1}$	*0 or 1 dummy*	0.060	0.238	0.059	0.235	0.062	0.242	0.059	0.236
$ACLQ_{i\,t\,2}$	*0 or 1 dummy*	0.061	0.240	0.060	0.237	0.064	0.244	0.060	0.238
$ACLQ_{i\,t\,3}$	*0 or 1 dummy*	0.062	0.241	0.060	0.238	0.064	0.245	0.061	0.240
$ACLQ_{i\,t\,4}$	*0 or 1 dummy*	0.063	0.243	0.061	0.240	0.065	0.247	0.062	0.241
$ACLQ_{i\,t\,5}$	*0 or 1 dummy*	0.063	0.244	0.062	0.241	0.066	0.248	0.063	0.242
$ACLQ_{i\,t\,6}$	*0 or 1 dummy*	0.064	0.244	0.062	0.242	0.066	0.249	0.063	0.243
$ACLQ_{i\,t\,7}$	*0 or 1 dummy*	0.065	0.246	0.064	0.244	0.067	0.250	0.064	0.245
$ACLQ_{i\,t\,8}$	*0 or 1 dummy*	0.064	0.245	0.063	0.243	0.065	0.247	0.063	0.242
$ACLQ_{i\,t\,9}$	*0 or 1 dummy*	0.065	0.246	0.064	0.244	0.066	0.248	0.063	0.243
$ACLQ_{i\,t\,10}$	*0 or 1 dummy*	0.066	0.249	0.065	0.247	0.067	0.250	0.064	0.245
$ACLQ_{i\,t\,11}$	*0 or 1 dummy*	0.068	0.251	0.067	0.249	0.069	0.253	0.066	0.248
$ACLQ_{i\,t\,12}$	*0 or 1 dummy*	0.069	0.254	0.068	0.252	0.070	0.256	0.067	0.251
$ACLQ_{i\,t\,13}$	*0 or 1 dummy*	0.071	0.257	0.070	0.255	0.072	0.259	0.069	0.254
$ACLQ_{i\,t\,14}$	*0 or 1 dummy*	0.073	0.260	0.072	0.258	0.074	0.261	0.071	0.256
$ACLQ_{i\,t\,15}$	*0 or 1 dummy*	0.070	0.255	0.069	0.253	0.072	0.258	0.068	0.251
$ACLQ_{i\,t\,16}$	*0 or 1 dummy*	0.072	0.258	0.070	0.256	0.073	0.261	0.069	0.254
$ACLQ_{i\,t\,17}$	*0 or 1 dummy*	0.067	0.251	0.065	0.246	0.067	0.250	0.064	0.245
$ACLQ_{i\,t\,18}$	*0 or 1 dummy*	0.066	0.248	0.063	0.242	0.064	0.245	0.062	0.240
$ACLQ_{i\,t\,19}$	*0 or 1 dummy*	0.067	0.250	0.064	0.244	0.066	0.248	0.063	0.243
$ACLQ_{i\,t\,20}$	*0 or 1 dummy*	0.069	0.253	0.066	0.248	0.068	0.251	0.065	0.246
$ACLEFFQ_{i\,t\,1}$	*0 or 1 dummy*	0.007	0.081	0.014	0.118	0.008	0.091	0.014	0.118
$ACLEFFQ_{i\,t\,2}$	*0 or 1 dummy*	0.007	0.082	0.014	0.119	0.009	0.092	0.014	0.119
$ACLEFFQ_{i\,t\,3}$	*0 or 1 dummy*	0.007	0.083	0.014	0.119	0.009	0.093	0.014	0.119
$ACLEFFQ_{i\,t\,4}$	*0 or 1 dummy*	0.007	0.084	0.014	0.119	0.009	0.094	0.014	0.119

Table 3.8 (continued). Descriptive statistics for ACL-concentration regression model variables

		BOD		TSS		Copper (Cu)		Cyanide (CN)	
Variable	Variable type (units)	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
$ACLEFFQ_{i\,t\,5}$	*0 or 1 dummy*	0.007	0.083	0.015	0.120	0.009	0.095	0.015	0.120
$ACLEFFQ_{i\,t\,6}$	*0 or 1 dummy*	0.007	0.081	0.015	0.121	0.009	0.096	0.015	0.121
$ACLEFFQ_{i\,t\,7}$	*0 or 1 dummy*	0.007	0.082	0.015	0.122	0.009	0.097	0.015	0.121
$ACLEFFQ_{i\,t\,8}$	*0 or 1 dummy*	0.007	0.082	0.015	0.122	0.010	0.098	0.015	0.120
$ACLEFFQ_{i\,t\,9}$	*0 or 1 dummy*	0.007	0.083	0.015	0.122	0.010	0.099	0.014	0.119
$ACLEFFQ_{i\,t\,10}$	*0 or 1 dummy*	0.007	0.084	0.016	0.124	0.010	0.100	0.015	0.120
$ACLEFFQ_{i\,t\,11}$	*0 or 1 dummy*	0.007	0.085	0.016	0.125	0.010	0.101	0.015	0.122
$ACLEFFQ_{i\,t\,12}$	*0 or 1 dummy*	0.008	0.086	0.016	0.126	0.011	0.103	0.015	0.123
$ACLEFFQ_{i\,t\,13}$	*0 or 1 dummy*	0.008	0.087	0.017	0.128	0.011	0.104	0.016	0.125
$ACLEFFQ_{i\,t\,14}$	*0 or 1 dummy*	0.008	0.088	0.017	0.129	0.011	0.105	0.016	0.126
$ACLEFFQ_{i\,t\,15}$	*0 or 1 dummy*	0.008	0.090	0.016	0.125	0.011	0.107	0.016	0.125
$ACLEFFQ_{i\,t\,16}$	*0 or 1 dummy*	0.008	0.091	0.016	0.126	0.012	0.108	0.016	0.126
$ACLEFFQ_{i\,t\,17}$	*0 or 1 dummy*	0.009	0.092	0.015	0.123	0.012	0.109	0.016	0.126
$ACLEFFQ_{i\,t\,18}$	*0 or 1 dummy*	0.009	0.093	0.015	0.121	0.012	0.111	0.016	0.126
$ACLEFFQ_{i\,t\,19}$	*0 or 1 dummy*	0.009	0.095	0.015	0.120	0.013	0.113	0.017	0.128
$ACLEFFQ_{i\,t\,20}$	*0 or 1 dummy*	0.009	0.096	0.015	0.122	0.013	0.114	0.017	0.130
$ACLY_{i\,t\,1}$	*0 or 1 dummy*	0.221	0.415	0.214	0.410	0.224	0.417	0.216	0.411
$ACLY_{i\,t\,2}$	*0 or 1 dummy*	0.229	0.420	0.222	0.416	0.233	0.423	0.224	0.417
$ACLY_{i\,t\,3}$	*0 or 1 dummy*	0.238	0.426	0.232	0.422	0.240	0.427	0.231	0.422
$ACLY_{i\,t\,4}$	*0 or 1 dummy*	0.252	0.434	0.246	0.430	0.255	0.436	0.244	0.430
$ACLY_{i\,t\,5}$	*0 or 1 dummy*	0.233	0.423	0.222	0.415	0.229	0.420	0.220	0.414
$ACLEFFY_{i\,t\,1}$	*0 or 1 dummy*	0.027	0.161	0.054	0.227	0.031	0.174	0.053	0.223
$ACLEFFY_{i\,t\,2}$	*0 or 1 dummy*	0.026	0.160	0.056	0.231	0.034	0.181	0.054	0.226
$ACLEFFY_{i\,t\,3}$	*0 or 1 dummy*	0.028	0.165	0.059	0.236	0.037	0.189	0.056	0.231
$ACLEFFY_{i\,t\,4}$	*0 or 1 dummy*	0.031	0.173	0.061	0.240	0.041	0.198	0.060	0.238
$ACLEFFY_{i\,t\,5}$	*0 or 1 dummy*	0.034	0.182	0.056	0.230	0.045	0.208	0.063	0.243

Table 3.9a. BOD concentration-Time regression slopes and ACL frequencies

FACILITY	TIME COEFFICIENT	All MMP ACLs				ACL addresses BOD violations			
		2000-2012	2000-2003	2004-2007	2008-2012	2000-2012	2000-2003	2004-2007	2008-2012
Rodeo	-0.104	4	1	1	2	2	1	0	1
Benicia	-0.079	7	4	2	1	1	1	0	0
Vallejo	-0.07	4	3	0	1	0	0	0	0
South SF-San Bruno	-0.066	5	3	1	1	2	1	1	0
Dublin	-0.043	1	0	1	0	0	0	0	0
Mt. View	-0.03	2	1	0	1	0	0	0	0
SF Airport Indus	-0.022	3	1	2	0	2	1	1	0
SBSA	-0.018	3	0	0	3	0	0	0	0
EBMUD	-0.016	1	0	0	1	0	0	0	0
San Mateo	-0.015	3	2	1	0	1	1	0	0
Burlingame	-0.014	5	4	1	0	0	0	0	0
FSSD Subregional	-0.01	3	2	0	1	0	0	0	0
San Jose	-0.007	1	1	0	0	0	0	0	0
Calera Ck	-0.006	4	1	1	2	0	0	0	0
SF Airport Sanitary	-0.005	4	2	1	1	0	0	0	0
Shell	-0.003	4	1	1	2	0	0	0	0
EBDA	-0.001	1	0	1	0	0	0	0	0
Central Contra Costa	0.001	0	0	0	0	0	0	0	0
North San Mateo	0.003	1	0	1	0	0	0	0	0
SF-SE, NP&BS	0.003	2	1	0	1	0	0	0	0
SAM	0.004	3	2	0	1	0	0	0	0
Sunnyvale	0.007	5	2	1	2	0	0	0	0
Delta Diablo	0.012	2	1	1	0	0	0	0	0
Golden Eagle	0.012	3	1	1	1	0	0	0	0
Sausalito	0.015	6	2	2	2	1	0	1	0
Palo Alto	0.016	5	3	2	0	0	0	0	0

Table 3.9b. TSS concentration-Time regression slopes and ACL frequencies

FACILITY	TIME COEFFICIENT	All MMP ACLs				ACL addreses TSS violations			
		2000-2012	2000-2003	2004-2007	2008-2012	2000-2012	2000-2003	2004-2007	2008-2012
Burlingame	-0.047	5	4	1	0	1	1	0	0
Dublin	-0.046	1	0	1	0	0	0	0	0
South SF-San Bruno	-0.045	5	3	1	1	1	1	0	0
EBDA	-0.037	1	0	1	0	0	0	0	0
Benicia	-0.034	7	4	2	1	2	1	0	1
Sausalito	-0.031	6	2	2	2	3	1	1	1
Rodeo	-0.025	4	1	1	2	1	1	0	0
Central Marin	-0.019	4	4	0	0	1	1	0	0
Delta Diablo	-0.019	2	1	1	0	0	0	0	0
Pinole	-0.015	4	2	0	2	2	1	0	1
SBSA	-0.015	3	0	0	3	1	0	0	1
SAM	-0.012	3	2	0	1	1	1	0	0
Golden Eagle	-0.011	3	1	1	1	0	0	0	0
Vallejo	-0.008	4	3	0	1	1	1	0	0
Central Contra Costa	-0.007	0	0	0	0	0	0	0	0
San Jose	-0.006	1	1	0	0	0	0	0	0
San Mateo	-0.006	3	2	1	0	2	1	1	0
Shell	-0.005	4	1	1	2	0	0	0	0
EBMUD	-0.004	1	0	0	1	1	0	0	1
Palo Alto	-0.004	5	3	2	0	0	0	0	0
Sunnyvale	-0.003	5	2	1	2	0	0	0	0
Calera Ck	-0.001	4	1	1	2	2	0	1	1
FSSD Subregional	0	3	2	0	1	0	0	0	0
Tiburon	0.001	1	0	0	1	1	0	0	1
Mt. View	0.003	2	1	0	1	0	0	0	0
SF Airport Sanitary	0.004	4	2	1	1	1	1	0	0
SF-SE, NP&BS	0.007	2	1	0	1	0	0	0	0
SF Airport Indus	0.009	3	1	2	0	0	0	0	0
North San Mateo	0.054	1	0	1	0	1	0	1	0
Millbrae	0.066	2	0	0	2	0	0	0	0

Table 3.9c. Copper concentration-Time regression slopes and ACL frequencies

FACILITY	TIME COEFFICIENT	All MMP ACLs				ACL addresses Copper Violations			
		2000-2012	2000-2003	2004-2007	2008-2012	2000-2012	2000-2003	2004-2007	2008-2012
Dublin	-0.316	1	0	1	0	0	0	0	0
Tiburon	-0.088	1	0	0	1	0	0	0	0
SF-SE, NP&BS	-0.065	2	1	0	1	0	0	0	0
SBSA	-0.051	3	0	0	3	0	0	0	0
SF Airport Sanitary	-0.049	4	2	1	1	0	0	0	0
EBMUD	-0.043	1	0	0	1	0	0	0	0
EBDA	-0.039	1	0	1	0	0	0	0	0
SF Airport Indus	-0.038	3	1	2	0	3	1	2	0
West County	-0.033	6	3	1	2	3	3	0	0
Golden Eagle	-0.029	3	1	1	1	0	0	0	0
Burlingame	-0.026	5	4	1	0	1	1	0	0
Sonoma Valley	-0.026	7	3	1	3	0	0	0	0
Shell	-0.02	4	1	1	2	0	0	0	0
Delta Diablo	-0.015	2	1	1	0	0	0	0	0
South SF-San Bruno	-0.014	5	3	1	1	0	0	0	0
Benicia	-0.006	7	4	2	1	1	0	1	0
FSSD Subregional	-0.006	3	2	0	1	1	1	0	0
Millbrae	-0.004	2	0	0	2	0	0	0	0
San Jose	-0.003	1	1	0	0	0	0	0	0
Vallejo	-0.001	4	3	0	1	0	0	0	0
American Canyon	0.002	3	0	1	2	1	0	1	0
Calera Ck	0.003	4	1	1	2	1	0	1	0
Central Contra Costa	0.003	0	0	0	0	0	0	0	0
Mt. View	0.005	2	1	0	1	0	0	0	0
Sausalito	0.007	6	2	2	2	0	0	0	0
Sunnyvale	0.009	5	2	1	2	0	0	0	0
Pinole	0.01	4	2	0	2	1	1	0	0
Central Marin	0.011	4	4	0	0	0	0	0	0
Palo Alto	0.013	5	3	2	0	1	1	0	0

Table 3.9d. Cyanide concentration-Time regression slopes and ACL frequencies

FACILITY	TIME COEFFICIENT	All MMP ACLs				ACL addresses Cyanide violations			
		2000-2012	2000-2003	2004-2007	2008-2012	2000-2012	2000-2003	2004-2007	2008-2012
South SF-San Bruno	-0.097	5	3	1	1	3	2	1	0
SF Airport Indus	-0.072	3	1	2	0	0	0	0	0
SF Airport Sanitary	-0.059	4	2	1	1	0	0	0	0
Sausalito	-0.053	6	2	2	2	1	0	1	0
Delta Diablo	-0.047	2	1	1	0	1	0	1	0
SF-SE, NP&BS	-0.041	2	1	0	1	0	0	0	0
Golden Eagle	-0.041	3	1	1	1	1	0	1	0
SBSA	-0.039	3	0	0	3	0	0	0	0
Dublin	-0.037	1	0	1	0	0	0	0	0
Benicia	-0.037	7	4	2	1	1	0	1	0
Calera Ck	-0.03	4	1	1	2	2	0	1	1
Sunnyvale	-0.028	5	2	1	2	3	2	1	0
San Jose	-0.028	1	1	0	0	0	0	0	0
Mt. View	-0.02	2	1	0	1	0	0	0	0
Burlingame	-0.02	5	4	1	0	2	1	1	0
West County	-0.02	6	3	1	2	1	1	0	0
Central Contra Costa	-0.018	0	0	0	0	0	0	0	0
Vallejo	-0.017	4	3	0	1	0	0	0	0
Central Marin	-0.017	4	4	0	0	0	0	0	0
Palo Alto	-0.015	5	3	2	0	0	0	0	0
Shell	-0.013	4	1	1	2	0	0	0	0
Tiburon	-0.011	1	0	0	1	0	0	0	0
Pinole	-0.01	4	2	0	2	0	0	0	0
San Mateo	-0.009	3	2	1	0	1	1	0	0
FSSD Subregional	-0.009	3	2	0	1	1	1	0	0
Sonoma Valley	-0.009	7	3	1	3	2	0	0	2
EBMUD	-0.007	1	0	0	1	0	0	0	0
American Canyon	-0.005	3	0	1	2	1	0	1	0
Millbrae	-0.004	2	0	0	2	2	0	0	2
EBDA	-0.003	1	0	1	0	0	0	0	0
Rodeo	0.003	4	1	1	2	0	0	0	0
Livermore	0.031	1	1	0	0	1	1	0	0

Table 3.10a. BOD Regression Model Results

Model Variable	Model 1		Model 2		Model 3		Model 4	
	Estimate	Signif.	Estimate	Signif.	Estimate	Signif.	Estimate	Signif.
(Intercept)	0.925	a	0.917	a	0.937	a	0.910	a
$EFF_{i\ (t-1\ month)}$	0.505	a	0.506	a	0.510	a	0.510	a
$EFF_{i\ (t-12\ month)}$	0.075	a	0.073	a	0.079	a	0.079	a
$CDOTSO_{i\ t}$	-0.046	d	-0.056	c	-0.046	d	-0.052	c
$ACLQ_{i\ t\ 1}$	-0.024							
$ACLQ_{i\ t\ 2}$	-0.044							
$ACLQ_{i\ t\ 3}$	0.043							
$ACLQ_{i\ t\ 4}$	-0.005							
$ACLQ_{i\ t\ 5}$	0.003							
$ACLQ_{i\ t\ 6}$	-0.008							
$ACLQ_{i\ t\ 7}$	0.006							
$ACLQ_{i\ t\ 8}$	-0.032							
$ACLQ_{i\ t\ 9}$	-0.028							
$ACLQ_{i\ t\ 10}$	-0.008							
$ACLQ_{i\ t\ 11}$	-0.019							
$ACLQ_{i\ t\ 12}$	0.011							
$ACLQ_{i\ t\ 13}$	0.010							
$ACLQ_{i\ t\ 14}$	-0.002							
$ACLQ_{i\ t\ 15}$	0.019							
$ACLQ_{i\ t\ 16}$	-0.036							
$ACLQ_{i\ t\ 17}$	-0.029							
$ACLQ_{i\ t\ 18}$	-0.056	c						
$ACLQ_{i\ t\ 19}$	-0.017							
$ACLQ_{i\ t\ 20}$	-0.035							
$ACLEFFQ_{i\ t\ 1}$			0.039					
$ACLEFFQ_{i\ t\ 2}$			-0.065					
$ACLEFFQ_{i\ t\ 3}$			0.159					
$ACLEFFQ_{i\ t\ 4}$			0.150					
$ACLEFFQ_{i\ t\ 5}$			-0.008					
$ACLEFFQ_{i\ t\ 6}$			-0.055					
$ACLEFFQ_{i\ t\ 7}$			0.037					
$ACLEFFQ_{i\ t\ 8}$			-0.101					
$ACLEFFQ_{i\ t\ 9}$			-0.075					
$ACLEFFQ_{i\ t\ 10}$			-0.059					
$ACLEFFQ_{i\ t\ 11}$			-0.019					
$ACLEFFQ_{i\ t\ 12}$			-0.033					
$ACLEFFQ_{i\ t\ 13}$			0.075					
$ACLEFFQ_{i\ t\ 14}$			-0.016					
$ACLEFFQ_{i\ t\ 15}$			0.086					
$ACLEFFQ_{i\ t\ 16}$			-0.014					
$ACLEFFQ_{i\ t\ 17}$			0.001					
$ACLEFFQ_{i\ t\ 18}$			0.070					
$ACLEFFQ_{i\ t\ 19}$			0.058					
$ACLEFFQ_{i\ t\ 20}$			0.016					
$ACLY_{i\ t\ 1}$					-0.009			
$ACLY_{i\ t\ 2}$					0.001			
$ACLY_{i\ t\ 3}$					-0.009			
$ACLY_{i\ t\ 4}$					-0.003			
$ACLY_{i\ t\ 5}$					-0.027	d		
$ACLEFFY_{i\ t\ 1}$							0.053	
$ACLEFFY_{i\ t\ 2}$							0.003	
$ACLEFFY_{i\ t\ 3}$							-0.038	
$ACLEFFY_{i\ t\ 4}$							0.031	
$ACLEFFY_{i\ t\ 5}$							0.025	
Adjusted R-squared	0.829		0.829		0.831		0.831	
DF	2328		2328		2568		2568	

