ULTRAVIOLET DISINFECTION FEASIBILITY STUDY

DRAFT REPORT

SEPTEMBER 1995

WASTEWATER RESEARCH GROUP
LIQUID WASTE MANAGEMENT DIVISION

BUREAU OF SANITATION
DEPARTMENT OF PUBLIC WORKS
CITY OF LOS ANGELES

Ultraviolet Disinfection Feasability Study

DRAFT REPORT
SEPTEMBER 1995

WASTEWATER RESEARCH GROUP
LIQUID WASTE MANAGEMENT DIVISION
BUREAU OF SANITATION
DEPARTMENT OF PUBLIC WORKS
CITY OF LOS ANGELES

EXECUTIVE SUMMARY

Municipal wastewater contains various pathogenic microoganisms that arise from different sources, including the human gastrointestinal tract. Since water and wastewater disinfection revolutionized disease prevention nearly a century ago, chlorination has been the primary mode of disinfection treatment. Today, disinfection by ultraviolet (UV) irradiation has appeared as a technically feasible and economically viable alternative. Since reclaimed water is now being considered as an additional source of water supply, concern about toxicity of chlorinated byproducts in receiving waters implies that alternative disinfection technologies need to be developed. As the City of Los Angeles has formally committed to a goal to reclaim and to beneficially reuse 40 percent of the wastewater produced by City residents by the year 2010, it has become imperative to investigate non-halogen disinfection methods as a means of maintaining effluent quality.

In addition to toxicity of chlorinated byproducts, there are safety reasons for changing from present disinfection methods. Chlorine gas (Cl_2) is presently used for disinfection at both City water reclamation plants, but the Tillman Water Reclamation Plant (TWRP) uses sulfur dioxide (SO_2) gas for dechlorination; and the Los Angeles-Glendale Water Reclamation Plant (LAGWRP) dechlorinates with sodium bisulfite ($NaHSO_3$). All of these chemicals are effective for the stated purposes, but they require care and prior training when used. Cl_2 gas and SO_2 gas are classified as acutely hazardous; therefore, they require extreme caution in handling, storage and use. Sodium hypochlorite (NaOCl) is scheduled to replace Cl_2 use at LAGWRP soon, but it is much more expensive. Terminal Island Treatment Plant (TITP) does not disinfect its effluent.

The effectiveness of UV disinfection in secondary effluent has been reported at more than 700 UV disinfection facilities now in operation throughout the country. In California alone, a number of UV disinfection systems are in operation, under construction, or in the pilot study stage.

UV disinfection uses ultraviolet light to disrupt the ribonucleic (RNA) and deoxyribonucleic acids (DNA) responsible for storing genetic information in the nuclei of microoganisms. These nucleic acids demonstrate maximum absorption of (and, thus, are most susceptible to) light within the wavelength range of 250 to 270 nanometers (nm). Low pressure mercury vapor lamps typically generate light near the short end of this range at a wavelength of 253.7 nm. Medium pressure lamps, a more development, produce more intense light at longer, but equally effective wavelengths.

The effectiveness of UV disinfection is influenced by a number of factors, such as UV transmittance (defined as the degree of transparency of the treatment stream to UV light), hydraulic flow characteristics, constituent concentrations in the influent flow stream and equipment design. High transmittance at 253.7 nm is a strong indicator of the potential for UV light to disinfect a flow stream.

The National Water Research Institute (NWRI) has developed the *UV Disinfection Guidelines for Wastewater Reclamation in California and UV Disinfection Research Needs Identification* (Guidelines), with the California Department of Health Services (DHS) as a cosponsor. This is intended to be a tool for potential users and regulatory agencies to develop, review and approve testing, design and operation of UV disinfection systems in California. The Guidelines address UV disinfection with low pressure lamps as an alternative to chlorination (and dechlorination) "for meeting Title 22 requirements where an oxidized, coagulated, filtered, disinfected effluent is required." The basis of the Guidelines is an equivalency of UV disinfection to chlorination, met with the same frequency as required for chlorination as follows.

- Filtered turbidity equal to or less than 2 NTU;
- Total coliform equal to or less than 2.2 MPN/100 ml; and
- 4-log virus inactivation based on poliovirus, or another similarly resistant virus.

A comprehensive computer model (UVDIS Version 3.1) was developed by Hydroqual, Inc., under a contract with the United States Environmental Protection Agency (USEPA). The computer program determines the required UV light intensity based on physical characteristics of the UV influent and the selected arrangement of UV lamps.

LAGWRP, with a design capacity of 20 mgd, provides primary, secondary and tertiary treatment, followed by chlorination and dechlorination. LAGWRP plans to convert from gaseous chlorine to sodium hypochlorite for its disinfection process, and recently completed conversion from sulfur dioxide to sodium bisulfite for dechlorination. Data on critical UV design parameters (e.g., percent transmittance, suspended solids (SS), turbidity, settleable solids (STS), coagulant use, oil and grease) at LAGWRP all appear to be within levels acceptable to an economic UV design.

TWRP, with a design capacity of 80 mgd (Phases I and II), provides the same type of treatment as the LAGWRP. The plant uses chlorine gas for chlorination and sulfur dioxide for dechlorination, with no plans to convert to sodium hypochlorite and/or sodium bisulfite. Effluent turbidity is usually near or above the Title 22 limit, but should decrease due to current efforts by the LWMD Process Improvement Group to improve filter performance. The other effluent characteristics appear well within the acceptable limit for an economic UV design.

TITP, with a design capacity of 30 MGD, provides primary and secondary treatment, anaerobic digestion, and solids handling. The plant effluent is not chlorinated as it discharges to the ocean. Tertiary treatment, consisting of tri-media filtration is under construction and scheduled for startup by July, 1996. A full-scale 5 mgd reclamation facility for ground water recharge and industrial use will be constructed by the end of 1999. A pilot filter study was conducted in 1993, but data on turbidity and SS was limited. The conventional tri-media filter produced product water with an average of 0.3 mg/l SS, 0.5 NTU and 55 percent transmittance from secondary effluent that was spiked to become 30-45 and 75-100 mg/l SS during the pilot run. Thus, the quality of the tertiary effluent appears likely to be satisfactory for UV disinfection.

An economic study was performed to determine the costs of using UV disinfection systems at LAGWRP, TWRP-Phase I, TWRP-Phase II and TITP and to compare these with the established chemical disinfection methods to evaluate the economic viability of any proposed shift to UV disinfection. Budgetary, Class C, estimates for UV disinfection systems, including the costs for operations and maintenance (O&M), were obtained from Trojan Technologies, Inc. (TTI), and Bailey-Fischer & Porter, Inc. (BFP), well-known suppliers of UV disinfection equipment from Ontario, Canada. TTI provided quotes for a low pressure-low energy, mercury vapor lamp system (UV3000) and for a medium pressure-high energy, mercury vapor lamp system (UV4000) with more advanced features, including an automatic four-step power controller and self-cleaning. BFP provided a quote for a low pressure-low energy, mercury vapor lamp system (70UV6000).

Cost estimates of UV systems for the LAGWRP range between $1.72 and $3.20 million based on a design flow of 18 mgd, with a UV influent flow of 5 mg/l SS and 65 percent transmittance. The annual O&M expense estimate runs between $415,000 and $463,000. On an annualized basis for a 60 year period, the combined capital investment and O&M cost is between $449, 000 and $519,000. In comparison, the total annualized cost of the planned sodium hypochlorite/sodium bisulfite system for the same period is estimated at $513,000; on the same basis, the existing chlorine/sodium bisulfite system costs about $202,000.

The designs submitted by both TTI and BFP appear too conservative with corresponding overestimates of costs. Some estimates are based on a UV dose of 140 mWs/cm^2, which is much higher than the 120 mWs/cm^2 used by a number of existing facilities with effluent characteristics similar to LAGWRP. Other estimates are based on different power supply requirements. Both vendors estimate spare part costs to be much higher than those which City staff found independently. For example, installations with a single effluent channel would be more economical (e.g., Elsinore Valley) than the proposed systems which specify four or more channels. We describe adjustments to the design to require fewer banks of UV lamps and effluent channels, with a corresponding reduction in capital and operational costs. Together, the capital and O&M costs savings could amount to nearly 40 and 30 percent, respectively. These estimates indicate that the total annualized cost for a UV system (capital and O&M) for LAGWRP would be $314,000 to $363,000, which is 20 to 30 percent less than that for the planned sodium hypochlorite/sodium bisulfite system.

The proposed pilot study would provide data to assess the technical feasibility and potential economic savings of the hypothesized modifications. If successful at LAGWRP, the less expensive approaches would also be applicable to TWRP-Phase I, TWRP-Phase II and TITP, reducing the costs per mgd of capacity correspondingly at all three plants.

The pilot tests at the LAGWRP, TWRP and TITP would require a total estimated cost of $362,000, plus a 20 percent contingency, excluding the salaries and wages of City staff. These studies would provide design data for full-scale UV disinfection systems for the three plants. Pilot testing would require 4-month test period using the City's low pressure-low energy UV2000 pilot unit, including 3 months for lamp fouling testing.

A second option is to pilot test the City-owned low pressure-low energy UV2000 system omitting virological analyses and performing all analyses in-house to accommodate present budgetary pressure on the wastewater program. Costs, in this case, would be reduced to approximately $56,000 for LAGWRP, $81,000 for all four sites. Although this test program would not fully verify compliance with Title 22, testing all other aspects of UV disinfection would provide critical information for future planning. As bacterial kill rate is well correlated with virus inactivation, a system that meets the other Title 22 requirements is likely to be close to compliance with the virological requirement. This option of holding a preliminary test without virology would increase the total cost of testing to fully verify Title 22 compliance, but would result in smaller costs in each fiscal year, except when virology testing is conducted by an outside lab.

It may also be possible to reduce costs by substituting the MS2 coliphage virus for poliovirus in the virus inactivation test. Using this virus would allow all virological work to be done in house. Doing this cannot be considered as a currently available option because Title 22 specifies the use of poliovirus, or another similarly resistant virus, but the proposed changes to Title 22 include a proposal to allow use of either poliovirus or MS2 coliphage. MS2 coliphage was use by the Cities of Pacifica and Riverside, California, during their tests of the TTI UV4000 system earlier this year.

Using the medium pressure-high energy UV4000 system in the pilot test is a third option, and could be expected to save some costs, compared with the UV2000 unit: $35,000 for testing at LAGWRP performing all lab analyses in-house; $95,000 for testing at all four sites. The UV4000 test unit is more self-contained, hence less costly to transport and install. Since it is self-cleaning, the pilot test at each plant requires only one month, instead of four months with the low pressure-low energy UV2000. However, because the City owns the UV2000 pilot test unit, but does not own the UV4000, there would be some costs for the rental. Although the energy and cleaning costs of medium pressure-high energy units are expected to be less than for low pressure-low energy systems, current annualized cost estimates for a full scale medium pressure system are the highest submitted. Careful consideration is needed to select among the currently available options.

Recommendations:

1. The Bureau of Sanitation directs the LWMD Research Group to develop a work plan and conduct a UV pilot study at LAGWRP using one of the test options compatible with the present available resources. The purpose is to determine the optimum dose required to meet the NWRI Guidelines, with pilot tests to follow at TWRP-Phase I, TWRP-Phase II and TITP, depending on the results at LAGWRP.

2. The Program Implementation Committee (PIC) appropriates funds to enable LWMD to conduct UV disinfection pilot studies as proposed under Item 1 as follows:

   a) The amount of $440,000 for pilot testing using the UV2000 that would include all Title 22 requirements.

   b) Approximately $100,000 for pilot testing using the UV2000 , but without the virological testing.

3. The Bureau of Sanitation directs LWMD's Research Group to develop concept reports on UV disinfection installations at each plant, including design criteria for a full scale facility.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS, SYMBOLS AND UNITS

ABBREVIATIONS

ALK	Alkalinity
BFP	Bailey-Fischer & Porter
BOD	Biochemical Oxygen Demand
BOE	Bureau of Engineering
BOS	Bureau of Sanitation
Cl_2	Gaseous Chlorine
CCCSD	Central Contra Costa Sanitary District
CCR	California Code of Regulations
CON	Consultant/Personal Service Contract
CSDOC	County Sanitation Districts of Orange County
CWRC	California Wastewater Reclamation Criteria
DHS	Department of Health Services
DNA	Deoxyribonucleic Acid
DWP	Department of Water and Power
EMD	Environmental Monitoring Division
HPC	Heterotrophic Plate Count
HTP	Hyperion Treatment Plant
JWPCP	Joint Water Pollution Control Plant
LACSD	Los Angeles County Sanitation Districts
LAGWRP	Los Angeles/Glendale Water Reclamation Plant
LWMD	Liquid Waste Management Division
MF	Microfiltration
MPN	Most Probable Number
$NaHSO_3$	Sodium Bisulfite
NaOCl	Sodium Hypochlorite
NPDES	National Pollution Discharge Elimination System
NWRI	National Water Research Institute

OCWD	Orange County Water District
ODW	Office of Drinking Water (of the DHS)
O&G	Oil and Grease
O&M	Operations and Maintenance
P	Pump
PFU	Plaque Forming Unit
pH	Negative logarithm of Hydrogen Ion Activty (or, Concentration)
PSD	Particle Size Distribution
PSS	Point Source Summation
Q	flow rate
Q_{ave}	average daily flow rate
Q_{md}	maximum daily flow rate
Q_{mw}	maximum weekly flow rate
RMPP	Risk Management Prevention Plan
RNA	Ribonucleic Acid
RO	Reverse Osmosis
RTD	Residence Time Distribution
RWQCB	Regional Water Quality Control Board
RWQCB-LAR	Regional Water Quality Control Board - Los Angeles Region
SO_2	Sulfur Dioxide
SS	Suspended Solids
STS	Settleable Solids
T	Tank
TITP	Terminal Island Treatment Plant
TOC	Total Organic Carbon
TTI	Trojan Technologies, Inc.
TULIP	Subroutine to Calculate UV Length Intensity Profile
TWRP	Tillman Water Reclamation Plant
UAT	University of Arizona at Tucson
UCD	University of California at Davis
UCR	University of California at Riverside
UFC	Uniform Fire Code
USEPA	United States Environmental Protection Agency
UV	Ultraviolet
UVDIS	USEPA Software to Calculate UV Intensity
VLAB	Virology Laboratory

WERF	Water Environment Research Foundation

SYMBOLS

a,b	rate coefficients
A	absorbance
Amp	ampere
C, m	particulate bacteria and suspended solids coefficients, respectively
Cl_2	gaseous chlorine
D	dose
Fe	iron
E	dispersion coefficient
I	intensity
I_{avg}	average intensity
K	inactivation rate constant
L_a	reactor length
N	microorganism number at time t
$NaHSO_3$	sodium bisulfite
NaOCl	sodium hypochlorite
N_0	initial microorganism number (at time t_0)
N_p	microorganism density relative to a particle size distribution
Q	flow rate
Q_{ave}	average daily flow rate
Q_{md}	maximum daily flow rate
Q_{mw}	maximum weekly flow rate
SO_2	sulfur dioxide
SS	suspended solids
STS	settleable solids
Sy	horizontal centerline distance between lamps
Sz	vertical centerline distance between lamps

%T	percent transmittance
T	tank
t	time, s
TDS	total dissolved solids
t_0	initial time, s
V	volume, L
X	characteristic reactor length, cm
λ	light, wavelenth, nm
η	viscosity, poise (dyne-sec/cm^2)
μ	liquid velocity, cm/s
σ^2	variance

UNITS OF MEASURE

amp	ampere
cm/sec	centimeters per second
cm^2/sec	square centimeters per second
$cm^2/\mu Ws$	square centimeters per microwatt second
gal	gallon
gpm	gallons per minute
Hz	hertz, or cycles per second
Kw	kilowatt
KWH	kilowatt hour
lb	pound
mgd	million gallons per day
mg/l	milligrams per liter
ml	milliliter
MPN	most probable number
mW/cm^2	milliwatts per square centimeter
mWs/cm^2	milliwatt seconds per square centimeter
nm	nanometer
NTU	Nephelometric Turbidity Unit
ppm	parts per million
v	volt
yr	year

CHAPTER 1

INTRODUCTION

1.1 PURPOSE

Municipal wastewater contains various pathogenic microorganisms that arise from different sources, including the human gastrointestinal tract. Until relatively recently, catastrophic outbreaks of water-borne diseases were frequent occurrences. The now-common practice of water and wastewater disinfection by chlorination, which was first introduced in the United States in 1906, represented a revolution in human disease prevention.

Today, disinfection by ultraviolet (UV) radiation has appeared as a technically feasible and economically viable alternative to chemical disinfection. There are several reasons for replacing chlorine-based disinfection of wastewater discharges. Gaseous chlorine (Cl_2) is an acutely hazardous chemical and there is increasing concern about the toxicity of chlorinated byproducts in receiving waters. In addition to chloride anions, chloramines are formed in the presence of ammonia and side reactions occur between Cl_2 and particular organic compounds (notably short-chain alkanes and alkenes), which are either formed in wastewater or introduced by industrial discharges. Even though the resulting concentrations are relatively low, this formation of chlorinated byproducts that are known to be toxic or carcinogenic to humans or aquatic life is now considered undesirable. Since reclaimed water is now being seriously considered as an additional source of water supply, these toxicity concerns imply that alternative disinfection technologies must be developed. Although organic and inorganic refractory byproducts could also be formed through UV radiation of wastewater, the concentrations are generally at or below detection levels, so UV disinfection now appears preferable.

Disinfection at the City's water reclamation plants, which currently produce about 50 million gallons per day of oxidized, coagulated, filtered and disinfected effluent, is accomplished using Cl_2 for chlorination, and sulfur dioxide (SO_2) or sodium bisulfite ($NaHSO_3$) for dechlorination. Plans call for changing from Cl_2 to sodium hypochlorite (NaOCl) at atleast one facility. SO_2 is also acutely hazardous; therefore, two chemicals require extreme caution in handling, storage and use. Moreover, although NaOCl is as effective a disinfectant as Cl_2, and much safer, it is also much more expensive. The City of Los Angeles has made a formal commitment to reclaim and to beneficially reuse 40 percent of the water used by City residents by the year 2010. Hence, it has become imperative to investigate non-halogen disinfection methods as a means to maintain effluent quality.

Over the last several years, environmental groups, such as Greenpeace, have begun to advocate the elimination of chlorine as a general-purpose disinfectant and oxidizer because of its effect on the ozone layer. Today, the United States Environmental Protection Agency (USEPA) is even considering a ban on the use of chlorine for wastewater disinfection. Similarly, recent amendments to Uniform Fire Code (UFC) regulations could force many users of Cl_2/SO_2 systems to convert over to $NaOCl/NaHSO_3$ systems, resulting in higher operational and maintenance costs.

In anticipation of a possible shift in USEPA policy with respect to chlorine disinfection, and in recognition of the potential of UV irradiation as a cost-effective alternative, the Water Environment Research Foundation (WERF) is currently investigating UV technology for the disinfection of secondary wastewater effluent. This investigation will compare the relative effectiveness and economics of UV disinfection with that of conventional technologies, taking into account the need for post-chlorination treatment practices, such as sulfonation.

The purpose of this report is to present a preliminary economic evaluation of chlorination/dechlorination and UV disinfection methods, along with a proposal to conduct UV disinfection pilot studies, to adequately evaluate the technical and economic potential for full-scale UV implementation at the City's water reclamation plants. The proposal focuses on site-specific pilot studies at the Los Angeles-Glendale (LAGWRP) and Tillman Water Reclamation Plants (TWRP) and the Terminal Island Treatment Plant (TITP). These pilot studies are necessary in the development and assessment of test protocols as mandated by the California Department of Health Services

(DHS), whose approval is required for non-halogen disinfection methods, including those now proposed for Title 22 of the California Code of Regulations (CCR) regarding the utilization of reclaimed water in augmenting sources of potable water supply.

This report also serves to fulfill a Bureau commitment to the Los Angeles Regional Water Quality Control Board (RWQCB) to conduct a feasibility study of UV disinfection for the LAGWRP and TWRP, which produce effluents that currently do not meet their National Pollution Discharge Elimination System (NPDES) waste discharge requirement for chloride. This problem, which was addressed in a series of discussions and workshops conducted by the Department of Public Works and the RWQCB over the past several years, is due primarily to drought-induced changes in the quality of imported water supplies. Although these plants now discharge chlorides under an interim limit set by the RWQCB, UV disinfection could provide a means of reducing effluent chlorides by minimizing the use of chlorine as a primary disinfectant. This might be especially beneficial for the TWRP facility, where Cl_2 use could be significantly reduced.

1.2 BACKGROUND

UV disinfection uses ultraviolet light to disrupt the ribonucleic (RNA) and deoxyribonucleic acids (DNA) responsible for storing genetic information in the nuclei of microorganisms. The nucleic acids demonstrate maximum absorption of light within the wavelength range of 250 to 270 nanometers (nm). Low pressure-low energy, mercury vapor lamps typically generate light near the short end of this range at a wavelength of 253.7 nm [Ref. b2]. Medium pressure-high energy, mercury vapor lamps, a recent development, produce more intense light at longer, but equally effective wavelengths.

The effectiveness of UV disinfection is influenced by a number of factors, such as UV transmittance (defined as the degree of transparency of the treatment stream to UV light), hydraulic flow characteristics, constituent concentrations in the influent flow stream and equipment design. High transmittance of the flow stream at 253.7 nm is a strong indicator of the disinfection capability of UV light. Plug flow characteristics, including axial mixing and a predictable residence time, are also essential to an efficient system.

The Bureau of Sanitation had previously acquired a UV2000 pilot unit manufactured by Trojan Technologies, Inc., (TTI) for the purpose of investigating the use of UV radiation as a disinfectant. This unit, shown in Figure 1.1a, was originally designed for a hydraulic capacity of 200 gallons per minute (gpm) through three serpentine channels to provide an effluent with a total coliform level no greater than 200/100 m measured as either most probable number (MPN) or plaque forming units (PFU). Modifications to this unit would enable it to meet current Title 22 standards that require no more than 2.2/100 ml total coliform count. If approved, a series of pilot tests using the modified UV2000 unit would be conducted at the City's water reclamation and wastewater treatment facilities to determine if this level of disinfection could be reliably and consistently achieved. Alternatively, the UV4000 medium pressure system in Figure 1.1b could be used.

Because UV transmittance of the flow stream is a primary criterion for effectiveness, UV disinfection is best utilized when the wastewater stream to be treated has undergone conventional primary and secondary treatments, followed by coagulation and filtration. These processes remove much of the suspended materials that could act as a UV "demand," or which physically occlude bacterial cells from UV irradiation. In view of this, the LAGWRP, TWRP-Phase I and TWRP-Phase II, as well as TITP, represent excellent test sites.

1.3 CALIFORNIA REGULATORY REVIEW

The National Water Research Institute (NWRI) has developed UV Disinfection Guidelines (Guidelines) for wastewater reclamation in California and has identified UV disinfection research needs, NWRI [Ref. b11]. These are intended to be used by potential users and regulatory agencies (e.g., the California State Water Resources Board (SWRB) and the fifteen RWQCB's) for

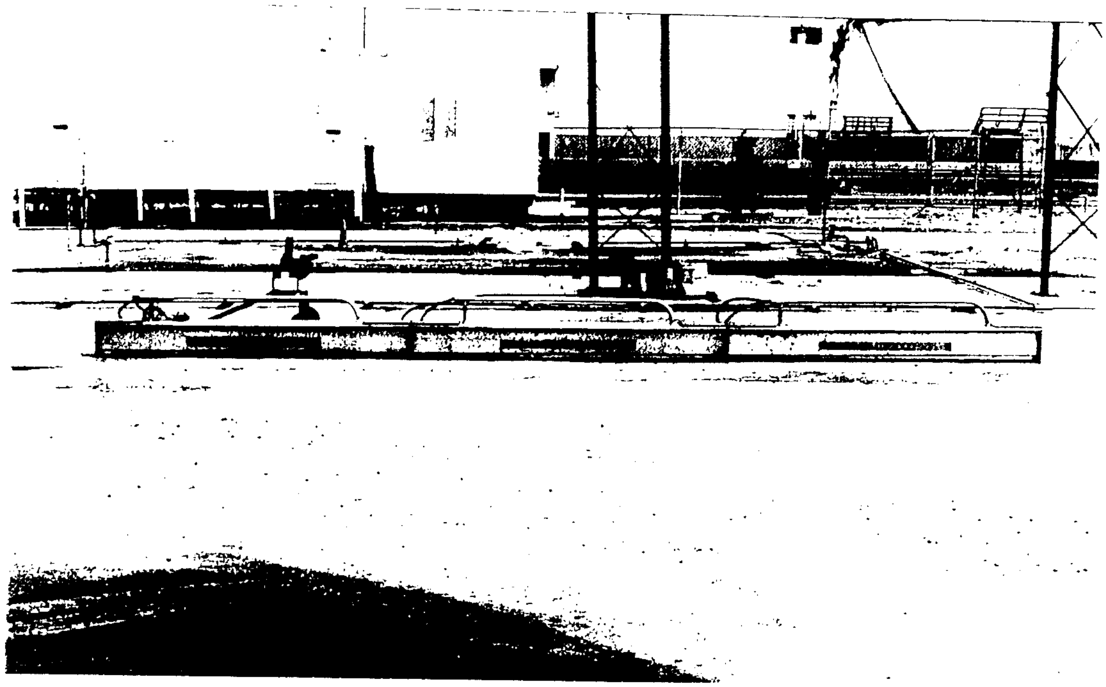


Figure 1.1a Trojan Technologies, Inc., UV2000 Pilot Unit

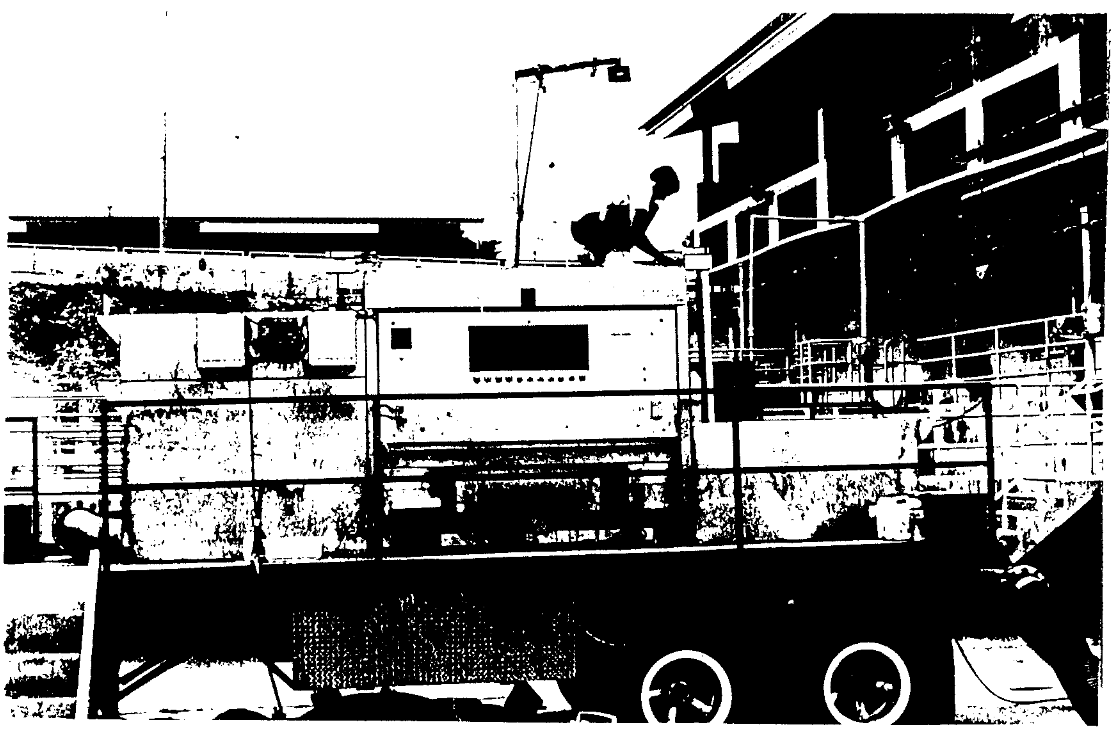


Figure 1.1b Trojan Technologies, Inc., UV4000 Pilot Unit

development, review and approval of testing, design, and operation of UV disinfection systems in California. The Guidelines have the endorsement of the DHS until it can publish official regulations governing the use of UV disinfection method.

The Guidelines specifically address UV disinfection, which has been proposed as an alternative to chlorination, for meeting Title 22 requirements where an oxidized, coagulated, filtered, disinfected effluent is required. The basis of the Guidelines is equivalence of UV disinfection to chlorination, met with the same frequency as required for chlorination as follows.

a) Filtered effluent turbidity equal to or less than 2 Nephelometric turbidity units (NTU);
b) Monthly median not to exceed 2.2/100 ml total coliform count;
c) Sample exceedance of 23/100 ml total coliform count no more than once in any 30-day period; and
d) 4-log (99.99%) virus (poliovirus) inactivation (proposed Title 22 regulation changes would allow the use of MS2 coliphage in place of poliovirus.

The Guidelines specify consideration of the following design parameters, based on the experience derived from pilot studies and prototype installations.

a) A minimum UV design dose of 140 milliwatt-seconds per square centimeter ($mW \cdot s/cm^2$) at maximum week flow and 100 $mW \cdot s/cm^2$ at peak flow (maximum day) to be achieved with a minimum of three banks in series;
b) The low-pressure mercury vapor UV lamps oriented parallel to the flow stream;
c) Open channel flow with flow parallel to the lamps, usually dictating the use of a horizontal configuration; and
d) A minimum 55% transmittance of filtered effluent.

UV disinfection users must demonstrate acceptability of their design configuration if the preceding requirements are not met. For instance, if a water or wastewater utility chooses to use a vertical lamp array or has a filtered effluent of less than 55% transmittance, a test must be conducted to demonstrate that sufficient pathogen kill/deactivation will be achieved. Such a demonstration would also be required for a utility that decides to use medium pressure-high energy lamps or to use a lower UV dose.

An engineering report must be submitted to the regulatory agencies, DHS and the RWQCB, to support the replacement of chlorination by UV disinfection. This report must include, but not be limited to, descriptive material on the producer, purveyor, raw wastewater, reclaimed wastewater, treatment processes, UV reactor design, residence time distribution, monitoring, reliability, operation and maintenance and contingencies. The proposed pilot studies presented in this report should provide essential information for the UV reactor, residence time distribution and monitoring section of the Engineering Report. The following items must be evaluated during pilot testing for application to any future design.

a) Number and dimensions of contact channels.
b) Theoretical and mean residence time in each channel, including the method of determining residence time.
c) Number and type of UV lamps, modules and banks.
d) Water level relative to UV lamps.
e) Lamp arc length.
f) Lamp arrangement.
g) Minimum UV dose under worst case conditions, accounting for
    - lamp output;
    - UV transmittance through quartz sleeves;
    - lowest anticipated UV transmittance;
    - maximum flow; and
    - exposure time.
h) Number, location and function of UV intensity and/or transmittance meters.

It should be noted that continuous monitoring is required for turbidity, transmittance and other parameters; daily monitoring would be required for total coliform and suspended solids (SS).

Engineering reports for nonconforming UV systems will not be approved by the regulatory agencies unless and until the California DHS has approved the nonconforming system as being capable of providing acceptable levels of treatment and reliability.

CHAPTER 2

LITERATURE REVIEW

Ultraviolet light is increasingly being used for disinfection around the country. The effectiveness of UV disinfection in secondary effluent has been reported at more than 700 UV disinfection facilities which are in operation in North America by Cairns [Ref. b2]. Similarly, the application of UV to disinfect tertiary effluent has been studied extensively by researchers in addressing the effluent discharge problems associated with chlorine.

2.1 PREVIOUS STUDIES

Since the early 70's, research has been conducted to determine and/or quantify the parameters affecting UV efficiency. Qualls, et. al., [Ref. b14] found that suspended particles can absorb and scatter UV light, causing spectrophotometers to overestimate UV absorbance. They also found greater success disinfecting filtered effluent than disinfecting unfiltered effluent. White et. al., [Ref. b21] evaluated the configuration of the lamps with respect to direction of flows, the frequency and method of cleaning the lamps, and equipment design. Kreft [Ref. b10] evaluated the hydraulics and cleaning of UV units. It was determined that plug flow is desirable to ensure that all water passing through the unit is irradiated uniformly and that the lamps should be cleaned regularly to maintain UV transmittance effectiveness. Recent studies by Darby, et. al., [Ref. B7] and Emerick and Darby [Ref. b23] evaluated the feasibility of using UV light on filtered and unfiltered wastewater effluent to meet the California Wastewater Reclamation Criteria (CWRC).

USEPA [Ref. b19] conducted in 1992 a detailed assessment of the design, operation and maintenance of 30 plants in the country. These are presented in Table 2.1 with their flows and effluent characteristics.

TABLE 2.1 Assessment of Plant Design and Current Operational Performance of 30 Selected Wastewater Treatment Plants.

Plant Location	Design Flows		Peak to Ave Ratio	Limit Total Coliform MPN/100ml	Current Average Performance			
	Peak Q mgd	Ave Q mgd			Ave Q mgd	BOD mg/l	TSS mg/l	Total Coliform MPN/100ml
Waldron. AL	1.2	1.0	1.2	(none)	0.8	n/a	n/a	n/a
Bridgeville, DE	1.2	0.8	1.5	200	0.2	6.1	3.7	25.0
Dakota City, IA	n/a	0.3	n/a	200	0.3	10.0	13.0	160.0
Cave City, KY	1.5	0.6	2.5	200	0.3	5.0	3.0	10.0
Edgewater, MD	0.5	0.5	1.0	14	0.1	6.1	4.7	1.8
Clearsprings, MD	0.4	0.2	2.0	200	0.1	10.0	10.0	2.0
Leadwood, MO	1.5	0.5	3.0	200	0.2	7.0	4.0	1.0
Olla, LA	n/a	0.3	n/a	25	0.3	5.0	0.5	1.0
Dewey, OK	1.1	0.4	2.8	200	0.2	20.0	78.0	31.0
Stoney Creek, VA	1.5	0.6	2.5	200	0.4	4.0	5.0	10.0
Petersburg, WV	1.8	0.6	3.0	200	0.5	10.0	10.0	20.0
Ozark, AL	5.3	2.1	2.5	1000	0.9	16.0	20.0	100.0
Jessup, MD	n/a	1.6	n/a	200	1.1	3.0	3.0	4.0
Lebanon, MO	3.5	2.3	1.5	400	2.1	n/a	n/a	n/a
Abbeville, LA	4.5	1.6	2.8	200	2.1	4.0	8.0	1.0
Hanover, NH	7.0	2.3	3.0	240	1.3	30.0	10.0	200.0
New Providence, NJ	6.0	2.0	3.0	200	0.5	10.0	5.0	100.0
Owasso, OK	3.0	2.3	1.3	200	1.3	10.0	10.1	5.0
Highspire, PA	3.8	2.0	1.9	200	1.0	10.0	10.0	30.0
Accomoc, VA	2.9	2.3	1.3	200	2.2	10.0	15.0	100.0
White Sulphur Spr., WV	4.0	1.6	2.5	200	1.1	5.0	3.0	10.0
Williamson, WV	5.0	3.0	1.6	200	1.0	15.9	11.5	45.0
Athens, AL	13.0	7.0	1.9	1000	6.8	8.0	13.0	324.0
Gunnison, CO	6.7	4.2	1.6	6000	1.0	10.0	10.0	200.0
East Chicago, IL	36.0	15.0	2.4	200	13.8	1.7	5.2	12.0
Olathe, KS	25.0	6.4	3.9	200	1.7	12.0	6.0	10.0
Okmulgee, OK	n/a	5.0	n/a	200	2.7	10.0	7.0	200.0
Willow Grove, PA	17.5	7.0	2.5	200	6.9	5.0	10.0	n/a
Warminster, PA	16.0	8.1	2.0	200	5.5	5.0	10.0	43.0
Collierville, TN	7.0	3.5	2.0	200	1.8	10.0	4.0	3.0

n/a = not available

tab2-1.wb2

The following is a list of recent UV disinfection projects which are designed for a total coliform disinfection standard of less than or equal to 2.2 MPN/100ml:

a) City of Pacifica, CA, has a design capacity of 0.2 million gallons per day (mgd); system is in operation.
b) Elsinore Valley, CA, has a design capacity of 4.0 mgd. This is the first full-scale UV disinfection system built and tested in California.
c) Chino Basin, CA, has a design capacity of 21.0 mgd; system is scheduled for operation in 1996.
d) Mountain View Sanitary District, CA, has a design capacity of 3.8 mgd; system is in operation.
e) Sacramento Regional Wetland, CA, has a design capacity of 1.2 mgd; system is in operation.
f) Municipality of Metropolitan Seattle, has a design capacity of 0.75 mgd; system is in operation.

