APPENDIX B

Carollo Engineers Technical Memoranda

Technical Memorandum 1.4 Groundwater Contaminants and Treatment Alternatives

Technical Memorandum 2-2 for Fresno Metro Plan

Technical Memorandum 2.4 Future-With-Project Alternative Refinement – supply

Technical Memorandum 2.6 Future-With-Project Alternative Refinement

City of Fresno

METROPOLITAN WATER RESOURCES MANAGEMENT PLAN UPDATE

TECHNICAL MEMORANDUM 1.4
GROUNDWATER CONTAMINANTS AND TREATMENT ALTERNATIVES

FINAL
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carollo engineers

CITY OF FRESNO

GROUNDWATER CONTAMINANTS AND TREATMENT ALTERNATIVES

TECHNICAL MEMORANDUM NO. 1.4

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GROUNDWATER CONTAMINANTS AND TREATMENT ALTERNATIVES

1.0 INTRODUCTION

1.1 Overview

The City of Fresno (City) has approximately 280 water production wells throughout the City's 115 square-mile area. In 2005, 239 of these wells were operational. The remaining wells were either off line to be destroyed, under rehabilitation of the wells, or in a process of installing treatment systems. According to the total production data from 2004, the annual average production from the groundwater is approximately 102,000 gpm. Based on more recent, one day production data (August 2, 2005), the total daily groundwater production peak ranged from 115,000 to 247,000 gpm. Due to various groundwater contamination issues, however, a number of wells have been shut down. As a result, the City has lost significant amount of groundwater production capacity over the years. The purpose of this Technical Memorandum (TM) is to evaluate the extent of groundwater contamination due to historical and emerging contaminants and summarize treatment alternatives.

1.2 Objectives

The main goals of this TM include the following.

- Identify and summarize the current and emerging groundwater contaminants in the City
- Evaluate the treatment alternatives for the major contaminants of concern
- Present general capital and O&M costs for each major contaminant identified by the City

The assumptions made for each subject are summarized in the following sections.

2.0 SUMMARY OF CONTAMINANTS OF CONCERN

In order to identify the major contaminants of concern (COC), a number of documents were reviewed. Table 1 lists the name, format, source, and date for each document reviewed and used for this TM.

Table 1	Metropolitan Water Resources Management Plan Update Documents reviewed to Identify Major Contaminants of Concern City of Fresno		
Document Name	**Format**	**Source**	**Date**
Fresno Metropolitan, Water Resources Management Plan	Phase 1 Report	CH2M Hill	January 1992
City of Fresno Plume Locations	PDF Map	City of Fresno	Early 1990's
Fresno Source Water Screened	Excel Spreadsheet	City of Fresno	May 2005
WQ Reports	Excel Spreadsheet	City of Fresno	April 2006
Water Quality Annual Report 2001	Report	City of Fresno	2001
Water Quality Annual Report 2002	Report	City of Fresno	2002
Water Quality Annual Report 2003	Report	City of Fresno	2003
Water Quality Annual Report 2004	Report	City of Fresno	2004

2.1 Known Plumes in the Area

There are a total of ten plumes located in the City, and Figure 1 shows eight of them without two new plumes. The size of these plumes range from 15 to 1,200 acres. The contaminants in the plumes include: trichloroethylene (TCE), tetrachloroethylene (PCE), total dissolved solids (TDS), chloride, salinity, VOCs, pesticides, iron, manganese, chromium, and nitrate. Table 2 shows the name, contaminants, size, and general location of each plume. The major COCs in these plumes are organics, pesticides, and inorganics as outlined in Table 2.

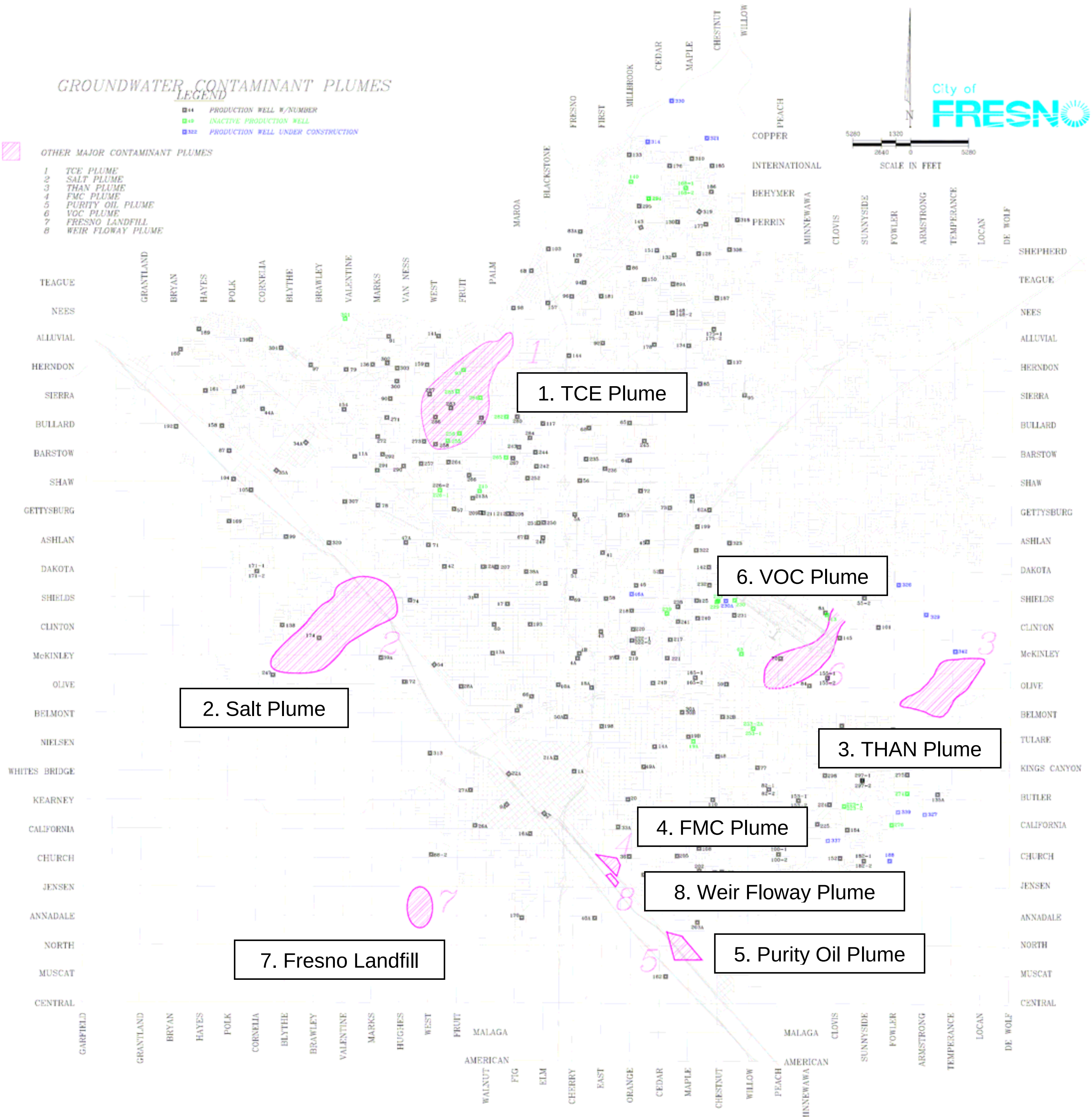

GROUNDWATER CONTAMINANT PLUMES
LEGEND
PRODUCTION WELL W/NUMBER
INACTIVE PRODUCTION WELL
PRODUCTION WELL UNDER CONSTRUCTION
OTHER MAJOR CONTAMINANT PLUMES
1 TCE PLUME
2 SALT PLUME
3 THAN PLUME
4 FMC PLUME
5 PURITY OIL PLUME
6 VOC PLUME
7 FRESNO LANDFILL
8 WEIR FLOWAY PLUME
City of FRESNO
SCALE IN FEET
1. TCE Plume
6. VOC Plume
2. Salt Plume
3. THAN Plume
4. FMC Plume
8. Weir Floway Plume
7. Fresno Landfill
5. Purity Oil Plume

Table 2	Metropolitan Water Resources Management Plan Update Known Plumes in the City of Fresno City of Fresno			
Plume Name	**Contaminant**	**Estimated Size (acre)**	**Cross Streets**	
			West- East	**North- South**
TCE Plume (Pinedale Groundwater Site – a.k.a. Vendo Plume)	TCE, chromium, 1,1, DCE, 1,1, DCA, PCE	1,020	West - Palm	Alluvial - Barstow
Salt Plume	TDS, chloride, salinity	1,200	Blythe - Hughes	Dakota - Olive
THAN Plume	VOCs and pesticides	500	Fowler - Locan	McKinley - Belmont
FMC Plume	VOCs, pesticides, and chromium	50	East - Orange	Church - Jensen
Purity Oil Plume	VOCs, Fe, Mn	105	Cedar - Chestnut	Annadale - Muscat
VOC Plume (Old Hammer Field Plume)	TCE, PCE	510	Peach - Clovis	Clinton - Olive
Fresno Landfill	TDS, chloride, nitrate	185	Hughes - West	Jensen - North
Weir Floway / Pinedale Groundwater Site	Pesticides	15	East - Orange	Church - Jensen
Former Dow Plume	TCE	NA	NA	PS201-203
Unibar USA Plume	TCE	NA	NA	NA
Data Source: City of Fresno Plume Location Map				

2.2 Summary of Contaminants of Concern

2.2.1 <u>Active Wells</u>

Based on the City's most recent Annual Water Quality Report and the water quality database, typical ranges and average concentrations of the major COCs are summarized as shown in Table 3. The values taken from the 2004 Annual report is a summary of limited number of active wells requiring sampling that year, whereas the values listed based on the City's water quality database covers more comprehensive sampling data.

Table 3	**Metropolitan Water Resources Management Plan Update Contaminants of Concern and Range City of Fresno**			
Contaminant of Concern	**Range**	**Average**	**MCL/NL[1]**	**Reference**
1,1 DCE (µg/L)	ND-16	0.24	6	2004 Annual WQ Report[2]
1,2 DCP (µg/L)	NA	NA	5	2004 Annual WQ Report
1,2,3-TCP (µg/L)	ND-0.67	0.24	0.005	Fresno WQ database
cis 1,2-DCE (µg/L)	ND-5	0.11	6	2004 Annual WQ Report
DBCP (ng/L)	ND-1300	117	200	2004 Annual WQ Report
EDB (ng/L)	ND-40	0.1	50	2004 Annual WQ Report
PCE (µg/L)	ND-8.6	1.65	5	2004 Annual WQ Report
TCE (µg/L)	ND-49	2.7	5	2004 Annual WQ Report
Arsenic (µg/L)[3]	ND-23	1.5	10	Fresno WQ database
Chromium (µg/L)	ND-15	0.5	50	2004 Annual WQ Report
Nitrate (mg/L)[4]	ND-98	48	45	Fresno WQ database
Hydrogen Sulfide	NA	NA	NA	NA
Iron (µg/L)	ND-5300	950	300	Fresno WQ database
Manganese (µg/L)	ND-1100	120	50	Fresno WQ database
Radon (pCi/L)[5]	ND-2708	710	300 or 4000	2004 Annual WQ Report

Notes:
1. MCL: Maximum Contaminant Level, NL: Notification Level
2. 2004 Annual report summarize a limited number of wells requiring sampling that year
3. New federal arsenic regulation of 10 ug/L was put into effect in January 2006. Department of Health Services (DHS) has an existing MCL for arsenic of 50 ug/L but has not yet adopted a new limit.
4. As nitrate, the MCL is 45 mg/L as nitrate.
5. The proposed MCL is 300 pCi/L and the proposed Alternative MCL is 4,000 pCi/L. The drinking water standard that would apply for a system depends on whether or not the State or community water system develops a multimedia mitigation (MMM) program.

2.2.2 Active Wells with Wellhead Treatment

The City has a number of GAC wellhead treatment systems (33 wells) installed for treating 1,2-Dibromo-3-Chloropropane (DBCP). Eight of these wells are inactive due to sand and/or nitrate issues. One well is also equipped with a temporary reverse osmosis (RO) system to treat nitrate. In addition, there are five wells with either granular activated carbon (GAC), packed tower aeration (PTA), or PTA / GAC systems for removing TCE from the groundwater. Table 4 shows the summary of treatment systems installed throughout the City.

Table 4 Metropolitan Water Resources Management Plan Update
Production Wells with Wellhead Treatment
City of Fresno

Well ID	DBCP	TCE	Method	Status
8A	X		GAC	Active
55-1	X		GAC	Active
70		X	PTA/GAC	Active
82-1	X		GAC	Active
85	X		GAC	Active
89A	X		GAC	Active
110	X		GAC	Inactive / sand and nitrate issues
135A	X		GAC	Active
137	X		GAC	Active
152	X		GAC	Active / temporary RO system for NO_3
153-2	X		GAC	Active
159		X	GAC	Active
164-2	X		GAC	Active
168-2	X		GAC	Inactive
175-2	X		GAC	Active
176	X		GAC	Active
180-2	X		GAC	Active
182-2	X		GAC	Active
184	X		GAC	Active
185	X		GAC	Inactive / nitrate issue
186	X		GAC	Active
201	X		GAC	Inactive / nitrate issue
202	X		GAC	Active
205	X		GAC	Active
224	X		GAC	Active
225	X		GAC	Active
253-2A	X		GAC	Inactive / nitrate issue
274	X		GAC	Inactive / nitrate issue
275	X		GAC	Active
276	X		GAC	Inactive / nitrate issue
277	X		GAC	Active
279		X	PTA	Active
283		X	GAC	Active
286		X	GAC	Active
289-2	X		GAC	Active
297-1	X		GAC	Inactive / sand and nitrate issues

Table 4	Metropolitan Water Resources Management Plan Update Production Wells with Wellhead Treatment City of Fresno		
297-2	X	GAC	Active
308	X	GAC	Active

2.2.3 Inactive Wells

Currently, there are approximately 31 wells off line due to various contamination throughout the City. The main contaminants that resulted in shutdown include nitrate (14 wells, 9,270 gpm), TCE/PCE (8 wells, 8,660), DBCP (3 wells, 3,570 gpm), arsenic (2 wells, 950 gpm), 1,2,3-Trichloropropane (1,2,3 TCP) (1 well, 950 gpm), and cis-1,2-dichloroethylene (cis 1,2-DCE) (1 well, 630 gpm) as summarized in Table 5. In addition, sand problems caused shut down of two wells with production capacity of 1,050 gpm.

Table 5 Metropolitan Water Resources Management Plan Update
Inactive Wells, Contaminants, and Capacity Lost
City of Fresno

Well	Shut down	Contaminants	Capacity (gpm)	Notes
63	03/15/05	1,2,3 TCP	950	Shut-off in March 2004 per DHS recommendation
Production Lost due to 1,2,3-TCP			**950**	
215	04/08/02	cis-1,2-DCE	630	Status unknown
Production Lost due to cis-1,2-DCE			**630**	
36	10/28/04	DBCP	1,800	GAC is planned by FMC/ERM
102	na	DBCP	1,470	Hovering around MCL (may be exceeding)
168-2	na	DBCP	300	Shut down for > 10 years
171-2	Na	DBCP	1,700	
Production Lost due to DBCP			**3,570**	
2B	09/06/05	PCE	2,500	Currently being evaluated for treatment selection
93	na	TCE	1,800	
255	na	TCE	836	
256	na	TCE	830	
265	10/29/03	TCE	588	BSK identifying a treatment plant site
281	na	TCE	700	The well may have been sold
282	na	TCE	595	Capacity from 1986 PGE pump test
285	na	TCE	808	Capacity from 1986 PGE pump test
Production Lost due to TCE/PCE			**8,657**	
135B	na	Arsenic	500	Development project: low As, no treatment planned
168-1	na	Arsenic	450	Filtronics: not working. down for >10 years
Production Lost due to Arsenic			**950**	
113	na	Nitrate	660	Destroyed
140	9/19/96	Nitrate	800	Used in summer 2002 with temporary IX units
155-2	na	Nitrate	600	Treated for DBCP

Table 5	Metropolitan Water Resources Management Plan Update Inactive Wells, Contaminants, and Capacity Lost City of Fresno			
185	na	Nitrate	2,000	Treated for DBCP
201	08/12/04	Nitrate	480	Treated for DBCP, also impacted by 1,1-DCE
223-1	na	Nitrate	280	Requires treatment for DBCP
226-1	na	Nitrate	531	Destroyed
226-2	01/05/06	Nitrate	540	Destroyed
253-1	na	Nitrate	540	
253-2A	na	Nitrate	800	Treated for DBCP
274	10/29/03	Nitrate	400	Treated for DBCP, blend plan, no sewer
276	11/10/00	Nitrate	450	Treated for DBCP, developing a line to blend, no sewer
294	na	Nitrate	340	
Production Lost due to Nitrate			**9,271**	
110	na	Sand	250	Treated for DBCP, also impacted by nitrate
249	na	Sand	850	
297-1	na	Sand	800	Treated for DBCP, also impacted by nitrate
Production Lost due to Sand			**1,050**	
TOTAL PRODUCTION LOST (gpm)			**25,078**	

2.2.4 Organic Contaminants in the City of Fresno

1,1 DCE, 1,2 DCP, cis 1,2-DCE

There have been detections of 1,1-Dichloroethylene (1,1 DCE), 1,2-Dichloropropane (1,2 DCP), and cis 1,2-DCE in the past. 1,1-DCE is used in the production of polyvinylidene chloride copolymers used in flexible packaging materials (e.g., food wrapper); as flame retardant coatings for fiber, carpet backing, and piping; as coating for steel pipes; and in adhesive applications. 1,2-DCP, on the other hand, is created as one of by-products during the manufacture of pesticides ethylene dibromide (EDB) and DBCP. cis 1,2-DCE may be released to the environment in air emissions and wastewater during its production and use. In addition, under anaerobic conditions that may exist in landfills, aquifers, or sediment, it is likely to find cis 1,2-DCE that are formed as breakdown products of TCE and PCE. Currently, cis-1,2-DCE is the only contaminant that resulted in well shut down (Well 215) among these contaminants.

1,2,3-TCP

1,2,3-TCP is also created as one of the by-products produced during the manufacture of pesticides EDB and DBCP. There is no enforceable standard for 1,2,3 TCP, but DHS has set a notification level (NL) of 0.005 µg/L. The monitoring was done for the City's wells according to the unregulated chemical regulation that required two samples be collected between May 1 and September 30, 2004 using EPA Method 504-1, which provided the necessary lower detection limit of 0.005 µg/L. Prior monitoring data had a detection limit of 0.5 ppb, using EPA Method 505.2.

The analytical results for 1,2,3-TCP concentrations detected in water samples collected from 35 of the City's wells (Well Nos. 219, 220, 230, 231, 240, 275, 277, 298, 014A, 018A, 021A, 039A, 040A, 048, 059, 063, 065, 085, 101, 110, 164-1, 277, 082, 165-2, 289-2, 135A, 137, 164, 135, 289, 184, 274, 275, 070, 110) exceeded the current NL according to a letter dated March 1, 2004 from DHS. One of these wells (Well 63) had a maximum concentration reading of 0.67 µg/L and was subsequently removed from operation based on the recommendation from DHS.

DBCP

DBCP is one of the active ingredients in pesticide (soil fumigant) preparations. According to the City Staff (Buche, 2006), there are 33 granular activated carbon (GAC) facilities throughout the City to remove DBCP. As mentioned eight of these wells are inactive as summarized in Table 4. The City is currently working with FMC and its consultant (ERM) on a GAC facility for treatment of Well 36. In addition, water from Well 102 has concentrations of DBCP near the MCL, and Well 168-2 has been shut down for more than 10 years due to high DBCP concentration.

EDB

EDB is also one of the active ingredients in pesticide (soil fumigant) preparations. Although the exact source is not known according to Water Resources Management Plan Existing Water Supply System Assessment Report (WRMP) (CH2M Hill, 1992), pesticide applications to agricultural lands may have contributed to the detection of EDB throughout the City. According to the 2002 Annual Report, PS 275 has a treatment using GAC for the removal of DBCP and EDB. There have been detections of EDB slightly exceeding the MCL, but the more recent 2004 Annual report shows the concentrations below the MCL.

TCE/PCE

TCE and PCE are common industrial solvents and have been historically one of the major contaminants in the City's groundwater. Well 2B currently has PCE concentrations greater than the MCL. The City is currently working with Boyle to select, design, and construct a treatment system for this well. Wells 93, 255, 256, 265, 281, 282, and 285 contain TCE concentrations greater than the MCL and thus currently shut down. Well 265 is located in the Pinedale Groundwater Site (a.k.a. Vendo Plume). The City also has five wellhead treatment systems (Wells 70, 159, 279, 283, and 286) for treating TCE as summarized in Table 4.