Signif. codes: 0 'a' 0.001 'b' 0.01 'c' 0.05 'd' 0.1 ' ' 1

Table 3.10b. TSS Regression Model Results

Model Variable	Model 1		Model 2		Model 3		Model 4	
	Estimate	Signif.	Estimate	Signif.	Estimate	Signif.	Estimate	Signif.
(Intercept)	0.912	a	0.972	a	0.763	a	0.809	a
$EFF_{i\,(t-1\,month)}$	0.472	a	0.477	a	0.485	a	0.494	a
$EFF_{i\,(t-12\,month)}$	0.075	a	0.083	a	0.079	a	0.084	a
$CDOTSO_{i\,t}$	-0.018		-0.002		-0.005		0.010	
$ACLQ_{i\,t\,1}$	0.912							
$ACLQ_{i\,t\,2}$	0.472							
$ACLQ_{i\,t\,3}$	0.075							
$ACLQ_{i\,t\,4}$	-0.001							
$ACLQ_{i\,t\,5}$	-0.014							
$ACLQ_{i\,t\,6}$	0.038							
$ACLQ_{i\,t\,7}$	0.024							
$ACLQ_{i\,t\,8}$	0.024							
$ACLQ_{i\,t\,9}$	0.035							
$ACLQ_{i\,t\,10}$	0.070	c						
$ACLQ_{i\,t\,11}$	0.045	d						
$ACLQ_{i\,t\,12}$	0.052	c						
$ACLQ_{i\,t\,13}$	0.032							
$ACLQ_{i\,t\,14}$	0.046	d						
$ACLQ_{i\,t\,15}$	0.045	d						
$ACLQ_{i\,t\,16}$	0.049	c						
$ACLQ_{i\,t\,17}$	0.008							
$ACLQ_{i\,t\,18}$	0.016							
$ACLQ_{i\,t\,19}$	-0.006							
$ACLQ_{i\,t\,20}$	-0.002							
$ACLEFFQ_{i\,t\,1}$			-0.068					
$ACLEFFQ_{i\,t\,2}$			-0.032					
$ACLEFFQ_{i\,t\,3}$			-0.090					
$ACLEFFQ_{i\,t\,4}$			-0.070					
$ACLEFFQ_{i\,t\,5}$			-0.079					
$ACLEFFQ_{i\,t\,6}$			-0.042					
$ACLEFFQ_{i\,t\,7}$			-0.079					
$ACLEFFQ_{i\,t\,8}$			-0.007					
$ACLEFFQ_{i\,t\,9}$			-0.088	d				
$ACLEFFQ_{i\,t\,10}$			0.021					
$ACLEFFQ_{i\,t\,11}$			0.033					
$ACLEFFQ_{i\,t\,12}$			0.063					
$ACLEFFQ_{i\,t\,13}$			0.001					
$ACLEFFQ_{i\,t\,14}$			-0.006					
$ACLEFFQ_{i\,t\,15}$			-0.002					
$ACLEFFQ_{i\,t\,16}$			0.000					
$ACLEFFQ_{i\,t\,17}$			-0.067					
$ACLEFFQ_{i\,t\,18}$			0.047					
$ACLEFFQ_{i\,t\,19}$			0.049					
$ACLEFFQ_{i\,t\,20}$			-0.011					
$ACLY_{i\,t\,1}$					-0.023			
$ACLY_{i\,t\,2}$					0.016			
$ACLY_{i\,t\,3}$					0.052	a		
$ACLY_{i\,t\,4}$					0.046	a		
$ACLY_{i\,t\,5}$					0.005			
$ACLEFFY_{i\,t\,1}$							-0.061	c
$ACLEFFY_{i\,t\,2}$							-0.034	
$ACLEFFY_{i\,t\,3}$							0.017	
$ACLEFFY_{i\,t\,4}$							-0.003	
$ACLEFFY_{i\,t\,5}$							-0.002	
Adjusted R-squared	0.877		0.876		0.867		0.876	
DF	2812		2812		3088		3088	

Signif. codes: 0 ‘a’ 0.001 ‘b’ 0.01 ‘c’ 0.05 ‘d’ 0.1 ‘ ’ 1

Table 3.10c. Copper Regression Model Results

Model Variable	Model 1		Model 2		Model 3		Model 4	
	Estimate	Signif.	Estimate	Signif.	Estimate	Signif.	Estimate	Signif.
(Intercept)	0.511	a	0.434	a	0.693	a	0.631	a
$EFF_{i\ (t-1\ month)}$	0.432	a	0.436	a	0.448	a	0.456	a
$EFF_{i\ (t-12\ month)}$	0.119	a	0.128	a	0.139	a	0.145	a
$CDOTSO_{i\ t}$	0.001		0.005		0.015		0.009	
$ACLQ_{i\ t\ 1}$	0.059	.						
$ACLQ_{i\ t\ 2}$	0.012							
$ACLQ_{i\ t\ 3}$	-0.012							
$ACLQ_{i\ t\ 4}$	0.017							
$ACLQ_{i\ t\ 5}$	-0.029							
$ACLQ_{i\ t\ 6}$	-0.033							
$ACLQ_{i\ t\ 7}$	-0.054	.						
$ACLQ_{i\ t\ 8}$	-0.043							
$ACLQ_{i\ t\ 9}$	-0.043							
$ACLQ_{i\ t\ 10}$	0.036							
$ACLQ_{i\ t\ 11}$	-0.009							
$ACLQ_{i\ t\ 12}$	-0.072	c						
$ACLQ_{i\ t\ 13}$	-0.037							
$ACLQ_{i\ t\ 14}$	-0.016							
$ACLQ_{i\ t\ 15}$	-0.050	d						
$ACLQ_{i\ t\ 16}$	-0.018							
$ACLQ_{i\ t\ 17}$	-0.034							
$ACLQ_{i\ t\ 18}$	-0.033							
$ACLQ_{i\ t\ 19}$	-0.049	d						
$ACLQ_{i\ t\ 20}$	0.018							
$ACLEFFQ_{i\ t\ 1}$			0.079					
$ACLEFFQ_{i\ t\ 2}$			-0.084					
$ACLEFFQ_{i\ t\ 3}$			0.277	c				
$ACLEFFQ_{i\ t\ 4}$			-0.067					
$ACLEFFQ_{i\ t\ 5}$			-0.202	d				
$ACLEFFQ_{i\ t\ 6}$			0.092					
$ACLEFFQ_{i\ t\ 7}$			0.072					
$ACLEFFQ_{i\ t\ 8}$			0.054					
$ACLEFFQ_{i\ t\ 9}$			0.047					
$ACLEFFQ_{i\ t\ 10}$			0.168	c				
$ACLEFFQ_{i\ t\ 11}$			0.002					
$ACLEFFQ_{i\ t\ 12}$			-0.145	d				
$ACLEFFQ_{i\ t\ 13}$			0.079					
$ACLEFFQ_{i\ t\ 14}$			-0.007					
$ACLEFFQ_{i\ t\ 15}$			0.061					
$ACLEFFQ_{i\ t\ 16}$			0.044					
$ACLEFFQ_{i\ t\ 17}$			0.013					
$ACLEFFQ_{i\ t\ 18}$			-0.054					
$ACLEFFQ_{i\ t\ 19}$			-0.023					
$ACLEFFQ_{i\ t\ 20}$			0.059					
$ACLY_{i\ t\ 1}$					0.003			
$ACLY_{i\ t\ 2}$					-0.044	c		
$ACLY_{i\ t\ 3}$					-0.046	b		
$ACLY_{i\ t\ 4}$					-0.036	c		
$ACLY_{i\ t\ 5}$					-0.019			
$ACLEFFY_{i\ t\ 1}$							0.009	
$ACLEFFY_{i\ t\ 2}$							-0.017	
$ACLEFFY_{i\ t\ 3}$							-0.033	
$ACLEFFY_{i\ t\ 4}$							0.036	
$ACLEFFY_{i\ t\ 5}$							0.005	
Adjusted R-squared	0.686		0.686		0.689		0.688	
DF	2569		2569		2836		2836	

Signif. codes: 0 ‘a’ 0.001 ‘b’ 0.01 ‘c’ 0.05 ‘d’ 0.1 ‘ ’ 1

Table 3.10d. Cyanide Regression Model Results

Model Variable	Model 1		Model 2		Model 3		Model 4	
	Estimate	Signif.	Estimate	Signif.	Estimate	Signif.	Estimate	Signif.
(Intercept)	0.147		0.138		0.120		0.122	
$EFF_{i\ (t-1\ month)}$	0.348	a	0.347	a	0.337	a	0.338	a
$EFF_{i\ (t-12\ month)}$	0.092	a	0.093	a	0.107	a	0.107	a
$CDOTSO_{i\,t}$	-0.081	d	-0.077	d	-0.099	c	-0.093	c
$ACLQ_{i\,t\,1}$	0.025							
$ACLQ_{i\,t\,2}$	0.007							
$ACLQ_{i\,t\,3}$	0.000							
$ACLQ_{i\,t\,4}$	0.080							
$ACLQ_{i\,t\,5}$	-0.007							
$ACLQ_{i\,t\,6}$	0.035							
$ACLQ_{i\,t\,7}$	-0.038							
$ACLQ_{i\,t\,8}$	0.111	c						
$ACLQ_{i\,t\,9}$	-0.036							
$ACLQ_{i\,t\,10}$	-0.028							
$ACLQ_{i\,t\,11}$	-0.013							
$ACLQ_{i\,t\,12}$	-0.027							
$ACLQ_{i\,t\,13}$	0.021							
$ACLQ_{i\,t\,14}$	-0.068							
$ACLQ_{i\,t\,15}$	0.030							
$ACLQ_{i\,t\,16}$	0.028							
$ACLQ_{i\,t\,17}$	0.027							
$ACLQ_{i\,t\,18}$	0.061							
$ACLQ_{i\,t\,19}$	-0.072							
$ACLQ_{i\,t\,20}$	0.049							
$ACLEFFQ_{i\,t\,1}$			0.143					
$ACLEFFQ_{i\,t\,2}$			-0.050					
$ACLEFFQ_{i\,t\,3}$			-0.166	d				
$ACLEFFQ_{i\,t\,4}$			0.110					
$ACLEFFQ_{i\,t\,5}$			0.031					
$ACLEFFQ_{i\,t\,6}$			0.063					
$ACLEFFQ_{i\,t\,7}$			-0.055					
$ACLEFFQ_{i\,t\,8}$			0.092					
$ACLEFFQ_{i\,t\,9}$			-0.094					
$ACLEFFQ_{i\,t\,10}$			0.001					
$ACLEFFQ_{i\,t\,11}$			0.076					
$ACLEFFQ_{i\,t\,12}$			0.016					
$ACLEFFQ_{i\,t\,13}$			0.063					
$ACLEFFQ_{i\,t\,14}$			0.093					
$ACLEFFQ_{i\,t\,15}$			-0.092					
$ACLEFFQ_{i\,t\,16}$			0.061					
$ACLEFFQ_{i\,t\,17}$			-0.084					
$ACLEFFQ_{i\,t\,18}$			0.042					
$ACLEFFQ_{i\,t\,19}$			-0.134					
$ACLEFFQ_{i\,t\,20}$			0.166	d				
$ACLY_{i\,t\,1}$					0.053	d		
$ACLY_{i\,t\,2}$					0.031			
$ACLY_{i\,t\,3}$					-0.024			
$ACLY_{i\,t\,4}$					-0.002			
$ACLY_{i\,t\,5}$					-0.002			
$ACLEFFY_{i\,t\,1}$							0.052	
$ACLEFFY_{i\,t\,2}$							0.014	
$ACLEFFY_{i\,t\,3}$							0.020	
$ACLEFFY_{i\,t\,4}$							0.014	
$ACLEFFY_{i\,t\,5}$							-0.013	
Adjusted R-squared	0.536		0.537		0.531		0.530	
DF	3009		3009		3303		3303	

Signif. codes: 0 ‘a’ 0.001 ‘b’ 0.01 ‘c’ 0.05 ‘d’ 0.1 ‘ ’ 1

Table 3.11. Significant results from ACL-concentration regression models

	Model 1 Total ACLs lagged by quarters		Model 2 Constituent-specific ACLs lagged by quarters		Model 3 Total ACLs lagged by years		Model 4 Constituent-specific ACLs lagged by years	
Constituent	coeffi-cient	lag	coeffi-cient	lag	coeffi-cient	lag	coeffi-cient	lag
BOD	-0.056	18 qtrs	---	---	-0.027	5 yrs	---	---
TSS	+0.070	10 qtrs	-0.088	9 qtrs	+0.052	3 Yrs	-0.061	1 yr
	+0.045	11 qtrs			+0.046	4 Yrs		
	+0.052	12 qtrs						
	+0.046	14 qtrs						
	+0.045	15 qtrs						
	+0.049	16 qtrs						
Copper (Cu)	-0.072	12 qtrs	+0.277	3 qtrs	-0.044	2 yrs		
	-0.050	15 qtrs	-0.202	5 qtrs	-0.046	3 yrs		
	-0.049	19 qtrs	+.168	10 qtrs	-0.036	4 yrs		
			-0.145	12 qtrs				
Cyanide(CN)	+0.111	8 qtrs	-0.166	3 qtrs	+0.053	1 yr		
			+0.166	20 qtrs				

Table 3.12a. BOD Pollution reduction calculations

Year	# ACLs issued in RB2	Coefficient of total ACL variable lagged 5 years	BOD Average Conc (mg/L)	Pollution reduction (mg/L)	Average WWTP flow *	average reduction mass pollution per day each WWTP (lbs/day)	Average reduction mass pollution per day all WWTPs (lbs/day)	Mass pollutant reduction per year All WWTPs (tons)	# MMP violations	MMP liability assessed ($)	cost per ton reduction ($)	Average cost per WWTP per year ($)	cost per million residents ($)
2000	8	-0.027	10.00						21	63,000			
2001	14	-0.027	9.43						148	444,000			
2002	7	-0.027	9.32						45	135,000			
2003	9	-0.027	9.51						74	222,000			
2004	8	-0.027	9.46						35	105,000			
2005	3	-0.027	9.03	0.075	31.6	19.9	516.2	94	7	21,000	69	26	94
2006	3	-0.027	8.55	0.125	31.6	33.0	858.0	157	138	414,000	2,835	109	397
2007	7	-0.027	7.88	0.057	31.6	15.2	393.9	72	106	318,000	1,878	72	263
2008	10	-0.027	7.85	0.074	31.6	19.4	505.5	92	20	60,000	2,406	93	337
2009	5	-0.027	7.96	0.066	31.6	17.5	455.0	83	62	186,000	1,264	49	177
2010	0	-0.027	7.84	0.024	31.6	6.4	167.6	31	---	---	686	26	96
2011	6	-0.027	7.80	0.024	31.6	6.4	166.9	30	12	36,000	13,592	523	1,901

* 26 wastewater treatment facilities

Table 3.12b. TSS Pollution reduction calculations

Year	# ACLs issued in RB2	Coefficient of constituent-specific ACL variable lagged 1 year	TSS Average Conc (mg/L)	Pollution reduction (mg/L)	Average WWTP flow *	average reduction mass pollution per day each WWTP (lbs/day)	Average reduction mass pollution per day all WWTPs (lbs/day)	Mass pollutant reduction per year All WWTPs (tons/year)	# MMP violations	MMP liability assessed ($)	cost per ton reduction ($)	Average cost per ton per WWTP ($)	cost per million residents ($)
2000	3	-0.061	9.91		28.0				5	15,000			
2001	2	-0.061	10.22	0.063	28.0	14.6	438	80	10	30,000	188	6	26
2002	3	-0.061	9.43	0.038	28.0	9.0	269	49	11	33,000	611	20	85
2003	3	-0.061	9.10	0.056	28.0	13.0	390	71	9	27,000	464	15	65
2004	0	-0.061	9.09	0.056	28.0	13.0	389	71	0	0	380	13	53
2005	1	-0.061	8.88	0.000	28.0	0.0	0	0	1	3,000	----	----	----
2006	1	-0.061	9.30	0.019	28.0	4.4	133	24	5	15,000	124	4	17
2007	2	-0.061	8.64	0.018	28.0	4.1	123	22	43	129,000	667	22	93
2008	3	-0.061	9.02	0.037	28.0	8.6	257	47	4	12,000	2748	92	384
2009	2	-0.061	8.95	0.055	28.0	12.8	383	70	3	9,000	171	6	24
2010	0	-0.061	8.70	0.035	28.0	8.3	248	45	0	0	199	7	28
2011	1	-0.061	8.89	0.000	28.0	0.0	0	0	1	3,000	----	----	----

* 30 wastewater treatment facilities

Table 3.12c. Copper Pollution reduction calculations

Year	# ACLs issued in RB2	Coefficient of total ACL variable lagged 4 years	Copper Average Conc (ug/L)	Pollution reduction (ug/L)	Average WWTP flow *	average reduction mass pollution per day each WWTP (lbs/day)	Average reduction mass pollution per day all WWTPs (lbs/day)	Mass pollutant reduction per year All WWTPs (lbs/year)	# MMP violations	MMP liability assessed ($)	cost per lb reduction ($)	Average cost per lb per WWTP ($)	cost per lb per million residents ($)
2000	11	-0.036	8.61						39	117,000			
2001	16	-0.036	8.78						165	495,000			
2002	7	-0.036	8.53						39	117,000			
2003	10	-0.036	8.53						142	426,000			
2004	8	-0.036	8.14	0.112	28.6	0.0267	0.8	282	35	105,000	414	14	58
2005	2	-0.036	7.91	0.159	28.6	0.0378	1.0	359	6	18,000	1379	48	193
2006	5	-0.036	6.48	0.057	28.6	0.0135	0.4	128	178	534,000	915	32	128
2007	6	-0.036	6.67	0.083	28.6	0.0199	0.5	188	98	294,000	2260	78	316
2008	14	-0.036	6.40	0.064	28.6	0.0152	0.4	145	52	156,000	727	25	102
2009	5	-0.036	5.82	0.014	28.6	0.0034	0.1	33	59	177,000	550	19	77
2010	0	-0.036	5.64	0.035	28.6	0.0084	0.2	79	0	---	6721	232	940
2011	9	-0.036	5.11	0.038	28.6	0.0091	0.2	86	37	111,000	3404	117	476

* 29 wastewater treatment facilties

Table 3.12d. Cyanide Pollution reduction calculations.

Year	# ACLs issued in RB2	Coefficient of constituent-specific ACL variable lagged 3 quarters	Cyanide Average Conc (ug/L)	Pollution reduction (ug/L)	Average WWTP flow *	average reduction mass pollution per day each WWTP (lbs/day)	Average reduction mass pollution per day all WWTPs (lbs/day)	Mass pollutant reduction per year All WWTPs (lbs/year)	# MMP violations	MMP liability assessed ($)	cost per lb reduction ($)	Average cost per WWTP per year ($)	cost per million residents ($)
2000	0	-0.166	6.160										
2001	2	-0.166	6.79	0.000	26.6	0.0000	0.0	0.0	4	12000	---	---	---
2002	2	-0.166	5.692	0.059	26.6	0.0132	0.4	153.9	8	24000	78	2	11
2003	5	-0.166	5.395	0.056	26.6	0.0125	0.4	145.9	24	72000	165	5	23
2004	2	-0.166	5.503	0.145	26.6	0.0321	1.0	374.9	3	9000	192	6	27
2005	1	-0.166	4.943	0.052	26.6	0.0114	0.4	133.6	2	6,000	67	2	9
2006	4	-0.166	5.026	0.026	26.6	0.0058	0.2	67.8	5	15,000	89	3	12
2007	2	-0.166	4.381	0.092	26.6	0.0204	0.7	238.1	4	12,000	63	2	9
2008	1	-0.166	4.405	0.046	26.6	0.0102	0.3	119.1	1	3,000	101	3	14
2009	1	-0.166	3.379	0.018	26.6	0.0039	0.1	45.6	1	3,000	66	2	9
2010	0	-0.166	3.188	0.017	26.6	0.0037	0.1	43.0	0	0	70	2	10
2011	2	-0.166	3.187	0.000	26.6	0.0000	0.0	0.0	7	21,000	---	---	---

* 32 wastewater treatment facilities

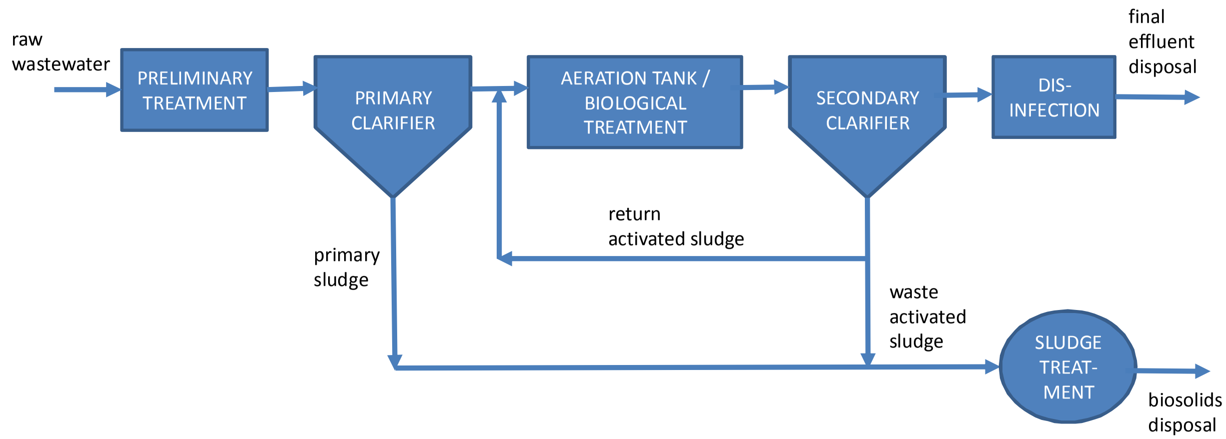


Figure 3.1. Conventional wastewater treatment sequence.

