SOLANO COUNTY WATER AGENCY

NORTH BAY AQUEDUCT ORGANIC CARBON TREATMENT STUDY

FINAL REPORT

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MWH

FINAL REPORT
NORTH BAY AQUEDUCT ORGANIC CARBON TREATMENT STUDY
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ABREVIATIONS

BSPP	Barker Slough Pumping Plant
CI	Confidence Interval
DBP	Disinfection By-products
DOC	Dissolved Organic Carbon
EBCT	Empty Bed Contact Time
GAC	Granular Activated Carbon
HAA5	Haloacetic Acids (5 species that are regulated)
MIEX	Magnetic Ion Exchange
NBA	North Bay Aqueduct
NOM	Natural Organic Matter
PODR	Point of Diminishing Returns
SCWA	Solano County Water Agency
SD	Standard Deviation
THM	Trihalomethanes
THMFP	THM Formation Potential
TOC	Total Organic Carbon
WTP	Water Treatment Plant

VERSION CONTROL

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DRAFT	Dec 3, 2008	Ken Mercer, Jeff Lodge	Bill Taplin	Progress draft for comment
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Executive Summary

There is significant interest at the state and federal level to restore wetlands in the Cache Slough Complex of the Sacramento – San Joaquin Delta. Tidal wetland restoration within the Cache Slough system is likely to result in increased total organic carbon (TOC) and dissolved organic carbon (DOC) at the Barker Slough Pumping Plant (BSPP) for the North Bay Aqueduct (NBA), ranging from negligible to significant depending on the extent and location of the restored area. This report was prepared to evaluate the potential water treatment cost impacts to users of the NBA resulting from potential future increases in baseline TOC and DOC levels in the raw water.

Modeling of the Barker Slough and Cache Slough Complex was undertaken to simulate the anticipated increases in TOC and DOC due to restoration of distinct acreages. Philip Williams & Associates (PWA) worked with the Solano County Water Agency (SCWA) to complete the modeling simulations for the restoration of what has been estimated to be up to 30,000 acres. The predicted increase in DOC resulting from wetland restoration ranges from 1 to 3 mg/L, which is a 25 to 50% increase in the average DOC level.

Interviews were conducted with operations staff at the six treatment plants to discuss the merits and overall goals of the study as they relate to treatment of NBA water. Water Treatment Plant (WTP) data collected from the six NBA users included chemical use, organic carbon in the influent as well as throughout the treatment plant, and source water blends (if applicable). Once the data was screened and organized according to prescribed criteria, the relationship between total organic carbon and treatment requirements was established (where TOC is mostly comprised of DOC).

Operational cost estimates were developed for each WTP using the general TOC/treatment requirement relationships developed for the NBA users. These cost estimates include increased chemical use and sludge production.

Based on the analysis, the total increase in combined annual costs for each 1 mg/L increase in TOC for all WTPs using the NBA could range from approximately $250,000 to $330,000 (2008 dollars). Based on the modeled potential increase in TOC in Barker Slough of 1 to 3 mg/L, the total increased costs could range from a lower limit of approximately $250,000 to an upper limit of $1,000,000.

Because the impacts to DBP formation are difficult to quantify, two technologies that are proven to reduce organic carbon levels were selected to make initial cost estimates for DBP mitigation, viz., ion-exchange (MIEX) or post-filter activated carbon contactors. Based on engineering and construction assumptions, the capital cost associated with implementation of one of these treatment technologies could range from $40M to $90M. The initial estimate of the range of annual operational costs for one of these processes is $9M to $29M.

1. Objectives

Tidal wetland restoration within the Cache Slough system is likely to result in increases in organic carbon, both total organic carbon (TOC) and dissolved organic carbon (DOC) at the Barker Slough Pumping Plant (BSPP) for the North Bay Aqueduct (NBA), ranging from negligible to significant depending on the extent and location of the restored area. This report has been prepared to evaluate the potential water treatment cost impacts to users of the NBA resulting from future increases in baseline dissolved and total organic carbon levels in the raw water. The type of wetland will influence not only the extent of increased DOC but also the season(s) in which DOC is impacted. Several wetland alternatives for this location show predicted increases in DOC as high as 1.5-3 mg/L or up to 25-50% higher DOC.

It is important to remember that predictions of changes in the overall DOC concentration do not necessarily capture the impacts of increased organic carbon because the character of the organic carbon plays a critical role in its removal and hence the costs of treatment. Organic carbon comprises a complex mixture of constituents that differ in form, reactivity, fate and effects in the ecosystem and for drinking water, and there is no single, simple characterization of organic carbon in the Delta for either ecosystem or drinking water (Healey, 2008). The reactivity of the increased organic carbon load has not been determined and estimates of this (as potentially characterized by UV_{254} absorbance) are difficult to make.

With this in mind, the report was prepared with the following objectives:

1. Gather and review data on the North Bay Aqueduct water users, including operating cost information provided by each plant, water use projections from SCWA, and published data in peer reviewed literature for best available technologies and construction costs. This data collection and review was used to develop criteria for which capital and operational improvements will be recommended.
2. Estimate the impacts of increased organic carbon on a unit cost basis for water treatment based on two approaches:
   a. Statistical analysis (i.e. linear regressions) of organic carbon effects on chemical use
   b. Engineering judgment based on implementation of best practices for mitigation of impacts to the health of finished water customers
3. Qualitatively describe the impacts of increased TOC/DOC on DBP regulation compliance through interviews with WTP staff members.

2. Background

2.1. Solano County Water Agency

The Solano County Water Agency (SCWA) is currently conducting a study to determine the economic impact of increased total organic carbon (TOC) at the NBA. The reason for this study is the significant interest at the state and federal level to restore wetlands in the Cache Slough Complex of the Sacramento – San Joaquin Delta which is shown in Appendix A. Several entities such as CalFed, the Bay Delta Conservation Plan, the State Water Project / Central Valley Project, and others are proposing to restore thousands of acres of wetlands in the Cache Slough Complex, and changes in water quality in Cache Slough will directly impact water treatment plants that rely on the NBA as part of their water supply as shown in Appendix A. The six water treatment facilities that currently receive raw water from the NBA are presented in Table 2-1.

Table 2-1 NBA Users and Treatment Plants

NBA User	Water Treatment Plant
City of Fairfield/Vacaville	North Bay Regional Water Treatment Plant
City of Benicia	Benicia Water Treatment Plant
City of Vallejo	Travis Air Force Base
City of Vallejo	Fleming Hill Water Treatment Plant
City of American Canyon	American Canyon Water Treatment Plant
City of Napa	Jamieson Water Treatment Plant

To assess the impacts to the NBA users, SCWA is conducting a study to estimate the likely increase in DOC for several wetland restoration scenarios. The resulting increase in DOC will then be used to calculate additional water treatment costs for all of the NBA treatment plants in Napa and Solano counties. To adequately estimate additional water treatment costs, MWH conducted interviews with each of the NBA water treatment plant operations personnel concerning current water treatment practices. The information and data collected from the water treatment plants was used to estimate the additional treatment cost from each facility as well as on the NBA collectively. These estimates will allow SCWA to determine if there will be a significant economic impact to the NBA users.

2.2. TOC, DBPs, and the NBA

Natural organic matter (NOM) in natural waters is generally derived from the decay of aquatic and terrestrial vegetative material. The reaction between organic carbon in natural waters and disinfectants such as chlorine and choramines has been proven to result in the formation of disinfection byproducts such as trihalomethanes (THM) and haloacetic acids (HAA). Concentrations of THM and HAA are currently regulated in finished drinking water by the USEPA Disinfectants/Disinfection Byproducts Rule. Current regulations for DBPs (80 ppb for THM, 60 ppb for HAA5) are based on running annual averages determined from quarterly measurements. However, new regulations will require an evaluation of the entire distribution system which will determine "trouble spots" that have the highest water age which can generally result in increased DBP formation. The monitoring frequency and number of sites is determined based on the systems source water and service population. The new regulations also call for local running averages to be determined at each monitoring station with inclusion of the peak historical month (i.e. the month with the highest measured THM and HAA5).

Parameters important in DBP formation include organic carbon (reactivity and concentration), pH, temperature, bromide concentration, disinfectant type and dose, and the total reaction time. Several studies have shown a strong correlation between DBP formation and the UV absorbance of the water, normally at wavelength 254 nm (UV_{254}) or the specific UV absorbance (SUVA), which is UV_{254} divided by the DOC concentration with units of L/g-m (Reckhow and Singer, 1990; Archer and Singer, 2006; Sohn, J. et al., 2004). UV light is absorbed by DOC, especially conjugated double bonds such as aromatic functional groups.

The sources of DOC in Delta waters include rivers, island drains, wastewater, wetlands, agricultural and urban runoff, and algae growth, among others (CALFED, 2008 – and following). The DOC may enter the Delta via groundwater and subsurface drainage, as well as via the surface water system. In terms of upstream sources, rivers — which drain agricultural, urban and natural watersheds into and through the Delta — are the largest source of DOC. In terms of in-Delta sources, island drains have long been thought to be a major contributor to DOC arriving at the drinking water export pumps. Most islands are highly subsided (up to 25 feet below sea level) because of oxidation of their peat soils. To offset the influx of water that seeps through the levees and accumulates from irrigation and precipitation, water must be continually pumped off the islands into neighboring Delta channels. Groundwater flow through oxidized peat soil layers may also contribute DOC.

Wetlands, both within the Delta and as part of upstream floodplains and riparian zones, are another source of DOC (CALFED, 2008 – and following). Wetland DOC concentrations may exceed 80 mg/L in surface water in the soils. However, wetlands are not automatically large sources of DOC; a particular wetland may release insignificant amounts of DOC, depending on its configuration. Older, larger and more developed wetlands tend to trap rather than export DOC because water flowing through them follows more complex channel configurations and encounters more diverse and dense vegetation. Most of the wetland relics still remaining in the Delta, however, are small and well connected to the river by tidal channels, attributes that yield larger amounts of DOC to the surrounding channel waters. Runoff from agricultural fields, natural landscapes and urban environments may lead to elevated DOC concentrations in surface waters, as well. Runoff and wastewater entering the Delta are also replete with nutrients that can stimulate algal production – another source of DOC. However, there is little evidence to suggest that algal production is a major contributor to elevated DOC concentrations in the Delta.