2.2.5 Inorganic and Radionuclide Contaminants

Arsenic

Arsenic occurs naturally in deep groundwater and has a federal MCL of 10 µg/L as of January 23, 2006. The State of California, however, has not yet adopted a new drinking water standard for arsenic. The existing standard, which is in place, is 50 µg/L. The new

DHS standard will be at least as stringent as the federal MCL. Two of the City's wells have been shut down due to arsenic contamination (Wells 135B and 168-1). Arsenic was also detected in Well 310 at concentrations ranging from 10 to 23 µg/L. The most recent concentration reading from this well was 10 µg/L on January 3, 2003. Since DHS has not yet adopted a new, lower arsenic MCL, this well is still in operation.

Chromium

Chromium is used in various industrial applications and manufacturing of alloys. Chromium detection is relatively low based on the monitoring data (up to 15 µg/L). However, both Pinedale Groundwater Site (a.k.a. Vendo Plume) and FMC Plume contain chromium that may impact City's wells in the future.

Hydrogen sulfide

Hydrogen sulfide is formed by sulfur bacteria that may occur naturally in water. These bacteria use the sulfur in decaying plants, rocks, or soil as their food or energy source and as a by-product produce hydrogen sulfide. There is limited occurrence data on hydrogen sulfide.

Iron

Iron occurs naturally and has a secondary MCL (SMCL) of 300 µg/L. It has been detected at concentrations greater than the SMCL in thirteen wells. The average concentration from all wells is about 111 µg/L.

Manganese

Manganese also occurs naturally and has a SMCL of 50 µg/L. DHS recently established a NL of 500 µg/L based on the health effects. Concentrations above the SMCL were detected in nine wells. The maximum concentration reading was 1,100 µg/L, which occurred in Well 083A on May 24, 2000. However, the average concentration from all wells is relatively low at about 17 µg/L.

Nitrate

Nitrate is the most common contaminant in groundwater and originates primarily from fertilizers, septic systems, and manure storage or spreading operations. Nitrate concentrations have exceeded 40 mg/L, or 90 percent of the MCL, in 27 wells throughout the City. The maximum concentration detected was 95 mg/L on June 12, 2003 from Well 155-2. The average concentration for all 27 wells is 50 mg/L. Water from Wells 140, 201, 226-2, 249, 253, 274, and 276 have concentrations greater than the MCL for Nitrate. Wells 226-1 and 226-2 have been abandoned due to nitrate contamination. The City is planning to acquire one or two replacement wells from the County's shallow wells. There is a blending plan set up for water from Well 274 and a similar plan for Well 276 is planned in the future. For a nitrate blending plan, DHS requires compliance of 80 percent of the MCL or 36 mg/L as the standard.

Radon

Radon occurs naturally in soil and thus in groundwater. The highest level of radon detected according to 2004 Annual report is about 2,700 pCi/L. The EPA proposed the Radon Rule in November 1999. The proposed rule would apply to all community water systems that use groundwater or mixed ground and surface water. The rule proposes an MCLG, an MCL, an alternative maximum contaminant level (AMCL), and requirements for multimedia mitigation (MMM) program plans to address radon in indoor air. The proposed MCLG for radon in drinking water is zero. The proposed regulation provides two options for the MCL. The proposed MCL is 300 pCi/L and the proposed AMCL is 4,000 pCi/L. The drinking water standard that would apply for a system depends on whether or not the state or community water system develops a MMM program. If an MMM program plan is developed by either the state or the community water system, the maximum level of radon allowed would be 4,000 pCi/L. If an MMM program plan is not developed, then the MCL of 300 pCi/L would apply. According to the City's database for radon that were sampled between 1991 and 1995, more than 97 percent of the wells sampled had detections of radon above the MCL of 300 pCi/L.

3.0 TREATMENT ALTERANTIVES FOR THE CONTAMINANTS OF CONCERN

A summary of treatment alternatives for each contaminant is shown in Table 6. The alternatives listed are the ones that are typically evaluated options and may not be suitable for certain applications depending on other conditions. More detailed discussion for specific type of contaminants is followed.

Table 6 Metropolitan Water Resources Management Plan Update
Summary of Contaminants and Treatment Alternatives
City of Fresno

Contaminants[3]	AS	GAC	AOP[1]	IX	RO	CF/OF	Media	Bio
Organics								
1,1 DCE	• (2)	• (2)	•					
1,2 DCP	• (2)	• (2)	•					
1,2,3-TCP	•	•	•					
cis 1,2-DCE	• (2)	• (2)	•					
DBCP		• (2)	•					
EDB		• (2)	•					
PCE	• (2)	• (2)	•					
TCE	• (2)	• (2)	•					
Inorganics								

Table 6 Metropolitan Water Resources Management Plan Update
Summary of Contaminants and Treatment Alternatives
City of Fresno

Arsenic				• (2)	• (2)	• (2)	•	
Chromium				• (2)	• (2)	• (2)	•	
Nitrate				• (2)	• (2)			•
Hydrogen Sulfide	•	•						
Iron					•	•		
Manganese					•	•		
Radionuclides								
Radon	•	•						

Notes:
1. Emerging technology
2. Best Available Technology (BAT) according to EPA,
3. AS: Air Stripping, GAC: Granular Activated Carbon, AOP: Advanced Oxidation, IX: Ion Exchange, RO: Reverse Osmosis, CF: Coagulation Filtration, OF: Oxidation Filtration, Media: Single-use media adsorption, Bio: Biological Reduction (anaerobic)

3.1 Organic Contaminants

Organic contaminants can either be treated by air stripping or GAC. These are the most common treatment systems, and the City also has a number of GAC and air stripping systems to treat organic contaminants. Volatile organics such as PCE/TCE can be easily removed by air stripping as well as GAC. Air stripping process often requires treatment of off-gas using gas- phase GAC, so the liquid phase GAC is sometimes preferred to minimize the process train. Pesticides such as, DBCP and EDB, cannot be effectively stripped, so only GAC can be used for those applications. Another emerging treatment option is advanced oxidation process (AOP) using either UV light or ozone with hydrogen peroxide. These are used where the contaminant cannot either be adsorbed to GAC or removed by air stripper.

3.1.1 Air Stripping-Packed Tower Aeration (PTA)

Air stripping or PTA is one of the most widespread treatment technologies for VOC removal and is listed as a best available technology (BAT) by EPA. Air stripping is a technology in which VOCs are separated from water by greatly increasing the surface area of the contaminated water exposed to air. Types of aeration methods include packed towers, diffused aeration, tray aeration, and spray aeration. The Henry's constant of a given contaminant determines the required air-to-water ratio for a given percent removal. The higher the Henry's constant, the lower the required ratio. Although increasing the temperature of the contaminated water increases the Henry's constant, such approach is impractical for most drinking water applications.

Off-gas treatment is typically required as part of the air-stripping process when the stripped off-gas from the process contains unacceptable levels of contaminants classified as air toxics. Gas-phase GAC adsorption or other carbonaceous adsorbent resins can be used to treat off-gas to comply with potential San Joaquin Valley Unified Air Pollution Control District (SJVUAPCD) regulations. When the gas phase GAC is saturated, the bed is replaced with new GAC.

3.1.2 Liquid Phase GAC

Liquid Phase GAC is another frequently used treatment for removal of organic compounds from water, and it is also listed as a BAT for a number of contaminants by EPA. GAC systems are efficient and relatively simple to operate if properly designed. GAC removes contaminants from water by the adsorption process in three consecutive steps. First, the contaminant molecule is transferred from the liquid phase to the exterior surface of the carbon. Second, the contaminant molecule is transported from the exterior of the carbon through the pores to an adsorption site. Finally, at some point in this transport process, the molecule is actually adsorbed and held to the pore surface.

The effectiveness of the GAC for removal of a particular contaminant is measured by its adsorptive capacity or isotherm. The higher the adsorptive capacity of a GAC, the less regeneration or change out it requires (i.e., longer period for the service cycle). The adsorptive capacity can be affected by the contaminant concentration, the empty bed contact time (EBCT) and the concentration of any interfering compounds such as natural organic matter (NOM). The adsorption isotherms are compound and water specific, so modeling or testing is required to assess the effectiveness of GAC for each contaminant. In the presence of multiple or competing compounds, the overall capacity is decreased.

3.1.3 Advanced Oxidation Processes (AOPs)

Advanced oxidation processes (AOPs) generate hydroxyl radicals that break down organic compounds. Among several options, ozone with hydrogen peroxide or UV with hydrogen peroxide are the most commonly used alternatives.

An AOP promotes formation of free hydroxyl radicals that accelerate oxidation of organics and other compounds. The hydroxyl radical is a strong oxidant, which can breakdown contaminants from water by chemically transforming them through oxidation. If bromide is present in sufficient concentrations, bromate may be formed as a by-product during ozone process, and thus in such case, use of ozone should be avoided. UV process also provides photolysis that can also attack certain organics such as NDMA in addition to generating hydroxyl radicals. Thus UV may provide a better approach over ozone depending on the target compounds.

Effective removal of organics can be achieved with hydrogen peroxide and UV under optimal consideration. The applied UV dose required for oxidation will vary depending on influent water quality (UV absorbance of background water and presence of radical scavengers). Advantages of UV over ozone include low profile units, small space requirements, capability of intermittent operation, and operator friendliness. However, removal of VOCs with UV is characterized with high costs due to high energy requirements. Other possible concerns and limitations for UV include: breaking of lamps and mercury leakage, interference due to turbidity, iron, and nitrate, fouling of lamps due to presence of iron and other precipitants. TOC and alkalinity directly interferes with UV light or reaction with hydroxyl radicals as free radical scavengers.

3.1.4 Summary of Organics Treatment

Table 7 summarizes the advantages and disadvantages of air stripping, GAC, and AOPs for the removal of organics. Because AOP is more energy intensive and labor intensive than the other two processes, air stripping and GAC are more common treatment options.

Table 7 Metropolitan Water Resources Management Plan Update
Advantages and Disadvantages of Organics and Pesticides Treatment
City of Fresno

Process	Advantages	Disadvantages
Air Stripping	• Established and proven technology	• Phase change, not destruction • Often requires off-gas treatment • Requires re-pumping of treated water to service pressure
GAC	• Removes multi contaminants • Established and proven technology • Simple operation • Familiarity (currently used by Fresno)	• Phase change, not destruction • Regeneration or replacement of GAC required
AOPs	• Destruction of organics • Compact footprint • Capable of intermittent operation	• High-energy cost • Breaking of UV lamps and potential mercury leakage • Interferences cause by various water quality parameters (TOC, Alk, NO_3) • Formation of by-products (e.g., bromate for ozone)

3.2 Inorganic and Radionuclide Contaminants

There are a number of technologies available to treat inorganic and radionuclide contaminants. These COCs in the City’s groundwater can be grouped into three categories based on their similar chemical characteristics. First group is inorganic anions, such as nitrate, arsenic, and chromium (chromium(VI)). The second category is iron and manganese, and the third one is radon and hydrogen sulfide. Since they share similar chemical properties, the treatment alternatives and thus discussion will be similar as shown below. Some of these processes generate either liquid or solid waste (or both), and the selection of a preferred treatment option may depend on the residual handling. Detailed discussions are given in the following sections.

3.2.1 Air Stripping-Packed Tower Aeration (PTA)

Similar to organics removal, air stripping or PTA is used to remove radon and hydrogen sulfide gas from water. As discussed previously for organics, air stripping packed towers, diffused aeration, tray aeration, and spray aeration can be used to remove radon and hydrogen sulfide from water. For hydrogen sulfide, the pH needs to be below 7 to convert hydrogen sulfide in the gaseous form.

3.2.2 Liquid Phase GAC

Again, similar to organics removal, GAC can be used to remove both radon and hydrogen sulfide. Once the GAC capacity is used up, the spent GAC is replaced with new GAC as discussed for organics application. GAC also has small capacity for nitrate, and depending on the operational condition, nitrate may slough from the carbon bed. The same phenomenon can also occur when GAC is used for organics removal. In fact, such sloughing has been observed at some of the City's GAC plants.

3.2.3 Ion Exchange (Anion Exchange)

The regenerable ion exchange process involves exchange of soluble ionic species with chloride ions on the surface of resins. Ion exchange is currently the most demonstrated and implemented technology for treatment of nitrate in drinking water, and it has been used for arsenic and chromium. Most resins are NSF certified, and a number of commercial systems accepted by DHS have been implemented in several locations throughout California. The common resins used are strong-base anion exchange resins in the chloride form, specifically either polyacrylic or polystyrene resins. As mentioned, the chloride ion (Cl^-) on the surface of the resin is exchanged for other anions present in the water (thus called anion exchange). Thus the process is impacted by the background concentrations of other anions including sulfate, alkalinity, uranium, etc.

After a certain service cycle, resins are typically loaded with nitrate or other anions and regenerated on-site with a salt solution (NaCl). In order for the chloride ion to substitute the nitrate ion loaded on the resin, a high concentration typically in the range of a several percent of chloride is required in the regenerant solution. Therefore, the spent brine solution can range from 6 percent salt (about 60,000 mg/L of NaCl) to as high as 20 percent salt (about 200,000 mg/L as NaCl) under special cases. Once the resin is reloaded with chloride, it is used again and the ion-exchange cycle is repeated. The spent brine solution produced during regeneration must be disposed of appropriately or reused for further regeneration following treatment. Depending on the local discharge regulation, discharge of high TDS spent regenerant solution is a challenge. For a small treatment system, spent brine can also be hauled off-site.

3.2.4 Reverse Osmosis

Reverse osmosis (RO) can remove the soluble forms of nitrate, arsenic, chromium, as well as iron and manganese. The true benefit of the high-pressure membrane treatment process is its ability to remove co-occurring dissolved contaminants at the same time. High capital and operating costs and concentrate stream disposal issues typically make it economically unfeasible to apply RO for a single contaminant only. In addition, iron and manganese foul RO membranes and typically, these constituents are reduced to low concentrations prior to RO treatment to prevent such fouling.

The presence of elevated levels of sulfate, iron, barium, magnesium, calcium, silica, and strontium may also affect the operation of RO. Scaling and fouling of membranes will decrease membrane performance. The presence of elevated levels of silica can significantly limit the recovery of high-pressure membranes. The EDR process uses an electric field to separate ions rather than using pressure, so EDR process may be used if silica is a concern. Although the concentration of TDS in the RO reject stream is much less than the brine from ion exchange process, significantly more volume needs to be discharged compared with that for the spent ion exchange brine.

3.2.5 Coagulation or Oxidation Filtration

Coagulation and oxidation filtration are different in that different types of chemicals are added. However, the common goal is to produce insoluble species that can be removed by the media filter downstream of either a coagulation or an oxidation step.

Arsenic and chromium can be removed by addition of ferric coagulant and forming insoluble flocs prior to a filtration step. After the filters are loaded with insoluble species, the filters need to be backwashed (typically once or twice daily), and the backwash water is discharged to sewer. Most of the backwash water may be recovered after the spent wash water is settled. Depending on the operation, the sludge from the backwash water may contain elevated levels of arsenic or chromium, which then requires special handling. If the contaminant level is high in the sludge, various discharge and disposal regulations apply. California regulations include total threshold limit concentration (TTLC), soluble threshold limit concentration (STLC), etc. The backwash frequency and efficiency of the process depends on the coagulant dose, water quality (pH, speciation of contaminants), and finished water goal.

Oxidation followed by filtration is the most commonly used process for iron and manganese removal. Under reducing conditions, iron and manganese are stable as soluble forms (ferrous (Fe^{2+}) and manganous (Mn^{2+})). When they are oxidized by chlorine or permanganate, they become insoluble ferric (Fe^{3+}) and manganic hydroxide (Mn^{3+}) species, and these can be physically removed with a filtration process. Chlorine and potassium permanganate are common oxidants applied in commercial packaged systems. It has been reported that soluble (Mn^{2+}) was rapidly oxidized by potassium permanganate, chlorine dioxide, and ozone in low DOC waters. When chlorine is used as an oxidant, however, it can react with naturally organic matter (NOM) in the raw water to form trihalomethanes

(THMs) and haloacetic acids (HAAs), which are regulated contaminants under the Stage 2 Disinfectants / Disinfection By-products (DBPs) Rule (D/DBPR). Therefore, if halogenated DBPs are an issue, other oxidants may offer benefits compared to chlorine, such as potassium permanganate, and chlorine dioxide. Testing may be required to confirm DBP formation potential with various oxidants.

3.2.6 Single-use Media Adsorption

Single-use media adsorption treatment technology relies on phase transfer methods to remove arsenic and chromium from water. Typically, there is limited generation of liquid waste during an initial installation of the media, and no backwash is required during the operation. Once the media is saturated with contaminants, new media is installed and the spent media is hauled off for landfill. There are more than 30 media available for arsenic removal, and some of them can also remove chromium. These include granular ferric hydroxide (GFH from US Filter), granular ferric oxide (GFO from Severn Trent, Engelhard, etc.), iron-incorporated resin (Arsenex NP from Purolite or ASM from Resin Tech), and TiO2 media (Adsorbsia from Dow) (Min et al., 2005). These single-use media for arsenic are generally replaced every few months to a year depending on the water quality and operations.

The spent media are disposed of in various classes of landfills depending on leaching test (TTLC and STLC) results. Initial backwash water from this process contains low levels of contaminants that can be discharged to sewer. Certain types of media, such as Arsenex NP may be regenerated off-site similar to GAC reactivation. During the chemical regeneration, deterioration of media occurs and the arsenic or chromium sorption capacity typically diminishes in the subsequent cycle.

Similar to GAC and regenerable ion exchange resin, other anions are still a competing factor and affect the run length of the single-use media until arsenic or chromium breakthrough. Single-use type media may not be suitable for such application where nitrate or other competing ion levels are high because the breakthrough of competing anions may have “peaking” effects where competing anion levels in the effluent becomes high for a short period of time. Other parameters affecting the process include contaminant concentration, uranium, pH, silica, etc, as prolonged run time may contribute to generation of spent media that are either hazardous (due to arsenic and chromium) or low level radioactive (due to uranium).

3.2.7 Biological Reduction (anaerobic)

Anaerobic biological process uses indigenous microorganisms that are able to metabolize nitrate and other compounds such as perchlorate and some organics. Depending on the levels of nitrate, anaerobic biological reduction offers lower operating cost than comparable physical / chemical processes. It may also produce less waste product that allows easier dewatering and disposal of residual unlike ion exchange process, which generates high TDS spent brine. However, anaerobic biological treatment requires specific raw water qualities and conditions, and not all groundwaters or surface waters can be treated economically using this technology. Success of this treatment process depends on several factors such as nutrient availability, oxidation/reduction conditions, temperature, and filter operation strategy. Anaerobic biological process may require a special permitting for implementation at full scale, but DHS has conditionally accepted this process for perchlorate and nitrate in drinking water.

An electron donor, such as acetic acid, is dosed to the feed line just before raw water enters the biological reactor. Because a portion of the biological reactor must be anaerobic to allow for nitrate reduction, the influent DO concentrations determine the acetic acid dose and the empty-bed contact time (EBCT). Effluent from the anaerobic biological reactor is aerated and pumped to an aerobic biological filter as a post treatment. This process sequence is designed to achieve four goals: 1) oxygenate the water, 2) remove (microbially oxidize) residual biodegradable organic carbon, 3) remove (microbially oxidize or strip by aeration) any sulfide formed in the anaerobic biological reactor, and 4) capture microorganisms that slough from the anaerobic bioreactor. Excess biosolids waste streams would be produced by both the anaerobic and aerobic biological reactors, which must be discharged. The anaerobic biological process train would minimally impact flow, pH, chloride, and TDS.

3.2.8 Summary of Inorganic and Radionuclide Treatment

A summary of the advantages and disadvantages for each of the alternatives for treatment of inorganic and radionuclide contaminants is presented in Table 8.

**Table 8 — Metropolitan Water Resources Management Plan Update
Advantages and Disadvantages of Inorganics and Radionuclides Treatment
City of Fresno**

Process	Advantages	Disadvantages
Air Stripping	• Established and proven technology	• Phase change, not destruction • Often requires off-gas treatment • Re-pumping required
GAC	• Removes multi contaminants • Established and proven technology • Simple operation • Familiarity (currently used by Fresno)	• Phase change, not destruction • Regeneration or replacement of GAC required • Potential nitrate sloughing
Ion Exchange (Regenerable)	• Proven technology • Can remove various anions • Resins are re-used after regeneration • Potentially high rate of	• Some resins may produce precursors to form NDMA in finished water • Efficiency depends on raw water quality

Table 8	Metropolitan Water Resources Management Plan Update Advantages and Disadvantages of Inorganics and Radionuclides Treatment City of Fresno	
Process	**Advantages**	**Disadvantages**
	treatment • Familiarity (currently used by Fresno)	• Generates brine with high TDS
Reverse Osmosis (RO)	• Can achieve rejection of multiple contaminants • Proven technology for drinking water	• High capital and O&M costs • Generates a large quantity of concentrate waste • TDS and silica reduce efficiency of removal.
Coagulation / Oxidation Filtration	• Proven process • Effective for number of contaminants (Fe/Mn/As/Cr) • Cost-effective	• Addition of chemicals (either oxidant for Fe/Mn or coagulant for As/Cr) • Generation of backwash water and sludge
Single-Use Media Adsorption	• Well-demonstrated technology • Does not produce liquid brine • Can be easily implemented	• Media must be replaced on a regular basis (high O&M cost) • Presence of uranium may limit run length to avoid generation of low level radioactive waste
Biological	• Complete destruction of nitrate • Can also remove some organics • Indigenous microorganisms can be used • Low O&M cost	• High capital cost • Public acceptance • No current full-scale applications for direct drinking water treatment (in the U.S.) • Requires a post-treatment train for potable water applications • Requires NSF certified electron donor

4.0 TREATMENT COST DATA

4.1 Treatment Cost Data Assumptions

The generic cost information provided here is not site specific and should be used for informational purposes only. In order to develop a planning level estimate, additional data such as water quality specific to each well, site information, preferred treatment alterative, operational limitations, etc. will be needed. In addition, there are a number of uncertainties that will influence the actual cost of a treatment system as discussed in Section 4.3. These may include factors such as, interfering compounds, cost of labor, materials, equipment, services provided by others, contractor's methods of determining prices, competitive bidding or market conditions, practices or bidding strategies. As such, the cost information provided here does not warrant or guarantee that proposals, bids or actual construction costs will not vary from the cost information presented herein. In order to compare options for the planning purpose, a more accurate site specific cost estimate must be developed.