Figure 3.2. Wastewater treatment facilities within the San Francisco Bay Regional Water Quality Control Board jurisdiction.

ID #	FACILITY
0	AMERICAN CANYON WWTP
1	BENICIA WWTP
2	BURLINGAME WWTP
3	CALERA CREEK WATER RECYCLING PLANT
4	CALISTOGA CITY DUNAWEAL WWTP
5	CENTRAL CONTRA COSTA SD WWTP
6	LIVERMORE WATER RECLAMATION PLANT
7	PINOLE WWTP
8	DELTA DIABLO SD WWTP
9	DUBLIN SAN RAMON SD WWTP
10	EBDA COMMON OUTFALL
11	EBMUD SD#1-WET WTHR BYPASS
12	EBMUD WPCP
13	FSSD SUBREGIONAL WWTP
14	LAS GALLINAS WWTP
15	MARIN CSD 5 - TIBURON WWTP
16	MARIN CSD 5 PARADISE COVE WWTP
17	MILLBRAE WWTP
18	MT. VIEW SANITARY DISTRICT WWTP
19	NAPA SD WWTP (Soscol Water Recycling Facility)
20	NORTH SAN MATEO COUNTY SANITATION DISTRICT WWTP
21	NOVATO AND IGNACIO WWTP
22	PALO ALTO REGIONAL WQCP
23	PETALUMA ELLIS CREEK WRF
24	PORT COSTA WWTP
25	RICHMOND WPCP
26	RODEO SANITARY DISTRICT WWTP
27	SAM (Sewer Authority Mid-Coastside) WWTP
28	SAN JOSE/SANTA CLARA WPCP
29	SAN MATEO WWTP
30	SASM WWTP
31	SAUSALITO MARIN CITY STP
32	SBSA WWTP
33	SF ARPRT MEL LEONG TP-INDUSTRIAL
34	SF ARPRT MEL LEONG TP-SANITARY WASTE
35	SF-SE WPCP, NORTH POINT & BAYSIDE
36	SHELL MARTINEZ REFINERY WWTP
37	SONOMA VALLEY COUNTY SD WWTP
38	SOUTH SAN FRANCISCO-SAN BRUNO WQCP
39	SUNNYVALE WPCP
40	VALLEJO SFCD WWTP
41	WEST COUNTY AGENCY OUTFALL
42	PACIFICA WWTP
43	GOLDEN EAGLE REFINERY WWTP

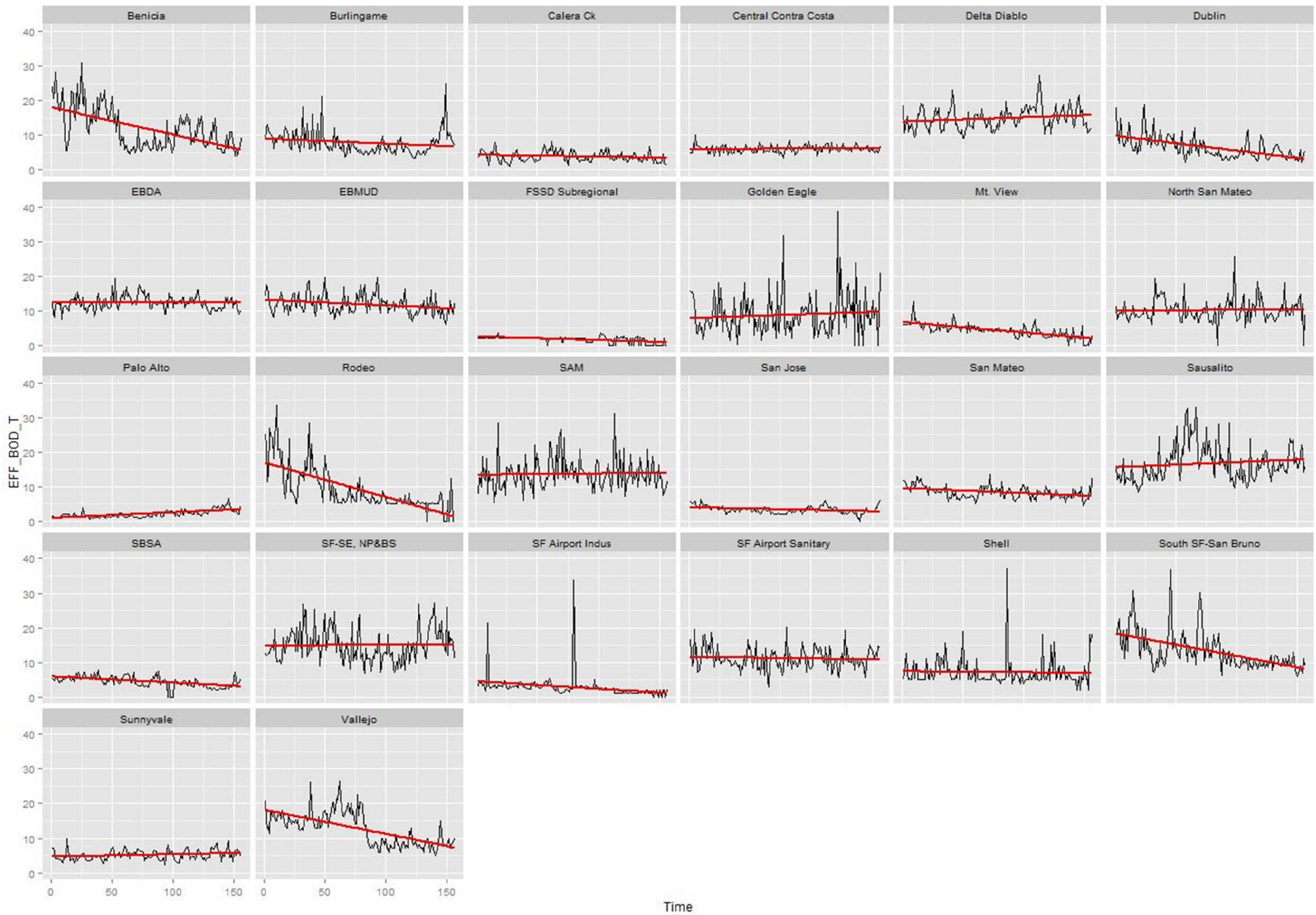


Figure 3.3a. Regression plots of wastewater treatment facility biochemical oxygen demand (BOD) effluent concentration (mg/L) vs. time.

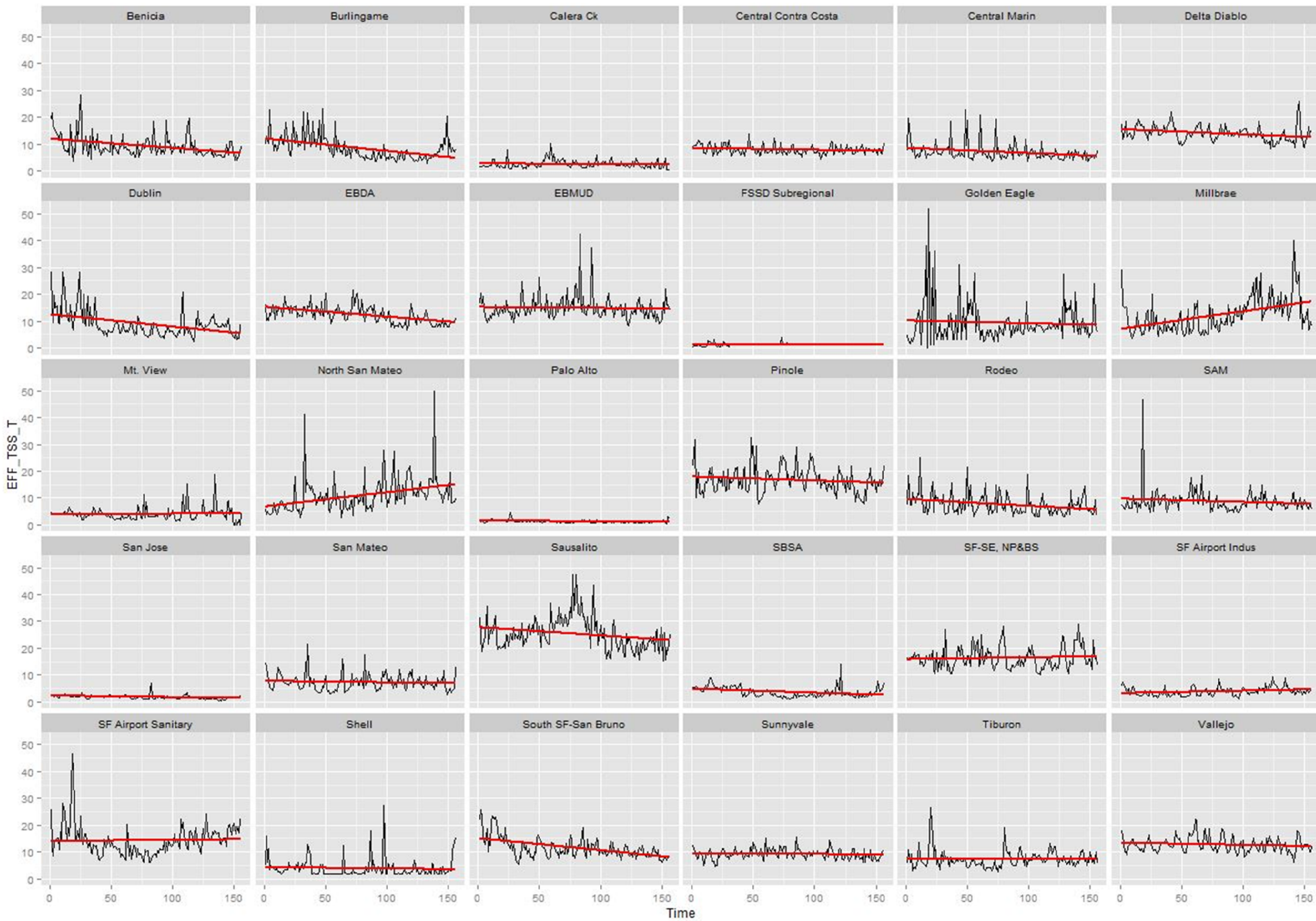


Figure 3.3b. Regression plots of wastewater treatment facility total suspended solids (TSS) effluent concentration (mg/L) vs. time

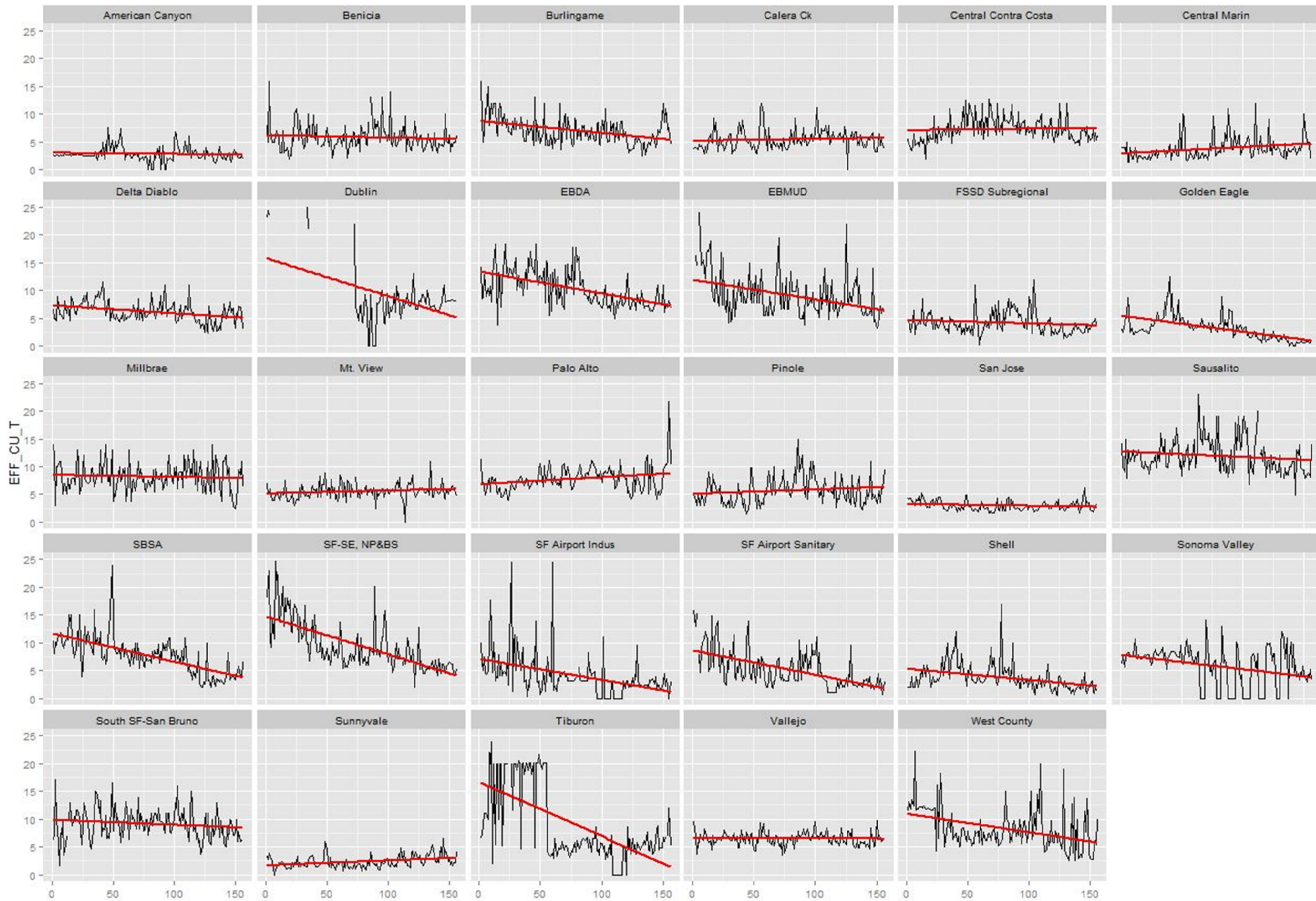


Figure 3.3c. Regression plots of wastewater treatment facility copper (Cu) effluent concentration (ug/L) vs. time.

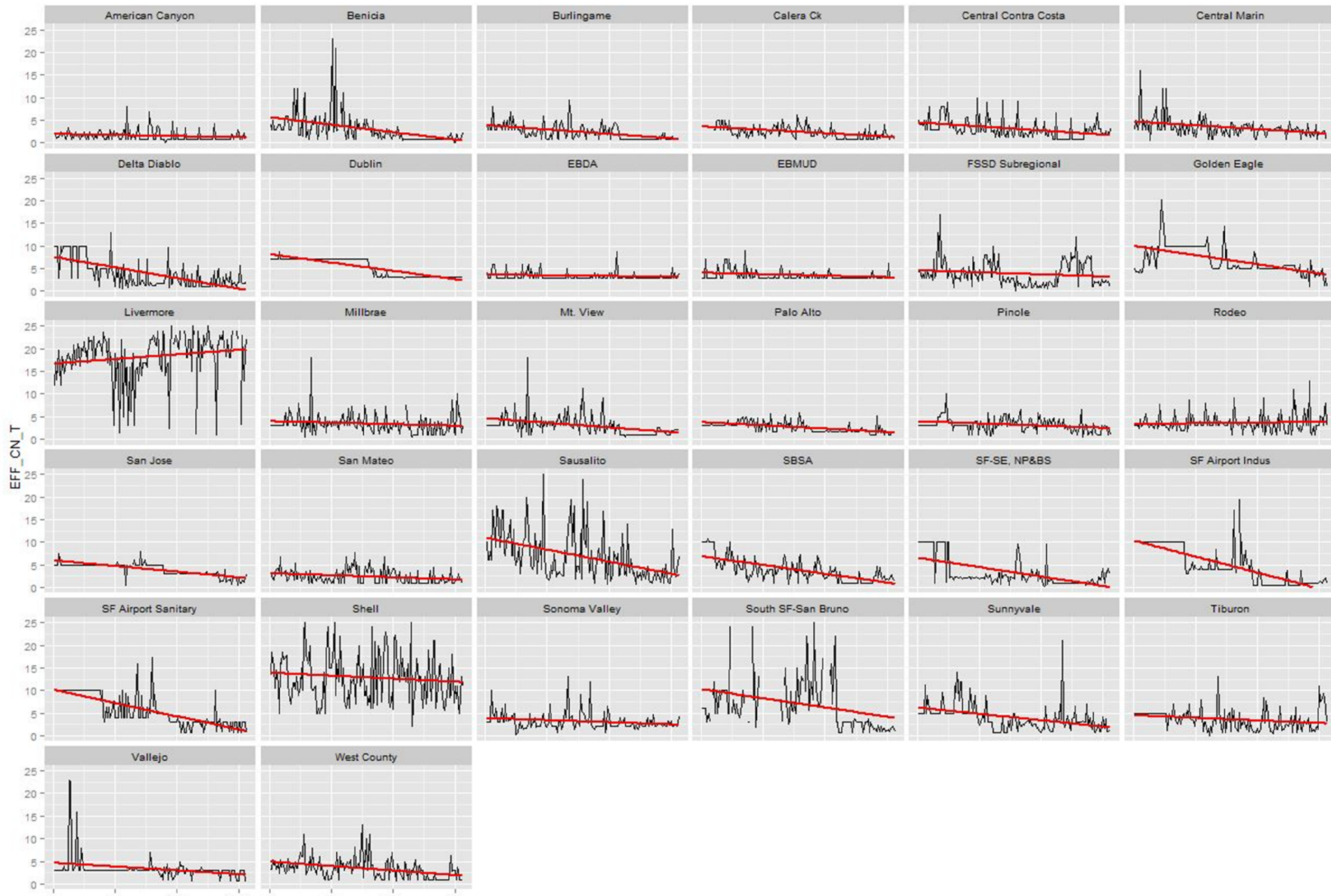


Figure 3.3d. Regression plots of wastewater treatment facility cyanide (CN) effluent concentration (ug/L) vs. time.