UV pilot studies have also been conducted by several agencies to evaluate the feasibility of meeting Title 22 and the Guidelines' disinfection requirements, and to establish UV disinfection process design criteria for full-scale facilities. These include the cities of Colton, San Bernardino, Seattle, and the Sanitation Districts of Central Contra Coast (CCCSD) and the County Sanitation Districts of Los Angeles County (CSDLAC). The Orange County Water District (OCWD) recently concluded pilot tests and is using those results to determine if UV disinfection will be installed there.

2.2 METHODS USED

2.2.1 Hydraulic Measurement

Evaluation of the hydraulics of the influent and effluent disinfection channels is essential to successful operation of a UV disinfection installation. Levenspiel [Ref. b22], the Guidelines and the USEPA

Manual on Disinfection [Ref. b18] describe in detail the necessary considerations and calculations, and the methods needed to determine flow conditions. A UV system should be designed for plug flow with maximum transverse disperison for maximum effectiveness. The dispersion coefficient, E, approaches zero for ideal plug flow conditions and infinity for ideal complete mixed conditions. An E less than 100 cm^2/sec is recommended for effective design.

Plug flow conditions must be maintained within the entire UV pilot unit and inlet chamber to provide equal exposure of each element of flow to UV light as the filtered effluent passes through the UV system. In a continuous plug flow system, exposure time is a function of reactor geometry and the flow rate throughout the unit. Qualls, et al., [b14] recommend a typical exposure time of 1 to 15 seconds per bank for UV disinfection. If two or three banks are used, detention time would be double or triple, respectively.

Evaluation of flow and reactor characteristics is based on measuring the Residence Time Distribution (RTD) curve. Tracer methods commonly used to develop the RTD curve in a channel or vessel are the step-dose method, in which the tracer is injected at a constant rate throughout the test, and the slug-dose method, in which a slug tracer is introduced at the start of the test. For these UV pilot tests, a fluorescent dye, such as Rhodamine WT, or a brine solution could be used. Either would be injected into the UV influent channel to determine the degree of axial and longitudinal mixing by measuring fluorescence or conductivity after each bank of lights at specific time intervals.

In a closed vessel, plug flow reactor flow dispersion may be described as a function of the dispersion number as indicated below.

Dispersion Number, E	Flow Dispersion
0	No dispersion
≤ 0.01	Low dispersion
0.01 - 0.1	Moderate dispersion
> 0.1	High Dispersion

Specifications from the Trojan UV2000 System Operating Manual, 1989 [Ref. b17] recommend a dispersion coefficient of less than 200 cm^2/second, a dispersion number of less than 0.1, a Reynolds Number greater than 10,000 at average flow, and a maximum headloss caused by each bank of modules not to exceed 2.5 inches at the peak flow. A study to verify that a pilot UV system has plug flow is a standard practice.

2.2.2 UVDIS Program

Current knowledge of UV disinfection has been incorporated into a comprehensive computer model (UVDIS Version 3.1) developed by Hydroqual, Inc., under a contract from the USEPA. UVDIS aids in the sizing of UV disinfection systems for wastewater disinfection, using horizontally submerged, low pressure-low energy, mercury vapor lamps. Based on the required influent and effluent bacterial levels for a specific treated wastewater effluent and other variables, the program calculates the expected UV intensity. The calculated UV intensity is also effected by the number and arrangement of lamps in a reactor.

Under ideal conditions, the first order equation that represents the inactivation of microorganisms by UV radiation is given by Kreft [Ref. b9]:

(1) $$N = N_0 \exp [-KI (t - t_0)]$$

where:

N : bacterial density, after exposure to UV for time t (MPN/100ml)

N_o: initial bacterial density, before exposure to UV

K : inactivation rate constant (cm^2/μWatts-sec)

I : intensity of UV at 253.7 nm (μWatts/cm^2)

It should be noted that the exponent in Eq (1) gives the energy dosage delivered to the liquid during the exposure time, or:

(2)
$$D = I \, x \, (t - t_0)$$

where D is the dosage in microwatt seconds per square centimeter (μWs/cm^2). From Eqs. (1) and (2), one can conclude that the rate constant, K, is the slope of the relationship $\ln(N/N_0)$ versus D.

The penetration of microorganisms by UV light is affected by microbial aggregation and particulate shielding resulting from suspended matter present in wastewater. Due to these and other non-ideal conditions in the field, the USEPA proposed a modified model [Ref. b18] for inactivation of microorganisms:

(3)
$$N = N_0 \, EXP \left\{ \frac{\mu X}{2E} \left[1 - \left(1 + \frac{4KE}{\mu^2} \right)^{1/2} \right] \right\} + N_P$$

where:

X: characteristic length of the reactor (cm), defined as the average distance traveled under direct UV exposure;

μ: liquid velocity (cm/sec);

E : dispersion coefficient (cm^2/sec), which quantifies the breadth of the residence time distribution about the mean time;

K : inactivation rate (sec^{-1});

N_p: bacterial density associated with the particulates and unaffected by exposure to UV (MPN/100ml).

The parameter μ is estimated by

(4)
$$\mu = \frac{XQ}{V}$$

where V is the liquid volume in the reactor in liters, and Q is the flow rate in liters/sec.

The RTD curve is needed to estimate the dispersion number, E, given by

(5) $$E = \frac{\mu\ X\ \sigma^2}{2\theta^2}$$

where θ is the mean residence time in seconds, and σ^2 is the variance of RTD in square seconds. This assumes that RTD can be approximated by a normal curve.

The parameter K is given by

(6) $$K = a\ (I_{avg})^b$$

where a and b are coefficients developed from a log-log regression of K and I_{avg}. The parameter N_p is given by

(7) $$N_p = C\ SS^m$$

where C and m are coefficients derived from a log-log regression of effluent bacterial density and suspended solids.

The inactivation coefficient K is a function of the average intensity in the UV reactor. The actual intensity produced by a multi-lamp system cannot be measured directly; a computational method, the USEPA Point Source Summation (PSS) Method, is available for this determination. The UVDIS program utilizes this method, which also considers the number of lamps in a reactor (UV density), and the absorptive properties of the liquid (UV absorbance coefficient). A subroutine (TULIP) is incorporated within the program to allow for the estimation of the average intensity in a reactor under specific lamp configuration and wastewater conditions. TULIP can be used to calculate the average nominal intensity of staggered or uniform arrangements and lamp arrays of any matrix size. For example, the lamps could be staggered and/or arranged in a 2x2, 3x3 or 4x4 array. The UVDIS parameters, obtained from the users manual [Ref. b9], are applied to UVDIS in Sec. 2.2.3.

2.2.3 UVDIS Application

A sensitivity analysis, using the UVDIS3.1 computer program, was conducted to determine how lamp intensity varies with lamp spacing, lamp configuration and wastewater UV transmittance. UVDIS3.1 asks for several parameters. Some of the parameters which characterize the wastewater and determine UV intensity are discussed in Section 2.2: suspended solids, SS (mg/l); initial bacterial density, N_o (organisms/100 ml); final bacterial density, N (organisms/100 ml); percent transmittance of wastewater at 253.7 nm; rate coefficients a and b; and the particulate bacteria and suspended solids coefficients c and m, respectively.

Initial values were selected for the parameters that represent UV use at a typical plant:

L_a = 75 cm	S_x = 3 cm
S_y = 3 cm	X_b = 75 cm
Q = 75.6 l/min or 20 gpm	E = 50 cm^2/s
D_q = 2.3; N_b = 3	W_{uv} = 13.5 watts
F_t = 0.7	F_p = 0.65; N_x = 2
N_y = 2	Staggered (0 is No, 1 is Yes)
SS = 15 mg/l	N_o=1.0 e+07 MPN/100ml
N = 5.0 e+03 MPN/100ml	C = 0.9
M = 1.96	A=1.38 e-05
B = 1.1	T = 55%

The program calculated an initial intensity, I, of 37,509 μwatts/cm^2 for a 55% transmittance. Intensity was determined as a function of lamp spacing for several design parameters. Table 2.2 and the corresponding family of curves shown in Figure 2.1 show that intensity increases with increasing transmittance for a given value of lamp spacing. In all cases, intensity decreases with increasing lamp spacing. The rate of decrease is higher for smaller lamp spacings.

Similarly, Table 2.3 and the corresponding curve shown in Figure 2.2 give information on changing the arc length from 75 to 147 cm, for which little change in intensity is observed. Figure 2.3, derived from Table 2.4, compares staggered with unstaggered lamp arrangements, wherein the staggered arrangement produces less than half the intensity of unstaggered lamps. Table 2.5 and the corresponding curve shown in Figure 2.4 show the change in lamp intensity for different lamp arrays; increasing the size of the array matrix from 2 x 2 to 4 x 4 causes a negligible change in intensity and implies that the smaller array is adequate for the test, thus saving money compared to using a larger 3 x 3 or 4 x 4 array. Table 2.6 presents the anticipated flow rates for the Trojan UV2000 pilot unit and the corresponding UV doses obtained from UVDIS 3.1.

TABLE 2.2 Intensity as a Function of Lamp Spacing for Selected Percent Transmittances using the UVDIS 3.1 Computer Model.*

Lamp Spacing	Percent Transmittance							
(cm)	40%	45%	50%	55%	60%	65%	70%	75%
3.0	31,504	33,391	35,401	37,509	39,757	42,162	44,747	47,553
3.5	21,565	23,105	24,737	26,444	28,268	30,229	32,352	34,680
4.0	16,298	17,644	19,116	20,701	22,445	24,372	26,518	28,936
4.5	12,657	13,852	15,158	16,571	18,133	19,873	21,831	24,067
5.0	9,449	10,502	11,668	12,948	14,382	16,004	17,858	20,011
5.5	7,973	8,881	9,896	11,061	12,282	13,726	15,395	17,356
6.0	6,569	7,355	8,242	9,234	10,367	11,676	13,207	15,032
6.5	5,654	6,342	7,124	8,000	9,008	10,180	11,562	13,225
7.0	4,729	5,339	6,034	6,820	7,731	8,798	10,068	11,612
7.5	4,121	4,662	5,279	5,980	6,797	7,759	8,911	10,322
8.0	3,302	3,775	4,320	4,946	5,681	6,554	7,609	8,914
8.5	3,096	3,528	4,026	4,596	5,266	6,063	7,030	8,232
9.0	2,554	2,935	3,380	3,894	4,501	5,231	6,121	7,236
9.5	2,553	2,897	3,301	3,768	4,322	4,989	5,807	6,837
10.0	2,030	2,336	2,703	3,126	3,631	4,244	5,000	5,958
10.5	2,013	2,297	2,633	3,020	3,485	4,049	4,747	5,635

* The following assumptions were made in computing these values.
1. Lamp array = 2 X 2
2. Lamp arc length = 147 cm
3. Lamp configuration = not staggered

tab2-2.wb2

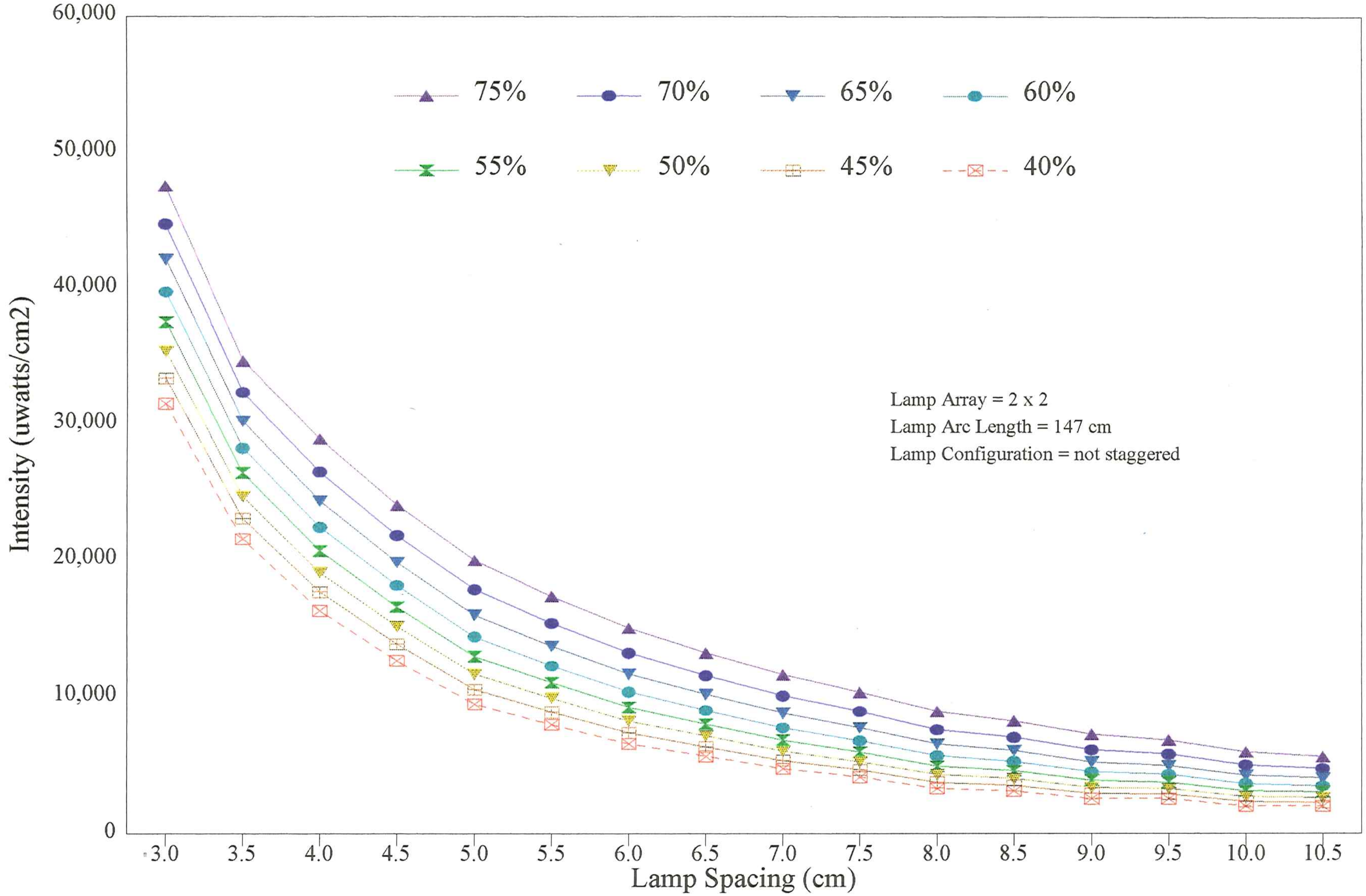


FIGURE 2.1 Intensity as a Function of Lamp Spacing for Selected Percent Transmittance Using the UVDIS 3.1 Computer Model.

tab2-2.wb2:f4.5L5.1

TABLE 2.3 Intensity as a Function of Lamp Spacing for Selected Arc Lengths using the UVDIS 3.1 Computer Model.*

Lamp Spacing (cm)	Arc Length 75 cm	Arc Length 147 cm
3.0	37,509	37,849
3.5	26,444	26,684
4.0	20,701	20,889
4.5	16,571	16,721
5.0	12,948	13,065
5.5	11,061	11,116
6.0	9,234	9,317
6.5	8,000	8,073
7.0	6,820	6,881
7.5	5,980	6,035
8.0	4,946	4,990
8.5	4,596	4,638
9.0	3,894	3,929
9.5	3,768	3,803
10.0	3,126	3,154
10.5	3,020	3,048

* The following assumptions were made in computing these values.
Lamp array = 2 x 2
Percent Transmittance = 55%
Lamp configuration = not staggered

tab2-3.wb2

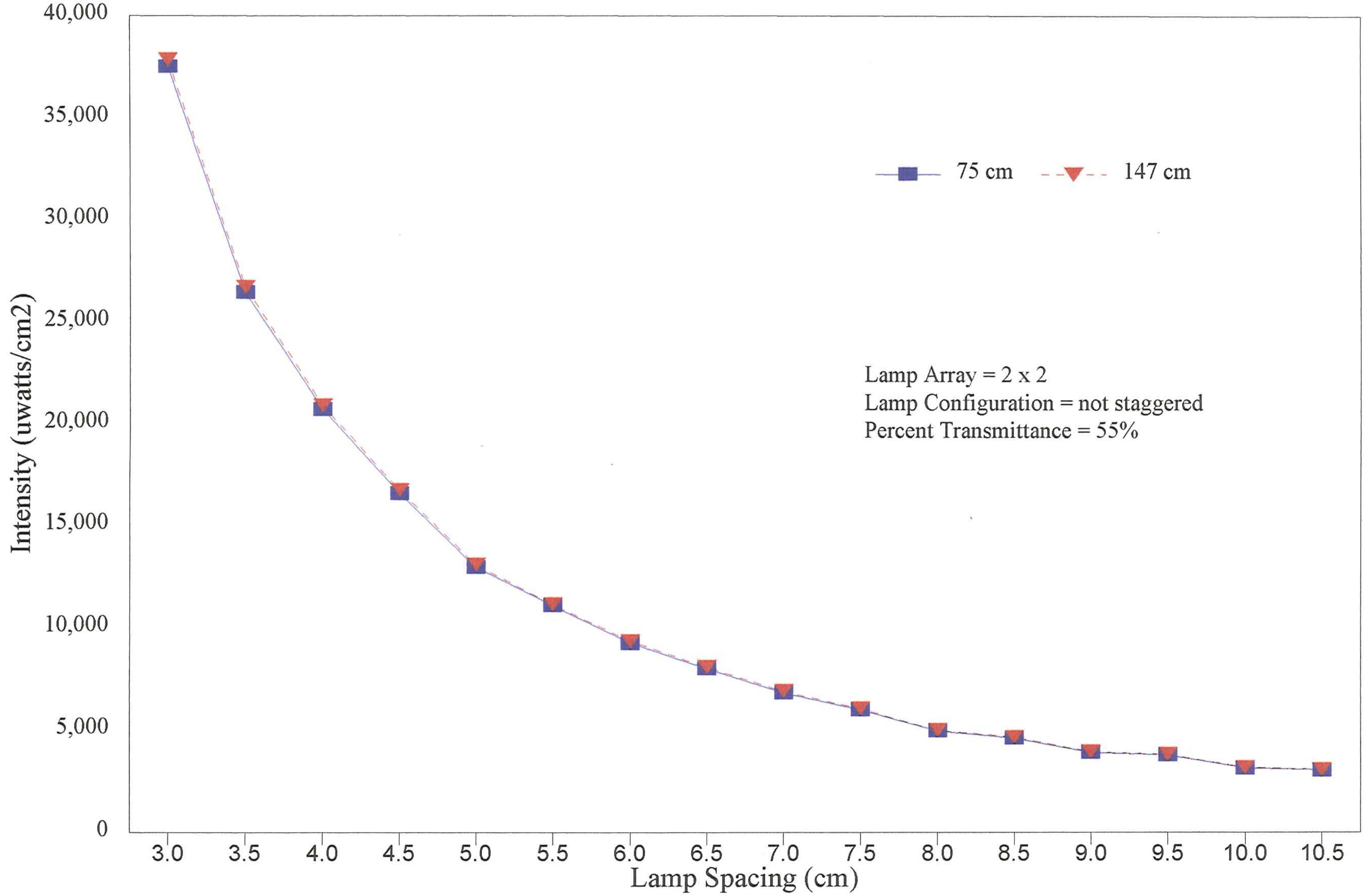


FIGURE 2.2 Intensity as a Function of Lamp Spacing for Selected Arc Lengths Using the UVDIS 3.1 Computer Model.

tab2.2.wb2:f4.5

TABLE 2.4 Intensity as a Function of Lamp Spacing for Selected Lamp Configuration using the UVDIS 3.1 Computer Model.*

Lamp Spacing (cm)	Configuration	
	Unstaggered	Staggered
3.0	37,509	11,850
3.5	26,444	10,710
4.0	20,701	8,520
4.5	16,571	7,114
5.0	12,948	5,512
5.5	11,061	4,996
6.0	9,234	4,030
6.5	8,000	3,744
7.0	6,820	3,024
7.5	5,980	2,897
8.0	4,946	2,316
8.5	4,596	2,232
9.0	3,894	1,823
9.5	3,768	1,791
10.0	3,126	1,496
10.5	3,020	1,440

* The following assumptions were made in computing these values.

1. Lamp array = 2 X 2
2. Percent transmittance = 55%
3. Lamp arc length = 147 cm

tab2-4.wb2

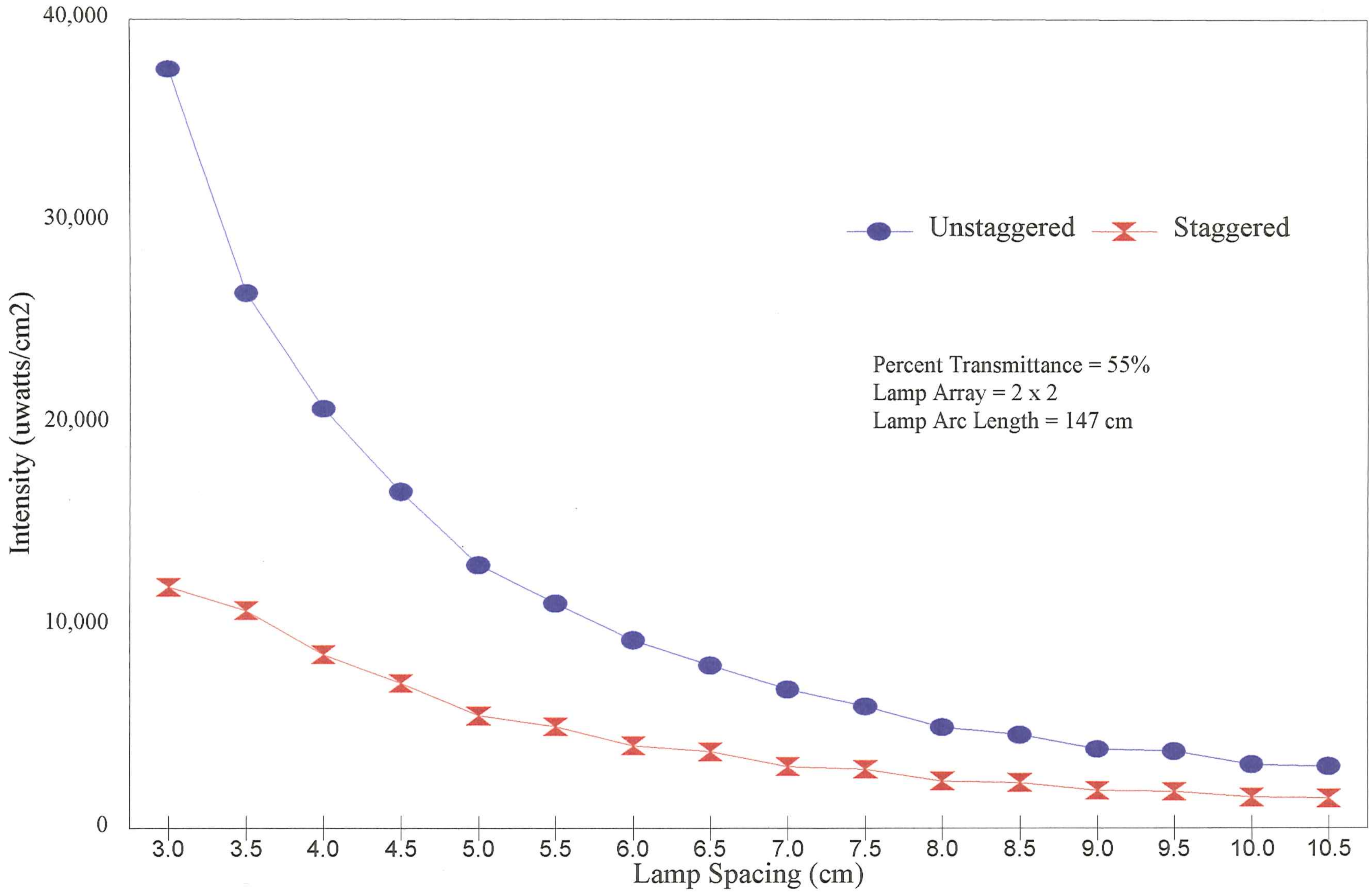


FIGURE 2.3 Intensity as a function of Lamp Spacing for Selected Configurations Using the UVDIS 3.1 Computer Model.

tab2-4.wb2:Graph1

TABLE 2.5 Intensity as a Function of Lamp Spacing for Selected Lamp Arrays using the UVDIS 3.1 Computer Model.*

Lamp Spacing (cm)	Lamp Array 2 x 2	3 x 3	4 x 4
3.0	37,509	37,136	39,845
3.5	26,444	28,586	29,242
4.0	20,701	20,115	21,368
4.5	16,571	17,020	17,113
5.0	12,948	12,381	12,926
5.5	11,061	11,211	11,172
6.0	9,234	8,653	9,122
6.5	8,000	7,818	7,737
7.0	6,820	6,336	6,580
7.5	5,980	5,825	5,728
8.0	4,946	4,791	4,905
8.5	4,596	4,620	4,484
9.0	3,894	3,769	3,849
9.5	3,768	3,736	3,445
10.0	3,126	3,106	3,114
10.5	3,020	2,958	2,902

* The following assumptions were made in computing these values.

1. Transmittance = 55%
2. Lamp arc length = 147 cm
3. Lamp configuration = not staggered

tab2-5.wb2

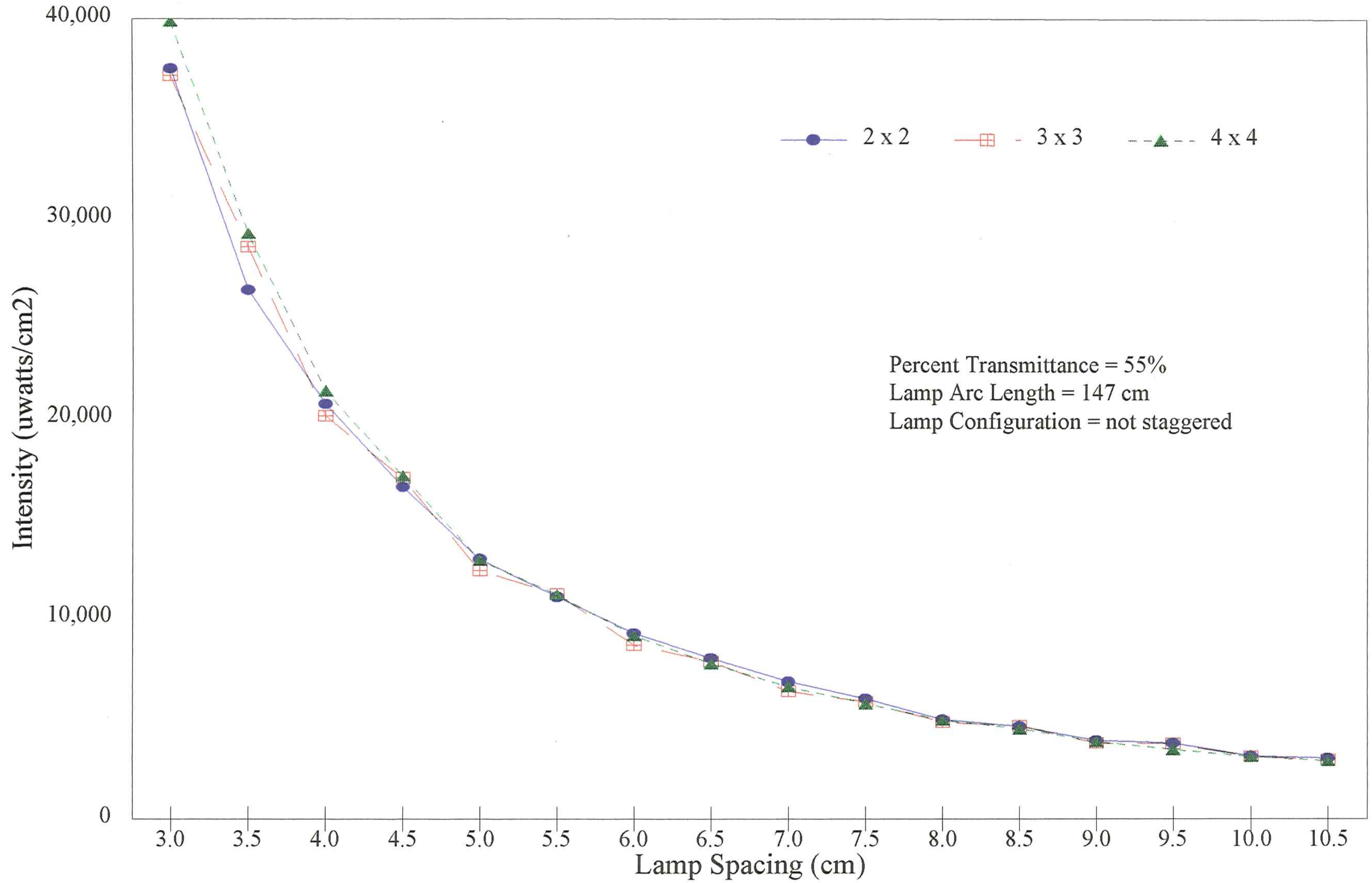


FIGURE 2.4 Intensity as a Function of Lamp Spacing for Selected Lamp Array from the UVDIS 3.1 Computer Model.

tab2-5.wb2:Graph1

Table 2.6 Pilot Test Flow Rates Assuming a 2 x 2, Low Pressure-Low Energy UV Lamp Matrix (eg., TTI's UV2000) with the Expected UV Doses using EPA's UVDIS 3.1 Software.

LAGWRP		TWRP - Phase I		TWRP - Phase II	
Flow Rate Q gpm	Expected UV Dose D mWs/sq cm	Flow Rate Q gpm	Expected UV Dose D mWs/sq cm	Flow Rate Q gpm	Expected UV Dose D mWs/sq cm
75	146.0	60	147.7	65	145.0
85	128.8	70	126.6	75	127.9
100	109.5	80	110.7	85	112.8
110	99.5	90	98.6	100	95.9

tab2-6.wb2

CHAPTER 3

EXISTING CONDITIONS

This chapter presents flow conditions, reclaimed water characteristics and existing disinfection facilities for the LAGWRP, TWRP-Phase I, TWRP-Phase II and TITP, including the proposed TITP advanced treatment. The three facilities, shown in Figures 3.1a, b and c, are sometimes referred to as the "outlying" plants; LAGWRP and TWRP serve the areas upstream of Hyperion Treatment Plant (HTP), while TITP serves the harbor area, south of downtown Los Angeles. LAGWRP and TWRP provide critical hydraulic relief for HTP, which processes the sludge and solids from these plants' primary clarification, waste activated sludge (WAS) and filter backwash. TITP functions completely independent of HTP, treating a flow of greatly varying hydraulics and constituent characteristics, processing both liquids and solids.

3.1 LOS ANGELES-GLENDALE WATER RECLAMATION PLANT

LAGWRP, with a design capacity of 20 mgd, is located at the southeast junction of the Los Angeles River and Colorado Boulevard between Griffith Park and the City of Glendale. LAGWRP provides primary, secondary and tertiary treatment, including chlorination and dechlorination for an average flow of 19.9 mgd. Primary solids, WAS and filter backwash, all of which typically contain 99.9% of the solids, are returned into the sewer for treatment at HTP.

3.1.1 Effluent Quality

Solids and other constituents are removed to provide quality reclaimed water and to comply with the plant's current NPDES permit. The Environmental Monitoring Division (EMD) is responsible for

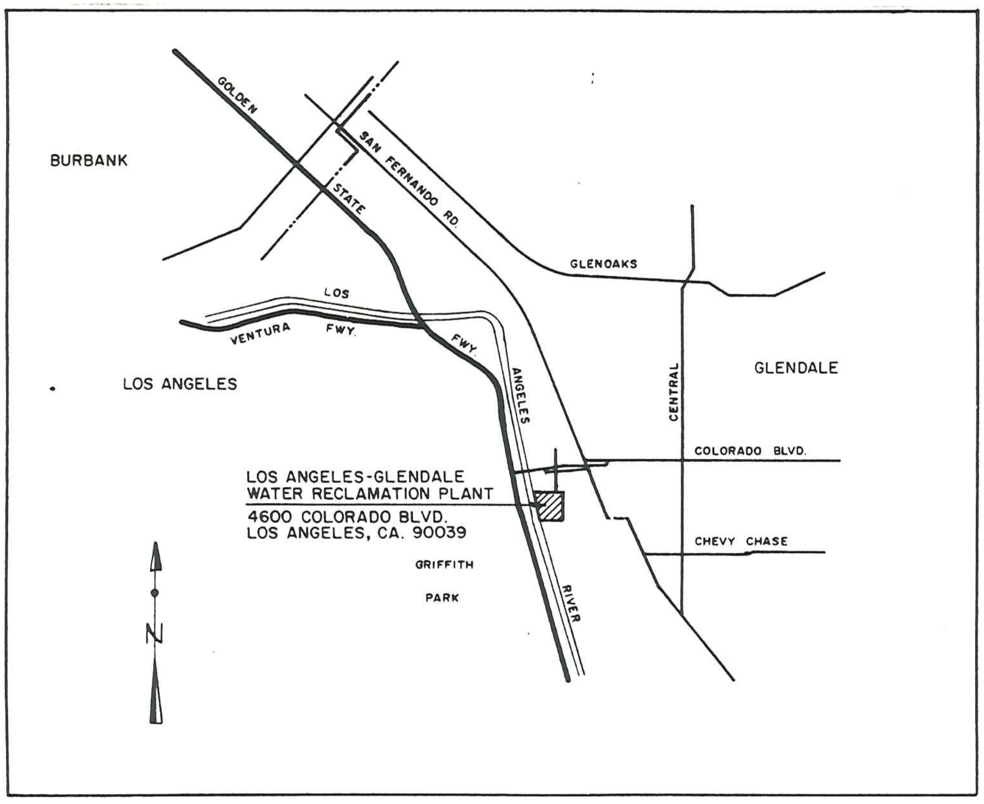


Figure 3.1a
Vicinity Map for the
Los Angeles-Glendale Water Reclamation Plant.