Monthly grab samples collected by California Department of Water Resources (DWR) from 1995 until present day characterize the seasonality of DOC at Barker Slough Pumping Plant (Rabidoux, 2008). DOC is highest during the rainy season (December to April) when runoff provides a transport mechanism from land to water body. For example, DOC can range from 4 to 21 mg/L in January. The variability during the rainy season probably results from both inter-annual and daily variation in rainfall and runoff. During the dry season (May to November), DOC falls to the annual minimum between 2-4 mg/L. The negligible precipitation and the end of growing season are probable causes for the dry season minima in DOC. These wet and dry trends can be seen in Appendix B Figure B.1 which shows plots of monthly TOC and DOC data for the Barker Slough Pumping Plant.

The following text is taken directly from the *Conceptual Model For Organic Carbon In The Central Valley And Sacramento–San Joaquin Delta: Final Report* April 14, 2006 (Roy et al., 2006):

> “There is general agreement in the literature that THM formation is correlated to TOC concentrations, although the relationship is more complex when a specific structural characteristic of DOC is compared with THM formation potential (THMFP). There is limited knowledge on the relative propensity of different sources to form THMs, although it appears that Delta island drainage is somewhat less reactive than tributary sources. The chemistry of organic carbon, and particularly the propensity of organic carbon from different sources to form THMs and other disinfection byproducts, continues to be investigated actively. However, because of the dynamics in the system (in the flows and production of organic carbon), available data are insufficient to draw conclusions about the quality or the THMFP of organic carbon from different sources. The data are especially lacking in much of the watershed upstream of the Delta. There is significant

> uncertainty associated with this information even though it is important for assessing drinking water impacts. A better understanding of the potential for disinfection byproduct formation of different sources of organic carbon could lead to more informed decisions on how to best manage organic carbon in the system. For the immediate future, total organic carbon will be the primary focus of the Central Valley Drinking Water Policy Workgroup because drinking water suppliers are regulated on the concentrations of total organic carbon in the source water, and the research to characterize the quality of carbon from the various sources in the Central Valley will be costly and time consuming."

Figure 2.1 shows THM formation (as µmol/L) as a function of DOC with water from the Banks Pumping Plant. The amount of THMs formed in samples containing the same concentration of DOC and collected from across the Delta varies by a factor of five, similar to the variability caused by changes in DOC concentration at Banks PP (CALFED, 2008). Figure 2.2 shows THM formation potential (as µg/L) for samples collected from the Sacramento/San Joaquin Rivers upstream of the Delta (Chow et al., 2007).

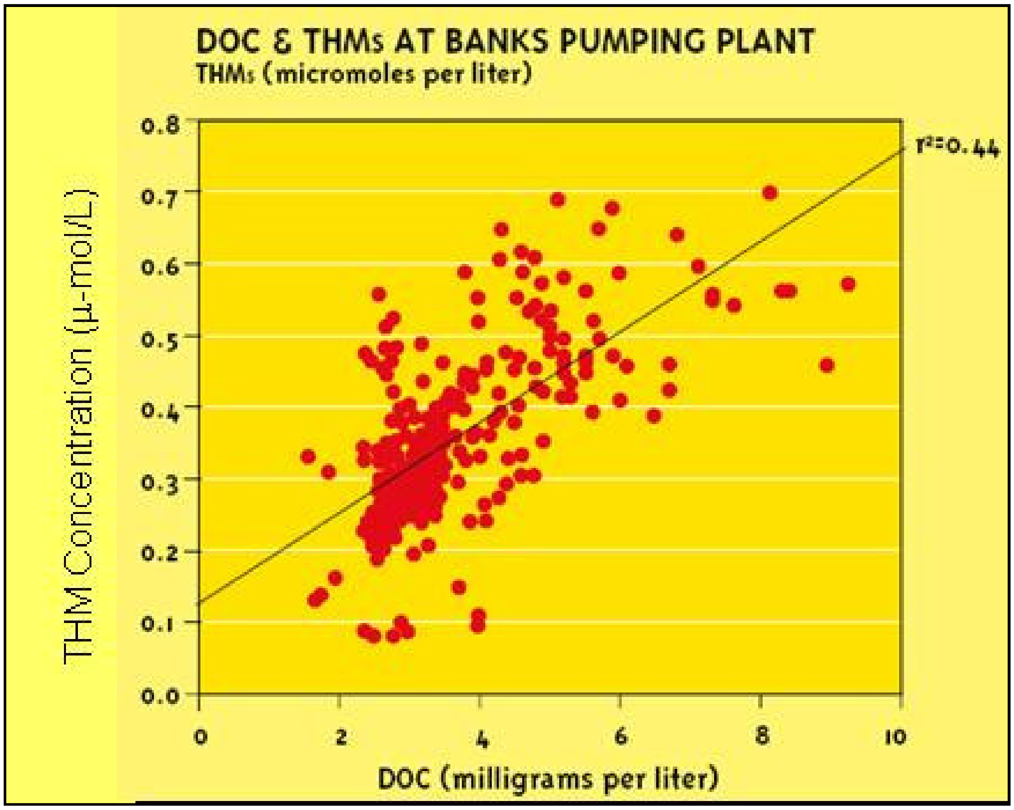

Figure 2.1 THM formation (in µmoles/L) as a function of DOC concentration (R^2 = 0.44) (CALFED, 2008)

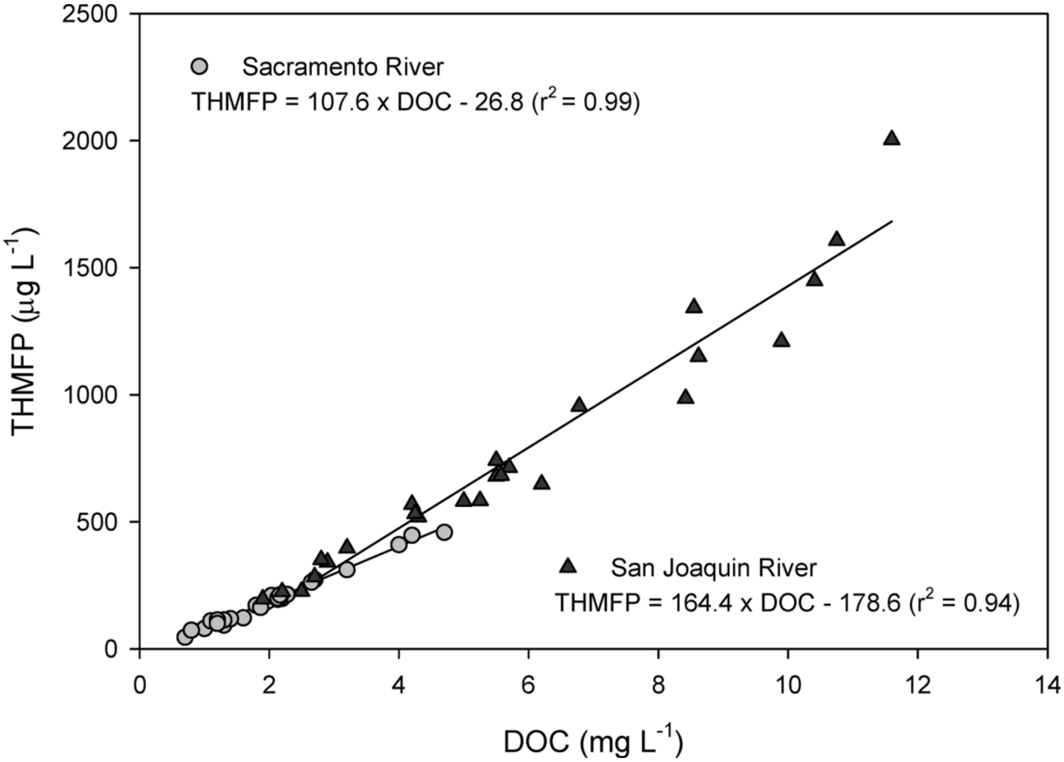

Figure 2.2 THM Formation Potential (in micrograms/L) for raw water samples from the Sacramento and San Joaquin Rivers (Chow et al., 2007)

Wetlands are highly productive and can increase DOC concentrations as well as change its chemical characteristics through internal processes and loading (Diaz et al., 2008); this study found that chlorine demand increased substantially in wetland drainage (~ 15 mg Cl_2/L) in comparison to the wetland inlet water (~ 7 mgCl_2/L) resulting from the DOC contribution of the wetland. USGS studies have shown that wetland-produced DOC in the Sacramento/San Joaquin Delta formed more THMs than most other sources, while island drains had higher HAA formation (CALFED, 2008).

A wetland restoration demonstration project (Fleck et al., 2004) examined the effects of DBP formation potential from Twitchell Island, in the Sacramento/San Joaquin Delta. This study found that conversion of agricultural land to a wetland changed many of the biogeochemical processes controlling dissolved organic carbon (DOC) release from the peat soils relative to the previous land use, identifying the importance of organic matter sources, microbial decomposition pathways and decomposition status of soil organic matter in the release of DOC and DBP precursors from delta soils under varying land-use practices. The THM formation potential of DOC extracted from the wetland soil was greater than that from agricultural sites after only 3 years of inundation

An additional study of the Delta by Fleck et al. (2007) reported that management of a restored wetland is important to potential DBP formation. Net loads of DOC and THM-precursors from a permanently flooded wetland supporting dense emergent vegetation can be similar in magnitude to the net loads produced by agricultural management of similar areas with peat soils; however, because the altered, oxidized shallow peat soil layer of drained peat islands contains a large reservoir of mobile DOC, minimizing net loads of DOC and THM-precursors from a wetland can require minimizing water flow through the shallow soil layer beneath the wetland. This study reported that seepage flow from the wetland would eventually flush the mobile DOC out of the shallow soils and that large net loads of DOC could be produced during the intervening 15 years.

3. Approach

3.1. Data Collection and Staff Interviews

A kickoff meeting was initially held to discuss required informational needs for operations at water treatment facilities. Treatment facility locations and contact information were assembled and initial telephone calls were made to each of the facilities to discuss the intent of the study and initiate a meeting. Meetings were scheduled with operations staff at the six treatment plants to further discuss the merits and the overall goals of the study as they relate to treatment of NBA water. Initial meetings with operations staff were held from June 6 to 13, 2008 at each of the respective treatment facilities. The meetings purpose included explanation of the study and the intent of restoration activities along with discussing the estimated increase to the DOC levels in the NBA.