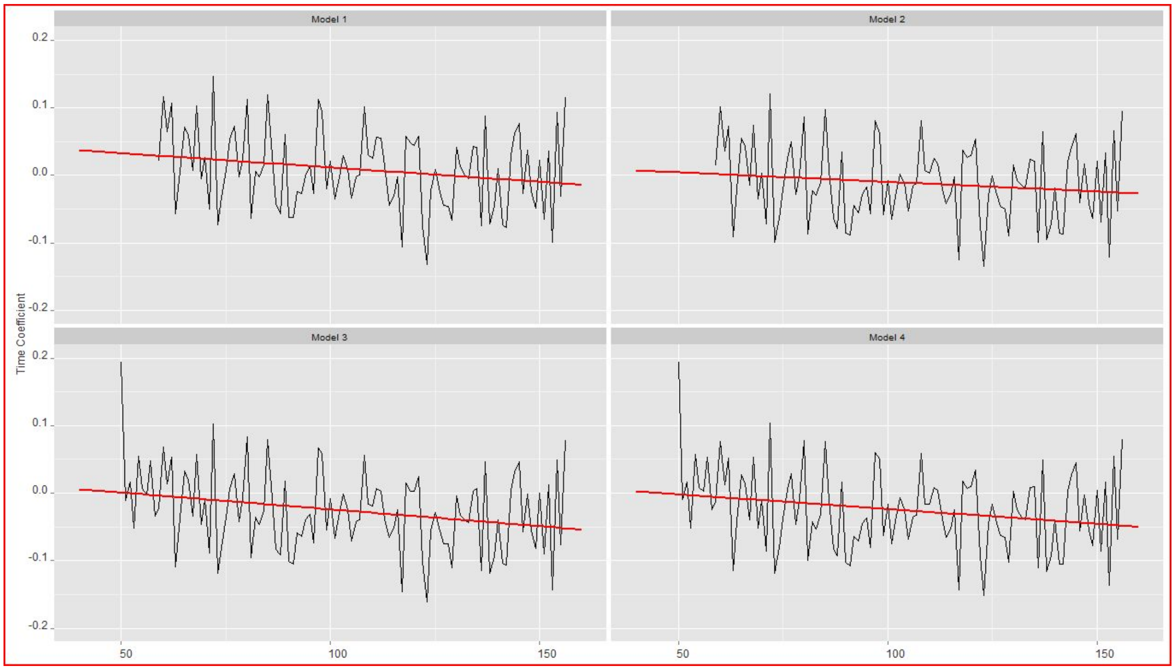


Figure 3.4a. Coefficients of TIME variable from BOD regression Models 1-4 plotted against TIME.

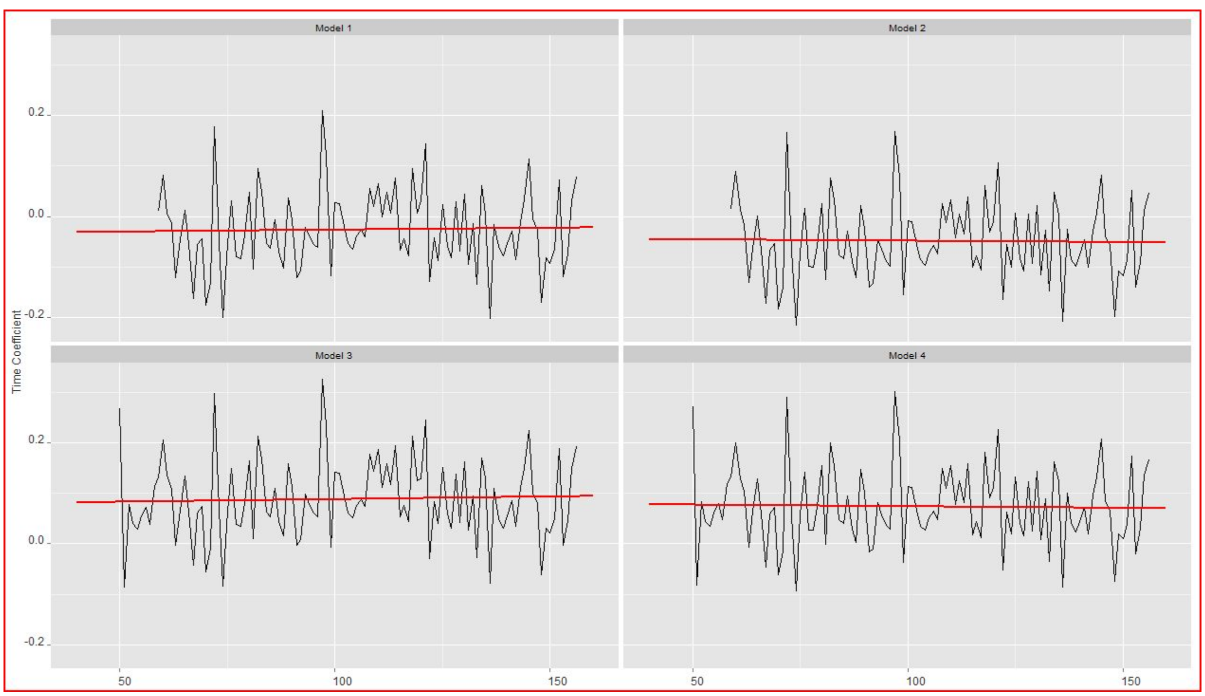


Figure 3.4b. Coefficients of TIME variable from TSS regression Models 1-4 plotted against TIME.

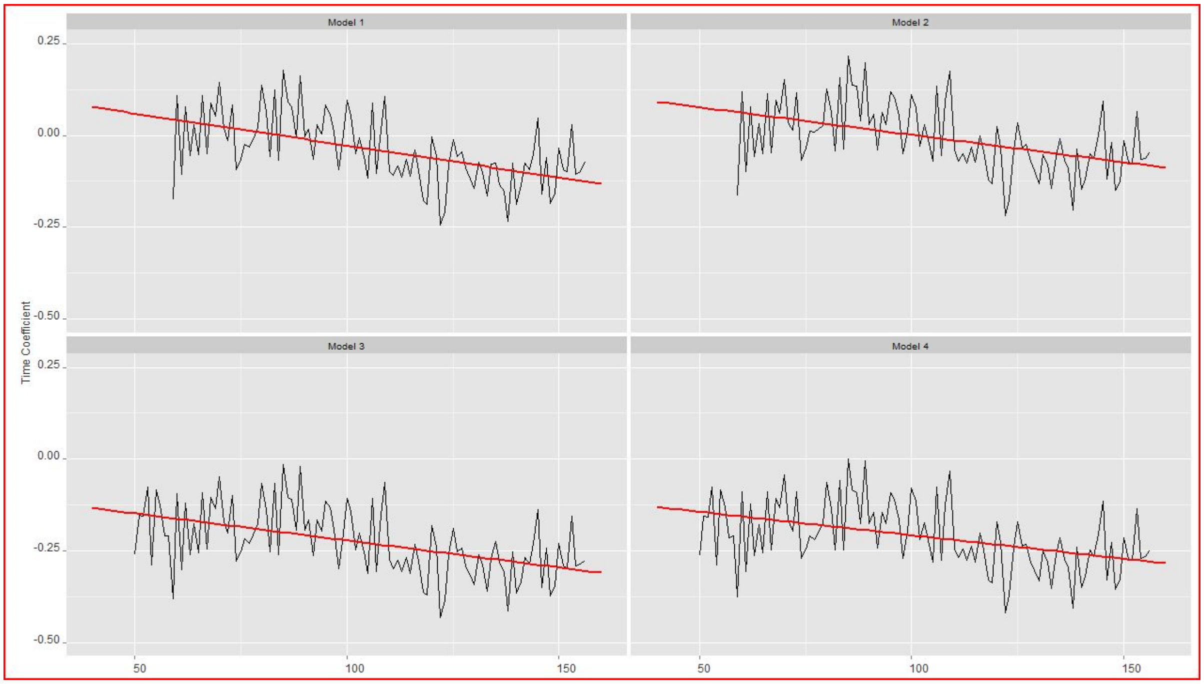


Figure 3.4c. Coefficients of TIME variable from Copper regression Models 1-4 plotted against TIME

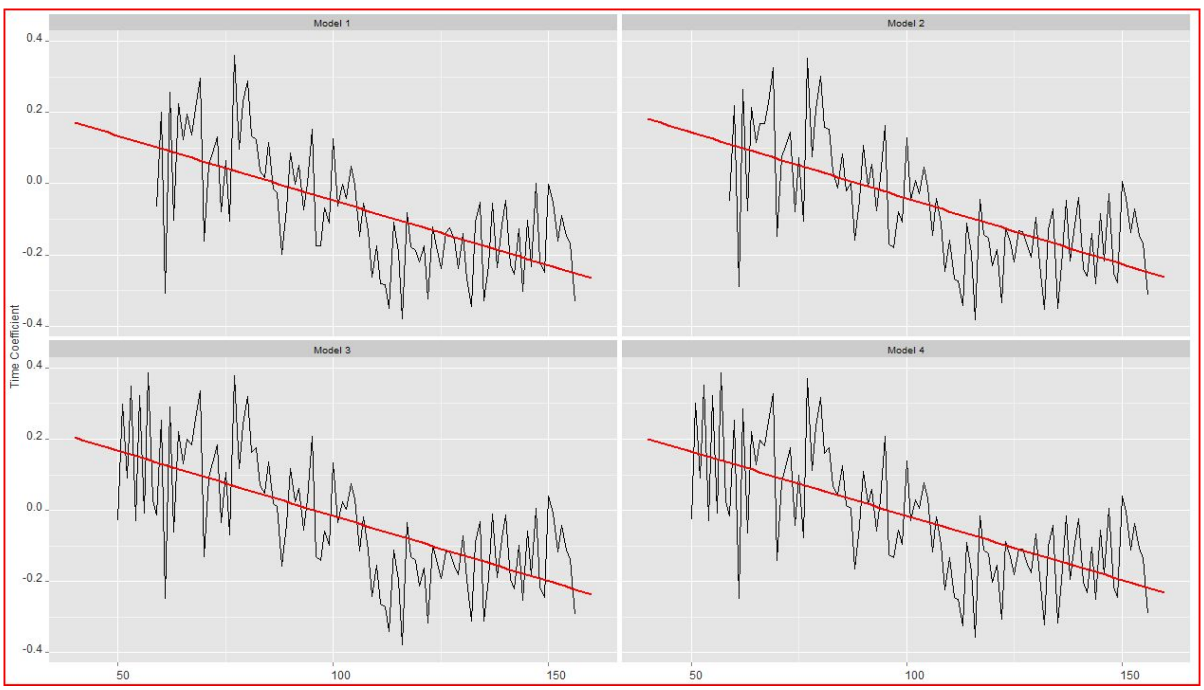


Figure 3.4d. Coefficients of TIME variable from Cyanide regression Models 1-4 plotted against TIME

6. References

Adrison V. (2007). Estimating the Effect of Penalties on Regulatory Compliance. PhD. Dissertation, Georgia State University.

Burian, S. J., Nix, S. J., Pitt, R. E., & Durrans, S. R. (2000). Urban wastewater management in the United States: Past, present, and future. *Journal of Urban Technology*, *7*(3), 33-62.

California State Water Resources Control Board (SWRCB). (May 2009). Report of the Statewide Initiative On Mandatory Minimum Penalty Enforcement.

California State Water Resources Control Board (SWRCB). (May 2010). Water Quality Enforcement Policy.

California State Water Resources Control Board (SWRCB). (June 2011). 2010 Annual Enforcement Report.

Copeland, C. (2010). Clean Water Act: A Summary of the Law. Congressional Research Service, Library of Congress.

Coyne, W &Metzger, L. (May 2004). Mandatory Minimum Penalties, An Effective Tool for enforcement of Clean Water Laws. TexPIRG Education Fund, Austin, Texas.

Earnhart, D. (2004a). Panel data analysis of regulatory factors shaping environmental performance. *Review of Economics and Statistics*, *86*(1), 391-401.

Earnhart, D. (2004b). Regulatory factors shaping environmental performance at publicly-owned treatment plants. *Journal of Environmental Economics and Management*, *48*(1), 655-681.

Ekster, A., & Jenkins, D. (1996). Nickel and copper removal at the San Jose/Santa Clara water pollution control plant. *Water environment research*,*68*(7), 1172-1178.

Gaudy Jr, A. F., Gaudy, E. T., Feng, Y. J., & Brueggemann, G. (1982). Treatment of cyanide waste by the extended aeration process. *Journal (Water Pollution Control Federation*), 153-164.

Goldstone, M. E., Atkinson, C., Kirk, P. W. W., & Lester, J. N. (1990). The behaviour of heavy metals during wastewater treatment III. Mercury and arsenic. *Science of the total environment*, *95*, 271-294.

Jahagirdar, S., & Coyne, W. (2003). Leaking Enforcement. Analyzing the Effectiveness of the 1999 Clean Water Enforcement and Pollution Prevention Act. Environment California Research and Policy Center, Los Angeles, California.

Laplante, B., & Rilstone, P. (1996). Environmental inspections and emissions of the pulp and paper industry in Quebec. *Journal of Environmental Economics and Management*, *31*(1), 19-36.

Lordi, D. T., Lue-Hing, C., Whitebloom, S. W., Kelada, N., & Dennison, S. (1980). Cyanide problems in municipal wastewater treatment plants. *Journal (Water Pollution Control Federation)*, 597-609.

Metcalf & Eddy. (1991). *Wastewater Engineering: Treatment, Disposal, and Reuse*. G. Tchobanoglou, & F. L. Burton (Eds.). McGraw-Hill.

Magat, W. A., & Viscusi, W. K. (1990). Effectiveness of the EPA's regulatory enforcement: The case of industrial effluent standards. *JL & Econ.*, *33*, 331.

Nielsen, J. S., & Hrudey, S. E. (1983). Metal loadings and removal at a municipal activated sludge plant. *Water Research*, *17*(9), 1041-1052.

R Development Core Team. (2008). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

Raco-Rands, V. E. (1989). Characteristics of Effluents from Small Municipal Wastewater Treatment Facilities in 1994. *Small Treatment Facilities*, *1990*, 1995.

Sato, R. and California State Water Resources Control Board (SWRCB). (October 2009). Deconstructing Enforcement, A Primer on Water Quality Enforcement.

Shimshack, J. P., & Ward, M. B. (2005). Regulator reputation, enforcement, and environmental compliance. *Journal of Environmental Economics and Management*, *50*(3), 519-540.

USEPA. (1991). Technical support document for water quality-based toxics control.

USEPA, Office of Water, Office of Wastewater Management. (September 2004). Primer for Municipal Wastewater Treatment Systems. EPA 832-R-04-001. .

USEPA, Office of Wastewater Management, Water Permits Division, State and Regional Branch. (September 2010). NPDES Permit Writer's Manual. EPA-833-K-10-001..

Wild, S. R., Rudd, T., & Neller, A. (1994). Fate and effects of cyanide during wastewater treatment processes. *Science of the Total Environment,* 156(2), 93-107.

Zheng, A., Dzombak, D. A., & Luthy, R. G. (2004a). Formation of free cyanide and cyanogen chloride from chloramination of publicly owned treatment works secondary effluent: Laboratory study with model compounds. *Water Environment Research*, 76(2), 113-120.

Zheng, A., Dzombak, D. A., Luthy, R. G., Kavanaugh, M. C., & Deeb, R. A. (2004b). The occurrence of cyanide formation in six full-scale publicly owned treatment works. *Water Environment Research,* 76(2), 101-112.

CHAPTER FOUR

Evaluation of correlations between effluent quality trends and enforcement actions under California's MMP enforcement program and impacts on water quality in the Sacramento-San Joaquin Delta

1. Introduction

In response to the documented failure by the RWQCBs to carry out enforcement actions to address thousands of violations of NPDES permits across the state, the California legislature enacted the 1999 Clean Water Enforcement and Pollution Prevention Act (CWEA), which amended the California Water Code, (Jahagirdar and Coyne, 2003). Beginning in January 2000, the California legislature has mandated California's nine Regional Water Quality Control Boards (RWQCBs) and the State Water Resources Control Board (SWRCB) to issue a mandatory minimum penalty (MMP) of $3,000 for each instance of serious violation of effluent limitations in NPDES permits and for each chronic effluent violation after the third violation, whether serious or chronic, that occurs within a six-month period. The goal of MMPs is to increase compliance by regulated dischargers with their NPDES permits (Jahagirdar and Coyne, 2003). MMPs presented both the regulated facilities in California and the SWRCB/RWQCBs with a new legal mechanism aimed towards improving water quality. The MMPS also presented the SWRCB/RWQCBs and the regulated facilities with programmatic challenges to equitably assess MMP amounts and evaluate effectiveness.

Early assessments of the effectiveness of the MMP enforcement program in California cited reductions in numbers of violations across the state and an increase in the number of enforcement actions and penalty amounts issued (Jahagirdar and Coyne, 2003; Coyne and Metzger, 2004). Since 2005, the SWRCB prepares an annual Enforcement Report which includes assessments of the MMP enforcement program in terms of number of violations subject to MMPs during the year, number of MMP enforcement actions taken, amount of civil penalties levied, number of facilities that have had violations subject to MMPs during the year, and the percentage of violations subject to MMPs within each RWQCB that have not been assessed the required MMP through an enforcement action (SWRCB, 2011). While such metrics are appropriate for management and administrative purposes, they do not provide information about the effects of MMPs in improving the environment.

Stein and Cadien (2009) point out that the effect of management actions under the Clean Water Act, such as enforcement actions, on environmental quality has not been comprehensively assessed. In addition, they point out that "process based performance measures [such as the tallying of number of facilities with violations] do not measure environmental endpoints . . . and are thus not a true measure of the effect of management action (Stein and Cadien, 2009)." Aside from facility-specific monitoring requirements contained in NPDES permits or program specific monitoring, the SWRQCB and RWQCBs do not have a comprehensive evaluation strategy to assess the impacts of the MMP enforcement program on improving the quality of California's surface waters.

Various approaches to quantify water quality improvements, used by the USEPA and others in cost-benefit analysis and regulatory impact analysis for proposed regulations and for valuation studies, may be used to evaluate the impacts of existing regulatory programs, such as the MMP enforcement program, on water quality. Measurement of individual water quality parameters, such as biochemical oxygen demand, is a commonly used approach in local or regional valuation studies (Griffiths et al, 2012). "Achievement of water quality criteria" is an approach used by USEPA which measures water quality in terms of achieving reductions in pollution levels which then allow a specified beneficial use for a water body (Griffiths et al, 2012). Use of a water quality index (WQI) is an approach which aggregate several individual water quality parameters into a single index to capture and communicate complex information about overall water quality to policy makers and the public (Griffiths et al, 2012;Walsh and Wheeler, 2011).

The objective of this study is to quantitatively estimate the impact of MMPs in improving effluent quality of wastewater treatment facilities that discharge directly or indirectly to the Sacramento-San Joaquin Delta and to determine if the impact of effluent quality changes on the water quality of the Sacramento and San Joaquin Rivers and the Delta can be quantified. There are over 30 wastewater treatment facilities of various sizes within 50 miles of the Delta that discharge treated effluent to surface waters. The water quality parameters considered in this study are total nitrogen and total copper for both effluent quality and surface water quality. These two parameters are appropriate for study because the Delta is listed in the 2010 303(d) list of impaired water bodies for metals and nutrients (Aquatic Science Center, 2012). The main contribution of this investigation is in the preliminary analyses performed on the unique data set collected and assembled from the NPDES and MMP enforcement program public record. Follow-up research will provide additional insights and conclusions regarding the effectiveness of the MMP enforcement program.

The Sacramento-San Joaquin Delta is a network of channels and islands where the Sacramento River and San Joaquin River converge (Monsen et al, 2007). The boundaries of the Delta are legally defined and include portions of the cities of Sacramento to the north and Stockton to the south and San Francisco Bay Area suburbs to the west, see Figure 4.1. The Delta covers 1400 km^2 of wetlands and agricultural land. The Sacramento River drains the northern Central Valley of California and enters the Delta from the north. The San Joaquin River is drains the southern Central Valley and enters the Delta from the south. The Delta empties into Suisun Bay, an arm of San Francisco Bay. The Delta is habitat to the endangered Delta smelt, and endangered or threatened steelhead trout and winter and spring runs of chinook salmon migrate through the Delta on their way to and from inland spawning grounds (DWR, 2007). The Delta is also a major source of water for the southern portion of the state, providing water for irrigation of farms in the southern San Joaquin Valley and up to 30 percent of .the drinking water for southern California cities, delivered via canals such as the California Aqueduct (Aquatic Science Center, 2012).

The Delta serves as the mixing zone for inflows from the Sacramento River, the San Joaquin River, and their tributaries; however, the hydrology of the Delta is made more complex due to the operation of cross channel gates in the north Delta, and pumping facilities for water export and a seasonal rock barrier across the Old River in the south Delta (Monsen et al, 2007). As shown in the system schematics in Figure 4.2, the bulk of Sacramento River flows bypass the central Delta when the cross-channel gates are closed to facilitate salmon outmigration, and the full flow of the lower quality San Joaquin River water is forced into the central Delta when the seasonal rock barrier is in place (Monsen et al, 2007). Furthermore, the export pumps induce southward flow from the central Delta (Monsen et al, 2007). Monsen et al (2007) showed through hydrologic modeling that water quality in the different subareas of the Delta will have localized variations due to the complex hydrology of the Delta.