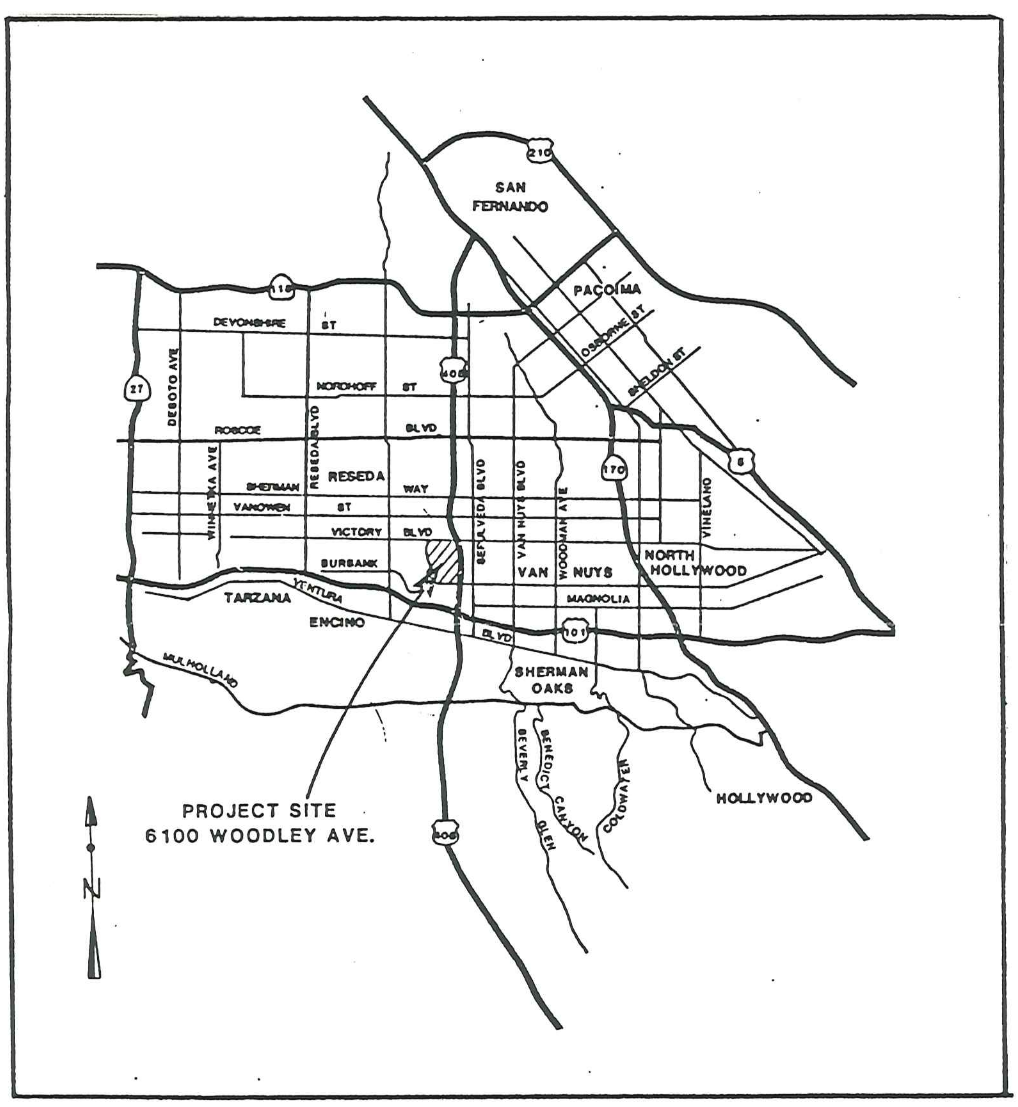


Figure 3.1b
Vicinity Map for the
Donald C. Tillman Water Reclamation Plant.

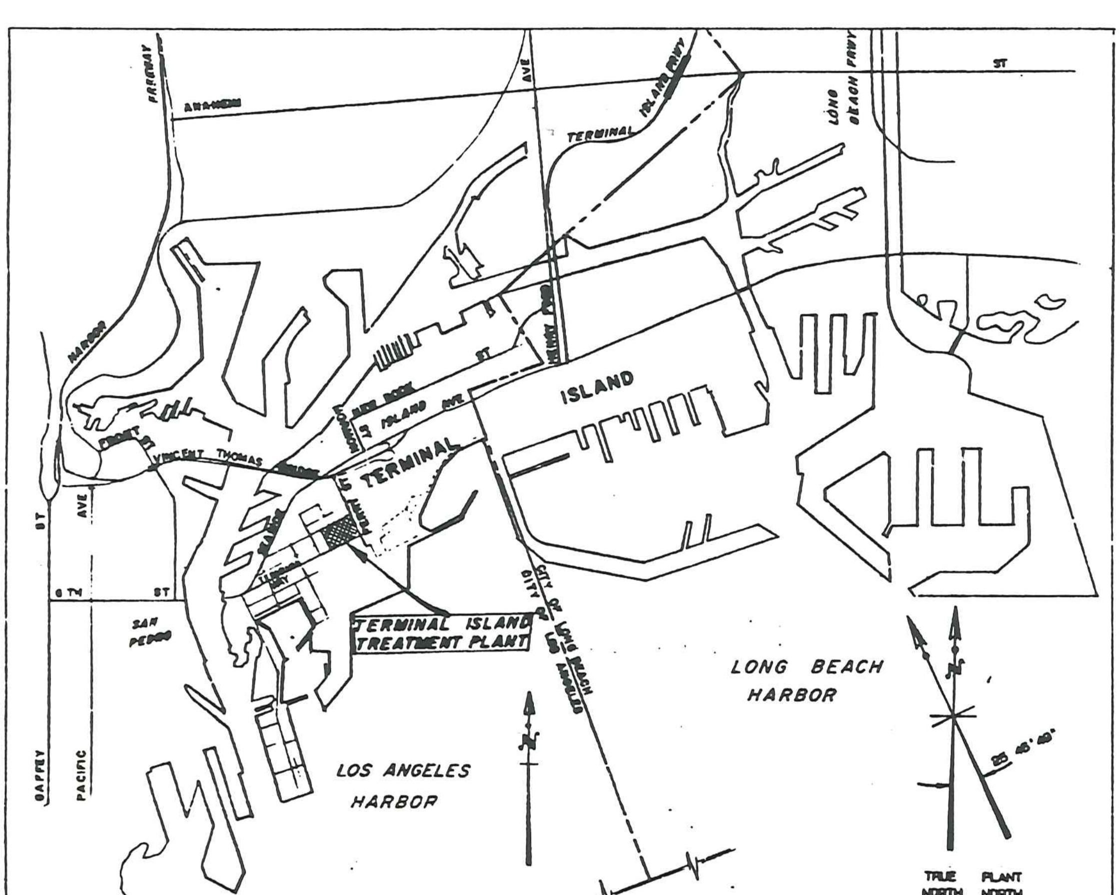


Figure 3.1c
Vicinity Map for the
Terminal Island Treatment Plant.

monitoring influent and effluent wastewater characteristics in accordance with the Monitoring and Reporting Program, which is required by the RWQCB.

EMD also provides a great amount of data for the LAGWRP Monthly Operating Reports. Some of this data is particularly useful in evaluating the effectiveness of the proposed UV disinfection pilot test: plant influent (Q_{inf}) and effluent (Q_{eff}) flow rates, effluent turbidity, suspended solids (SS), biochemical oxygen demand (BOD_5), residual chlorine and settleable solids (STS). Alum feed concentration, oil and grease (O&G) and effluent total coliform are also factors that could affect UV disinfection efficiency. Data for the past few years are shown in Table 3.1, the most critical of which are plotted in Figure 3.2. Typical values, regulatory limits and effects on UV Disinfection are listed in Table 3.2. The average filtrate flow rate, 15.6 mgd, is significantly less than the average plant influent flow rate, 19.9 mgd, due to primary solids, filter backwash, skimmings and WAS all being routed to HTP for treatment. SS, considered to be a key parameter due to the potential to interfere with UV irradiation as occluded mass, averages 2.0 mg/l. Turbidity averages less than 1.0 NTU, significantly lower than the 2 NTU limit, above which transmittance interferences would be attributed partly to turbidity. BOD_5 averages 6.6 mg/l, ranging from 4.5 to 10.2 mg/l. STS averages 0.4 mg/l, with a recorded high of 2.0 mg/l and a minimum of 0.1 mg/l. Oil and grease, a UV light absorber, varies from negligible concentration to 1.5 mg/l, with an average of 0.4 mg/l. Alum, which causes scaling on the quartz sleeves, is used sparingly, averaging about 0.5 mg/l. Total coliform averages 1.0 CFU/100 ml, ranging from 0.6 to 2.4 CFU/100 ml.

3.1.2 Disinfection Facilities

LAGWRP recently completed its dechlorination process conversion from SO_2 to $NaHSO_3$ and is planning a disinfection process conversion from Cl_2 to NaOCl. Conversions to non-gaseous methods of chlorination and dechlorination comply with the Risk Management Prevention Program (RMPP) recommendations for a safer working environment.

TABLE 3.1. Average Daily Effluent Flow Rates and Selected Parameters at LAGWRP.

Year	Month	Qinf	Qrecl	SS	BOD	Turbidity	Cl2 Res., mg/l		STS	O&G	Alum	T-Col
		mgd	mgd	mg/l	mg/l	NTU	CTE	Pond	mg/l	mg/l	mg/l	CFU
1992	Jan	19.9	17.2	1.0	8.5	1.1	4.4	n/a	1.0	0.6	0.4	1.0
	Feb	20.5	17.7	1.0	7.6	0.9	4.6	n/a	2.0	0.9	0.3	1.0
	Mar	20.4	17.1	1.0	7.5	0.9	4.3	n/a	0.5	0.0	0.3	1.0
	Apr	20.3	17.5	1.0	7.7	1.0	4.3	n/a	0.2	0.4	0.4	<1
	May	20.3	17.8	0.9	7.6	0.9	4.2	n/a	0.2	0.2	0.3	1.0
	Jun	20.0	17.5	1.0	6.7	1.1	4.1	n/a	0.1	0.4	0.3	1.0
	Jul	20.1	17.8	1.3	5.5	1.0	3.7	n/a	0.7	0.2	0.3	<1
	Aug	20.3	18.4	1.0	4.8	2.2	4.1	n/a	0.1	0.0	0.3	1.0
	Sep	20.2	18.0	1.4	5.4	2.3	4.2	n/a	0.3	1.5	0.3	1.0
	Oct	19.9	16.9	1.3	6.5	1.1	4.2	n/a	0.2	0.5	0.3	1.0
	Nov	19.7	18.2	1.4	6.2	2.0	4.8	2.5	0.1	0.4	0.3	1.0
	Dec	20.6	16.7	1.0	7.6	0.8	4.7	3.4	0.1	0.3	0.3	1.0
1993	Jan	22.5	16.7	1.6	10.2	0.7	4.9	3.5	n/a	0.3	0.2	2.4
	Feb	21.9	16.0	1.0	7.4	0.7	5.3	3.9	0.1	0.1	0.2	1.0
	Mar	20.5	16.3	1.3	8.5	0.7	5.3	3.8	0.2	0.3	0.2	1.0
	Apr	20.4	17.1	1.5	6.7	0.8	4.4	3.1	0.2	0.8	0.3	1.4
	May	20.0	11.7	2.2	4.5	0.7	4.4	2.7	0.2	0.7	0.2	1.0
	Jun	18.3	14.4	2.9	5.8	0.7	3.9	2.0	0.4	0.0	0.3	0.9
	Jul	19.7	14.9	3.5	8.0	0.8	2.6	1.1	0.3	0.0	0.2	0.7
	Aug	20.0	15.2	3.0	6.7	0.7	3.4	1.5	0.2	0.0	0.2	0.9
	Sep	21.0	14.8	2.2	6.7	0.8	4.0	1.9	0.2	0.0	0.2	2.1
	Oct	20.5	15.2	1.9	6.2	0.7	4.6	2.4	0.3	0.3	0.3	0.8
	Nov	20.0	15.3	3.8	6.5	0.8	4.2	2.3	0.4	1.0	0.3	0.7
	Dec	20.2	15.2	1.7	5.1	1.0	4.7	3.4	0.4	0.3	0.3	1.3
1994	Jan	19.6	13.8	2.3	5.2	0.5	4.6	3.0	0.2	n/a	0.3	0.6
	Feb	20.3	14.1	4.3	5.8	0.6	4.5	3.2	0.3	n/a	0.3	0.9
	Mar	19.9	13.7	3.7	6.3	0.8	4.4	3.0	0.3	2.0	0.4	0.8
	Apr	19.9	14.2	1.8	5.1	0.6	4.2	2.6	0.4	0.5	0.3	0.7
	May	19.9	15.4	2.4	5.2	0.5	3.9	2.4	1.0	1.0	0.3	0.8
	Jun	18.7	13.7	2.5	6.8	0.5	4.2	2.2	1.0	0.0	0.3	1.2
	Jul	18.6	13.2	4.0	9.1	0.4	4.3	2.1	1.0	1.0	1.8	2.4
	Aug	17.9	13.3	2.1	6.1	0.7	4.2	1.9	1.0	1.0	2.0	0.7
	Sep	17.9	13.6	2.3	6.1	0.4	3.9	2.0	0.5	n/a	1.8	0.7
	Oct	17.3	13.6	3.1	5.2	0.6	4.1	1.9	1.0	n/a	2.1	0.7
	Nov	19.5	13.5	2.8	5.5	0.6	4.5	2.2	0.4	n/a	1.8	0.6
	Dec											
1995	Jan											
	Feb	18.7	14.6	2.0	7.7	1.1			0.0			1.0
	Mar											
Averages:		19.9	15.6	2.0	6.6	0.9	4.3	1.8	0.4	0.4	0.5	1.0

Legend:

n/a = not available
Qrecl = filter effluent (reclamation) flow rate, mgd
Cl2 Res. = residual chlorine, mg/l
T-Col = total coliform, CFU
CTE = chlorine tank effluent
CFU = colony forming units; either MPN or CFU can be used

A:Tables &Figures\tfb\T3-1.WB2\T31

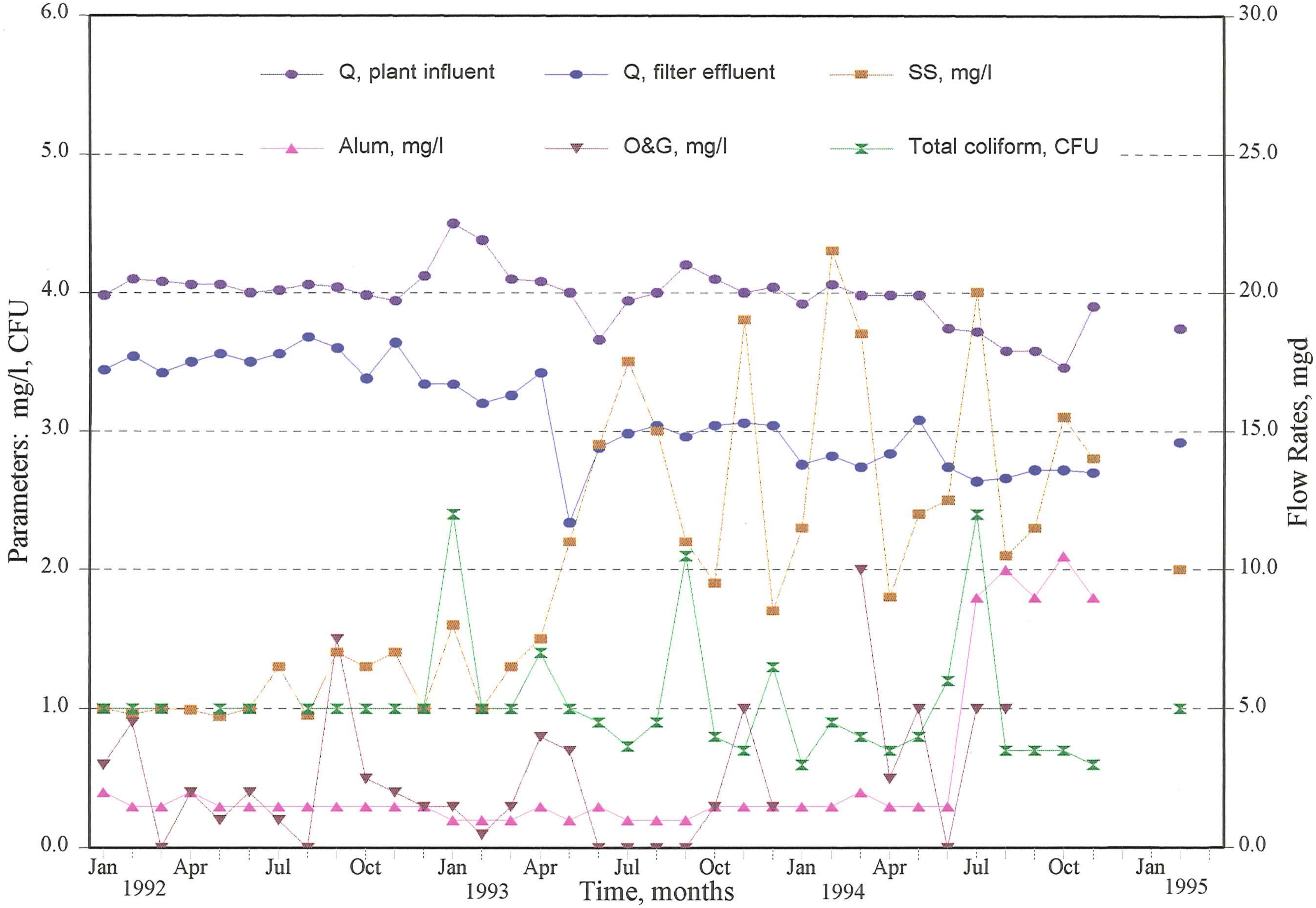


Figure 3.2. Average Daily Flow and Selected Parameters for LAGWRP.

tf\ T3-1.WB2:Fig3.2

TABLE 3.2. Selected LAGWRP Process Performance Parameters, Ranges, Regulatory Limits and Effects on UV Disinfection

Process Performance Parameter	Usual Range	NPDES 30-day Average Regulatory Limits	Effect on UV Disinfection
Influent Flow , Rate	17-21 mgd	20 mgd plus storm flow (not an NPDES limit)	n/a
Filtered Effluent Flow Rate (Flow to be disinfected)	13-18 mgd	n/a	Design capital cost for 20 mgd Design operations for 16 mgd
Suspended Solids	1-4 mg/l	15 mg/l	High SS increases likelihood of occluded masses, and interference with and absorbance of UV irradiation
Alum	0.2-2.1 mg/l	n/a	Causes scaling on quartz sleeves
Oil and Grease	0-2.0 mg/l	10 mg/l	Absorbs UV irradiation
Total Coliform	0.6-2.4 CFU	2.2 CFU/100 ml (also Title 22)	One of four bases for evaluating UV disinfection effectiveness
Biochemical Oxygen Demand	5-10 mg/l	20 mg/l	High BOD increases likelihood of occluded masses, and interference with and absorbance of UV irradiation
Turbidity	0.4-2.3 NTU	2 NTU (also Title 22)	High turbidity increases likelihood of occluded masses, and interference with and absorbance of UV irradiation
Chlorine Residual	2-4 mg/l	0.1 mg/l	Absorbs UV irradiation
Settleable Solids	<0.1 ml/l	0.1 ml/l	In a storm situation, could interfere with UV irradiation

n/a = not applicable

tf\fab3-2.wb2

The chlorination facility consists of sixteen 1-ton liquid Cl_2 containers, three evaporators, four chlorinators, chlorine residual analyzers and two serpentine contact tanks. Liquid Cl_2 is trucked to the plant five times a month, stored, connected and delivered through a 1-inch pipe into the evaporators. Chlorine gas is then passed through a vacuum regulating valve and drawn to the chlorinators which control the gas dosage into the stream.

Construction of the NaOCl facility is planned to begin in late 1995. This upgrade will consist of two large storage tanks (10 ft diameter by 10 ft high), chemical feed pumps, a containment wall around the tanks and appurtenant piping.

3.2 TILLMAN WATER RECLAMATION PLANT

The TWRP, with a design capacity of 80 mgd, is located in the Sepulveda Dam Basin in the San Fernando Valley. TWRP provides primary, secondary and tertiary treatment, including chlorination and dechlorination. Primary sludge, WAS and filter backwash are returned to the sewers for treatment at HTP. Phases I (TWRP-Ph I) and II (TWRP-Ph II) operate almost independently of each other.

3.2.1 Effluent Quality

Solids and other constituents are treated to provide quality reclaimed water and to comply with the current NPDES permit. EMD monitors influent and effluent wastewater parameters in accordance with the Monitoring and Reporting Program required by the RWQCB.

EMD also provides a great amount of data for the TWRP Monthly Operating Reports. Some of this data is particularly useful in evaluating the effectiveness of the proposed UV disinfection pilot test. Monthly data for TWRP-Phase I for the last three years are shown in Table 3.3(a), from which critical parameters are plotted in Figure 3.3(a). The same parameters are presented for TWRP-Phase II in

TABLE 3.3a Average Daily Flow Rates And Selected Parameters For TWRP-Phase I.

Year	Month	Qave	FeCl3	Polymer	SS	BOD	Turbidity, NTU		Cl2 dose, mg/l		Chloride	O&G	TDS	T-Coli
		mgd	mg/l	mg/l	mg/l	mg/l	Ph I	Net Eff	pre-Filter	post-Filter	mg/l	mg/l	mg/l	Mean CFU
1992	Jan	20.4	0.00	0.07	4	8	2.3	1.4	7.1	13.1	125	0.3	519	1
	Feb	21.8	0.00	0.06	3	8	1.5	1.3	7.0	13.5	164	1.0	654	1
	Mar	21.6	0.00	0.07	4	8	1.4	1.3	8.1	13.1	151	1.2	670	1
	Apr	21.3	0.00	0.10	4	6	1.8	1.3	8.6	14.9	n/a	1.4	n/a	n/a
	May	21.6	0.00	0.10	4	8	2.1	1.4	7.3	14.3	137	0.9	576	1
	Jun	19.5	0.00	0.10	4	8	1.8	1.4	6.6	16.9	146	2.6	608	1
	Jul	18.4	0.03	0.10	3	6	1.6	1.3	9.9	14.1	132	0.7	554	1
	Aug	15.7	0.00	0.11	3	7	1.7	1.2	10.9	15	n/a	0.6	567	1
	Sep	16.8	0.00	0.10	4	8	1.5	1.4	9.8	14.2	144	1.2	607	1
	Oct	18.1	0.04	0.08	3	7	1.7	1.5	8.2	12.2	157	0.7	628	1
	Nov	20.8	0.00	0.07	4	7	1.6	1.8	7.7	13.2	155	0.5	639	1
	Dec	24.2	0.00	0.07	4	7	1.6	1.4	7.1	13.3	146	0.1	621	1
1993	Jan	26.1	0.00	0.07	4	9	1.7	1.7	9.2	14.8	515	0.4	692	3
	Feb	27.0	0.00	0.07	4	9	1.8	1.8	7.5	15.6	166	2.7	754	3
	Mar	25.1	0.00	0.07	4	8	1.8	1.7	10.2	16.7	130	1.3	764	1
	Apr	22.8	0.00	0.08	4	8	2.1	1.8	12.0	18.7	141	1.5	748	1
	May	19.3	0.00	0.09	4	6	1.4	1.7	8.8	17.1	135	0.7	676	1
	Jun	19.5	0.00	0.09	4	8	1.6	1.8	10.3	16.8	127	0.9	598	1
	Jul	18.8	0.00	0.09	3	10	1.4	1.7	8.3	16.9	127	1.1	545	1
	Aug	21.2	0.00	0.08	3	7	1.2	1.2	8.2	15.2	126	0.4	545	1
	Sep	21.8	0.02	0.09	3	9	1.3	1.2	6.8	13.8	120	<0.1	536	1
	Oct	21.3	0.00	0.08	3	8	1.9	1.8	5.4	11.9	126	0.5	564	1
	Nov	22.5	0.00	0.10	3	8	1.9	1.9	3.9	12.5	131	2.2	632	1
	Dec	23.2	0.00	0.09	3	9	1.9	1.6	3.1	14.3	118	2.5	585	1
1994	Jan	21.6	0.00	0.09	4	8	1.9	1.8	4.7	13.7	136	<0.1	584	1
	Feb	25.9	0.00	0.09	4	11	1.8	1.8	7.3	9.4	117	2.1	567	1
	Mar	27.5	0.00	0.09	4	11	1.9	2.0	9.0	11.6	132	<0.1	615	1
	Apr	31.1	0.00	0.10	3	7	1.5	1.7	8.6	8.6	141	0.4	631	1
	May	30.6	0.00	0.10	3	7	1.7	1.6	8.7	9.2	151	1.2	643	1
	Jun	33.0	0.00	0.10	3	7	1.4	1.5	8.0	9.3	147	2.7	597	1
	Jul	32.6	0.00	0.09	3	9	1.6	1.5	10.0		131	1.2	564	1
	Aug	31.8	0.00	0.10	3	9	1.4	1.6	8.4		123	1.7	541	1
	Sep	30.6	0.00	0.09	3	7	1.6	1.8	8.1		129	0.9	563	1
	Oct	28.7	0.00	0.10	3	8	1.8	1.7	7.4		130	1.0	569	1
	Nov	25.9	0.00	0.10	3	7	2.2	1.9	8.6		122	1.3	567	1
	Dec	25.7	0.00	0.08	3	7	2.0	2.1	8.5		129	0.5	565	1
1995	Jan	27.4	0.00	0.08	3	8	2.0	1.9	9.7		99	0.7	527	1
	Feb	22.1	0.00	0.09	3	6	2.2	2.1	9.6		102	1.9	612	1
	Mar	22.9	n/a	0.08	2	6	1.4	1.6	9.1		111	<2.8	732	1
Averages		23.7	0.00	0.09	3	8	1.7	1.6	8.1	13.8	130	1.1	594	1

n/a = not available

A:tf\Tab3-3a.WB2:B

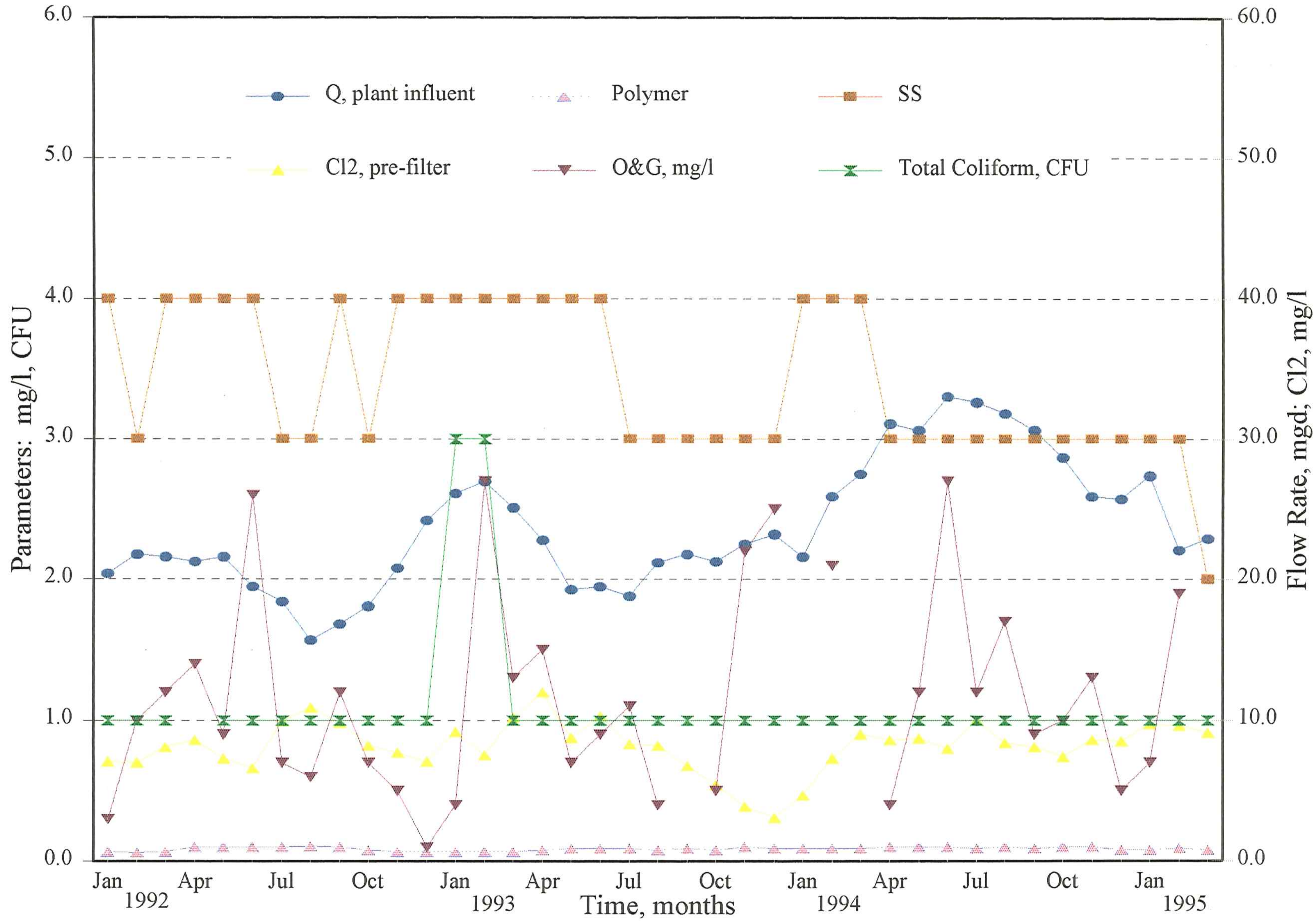


Figure 3.3a. Average Daily Flow and Selected Parameters for TWRP - Phase I.

tf\ T3-3a.WB2:Fig3.3a

Table 3.3(b) and plotted in Figure 3.3(b). Filtrate flow rate, SS, BOD_5, polymer feed concentration, ferric chloride dosage and pre-filtration chlorine feed concentration are factors that affect UV disinfection dose and efficiency. The monthly average values of each parameter in both phases are nearly equal, except for the effluent flows of only 23.7 mgd from Phase I and 36.3 mgd from Phase II. Ferric chloride addition is used sparingly, and is negligible when used, while polymer addition averages 0.08 and 0.09 mg/l for Phases I and II, respectively. SS, O&G and total coliforms average 3 mg/l, 1.1 mg/l and 1 CFU/100 ml, respectively, for both phases. The pre-filter Cl_2 dose averages 6.9 mg/l for Phase I, and 8.1 mg/l for Phase II.

3.2.2 Disinfection Facilities

The existing chlorination facility consists of an unloading area, two 17-ton Cl_2 container tanks, four evaporators, nine chlorinators, four residual analyzers, one in-channel diffuser each for Phases I and II and four serpentine contact tanks. Liquid Cl_2 is drawn from the 17-ton container to a 1-inch pipe and into the evaporators for gas conversion. Cl_2 gas passes through a vacuum regulator valve to a chlorinator. From the chlorinator, Cl_2 gas passes through an ejector where the$_2$Cl dosage is controlled. The Cl_2 storage facility is equipped with a weighing and a leak-alarm system. The storage tanks themselves are equipped with pressure indicators. Equipment replacement is expected by the year 2005 [Ref. a3].

SO_2 is used for dechlorination. The dechlorination facility consists of an unloading dock, two 25-ton storage tanks, four evaporators and four sulfonators. SO_2 is drawn from the 25-ton storage vessel to a 1-inch pipe into the evaporators for gas conversion. SO_2 passes through a vacuum regulator valve to the sulfonator, then through an ejector into the effluent flow stream. The SO_2 facility includes a leak emergency system with SO_2 detectors, a venturi scrubber, a sodium hydroxide (NaOH) caustic pump and a SO_2 vent scrubber, as required by the RMPP [Ref. a3].

TABLE 3.3b Average Daily Flow Rates And Selected Parameters For TWRP-Phase II.

