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This study was performed in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. ABSTRACT
The use of drip emitters to irrigate highway landscaping helps to conserve two of our critical resources, water and energy. The California Department of Transportation used drip emitters for many projects during the 1970's and early 1980's. The use of drip emitters has decreased since 1980 because of clogging problems.

Transportation Laboratory personnel conducted a study to determine the causes of emitter clogging. Three field locations were selected to study these problems. The primary water quality parameters selected for this study were total dissolved solids and turbidity.

As a result of studies at these sites and other field investigations, it was found that waters containing high levels of total dissolved solids and that were given continuous chemical treatment created the most severe emitter clogging problems. Most of the flow reduction occurred after the watering schedule was changed to twice per week for a total of 10.5 hours per week.

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STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF CONSTRUCTION
OFFICE OF TRANSPORTATION LABORATORY

DRIP IRRIGATION STUDY

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CONVERSION FACTORS

English to Metric System (SI) of Measurement

Quality	English unit	Multiply by	To get metric equivalent
Length	inches (in)or(")	25.40 .02540	millimetres (mm) metres (m)
	feet (ft)or(')	.3048	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in^2) square feet (ft^2) acres	6.432×10^{-4} .09290 .4047	square metres (m^2) square metres (m^2) hectares (ha)
Volume	gallons (gal) cubic feet (ft^3) cubic years (yd^3)	3.785 .02832 .7646	litre (l) cubic metres (m^3) cubic metres (m^3)
Volume/Time (Flow)	cubic feet per second (ft^3/s	28.317	litres per second 1/s)
	gallons per minute (gal/min)	.06309	litres per second (1/s)
Mass	pounds (lb)	.4536	kilograms (kg)
Velocity	miles per hour (mph) feet per second (fps)	.4470 .3048	metres per second (m/s) metres per second (m/s)
Acceleration	feet per second squared (ft/s^2)	.3048	metres per second squared (m/s^2)
	acceleration due to force of gravity (G) (ft/s^2)	9.807	metres per second squared (m/s^2)
Density	(lb/ft^3)	16.02	kilograms per cubic metre (kg/m^3)
Force	pounds (lbs) (1000 lbs) kips	4.448 4448	newtons (N) newtons (N)
Thermal Energy	British termal unit (BTU)	1055	joules (J)
Mechanical Energy	foot-pounds (ft-lb) foot-kips (ft-k)	1.356 1356	joules (J) joules (J)
Bending Moment or Torque	inch-pounds (in-lbs) foot-pounds (ft-lbs)	.1130 1.356	newton-metres (Nm) newton-metres (Nm)
Pressure	pounds per square inch (psi)	6895	pascals (Pa)
	pounds per square foot (psf)	47.88	pascals (Pa)
Stress Intensity	kips per square inch square root inch ($ksi\sqrt{in}$)	1.0988	mega pascals$\sqrt{metre}$ ($MPa\sqrt{m}$)
	pounds per square inch square root inch ($psi\sqrt{in}$)	1.0988	kilo pascals$\sqrt{metre}$ ($KPa\sqrt{m}$)
Plane Angle	degrees (°)	0.0175	radians (rad)
Temperature	degrees fahrenheit (F)	$\frac{+F - 32}{1.8} = +C$	degrees celsius (°C)

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1. INTRODUCTION

The California Department of Transportation (Caltrans) Office of Landscape Architecture initially requested that the Office of Transportation Laboratory (TransLab) conduct a drip irrigation study. Caltrans is using a large number of emitters that are clogging due to various reasons. The objective of this project was to evaluate the problems and recommend solutions for a problem-free system.

Drip irrigation can be defined as a method of irrigation where the water is applied at a low rate and at frequent intervals through mechanical devices called emitters. It is a system for supplying filtered water, fertilizer or other chemical amendments directly onto or into the soil. This method eliminates water runoff and avoids periodic stress on the individual plants. This system provides a soil-water-plant relationship that is conducive to better growth and better plant yields, most often with less water applied. The emitters are located at selected points on pipelines and frequently along the water delivery lines. Most emitters are placed on the ground surface, but with proper design can be buried at shallow depths.

Caltrans has learned from past experience and research that there are numerous important reasons that recommend the continued use of drip irrigation; these can be summarized as follows:

1. Significant water and energy conservation is realized (allows for deep watering).

2. Retards weed growth outside the basin area.

3. Less slope erosion facilitates slope maintenance.

4. Eliminates windblown water on the roadway.

5. Flexibility and ease of fertilization.

6. Landscape maintenance forces can do other work in the area while irrigation is in progress.

7. Irrigation can take place at any convenient time.

8. Reduces plant disease caused by overhead watering.

In an effort to conserve water and energy, Caltrans began using drip irrigation on an experimental basis in 1968 at a site near Los Angeles on Route 10. Since that time up to 1984, the number of drip irrigation sites and emitters designed and maintained by Caltrans has grown to over 250 sites and over 350,000 emitters (Table 1). The interim period between 1968 and 1979 was a period of "trial and error" as far as emitter design is concerned. Several types of emitters were tested and a number of installation and maintenance procedures were tried (Figure 1 shows widespread use of drip irrigation sites maintained by Caltrans up to 1980). Lack of technical knowledge in installation design and maintenance, particularly in the area of emitter clogging, was the primary cause of failure. Some early systems were actually abandoned or converted to other less efficient methods. By the beginning of 1980, many landscape architects, designers and maintenance personnel began to develop a negative perspective toward drip irrigation systems because of the operating problems and high level of maintenance. In recent years, Caltrans has used drip irrigation as an alternative method of irrigation. Figure 2 shows the decline in the number of emitters used by Caltrans from 1979 to 1984 (details in Appendix 1).

Along with the many advantages that drip irrigation has to offer, there are some problems. Some of the problems associated with design, construction and maintenance of early drip irrigation systems have either been solved or eliminated by this time. Those problems which remain are as follows:

1. Clogging of emitters.

2. Rodents chewing the flexible polyethylene and polyvinyl chloride hose.

3. Unreliable design data from manufacturers.

4. Vandalism and theft of parts.

5. Breakage of supply lines causes clogging of emitters in some cases.

6. Difficulty of watering-in granular fertilizer.

7. Unreliable emitters.

8. Lack of adequately trained maintenance personnel who have the time and knowledge to perform preventative maintenance.

9. Except for a few large manufacturers, there is a lack of long-term stability in the drip industry.

In many cases, the attempt to conserve water and energy has resulted in additional costs due to maintenance problems. Emitter clogging is of primary importance. Clogging will adversely affect the rate of water application and uniformity of water distribution, and increase operating costs as it becomes necessary to inspect and replace clogged emitters. However, the greatest loss can be the designers loss of confidence in drip irrigation operation.

There are two logical approaches that may be used to solve the clogging problems. The first is to develop an emitter device suitable for a specified water quality with a recommended level of filtration which may require less or minimum maintenance(1)(2). This is done by drip irrigation manufacturers. Major advances have been made in emitter fabrication.

Improved production techniques and emitter designs have reduced the individual flow variability and also somewhat the possibility of clogging.

TABLE 1

SUMMARY OF EMITTERS USED
IN CALTRANS 1968-1984

	DISTRICT										
YR.	01	02	03	04	05	06	07	08	10	11	Total
68-76											20000*
77	0	0	0	7494	0	0	0	0	0	35984	43478
78	0	1330	410	23389	0	2000	10339	0	0	24119	61587
79	1102	0	10019	13451	0	4721	17785	1290	2266	18978	69612
80	115	1951	6056	5317	0	0	41825	0	1236	2304	58804
81	0	215	0	795	0	0	1165	0	0	69	2244
82	0	1580	1338	1412	2020	0	20912	0	0	12303	39565
83	0	0	2875	1087	0	54	6993	7097	0	13652	31758
84	0	202	0	0	0	0	12180	6464	0	10857	29703
TT	1217	5278	20698	52945	2020	6775	111199	14851	3502	118266	356751

*Estimated values based on 2500 emitters per year.

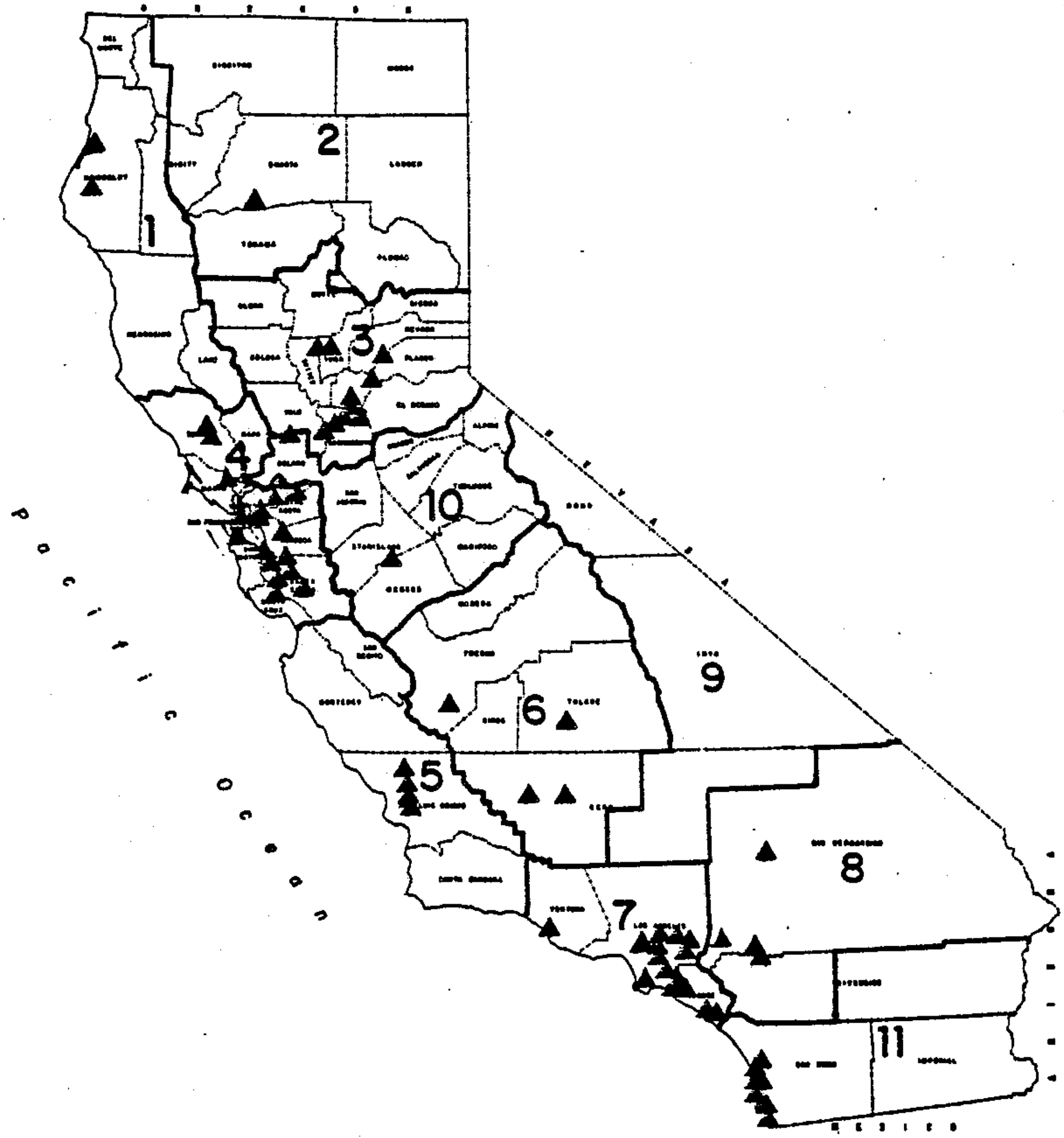


Fig. 1. DRIP IRRIGATION SITES MAINTAINED BY CALTRANS UP TO 1980

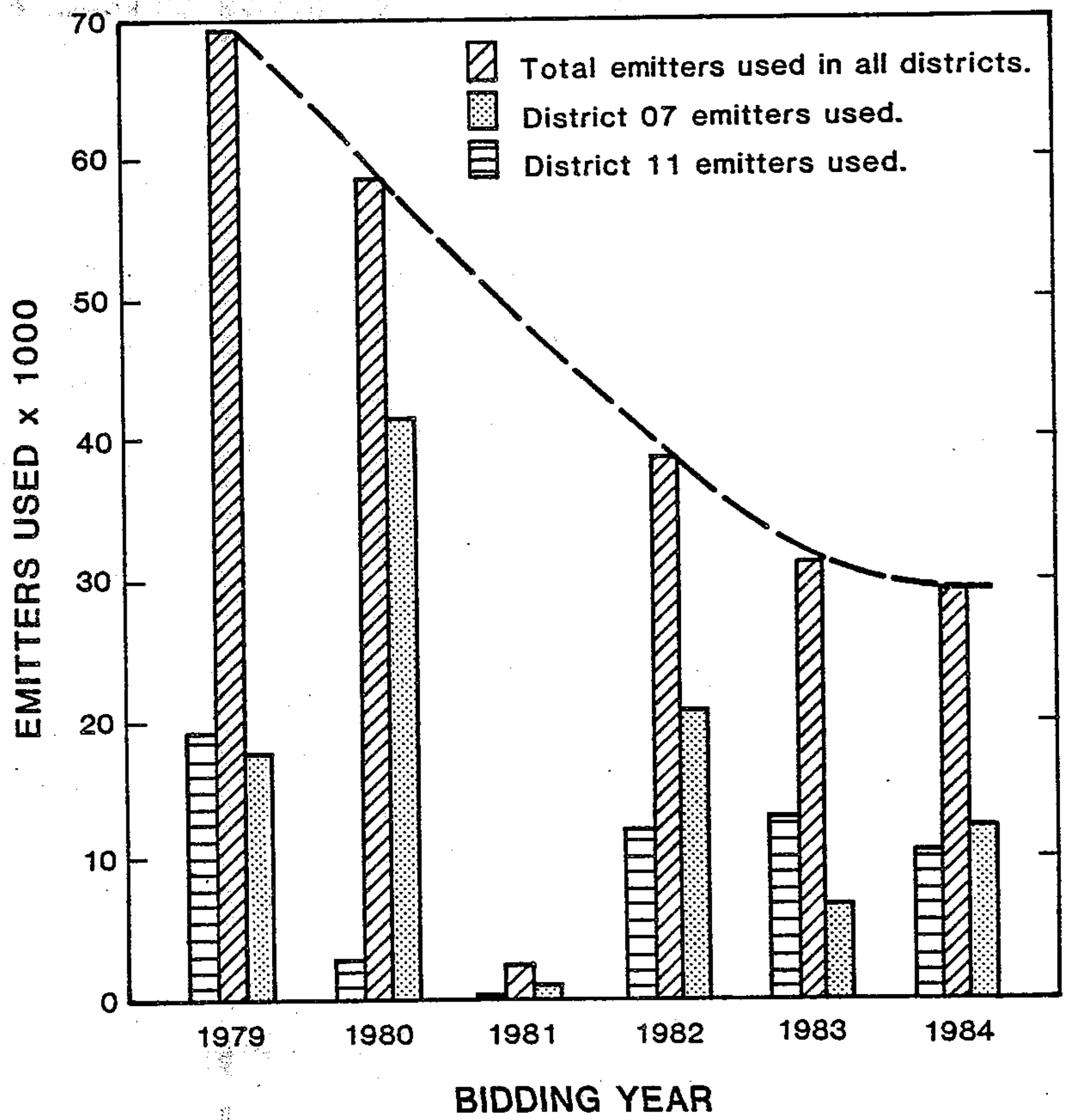


Fig. 2. DECLINE IN DRIP EMITTERS USED IN CALTRANS

A second approach, which is the subject of this paper, is to improve the quality of water suitable for drip irrigation using a specified type of emitter device.

The five emitters selected for evaluation in this study are called emitters A, B, C, D and E in this report. The names of these emitters are Agrifim (N8c), Rainbird (EM-M10), Global Flapper (STF-2), Drip-Eze and Vortex (3001-1), respectively. These emitters were selected because they represent units preferred by Caltrans field maintenance personnel.

The following conditions existed at the sites used for this study:

a. The three sites selected for conducting the research study all provided a source of water that was suitable for drinking.

b. The water quality parameters of primary concern in this study were total dissolved solids (TDS) and turbidity of the water sources.

c. The TDS concentrations at the Sacramento, San Jose and Kramer Junction sites were approximately 100, 400, and 1,500 milligrams per liter (mg/l), respectively.

d. A wide range of treatment was given to the water at each study site ranging from filtration to intermittent chlorination and/or acid treatment to continuous filtration, chlorination and acid treatment.

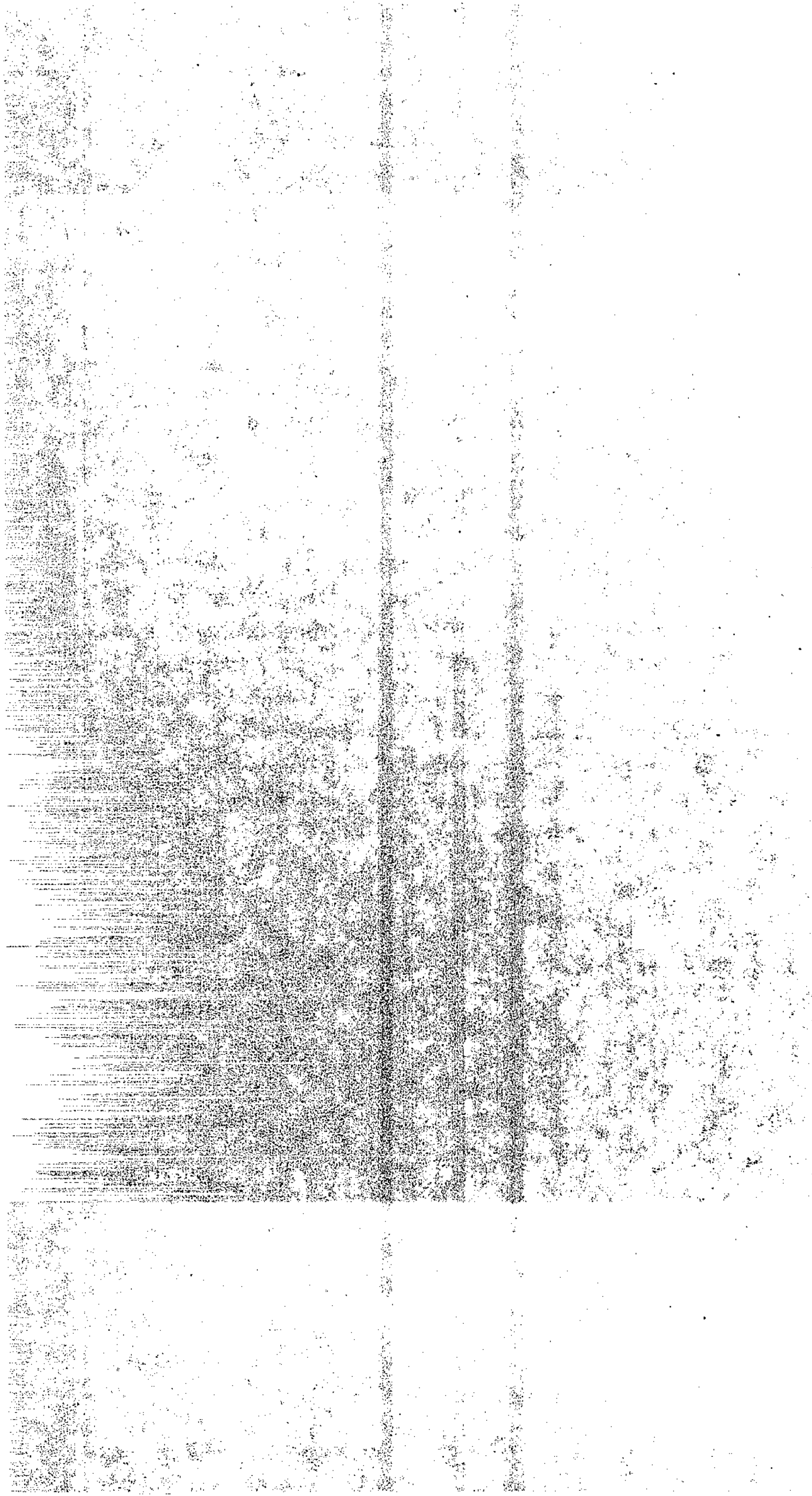
2. PURPOSE OF STUDY

Drip irrigation conserves both energy and water because the irrigation water is applied to only a portion of the land surface. These types of irrigation systems are normally not used for lawns or grassy areas. They are best suited for watering individual plants, such as trees, vines and bushes.

The problem that requires a solution is that drip emitters become clogged due to various reasons and the plants receive either insufficient or zero quantity of water. The major factors that cause clogging of emitters are either physical, chemical or biological or in some cases all of these factors contribute to the clogging process.

Caltrans designers used drip emitters in many irrigation system designs in the 1968-1979 time period. After 1980, the use of drip emitters declined because of the many clogging problems. The natural tendency is to shut down an entire drip system when a few heads become plugged. Replacement systems are usually more expensive to construct and operate, not only from the standpoint of construction materials but also because of increased usage of energy and water resources. In this age of declining available energy and water supplies, it is necessary for society to use these resources sparingly.

The results of this research study will be helpful for designers of irrigation systems since the major limitations of drip emitters will be determined. Recommendations will be made as to where and under what conditions drip emitters may best be utilized by Caltrans.



3. OBJECTIVES

The major objectives of this research project are as follows:

1. To find which water quality factors have the greatest influence on clogging of emitters by biological growths and mineral deposits in a test situation.

2. To determine which water treatment methods are most effective and least effective for use with emitters that are available for use in landscaping operations in Caltrans.

3. To determine whether the performance of emitters and associated equipment is related to the length of time the emitter has been in service.

4. To prepare recommendations for emitter use for designers, inspectors and maintenance personnel in order to produce a drip irrigation system that is as reliable and maintenance free as is possible.

4. CONCLUSIONS

At the end of the two year test period (1983-85), the following conclusions were reached:

1. The two most important factors that influence emitter clogging and discharge reduction rates were the TDS concentration and the type of water treatment given by Caltrans to the municipal supply waters (Table 11).

2. There appears to be a correlation between the number of clogged emitters found in this study and the TDS concentration of the water. The water at Kramer Junction (TDS of 1,500 mg/l) produced ten clogged emitters at the end of the study period while the waters with lower TDS concentrations at San Jose and Sacramento had three and five clogged emitters, respectively (Table 12).

3. Other factors that may influence clogging of emitters are changes in water temperature, variations in the water pH and high concentrations of materials such as fertilizers, calcium, iron, manganese, magnesium and carbonates. The relationship between these factors and clogging of emitter was not established during this study. It is assumed that all these factors affect the clogging process of drip emitters, but the complexity of a complete chemical, physical and biological evaluation of these waters was beyond the scope of this study.

4. The effectiveness of water treatment with regard to water flow rates at each of the three study sites was:

At Kramer Junction

Most effective water treatments: (a) 200 mesh filtration and (b) intermittent combination of intermittent acid and chlorination treatment once a week.

Least effective water treatment was a combination of continuous acid and chlorination treatment.

At San Jose

Most effective water treatment was found to be continuous chlorination.
Least effective water treatment was found to be continuous acid treatment.

At Sacramento

Most effective water treatment was found to be a combination of acid and chlorination treatment every two weeks.
Least effective water treatment was found to be a combination of continuous acid and chlorination treatment.

(Water flow rates are affected by both fully clogged and partially clogged emitters.)

5. At the three study sites, six emitters that were receiving water that had been given a combination of continuous chlorination and acid treatment, were clogged. (Clogged means an emitter is passing less than 25 percent of the initial flow rate.) This type of water treatment produced the greatest amount of clogged emitters at two of the three sites.

6. The next to worst clogging condition at the three sites was produced by the water receiving continuous chlorination treatment. The number of emitters clogged was found to be three for this condition.

7. A combination of continuous acid and chlorination treatment of the water at the three study sites caused the greatest reduction in flow rates through the emitters. This reduction being 41, 33 and 10 percent at Kramer Junction, Sacramento and San Jose, respectively (Table 11). Flow reduction is caused by both clogged emitters and partially clogged emitters.

8. As may be noted in Table 12, no clogged emitters were found at any of the three study sites in the two-year study period where the water was either given 200 mesh filtration treatment or where an acid-chlorination combination treatment was given every two weeks.

9. No direct correlation was discovered to exist between the performance of emitters and the length of time they were in service. The length of the study was approximately two years which appears inadequate for measurable performance results to be produced for all the emitters.

10. In the two-year study period at all three sites, no Emitter B nor Emitter D units became clogged.

11. Of the total of 240 emitters tested at Kramer Junction, 10 were clogged at the end of the two-year study period (Table 12).

12. Of the total of 200 emitters tested at Sacramento, 5 emitters were clogged at the end of the study period (Table 12). Results were obtained only for the emitters receiving municipal water (does not include simulated water quality conditions described in Table 10, Section 8).

13. Of the total of 240 emitters tested at San Jose, 3 emitters were clogged at the end of the study period (Table 12).

14. Regular maintenance including periodic flushing of the emitter supply lines was found to minimize clogging of the emitters to a significant degree. Chemical concentrations were checked on a regular basis.

15. In the limited pressure-discharge experiment, it was found that Emitter B showed the least variation in flow rate caused by pressure change in the 10 to 45 psi range. The greatest increases in flow rate occurred in Emitter E when the pressure was increased from 10 to 45 psi.

16. The coefficient of variation of Emitter E was determined to be the highest of the five types of emitters tested at the three sites. This value was found to be 0.13 for Emitter E. The coefficient of variation is a term used to describe the anticipated variation in discharge rate of a sample of new emitters when operated at any given pressure. In the case of emitters

with small flow channels, the size of the these channels may vary to a small extent due to imperfect manufacturing processes. Ideally, the coefficient of variation should be zero, but realistically, it may range between 0 and 0.20.

17. In field tests that were conducted to determine the relationship between temperature change and emitter discharge variation, Emitter D showed the greatest positive percent discharge variation with increases in water temperature (15 to 51 degrees C), as may be noted in Figure 13. This means that with increases in temperature, this emitter showed the greatest percent increase in discharge rate. For same temperature range, Emitter E showed the greatest negative percent discharge variation or the greatest percent decrease in discharge rate.

5. RECOMMENDATIONS

1. That all drip emitter source water have a TDS concentration of 1500 milligrams per liter or less, and a turbidity level of 5 turbidity units (TU) or less. High TDS concentration waters may be found in ground water such as Midway SRRA (Appendix 5, Table 5C).

2. That all new and remodeled drip irrigation systems used by Caltrans be served water from either a municipal source (well or treated surface water) or reclaimed wastewater that has received tertiary treatment. Generally, wastewater is tested to remove disease-producing organisms and suspended solids.

3. That filtration treatment (200 mesh) be given to all water passing through the emitters to remove solid particles that may cause clogging problems. In exceptional cases, finer filters may be required.

4. That intermittent acid and chlorination treatment may be given to water on a once in two- or four-week basis to minimize bacterial slime growths.

5. That either a manual or an automatic drain valve be placed at the downstream end of the water supply line that serves the emitters. This valve is to be used to flush and clear the supply line.

6. That all drip irrigation installations be inspected at least twice per month or more frequently if clogging has been a problem.