The individual cost estimate curves presented below are from the United States Bureau of Reclamation (USBR) Fact Sheet cost curves derived from USBR's WaTER program, which is available at http://www.usbr.gov/pmts/water/primer.html#factsheets. The following is a disclaimer provided by the WaTER program on the cost estimate. "Construction and annual O&M costs were derived from the WaTER Program; Estimating Water Treatment Costs, volumes 1 and 2 of EPA-600/2-79-162a, August 1979; or from manufacturer's product data information. Cost estimates are as of March 2001, are considered accurate within +30 percent to -15 percent, and are primarily intended as a guide for comparing alternative water treatment options. More accurate cost estimates can be determined given site specific data and verification of assumptions." Additional assumptions from USBR are provided in Appendix A of this memo.

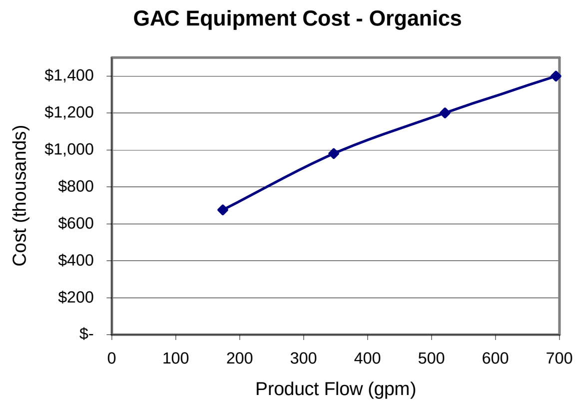
The cost curves are presented here without any adjustment except to convert the flowrates from gallons per day (GPD) to gallons per minute (GPM). Unlike other cost estimation programs that require the user to have information about the size of equipment and chemical dosage rates, the only inputs required for the WaTER program are the production capacity and raw water quality composition. The program employs cost indices as established by the Engineering News Record, Bureau of Labor Statistics, and the Producer Price Index, and derives cost data from Estimating Water Treatment Costs; Volumes 1 and 2; EPA-600/2-79-162a; August 1979. The Cost Assumptions Fact Sheet provided by USBR for these generic cost curves are included in Appendix A.

The cost ranges in Figure 9 are based on the Cost Estimates for Treatment Technologies from http://www.ci.modesto.ca.us/omd/01_ccr/pdf/phg_cost_treat.pdf and a presentation by Boodoo (2004). The Cost Estimate for Treatment Technologies provides a table with 24 case studies with conditions and total annual cost range (annualized capital cost and O&M cost) for each case study. The actual table used in compiling the cost range data is included as Appendix B. This includes short summaries of conditions, capacity, etc. for each case study.

4.2 Generic Cost Estimate for Contaminants of Concern

4.2.1 <u>Generic Cost Estimate for Organics and Pesticides</u>

As mentioned previously, the actual O&M cost of a GAC system will depend on the type of contaminant and its adsorption isotherm for a specific GAC type. This is true for packed tower air stripping as well. For some organics, such as DBCP and EDB, only GAC system can be used as air stripping is not effective for these contaminants (see Table 6). Figure 2 shows the capital and O&M costs for a GAC adsorption system in 2001 dollars. As mentioned, these generic cost curves are based on the assumptions provided previously. Air stripping cost strongly depends on the site conditions, and thus generic cost is not available.



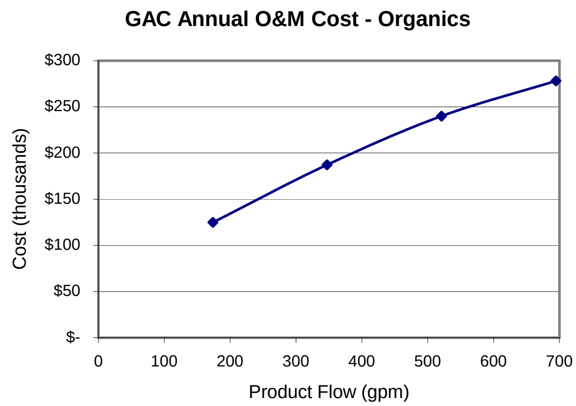
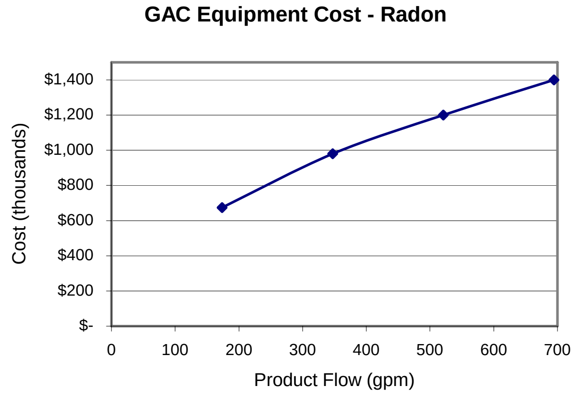


Figure 2. Capital and O&M costs for GAC to treat organics (USBR data in 2001 dollars)

4.2.2 <u>Generic Cost Estimate for Radon</u>

Similar to organics and pesticides, both radon and hydrogen sulfide may be removed with either GAC or air stripping. WaTER cost database does not provide cost data for hydrogen sulfide, so only GAC cost curves for Radon are included (Figure 3). Also, as mentioned previously, due to the site specific nature of the air stripping system, the generic costs curves are not available for Radon.



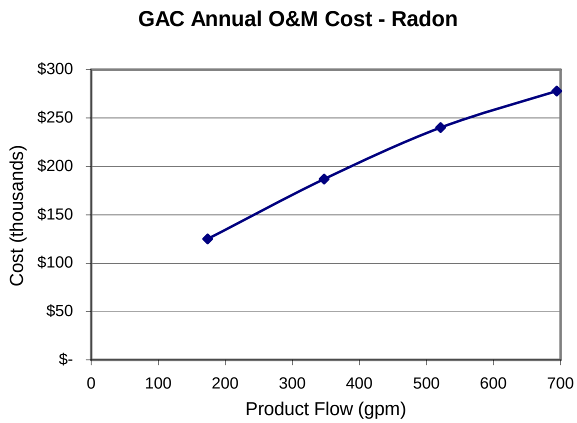


Figure 3. Capital and O&M costs for GAC to treat Radon (USBR data in 2001 dollars)

4.2.3 <u>Generic Cost Estimate for Oxyanions (Arsenic, Chromium, and Nitrate)</u>

Arsenic and chromium are similar in their chemical properties. The costs provided in Figures 4 and 5 are specific to coagulation/filtration for arsenic and ion exchange for chromium respectively. However, the cost curve for coagulation can also apply for chromium, and the cost curve for ion exchange can be used for arsenic as the cost range will be similar between the contaminants for each process.

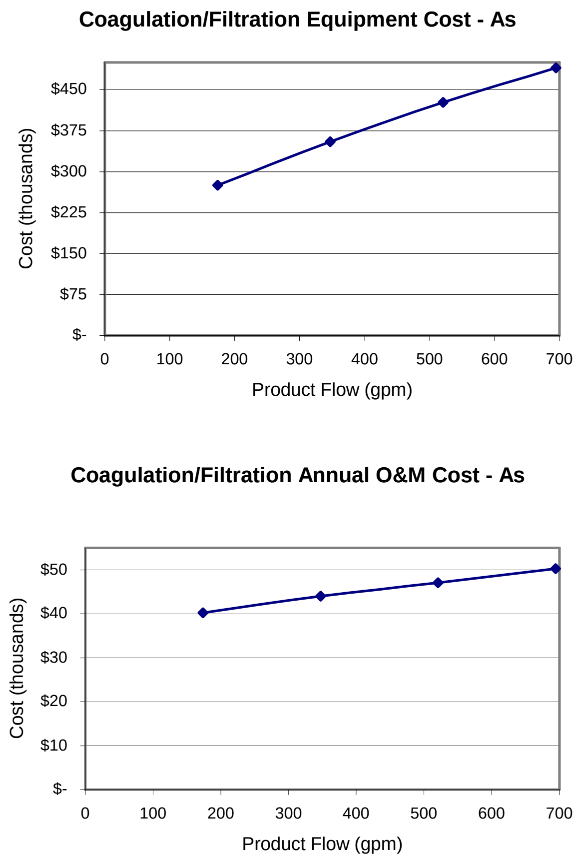
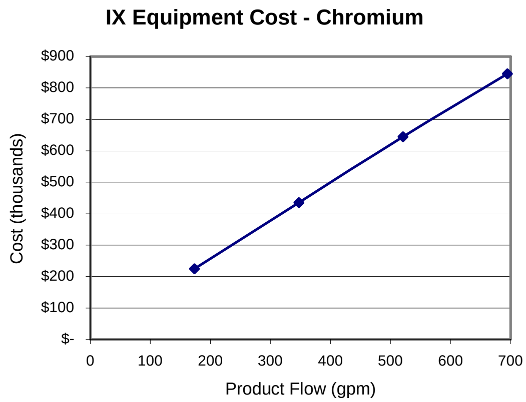


Figure 4. Capital and O&M costs for CF to treat arsenic (USBR data in 2001 dollars)



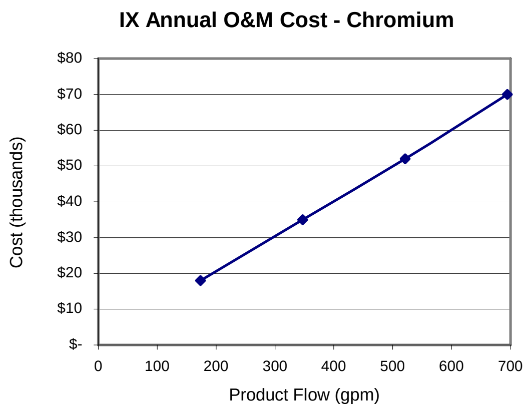
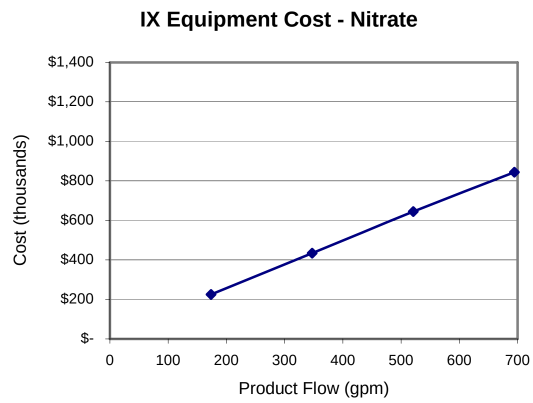


Figure 5. Capital and O&M costs for IX to treat chromium (USBR data in 2001 dollars)

Two treatment option costs are provided for nitrate below. Figure 6 shows the costs for ion exchange while Figure 7 shows the costs for RO option. These are costs associated with treatment only. If discharge of the brine will be a problem or if there are co-occurring contaminants, then RO option may be more acceptable alternative.



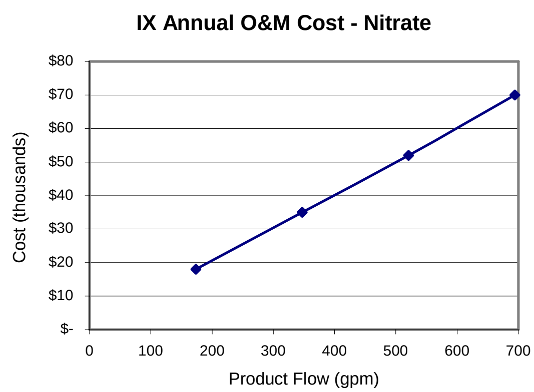
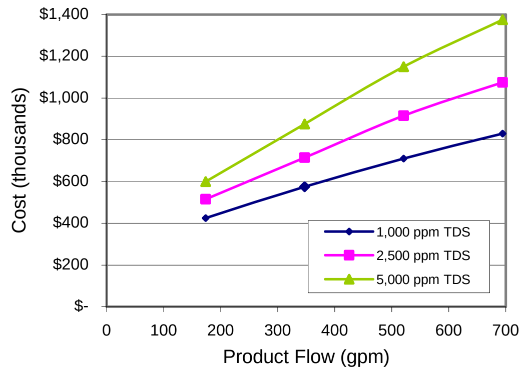


Figure 6 Capital and O&M costs for IX to treat nitrate (USBR data in 2001 dollars)

RO Equipment Cost - Nitrate



RO Annual O&M Cost - Nitrate

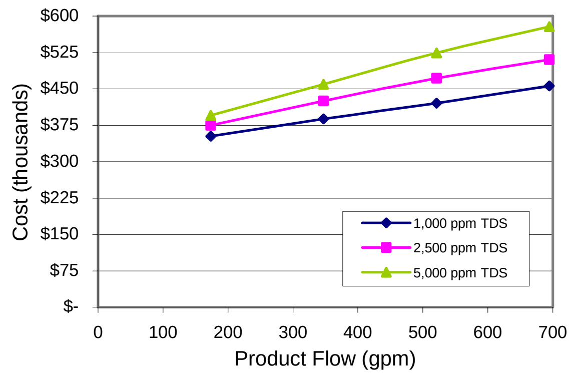
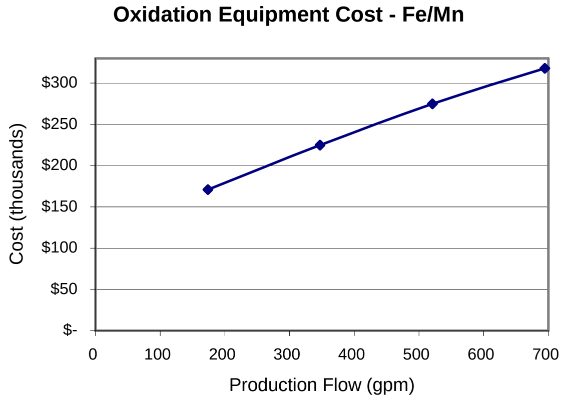


Figure 7 Capital and O&M costs for RO to treat nitrate (USBR data in 2001 dollars)

4.2.4 Generic Cost Estimate for Iron and Manganese

As previously mentioned, the most widely used option for iron and manganese is oxidation filtration. Figure 8 shows the oxidation option costs. The costs curves are similar to those for the coagulation filter option shown for arsenic. In fact, with minimum retrofit, oxidation filtration system can be modified to also remove arsenic or chromium by adding additional coagulant as required.



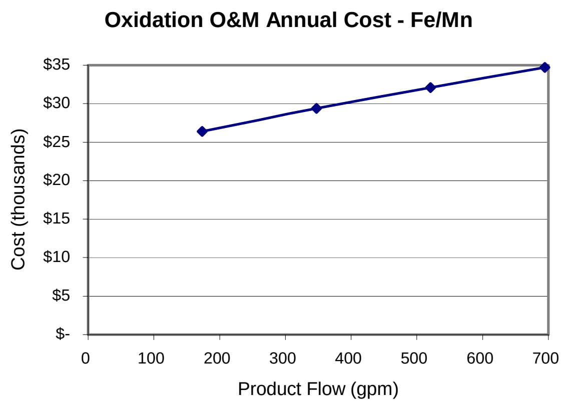


Figure 8 Capital and O&M costs for Oxidation Filtration to treat Fe/Mn (USBR data in 2001 dollars)

4.3 Cost Estimate Range by Process

As mentioned previously, the costs presented from WaTER estimates published by USBR are generic costs based on a number of assumptions. In addition to the contaminant concentrations, the actual cost of treatment process will be affected by potential water quality interferences summarized in Table 9. Site specific conditions will also affect the cost, such as vessel, pump, tank size, etc. As such, based on the limited information available, the comparison of the range of total cost in $/AF is presented in Figure 9 to illustrate the variability.

Table 9	Metropolitan Water Resources Management Plan Update Treatment Processes and Potential Interferences City of Fresno	
Process	**Target Compounds**	**Potential Water Quality Interferences**
Air Stripping	VOC, SVOC, radon, H_2S	NOM, iron, pH
Coagulation/oxidation Filtration	arsenic, chromium, iron, manganese	pH, hardness
Reverse Osmosis	nitrate, arsenic, chromium, iron, manganese	NOM, silica, barium, hardness, pH
Ion Exchange	nitrate, arsenic, chromium	sulfate, alkalinity, pH, hardness
Single-Use Media	arsenic, chromium	NOM, silica, hardness, pH, iron, manganese, vanadium
GAC	VOC, SVOC, pesticides, radon, H_2S	NOM, nitrate

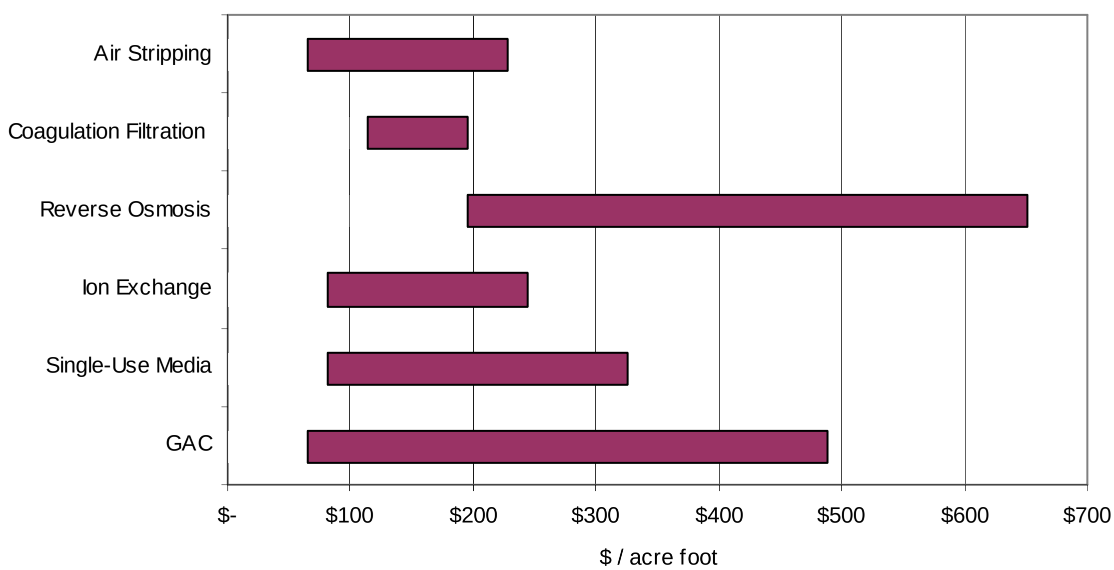


Figure 9 Comparison of the ranges of cost for the processes discussed (2001 dollars)

5.0 SUMMARY AND RECOMMENDATIONS

5.1 Summary

Based on the review of available documents provided by the City and other resources from similar projects, the following summary is provided.

- There are ten documented plumes in the City of Fresno that threaten the groundwater quality.
- The major contaminants include DBCP, TCE, and nitrate based on the number of impacted wells by these contaminants.
- New contaminants which may require treatment include 1,2,3-TCP and arsenic.
- Other contaminants include 1,2 DCP, cis 1,2-DCE, EDB, PCE , chromium, hydrogen sulfide, iron, manganese, and radon.
- The total number of wells currently shut down due to contamination is 31.
- Groundwater production lost due to contaminated wells is 25,000 gpm.
- USBR's cost curves for contaminant specific processes are presented (capital and O&M), and cost ranges are provided for a various treatment processes. The cost estimates are suitable for initial planning-level efforts but will need to be refined for future planning and alternative selection purposes. Fresno will have to extrapolate beyond 700 gpm for their high capacity wells.

5.2 Recommendations

In order to use the groundwater treatment cost information to compare with other project alternatives, the following recommendations are made.

- Develop well-specific treatment evaluation based on well capacity, water quality, site constraints, truck access, piping requirements, etc.
- Develop a site specific cost estimate for each contaminated well based on the preferred treatment alternative.
- Consider centralized treatment if the well locations are conducive and the infrastructure exists such as pipeline, etc. for selected wells.
- Evaluate discharge impacts and cost of residual handling (e.g., discharge) for ion exchange, reverse osmosis, and coagulation / oxidation filtration technologies.