Year	Month	Qave	FeCl3	Polymer	SS	BOD	Turbidity, NTU		Cl2 dose, mg/l		Chloride	O&G	TDS	T-Coli
		mgd	mg/l	mg/l	mg/l	mg/l	Ph II	Net Eff	pre-Filter	post-Filter	mg/l	mg/l	mg/l	Mean CFU
1992	Jan	34.6	0.00	0.06	4	8	1.7	1.4	11.1	11.5	125	0.3	519	1
	Feb	38.8	0.00	0.06	3	8	1.6	1.3	7.0	10.4	164	1.0	654	1
	Mar	40.4	0.00	0.06	4	8	2.5	1.3	7.3	9.9	151	1.2	670	1
	Apr	39.9	0.00	0.08	4	6	2.3	1.3	7.6	10.3	n/a	1.4	n/a	n/a
	May	38.7	0.00	0.08	4	8	1.2	1.4	6.2	11.5	137	0.9	576	1
	Jun	40.5	0.00	0.08	4	8	1.4	1.4	4.6	12.2	146	2.6	608	1
	Jul	42.0	0.03	0.08	3	6	1.3	1.3	6.9	11.6	132	0.7	554	1
	Aug	45.9	0.00	0.08	3	7	1.0	1.2	6.7	9.2	140	0.6	567	1
	Sep	44.5	0.00	0.08	4	8	1.1	1.4	7.1	10.1	144	1.2	607	1
	Oct	41.7	0.04	0.09	3	7	1.3	1.5	6.6	9.9	157	0.7	628	1
	Nov	36.9	0.00	0.10	4	7	1.5	1.8	6.1	10.2	155	0.5	639	1
	Dec	35.1	0.00	0.10	4	7	1.4	1.4	5.8	10.3	146	0.1	621	1
1993	Jan	38.8	0.00	0.09	4	9	1.7	1.7	5.3	10.4	143	0.4	692	1
	Feb	41.3	0.00	0.09	4	9	1.6	1.8	5.3	11.7	166	2.7	754	3
	Mar	39.2	0.00	0.09	4	8	2.0	1.7	7.1	14.3	130	1.3	764	1
	Apr	38.6	0.00	0.09	4	8	2.0	1.8	7.6	14.2	141	1.5	748	1
	May	40.4	0.00	0.09	4	6	2.0	1.7	5.0	10.0	135	0.7	676	1
	Jun	40.0	0.00	0.09	4	8	2.0	1.8	5.0	12.4	127	0.9	598	1
	Jul	40.2	0.00	0.09	3	10	2.1	1.7	5.3	12.5	127	1.1	545	1
	Aug	39.1	0.00	0.09	3	7	1.8	1.2	9.7	12.4	126	0.4	545	1
	Sep	39.8	0.02	0.07	3	9	1.6	1.2	5.6	10.0	120	<0.1	536	1
	Oct	41.0	0.00	0.09	3	8	2.1	1.8	4.3	9.9	126	0.5	564	1
	Nov	38.6	0.00	0.11	3	8	2.0	1.9	3.2	10.6	131	2.2	632	1
	Dec	37.2	0.00	0.09	3	9	1.6	1.6	3.7	11.2	118	2.5	585	1
1994	Jan	35.9	0.00	0.09	4	8	1.9	1.8	4.7	12.9	136	<0.1	584	1
	Feb	34.5	0.00	0.09	4	11	2.0	1.8	6.9	10.8	117	2.1	567	1
	Mar	31.9	0.00	0.08	4	11	2.2	2.0	8.8	8.8	132	<0.1	615	1
	Apr	25.5	0.00	0.09	3	7	2.2	1.7	10.4	9.2	141	0.4	631	1
	May	26.3	0.00	0.08	3	7	1.7	1.6	9.6	9.6	151	1.2	643	1
	Jun	25.7	0.00	0.07	3	7	1.8	1.5	9.5		147	2.7	597	1
	Jul	24.6	0.00	0.07	3	9	1.7	1.5	9.6		131	1.2	564	1
	Aug	26.6	0.00	0.08	3	9	1.5	1.6	9.6		123	1.7	541	1
	Sep	27.2	0.00	0.08	3	7	1.6	1.8	9.0		129	0.9	563	1
	Oct	28.4	0.00	0.09	3	8	1.7	1.7	6.8		130	1.0	569	1
	Nov	31.2	0.00	0.09	3	7	2.1	1.9	7.2		122	1.3	567	1
	Dec	29.9	0.00	0.07	3	7	2.5	2.1	9.8		129	0.5	565	1
1995	Jan	35.4	0.00	0.09	3	8	2.2	1.9	9.9		99	0.7	527	1
	Feb	37.1	0.00	0.09	3	6	2.2	2.1	8.8		102	1.9	612	1
	Mar	40.7	n/a	0.08	2	6	1.8	1.6	13.5		111	<2.8	732	1
Averages		36.3	0.00	0.08	3	8	1.8	1.6	6.9	10.6	124	1.1	594	1

n/a = not available

A:\tf\Tab3-3b.WB2:C

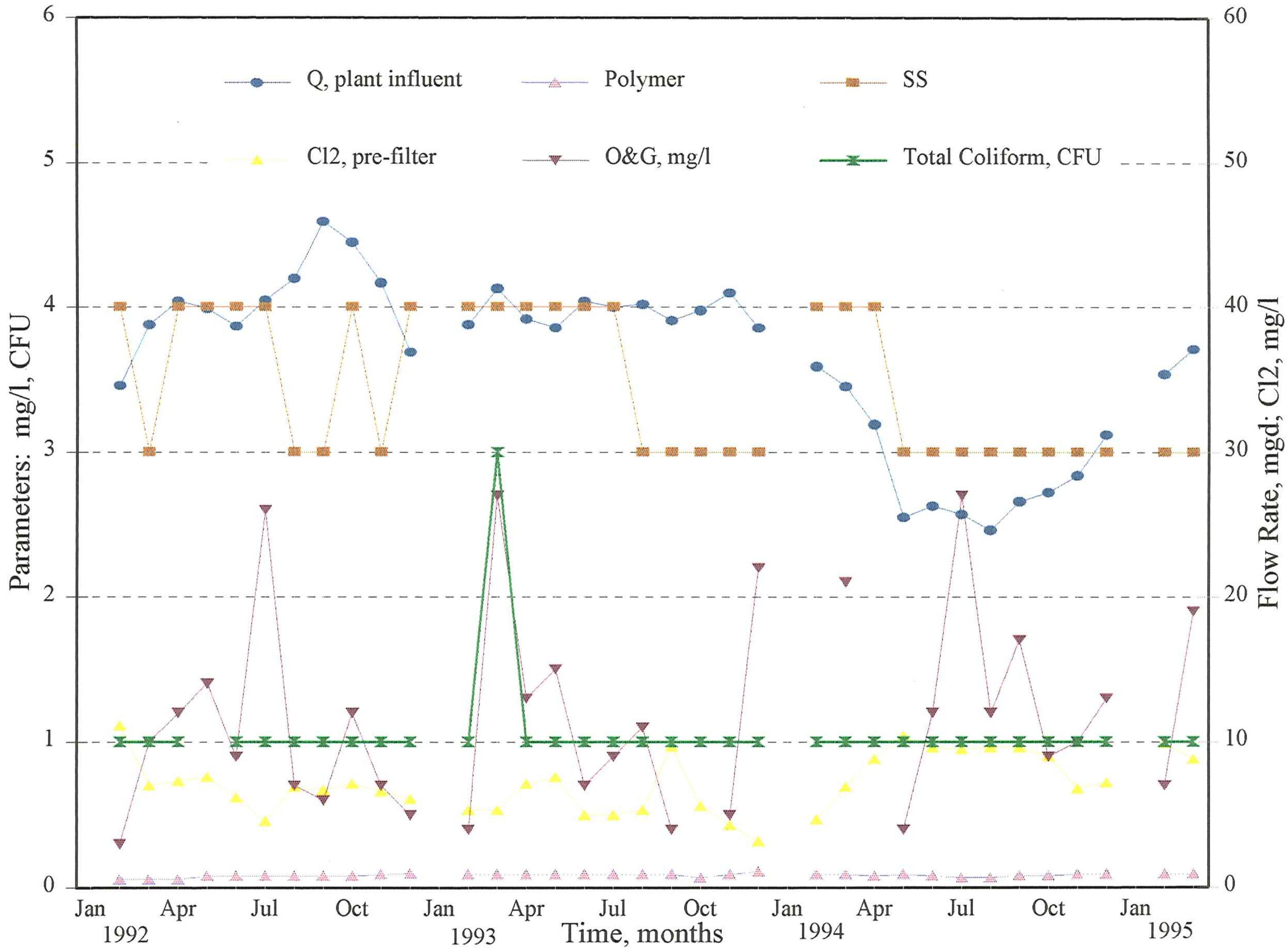


Figure 3.3b. Average Daily Flow and Selected Parameters for TWRP - Phase II.

tf\ T3-3b.WB2:Fig3.3b

3.3 TERMINAL ISLAND TREATMENT PLANT

TITP, with a design capacity of 30 mgd, is located in the Los Angeles Harbor area at the northwest corner of Terminal Way and Ferry Street. TITP serves those portions of the City of Los Angeles known as San Pedro, Wilmington, Harbor City, and a small strip of the City along the Harbor Freeway.

TITP provides primary, secondary and solids treatment. The plant effluent is not chlorinated as it discharges to the ocean. Tertiary treatment, consisting of tri-media filters, is presently under construction, with completion scheduled for June 1996. The Department of Water and Power (DWP) is conducting a pilot test on microfiltration (MF) and reverse osmosis (RO), which is part of the TITP NPDES Permit and of an agreement with the RWQCB to produce 5.0 mgd of reclaimed water by the end of 1999. Most of this reclaimed water is planned to be used by the County of Los Angeles for groundwater recharge into the Dominguez Gap to serve as a seawater barrier. DWP intends to use the remainder of reclaimed water for boiler water feed at its Harbor Generating Station.

3.3.1 Effluent Quality

Data from the 1993 Pilot Filter Study is available, but in limited quantity. Data for transmittance, turbidity and SS are presented in Table 3.4 and plotted in Figure 3.4. Transmittance data taken during the pilot filter test is included and discussed in Section 3.4. Considering the high levels of SS and BOD_5 in the filter feed (clarified secondary effluent, spiked with mixed liquor), the conventional tri-media filter performed very well to produce product water with an average of 0.3 mg/l SS and 0.5 NTU during the pilot run. It should be pointed out that the test did not include running normal secondary clarified effluent through the filters, which may normally result in higher quality product water and/or greater filter efficiency.

TABLE 3.4 Conventional Trimedia Filter Influent and Effluent Absorbance, Percent Transmittance and Selected Characteristics from the 1993 TITP Pilot Filter Test.

Date/Time	Absorbance		% Transmittance		Filter rate	Spiked SS	Coagulant	SS, mg/l		NTU	
m-d-hr	Inf.	Eff.	Inf.	Eff.	gpm/ft2	mg/l	mg/l	Inf.	Eff.	Inf.	Eff.
3-23@1000	0.332	0.244	46.6	57.0	4	30-45	1.5	31	0.2	13	0.4
3-23@1300	0.397	0.241	40.1	57.4	4	30-45	1.5	44	1.6	16	0.3
4-6@0300	0.540	0.285	28.8	51.9	2	75-100	NU	122	0.4	55	0.5
4-7@2000	0.345	0.289	45.2	51.4	2	30-45	NU	36	0.3	12	0.6
4-8@0300	0.365	0.300	43.2	50.1	4	30-45	NU	28.5	0.3	13	0.4
4-8@1000	0.363	0.288	43.4	51.5	4	30-45	NU	40	0.4	16	0.5
4-8@1300	0.382	0.310	41.5	49.0	4	30-45	NU	38	0.2	19	0.4
4-8@2000	0.419	0.280	38.1	52.5	4	30-45	NU	61	0.3	27	0.4

Notations:

Spiked SS: Target range for spiking pilot filter influent with mixed liquor.
SS Inf: Influent suspended solids spiked with mixed liquor.
SS Eff: Filter effluent suspended solids.
NTU Inf: Filter influent turbidity spiked with mixed liquor.
NTU Eff: Filter effluent turbidity.
NU: No coagulant used.

A:\tf\Tab3-4&5.WB2:T33

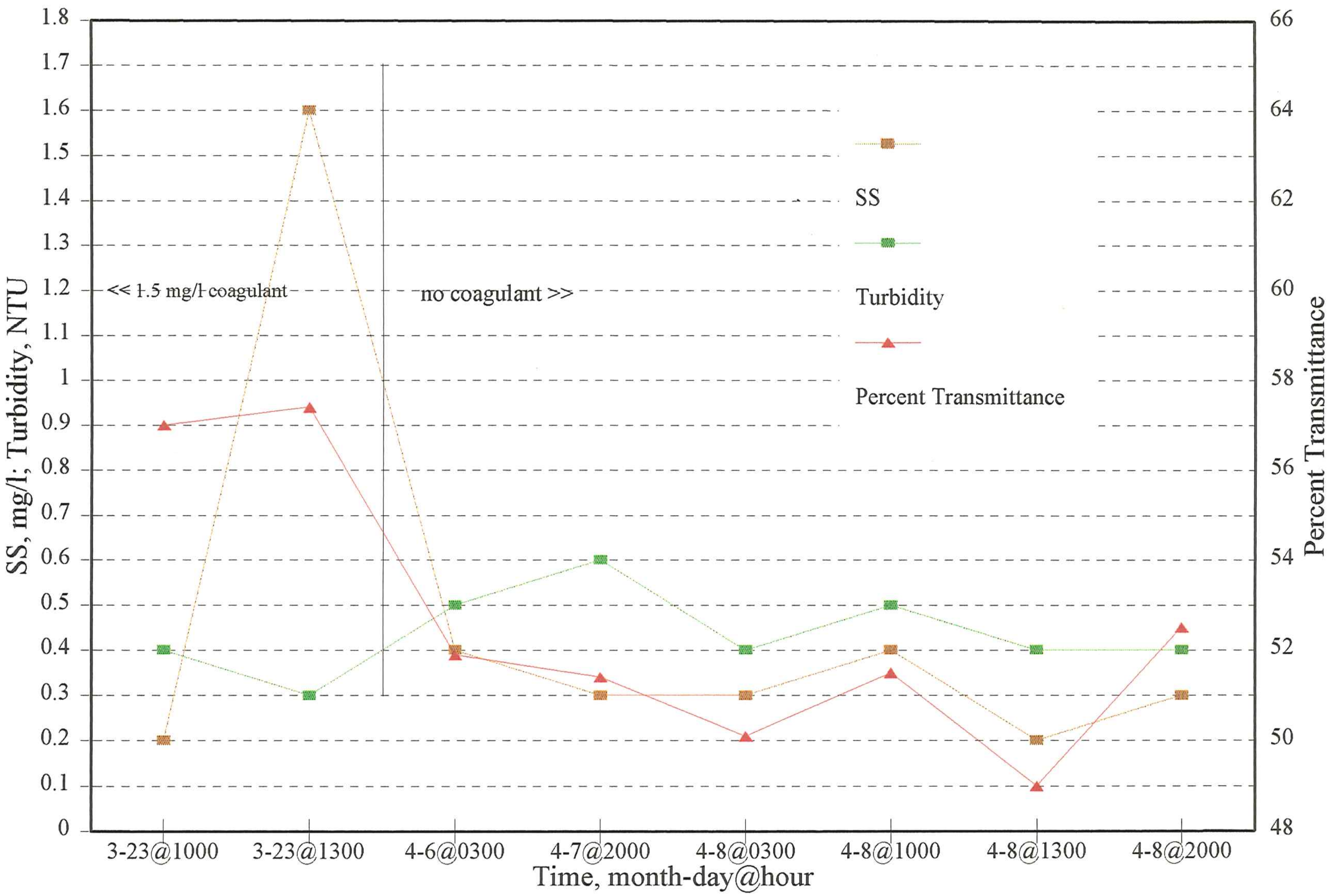


Figure 3.4. Selected TITP Pilot Filter Effluent Data from the Conventional Tri-Media Pilot Filter.

A:\ tf T3-4&5.WB2:F3.4

3.3.2 Tertiary Treatment and Proposed Reclamation

The EPA and State policy for enclosed bays and estuaries requires either the cessation of municipal wastewater discharges to these water bodies or a demonstration of enhancements of the quality due to the continuing discharge. Although recent court rulings have struck down the Bays and Estuaries Plan, the prior Cease and Desist Order to stop discharging the TITP effluent to the harbor still stands. A petition for an exception to the State policy for the TITP effluent discharge has been approved by the RWQCB-Los Angeles Region and is under evaluation by the SWRB. If this petition is rejected, then the City is obligated to pursue water reclamation, unless it decides to proceed with extending the outfall beyond the harbor at a significant cost. On July 19, 1994, the City Council resolved that water reclamation is the best response to the State's requirements. This resolution is supportive of the City's policy to recycle 40 percent of all treated wastewater by the year 2010. The Local Water Reuse Project, developed by the Wastewater Program Management Division (WPMD) in 1991, includes plans to reclaim from 2 to 8 mgd of the TITP effluent for reuse by local industries. The proposed advanced treatment would include tri-media filters, reverse osmosis, chlorination and dechlorination.

DWP is proceeding with their pilot testing of microfiltration and revese osmosis for advanced treatment. The ultimate goal is to produce 5.0 mgd of reclaimed water by 1999, 10 mgd by 2005 and full reclamation of the plant effluent by 2020.

3.4 EFFLUENT TRANSMITTANCE

Percent transmittance of treated wastewater is considered to specifically indicate the degree of UV irradiation required to disinfect the given flow stream, somewhat analogous to oxidation-reduction potential (ORP) and to Cl_2 demand. Transmittance is defined as (-)absorbance raised to the power of ten [ref. b18], where absorbance is the parameter directly measured to monitor the requirement for the UV disinfection dose. Most studies use percent transmittance as an indicator for treatability of an effluent by UV disinfection, where higher transmittance is indicative of more effective UV disinfection and, thus, a lower UV dose is needed. The USEPA uses percent transmittance to calculate UV intensity as discussed in Chapter 2. Emerick and Darby (Ref. b23) use percent transmittance as a significant factor to calculate the water quality factor, f, for which SS is also an important consideration. Continuous transmittance monitoring is recommended, but grab samples must be evaluated with laboratory bench-top analyzers until continuous monitoring equipment can be tested and purchased.

Table 3.5 presents a statistical summary of the transmittance data from grab samples at LAGWRP, TWRP Phase I, TWRP Phase II and TITP during October, November and December of 1993, including that of residual Cl_2, a known UV absorber. These are plotted as histograms in Figures 3.5(a), (b), (c) and (d), respectively. Table 3.6 presents the data from which Table 3.5 and Figures 3.5(a), (b), (c) and (d) were developed. The 64% average transmittance at LAGWRP is significantly higher than the 55% minimum specified under the NWRI Guidelines. TWR- Phase I and TWRP-Phase II produce average transmittances of 55.8% and 59.1%, respectively. The TITP clarified secondary effluent has a 53.3% average transmittance, but tertiary filtration is likely to provide a significantly higher quality effluent. In the 1993 TITP pilot filter study, it was found that the proposed conventional tri-media filters consistently produced effluent with transmittance above 50% at SS loadings up to 122 mg/l at 2 gpm/ft^2 and up to 61 mg/l at 4 gpm/ft^2. When ferric chloride was added as the coagulant, an average of 57.2 % transmittance was achieved. No data is available on percent transmittance for this filter for normal daily SS and BOD loadings.

3.5 POTENTIAL EFFLUENT QUALITY BENEFIT OF UV DISINFECTION

From the standpoints of effluent quality, receiving water impact and wastewater reuse, substantial benefits could be derived from UV disinfection because of its potential to reduce or eliminate the need for chlorine or other halogen-based disinfectants. Chlorination data compiled from upstream reclamation plants indicates near proportionality between added chlorine and supplemental effluent

TABLE 3.5 Statistical Review of Percent Transmittance* of Plant Effluent at LAGWRP, TWRP Phases I and II, and TITP.

Plant	Sampling Dates m/d/y	Percent Transmittance Ave %T	Standard Deviation	%T Max	%T Min	No. of Samples	Residual Cl2 Average mg/l
LAGWRP	11/15 - 23/93	64.0	3	70	54	151	n/a
TWRP Ph I	11/30 - 12/6/93	55.8	3.5	63.7	45.4	132	0.35
TWRP Ph II	12/16-19, 26-30/93	59.1	5.3	68.4	35.4	143	0.56
TITP (1)	10/11, 13-15, 17/93	53.3	4.6	57.8	31.9	120	NU
TITP (2)	4/6/93	51.9	N/A	N/A	N/A	1	NU
TITP (3)	4/7/93	51.4	N/A	N/A	N/A	1	NU
TITP (4)	4/8/93	50.8	N/A	52.5	49.0	4	NU
TITP (5)	3/23/93	57.2	N/A	57.4	57.0	2	NU

Notations:
n/a: Not available
NU: Chlorine not used.
N/A: Not applicable
* Percent transmittance of grab samples; absorbance measured at 253.7 nm.
(1) Unfiltered, secondary effluent.
(2) Conventional trimedia pilot filter test at high (75-100 mg/l SS) spike loadings @ 2gpm/sq ft.
(3) Conventional trimedia pilot filter test at normal (30-45 mg/l SS) spike loadings @ 2gpm/sq ft.
(4) Conventional trimedia pilot filter test at normal (30-45 mg/l SS) spike loadings @ 4 gpm/sq ft.
(5) Conventional trimedia pilot filter test at normal (30-45 mg/l SS) spike loading and 1.5 mg/l coagulant added @ 4 gpm/sqft

A:\tf\Tab3-4&5.WB2:T34

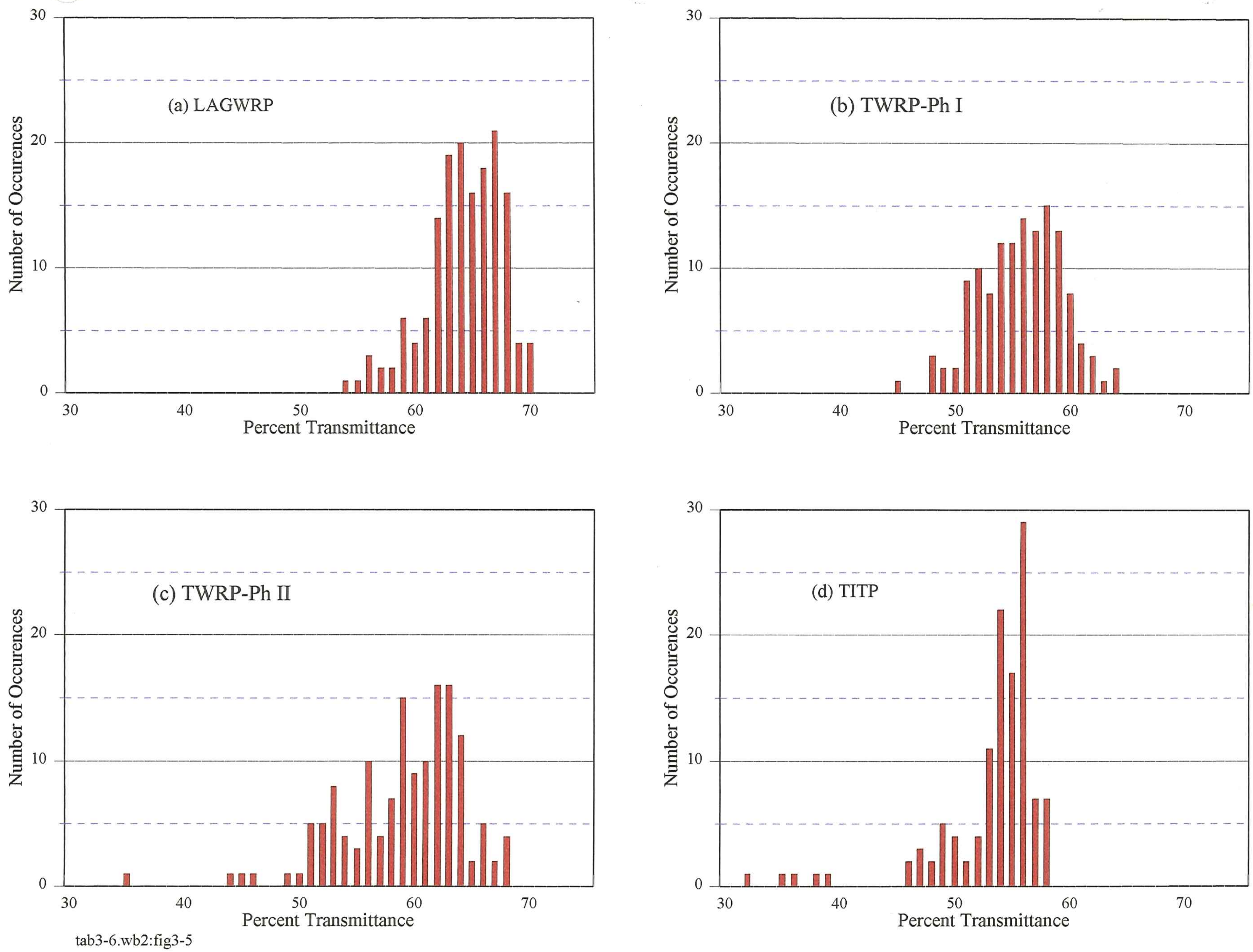


Figure 3.5 UV Transmittance Histograms for LAGWRP, TWRP Phases I and II, and TITP.

Table 3.6 Percent Transmittance for LAGWRP, TWRP-Phase I, TWRP-Phase II and TITP.

Percent Transmittance	Number of Occurences			
	LAGWRP	TWRP - Ph I	TWRP - Ph II	TITP
30				
				1
35			1	1
				1
				1
				1
40				
			1	
45		1	1	
			1	2
				3
		3		2
		2	1	5
50		2	1	4
		9	5	2
		10	5	4
		8	8	11
	1	12	4	22
55	1	12	3	17
	3	14	10	29
	2	13	4	7
	2	15	7	7
	6	13	15	
60	4	8	9	
	6	4	10	
	14	3	16	
	19	1	16	
	20	2	12	
65	16		2	
	18		5	
	21		2	
	16		4	
	4			
70	4			
75				

A:\tf\tab3-6.wb2

chloride levels. As a result, any reduction in chlorine use as a disinfectant translates into a similar reduction in effluent chloride. Water reclamation chloride limitations are 150 mg/L and 100 mg/L, respectively, for LAGWRP and TWRP, although the current interim chloride limit is equal to the water supply chloride level plus 85 mg/l, or 250 mg/l, whichever is smaller. A reduction of only 5 mg/l would be significant in terms of compliance with the interim chloride limit.

Table 3.7 presents and Figures 3.6a and b show the combined histories of chloride concentration in the water supply, plant influent and plant effluent, and the interim chloride limit from April 1990 through July 1994 for LAGWRP and TWRP, respectively. These data indicate that a 5 mg/l chloride reduction would have resulted in 10 fewer exceedances of the limit at LAGWRP during the past 5 years, 2 fewer exceedances at TWRP. Although the water supply, the quality of which has been degraded in recent years due to drought and water conservation/management measures, is by far the most significant source of effluent chloride, little could be done with respect to mitigation because contamination could not be avoided and treatment is so costly as to be prohibitive. As a result, incremental chloride reduction by industrial and domestic users and the reclamation plants is probably the only feasible approach (other than UV disinfection of reclaimed wastewater) until the water supply picture improves.

Table 3.7 Monthly Average Chloride Concentrations for LAGWRP and TWRP: Water Supply, Interim Limit, Plant Influent and Plant Effluent.

		TWRP				LAGWRP			
Year	Date	Water Supply [Cl-] mg/l	Interim Limit (a) [Cl-] mg/l	Plant Influent [Cl-] mg/l	Plant Effluent [Cl-] mg/l	Water Supply [Cl-] mg/l	Interim Limit (b) [Cl-] mg/l	Plant Influent [Cl-] mg/l	Plant Effluent [Cl-] mg/l
1990	Jan								
	Feb								
	Mar								
	Apr	65	150		134	90	175		157
	May								
	Jun	86	171		143	109	194		189
	Jul	99	184		152	109	194		189
	Aug	102	187		162	106	191		177
	Sep	111	196		165	108	193		185
	Oct	96	181		156	106	191		170
	Nov	96	181		154	103	188		177
	Dec	98	183	148	164	100	185	164	187
1991	Jan	75	160	138	145	98	183	157	180
	Feb	69	154	131	138	98	183	159	176
	Mar	43	128	87	101	89	174	145	165
	Apr	47	132	84	102	94	179	151	161
	May	65	150	121	135	101	186	162	176
	Jun	49	134	91	113	97	182	157	173
	Jul	55	140	105	118	100	185	166	178
	Aug	74	159	119	140	99	184	166	194
	Sep	76	161	142	170	101	186	176	191
	Oct	88	173	144	179	103	188	186	198
	Nov	82	167	163	178	106	191	182	196
	Dec	72	157	133	153	102	187	165	180
1992	Jan	51	136	104	125	92	177	154	166
	Feb	89	174	145	164	90	175	157	164
	Mar	43	128	129	154	99	184	158	162
	Apr	78	163	148	162	109	194	164	168
	May	78	163	117	137	103	188	170	175
	Jun	95	180	132	146	104	189	186	190
	Jul	88	173	113	132	101	186	179	190
	Aug	91	176	122	140	101	186	171	183
	Sep	92	177	134	144	101	186	162	168
	Oct	98	183	137	157	102	187	168	175
	Nov	88	173	137	155	90	175	162	165
	Dec	87	172	132	146	90	175	159	170
1993	Jan	95	180	124	143	101	186	166	177
	Feb	96	181	157	166	101	186	169	171
	Mar	80	165	105	130	95	180	149	158
	Apr	85	170	117	141	98	183	156	162
	May	54	139	109	135	91	176	168	177
	Jun	54	139	103	127	88	173	169	178
	Jul	48	133	107	127	89	174	177	174
	Aug	39	124	101	126	81	166	152	156
	Sep	52	137	100	120	82	167	156	157
	Oct	57	142	117	126	79	164	151	141
	Nov	58	143	114	131	71	156	143	153
	Dec	50	135	95	118	70	155	144	152
1994	Jan	46	131	112	135	65	150	144	154
	Feb	46	131	93	117	66	151	149	157
	Mar	37	122	107	132	60	145	145	156
	Apr	59	144	126	141	67	152	143	155
	May	48	133	126	151	65	150	160	168
	Jun	54	139	131	147	66	151	153	162
	Jul	46	131	112	131	77	162	150	161
	Aug								
	Sep								
	Oct								

(a) TWRP water reclamation chloride limit is 100 mg/l.
(b) LAGWRP water reclamation chloride limit is 150 mg/l.

tab3-7.wb2:c

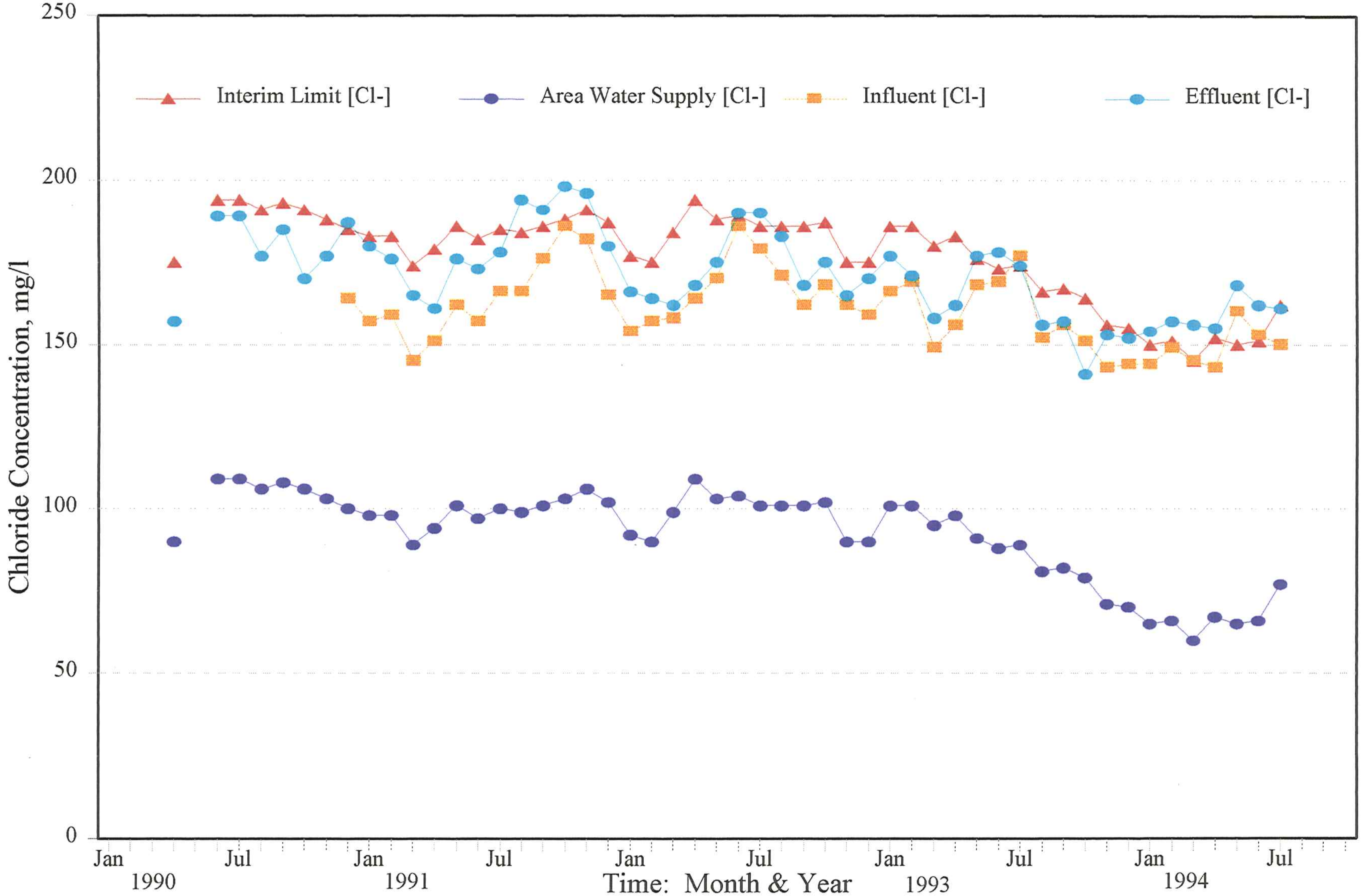


Figure 3.6a History of Chloride Concentrations at LAGWRP: Water Supply, Interim Limits, Plant Influent and Plant Effluent.

tab3-7.wb2:fig3-6a

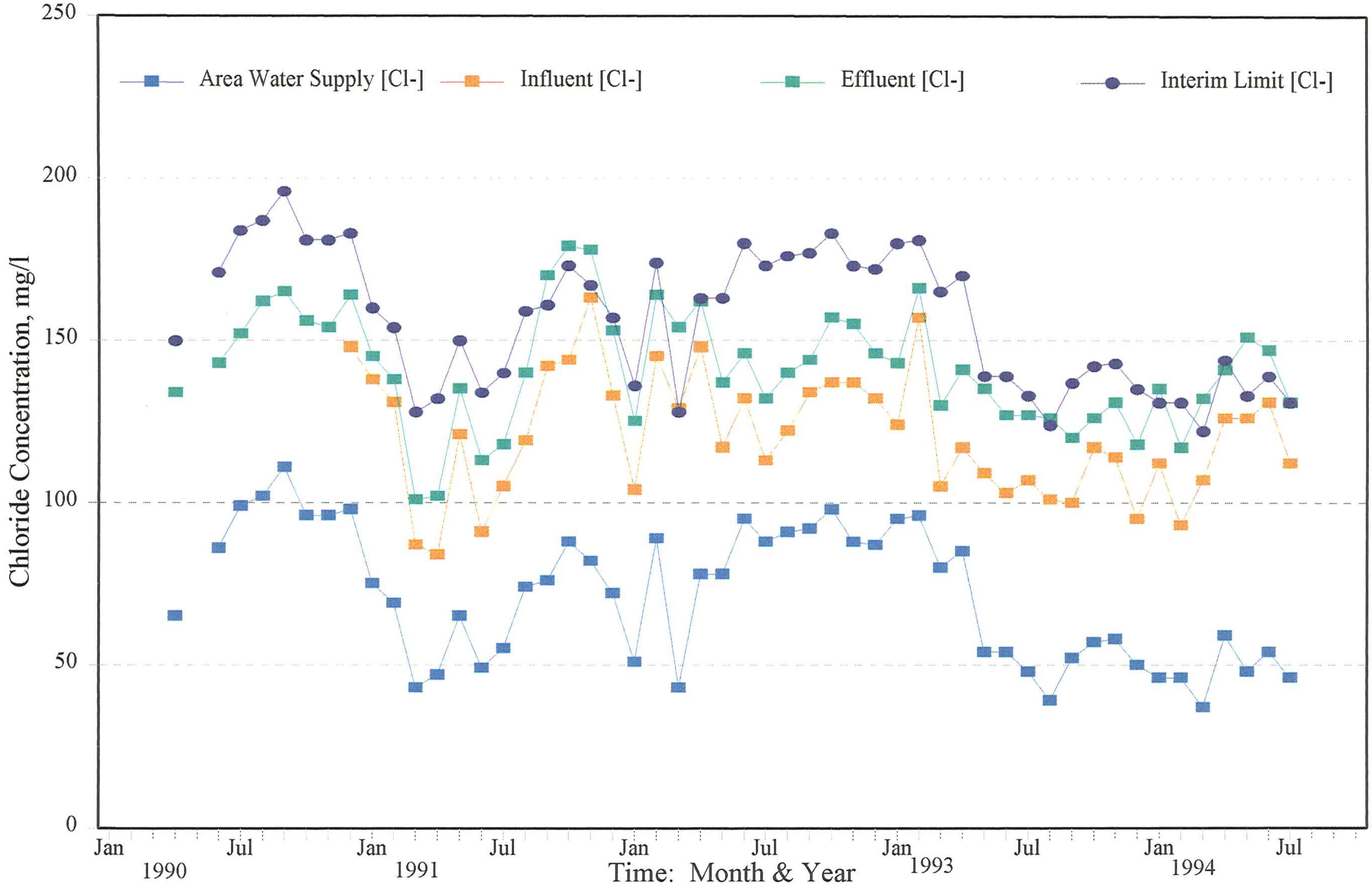


Figure 3.6b History of Chloride Concentrations at TWRP: Water Supply, Interim Limit, Plant Influent and Plant Effluent.

tab3-7.wb2:fig3-6b

CHAPTER 4

ECONOMIC ANALYSES

This chapter presents economic realities of using a UV disinfection system at the three outlying plants (i.e., LAGWRP, TWRP and TITP) as an alternative to chlorination/dechlorination systems. Cost comparisons are made with the traditional disinfection methods of chlorine/sodium hypochlorite and sulfur dioxide/sodium bisulfite to evaluate the economic viability of any proposed shift to UV disinfection compared to maintaining current operating philosophies. Capital costs and operating and maintenance (O&M) expenses are presented for full-scale UV facilities at all three outlying facilities. A rigorous economic comparison between the chlorination/dechlorination and UV disinfection methods is presented for LAGWRP due to the availability of needed data.