Depending on the number of facilities that discharge to a water body and the daily volume discharged from the facilities, wastewater treatment facilities can be a significant source of total nitrogen in estuaries and rivers (Carey and Migliaccio, 2009). Other sources of total nitrogen are agricultural operations, which are significant in the Central Valley, and atmospheric deposition.

Once in the water body, removal of total nitrogen may occur through denitrification by bacteria which converts to total nitrogen to nitrogen gas (N_2) or nitrogen oxide (N_2O), uptake by algae and other aquatic plants, or sedimentation (Saunders and Kalff, 2001). Greater total nitrogen removal occurs in wetlands than in rivers due to longer residence time in wetlands which are conducive to denitrification and sedimentation (Saunders and Kalff, 2001). Denitrification was found to be more efficient upstream of wastewater treatment facility discharge points than downstream (Lofton et al, 2007), which may be due to lower removal efficiencies as nutrient load increase (Marti et al, 2004). Consequently, total nitrogen discharged to the rivers and streams of the Central Valley would likely to be transported into the Delta rather than removed

The total copper discharged from wastewater treatment facilities may be in particulate form or in the dissolved phase, with copper in the dissolve phase comprising 47% to 92% of the total (Shi eta al, 1997). Once discharged to freshwater receiving waters, dissolved copper may become adsorbed to organic and non-organic particles and suspended matter in the receiving water and may either become transported downstream or settle into the sediments (Shi, 1997; Helz, 1975; Sodre and Grassi, 2006). However, upon entering higher salinity waters in estuaries, copper is again released into the dissolved phase from particles, suspended matter, and sediments (Windom et al, 1983). Consequently, total copper discharged from wastewater treatment facilities to surface waters in the Central Valley is likely ultimately transported to the Delta either in particulate or dissolved form.

2. Data and Methods

2.1. General Approach

This study analyzes the correlation between the quality of the effluent discharged by wastewater treatment facilities to surface waters under an NPDES permit and the MMP enforcement actions taken by a regulatory agency. Monthly effluent concentration data for several discharging facilities were correlated with the occurrence of enforcement actions using linear regressions. The discharging facilities considered in this study are the major (i.e., discharging one million gallons per day or greater) municipal wastewater treatment facilities that discharge treated wastewater effluent either directly or indirectly to the Sacramento-San Joaquin Delta, as shown in Figure 4.3. All facilities are within the jurisdiction of the Sacramento and Fresno offices of the Central Valley RWQCB except for one located within the San Francisco Bay RWQCB. This study also quantifies the level of pollution prevented, if any, as a result of MMP enforcement actions and whether a measurable effect on the water quality of the Delta is possible to observe using a simple mass balance model using observed natural freshwater flowrates through the Delta.

2.2. Data

2.2.1. Effluent Data

Twenty major wastewater treatment facilities regulated under NPDES permits located within 50 miles of the legal boundary of the Sacramento-San Joaquin Delta were identified. Effluent concentration data for these twenty facilities were obtained in electronic format from the Permit Compliance System (PCS) and Integrated Compliance Information System (ICIS) databases maintained by the USEPA and which can be accessed through USEPA's Envirofacts website[1]. Effluent concentration data for the constituents total nitrogen and total copper were obtained for the period 2000-2012 with the goal of constructing a continuous time series of quarterly effluent concentration values or quarterly averages covering as many years as were available. Depending on the frequency of monitoring required by the respective NPDES permits for the facilities,

[1] http://www.epa.gov/enviro/

monthly, quarterly or only semiannual results were available. Quarterly averages were calculated when monthly results were available, while semiannual results were assigned to the quarter in which the sample result was taken. When the quarterly series have missing values, these were filled in using averages of available data when there was no apparent pattern to the occurrence of missing values. For some facilities, significant portions of the monthly data series were missing, and it was necessary to eliminate those facilities from the study, as discussed below. Out of the 20 facilities considered, 16 facilities had substantially complete quarterly effluent concentration series for total nitrogen and 17 facilities for total copper for the period January 2004 through December 2012. A plot of the quarterly total nitrogen and total copper effluent concentration data were plotted against time for each facility, as shown in Figures 4.4a and 4.4b.

2.2.2. ACL and CDO/TSO enforcement action data

ACL and CDO/TSO enforcement action data were obtained from the California Integrated Water Quality System (CIWQS) database website[2] maintained by the SWRCB. The CIWQS database contains a large range of information regarding discharging facilities and regulatory actions. The CIWQS query identified 62ACLs issued to the 16 facilities considered for the total nitrogen statistical analysis and 64 ACLs issued to the 17 facilities considered for the total copper statistical analysis. The CIWQS query identified 74 CDOs or TSOs issued to the16 facilities considered for the total nitrogen statistical analysis and 75 CDOs or TSOs issued to the 17 facilities considered for the total copper statistical analysis. The CIWQS query results provide the effective dates of the enforcement actions. Additional details about CIWQS and how

[2] http://www.waterboards.ca.gov/water_issues/programs/ciwqs/publicreports.shtml

ACL and CDO/TSO enforcement action data is queried from CIWQS is provided in Section 2.2.3 of Chapter 3 of this dissertation.

2.3. Delta flowrates

Flowrate data for the various freshwater inputs to the Delta were obtained from the California Department of Water Resources Dayflow website[3] for use in Delta mass balance models. Monthly volumes of water entering the Delta from the Sacramento River, San Joaquin River, various tributaries, and precipitation were obtained for the period 2008 through 2012. Quarterly volume flow totals were calculated from the monthly flow data and are given in Table 4.1.

2.4. Linear Regression Model

2.4.1. General Approach

Linear regression was used to investigate the possible effect of ACL enforcement actions through several regression models. The linear regression models have the form:

$$y = \alpha + \Sigma\beta_i X_i + \varepsilon \qquad \text{(Equation 4.1)}$$

where y is the dependent variable, α is the model intercept, β_i is the regression coefficient for explanatory variable X_i, and ε is the error term. The statistical analyses were conducted using the R computing software (R Development Core Team, 2008). The linear regression analysis conducted for this study is the same approach utilized in Chapter 3 of this dissertation; a brief explanation of the regression model and model variables is provided below; however, additional explanatory details are provided in Section 2.4 of Chapter 3 of this dissertation.

The regression models are based on the premise that effluent concentrations are affected by the issuance of ACL enforcement actions. The effect on a particular facility's effluent

[3] http://www.water.ca.gov/dayflow/documentation/dayflowDoc.cfm

concentrations may be direct, if ACLs are issued directly to the particular facility, or indirect, if ACLs are issued to other facilities and a particular facility decides to improve its effluent concentration in order to avoid being issued an ACL. The effect of ACLs may also be delayed since facility improvements may take several years to implement. In addition, other factors may affect effluent concentrations, such as facility to facility variations, past facility performance, and whether or not a facility is also subject to a CDO/TSO enforcement action.

The estimating equations have the form:

$$Log(EFF_{i\,t}) = \alpha + \beta_1\, TIME_t + \beta_2\, FACILITY_i + \beta_3 \log[\, EFF_{i\,(t-1)}\,] + \beta_4\, Log[\, EFF_{i\,(t-4)}\,] + \beta_5\, CDOTSO_{i\,t} + \sum_{q=1}^{20} \theta_q\, ACLQ_{i\,t\,q} + \sum_{y=1}^{5} \phi_y\, ACLY_{i\,t\,y} + \varepsilon$$

(Equation 4.2)

The variable $EFF_{i\,t}$ is the dependent variable and is the effluent concentration of facility i for one of the selected constituents. The explanatory variable $EFF_{i\,(t-1)}$ is the effluent concentration lagged by one quarter and accounts for the status of the wastewater treatment facility from the preceding month that may be persisting and impacting the effluent concentration at time t. The explanatory variable $EFF_{i\,(t-4)}$ is the effluent concentration lagged by four quarters and accounts for annual seasonal effects as well as the longer term performance of a facility (i.e., a well-operated facility would be expected to continue to perform well). Based on statistical distribution analysis not presented here, using the data for this study, the natural log transformation of the effluent variables were used in the estimating model equations because better model fits were obtained. In addition, natural log transformations are commonly used for statistical analysis of effluent data (USEPA, 1991).

The primary explanatory variables in this study are related to the occurrence of ACL enforcement actions issued to the various wastewater treatment facilities. To account for lagged effects that may occur anywhere from three months to five years after ACL issuance, serial lagged ACL-related dummy variables are utilized as explanatory variables in the estimating model equations. The variable $ACLQ_{i\,tq}$ is a series of dummy variables that are lagged by 1 to 20 quarters as indicated by the index q. The variable $ACLQ_{i\,t\,q}$ would have a value of 1 if an ACL was issued during any of the three months following the lag period. The variables series $ACLY_{i\,t\,y}$ are analogous, but the lag periods are one to five year lags and the variables reflect the occurrence of ACLs during the 12 months preceding the lag period. The variables series $ACLY_{i\,t\,y}$ is included in this study to investigate if the possible effects of ACLs on effluent concentrations extend further from the date of ACL issuance, by up to 12 months. In applying the estimating model equations, Equation 4.2, only the quarterly lagged variables series $ACLFQ_{i\,t\,j}$ or only the yearly lagged variables series $ACLY_{i\,t\,k}$ were included in the estimating equations, but not simultaneously.

The variable *TIME* is a factor variable with 156 levels, with a value from 1 to 156, representing each month during the period 2000-2011. The *TIME* variable is included as a factor variable rather than a sequential numeric variable to serve the function of capturing month-specific effects and seasonal effects. Other studies have included similar time series variables for similar reasons (Magat and Viscusi, 1990).

The variable $FACILITY_i$ is a factor variable corresponding to each of the facilities included in the study. The $FACILITY_i$ factor variables are included to capture facility-specific effects on $EFF_{i\,t}$ that would otherwise be become attributed to other explanatory variables in the model.

The variable $CDOTSO_{i\,t}$ *is* a dummy variable included to account for effects on $EFF_{i\,t}$ due to CDOs and TSOs that may be in effect for a particular facility. The value of $CDOTSO_{i\,t}$ is 1 if at time t there is one or more CDO or TSO in effect for the facility corresponding to $EFF_{i\,t}$.' otherwise its value is 0.

A summary of the descriptive statistics for the dependent and explanatory variables is provided in Table 4.2.

3. Results

3.1. General results

For each effluent constituent, total nitrogen and total copper, two model regressions were conducted. The basic model equations for the two model regressions include the explanatory variables $TIME$, $FACILITY_i$, $CDOTSO_{i\,t}$, and the log of the lagged effluent variables $EFF_{i(t-1)}$ and $EFF_{i\,(t-12)}$. Model 1 includes the ACL variable series $ACLQ_{i\,tq}$ lagged by quarters. Model 2 includes the ACL variable series $ACLY_{i\,ty}$ lagged by years. Initial runs of the regression models identified three data points each in the total nitrogen and total copper data sets, which if removed, gave much different coefficient results and p-values for the regression models. Consequently, these outliers were removed from the data sets for the final regression analyses. The coefficients for the explanatory variables obtained from the linear regressions are given in Tables 3a and 3b. The statistical significance of the coefficients is indicated with the letters *a, b, c* or *d* alongside the coefficient results as explained in the table footnotes. The adjusted R-squared values were 0.76 and 0.81 for total nitrogen and total copper, respectively, for Models 1 and 2, indicating a relatively good fit for the linear regression. A review of the standard error of residuals for all constituents and regression models further indicate relatively good fit...

The effect of explanatory variables, other than the ACL-related variables, is as follows:

- The regression coefficient results for the *TIME* factor variables are not significant. The ANOVA analysis for Type II error also indicates that the *TIME* factor variables, taken as a whole, are not significant and do not provide additional information about the effluent concentration at each month.
- The coefficient of the natural log of the effluent concentration lagged one quarter, $EFF_{i\,t-1}$, was significant for both Models 1 and 2 for total nitrogen and total copper. As shown in Tables 3a and 3b, coefficient values ranged from +0.512 to +0.572, which indicates that the performance of the wastewater treatment plant during the previous quarter predicts over half the magnitude of the current effluent concentration.
- The coefficient of the natural log of the effluent concentration lagged four quarters, $EFF_{i\,t-4}$, was significant only for Model 1 for total copper and was significant for Model 2 for total nitrogen. As shown in Tables 3a and3b, coefficient values ranged from +0.058 to +0.071, which indicates that the performance of the wastewater treatment plant one year prior predicts less than eight percent of the magnitude of the current effluent concentration. This is in contrast to other studies, which did not include a short-term past performance variable, which found that long-term past performance explained a large part of present performance (Magat and Viscusi, 1990).
- As shown in Tables 3a and 3b, the contemporaneous effect on the dependent variable $EFF_{i\,t}$ by the variable $CDOTSO_{i\,t}$ for the presence of CDOs and TSOs was significant for Model 1 only for total copper but was significant for Model 2 for both total nitrogen and total copper. As shown in Tables 3a and 3b, the coefficients ranged from +0.215 to +0.377. These coefficient results are in contrast to the sign and magnitude for the variable $CDOTSO_{i\,t}$ in the study discussed in Chapter 3 of this dissertation. The positive

sign and larger magnitude of the $CDOTSO_{i\,t}$ coefficients in this study may reflect the larger number of CDOs and TSOs that were issued to the wastewater treatment facilities considered in this study. Furthermore, the positive and larger effect of CDOs and TSOs may indicate that effluent concentrations may not have been improving during the period that a CDO or TSO is in effect because a corrective action required under the CDO or TSO is pending completion.

3.2. Effect of ACLs on total nitrogen effluent concentrations

The results of the Model 1 and 2 linear regressions for total nitrogen are shown in Table 4.3a. The coefficient for the ACL variable lagged 7 quarters was -0.313 and was statistically significant with a p-value less than 0.05. Because of the logarithmic form of the regression estimating equations, this result suggests that the total nitrogen concentration of the effluent from a wastewater treatment facility at a given time is reduced by about 31.3% if an ACL enforcement action had been issued to the facility 7 quarters previously. The ACL variables lagged 1, 2 and 5 years were statistically significant and had coefficients of -0.174, -0.255, and -0.275, respectively, with p-values all less than 0.05 or 0.1. These results suggest that the total nitrogen concentration of the effluent from a wastewater treatment facility at a given time is reduced by about 17.4%, 25.5 %, or 27.5% if an ACL enforcement action had been issued to the facility 1, 2 or 5 years previously. These results suggest that corrective actions for total nitrogen might be implemented, and are effective, soon after ACL issuance and have a permanent effect of reducing total nitrogen concentrations. Corrective actions to improve effluent total nitrogen concentrations could be implemented within a short time, requiring only optimizing of the performance of existing denitrification processes at a facility, or may require a more extensive facility upgrade to incorporate denitrification processes. Some studies however suggest that denitrification may be achieved with less extensive modifications to existing treatment processes at a facility. (Collivignarelli and Bertanza, 1999; Borregaard, 1997; Munch et al, 2000).

3.3. Effect of ACLs on total copper effluent concentrations

The results of the Model 1 and 2 linear regressions for total copper are shown in Table 4.3b. The coefficients for the ACL variable lagged 12 quarters was -0.281 and was statistically significant with a p-value less than 0.05. This result suggests that the total copper concentration of the effluent from a wastewater treatment facility at a given time is reduced by about 28.1% if an ACL enforcement action had been issued to the facility 12 quarters previously. The ACL variable lagged 3 years was -0.233 and statistically significant with a p-value less than 0.05. This result suggests that the total copper concentration of the effluent from a wastewater treatment facility at a given time is reduced by about 23.3% if an ACL enforcement action had been issued to the facility 3 years previously.

The negative coefficients for the ACL variables lagged 12 quarters and three years that were statistically significant may indicate that corrective measures for total copper take two to three years to implement or become effective, and copper removal efficiency may not improve until then. Since more than half of the copper in wastewater is removed during the primary sedimentation phase of the treatment process (Goldstone et al, 1990; Nielsen and Hrudey, 1983; Ekster and Jenkins, 1996), corrective actions to remove copper may involve upgrades to primary sedimentation units.

4. Discussion and Recommendations

The results from the linear regression models in this study suggest that MMP ACL enforcement actions result in long-term reduction of total nitrogen and total copper concentrations in treated wastewater effluent. Since the ultimate goal of pollution prevention is to improve the environment, it would be useful information to determine whether the long term reductions in effluent concentrations of total nitrogen and total copper can result in measurable reductions in concentrations in the receiving waters, in this case the Sacramento-San Joaquin Delta.

As discussed in the Results section, because of the logarithmic form of the regression estimating equations, the coefficients of the ACL variables in the regression models approximately indicate the percentage by which an ACL reduces effluent concentrations. Assuming that the statistical regression models can be taken as approximate physical models, the pollution reduction resulting from ACL enforcement actions may be estimated by rearranging Equation 4.2. For the Model 1 equation (i.e., estimating equations with ACL variables lagged by quarters) the pollution concentration reduction, Δc_{it}, for facility *i* at time *t* is derived from Equation 4.2 as shown in Equations 4.3a through 4.3d below :

$$log(EFF_{i\,t}) = log(EFF^*_{i\,t}) + \sum_{q=1}^{20} \theta_q \, ACLQ_{i\,t\,q} \qquad \text{(Equation 4.3a)}$$

$$log(EFF^*_{i\,t}) = \alpha + \beta_1 \, TIME_t + \beta_2 \, FACILITY_i + \beta_3 \, log[\, EFF_{i\,(t-1)}\,] + \beta_4 \, log[\, EFF_{i\,(t-4)}\,] + \beta_5 \, CDOTSO_{i\,t} \qquad \text{(Equation 4.3b)}$$

$$EFF^*_{i\,t} = exp[log(EFF_{i\,t}) - \sum_{q=1}^{20} \theta_q \, ACLQ_{i\,t\,q}] \qquad \text{(Equation 4.3c)}$$

$$\Delta c_{it} = EFF^*_{i\,t} - EFF_{i\,t} \qquad \text{(Equation 4.3d)}$$

Equation 4.3d for total nitrogen is given by

$$\Delta c_{it} = exp[log(EFF_{i\,t}) - \theta_7 \, ACLQ_{i\,t\,7}\,] - EFF_{i\,t} \qquad \text{(Equation 4.4a)}$$

Equation 4.3d for total copper is given by

$$\Delta c_{it} = exp[log(EFF_{i\,t}) - \theta_{12} \, ACLQ_{i\,t\,12}\,] - EFF_{i\,t} \qquad \text{(Equation 4.4b)}$$

The pollution concentration reduction Δc_{it} can be calculated for each facility i at time t by substituting for the known values of EFF_{it}, θ_q and $ACLQ_{itq}$. The results of this calculation for the period 2008-2012 are shown in Tables 4a and 4b for total nitrogen and total copper, respectively. These results indicate that a pollution concentration reduction occurred only during certain quarters for each facility. These results reflect the definition of the variable $ACLQ_{itq}$ as having a value of "1" if an ACL had been issued to a facility during a quarter a certain number of quarters prior to the current quarter. Because not every ACL variable lagged by quarters was found significant in the linear regression models, as given in Equations 4.4a and 4.4b, the effect of ACLs were limited to non-consecutive quarters. However, the coefficient results for the variable $ACLY_{i\,t\,y}$ in Model 2 (i.e., model with ACL variables lagged by years) captures the effect of an ACL that may extend up to a year and not limited to the quarter that an ACL was issued.

The mass of pollution that is prevented from being discharged to the environment per day from each wastewater treatment facility can be approximated by multiplying the pollution concentration reduction Δc_{it} by the design flow rate of the wastewater treatment, $Q_{i.}$. Design flow rates were obtained from the USEPA's Envirofacts database and are tabulated in Table 4.5. The mass of pollution prevented from being discharged from each facility for the period 2008-2012 are given in Tables 6a and 6b for total nitrogen and total copper, respectively. For total nitrogen, the mass of pollution prevented from discharge averaged 28 lbs per quarter for a small facility and 67,000 pounds per quarter for the largest facility; however, three facilities indicated no pollution mass prevented from discharge. For total copper, the mass of pollution prevented from discharge averaged 0.05 lbs per quarter to 11.8 pounds per quarter; however, two facilities indicated zero copper mass prevented from discharge.