7. That all water supply lines be flushed to remove sediment at least once per month. In cases where repairs have recently been made and soil may have entered the lines, flushing should be completed before placing the emitters back in service. In cases where the TDS concentrations are high (1000 to 1500 mg/l), weekly flushing may be required.

8. That all emitter orifices and/or discharge openings of spaghetti tubing be located at an elevation that will prevent back-siphonage of the irrigation water into the irrigation system.

9. That all waters being considered for use in a drip emitter system be given the essential physical, chemical and biological tests that are described in the Water Quality section of this report.

6. IMPLEMENTATION

Copies of this final report will be distributed to Caltrans District and Headquarters Offices and the Federal Highway Administration for implementation. Information derived from this research study will be made available to landscape designers and landscape maintenance personnel to improve the performance of both new and existing drip irrigation systems. The Divisions of Construction and Maintenance and the Office of Landscape Architecture will be responsible for implementing the recommendations and findings of this study. Transportation Laboratory (TransLab) personnel will assist with technical problems as requested, including state-wide training sessions for Caltrans maintenance personnel. The results of this study may also serve as the basis for additional studies concerning the construction and maintenance of drip irrigation systems.

7. WATER QUALITY AND SOURCES

7.1 Water Quality

Water quality is the most important factor to consider when deciding on the type of irrigation system to use(3). Applying a thorough understanding of relationships between water quality, emission device sensitivity to clogging, filtration, mitigation treatment and maintenance level may result in a much greater longevity for a drip irrigation system. Water quality will vary greatly from source to source and may vary with time depending on the season, demand, rainfall, etc.

An examination of water quality is a logical step toward an improved drip irrigation system because the most essential requirement in drip irrigation is water quality(4).

During the summer of 1980, TransLab conducted a statewide telephone survey requesting that landscape personnel identify existing drip irrigation sites, problems associated with the operation of drip irrigation systems and the name and address of water purveyors serving their respective irrigation sites. Water purveyors supplied information concerning the sources, seasonal variations, and the type of water treatment used. Also, they were requested to submit results of water laboratory analyses to TransLab for review. Most of the water purveyors complied with this request. The information collected is summarized in Appendices 2, 3 and 4. In addition to the 1980 survey, TransLab investigated 14 existing drip irrigation installations. Emitter types were identified and measurements of temperature, electrical conductivity, dissolved oxygen, and pH were made with a Martek Mark V instrument. Water samples were collected and returned to TransLab for chemical analysis. A summary of the results can be found in Tables 5A and 5B in Appendix 5. All samples appear to meet drinking water standards except for Sacramento I-80 at Madison Avenue off-ramp and Irvine I-5 at Culver Drive.

Also, the water examination at 16 sites including maintenance stations and safety roadside rest areas (SRRA) were made to determine the worst water quality that exists within Caltrans. Midway SRRA in District 8 showed the maximum TDS concentration of 2880 ppm. Drip irrigation was not used for most of these sites (locations and water analysis of these sites are listed in Table 5C in Appendix 5).

Caltrans generally utilizes municipal water in drip irrigation installations for highway landscaping. Municipal water purveyors usually employ complete treatment to meet minimum drinking water standards. The California Safe Drinking Water Act (PL-93-523) sets the following standards for those parameters (Table 2).

TABLE 2

CALIFORNIA DRINKING WATER STANDARDS

Constituent:	Fe	Mn	TDS	Sp. Cond.	Cl	Sulfate	Turbidity
Max. Conc. in mg/l	0.3	0.05	1000	1600 (mhos/cm)	500	500	5 TU

No maximum contaminant level for other suspected clogging parameters, such as calcium, carbonate, bicarbonate, nitrate and pH has been established in the drinking water standards.

Table 3 shows the maximum concentrations, range of variation and average value of each constituent within all of the sites used for drip irrigation and reported by water purveyors. This indicates that some levels of Fe, Mn, and TDS exceed the drinking water standards.

TABLE 3

WATER QUALITY DATA AS REPORTED BY PURVEYORS

Constituent	pH	Ca	HCO_3	TDS	Ec	Mg	Mn	Fe	SO_4	Na	Cl	SiO_2	CO_3	NO_3	PO_4	Li
Max. Level	9.9	138	377	1440	2340	41	0.47	0.47	420	332	256	60	3.8	46	30	
Location*	8-3-a	7-1-c	4-4-b	8-3-a	8-3-a	4-4-b	3-1-c	5-1-a	8-3-a	8-3-a	8-3-a	3-2-a	11-1-b	7-3-b	8-3-a	11-1-b
Range	6.5-9.9	1-138	4-377	15-1440	8-2340	2-41	0-0.47	0-0.47	0.2-420	0.6-332	0-256	2-60	0-3.8	0-46	———	———
Average	7.9	40.7	143	340	523	16.2	0.02	0.080	76.7	52.4	44.0	17.2	0.51	6.4	0.9	0.12

*For details of sites where analyses were made, see Appendix 2.

Locations of drip irrigation sites are broken down as follows:

Example Site 8-3-a, District is "8", Landscape Maintenance Area is "3", Subarea is "a"

TransLab observed a number of clogged drip irrigation systems where clogging was due to chemical precipitation, but chemical examination of the water indicated that the levels of constituents in the examined water were well below those allowed by drinking water standards. This indicates that the use of drinking water standards may not be suitable for evaluation of drip irrigation systems because they are too high in value in some cases.

7.2 Water Sources

The sources of water used by Caltrans for drip irrigation are comprised of three types: surface water, groundwater, and reclaimed wastewater. Surface water taken from rivers and lakes is generally high in nutrients and suspended solids and, unless treated, contains bacteria, algae and other aquatic life. Colorado River water is noted for being high in dissolved solids. Groundwater from wells varies in quality, some metropolitan area groundwater basins have high nitrate levels. Approximately 40 percent of the water purveyors derive all or a portion of their supply from groundwater basins. Reclaimed wastewater contains large amounts of dissolved solids and nitrates. Table 4 presents a partial list of water sources for each of the 11 Caltrans Districts. For water source details, refer to Appendix 3. Municipal or domestic water sources sometimes vary greatly in that they draw their water from different sources such as reservoirs and wells which may be blended together.

7.2.1 Water Sources and Treatment

There is no exact proven method that can determine the degree of slime growth or precipitates that may be formed from a given water. Much specialized work remains to be done in this field(5).

University researchers, drip irrigation experts, and water quality specialists are searching to find the water quality clogging parameters and how to deal with them. Much work has been done and many reports have been

TABLE 4

PARTIAL LIST OF CALTRANS WATER SOURCES*

District	
1-8, 10	Groundwater Basins
1	Mad River
3	Sacramento River
3	American River
3	Folsom Lake
4	Stafford Lake
4	Russian River
4	Mokelumne River
4	Sacramento-San Joaquin River Delta System
4	Tuolumne River
5	Salinas River
6, 7, 11	Feather River
7	Mono Lake
7, 8	Reclaimed Wastewater
7, 11	Colorado River
11	Lake Wohlford
11	Lake Dixon
11	Lake Skinner
11	Lake Hodges
11	Otay River

*Refer to Appendix 3 for a more detailed list of municipal water sources.

published on this subject. Unfortunately, progress has mostly been made in the field of agriculture which operates somewhat differently than operations conducted on highway landscapes.

These differences may be shown to be quite significant. In agriculture, the area under irrigation is generally confined to a number of blocks. Usually these blocks are fully maintained by a knowledgeable, experienced irrigator. The system generally consists of a mono culture practice using a single type of irrigation system (drip emitter). The emitters can be easily located and checked for proper operation. The water quality used for agriculture is generally poor. The water sources ranging from municipal to rain and runoff water collected in a pond or basin.

In contrast, Caltrans utilizes relatively clean water (municipal), however, the monitoring and maintenance of the drip systems are quite limited. Lack of knowledge of drip irrigation systems by maintenance personnel, manpower shortages and difficulty in locating emitters are major problems. Finding the emitters is especially a problem a few years after operations begin, where projects contain multiplant species and multiirrigation systems such as drip, sprinkler and bubblers.

In this section of the report, some of the agricultural information concerning emitter clogging has been changed to a form that is applicable to Caltrans operations. This information was then incorporated into this Caltrans study.

In the following subsection, the clogging parameters are discussed and tests to quantify the intensity of clogging are established. Mitigation treatment for each of the physical, chemical and biological clogging parameters that are discussed in this chapter are those that are related to water quality. Other causes of clogging are related to breakage of supply lines, gophers chewing the pipes, improper design, installation, etc.

7.2.2 Field Studies

Observations were made on 19 clogged and abandoned Caltrans drip irrigation installations to help identify clogging parameters. Table 5 lists the site locations, the type of emitter used, the nature of the problems (if known to landscape personnel) and an analysis of the water used at each respective site. The water analyses were reported by the water purveyors that were delivering water to the site.

In many cases, it was difficult to determine the exact cause of the clogging problem. Factors that had to be considered in most cases included information being transmitted by telephone; some landscape personnel were not familiar with technical terminology, water quality conditions may have changed with time, etc. A best estimate was made to determine the cause or causes of the problem under field conditions.

7.3 Three Major Types of Clogging

The major causes of emitter clogging or flow reduction in drip irrigation units can be divided into three major categories as follows:

1. Physical clogging
2. Chemical clogging
3. Biological clogging

The clogging parameters in each of the three categories have also been divided into three subdivisions: Primary, Secondary and Tertiary parameters (Table 6).

The primary parameters are those most influential in emitter clogging of Caltrans systems. The secondary parameters are those that have been seen in Caltrans drip operations and cause some problems. The tertiary parameters can cause clogging, but Caltrans drip systems have not yet been affected.

TABLE 5

FIELD CLOGGING PROBLEM SITES

Location	Emitter Type	Clogging Problem	Fe	Mn	TDS	Cl	SO_4	NO_3	Ca	HCO_3	pH
2-1-a	Quadrajet	Dirt, Algae	.04-.15	0.1	100-140	2.8-5.8	1.0	5.6-7.2	3.3-7.4	63-105	7.3-7.9
3-1-a	Vortex	Unknown	0.01	0.01	46-110	5.2-9.5	6.0-14.0	5.6-7.2	9.5-18	23-620	8.5-8.8
3-1-c	Vortex	Unknown	0-.15	0-.47	200-338	22-99	1-6	0.04-.65	18-31	104-121	7.6-8.0
3-1-e	Quadra	Unknown	.02-.21	0.02	120-250	6-43	4-9.2	0.4-7.1	12-31	58-131	7.9-8.1
3-2-a	-	Dirt, Debris	0.02	0.01	296	10	28	10	31	219	7.5
3-2-b	-	Dirt, Debris	0.04	0.01	75	61	9.0	.01	13.4	51	8.3
4-1-a	Salco	Unknown	0.01	0.01	213-224	21-27	0-.03	0.5-1.3	24-30	86-108	8.1-8.6
4-6-a	-	Precipitates	0.02	0-0.12	516-605	77-89	79-88	10-13	36-50	321-356	7.6-7.8
5-1-c	-	Silt, Insects, Precipitates	0.47	0.02	805	103	102	13	9.0	310	8.2
5-1-d	-	Silt	0.02	0.02	560	50	165	18	89	230	8.1
6-1-a	Quadra	Precipitates	0.02	0.01	219-364	29-61	26-56	2-21	42-69	139-163	7.1-7.6
7-1-a	Vortex	Algae	-	-	296-694	26-144	84-296	0.1-22.5	70-99	50-161	6.8-8.3
7-4-a	Salco	Unknown	0-0.08	0	230-331	16-31	0-0.08	-	49-73	164-217	7.6-7.8
7-4-b	Salco	Unknown	-	-	-	-	-	-	-	-	-
8-1-a	Vortex	Sand, Calcium Deposit	0.02-0.03	0	350-528	42-43	.02-.03	10-38	40-65	220-340	7.7-8.0
8-1-b	Salco	Sand, Calcium Deposit	0.08	0.01	398	45	82	11	41	205	7.9
8-3-a	Vortex	Mineral Deposit	-	-	1440	256	420	20	106	256	7.2
11-1-a	Subterrain	Insects	.02	-	282	49	69	.59	36	109	7.3
11-1-b	Subterrain	Insects	0.02	-	684-714	89-92	294-314	0	79-86	133-154	8.2-8.4

*Location of Site 2-1-a for example, District is "2", Landscape Maintenance Area is "1", Subarea is "a"

TABLE 6

Potential Clogging Parameters of Drip Emitters in Caltrans

Physical (Suspended Solids)	Chemical (Dissolved Solids)	Biological (Bacterial/Algae)
Primary °Plastic particles °Sand °Silt °Clay	Primary °Calcium (Ca^{++}) °Bicarbonate (HCO_3) °pH	Primary °Bacterial Slimes a) Iron (Gallionella, Leptothrix Toxothrix, Crenothrix, Spaerotilus, Pseudomonas, Aerobactor b) Sulfate, Thiothrix, Beggiatoa, Thiobacillus
Secondary °Body parts of insects and animals	Secondary °Iron °Manganese °Magnesium	Secondary °Algae
Tertiary °Aquatic plants °Aquatic animals	Tertiary °Carbonate °Sulfate °Fertilizer a) Phosphate b) Aqueous ammonia c) Iron, zinc, copper and manganese	Tertiary °Vitreoscilla °Pseudomonas

7.3.1 Physical Clogging

Physical clogging in Caltrans drip irrigation systems is caused by suspended solids in the water becoming lodged in the emitter orifices. These solids may be present in the system primarily due to poor installation practices and/or breakage of the distribution system which allow soil particles to enter before repair is completed and secondarily due to the presence of suspended solids in the water supply which pass through any filtration device that is available to the system. Poor installation practices may be avoided by inclusion of a section on this topic in the design specifications, proper inspection practices and training of maintenance personnel who deal with drip irrigation systems repair. Leaves and even some small animals can lodge themselves in the orifice thus blocking the water passage. The size of the particle causing blockage depends on the water pattern outlet (orifice) size and shape. Particles larger than 74 microns (the size of very fine sand) usually will produce clogging. Smaller particles can also cause clogging by sticking together with the aid of a binding agent such as carbonates or algae which form a larger mass that blocks the emitter orifices.

7.3.2 Chemical Clogging

Chemical clogging of drip system emitters in Caltrans is caused by chemical deposits (precipitates) forming in the vicinity of the orifice. These deposits disrupt the passage of water through the orifice, thus reducing flow. The primary chemical deposit of concern in drip irrigation is calcium carbonate ($CaCO_3$). Calcium carbonate is a powdery white precipitate which is quite insoluble in water (solubility is 7.3 mg/l)(6). Precipitation of calcium carbonate is common in arid regions with water rich in calcium and bicarbonates. Another primary chemical clogging parameter is the pH of the water. Although the high pH of the water by itself does not cause a clogging problem, nearly all chemical reactions including precipitation and oxidation are pH dependent. For example, when the pH is above 7.8, the calcium concentration is more than 60 mg/l and the bicarbonate level exceeds 80 mg/l, precipitation is likely.

The secondary parameters causing some chemical clogging problems in Caltrans drip irrigation systems are iron, manganese and magnesium. Iron ions are used by iron bacteria to produce gelatinous slimy brown colored deposits of ferric hydroxide. Iron precipitates, along with iron fixing bacteria, are probably the most unsolved chemical problems in drip irrigation(7). Fortunately, very little of the water used by Caltrans exceeds the guidelines for iron. The sources exceeding the iron limit may be blended with water from other sources to provide an acceptable product for use in drip systems. Manganese in water can lead to manganese oxide precipitates which are purplish-black in color. In only a few instances is the manganese content unsatisfactory for drip irrigation use. Here again, the problem sources may be blended with water from better sources.

Magnesium in the water, along with high carbonates and high pH, can lead to formation of magnesium carbonate - a white precipitate. While no water purveyor in this study supplies water that exceeds the guidelines, the value is approached in a few instances.

Water that has undergone treatment for drinking purposes may not have problems with iron and manganese. The removal of inorganic iron and manganese is an oxidation process where precipitation is followed by settling and filtration(8).

Tertiary parameters which include carbonate, sulfate and fertilizers can cause clogging in drip systems, but Caltrans drip systems are not thus affected. The maximum concentrations of carbonate and sulfate in Caltrans drip irrigation water are far below acceptable values. An excessive amount of carbonate in the water requires a pH above the acceptable pH level for irrigation water.

Though numerical guidelines have not been given for phosphate, nitrate, and silica, these chemicals also are known to cause clogging(4). Analysis of water quality data from the water purveyors leads to certain observations. When calcium was at 106 mg/l and phosphate was at 30 mg/l, the emitters clogged at one site. The precipitate was probably not calcium carbonate because the pH was too low. Langelier's Index indicates slightly corrosive conditions, which is not conducive to formation of deposits. Langlier's Index is a saturation index which serves as a measure of a water's potential to either cause calcium carbonate precipitation to occur or for it to dissolve existing scale. A positive value for this index means that precipitation is occurring while a negative value means scale is dissolving. A calcium phosphate compound is more likely, as phosphate reacts with any calcium in the water to form a precipitate which can clog fine-mesh filters and emitters.

The concentration of silica that will lead to clogging is unknown. The highest concentration of silica was found to be 60 mg/l which may be sufficient to cause clogging. The particular drip irrigation installation using water of this quality has experienced clogging problems. The problem reported was dirt and debris intrusion; however, silica may also be a factor.

Certain conditions can affect precipitation of salt in the irrigation system. Temperature rise is one such factor. When black pipes are placed on the surface of the ground, the temperature of the water can reach as high as 70°C, especially when there is no flow in the piping system.

7.3.3 Biological Clogging

The biological clogging of a drip irrigation system involves the plugging of emitters by various microorganisms and/or their by-products. Although this problem may not be as widespread as clogging due to chemical or physical factors in Caltrans, biological clogging can present problems that are very difficult to solve. Difficulties in detecting microbial growth within a system, coupled with the large seasonal variation in many aquatic populations, makes treatment a complicated process. The quality of the water source used for a particular drip irrigation system is the determining factor in predicting the potential for biological clogging. Thus, water quality measurements are vital to the identification and control of biological clogging.

The two main contributors to biological clogging are: 1) algae which can plug both filters and emitters; and 2) certain bacteria which produce chemical deposits in the form of emitter-clogging slimes. The most serious problems are associated with the group of organisms known as iron and sulfur bacteria. These organisms are capable of transforming or depositing large amounts of iron or sulfur, usually in the form of slimes in conduits and emitters. The characteristics of bacteria within this group vary greatly from one organism to the next. Some are single-celled while others are filamentous types consisting of long chains of cells enclosed in a sheath. Some types need oxygen for survival, while others are anaerobic and grow in water lines which allow no oxygen to enter.

Iron bacteria are capable of withdrawing iron from the surrounding water and depositing it in the form of a reddish-brown slime consisting mainly of ferric oxide. These iron bacteria can be filamentous such as Gallionella, Leptothrix, Toxothrix, Crenothrix and Sphaerotilus or may be unfilamentous aerobic slime bacteria of the genera Pseudomonas and Aerobacter. The slime is produced through an oxidizing process in which the bacteria convert iron in its ferrous ion form to ferric ions. The iron bacteria carry out this process in order to obtain energy for growth. The amount of slime deposits produced are quite large compared to the mass of bacteria which produce them.

Like the iron bacteria, the organisms known as sulfur bacteria have very diverse characteristics. They have been divided into three main groups: 1) the sulfate-reducing bacteria, 2) the photosynthetic green and purple sulfur bacteria, and 3) the aerobic oxidizers. These bacteria utilize hydrogen sulfide in a metabolic process which leaves white slime deposits containing large amounts of sulfur. Of importance in the drip irrigation field are the sulfate reducing bacteria which are single-celled organisms that grow without oxygen. Some of these bacteria also produce sulfuric acid, as well as sulfur slimes, which may contribute to the corrosion of metals to which they are exposed.

Slime bacteria grow best at temperatures between 20 to 30°C, but can grow at slower rates at lower temperatures. They are known to grow within a large pH range extending from 3.5 to 8.5. Slime bacteria can attach themselves to plastics and metals and are not easily rinsed off. The slimes produced by these various organisms trap soil particles from the water resulting in the accumulation of large masses within the irrigation lines and emitters. As these masses grow, some emitters begin to clog and the system loses its uniformity.

Adding to the problems associated with slime deposits are contributions from filamentous algae. The ruptured cells of these algae form deposits which can accumulate iron and support the growth of many slime-forming bacteria.

Algae grow best in still water where light is present; sunlight and water high in nutrients encourage its growth. Algae may grow in the water that stands in an emitter after the irrigation stops and the system is turned off. Once algae gets into the line, it is difficult to remove. The use of black PVC pipes helps to minimize the amount of light that can reach the water and inside the pipe walls.

The extent of clogging due to biological factors is directly related to the quality of the water being used in a drip irrigation system. Biological clogging has been found to be very serious in systems with water containing organic sediments plus iron or hydrogen sulfide.

Water which has been treated for domestic use is closest to ideal to minimize biological clogging because of the high treatment level which may include chlorination. During the study period there were a few reports of biological (algae) clogging although municipal water was being used. For example, at one site emitters were reported clogged due to algae problems. Examination of water quality showed that the nitrate concentration was in the range of 5.6 to 7.2 mg/l which, under certain conditions, may promote algal growth. Nitrate is a nutrient that is necessary for microbial growth(9). It should be noted that the clogging problems were reported by Caltrans maintenance workers who may have a limited knowledge of how to identify clogging problems. Thus, algae and slime bacteria terms may have been used interchangeably in this case.

Other personal observations in the field (Hwy. 91 ramps in Bellflower in 1984) indicated the system was clogged due to algal growth, but no indication of potential for biological clogging had been found in the examined water quality. In this case, the problem may have been due to the design and installation practices rather than the water quality. Field observation showed that some emitters were installed downslope from the plant which may have caused biological and/or physical clogging. During irrigation, water was running from emitters into the microtubing and flowed into the basin around the tree located 2-3 feet upslope from the emitter. Since the percolation rate was very low, this discharged water formed puddles around the basin of the tree. As the irrigation stopped, negative pressure built up near the outlet end of the microtubing and created a back siphonage condition (especially at higher elevations). As a result of this back siphonage, any bacteria that were present in the soil or any possible formation of algae in the water puddle and/or any suspended solids that were present in the puddle may have been drawn into the microtubing and eventually into the drip emitter and may have caused emitter clogging.

7.4 Tests for Water Quality Clogging

It is essential that certain water quality tests be performed to establish the potential for emitter clogging before installation of the irrigation system. Once the clogging problem of a system is determined and the suspected clogging parameters are identified, then it is necessary to quantify the intensity of the problem. In this section of the report, tests are suggested to identify and measure the intensity of each of the physical, chemical and biological parameters of emitter clogging.

Obtaining a representative water sample is an important first step in any water examination. Since water quality can change with the season, water samples should be taken at different time periods to determine the most severe situation. A sufficient volume of water must be collected to complete the physical, chemical and biological examinations. Refer to "Standard Methods for the Examination of Water and Wastewater" for proper sampling and collection practices(6). Certain analyses, including turbidity, iron, pH, and free available chlorine should be made in the field because the concentration of these constituents tend to change by the time the samples are taken to the laboratory.

7.4.1 Tests for Physical Clogging

Physical analyses can be made on the water to quantify the suspected physical clogging parameters and to determine the filtration needs, as well as to obtain some indication of the amount of sediment buildup in the line.

The physical analysis of water in the laboratory can be most accurately and conveniently performed by use of the standard test method of total suspended solids dried at 103 to 105°C(6). In this method, a well-mixed sample is filtered through a glass fiber filter and the residue retained on the filter is dried at a constant temperature of 103 to 105°C. If nonmunicipal water or a water with a high concentration of suspended solids is used, a particle size analysis can be made on the retained solids following the total suspended solids test to determine the quantities of the various size fractions present in the water.

A general estimate of the suspended particulate load can be obtained by shining a beam of light through a glass bottle containing the water sample.

A thick white cloud in the light beam suggests the presence of considerable suspended materials, but gives very little information concerning the size or concentration of the particles. The clarity of water in the field can be determined by the standard test method for turbidity(6). Turbidity in water is caused by the presence of suspended material, such as clay, silt, finely divided organic and inorganic matter(6). Turbidity levels in a water sample can be measured because the turbidity particles scatter or absorb light rather than transmit it in a straight line. It should be understood that the term turbidity is a nonquantitative term; it is used much in the same manner as the term "warmth". One does not measure warmth, one measures temperature(10). The California Department of Health has set a turbidity standard for drinking water at not greater than 5 TU (Table 2). Water that meets the California drinking water turbidity standard is perhaps the best water to be used for drip irrigation systems to prevent clogging caused by physical factors.

7.4.2 Tests for Chemical Clogging

To identify and quantify the intensity of chemical clogging parameters, analyses for the following constituents are made: calcium, bicarbonate, pH, total dissolved solids, temperature, iron, manganese, magnesium, carbonate, sulfate and chloride. Generally, a general mineral analysis or an irrigation analysis of water quality is made to measure the levels of these materials. These analyses are routinely made at most state health certified laboratories statewide.

Iron, manganese, pH, and temperature of the water should, if possible, be examined in situ as they are sampled. The reduced forms of iron and manganese can become oxidized to the insoluble form between the field and laboratory, and pH of the sample can changed drastically by contact with atmospheric carbon dioxide and by temperature changes. Portable kits are available that can be used in the field for measuring the levels of these constituents.

Chemical precipitation of calcium carbonate ($CaCO_3$) can be estimated from the chemical composition of irrigation water by use of Langelier's Index. The constituents involved in this index are calcium ion concentration, alkalinity (carbonate plus bicarbonate), pH, temperature and total dissolved solids by definition(11).

Langelier's Index = $pH - pH_s$, where

pH = water sample pH measured in the field

pH_s = A+B-Log(Ca^{2+})-Log (alkalinity)

A = function of temperature (Table 7)

B = function of total dissolved solids (TDS) (Table 7)

Ca^{2+} and alkalinity (HCO_3) concentrations are expressed in mg/l as $CaCO_3$.

TABLE 7

LANGELIER CONSTANTS

Constant A as Function of Water Temperature		Constant B as function of TDS	
Temp. °C	A	TDS(mg/l)	B
0	2.60	0	9.70
4	2.50	100	9.77
8	2.40	200	9.83
12	2.30	400	9.86
16	2.20	800	9.89
20	2.10	1000	9.90

Using Langelier's Index, a negative number in the presence of oxygen would tend to indicate a condition amenable to corrosion of ferrous metals. A positive number indicates a tendency for calcium carbonate to precipitate from solution. For example, water analysis at the field location (5-1-b) indicates: measured pH=8.1, Ca=89, CO_3=0, HCO_3=230 mg/l, TDS=560 and temp.=20.0°C

The calculation of Langelier's Index is as follows;

$$L.I. = pH - pH_s$$
$$pH_s = A + B - Log(Ca^{2+}) - Log\ (alkalinity)$$
$$A = 2.10,\ B = 9.872$$
$$pH_s = 2.10 + 9.872 - Log(89) - Log(230)$$
$$pH_s = 7.66$$
$$L.I. = 8.10 - 7.66 = +0.44$$

Precipitation of calcium carbonate for this water sample is likely. If the pH of this water were adjusted to 7.60 by acid addition, the saturation index would become -0.06 and carbonate precipitation would not occur. The pH_s value of 7.66 means that the water will neither dissolve nor precipitate calcium carbonate at that pH.

Calcium carbonate precipitation may also be estimated using the carbonate precipitation chart (Figure 3). The relative effects of temperature, pH and hardness for some typical waters are shown in Figure 3.