4.1 DESIGN CONSIDERATIONS

Principal design parameters for full scale implementation of a UV disinfection system include effluent characteristics and flow rate, UV transmittance, and required UV dose. Other considerations include spare parts availability and costs, equipment specifications, the existing plant layout and other expected projects. The required UV dose, flow rate and power consumption determine electrical and emergency power requirements. Existing plant facilities and other proposed projects will dictate the exact arrangement and location of equipment. The resultant arrangement may also affect cleaning of the quartz sleeves and power input adjustment to conform with the changing amount of flow and/or wastewater characteristics. All of these factors play an important role in determining the cost of installing, operating and maintaining a UV disinfection system.

Budgetary estimates were based on the complex set of design parameters presented in Table 4.1. Several additional comments are pertinent. For instance, the average LAGWRP influent flow rate is 19.9 mgd, whereas the average LAGWRP filter effluent flow rate is significantly less, averaging

Table 4.1 Design Parameters for UV Disinfection Systems at LAGWRP, TWRP Phases I and II, and TITP Assuming 100 mWs/cm^2 for Maximum Daily Flow (Q_{MD}) and 120 mWs/cm^2 at Maximum Weekly Flow (Q_{MW}) and Average Daily Flow (Q_{AVE}).

Facility	Q_{OD} mgd	Q_{MD} mgd	Q_{MW} mgd	Q_{AVE} mgd	T_{min} %	T_{ave} %	Ss_{max} mg/l
LAGWRP	20.0	29.1	25.2	18.0	55	64	5
TWRP-Ph I	40.0	35.7	32.0	21.6	50	55.3	5
TWRP-Ph II	40.0	52.7	47.0	37.8	50	59.1	5
TITP-Ph I	5.9[a]	5.9	5.9	5.9[a]	60	60	5
TITP-Ph II	11.8[a]	11.8	11.8	11.8[a]	55	60	5
TITP-Ph III	26.9[a]	26.9	24.0	17.5[a]	55	60	5

Q_D Design influent flow, as originally designed for LAGWRP, TWRP and TITP.

Q_{MD} Maximum daily flow as defined by the NWRI Guidelines, for which a dose of 100 mWs/cm^2 must be used as a design basis for capital cost.

Q_{MW} Maximum weekly flow as defined by the NWRI Guidelines, for which a dose of 140 mWs/cm^2 must be used as a design basis for capital cost.

Q_{AVE} Average daily flow observed for 1992, 1993 and 1994, for which operating costs are calculated.

$\%T_{min}$ Minimum percent transmittance at 253.7 nm, for which capital costs are calculated.

$\%T_{ave}$ Average percent transmittance at 253.7 nm, for which operating costs are calculated.

Ss_{max} Maximum average suspended solids concentration expected.

a Q_D and Q_{AVE} for the existing TITP primary and secondary processes upstream from the proposed reclamation processes are 30 and 17.5 mgd, respectively.

tf\ttab4-1.wpd

15.6 mgd during the past three water-conservation years, 12.9 mgd in 1994, as shown in Table 3.1 and Figure 3.2. Table 4.1 presents the TITP reclamation flow rates for phases I and II as 5.9 and 11.8 mgd, respectively, because UV disinfection would be placed between microfiltration and reverse osmosis, each of which would produce about 85 percent product water and 15 percent waste or brine, respectively. An additional UV dose might be required for low values of transmittance and high values of suspended solids. The costs of using chemical disinfection include the costs of safety measures, which are assumed to remain constant, except for inflation, because safety regulations would not change.

4.2 COST OF A FULL SCALE UV SYSTEM

The costs to install and operate a full-scale UV facility rise rapidly with decreases in transmittance because more lamps are required and more power is needed to deliver a given dose. The price is also approximately proportional to the design flow rate. The proportionality factors incorporate considerations like local wage rates, construction costs, unit power costs, vendor prices, and differing efficiencies of different types of UV systems used. In general, the capital cost of construction and O&M expense can be estimated with some confidence from information about existing UV disinfection facilities.

In the following discussion, allowances must be made for errors and estimates of efficiency and for differences in ways that vendors run equipment and calculate costs. For example, one vendor of the low pressure systems calculated costs using a dose of 140 mWs/cm^2, although the product water required can probably be produced using 120 mWs/cm^2. In another quote, the vendor used a peak flow rate rather than the average flow rate to determine operating costs.

All current quotes are considered to be conservative Class C estimates. The estimated numbers of lamps and other equipment are very likely to decrease as a result of pilot testing, and only dramatic increases in item costs or inflation would increase the total cost estimates. In all cases, the proposed UV equipment is designed to meet the Title 22 standards.

4.2.1 Capital Costs

Table 4.2 presents data published at recent conferences together with data from previous sections about LAGWRP, TWRP-Phase I, TWRP-Phase II and TITP, as well as vendor cost estimates. Cost estimates for supplying and installing a UV disinfection system in each of the three outlying plants were received in October 1994 from Trojan Technologies, Inc. (TTI) and Bailey-Fischer & Porter (BFP). Both are well-known suppliers of UV disinfection equipment, located in Ontario, Canada.

The budgetary estimates to install low pressure UV systems differ between BFP's 70UV6000 and TTI's UV3000. For the LAGWRP, estimates are $1.7 (BFP) and $3.2 (TTI) million, based on filtered effluent with 5 mg/l SS and a UV transmittance of 65%. The respective estimated costs for similar systems for TWRP Phase I are $3.4 and $4.5 million; and $4.8 and $6.8 million for Phase II, respectively, based on filtered effluent with 5 mg/l SS and a UV transmittance of about 55%. The estimated cost of a similar low pressure unit for the TITP Phase 1 reclamation project is $0.74 million for a filtered effluent with 5 mg/l SS and UV transmittance of 60%, which assumes that the conventional tri-media filters will produce a product water comparable to that of LAGWRP.

The budgetary estimates for Trojan's medium pressure lamp system, the UV4000, are $2.8 million for LAGWRP, $4.1 million for TWRP-Ph I, $5.6 million for TWRP-Ph II and $1.0 million for TITP-Ph I. The differences from the prices for the low pressure systems result because a much smaller footprint is required, the unit automatically cleans its quartz sleeves, and installation is easier, but the equipment itself is more expensive.

These budgetary estimates appear to be within the (+)50, (-)30 percent guidelines of a Class C estimate. Although the estimates given by TTI and BFP differ due to use of different assumptions,

TABLE 4.2 Estimated Total Capital Costs and Key UV Parameters for LAGWRP, TWRP - Ph I, TWRP - Ph II, TITP and Four Similar Facilities.

Parameter	Ref. b12	Ref. b6	Ref. b5	Ref. b15	LAGWRP	TWRP-Ph I	TWRP-Ph II	TITP-PhI	TITP-PhII	TITP- PhIII
Average Daily UV Flow, mgd	149	39	35	28	14(18#)	21.6	37.8	5.9	11.8	17.5
Maximum Weekly Flow, mgd					25.2	32.0	47.0	5.9	11.8	17.5
Maximum Daily Flow, mgd					29.1	35.7	52.7	5.9	11.8	17.5
Peak Hourly Flow, mgd	257	39	70	56						
UV Transmittance, Percent	65	85	70	70	64	50-55	50-59	55-60	55-60	55-60
Total SS, mg/l	10				2	3	3	0.5	0.5	0.5
BOD, mg/l	5				7	8	8	n/a	n/a	n/a
Temperature, C	20				24	26-31	26-31	24-29	24-29	24-29
Influent Coliform*, MPN/100ml	200,000				1.0E+07					
Effluent Coliform*, MPN/100ml	200	2.20	2.20		1.0	1	1	2.2	2.2	2.2
Estimated Capital Cost, $ million	4.95	5.26	12.97	7.97	3.34					
Bailey-Fischer&Porter 70UV6000					1.72#	3.41	4.82	0.74	1.35	1.86
Trojan UV3000, 3/23/95					3.20	4.50	6.80	0.72	1.45	2.95
Trojan UV4000, 3/22/95					2.80	4.14	5.62	1.04	2.05	3.00
Estimated Capital Cost, $1,000's/mgd	19.3	137	185	136	185.0					
Bailey-Fischer&Porter 70UV6000					95.6	106	102	125	114	106
Trojan UV3000, 3/23/95					178	125	128	122	123	168
Trojan UV4000, 3/22/95					156	115	106	176	174	181

* Fecal Coliform is the specified parameter for Reference b12; Total Coliform for LAG.

Quotes recieved were normalized to 18 gpm average influent flow, although the reclaimed water flow averages only 14 mgd (see Figure 3).

n/a: not available, missing data are not reported in the references.

Ref. b12: Nick Ammons, Brown & Caldwell, Atlanta - Calgary, Comparison of Ultraviolet Disinfection Systems

Ref. b6: CH2M Hill, UV Disinfection Pilot Study, Rapid Infiltration/Extraction (RIX), Demonstration Project, August 1992. Estimate for RIX effluent.

Ref. b5: CH2M Hill, UV Disinfection Pilot Study, Rapid Infiltration/Extraction (RIX), Demonstration Project, August 1992. Estimate for conventional filtration effluent.

Ref. b15: Soroushian, P.E., et. al., Disinfecting Reclaimed Water with Ultraviolet Light, Water Environment Federation, 65th annual Conference, September 1992.

tab4-2&3.wb2:a

both vendors provided quotes based on realistic assumptions. These quotes will be refined as this project progresses.

Table 4.2 also shows the total capital investment for four facilities in other cities, with average daily flows ranging from 28 mgd [Ref b15] to 149 mgd [Ref b12]. Each facility presents slightly differing sets of conditions and corresponding costs. The notably low capital cost of $19,300 per mgd for the Calgary plant [Ref b12] results from the very lenient fecal coliform treatment standards of 200 MPN/100 ml and a UV transmittance of 65%. The capital cost of $137,000 per mgd is required for the RIX facility [Ref b6] with an 85 percent transmittance to meet the Title 22 standard of 2.2 MPN/100 ml limit for total coliform and 4-log virus removal efficiency. The Reference b5 study, using effluent of 70 percent transmittance from a conventional tertiary treatment facility would provide the same degree of disinfection treatment as the RIX process, but at the higher cost of $185,000 per mgd. Estimates for LAGWRP, TWRP-PhI, TWRP-PhII and TITP are all lower than this. BFP's estimates for the 70UV6000 range from $95,600 to $125,000/mgd; TTI's UV3000 from $122,000 to $178,000/mgd; and TTI's UV4000 from $106,000 to $181,000/mgd.

4.2.2 Operating and Maintenance Costs

Table 4.3 presents O&M cost estimates. Available data from three facilities that use or have tested UV disinfection are also presented. The O&M estimates from BFP and TTI are provided at the bottom of the table. Data gathered from faxed quotes on parts that require significant expense (i.e., lamps, quartz sleeves and electronic ballasts) are given in the table and summed above the vendor quotes for easy comparison. It should be noted that the vendors use much higher prices for spare parts than what City staff found to be available.

Table 4.3 lists the major O&M expense items for the three referenced facilities compared with those for LAGWRP, TWRP, Phases I and II, and TITP. It should be pointed out that, of the three referenced facilities, only the Calgary plant in Canada is currently in operation. The data on the other two facilities are based on the results of detailed feasibility studies. As can be seen from Table 4.3, parts replacement and power consumption are comparatively much greater than labor costs. Lamp life is projected at 13,000 hours. Power cost is calculated assuming $0.08/Kwh. Labor for O&M

TABLE 4.3 Estimated Operation and Maintenance Costs* for LAGWRP, TWRP-PhI, TWRP-PhII and TITP; and Three Similar Facilities.

Item	Ref. b12	Ref. b6	Ref. b5	LAGWRP	TWRP - Ph I	TWRP - Ph II	TITP-Ph I	TITP-Ph II	TITP-Ph III
PARTS REPLACEMENT COSTS									
(low pressure systems)									
Average Design Flow, mgd			28	18	22	38	5.9	11.8	17.5
Peak Design Flow, mgd		44	56	29	36	53	5.9	11.8	17.5
Unit Costs:									
Lamps, $	60	56	25 - 50	25	25	25	25	25	25
Quartz Sleeve, $	50			20	20	20	20	20	20
Ballast, $	80		50 - 75	60	60	60	60	60	60
Average Number of Lamps Used									
Bailey-Fischer&Porter, 70UV6000				5376	6240	10752	1760	3520	4928
Trojan UV3000				6691	n/a	n/a	1699	1699	1699
System Utilization, %	40		50	66	50	50	60	60	60
Life cycle (8760 hrs/yr):									
Replacement cycle per lamp, hrs	12,500	13,000		13,000	13,000	13,000	13,000	13,000	13,000
Quartz Sleeve, yrs	10			10	10	10	10	10	10
Ballast, yrs	10			10	10	10	10	10	10
Annual Costs:									
Lamps, $/lamp/yr	16	37		11.12	8.42	8.42	10.11	10.11	10.11
Quartz Sleeve, $/lamp/yr	5			2.00	2.00	2.00	2.00	2.00	2.00
Ballast $/lamp/yr	4			3.00	3.00	3.00	3.00	3.00	3.00
Miscellaneous parts/repair, $/lamp/yr	12			12.00	12.00	12.00	12.00	12.00	12.00
Total Annual Costs, $/lamp/yr				28.12	25.42	25.42	27.11	27.11	27.11
Total Annual Costs, $1,000's/yr				151	159	273	48	95	134
POWER COSTS (low pressure systems)									
Power requirement per lamp, W	100	70	70 - 100	65	65	65	65	65	65
Power rate, $/KWH	0.08		0.03 - 0.06	0.08	0.08	0.08	0.08	0.08	0.08
Total power cost, $1,000's/yr				162	142	245	48	96	135
LABOR COSTS (low pressure systems)									
Labor rate, $/hr	20	18		30	30	30	30	30	30
Cleaning Frequency, #/yr		12		12	12	12	6	6	6
Cleaning time, min/tank		60		15-120	15-120	15-120	15-120	15-120	15-120
Cleaning time, hr/lamp				5/100	5/100	5/100	5/100	5/100	5/100
hr/mgd/yr				30	30	30	30	30	30
Other O & M labor, hr/mgd/yr				27	27	27	27	27	27
Total labor, hr/mgd/yr				57	57	57	57	57	57
Total Labor cost, $/mgd/yr				1,710	1,710	1,710	1,710	1,710	1,710
Total Labor cost, $1,000's/yr				31	38	65	10	20	30
ANNUAL O&M COSTS, $1,000's/yr				344	338	583	106	212	298
$1,000's/mgd	6.50 to 7.50	3.59	2.10 to 3.40	19	15	15	18	18	17
VENDOR QUOTED ANNUAL O&M COSTS (low and medium pressure systems)**									
$1,000's/yr									
Bailey-Fischer&Porter, 70UV6000 (low pressure)				415	452	829	152	304	385
				23.0/mgd	20.9/mgd	21.8/mgd	25.8/mgd	25.8/mgd	25.8/mgd
Trojan Technologies, UV3000 (low pressure)				420	565	966	137	137	137
				23.3/mgd	26.2/mgd	25.4/mgd	23.2/mgd	23.2/mgd	23.2/mgd
Trojan Technologies, UV4000 (medium pressure)				463	656	1,140	156	156	156
				25.7/mgd	30.4/mgd	30.0/mgd	26.4/mgd	26.4/mgd	26.4/mgd

* : Estimates for LAGWRP, TWRP Phases I and II, and TITP are based on independently obtained quotes for lamps, quartz sleeves and ballasts; prevailing power and labor rates; and information derived from the three referenced facilities.

**: Quotes from the specified vendors for the specified equipment are for full-scale installation. See Section 4.4 for a comparative discussion on the equipment and O&M costs.

n/a: not available, missing data are not reported in the references.

Ref. b12: Nick Ammons, Brown & Caldwell, Atlanta - Calgary, Comparison of Ultraviolet Disinfection Systems

Ref. b6: CH2M Hill, UV Disinfection Pilot Study, Rapid Infiltration/Extraction (RIX), Demonstration Project, August 1992. Estimate for RIX effluent.

Ref. b5: CH2M Hill, UV Disinfection Pilot Study, Rapid Infiltration/Extraction (RIX), Demonstration Project, August 1992. Estimate for conventional filtration effluent.

Ref. b15: Soroushian, P.E., et. al., Disinfecting Reclaimed Water with Ultraviolet Light, Water Environment Federation, 65th annual Conference, September 1992.

tab4-2&3.wb2:b

could be combined with other plant activities, but is itemized here. From these data, the annual O&M costs are estimated to be $344,000 for LAGWRP, $338,000 for TWRP-Phase I, $583,000 for TWRP-Phase II and $106,000 for TITP-Phase I. Vendor estimates for annual O&M range from $415,000 to $463,000 for LAGWRP, $452,000 to $656,000 for TWRP-Phase I, $829,000 to $1,140,000 for TWRP-Phase II and $137,000 to $156,000 for TITP-Phase I.

4.3 CHEMICAL DISINFECTION

As noted in Chapter 3, disinfection strategies differ at each of the three outlying plants. LAGWRP completed conversion from SO_2 to $NaHSO_3$ in 1994 and plans to convert from Cl_2 to NaOCl in 1995 or 1996. TWRP is maintaining its use of Cl_2 and SO_2 in spite of the RMPP requirement upgrades; the gaseous system and required appurtenant equipment are in place and work well. TITP does not disinfect; the cost to install and maintain RMPP [Ref a4] requirements for the small amount of Cl_2 that would be used, the toxicity of residual Cl_2 and chlorination byproducts to marine animals, and the NPDES permit requirements favor operating the plant without disinfection.

Monthly chlorination chemical use at LAGWRP is presented in Table 4.4 and Figure 4.1, while dechlorination chemical use is presented in Table 4.5 and Figure 4.2. Several aspects of these data are relevant for comparing with the costs of UV disinfection. Most notably, the use of Cl_2 has decreased and stabilized during the past few years, decreasing at nearly the same rate as the reclaimed water flow rate during the past five years; the influent flow rate has little to do with the rate of chemical consumption. Use of SO_2 and $NaHSO_3$ for dechlorination has decreased markedly during the past five years. Use of dechlorination chemicals is more variable than Cl_2 use, but has decreased much more than the flow rate during the past five years and has stabilized during the past year and a half. These changes are largely attributable to water conservation methods and better in-plant controllers.

The tables and figures present costs in 1995 dollars. The actual costs are given for Cl_2 and estimated costs are given for the other three chemicals as follows. For NaOCl, which was not used for disinfection during this period, the costs are estimates for the amount of NaOCl that would be equivalent to the amount of Cl_2 that was actually used. For dechlorination, SO_2 was used until June,

Table 4.4 LAG Chlorination: Past Use and Cost of Chlorine and Sodium Hypoc

Year	Month	Average Cl2 lbs/dy	Average Cl2 lbs/mo.	Est'd Cost 1995 $$ Cl2 $/month	Cl2 as NaOCl gals/dy	Cl2 as NaOCl gals/mo.	Est'd Cost 1995 $$ NaOCl $/month	Qinf mgd	Qrecl mgd
Sample	Calc'n:	100	3000	$528	100	3000	$2,010		
1990	Jan	2591	80321	14,128	2591	80321	53,815	17.8	17.1
	Feb	1920	53760	9,456	1920	53760	36,019	19.6	18.9
	Mar	2009	62279	10,955	2009	62279	41,727	20.6	19.9
	April	1781	53430	9,398	1781	53430	35,798	20.4	19.7
	May	2144	66464	11,691	2144	66464	44,531	20.0	19.3
	June	1982	59460	10,459	1982	59460	39,838	19.8	14.9
	July	2600	80600	14,178	2600	80600	54,002	19.7	16.0
	Aug	2764	85684	15,072	2764	85684	57,408	19.4	15.6
	Sept	2908	87240	15,346	2908	87240	58,451	19.9	15.7
	Oct	3440	106640	18,758	3440	106640	71,449	20.1	16.4
	Nov	3110	93300	16,411	3110	93300	62,511	20.1	15.5
	Dec	2878	89218	15,693	2878	89218	59,776	20.2	14.7
Average:				$13,462			$51,277	19.8	17.0
1991	Jan	2932	90892	15,988	2932	90892	60,898	19.7	17.4
	Feb	2344	65632	11,545	2344	65632	43,973	19.5	17.3
	Mar	2431	75361	13,256	2431	75361	50,492	20.5	18.4
	April	1874	56220	9,889	1874	56220	37,667	20.2	18.0
	May	1863	57753	10,159	1863	57753	38,695	16.0	13.6
	June	1794	53820	9,467	1794	53820	36,059	15.9	12.6
	July	1908	59148	10,404	1908	59148	39,629	16.4	12.9
	Aug	2431	75361	13,256	2431	75361	50,492	16.0	12.6
	Sept	2181	65430	11,509	2181	65430	43,838	16.2	13.5
	Oct	1927	59737	10,508	1927	59737	40,024	16.5	13.9
	Nov	2201	66030	11,615	2201	66030	44,240	18.2	15.7
	Dec	2408	74648	13,131	2408	74648	50,014	20.2	17.9
Average:				$11,727			$44,668	17.9	15.3
1992	Jan	2049	63519	11,173	2049	63519	42,558	19.9	17.2
	Feb	1482	41496	7,299	1482	41496	27,802	20.5	17.7
	Mar	1597	49507	8,708	1597	49507	33,170	20.4	17.1
	April	1630	48900	8,602	1630	48900	32,763	20.3	17.5
	May	1549	48019	8,447	1549	48019	32,173	20.3	17.8
	June	1875	56250	9,894	1875	56250	37,688	20.0	17.5
	July	1954	60574	10,655	1954	60574	40,585	20.1	17.8
	Aug	1960	60760	10,688	1960	60760	40,709	20.3	18.4
	Sept	1850	55500	9,762	1850	55500	37,185	20.2	18.0
	Oct	1458	45198	7,950	1458	45198	30,283	19.9	16.9
	Nov	1282	38460	6,765	1282	38460	25,768	19.7	18.2
	Dec	1190	36890	6,489	1190	36890	24,716	20.6	16.7
Average:				$8,869			$33,783	20.2	17.6
1993	Jan							22.5	16.7
	Feb	1712	47936	8,432	1712	47936	32,117	21.9	16.0
	Mar	1782	55242	9,717	1782	55242	37,012	20.5	16.3
	April	1360	40800	7,177	1360	40800	27,336	20.4	17.1
	May	1407	43617	7,672	1407	43617	29,223	20.0	11.7
	June	1448	43440	7,641	1448	43440	29,105	18.3	14.4
	July	1301	40331	7,094	1301	40331	27,022	19.7	14.9
	Aug	1495	46345	8,152	1495	46345	31,051	20.0	15.2
	Sept	1586	47580	8,369	1586	47580	31,879	21.0	14.8
	Oct	1573	48763	8,577	1573	48763	32,671	20.5	15.2
	Nov	1614	48420	8,517	1614	48420	32,441	20.0	15.3
	Dec	1565	48515	8,534	1565	48515	32,505	20.2	15.2
Average:				$8,171			$31,124	20.4	15.2
1994	Jan	1325	41075	7,225	1325	41075	27,520	19.6	13.8
	Feb	1303	36484	6,418	1303	36484	24,444	20.3	14.1
	Mar	1304	40424	7,111	1304	40424	27,084	19.9	13.7
	April	1312	39360	6,923	1312	39360	26,371	19.9	14.2
	May	1404	43524	7,656	1404	43524	29,161	19.9	15.4
	June	1452	43560	7,662	1452	43560	29,185	18.7	13.7
	July	1645	50995	8,970	1645	50995	34,167	18.6	13.2
	Aug	1697	52607	9,254	1697	52607	35,247	17.9	13.3
	Sept	1669	50070	8,807	1669	50070	33,547	17.9	13.6
	Oct	1764	54684	9,619	1764	54684	36,638	17.3	13.6
	Nov	1680	50400	8,865	1680	50400	33,768	19.5	13.5
	Dec	1546	47926	8,430	1546	47926	32,110		
Average:				$8,078			$30,770	19.0	13.8
1995	Jan	1617	50127	8,817	1617	50127	33,585	18.7	14.6
	Feb	2150	60200	10,589	2150	60200	40,334		
	Mar	1621	50251	8,839	1621	50251	33,668		
Average:				$9,415			$35,862	18.7	14.6
Daily Averages:		1881			1881			19.4	15.8
Monthly Averages:		56,433	57,196	$10,061	56,433	57,196	$38,322	583	473
Annual Averages:		686,606	686,357	$120,730	686,606	686,357	$459,859	7,088	5,760
Since January 1992 **Daily Averages:**								19.8	15.6
Monthly Average:				$8,379			$31,914	595	467
Annual Average:				$100,545			$382,973	7,238	5,679

TAB4-4A.WB2

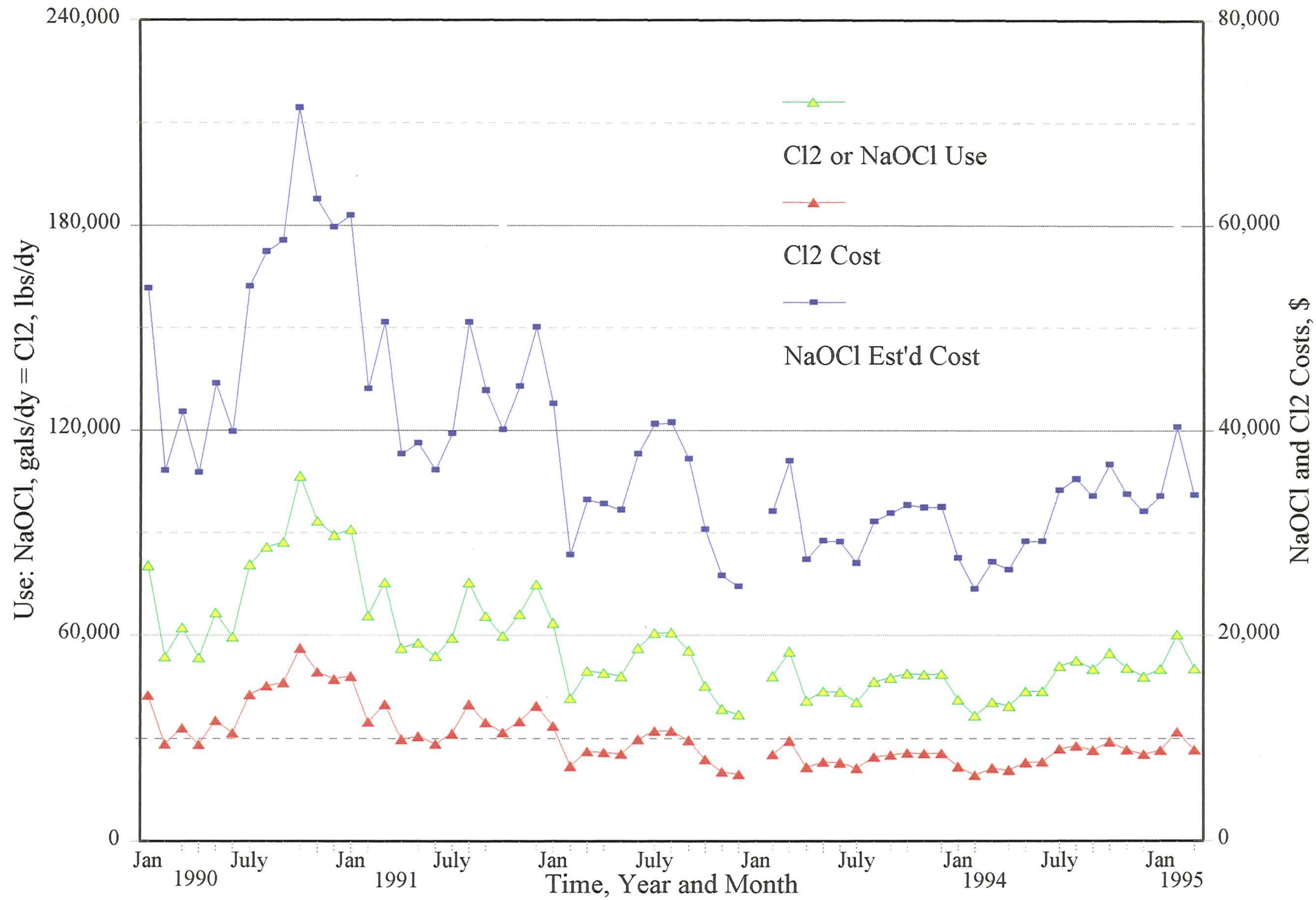


FIGURE 4.1 Use and Cost of Chemical Chlorination at LAGWRP.

tab4-4.wb2:f4-1

Table 4.5 LAG Dechlorination: Past Use of Sulfur Dioxide and Sodium Bisulfite.