Modeling of the Barker Slough and Cache Slough Complex was undertaken to simulate the anticipated increase in DOC due to restoration of distinct acreages. Philip Williams & Associates (PWA) worked with SCWA to complete the modeling simulations for the restoration of what has been estimated to be up to 30,000 acres. Initial estimates for the level of increase in TOC due to restoration is on the order of 1 mg/l based on initial findings and could be up to 3 mg/L.

3.2. Treatment Data Screening and Statistical Analysis

WTP data collected from the NBA users presented in Table 2-1 included chemical use, organic carbon in the influent as well as throughout the treatment plant, and source water blends (if applicable). Data was screened to include only those instances where the WTPs used NBA water as well as “good treatment” as defined for each plant. Once the data was organized according to these criteria, the relationship between total organic carbon and treatment requirements was established.

3.3. Cost Estimate Models

Operational cost estimates were developed for each WTP using the general TOC/treatment requirement relationships developed for the NBA users. These cost estimates include increased chemical use and sludge production. Increased energy use, and operation and maintenance requirements were considered but proved difficult to quantify and so not included in the model.

3.4. Engineering Evaluation and Opinion of Probable Construction Costs

Following the development of the increased treatment estimates, engineering evaluations and probable construction costs were made for each of the NBA users using best available technologies for TOC removal or reduction in disinfection by-product formation.

4. Data Collection and Staff Interviews

4.1. NBA Users and Annual NBA Withdrawals

The North Bay Aqueduct (NBA), part of the State Water Project, is a 27-mile underground pipeline serving municipal and industrial water users in Napa and Solano counties. At the Barker Slough Pumping Plant located halfway between the cities of Dixon and Rio Vista, NBA water begins its journey westward through a six-foot diameter pipeline to the Cordelia Pumping Plant Forebay. Water is delivered to Travis Air Force Base and the North Bay Regional WTP through two turnouts along the way. The North Bay Regional WTP serves both the cities of Vacaville and Fairfield with NBA water. At the Cordelia Pumping Plant Forebay water is pumped and delivered to the cities of Benicia, Vallejo, Napa, and American Canyon. An overview of the NBA users and their preferred strategy for dealing with increased NBA TOC is presented in Table 4-1.

Water use at each of the six NBA water users was estimated based on an annual basis. Average and maximum annual NBA withdrawals from the period 2004 to 2007 are summarized Table 4-1.

Table 4-1 NBA Users and Treatment Plant Descriptions

WTP	City	Capacity	Raw water source	Unit Processes	High NBA TOC Strategy	Average Annual Water Treated	Maximum (Year)
North Bay Regional WTP	Cities of Fairfield and Vacaville	40 MGD	NBA and Lake Berryessa	Inlet, pre ozonation, flocculation sedimentation, deep bed dual media GAC and sand filtration, post ozone, chlorination.	Increased chemical use/Shorter filter run lengths / Stop NBA/Shut down completely	5,300 MG	5,930 MG (2004)
Benicia WTP	City of Benicia	12 MGD	NBA (primary), Putah South Canal/Lake Berryessa (alt.) and Lake Hermon (emergency).	Inlet, pre-chlorination, flocculation sedimentation, filtration, chlorination.	Blend sources	2,280 MG	2,480 MG (2004)
Travis Air Force Base	Operated by City of Vallejo to serve Travis AFB	6 MGD	NBA: 3 MGD Wells: 3 MGD.	NBA source: Flash mix, coagulation, flocculation, sedimentation and dual-media filtration on GAC and sand. Pre ozone (liquid oxygen) to aid coagulation and pre- and post-chlorination. Wells: chlorination only	Shut down. Go to wells.	800 MG	900 MG (2005)
Fleming Hill WTP	City of Vallejo	42 MGD	NBA and Lake Berryessa.	Inlet chamber, pre ozone (liquid oxygen), Flash mix, flocculation sedimentation, intermediate ozone, filtration (GAC and sand), chlorination.	Stop NBA or blend. Use water stored in raw water reservoirs.	3,660 MG	5,230 MG (2007)
Jamieson Canyon WTP	City of Napa	14 MGD/ 20 MGD future	NBA only	Pre-chlorination or pre ozonation (liquid oxygen), rapid mixer, flocculation sedimentation, filters, chlorination	Shut down	1,630 MG	2,300 MG (2007)
American Canyon WTP	City of American Canyon	3.5 MGD	NBA only	Flash mix, pre-chlorination horizontal flocculation sedimentation, mixed media filtration, chlorination. Second stream membrane - 1mm strainer, acid alum dose, rapid mixer, flocculation, membrane filtration, chlorination.	Shut down and import treated water from Vallejo.	1,170 MG	1,220 MG (2007)

4.2. Plant Staff Interviews

Representatives from each water treatment plant as well as MWH internal experts were interviewed during the course of data collection. Plant staff provided treatment details where possible including influent TOC, chemical doses, unit operation details, and TOC removal through different unit processes. General chemical costs were also developed from plant staff interviews. In addition to questions concerning operation and treatment plant performance, interviewees were also asked to provide their qualitative impressions of how an increase in feedwater TOC could potentially impact the plants ability to comply with existing and impending DBP regulations. The responses to this can be generalized as follows:

- The majority of TOC in the NBA is normally in the dissolved form (typically 80% or greater)
- Coagulant dose is normally determined by the influent TOC concentration, therefore, any increase in the raw water organic carbon will certainly increase the cost of the treatment if not WTP performance.
- The single biggest challenges faced by operators of the various water treatment plants drawing water from the NBA are rainfall events in the NBA watershed that can bring about rapid changes in water quality such as sharp spikes in raw water turbidity (and probably pathogens including Cryptosporidium), as well as total and dissolved organic carbon, coupled with a simultaneous sharp drop in raw water alkalinity. This combination of simultaneous events renders control of effective coagulation extremely difficult.
- In extreme cases the combination of high turbidity and dissolved organic carbon with low alkalinity has forced some plants to go off-line or use alternative raw water supplies due to treatability issues with NBA water. This typically occurs during periods of abundant Delta outflow resulting in inefficient use of the available NBA water supply.
- Increased raw water TOC could also impact costs if alternative water must be used or blended with NBA water. It should be noted that alternative water sources are usually more expensive than NBA water and are also limited in terms of quantity available for withdrawal. If alternative source water is used in the winter when weather-related spikes in NBA TOC must be mitigated, they may not be available in the spring or summer to offset the impacts of upstream wetlands.
- During normal operation with relatively low raw water TOC (3 to 4 mg/L), the impacts of an increase of 1 mg/L of TOC would probably not impact treatment or regulatory compliance.

However, an increase of up to 3 mg/L in the influent TOC may impact DBP compliance at trouble spots in the distribution system.

- Seasonal effects such as periods of warm water that could result in increased DBP formation may become significant during periods of normally low TOC.
- During times of elevated raw water TOC (> 4 mg/L), an increase of 1 mg/L of TOC in the influent could impact treatment and regulatory compliance (depending on the nature of the organic carbon). The effect of increased raw water TOC would be especially problematic when the TOC in the NBA spikes to levels greater than 15 mg/L. There seems to be an exponential effect of increased TOC on DBP formation during times of elevated raw water TOC.

5. Treatment Data Screening and Statistical Analysis

5.1.1. Linear Regression Chemical Demand Model

Archer and Singer (2006) conducted coagulation experiments with 27 raw waters within the different categories defined by the Stage 1 D/DBPR enhanced coagulation requirements for total organic carbon (TOC) removal based on raw water TOC and alkalinity. Experiments were performed to determine the point of diminishing returns (PODR), defined as the coagulant dose which no longer reduces the TOC concentration by at least 0.3 mg/L. An average of 0.61 mg-Al/mg-C was reported across all the waters treated in the study, while *for NBA water*, the PODR was reported to be 0.74 mg-Al/mg-C. Based on this work and that of other researchers, a simplified linear regression between coagulant and TOC may be used to make initial estimates of changes in treatment requirements and associated costs.

Dissolved organic carbon is normally a large fraction of the total organic carbon. Figure B.1 (appendix B) shows the relationship between DOC and TOC from the NBA as measured at Barker Slough by the California Department of Water Resources (DWR) from 2001 through 2008. The average ratio of DOC to TOC over this period is 0.80 with a standard deviation of 0.14.

5.1.2. Data Screening and Analysis

The first step in modeling organic carbon removal was to generate a consistent data set. This entailed removing data points not related to NBA water or those that represented non-optimized treatment (based on organic carbon removal). Data from Travis Air Force Base, Fleming Hill WTP, and American Canyon was not included in this data set because organic carbon levels were calculated based on UV_{254} absorbance and not actually measured, thereby adding another level of uncertainty to estimating chemical usage.

Jamieson Canyon Water Treatment Plant

For the Jamieson Canyon WTP, only TOC was measured in the raw and treated water; no DOC measurements were made. Based on the limited number of data points where ferric chloride was used as for coagulation, only treatment data with alum coagulation were included. Adequate treatment was defined on an operational basis with consideration of organic carbon removal based on the raw water level. Treatment data provided by the Jamieson Canyon WTP was screened based on the following criteria and data not meeting these criteria were **removed and not used** for modeling purposes:

- > 40% Organic removal through clarification
- Filtered organic carbon: Settled organic carbon < 110%
- TOC > 14 mg/L (TOC analyzer upper limit is 15 mg/L)

The TOC analyzer onsite had an upper limit of 15 mg/L, hence measurements at levels close to or higher than this were considered questionable.

Following the data screen, the coagulant demand at Jamieson Canyon WTP was calculated to be 3.2 mg-Al/mg-C (SD: 1.7). The coefficient of determination (R^2) for a linear fit of this data was 0.77. R^2 is a statistical measurement of the proportion of variability in a data set that is accounted for by a given model; the closer this value is to 1, the more variability is described by the model. This data and the linear model are shown in Figure B.2.

Benicia Water Treatment Plant

For the Benicia WTP, only TOC was measured in the raw and treated water; no DOC measurements were made. Treatment data provided by the Benicia WTP was screened based on the following criteria and data not meeting these criteria was **removed and not used** for modeling

- From March 21 - April 3 the plant switches to 100% Putah South Canal water while the NBA undergoes maintenance
- Data points where plant staff indicated the analyzer was off-line or being calibrated
- > 40% Organic removal through clarification

After sorting on the previous criteria, the average mg-aluminum: mg-TOC ratio was 2.4 with standard deviation 0.7. The data was then sorted to remove data three standard deviations (SD) away from the average as these were likely instances of chemical overdosing. The Benicia WTP data set was the only one analyzed that had mg-aluminum: mg-TOC data outside of three standard deviations from the average. The raw water TOC of the seven data points that were excluded ranged from 3.2 to 5.5 mg/L.