Also, direct testing on the water sample can be performed for any chemical to be added into the water to determine if precipitates will form. This can be done by taking a water sample in a clear glass jar, adding the material to make the concentration to be used, and setting it in a dark room for 12 hours. A light can be then directed at the bottom of the jar to determine if there is a precipitate.

7.4.3 Tests for Biological Clogging

Biological examination of water is difficult to perform and also is generally expensive. However, it is essential that certain chemical and biological tests be performed before installation of the irrigation system to determine the potential for biological clogging. Complete analysis includes measurement of hydrogen sulfide, iron complex material, pH, temperature, chlorine content, nitrate, CO_2, HCO_3 and the presence of algae and bacterial slimes.

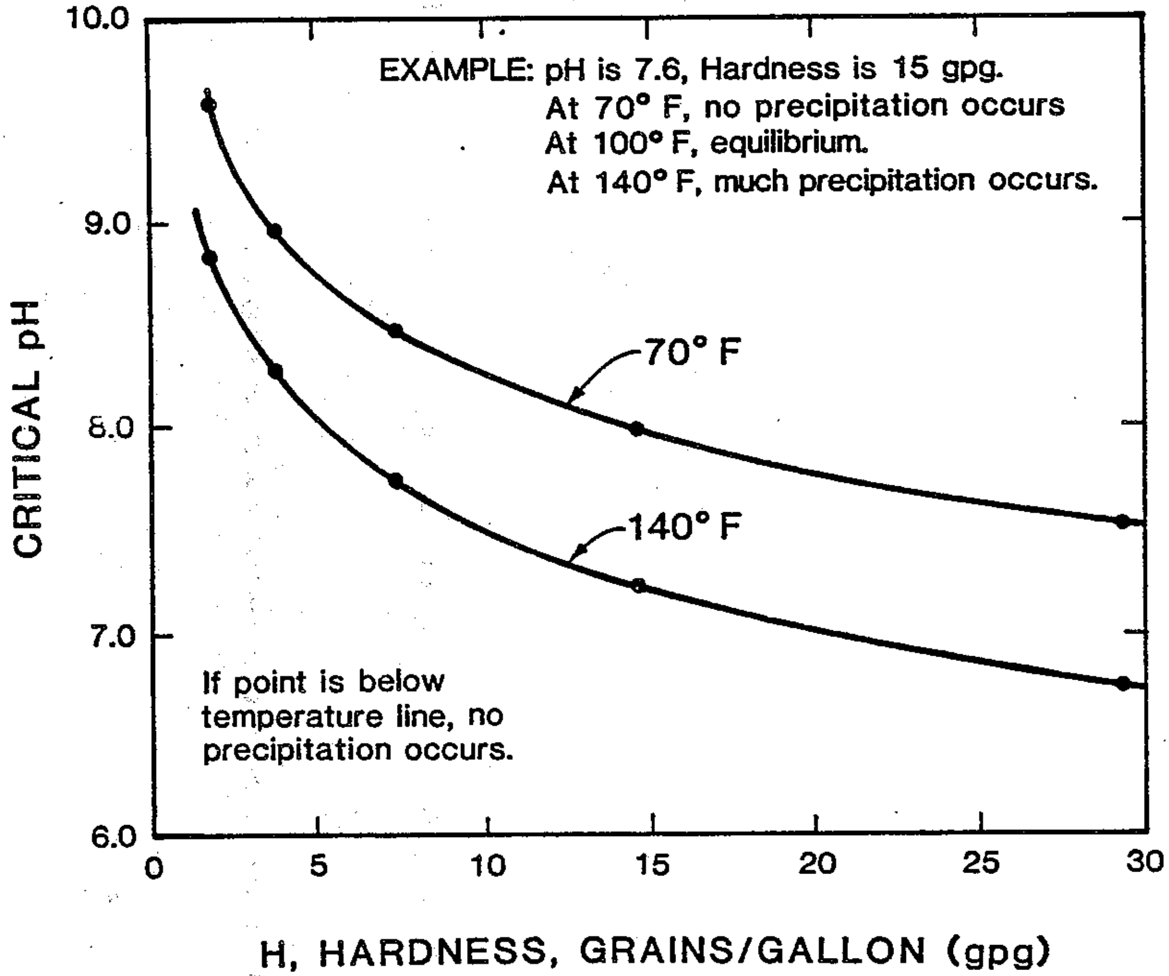


Fig. 3. CARBONATE PRECIPITATION CHART
(Typical pH–hardness–temperature relationship)

Adapted from Cooperative Extension Northeast Regional Agricultural Engineering Service, 1980.

It is preferable to check for iron and sulfides directly at the site, however, this is not always practical for Caltrans personnel. When samples must be transported to laboratories, samples for iron analysis should be acidified at the site to keep the iron in solution.

Iron can be detected at the site from water secured from drip irrigation lines with portable test kits utilizing the ortho-phenanthroline procedures(12).

Hydrogen sulfide can be measured with test kits such as the methylene blue visual color matching system which is recommended in "Standard Methods for the Examination of Water and Wastewater"(6).

The pH and temperature can be easily measured in the field using pH and temperature probes.

Nitrate, CO_2 and HCO_3 can serve as inorganic energy sources for certain slime-forming bacteria. These constituents can be examined at the chemical laboratory. Chlorine content should be measured at the site because chlorine concentration decreases with time. A good quality D.P.D. (N,N-diethyl-p-phenylene diamine) test kit will read both total chlorine and free chlorine. TransLab successfully used a minispectrophotometer to measure the chlorine concentration for this study.

The presence of algae can be checked and iron and sulfate bacteria counts may be performed by state health certified laboratories located throughout the state.

7.5 Water Treatment

7.5.1 Physical Treatment

Prevention of blockages caused by suspended particles can best be accomplished by the filtration process. Filtration is adequate, practical and the most economical method of separating suspended solids from municipal water. Caltrans successfully utilizes screen mesh filters and cartridge filters in its landscape irrigation projects.

Screen filters, may be made of slotted PVC, perforated stainless steel, stainless steel wire mesh, synthetic cloth and synthetic wire mesh and are enclosed in a special housing. Some screens must be disassembled for cleaning while others can be straight flushed or back-flushed without disassembly either in an automatic or manual mode. Filter screens that either flutter during flushing or expand slightly during back flushing are generally more effective in dislodging collected material than the rigid screens. The degree of filtration of screen filters is usually measured in terms of screen mesh size, which range from 10 to 270 mesh. The mesh number refers to the number of wires per inch in the filter screen.

Table 8 shows the relationship of mesh to the spacing between wire in English and metric units. This table should be beneficial in determining filtration requirements because it relates standard soil classification to common filter measurements.

TABLE 8
WIRE MESH SPACINGS

Standard Soil Particles	mm	Inches	Microns	Screen Mesh
Very coarse sand	1.00-2.00	0.0393-0.0786	1000-2000	18-10
Coarse sand	0.50-1.00	0.0197-0.0393	500-1000	35-18
Medium sand	0.25-0.50	0.0098-0.0197	250-500	60-35
Fine sand	0.10-0.25	0.0039-0.0098	100-250	160-60
Very fine sand	0.05-0.10	0.0020-0.0039	50-100	270-160
Silt	0.002-0.05	0.00008-0.0020	2-50	400-270
Clay	<0.002	<0.00008	<2	-

In selecting the type, size and filter capacity (total surface area), the primary factors to be considered are initial water quality and the type of emitter design. Screen and cartridge filters are best suited to remove physical contamination, but they do not affect the chemical or biological water quality since dissolved minerals, algae cells and bacteria pass through filters and form blockages at the orifice of the emitters.

Emitters are designed to produce a low water application rate, which requires small orifices. The size of the orifice (passage width) in drip irrigation emitters ranges from 5/16 to 1/10,000 inch(7). The range of sizes of the emitter openings must be considered when selecting a filter for a drip irrigation installation.

The size of the filter should be large enough to permit passage of the rated waterflow without frequent cleaning or replacement of the filter.

Generally, the greater the amount of suspended solids that can be removed from the water, the better the chances for the longevity of a maintenance-free drip irrigation system. Obviously, particulate matter larger than the orifice must be removed. Additionally, the particle size must be reduced further to prevent the possibility of particles bridging or of two or more particles arriving at an orifice at the same time.

Of equal or greater importance than particle size and bridging is the possibility of slime producing bacteria proliferation in the system to a point where slime acts as a "glue" incorporating the particulate matter and creates large gelatinous agglomerations. It is also possible for calcium carbonate precipitates to combine with particulate matter to form "cemented" blockages at the orifices.

Recommendations of drip irrigation manufacturers concerning the degree of filtration required should be followed when available. Most manufacturers recommend 100 or 200 mesh screen filters, while a few recommend a coarser screen of 30 mesh. When manufacturers recommendations are not available, filter openings of one-tenth the diameter of the emitters smallest opening may be used. For most emitters using municipal water, a 200-mesh screen filter was found to be effective and adequate. In addition to filtration, flushing the lateral lines periodically has shown positive results in maintaining a drip irrigation system. Observations made at the end of the lateral lines during the experimental period showed that suspended material in the municipal water (mostly sand and iron) has passed through the 200 mesh filter and accumulated at the end of the lateral lines. This material was flushed out manually.

7.5.2 Chemical Treatment

Treatment of water containing high levels of calcium, magnesium, carbonate, bicarbonate and sulfate to reduce or eliminate chemical emitter clogging can be established using pH control. Adding acid to the water will lower the pH and reduce chemical precipitates. The amount of the acid addition needed to adjust the water pH to a lower level is dependent on the water quality and type of the acid used, and is based on acid titration of the water. Acids commonly used to control pH are: sulfuric acid, hydrochloric acid and phosphoric acid. The latter can also be used as fertilizer for the plants. Perhaps economic and safety considerations are the key factors to take into account when selecting the type of acid to be used. In this study hydrochloric acid (36%) was used to reduce the pH. The titration process to determine the amount of acid needed to reduce the pH of the water is carried out by adding known increments of acid to the water and determining the associated pH changes.

Two different rates of acid treatment, continuous and intermittent, were tried in the experimental project to compare the effectiveness, cost and level of maintenance for each treatment rate. The use of the continuous treatment alternative was found to be rather expensive at the initial setup, as well as requiring a continuous acid supply. It also requires extensive maintenance to continuously maintain the pH of the treated water to the

TABLE 6E

PRESSURE DISCHARGE EVALUATION
AT SACRAMENTO SITE
(Emitter D)

Emitter	10 psi	12 psi	15 psi	17 psi	20 psi	22 psi	25 psi	28 psi	30 psi	32 psi	35 psi	38 psi	40 psi	45 psi
D_1	760	866	930	941	1029	1018	1082	1098	1120	1120	1127	1129	1140	1156
D_2	1053	1123	1220	1270	1279	1311	1349	1320	1350	1359	1370	1378	1400	1450
D_3	816	950	1020	1060	1113	1120	1191	1210	1230	1234	1230	1239	1261	1281
D_4	940	1000	1092	1088	1150	1188	1260	1290	1311	1320	1340	1353	1401	1445
Min. Max.	760 1053	866 1123	930 1220	941 1270	1029 1279	1018 1311	1082 1349	1098 1320	1120 1350	1120 1359	1127 1370	1129 1378	1140 1400	1156 1450
$\overline{X}$	892	984	1065	1089	1142	1159	1220	1229	1253	1258	1266	1274	1300	1333
SD	131	107	122	136	104	123	113	99	102	106	111	114	126	142

Temperature of Water 20 degrees C, Air Temperature 25 degrees C, Test Duration - 10 minutes,
Data Units - grams

Chlorine gas is widely and effectively used to control microbiological activity in drip irrigation systems. Chlorine gas reacts with water to form hypochlorous acid (HOCl), Hydrogen (H^+) and chloride (Cl^-) ions (equation 1). The HOCl can further dissociate to form hypochlorite ions (OCl^-) and hydrogen (H^+) ions (equation 2).

$$Cl_2 + H_2O \quad H^+ + Cl^- + HOCl \qquad (1)$$
$$HOCl \quad H^+ + OCl^- \qquad (2)$$

Chlorine gas produces an acid reaction with water. In the above reactions, the hydrogen ions (H^+) that are formed will lower the pH of the solution. Lowering the pH of water may result in less chemical precipitation and, thus, reduce cogging of drip emitters.

Safety devices should be provided to protect workers against gas leakage where chlorine gas is stored under pressure. Most modern gas chlorinators are completely vacuum operated and equipped with a spring-opposed inlet valve that seals off the gas supply in event of a vacuum loss. Chlorine also may be obtained in liquid and solid forms. Sodium hypochlorite (NaOCl) in the form of liquid, also known as household or swimming pool bleach, and calcium hypochlorite [$Ca(OCl)_2$]in solid form both react with water to form hypochlorous acid (HOCl) and either sodium hydroxide or calcium hydroxide [equations (3) and (4)].

$$NaOCl + H_2O \quad Na^+ + OH^- + HOCl \quad NaOH + HOCl \qquad (3)$$
$$Ca(OCl)_2 + 2H_2O \quad Ca^{2+} + 2OH^- + 2HOCl \quad Ca(OH)_2 + 2HOCl \qquad (4)$$

Both sodium and calcium hypochlorite produce an alkaline reaction in water, because hydroxyl ions (OH^-) are produced which raises the pH of water. If the water is already alkaline, an acid must be added separately to reduce the pH.

When chlorination is practiced, regardless of the source of chlorine, tests for free residual chlorine should be made to determine the concentration of chlorine in the water. The chlorine level in the irrigation water is normally found by a "trial and error" process. The injection rates are usually estimated and then modified as necessary to maintain the desired concentration of free residual chlorine at the end of the pipe line.

Chlorination works best when the system's water has a pH below 7.5 since the hypochlorous acid (the active ingredient in chlorination) is more abundant. Acid treatment can be used to lower the pH of water which is alkaline. Chlorination is not recommended when a water source contains more than 0.4 mg/l of dissolved iron because of a possible chemical reaction which produces an iron oxide precipitate that could block emitters.

The amount of chlorine necessary for biological control varies from system to system and even from day to day. Chlorine injected into water reacts with organic substances to form combined chlorine. Some also reacts with ammonium ions to form chloramines. In the presence of hydrogen sulfide or iron, chlorine can react to form a chloride. Any remaining chlorine that has not reacted is called free chlorine. It is this free chlorine which kills bacteria present in the water. If chlorine is injected continuously into a system, a free chlorine residual of 1 mg/l is adequate to control bacterial growth. For intermittent treatments, a free chlorine level of 10 mg/l for 30 minutes per treatment is effective. If pH is above 7.5, the free chlorine level must be increased two to three times. Other chemicals such as ozone and iodine have been considered for biological control, but they are generally more expensive and may be harmful to plants.

8. EXPERIMENTAL DESIGN

8.1 Project Layout

The experimental study was conducted at three sites. These sites were located at Kramer Junction, San Jose and Sacramento with water qualities of poor, moderate and good water, respectively (Figure 4). The experimental layouts for the Kramer Junction and San Jose sites were identical with 12 pipe lines representing 12 different water conditions. The Sacramento site was made up of 20 lines, therefore, 20 water conditions could be simulated. The first 10 lines (conditions) were used to produce forced emitter failure, followed by the other 10 lines that produced water quality conditions that were very similar to those at the San Jose and Kramer Junction sites.

A typical line setup used at all of the three sites is shown in Figure 5. As indicated in Figure 5, five types of emitters, A, B, C, D and E are replicated four times on each line for a total of 20 emitters per line. This adds up to a grand total of 880 emitters to be tested in all three sites. The schematic drawing of the line setup at the three sites is shown in Figure 6.

Although the experiment was undertaken in the field, the layout of the project is somewhat different than conditions actually found in the field. In contrast with Caltrans drip irrigation, in which emitters are either buried or laid on the ground, the emitters for this project were elevated about 12-18 inches above the ground for ease of monitoring (Figures 7 and 8). This type of layout would tend to minimize biological clogging problems since back siphonage would not occur under these experimental conditions.