Year	Month	Average NaHSO3 gals/dy	Average SO2 lbs/dy	SO2 as NaHSO3 gals/dy	Total Average NaHSO3 gals/dy	Total Average NaHSO3 gals/month	Est'd Cost 1995 $$ NaHSO3 $/month	Actual Cost NaHSO3 $/month	NaHSO3 as SO2 lbs/dy	Total Average SO2 lbs/dy	Total Average SO2 lbs/month	Est'd Cost SO2 $/month	Qinf mgd	Qrecl mgd
Sample	Calc'n:	100	100	64.8	164.8	4,944	2,153		154	254	7,630	2,392		
1990	Jan		1378	893	893	26,788	11,664		0	1,378	41,340	12,960	17.8	17.1
	Feb		1606	1,041	1,041	31,221	13,593		0	1,606	48,180	15,104	19.6	18.9
	Mar		1575	1,021	1,021	30,618	13,331		0	1,575	47,250	14,813	20.6	19.9
	April		1542	999	999	29,976	13,052		0	1,542	46,260	14,503	20.4	19.7
	May		1792	1,161	1,161	34,836	15,168		0	1,792	53,760	16,854	20.0	19.3
	June		1711	1,109	1,109	33,262	14,482		0	1,711	51,330	16,092	19.8	14.9
	July		1613	1,045	1,045	31,357	13,653		0	1,613	48,390	15,170	19.7	16.0
	Aug		1810	1,173	1,173	35,186	15,320		0	1,810	54,300	17,023	19.4	15.6
	Sept		1718	1,113	1,113	33,398	14,541		0	1,718	51,540	16,158	19.9	15.7
	Oct		1686	1,093	1,093	32,776	14,271		0	1,686	50,580	15,857	20.1	16.4
	Nov		1973	1,279	1,279	38,355	16,700		0	1,973	59,190	18,556	20.1	15.5
	Dec		1753	1,136	1,136	34,078	14,838		0	1,753	52,590	16,487	20.2	14.7
	Average						14,218					15,798	19.8	17.0
1991	Jan		1575	1,021	1,021	30,618	13,331		0	1,575	47,250	14,813	19.7	17.4
	Feb		1280	829	829	24,883	10,834		0	1,280	38,400	12,038	19.5	17.3
	Mar		1294	839	839	25,155	10,953		0	1,294	38,820	12,170	20.5	18.4
	April		1180	765	765	22,939	9,988		0	1,180	35,400	11,098	20.2	18.0
	May		1123	728	728	21,831	9,505		0	1,123	33,690	10,562	16.0	13.6
	June		1071	694	694	20,820	9,065		0	1,071	32,130	10,073	15.9	12.6
	July		1235	800	800	24,008	10,453		0	1,235	37,050	11,615	16.4	12.9
	Aug		1177	763	763	22,881	9,962		0	1,177	35,310	11,070	16.0	12.6
	Sept		1208	783	783	23,484	10,225		0	1,208	36,240	11,361	16.2	13.5
	Oct		1264	819	819	24,572	10,699		0	1,264	37,920	11,888	16.5	13.9
	Nov		1391	901	901	27,041	11,774		0	1,391	41,730	13,082	18.2	15.7
	Dec		1663	1,078	1,078	32,329	14,076		0	1,663	49,890	15,641	20.2	17.9
	Average						10,905					12,118	17.9	15.3
1992	Jan		1672	1,083	1,083	32,504	14,152		0	1,672	50,160	15,725	19.9	17.2
	Feb		1540	998	998	29,938	13,035		0	1,540	46,200	14,484	20.5	17.7
	Mar		1433	929	929	27,858	12,129		0	1,433	42,990	13,477	20.4	17.1
	April		1497	970	970	29,102	12,671		0	1,497	44,910	14,079	20.3	17.5
	May		1375	891	891	26,730	11,638		0	1,375	41,250	12,932	20.3	17.8
	June		1307	847	847	25,408	11,063		0	1,307	39,210	12,292	20.0	17.5
	July		1314	851	851	25,544	11,122		0	1,314	39,420	12,358	20.1	17.8
	Aug		1392	902	902	27,060	11,782		0	1,392	41,760	13,092	20.3	18.4
	Sept		991	642	642	19,265	8,388		0	991	29,730	9,320	20.2	18.0
	Oct	759	230	149	908	27,241	11,861		1,171	1,401	42,039	13,179	19.9	16.9
	Nov	755	370	240	995	29,843	12,994		1,165	1,535	46,054	14,438	19.7	18.2
	Dec	616	130	84	700	21,007	9,147		951	1,081	32,419	10,163	20.6	16.7
	Average						11,665					12,962	20.2	17.6
1993	Jan												22.5	16.7
	Feb	558	189	122	680	20,414	8,888		861	1,050	31,503	9,876	21.9	16.0
	Mar	523	162	105	628	18,839	8,203		807	969	29,073	9,114	20.5	16.3
	April	521	339	220	741	22,220	9,675		804	1,143	34,290	10,750	20.4	17.1
	May	447	582	377	824	24,724	10,765		690	1,272	38,154	11,961	20.0	11.7
	June	234	451	292	526	15,787	6,874		361	812	24,363	7,638	18.3	14.4
	July	264	244	158	422	12,663	5,514		407	651	19,542	6,126	19.7	14.9
	Aug	305	249	161	466	13,991	6,091		471	720	21,590	6,769	20.0	15.2
	Sept	333	259	168	501	15,025	6,542		514	773	23,187	7,269	21.0	14.8
	Oct	372	180	117	489	14,659	6,383		574	754	22,622	7,092	20.5	15.2
	Nov	333	203	132	465	13,936	6,068		514	717	21,507	6,742	20.0	15.3
	Dec	420	209	135	555	16,663	7,255		648	857	25,714	8,061	20.2	15.2
	Average						6,855					7,617	20.4	15.2
1994	Jan	396	218	141	537	16,118	7,018		611	829	24,873	7,798	19.6	13.8
	Feb	409	287	186	595	17,849	7,772		631	918	27,545	8,635	20.3	14.1
	Mar	388	183	119	507	15,198	6,617		599	782	23,453	7,353	19.9	13.7
	April	336	174	113	449	13,463	5,862		519	693	20,776	6,513	19.9	14.2
	May	408	210	136	544	16,322	7,107		630	840	25,189	7,897	19.9	15.4
	June	397	102	66	463	13,893	6,049		613	715	21,440	6,721	18.7	13.7
	July	388		0	388	11,640	5,068		599	599	17,963	5,631	18.6	13.2
	Aug	436		0	436	13,080	5,695		673	673	20,185	6,328	17.9	13.3
	Sept	424		0	424	12,720	5,538		654	654	19,630	6,154	17.9	13.6
	Oct	277		0	277	8,310	3,618		427	427	12,824	4,020	17.3	13.6
	Nov	343		0	343	10,290	4,480		529	529	15,880	4,978	19.5	13.5
	Dec	457		0	457	13,710	5,969		705	705	21,157	6,633		
	Average						5,899					6,555	19.0	13.8
1995	Jan	666		0	666	19,980	8,699	$8,699	1,028	1,028	30,833	9,666	18.7	14.6
	Feb	618		0	618	18,540	8,072	$8,072	954	954	28,611	8,970		
	Mar	372		0	372	11,160	4,859	$4,859	574	574	17,222	5,399		
	Average						7,210					8,012		
Daily Averages:		425	966	546	749				312	1,155			19.5	15.8
Monthly Averages:		12,755	28,969	16,388	22,462	22,462	$9,780		9,373	34,664	34,664	$10,867		
Annual Averages:		155,186	352,457	199,390	273,288	269,544	$117,360		114,040	421,741	415,964	$130,405		
Since January 1993														
Monthly Average:							$6,655					$7,394		
Annual Average:							$79,857					$88,734		

tab4-5.wb2

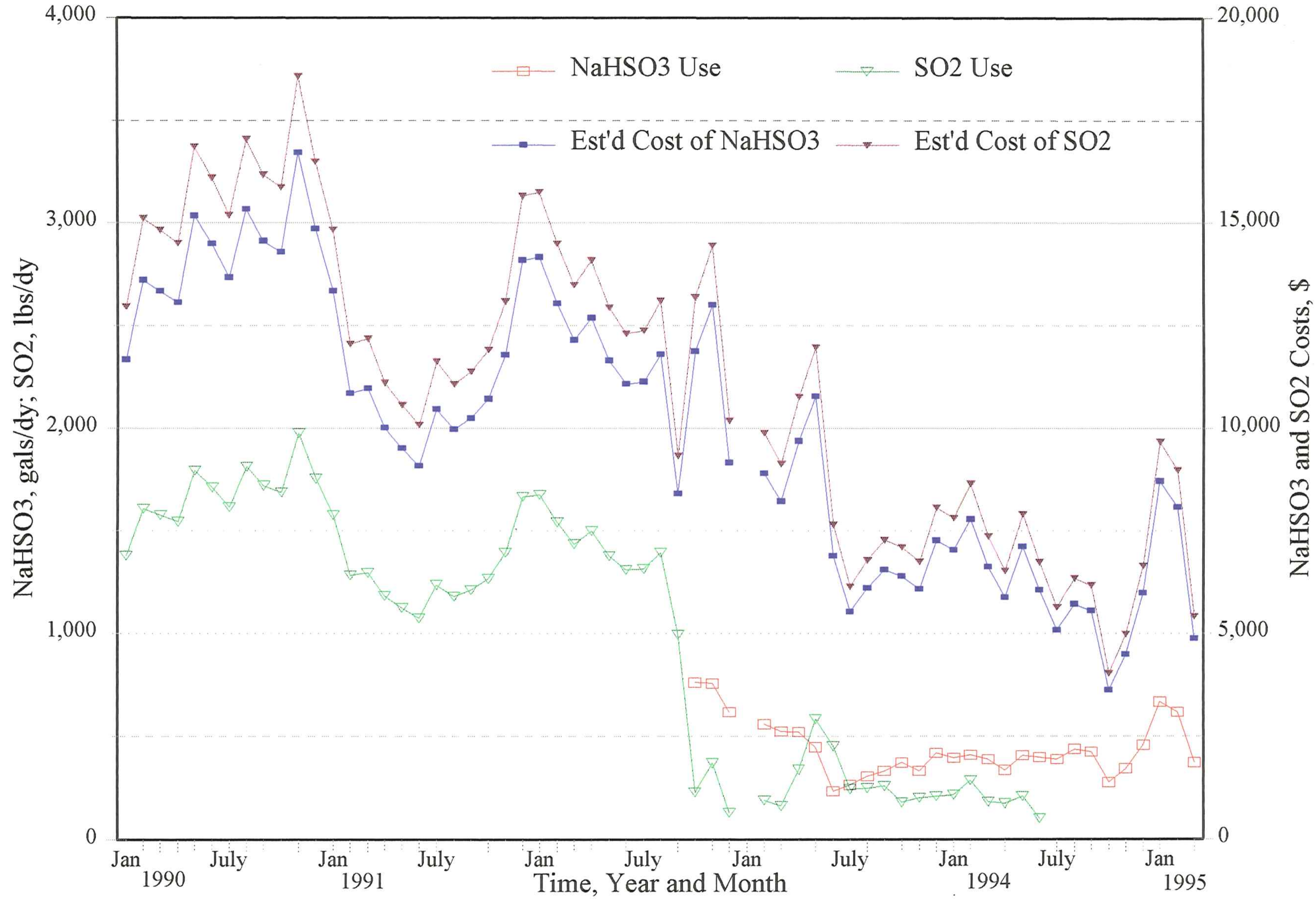


FIGURE 4.2 LAGWRP Chemical Dechlorination Use and Costs.

tab4-5.wb2:f4-2

1994, and $NaHSO_3$ use began in October, 1992. Since one can estimate equivalent quantities of one chemical when the other was the only one used, it is possible to estimate the costs that would have been incurred if either had been used exclusively for the whole period. This has been done to extend the cost estimates through the whole period. Since SO_2 use ended and $NaHSO_3$ use began during this period at LAGWRP, equivalence and estimates are used to provide a more uniform comparison. The estimated cost of NaOCl is about four times that of liquid Cl_2. $NaHSO_3$ is slightly lower in cost than SO_2; as recently as early 1994, $NaHSO_3$ was much more expensive than SO_2. Unit costs and useful equivalencies are summarized in Table 4.6.

TABLE 4.6 Chlorination/Dechlorination Unit Costs and Reaction Equivalencies.

Unit Costs	Reaction Equivalencies
\$351.81/ton Cl_2	1 lb Cl2 = 1 gal 12% NaOCl
= \$0.17590/lb Cl	1 lb Cl2 = 0.901 lbs SO_2
	1 lb Cl2 = 1.46 lbs $NaHSO_3$
\$0.67/gallon 12% NaOCl	
\$627/ton SO_2	
= \$0.3135/lb SO_2	
\$0.1745/lb $NaHSO_3$	1 gal 25% $NaHSO_3$
= \$0.4354/gal 25% $NaHSO_3$	= 2.5 lbs $NaHSO_3$

The principal benefit accrued by LAGWRP converting from gaseous to liquid disinfection is greater safety. At current consumption, Cl_2 costs \$101,000/yr, compared to \$383,000/yr for NaOCl for equal amounts of effectiveness. The projected annual expense for using $NaHSO_3$, \$80,000/yr, is lower than the projected expense for SO_2, \$89,000/yr.

Table 4.7 lists the capital costs required for each disinfection chemical at LAGWRP. The net present value for Cl_2 gas equipment replacement is \$209,000 or an annualized cost of \$4,180. The net present value (NPV) for constructing the NaOCl system will be approximately \$472,000; the annualized cost is \$9,440, twice that of Cl_2, but much safer. Replacement of the SO_2 equipment will require about \$179,000, which translates to an annualized cost of \$3,580. The recent installation of

$NaHSO_3$ equipment cost about \$255,000; replacement costs may be about the same, for an annualized cost of \$5,100. Use of both SO_2 and $NaHSO_3$ has a NPV of \$377,000, or an annualized cost of \$7,540.

TABLE 4.7 Annualized Costs of Chlorination/Dechlorination Facilities at LAGWRP.

Treatment Type	Initial Capital Costs	N.P.V. Replacement Costs	Annualized Cost @ 2%
Chlorine Gas, Cl_2	N/A(1)	\$209,000	\$4,180
Sodium Hypochlorite, NaOCl	\$472,000	\$472,000	\$9,440
Sulfur Dioxide, SO_2	N/A(1)	\$179,000	\$3,580
Sodium Bisulfite, $NaHSO_3$	N/A(1)	\$198,000	\$3,960
Sulfur Dioxide (SO_2) & Sodium Bisulfite ($NaHSO_3$)	\$255,000	\$255,000	\$5,100

(1) Existing facilities

It is assumed that the Fire Department will keep the RMPP requirements in the Code for an indefinite period of time. It is also assumed that LAGWRP will continue the change to NaOCl from gaseous Cl_2, and that $NaHSO_3$ will continue to be used without SO_2.

4.4 COMPARATIVE ANALYSIS

This study projects a 60 year period because the useful life of newly constructed concrete structures and storage tanks is currently estimated to be 60 years and this analysis assumes replacement of equipment that has a shorter useful life.

The annualized cost comparison is calculated as follows. The sum of the costs for construction of new facilities and equipment, including appurtenant piping, and a 20 percent allowance for contingencies gives the capital cost of the project. Operation and maintenance expenses are based on the Monthly Operating Reports for chemical usage, estimated power consumption, replacement parts and labor costs.

Several accounting assumptions are made: Because most cost data was given for 1991, 1991 is considered the base year (n=0). A 5% increase in equipment cost per year is assumed. Labor is assumed to be 7% of all O&M costs. Inflation is assumed to be 4% per year for the next 60 years. Inflation during the previous 20 years is assumed to average 10%. The rate at which the City increases revenue or gains revenue due to bonds and other investments is assumed to be 2%. It is worth noting that these assumptions imply much greater economic stability than was seen in the 60 year period from 1935 to 1995.

Results of this economic analysis, shown in Table 4.8, indicate that UV disinfection is as good or better than disinfection using NaOCl. When Cl_2 and SO_2 were the only chemicals used at the LAGWRP, the total annualized cost was about $211,000. Currently, with $NaHSO_3$ being used instead of SO_2, the total annualized cost has become about $203,000. When current plans to implement use of NaOCl in place of Cl_2 are completed, the total annualized disinfection cost will be $307,000 more for a total of $510,000. The TTI UV4000 unit, considered the most advanced among those available in the market, has an annualized cost of about $519,000. The other two models, BFP 70UV6000 and TTI UV3000, appear more competitive with lower total annualized costs of $449,000 and $484,000, respectively. The City UV estimate and the TTI UV4000 estimate are not significantly different from this, when one considers the uncertainties in the projection of the inflation rate, equipment costs, vendor operations methods, vendor estimating methods, etc., but the BFP 70UV6000 and TTI UV3000, the low pressure UV systems, are significantly lower.

These encouraging results support moving ahead with a pilot study, particularly because several of the assumptions in the current estimates are conservative. For example, these estimates assume a dose of 140 mWs/cm^2, but the RIX (Ref b5), Pomona and Chino (Ref b15) studies mentioned in Table 4.2 used only 129 mWs/cm^2. However, these facilities have higher average transmittance than the 64% average at LAGWRP. The proposed 20 banks of lamps in the current estimates also provide more capacity and redundancy than is common in existing systems. The highest flows occur during storms when the normal sewage flow is diluted by runoff and infiltration, so that it is excessively conservative to design for the same microorganism concentration at the highest flows. Likewise, the assumption of five lamp banks per channel to have a spare bank in each channel at times of high flow is too conservative, given the durability of present equipment and the quality of City maintenance.

Table 4.8 Comparative Annualized Costs of Disinfection Treatment at LAGWRP

Disinfection Chemical	Net Present Value $1,000's	Annualized Capital Cost $1,000's	Annualized (a) Chemical Cost $1,000's	Operating Costs @ 7% Labor $1,000's	Total Annualized Costs $1,000's
Chlorine Gas, Cl2	209	4.2	101	108	112
Sodium Hypochlorite, NaOCl	472	9.4	383	410	419
Sulfur Dioxide, SO2	179	3.6	89	95	99
Sodium Bisulfite, NaHSO3	255	5.1	80	86	91

Disinfection Method	Net Present Value $1,000's	Annualized Capital Cost $1,000's	Annualized Chemical Cost $1,000's	Operating Costs @ 7% Labor $1,000's	Total Annualized Costs $1,000's
Cl2 + SO2	388	7.8	190.0	203	211
Cl2 + NaHSO3	464	9.3	181.0	194	203
NaOCl + SO2	651	13	472	505	518
NaOCl + NaHSO3	727	15	463	495	510
City UV Estimate (b)	3,340	67	N/A	344	419
BFP, 70UV6000 (b)	1,720	34	N/A	415	449
TTI, UV3000 (b)	3,200	64	N/A	420	484
TTI, UV4000 (b)	2,800	56	N/A	463	519

(a) Annual chemical costs are based on use beginning January , 1992, for Cl2 and NaOCL; January, 1993, for SO2 and NaHSO3.

(b) UV estimates for Net Present Value, Annualized Capital Cost, Operating Costs and Total Annualized Costs may be reduced by up to 30% (to $314,000 to $363,000) based on pilot testing that validates the use of lower dose, design that precludes excessive redundancy and operations that, in the case of the UV4000 equipment, significantly reduce labor costs for cleaning.

N/A Not applicable

tf\tab4-8.wb2

As dose, capacity and redundancy are the three areas of excessive conservatism that have been identified in the present proposals, we have estimated reasonable reduction factors for each. Cutting the dose from 140 to 120 mWs/cm^2 would be a reduction of 1/7 to 85.7% of the present designs. Reducing from 20 banks in the channels to 16 with 2 spares and an inexpensive gantry for quick changing would be a 10% reduction in the number of banks. We also estimate that a capacity per bank sufficient to apply a dose of 140 mWs/cm^2 to any flow up to the 95th percentile could be achieved for the design transmittance and SS concentration with about 80% of the number of lamps per bank in the present proposals.

If all of the reductions could be combined, the result would be a system that is 61.7% as expensive to build as the current proposals. The O&M costs for power, lamp replacement, etc., would be 68.7% of the present vendor estimates, since the extra spare banks would not be used. Hence, reducing the number of spares would not adversely effect the O&M costs. Making allowances for system components that would not scale exactly, it is reasonable to estimate that the best possible reduction in the costs of the UV systems listed in Table 4.8 might be about 30%. The annualized cost of UV systems would then range from about $314,000 to $363,000, all of which would be major savings from the costs of disinfection with NaOCl. The City estimate for annualized cost, $419,000, includes a total capital cost of $3,340,000 based on conservative comparisons to referenced similar facilities, and an annualized operating cost of $344,000 based on referenced similar facilities and quotes for spare parts from the parts vendors.

In addition to savings from reducing the present designs, other forms of savings may be possible. For example, it might cut construction costs if the UV bank frames were installed in the existing chlorine contact channels. More work would be needed to know if this could be done, but it suggests what might be found by a search for further economies.

Just as the present estimates for UV disinfection costs in Table 4.8 are overly conservative, so is it doubtlessly too optimistic to expect them to be reduced by a full 30%. This analysis was not intended to be definitive but has identified areas of potential cost reduction and issues that potentially should be addressed during a pilot study. Savings could be less than 30% and still be sufficient to provide a decisive cost advantage over chemical disinfection.

CHAPTER 5

PROPOSED PILOT PROJECT

5.1 PILOT TESTS

The proposed pilot tests outlined in this chapter would determine the minimum dose necessary to meet the Title 22 Guidelines [Ref b11] for reclamation. Capital costs, as well as operating and maintenance expenses, for a prototype system would be derived from these pilot tests and compared to those for chemical disinfection. Tests at LAGWRP, TWRP and TITP would closely follow the pilot study recently completed at the OCWD with a few site-specific differences. OCWD's extensive study has been approved and monitored by many leading experts, including George Tchobanoglous of the University of California at Davis (UCD), Charles Gerba of the University of Arizona at Tucson (UAT), and Bob Hultquist of the Office of Drinking Water Standards, DHS.

Intrinsic distinctions among the LAGWRP, TWRP, TITP and OCWD sites are important to note. LAGWRP treats mostly residential flows, with occasional spike loadings from industries. TWRP treats a combination of residential and industrial flows, the former being greater. TITP treats exceptionally variable diurnal flow, which is dominated by industrial contributions during the day. The LAGWRP, TWRP and TITP sites would use the UV2000, a low pressure-low energy pilot unit with electromagnetic ballasts. OCWD used the UV3000, a low pressure-low energy pilot unit with electronic ballasts that generate very little heat and requires significantly less power consumption. Alternatively, the UV4000, medium pressure-high energy pilot unit, could be used.

5.1.1 General Layout

Specific sites at LAGWRP, TWRP AND TITP best suited to accomodate a UV pilot test unit are shown in Figures 5.1, 5.2 and 5.3, respectively. The LAGWRP site would be the new, large, centrally located parking lot, west of the final clarifiers and north of the west chlorine contact tank (between

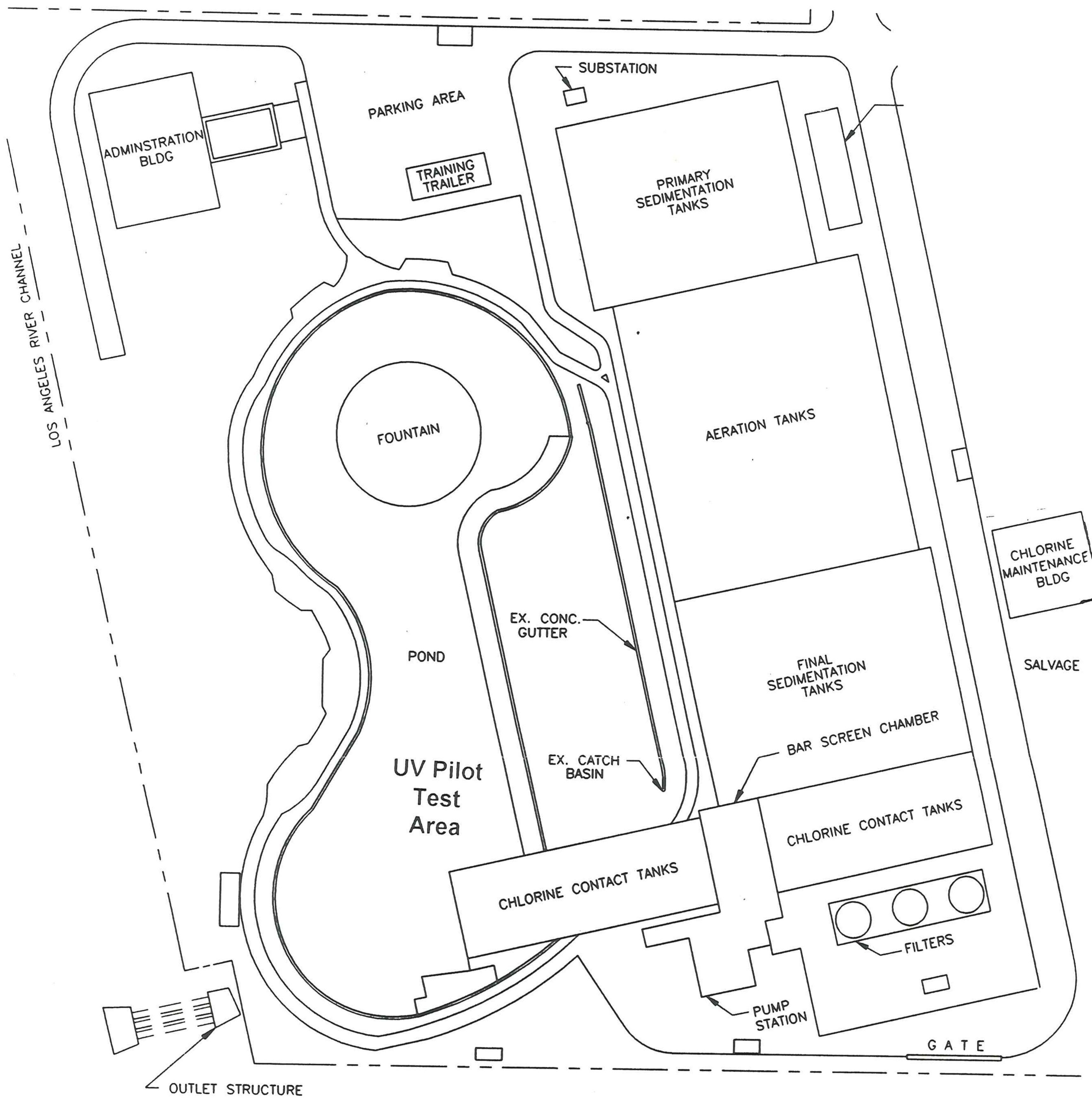


Figure 5.1 Site for the UV Pilot Test at LAGWRP.

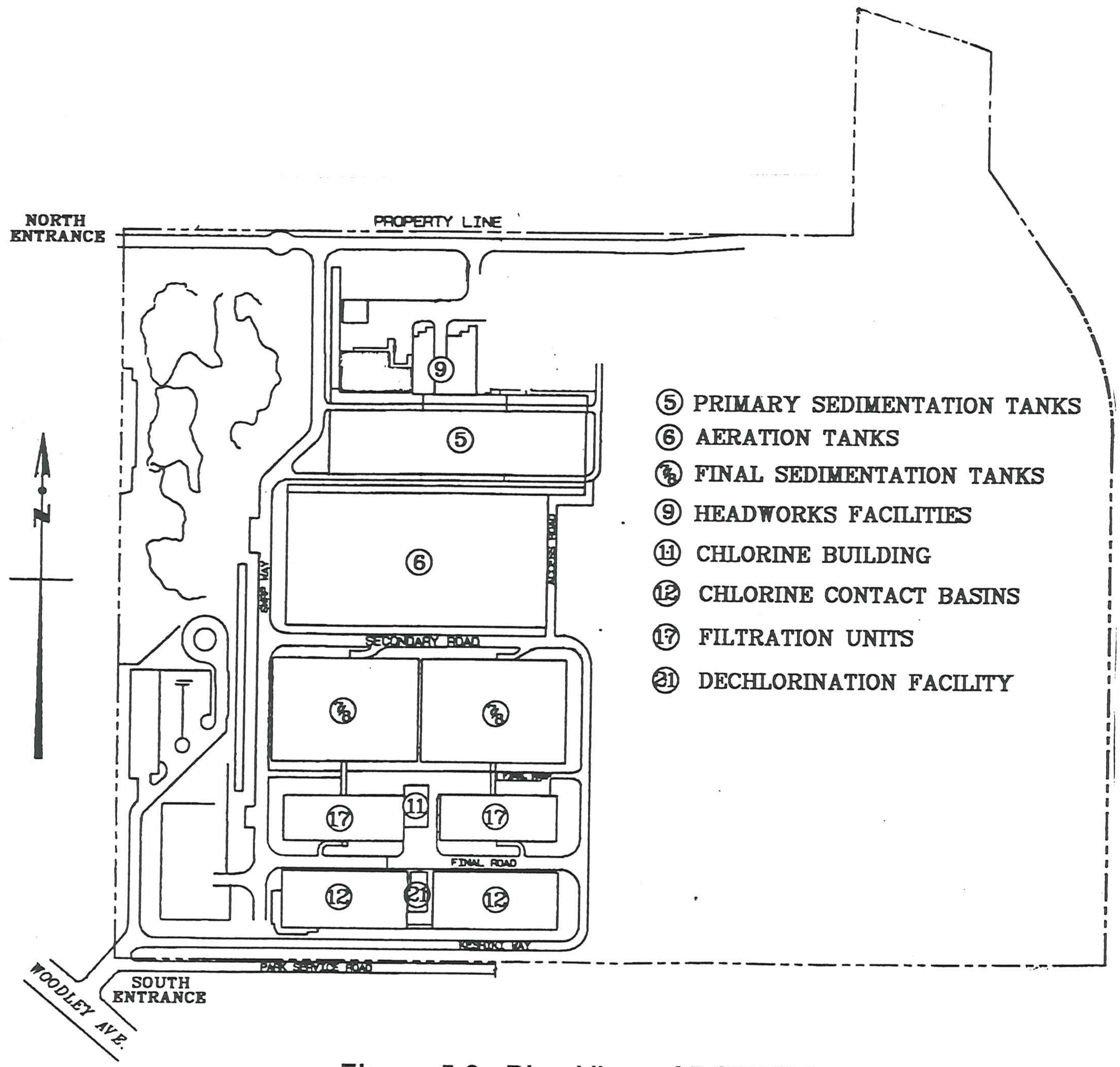


Figure 5.2a Plan View of DCTWRP.

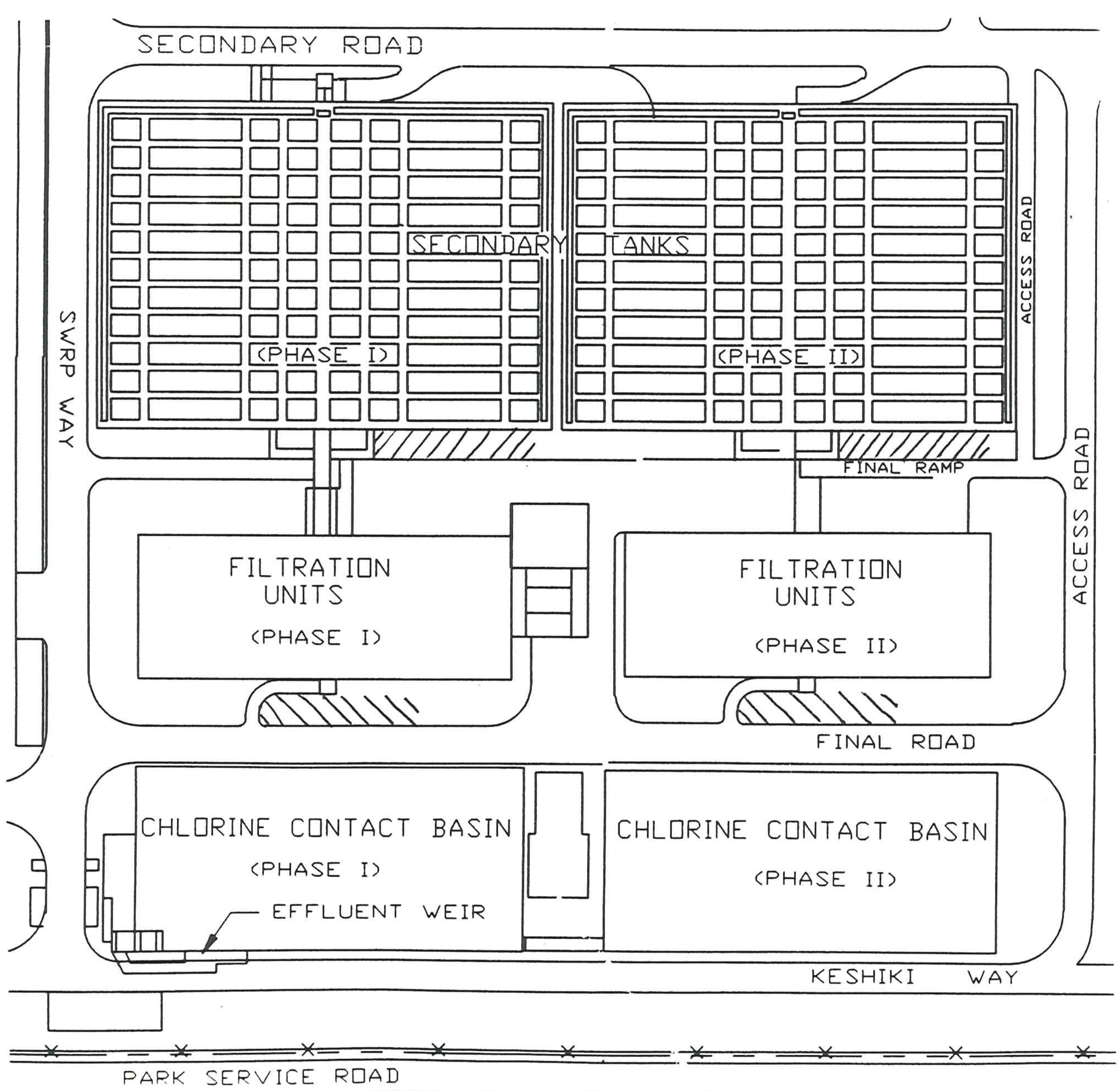
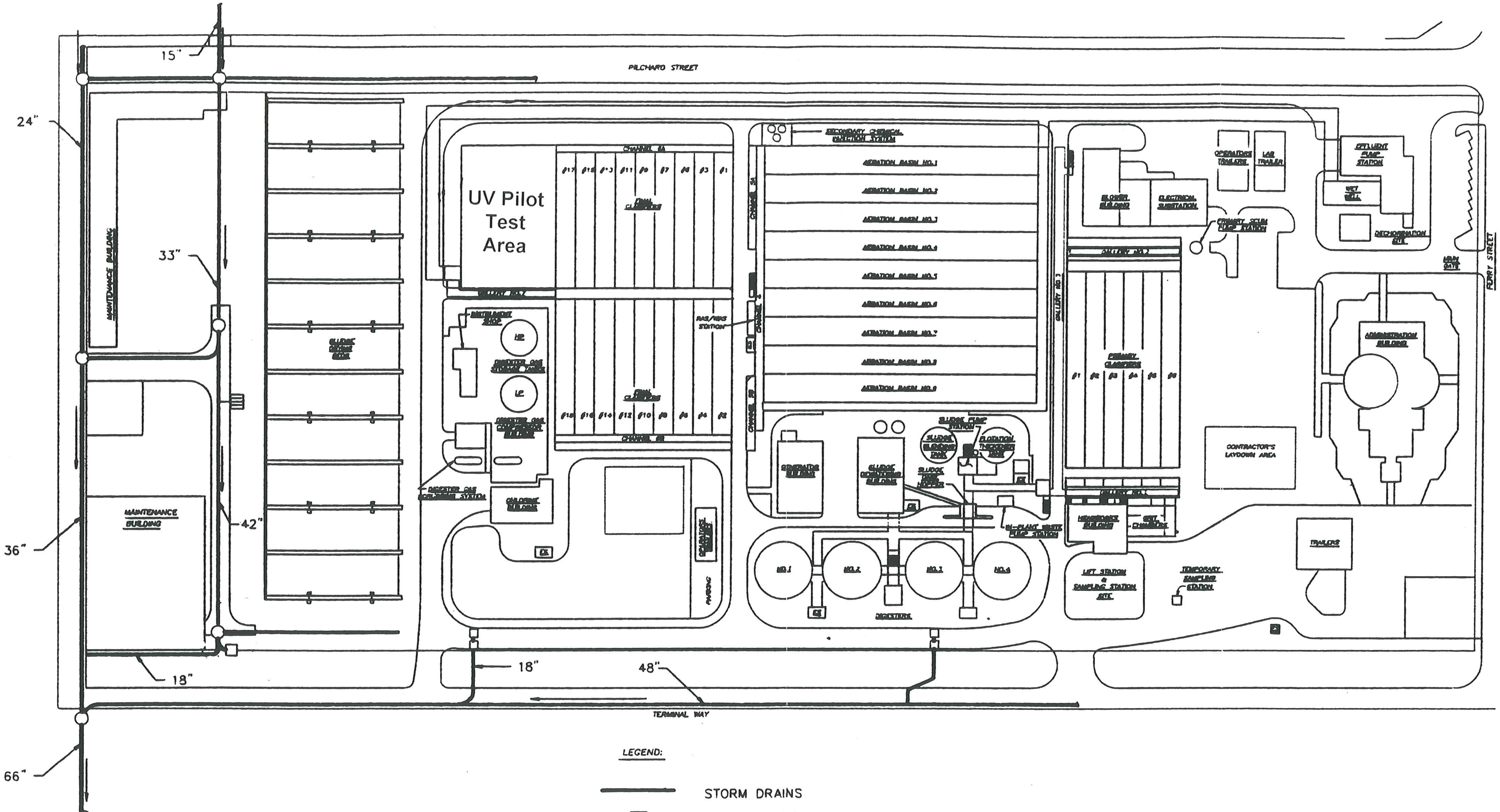


Figure 5.2b Site for the UV Pilot Test at DCTWRP.

UV Pilot Test Areas: ▨ UV2000 ▧ UV4000



LEGEND:

STORM DRAINS

CATCH BASINS

GRATING

MANHOLE COVERS

Figure 5.3 Site for the UV Pilot Test at TITP.

the lagoon and secondary aeration). The best site at TWRP would be immediately south of the Phase 1 Final Sedimentation Tanks, east of the flow channel between the secondary clarifiers and the filters. The TITP site would be the same site used for the 1993 Pilot Filter Study.

At the LAGWRP, the pilot unit suction side could be a new tap on the filter product water piping, or from a submersible pump anchored to the pipe invert a few feet prior to the existing chlorination point. The pilot test effluent would be discharged to the filter backwash wet well, to the in-plant sewer or to the closest upstream process unit. Alternatively, plant staff has suggested temporarily relocating the chlorination point downstream far enough that the pilot unit effluent could be discharged downstream from the suction side withdrawal and upstream from the chlorination point.

At TWRP, for either Phase I or Phase II, the pilot unit could be placed between the filters and the aeration tanks with the suction hose and submersible pump being hung into the filter product water channel upstream from the weir where the flow is chlorinated with the discharge hose directed to a nearby in-plant sewer.

5.1.2 UV2000 Pilot Testing

Pilot tests would be conducted using the Trojan UV 2000 pilot unit, Model 2250, rated at 1 Kw at 120 v, 60 Hz. This unit includes three horizontal 8-foot long, 6-inch x 9-inch stainless steel channels in series, and a control panel with six electromagnetic ballasts and a UV intensity sensor. Each channel supports two modules of two low pressure mercury lamps in a 2 x 2 array. Each module requires a ballast rated at 1.45 amp, 120 v, 60 Hz, to provide power for the two lamps. The channels would be aligned in series with 4-foot entrance and exit channels, an influent chamber before and an effluent chamber beyond.