As discussed in the Introduction section for this chapter, the Sacramento-San Joaquin Delta is a complex system of channels, with Delta water quality being affected by diversions, tides, and the operation of two barriers. In order to illustrate an estimate of the changes in Delta water quality that may be observed as a result of pollution reductions from wastewater treatment facilities associated with the issuance of MMP ACL enforcement actions, a simple mass balance is considered for the Delta and the inflows from the Sacramento River and San Joaquin River, and their tributaries, into the Delta. Using actual flow data for the Sacramento River, San Joaquin River, their tributaries, and Delta precipitation, from the California Department of Water Resources Dayflow model website[4], and wastewater treatment facility design flow rates and pollution concentration reduction, as discussed above, the general simple mass balance equation at time *t* at a given geographic location has the form:

$$\Delta c_{tot,t}\, Q_{tot,t} = \Delta c_{tot,t}\left(\sum_{r=1}^{k} Q_{rt} + Q_{precip} + \sum_{i=1}^{l} Q_i\right) = \sum_{i=1}^{l} \Delta c_{it}\, Q_i \qquad \text{(Equation 4.5)}$$

where k is the number of river or tributary inflows to a given geographic location and l is the number of wastewater treatment facilities that discharge upstream of the given geographic location.

Mass balances were calculated to estimate pollution concentration reductions, $\Delta c_{tot,t}$, in the receiving water at five locations, namely, 1) the Sacramento River at Clarksburg before the confluence with the Yolo Bypass, 2) the Sacramento River at Antioch south of the confluence with the Yolo Bypass, 3) the San Joaquin River at PID pumps south of Modesto, 4) the San Joaquin River at Antioch, and 5) the Delta at Pittsburgh representing Delta-wide total flows. It is emphasized that the mass balances for these locations are only approximations that do not account for tides, diversions and the barriers; the mass balance at location 5, representing the

[4] http://www.water.ca.gov/dayflow/

outflow from the Delta near Pittsburgh prior to entering San Francisco Bay, is likely the least accurate approximation. The calculated pollution concentration reductions at these five locations for the period 2008 to 2012 are given in Tables 4.7a and 4.7b for total nitrogen and total copper, respectively. For total nitrogen, the mass balances indicate quarterly reductions in receiving water quality ranging from 0.0002 mg/L to 0.036 ug/L and quarterly average reductions of 0.009 mg/L to 0.020 mg/L at the five locations. For total copper, the mass balances indicate quarterly reductions in water quality ranging from 0.0003 ug/L to 0.036 ug/L, and quarterly average reductions of 0.001 ug/L to 0.006 ug/L at the five locations.

In order to obtain perspective on the magnitude of the estimated pollution concentration reductions at the five mass balance geographic locations, actual water quality data at the same or approximately the same geographic locations were obtained for comparison with the estimated receiving water quality improvements. A limited number of water quality data at several locations are available from the California Environmental Data Exchange Network (CEDEN) website[5], as summarized in Tables 8a and 8b. The corresponding mass balance geographic locations for comparison are also indicated in Tables 8a and 8b. For total nitrogen, the estimated pollution concentration reduction may be less than 1% and up to 3.5% of the receiving water concentrations; however, the median percentage is less than 1%. Similarly, for total copper, the estimated pollution concentration reduction may be less than 1%, and up to 1.4%, of the receiving water concentrations; however, the median percentage is also less than 1%. The comparison of the estimated pollution concentration reductions with actual water quality observations indicate that improvements in water quality due to MMP ACL enforcement actions may be measurable during certain time periods; however, the magnitude of the reductions long term may not be large.

[5] http://www.ceden.us/AdvancedQueryTool

Again, the comparison between calculated pollution concentration reduction and actual water quality observed is only for illustration purposes and is approximate since the mass balance models represented by Equation 4.5 is a simple model of the complex Delta circulation system. Certain subregions of the Delta may have higher or lower concentration reductions depending on true circulation in the Delta. As also discussed in the Introduction section of this chapter, other processes, such as denitrification and copper adsorption, are also not considered by the simple mass balance model; therefore, the calculated estimated pollution concentration reduction may actually be smaller. The contributions of total nitrogen and total copper from stormwater runoff, agricultural runoff, and air deposition, may also result in higher receiving water concentrations than otherwise, and result in masking the magnitude of the reductions from MMP ACL enforcement actions. Furthermore, actual water quality data in the Delta is uncoordinated and monitoring is not conducted routinely or with a defined purpose; consequently, resulting in a ‘data rich, information poor” syndrome whereby much disjointed data is available from various programs but insufficient to comprehensively inform any program (Ward et al, 1986). Therefore, understanding the long term effects of pollution reduction on improving Delta receiving water quality is limited. Lastly, the period considered for pollution reduction in receiving waters is only from 2008 to 2012 due to incomplete effluent quality data for the wastewater treatment plants; therefore, pollution reductions during the earlier years of the MMP enforcement program were not evaluated.

In order to quantify the effect of management programs on improving the environment, such as the MMP enforcement program, a comprehensive evaluation program is recommended. Currently, monitoring programs are not consistent and results in data gaps. For example, some facilities may be required to monitor for one constituent at a certain frequency while another facility may be required to monitor for that constituent at a different frequency or not at all. Furthermore, some constituents may be required to be monitored in the effluent but not in the receiving water, and therefore, the relationship between effluent discharged and receiving water quality cannot be established. In a comprehensive evaluation program, certain representative indicator constituents should be chosen as the core set of constituents to be consistently monitored in the effluent discharged by all facilities and in the receiving waters in order to address the data deficiencies encountered in this study. The set of core constituents may be chosen so as to form and water quality index (WQI) which would communicate complex information about water quality to decision makers and the public (Griffiths et al, 2012;Walsh and Wheeler, 2011). Monitoring frequencies for the core constituents for both effluent and receiving water monitoring should also be consistent, e.g., quarterly. The core constituents and monitoring frequency should be required across all monitoring programs conducted (i.e., as required by, conducted by, or funded by the RWQCBs and SWRCB), in addition to the constituents of focus of the monitoring program, so that the eventual set of available monitoring data for the core constituents is larger. For example, a two year monitoring effort to monitor pesticides in the Delta should also require that core constituent monitoring be conducted.

5. Conclusion

This investigation analyzed the correlation between effluent quality discharged by wastewater treatment plants that discharge directly or indirectly to the Sacramento-San Joaquin Delta and MMP enforcement actions issued to those facilities. Although the results of this investigation are preliminary, the linear regression results indicated that the issuance of MMP enforcement actions result in long-term decreases in concentrations of total nitrogen and total copper in wastewater treatment plant effluent. The resulting reduction in mass of pollution prevent from being discharged range from under a pound of total copper per quarter for some facilities and up to several thousand pounds of total nitrogen per quarter for some facilities. An illustrative evaluation using a simple model of Delta flows to calculate the impact of pollution reductions from discharges on the Delta's water quality indicate that improvements of water quality in receiving waters may be measurable. However, comparison with actual water quality monitoring data from the Delta indicate that long-term improvements of water quality in receiving waters may not be large or may be masked by other pollutant inputs and fate and transport processes in the Delta. While the preliminary results of this study do suggest that some pollution reduction occurs as a result of the MMP enforcement program, a comprehensive monitoring program for both effluent quality and receiving water quality is recommended with the goal of evaluating MMP enforcement program effectiveness. Follow-up research will provide additional insights and conclusions regarding the effectiveness of the MMP enforcement program.

Table 4.1. Quarterly total flows in the Sacramento-San Joaquin Delta, in thousands of acre-feet. *(Source: California Department of Water Resources, Dayflow website)*

Quarter	Sacra-mento R	Yolo Bypass	Cos-umnes R	Moke-lumne R	East tributa-ries	San Joaquin R	East Delta	Total Delta	Precip-itation
2008-Q1	3,738	199	66	34	10	409	519	4,456	400
2008-Q2	1,820	101	38	23	32	374	467	2,388	2
2008-Q3	2,050	101	1	6	35	160	203	2,353	-
2008-Q4	1,603	20	6	28	8	213	255	1,878	211
2009-Q1	3,090	108	105	30	7	235	377	3,575	373
2009-Q2	2,528	88	81	31	29	287	428	3,044	59
2009-Q3	2,754	100	2	7	31	131	171	3,026	18
2009-Q4	1,790	19	7	69	8	277	361	2,170	237
2010-Q1	4,473	347	88	47	6	435	576	5,396	364
2010-Q2	3,429	114	161	134	17	804	1,116	4,660	188
2010-Q3	3,085	99	7	61	28	308	403	3,587	-
2010-Q4	4,324	96	125	207	8	687	1,027	5,448	418
2011-Q1	7,080	1,904	350	239	149	2,047	2,785	11,769	391
2011-Q2	7,795	518	266	418	31	2,982	3,697	12,011	105
2011-Q3	3,639	99	23	203	42	1,114	1,382	5,120	11
2011-Q4	2,732	17	11	112	24	585	732	3,481	105
2012-Q1	2,889	31	62	42	7	302	414	3,334	251
2012-Q2	3,194	84	98	24	26	427	575	3,853	129
2012-Q3	3,260	100	3	7	36	163	209	3,569	-
2012-Q4	4,233	244	68	47	10	308	433	4,910	398

Notes: *East Delta = East Tributaries + Cosumnes R + Mokelumne R + San Joaquin R*
Total Delta = Sacramento R + Yolo Bypass + East Delta

Table 4.2. Descriptive statistics for ACL-concentration regression model variables

		Total Nitrogen [a]		Total Copper [b]	
Variable	Variable type (units)	Mean	Std. Dev.	Mean	Std. Dev.
$EFF_{i\,t}$	*continuous (mg/L)* [a]*, (ug/L)* [b]	10.140	8.616	4.446	6.274
$EFF_{i\,(t\text{ - }1\text{ month})}$	*continuous (mg/L)* [a]*, (ug/L)* [b]	10.137	8.658	4.419	6.301
$EFF_{i\,(t\text{ - }12\text{ month})}$	*continuous (mg/L)* [a]*, (ug/L)* [b]	9.981	8.585	4.322	6.288
$ACLQ_{i\,t\,1}$	*0 or 1 dummy*	0.073	0.261	0.071	0.258
$ACLQ_{i\,t\,2}$	*0 or 1 dummy*	0.075	0.264	0.074	0.261
$ACLQ_{i\,t\,3}$	*0 or 1 dummy*	0.078	0.268	0.076	0.265
$ACLQ_{i\,t\,4}$	*0 or 1 dummy*	0.080	0.272	0.078	0.269
$ACLQ_{i\,t\,5}$	*0 or 1 dummy*	0.083	0.276	0.081	0.273
$ACLQ_{i\,t\,6}$	*0 or 1 dummy*	0.085	0.280	0.083	0.277
$ACLQ_{i\,t\,7}$	*0 or 1 dummy*	0.082	0.275	0.080	0.271
$ACLQ_{i\,t\,8}$	*0 or 1 dummy*	0.074	0.262	0.071	0.258
$ACLQ_{i\,t\,9}$	*0 or 1 dummy*	0.074	0.262	0.072	0.258
$ACLQ_{i\,t\,10}$	*0 or 1 dummy*	0.075	0.263	0.075	0.263
$ACLQ_{i\,t\,11}$	*0 or 1 dummy*	0.075	0.264	0.075	0.264
$ACLQ_{i\,t\,12}$	*0 or 1 dummy*	0.076	0.265	0.078	0.269
$ACLQ_{i\,t\,13}$	*0 or 1 dummy*	0.065	0.247	0.068	0.252
$ACLQ_{i\,t\,14}$	*0 or 1 dummy*	0.068	0.252	0.071	0.257
$ACLQ_{i\,t\,15}$	*0 or 1 dummy*	0.068	0.253	0.071	0.258
$ACLQ_{i\,t\,16}$	*0 or 1 dummy*	0.063	0.242	0.063	0.242
$ACLQ_{i\,t\,17}$	*0 or 1 dummy*	0.046	0.210	0.046	0.210
$ACLQ_{i\,t\,18}$	*0 or 1 dummy*	0.038	0.192	0.038	0.192
$ACLQ_{i\,t\,19}$	*0 or 1 dummy*	0.033	0.179	0.037	0.189
$ACLQ_{i\,t\,20}$	*0 or 1 dummy*	0.023	0.152	0.027	0.163
$ACLY_{i\,t\,1}$	*0 or 1 dummy*	0.275	0.447	0.264	0.441
$ACLY_{i\,t\,2}$	*0 or 1 dummy*	0.295	0.456	0.281	0.450
$ACLY_{i\,t\,3}$	*0 or 1 dummy*	0.273	0.446	0.268	0.444
$ACLY_{i\,t\,4}$	*0 or 1 dummy*	0.247	0.432	0.250	0.434
$ACLY_{i\,t\,5}$	*0 or 1 dummy*	0.125	0.331	0.133	0.340
$CDOTSO_{i\,t}$	*0 or 1 dummy*	0.536	0.499	0.509	0.500

Table 4.3a. Total Nitrogen Regression Model Results

Model Variable	Model 1		Model 2	
	Estimate	Signif. Code	Estimate	Signif. Code
(Intercept)	0.484	c	0.565	c
$EFF_{i\ (t-1\ month)}$	0.572	a	0.563	a
$EFF_{i\ (t-12\ month)}$	0.062		0.066	d
$CDOTSO_{i\ t}$	0.218		0.215	d
$ACLQ_{i\ t\ 1}$	-0.007			
$ACLQ_{i\ t\ 2}$	-0.064			
$ACLQ_{i\ t\ 3}$	-0.130			
$ACLQ_{i\ t\ 4}$	-0.136			
$ACLQ_{i\ t\ 5}$	-0.167			
$ACLQ_{i\ t\ 6}$	-0.181			
$ACLQ_{i\ t\ 7}$	-0.313	c		
$ACLQ_{i\ t\ 8}$	-0.166			
$ACLQ_{i\ t\ 9}$	-0.098			
$ACLQ_{i\ t\ 10}$	-0.063			
$ACLQ_{i\ t\ 11}$	-0.108			
$ACLQ_{i\ t\ 12}$	-0.042			
$ACLQ_{i\ t\ 13}$	0.033			
$ACLQ_{i\ t\ 14}$	-0.099			
$ACLQ_{i\ t\ 15}$	-0.014			
$ACLQ_{i\ t\ 16}$	-0.041			
$ACLQ_{i\ t\ 17}$	-0.270			
$ACLQ_{i\ t\ 18}$	-0.374			
$ACLQ_{i\ t\ 19}$	-0.211			
$ACLQ_{i\ t\ 20}$	-0.027			
$ACLY_{i\ t\ 1}$			-0.174	d
$ACLY_{i\ t\ 2}$			-0.255	c
$ACLY_{i\ t\ 3}$			-0.067	
$ACLY_{i\ t\ 4}$			-0.072	
$ACLY_{i\ t\ 5}$			-0.275	c
Adjusted R-squared	0.860		0.871	
DF	172		187	

Signif. codes: 0 ‘a’ 0.001 ‘b’ 0.01 ‘c’ 0.05 ‘d’ 0.1 ‘ ’ 1

Table 4.3b. Total Copper Regression Model Results

Model Variable	Model 1		Model 2	
	Estimate	Signif. Code	Estimate	Signif. Code
(Intercept)	0.529	c	0.460	c
$EFF_{i\,(t-1\,month)}$	0.512	a	0.531	a
$EFF_{i\,(t-12\,month)}$	0.071		0.058	
$CDOTSO_{i\,t}$	0.377	b	0.354	b
$ACLQ_{i\,t\,1}$	-0.062			
$ACLQ_{i\,t\,2}$	0.180			
$ACLQ_{i\,t\,3}$	-0.100			
$ACLQ_{i\,t\,4}$	-0.072			
$ACLQ_{i\,t\,5}$	-0.022			
$ACLQ_{i\,t\,6}$	-0.175			
$ACLQ_{i\,t\,7}$	0.065			
$ACLQ_{i\,t\,8}$	0.026			
$ACLQ_{i\,t\,9}$	-0.123			
$ACLQ_{i\,t\,10}$	0.050			
$ACLQ_{i\,t\,11}$	-0.131			
$ACLQ_{i\,t\,12}$	-0.281	c		
$ACLQ_{i\,t\,13}$	-0.056			
$ACLQ_{i\,t\,14}$	-0.174			
$ACLQ_{i\,t\,15}$	0.073			
$ACLQ_{i\,t\,16}$	0.201			
$ACLQ_{i\,t\,17}$	0.123			
$ACLQ_{i\,t\,18}$	0.100			
$ACLQ_{i\,t\,19}$	0.037			
$ACLQ_{i\,t\,20}$	-0.034			
$ACLY_{i\,t\,1}$			-0.079	
$ACLY_{i\,t\,2}$			-0.135	
$ACLY_{i\,t\,3}$			-0.233	c
$ACLY_{i\,t\,4}$			-0.108	
$ACLY_{i\,t\,5}$			-0.067	
Adjusted R-squared	0.871		0.872	
DF	152		167	

Signif. codes: 0 ‘a’ 0.001 ‘b’ 0.01 ‘c’ 0.05 ‘d’ 0.1 ‘ ’ 1

Table 4.4a. Calculated wastewater treatment facility effluent total nitrogen pollution concentration reduction in mg/L. Top row indicates receiving waters, second row indicates wastewater treatment facility.

	Yolo Bypass				Sacramento River			Delta		San Joaquin River					East tributaries	
Quarter	Davis	Wood -land	UC Davis	Easter ly	Sacra-mento Regio-nal	Dry Creek	Hang-town	Brent-wood	Disco-very Bay	Stock-ton Regio-nal	Man-teca	Mer-ced	Mo-desto	Tur-lock	Deer Ck	Galt
2008-Q3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0
2008-Q4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2009-Q1	2.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2009-Q2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2009-Q3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2009-Q4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.3	0.0
2010-Q1	0.0	0.0	0.0	8.4	0.0	0.0	0.0	0.0	0.0	0.0	2.2	0.0	0.0	0.0	0.0	0.0
2010-Q2	0.0	0.0	3.1	0.0	0.0	3.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0	0.0
2010-Q3	1.4	7.7	0.0	0.0	8.7	0.0	0.0	0.0	0.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0
2010-Q4	0.0	0.0	2.3	0.0	0.0	0.0	1.1	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2011-Q1	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.2	0.0	0.0	0.0	0.0	0.0	0.0
2011-Q2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2011-Q3	1.7	0.0	1.9	0.0	0.0	0.0	1.5	0.0	1.5	0.0	2.4	0.0	0.0	0.0	0.0	0.0
2011-Q4	0.0	0.0	0.0	0.0	0.0	5.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2012-Q1	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2012-Q2	0.0	0.0	0.0	8.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2012-Q3	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2012-Q4	0.0	7.4	1.6	0.0	0.0	0.0	0.0	0.0	0.0	7.6	2.3	0.0	0.0	5.2	0.0	0.0

Table 4.4b. Calculated wastewater treatment facility effluent total copper pollution concentration reduction in ug/L. Negative values indicate an increase in effluent concentration, not a reduction. Top row indicates receiving waters, second row indicates wastewater treatment facility.

	Yolo Bypass			Sacramento River			Delta			San Joaquin River						East Tributaries	
Quarter	Davis	UC Davis	Wood land	Sacra-mento Regio-nal	Yuba City	Hang-town Ck	Brent wood	Disco very Bay	Delta Dia-blo	Man-teca	Mer-ced	Mo-desto	Stock-ton Regio -nal	Tur-lock	Tracy	Deer Ck	Galt
2008-Q1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2008-Q2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2008-Q3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2008-Q4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2009-Q1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2009-Q2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2009-Q3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2009-Q4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2010-Q1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2010-Q2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2010-Q3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2010-Q4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2011-Q1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0	0.0	0.0	0.0	2.4	0.0	0.0	0.0	0.6	0.0
2011-Q2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2011-Q3	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	1.5	0.0	0.0
2011-Q4	0.2	0.0	4.3	1.5	1.1	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.6	0.0	0.0	0.0	0.0
2012-Q1	0.0	0.2	0.0	0.0	0.0	0.1	0.0	10.3	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
2012-Q2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
2012-Q3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2012-Q4	0.0	0.2	0.0	0.0	0.0	0.4	0.0	5.2	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 4.5. Wastewater treatment facility design flow rates in million gallons per day (MGD). Last two columns indicate if facility was included in the total nitrogen and/or total copper model regressions. *(Source: USEPA Envirofacts website)*

Wastewater treatment facility	Design flow rate	In total nitrogen model	In total copper model
Brentwood	5	Y	Y
Davis	7.5	Y	Y
Deer Creek	2.5	Y	Y
Delta Diablo	16.5	N	Y
Discovery Bay	2.1	Y	Y
Galt	4.5	y	Y
Hangtown	2.3	Y	Y
Manteca	6.95	Y	Y
Merced	20	Y	Y
Modesto	70	y	Y
Sacramento Regional	181	Y	Y
Stockton Regional	55	Y	Y
Tracy	16	N	Y
Turlock	20	Y	Y
UC Davis	3.6	Y	Y
Woodland	7.8	Y	Y
Yuba City	10.5	N	Y
Dry Creek	18	Y	N
Easterly	12	Y	N

Table 4.6a. Calculated wastewater treatment facility effluent total nitrogen pollution mass discharged reduction in thousand lbs per quarter. Top row indicates receiving waters, second row indicates wastewater treatment facility.