Following the data screen, the coagulant demand at the Benicia WTP was calculated to be 2.4 mg-Al/mg-C (SD: 0.6). The coefficient of determination (R^2) for a linear fit of this data was 0.63. This data and the linear model are shown in Appendix B Figure B.3.

North Bay Regional Water Treatment Plant

For the NBR WTP, only TOC was measured in the raw and treated water; no DOC measurements were made. Only days when the influent water was entirely from the NBA were included in this evaluation. The only treatment data provided by the NBR WTP that was **removed and not used** for modeling were three data points where less than 40% organic removal was achieved through clarification (i.e. treatment was not considered adequate). Following the data screen, the alum demand of organic carbon at the NBR WTP was calculated to be 2.4 mg-Al/mg-C (SD: 0.6). The coefficient of determination (R^2) for a linear fit of this data was 0.55. This data and the linear model are shown in Appendix B Figure B.4.

Ozone Application

Ozone demand and decay tests were conducted as a part of the Ion Exchange Organic Carbon Removal Study (MWH, 2004). Water was collected during a TOC spike in the NBA and ozone demand tests were conducted on raw and coagulated/settled water; the latter assumed the same demand for intermediate as well as post-ozonation. A summary of these results are presented in Table 5-1. Based on these results, the specific ozone demand (mg/L-ozone demand/mg/L-TOC) of the raw and settled waters were estimated to be 0.43 and 0.21, respectively. Error estimates of these demands were not made based on the limited data available.

Table 5-1 NBA Water Estimated Ozone Demand and Unit Costs (MWH, 2004)

Location	TOC (mg/L)	Ozone Demand (mg/L)	Specific Ozone Demand	Ozone Req. (lb-0$_3$/mg-TOC/L/mgd)	LOX ($/mgd/mg-TOC/L)	Air Prep ($/mgd/mg-TOC/L)
Raw Water	16.2	7.0	0.43	3.60	7.81	4.47
Coagulated/ Settled	5.8	1.2	0.21	1.72	3.82	2.14

Ozone gas generation specific energy was estimated to be 5.2 kw-hr/lb ozone for liquid oxygen (LOX) and 10.4 for air feed (including specific feed gas energy). The average ozone production gas concentration was assumed to be 5.3% by wt for LOX and 2.5% by wt for air-prep. The cost of LOX was assumed to be $0.65/100 cf and the LOX requirements for the raw and settled waters were estimated to be 0.65 standard cubic feet per minute (scfm) per mgd and 0.33 scfm per mgd, respectively. For an assumed cost of energy of $0.11/kWh, Table 5-1 presents the estimated unit costs ($/mgd/mg-TOC/L) for raw and settled waters using LOX or air preparation systems. These estimates do no include the maintenance costs associated with each system (usually much higher for air preparation systems).

5.1.3. Combined Treatment Data Analysis

Screened data from the North Bay Regional WTP, the Jamieson Canyon WTP, and the Benicia WTP were merged to create a general data set to assess the impacts of TOC on water treatment chemical use. For the combined NBA dataset, linear relationships were established for chemical demand as a function of influent TOC are shown in Table 5-2 along with their associated R^2 values. It has been assumed that cationic polymer molecular weight and characteristics are similar for each plant. Chemical demand figures for the combined data sets are presented in Figure B.5, Figure B.6, and Figure B.7. A positive correlation between influent TOC and caustic soda was not established; likewise, a positive correlation was not found between influent TOC and chlorine use. However, the impacts of caustic soda will be addressed in terms of replacing the alkalinity lost by coagulant addition (see next section).

Table 5-2 General NBA Water Treatment Chemical Demands as a Function of Influent TOC

Treatment Chemical	Linear Model	Coefficient of Determination (R^2)	Upper and Lower Limit on Slope (95% CI)
Alum	mg-$Al_2(SO_4)_3$/L = 4.02 x (TOC_{INF}) + 31.73	0.39	4.33/3.70
Cationic Polymer	mg-CatPoly/L = 0.044 x (TOC_{INF}) + 0.44	0.11	0.052/0.036
Chlorine (At Influent)	mg-Cl_2/L = 0.039 x (TOC_{INF}) + 0.36	0.49	0.032/0.046
Pre-ozonation	mg-O_3/L = 0.43 x (TOC_{INF})	-	-
Intermediate or Post-ozonation	mg-O_3/L = 0.21 x (TOC_{INF})	-	-

Jamieson Canyon was the only WTP that reported data for pre-chlorination, however discussions with operations staff revealed that the Benicia and American Canyon WTP practice pre-chlorination, although pre-treatment data was not available. NBR WTP did not include ozone use or costs in the treatment data that was provided. ANOVA tables for each of the linear relationships are presented in Table B9-1, Table B9-2, and Table B3, respectively. The relationships presented in Table 5-2 were used to characterize the increased chemical demands for all treatment plants based on increased influent TOC in the following section.

Ozone upper and lower costs in the following section were estimated using an average cost between LOX and air preparation, with the upper bound taken as the cost of LOX and the lower bound established by the cost air preparation system (neglecting maintenance).

6. Cost Estimates Based on Statistical Models

Cost estimates for increased treatment resulting from changes in water quality (specifically increased organic carbon) include increased chemical usage and energy requirements, increased sludge production and removal, and changes to existing processes at the treatment plants using NBA water.

- Increased chemical demands (as described in previous section)
- Associated increase in caustic to make up alkalinity consumed by increased coagulant dose
- Additional sludge generation (removal and disposal)

6.1. Chemical Costs and Associated Cost Projections

Uniform chemical costs were assumed for all locations and unit chemical costs are listed in Table 6-1. 2008/09 rates from the North Bay Chemical Agency Pool were adopted where possible.

Table 6-1 Unit Costs of Chemicals

Chemical	Use	Unit Cost ($/lb)
Alum ($Al_2(SO_4)_3$)	Coagulant	0.195
Cationic Polymer	Coagulant Aid	0.490
Chlorine	Pre-oxidation	0.225
Ozone	Oxidation	LOX: 2.11 Air Prep: 1.14
Caustic Soda (NaOH)	Increase Alkalinity	0.300

Based on the annual NBA withdrawals of each plant presented in Table 4-1 and the increased chemical demands resulting from increased raw water TOC presented in Table 5-2, projections of increased chemical costs at each plant have been developed. The estimated cost increases associated with alum, cationic polymer, pre-chlorine, pre-ozonation, and intermediate ozonation presented for each WTP in Table 6-2 through Table 6-7 respectively. Although Jamieson Canyon reported pre-chlorination data, pre-ozonation was used for cost estimates based on their on-going implementation of an ozone system.

Because alum consumes alkalinity, which can be relatively low to begin within the NBA water, addition of caustic soda (NaOH) has been assumed at each plant. Addition of caustic soda to compensate for the additional alkalinity consumed by increased coagulant use for a 1 mg/L increase in the influent TOC is presented in Table 6-7.

Table 6-2 Annual Alum (as $Al_2(SO_4)_3$ Costs for 1 mg/L Increase in Influent TOC

WTP	Lower Limit (95% CI)	Median	Upper Limit (95% CI)
North Bay Regional WTP	$31,760	$34,507	$37,168
Benicia WTP	$13,663	$14,845	$15,989
Travis Air Force Base	$4,794	$5,209	$5,610
Fleming Hill WTP	$21,933	$23,830	$25,667
Jamieson Canyon WTP	$9,768	$10,613	$11,431
American Canyon WTP	$7,011	$7,618	$8,205
Total	$88,929	$96,620	$104,071

Table 6-3 Annual Cationic Polymer Costs for 1 mg/L Increase in Influent TOC

WTP	Lower Limit (95% CI)	Median	Upper Limit (95% CI)
North Bay Regional WTP	$779	$952	$1,125
Benicia WTP	$335	$409	$484
Travis Air Force Base	$118	$144	$170
Fleming Hill WTP	$538	$657	$777
Jamieson Canyon WTP	$239	$293	$346
American Canyon WTP	$172	$210	$248
Total	$2,180	$2,664	$3,149

Table 6-4 Annual Pre-Chlorine Costs for 1 mg/L Increase in Influent TOC

WTP	Lower Limit (95% CI)	Median	Upper Limit (95% CI)
Benicia WTP	$95	$116	$137
American Canyon WTP	$49	$59	$70
Total	$144	$175	$207

Table 6-5 Annual Pre-Ozonation Costs for 1 mg/L Increase in Influent TOC

WTP	Lower Limit (95% CI)	Median	Upper Limit (95% CI)
North Bay Regional WTP	$23,713	$32,550	$41,386
Travis Air Force Base	$3,579	$4,913	$6,247
Fleming Hill WTP	$16,375	$22,478	$28,580
Jamieson Canyon WTP	$7,293	$10,011	$12,728
Total	$50,960	$69,951	$88,942

Table 6-6 Annual Intermediate or Post-Ozonation Costs for 1 mg/L Increase in Influent TOC

WTP	Lower Limit (95% CI)	Median	Upper Limit (95% CI)
North Bay Regional WTP	$11,354	$16,068	$20,782
Fleming Hill WTP	$7,841	$11,096	$14,352
Total	$19,195	$27,164	$35,134

Table 6-7 Increased Costs Associated with Caustic Soda Use for 1 mg/L Increase in Influent TOC

WTP	Lower Limit (95% CI)	Median	Upper Limit (95% CI)
North Bay Regional WTP	$31,494	$34,218	$36,857
Benicia WTP	$13,548	$14,720	$15,855
Travis Air Force Base	$4,754	$5,165	$5,563
Fleming Hill WTP	$21,749	$23,630	$25,452
Jamieson Canyon WTP	$9,686	$10,524	$11,335
American Canyon WTP	$6,952	$7,554	$8,136
Total	$88,184	$95,810	$103,199

6.2. Sludge Production

Solids production from alum coagulation can be determined using 0.44kg-sludge/kg-Alum-added (AWWA/ASCE, 1998). Based in the increased alum use described previously, the estimated increase in sludge produced for a unit increase in TOC is presented in Table 6-8. In addition, the increased costs of handling these solids, based on a unit cost of solids handling of ($60/ton), is also presented in . Based on these calculations, the upper limit (95% CI) in yearly annual cost of increased sludge production for a 1 mg/L increase in TOC for all WTPs using the NBA is estimated to be approximately $7,000.