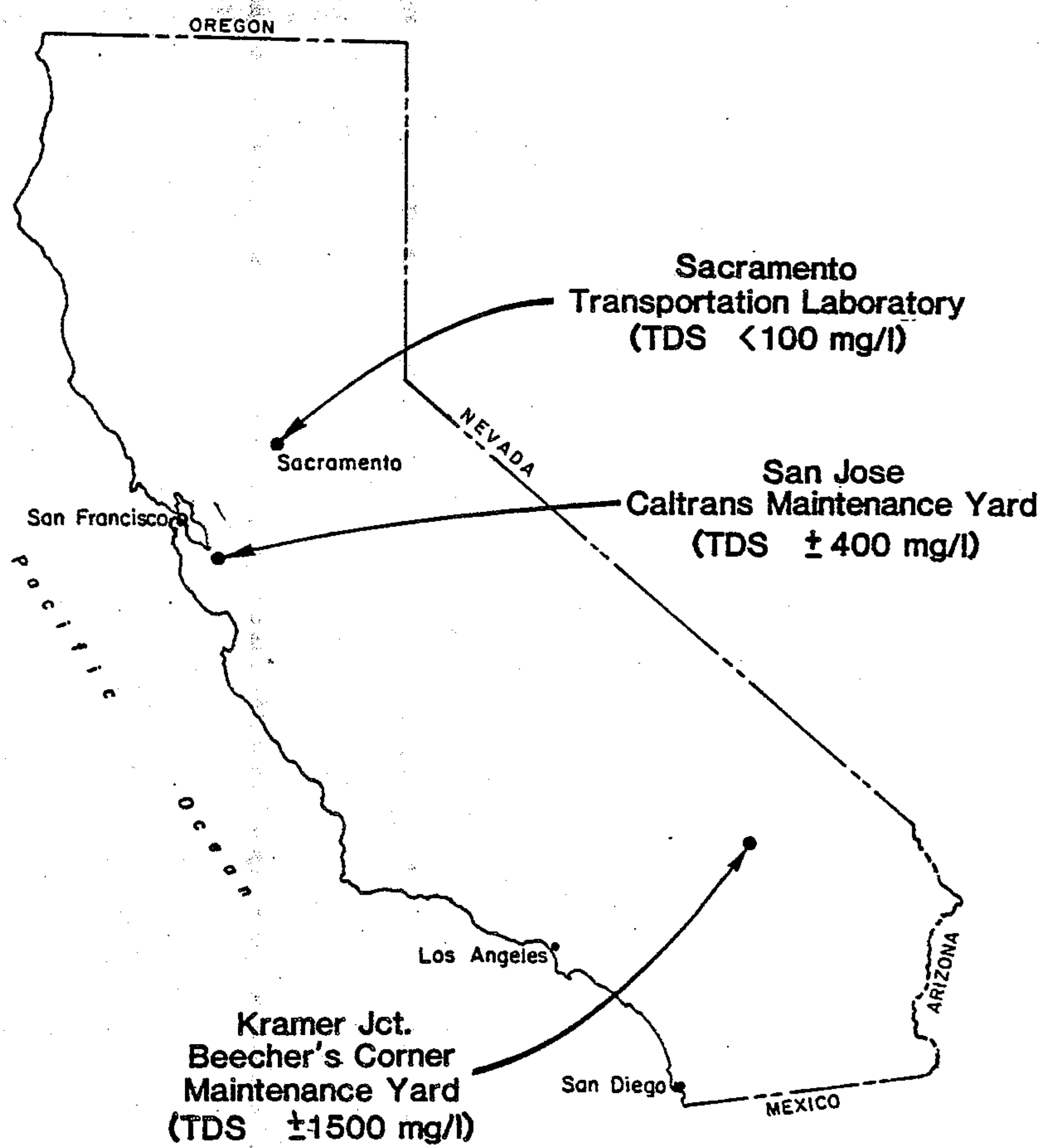


Fig. 4. LOCATION OF THE THREE SELECTED SITES

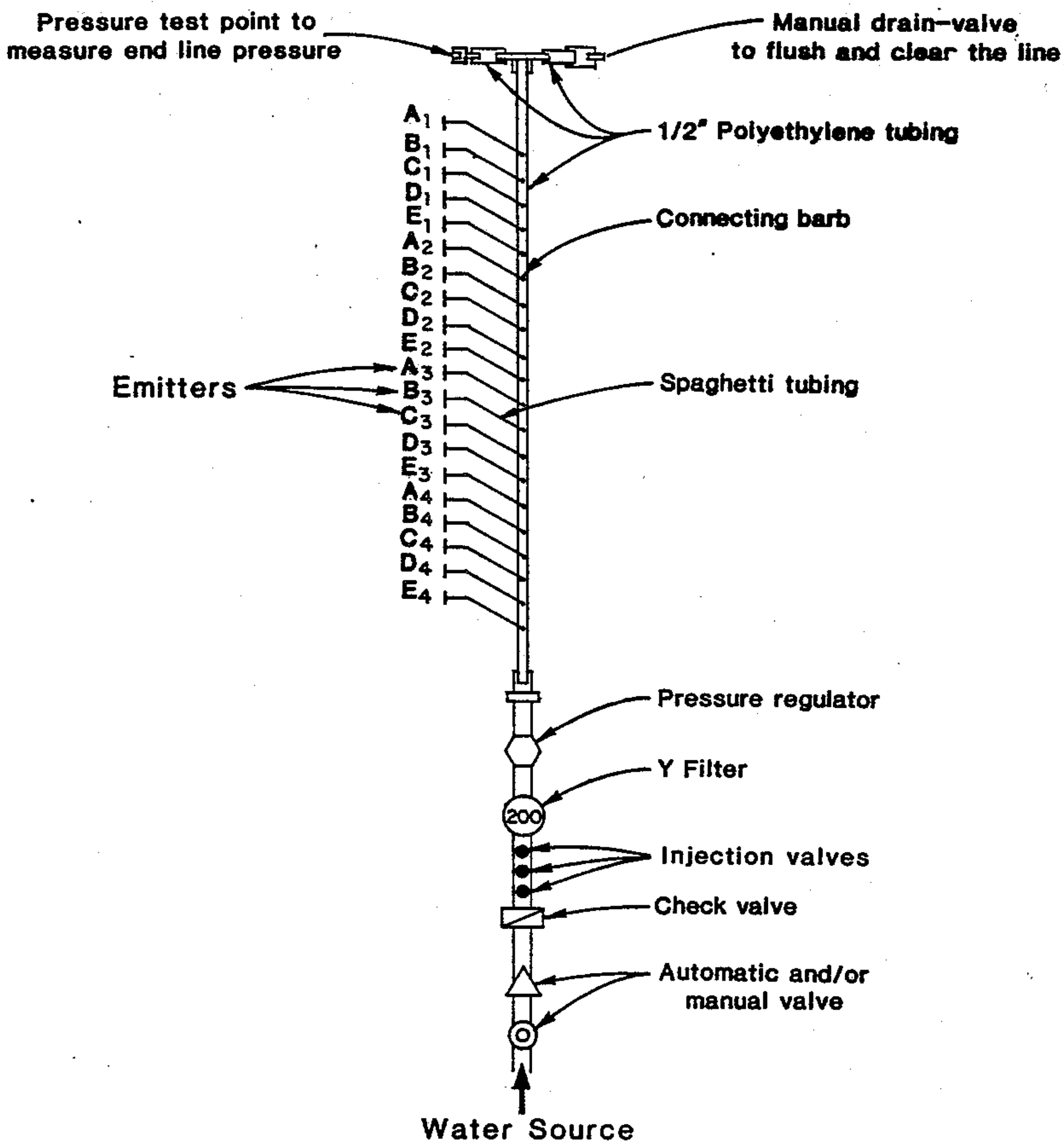


Fig. 5. TYPICAL LINE SETUP

KRAMER JCT. AND SAN JOSE MAINTENANCE YARD

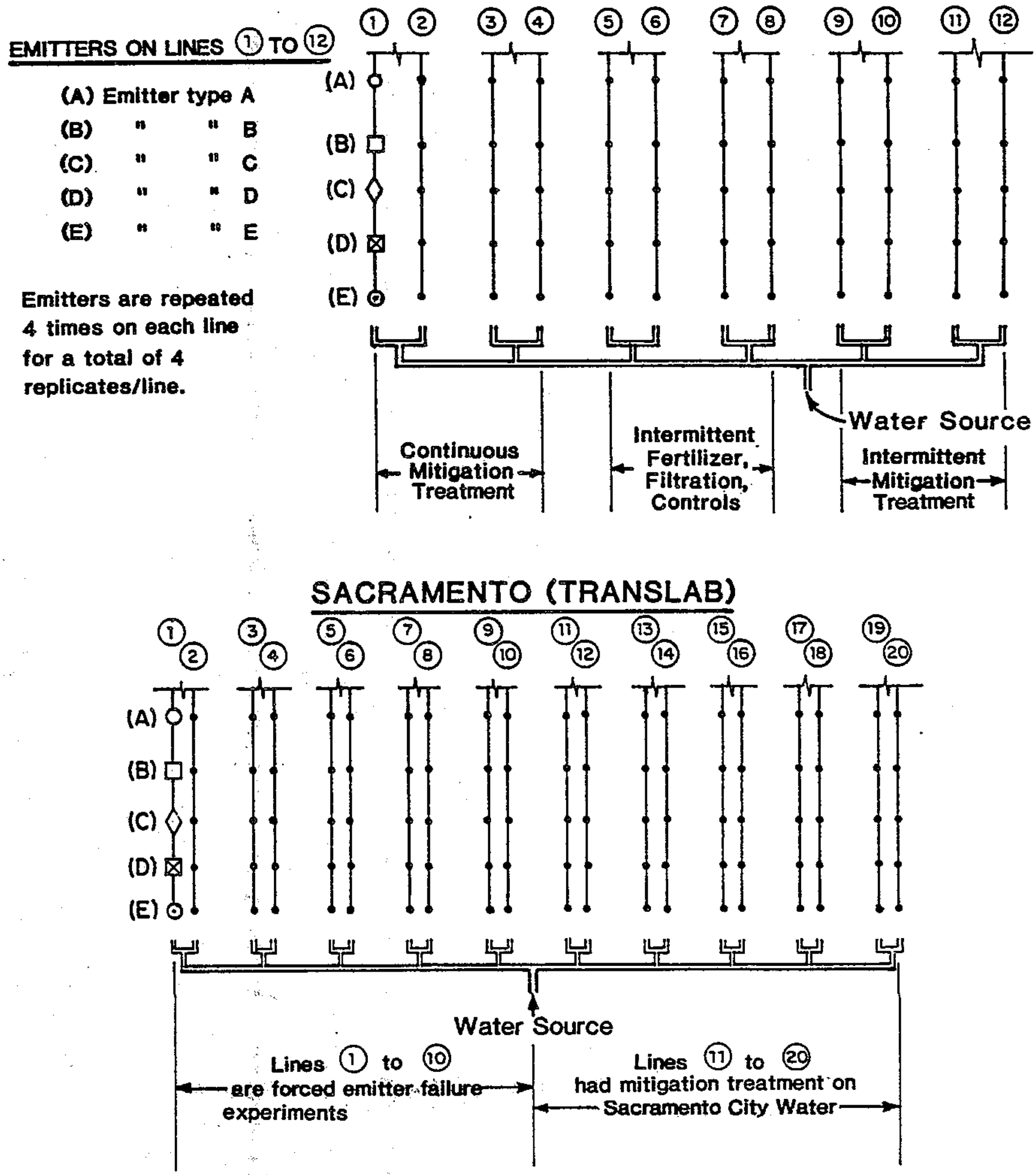


Fig. 6. DRIP IRRIGATION LINE SETUP

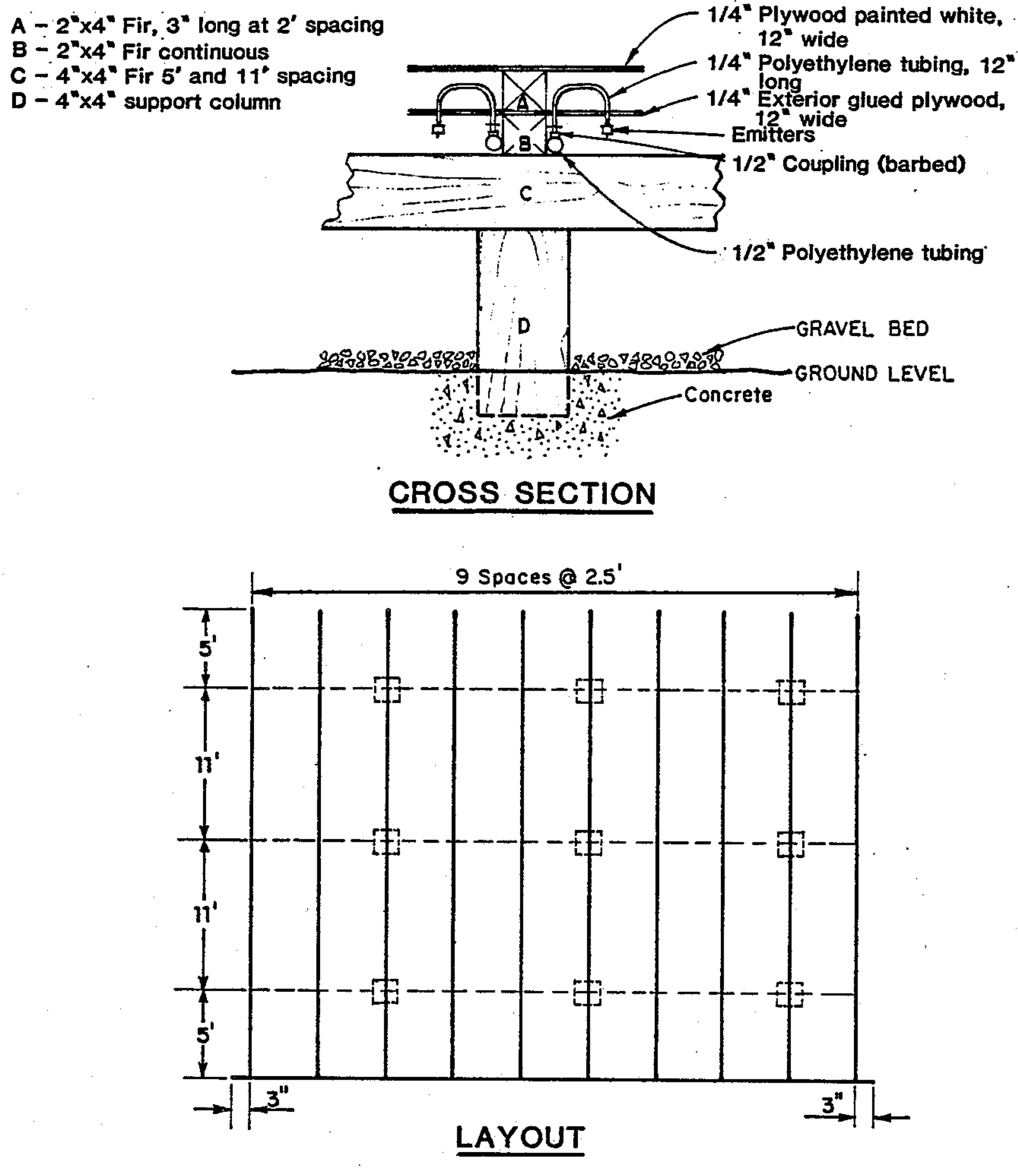
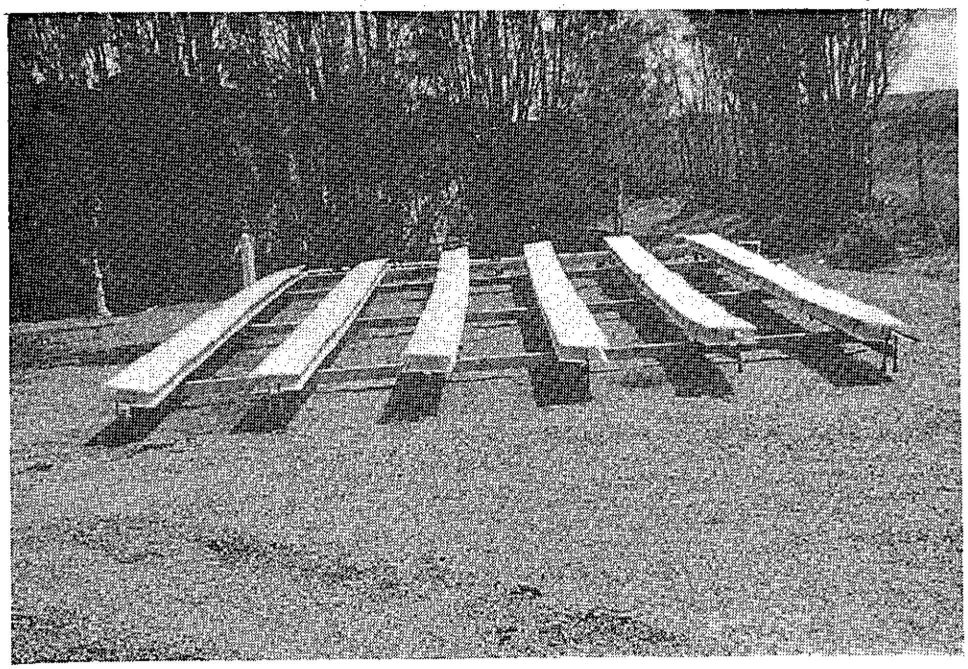
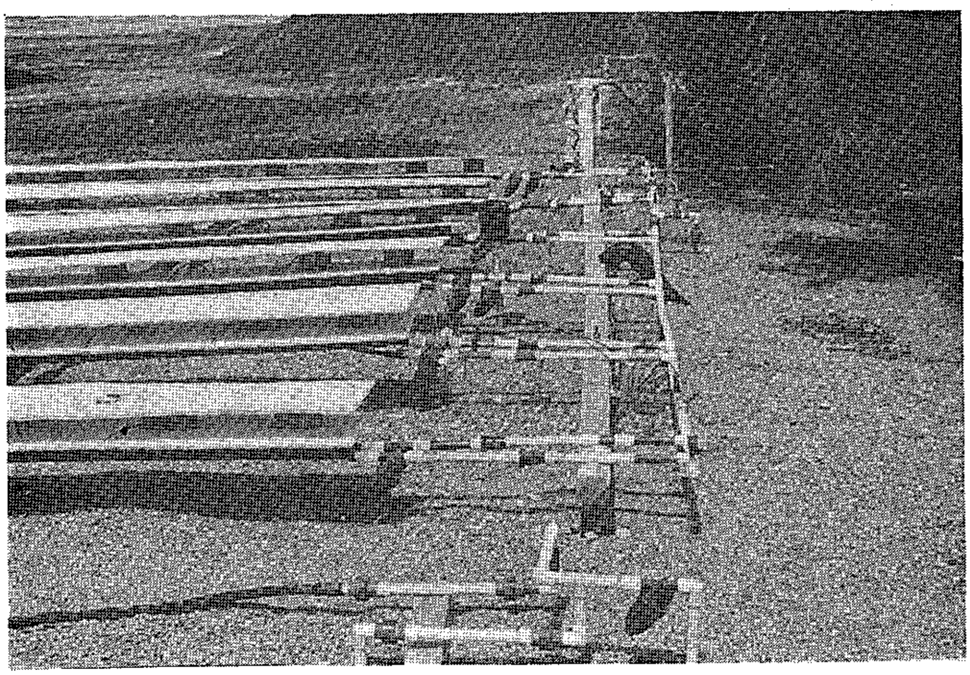


Fig. 7. TYPICAL CROSS SECTION AND LAYOUT





Layout and Piping Manifold of a Typical Installation

FIGURE 8

8.2 Emitter Selection

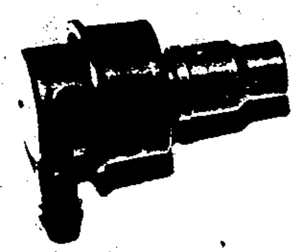
Five different types of emitters were selected for evaluation by personnel of the Offices of Landscape Architecture and Highway Maintenance. Selection of the emitters was generally based on field experience and previous field evaluations of emitters. Specific considerations utilized for selecting these emitters were: pressure compensation, durability, longevity, susceptibility to clogging, availability of emitters statewide, probability that the manufacturer would stay in business and carry the same type of emitter for a length of time after initial installation for possible replacement, and general installation and operation characteristics. Descriptions of the five emitters selected for evaluation are as follows:

Emitter No.	Type	Flow Rate GPH	Comments
A	Agrifim (N8C)	2	Semi long path, turbulent flow
B	RainBird (EM-M10)	1	Short path, self flushing
C	Global Flapper (STF-2)	2	Expandable orifice, diaphragm
D	Drip-Eze	2	Long path, spiral grooved, (DPC-08) (manual flush)
E	Vortex (3001-1)	1	Single vortex with vortex chamber

Photographs of the selected emitters are shown in Figures 9 and 10.

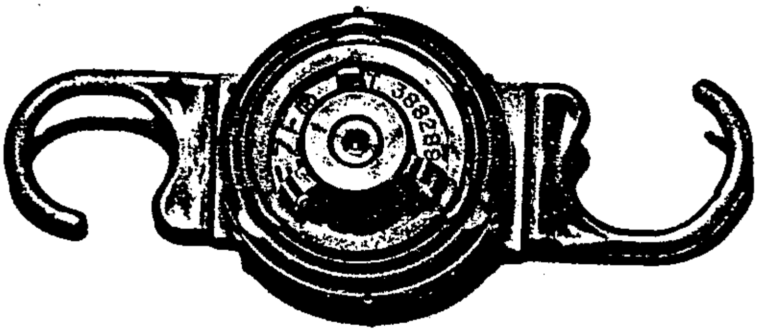
EMITTER A

EMITTER B



EMITTER C

FIGURE 9



EMITTER D

EMITTER E

FIGURE 10

8.3 Water Types and Locations of Test Plots

At the outset of this research, it was decided to test all preselected emitters under a variety of water quality conditions as wide as possible and consistent with the project timetable and funding. Three different types of water with "good", "moderate", and "poor" quality were selected for testing and evaluation. In addition to a given water quality, it was essential to select a site that had the following additional characteristics:

° Test site must have easy access for the purpose of monitoring.

° Test site must be clear of obstacles and available to TransLab personnel without any possible interference for up to three years.

° Test site must have access to a water source and electrical power.

° Test site must be secure from acts of vandalism.

In 1982, TransLab conducted a field investigation and a water quality testing program to select the best suitable sites that would meet all of the above requirements. Twenty-one sites were investigated and the water was examined for conductivity, pH, temperature and chlorine level. As a result of this investigation, the following three sites were selected.

1. Transportation Laboratory, in Sacramento, represents a good water quality site (TDS<100 mg/l). The water is supplied by the city of Sacramento and is mostly treated American River water.

2. Maintenance yard in San Jose is served a water of moderate quality. This water is supplied to Caltrans by the city of San Jose and is treated well water (TDS is 400 mg/l).

3. Beecher's Corner maintenance yard in Kramer Junction describes a poor water quality site (TDS is 1500 mg/l). This water comes directly from a well and has no previous treatment.

The results of water quality examination for the three selected sites are shown in Table 9.

In addition to three water types in the field, attempts were made to simulate 10 different types of water in the lab to confirm the causes of emitter clogging and to evaluate the emitters under controlled conditions. This was accomplished by adding various physical, chemical and biological characteristics to the Sacramento water. Calculations were made for chemical mass balance, equilibrium, pH balance, solubility and compatibility to determine the source and amount of each substance needed to produce the desired water quality using the Sacramento water as the base material.

TABLE 9

WATER QUALITY AT THREE SITES*

	Sacramento	San Jose	Kramer Junction
Carbonates	2.00	0 .00	0.0
Bicarbonates	23.00	235.50	244/277
Cl	5.20	36.10	370/375
SO_4	6.00	50.30	440/294
Nitrates	0.04	5.90	33/31.9
Ca	9.50	67.30	27/39
Mg	1.50	26.00	13/12.4
Sodium	2.30	34.70	500/430
Boron	-	0.10	3.1/3.0
Iron (Fe)	0.01	0.03	0.08
Hardness as $CaCO_3$	3.00	274.50	120/148
Total Solids	46.00	390.00	1600/1468
pH	8.8	7.7	7.5/7.9

* All results expressed in milligrams per liter except pH which is in pH units.

Calculated amounts of constituents were diluted with Sacramento water and injected separately with chemical injection pumps into each irrigation line.

Suspended solids were made of local soil (a combination of sand, silt and clay) passed through 100 mesh screen and mixed into the water to form a muddy liquid. This muddy liquid was then injected into the irrigation line by diaphragm pumps. A small three-speed fan motor was attached to the propeller to keep the solution in suspension. Water was examined periodically at the last emitter on the line to verify the proper concentration of suspended constituents. Table 10 shows the constituents injected into each line and their concentrations and sources. The clogging results obtained from this portion of the experiment were inconsistent and inconclusive.

TABLE 10

FORCED EMITTER FAILURE EXPERIMENTS
AT SACRAMENTO

Line		
1	40 mg/l suspended soilds	Physical Clogging
2	80 mg/l suspended soilds	Physical Clogging
3	180 mg/l suspended solids	Physical Clogging
4	500 mg/l dissolved solids	Chemical Clogging
5	1000 mg/l dissolved solids	Chemical Clogging
6	1500 mg/l dissolved solids	Chemical Clogging
7	0.5 mg/l Fe + 50 mg/l fertilizer	Biological Clogging
8	1.0 mg/l Fe + 100 mg/l fertilizer	Biological Clogging
9	1.5 mg/l Fe + 200 mg/l fertilizer	Biological Clogging
10	40 mg/l susp. solids + 500 mg/l dis. solids	Combined Clogging

Lines 1 to 10 have 120 mesh filters.

Dissolved solids for the water containing 1500 mg/l of TDS consist of:

Constituent	Concentration After Being Injected Into The Water	Sources of Constituent
Calcium	150 mg/l	Calcium Chloride
Magnesium	50 mg/l	Magnesium Sulfate
Bicarbonate	400 mg/l	Sodium Carbonate
Sulfate	400 mg/l	Sodium and Magnesium Sulfate
Other non clogging substances	500 mg/l	Sodium, Chloride, etc.
Total	1500 mg/l	

8.4 Water Treatment

Water treatment processes were selected based on an evaluation of the results obtained by researchers who successfully prevented emitter clogging with other water sources under different environmental and field conditions. The types of water treatment were varied by the degree of filtration for removal of suspended solids and types of chemicals to control the pH of the water and the prevention of biological slime development. These types of treatment include continuous injection of acid and chlorine, continuous acid, continuous chlorine, single and double water filtration, and intermittent injection of acid and chlorine for each of the three sites. Treated water was examined at the last emitter on each line for pH level and chlorine concentration. Descriptions of treatment given the water in each line at all three sites are as follows:

San Jose and Kramer Junction

Line 1 Continuous acid + chlorination + double filtration
Line 2 Continuous acid + chlorination
Line 3 Continuous acid
Line 4 Continuous chlorination
Line 5 Double filtration
Line 6 Intermittent fertilizer
Line 7 200 mesh filter control
Line 8 120 mesh filter control
Line 9 Acid + chlorination applied every week
Line 10 Acid + chlorination applied every 2 weeks
Line 11 Acid + chlorination applied every 4 weeks
Line 12 Acid + chlorination applied every 4 weeks with double filtration

Sacramento

Line 11 120 mesh filter control
Line 12 Intermittent fertilizer
Line 13 200 mesh filter control
Line 14 Continuous acid + chlorination
Line 15 Continuous chlorination
Line 16 Continuous acid
Line 17 Acid + chlorination applied every 2 weeks
Line 18 Acid + chlorination applied every 4 weeks
Line 19 Acid + chlorination applied every 6 weeks
Line 20 Acid + chlorination applied every 8 weeks

In the continuous mitigation treatment, dilute sodium hypochlorite and/or hydrochloric acid solutions were injected separately into the inlet side of the filters. Injection rates of the chemicals were adjusted to attain a pH of 7 and the free available chlorine in the water at the last emitter on the line was about 1.0 mg/l.

In the intermittent treatment, the same types of acid and chlorine were injected for 30 minutes in the appropriate line and based on the intermittent treatment schedule. The injector pumps were adjusted to produce a pH of about 4 and the free available chlorine in the water measured at the last emitter of the line to be about 10 mg/l.

All chemicals were injected into the system by injection pumps before the water was filtered to reduce chances of precipitation after filtration.

8.5 Experimental Operation and Monitoring

The experimental project was operated and monitored for a two-year period at all three sites. During the first year of operation, the controllers were set up to irrigate three times every day, starting at 6 a.m., 1 p.m. and

7 p.m. for a period of 30 minutes. This adds up the total irrigation time of 10.5 hours a week at each site. Although this watering schedule was different from what Caltrans practices in the field, it was designed to accelerate the chemical clogging procedures based on the following assumption.

Chemical precipitation develops and accumulates as the water containing a high concentration of dissolved solids evaporates at the orifice of an emitter. Therefore, the number of repetitions of wetting and drying of the emitter orifices would be the critical factor for emitter clogging rather than the actual life of the drip irrigation system. Based on this assumption, chemical precipitation accumulated in one year of operation under an accelerated watering schedule would be equivalent to 10 years under a normal watering schedule, taking into account that Caltrans generally waters the plants two times a week when drip irrigated.

At the end of the first year of operation, evaluations of water quality and emitter performance were made for the three sites. From the data that were obtained from this first year of operation where 3 times per day irrigation was practiced, it was found that no significant amount of emitter clogging was occurring. It was then decided to continue testing for another year but to change the watering schedule from every day to twice per week. The total time of watering was held at 10.5 hours per week but the irrigation was scheduled to occur on Mondays and Thursdays only to better resemble Caltrans field operations. It was assumed that the more frequent watering might be causing the organisms that developed in the emitters to be flushed out before they had a chance to multiply and grow to a significant size.

Monitoring at all the sites was accomplished by placing a one-gallon plastic container under each emitter and collecting the discharged water for a period of 20 minutes. The height of the water in the container for each emitter was measured and this measurement was converted into the weight of water in grams. Using lightweight plastic containers for collecting the emitter discharge created a problem on windy days when the containers would blow away from the site.

All three field test sites were shut off during the winter months and were monitored on an average of once a month during the rest of the year. The complete monitoring consists of the following steps:

1. Measurement of each emitter discharge
2. Measurement of the pH and temperature of the water
3. Cleaning the filters
4. Flushing the lines
5. Maintaining a full supply of required chemicals
6. Assuring that the pressure at the end of the line was 20 psi
7. Adjusting the chemical pumps to ensure that adequate chemicals were present in the water
8. General operational maintenance.

All chemicals were injected into the system before the water was filtered to minimize precipitation after filtration.

9. RESULTS

Basic data that was collected during the study are available from the Enviro-Chemical Branch of the Transportation Laboratory in Sacramento.

Water quality data that were provided by the water purveyors for water being used at field sites where clogging problems were reported are shown in Appendix 4 of this report. The first column in Appendix 4 shows the location of the site where clogging problems occurred. For example Site 1-1-b, the District is "1", Maintenance Region is "1" and Subarea is "b". The water quality data are furnished by the supplier at this site.

A summary of water quality information that was obtained at 14 Caltrans drip irrigation sites in 1980 is presented in Tables 5A and 5B of Appendix 5. This information was collected by TransLab researchers.

In order to determine suitable locations to conduct this emitter clogging study, a water quality survey was made at 16 maintenance stations and safety roadside rest areas. The results of this survey are presented in Table 5C in Appendix 5.

Data that were derived from a pressure-discharge experiment on the five selected drip emitters are presented in Tables 6A, 6B, 6C, 6D, 6E and 6F in Appendix 6. This experiment was conducted at the Sacramento site.

An experiment to determine the degree of uniformity of emission from each type of drip emitter was conducted at TransLab. The results of this experiment are presented in Table 6G in Appendix 6.

The relationship between drip emitter discharge rate and water temperature was also a factor to be considered. The data obtained in this experiment which was conducted in Sacramento at constant water pressure conditions are presented in Tables 6H, 6I, 6J, 6K, 6L and 6M in Appendix 6.

The results of the two-year study showing the percent reduction in flow rate are shown in Tables 6N, 6P and 6Q in Appendix 6 for the sites at Kramer Junction, San Jose and Sacramento, respectively. These tables show the percent reduction in flow for each type of emitter for each type of water treatment. The types of water treatment at Kramer Junction, San Jose and Sacramento are ranked from most to least effective in Tables 6R, 6S and 6T in Appendix 6, respectively.

Tables 6U, 6V and 6W in Appendix 6 contain data that show the relationship between duration of water flow and the number of each type emitter that became clogged during the two year study with the various types of water treatments at Kramer Junction, San Jose and Sacramento, respectively.

10. DATA ANALYSIS

10.1 Emitter Evaluation

A complete evaluation of emitters is essential when selecting an emission device for drip irrigation systems since the potential success and efficiency of a drip system depends greatly on the performance characteristics of the device used. Generally, the performance of an emitter is related to the details of its particular design; the selection of proper plastic, elastomer and other materials used; and the care and consistency with with the emitter is manufactured(2). When selecting a particular emitter to be used in a drip irrigation system, seven fundamental factors should be considered. Some of these can be considered engineering performance factors, and, hence, can be measured and evaluated numerically. Others are judgmental factors and can be evaluated only subjectively(2).

These factors are:

1. General suitability
2. Pressure-flow relationships
3. Manufacturing variability and emission uniformity
4. Sensitivity to water temperature
5. Sensitivity to clogging
6. Economic analysis (cost of emitters)
7. Reliability of manufacturer.

10.1.1 General Suitability

A detailed discussion of suitability of emitters is not made in this report. Evaluation of a factor of this type should be made by the designer. General suitability refers to how well the device will fit into the situation being dealt with. Specifically, how well does the device match the current plant size and water requirements. Also, one should try to estimate future needs of the plants.

In the following five sections, other factors that are considered in evaluating emitters are examined. This evaluation is made to compare emitters and may or may not be helpful information for Caltrans landscape designers in estimating the performance characteristics of each emission device.

10.1.2 Pressure-Flow Relationships

An important item to consider when designing a drip irrigation system is how well the emitters respond to changes in water pressure. Variation in pressure throughout the drip irrigation system due to a combination of frictional losses and elevational differentials may be significant in Caltrans highway landscape installations. It is desirable to select an emitter that can compensate for variations in pressure and still emit nearly the same flow rate. Most manufacturers provide a "pressure-flow curve" for their prospective emitter to demonstrate the pressure-flow relationship (Figure 11). In such displays, the steeply rising curves indicate larger flow rate variation with changes in pressure than flat or gently rising curves. This type of interpretation can be misleading since changing the scales on which the curve is plotted can make a steep curve appear not so steep, and vice versa.

The best way to assess the flatness of a particular curve is to define the curve with the following equation developed by Solomon(2).

$$q = kp^x$$

in which

q = flow rate
p = working pressure
x = emitter exponent
k = a constant dependent on the emitter and the units for p and q

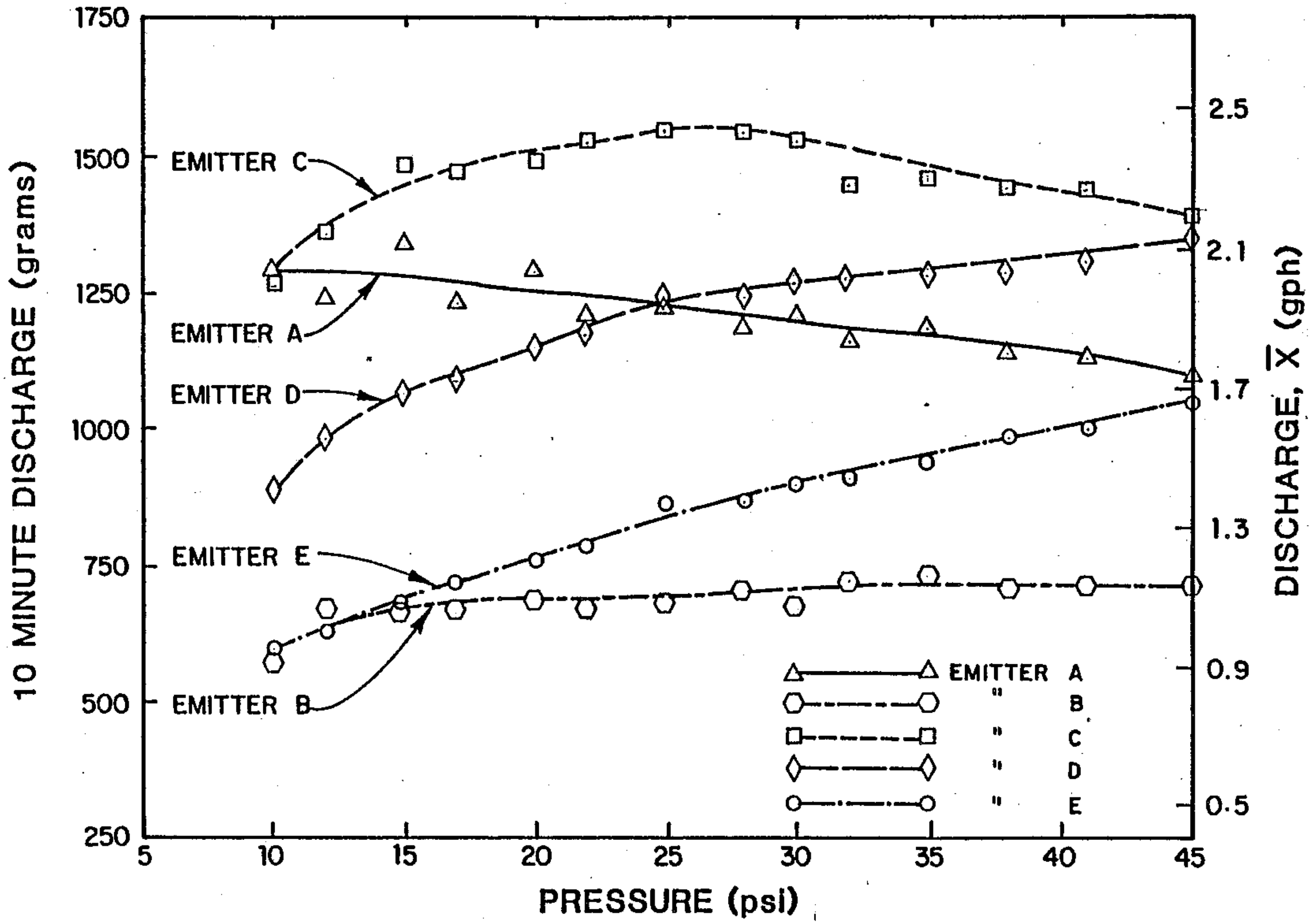


Fig. 11. PRESSURE-DISCHARGE RELATIONSHIP
AT WATER TEMPERATURE OF 20°C

The emitter exponent (x) is a measure of flatness of the pressure-flow curve. Thus, it is the slope of the pressure-flow curve when plotted on log-log paper and can be expressed as follows:

$$x = \frac{\text{Log}(Q_1/Q_2)}{\text{Log}(P_1/P_2)}$$

where Q_1 and Q_2 represent the flow rates at the pressure P_1 and P_2, respectively, and x is the emitter exponent which is a measure of the pressure compensating ability of an emitter, with lower numbers indicating a greater pressure compensating ability (Figure 12). A perfect pressure compensating emitter would have an emitter exponent of zero.