	Yolo Bypass				Sacramento River			Delta		San Joaquin River					East tributaries	
Quarter	Davis	Wood-land	UC Davis	Easterly	Sacra-mento Regio-nal	Dry Crk	Hang-town	Brent-wood	Disco-very Bay	Stock-ton Regio-nal	Man-teca	Mer-ced	Mo-desto	Tur-lock	Deer Ck	Galt
2008-Q3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.7	0.0	0.0	0.0	0.0	0.0
2008-Q4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2009-Q1	16.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2009-Q2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2009-Q3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2009-Q4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.4	0.0	0.0	0.0	0.0	0.0	0.5	0.0
2010-Q1	0.0	0.0	0.0	75.8	0.0	0.0	0.0	0.0	0.0	0.0	11.5	0.0	0.0	0.0	0.0	0.0
2010-Q2	0.0	0.0	8.5	0.0	0.0	43.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	76.4	0.0	0.0
2010-Q3	8.1	46.2	0.0	0.0	1,201.4	0.0	0.0	0.0	0.0	254.5	0.0	0.3	0.0	0.0	0.0	0.0
2010-Q4	0.0	0.0	6.4	0.0	0.0	0.0	2.0	0.0	2.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2011-Q1	10.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	338.3	0.0	0.0	0.0	0.0	0.0	0.0
2011-Q2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2011-Q3	9.8	0.0	5.2	0.0	0.0	0.0	2.6	0.0	2.4	0.0	12.8	0.0	0.0	0.0	0.0	0.0
2011-Q4	0.0	0.0	0.0	0.0	0.0	71.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2012-Q1	0.0	0.0	0.0	0.0	0.0	0.0	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2012-Q2	0.0	0.0	0.0	80.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2012-Q3	8.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2012-Q4	0.0	44.2	4.5	0.0	0.0	0.0	0.0	0.0	0.0	319.5	12.3	0.0	0.0	80.1	0.0	0.0
Average	2.9	5.0	1.4	8.7	66.7	6.4	0.4	0.00	0.4	50.7	2.4	0.02	0.00	8.7	0.03	0.00

Table 4.6b. Calculated wastewater treatment facility effluent total copper pollution mass discharged reduction in lbs per quarter. Top row indicates receiving waters, second row indicates wastewater treatment facility.

	Yolo Bypass			Sacramento River			Delta			San Joaquin River						East Tributaries	
Quarter	Davis	UC Davis	Wood land	Sacra-mento Regio-nal	Yuba City	Hang-town Ck	Brent wood	Disco very Bay	Delta Dia-blo	Man-teca	Mer-ced	Mo-desto	Stock-ton Regio -nal	Tur-lock	Tracy	Deer Ck	Galt
2008-Q1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2008-Q2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2008-Q3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2008-Q4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2009-Q1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2009-Q2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2009-Q3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2009-Q4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2010-Q1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2010-Q2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2010-Q3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2010-Q4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2011-Q1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.7	0.0	0.0	0.0	126.4	0.0	0.0	0.0	1.1	0.0
2011-Q2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2011-Q3	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.9	18.6	0.0	0.0
2011-Q4	1.0	0.0	25.7	212.8	8.8	0.0	0.0	0.0	0.0	0.0	14.7	0.0	26.5	0.0	0.0	0.0	0.0
2012-Q1	0.0	0.5	0.0	0.0	0.0	0.2	0.0	16.2	0.0	0.0	0.0	0.0	0.0	0.0	3.7	0.0	0.0
2012-Q2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6	0.0	0.0	0.0	0.0
2012-Q3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2012-Q4	0.0	0.7	0.0	0.0	0.0	0.6	0.0	8.3	0.0	2.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Average	0.1	0.1	1.4	11.8	0.5	0.05	0.00	2.2	1.3	0.5	0.8	7.0	1.6	1.4	1.2	0.06	0.00

Table 4.7a. Calculated receiving water total nitrogen pollution concentration reduction in mg/L. Bold indicates a reduction in concentration.

Quarter	Delta-wide at Pittsburg	Sacramento R. at Pt Sacramento	San Joaquin R. at Antioch	Sacramento R at Hood	San Joaquin R at PID pumps (south of Modesto)
2008-Q3	**0.001**	0	**0.005**	0	**0.015**
2008-Q4	0	0	0	0	0
2009-Q1	**0.001**	**0.002**	0	0	0
2009-Q2	0	0	0	0	0
2009-Q3	0	0	0	0	0
2009-Q4	**0.0004**	0	**0.002**	0	0
2010-Q1	**0.005**	**0.006**	**0.004**	0	**0.009**
2010-Q2	**0.009**	**0.005**	**0.014**	**0.005**	**0.034**
2010-Q3	**0.150**	**0.142**	**0.118**	**0.141**	**0.0003**
2010-Q4	**0.001**	**0.001**	**0.0005**	**0.0002**	0
2011-Q1	**0.010**	**0.0004**	**0.025**	0	0
2011-Q2	0	0	0	0	0
2011-Q3	**0.002**	**0.002**	**0.002**	**0.0003**	**0.004**
2011-Q4	**0.007**	**0.009**	0	**0.009**	0
2012-Q1	**0.0002**	**0.0003**	0	**0.0003**	0
2012-Q2	**0.007**	**0.009**	0	0	0
2012-Q3	**0.001**	**0.001**	0	0	0
2012-Q4	**0.031**	**0.004**	**0.189**	0	**0.106**
Average	**0.013**	**0.010**	**0.020**	**0.009**	**0.009**

Table 4.7b. Calculated receiving water total copper pollution concentration reduction in ug/L. Bold indicates a reduction in concentration.

Quarter	Delta-wide at Pittsburg	Sacramento R. at Pt Sacramento	San Joaquin R. at Antioch	Sacramento R at Hood	San Joaquin R at PID pumps (south of Modesto)
2008-Q1	0	0	0	0	0
2008-Q2	0	0	0	0	0
2008-Q3	0	0	0	0	0
2008-Q4	0	0	0	0	0
2009-Q1	0	0	0	0	0
2009-Q2	**0.00003**	0	**0.0002**	0	**0.0003**
2009-Q3	**0.003**	0	**0.0359**	0	0
2009-Q4	**0.0004**	0	**0.0024**	0	**0.004**
2010-Q1	0	0	0	0	0
2010-Q2	0	0	0	0	0
2010-Q3	0	0	0	0	0
2010-Q4	0	0	0	0	0
2011-Q1	**0.004**	0	**0.0185**	0	0
2011-Q2	**0.0001**	0	**0.0003**	0	**0.0004**
2011-Q3	**0.003**	**0.000**	**0.0113**	0	**0.008**
2011-Q4	**0.029**	**0.033**	**0.0191**	**0.029**	**0.009**
2012-Q1	**0.002**	**0.000**	**0.0155**	**0.00003**	0
2012-Q2	**0.0002**	0	**0.0015**	0	0
2012-Q3	0	0	0	0	0
2012-Q4	**0.001**	**0.0001**	**0.0084**	**0.0001**	**0.003**
Average	**0.002**	**0.002**	**0.006**	**0.001**	**0.001**

Table 4.8a. Observed receiving water total nitrogen concentrations at stations within or near the Delta, in units of mg/L. (Source: California Environmental Data Exchange Network)

		Upstream →			Upstream →			
Date	**Delta-wide at Pittsburg**	**Sacramento R at Point Sacramento**	**Sacramento R at Hood**	**Sacramento R at Garcia Bend**	**San Joaquin R off Antioch**	**San Joaquin R at Turner Cut**	**San Joaquin R at Vernalis**	**San Joaquin R at PID Pumps (south of Modesto)**
2008-Q3								
2008-Q4								
2009-Q1		0.98	0.98	0.42	1.05	3.42	2.10	2.99
2009-Q2		0.72	0.75	0.33	0.75	1.63	1.29	
2009-Q3		1.13	1.03	0.33	0.97	1.55	1.78	
2009-Q4		0.98	0.98	0.35	0.84	1.37	1.85	6.30
2010-Q1		1.41	0.92	0.71	1.15	2.94	2.44	4.50
2010-Q2								
2010-Q3								
2010-Q4								29.71
2011-Q1								
2011-Q2	0.29							
2011-Q3								
2011-Q4								
2012-Q1	0.60							
2012-Q2	0.48							
2012-Q3								
2012-Q4								
Max	0.605	1.405	1.030	0.705	1.153	3.420	2.435	29.710
Min	0.290	0.723	0.754	0.325	0.749	1.370	1.289	2.990
Average	0.458	1.042	0.931	0.425	0.952	2.181	1.891	10.875

Table 4-8b. Observed receiving water total copperconcentrations at stations within or near the Delta, in units of ug/L. (Source: California Environmental Data Exchange Network)

		Upstream →		Upstream →		
Date Qtr	**Delta-wide Pittsburg**	**Sacramento River (BG20)**	**Sacramento R at Point Sacramento**	**San Joaquin River (BG30)**	**South Webb Tract Drain**	**San Joaquin River at PID Pumps**
2008-Q1						
2008-Q2		3.020		3.140		
2008-Q3					2.033	2.400
2008-Q4					5.100	2.700
2009-Q1					2.800	2.867
2009-Q2					2.500	3.500
2009-Q3		0.640		2.460	0.965	3.225
2009-Q4					0.770	1.900
2010-Q1						5.133
2010-Q2						
2010-Q3		2.780		2.275		2.667
2010-Q4						4.867
2011-Q1						2.333
2011-Q2	3.103		2.284			3.275
2011-Q3						2.925
2011-Q4						1.700
2012-Q1	5.120		4.570			2.900
2012-Q2	4.456		4.068			3.550
2012-Q3						4.800
2012-Q4						
Max	5.120	3.020	4.570	3.140	5.100	5.133
Min	3.103	0.640	2.284	2.275	0.770	1.700
Average	4.226	2.147	3.641	2.625	2.361	3.171

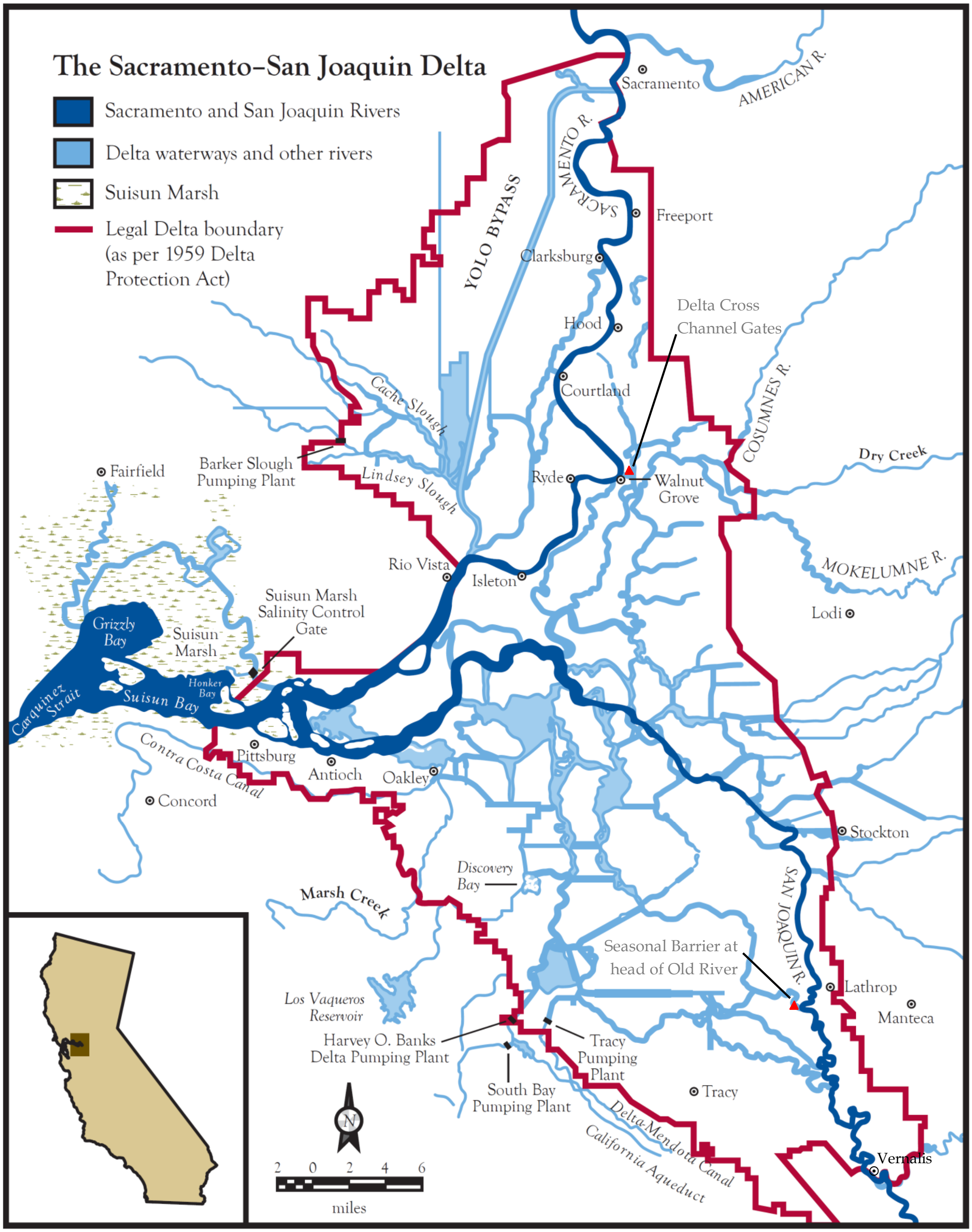


Figure 4.1. Map of Sacramento-San Joaquin Delta showing legal Delta boundaries, main rivers and channels, major cities and towns, Delta cross channel gates, seasonal barrier at Old River, and export pumping facilities.
(Source: http://www.swrcb.ca.gov/images/programs/delta_wm/deltamap_big.jpg)

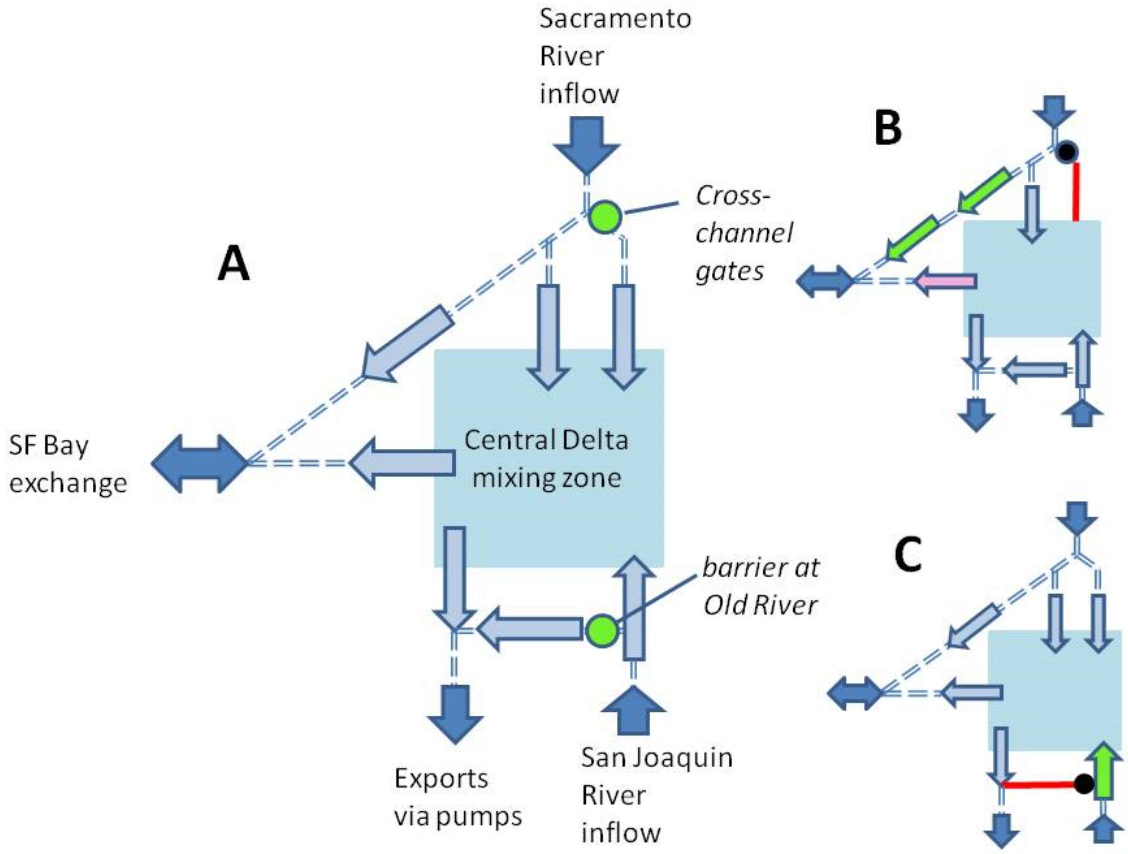


Figure 4.2. Schematics of Delta hydrology showing flow into central Delta from the Sacramento and San Joaquin Rivers when the Delta cross channel gates and the head of Old River season barrier are open (A), when the Delta cross channel gates are closed (B) and when the head of Old River seasonal barrier is in place (C). Export pumps always induce a southward flow from the central Delta when pumping for exports. *(Adapted from Monsen et al, 2007)*

Figure 4.3. Delta and vicinity showing locations of major wastewater treatment facilities and water quality monitoring stations.

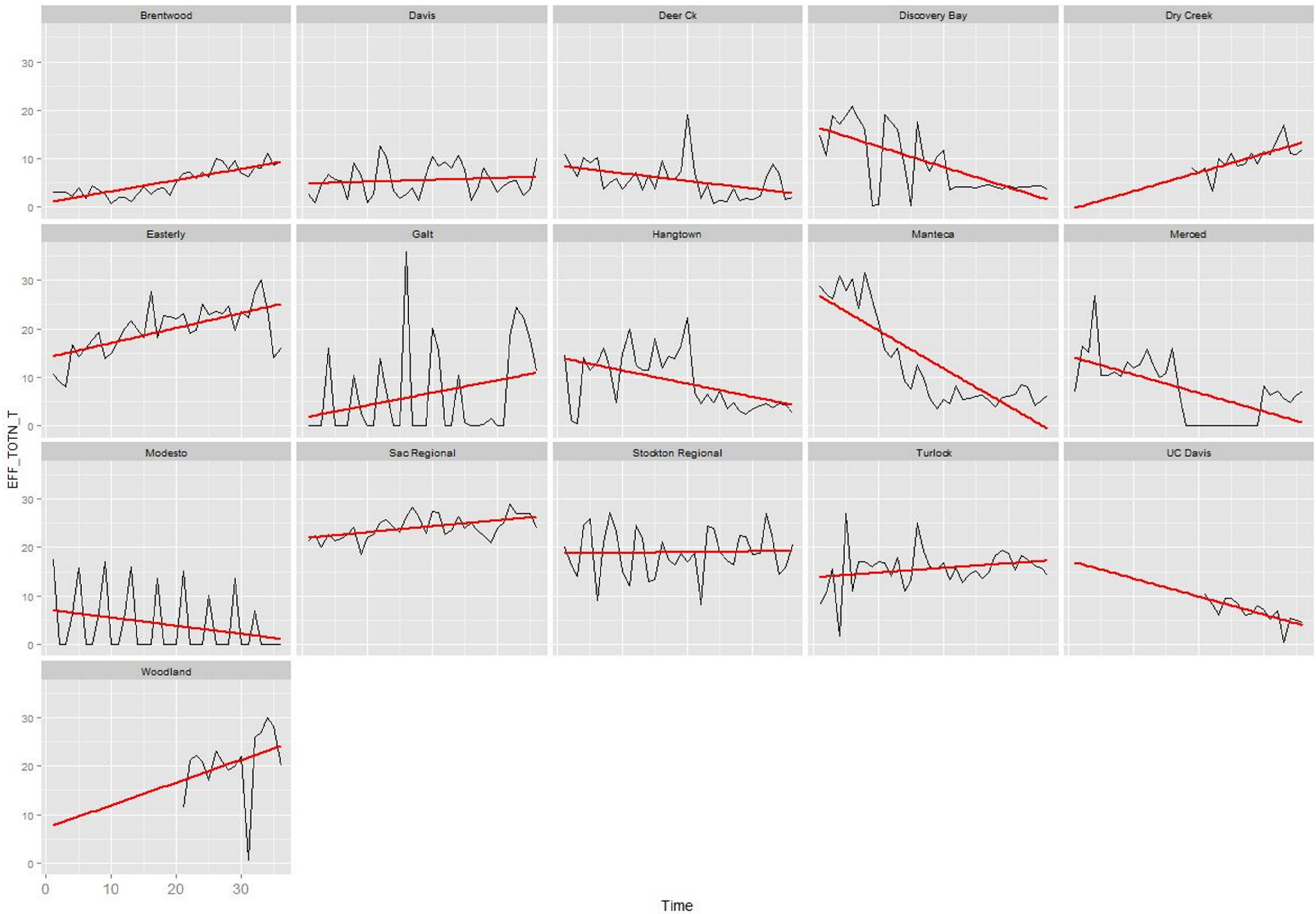


Figure 4.4a. Regression plots of wastewater treatment facility total nitrogen effluent concentration vs. time.