6.0 REFERENCES

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APPENDIX A - USBR'S COST FACT SHEET ASSUMPTIONS

WaTER PROGRAM

FOR CONTAMINANT FACT SHEETS

See related Fact Sheets: Acronyms & Abbreviations; Glossary of Terms; Cost Assumption; Raw Water Composition; and Total Plant Costs.

Water Treatment Estimation Routine (WaTER)

Some cost estimates used to develop some of the contaminant Fact Sheet cost curves and the Total Plant Cost curves were derived from Reclamation's WaTER program. WaTER is an Excel spreadsheet application developed for use with Reclamation's MTP. The program is a result of a cooperative effort between Reclamation and the National Institute of Standards and Technology.

Unlike other cost estimation programs that require the user to have information about the size of equipment and chemical dosage rates, the only inputs required for the WaTER program are the production capacity and raw water quality composition. The program employs cost indices as established by the *Engineering News Record*, Bureau of Labor Statistics, and the Producer Price Index, and derives cost data from *Estimating Water Treatment Costs*; volumes 1 and 2; EPA-600/2-79-162a; August 1979. Refer to the Cost Assumptions Fact Sheet for detailed cost data information.

The program has the following capabilities: (1) provides cost estimates for all treatment processes used in the MTP; (2) contains default values which can be customized if more accurate values are available; (3) is expandable to include new processes as they are developed; and (4) is user friendly.

The following processes are included in the program: pumping systems; centrifugal pumps; metering pumps; alum coagulation (dry/liquid); ferric sulfate coagulation; lime-soda ash softening; acid feed; polymer addition; potassium permanganate oxidation; ion exchange; upflow solids contact clarifier; gravity filtration (sand/dual/mixed); granular activated carbon filtration; microfiltration; reverse osmosis; nanofiltration; electrodialysis; clearwell storage; chlorine disinfection; chloramine disinfection; and ozone disinfection.

The program (suitable for PC or Mac environments) and user manual are available for distribution to interested parties. Or they can be accessed at:
http://www.usbr.gov/pmts/water/desal.html - Task E (separate program for PC users and Mac users)
http://www.usbr.gov/pmts/water/reports.html - #43 (user manual)

As discussed on the Cost Assumptions Fact Sheet, construction and annual O&M costs not estimated by the WaTER program were derived from *Estimating Water Treatment Costs*, volumes 1 and 2, EPA-600/2-79-162a, August 1979; or from equipment manufacturer's product data information.

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Water Treatment Engineering and Research Group, D-8230
PO Box 25007, Denver CO 80225 (303) 445-2260

Revision Date: 09/11/03

COST ASSUMPTIONS

FOR CONTAMINANT FACT SHEETS

See related Fact Sheets: Acronyms & Abbreviations; Glossary of Terms; Raw Water Composition; Total Plant Costs; and WaTER Program.

1. COST INDEX DATA

Construction and annual O&M costs were derived from: the WaTER Program; *Estimating Water Treatment Costs*, volumes 1 and 2 of EPA-600/2-79-162a, August 1979; or from manufacturer's product data information. Cost estimates are as of March 2001, are considered accurate within +30% to -15%, and are primarily intended as a guide for comparing alternative water treatment options. More accurate cost estimates can be determined given site specific data and verification of assumptions.

EPA cost index updates as follows:
October 1978 ENR construction cost index = 2581; February 1999 = 5992; March 2001 = 6273.
October 1978 PPI O&M materials index = 71.6; February 1999 = 130.8; March 2001 = 137.8.
October 1978 PPI O&M energy cost = $0.03/kW-hr; February 1999 & March 2001 = $0.07/kW-hr.
October 1978 PPI O&M labor cost = $10/hr; February 1999 = $30/hr; March 2001 = $32.5/hr.
Total annual O&M cost = sum of materials, energy, and labor costs.

The following WaTER Program cost components are based on those used by *ENR* at www.enr.com or 212-512-2000:

Category	2001 Value	Used For
Construction cost index	6,279.45	Manufactured & electrical equipment
Building cost index	3,541.01	Housing
Skilled labor index	5,874.20	Excavation, site work, & labor
Materials index	2,115.65	Piping & valves
Steel cost ($/cwt)	28.01	Steel
Cement cost ($/ton)	80.35	Concrete
Materials index	2,115.65	Maintenance materials
Electricity cost ($/kWhr)	0.07	Power
Labor rate ($/hr)	32.5	Labor

2. PROCESS ASSUMPTIONS

A. Raw Water Pumps: Costs derived from WaTER program. No. of pumps: 2 centrifugal single stage. Pump efficiency: 75%, motor efficiency 90%. Horsepower based on flowrate.

B. Screening/Straining: Costs derived from manufacturer's product data information. Velocity: 2.5 ft/sec, "Water Supply and Pollution Control;" second edition; J.W. Clark, W. Viessman Jr., and M.J. Hammer. Screen size opening: 1/4-inch. 3-, 4-, 5-, and 6-inch diameter screens for flows 0.25, 0.50, 0.75, and 1.0 MGD, respectively. Estimated annual O&M for all flows: $1,000.

C. Rapid Mix: Costs derived from "Estimating Water Treatment Costs." DT: 30 sec, "Recommended Standards for Water Works;" 1982. G value = 900.

D. Polymer Addition: Costs derived from WaTER program. General settling aid: $1.50/lb. Dosage: 3.0 mg/L.

E. Antiscalant: Costs derived from WaTER program. RO and EDR membrane aid: $1.50/lb. Dosage: 0.5 mg/L.

F. Dry Alum Coagulation: Costs derived from WaTER program. $Al_2(SO_4)_3$ cost: $22/100 lbs. Dosage: 230 mg/L.

G. Ferric Sulfate Coagulation: Costs derived from WaTER program. $Fe_2(SO_4)_3$ cost: $260/short ton. Dosage: 3.0 mg/L.

H1. Lime Softening with Upflow Solids Contact Clarifier: Costs derived from WaTER program. $Ca(OH)_2$ cost: $340/ton. Dosage: 84.3 mg/L. Two SCC units, each sized for ½ total flow. SCC DT: 120 min. SCC O&M G value = 150.

H2. Lime/Soda Ash Softening with Upflow Solids Contact Clarifier: Costs derived from WaTER program. $Ca(OH)_2$ cost: $340/ton. Na_2CO_3 cost: $340/ton. $Ca(OH)_2$ dosage: 84.3 mg/L; Na_2CO_3 dosage: 278 mg/L. Two SCC units, each sized for ½ total flow. SCC DT: 120 min. SCC O&M G value = 150.

I. Horizontal Paddle Flocculator: Costs derived from "Estimating Water Treatment Costs." DT: 30 min, "Recommended Standards for Water Works;" 1982. G value = 80.

J1. Circular Clarifier: Costs derived from "Estimating Water Treatment Costs." SLR: 1.0 gal/min/ft², "Recommended Standards for Water Works;" 1982. DT @ 12' sidewall depth: 90 min. Structure is concrete.
J2. Tube Settler: Costs derived from "Estimating Water Treatment Costs." SLR: 2.5 gal/min/ft², "Estimating Water Treatment Costs;" volumes 1 and 2; EPA-600/2-79-162a; August 1979.

K. Dual Media Gravity Filter: Costs derived from WaTER program are based on two concrete basins. Dual media cost: $938/m³@0.25 MGD; $815/m³@0.50 MGD; $701/m³@0.75 MGD; & $582/m³@1.0 MGD. Dual media FLR: 5.0 gal/min/ft², "Estimating Water Treatment Costs;" volumes 1 and 2; EPA-600/2-79-162a; August 1979. 2 units, each sized for plant capacity. 24 hr wash cycle. Media depth: 1 m. Media volume: 3.2 m³@0.25 MGD; 6.5 m³@0.50 MGD; 9.7 m³@0.75 MGD; 12.9 m³@1.0 MGD. TSS density: 35 g/L. Costs include backwash pump, filter structure, and pipe gallery housing. Backwash piping: 7 ft/sec. Backwash pump: 50' TDH. Maximum backwash rate: 18 gal/min/ft².

L. Chlorine Disinfection: Costs derived from WaTER program. Gaseous Cl_2 cost: $500/short ton, tank. Dosage (2.5 mg/L) = demand (2 mg/L) + residual (0.5 mg/L). Free chlorine residual of 0.2 - 0.5 mg/L and DT of 30 min for groundwater or 2 hrs for surface water, "Recommended Standards for Water Works;" 1982. Free chlorine residual = chlorine available as HOCl and OCl^-.

M1. Ion Exchange (Anion): Costs derived from WaTER program. Regeneration cycle: 14 days. Resin cost: $5,227/m³; 1.0 nominal equivalent/liter of resin for NO_3^-. NaCl regeneration at 10% strength. Regenerant storage tank included.
M2. Ion Exchange (Cation): Costs derived from WaTER program. Regeneration cycle: 14 days. Resin cost: $1,819/m³; 1.9 nominal equivalent/liter of resin. NaCl regeneration at 10% strength.
M3. Ion Exchange (Mixed Bed): Costs derived from WaTER program. Regeneration cycle: 14 days. Nuclear grade resin mixture (cation:anion) generally 1:1. Resin cost: $4,662/m³; 1.9 nominal equivalent/liter (cation) resin; and 1.4 nominal equivalent/liter (anion) resin. NaCl regeneration at 10% strength.

N. Oxidation with $KMnO_4$ followed by Greensand Filtration: Costs derived from WaTER program, adjusting gravity filtration for greensand filtration. $KMnO_4$ cost: $2.10/lb (hopper truck). $KMnO_4$ dosage: 1.1 mg/L. Total gravel, greensand, and anthracite costs: $1,750m³@0.25 MGD; $1,539/m³@0.50 MGD; $1,361/m³@0.75 MGD; & $1,202/m³@1.0 MGD. Greensand loading rate: 5.0 gal/min/ft². 2 units, each sized for plant capacity. 24 hr wash cycle. Media depth: 1 m. Media volume: 3.2 m³@0.25 MGD; 6.5 m³@0.50 MGD; 9.7 m³@0.75 MGD; 12.9 m³@1.0 MGD. TSS density: 35 g/L. Costs include backwash pump and filter structure.

O. Granular Activated Carbon: Costs derived from WaTER program. 6 month bed life.

P. Reverse Osmosis: Total direct capital costs derived from WaTER program and include cleaning system and some pretreatment (antiscalant) filters/chemicals. Operating pressure: 1380 kPa (200 psi). Membrane cost: $525 per 8" module. Membrane life: 3 years. Product quality: 500 mg/L TDS. Two stage unit operating at 80% recovery with blending. Pretreatment not included.

Q. Microfiltration: Total direct capital costs derived from WaTER program and include cleaning system and some pretreatment filters/chemicals. Design feed pressure: 207 kPa (30 psi). Membrane cost: $650. Membrane life: 5 years.

R. Electrodialysis Reversal: Costs derived from WaTER program and Ionics, Inc. Unit operates at 80% recovery. Product quality: 500 mg/L TDS. Pretreatment not included.

S. Clearwell: Costs derived from WaTER program. Below ground concrete tank sized based on water source (30 min DT for groundwater or 2 hr DT for surface water) and flowrate.

3. RAW WATER VARIABLES

An assumed raw water composition is shown on the Raw Water Composition Fact Sheet. Following are the only raw water variables used to determine the cost curves:

A. Flow: Costs for each BAT were prepared for flows of 0.25, 0.50, 0.75, and 1.0 MGD.

B. TDS: A TDS of 2,500 mg/L was assumed for all processes; except for RO and EDR where three TDS ranges were estimated at 1,000, 2,500, and 5,000 mg/L.

C. TSS: For dual media gravity and greensand filtration a TSS of 13.0 mg/L was estimated.

RAW WATER COMPOSITION

FOR CONTAMINANT FACT SHEETS

See related Fact Sheets: Acronyms & Abbreviations; Glossary of Terms; Cost Assumptions; Total Plant Costs; and WaTER Program.

The following raw water composition was used in determining cost curves for various treatment processes:

	Component	Valence	MW	MCL/SMCL (mg/L)	Units	Concentration
METALS	Aluminum	3	26.97	0.05-0.2	mg/L	0.005
	Antimony	3	121.75	0.006	mg/L	--
	Arsenic	3	74.92	0.05	mg/L	0.002
	Barium	2	137.33	2	mg/L	0.11
	Beryllium	2	9.01	0.004	mg/L	--
	Cadmium	2	112.41	0.005	mg/L	0.001
	Calcium	2	40.08	--	mg/L	99
	Chromium	2	52	0.1	mg/L	0.002
	Copper	2	63.55	1	mg/L	0.001
	Iron	2	55.85	0.3	mg/L	0.005
	Lead	2	207.2	0.015	mg/L	--
	Magnesium	2	24.3	--	mg/L	19
	Manganese	2	54.94	0.05	mg/L	0.003
	Mercury	2	200.59	0.002	mg/L	--
	Nickel	2	58.71	0.1	mg/L	0.002
	Potassium	1	39.1	--	mg/L	12
	Selenium	4	78.96	0.05	mg/L	--
	Silver	1	197.87	0.1	mg/L	0.001
	Sodium	1	22.99	--	mg/L	31
	Strontium	2	87.6	--	mg/L	0.61
	Thallium	1	204.37	0.002	mg/L	--
	Zinc	2	65.38	5	mg/L	0.02
OTHER INORGANICS	Alkalinity-HCO_3^-	-1	61	--	--	100
	Alkalinity-CO_3^{-2}	-2	60	--	--	--
	Carbon Dioxide (aq)	0	44	--	--	--
	Asbestos	--	--	7	MF/L	--
	Chloride	-1	35.45	250	mg/L	--
	Residual disinfectant	--	71	detectable	mg/L	--
	Color	--	--	15	cu	--
	Conductivity	--	--	--	--	920
	Corrosivity	--	--	non-corrosive	mg/L	--
	Cyanide	--	--	0.2	mg/L	--
	Fluoride	-1	19	4	mg/L	0.2
	Foaming agents	--	--	0.5	mg/L	--
	Nitrate (as N)	-1	14	10	mg/L	12
	Nitrite (as N)	-1	14	1	mg/L	--
	Ammonium	1	--	10	mg/L	--
	Odor	--	--	3	ton	--
	pH	--	--	6.5-8.5	pH	7.2
	o-Phosphate	-3	95	--	--	--
	Silica	--	--	--	--	--
	Silicon	--	--	--	--	28
	Solids (TDS)	--	--	500	mg/L	2500
	Sulfate	-2	96	250	mg/L	130
	Temperature	--	--	--	--	13
	Solids (TSS)	--	--	--	mg/L	--

Bureau of Reclamation, Technical Service Center
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Revision Date: 09/21/01

Following are the only raw water variables applied to the above:

A. TDS: For RO and EDR, three TDS ranges were estimated at 1,000, 2,500, and 5,000 mg/L.

B. TSS: For dual media gravity and greensand filtration, a TSS of 13.0 mg/L was estimated.

C. Metals for Cl_2: The following concentrations were adjusted for use with Cryptosporidium/Giardia and Total Coliform/E-Coli:

Iron	550 mg/L
Manganese	550 mg/L
Chromium	200 mg/L
Nickel	200 mg/L
Nitrite	200 mg/L

Appendix B

Cost Estimate for Treatment Technologies Case Studies

COST ESTIMATES FOR TREATMENT TECHNOLOGIES
(INCLUDES ANNUALIZED CAPITAL AND O&M COSTS)

No.	Treatment Technology	Source of Information	Estimated 2001* Unit Cost ($/1,000 gallons treated)
1	Granular Activated Carbon	Reference: Malcom Pimie estimated for California Urban Water Agencies, large surface water treatment plants treating water from the State Water Project to meet Stage 2 D/DBP and bromate regulation, 1998	0.371 - 0.7084
2	Granular Activated Carbon	Reference: Carolio Engineers, estimate for VOC treatment (PCE), 95% removal of PCE, Oct. 1994, 1900 gpm design capacity	0.17
3	Granular Activated Carbon	Reference: Carolio Engineers, est. for large No.Calif. Surface water treatment plant (90 mgd capacity) treating water from State Water Project, to reduce THM precursors, ENT construction cost index = 6262 (San Francisco area) - 1992	0.82
4	Granular Activated Carbon	Reference: CH2M Hill study on San Gabriel Basin, for 135 mgd central treatment facility for VOC and SOC removal by GAC, 1990	0.318 - 0.4664
5	Granular Activated Carbon	Reference: Southern California Water Co. - actual data for "rented" GAC to remove VOC's (1.1-DCE), 1.5 mgd capacity facility, 1998	1.47
6	Granular Activated Carbon	Reference: Southern California Water Co.-actual data for permanent GAC to remove VOC's (TCE), 2.16 mgd plant capacity, 1998	0.95
7	Reverse Osmosis	Reference: Malcolm Pimie estimate for California Urban Water Agencies, large surface water treatment plants treating water from the State Water Project to meet Stage 2 D/DBP and bromate Regulation, 1998	1.1024 - 2.1094
8	Reverse Osmosis	Reference: Boyle Engineering, RO cost to reduce 1000 ppm TDS in brackish groundwater in So. Calif., 1.0 mgd plant operated at 40% of design flow, high brine line cost, May 1991	2.60
9	Reverse Osmosis	Reference: Boyle Engineering, RO cost to reduce 1000 ppm TDS in brackish groundwater in So. Calif., 1.0 mgd plant operated at 100% of design flow, high brine line cost, May 1991	1.60
10	Reverse Osmosis	Reference: Boyle Engineering, RO cost to reduce 1000 ppm TDS in brackish groundwater in So. Calif., 10.0 mgd plant operated at 40% of design flow, high brine line cost, May 1991	2.15
11	Reverse Osmosis	Reference: Boyle Engineering, RO cost to reduce 1000 ppm TDS in brackish groundwater in So. Calif., 10.0 mgd plant operated at 100% of design flow, high brine line cost, May 1991	1.34
12	Reverse Osmosis	Reference: Arsenic Removal Study, City of Scottsdale, AZ - CH2M Hill, for a 1.0 mgd plant operated at 40% of design capacity, Oct. 1991	4.35
13	Reverse Osmosis	Reference: Arsenic Removal Study, City of Scottsdale, AZ - CH2M Hill, for a 1.0 mgd plant operated at 100% of design capacity, Oct. 1991	2.57
14	Reverse Osmosis	Reference: Arsenic Removal Study, City of Scottsdale, AZ - CH2M Hill, for a 10.0 mgd plant operated at 40% of design capacity, Oct. 1991	1.93
15	Reverse Osmosis	Reference: Arsenic Removal Study, City of Scottsdale, AZ - CH2M Hill, for a 10.0 mgd plant operated at 100% of design capacity, Oct. 1991	1.19

COST ESTIMATES FOR TREATMENT TECHNOLOGIES
(INCLUDES ANNUALIZED CAPITAL AND O&M COSTS)

No.	Treatment Technology	Source of Information	Estimated 2001* Unit Cost ($/1,000 gallons treated)
16	Reverse Osmosis	Reference: CH2M Hill study on San Gabriel Basin, for 135 mgd central treatment facility with RO to remove nitrate, 1990	1.1972 - 2.1094
17	Packed Tower Aeration	Reference: Analysis of Costs for Radon Removal...(AWWARF publication), Kennedy/Jenks, for a 1.4 mgd facility operating at 40% of design capacity, Oct. 1991	0.69
18	Packed Tower Aeration	Reference: Analysis of Costs for Radon Removal...(AWWARF publication), Kennedy/Jenks, for a 14.0 mgd facility operating at 40% of design capacity, Oct. 1991	0.37
19	Packed Tower Aeration	Reference: Carollo Engineers, estimate for VOC treatment (PCE) by packed tower aeration, without off-gas treatment, O&M costs based on operation during 329 days/year at 10% downtime, 15 hr/day air stripping operation, 1900 gpm design capacity, Oct. 1994	0.18
20	Packed Tower Aeration	Reference: Carollo Engineers, for PCE treatment by Ecolo-Flo Enviro-Tower air stripping, without off-gas treatment, O&M costs based on operation druing 329 days/year at 10% downtime, 16 hr/day air stripping operation, 1900 gpm design capacity, Oct. 1994	0.19
21	Packed Tower Aeration	Reference: CH2M Hill study on San Gabriel Basin, for 135 mgd central treatment facility - packed tower aeration for VOC and radon removal, 1990	0.2968 - 0.4876
22	Advanced Oxidation Processes	Reference: Carollo Engineers, estimate for VOC treatment (PCE) by UV Light, Ozone, Hydrogen Peroxide, O & M costs based on operation during 329 days/year at 10% downtime, 24 hr/day AOP operation, 1900 gpm capacity, Oct. 1994	0.36
23	Ozonation	Reference: Malcolm Pimie estimate for CUWA, large surface water treatment plants using ozone to treat water from the State Water Project to meet Stage 2 D/DBP and bromate regulation, *Cryptisporidium* inactivation requirements. 1998	0.0848 - 0.1678
24	Ion Exchange	Reference: CH2M Hill study on San Gabriel Basin, for 135 mgd central treatment facility - ion exchange to remove nitrate, 1990	0.4028 - 0.5194

Note:

*Costs were escalated from date of original estimates to present, where appropriate, using Engineering News Record (ENR) construction indices for Los Angeles and San Francisco.