In this study, pressure-flow experiments were conducted at Sacramento under identical testing conditions. The pressure-flow curves were developed on the same scale and the emitter exponent was determined for each of the tested emitters (Figure 11).

10.1.2.1 Experimental Setup

The test line contained 20 new emitters picked randomly from the shelf. Five types of emitters were replicated four times and connected to the polyethylene lateral line as shown in Figure 5. A 120 mesh filter followed by a 3/4" "Wilkings" adjustable pressure regulator (0-50 psi) downstream from the filter and two sets of pressure gauges ranging from 0 to 30 psi and 0 to 60 psi for low and high pressure measurement were used. Sacramento water was utilized at a water temperature of 20°C and an ambient temperature of 25°C.

Plastic containers were placed under each emitter and the discharge flow was collected over 10 minute intervals. The weight of water in the containers was measured in grams and recorded. The pressure at the end of the line was measured for each pressure change to confirm the pressure setting at the beginning of the line.

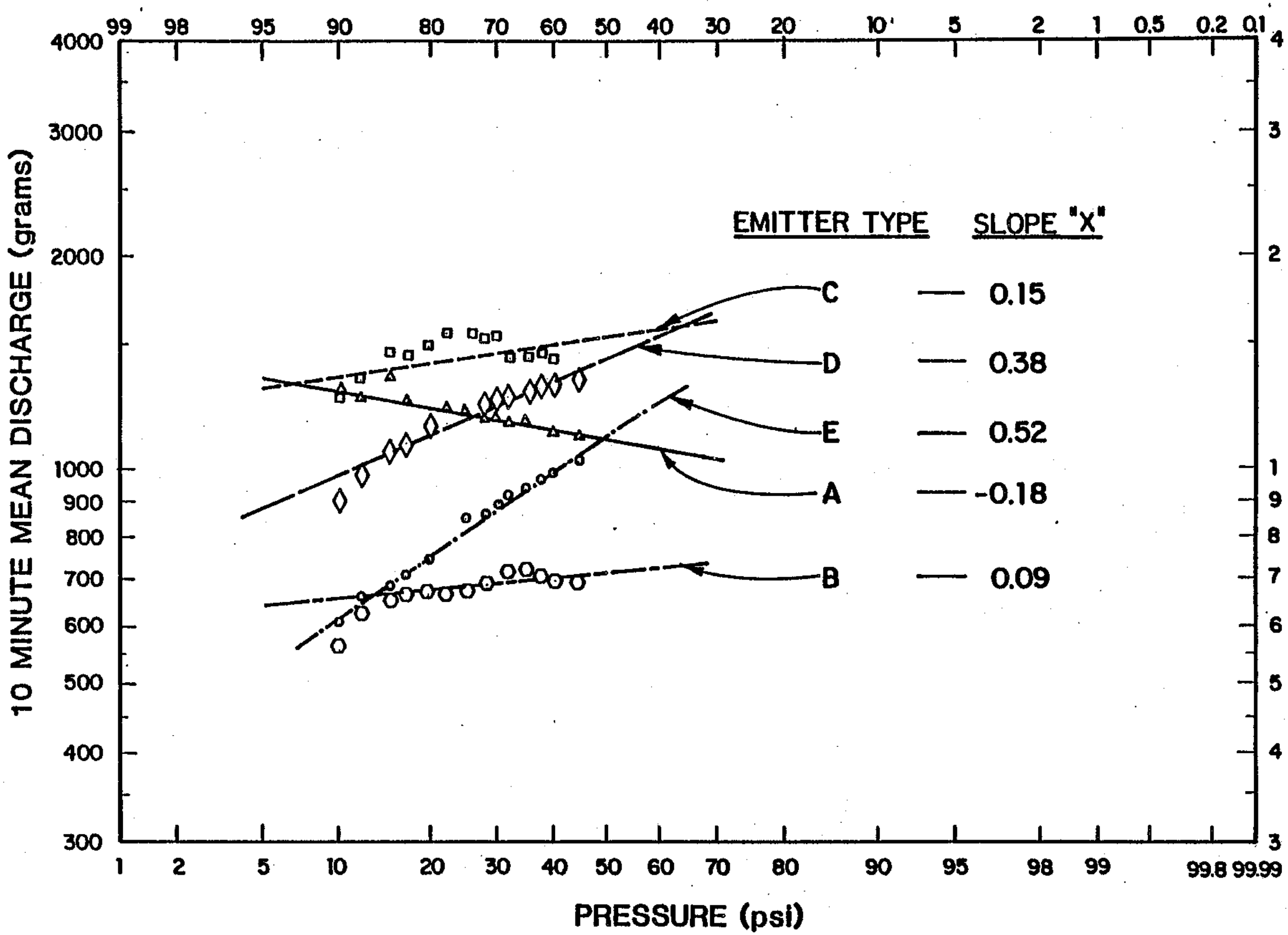


Fig. 12. EMITTER EXPONENTS

10.1.2.2 Results and Analysis

Emitter discharges were measured in grams weight and raw data were averaged to calculate a mean value for each emitter. Pressure-discharge data obtained at the Sacramento site are shown for each emitter in Tables 6B, 6C, 6D, 6E, and 6F in Appendix 6. The mean discharge for 10 minute intervals was plotted versus the pressure variation to obtain the pressure discharge relationship as shown in Figure 11. The minimum and maximum values and the standard deviations were calculated to determine the dispersion of the data (Table 6A, in the Appendix 6). In addition, the pressure-flow curves were plotted on log-log paper to determine the emitter exponent (Figure 12). Based on Figure 11, tested emitters had varying degrees of pressure compensation ability. The pressure-discharge curves for both D and E emitters are steeper than other curves with increasing discharge rate as the pressure increases. This flow increase can be expressed by emitter exponent values of 0.38 and 0.52 for emitter D and E, respectively. In contrast with other emitters, the discharge rate for emitter A decreased slightly with increasing pressure. The degree of variation may be found by noting the emitter exponent of -0.18. The negative sign indicates the inverse relationship between pressure and discharge rate for this particular emitter. Emitter B showed excellent pressure compensating ability above 25 psi as shown by the nearly flat line in Figure 11 and the emitter exponent of 0.09. Although the emitter exponent value for Emitter C is 0.15 which is relatively small, Figure 11 shows that the emitter discharge increased from an operating pressure of 10 to about 28 psi and then the discharge decreased as the pressure increased; however, this variation was rather small. The maximum measured discharge variation in the operating pressure range of 20 to 40 psi was about 7%.

10.1.2.3 Conclusions

1. Most pressure compensating emitters with a low exponent have some physical parts which respond to pressure such as a flexible or a rubber diaphragm. In general, pressure compensating emitters that contain rubber

diaphragm discs or pliable materials usually experience a degradation in performance with time that is largely due to a gradual hardening of the rubber or pliable material. This will affect long-range performance and should be considered when selecting an emitter.

2. Due to the capacity limitation of our test apparatus, only 20 emitters, four of each type, were tested in the pressure-flow study. Thus, the standard deviation of the mean value for each emitter is relatively high. These high standard deviation values suggest an insufficient number of emitters were tested as a sample of the total population. It would have been preferable to test 100 or more emitters of each type for such an evaluation. Furthermore, the information found in this study should only be used as a guideline for evaluating emitters, not as a specification. Most manufacturers provide a pressure-flow curve and sometimes emitter exponent values are furnished upon request. Exponents can be computed as shown above from the manufacturer's published pressure-flow data. Using this value to judge the pressure compensating ability of an emitter enables the designer to objectively reduce the problem to the evaluation of a single number that does not depend upon the units used to measure or graph the flow rate and/or pressure.

The Center for Irrigation Technology at California State University, Fresno tests emission devices for pressure-flow relationships routinely. They include in their reports temperature effects, coefficients of manufacturer variability, emission uniformity and uniformity coefficients. There is a fee for such an evaluation.

10.1.3 Manufacturing Variability and Emission Uniformity

Because flow channels in emission devices are small, it is important that manufacturing processes for producing the emitters be precise. Small deviations in orifice size can have a relatively large effect on the flow rate. Since it is impossible to manufacture any two devices exactly identical in every respect, some variation in flow rate (at a given reference pressure) may be expected from one emission unit to the next. For good emission uniformity, this manufacturing variation should be as small as possible.

The manufacturer's coefficient of variation is a term used to describe the anticipated variation in discharge rate of a sample of new emitters when operated at any given pressure. Keller and Karmell introduced the coefficient of variation as a statistical measure for emitter manufacturing variation(13). v is defined as a ratio of standard deviation to the mean of the flow rates measured for a sample of emitters.

$$v = \frac{SD}{\bar{Q}}$$

Where: SD = Standard deviation for a sample of emitters.
Q = Mean discharge from a sample of emitters.

The ratio, v, is a measure of the variation in discharge occurring as a result of variation in the manufacturing process.

Typical values of v and the rating for prospective values are as follows:

v values	rating
0	
0.02	excellent
0.04	good
0.06	
0.08	average
0.10	
0.12	marginal
0.14	
0.16	poor
0.18	
0.20	

10.1.3.1 Emission Uniformity

The relationship between the minimum and average emitter discharge rates within the system is related to manufacturing variability and is defined as emission uniformity (EU). EU is expressed as a percentage of the average discharge rate for the lowest 25% of the field data divided by the average discharge rate of all data. The average of the lowest 25% was selected as a practical value for the minimum discharge rate, as recommended by the U.S. Soil Conservation Service for field evaluation of an irrigation system.

By definition:

$$EU = \frac{Q25\%}{\bar{Q}} (100)$$

in which

EU = Emission uniformity, percentage

Q25% = Average of the lowest 25% of the emitter discharge rates

Q = Average of all emitter discharge rates

No classification system is presented for this parameter, however, values of greater than 95% generally can be considered very good.

In this study, the v and EU values for each of the five tested emitters were computed based on the data adapted from the initial measurement of the experimental test project. These values are presented in Table 6G in Appendix 6.

10.1.3.2 Experimental Setup

A total of 880 new off-the-shelf emitters were utilized in three locations. The emitters consisted of five different types with a total of 176 sample units for each type. All emitters were flushed out and checked for proper performance by operating the system 10 hours prior to doing any testing. This allowed for stabilization to take place before testing the units.

Each test line contained 20 emitters (5 of each type replicated four times as shown in Figure 5), a 20 psi fixed pressure regulator, and a of 100 mesh filtration unit located upstream from the pressure regulator. Pressures were checked at the end of the line to confirm the inlet pressure. No chemicals were injected into any of the lines prior to or during the test period. The quality of the municipal water varied among the three sites. Table 9 lists values of constituents contained in each of the waters used. One gallon plastic containers were placed under each emitter and the discharge was collected during 20 minute intervals, and weighed and the weight recorded.

10.1.3.3 Results and Analysis

The raw data was averaged to calculate the sample mean, standard deviation, coefficient of variation and emission uniformity values as was defined earlier. These values were calculated for each test site (Kramer Junction, San Jose and Sacramento) each with a different water temperature and water quality. The sample population for each of the above mentioned sites was 48, 48, and 80 emitters, respectively. The values were also calculated for all three sites with a total of 176 sample points for each emitter and listed in Table 6G in Appendix 6. As indicated in Table 6G, the coefficients of variation (v) for emitters A, B, C, and D at all three sites combined are relatively close with a range between 0.06 and 0.08 which is considered to be an average manufacturing variation. Emitter E, however, has a value of 0.13 for v for all three sites combined which is higher than the others and puts this emitter device into the marginal rating. The high value of v for Emitter E may be partially due to the sensitivity of the emission device to changes in water temperature.

Emission uniformity showed the same trend of variation among the emitter types with the lowest value of 85% for emitter Type E.

10.1.4 Emitter Sensitivity to Water Temperature Changes

Earlier in this discussion, emitter discharge variation was found to be affected by manufacturing variability and variation in operating pressure. Indications are, though, that an additional factor which could result in emitter discharge variation is water temperature(14).

An emitter may be sensitive to water temperature for one of two reasons. 1) Some emitters are designed so that flow rate depends on the viscosity of the water which changes with temperature. This is especially true with the laminar flow type emitter. Keller and Karmell, in 1974, listed the theoretical discharge variations based on viscosity changes in the temperature range 5 to 40°C (41 to 104°F)(13). In this temperature range, the theoretical variation in discharge rate relative to the discharge rate at 20°C (68°F) is approximately 2.8% per °C. 2) Emitters which have parts made of resilient material, such as pressure compensating emitters, may be subject to flow variation due to changes in material characteristics caused by temperature variations.

Water temperature variation may occur in a number of ways. Temperature variation occurs over a period of time with day-night, day-to-day and seasonal weather changes and from end to end of lateral lines due to the solar heating of laterals and black microtubing that are exposed to the sun. This solar heating effect is more pronounced in the desert area and in Southern California. Flow rate sensitivity to water temperature may be expressed graphically by plotting water temperature versus percent of variation of the flow rate at some water temperature expressed as a percent of the flow rate at 25°C water (Figure 13)(Table 6H in Appendix 6).

$$\text{Percent Flow Rate Variation} = \frac{\text{Flow rate at x °C} - \text{Flow rate at 25°C}}{\text{Flow rate at 25°C}} \times 100$$

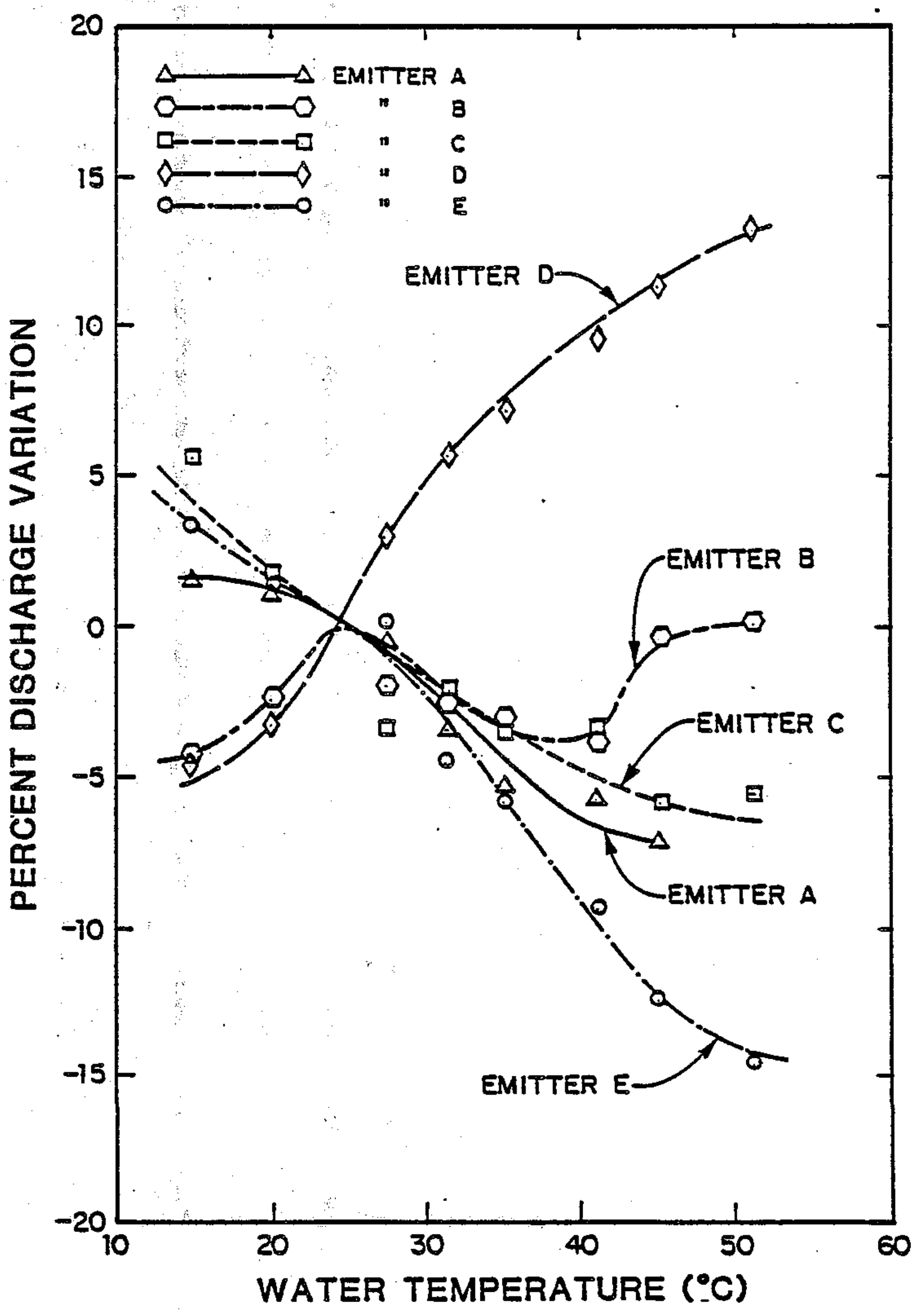


Fig. 13 TEMPERATURE–DISCHARGE VARIATION RELATIONSHIP AT A PRESSURE OF 20 PSI

10.1.4.1 Experimental Setup

The same experimental setup that was used for pressure-discharge relationship was utilized for the temperature study. Flow rates were determined by collecting the emitter discharges in one gallon containers over 10 minute intervals and measuring the weight of the water in each container. Temperature was controlled by adjusting the relative volumes of hot and cold water from a Sacramento city water faucet at the TransLab installation for temperatures from 15 to 51°C. Using 25°C as the standard operating temperature, percentage variation from the discharge rate at this temperature was calculated. A 100 mesh filter was used for filtration and the water pressure at the beginning of the line was kept at 20 psi during the testing period. Emitters that were tested in the one line contained 20 emitters, five types of each emitter, replicated four times. The test was repeated two times to obtain eight sample points per emitter type for each of the temperature intervals.

10.1.4.2 Results and Analysis

Emitter discharges were measured in grams and the raw data were then averaged to obtain the flow rate index at 25°C as was defined earlier. Raw data of flow rates and temperatures for each emitter are tabulated in Tables 6I, 6J, 6K, 6L and 6M in Appendix 6. The maximum and minimum range, mean standard deviation values as the percent of flow variation normalized at 25°C are listed in Table 6H in Appendix 6. Negative numbers indicate decreases in emitter flow rates and positive an increase. Normalized flow rates for each device were plotted as a function of water temperature in Figure 13.

As shown in Figure 13, variations in discharge rate resulting from water temperature changes can cause nonuniformity of water application, depending upon the type of emitter used. This effect is most pronounced for Emitters D and E. Variation in discharge rates for Emitters A, C and E are inversely related to water temperature increases with Emitter E being most affected. The maximum measured percentage discharge increases for the temperature range 25 to 51°C were -7.1, -5.9 and -14.8 for emitters A, C and E, respectively.

In contrast to other types of emitters, discharge rates for Emitter D increased with increasing water temperature. The rate of change in flow rate is very similar to that of the Emitter E in the opposite direction. The maximum percentage discharge increase measured in the field was 13.8 for the temperature range 25 to 51°C.

Emitter B, however displayed a nonuniform and inconsistent relationship between discharge rate and water temperature. This inconsistent and fluctuating pattern is similar to a sine curve. The reason for this fluctuation may be due to one or a combination of factors, such as, design, configuration, size and materials used. Emitters of the same design may have quite different performance characteristics depending on the care and precision with which these emitters are manufactured. Therefore, care must be exercised in making general statements based upon such data. An increase in discharge rate for Emitter D may be due to the laminar flow characteristics of the device and the decrease in discharge rate for Emitter E may be caused by increased vortex action as viscosity decreases

10.1.5 Sensitivity to Clogging

Of all the design parameters used to select an emitter, the most important is the sensitivity to clogging under field conditions. The emitters were tested at the three experimental sites (Kramer Junction, San Jose and Sacramento) where water sources were used that were of poor, moderate and good quality, respectively. The quality evaluation was based upon TDS concentrations. The TDS concentrations at Kramer Junction, San Jose and Sacramento were approximately 1500, 400 and 100 milligrams per liter respectively.

Various types of water treatment, ranging from 120 mesh filtration to continuous chlorination and acid treatment followed by double filtration, were given to the three water sources. These types of water treatment are more fully explained in Section 8.4 of this report.

10.1.5.1 Reduction of Flow Capacity During the Study Period

Flow measurements were taken on a monthly basis during the irrigation season (except winter months) for two years. Emitters that were allowing less than 25 percent of initial flow rates to pass were noted as being clogged. Reduction in flow percentages for all emitters under varying water quality and treatment conditions was calculated using the first three monthly flow measurements and the last three monthly flow measurements. The flow measurements for the five emitters at each of the three experimental sites were analyzed to determine the percent loss of flow rate during the two year study period. The summary of the loss of flow capacity at the three experimental sites, where varying water treatment systems were used, is shown in Table 11.

The greatest reduction in flow capacity occurred in the emitters attached to the line receiving continuous acid and chlorination treatment. Emitters receiving only acid treatment and continuous acid and chlorination plus double filtration treatment also showed significant loss in flow capacity. The least reduction in flow capacity occurred in the emitters attached to the lines receiving only filtration treatment and weekly acid and chlorination treatment.

Flow reduction data for individual emitters at each of the three experimental sites are shown in Tables 6N, 6P and 6Q in Appendix 6. It should be noted that when a plus sign precedes a number, that this means that flow capacity has increased during the study period.

TABLE 11

Summary of Percent Diminished Flow at Three Study Sites
For
All Types of Water Treatment and Emitters

Water Treatment	San Jose (TDS = 400)	Kramer Jct. (TDS = 1500)	Sacramento (TDS <100)	Total
Continuous acid and chlorination and double filtration	10	26	-	36
Continuous acid and chlorination	10	41	33	84
Continuous acid	20	29	+5	44
Continuous chlorination	2	13	+2	13
Double filtration (120 and 200 mesh filters)	7	6	-	13
Intermittent fertilizer	10	7	+5	12
200 mesh filter	9	+3	1	7
120 mesh filter	12	5	+4	13
Acid and chlorination every week	7	+3	-	4
Acid and chlorination every two weeks	11	12	+7	16
Acid and chlorination every four weeks	13	10	+2	21
Acid and chlorination every four weeks and double filters	14	8	-	22
Acid and chlorination every six weeks	-	-	8	8
Acid and chlorination every eight weeks	-	-	1	1

An increase in flow rate may occur in a drip emitter throughout a study of this type due to the use of pressure compensating emitters. Some of these emitters use diaphragm discs of rubber or other pliable materials to compensate for pressure changes in the system. These materials may become less pliable when exposured to the oxygen in the air or oxidizing agents in the treated water and not function as designed. This might result in an increase in flow capacity over that initially measured.

The types of water treatment are ranked from most effective to least effective for the sites at Kramer Junction, San Jose and Sacramento in Tables 6R, 6S and 6T, respectively. These tables are located in Appendix 6.

At Kramer Junction, the most effective treatments were found to be the 200 mesh filtration and the acid and chlorination treatment performed once a week. The least effective treatment here was found to be the continuous acid and chlorination process. At San Jose, the most effective treatment was found to be continuous chlorination, while the least effective process was continuous acid treatment. At the Sacramento site, the most effective treatment was the acid and chlorination treatment applied once every two weeks, while the least effective system was continuous acid and chlorination treatment.

At the three sites, the most effective treatment appears to be the type where either no chemical treatment is performed (200 mesh filtration) or where the chemical treatment is intermittent in nature, such as, once in two weeks or once a week.

The least effective treatment at all the sites appeared to be either continuous acid treatment or continuous acid and chlorination treatment.

10.1.5.2 Clogging of the Emitters During the Study Period

Throughout the study period when an emitter was passing less than 25 percent of the initial flow rate, it was noted as being clogged. At the end of the study period, it may be noted in Table 12 that six emitters were clogged in the lines that were receiving water which was given continuous acid and chlorination treatment. It should also be noted that five of the six emitters were of Type A and the other one was of Type E. In water lines receiving continuously chlorinated water, three emitters became clogged during the study (Table 12).

As may be noted in Table 12, no clogging occurred in emitters that received water that was treated with 200 mesh filters and the combination of acid and chlorine treatment every two weeks.

The breakdown of the types of emitters, the water treatment given and the numbers of emitters clogged during various amounts of waterflow is given in Tables 6U, 6V and 6W in Appendix 6 for sites at Kramer Junction, San Jose and Sacramento, respectively. A review of the clogging data that are presented in these three tables will show that some emitters became unclogged during the flow process. For water receiving continuous acid and chlorination treatment at Kramer Junction as shown in Table 6U, between 758 hours and 833 hours, 1 type E emitter and 1 Type C emitter became unclogged.

There appears to be a direct relationship between the number of clogged emitters and the total dissolved solids concentration of the water. The water at Kramer Junction (TDS of 1500 mg/liter) produced 10 clogged emitters at the end of the study while the waters with lower total dissolved solids concentrations at San Jose and Sacramento had 3 and 5 clogged emitters, respectively.

The clogging process is very complex and can be caused by a variety of factors such as pH level, concentration of suspended solids, dissolved solids, calcium, sulfates, carbonate-bicarbonates, chlorides and nutrients. Changes in temperature and evaporation rate will also cause variations in emitter clogging rates.

TABLE 12

Summary of Clogged Emitters at Three Study Sites
For
All Types of Water Treatment at the Completion of the Study

Water Treatment Type	San Jose	Kramer Jct.	Sacramento	Total
Continuous acid, chlorination, double filtration	0	1(1E)	-	1(1E)
Continuous acid and chlorination	0	2(1A,1E)	4(4A)	6(5A,1E)
Continuous acid	0	1(1E)	0	1(1E)
Continuous chlorination	0	2(2E)	1(1C)	3(1C,2E)
Double filtration	0	1(1E)	-	1(1E)
Intermittent fertilizer	0	1(1E)	0	1(1E)
200 mesh filter	0	0	0	0
120 mesh filter	1(1E)	0	0	1(1E)
Acid and chlorination every week	0	2(1C,1E)	-	2(1C,1E)
Acid and chlorination every two weeks	0	0	0	0
Acid and chlorination every four weeks	1(1A)	0	0	1(1A)
Acid and chlorination every four weeks and double filters	1(1A)	0	-	1(1A)
Acid and chlorination every six weeks	-	-	0	0
Acid and chlorination every eight weeks	-	-	0	0

An emitter is considered clogged when actual flow is less than 25 percent of initial flow.

A is emitter A, B is emitter B, C is emitter C, etc.

There are some indications that biological clogging is not the primary cause of clogging at the Kramer Junction, San Jose and Sacramento experimental sites. As may be noted in Table 5, biological clogging normally occurs in emitters and/or spaghetti tubing that are exposed to nutrients in water as well as living organisms that feed upon these nutrients. It was found in the study of existing field installations where biological clogging was a problem, that nutrient and organism laden water, in many instances, had been drawn into the spaghetti tubing attached to the emitters. The siphonage may be caused by hydraulic head differences, changes in temperature, capillary attraction, etc. In this experimental study, the geometrics were established in a manner that allowed free fall from the emitters to the measuring containers and nutrient levels were generally found to be very low.