Table 6-8 Increased Annual Sludge Production and Costs for 1 mg/L Increase in Influent TOC

WTP	Tons of Sludge for Upper Limit (95% CI)	Solids Handling Costs
North Bay Regional WTP	42	$2,522
Benicia WTP	18	$1,085
Travis Air Force Base	6	$381
Fleming Hill WTP	29	$1,742
Jamieson Canyon WTP	13	$776
American Canyon WTP	9	$557
Total	**118**	**$7,063**

6.3. Summary of Total Increased Annual Costs

The total average annual NBA withdrawal was 14,840 MG as presented in Table 4-1 for water years 2004 through 2007. This results in a unit cost increase of approximately $16.82, $19.70, and $22.55 per MG for the lower, median and upper limit respectively for treating each mg/L increase in TOC. As shown in Table 6-9, the total increased annual costs for a 1 mg/L increase in TOC (based on 2008 dollars and costs) for all WTPs using the NBA is estimated to be approximately $250,000, $290,000 and $330,000 for the lower, median and upper limit respectively. Applying these unit costs to the range of potential TOC increases (1 to 3 mg/L) yields an upper limit annual cost of $1,000,000 as presented in Table 6-10.

Table 6-9 Summary of Increased Annual Costs for 1 mg/L Increase in Influent TOC

Component	Lower Limit (95% CI)	Median	Upper Limit (95% CI)
Alum	$88,929	$96,620	$104,071
Cationic Polymer	$2,180	$2,664	$3,149
Pre-Chlorine	$144	$175	$207
Pre-Ozonation	$50,960	$69,951	$88,942
Intermediate Ozonation	$19,195	$27,164	$35,134
Caustic Soda	$88,184	$95,810	$103,199
Solids Handling	$6,035	$6,557	$7,063
Total	**$249,592**	**$292,386**	**$334,701**

Table 6-10 Summary of Increased Annual Costs for annual average NBA withdrawal of 16,510 MG

Increase in Influent TOC Increase	Lower Limit Lower Limit, 95% CI ($18.94/MG*mg/L)	Median Median ($21.95/MG*mg/L)	Upper Limit Upper Limit, 95% CI ($24.92/MG*mg/L)
1 mg/L	$249,592	$292,386	$334,701
2 mg/L	$499,183	$584,772	$669,402
3 mg/L	$748,775	$877,157	$1,004,104

7. Engineering Judgment of Best Practices for Organic Carbon Removal

7.1. DBP formation Due to Increased Organic Carbon

A review of organic carbon reactivity in forming disinfection byproducts such as trihalomethanes (THM) and haloacetic acids (HAA5) was provided in Section 2.2 However, an important point to consider is that if the allowable THM and HAA5 limits in current drinking water regulations are lowered, or if additional compounds are added to the list of regulated chemicals, water suppliers may well face significant challenges in meeting such standards. Current regulations are changing in terms of sample location, where trouble spots, i.e. locations with long water residence times and therefore higher DBP formation potential than locations with shorter water residence times, will need to be included in regular sampling. Quantification of the impacts to changes in regulation is difficult and will likely require an ad-hoc approach once more water quality data is available.

Because the health impacts resulting from increased TOC and increased DBP formation are so difficult to quantify, it is recommended to use the costs associated with implementation of entirely new systems as estimates for mitigation of the impacts resulting from elevated raw water TOC and potentially higher levels of regulated DBPs. Two technologies were identified as best practices for organic carbon removal: the MIEX ion-exchange process, which is specifically designed to reduce raw water organic carbon levels, and post-filtration activated carbon contactors, which can reduce the organic carbon in contact with disinfectants which can form DBPs. Cost estimates based on these processes are provided in the following sections.

7.2. Ion-Exchange

The magnetic ion exchange (MIEX®) process developed by Orica Watercare uses a strong base anion exchange resin with a microporous structure and quaternary ammonium active sites attached to a magnetic core. Organic matter and other anions adsorb to the active sites of the resin, while its magnetic properties allow the resin to form large agglomerates that can be recovered, regenerated and reused.

Although a new upflow configuration has been developed, cost estimates based on this configuration are not yet available. Construction cost estimates for implementation of MIEX systems (based on plant sizes 0.2, 6, 30, and 60 MGD) were made based on equipment costs received from the vendor and planning level data ; these construction cost estimates have an assumed accuracy of -30% to +50%. Costs do not include site acquisition, engineering environmental services, brine disposal, or building requirements. Initial MIEX process construction and operational costs are presented in Table 7-1.

Table 7-1 Initial Cost Estimates for Implementation of MIEX

WTP	Capacity	Estimated Construction Costs (2008)	Estimated Annual Operational Costs (2008)
North Bay Regional WTP	40 MGD	$12,303,220	$2,920,000
Benicia WTP	12 MGD	$5,426,421	$876,000
Travis Air Force Base	3 MGD (NBA only)	$2,114,331	$219,000
Fleming Hill WTP	42 MGD	$12,718,192	$3,066,000
Jamieson Canyon WTP	20 MGD (future expansion)	$7,679,775	$1,460,000
American Canyon WTP	3.5 MGD	$2,347,957	$256,000
Total	**121 MGD**	**$43,862,783**	**$8,797,000**

7.3. Activated Carbon

Granular activated carbon (GAC) is known to adsorb both DBPs and DBP precursors. Initial design and cost estimates for post-filter granular activated carbon GAC contactors were made in a 2005 study examining DBP control (Booth et al., 2005).

Key design criteria of this initial design were:

- Empty bed contact time (EBCT) = 15 minutes
- Carbon utilization rate = 0.045 g carbon/L treated water
- 180 day replacement frequency at 20 mgd flow rate

Operational costs were estimated using $650/MG of treated water. Initial GAC-absorber construction and operational costs are presented in Table 7-2.

Table 7-2 Initial Cost Estimates for Implementation of Post-Filter GAC Contactors

WTP	Capacity	Estimated Construction Costs (2008)	Estimated Annual Operational Costs (2008)
North Bay Regional WTP	40 MGD	$28,554,000	$9,490,000
Benicia WTP	12 MGD	$8,567,000	$2,847,000
Travis Air Force Base	3 MGD (NBA only)	$2,142,000	$711,750
Fleming Hill WTP	42 MGD	$29,982,000	$9,964,500
Jamieson Canyon WTP	20 MGD (future expansion)	$14,277,000	$4,745,000
American Canyon WTP	3.5 MGD	$2,499,000	$830,375
Total	**121 MGD**	**$86,017,000**	**$28,588,625**

Based on these cost estimates, implementation of MIEX systems is more economical than GAC absorbers. Assuming this course of action was followed, a rough estimate of the range of total capital costs for treatment of NBA water is approximately $40M to $90M. An initial estimate of the range of annual operational costs for these processes is $9M to $29M.

8. Conclusions

The impacts of increased TOC in the NBA as a result of upstream wetland restoration are difficult to quantify for several reasons including the following:

- The amount of increased TOC is not known
- The nature/reactivity of the organic carbon, in terms of both treatment and DBP formation potential, cannot be estimated
- The time frame in which TOC may increase depends on the type and size of the wetlands, which has not yet been decided

To overcome these information gaps, current treatment data from the NBA water users was generalized to provide initial estimates of increased treatment costs. The different factors and associated costs are presented in Table 8-1. Based on these estimates, the impact of a 1 mg/L increase in the NBA TOC level could increase treatment costs for all WTPs by roughly $330,000 on an annual basis.

Table 8-1 Summary of Increased Annual Costs for 1 mg/L Increase in Influent TOC

Component	Lower Limit (95% CI)	Median	Upper Limit (95% CI)
Alum	$88,929	$96,620	$104,071
Cationic Polymer	$2,180	$2,664	$3,149
Pre-Chlorine	$144	$175	$207
Pre-Ozonation	$50,960	$69,951	$88,942
Intermediate Ozonation	$19,195	$27,164	$35,134
Caustic Soda	$88,184	$95,810	$103,199
Solids Handling	$6,035	$6,557	$7,063
Total	**$249,592**	**$292,386**	**$334,701**

Because the impacts to DBP formation are difficult to quantify, two technologies that are proven to reduce organic carbon levels were selected to make initial cost estimates for DBP mitigation. The costs of implementing ion-exchange (MIEX) or activated carbon systems as described in Chapter 7 are presented in Table 8-2. Cost estimates for implementation of MIEX systems (based on plant sizes 10, 50, and 150 MGD) for treatment of NBA water (as retrofits) were made in a previous study (MWH, 2004); these construction costs were based on planning level data and have an assumed accuracy of -30% to +50%. Construction costs estimates for post-filter GAC contactors were based on a 2005 study examining DBP control (Booth et al., 2005) while GAC operational cost estimates were made using current industry practice. Based on these estimates, the capital cost associated with implementation of one of these treatment technologies could range from $40M to $90M. The initial estimate of the range of annual operational costs for one of these processes is $9M to $29M.

Table 8-2 Initial Cost Estimates for Implementation of MIEX and Post-Filter GAC Contactors

WTP	Capacity	MIEX		Post-Filter GAC Contactors	
		Estimated Construction Costs (2008)	Estimated Annual Operational Costs (2008)	Estimated Construction Costs (2008)	Estimated Annual Operational Costs (2008)
North Bay Regional WTP	40 MGD	$12,303,220	$2,920,000	$28,554,000	$9,490,000
Benicia WTP	12 MGD	$5,426,421	$876,000	$8,567,000	$2,847,000
Travis Air Force Base	3 MGD	$2,114,331	$219,000	$2,142,000	$711,750
Fleming Hill WTP	42 MGD	$12,718,192	$3,066,000	$29,982,000	$9,964,500
Jamieson Canyon WTP	20 MGD	$7,679,775	$1,460,000	$14,277,000	$4,745,000
American Canyon WTP	3.5 MGD	$2,347,957	$256,000	$2,499,000	$830,375
Total	**121 MGD**	**$43,862,783**	**$8,797,000**	**$86,017,000**	**$28,588,625**

In summary, the impacts of wetland restoration in the Sacramento/San Joaquin Delta could severely impact the operation and performance of the treatment plants that use the North Bay Aqueduct as their water source. If the organic carbon levels increase, treatment costs will certainly increase, most likely in a linear fashion with respect to coagulant use. However, the impacts of potentially increased disinfection by-product formation are very difficult to quantify, so care should be taken to mitigate any potential health impacts to residents in the service area.