3/19/01

http://www.ci.modesto.ca.us/omd/01_ccr/pdf/phg_cost_treat.pdf

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Interoffice Memorandum

To: Dave Peterson - PBP Consulting, Inc.
Gerry Nakano, Elizabeth Drayer - West Yost Associates

Copies To: Steve Hogg, Rosa Lau-Staggs, Mohammad Moaddab

From: Penny Carlo

Date: April 28, 2008 **WO#:** 7452A.01

Subject: TM 2-2 for Fresno Metro Plan

The purpose of this memorandum is to summarize the City of Fresno's current water recycling activities and how the City plans to expand recycled water use in the future as part of its overall supply plan.

A second objective is to evaluate opportunities for desalting the City's water supply, as required by the UWMP Guidelines.

1.0 CURRENT WATER RECYCLING ELEMENTS

1.1 Regional Wastewater Reclamation Facilities (RWRF)

The majority of the wastewater treated at the RWRF is discharged to percolation ponds. Approximately 10 percent of the total effluent flow is discharged directly to neighboring farmland for irrigation of feed/fodder and fiber crops. Approximately 30 percent of the total effluent flow is extracted from beneath the percolation ponds and discharged to the FID canals for unrestricted irrigation. In 2007, the RWRF discharged 10,935 AF to neighboring farmland and 27,000 AF to the FID canals for a total of 31,000 AF.

The City of Fresno operates under an agreement with FID that allows discharge of the percolated effluent into the FID canals. The terms of the agreement are discussed in detail in TM 1.9 (Existing Institutional Arrangements). The agreement specifies that 30,000 AF/year can be extracted and discharged to the FID canals, and that for every AF discharged, FID delivers 0.45 AF of surface water to the City. The agreement also stipulates that the City will retain its effluent within the FID boundaries unless approval from FID is obtained. The City will need to work with FID to modify the terms of the original agreement to allow increased discharges to FID or discharges outside of FID.

1.2 Copper River Wastewater Reclamation Facilities (WRF) Satellite Plant

The Copper River WRF was recently built to serve the Copper River development and golf course in north Fresno. The plant has been permitted and start-up is expected in 2008. The permitted capacity of the plant is 0.71 mgd (average monthly flow) and 1.08 mgd (maximum daily flow). The plant is master planned for expansion to 1.25 mgd average monthly flow at build-out.

Disinfected tertiary recycled water will be used to irrigate the Copper River golf course. The golf course is within the city limits of Fresno. Until now, the golf course has been irrigated almost exclusively with FID water, with apparently a minimal amount from an agricultural well.

During wet weather months, recycled water in excess of turf demands will be dechlorinated and discharged to a nearby percolation basin owned by the Fresno Metropolitan Flood Control District, and used to irrigate landscaped areas within the basin. Projected recycled water use ranges from about 750 AF/year initially to about 1250 AF/year at build-out.

2.0 FUTURE WATER RECYCLING ELEMENTS

The City of Fresno plans to expand recycled water use in the future, beyond the current 31,000 AF/yr recycled for agricultural irrigation, as part of its overall water supply plan. The City has established a goal to provide 25,000 AF/year of recycled water by the year 2025, for future landscape irrigation demands and other non-potable demands within the City service area. Their objectives and policies are summarized below.

Objectives

- Increase the use of recycled water to help offset existing/future potable water demands
- Use maximum available recycled water recharge exchange supply from the FID agreement

Policies

- Require new developments Citywide to install purple pipe for recycled water use on parks, common areas, roadway medians, etc.
- Look for opportunities to install purple pipe near existing landscaped areas (e.g., parks, sports fields) (i.e., piggyback on other pipeline installation/replacement projects)
- Work with FID and/or others to develop an agreement to better use the percolated treated effluent from the RWRF
- Further develop partnerships with FID, Clovis, and others to maximize available water resources (i.e. developing joint projects with Clovis, modifying the exchange agreement with FID, etc.)
- Allow new development to create “new” supplies by participation in the implementation of recycled water facilities
- Fund and adopt the required Recycled Water Master Plan by 2010
- Provide additional staff and program-specific financial resources required to implement/manage the recycled water use program.

2.1 Recycled Water Master Plan

The projected recycled water demands and locations of demand for the years 2025 and 2060 have not been established. The City will begin work on a Recycled Water Master Plan in the fall of 2008. The Master Plan will identify potential uses, general locations, and project the future demand. It will establish the regulatory requirements, infrastructure needs, timing, and capital improvement program.

Two potential projects intended to provide recycled water within the City are a satellite wastewater treatment plant in southeast Fresno, and a tertiary plant to treat a portion of the RWRF effluent flow. The Recycled Water Master Plan will identify the potential users and demand of water from these sources.

Potential uses of the tertiary treated recycled water from either of the two proposed plants include: 1) industrial, residential, and commercial landscape irrigation; 2) cemeteries; 3) golf courses; 4) freeway corridors; 5) unrestricted agricultural irrigation; 6) industrial use, and; 7) parks.

Tertiary water from either of these plants would also be suitable for groundwater recharge to replenish a potable groundwater supply. Treatment requirements for recycling and recharge will be discussed in Technical Memorandum No. 2.4.

2.2 SEGA Satellite Plant

The City is considering building a satellite WWTP in the Southeast Growth Area (SEGA) of the City. Two possible locations for the plant were identified in this general area. Based on an analysis of the service areas, the capacities would be either 12 mgd or 15 mgd. At this time, it is not known which general location will be selected or the ultimate capacity of the plant.

In addition to distributing the recycled water to various users mentioned above, flows would also be discharged to the Fresno Irrigation District (FID) canals for unrestricted irrigation. During the winter months, flows would be discharged to percolation ponds.

Estimated project costs for the proposed satellite plants, updated to the twenty cities August 2007 ENRCCI, are $143 million for the Southeastern Plant, and $164 million for the Southwestern Plant. Estimated annualized project costs (including project and O&M costs) for the proposed satellite plants, updated to the twenty cities August 2007 ENRCCI, range from $13.7 million for the Southeastern Plant, to $15.6 million for the Southwestern Plant. This equates to approximately $1,000/AF for either option.

2.3 RWRF Tertiary Plant

The City plans to build facilities to treat a portion of the RWRF secondary effluent to the disinfected-tertiary level. The capacity of the tertiary plant is estimated at 10 mgd. The recycled water would be distributed from the RWRF to various users mentioned above.

Costs for the RWRF tertiary facilities have not been established at this time. The Recycled Water Master Plan will identify potential users and the distribution system.

3.0 DESALINATION OF WATER SUPPLY

The Metro Plan must address opportunities to develop desalinated water, including ocean water, brackish water, and groundwater, as a long-term supply. This is stipulated in

Section 10631 of the California Water Code Division 6.

Because the City is not located in a coastal area, seawater desalination is not applicable to Fresno. In addition, the groundwater that underlies Fresno is not brackish in nature and does not require desalination. However, the City could provide financial assistance to other purveyors in exchange for water supplies. Should the need for this type of exchange arise, the City may consider one of these options in the future.

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City of Fresno
Metropolitan Water Resources Management Plan Update

FUTURE-WITH-PROJECT ALTERNATIVE REFINEMENT - SUPPLY

TECHNICAL MEMORANDUM NO. 2.4

FINAL
January 2009

CITY OF FRESNO

METROPOLITAN WATER RESOURCES MANAGEMENT PLAN UPDATE

TECHNICAL MEMORANDUM
NO. 2.4

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FUTURE-WITH-PROJECT ALTERNATIVE REFINEMENT - SUPPLY

The purpose of this technical memorandum (TM) is to summarize the water quality of each supply source as it relates to suitability for urban uses, and to identify treatment needs for those uses. The supply sources are: recycled water, groundwater, and surface water.

The quality of the City of Fresno's (City) groundwater supply, as it pertains to current and emerging groundwater contaminants and possible wellhead treatment needs were summarized in TM 1.4. While the inventory of wells and contaminant concentrations may differ somewhat from the publication of TM 1.4 (January 2007), the findings from that TM are generally still representative and applicable for estimating long term system needs, and are not repeated here.

1.0 RECYCLED WATER

1.1 Unrestricted Irrigation Use - Title 22 Regulations

Health laws related to the use of recycled water in the state of California are found in Chapter 3 of Division 4 of Title 22 of the California Code of Regulations (Title 22). The type of recycled water that is required for unrestricted irrigation, the highest nonpotable quality of reuse water in California, is disinfected tertiary recycled water. Section 60304 of Title 22 specifies that recycled water used for the following irrigation uses shall be "disinfected tertiary recycled water":

- Food crops, including all edible root crops, where the recycled water comes into contact with the edible portion of the crop
- Parks and playgrounds
- Schoolyards
- Residential landscaping
- Unrestricted access golf courses, and
- Any other irrigation use not specified in this section and not prohibited by other sections of the California Code of Regulations

Table 1 contains a summary of Title 22 water quality criteria for disinfected tertiary recycled water. The California water quality criteria and the treatment system requirements as specified in Title 22 (Section 60301 and 60304) are discussed below.

**Table 1 Title 22 Water Quality Criteria for Disinfected Tertiary Water
Metropolitan Water Resources Management Plan Update
City of Fresno**

Parameter	Compliance Period	Regulated Limit
Turbidity(2)	Average within a 24 hour period	2 NTU
	Not to exceed more than 5 percent of the time with in a 24 hour period	5 NTU
	Never to exceed	10 NTU
Polio virus log reduction(3)	Minimum during operation	5-log
Coliform	7 day median	2.2 MPN/100 mL
	Not to exceed in more than one sample in any 30 day period	23 MPN/100 mL
	Not to Exceed in any one sample	240 MPN/100 mL

Notes: MPN most probable number

1. Requirements for wastewater that has been coagulated and passed through natural undisturbed soils or a bed of filter media.
2. Reduction of microorganisms is achieved through filtration and subsequent disinfection.

1.2 Treatment Requirements for Title 22 Disinfected Tertiary Recycled Water

Disinfected tertiary recycled water is defined as a "coagulated, filtered, and subsequently disinfected wastewater" (Section 60301.230). For unrestricted irrigation, the City of Fresno Regional Wastewater Reclamation Facilities (RWRF) would need to coagulate, filter, and subsequently disinfect their secondary-treated wastewater to meet the requirements shown in Table 1.

1.2.1 Coagulation

According to Section 60304(a), coagulation need not be used as part of the treatment process provided that the filter effluent turbidity does not exceed 2 nephelometric turbidity unit (NTU), the turbidity of the influent to the filters is continuously measured, the influent turbidity does not exceed 5 NTU for more than 15 minutes and never exceeds 10 NTU, and there is the capability to automatically activate chemical addition or divert the wastewater should the filter influent turbidity exceed 5 NTU for more than 15 minutes.

1.2.2 Filtration

"Filtered wastewater" is defined in Section 60301.320 as an "oxidized wastewater that meets the criteria in subsection (a) or (b)" provided below.

a) Has been coagulated and passed through natural undistributed soils or a bed of filter media pursuant to the following:

   1) At a rate that does not exceed 5 gallons per minute per square foot of surface area in mono, dual, or mixed media gravity, upflow or pressure filtration systems, or does not exceed 2 gallons per minute per square foot of surface area in traveling bridge automatic backwash filters; and

   2) So that the turbidity of the filtered wastewater does not exceed any of the following:

      a. Average 2 NTU within a 24-hour period;

      b. 5 NTU more than 5 percent of the time within a 24-hour period;

      c. 10 NTU at any time.

b) Has been passed through a microfiltration, ultrafiltration, nanofiltration, or reverse osmosis membrane so that the turbidity of the filtered wastewater does not exceed the following:

   1) 0.2 NTU more than 5 percent of the time within a 24-hour period; and

   2) Never to exceed 0.5 NTU at any time.

The Title 22-approved filtration technologies include granular media filters, cloth filters, other media filters (Fuzzy Filter) and membrane technologies.

1.2.3 Disinfection

The filtered wastewater must then be disinfected by either a chlorine disinfection process that provides a 450 mg-min/L contact time (CT) with a modal contact time of 90 minutes, or a disinfection process that when combined with filtration inactivates and/or removes 5-log of MS2 coliphage or poliovirus.

Title 22 approved technologies for disinfection include chlorine, ultraviolet light, and pasteurization. Title 22 approval of the HiPOx (ozone and hydrogen peroxide) disinfection system is pending and expected to be approved in 2008 or 2009.

1.3 Groundwater Recharge - Title 22 Draft Regulations

Groundwater recharge projects are governed by regulations developed by the California Department of Public Health (DPH) and provided in Title 22, Chapter 3 of Division 4, Sections 60301 - 60323). The recharge regulations are currently undergoing revision by DPH. The latest draft is dated August 5, 2008. The draft regulations stipulate control of pathogenic microorganisms, nitrogen compounds, and regulated chemicals and physical characteristics.

The control of pathogenic microorganisms is dictated by the tertiary disinfection treatment requirement for the recycled water, and the minimum travel time of six months underground prior to extraction.

Nitrogen control is dictated by the maximum concentration limits (either 5 mg/L or 10 mg/L total nitrogen) for the blended recharge water. The 10 milligrams per liter (mg/L) limit could be justified in the water prior to application or prior to reaching the groundwater table, provided bioconversion to nitrate and nitrite does not occur to cause exceedance of these maximum contaminant levels (MCLs). Use of this method to control nitrogen requires frequent testing of all nitrogen species, dissolved oxygen (DO) and biochemical oxygen demand (BOD_5). It also requires submittal of an engineering report that documents the adequacy of this method to control nitrogen.

The recycled water must be monitored quarterly to demonstrate compliance with the water quality parameters listed in Title 22's drinking water standards. These are the primary MCLs for inorganic and organic chemicals, radionuclides, disinfection byproducts, and lead and copper.

The draft regulations also provide two categories of recharge, either surface and subsurface application of recycled water. Various requirements are established to protect the quality of the downgradient potable water. These include dilution of the recycled water with a high quality water source (diluent water) approved by the DPH, a minimum 6-month retention time below ground before being extracted by a drinking water well, and water quality monitoring requirements.

Due to constraints mandated on the quality of the diluent water, the use of stormwater as the diluent for recharge in stormwater basins may be problematic.

- The draft Title 22 regulations provide three "recycled water concentration" (RWC) dilution ratios for diluting the recycled water with "diluent" water. The options for the RWC are:
  - 0.5 for subsurface application (one part recycled water and one part diluent water)
  - 0.5 for surface application, following reverse osmosis (RO) and advanced oxidation of the recycled water, to provide a level of treatment equivalent to 1.2 log nitrosodimethylamine (NDMA) reduction and a 0.5 log 1,4 dioxane reduction
  - 0.2 for surface application (one part recycled water and four parts diluent water) for non-RO surface application
- The ratio of recycled water may be increased if the total organic carbon (TOC) concentration in the blended recharge water does not exceed the following:

$$TOC\ max = 0.5\ mg/L\ /\ RWC\ proposed$$

For a RWC of 0.20 for non-RO surface application, the TOC max of the blended recharge water calculated to 2.5 mg/L TOC (diluted). If the diluent water has little or no TOC, the recycled water could have as much as 12.5 mg/L TOC. In reality, the recycled water would need to be closer to 7 mg/L TOC.

The draft recharge regulations do not address the antidegradation policy established in the Water Quality Control Plan for the Tulare Lake Basin (Basin Plan). The antidegradation policy may trigger more stringent treatment requirements of the plant effluent to prevent any potential degradation. The constituent of most concern is salinity. If the 0.20 RWC option is implemented (surface spreading), the final blended salinity concentration may not be an issue. If subsurface injection is pursued (RWC = 0.50), the potential for salinity degradation may be an issue.

1.4 Treatment Process Options for Satellite Plants

1.4.1 <u>Production of Recycled Water for Unrestricted Use</u>

The minimum level of treatment for a satellite plant to provide recycled water for unrestricted use would be disinfected tertiary, as described previously. There are several options for the types of processes that would be utilized to achieve disinfected tertiary. Process selection will depend on multiple factors and a detailed study of alternatives.

Unless the satellite plant is designed to treat only a constant flow from the sewer system (and peak flows are diverted to the RWRF), the plant must be designed to handle peak hour flows. Standby power capabilities will be required to maintain operation during power outages. Emergency storage ponds are an option for diverting and temporarily storing untreated or partially treated flows that occur during power outages. If onsite emergency storage is not available, then the plant must be designed with redundancy to assure full treatment during peak hour flow events.

A satellite treatment plant would consist of some or all of the following unit processes, depending on design and planning decisions.

- <u>Preliminary Treatment</u> - This would consist of inlet pumps, screening, possible grit removal and dewatering, flow metering, possible flow equalization, and possible chemical addition facilities. Chemical and/or biological scrubbers will most likely be needed for odor control. The need for chemical addition will depend on the process chosen. Grit removal may not be used if an oxidation ditch is selected as the secondary treatment process, but is critical for membrane bioreactors (MBRs).

- <u>Primary Treatment</u> - This would typically form part of the process of a wastewater treatment plant, but may be omitted under certain circumstances (oxidation ditch plants or membrane bioreactor plants)

- Advanced Secondary Biological Treatment with Nitrogen Removal - Nitrogen removal would be needed to protect the underlying groundwater during nonirrigation times when plant effluent may be discharged to ponds or irrigation canals. Potential process options that could be designed to achieve nitrogen removal include activated sludge, sequential batch reactors, oxidation ditch, MBRs, biological aerated filters, and modern attached growth processes such as moving bed bioreactors and integrated fixed film activated sludge.

- Tertiary Treatment - The Title 22 approved technologies for coagulation and filtration mentioned in Section 1.2 are potential options.

- Disinfection - The Title 22 approved technologies mentioned in Section 1.2 are potential options.

- Solids Processing and Handling - Solids processing could be achieved at the satellite plant or the solids could be discharged to the sewer system for treatment at the RWRF. If onsite solids processing is selected, the processes could involve thickening, stabilization (digestion), and dewatering. Dewatered solids would be hauled offsite for reuse/disposal.

- Effluent Discharge - This would include effluent pipelines to offsite reuse locations, and may include onsite storage tanks or ponds if year-round discharge is not feasible. Transport of recycled water to an area outside of the Fresno Irrigation District (FID) may require the consent of FID. TM 1.9 discusses the exchange agreements between the City and FID. Discharge to an irrigation district canal is typically allowed for only ten to eleven months per year due to routine scheduling of canal maintenance. Direct irrigation demands also diminish in the winter, typically for four months, and therefore other disposal options are needed for year-round reliability.

1.4.2 Production of Recycled Water for Groundwater Recharge

The preferred method to recharge in the Valley would likely be surface recharge with dilution and no RO treatment. RO capital costs, power demand, and brine disposal pose significant barriers for RO use. Based on the summary provided in Section 1.3, surface recharge would require:

- Treatment of the wastewater by a nitrogen removal process followed by tertiary treatment and disinfection.

- Dilution ratio of one part recycled water and four parts diluent. Less dilution (one part recycled water and one part diluent) is allowed for RO-treated effluent and/or subsurface application.

- Minimum six months of groundwater travel time to nearest drinking water well.

- Diluted recycle water must be below 5 mg/L total nitrogen unless the diluted water is routinely tested for DO and BOD_5, and the groundwater is tested for DO.

- Diluent water must meet Department specified primary MCLs and notification levels (stormwater as the diluent may be problematic).

- A likely upper limit on the recycled water TOC concentration of approximately 7 mg/L (see Section 1.3). A satellite plant that utilizes advanced secondary treatment with nitrogen removal prior to tertiary treatment should be able to achieve the target TOC concentration of 7 mg/L.

In addition to the above requirements, due to RWQCB concerns for introducing disinfection byproducts into the underlying groundwater, chlorination would not be a feasible disinfection alternative. One of the other options mentioned in Section 1.2 would be needed.

1.5 Treatment Process Options for a RWRF Sidestream Tertiary Treatment Plant

1.5.1 Production of Recycled Water for Unrestricted Use

The Title 22 requirements for producing disinfected tertiary water are the same as those for a satellite plant, however since the RWRF already produces secondary effluent, the sidestream treatment plant would be only need to provide tertiary and disinfection processes.

Tertiary treatment could be provided by either filtration or MBRs. Disinfection could be provided by any of the approved methods mentioned in Section 1.2.

A sidestream plant would be designed to handle a constant flow from the RWRF; therefore considerations for handling peak hour flows would not be needed. The solids stream would be returned to the RWRF for treatment. Power would be provided by the RWRF. In the event of a power failure at the RWRF, flows to the tertiary plant would be stopped. In case of equipment failure at the tertiary plant, partially treated flows could be diverted back to the RWRF for treatment.

1.5.2 Production of Recycled Water for Groundwater Recharge

The treatment requirements for recharge would be generally the same as those mentioned in Section 1.4.2 (tertiary and nonchlorine disinfection).