Most of the emitter clogging in this study may be thought to have been produced by physical and chemical factors, such as, suspended and dissolved solids concentration of the water, stability-instability of the materials found in water as measured by Langlier's Index, evaporation at the emitter outlet, chemical resistance of the pressure compensating materials in the emitter orifice of each unit, irrigation frequency, etc.

A review of Table 12 will show that most clogged emitters were located at the Kramer Junction site where the water contained high concentrations of dissolved solids. Another clogging factor appears to be the acid and/or chlorine treatment given to the water passing through the emitters. It appears reasonable to assume that both high solids concentrations and acid and/or chlorine treatment are required to cause many emitters to become clogged. The chemical treatment may cause instability of the solids in the water to the degree that deposition will not occur until the time when the water is passing through the emitters.

One possible explanation for chemical and physical clogging of emitters is that at the termination of every irrigation cycle, droplets of this solids-laden water cling to the emitter orifice. In a very dry atmosphere, evaporation of the liquid portion occurs leaving the solids which gradually build up around the orifice. Alternate wetting and drying around the orifice causes a solids buildup which will gradually form a thick enough scale layer to interfere with the flow though the emitter. It should be noted that nearly all the emitters remained free flowing in this study when little or no chemical treatment was given to the water. Chemical treatment seemed to encourage solids deposition at the emitter orifice. Water that is very similar in quality to that produced from the Kramer Junction well may be used in drip emitters and given filtration treatment only. Based upon this study, this type of water treatment does not produce significant clogging problems.

10.1.6 Economic Analysis (Cost of Emitters)

Although the cost of emitters appears to be relatively small compared to the total project cost in highway landscape projects, one must consider the hidden cost associated with the emitter. If the total system cost is considerable, then the cost of the other equipment influenced by the emitter characteristics, as well as cost of the emitter themselves, must be taken into account.

The major cost consideration relating to the emitter characteristics include the degree of difficulty and the cost of installation of the emitter on the lateral line or risers, the filtration requirements which relate back to the sensitivity of the emission device to clogging and any additional friction losses caused by the emitter connections to the lateral pipe. Higher friction losses usually result in additional costs of pumping to boost the pressure to the desired value. In this study, the unit cost of each emitter and the filtration required or suggested by manufacturers for their emitters were investigated and listed in Table 13.

TABLE 13

EMITTER COST COMPARISON

Emitter Type	Unit Cost	Filtration Requirement	Connection Fitting
A	40¢	155 Mesh	Barb
B	80¢	140 Mesh	Barb
C	63¢	155 Mesh	Barb
D	74¢	100 Mesh	Barb
E	30¢	150 Mesh	Barb

The unit price was quoted based on the manufacturers suggested "list price" when purchasing 100 or less units. Filtration requirements were based on the manufacturer's recommendation for emitter operation using an average water quality.

10.1.6.1 Results and Analysis

As indicated in Table 13, the unit prices of the emitters ranged from 30¢ for Emitter E to 80¢ for Emitter B and the filtration requirements of 155 mesh for Emitter A and C to 100 mesh for Emitter D. The differences between the maximum and minimum cost and filtration requirements are more than 160 percent and 50 percent, respectively. There was no correlation between the cost and the size or the number of the parts making up the emitter. It appears that emitters that are classified by the manufacturer as pressure compensating and emitters that require minimal filtration are more expensive than the ones that are not pressure compensating or that require more filtration.

10.1.7 Reliability of Manufacturers

A detailed discussion is not made of the reliability of the drip emitter manufacturers in this report.

The reliability of manufacturers is mainly concerned with the reputation of the company for guaranteeing the quality of its products. Questions to be resolved are of the nature of, will the company replace defective units that are shipped to the job site and will parts be available for repair of the units within the design life of the emitter? This type of an evaluation is largely subjective and is difficult to make in a research study of this type. We are hopeful that we selected reliable manufacturers by studying emitters that were already being utilized by Caltrans before this study was initiated.

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APPENDIX 1

APPENDIX 1

Caltrans Drip Irrigation Emitter Inventory

The following information was adopted from Caltrans "Contract Item by Item Cost Data," under 208525 and 208222 item numbers. These item numbers represent sprinklers Type D (emitter) and irrigation lines, respectively. The quantities listed under item 208222 are the linear feet of irrigation line possibly used for drip irrigation. The actual number of emitters used for items under 208222 (irrigation line) is not known, estimates are made for these figures.

APPENDIX 1

CONTRACT ITEM BY ITEM FROM CONTRACT COST DATA

OPENING BID DATE	CONTRACT NO.	DIST.	UNIT	EMITTERS	UNIT PRICE
01-31-73	04343904	4	EA	2771	15.00
02-21-73	04165204	4	EA	190	1.50
04-11-73	04352104	4	EA	200	1.00
08-15-73	04419934	4	EA	358	1.50
12-19-73	04381254	4	EA	590	2.15
11-27-74	04403444	4	EA	200	2.00
11-21-74	11128244	11	EA	575	2.00
12-12-74	11128264	11	EA	565	2.50
01-19-75	04429634	4	EA	1150	2.50
06-18-75	04344604	4	EA	596	1.00
09-17-75	04110404	4	EA	100	3.00
01-07-76	04397334	4	EA	124	1.80
01-07-76	04394034	4	EA	30	1.80
01-03-76	04391194	4	EA	285	2.00
09-22-76	04394034	4	EA	30	10.00
04-20-77	04398144	4	EA	3134	1.26
06-29-77	04398154	4	EA	1315	0.50
09-20-77	04394684	4	EA	3005	3.00
07-09-77	11163914	11	EA	1030	1.50
09-09-77	11164064	11	EA	14570	5.40
07-28-77	11163214	11	EA	20384	1.25
05-17-78	02060914	2	EA	1330	5.00
05-10-78	03211904	3	EA	410	7.50
02-01-78	04302524	4	EA	220	3.00
04-05-78	04432704	4	EA	2010	0.50
04-26-78	04344204	4	EA	3335	2.70
04-26-78	04409904	4	EA	2591	1.00
04-26-78	04402164	4	EA	152	1.00
05-03-78	04213944	4	EA	199	5.00
05-10-78	04396494	4	EA	1755	5.00
05-24-78	04416844	4	EA	881	14.00
06-14-78	04402324	4	EA	798	2.00
06-28-78	04402024	4	EA	121	14.00
07-12-78	04394134	4	EA	2312	0.25
09-20-78	04398634	4	EA	755	1.00
10-04-78	04377134	4	EA	347	1.10
10-11-78	04393784	4	EA	535	8.00
10-18-78	04273854	4	EA	211	3.00
11-01-78	04402174	4	EA	504	1.00
11-15-78	04401904	4	EA	75	5.00
12-06-78	04411104	4	EA	1008	3.50
12-06-78	04390574	4	EA	5580	0.50
02-01-78	06167004	6	EA	2000	0.47
02-20-78	07349614	7	EA	637	5.00

OPENING BID DATE	CONTRACT NO.	DIST.	UNIT	EMITTERS	UNIT PRICE
04-27-78	07226224	7	EA	4225	5.37
05-04-78	07373704	7	EA	958	5.50
05-11-78	07095524	7	EA	2097	5.75
05-18-78	07256444	7	EA	807	5.50
06-15-78	07282144	7	EA	1615	3.00
03-09-78	11148774	11	EA	2014	1.25
03-09-78	11164094	11	EA	2290	2.30
03-23-78	11164074	11	EA	1680	3.00
03-30-78	11133584	11	EA	425	2.82
05-18-78	11184334	11	EA	405	2.50
06-01-78	11148744	11	EA	6230	2.35
06-15-78	11143114	11	EA	186	20.00
06-22-78	11133534	11	EA	9762	2.40
10-19-78	11184314	11	EA	941	2.40
12-21-78	11143114	11	EA	186	25.00
05-02-79	01165004	1	EA	1102	2.50
02-28-79	03073414	3	EA	278	1.60
04-04-79	03093834	3	EA	6323	0.55
04-11-79	03210704	3	EA	3070	1.00
06-06-79	03224004	3	EA	85	20.00
06-20-79	03211914	3	EA	263	9.79
04-25-79	04033014	4	EA	29	25.00
06-06-79	04380174	4	EA	2981	1.00
07-11-79	04043344	4	EA	219	6.00
07-11-79	04358744	4	EA	2243	2.00
08-08-79	04398694	4	EA	338	10.00
08-09-79	04380464	4	EA	250	1.50
08-02-79	04380334	4	EA	2055	1.50
09-12-79	04380574	4	EA	3950	1.00
11-07-79	04380924	4	EA	1386	0.50
08-15-79	06181704	6	EA	441	6.45
11-21-79	06180204	6	EA	4280	4.00
02-15-79	07188504	7	EA	4425	5.00
03-15-79	07432504	7	EA	474	5.00
04-12-79	07415804	7	EA	213	3.57
05-03-79	07425204	7	EA	3243	5.00
05-17-79	07425304	7	EA	1130	5.80
05-31-79	07431704	7	EA	714	5.00
06-07-79	07188514	7	EA	489	5.00
06-21-79	07373617	7	EA	3140	6.00
07-19-79	07468404	7	EA	1489	7.95
07-26-79	07373634	7	EA	1392	6.20
10-25-79	07380004	7	EA	98	12.00
11-01-79	07423404	7	EA	576	29.00
12-06-79	07432304	7	EA	402	6.00
04-26-79	08206504	8	EA	1290	0.65
05-30-79	10251404	10	EA	1394	1.00
06-13-79	10218404	10	EA	872	5.00
02-15-79	11184344	11	EA	358	2.25
02-22-79	11184324	11	EA	1057	2.50
03-22-79	11148754	11	EA	2367	2.50
04-20-79	11095094	11	EA	1241	16.00
04-14-79	11184354	11	EA	684	3.40
04-08-79	11133544	11	EA	11795	4.55

OPENING BID DATE	CONTRACT NO.	DIST.	UNIT	EMITTERS	UNIT PRICE
11-15-79	11133554	11	EA	1476	2.60
08-10-80	01186624	1	EA	115	1.05
09-03-80	02143304	2	EA	242	8.25
09-24-80	02060954	2	EA	1709	5.00
04-30-80	03224104	3	EA	286	10.00
05-21-80	03148504	3	EA	3509	0.90
07-16-80	03223704	3	EA	2261	0.75
03-12-80	04344524	4	EA	790	3.00
04-16-80	04380054	4	EA	634	5.00
04-23-80	04380474	4	EA	41	10.00
04-30-80	04402334	4	EA	1803	4.00
07-02-80	04380314	4	EA	1930	4.00
11-26-80	04416854	4	EA	119	25.00
01-10-80	07203554	7	EA	222	10.00
02-28-80	07424704	7	EA	1406	5.00
06-26-80	07431904	7	EA	766	6.00
07-03-80	07425504	7	EA	12874	1.00
07-24-80	07373624	7	EA	16272	4.50
08-28-80	07399004	7	EA	1818	6.00
09-11-80	07437004	7	EA	108	13.00
09-25-80	07499724	7	EA	370	14.00
10-23-80	07425804	7	EA	6769	4.50
12-11-80	07288940	7	EA	1220	5.00
06-04-80	10265804	10	EA	1236	5.00
02-07-80	11184364	11	EA	97	2.50
05-08-80	11048184	11	EA	441	5.00
07-30-80	11105624	11	EA	580	4.75
10-30-80	11167324	11	EA	392	6.50
10-13-80	11048194	11	EA	794	6.40
11-18-81	02154504	2	EA	215	10.00
01-07-81	04402444	4	EA	668	1.95
10-07-81	04380854	4	EA	127	7.00
05-21-81	07070004	7	EA	968	20.00
09-10-81	07427604	7	EA	197	11.00
01-22-81	11191124	11	EA	47	8.00
08-06-81	11144874	11	EA	22	12.72
01-06-82	02152504	2	EA	1550	8.00
05-26-82	02182704	2	EA	30	4.00
07-07-82	03224504	3	EA	173	8.40
09-29-82	03223714	3	EA	1165	8.80
08-18-82	04182004	4	EA	1412	1.83
05-26-82	05285604	5	EA	2020	10.00
03-04-82	07001364	7	EA	395	7.00
04-08-82	07445204	7	EA	822	2.00
05-20-82	07445304	7	EA	222	2.00
07-08-82	07445504	7	EA	533	2.00
07-29-82	07442804	7	EA	1321	4.00
07-29-82	07424504	7	EA	2940	2.50
08-26-82	07441904	7	EA	2450	4.00
09-16-82	07472504	7	EA	793	7.00
10-14-82	07002834	7	EA	1503	4.00
10-21-82	07424340	7	EA	3283	4.80

OPENING BID DATE	CONTRACT NO.	DIST.	UNIT	EMITTERS	UNIT PRICE
10-28-82	07441804	7	EA	3694	4.70
11-04-82	07424904	7	EA	962	4.00
11-18-82	07424404	7	EA	815	5.00
05-08-82	07425904	7	EA	1179	5.85
05-13-82	11164034	11	EA	1344	2.00
05-27-82	11147414	11	EA	195	3.12
06-17-82	11189824	11	EA	648	3.30
07-08-82	11164044	11	EA	1082	8.00
08-12-82	11144814	11	EA	374	4.00
09-02-82	11184374	11	EA	3673	4.35
09-16-82	11184384	11	EA	711	4.50
09-23-82	11184394	11	EA	834	7.00
09-23-82	11193724	11	EA	2040	4.75
10-07-82	11164024	11	EA	1001	4.87
11-18-82	11128314	11	EA	401	5.50
06-01-83	03262104	13	EA	161	1.00
06-28-83	03137354	3	EA	2714	4.00
01-12-83	04380184	4	EA	129	5.00
08-17-83	04105994	4	EA	49	0.75
08-23-83	04428504	4	EA	909	3.16
04-20-83	06206404	6	EA	54	5.00
04-14-83	07214644	7	EA	647	5.00
04-14-83	07424204	7	EA	1300	8.50
05-05-83	07002674	7	EA	790	4.00
06-16-83	07002754	7	EA	2403	3.00
08-04-83	07466204	7	EA	350	10.50
08-11-83	07050464	7	EA	274	1.50
08-22-83	07002764	7	EA	593	6.50
10-13-83	07001434	7	EA	636	6.00
01-20-83	08248604	8	EA	1960	5.10
01-27-83	08164514	8	EA	1214	5.00
10-27-83	08164714	8	EA	589	10.00
11-10-83	08205604	8	EA	1374	10.00
12-19-83	08248614	8	EA	1960	5.00
02-24-83	11166494	11	EA	49	3.90
03-10-83	11108454	11	EA	5180	8.73
05-26-83	11144824	11	EA	129	5.00
05-26-83	11195024	11	EA	2982	5.00
06-16-83	11148704	11	EA	2059	4.05
06-16-83	11161124	11	EA	1400	5.00
08-11-83	11152374	11	EA	585	4.80
09-01-83	11108014	11	EA	276	4.50
12-15-83	11169614	11	EA	992	6.00
04-11-84	02200004	2	EA	202	6.00
01-12-84	07002854	7	EA	278	7.33
01-19-84	07000474	7	EA	2106	5.50
04-26-84	07002814	7	EA	426	5.55
06-14-84	07002804	7	EA	2536	6.55
06-21-84	07061834	7	EA	2789	6.00
07-19-84	07002794	7	EA	375	5.50
10-10-84	07050111	7	EA	3670	5.69
09-08-84	08181024	8	EA	6464	6.40
09-08-84	11195014	11	EA	2167	5.56

OPENING BID DATE	CONTRACT NO.	DIST.	UNIT	EMITTERS	UNIT PRICE
03-29-84	11183624	11	EA	1093	10.00
07-12-84	11113334	11	EA	629	5.60
07-18-84	11108034	11	EA	4304	4.51
07-14-84	11108084	11	ER	276	5.00
12-13-84	11108024	11	EA	2388	8.00

CONTRACT ITEM BY ITEM FROM CONTRACT COST DATA

OPENING BID DATE	CONTRACT NO.	DIST.	UNIT	QUANTITY	UNIT PRICE
06-14-67	06059704	6	LF	1700	0.34
01-25-67	10094904	10	LF	4314	0.34
08-16-67	06056204	6	LF	8600	0.30
07-20-67	07160104	7	LF	600	0.27
09-21-67	07115004	7	LF	205	0.27
09-07-67	08113004	8	LF	5350	0.30
08-17-67	11038014	11	LF	1450	0.60
03-20-68	04335504	4	LF	410	0.30
01-30-68	04342004	4	LF	270	0.48
10-16-68	04345004	4	LF	2230	0.31
04-03-68	04119984	4	LF	3160	0.30
08-27-69	04341504	4	LF	44440	0.46
05-21-69	06092004	6	LF	1550	0.30
07-22-70	04414140	4	LF	2200	0.70
09-02-70	04385004	4	LF	167250	0.35
10-14-70	04411604	4	LF	5200	0.60
04-09-70	07161504	7	LF	4000	0.50
04-10-71	04344314	4	LF	1920	0.64
04-28-71	04385014	4	LF	5070	0.40
06-09-71	04344304	4	LF	3010	0.33
06-06-73	03082774	3	LF	16000	0.40
05-09-73	04427904	4	LF	1100	1.00
05-17-73	08156514	8	LF	12500	0.50
05-31-73	08159604	8	LF	38500	0.36
08-30-73	08158224	8	LF	82	2.00
12-20-73	08156524	8	LF	8700	0.18
03-21-73	10158914	10	LF	7800	0.40
03-13-74	03082784	3	LF	24300	0.30
01-09-74	05223604	1	LF	650	0.75
01-23-74	05215024	1	LF	10000	0.60
02-28-74	08166624	2	LF	7810	0.44
01-08-75	06114214	6	LF	11870	0.59
02-06-75	08149804	8	LF	16000	0.62
02-20-75	08109904	8	LF	32000	0.54
04-28-76	03195004	4	LF	200	0.75
08-25-76	10239404	8	LF	5350	0.66
04-28-76	03195004	3	LF	200	0.75
08-25-76	10239404	10	LF	5350	0.66
08-10-77	01156104	1	LF	49200	0.65
04-06-77	03179804	3	LF	565	1.80
04-20-77	04398144	4	LF	7635	0.36
06-20-77	04398154	4	LF	1750	0.60

APPENDIX 2

APPENDIX 2

Existing Drip Irrigation Sites and Problems in Caltrans
up to 1980

A telephone survey was made in the summer of 1980 to locate the existing Caltrans drip irrigation sites used for maintaining highway landscapes and to determine the problems associated with drip irrigation systems. The following drip irrigation sites are listed by series of numbers followed by a single letter. The first number indicates the district, separated by a -, the second number is an arbitrary number and represents the district landscape maintenance territory, and the letter identifies the particular location within the territory. The names of the Caltrans personnel and position at the time of interview precedes the information given.

APPENDIX 2

Drip Irrigation Sites

Abbreviations:

LS	Landscape Specialist
LA	Landscape Architect
LSp	Landscape Supervisor
HqLS	Headquarters Landscape Specialist
HLS	Highway Landscape Specialist
DLS	District Landscape Specialist
Supt.	Superintendent
Terr.	Territory

The name of the source precedes the information given.

<u>District 1</u>

Donald Byrne, LS II

2 drip irrigation sites

1-1-a) Hwy 101 Interchange in Rio Dell, small system
1-1-b) Hwy 101 in Arcata, extensive system

The drip irrigation systems work fine, but they are used only in the summer because the region receives plenty of rainfall.

District 2

Ray Campbell, LS

2-1-a) Drip irrigation site along I-5 in the city of Anderson.

None of it works, never gets out of the flush cycle, design problems, too many heads per valve, automatic system, plugged heads, and algae in the water.

Vicki Bacon, LA

1330 Quadrajet emitters, Y-strainers

Problems: a) broken, b) stolen, c) needs more water pressure, and d) dirt in the lines during installation.

District 3

Roger Miles, Hq. LS I; Sacto Supt. Terr.
Howard Mallory, lead worker; North Sacto Landscape Unit.

5 drip irrigation sites

3-1-a) I-5 and Sutterville (Northgate Landscape) Vortex emitters, black tubing, plugging of emitters.
3-1-b) Hwy 80, PM 7.2, El Camino off ramp 200-300 spray type emitters, one year in operation.
3-1-c) Hwy 80 from Madison to Douglas Blvd. 6000-7000 Vortex emitters, black tubing, recently taken over from contractor, new plantings, plugging of emitters.

3-1-d) Hwy 80, PM 10.2, S. Watt Ave., off ramp 40 Vortex emitters, 20 live plants, Johns Manville filter, black tubing, 4-5 years in operation.

3-1-e) In vicinity of Hwy 80 - Hwy 880 fork near Silver Spur Way 200 Quadra emitters, a few thousand spray type emitters, minor clogging problems.

Disposable paper filters, 100 mesh; hitchhikers come along and kick the emitters thereby expanding the holes in the tubing. The emitters pop out under high pressure.

District 3 (2)

Larry Shields, LSp: Marysville Ldsp.

2 drip irrigation Sites

3-2-a) Hwy 20 between Feather River and 9th in Yuba County - 100 emitters

3-2-b) Hwy 20 in Yuba City between Plumas St. and Feather River - 100 emitters.

Systems have plastic screen filters shaped like a washer with coarseness of a window screen. Dirt and debris clog, emitters are covered by soil.

District 3 (3)

Donald King, LSp: Nevada City Ldsp.

2 drip irrigation sites

3-3-a) Hwy 49, PM 6.7 south of Rock Creek in Auburn

3-3-b) Hwy 80 off ramp to Grass Valley - 100 emitters on tree planting.

District 4

Sam Ojeda, LS: Petaluma Supt. Terr.

4 drip irrigation sites

4-1-a) Hwy 101 from Novato Creek to Atherton Ave., in Novato - 2000 emitters - child vandalism, system not buried deep enough, emitters are clogging

4-1-b) Hwy 12 and Hwy 101 Interchange in Santa Rosa - 200 emitters

4-1-c) Hwy 101, Russell Ave. Overcrossing; Bicentennial area of Santa Rosa - 200 emitters, one year in operation.

4-1-d) Hwy 101 southbound, San Pedro Road off ramp - 500 emitters, one year in operation.

No automatic systems, Salco emitters, problems with emitters separating, filters in use.

District 4 (2)

Manuel Miranda, LS I: San Leandro Supt. Terr.

3 drip irrigation sites

4-2-a) Hwy 92 near Hwy 17 - 300 emitters

4-2-b) Hegenberger Overcrossing on Hwy 17, in Oakland

4-2-c) Hwy 238 and Hwy 17 crossing, filters in use - 500 emitters

Vortex emitters, problem with leaking.

District 4 (3)

Frank Valentine, LS I: Walnut Creek Supt. Terr.

2 drip irrigation sites

4-3-a) Hwy 680: Crow Canyon Road - San Ramon - south of Danville - Alamo - Walnut Creek - Pleasant Hill - Concord - 1000 emitters

4-3-b) Hwy 4: Martinez - Pittsburgh - Antioch Bridge - 500 emitters

Contract to put in new system along Hwy 680. Vortex emitters, Johns-Manville 50 fibrous filter, changed once a year. Black tubing laid on top of ground, absorbs heat, expands and bursts emitter holes which expand from heat and pop out.

District 4 (4)

Bud Cox, LS I: Foster City Supt. Terr.

3 drip irrigation sites

4-4-a) Hwy 101 from county line separating San Mateo and Santa Clara Counties to University Ave. in Palo Alto

4-4-b) Hwy 101 on southbound side at Candlestick Park, experimental - 75 various emitters

4-4-c) Hwy 101 around Sharps Park Overpass in Pacifica - Automatic system, filters in use.

District 4 (5)

Finley Harbour, LS I: San Jose Supt. Terr.

4 drip irrigation sites

4-5-a) Hwy 17, PM 14-16 in San Jose
4-5-b) Hwy 17, PM 8.8-12.3
4-5-c) Hwy 17, PM 19.5-23 from Trimble Road to Calaveras Road
4-5-d) Hwy 280 - Hwy 680, PM 0.5-5.5, spray type emitters, brown tubing

All the drip systems have filters.

District 4 (6)

Mel Campbell, LSp: San Francisco Supt. Terr.
Howard Washington, lead worker
Ray Nevilles, HSp

2 drip irrigation sites

4-6-a) Hwy 280 from PM 10 to PM 30 - 1000 emitters - Filters in use, filters have not been changed in 3 years, precipitates cause clogging problems with plastic cracking and cars hitting the lines, difficult to find replacement parts.
4-6-b) Hwy 101 from PM 30 to PM 40 - 5 emitters, filters in use, new system in San Francisco, hospital curve area.

District 5

Bob Williams, LSp: Templeton Ldsp
Bud Hall, lead worker

4 drip irrigation sites

5-1-a) Hwy 101, PM 55.68-58.79 in Paso Robles - 700 fan type emitters, white tubing, three years in operation, successful system.

5-1-b) Hwy 101, PM 44.01-46.87 in Atascadero - 1500 fan type emitters, white tubing, successful system.

5-1-c) Santa Rosa Overhead of Hwy 101 in Atascadero - 100 emitters, plugging of emitters with silt, brown tubing, gophers chew tubing, three years in operation.

5-1-d) Curbril Overhead of Hwy 101 in Atascadero, plugging of emitters with silt, brown tubing, gophers chew tubing.

Insects and ants clog emitters, lines are flushed periodically, no filters, temperatures during the summer can change from 60's to 100°F within 24 hours.

Bick Moe, Supt: Templeton Supt. Terr.

Drip systems have pressure valves and y-strainers, pipes get brittle and the emitters pop out.

District 6

Lonnie Johnson, DLS II: District 6 office

4 drip irrigation sites

6-1-a) I-5, PM 53.9, Buttonwillow Rest Area, Quadra emitter with 200 mesh filtering system. There have been problems with infrequent clogging and pipe blockage which required us to make cleanouts. Also, exposed portions have been vandalized. This system should be upgraded to be automatically controlled.

6-1-b) Hwy 58, PM 52.9 to PM 55.6 in Bakersfield Dripeze Pressure Compensating emitter with 200 mesh filtering system. The system is presently being installed and it has not acquired a performance record.

6-1-c) Hwy 65, PM 18.8 to PM 20.4 in Porterville Quadra emitter with 200 mesh filtering system. No failures have been reported at this time.

6-1-d) I-5, PM 0.04, Coalinga-Avenal Rest Area Quadra emitter with 200 mesh filtering system. The above ground portions have been vandalized. This system upgraded to be automatically controlled.

District 7

Frank Lishey, HLS I: Orange Terr.
Ike Ikeda, HLS I: Orange Terr.

7 drip irrigation sites

7-1-a) I-5 and Culver Drive in Irvine - 3000 Vortex emitters, brown tubing, filters, backflow with y-strainer, algae in the water.

7-1-b) Near I-5 and Pacific Coast Hwy 1 Junction in Capistrano Beach - 1000 emitters, emitters buried beneath ground, backflow with no y-strainer.

7-1-c) I-5, PM 38.4-39.5 in Anaheim - 774 emitters

7-1-d) I-5, PM 30.5-32.9 in Santa Ana - 420 emitters

7-1-e) I-5 and Hwy 91 Interchange, PM 41.8 to 42.5 through Fullerton, Buena Park, and Anaheim - 8320 emitters

7-1-f) I-5, PM 34.8 to 35.6 through Orange and Anaheim - 1382 emitters

7-1-g) I-5 between Artesia Blvd. and Stanton Ave., in Buena Park, new system

District 7 (2)

Nick Hernandez, LSp: Long Beach Terr.