Figure 5.4 presents a schematic of the proposed pilot test apparatus. Filtered effluent is pumped by P-1 through a 2-inch PVC pipe to a 3000 gallon seeding tank, T-1, where the virus seed is introduced by a virologist. A minimum of three seeded tests will be run to determine the kill capability of the UV

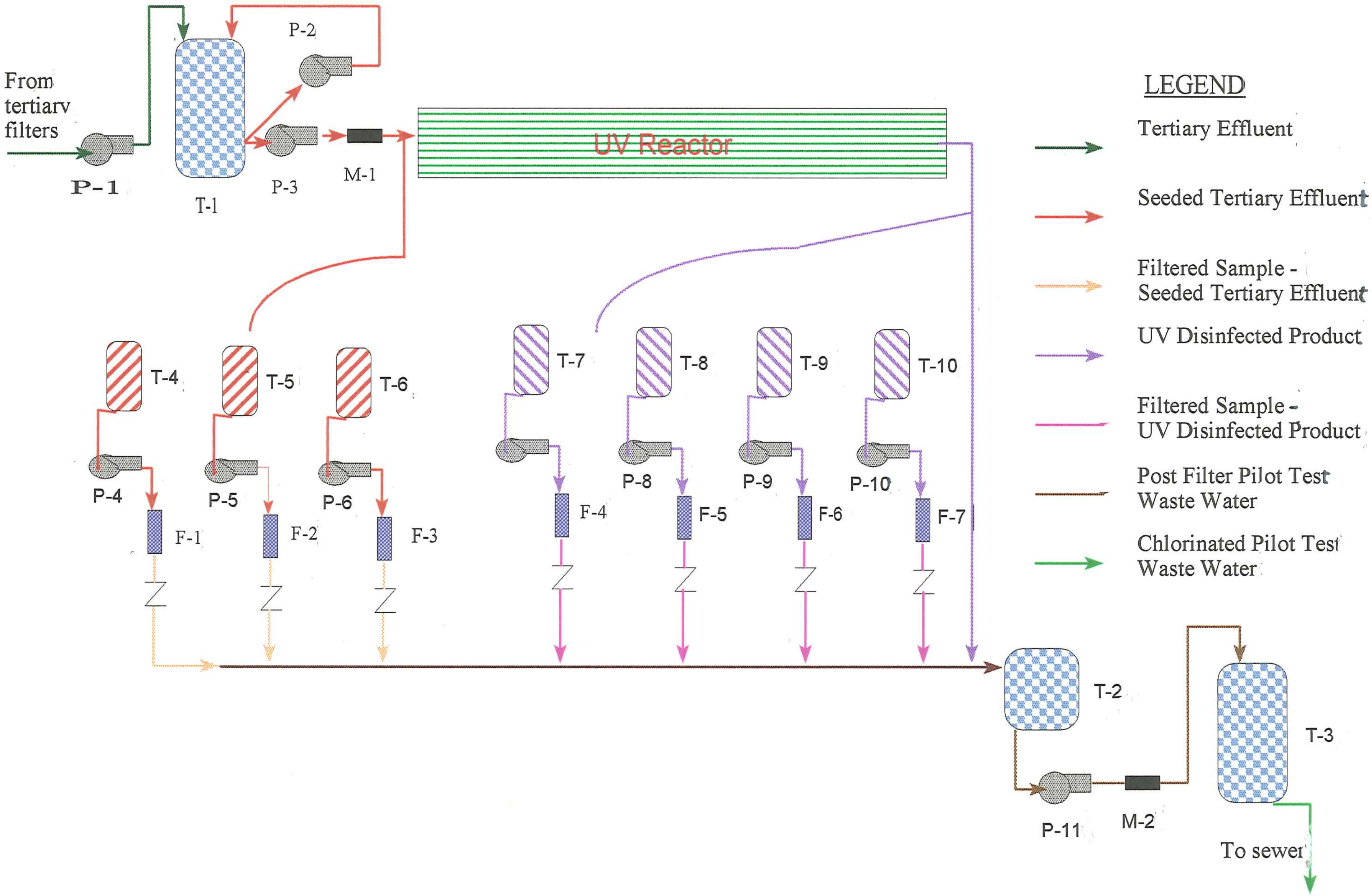


Figure 5.4 Schematic of the Proposed Low Pressure-Low Energy Pilot Test Apparatus.

pilot system. Uniform mixing will be achieved by using a 100 gpm, 15 feet head centrifugal pump, P-2, which draws flow from the bottom and discharges to the top of the tank, which can use either an impeller mixer or a recirculating pump. Two-inch pipe will be used throughout the pilot system. A centrifugal pump, P-3, rated at 140 gpm and 10 feet head, transfers the seeded liquid to the UV unit. Prior to entering the UV pilot unit, 300 gallon samples of the seeded flow are taken in sample tanks T-4, T-5 and T-6 at the beginning and end of the test to evaluate the attenuation of the viruses due to environmental factors during the test run. Effluent from the UV unit flows by gravity to sample tanks T-7, T-8, T-9 and T-10 wherein 300 gallon samples are collected for four different UV doses, at four different flow rates. From each sample tank, the sample is pumped using 10 gpm variable speed pumps, P-4 thru P-10, through cartridge filters, F-1 thru F-7, to the interim storage tank, T-2, from which a centrifugal pump, P-11, transfers the disinfected liquid to a final 3000 gallon holding tank, T-3. Flow meters are placed downstream from each pump. Pressure gages are placed adjacent to sample pumps.

The 2 x 2 horizontal matrix is the smallest practicable unit for pilot testing. It is an inexpensive design capable of handling flow rates up to 200 gpm. Channels with only one or two lamps do not provide an adequate geometric configuration for scale-up comparison. Larger pilot units are available from various vendors, including a 3 x 3 matrix unit from Trojan. Much larger units are also available in both horizontal and vertical array configurations. These units, however, require considerably larger flows and equipment without providing significantly more accurate results. The use of electronic ballasts is preferable over the electromagnetic type due to the ability to closely monitor the exact energy consumption.

Several precautionary measures are necessary to ensure that the system is not contaminated for subsequent testing. The tank contents are disinfected overnight by chlorine shocking and discharged to the in-plant sewer the following day. The entire UV system is, likewise, disinfected by allowing each container to hold a full volume of chlorinated liquid overnight. Bleach or NaOCl would be used for chlorination throughout the pilot testing for safety reasons and ease of use. Lamps are cleaned immediately prior to each test run.

5.1.3 UV2000 Sampling Plan

To determine the effectiveness of each test run, measurements of selected parameters must be made on site and in the laboratory. Flow rates, amount of flow, pressures, and general weather conditions must be recorded on site. Samples for laboratory analyses must be taken to provide adequate physical, chemical and microbiological characterization of the UV system filtered influent and disinfected effluent.

Laboratory support is anticipated from three different sources. Analyses of chemical and physical characteristics would be performed by the EMD staff at TITP and HTP, which could also perform some bacteriology (particularly total coliform and heterotrophic plate count). Virology and other bacteriology testing would be contracted out to UCR with Marilyn Yates as the principal investigator or to the County Sanitation Districts of Orange County (CSDOC) Technical Services Division. Consultation with a number of experts, including these agencies, during the past two years has resulted in the development of the sampling plan for the proposed UV Pilot Test.

Tentatively, the pilot study is divided into four phases. The total duration is estimated to be four months at each plant site. The decision to reduce any testing to less than this period would be made only upon consultation with the experts and the DHS. The initial flow rates will be based on the data in Table 2.6, which were computed by the UVDIS 3.1 program. Tables 5.1a and b present the expected sampling and laboratory analysis schedules for Phases II, III and IV, including lead agencies, for pilot testing low pressure-low energy and medium pressure-high energy systems, respectively.

Pre-UV Testing (Phase I). This phase will require up to two weeks for completion of its two subtasks. The first subtask will be conducting a full hydraulic study based on tracer tests using either a dye, detected by a fluorometer, or a salt, detected by a conductivity meter. This will be monitored at the inlet, outlet and between UV banks. Minimum, average and maximum anticipated flow rates will be used.

Table 5.1a Sampling and Analysis Schedule for Pilot Testing of Low Pressure-Low Energy UV Disinfection Systems.

Task Area	Sampling/Analyses Tasks	Phase II, Part 1	Phase II, Part 2	Phase III	Phase IV	Lead Agency
A	Total Coliform	8/dy * 2 dys	3/wk * 4 wks	4/dose curve	2/wk * 3 mo.s	VLAB
	HPC	8/dy * 2 dys	3/wk * 4 wks	4/dose curve	2/wk * 3 mo.s	VLAB
	Natural Coliphages	n/a	3/wk * 4 wks	n/a	2/wk * 3 mo.s	VLAB
	Natural Enteric Viruses	n/a	3/wk * 4 wks	n/a	2/wk * 3 mo.s	VLAB
	MS2 Phage Seed	n/a	n/a	1/dose curve	n/a	VLAB
	MS2 Assays	n/a	n/a	1/dose curve	n/a	VLAB
	SS	8/dy * 2 dys	N/wk * 4 wks	1/dose curve	F/wk * 3 mo.s	EMD
	TDS	8/dy * 2 dys	N/wk * 4 wks	1/dose curve	F/wk * 3 mo.s	EMD
	Residual Cl	8/dy * 2 dys	N/wk * 4 wks	1/dose curve	F/wk * 3 mo.s	EMD
	Fe	8/dy * 2 dys	N/wk * 4 wks	1/dose curve	F/wk * 3 mo.s	EMD
B	TOC	8/dy * 2 dys	N/wk * 4 wks	1/dose curve	F/wk * 3 mo.s	EMD
	Hardness	8/dy * 2 dys	N/wk * 4 wks	1/dose curve	F/wk * 3 mo.s	EMD
	ALK	8/dy * 2 dys	N/wk * 4 wks	1/dose curve	F/wk * 3 mo.s	EMD
C	% Transmittance	continuous	continuous	continuous	continuous	LWMD
	Turbidity	continuous	continuous	continuous	continuous	LWMD
	Conductivity	continuous	continuous	continuous	continuous	EMD
	pH	continuous	continuous	continuous	continuous	EMD
	Temperature	continuous	continuous	continuous	continuous	EMD
	Particle Count	continuous	continuous	continuous	continuous	LWMD
D	Miscellaneous	as needed				EMD/LWMD

Phase I hydraulic testing is not included in the above, but would require 3-5 days.
VLAB: Virology Laboratory, UCR.
CON: Consultant/Personal Services Contract.
N: Frequency of sampling depends on results from Phase II, Part 1, concentrated diurnal sampling.
F: Frequency of sampling depends on results from Phases I, II and III.

Phase I: Hydraulic Testing.
Phase II: Collection of Basic Influent Data: Part 1, Concentrated Diurnal Sampling; and Part 2, Extended Pre-UV Test Analyses.
Phase III: UV Disinfection Efficiency and Dose Response for Microorganisms and Viruses, using Seed Batch Sampling.
Phae IV: Lamp Fouling Monitoring.

tab5-1a.wb2

Table 5.1b Sampling and Analysis Schedule for Pilot Testing of a Medium Pressure-High Energy UVDisinfection System.

Task Area	Sampling/Analyses Tasks	Phase II, Part 1	Phase II, Part 2	Phase III	Lead Agency
A	Total Coliform	8/dy * 2 dys	3/wk * 4 wks	4/dose curve	VLAB
	HPC	8/dy * 2 dys	3/wk * 4 wks	4/dose curve	VLAB
	Natural Coliphages	n/a	3/wk * 4 wks	n/a	VLAB
	Natural Enteric Viruses	n/a	3/wk * 4 wks	n/a	VLAB
	MS2 Phage Seed	n/a	n/a	1/dose curve	VLAB
	MS2 Assays	n/a	n/a	1/dose curve	VLAB
	SS	8/dy * 2 dys	N/wk * 4 wks	1/dose curve	EMD
	TDS	8/dy * 2 dys	N/wk * 4 wks	1/dose curve	EMD
	Residual Cl	8/dy * 2 dys	N/wk * 4 wks	1/dose curve	EMD
	Fe	8/dy * 2 dys	N/wk * 4 wks	1/dose curve	EMD
B	TOC	8/dy * 2 dys	N/wk * 4 wks	1/dose curve	EMD
	Hardness	8/dy * 2 dys	N/wk * 4 wks	1/dose curve	EMD
	ALK	8/dy * 2 dys	N/wk * 4 wks	1/dose curve	EMD
C	% Transmittance	continuous	continuous	continuous	LWMD
	Turbidity	continuous	continuous	continuous	LWMD
	Conductivity	continuous	continuous	continuous	EMD
	pH	continuous	continuous	continuous	EMD
	Temperature	continuous	continuous	continuous	EMD
	Particle Count	continuous	continuous	continuous	LWMD
D	Miscellaneous	as needed			EMD/LWMD

Phase I hydraulic testing is not included in the above, but would require 3-5 days.
VLAB: Virology Laboratory, UCR.
CON: Consultant/Personal Services Contract.
N: Frequency of sampling depends on results from Phase II, Part 1, concentrated diurnal sampling.
F: Frequency of sampling depends on results from Phases I, II and III.

Phase I: Hydraulic Testing.
Phase II: Collection of Basic Influent Data: Part 1, Concentrated Diurnal Sampling; and Part 2, Extended Pre-UV Test Analyses.
Phase III: UV Disinfection Efficiency and Dose Response for Microorganisms and Viruses, using Seed Batch Sampling.
Phae IV: Lamp Fouling Monitoring.

tab5-1b.wb2

The second subtask will be to burn in the UV lamps to 100 hours or more. This will give the remaining test a constant representative drop in lamp intensity for the duration of the lamp life.

Collection of Basic UV Influent Data (Phase II). This phase will require up to two months for completion of two subtasks. The first subtask will require intensive sampling to determine diurnal variations. Samples will be taken from the influents and effluents of the tertiary filter and the UV unit. Removal rates and log kills of various species will be determined for total coliform, Heterotrophic Plate Count (HPC) and indigenous enteric viruses. All other samples will be taken only at the UV influent. Pipes and conduits upstream from the UV channels should be disinfected and flushed prior to data collection.

The second subtask will be based on the first to establish testing frequency for this subtask. Indigenous enteric viruses could exhibit similar diurnal patterns as total coliform. Therefore, if practicable, testing for viruses and other microorganisms will be conducted during time periods when total coliform is at its highest concentration. Based on the results of Phase II, the background concentrations of microorganisms will be established. Virus seeding will be necessary if adequate concentration of an indigenous virus is not present in the process.

UV Disinfection Efficiency and Dose Response for Microorganisms and Viruses (Phase III). Phase III will take up to one month and will require seed-batch testing with MS2 Coliphage and an indigenous enteric virus, if needed, will be conducted. Seed solution will be introduced into the mixing tank by VLAB personnel. Total coliform and HPC will also be analyzed.

Four seed dose tests will be conducted. Four UV dose tests (i.e., the same seed dose at 4 different flow rates) will be conducted during each seed dose test. Between seed dose tests, all equipment that will have been exposed to a seeded virus will be heavily chlorinated. UV dose will be increased by reducing the flow rate through the UV unit and decreased by increasing the flow rate. All UV lamps will be cleaned prior to each run.

In addition to the seeded viruses, the parameters monitored in Phase II will also be monitored in Phase III, except at a less frequent level.

UV Lamp Fouling (Phase IV). UV lamps will be monitored for fouling and a schedule will be established for cleaning maintenance at a flow rate based on results from Phases II and III. The parameters monitored in Phases II and III will also be monitored in Phase IV, but at a longer frequency. Parameters on which lamp cleaning frequency will be based include Total Coliform and HPC.

Lamp cleaning events after Phase III completion will be necessary to accurately evaluate UV lamp fouling. UV quartz lamp sleeves will be cleaned only when consecutive samples for critical process parameters exceed acceptable levels. At least two lamp cleaning events after Phase III will be required to assess lamp cleaning needs and maintenance requirements.

5.2 ANTICIPATED RESULTS

These studies should be able to quantifiably demonstrate the effectiveness of UV disinfection as an alternative to chlorination/dechlorination at the LAGWRP, TWRP and TITP. Testing will determine the minimum UV dose required to meet Title 22 standards for treatment for unrestricted reclamation and to obtain approval by the California DHS in accordance with the NWRI Guidelines. Data from these tests will determine:

1. the minimum allowable UV dose to meet Title 22 and NWRI Guidelines, especially as pertaining to Total Coliform and MS2 Coliphage removals;
2. operations and maintenance requirements, including cleaning frequency and energy conservation;
3. relationships among UV dose, UV transmittance, turbidity, suspended solids and other effluent constituent characteristics;

4. the economic viability of the UV disinfection alternative compared to gaseous chlorine and sulfur dioxide, and sodium hypochlorite and sodium bisulfite, based on Item Nos. 1, 2 and 3; and
5. site-specific criteria for design of full-scale facilities.

Other agencies, including the DHS, will be provided with the test data and results to correlate them with their own test data for purposes of an expanded (State-wide) database of UV disinfection information.

The pilot study will evaluate the minimum dosage necessary to obtain 4-log virus inactivation over a wide range of flow rates. In particular, data from this study will determine the precise dose required to achieve the bacterial and virus removals specified in Section 1.3. Each pilot study will determine a site-specific dose.

The matrix of seed doses and UV doses will indicate a minimum acceptable UV dose for purposes of public safety. By testing with four different concentrations of bacteria and attenuated virus, disinfection within the probable range of pathogens will be tested and the data from each site-specific study will indicate the capability of the UV pilot system to disinfect pathogens within this range. By testing with four flow rates or varying UV intensities, disinfection within the probable ranges of weekly maximum, daily maximum and low flow will be tested. The data will indicate the UV dose necessary to disinfect pathogens to a particular limit within the expected range of flow rates and influent pathogen concentrations. UV dose may be correlated with any of the measured parameters, from which any strong correlation with virus removal should indicate the most acceptable UV dose. Otherwise, a simple plot of virus removal versus UV intensity will determine the minimum acceptable UV dose. An attempt will also be made to correlate seeded virus removal with the other parameters, particularly Total Coliform and HPC.

Several key UV effluent characteristics for LAGWRP are given in Table 3.1. Flow rates of 75, 85, 100 and 110 gpm, when used in UVDIS, yield estimated doses of 146, 129, 110 and 100 milliwatt-seconds/cm_2, respectively. From the seeded tests, we can estimate the appropriate pathogen reduction for any given dose.

5.3 COSTS OF PILOT TESTS

5.3.1 Costs of Pilot Tests for Title 22 Requirements

The total cost for UV pilot testing the UV2000 at the three outlying plants is approximately $435,000 based on a Class C estimate: $154,000 for LAGWRP; and $94,000 for TWRP-Ph I, TWRP-Ph II and TITP, each.. This includes purchase of neccessary materials, supplies and equipment, installation and mobilization costs, testing and a 20 percent contingency factor as given in Table 5.2. This does not include renumeration for consultants and DHS ($65/hr plus expenses) staff who will review the work plan and test results, including the final report; RWQCB staff also review the work plan and test results, but at no cost. A suggested budget is to provide a personal services contract of up to $5,000 for each individual/organization. Another cost is that of hydraulic testing, which can be accomplished by hiring individuals from UCD for as little as $3000, as done by OCWD, although efforts will be made to have this task performed by in-house staff (probably the from Hydraulic Lab).

The City already owns a low pressure-low energy pilot unit, the Trojan Model UV2000. However, miscellaneous piping, valves, metering devices, filter cartridges, tanks and other construction materials will be needed. This will cost approximately $23,000. An on-line UV transmittance monitor would also be purchased for about $19,000.

Actual testing expenses are estimated at $71,500 per site. The cost of testing is dominated by the microbial analyses, particularly virological testing, which are estimated at $70,200 per site. EMD's costs to run chemical and physical tests are not included, nor EMD's expenses for possibly running all the bacteriology (and virology) tests. The power cost for twelve 26.7 watt UV lamps that burn

Table 5.2 Estimated Costs for UV Pilot Testing at LAGWRP, TWRP Phases I and II, and TITP.

INSTALLATION AND MOBILIZATION	LAGWRP	TWRP-Ph I	TWRP-Ph II	TITP	Totals
Installation					
Piping Materials	20,300	1,000	1,000	1,000	23,300
UV Pilot Unit Support	2,500	1,000	1,000	1,000	5,500
UV On-line Transmittance Monitor	18,785				18,785
Sub-Total - Installation	41,585	2,000	2,000	2,000	$47,585
Mobilization					
Transportation	3,000	3,000	3,000	3,000	12,000
Assembly	8,320	1,000	1,000	1,000	11,320
Disassembly	2,288	1,000	1,000	1,000	5,288
Sub-Total - Mobilization	13,608	5,000	5,000	5,000	$28,608
Total - Installation and Mobilization	**55,193**	**7,000**	**7,000**	**7,000**	**$76,193**
TESTING					
Microbial/Virus Analyses	70,211	70,211	70,211	70,211	280,844
Cleaning	100	100	100	100	400
Power	180	180	180	180	720
Spare Parts: UV Lamps, Quartz Sleeves, etc.	1,000	1,000	1,000	1,000	4,000
	71,491	71,491	71,491	71,491	$285,964
Total - Testing	**71,491**	**71,491**	**71,491**	**71,491**	**$285,964**
SITE SUBTOTAL	**126,684**	**78,491**	**78,491**	**78,491**	**$362,157**
CONTINGENCIES					
Contingencies, 20%	25,337	15,698	15,698	15,698	$72,431
TOTAL FOR PILOT TESTING AT EACH SIT	**$152,021**	**$94,189**	**$94,189**	**$94,189**	**$434,588**

tab5-2.wb2:B

for 2,000 hours with a 27 percent efficiency is about $237 per plant, assuming an electrical rate of $0.10/KWH (mid-day peak rate).

Mobilization assumes a crew of two or more working together. Initial assembly requires the greatest amount of labor and corresponding cost; the ease of reassembly at the second and third test sites requires a lower cost. Disassembly is similarly made easy by the use of many unions and flanged fittings. Transfer of equipment to and from each site by plant maintenance staff reflects the need for forklifts and small cranes, available at the plants, for the UV pilot unit and larger tanks.

A 20 percent contingency is added to the total cost.

An alternative UV pilot unit would be a trailer mounted Trojan UV4000. This model uses medium pressure-high energy lamps, resulting in the use of fewer lamps. It also incorporates a self-cleaning mechanism for the quartz sleeves, and requires a smaller footprint in full scale application. No problem is anticipated in locating the intake and discharge points, as flexible hose could be used. This system is being leased by TTI for about $20,000 for a one-month pilot test, and includes the services of two technicians who would be taking the samples.

Costs for pilot testing with the UV4000 are firm. This is a new pilot unit, which has been evaluated by DHS and is being considered by the Santa Ana RWQCB after being tested by the City of Riverside during May, 1995. Instead of all the electrical and mechanical construction, which is typical of pilot testing, the UV4000 is self-contained, and the self-cleaning feature would eliminate the cost and duration of the fouling test. If conducted similarly to the Riverside test, sampling would include several runs at 20, 40, 60, 80, 100 and 120 mWs/cm^2, with 30-50 total coliform samples, 5-10 HPC samples and 4-6 MS2 phage samples at each dose. Pilot testing would require only 30 days per site compared to four months at each site proposed for our UV2000. The performance history for this new technology is limited and the regulatory policies and oversight may require small, but significant, modifications to the proposed equipment and work plan.

5.3.2 Preliminary Testing Options

The major expense associated with the pilot test to verify compliance with Title 22 is the cost of virological analyses, estimated at about $70,000 per site. If virological testing were omitted from a pilot test using low pressure-low energy lamps, costs would be reduced to approximagely $57,000 plus contingencies for testing at LAGWRP, $82,000 plus contingencies for all testing. This could provide Management preliminary, but critical, data on the economic and technical viability of shifting to UV disinfection in the future. This option may be better suited to current wastewater program budget constraints. An added benefit would be the experience to be gained by our engineers in this field.

All other aspects of the previously described plan would be carried out. If a commitment were made to pursue UV disinfection, then a virological pilot test program would have to be conducted later to verify compliance with Title 22. This would increase the total cost of pilot testing before full implementation of UV disinfection, but it would defer the costs of virological testing to a later fiscal year.

A third option is to pilot test the medium pressure-high energy, UV4000 system using MS2 coliphage instead of virus, as done by the Cities of Pacific and Riverside. Assuming that all analyses are performed in-house, costs would be reduced to approximately $35,000 plus contingencies for LAGWRP, $95,000 plus contingencies for all testing. The CSDOC Technical Services Laboratory would train EMD staff in techniques involving MS2 phage testing and act in advisory capacity. This test program would fully verify compliance with Title 22, assuming the proposed Title 22 regulations are approved.

CHAPTER 6

OVERALL WORK PLAN

6.1 PROPOSED SCHEDULE

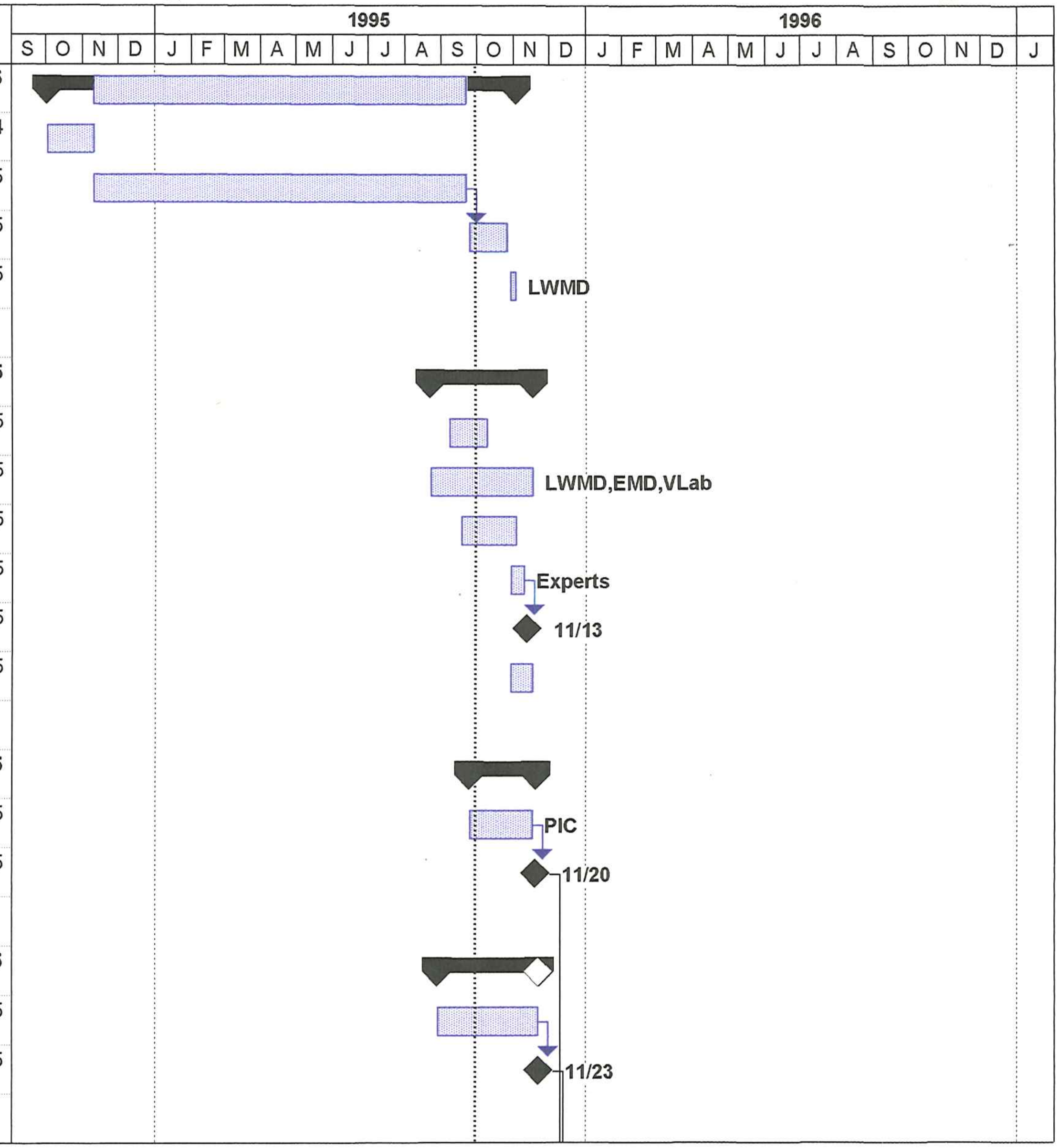
Major tasks of the proposed pilot project activities are outlined in Figures 6.1 and 6.2, respectively, for testing low pressure-low energy and medium pressure-high energy pilot units. This draft feasibility report by the Liquid Waste Management Division's Wastewater Research Group is scheduled for completion by the end of September, 1995. The draft report will be distributed to the various appropriate divisions within the Bureaus of Sanitation and Engineering for review and comments. This will allow them to review the technology, economics of UV disinfection, testing requirements and dynamics of the regulatory process. A preliminary draft report was submitted to the RWQCB in late 1994.

A request for funding may be submitted to the Program Implementation Committee (PIC). Although management has indicated that this project may receive the necessary approvals and funding without formally addressing PIC, such a presentation is scheduled for November 20, 1995. Once funding is confirmed, a detailed work plan for the pilot testing will be developed.

Completion of the Pilot Study Work Plan, including detailed drawings or plans, will be completed during November, 1995. During work plan development, meetings with DHS staff, RWQCB staff, and UV disinfection experts, will be held to gain from their experience and to facilitate approval of the work plan by the regulatory agencies. Submittal of the Work Plan to regulatory agencies for approval is scheduled for October, 1995; DHS approval is anticipated in late November, while RWQCB will probably give tacit approval within the following two weeks.

The low pressure-low energy, UV2000 pilot unit will require up to two months for procurement and delivery of equipment, materials and supplies, these tasks to be started with site layout. Actual

ID	Task Name	Duration	Start	Finish
1	**Feasibility Report**	**285d**	**10/3/94**	**11/3/95**
2	Preliminary Draft Report	30d	10/3/94	11/11/94
3	Draft Report	226d	11/11/94	9/22/95
4	City & Expert Comments	25d	9/25/95	10/27/95
5	Final Report	5d	10/30/95	11/3/95
6				
7	**Test Protocols**	**63d**	**8/23/95**	**11/17/95**
8	Preliminary Outline	23d	9/8/95	10/10/95
9	Virology Contract	63d	8/23/95	11/17/95
10	Expert Contracting	35d	9/18/95	11/3/95
11	Expert Review	10d	10/30/95	11/10/95
12	Exp't Rev'w Completed	1d	11/13/95	11/13/95
13	Final Protocol	15d	10/30/95	11/17/95
14				
15	**PIC Approval Process**	**41d**	**9/25/95**	**11/20/95**
16	Approval Process	40d	9/25/95	11/17/95
17	Presentation	1d	11/20/95	11/20/95
18				
19	**DHS Test Approval**	**63d**	**8/29/95**	**11/23/95**
20	Pre-test Coordination	62d	8/29/95	11/22/95
21	Test Approval	1d	11/23/95	11/23/95
22				



UV Disinfection Pilot Test
Liquid Waste Management Division
9/11/95

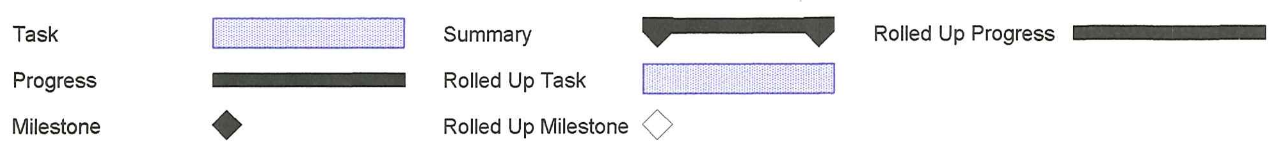
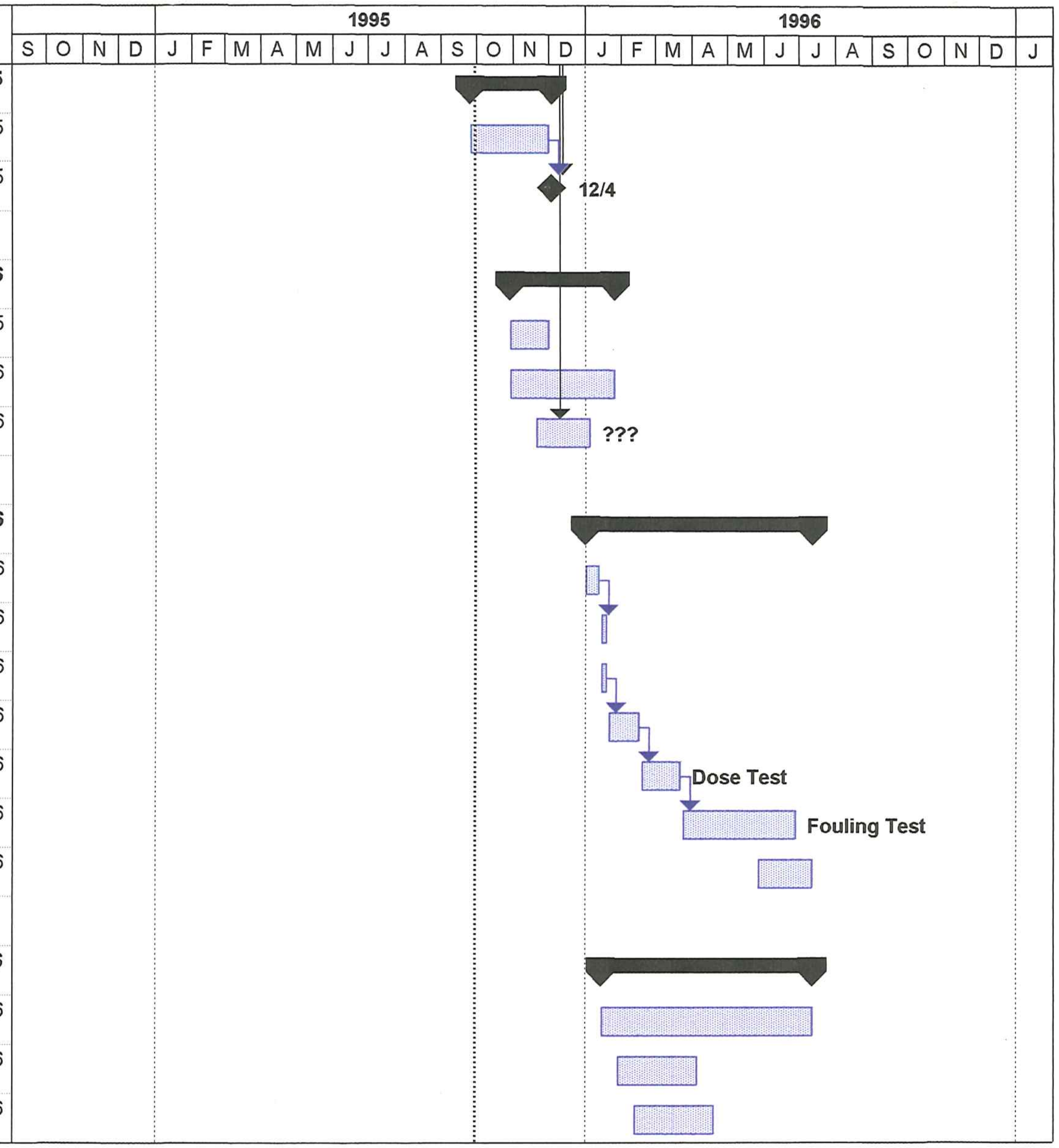


Figure 6.1 UV Pilot Test Schedule for a Low Pressure-Low Energy UV System.