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Appendix A- Location map


Lake Berryessa
Lake Hennessey
North Bay Regional WTP
Baker Slough PP
Jameson Canyon WTP
American Canyon WTP
North Bay Aqueduct
Travis AFB WTP
Flemming Hill WTP
Lake Hermon
Benicia WTP
Lake Berryessa
Spanish Flat
Lake Hennessey Recreation Area
Atlas
Yountville
Napa Soda Springs
Oak Knoll
Vichy Springs
Napa
Rocktram
Stanley
Cuttings Wharf
Middleton
Squab
Lombard
American Canyon
Chabot Terrace
Island Number 1
Vallejo
Carquinez Heights
Glencove
Crockett
Port Costa
Benicia
Selby
Tormey
Rodeo
San Pablo Bay
Mococo
Winters
Norton
Allendale
Hartley
Bucktown
Vacaville
Town
Elmira
Cannon
Vacaville Junction
Fairfield
Suisun City
Travis AFB
Rockville
Thomasson
Jacksnipe
Cygnus
Bahia
Suisun Bay
Grizzly Island
Dixon
Sucro
Batavia
Binghamton
Dozier
Vale
Creed
Rio Vista Junction
Birds Landing
Molena
Montezuma
Collinsville
Nichols
Ambrose
Port Chicago
Pittsburg
Sherman Lake
Plainfield
County Rd 27
County Rd 29
County Rd 31
Russell Blvd
Putah Creek Rd
Dixon Ave W
Midway Rd
Binghamton Rd
Rio Vista Rd
Jameson Canyon Rd
Cordelia Rd
Air Base Pkwy
E Tabor Ave
Sears Point Rd
Soma-Napa Hwy
Silverado Trail
Capell Valley Rd
Pleasants Valley Rd
Peabody Rd
Alamo Dr
505
80
680
780
113
128
121
29
12
37

MWH

Appendix B – Chemical Demand and UFRV as a Function of Influent TOC

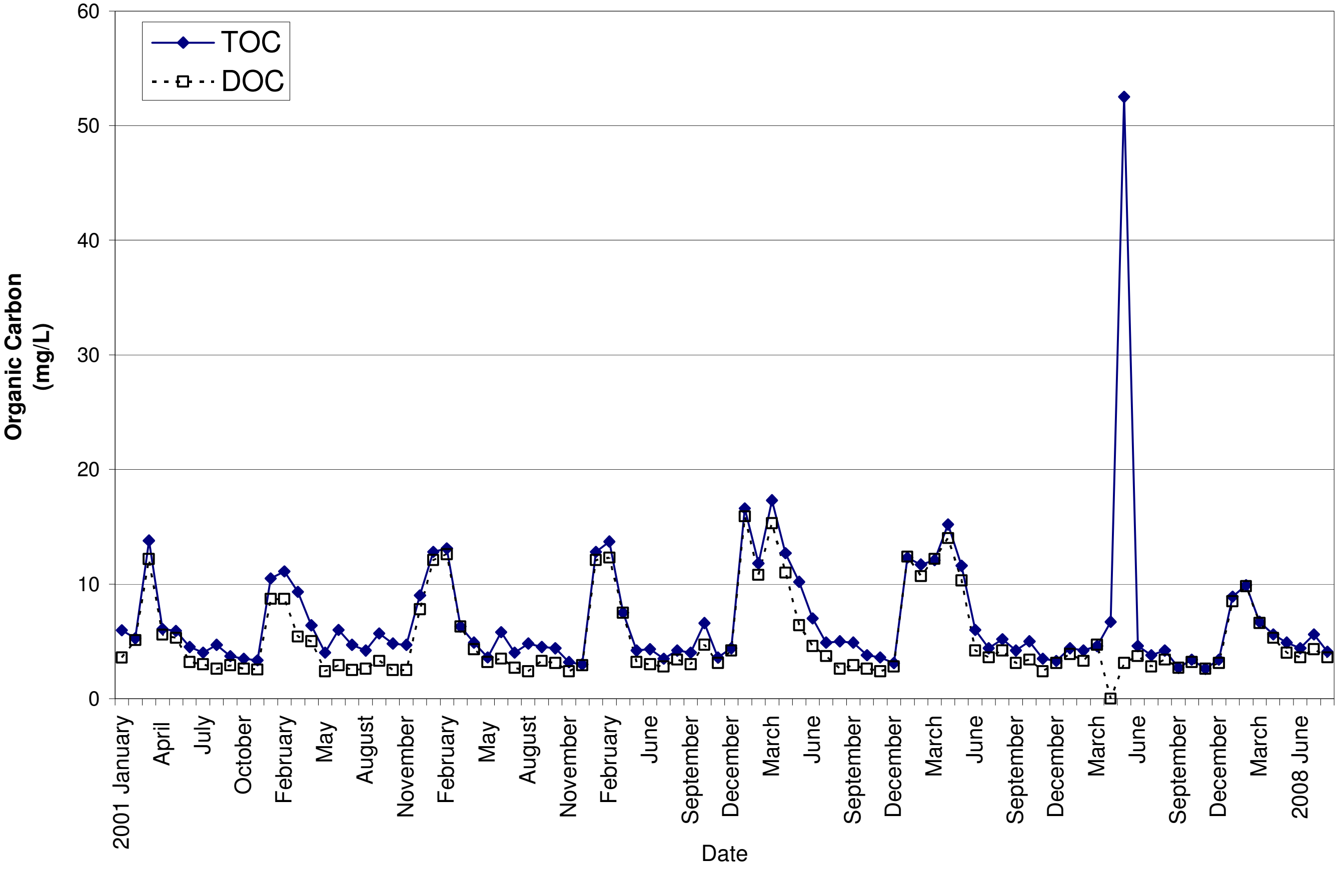

Figure B.1 TOC and DOC at North Bay Aqueduct, Barker Slough - 2001-2007.