2 drip irrigation sites

7-2-a) Hwy 91 and Santa Fe in Compton - 400 emitters

7-2-b) Hwy 91 near Avalon in Carson - 100 emitters, Quadra, no problems with clogging, problems with gophers

District 7 (3)

Ted Harris, HLS I: Eastern Terr.

3 drip irrigation sites

7-3-a) I-10 from Puente Ave. to Holt Ave. in West Covina - 6000 Dripeze emitters

7-3-b) I-10 from Campus Ave. to Ramona Ave. in Alhambra - 1000 Quadra emitters

7-3-c) I-5 and Hwy 7 Interchange in Commerce - 500 Quadra emitters

District 7 (4)

Joe Montelongo, lead worker: Foothill Ldsp

2 drip irrigation sites

7-4-a) 210 Fwy eastbound on ramp, in Monrovia on Myrtle - 200 emitters

7-4-b) 210 Fwy east and westbound in Azusa between Bernon and Azusa off ramps - 200 emitters

Salco emitters, no filters, clogging throws pressure off, possibly bacterial clogging if not adjusted perfectly, the pressure is thrown off, systems not used during winter time.

District 7 (5)

Frank Valenzuela, LSp: Metropolitan Terr.

3 drip irrigation sites

7-5-a) Hwy 2 between San Fernando Road and Broadway, >700 Vortex and Quadra emitters

7-5-b) Hwy 101 between Santa Monica Blvd. and Highland

7-5-c) Hwy 134 between Orange Grove and San Fernando Road

District 7 (6)

Gerald Downey, HLS I: Ventura Terr.

1 drip irrigation site

7-6-a) Hwy 101 and Vineyard Ave. in Oxnard, 1000's of Quadra emitters, in line y-strainer, large filter at backflow, problems with breaks in the line and inconsistent flow of water, gophers get to PE tubing, no problem with clogging.

District 8

Ray Galvan, LS I: San Bernardino Supt. Terr.
Wilbur Jakes, Construction

2 drip irrigation sites

8-1-a) I-10 and Tippecanoe Interchange in Loma Linda, 5 miles south of San Bernardino - 500 Vortex emitters

8-1-b) I-15 east between 5th and 13th through San Bernardino - 500-1000 Salco emitters

Problems with sand, clogging caused by calcium deposits, rodents, landscape needs to be better matched with the emitter system, shrubs extend and cover emitters.

District 8 (2)

Felix Zavalla, LS: Barstow Supt. Terr.
Wilbur Jakes, Construction

1 drip irrigation site

8-2-a) Hwy 15 from 0.2 mile south of West Main St. off ramp Overcrossing to 0.1 mile south of "H" St. Overcrossing

1700 Vortex emitters, brass filter case, no problems, end lines flushed to unclog.

District 8 (3)

Dave Carroway, Sp: Needles Crew

1 drip irrigation site

8-3-a) Hwy 40 from PM 141 to PM 144, 800 Vortex emitters, no filters

When the lateral lines are exposed, the sun superheats the water and blows the hoses out. The plastic expands and the water pressure pops the emitters out. The high mineral content in the water causes emitter plugging. The lines are buried 2" below the surface and hoeing damages them. Vandals cut the vinyl lines to get a drink.

District 10

Daniel Pollock, LSp: Modesto LS Crew

1 drip irrigation site

10-1-9) Hwy 99 and West Main St. in Turlock, 9 months in operation, multiple head emitters, screw-on filters, Rainbird clock working well.

Since the T's and couplers were connected by wiring only, the connections pop off. 252 Vortex emitters, 872 multiple orifice emitters (Quadra), 3 miles of emitters. Gophers chew brown PE tubing, minor problems with clogging.

District 11

Doug Mitchell, LS I: Escondido Supt. Terr.

2 drip irrigation sites

11-1-a) I-15 from PM 25.90 to PM 31.32, through Escondido - 9700 emitters, Johns-Mansville stainless steel filters at every valve, 1-1/2 years in operation

11-1-b) I-15 from PM 31.32 to PM 33.60, through Escondido - 10,600 emitters, sand filter plus Johns-Manville filter, recently installed

Global Flapper Subterrain emitters on 1/2 inch riser, problems with clogging by spiders, ants, and other insects, the system gets stuck in the purge position.

District 11 (2)

John Hasiguchi, LS I: San Diego Supt. Terr.

8 drip irrigation sites

11-2-a) Hwy 805, PM 1.6-3.7 - 684 subterrain emitters with 35 Johns-Manville filters. Just took over this contract, not enough time to evaluate.

11-2-b) Hwy 805, PM 10.9-11.8 - 1676 subterrain emitters with 36 Johns-Manville filters, works good in this area

11-2-c) Hwy 805, PM 11.8-13.4 - 14,667 Drip-Eze emitters with 57 Johns-Manville filters, Drip-Eze non-operable discontinued product. Approximately 60% of Drip-Eze has been changed to subterrain.

11-2-d) Hwy 805, PM 13.4-14.4 - 6230 subterrain emitters with 67 Johns-Manville filters, works good in this area.

11-2-e) Hwy 15, PM 15.2-18.5 - 358 subterrain emitters with 12 Johns-Manville filters, works good in this area.

11-2-f) Hwy 163, PM 7.4-9.0 - 4582 subterrain emitters with 30 Johns-Manville filters, last year storms have caused a lot of repairs and flushing of lines but now seems to be working alright.

11-2-g) Hwy 5, PM 5.9-7.3 - 2014 subterrain emitters with 27 Johns-Manville filters, works good in this area.

11-2-h) Hwy 5, PM 7.3-8.6 - 2384 Drip-Eze emitters with 28 Johns-Manville filters. This particular area the Drip-eze have had vandalism problems and parts are discontinued and are being replaced with subterrain.

APPENDIX 3

APPENDIX 3

Municipal Water Sources
(1980)

The comments to the right of the water purveyors give source, seasonal variation, and water treatment method.

District 1

1-1-a)	City of Rio Dell 675 Wildwood Avenue Rio Dell, CA 95562 (707)764-5312	well water no seasonal variation chlorination
1-1-b)	Humboldt Bay Municipal Water District P.O. Box 95 Eureka, CA 95501 (707)822-2918	Mad River no seasonal variation chlorination water sold to City of Arcata, which supplies water to Caltrans

District 2

2-1-a)	City of Anderson 1887 Howard Street Anderson, CA 96007 (916)365-2523	well water chlorination

District 3

3-1-a)	City of Sacramento Div. of Waters & Sewers Amerioan River Water Treatment Plant 1301 Jed Smith Drive Sacramento, CA 95819 (916)449-5366	alternation of Sacramento River and American River water some variation chlorination, aluminum sulfate to remove turbidity, lime
3-1-b)	Same as a)	
3-1-c)	Northridge Park County Water District 5331 Walnut Avenue Sacramento, CA 95610 (916)332-4111	21 wells no seasonal variation chlorination

	City of Roseville Water Production 316 Vernon Street Roseville, CA 95678 (916)791-4586	Folsom Lake no seasonal variation chlorination, aluminum sulfate, polyelectrolytes filtration, lime
	Citizens Utilities Co. of California Water Department 3335 Longview Dr. North Highlands, CA (916)481-7350	85 wells - blend no seasonal variation chlorination
3-1-d)	state well	
3-1-e)	state well	
3-2-a)	California Water Service Company P.O. Box 1109 Marysville, CA 95901 (916)742-6911	12 deep water wells seasonal and geographical variation chlorination at wells
3-2-b)	City of Yuba City City Hall 441 Colusa Avenue Yuba City, CA 95991 (916)674-1210	well water turbidity variation chlorination, alum, lime

<u>District 4</u>

4-1-a)	North Marin County Water Dist. P.O. Box 146 999 Rush Creek Place Novato, CA 94947 (415)897-4133	Stafford Lake (1/3) and Russian River (2/3) little variation chlorination full water treatment
4-1-b)	City of Santa Rosa Public Works Dept. 100 Santa Rosa Avenue P.O. box 1678 Santa Rosa, CA 95403 (707)528-5141	Russian River no seasonal variation chlorination
4-1-c)	same as b)	
4-1-d)	Marin Municipal Water District 220 Nellen Avenue Corte Madera, CA 94925 (415)924-4600	surface lakes, Russian River, conventional complete water treatment

4-2-a)	East Bay Municipal Utility District P.O. Box 24055 2130 Adeline Street Oakland, CA 94623 (415)835-3000	Mokelumne River no seasonal variation chlorination, lime, fluoridation, 1 ppm
4-2-b)	same as (2)a)	
4-2-c)	same as (2)a)	
4-3-a)	same as (2)a)	
4-3-b)	Partially same as (2)a) and partially: Contra Costa County Water District 1331 Concord Avenue Concord, CA (415)682-5950	Sacramento-San Joaquin River Delta System, Contra Costa Canal small variation chlorination, alum, lime, fluoride
4-4-a)	San Mateo County Dept. of Public Works 590 Hamilton Street Redwood City, CA 94063 (415)364-5600	SF Water Department no seasonal variation no water treatment
4-4-b)	San Francisco Water Department 425 Mason San Francisco, CA (415)697-4424	water treatment
4-4-c)	North Coast County Water District P.O. Box 1039 Pacifica, CA 94044 (415)355-3462	SF Water Department Hetch Hetchy Reservoir Crystal Springs Reservoir no seasonal variation
4-5-a)	San Jose Municipal Water System P.O. Box 21267 San Jose, CA 95151 (408)277-4036	South Bay Aqueduct hardness variation chlorination, filtration
4-5-b)	same as (5)a)	

4-5-c)	City of Milpitas 455 E. Calaveras Blvd. Milpitas, CA 95035 (408)262-2310	Hetch Hetchy Reservoir SF Water Department no water treatment
4-5-d)	San Jose Water Works 374 W. Santa Clara P.O. Box 229 San Jose, CA 95196 (408)279-7826	well water, South Bay Aqueduct, blend well water is not treated Santa Clara Water Dist. treats aqueduct water
4-6-a)	same as (4)b)	
4-6-b)	same at (4)b)	

District 5

5-1-a)	City of El Paso de Robles 1030 Spring Street P.O. Box 307 Paso Robles, CA 93446 (805)238-2262	well water chlorination
5-1-b)	Atascadero Mutual Water Company P.O. Box 790 Atascadero, CA 93422 (805)466-2428	9 wells, Salinas River no seasonal variation chlorination
5-1-c)	same as b)	
5-1-d)	same as b)	

District 6

6-1-a)	state well	
6-1-b)	California Water Service 1720 North First Street P.O. Box 1150 San Jose, CA 95108 (408)298-1414	well water alkalinity variation
6-1-c)	City of Porterville P.O. Box 432 Porterville, CA 93258 (209)784-1400	25 wells no seasonal variation no water treatment

6-1-d)	City of Avenal P.O. Box 128 Avenal, CA 93204 (209)386-5766	California Aqueduct no seasonal variation chlorination, aluminum sulfate

District 7

7-1-a)	Irvine Ranch Water District P.O. Box D-1 4201 Campus Dr. Irvine, CA 92716 (714)833-1223	reclaimed wastewater, Colorado River, runoff from foothills, increase in filterable residue toward end of summer filtration
7-1-b)	Capistrano Beach County Water District P.O. Box 2515 Capistrano Beach, CA 92624 (714)496-5261	well water, MWD
7-1-c)	City of Anaheim Water Engineering Div. Water Quality Section 518 S. Anaheim Blvd. Anaheim, CA 92805 (714)533-5428	35 wells (70%), MWD (30%) no seasonal variation chlorination
7-1-d)	same as c)	
7-1-e)	same as c)	
7-1-f)	same as c)	
7-1-g)	City of Buena Park City Engineer 6650 Beach Blvd. Buena Park, CA 90620 (714)521-9900	city wells, MWD
7-2-a)	City of Compton City Hall 205 S. Willowbrook Ave. Compton, CA 90220 (213)537-8000	well water, MWD-blend little seasonal variation

7-2-b)	Southern Calif. Water Company Southwest District 3625 W. Sixth Street Los Angeles, CA 90020 (213)383-7800	two wells, MWD no seasonal variation chlorination on well water
7-3-a)	Southwest Suburban Water Company 16326 E. Maplegrove Valinda, CA (213)918-1231	well water, spring water-blend, changes daily, some seasonal variation, filtration, chlorination
7-3-b)	Dept. of Public Works City of Alhambra P.O. Box 351 Alhambra, CA 91802 (213)570-5067	2 groundwater basins, MWD-blend no seasonal variation in groundwater well water chlorinated zinc orthophosphate added to MWD
7-3-c)	California Water Service East Los Angeles System 3316 W. Beverly Blvd. Montebello, CA (213)722-8601	well water, MWD-blend seasonal variation no treatment on well water
7-4-a)	City of Monrovia 415 S. Ivy Avenue Monrovia, CA 91016 (213)359-3231, Ext.249	well water no seasonal variation chlorination
7-4-b)	City of Azusa 777 North Alameda Azusa, CA 91762 (213)334-5125	
7-5-a)	Dept. of Water & Power City of Los Angeles P.O. Box 111 Los Angeles, CA 90051 (213)481-4211	MWD Eagle Rock Reservoir LA River Supply Conduit some seasonal variation chlorination, polymer coagulate
7-5-b)	same as (5)a)	
7-5-c)	City of Glendale 119 No. Glendale Avenue Glendale, CA 91206 (213)956-2062	MWD (90%), well water (10%) chlorination

7-6-a)	Dept. of Public Works Division of Water 217 E. Third Oxnard, CA 93030 (805)486-2601, Ext.427	MWD, well water-blend no seasonal variation no water treatment on well water

District 8

8-1-a)	City of Loma Linda P.O. Box 965 Loma Linda, Ca 92354 (714)796-2531	well water no water treatment
8-1-b)	City of San Bernardino Water Reclamation Dept. 300 N. "B" Street San Bernardino, CA 92418 (714)383-5002	tertiary water some seasonal variation chlorination, sand filtering, chemical clarification
8-2-a)	Southern California Water Company 3625 W. Sixth Street Los Angeles, CA 90020 (213)386-7800	well water geographical variation no seasonal variation chlorination
8-3-a)	City of Needles Water Dept., City Hall 1111 Bailey Avenue Needles, CA (714)326-2113	well water no water treatment

District 10

10-1-a)	City of Turlock Drawer T Turlock, CA 95380 (209)634-5831	well water no seasonal variation no water treatment

District 11

11-1-a,b)	City of Escondido 620 N. Ash Escondido, CA 92025 (714)745-2200	Lake Wohlford, Lake Dixon-blend seasonal variation, Wohlford water treated with copper sulfate to kill algae conventional water treatment

	City of Carlsbad 1200 Elm Avenue Carlsbad, CA 92008 (714)438-5621)	Colorado River Water chlorination
11-1-a,b)	San Diequito Irrigation District P.O. Box 2081 Rancho Santa Fe, CA 92067 (714)756-2854	Lake Skinner, Lake Hodges, no seasonal variation chlorination, alum, lime $KMnO_4$
11-2-a)	City of San Diego Water Utilities Dept. 7100 Colorado Avenue La Mesa, CA 92041 (714)236-5600	11 reservoirs feed Alvarado and Lower Otay filter plants Feather River and Colorado River feed Miramar filter plant seasonal variation chlorination, coagulation, filtration
11-2-b)	same as (2)a)	
11-2-c)	same as (2)a)	
11-2-d)	same as (2)a)	
11-2-e)	same as (2)a)	
11-2-f)	same as (2)a)	
11-2-g)	California-American River District 2602 Hoover Avenue National City, CA 92050	Otay River depending on season, blended with California aqueduct and San Diego aqueduct seasonal variation, Otay filter plant

Additional

Helix Irrigation Water District 8111 University Avenue La Mesa, CA 92041 (714)466-0585	Colorado River (90%), mountain rainfall (10%) no seasonal variation chlorination, filtration

Sweetwater Authorities 386 - 3rd Avenue Chula Vista, CA 92011 (714)420-1413	lake water(90%),Colorado River(10%) seasonal variation chlorination, coagulation, filtration
Otay Municipal Water District 10595 Jamacha Blvd. Spring Valley, CA 92077 (714)462-2222	Feather River, Colorado River-blend no seasonal variation treated by MWD

APPENDIX 4

APPENDIX 4 - PURVEYORS LABORATORY TEST RESULTS

Water Supplier	pH	Ca	HCO_3	TDS	EC	Mg	Mn	Fe	SO_4	Na	Cl	SiO_2	CO_3	NO_3	PO_4	Langlier
1-1-b	7.45 8.7	22.0 32.0	63.0 86.0	96 120	170 250	3.4 4.3	0.005 0.008	<0.01	9.3 14.0	3.5 4.7	1.5 4.7	7.1 7.9	<1	0.5 0.84	0.01 0.02	
2-1-a	7.5	7.4	105	140	215	11.9	<0.01	0.015	1.0	12.2	5.1		0	6.8		
3-1-a	8.5 8.8	9.5 18.0	23.0 62.0	46 110	74 165	1.5 4.5	<0.01	<0.01	6.0 14.0	2.3 9.6	5.2 9.5		2.0 3.0	0.03 0.04		
3-1-c	7.6 8.0	18.0 31.2	104 121	207 338	211 560	9.8 12.5	<0.01 0.47	<0.01 0.80	<1 16.0	10.0 48.0	15.9 99.0	48.0 79.0	0	<0.04 3.9		
3-2-a	7.49	39	219	296	435	25	<0.01	<0.02	28	14	10	60	0.5	10	0.26	-0.08
	7.59	30	182	233	340	19	<0.01	<0.05	18	11	7	49	0.5	5	0.3	-0.16
3-2-b	8.3	13.4	51.1	75	103	4.3	<0.01	0.04	9.0	3.6	6.1	10	2.0	<0.01		
4-1-a	7.6 8.6	21.6 26.4	78 105	177 213	325 390	11.7 14.1	<0.01	<0.01 0.01	13 37	9 31	8 21		0	16.60		
4-1-b	7.5	23	140	110	260	14	<0.05	<0.10	13	6.9	4.7		<1.0			
4-2-a	7.9	32.8	117.2	227	384	12.4	0.009	0.04	38.8	26.1	32	5.0	0.5	0.47	0.023	
4-4-a	7.5	10.4	33.3	52	82	1.5	<0.01	<0.08	5.5	1.9	6.5	3.7	0	0	<0.01	
4-4-b	7.4	49.7	197	258	402	15.1	<0.01	<0.08	34.2	20.3	17.0	13.5	0	9.1	<0.10	
4-4-c	7.7	11.2	40.8	69.4	115	3.4	<0.01	<0.08	9.4	8.1	10.4	8.0	0	0.2	0.07	
4-5-a	8.2	27.2	124	380	395	15.6	<0.01	<0.05	60	22	21		0	1.0	<0.01	-0.04
4-5-d	7.85	50	356	605	1030	10	0.12	<0.02	88	157	89	17	1.7	13	0.17	+0.56
5-1-a	8.2	9.0	310	805	1150	3.4	<0.02	4.7	102	280	103		0	13		
5-1-a	8.0	11.0	360	770	1100	4.8	<0.02	0.21	80	280	82		0	1.0		
5-1-b	8.1	89	230	560	800	42	<0.02	<0.02	165	37	50		0	18		

All concentrations except pH, EC and Langlier Index in milligrams per liter, mg/l.

APPENDIX 4 - PURVEYORS LABORATORY TEST RESULTS (continued)

Water Supplier	pH	Ca	HCO_3	TDS	EC	Mg	Mn	Fe	SO_4	Na	Cl	SiO_2	CO_3	NO_3	PO_4	Langlier
6-1-b	7.64	69	163	364	595	12	<0.01	<0.02	56	34	61	28	0.5	21	0.01	0.17
6-1-c	7.8	26	162		364	10.0	<0.01	0.08	26	37	18		0	9.5		
7-1-a	8.3	79	143	694	1120	31.5			296	107	95			0.1		
	6.8	71.9	50	856	1110	28.6			307	129	144			22.5		
7-1-c	7.3 8.2	50 138	121 293	435 824	825 1225	9.5 31	<0.01 .02	<0.01 0.16	101 304	41 108	47 129	6.7 28	0 0.95	0.2 32.3		
7-1-g	7.66	53	122	578	840	21.3	<0.03	0.39	164	90	106	10.8	0	3.29		
7-2-b	8.24	56	121	494	808	21			196	76	70	9.7	0	0.7		
7-3-b	7.5	39.5	151	284		12		0.18	25.5	36.5	26.5			17.5		
7-3-c	7.61	84	199	463	820	18	<0.01	<0.02	107	47	70	24	0.6	12	0.05	0.29
7-4-a	7.4	73	217	331	525	18	<0.01	0.08	41	20	31	29		8.2		
7-5-a	8.05	54	102	502	814	21			191	82	75	11		2.3		
7-6-a	7.2	92	171	595	820	27	<0.05	<0.1	271	63	47		0	6		
8-1-a	7.72	65	342	528	890	30	<0.01	0.03	62	71	43		0	36		
8-2-a	7.92	42	205	398	670	12.8	<0.01	0.08	32	80	45		0	11		
8-3-a	7.2	106	256	1440	2340	40			420	332	256		0	20	30	
10-1-a	9.92	15	93.4	132	183	3.6	<0.01	<0.05	4.1	19.2	6.7		0	6.2		
11-1-b	8.4	86	154	714	1120	31		0.10	314	108	92	8.7	2.0	0.5		
11-2-a	8.4	47	133	469	700	17	0	0.01	128	77	87		3.6			0.61

All concentrations except pH, EC and Langlier Index in milligrams per liter, mg/l.

APPENDIX 5

TABLE 5A

TRANSLAB ANALYSES OF SAMPLED WATER

City	Location	Ca	HCO_3	TDS (FR)	Mg	Mn	Fe	SO_4	Na	Cl	SiO_2	CO_3	NO_3	PO_4	LI	TSS (NFR)	NH_4-N
Sacramento	Hwy 80, PM 10.2 east side of S.Hatt.off ramp		140	202		0.01	0.06	1.0			76	0	1.95	0.34		3.6	0.00
"	Hwy 80, PM 10.2 west side of S. Hatt off ramp		139	204		0.01	0.05	0.7			76	0	0	0.34		6.2	0.00
"	Hwy 80, PM 7.2 El Camino on ramp		143	337		0.00	0.03	3.0			69	0	0.49	0.14		0.0	0.00
"	Hwy 80, Madison Ave. off ramp		126	261		0.20*	0.10	2.0			76	0	1.24	0.31		114*	0.07
San Jose	Hwy 680, btwn Berryessa Rd & Hostetter Rd.		188*	174		0.00	0.02	40			13	1.2	0.93	0.07		0.0	0.11
San Francisco	Hwy 101, Candlestick Pk.		51	73		0.01	0.10	8.0			5.0	0	0	0.07		0.4	0.14
Turlock	Hwy 99, W. Main St.		105	206		0.00	0.03	1.7			45	0	2.43	0.10		0.0	0.05
Avenal	Hwy 5, Coalinga-Avenal Safety Rest Area		55	302		0.01	0.07	70			13	0	1.99	0.03		0.0	0.06
Carson	Bitterlake St. parallel to Hwy. 91, PM 7.8 btwn Central and Avalon	53	111	509									1.4	<0.060	0.3		
Los Angeles	Hwy 2, Verdugo Rd. off ramp by Ave. 36 overcrs.	76*	224*	513									16	0.067	-0.4		
Irvine	Hwy 5, Culver Drive		179	603		0.11*	0.10	220			14	3.6	1.20	611		5.0	0.27
Capistrano Beach	Pacific Coast Hwy 1 Doheny Park Rd. off ramp (backflow)		109	489		0.00	0.03	160			10	0	0.18	0.14		1.4	0.08
Escondido	Hwy 15, Felicita Rd. off ramp		103	402		0.01	0.06	120			15	0	0.27	0.07		0.9	0.14
San Diego	Hwy 805, Clairemont Mesa on ramp		123	528		0.01	0.01	180			10	0	0	0.07		0.0	0.14

*Maximum & Minimum

TABLE 5B

INVESTIGATION OF DRIP IRRIGATION INSTALLATIONS BY TRANSLAB

City	Location	Emitter	Comments	T°C	EC	DO	pH
Sacramento	Hwy 80, PM 10.2 east side of S. Watt off ramp	Vortex	Half the emitters are plugged S= end line	25.19	251	6.0	6.98
"	Hwy 80, PM 10.2 west side of S. Watt off ramp		S= before control box	23.41	250	6.3	7.24
"	Hwy 80, PM 7.2, El Camino off ramp	spray type	S= end line	25.41	519	2.70	7.30
"	Hwy 80, Madison Ave. off ramp	Vortex	S= end line plugging	31.4	437	4.20	7.32
San Jose	Hwy 680, between Berryessa Rd. and Hostetter Road	spray type	S= end line	26.95	321	7.20	7.96
San Francisco	Hwy 101, Candlestick Park	various	S= hole in lateral line	20.49	100*	8.4	7.54
Turlock	Hwy 99, W. Main St.	Vortex Quadra	S= emitter gophers, clogging	23.62	237	3.68	7.25
Avenal	Hwy 5, Coalinga-Avenal Safety Rest Area	Quadra	S= emitter buried emitters plugging	28.54	539	6.81	6.52*
Carson	Bitterlake St. parallel to Hwy 91 PM 7.8 between Central & Avalon	Quadra	S= emitter gophers	24.68	764	6.69	7.61
Los Angeles	Hwy 2, Verdugo Rd. off ramp by Avenue 36 overcrossing	Quadra	S= emitter no problems	26.26	693	8.60	7.41
Irvine	Hwy 5, Culver Drive	Vortex	S= backflow plants growing well	31.27	1080*	4.91	7.82
Capistrano Beach	Pacific Coast Hwy 1 Doheny Park Rd off ramp (backflow)	?	S= backflow buried emitters	26.35	832	7.46	8.00*
Escondido	Hwy 15, Felicita Rd off ramp	Subterrain	S= control box before filter	30.28	656	5.90	7.11
San Diego	Hwy 805, Clairemont Mesa on ramp	Subterrain	S= emitter clogging with dirt	27.57	944	7.10	7.95