TOC concentrations in the RWRF effluent have been detected in the range of 8 mg/L to 10 mg/L. The organic upgrade construction project (currently underway) will improve treatment of BOD_5 and provide partial nitrification/denitrification of the wastewater. A sidestream facility that adds filtration and disinfection to the RWRF effluent will likely bring

TOC levels down to meet the TOC target concentration of 7 mg/L. Pilot testing is recommended to confirm this.

Assuming the RWRF effluent total nitrogen concentration is 10 mg/L following the organic upgrade, the diluted recycle water may contain total nitrogen concentrations above 5 mg/L. It is likely the recharge project may require routine monitoring for DO and BOD_5 as discussed in Section 1.3.

2.0 SURFACE WATER

This Section characterizes the raw water quality from the City of Fresno's proposed future source of supply for the existing Northeast Water Treatment Facility (WTF) and proposed Southeast WTF and describes treatment needs from the preliminary raw water quality data set that is currently available. In TM No. 1.8, cost estimates were prepared for expansion of the existing Northeast WTF and a new Southeast WTF, and were based on the current treatment processes. This TM determines whether the existing treatment processes are still applicable for both projects, based on additional information and water quality data. This TM also provides anticipated space required for the expanded Northeast WTF and the new Southeast WTF, and recommends clearwell sizes for proper treatment facility operation.

2.1 Water Quality Regulations

The United States Environmental Protection Agency (US EPA) develops drinking water regulations under the federal Safe Drinking Water Act (SDWA). Primacy for adopting these federal regulations or developing its own regulations with more stringent standards has been granted to the California Department of Public Health (CPDH). CDPH regulates water utilities based on size, water source, and treatment methods.

The City's Northeast WTF has met all of the current regulatory requirements since it was commissioned. However, two new regulations have been promulgated since plant operation commenced, the Stage 2 Disinfectant/Disinfection By-Product Rule (Stage 2 D/DBPR) and the Long-Term 2 Enhanced Surface Water Treatment Rule (LT2 ESWTR). The goal of these two regulations is to balance the risks from microbial pathogens with those from carcinogenic by-products produced through disinfection. As such, the rules include new requirements for treatment efficacy and Cryptosporidium inactivation/removal, as well as new standards for disinfection by-products (DBPs).

DBP compliance involves many factors including source water quality, treatment process, and distribution system characteristics and operation. While evaluating all of these factors falls outside the scope of this work, source water quality and treatment processes will be discussed as it relates to DBP precursors to assist the City with meeting the new DBP regulation requirements.

2.1.1 Finished Water Quality Goals

In order to select treatment processes, both raw water quality and finished water quality goals must be established. It is not known whether specific finished water quality goals are in place for the current Northeast WTF operation. Meeting all applicable regulations is the primary goal, but others may also exist. It is proposed that the goals consist of at least those items listed in the table below. Others may also be applicable.

Table 2 Finished Water Quality Goals
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Parameter	Units	Finished Water Goal
General Physical/Chemical		
Turbidity	NTU	
TOC	percent reduction	30-45
Odor	TON	<3
Microbial and Turbidity		
Giardia Inactivation	Log removal	3
Cryptosporidium Inactivation	Log removal	3a
Virus Inactivation	Log removal	4
Distribution System		
pH	-	Match Existing
Alkalinity	mg/L as $CaCO_3$	30-50
Chlorine Concentration	mg/L	To Meet Residual Requirements

Note:
1. a- Actual requirements may be higher based on source water sampling under LT2 ESWTR.

2.2 Northeast WTF Source Water Supply and Treatment Processes

2.2.1 Current Source Water Supply

Precipitation and snow melt from the Kings and San Joaquin watersheds are provided by the City's federal Central Valley Project contract and Fresno Irrigation District entitlements. The snowmelt from the Sierra Nevada Mountains runs into the Kings and San Joaquin Rivers. Currently, water is supplied to the Northeast WTF via the Enterprise Canal, a 25-mile open channel that winds its way through agricultural and urban areas. The Enterprise Canal can deliver from either of the City’s water supply sources.

In the near future, a five-mile pressure pipeline will be constructed directly from the Friant-Kern Canal to the Treatment Facility. After pipeline completion, the Enterprise Canal will become a secondary supply source.

2.2.2 Existing Treatment Process

The Northeast WTF utilizes a modified conventional treatment plant process to treat its Enterprise Canal source water. The treatment process includes coagulation, flocculation, high-rate ballasted sedimentation, intermediate ozonation, and granular activated carbon (GAC) filtration, followed by a small finished water reservoir. Chlorine is added as a secondary disinfectant. The plant began treatment and production in the summer of 2004 and has a current capacity of 30 mgd. Expansion was planned in 15 mgd increments to a total capacity of 60 mgd. The current plan is to expand the plant in the next phase directly to 60 mgd (average annual production) and 70 mgd total capacity, and switch the primary source of water supply from the Enterprise Canal to the Friant-Kern Canal.

2.2.3 Anticipated Friant-Kern Canal Water Quality

There is limited water quality data available on the Friant-Kern Canal that is applicable to the NE WTF. In general, it is anticipated that the water quality will be improved from the current Enterprise Canal source water. This section of the TM reviews the limited water quality data available for the Friant-Kern Canal supply to determine appropriate treatment processes for expansion and construction of the City's WTF's treating this new source water in the future.

Water quality data has been collected regularly at several points along the various canals in the Fresno area. Two of these points are of interest to the Northeast WTF. The first sampling point, labeled as either Sample Point 0, or Sample Point 6, is located at the discharge of the dam, where the canal begins. An additional sample point, known as Sample Point 1, Sample Point 5, or Sample Point 7, is located one mile downstream of the dam. Both of these locations are worth evaluating for potential source water quality information.

Table 3 lists the regularly sampled water quality parameters at both sample locations. The data have been analyzed to determine minimum, maximum, average, and total number of samples analyzed during the sample period. Most samples were taken during 1997 and 1998.

For many of the parameters evaluated, there are not enough data points to determine seasonal characteristics. However turbidity at both sample locations remained consistently between 0 and 4 NTU, except for the late winter and early spring of 1998, where turbidities peaked at 10 NTU. Even during this peak turbidity event, the water quality is considered very high and treatable through the proposed treatment processes.

Table 3 Friant-Kern Canal Source Water Quality Data for Northeast WTF (February 1997 - November 1998)
Metropolitan Water Resources Management Plan Update
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Water Quality Parameter	Units	MCL	Sample Points 0,6 (at Dam Discharge)				Sample Points 1,5,7 (1-Mile Downstream of Dam Discharge)			
			No. of Samples	Min	Max	Average	No. of Samples	Min	Max	Average
Aluminum	ug/L	1,000a	8	0.08	300	83.85	1	0.09	0.09	0.09
Apparent Color (Unfiltered)	Units	15.00a	53	0	105	19.66	13	0	106	22.46
Arsenic	ug/L	10.00	2	2.8	4.0	3.4	0	-	-	-
Bicarbonate	mg/L	N/A	30	6	48	15.42	5	4	16	8.4
Calcium	mg/L	N/A	9	1.8	5.7	3.37	3	2	4.2	2.93
Chloride	mg/L	600	8	1	4	1.75	5	1	3	1.8
Copper	mg/L	1.30b,c	1	10	10	10	0	-	-	-
Iron	mg/L	0.3a	4	0.07	0.15	.11	1	0.14	0.14	0.14
Lead	ug/L	15b	2	7.2	23	15	1	6	6	6
Magnesium	mg/L	N/A	15	0.3	1.1	0.57	7	0.4	0.73	0.56
Nickel	ug/l	0.1	2	0.01	16	8	0	-	-	-
Nitrate	mg/L	45	1	2	2	2	1	3	3	3
Odor	TON	3.0a	28	1	4	1.46	9	1	3	1.56
pH	Units	N/A	42	5.14	7.61	6.61	8	5.67	8.59	6.85
Potassium	mg/L	N/A	3	1.4	1.6	1.53	3	1	1.1	1
Selenium	ug/L	50	1	3	3	3	0	-	-	-

Table 3 Friant-Kern Canal Source Water Quality Data for Northeast WTF (February 1997 - November 1998)
Metropolitan Water Resources Management Plan Update
City of Fresno

			Sample Points 0,6 (at Dam Discharge)				Sample Points 1,5,7 (1-Mile Downstream of Dam Discharge)			
Water Quality Parameter	**Units**	**MCL**	**No. of Samples**	**Min**	**Max**	**Average**	**No. of Samples**	**Min**	**Max**	**Average**
Sodium	mg/L	N/A	11	1	20	4.19	4	1	3.6	2.14
Temperature	deg C	N/A	33	10	28.7	16.8	4	14.7	26.3	21.83
Specific Conductance	umhos	2,200	44	19	110	41.11	8	20.6	48.8	27.9
Sulfate	mg/L	600	3	3	4	3.67	0	-	-	-
Total Alkalinity	mg/L as $CaCO_3$	N/A	27	4	48	14.77	7	6	20	12.84
Total Dissolved Solids	mg/L	1,500	40	8	62	20.6	10	9	36	20.1
Total Organic Carbon	mg/L	N/A	20	0.3	3.8	1.89	2	1.4	2	1.7
Total Hardness	mg/L as $CaCO_3$	N/A	14	6	14	8.86	2	8	16	12
Turbidity	NTU	5	40	0.65	2.6	2	8	0.52	10.2	3.96
Zinc	mg/L	5.0	0	-	-	-	1	0.01	0.01	0.01

Note:
1. a-0.2 Secondary MCL b- Regulatory Action Level c- 1 mg/L Secondary MCL.

TOC is another measure of overall raw water quality. TOC displayed similar characteristics to turbidity, maintaining concentrations between 0.25 and 2 mg/L throughout most of the sample period, except for the late winter and early spring of 1998, where it spiked to almost 4 mg/L. The increased TOC concentration during this time period would require additional coagulant to reduce the TOC and turbidity to acceptable levels through the treatment plant, which can be achieved with the proposed treatment process.

Both the turbidity and TOC increase during this time of year is typical of many water supplies when flows begin to rise and scouring of the rivers and canals draws more debris and silt into the water.

The raw water quality results in the table indicate that in general, the source water appears to be of a high quality. Additional analysis is provided below.

2.2.3.1 Turbidity

Turbidities at both sample locations averaged 2 and 4 NTUs, with a maximum of 10.2 at the downstream sampling point. While only 48 samples were taken, this would appear to indicate that in general the canal water contains very low turbidity water. It would be advisable to continue analyzing the canal for turbidity, especially during storm events, to determine how turbidity changes with local weather events and canal flow changes. Some source waters can experience flashes of high turbidity during these times that can be more challenging for the plant to treat.

2.2.3.2 pH

pH ranged from 5.14 to 8.59 at the two sampling locations. This wide range of source water pH indicates that there is a strong upstream influence on the water’s pH. To effectively treat the water and provide noncorrosive potable water to the distribution system, chemicals must be available to adjust pH as necessary at the head of the plant for coagulation, and again prior to pumping to the distribution system for corrosion control.

2.2.3.3 Total Organic Carbon

TOC is another general indicator of the overall quality of a source water. TOC averaged 1.89 and 1.7 mg/L at the upstream and downstream sampling locations, respectively, with maximums of 3.8 and 2 mg/L. This indicates a low organic water on average. However there were periods with increased organic loadings that will require the treatment process to be modified, especially the coagulant dose, to effectively treat the higher coagulant demand that the water will contain under these conditions.

Enhanced coagulation is required for many plants to provide the necessary removal of organic disinfection by-product precursors. Plants can be exempt from these requirements if they meet any one of several criteria established by California’s Title 22 Drinking Water Regulations. Article 5, Section 64536 states that if the quarterly average raw water TOC is below 2.0 mg/L, then enhanced coagulation is not required. From the limited sampling, it would appear that this source water could meet that requirement and be exempt from the enhanced coagulation requirement. If enhanced coagulation is required, because of the low alkalinity of the water, most likely a pH adjustment chemical such as lime, caustic soda, or soda ash would be required to prevent the pH from depressing beyond the optimum pH range for coagulation.

2.2.3.4 Organics

Treated water must meet all applicable MCLs for organics established by US EPA and CDPH. Organics are typically segregated into two categories, volatile organic chemicals (VOCs) and non-volatile synthetic organic chemicals (SOCs). Many of these products have been used historically for industrial or agricultural applications and can end up in source waters through runoff or groundwater contamination. No data were available regarding these chemicals for the Friant-Kern Canal. However, because of the large agricultural land uses along the waterway, methods to treat for the more common agricultural chemicals should be considered for the expanded treatment plant, similar to processes at the existing plant.

2.2.3.5 Inorganics

Treated water must also meet all applicable MCLs for inorganics established by US EPA and CDPH. With good quality source waters many of these constituents are not of concern and do not require specific treatment processes. However, in the source water sampling results both lead and copper results were above their respective Regulatory Action Levels. It is not known whether there was an error in sampling, analysis, or data entry, however these values are atypical for most surface water supplies. Additional sampling is suggested to determine if a larger data set would yield different results. In many irrigation type canals copper based algaecides are used to control algae growth along the canals. It is not known whether this is practiced on the Friant-Kern Canal at this time, but it is suggested that additional investigations be performed if future copper analyses are consistent with the data collected to-date. Additionally, because of the existing ozone treatment at the plant, bromide concentration should be investigated to verify that bromate in the finished water can be kept below 10 ug/L.

2.2.3.6 Taste and Odor

No analysis data was available on the most common taste and odor (T&O) causing compounds, methylisoborneol (MIB) and geosmin. However, Threshold Odor Number (TON) analysis was performed at both sampling locations. Although many utilities have found TON to be less reliable than directly measuring problematic T&O compounds directly, it still can be useful in providing treatment methods to reduce customer complaints regarding taste and odor.

CDPH has established a secondary MCL for TON of 3.0. While samples at both locations averaged around 1.5, the upstream sampling location did experience TONs above three, up to four. It is also interesting to note that the two highest odor readings were in January and May. Based on these readings, it is recommended that a treatment process be selected to treat for T&O episodes.

2.2.3.7 Microbial Control

While no data are available on the existence of microbial pathogens in the source water, the regulations require that specific removal goals be achieved. Both *Giardia* and virus removal/disinfection requirements are fixed at 3 and 4-log removal. *Cryptosporidium* removal/inactivation requirements are based on the 2-year source water assessment results. Higher concentrations of *Cryptosporidium* in the source water trigger higher removal/inactivation requirements at the treatment facility based on categorization of the results into 1 of four bins. Most utilities are expected to fall into Bin 1, requiring only conventional treatment. However, if the source water falls into Bins 2-4, additional 1 to 2.5-log of treatment is required.

2.2.3.8 Process Selection for Facility Expansion

Process selection is based on the raw water quality and finished water quality goals established above. The existing Northeast WTF consists of a modified conventional treatment process with intermediate ozonation and GAC media for filtration and adsorption. Based on the raw water quality, this process can be successfully applied to the new supply and meet all of the identified finished water quality goals. One unknown is the required level of Cryptosporidium removal/inactivation that will be required based on the LT2 ESWTR source water sampling. For this reason, the ozonation system should be designed at the conceptual level to achieve Cryptosporidium disinfection as well as address other goals such as T&O reduction and organics reduction.

For solids handling, the plant is currently installing a Deskins "Quick Dry" Filtration Process™ system to replace the original unlined lagoons. If this system proves acceptable with the current operation, it could be expanded to handle the increased solids production of the 60 mgd plant.

2.2.3.9 Clearwell Sizing

Currently the plant has a 1.5 million gallon (MG) clearwell. For a 30-mgd treatment plant this is undersized and does not allow enough buffer between treatment plant operation and distribution system demands. Because the plant achieves all of the required disinfection with the intermediate ozonation system, a separate chlorine contact basin to achieve contact time is not required, nor should it be with the expanded plant. Therefore, the clearwell can be used solely for storage. It is recommended to have approximately two to four hours of storage at plant design capacity for operational flexibility. Storage should be increased based on other factors such as system storage requirements, system peaking characteristics, and fire flow requirements. For a 70 mgd plant, at least a 5 MG new clearwell is recommended, for a total storage capacity of 6.5 MG. To gain an additional 5 MG of storage on the existing site, it will be most practical and cost effective to construct two 2.5 MG reservoirs, locating them adjacent to the existing reservoir, at the front of the property. This allows more flexibility for operation and maintenance than a single reservoir, and fits within the available plant site space.

2.2.3.10 Expansion Footprint

The existing plant was master planned for future expansion to 60 mgd with similar treatment processes. Expansion of the Actiflo® system and intermediate ozonation basins can occur to the east of the existing basins. Additional GAC filters can be added to the south of the existing filters. Additional Deskins sludge drying beds can be added at the east side of the property. If the Deskins system is not feasible for expansion, additional space will be required for future solids drying beds. While solids drying calculations have not been performed as part of this evaluation, if the bed area was doubled, it would require approximately an additional five to seven acres. Additional clearwell storage can be added along Chestnut Avenue. In general, it would appear that the plant could be expanded within the existing fence line.

2.3 Southeast WTF Source Water Supply and Treatment Processes

Construction is planned for the new Southeast WTF in an area southeast of the airport to support growth in that area of the City's service area. The anticipated water supply source will be the Mill Ditch. Historical water quality were not available, so a single sampling set was performed to generate an initial water quality data on the source of supply. The purpose of this section is to determine the source water quality of the new supply and determine whether the treatment system currently utilized for the Northeast WTF is applicable for the new facility. The plant will be sized for production of 70 mgd at initial construction.

2.3.1 Anticipated Mill Ditch Water Quality

There is only a single set of water quality data available for the Mill Ditch supply. Sampling was performed in May 2008 for many water quality parameters of interest. Results are shown in the table below.

Table 4	Mill Ditch Source Water Quality Data for Southeast WTF - May 2008 Metropolitan Water Resources Management Plan Update City of Fresno		
Water Quality Parameter	**Units**	**MCL**	**Result**
Apparent Color (Unfiltered)	Units	15.00[a]	15
Bromide	ug/L	N/A	ND
Bicarbonate	mg/L	N/A	15
Calcium	mg/L	N/A	4.2
Iron	mg/L	0.3a	0.32
Manganese	mg/L	0.05	0.015
Magnesium	mg/L	N/A	0.9
PH	Units	N/A	7.6
Total Alkalinity	mg/L as $CaCO_3$	N/A	15
Total Dissolved Solids	mg/L	1,500	29
Total Organic Carbon	mg/L	N/A	1.7
Specific UV Absorbance	L/mg M	-	3.3
UV Absorbance @ 254 nm	1/cm	-	0.053
Total Hardness	mg/L as $CaCO_3$	N/A	14
Turbidity	NTU	5	1.8
Dissolved Organic Carbon	mg/L	N/A	1.6
Algae Enumeration	#/ml	-	258
Geosmin	ng/L	-	ND
Methylisoborneol (MIB)	ng/L	-	ND
Cryptosporidium	oocysts/L	-	0
Giardia	cysts/L	-	0

Notes:
1. ND = Non Detect N/A = not available
2. a = Based on single sample May 2008.

It is not advisable to select treatment processes based on analysis of a single raw water sample. As can be seen by the available data on the Friant-Kern Canal, seasonal variations in water quality must be understood to ensure that the treatment plant can be designed to treat all potential water quality scenarios that it may experience throughout the year. Development and implementation of a rigorous sampling program over the course of a year is advised before continuing the facility planning process. The following evaluation comments are made with that understanding. Similar to the Friant-Kern Canal source water, the Mill Ditch water appears to be of similar good to high quality.

2.3.1.1 Turbidity

Turbidity of 1.8 indicates a low turbidity source water. As with the Friant-Kern water, it would be advisable to continue analyzing the canal for turbidity, especially during storm events, to determine how turbidity changes with local weather events and canal flow changes. Some source waters can experience flashes of high turbidity during these times that can be more challenging for the plant to treat.

2.3.1.2 pH

The water exhibited a slightly higher than neutral pH of 7.6, typical for many surface waters. Diurnal variability as well as seasonal variability are unknown.

2.3.1.3 Total and Dissolved Organic Carbon

Total organic carbon (TOC) and dissolved organic carbon (DOC) are other general indicators of the overall quality of source water. TOC and DOC were 1.7 and 1.6 mg/L, respectively, indicating a low organic component in the water. Most of the organics are dissolved, which is also very typical. The Specific UV Absorbance (SUVA) result of 3.3 L/mg-M indicates that a significant fraction of the dissolved organic carbon is aromatic in nature (double bonded). With free electrons, these aromatic carbon compounds, such as humic acids, combine readily with chlorine, forming disinfection by-products (DBPs). Additionally, these compounds also are amenable to reacting with coagulants, allowing for partial removal upstream of chlorine addition.

Enhanced coagulation is required for many plants to provide the necessary removal of organic disinfection by-product precursors. Plants can be exempt from these requirements if they meet any one of several criteria established by California's Title 22 Drinking Water Regulations. Article 5, Section 64536 states that if the quarterly average raw water TOC is below 2.0 mg/L, then enhanced coagulation is not required. Because of the relative proximity to the 2.0 mg/L limit for exemption from enhanced coagulation, it is recommended that the ability to enhance coagulate be included for the treatment process and solids handling systems.