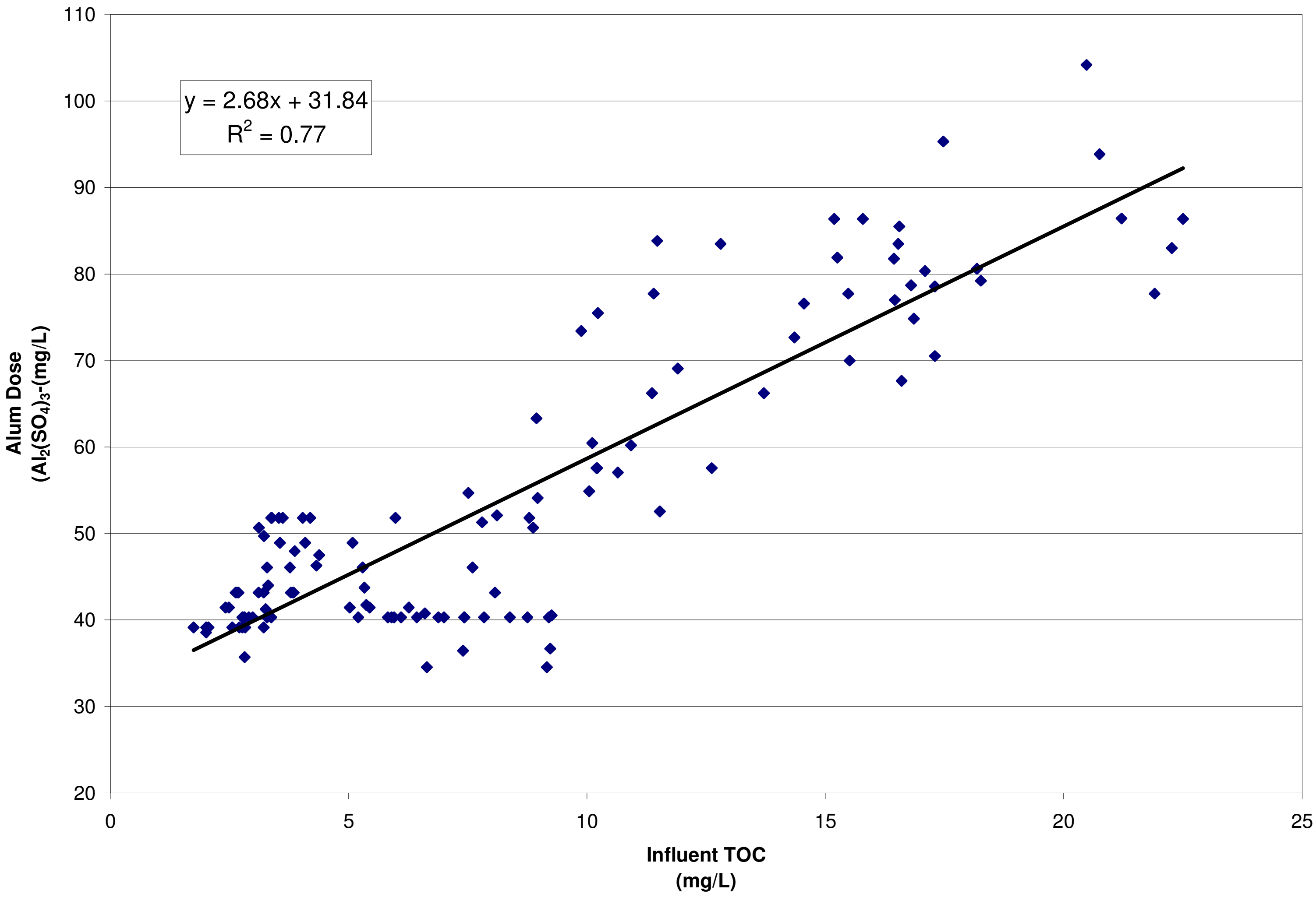

Figure B.2 Jamieson Canyon WTP Coagulant Demand

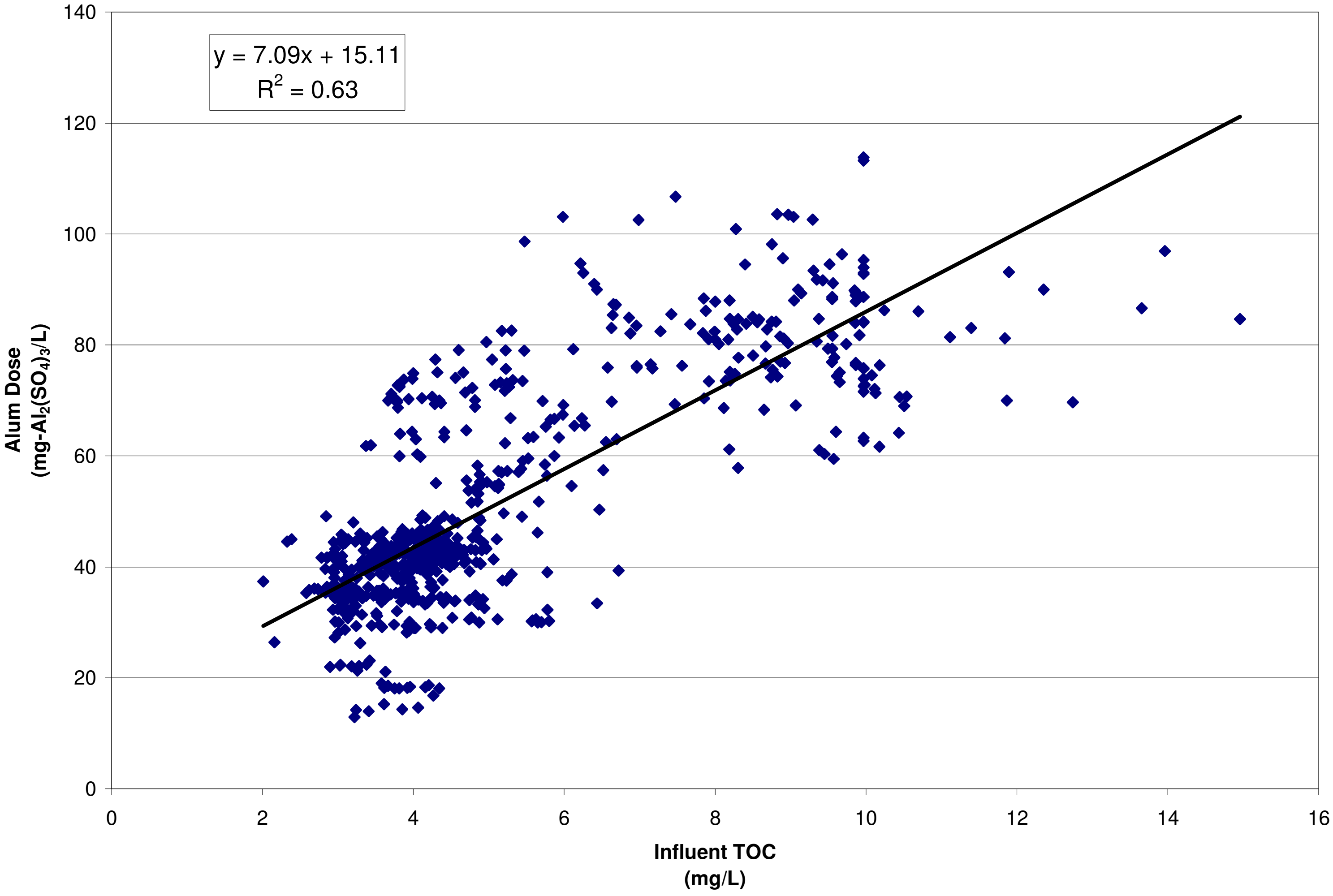

Figure B.3 Benicia WTP Coagulant Demand

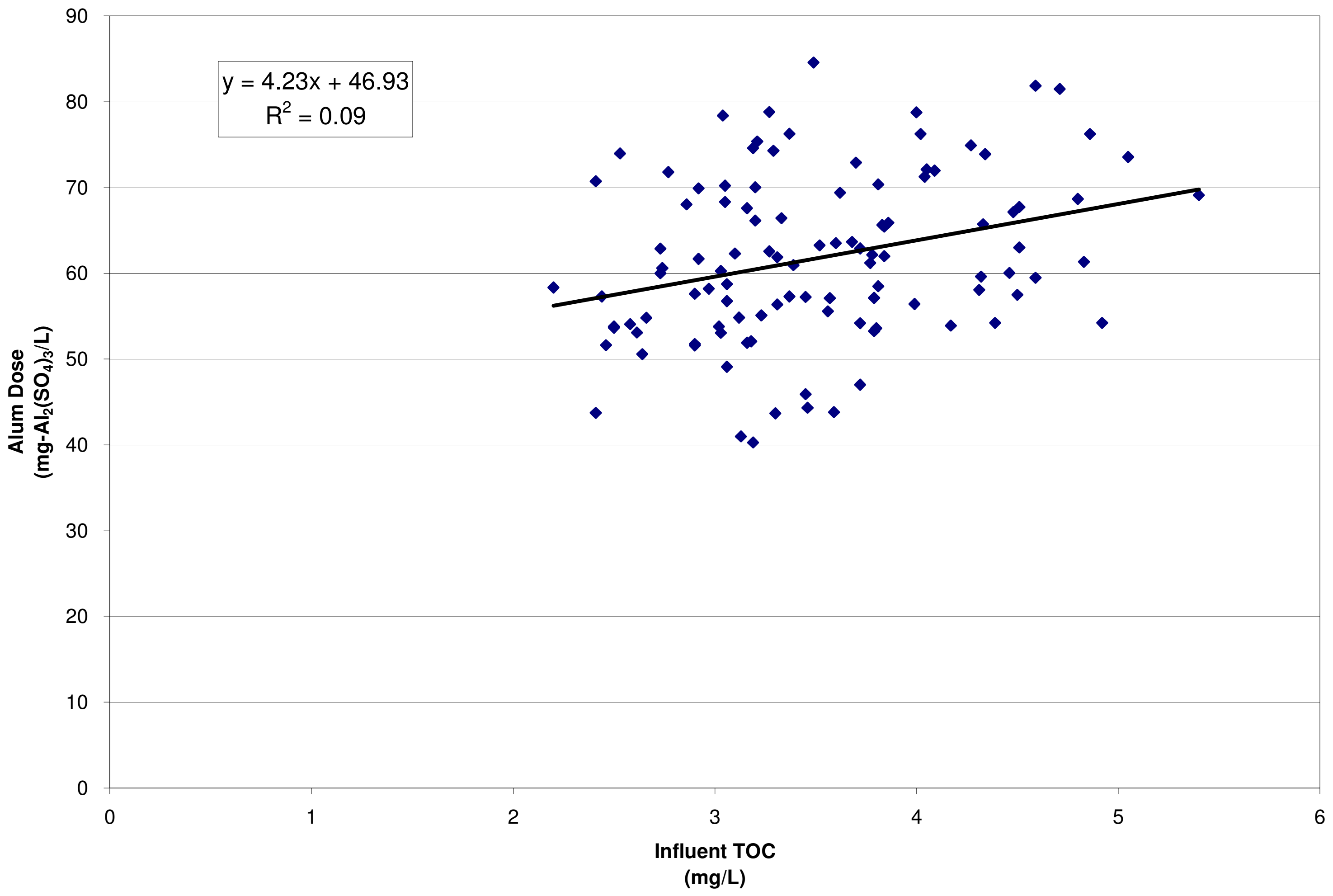

Figure B.4 North Bay regional (NBR) WTP Coagulant Demand

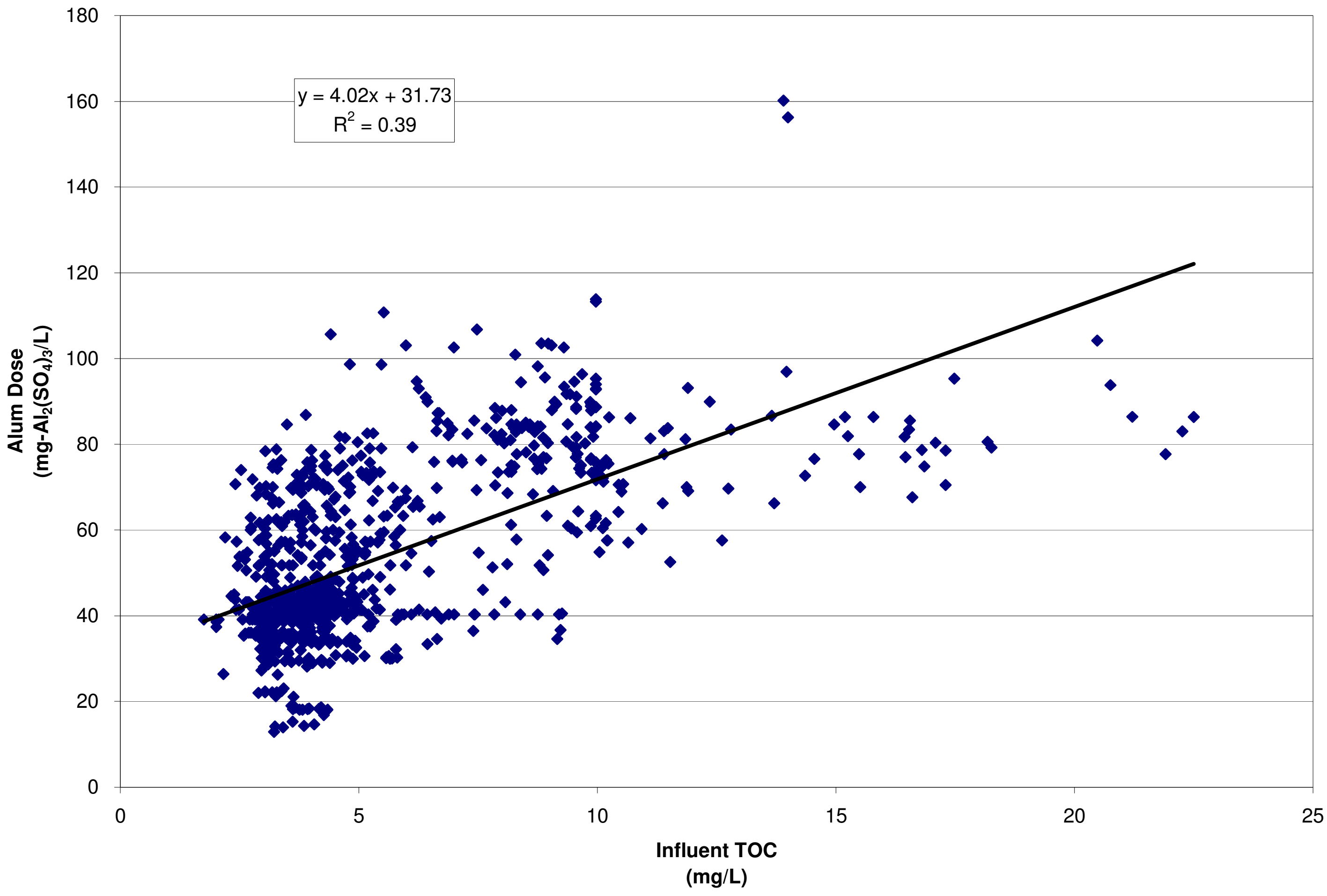

Figure B.5 Combined WTP Data for Alum Demand as a Function of Influent TOC

Table B9-1 Statistical Analysis of Linear Relationship between Influent TOC and Alum Dose