ID	Task Name	Duration	Start	Finish
23	**RWQCB Test Approval**	**50d**	**9/26/95**	**12/4/95**
24	Pre-Test Coordination	49d	9/26/95	12/1/95
25	Test Approval	1d	12/4/95	12/4/95
26				
27	**Pilot Plant**	**65d**	**10/30/95**	**1/26/96**
28	Dwgs & Coord	25d	10/30/95	12/1/95
29	Procurement	65d	10/30/95	1/26/96
30	Construction	34d	11/21/95	1/5/96
31				
32	**Testing - Sampling**	**139d**	**1/2/96**	**7/12/96**
33	Shakedown	9d	1/2/96	1/12/96
34	Ph I - Hydraulics	5d	1/15/96	1/19/96
35	Ph II-1, Diurnal Data	5d	1/15/96	1/19/96
36	Ph II-2, More Data	20d	1/22/96	2/16/96
37	Ph III, Dose Data	25d	2/19/96	3/22/96
38	Ph IV, Fouling Data	70d	3/25/96	6/28/96
39	Move Unit to TWRP	34d	5/28/96	7/12/96
40				
41	**Test Evaluation**	**130d**	**1/15/96**	**7/12/96**
42	EMD Lab Analyses	130d	1/15/96	7/12/96
43	VLab Work & Analyses	50d	1/29/96	4/5/96
44	Data Analyses-Doses	50d	2/12/96	4/19/96



UV Disinfection Pilot Test
Liquid Waste Management Division
9/11/95

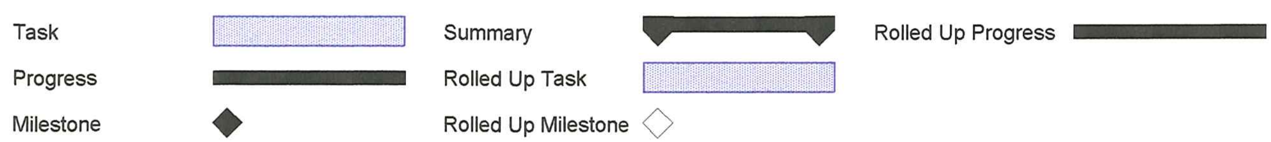
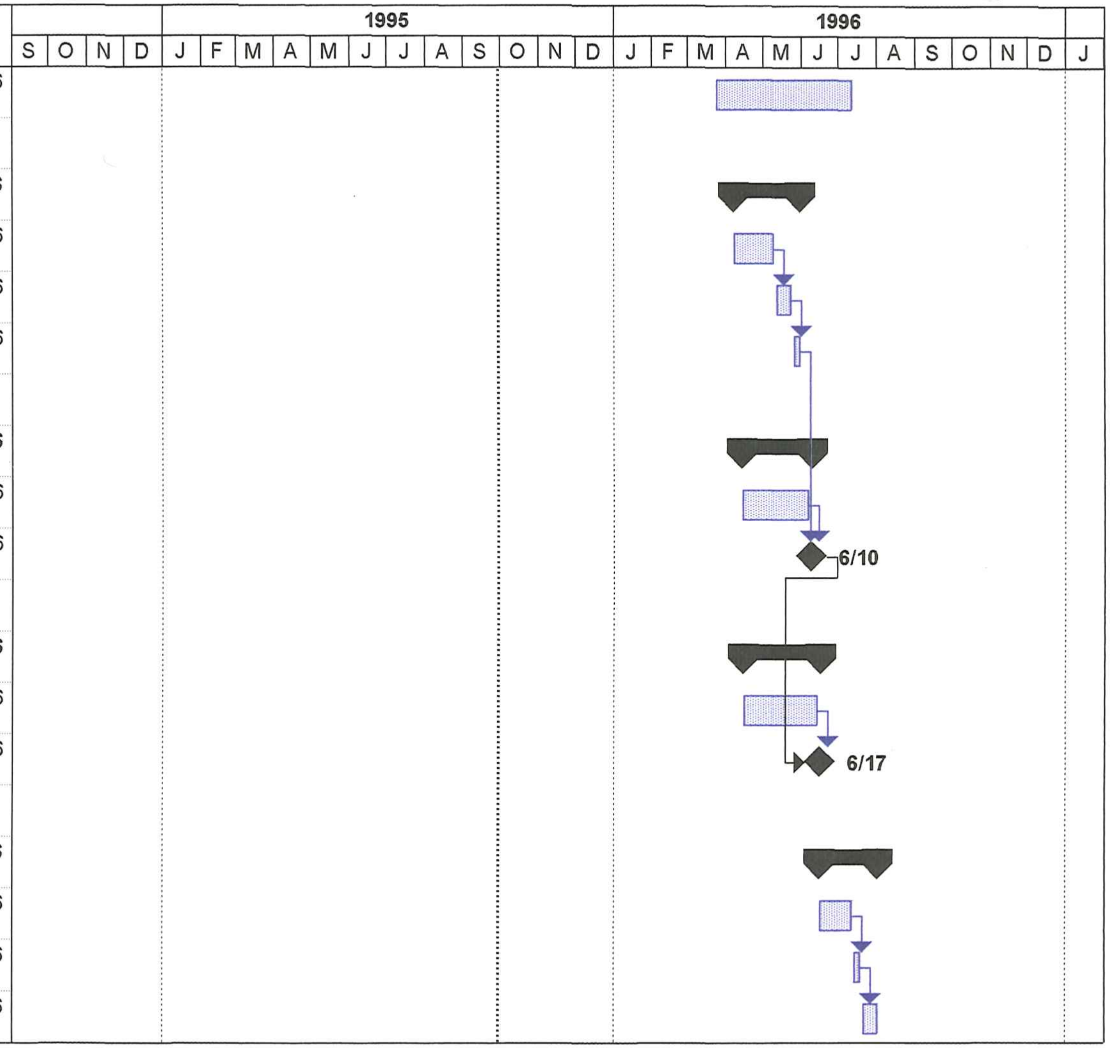


Figure 6.1 UV Pilot Test Schedule for a Low Pressure-Low Energy UV System.

ID	Task Name	Duration	Start	Finish
45	Data Analyses-Fouling	80d	3/25/96	7/12/96
46				
47	**Dose Test Report**	**40d**	**4/8/96**	**5/31/96**
48	Draft Report	25d	4/8/96	5/10/96
49	Expert Comments	10d	5/13/96	5/24/96
50	Final Report	5d	5/27/96	5/31/96
51				
52	**DHS Final Approval**	**41d**	**4/15/96**	**6/10/96**
53	Results Evaluation	40d	4/15/96	6/7/96
54	Final Approval	1d	6/10/96	6/10/96
55				
56	**RWQCB Final Approval**	**45d**	**4/16/96**	**6/17/96**
57	Results Evaluation	44d	4/16/96	6/14/96
58	Final Approval	1d	6/17/96	6/17/96
59				
60	**Fouling Test Report**	**35d**	**6/17/96**	**8/2/96**
61	Draft Report - Fouling	20d	6/17/96	7/12/96
62	Expert Comments - Fouli	5d	7/15/96	7/19/96
63	Final Report	10d	7/22/96	8/2/96



UV Disinfection Pilot Test
Liquid Waste Management Division
9/11/95

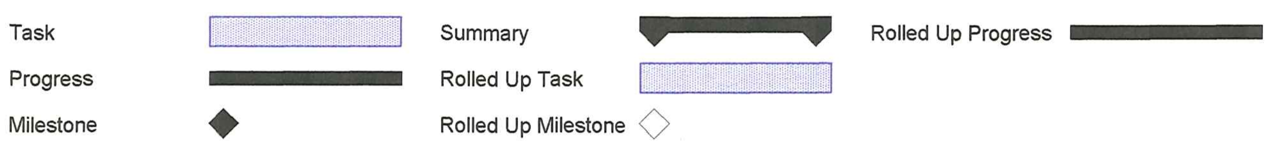
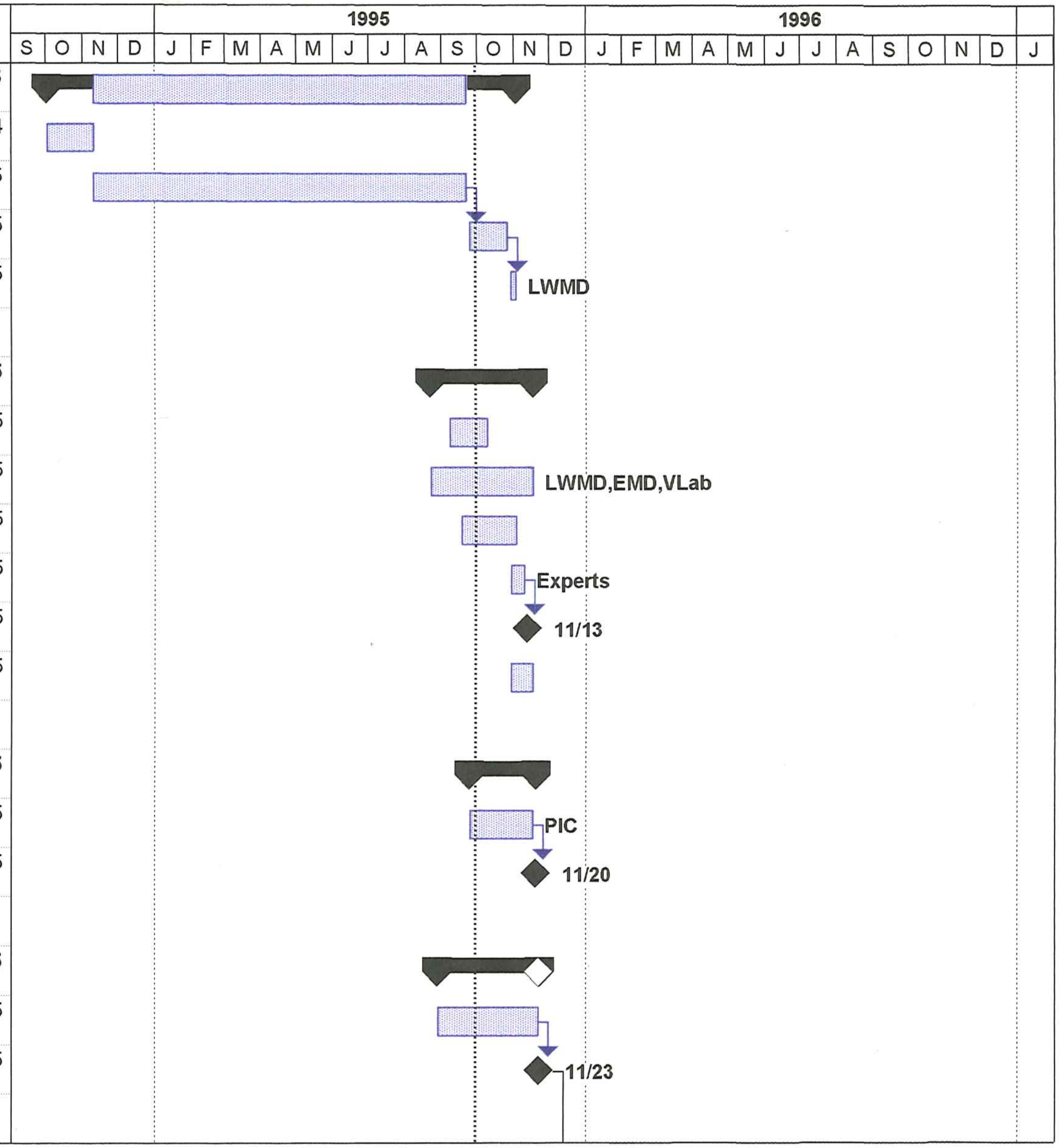


Figure 6.1 UV Pilot Test Schedule for a Low Pressure-Low Energy UV System.

ID	Task Name	Duration	Start	Finish
1	**Feasibility Report**	**285d**	**10/3/94**	**11/3/95**
2	Preliminary Draft Report	30d	10/3/94	11/11/94
3	Draft Report	226d	11/11/94	9/22/95
4	Comments	25d	9/25/95	10/27/95
5	Final Report	5d	10/30/95	11/3/95
6				
7	**Test Protocols**	**63d**	**8/23/95**	**11/17/95**
8	Preliminary Outline	23d	9/8/95	10/10/95
9	Virology Contract	63d	8/23/95	11/17/95
10	Expert Contracting	35d	9/18/95	11/3/95
11	Expert Review	10d	10/30/95	11/10/95
12	Exp't Rev'w Completed	1d	11/13/95	11/13/95
13	Final Protocol	15d	10/30/95	11/17/95
14				
15	**PIC Approval Process**	**41d**	**9/25/95**	**11/20/95**
16	Approval Process	40d	9/25/95	11/17/95
17	Presentation	1d	11/20/95	11/20/95
18				
19	**DHS Approval Process**	**63d**	**8/29/95**	**11/23/95**
20	Pre-test Coordination	62d	8/29/95	11/22/95
21	Test Approval	1d	11/23/95	11/23/95
22				

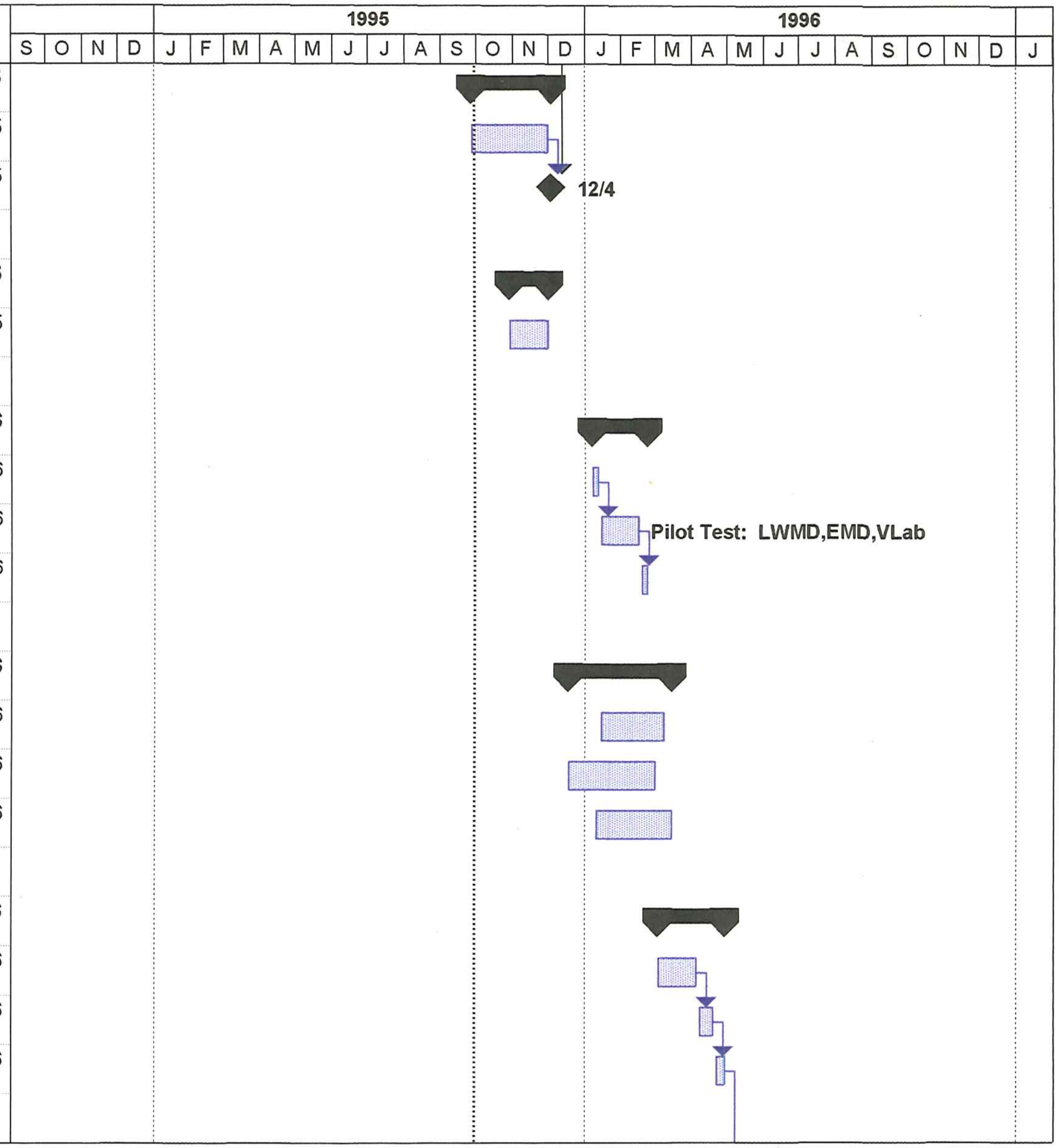


UV Disinfection Pilot Test
Liquid Waste Management Division
9/11/95

Task — Progress — Milestone — Summary — Rolled Up Task — Rolled Up Milestone — Rolled Up Progress

Figure 6.2 UV Pilot Test Schedule for a Medium Pressure-High Energy UV System.

ID	Task Name	Duration	Start	Finish
23	**RWQCB Approval Process**	**48d**	**9/28/95**	**12/4/95**
24	Pre-Test Coordination	47d	9/28/95	12/1/95
25	Test Approval	1d	12/4/95	12/4/95
26				
27	**Pilot Plant**	**25d**	**10/30/95**	**12/1/95**
28	Dwgs & Coord	25d	10/30/95	12/1/95
29				
30	**Testing**	**35d**	**1/8/96**	**2/23/96**
31	Set-up, Shakedown	5d	1/8/96	1/12/96
32	Phase III, Dose Data	25d	1/15/96	2/16/96
33	Move Unit to TWRP	5d	2/19/96	2/23/96
34				
35	**Test Evaluation**	**64d**	**12/19/95**	**3/15/96**
36	EMD Lab Analyses	40d	1/15/96	3/8/96
37	VLab Work & Analyses	54d	12/19/95	3/1/96
38	Data Analyses-Doses	47d	1/11/96	3/15/96
39				
40	**Dose Test Report**	**41d**	**3/4/96**	**4/29/96**
41	Draft Report	25d	3/4/96	4/5/96
42	Expert Comments	10d	4/8/96	4/19/96
43	Final Report	6d	4/22/96	4/29/96
44				

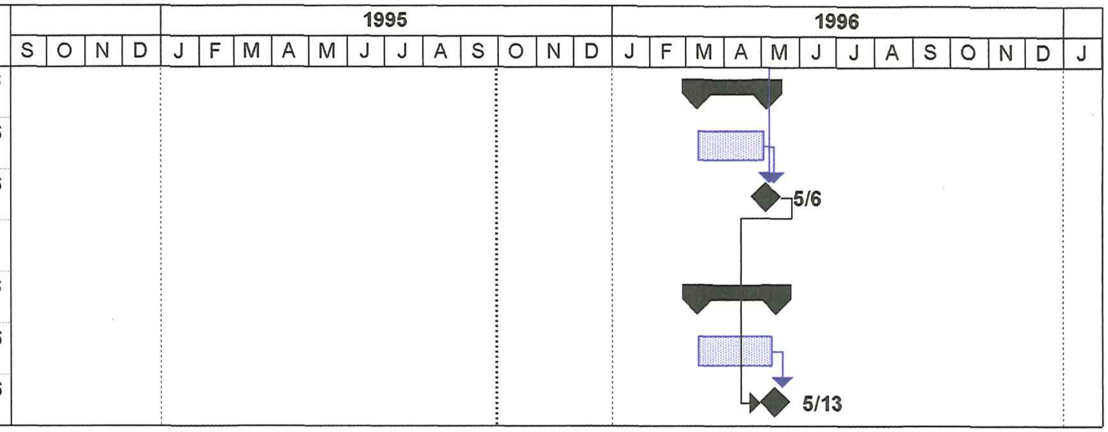


Task | Progress | Milestone | Summary | Rolled Up Task | Rolled Up Milestone | Rolled Up Progress

UV Disinfection Pilot Test
Liquid Waste Management Division
9/11/95

Figure 6.2 UV Pilot Test Schedule for a Medium Pressure-High Energy UV System.

ID	Task Name	Duration	Start	Finish
45	**DHS Final Approval**	**41d**	**3/11/96**	**5/6/96**
46	Results Evaluation	40d	3/11/96	5/3/96
47	Final Approval	1d	5/6/96	5/6/96
48				
49	**RWQCB Final Approval**	**46d**	**3/11/96**	**5/13/96**
50	Results Evaluation	45d	3/11/96	5/10/96
51	Final Approval	1d	5/13/96	5/13/96



UV Disinfection Pilot Test
Liquid Waste Management Division
9/11/95

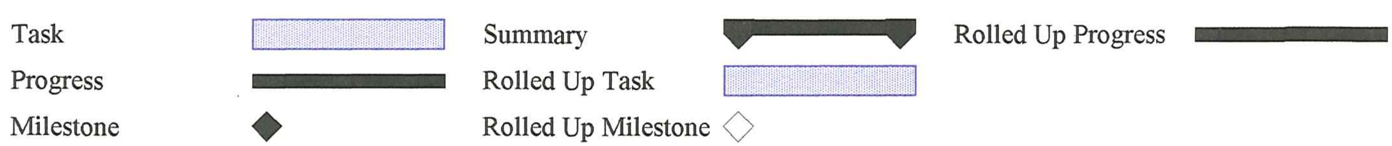


Figure 6.2 UV Pilot Test Schedule for a Medium Pressure-High Energy UV System.

procurement and installation will start upon DHS approval of the Work Plan. Testing at each plant is planned for four months, which includes the usual shake-down and the four phases of data collection. Pre-UV testing (Phase I) requires a 100 hours lamp burn-in period and hydraulic testing, which can be combined with testing for disinfection efficiency and dose response for microorganisms and viruses (Phase III). Collection of basic data (Phase II) can be performed during any 2-3 week period after obtaining DHS approval. Dose response (Phase III) will be conducted over a 4-5 week period, ending March 22, 1996. Lamp fouling (Phase IV) will require the remaining three months, ending June 28, 1996.

Tests using the medium pressure-high energy, UV4000 pilot unit at each plant would require four to five weeks, including shake-down and data collection. Pre-UV testing (Phase I) may require a short burn-in period, no longer than 100 hours; hydraulic testing is thought to not be an issue. Collection of basic data (Phase II) can be performed prior to pilot testing and may best be accomplished during testing to more closely correlate data; Phase II may not be required, if a protocol similar to that for the City of Riverside is used. Dose response (Phase III) would be conducted over a 4-5 week period, ending February 16, 1996, assuming the pilot unit is available. Lamp fouling (Phase IV) would not be required, because the UV4000 has automatic mechanical wipers.

The results for each phase of testing will be reviewed as the test proceeds. The laboratories are expected to provide timely analytical results so that the test performance can be assessed quickly enough to allow modifying remaining runs if necessary.

Reports will be provided in three ways. Preliminary lab results and operational problems will be circulated to all concerned parties as early as practicable to ensure that valid data is obtained and that the tests proceed as scheduled. Each laboratory, EMD and the selected virology laboratory, will submit a final report to LWMD 4 weeks after the last dose run. LWMD, as a result of continuing discussions with the experts, laboratories and regulatory agencies will publish a draft report 3 weeks later. This report will be reviewed by the experts and all other concerned parties. Comments made during a 2 week period will be included in a formal report that will be submitted to the DHS and

RWQCB. If the UV2000 pilot unit is used, final regulatory approval of the LAGWRP Pilot Test could be expected by June 17, 1996; January 13, 1997 TWRP - Phase I. If the UV4000 pilot unit is used, final approval of the LAGWRP Pilot Test could be expected by May 13, 1996; as soon as June 24, 1996, for TWRP - Phase I. Testing for TWRP - Phase II and TITP would follow.

6.2 STAFF ALLOCATION

City staff time for developing the testing and sampling protocols, procurement of equipment, supplies and materials and actual testing work is not accounted for in the economic evaluation presented in Chapter 4. A realistic estimate for development of the testing and sampling protocols for the UV2000 requires approximately 80 man-hours of engineering staff extending over a 2-month period. Preparation of plans would require approximately 120 man-hours for the UV2000, including several sketches. Installation of the UV pilot unit, including the necessary piping, equipment and tanks would require approximately 120 man-hours for supervision. Testing would require at least two engineering staff (a project engineer and a sanitary engineering assistant), plus four to six lab staff.

The UV4000 would require significantly less engineering effort and significantly less lab effort (i.e., use of MS2 phage for virus testing) than the UV2000, as the DHS has approved this technology. Evaluation and report preparation require approximately 200 man-hours of staff time for each site. Approximately 200 staff-hours of administrative staff time would be needed for the preparation and processing of purchase orders for items that need to be procured, for report typing, printing and binding, and for other miscellaneous administrative tasks.

Existing City contracts would be utilized as much as possible for the purchase of the necessary equipment, supplies and materials. An Authority for Expenditure would be used to contract each of the various experts and the virology laboratory.

Our engineering staff will develop detailed sketches for assembly and installation of all pilot plant equipment, including support utilities required. LWMD-WWRG staff will coordinate and supervise the installation, relocation and assembly of the UV unit at each treatment facility. Plant maintenance staff will be utilized to set up the pilot test unit and the necessary adjuncts.

Actual test runs will be done by our engineering staff in coordination with the contracted virology laboratory, EMD, plant maintenance staff and operations personnel.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

1. Previous pilot tests and demonstration scale tests verify the capability of UV disinfection to meet Title 22 requirements imposed upon chlorination users: oxidized, coagulated, filtered, disinfected effluent must have
   a) filtered turbidity of equal to or less than 2 NTU;
   b) total coliform equal to or less than 2.2 MPN/100 ml; and
   c) 4-log (99.99%) virus inactivation, based on poliovirus (or MS2 coliphage).

2. The DHS endorses the NWRI UV Disinfection Guidelines for treating wastewater to ensure that pathogens are sufficiently inactivated, specifying the use of low pressure and low energy mercury vapor lamps in a horizontally, non-staggered, parallel with the flow configuration in a non-pressured channel and having a 55% or greater transmittance at 253.7 nm.

3. The cost of UV disinfection is similar to the cost of using NaOCl to disinfect wastewater at LAGWRP, based on annualized cost of the presently proposed UV system designs. The budgetary capital investment estimate of $1.7 to 3.2 million, corresponds to an annualized capital investment of $34,000 to $64,000, while the annual O&M expense of $415,000 to $463,000 translates into a total annualized cost between $449,000 and $519,000, based on an assumed UV dose of 140 mWs/cm². By designing for a dose of 120 mWs/cm², accounting for the 95 percentile flows, and reducing the number of spare banks, the capital cost could be reduced to 61.7 percent of the original budgetary estimated costs. Similarly, by considering the effect of the lower UV dose, the lesser number of banks, and the fact that the spare banks do not contribute to those costs, the corresponding O&M cost is reduced to as low as 68.8 percent of the originally estimated expense. The total annual cost (capital plus

O&M) could be $314,000 to $363,000, which is far less than the estimated annualized cost of $510,000 for using sodium hypochlorite and sodium bisulfite as the disinfection method at LAGWRP. This estimate could be verified by conducting a pilot study of UV disinfection.

4. The costs per mgd would be similar at TWRP and TITP to the costs at LAGWRP. The total costs for each (parallel) phase at TWRP would be proportional to the capacity of each phase, while the costs for each sequential phase at TITP would be less due to provisions for redundancy being met with the first phase. However, current chemical disinfection costs at TWRP have not been analyzed in the same detail as have been done for LAGWRP. TITP does not currently disinfect its effluent, however, the proposed water reclamation and the need for disinfection could make the UV system a viable alternative.

5. The need exists to conduct site-specific UV pilot studies at the three outlying plants to develop appropriate design parameters for full scale UV disinfection systems for these plants. The study should delineate the following parameters.

   a) number and dimensions of contact channels;
   b) theoretical and mean residence time in each channel, including the method of determining residence time;
   c) number and type of UV lamps, modules and banks;
   d) water level relative to UV lamps;
   e) lamp arc length;
   f) lamp arrangement;
   g) minimum UV dose under worst case conditions; and
   f) number, location and function of UV intensity and/or transmittance probes.

6. Pilot testing with the UV2000 would require an estimated $362,000 plus 20 percent contingencies for the four sites at the three outlying plants, excluding salaries and wages of City staff; $127,000 plus 20 percent contingencies for the LAGWRP pilot test.

7.2 RECOMMENDATIONS

We recommend that:

1. The Bureau of Sanitation direct the LWMD-Research Group to select one of the options for testing to develop a work plan and conduct a UV pilot study at LAGWRP to determine the optimum dose required to meet the NWRI Guidelines; pilot tests to follow at TWRP-Phase I, TWRP-Phase II and TITP, depending on the results at LAGWRP.

2. The Program Implementation Committee (PIC) approve LWMD-RG to conduct UV disinfection pilot studies at LAGWRP, TWRP-Phase I, TWRP-Phase II and TITP according to the option selected in Item 1, above, as follows (plus 20% contingency).

    a) Approximately $362,000 for pilot testing using the UV2000 that would include all Title 22 requirements.
    b) Approximately $81,000 for pilot testing using the UV2000 that would not include virological testing.

3. The Bureau of Sanitation directs LWMD's Research Group to develop a concept report on UV disinfection installations at each plant, including design criteria for a full scale facility.

REFERENCES

CITY REPORTS:

a1 "Alternative Wastewater Disinfection Study," City of Los Angeles, May 1991, James M. Montgomery.

a2 "Local Water Reuse Project," City of Los Angeles, 1991, Wastewater Program Mangement Division (WPMD).

a3 "Risk Management Prevention Program" (RMPP) at the TWRP, City of Los Angeles, December 1992, Engineering and Science, Inc.

a4 "Risk Management Prevention Program" (RMPP) at the LAGWRP, City of Los Angeles, December 1992, Engineering and Science, Inc.

a5 "LAGWRP Monthly Operating Report," Environmental Monitoring Division, City of Los Angeles, January 1992 - April 1994.

a6 "DCTWRP Monthy Operating Report," Environmental Monitoring Division, City of Los Angeles, January 1992 - April 1994.

a7 "TITP Monthly Operating Report," Environmental Monitoring Division, City of Los Angeles, January 1992 - April 1994.

LITERATURE:

b1 Asano, Takashi, et. al., "The Cost of Wastewater Reclamation in California," Universtiy of California, Davis, November 1992.

b2 Cairns, W., Trojan Industries, Inc., 1992.

b3 CH_2M Hill, "Ultraviolet Disinfection, Process Overview Applications Design Considerations Monitoring and Controls Pilot Testing."

b4 CH_2M Hill, "Ultarviolet Disinfection Piloting Project for Orange County Water District and County Sanitation Districts of Orange County," July 1993.

b5 CH_2M Hill "UV Disinfection Pilot Study, Rapid Infiltration/Extraction (RIX), Demostration Project," Estimate for Coventional Filtration Effluent, August 1992.

b7 Darby, Jeannie L., Snider, Kile E., Tchobanoglous, G., "Ultraviolet Disinfection for Wastewater Reclamation and Reuse Subject to Restrictive Standards", Water Environment Research, Vol. 65, No. 2, pp 169 - 180, March/April 1993.

b8 Fischer & Porter Co., "Budgetary Proposal for a Ultraviolet Disinfection System."

b9 HydroQual Inc., "UV Disinfection Process Design Manual, Users Manual for UVDIS Version 3.1, "Risk Reduction Laboratory, Cincinnati, Ohio, EPAG0703/68-C8-0023, April 1992.

b10 Kreft, P., Scheilbe, O. Karl, Venosa, Albert, "Hydraulics Studies and Cleaning Evlauation of Ultraviolet Disinfection Units," Journal WPCF, Vol. 58, No. 12, pp 1129 - 1137, December 1986.

b11 National Water Research Institute, "UV Disinfection Guidelines for Wastewater Reclamation in California and UV Disinfection Research Needs Identification," September 1993.

b12 Nick, Ammons, Brown & Caldwell, Atlanta-Calgary, "Comparison of Ultraviolet Disinfection Systems."

b13 Nick, Ammons, Brown & Caldwell, "Introduction to UV Disinfection and Overview," June 1993.

b14 Qualls, Robert G., et. al., "The Role of Suspended Particles in Ultraviolet Disinfection," Journal WPCF, Vol. 55, No. 10, pp 1280 - 1284, October 1983.

b15 Soroushian, P.E., et. al., "Disinfecting Reclaimed Water with Ultraviolet Light," Water Environment Federation, 65th Annual Conference, September 1992.

b16 Tchobanoglous, G., et. al., " Ultraviolet Disinfection the California Guidelines for Wastewater Reclamation."

b17 Trojan UV2000 System Operating Manual, 1989.

b18 USEPA, "Design Manual: Municipal Wastewater Disinfection," Office of Research and Development, EPA 625/1/86/021, Washington D.C., October 1986.

b19 USEPA, "Ultraviolet Disinfection Technology Assesment," Office of Wastewater Enforcement and Compliance, EPA 832-R-92-004, Washington D.C., September 1992.

b20 Whitby E.G. and Palmateer G., "Disinfection of Wastewater with Ultraviolet Light."

b21 White, Sam C., et. al., "A Study of Operational Ultraviolet Disinfection Equipment at Secondary Treatment Plants," Journal WPCF, Vol. 58, No. 3, pp 181 - 192, March 1986.

b22 Title 22, California Code of Regulations, Division 4. Environmental Health, Chapter 3. Reclamation Criteria.

b23 Emerick, Robert W., and Darby, Jeannie L., "Ultraviolet Light Disinfection of Secondary Effluents: Predicting Performance Based on Water Quality Parameters," Specialty Conference Proceedings: Planning, Design and Operations of Effluent Disinfection Systems, Water Environment Federation, May 1993.

b24 Scheible, O. Karl, "Current Assessment of Design and O&M Practices for UV Disinfection," Specialty Conference: Planning, Design and Operations of Effluent Disinfection Systems, Water Environment Federation, May 1993.

b25 Levenspiel,

b26 Oppenheimer, Joan A.; Hoagland, John E.; Laine, Jean-Micheal; Jacangelo, Joseph G.; and Bhamrah, Ajit, "Microbial Inactivation and Characterization of Toxicity and By-Products Occurring in Reclaimed Wastewater Disinfected with UV Radiation," Specialy Conference: Planning, Design & Operations of Effluent Disinfection Systems, Water Environment Federation, May, 1993.

PERSONAL COMMUNICATIONS:

c1 De Leon, Ricardo, University of California, Irvine, January 1994.

c2 Newton, Jim, James M. Montgomery, April 1994.

c3 Zimmerman, Bruce, Coombs-Hopkins Company, Carlsbad, California, October 31, 1992.

c4 Zimmerman, Bruce, Coombs-Hopkins Company, Carlsbad, California, October 31, 1994.

c5 Loge, Frank, University of California at Davis, March 24, 1995.

c6 Hultquist, Robert, California Department of Health Services, Office of Drinking Water, August 31, 1995.

referenc.wpd