2.3.1.4 Organics

Treated water must meet all applicable MCLs for organics established by US EPA and CDPH. Organics are typically segregated into two categories, VOCs and non-volatile SOCs. Many of these products have been used historically for industrial or agricultural applications and can end up in source waters through runoff or groundwater contamination. No data were available regarding these chemicals for the Mill Ditch. However, because of the large agricultural land uses along the waterway, methods to treat for the more common agricultural chemicals should be considered for the expanded treatment plant, similar to processes at the existing plant.

2.3.1.5 Inorganics

Treated water must also meet all applicable MCLs) for inorganics established by US EPA and CDPH. With good quality source waters many of these constituents are not of concern and do not require specific treatment processes. In general, the Mill Ditch water is low in minerals, with a hardness of 14 mg/L and a total dissolved solids (TDS) of 29 mg/L. A low concentration of manganese was detected (0.015 mg/L) and an iron concentration (0.32 mg/L) slightly over the secondary MCL (0.3 mg/L). If an oxidation process such as ozone is used, it should oxidize the iron and allow it to be removed through the filtration process.

2.3.1.6 Taste and Odor

Analyses for MIB and geosmin were performed and both samples returned a nondetect. Because of the seasonal nature of taste and odor causing compounds, and the vast array of potential compounds, it is recommended that treatment for T&O still be considered for the Southeast WTF, especially because of the T&O issues in other canal water, such as the Enterprise and Friant-Kern.

2.3.1.7 Microbial Control

The sample was analyzed for *Cryptosporidium* oocycsts and *Giardia* cysts, with both resulting in nondetects. While treatment requirements for *Giardia* are independent of source water concentrations, higher concentrations of *Cryptosporidium* in the source water trigger higher removal/inactivation requirements at the treatment facility based on categorization of the results into one of four bins. Most utilities are expected to fall into Bin 1, requiring only conventional treatment. However, if the source water falls into Bins 2-4, additional 1 to 2.5-log of treatment is required. Additional source water sampling, following protocols outlined in the LT2 ESWTR Guidance Manual is recommended as soon as possible to establish a history of results on which to base the treatment facility design.

2.3.1.8 Process Selection for Facility Expansion

Process selection is based on the raw water quality and finished water quality goals established above. Based on the raw water data and finished water goals, a conventional treatment facility consisting of coagulation, flocculation, sedimentation, and filtration using GAC media is an appropriate design basis. The addition of a treatment process to provide control of taste and odor causing compounds and provide potential additional disinfection of *Cryptosporidium* should also be considered.

The existing Northeast WTF consists of a modified conventional treatment process with intermediate ozonation and GAC media for filtration and adsorption. To reduce plant footprint, instead of traditional sedimentation basins, the Actiflo® process was provided. This process can be successfully applied to the new Southeast WTF and meet all of the identified finished water quality goals. One unknown is the required level of *Cryptosporidium* removal/inactivation that will be required based on the LT2 ESWTR source water sampling. For this reason, the ozonation system should be designed at the conceptual level to achieve Cryptosporidium disinfection as well as address other goals such as T&O reduction and organics reduction.

For solids handling, the Northeast WTF is currently installing a Deskins “Quick Dry” Filtration Process™ system to replace the original unlined lagoons. If this system proves acceptable at that facility, it should be considered for the Southeast WTF also. Alternately, if available land is an issue, a mechanical solids handling system could be installed with a higher cost, but significantly less footprint required.

2.3.1.9 Clearwell Sizing

It is recommended to have approximately 2-4 hours of storage at plant design capacity for operational flexibility. Storage should be increased based on other factors such as system storage requirements, system peaking characteristics, and fire flow requirements. For a 70 mgd plant, a 6 MG clearwell is recommended for operational storage. Because of the size, and to allow flexibility in operation, two 3 MG clearwells could also be considered. Other storage needs for the distribution system should be in addition to the 6 MG. This will allow operators to minimize plant flow changes, which have the potential to cause plant upsets, especially through the filtration process.

2.3.1.10 Treatment Facility Footprint

If the SE WTF is configured similar to the NE WTF, it is estimated that the land required for the new 60 mgd facility will be approximately 30 acres. The NE facility is currently situated on approximately 22 acres. To double the capacity, the site would need to be expanded to handle the increased solids handling system. The solids handling system will have a significant impact on required land.

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METROPOLITAN WATER RESOURCES MANAGEMENT PLAN UPDATE

FUTURE-WITH-PROJECT ALTERNATIVE REFINEMENT

TECHNICAL MEMORANDUM No. 2.6

FINAL
January 2009

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CITY OF FRESNO

METROPOLITAN WATER RESOURCES MANAGEMENT PLAN UPDATE

TECHNICAL MEMORANDUM NO. 2.6

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FUTURE-WITH-PROJECT ALTERNATIVE REFINEMENT: FACILITIES

1.0 INTRODUCTION

The purpose of this Technical Memorandum (TM) is to provide planning level estimates for capital and operations and maintenance (O&M) costs for groundwater, surface water, and recycled water treatment facilities. This TM builds on information provided in the previous TMs:

- TM 1.4 identified current and emerging groundwater contaminants in the City of Fresno's (City) drinking water wells, evaluated treatment alternatives for the major contaminants of concern, and provided general cost curves for capital and O&M costs for the various treatment technologies.
- TM 1.8 presented cost estimates for doubling the treatment capacity of the City's surface water treatment plant (SWTP) to 60 million gallons per day (mgd), and for building a new 60 mgd SWTP in the southeast area of the city.
- TM 2.4 evaluated the water quality of the two water supplies for the northeast SWTP and future southeast SWTP. The TM also summarized the treatment requirements for recycled water for the purposes of unrestricted irrigation or groundwater recharge.

Capital costs provided in this TM are based on the twenty-cities Engineering News Record (ENR) Construction Cost Index value of 8551 for December 2008. O&M Costs reflect 2008 dollars. These budgetary cost estimates are considered within an accuracy range of +30 percent to -15 percent and are intended for planning level uses only.

2.0 GROUNDWATER TREATMENT

TM 1.4 identified the main groundwater contaminants found in the City's water production wells and potential treatment options (Table 1). The TM, which was prepared in 2006, provided a snapshot of the water quality issues in the current production wells at the time. With over 250 water production wells in the City's inventory, it is expected that the well inventory will vary over time - new wells will be added while some will be taken out of service. The water quality will vary to some extent overall and within some wells. This TM does not attempt to revisit the inventory of wells or the water quality issues identified previously, but rather to provide a budgetary-level estimate of capital and O&M costs that can be used for future planning purposes, given the list of water quality contaminants identified in TM 1.4.

Capital and O&M costs assume two well capacities: 800 gallons per minute (gpm) and 2000 gpm. Five treatment technologies are considered. The contaminants and treatment technologies are listed in Table 1. Details of each technology are provided in TM 1.4.

2.1 Treatment Cost Estimates

2.1.1 Data Assumptions

In order to develop a planning level estimate, additional data such as water quality specific to each well, site information, preferred treatment alternative, operational limitations, etc., would be needed. Because specific planning information and/or decisions will be addressed at later dates, the cost information provided in this TM was generated from previous case studies (both at design levels and at planning levels) that address water quality concerns similar to the City.

There are a number of uncertainties and assumptions that will influence the actual cost of a treatment system installed. These may include factors such as, interfering compounds, cost of labor, materials, equipment, services provided by others, contractor's methods of determining prices, competitive bidding or market conditions, practices or bidding strategies. As such, the cost information provided herein does not warrant or guarantee that proposals, bids or actual construction costs will not vary from the costs information presented herein. In order to compare options for the planning purpose, a more accurate site specific cost estimate must be developed.

Granular Activated Carbon (GAC) Treatment Costs

The GAC treatment costs presented in Table 2 are based on estimated costs for the removal of trace organic contaminants; however, GAC could also be used for the removal of hydrogen sulfide and radon. The reference costs are from a paper study by Carollo Engineers, P.C. (Carollo) for the removal of TCE, PCE and 1,2,3-TCP. Influent 1,2,3-TCP concentrations ranged from 0.5 to 3.2 ppb and the target treatment goal was set at 0.005 ppb.

Ion Exchange (IX) Treatment Costs

The IX treatment costs presented in Table 3 are based on estimated costs for removal of nitrates. The costs were extrapolated from two design projects where the influent nitrate concentration ranged from 45 to 55 milligrams per liter (mg/L). The target finished water quality for both plants was less than 35 mg/L nitrate.

Reverse Osmosis (RO) Treatment Costs

The RO treatment costs presented in Table 4 are based on estimated costs for the removal of salinity and other inorganic constituents such as nitrates from 30 mg/L as N to less than 10 mg/L as N in the finished water. The reference costs originated from a USBR report prepared by Carollo in examining treatment technologies for zero liquid discharge. Costs include a brine concentrator and disposal of residuals in a landfill.

Coagulation/Filtration (CF) Treatment Costs

The C/F treatment costs presented in Table 5 are based on estimated costs for the removal of iron and manganese. The costs were developed from in-house cost templates used for planning purposes for ferric chloride coagulation and downstream filtration.

Oxidation/Filtration (OF) Treatment Costs

The O/F treatment costs presented in Table 6 are based on estimated costs for the removal of arsenic and chromium. The costs were extrapolated from two recent design projects at the South Tahoe Public Utility District arsenic treatment facility for the Arrowhead Well and also the Elsinore Valley Municipal Water District's Back Basin Groundwater Treatment Plant.

Summary and Recommendations

Capital and O&M costs were developed for the following treatment technologies: GAC, IX, RO, C/F and O/F. Costs were based on two capacities - 800 gpm and 2000 gpm. The cost estimates are suitable for initial planning-level efforts only. The costs will need to be refined for future planning and alternative selection purpose.

In order to use the groundwater treatment cost information to compare with other project alternatives, the following recommendations are made.

- Develop well-specific treatment evaluation based on well capacity, water quality, site constraints, truck access, piping requirements, etc., to determine most preferred treatment alternative
- Develop a site-specific cost estimate for each contaminated well based on the preferred treatment alternative.
- Consider centralized treatment if the well locations are conducive to centralized treatment and the pipeline infrastructure exists
- Evaluate discharge impacts and cost of residual handling (e.g., off-site disposal) for ion exchange, reverse osmosis, and coagulation / oxidation filtration technologies. Residuals include filter backwash waste residuals or brine from IX and RO.

3.0 SURFACE WATER

The purpose of this section is to present cost estimates for two proposed projects to add surface water treatment capacity to the City's system. These two alternatives are as follows:

- Project 1: expansion of the existing Northeast Surface Water Treatment Plant (SWTP) by 40 mgd for a total capacity of 70 mgd
- Project 2: construction of a new Southeast 70 mgd surface water treatment plant

Cost estimates include both construction and O&M costs, for the treatment processes of both projects. Cost estimates are based on construction costs initially derived in TM 1.8 and supply water quality analysis provided in TM 2.4. Costs are updated here based on the City's decisions on proposed plant capacities and the water quality evaluation in TM 2.4.

3.1 Treatment Processes

Based on the findings in TM 2.4, it is assumed that the treatment processes in the existing SWTP, that include carbon dioxide addition, ballasted flocculation, intermediate ozonation, and GAC/sand biologically active filtration, will be retained for the plant expansion alternative. The treatment processes are appropriate to treat the future source water supply from the Friant-Kern Canal, and there is no reason to consider different processes, at this time.

With respect to a new Southeast plant, it is anticipated to be located southeast of the airport. The water supply source will be Mill Ditch. Based on limited water quality data for the Mill Ditch water supply (described in TM 2.4), it is assumed the same treatment train would be appropriate for the new treatment plant. Therefore, the treatment processes in the existing SWTP have been assumed to be included for both Northeast and Southeast plant projects for this cost comparison.

In addition to existing processes, and as a place holder for potentially more stringent disinfection requirements, costs for new ultraviolet (UV) light disinfection facilities have also been included in the construction cost estimates for both projects. UV costs are added as a contingency for dealing with potential unknowns in water quality with respect to Cryptosporidium. Higher concentrations of this microbe in the raw water could trigger higher removal/inactivation requirements by the CDPH. Removal/inactivation requirements are based on a 2-year required source water sampling period in accordance with the USEPA Long Term 2 Enhanced Surface Water Treatment Rule. Until this source water sampling is complete, and the average Cryptosporidium concentration is known for this water supply. For this reason, it is prudent to budget for possible future UV treatment if higher levels of disinfection (beyond what can be achieved by the current ozone process) are required.

3.2 Land Requirements

It is estimated that 17 acres will be needed to expand the Northeast Plant, and the City owns sufficient land adjacent to the existing SWTP for the planned expansion. For the Southeast Plant, it is estimated that 30 acres are needed for the facilities. The City is looking to acquire a 54 acre parcel for the Southeast Plant.

3.3 Capital Cost Estimates

Capital cost estimates for both alternatives are based upon the cost to construct the existing SWTP, because construction was recently completed for that facility (i.e. commissioning in summer 2004) and the treatment processes are expected to be the same. That construction cost was modified appropriately, as described below for each alternative. In addition costs were then escalated from the mid-point of construction (April 2003, ENR = 6635) to December 2008 (ENR = 8551).

3.3.1 <u>Capital Cost Estimate - Northeast Plant Expansion</u>

Design criteria developed as part of the design of the existing SWTP formed the basis for the cost estimates were previously provided in TM 1.8. The plant design also included design criteria for expansion of the design capacity to 60 mgd and the hydraulic capacity to 100 mgd. The plant expansion alternative considered herein increases the hydraulic capacity of the plant from 30 to 70 mgd, and not to 100 mgd. Therefore, the criteria used for estimating the cost of this expansion differ, in some cases, from those presented in the original plant design. The specific criteria and assumptions used to develop the costs are presented in the following paragraph.

Estimated costs for the plant expansion include the cost of the addition of two larger raw water pumps, for a total of six. The existing ozone generator was designed with excess capacity and therefore no new ozone generators have been included in the cost of the plant expansion. Four new clarification basins are included to provide a total of six basins. The existing backwash pump capacity is sufficient for the expansion, and therefore no new backwash pumps have been included. One additional treated water pump has been included (for a total of five). Four additional ozone contact basins (eight-stage counter/co-current) are also included. Costs for UV disinfection have been included. The cost of the installation of eight new GAC/sand filters and a new filter building has also been included. The cost of a 5.0 million gallon (MG) treated water reservoir has been included, to provide a total treated water storage capacity of 6.5 MG on site. TM 2.4 stated that it may be more feasible to build two 2.5 MG reservoirs. The cost estimate is adequate for either one 5.0 MG reservoir or two 2.5 MG reservoirs. Costs for solids handling facilities include equalization, clarification, return pumping, and two solids drying beds, for a total of six. The costs are adequate to cover costs for an optional Deskins drying system to replace the unlined drying beds.

The expansion does not include any significant changes to the plaza area or operations building. The capital cost and project cost estimates are presented in Table 7.

3.3.2 <u>Capital Cost Estimate - Southeast Plant</u>

For construction of a new plant in the Southeast area of Fresno, construction costs have been based upon the design criteria for the existing SWTP, adjusted for a design capacity of 70 mgd including the cost of a 6 MG treated water reservoir. The capital cost and project estimates are presented in Table 8.

3.4 Operations & Maintenance Cost Estimates

O&M costs for both alternatives are based upon the cost to operate and maintain the existing SWTP, because the treatment processes, chemical usage, and power requirements are expected to be similar. The cost elements included in the O&M costs are chemicals, power, labor, and maintenance. O&M costs are based upon the average annual production (60 mgd) for both the Northeast and Southeast plants, rather than their design capacities of 70 mgd.

Chemical usage for both alternatives is expected to be essentially the same because both options include the same treatment processes and would be treating similar source waters. A single estimate of chemical costs has been developed, based upon chemical usage at the existing SWTP (Table 9), because no significant difference between the alternatives is anticipated.

Operations and maintenance costs were developed for the new 70 mgd plants and include cost components for chemicals (including LOX for ozone generation), electrical power, labor and routine equipment maintenance and service. Chemical and electric power consumption was calculated based upon treating an average annual flow of 60 mgd (21,900 MG). Electricity costs include assumptions for raw and finished water pumping, ozone generation and UV disinfection. Labor estimates were developed assuming two operators, two maintenance, and one instrumentation technician on duty for an 8-hour shift each day; followed by one plant operator to cover two, eight-hour shifts each for a total of 56 personnel hours per 24-hour day.

A summary of the O&M costs for 60 mgd average annual production is presented in Table 10. Given the same assumptions, the expanded SWTP would have similar annual operations and maintenance costs as the new Southeast Plant.

4.0 RECYCLED WATER TREATMENT

This section summarizes capital and O&M costs for new satellite plants and/or a tertiary plant at the Regional Wastewater Reclamation Facilities (RWRF). Potential uses of the recycled water are unrestricted irrigation, groundwater recharge, and other nonpotable uses.

The City’s goal is to implement 25,000 acre-feet/year (af/y) (22 mgd) of recycled water use by the year 2025 to offset potable water use. It is not known at this time where the recycled water treatment facilities will be located, the number of facilities that will be built, or their capacities. The City will evaluate these options in a separate Recycled Water Master Plan.

For the purpose of developing long term planning costs for this TM it is assumed the 22 mgd production will be split between the RWRF (50 percent of total capacity, or 11 mgd) and two satellite locations (two at 5.5 mgd each). The City previously studied the feasibility of a satellite plant in the southeast area of the City. Previous studies have also looked at siting two satellite plants, one in the southeast area and a second in the northwest area of the City, to optimize recycling opportunities. For this reason, two 5.5 mgd satellite plant locations are assumed for cost estimating purposes. This approach provides more conservative costs than planning for one 11 mgd satellite plant. One 11 mgd satellite plant (e.g., in the southeast area), would be expected to cost less than two 5.5 mgd plants due to economies of scale and the need to purchase land at only one site.

This TM also assumes 100 percent of the water produced at the facilities will be recycled - either through irrigation or groundwater recharge. This total recycle volume does not include the volume that will be generated at the City's North Fresno Satellite Plant on Copper River Avenue.

Tertiary/UV disinfected recycled water produced at the plants will meet the Title 22 requirements suitable for irrigation or recharge. This treatment technology is adequate for recharging an aquifer by surface spreading, provided the recycled water is discharged to spreading basins and diluted (1 part recycled water to 4 parts dilution water). For less dilution during surface spreading or for subsurface injection, the recycled water would require more costly treatment by reverse osmosis and advanced oxidation (RO/AO). However, the costs provided herein do not include RO/AO. It is assumed recharge projects in Fresno can be successfully implemented using spreading basins based on the 1:4 dilution.

Recharge also requires the blended recycled water/diluent total nitrogen concentration be less than 5 mg/L, or less than 10 mg/L if nitrification/denitrification can be achieved in the vadose zone beneath the spreading basin, and before reaching the potable water aquifer (see TM 2.4). Recycled water from either the satellite plants or the RWRF tertiary facility is expected to have total nitrogen concentrations less than 10 mg/L. Estimated costs for the satellite plants and the RWRF tertiary plant are based on the premise that the secondary processes at these plants will produce a denitrified effluent of less than 10 mg/L total nitrogen and be capable of meeting regulatory requirements for groundwater recharge.

4.1 Capital Costs -Tertiary Treatment at RWRF

The RWRF tertiary plant would treat 11 mgd of denitrified secondary effluent from the RWRF. At the present time, the RWRF is being upgraded to increase the plant's organic treatment capacity. Once the project is completed in 2009, operation of the RWRF will be optimized to provide nitrification/denitrification. It is expected that the RWRF will produce effluent at or below 10 mg/L total nitrogen. The tertiary plant would be located within the RWRF, at a location that is convenient to receive secondary effluent flows, then following disinfection, convey them to a distribution system along Jensen Avenue.

The estimated capital costs for the tertiary plant are provided in Table 11. The tertiary plant would be sized to treat a constant flow delivered to the structure via a new pump station. The coagulation/filtration facilities would include: rapid mix, coagulant/polymer feed, filter media and equipment. Costs are based on cloth media filters. The UV disinfection equipment is based on a low pressure high intensity (LPHI) system contained in two channels. Costs also include a finished water 11 mgd pump station and a 0.5 mile force main (diameter = 24 inches) to connect to the main transmission line, that would extend from the RWRF along Jensen Avenue to the distribution points. Estimates for transmission mains are provided elsewhere in the Metro Plan Update.

Since the tertiary plant will treat a constant daily flow from the RWRF, it is assumed that flows would be distributed to recharge basins during times when there is lower irrigation demand. This approach avoids the need for system storage.

4.2 Capital Costs - Satellite Plants

TM 2.4 summarized various treatment options available for producing tertiary disinfected water for unrestricted reuse or recharge at satellite plants. For this TM, the treatment processes are based on recommendations from the 2006 Satellite Plant Study Update, prepared by Carollo Engineers. The treatment process is high rate activated sludge with nitrification/denitrification, coagulation/filtration, and ultraviolet (UV) disinfection.