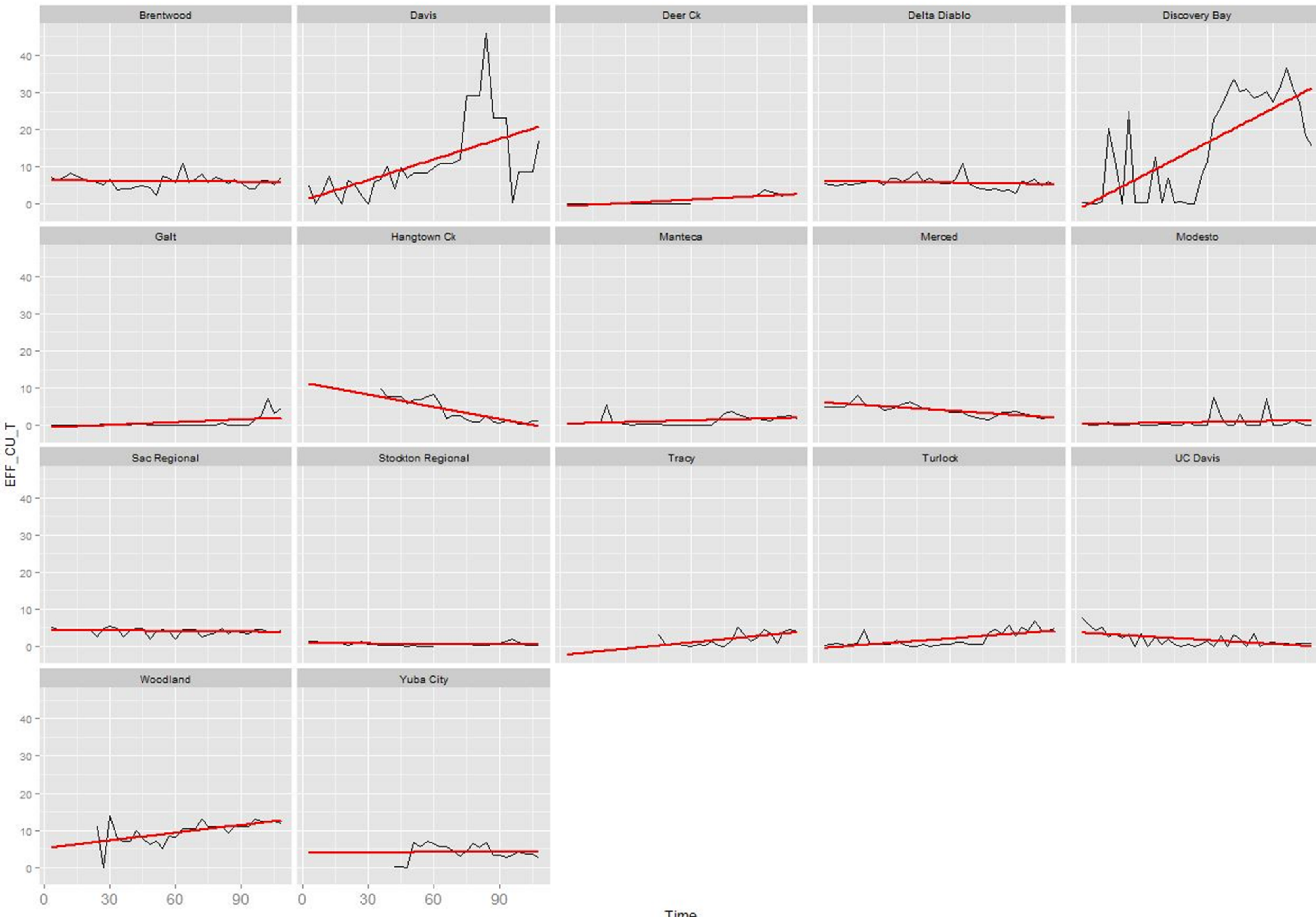


Figure 4.4b. Regression plots of wastewater treatment facility total copper effluent concentration vs. time.

6. References

Aquatic Science Center. (2012). The Pulse of the Delta: Linking Science & Management through Regional Monitoring. Contribution No. 660. Aquatic Science Center, Richmond, CA.

Borregaard, V. R. (1997). Experience with nutrient removal in a fixed-film system at full-scale wastewater treatment plants. *Water Science and Technology*, *36*(1), 129-137.

California Department of Water Resources (DWR), prepared by URS Corp. (March 2007). Status and Trends of Delta-Suisun Services, Public Review Draft. .

California State Water Resources Control Board (SWRCB). (June 2011). 2010 Annual Enforcement Report.

Carey, R. O., & Migliaccio, K. W. (2009). Contribution of wastewater treatment plant effluents to nutrient dynamics in aquatic systems: a review. *Environmental Management*, *44*(2), 205-217.

Collivignarelli, C., & Bertanza, G. (1999). Simultaneous nitrification-denitrification processes in activated sludge plants: Performance and applicability. *Water Science and Technology*, *40*(4), 187-194.

Coyne, W &Metzger, L. (May 2004). Mandatory Minimum Penalties, An Effective Tool for enforcement of Clean Water Laws. TexPIRG Education Fund, Austin, Texas.

Ekster, A., & Jenkins, D. (1996). Nickel and copper removal at the San Jose/Santa Clara water pollution control plant. *Water Environment Research*,*68*(7), 1172-1178.

Goldstone, M. E., Atkinson, C., Kirk, P. W. W., & Lester, J. N. (1990). The behaviour of heavy metals during wastewater treatment III. Mercury and arsenic.*Science of the Total Environment*, *95*, 271-294.

Griffiths, C., Klemick, H., Massey, M., Moore, C., Newbold, S., Simpson, D., & Wheeler, W. (2012). US Environmental Protection Agency valuation of surface water quality improvements. *Review of Environmental Economics and Policy*, *6*(1), 130-146.

Helz, G. R., Huggett, R. J., & Hill, J. M. (1975). Behavior of Mn, Fe, Cu, Zn, Cd and Pb discharged from a wastewater treatment plant into an estuarine environment. *Water Research*, *9*(7), 631-636.

Jahagirdar, S., & Coyne, W. (2003). Leaking Enforcement. Analyzing the Effectiveness of the 1999 Clean Water Enforcement and Pollution Prevention Act. Environment California Research and Policy Center, Los Angeles, California.

Lofton, D. D., Hershey, A. E., & Whalen, S. C. (2007). Evaluation of denitrification in an urban stream receiving wastewater effluent. *Biogeochemistry*, *86*(1), 77-90.

Magat, W. A., & Viscusi, W. K. (1990). Effectiveness of the EPA's regulatory enforcement: The case of industrial effluent standards. *JL & Econ.*, *33*, 331.

Marti, E., Aumatell, J., Godé, L., Poch, M., & Sabater, F. (2004). Nutrient retention efficiency in streams receiving inputs from wastewater treatment plants. *Journal of Environmental Quality*, *33*(1), 285-293.

Monsen, N. E., Cloern, J. E., & Burau, J. R. (2007). Effects of flow diversions on water and habitat quality: Examples from California's highly manipulated Sacramento-San Joaquin Delta. *San Francisco Estuary and Watershed Science*, *5*(3).

Munch, E., Barr, K., Watts, S., & Keller, J. (2000). Suspended carrier technology allows upgrading high-rate activated sludge plants for nitrogen removal via process intensification. *Water Science and Technology*, 41(4-5), 5-12.

Nielsen, J. S., & Hrudey, S. E. (1983). Metal loadings and removal at a municipal activated sludge plant. *Water Research*, *17*(9), 1041-1052.

R Development Core Team. (2008). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

Saunders, D. L., & Kalff, J. (2001). Nitrogen retention in wetlands, lakes and rivers. *Hydrobiologia*, *443*(1-3), 205-212.

Shi, B., Allen, H. E., & Grassi, M. T. (1998). Changes in dissolved and particulate copper following mixing of POTW effluents with Delaware River water. *Water Research*, *32*(8), 2413-2421.

Sodré, F. F., & Grassi, M. T. (2007). Changes in copper speciation and geochemical fate in freshwaters following sewage discharges. *Water, air, and soil pollution*, *178*(1-4), 103-112.

Stein, E. D., & Cadien, D. B. (2009). Ecosystem response to regulatory and management actions: The southern California experience in long-term monitoring. *Marine pollution bulletin*, *59*(4), 91-100.

USEPA. (1991). Technical support document for water quality-based toxics control.

Ward, R. C., Loftis, J. C., & McBride, G. B. (1986). The "data-rich but information-poor" syndrome in water quality monitoring. *Environmental Management*, *10*(3), 291-297.

Walsh, P., & Wheeler, W. (2011). Water quality index aggregation and cost benefit analysis. *US EPA National Center for Environmental Economics working paper, Washington, DC*.

Windom, H., Wallace, G., Smith, R., Dudek, N., Maeda, M., Dulmage, R., & Storti, F. (1983). Behavior of copper in southeastern United States estuaries. *Marine Chemistry*, *12*(2), 183-193.

CHAPTER FIVE

Conclusion

1. Summary

Mandatory minimum penalties were adopted and implemented in California beginning in 2000 and required the SWRCB and the RWQCBs to issue a $3,000 penalty for each serious violation of effluent limitations contained in NPDES permits and for each chronic violation after the third violation in a six month period. The goal of MMPs is to increase compliance by regulated facilities with their NPDES permits (Jahagirdar and Coyne, 2003). Evaluations of the effectiveness of the MMP enforcement program have focused on tallies of violations and enforcement actions during a given year. However, there have been no long-term investigations of the relationship between number of violations that occur and MMP enforcement. There have also not been any studies that consider improvements in environmental quality as end points to determine the effectiveness of the MMP enforcement program. The objective of this dissertation was therefore to provide an initial quantitative assessment ofthe apparent effects of the MMP enforcement program on number of violations and on improvements in water quality.

In Chapter 2, the correlation between the number of effluent violations and the number of MMP enforcement actions was investigated through linear regression models using data from the period 2000-2011for the twelve RWQCBs. The preliminary results indicate that the number of violations within an RWQCB region in a given year are reduced by approximately 2% for each MMP administrative civil liability (ACL) enforcement action taken by the RWQCB during the year. The results also indicate that MMP enforcement actions have additional lagged effects which extend their impacts beyond the year of issuance, and the number of violations within an

RWQCB region is further reduced by approximately 4% for each MMP enforcement action taken by the RWQCB three years prior and by approximately 6% for each MMP enforcement action taken five years prior. The study also considered the effects of the probability that a violation will result in an MMP enforcement action, and the results suggest that the issuance of MMP enforcement actions appear to be most effective when issued closer in time to when the violations occurred. Lastly, the study considered the effects of cease and desist order (CDO) and time schedule orders (TSO), which require facilities to take corrective action but also allow facilities to continue operations. The results indicate that the number of violations is reduced by 9% if a CDO or TSO during the previous year; however, the longer-term effect of CDOs and TSOs appear to result in an increase in the number of violations. The results also indicate that although CDOs and TSOs exempt certain violations from MMPs, these exemptions do not impact the number of violations that are subject to MMPs. Consequently, the results indicate that provisions in enforcement programs that exempt some violations, such as through cease and desist orders, provide needed relief to certain communities working towards corrective action to prevent future

In Chapter 3, the correlation between the effluent concentrations discharged by wastewater treatment facilities within the San Francisco Bay region and MMP enforcement actions issued by the San Francisco Bay RWQCB was investigated through linear regression models using data from the period 2000-2011. The preliminary results indicate that modest reductions in a facility's effluent concentrations for biochemical oxygen demand (BOD), total suspended solids (TSS), copper (Cu) and cyanide (CN) were achieved on the order of 2% to 16% due to the issuance of MMP ACL enforcement actions to the facility. However, the results also suggest that MMP enforcement actions appear to result in higher effluent concentrations of TSS or CN, on the order of 2% to 11%, if an MMP ACL enforcement action is issued to a facility that only addresses violations of constituents other than TSS or CN. The results also indicate that MMP ACL enforcement actions have lagged effects of up to five years, possibly due to the delay between occurrence of violations and the issuance of MMP enforcement actions and the time needed to upgrade facilities to prevent future violations. The regression results indicate that the effluent concentration reductions are due to facility-specific effects, but overall decreases in concentration trends over time also suggest that reductions are also due to enhancement of the regulatory agency's enforcement reputation. This study also suggests that the effects of MMP enforcement actions on effluent concentrations varied between the four constituents considered, possibly due to the different corrective actions, and the time necessary to complete those actions, that are possible or achievable for each constituent. A separate analysis suggests that effluent concentrations did not differ from the period prior to the MMP enforcement program until four to six years after the start of the program, possibly due to the delay in issuing MMP enforcement actions after violations occur and the time needed to complete corrective actions at the facilities to prevent future violations.

In Chapter 4, the correlation between effluent quality discharged by wastewater treatment plants that discharge directly or indirectly to the Sacramento-San Joaquin Delta and MMP ACL enforcement actions issued to those facilities was investigated. As in Chapter 3, the preliminary results indicate that the issuance of MMP enforcement actions result in long-term decreases in effluent concentrations for the constituents considered (total nitrogen and total copper); however, the reductions are higher than in Chapter 3 and range between about 17.4% to 31.3%. An illustrative evaluation using a simple model of Delta flows to calculate the impact of the reductions of effluent concentrations on the Delta's water quality indicates that improvements of water quality in receiving waters may be measurable. However, comparisons with actual water quality monitoring data from the Delta indicate that long-term improvements of the water quality in receiving waters may not be sufficiently large to be observable or are masked by other pollution sources and fate and transport processes.

Overall, the preliminary results from the three investigations presented in this dissertation indicate that California's MMP enforcement program has resulted in a decrease in the number of NPDES effluent limitation violations across the state and in improvements in effluent quality discharged to San Francisco Bay and the Sacramento-San Joaquin Delta, although improvements in receiving water quality may not be large or observable. The results indicate that the effects may be due to both facility-specific effects as well as enhancement of the regulatory agency's enforcement reputation. However, because the violations or pollution reducing effects due to MMPs are modest and because violations do continue, the results may also suggest that the MMP enforcement program could be optimized to achieve larger effects. Nevertheless, the prelimininary results from this dissertation indicate that the MMP enforcement program contributes to achieving clean environment goals and that, coupled with provisions to provide enforcement relief when a violator is working towards prevention of future violations, is an effective government regulatory policy. Further research utilizing the data sets collected and assembled for this dissertation will provide additional insights and conclusions regarding the effectiveness of the MMP enforcement program.

2. Relation to enforcement literature

The results from this dissertation suggest that mandatory minimum penalties are effective in promoting compliance and achieving reductions in pollution. Because the RWQCBs were mandated to issue MMP enforcement actions and because issuance of MMPs were procedurally faster than discretionary penalties, the MMP enforcement program resulted in an increase in the frequency of enforcement actions, and imposing more frequent penalties has been suggested as a means to increase the probability of compliance by facilities (Adrison, 2007). However, violations of effluent limitations do continue in California despite the MMP enforcement program, and the relatively modest reductions in violations or modest improvements in effluent quality may suggest that there is room for further enforcement stringency. MMPs may be similar to Class I penalties issued by the US Coast Guard for oil spills, which Weber and Crew (2000) described as "administratively the easiest to prepare" but limited to $10,000 per violation; Weber and Crew suggest that larger penalties are necessary to effect greater compliance. Nevertheless, the impact of the MMP enforcement program in pollution reduction has been demonstrated in this dissertation, and the true value of the MMP enforcement program might possibly be summarized by similar conclusions reached by Magat and Viscusi (1990) regarding the USEPA enforcement in the paper pulp industry, i.e., "the real issue is whether water quality would have been worse in the absence of EPA enforcement , not whether the overall level of water quality has improved" in light of continuing economic growth and a fixed assimilative capacity of the environment.

3. Monitoring recommendations for future evaluations

The MMP enforcement program has evolved since it was first implemented in 2000 and continues to evolve. In 2010, the SWRCB adopted a new Enforcement policy which included and expectation that MMP enforcement actions will be taken by the RWQCBS within 18 months of discovery of a violation (SWRCB, 2010). The SWRCB is also promoting the issuance of MMPs through expedited payment letters in order to further streamline the process of issuing ACLs. The effects of these two changes may not be evident for several more years. There is a need to evaluate the effectiveness of changes to the MMP enforcement program as well as the continued impacts of MMPs in general. One challenge in conducting the investigations for this dissertation has been assembling sufficient necessary data to assess the impacts of the MMP enforcement program, both in terms of promoting compliance and in measuring improvements in the quality of surface waters.

The challenge of evaluating program impacts likely carries across the various programs implemented by the SWRCB and RWQCBs, and deficiencies in developing and implementing effective and meaningful monitoring programs has been identified by others previously as a major shortcoming of environmental programs and characterized as a "data rich, information poor syndrome" (Ward et al, 1986). Therefore, a common comprehensive evaluation program is recommended to be a component of all SWRCB and RWQCB programs. Certain representative indicator constituents should be chosen as the core set of constituents to be consistently monitored, at the same monitoring frequencies, in the effluent discharged by all facilities and in the receiving waters in order to address the data deficiencies encountered in the investigations in this dissertation. The set of core constituents may be chosen so as to form a water quality index (WQI) which would communicate complex information about water quality to decision makers and the public (Griffiths et al, 2012;Walsh and Wheeler, 2012).

4. Future Investigations

Finally, the investigations in this dissertation only begin to assess the impacts of MMPs. While linear regressions were the primary analysis method used in this dissertation, other analytical approaches could be applied to the data collected for this dissertation in the future to further investigate the impacts of the MMP enforcement program. Comprehensively quantifying the impacts of MMPs on improving water quality remains yet to be conducted in the context of other SWRCB and RWQCB programs and other pollution sources. Further investigations could also identify the interval between enforcement actions and the level of mandatory minimum penalty necessary that would achieve greater desired level of compliance and environmental improvement. Investigating the impacts of the MMP enforcement program on decision-makers, both at the regulated facilities and at the SWRCB and RWQCBs, and how those parties have had to adapt to a new enforcement paradigm, may also provide guidance on how other regulatory programs could be developed and implemented effectively.

5. References

Adrison V. (2007). Estimating the Effect of Penalties on Regulatory Compliance. PhD. Dissertation, Georgia State University.

California State Water Resources Control Board (SWRCB). (May 2010). Water Quality Enforcement Policy.

Griffiths, C., Klemick, H., Massey, M., Moore, C., Newbold, S., Simpson, D., & Wheeler, W. (2012). US Environmental Protection Agency valuation of surface water quality improvements. *Review of Environmental Economics and Policy*, *6*(1), 130-146.

Jahagirdar, S., & Coyne, W. (2003). Leaking Enforcement. Analyzing the Effectiveness of the 1999 Clean Water Enforcement and Pollution Prevention Act. Environment California Research and Policy Center, Los Angeles, California.

Magat, W. A., & Viscusi, W. K. (1990). Effectiveness of the EPA's regulatory enforcement: The case of industrial effluent standards. *JL & Econ.*, *33*, 331.

Ward, R. C., Loftis, J. C., & McBride, G. B. (1986). The “data-rich but information-poor” syndrome in water quality monitoring. *Environmental Management*, *10*(3), 291-297.

Walsh, P., & Wheeler, W. (2011). Water quality index aggregation and cost benefit analysis. *US EPA National Center for Environmental Economics working paper, Washington, DC*.

Weber, J. M., & Crew Jr, R. E. (2000). Deterrence theory and marine oil spills: Do coast guard civil penalties deter pollution? *Journal of Environmental Management*, *58*(3), 161-168.