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.63
R Square	0.39
Adjusted R Square	0.39
Standard Error	15.50
Observations	978

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	151427.9571	151428	630.2084	1.0709E-107
Residual	976	234515.5837	240.2824		
Total	977	385943.5408			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	31.73	0.99	32.1	6.2E-155	29.8	33.7
X Variable 1	4.02	0.16	25.1	1.1E-107	3.7	4.3

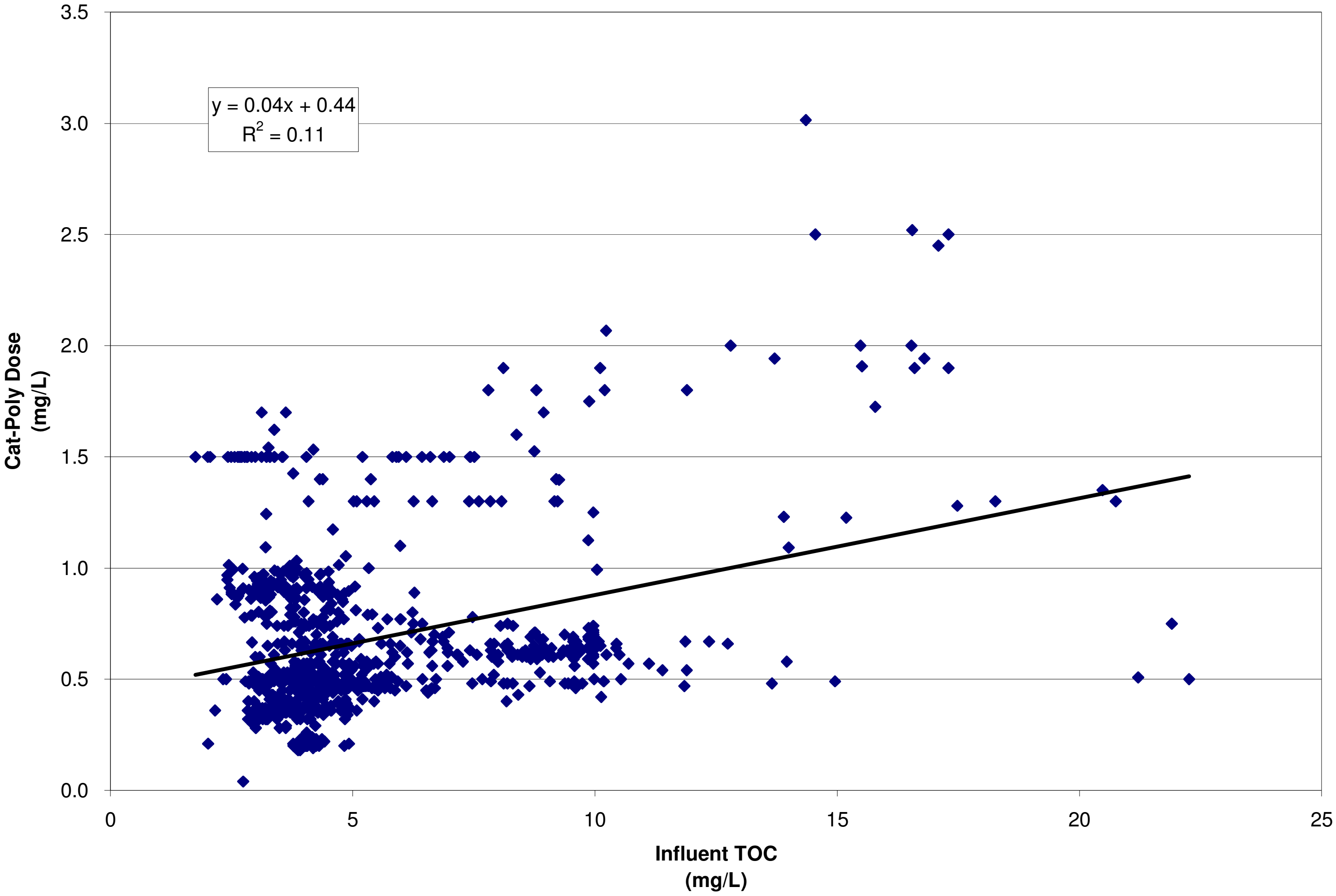

Figure B.6 Combined WTP Data for Cationic Polymer Demand as a Function of Influent TOC

Table B9-2 Statistical Analysis of Lin. Relationship between Influent TOC and Cationic Polymer Dose

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.338331403
R Square	0.114468138
Adjusted R	0.113457257
Standard E	0.362350801
Observatio	878

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regressior	1	14.86767249	14.86767	113.236	5.92805E-25
Residual	876	115.0171382	0.131298		
Total	877	129.8848107			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0.44	0.025	17.6	7.63E-60	0.39	0.49
X Variable	0.044	0.004	10.6	5.93E-25	0.036	0.052

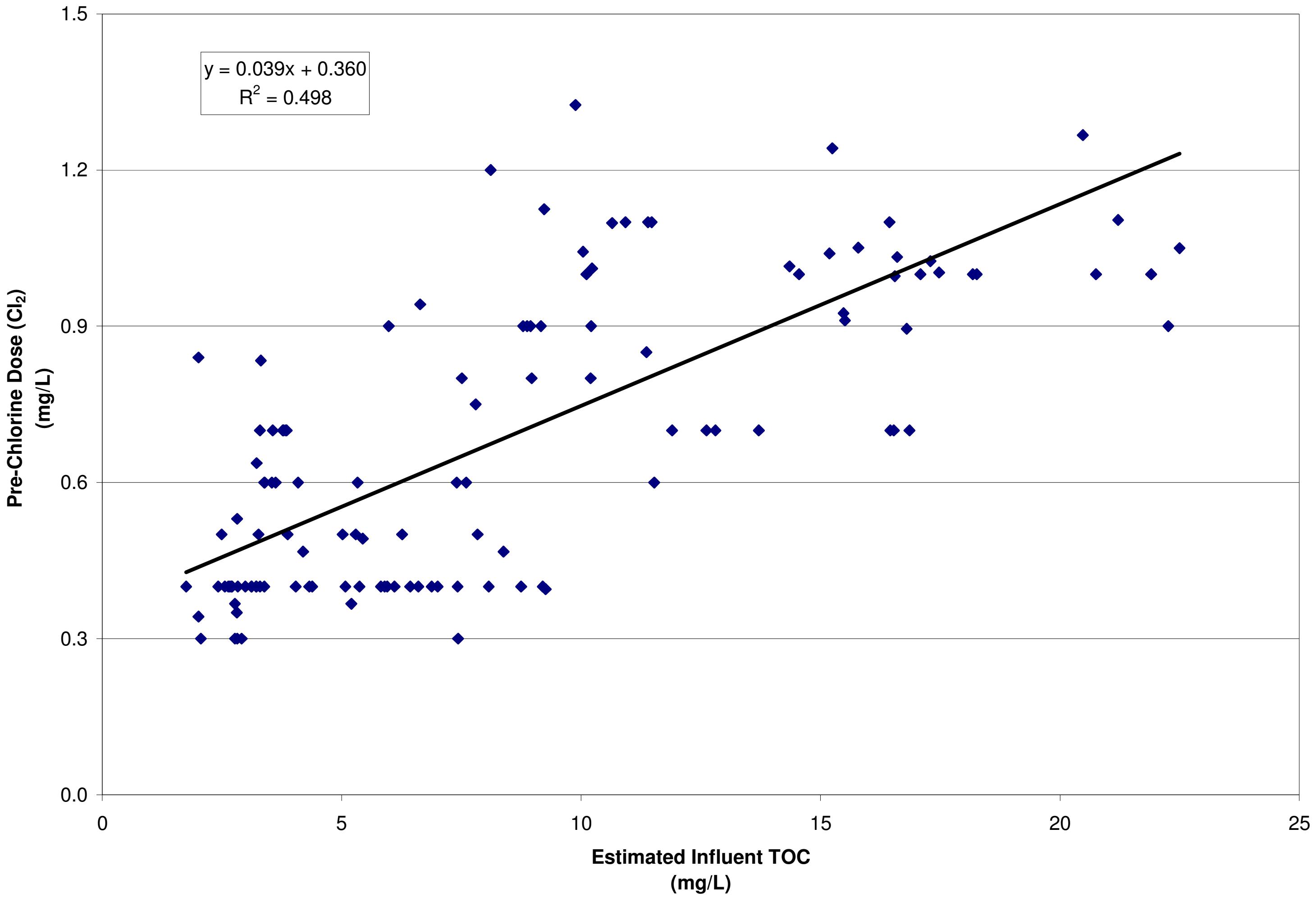

Figure B.7 Jamieson Canyon WTP Data for Pre-Chlorine Demand as a Function of Influent TOC

Table B9-3 Statistical Analysis of Linear Relationship between Influent TOC and Pre-Chlorine Dose

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.705714766
R Square	0.498033331
Adjusted R Square	0.493884846
Standard Error	0.2190526
Observations	123

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	5.760573508	5.760573508	120.0518614	7.91337E-20
Residual	121	5.806069029	0.047984042		
Total	122	11.56664254			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.359829636	0.035829147	10.04293071	1.25133E-17	0.288896391	0.430762881	0.288896391	0.430762881
X Variable 1	0.03874161	0.003535845	10.95681803	7.91337E-20	0.031741472	0.045741748	0.031741472	0.045741748