The satellite plants would function as “scalping plants,” which treat only average flows while allowing peak flows to pass untreated to the RWRF via the City’s collection system. Sludge resulting from the treatment process would also be discharged to the collection system for treatment at the RWRF. A scalping plant saves considerable costs by avoiding the extra facilities needed to treat peak flows or solids. Additionally, solids handling onsite brings with it odor issues that are avoided at scalping plants. Primary settling would not be included, due to high O&M costs and odor issues. The aeration basins would be sized to handle the loadings that would ordinarily be removed by primary treatment.

It is assumed the recycled water would be discharged directly to irrigation users via a distribution system, an irrigation canal, and recharge basins. For this cost estimate, it is assumed the canal is one-half mile from the satellite plant. Costs are also provided for an influent force main, assumed to be one-half mile upstream of the plant, to deliver influent flows from an offsite lift station. Costs for all other transmission mains and distribution pipelines to deliver the water to recharge basins, or domestic, commercial, and agricultural users are not included here. Those costs are provided elsewhere in the Metro Plan Update.

The estimated capital costs for a 5.5 mgd satellite plant are provided in Table 12. Estimated costs are based on the costs developed in the 2006 Satellite Plant Update and escalated to December 2008, and other recent projects at the design or planning level. Additional contingency is provided in the cost estimate to cover more costly alternatives that were found infeasible in 2006, but could potentially become attractive options in the future (e.g., adding membrane bioreactors [MBRs] instead of tertiary filters).

The treatment processes assumed for the satellite plant are listed below.

- Preliminary Treatment - Screening, grit removal and dewatering, flow metering, and odor control facilities
- Secondary Treatment with Nitrification/Denitrification - Aeration basins, blowers, secondary clarifiers, return activated sludge/waste activated sludge pump station
- Coagulation/Flocculation and cloth media filters - Two channels with 12 filter discs each, and a loading rate of 3 gpm/sf
- UV Disinfection - An open channel system using low pressure high intensity lamps, a UV dose of 100 mJ/cm^2, and 55 percent transmittance

As with the tertiary plant at the RWRF, it is assumed that flows would be distributed to recharge basins during times when there is lower irrigation demand. This approach avoids the need for day tanks.

4.3 O&M Costs - Satellite Plants and Tertiary Plant at the RWRF

Table 13 summarizes the O&M costs for the satellite plants and the RWRF tertiary plant. The annual costs are based on 2008 costs.

For the 11.0 mgd RWRF tertiary plant, labor is based on one employee three hours/day. Power costs are primarily due to the power consumption of the UV system, but also include costs for pumping. Annual costs for materials include annual replacement costs for UV components (lamps, ballasts, sleeves, wipers) and filter media replacement. Filter media are replaced every five years, and this cost has been annualized for this estimate.

For the two 5.5 mgd satellite plants, labor is based on five employees working eight hours shifts, working a total of 40 hours/day for weekdays, and three employees working a total of 24 hours/day for weekend days. Power costs are due primarily to pumping, aeration, and the UV system. Annual material replacement needs cover maintenance work for all preliminary, secondary, and tertiary process equipment.

4.4 Summary of Estimated Total Costs for 22 MGD (25,000 af/y)

Table 14 summarizes the estimated total project costs for constructing two 5.5 mgd satellite plants and the RWRF tertiary plant as well as the annual O&M costs for the three facilities. The total costs are considered adequate for long term planning purposes for producing 25,000 af/y of recycled water, even though the locations, capacities, and number of plants are not known at this time.

Table 1	Summary of Contaminants and Treatment Alternatives Metropolitan Water Resources Management Plan Update City of Fresno				
Contaminants	**GAC**	**IX**	**RO**	**CF**	**OF**
1,1 Dichloroethylene (1,1 DCE)	●				
1,2 Dichloropropene (1,2 DCP)	●				
1,2,3-Trichloropropane (1,2,3-TCP)	●				
Cis 1,2- Dichloroethylene (cis 1,2-DCE)	●				
Dibromochloropropene (DBCP)	●				
Ethylene dibromide (EDB)	●				
Perchloroethylene (PCE)	●				
Trichloroethylene (TCE)	●				
Arsenic		●	●		●
Chromium		●	●		●
Nitrate		●	●		
Hydrogen Sulfide	●				
Iron			●	●	●
Manganese			●	●	●
Radon	●				

GAC: Granular Activated Carbon, IX: Ion Exchange, RO: Reverse Osmosis, CF: Coagulation Filtration, OF: Oxidation Filtration

Table 2	Capital and O&M Costs for Granular Activated Carbon (GAC) Treatment Metropolitan Water Resources Management Plan Update City of Fresno	
Items	**800 GPM**	**2000 GPM**
General Conditions and Requirements (10%)[(1)]	$119,000	$178,000
GAC Equipment and Installation	$765,000	$1,148,000
Pipework (15%)[(2)]	$115,000	$172,000
Sitework (15%)[(2)]	$115,000	$172,000
Electrical and Instrumentation (25%)[(3)]	$191,000	$287,000
Construction Subtotal	**$1,305,000**	**$1,957,000**
Construction Contingency (30%)[(4)]	$392,000	$587,000
Total Construction Cost	**$1,697,000**	**$2,544,000**
Contingencies and Other Project Fees (50%)	$849,000	$1,272,000
Total Project Cost	**$2,546,000**	**$3,816,000**
O&M Costs		
GAC media change-out and disposal cost	$720,000[(5)]	$720,000[(6)]
Power demand (pumping)	$227,000	$340,000
Labor demand[(7)]	$31,000	$31,000
O&M Subtotal	**$978,000**	**$1,091,000**
Contingency (50%)[(4)]	$489,000	$546,000
Annual O&M Cost ($/yr)	**$1,467,000**	**$1,637,000**
Annual O&M Cost ($/MG)	**$3,495**	**$3,630**

Notes:

1. 10% of all construction items (equipment through electrical/instrumentation).
2. 15% of equipment and installation cost.
3. 25% of equipment and installation cost.
4. Contingency to account for unknown variables since the actual wells to be treated are not known at this time.
5. Two GAC systems with two vessels each. Assume vessel change-out is monthly (12 times/yr.).
6. Three GAC systems with two vessels each. Assume vessel change-out occurs every 1-1/2 months (8 times/yr.).
7. Labor demand was assumed at $60/hour and 10 hours/week for one operator. Cost numbers were referenced for a Liquid GAC treatment system where the target treatment is to lower 1,2,3-TCP from 3 ppb to 0.005 ppb.

Table 3 Capital and O&M Costs for ION Exchange (IX) Treatment
Metropolitan Water Resources Management Plan Update
City of Fresno

Items	800 GPM	2000 GPM
General Conditions and Requirements (10%)[(1)]	$286,000	$408,000
IX Equipment and Installation	$1,848,000	$2,634,000
Pipework (15%)[(2)]	$277,000	$395,000
Sitework (15%)[(2)]	$277,000	$395,000
Electrical and Instrumentation (25%)[(3)]	$462,000	$659,000
Construction Subtotal	**$3,150,000**	**$4,491,000**
Construction Contingency (30%)[(4)]	$945,000	$1,347,000
Total Construction Cost	**$4,095,000**	**$5,838,000**
Contingencies and Other Project Fees (50%)	$2,048,000	$2,919,000
Total Project Cost	**$6,143,000**	**$8,757,000**
O&M Costs		
Consumables[(5)]	$84,000	$108,000
Power demand[(6)]	$70,000	$228,000
Annual brine disposal[(7)]	$6,000	$19,000
Labor demand[(8)]	$31,000	$31,000
O&M Subtotal	**$191,000**	**$386,000**
Contingency (50%)[(4)]	$96,000	$193,000
Annual O&M Cost ($/yr)	**$287,000**	**$579,000**
Annual O&M Cost ($/MG)	**$684**	**$551**

Notes:
1. 10% of all construction items (equipment through electrical/instrumentation).
2. 15% of equipment and installation cost.
3. 25% of equipment and installation cost.
4. Contingency to account for unknown variables since the actual wells to be treated are not known at this time.
5. Resin replacement and sodium hypochlorite.
6. For pumping and power for IX system.
7. Spent backwash brine hauled away to be regenerated offsite.
8. Labor demand was assumed at $60/hour and 10 hours/week for one operator.
   Cost numbers were referenced from two IX nitrate treatment plants where the influent nitrate concentration ranges from 45-55 mg/L and target treatment goal is below 35 mg/L.

Table 4	Capital and O&M Costs for Reverse Osmosis (RO) Treatment Metropolitan Water Resources Management Plan Update City of Fresno	
Items	**800 GPM**	**2000 GPM**
General Conditions and Requirements (10%)(1)	$1,927,000	$3,225,000
RO Equipment and Installation	$1,152,000	$2,880,000
Brine Concentrator and Installation	$11,280,000	$17,926,000
Pipework (15%)(2)	$1,865,000	$3,121,000
Sitework (15%)(2)	$1,865,000	$3,121,000
Electrical and Instrumentation (25%)(3)	$3,108,000	$5,202,000
Total Construction Cost ($)	**$21,197,000**	**$35,475,000**
Contingencies and Other Project Fees	$10,599,000	$17,738,000
Total Project Cost ($)	**$31,796,000**	**$53,213,000**
O&M Costs		
RO Consumables(4)	$67,000	$242,000
RO Power demand (pumping)	$38,000	$95,000
Concentrator Power Demand	$1,130,000	$2,667,000
Concentrator Spare Equipment	$168,000	$293,000
Concentrator - Consumables(4)	$76,000	$120,000
Annual brine disposal ($50/ton to landfill)	$585,000	$1,468,000
Labor demand(5)	$125,000	$125,000
Annual O&M Cost	**$2,189,000**	**$5,010,000**
Annual O&M Cost ($/MG)	**$5,215**	**$4,766**

Notes:

1. 10% of all construction items (equipment and installation through sitework).
2. 15% of equipment and installation cost.
3. 25% of equipment and installation cost.
4. Antiscalants, cleaning solution, etc.
5. Labor demand was assumed at $60/day for 40 hours/week for one operator.

Table 5	Capital and O&M Costs for Coagulation and Filtration (C/F) Treatment Metropolitan Water Resources Management Plan Update City of Fresno	
Items	**800 GPM**	**2000 GPM**
General Conditions and Requirements (10%)(1)	$94,000	$300,000
C/F Equipment and Installation	$606,000	$1,934,000
Pipework (15%)(2)	$91,000	$290,000
Sitework (15%)(2)	$91,000	$290,000
Electrical and Instrumentation (25%)(3)	$152,000	$484,000
Construction Subtotal	**$1,034,000**	**$3,298,000**
Construction Contingency (30%)(4)	$310,000	$989,000
Total Construction Cost ($)	**$1,344,000**	**$4,287000**
Contingencies and Other Project Fees (50%)	$672,000	$2,144,000
Total Project Cost ($)	**$2,016,000**	**$6,431,000**
O&M Costs		
Chemicals(5)	$12,000	$31,000
Filter Media Replacement	$6,000	$8,000
Power demand (pumping)	$42,000	$106,000
Labor demand(6)	$31,000	$31,000
O&M Subtotal	**$91,000**	**$176,000**
Contingency (50%)(4)	$46,000	$88,000
Annual O&M Cost	**$137,000**	**$264,000**
Annual O&M Cost ($/MG)	**$327**	**$251**

Notes:

1. 10% of all construction items (equipment through electrical/instrumentation).
2. 15% of equipment and installation cost.
3. 25% of equipment and installation cost.
4. Contingency to account for unknown variables since the actual wells to be treated are not known at this time.
5. Based on arsenic treatment (ferric chloride, potassium permanganete, chlorine). Chemical usage will differ depending on water quality of constituents being treated and treatment goals.
6. Labor demand was assumed at $60/day for 10 hours/week for one operator.

Table 6 Capital and O&M Costs for Oxidation and Filtration (O/F) Treatment
Metropolitan Water Resources Management Plan Update
City of Fresno

Items	800 GPM	2000 GPM
General Conditions and Requirements (10%)(1)	$86,000	$148,000
O/F Equipment and Installation	$552,000	$957,000
Pipework (15%)(2)	$83,000	$144,000
Sitework (15%)(2)	$83,000	$144,000
Electrical and Instrumentation (25%)(3)	$138,000	$239,000
Construction Subtotal	**$942,000**	**$1,632,000**
Construction Contingency (30%)(4)	$283,000	$490,000
Total Construction Cost ($)	**$1,225,000**	**$2,122,000**
Contingencies and Other Project Fees	$613,000	$1,061,000
Total Project Cost ($)	**$1,838,000**	**$3,184,000**
O&M Costs		
Chemicals(5)	$32,000	$80,000
Media/Equipment Replacement(6)	$13,000	$31,000
Power demand (pumping)	$5,000	$13,000
Labor demand(7)	$31,000	$31,000
O&M Subtotal	**$81,000**	**$155,000**
Contingency (50%)(4)	$41,000	$78,000
Annual O&M Cost ($/yr)	**$122,000**	**$233,000**
Annual O&M Cost ($/MG)	**$291**	**$222**

Notes:

1. 10% of all construction items (equipment through electrical/instrumentation).
2. 15% of equipment and installation cost.
3. 25% of equipment and installation cost.
4. Contingency to account for unknown variables since the actual wells to be treated are not known at this time.
5. Oxidants (e.g. Chlorine @ 4 mg/L dosage).
6. Includes annual media replacement and maintenance on equipment parts.
7. Labor demand was assumed at $60/day for 10 hrs/week for one operator.

Table 7	Capital Cost Estimate - Expanding Northeast SWTP from 30 mgd to 70 mgd Metropolitan Water Resources Management Plan Update City of Fresno
Items	**Estimate**
General Conditions and Requirements (10%)(1)	$7,400,000
Civil Site work	$670,000
Yard Piping	$4,000,000
Raw Water Pump Station Upgrades (2 new larger pumps)	$670,000
Pretreatment Basins (Actiflo) (4 new)	$12,000,000
Ozonation Facilities (Contactors) (4 new)	$5,600,000
Filter Absorbers (8 new filters)	$13,470,000
Clearwell (5.0 MGl)	$6,250,000
Finished Water Pump Station Upgrades (1 new larger pump)	$330,000
Chemical Feed Facility Upgrades	$4,000,000
Solids Handling Facilities	$4,670,000
UV Disinfection Facilities (70 mgd)(2)	$7,580,000
Electrical and instrumentation (25%)(3)	$14,810,000
Construction Subtotal	**$81,450,000**
Contingencies and Other Project Fees (50%)	$40,725,000
Total Project Cost	**$122,175,000**

Notes:
1. 10 percent of costs for civil site work through electrical and instrumentation items
2. Contingency for potential need for higher levels of disinfection in future (see Section 3.1)
3. 25 percent of costs for civil site work through UV disinfection items

Table 8	Capital Cost Estimate - New 70 mgd Southeast SWTP Metropolitan Water Resources Management Plan Update City of Fresno
Items	**Estimate**
General Conditions and Requirements (10%)(1)	$15,379,000
Civil Site work	$2,917,000
Yard Piping	$10,500,000
Raw Water Pump Station	$1,750,000
Pretreatment Basins (Actiflo) (6 basins)	$19,833,000
Ozonation Facilities (6 contactors)	$26,250,000
Filter Absorbers (14 filters)	$21,467,000
Clearwell (6.0 MGI)	$7,500,000
Finished Water Pump Station	$3,967,000
Chemical Feed Facility	$10,267,000
Solids Handling Facilities	$7,000,000
UV Disinfection Facilities(2)	$7,583,000
Operations Building and Facilities	$3,500,000
Electrical and instrumentation (25%)(3)	$30,630,000
Land (54 acres)(4)	$3,780,000
Construction Subtotal	**$172,260,000**
Contingencies and Other Project Fees (50%)	$86,130,000
Total Project Cost Estimate	**$258,390,000**

Notes:
1. 10 percent of costs for civil site work through electrical and instrumentation items
2. Contingency for potential need for higher levels of disinfection in future (see Section 3.1)
3. 25 percent of costs for civil site work through operations building and facilities items.
4. $70,000 per acre

Table 9	Estimated Chemical Usage and Costs for Either NE or SE SWTPs Metropolitan Water Resources Management Plan Update City of Fresno		
Chemical	**Average Annual Dose (mg/L)**	**Unit Cost ($/lb)**	**Estimated Annual Cost**
Aluminum Sulfate	40	0.17	$1,240,000
Sodium Hydroxide	10	0.50	$912,000
Sodium Hypochlorite	5	0.40	$365,000
Magnafloc LT22S	1	1.40	$255,000
Carbon Dioxide	10	0.50	$912,000
Ortho/Polyphosphate	5	0.50	$456,000
Calcium Thiosulfate	2	0.75	$274,000
Liquid Oxygen (LOX)	2 (O_3)	0.55	$200,000
Total Annual Chemical Cost Estimate			**$4,600,000**

Table 10	Operations & Maintenance Cost Estimate Summary - NE or SE SWTP Metropolitan Water Resources Management Plan Update City of Fresno
Cost Estimate	**Estimated Annual Cost**
Chemicals	$4,600,000
Electrical Power	$1,870,000
Labor	$6,990,000
Maintenance	490,000
Total Annual O&M Cost Estimate	$14,000,000
O&M Cost Estimate ($/MG)	$639

Annual O&M costs calculated based upon treating 60 mgd average annual flow rate.
Power cost estimated based upon $0.10/kwh, existing SWTP power usage and comparison to data for similar plants with raw and finished water pumping, ozonation, and UV.
O&M staffing total of 56 hours per day at $60/hour.
Maintenance cost = 0.25% of construction cost of SE plant (with 30% construction contingency).

Table 11	Estimated Capital Cost - 11 mgd Tertiary Treatment Plant at RWRF[(1)] Metropolitan Water Resources Management Plan Update City of Fresno
General Conditions and Requirements (10%)[(2)]	$2,183,000
Influent Pump Station[(3)]	$848,000
Coagulation/Filtration[(3)]	$7,000,000
UV Disinfection[(3)]	$8,450,000
11.0 mgd Finished Water Pump Station and Force Main 24 inch diameter, (0.5 mile)[(2)]	$5,530,000
Construction Subtotal	**$24,011,000**
Contingencies and Other Project Fees (50%)	$12,006,000
Total Project Cost	**$36,017,000**

Notes:
1. 11.0 mgd constant flow, treating secondary effluent pumped from RWRF.
2. 10% of all construction items.
3. Costs include yard piping, electrical and instrumentation, and site work.

Table 12	Estimated Capital Costs - 5.5 mgd Satellite Plant(1)(2) Metropolitan Water Resources Management Plan Update City of Fresno
General Conditions and Requirements (10%)(3)	$5,758,000
5.5 mgd Influent Pump Station and 0.5 mile force main (diameter = 18 inch)	$1,262,000
Preliminary Treatment	$2,175,000
Secondary Treatment(4)	$18,120,000
Coagulation/Filtration	$4,800,000
UV Disinfection	$5,800,000
Effluent Pump Station	$500,000
Finished Water Pump Station and Pipeline to Canal (18 inch diameter, 0.5 mile)	$1,423,000
Operations/Lab and Maintenance Buildings	$3,000,000
Contingency for Alternative MBR Process(5)	$20,500,000
Land - WWTP (40 acres at $150,000/acre)	$6,000,000
Construction Subtotal	**$69,338,000**
Contingencies and Other Project Fees (50%)	$34,669,000
Total Project Cost	**$104,007,000**

Notes:

1. 5.5 mgd fixed treatment capacity. Peak flows are bypassed to main collection system for treatment of the RWRF.
2. Costs include markups for site work, yard piping, electrical and instrumentation.
3. 10% of all construction items (influent pump station through alternative MBR process).
4. Solids are returned to collection system for treatment at the RWRF.
5. Contingency in case future planning finds MBRs feasible. Adjusted by increasing secondary costs by 40% (to account for higher MBR costs) and subtracting out tertiary filters which would not be needed.

Table 13	**O&M Costs - Recycled Water Facilities Metropolitan Water Resources Management Plan Update City of Fresno**	
Item	**5.5 mgd Satellite Plant**	**RWRF 11 mgd Tertiary Plant**
Labor	$774,000	$65,700
Power	$442,000	$85,000
Chemicals/Supplies	$101,000	$15,000
Materials (media, lamps, other equipment, etc.)	$279,000	$368,000
Regulatory Compliance Testing	$250,000	$24,000
Education/Training	$50,000	$10,000
Annual O&M Costs	**$1,896,000**	**$568,000**
Annual O&M Costs ($/MG)	**$944**	**$283**

Table 14	**Combined Capital & Annual Costs for Three Water Recycling Facilities Metropolitan Water Resources Management Plan Update City of Fresno**	
	Capital Costs(1),(2)	**Annual O&M Costs(3)**
RWRF Tertiary Plant (11.0 mgd = 12,500 af/y)	$36,017,000	$568,000
Two Satellite Plants (2 @ 5.5 mgd = 12,500 af/y)	$208,014,000	$3,792,000
Total for 22 mgd (25,000 af/y)	**$244,031,000**	**$4,360,000**

Notes:
1. Total Project costs; include construction cost, Engineering, Legal and Administrative costs.
2. December 2008 Twenty Cities ENR: 8551.
3. December 2008 costs.