Note: S = sampling point

*Maximum & Minimum

TABLE 5C

MAINTENANCE STATION AND SRRA WATER ANALYSES

Station	TDS	Conduct. mhos/cm	Hardness $CaCO_3$	Ca	HCO_3	SO_4	Mg	Fe	pH	SiO_2	Na	NO_3	CL Chlorine	Date Sample Taken	Comments
Diamond Bar	710	1107	333	84	156	300	30	-	8.2	9	107	0.7	96	Mar. 82	-
Pomona	318	520	240	60	141	62	10.5	<0.09	8.1	21	35	4.5	44	June 81	Nitrate as N
Ontario	230.7	365	145	43.5	175	16.8	8.6	<0.024	7.6	-	19.1	14	10.8	Average 81-82	Average of 23 wells
Corona	666	1250	383	112.2	240	199	24.9	0.07	7.8	-	109.3	-	123	Sept.82	Estimated values by City of Corona
Riverside	320	520	176	55.9	177	60.7	10.8	-	7.3	-	38.2	16.4	25.5	June 82	-
Colton	267	226	226	71.4	220	67.1	11.5	0.04	7.7	-	12.2	6.8	11.4	July 82	Average of 10 wells
Victorville	215	340	67	20	122	2.5	4	0.03	7.8	-	45	5	27	Aug. 82	-
Beecher's Corner	-	2180	155	44	296	319	11	-	7.7	64 silica	412	20	324	Aug. 82	Values are taken from D.W.R. print-out
Barstow	475	-	220	166	-	160	60	-	7.3	-	68	-	50	July 82	Data is taken from City of Barstow by phone
Baker	-	5564	902	154	235	225	125	-	7.9	-	888	16.2	1691	Oct. 61	Values are taken from D.W.R. print-out
Palm Springs	41	62	25 total	7	34	1	0.8	<0.01	7.2	-	4	-	4	May 80	Snow Creek values - Water is blended
Banning	-	-	141	36.3	14.9	26.3	12	0.047	7.0	-	8.5	5.2	7	Nov. 81	-
Paradise Valley SRRA	140	250	70	20	104	.9	5	0.02	7.8	-	28	12	16	July 82	Private well
Desert Oasis SRRA	-	1732	79	25	146	369	4	-	8.0	61 silica	341	0.40	259	Sept.60	Values are taken from D.W.R. print-out
Mid-Way SRRA	2880	4800	102.6	71.8	198.4	718	34.2	0.1	8.0	72	2120	3.3	1306	Nov.13, 1981	Private well
White Water SRRA	-	414	190	57.3	231	27	11	0.08	7.8	23	21	10.3	13.6	Aug. 73	Values are taken from D.W.R. print-out

APPENDIX 6

TABLE 6A

PRESSURE DISCHARGE COMPARISON
AT SACRAMENTO SITE

"X"	Emitter	Value	10 psi	12 psi	15 psi	17 psi	20 psi	22 psi	25 psi	28 psi	30 psi	32 psi	35 psi	38 psi	40 psi	45 psi
-0.18	A	Min.	1232	1219	1278	1200	1220	1168	1092	1140	1101	1121	1120	1100	1045	1010
		Max.	1374	1328	1440	1301	1370	1293	1310	1253	1278	1230	1350	1210	1221	1168
		$\overline{X}$	1282	1249	1335	1229	1283	1203	1200	1176	1196	1158	1165	1132	1122	1084
		SD	65	53	72	48	63	60	89	52	62	49	58	55	69	65
0.09	B	Min.	522	592	561	618	589	580	609	635	580	600	571	560	510	534
		Max.	700	769	725	710	751	729	769	741	770	770	850	779	859	840
		$\overline{X}$	576	663	651	664	673	662	689	695	670	718	722	697	700	694
		SD	83	75	75	40	80	63	79	49	95	80	115	96	144	125
0.15	C	Min.	1160	1310	1381	1340	1332	1351	1370	1390	1350	1286	1270	1279	1239	1736
		Max.	1358	1460	1569	1560	1670	1710	1760	1751	1820	1810	1817	1779	1840	1120
		$\overline{X}$	1260	1352	1470	1465	1497	1516	1540	1530	1524	1437	1451	1434	1432	1330
		SD	97	72	93	104	149	156	168	168	216	250	252	236	278	280
0.38	D	Min.	760	866	930	941	1029	1018	1082	1098	1120	1120	1127	1129	1140	1156
		Max.	1053	1123	1220	1270	1279	1311	1349	1320	1350	1359	1370	1378	1400	1450
		$\overline{X}$	892	984	1065	1089	1142	1159	1220	1229	1253	1258	1266	1274	1300	1333
		SD	131	107	122	136	104	123	113	99	102	106	111	114	126	142
0.52	E	Min.	550	625	650	690	744	753	817	831	869	876	902	943	950	994
		Max.	675	650	710	736	788	821	930	910	950	960	1000	1032	1058	1141
		$\overline{X}$	598	634	682	716	756	786	854	860	894	909	935	974	991	1046
		SD	56	11	25	19	22	28	51	34	37	36	45	40	47	66

Water Temperature 20 degrees C, Air Temperature 25 degrees C, Test Duration - 10 Minutes, Data Units - grams

TABLE 6B

PRESSURE DISCHARGE EVALUATION
AT SACRAMENTO SITE
(Emitter A)

Emitter	10 psi	12 psi	15 psi	17 psi	20 psi	22 psi	25 psi	28 psi	30 psi	32 psi	35 psi	38 psi	40 psi	45 psi
A_1	1240	1220	1278	1200	1220	1168	1189	1151	1130	1140	1139	1100	1095	1069
A_2	1232	1230	1299	1205	1270	1179	1210	1159	1200	1142	1151	1130	1120	1089
A_3	1374	1328	1440	1301	1370	1293	1310	1253	1278	1230	1250	1210	1221	1168
A_4	1281	1219	1325	1210	1271	1172	1092	1140	1171	1121	1120	1089	1078	1010
Min. Max.	1232 1374	1219 1328	1278 1440	1200 1301	1220 1370	1168 1293	1092 1310	1140 1253	1171 1278	1121 1230	1120 1250	1100 1210	1095 1221	1010 1168
$\bar{X}$	1282	1249	1335	1229	1283	1203	1200	1176	1195	1158	1165	1132	1128	1084
SD	65	53	72	48	63	60	89	52	62	49	58	55	64	65

Temperature of Water 20 degrees C, Air Temperature 25 degrees C, Test Duration - 10 mintues, Data Units - grams

TABLE 6C

PRESSURE DISCHARGE EVALUATION
AT SACRAMENTO SITE
(Emitter B)

Emitter	10 psi	12 psi	15 psi	17 psi	20 psi	22 psi	25 psi	28 psi	30 psi	32 psi	35 psi	38 psi	40 psi	45 psi
B_1	641	769	561	650	589	688	631	677	580	770	850	779	859	840
B_2	900	651	725	680	752	580	769	729	770	762	740	739	733	695
B_3	522	592	618	618	620	650	609	635	600	600	571	560	510	534
B_4	543	639	700	710	731	729	740	741	732	740	729	710	700	709
Min. Max.	522 700	592 769	561 725	618 710	589 751	680 729	609 769	635 741	680 770	600 770	571 850	660 779	510 859	534 840
$\bar{X}$	576	663	651	664	673	662	687	695	670	718	722	697	700	694
SD	83	75	75	40	80	63	79	49	95	80	115	96	144	125

Temperature of Water 20 degrees C, Air Temperature 25 degrees C, Test Duration - 10 minutes, Data Units - grams

TABLE 6D

PRESSURE DISCHARGE EVALUATION
AT SACRAMENTO SITE
(Emitter C)

Emitter	10 psi	12 psi	15 psi	17 psi	20 psi	22 psi	25 psi	28 psi	30 psi	32 psi	35 psi	38 psi	40 psi	45 psi
C_1	1327	1310	1529	1540	1561	1565	1570	1572	1550	1341	1420	1399	1381	1285
C_2	1358	1460	1569	1560	1670	1710	1760	1751	1820	1810	1817	1779	1840	1736
C_3	1160	1319	1400	1420	1425	1438	1460	1409	1377	1310	1270	1280	1271	1176
C_4	1194	1310	1381	1340	1332	1351	1330	1390	1350	1286	1298	1279	1239	1120
Min. Max.	1160 1358	1310 1460	1381 1669	1340 1560	1332 1670	1351 1710	1370 1760	1390 1751	1350 1820	1286 1810	1270 1817	1279 1779	1239 1840	1736 1120
$\overline{X}$	1260	1352	1470	1465	1497	1516	1540	1530	1524	1437	1451	1434	1432	1330
SD	97	72	93	104	149	156	168	168	216	250	252	236	278	280

Temperature of Water 20 degrees C, Air Temperature 25 degrees C, Test Duration - 10 minutes, Data Units - grams

TABLE 6E

PRESSURE DISCHARGE EVALUATION
AT SACRAMENTO SITE
(Emitter D)

Emitter	10 psi	12 psi	15 psi	17 psi	20 psi	22 psi	25 psi	28 psi	30 psi	32 psi	35 psi	38 psi	40 psi	45 psi
D_1	760	866	930	941	1029	1018	1082	1098	1120	1120	1127	1129	1140	1156
D_2	1053	1123	1220	1270	1279	1311	1349	1320	1350	1359	1370	1378	1400	1450
D_3	816	950	1020	1060	1113	1120	1191	1210	1230	1234	1230	1239	1261	1281
D_4	940	1000	1092	1088	1150	1188	1260	1290	1311	1320	1340	1353	1401	1445
Min. Max.	760 1053	866 1123	930 1220	941 1270	1029 1279	1018 1311	1082 1349	1098 1320	1120 1350	1120 1359	1127 1370	1129 1378	1140 1400	1156 1450
$\overline{X}$	892	984	1065	1089	1142	1159	1220	1229	1253	1258	1266	1274	1300	1333
SD	131	107	122	136	104	123	113	99	102	106	111	114	126	142

Temperature of Water 20 degrees C, Air Temperature 25 degrees C, Test Duration - 10 minutes,
Data Units - grams

TABLE 6F

PRESSURE DISCHARGE EVALUATION
AT SACRAMENTO SITE
(Emitter E)

Emitter	10 psi	12 psi	15 psi	17 psi	20 psi	22 psi	25 psi	28 psi	30 psi	32 psi	35 psi	38 psi	40 psi	45 psi
E_1	600	650	710	736	788	821	930	910	950	960	1000	1032	1058	1141
E_2	550	625	650	690	744	753	817	831	869	876	902	943	950	994
E_3	675	630	680	720	751	789	831	850	880	907	930	970	988	1040
E_4	566	631	690	720	740	780	839	850	880	895	910	950	969	1009
Min. Max.	530 675	625 650	650 710	690 736	744 788	753 821	817 930	831 910	869 950	876 960	902 1000	943 1032	950 1058	994 1141
$\overline{X}$	598	634	682	716	756	786	854	860	894	909	935	974	991	1046
SD	56	11	25	19	22	28	51	34	37	36	45	40	47	66

Temperature of Water 20 degrees C, Air Temperature 25 degrees C, Test Duration - 10 minutes,
Data Units - grams

TABLE 6G

MANUFACTURING VARIABILITY EVALUATION

Site Location	Emitter Type	Average Discharge $\bar{a}$ (gram)	Standard Deviation SD (gram)	Coefficient of Variation v	Emission Uniformity EU%
Kramer Junction (48 sample points)	A	2394	149	0.06	93
	B	1499	91	0.06	93
	C	2943	240	0.08	90
	D	2317	160	0.07	92
	E	1459	293	0.20	85
San Jose (48 sample points)	A	2515	157	0.06	92
	B	1518	63	0.04	95
	C	2864	198	0.07	92
	D	2372	188	0.08	91
	E	1579	150	0.10	89
Sacramento (80 sample points)	A	2408	179	0.07	91
	B	1499	101	0.07	92
	C	2916	239	0.08	90
	D	2339	127	0.05	93
	E	1538	137	0.09	87
All Three Sites Combined (176 sample points)	A	2434	172	0.07	91
	B	1504	89	0.06	93
	C	2909	230	0.08	90
	D	2342	155	0.07	92
	E	1528	199	0.13	85

TABLE 6H

TEMPERATURE DISCHARGE EVALUATION

Emitter	Value	15°C	20°C	25°C	27°C	31°C	35°C	41°C	45°C	51°C
A	Min. Discharge	1165	1170	1127	1124	1110	1100	1095	1060	1069
	Max. Discharge	1220	1209	1216	1225	1180	1151	1125	1152	1153
	$\bar{X}$	1195	1193	1182	1176	1143	1120	1113	1098	1111
	SD	19.7	15.3	27.0	32.6	27.0	24.9	26.3	34.8	31.5
	$\frac{\bar{X}_t-\bar{X}_{25}}{\bar{X}_{25}}$	+1.1	+0.9	0	-0.5	-3.3	-5.2	-5.8	-7.1	+6.0
B	Min. Discharge	582	592	563	635	537	575	543	688	682
	Max. Discharge	753	760	792	766	722	734	746	742	725
	$\bar{X}$	666	682	699	685	683	679	672	695	699
	SD	62.9	58.5	78.9	69.2	71.7	57.3	74.6	38.6	19.9
	$\frac{\bar{X}_t-\bar{X}_{25}}{\bar{X}_{25}}$	-4.7	-2.4	0	-2.0	-2.3	-2.9	-3.9	-0.6	0
C	Min. Discharge	730	700	696	690	659	640	600	615	599
	Max. Discharge	801	800	791	842	792	785	764	690	691
	$\bar{X}$	764	750	741	741	707	697	671	648	631
	SD	31.5	38.8	38.1	50.2	43.0	48.3	57.9	32.9	31.9
	$\frac{\bar{X}_t-\bar{X}_{25}}{\bar{X}_{25}}$	+3.1	+1.2	0	0	-4.6	-5.9	-9.4	-12.5	-14.8
D	Min. Discharge	1029	1039	1042	1089	1125	1140	1164	1191	1201
	Max. Discharge	1200	1220	1259	1288	1297	1299	1350	1387	1381
	$\bar{X}$	1110	1129	1166	1201	1231	1248	1276	1299	1327
	SD	56.2	60.0	76.3	75.1	74.6	67.9	69.1	73.3	63.3
	$\frac{\bar{X}_t-\bar{X}_{25}}{\bar{X}_{25}}$	-4.8	-3.2	0	+3.0	+5.6	+7.0	+9.4	+11.4	+13.8
E	Min. Discharge	1299	1268	1239	1175	1197	1173	1215	1201	1188
	Max. Discharge	1606	1521	1558	1539	1540	1528	1540	1560	1530
	$\bar{X}$	1458	1408	1386	1338	1354	1337	1337	1303	1310
	SD	113.5	93.3	112.3	122.7	120.9	120.8	121.3	121.0	118.8
	$\frac{\bar{X}_t-\bar{X}_{25}}{\bar{X}_{25}}$	+5.2	+1.6	0	-3.5	-2.1	-3.5	-3.5	-5.9	-5.4

Operating pressure: 20 psi, ambient temperature: 25°C, test duration: 10 minutes

TABLE 6I

TEMPERATURE - FLOW DATA
(Emitter A)

Emitters	15°C	20°C	25°C	27°C	31°C	35°C	41°C	45°C	51°C
$1A_1$	1175	1776	1127	1124	1110	1151	1100	1060	1069
$1A_2$	1208	1202	1178	1166	1156	1150	1125	1102	1120
$1A_3$	1210	1200	1208	1190	1170	1146	1120	1152	1098
$1A_4$	1198	1204	1176	1225	1150	1091	1164	1120	1153
$2A_1$	1209	1205	1216	1200	1180	1121	(1620)	1130	1151
$2A_2$	1220	1209	1185	1172	1151	1100	1101	1084	1099
$2A_3$	1181	1280	1176	1156	1122	1102	1086	1052	1090
$2A_4$	1165	1270	1195	(1314)	1108	1104	1095	1081	(640)
Min. Max.	1165 1220	1170 1209	1127 1216	1124 1225	1110 1180	1100 1151	1095 1125	1060 1152	1069 1153
$\overline{X}$	1195	1193	1182	1176	1143	1120	1113	1098	1111
SD	19.7	15.3	27.0	32.6	27.0	24.9	26.3	34.8	31.5
$\frac{\overline{X}_t - \overline{X}_{25}}{\overline{X}_{25}}$	+1.1	+0.9	0	-0.5	-3.3	-5.2	-5.8	-7.1	6.0

Note: Encircled numbers were not used in the calculations.
Flow Data Units - grams

TABLE 6J

TEMPERATURE - FLOW DATA
(Emitter B)

Emitters	15°C	20°C	25°C	27°C	31°C	35°C	41°C	45°C	51°C
$1B_1$	680	592	(492)	635	537	575	543	688	725
$1B_2$	587	700	655	764	722	732	710	714	687
$1B_3$	633	609	563	567	(395)	609	574	611	(562)
$1B_4$	582	669	680	631	705	698	686	686	687
$2B_1$	753	760	792	766	(815)	734	946	715	701
$2B_2$	719	709	711	706	710	692	693	700	682
$2B_3$	718	781	787	711	712	706	743	742	725
$2B_4$	660	690	706	702	712	693	684	700	682
Min. Max.	582 753	592 760	563 792	635 766	537 722	575 734	543 746	688 742	682 725
$\overline{X}$	666	682	699	685	683	679	672	695	699
SD	62.9	58.5	78.9	69.2	71.7	57.3	74.6	38.6	19.9
$\frac{\overline{X}_t-\overline{X}_{25}}{\overline{X}_{25}}$	-4.7	-2.4	0	-2.0	-2.3	-2.9	-3.9	-0.6	0

Note: Encircled numbers were not used in the calculations.
Flow Data Units - grams

TABLE 6K

TEMPERATURE - FLOW DATA
(Emitter C)

Emitters	15°C	20°C	25°C	27°C	31°C	35°C	41°C	45°C	51°C
$1C_1$	1443	1512	1400	1320	1315	1299	1280	1220	1203
$1C_2$	1482	1489	1550	1539	1532	1528	1540	1560	1530
$1C_3$	1532	1414	1321	1299	1300	1303	1289	1258	1316
$1C_4$	1581	1420	1239	1175	1197	1103	1215	1268	1362
$2C_1$	1400	1351	1363	1331	1357	1320	1312	1298	1281
$2C_2$	1323	1305	1338	1285	1311	1294	1286	1221	1188
$2C_3$	1606	1508	1558	1502	1540	1510	1517	1399	1400
$2C_4$	1299	1268	1332	1255	1282	1272	1261	1201	1204
Min. Max.	1299 1606	1268 1521	1239 1558	1175 1539	1197 1540	1123 1528	1245 1540	1201 1560	1188 1530
$\overline{X}$	1458	1408	1386	1338	1354	1337	1337	1303	1310
SD	113.5	93.3	112.7	122.3	120.9	120.8	121.3	1.2	118.8
$\frac{\overline{X}_t - \overline{X}_{25}}{\overline{X}_{25}}$	+5.2	+1.6	0	-3.5	-2.1	-3.5	-3.5	-5.9	-5.4

Flow Data Units - grams

TABLE 6L

TEMPERATURE - FLOW DATA
(Emitter D)

Emitters	15°C	20°C	25°C	27°C	31°C	35°C	41°C	45°C	51°C
$1D_1$	1100	1120	1080	1102	1128	1150	1164	1191	1201
$1D_2$	1039	1057	1186	1288	1312	1323	1352	1387	1395
$1D_3$	1132	1147	1207	1213	1237	1260	1275	1306	1321
$1D_4$	1151	1153	1239	1275	1297	1245	1315	1299	1362
$2D_1$	1029	1039	1042	1089	1125	1140	1189	1200	1280
$2D_2$	1200	1220	1259	1260	1280	1289	1299	1340	1360
$2D_3$	1111	1120	1129	1180	1194	1280	1270	1298	1320
$2D_4$	1121	1180	1189	1201	1280	1299	1350	1380	1381
Min. Max.	1029 1200	1039 1220	1092 1259	1089 1288	1125 1297	1140 1299	1164 1350	1191 1387	1201 1381
$\overline{X}$	1110	1129	1166	1201	1231	1248	1276	1299	1327
SD	56.2	60.0	76.3	75.1	74.6	67.9	69.1	73.3	63.3
$\frac{\overline{X}_t-\overline{X}_{25}}{X_{25}}$	-4.8	-3.2	0	+3.0	+5.6	+7.0	+9.4	+11.4	+13.8

Flow Data Units - grams

TABLE 6M

TEMPERATURE - FLOW DATA
(Emitter E)

Emitters	15°C	20°C	25°C	27°C	31°C	35°C	41°C	45°C	51°C
$1E_1$	798	800	762	759	732	733	710	689	619
$1E_2$	756	702	698	700	673	663	634	620	624
$1E_3$	730	735	218	842	792	785	764	666	654
$1E_4$	721	700	696	701	690	688	600	(471)	(241)
$2E_1$	753	750	781	721	700	698	675	640	631
$2E_2$	799	772	769	746	732	721	730	690	691
$2E_3$	801	800	791	769	659	640	631	620	599
$2E_4$	760	742	720	690	681	650	628	615	603
Min. Max.	730 801	700 800	696 791	690 842	659 792	640 785	600 764	615 640	595 691
$\overline{X}$	764	750	741	741	707	697	671	648	631
SD	31.5	38.8	38.1	50.2	43.0	48.3	57.9	32.9	31.9
$\frac{\overline{X}_t - \overline{X}_{25}}{\overline{X}_{25}}$	+3.4	+1.2	0	0	-4.6	-5.9	-9.4	-12.5	-14.8

Note: Encircled numbers were not used in the calculations.
Flow Data Units - grams

TABLE 6N

KRAMER JUNCTION

PERCENT DIMINISHED FLOW

788 HOURS

Treatment Type	Emitter A	Emitter B	Emitter C	Emitter D	Emitter E	Average Percent Loss
Continuous acid chlorination double filtration	44	4	37	4	41	26
Continuous acid and chlorination	64	28	58	6	51	41
Continuous acid	63	11	36	9	27	29
Continous chlorination	+2	5	2	8	50	13
Double filtration	+11	+5	1	7	37	6
Intermittent fertilizer	+6	3	6	4	26	7
200 mesh filter	+8	0	3	+2	+7	+3
120 mesh filter	+1	7	6	7	5	5
Acid and chlorination every week	+8	3	+4	+1	+3	+3
Acid and chlorination every two weeks	30	+15	30	9	6	12
Acid and chlorination every four weeks	+2	11	25	10	5	10
Double filtration, acid and chlorination every four weeks	4	9	24	6	+3	8

TABLE 6P

SAN JOSE

PERCENT DIMINISHED FLOW

752 HOURS

Treatment Type	Emitter A	Emitter B	Emitter C	Emitter D	Emitter E	Average Percent Loss
Continuous acid chlorination double filtration	33	9	+22	11	20	10
Continuous acid and chlorination	45	0	+22	10	17	10
Continuous acid	19	19	7	23	32	20
Continous chlorination	7	+29	12	16	2	2
Double filtration	2	7	4	19	5	7
Intermittent fertilizer	1	5	6	25	12	10
200 mesh filter	3	4	10	23	7	9
120 mesh filter	4	6	7	23	19	12
Acid and chlorination every week	+1	2	15	12	6	7
Acid and chlorination every two weeks	23	+1	14	7	12	11
Acid and chlorination every four weeks	44	11	+4	11	3	13
Double filtration, acid and chlorination every four weeks	33	17	6	10	5	14

TABLE 6Q

SACRAMENTO

PERCENT DIMINISHED FLOW

797 HOURS

Treatment Type	Emitter A	Emitter B	Emitter C	Emitter D	Emitter E	Average Percent Loss
120 mesh filter	+7	+17	3	1	+2	+4
Intermittent fertilizer	4	+36	5	3	+2	+5
200 mesh filter	0	+5	10	3	+1	1
Continuous acid and chlorination	100	30	40	+4	+1	33
Continuous chlorination	1	+32	12	9	+1	+2
Continuous acid	+5	+8	+11	9	+10	+5
Acid and chlorination every two weeks	11	+42	+4	+2	1	+7
Acid and chlorination every four weeks	14	3	+9	+14	+6	+2
Acid and chlorination every six weeks	14	+1	21	2	2	8
Acid and chlorination every eight weeks	4	7	+3	+2	+2	1

TABLE 6R

KRAMER JUNCTION

Ranking of Water Treatments (Most effective to least effective)	Average Percent Loss
200 mesh filter	+3
Acid and chlorination every week	+3
120 mesh filter	5
Double filtration	6
Intermittent fertilizer	7
Double filtration acid and chlorination every four weeks	8
Acid and chlorination every four weeks	10
Acid and chlorination every two weeks	12
Continuous chlorination	13
Continuous acid, chlorination double filtration	26
Continuous acid	29
Continuous acid and chlorination	41

TABLE 6S

SAN JOSE

Ranking of Water Treatments (Most effective to least effective)	Average Percent Loss
Continuous chlorination	2
Acid and chlorination every week	7
Double filtration	7
200 mesh filter	9
Intermittent fertilizer	10
Continuous acid and chlorination	10
Continuous acid, chlorination double filtration	10
Acid and chlorination every two weeks	11
120 mesh filter	12
Acid and chlorination every four weeks	13
Double filtration, acid and chlorination every four weeks	14
Continuous acid	20

TABLE 6T

SACRAMENTO

Ranking of Water Treatments (Most effective to least effective)	Average Percent Loss
Acid and chlorination every two weeks	+7
Intermittent fertilizer	+5
Continuous acid	+5
120 mesh filter	+4
Acid and chlorination every four weeks	+2
Continuous chlorination	+2
Acid and chlorination every eight weeks	1
200 mesh filter	1
Acid and chlorination every six weeks	8
Continuous acid and chlorination	33

TABLE 6U

KRAMER JUNCTION

NUMBER OF CLOGGED EMITTERS VERSUS DURATION OF FLOW

Treatment Type	After 343 Hours	After 758 Hours	After 833 Hours
Continuous acid, chlorination, double filtration	0	2(1B,1E)	1(1E)
Continuous acid and chlorination	0	4(1A,1C,2E)	2(1A,1E)
Continuous acid	0	1(1A)	1(1E)
Continuous chlorination	0	2(2E)	2(2E)
Double filtration	0	1(1E)	1(1E)
Intermittent fertilizer	0	1(1E)	1(1E)
200 mesh filter	0	0	0
120 mesh filter	0	0	0
Acid and chlorination every week	0	1(1E)	2(1C,1E)
Acid and chlorination every two weeks	0	0	0
Acid and chlorination every four weeks	0	0	0
Double filtration, acid chloration every four weeks	0	0	0

Clogged emitter is when flow is less than 25 percent of initial flow.

A is emitter A, B is emitter B, etc.

TABLE 6V

SAN JOSE

NUMBER OF CLOGGED EMITTERS VERSUS DURATION OF FLOW

Treatment Type	After 206 Hours	After 302 Hours	After 722 Hours	After 783 Hours
Continuous acid, chlorination, double filtration	1(1A)	4(4A)	0	0
Continuous acid and chlorination	0	4(4A)	0	0
Continuous acid	0	0	0	0
Continuous chlorination	0	0	0	0
Double filtration	0	0	0	0
Intermittent fertilizer	0	1(1B)	0	0
200 mesh filter	0	0	0	0
120 mesh filter	0	0	1(1E)	1(1E)
Acid and chlorination every week	0	0	0	0
Acid and chlorination every two weeks	0	0	0	0
Acid and chlorination every four weeks	1(1A)	1(1A)	1(1A)	1(1A)
Double filtration, acid chloration every four weeks	1(1A)	1(1A)	1(1A)	1(1A)

Clogged emitter is when flow is less than 25 percent of initial flow.

A is emitter A, B is emitter B, etc.

TABLE 6W

SACRAMENTO

NUMBER OF CLOGGED EMITTERS VERSUS
DURATION OF FLOW

Treatment Type	After 209 Hours	After 562 Hours	After 632 Hours	After 797 Hours
120 mesh filter	0	0	0	0
Intermittent fertilizer	0	0	0	0
200 mesh filter	0	1(1C)	0	0
Continuous acid and chlorination	3(3A)	5(4A,1C)	4(4A)	4(4A)
Continuous chlorination	0	0	0	1(1C)
Continuous acid	0	0	0	0
Acid and chlorination every two weeks	0	0	0	0
Acid and chlorination every four weeks	0	0	0	0
Acid and chlorination every six weeks	0	0	0	0
Acid and chlorination every eight weeks	0	0	0	0

Clogged means flow is less than 25 percent of initial flow.

A is emitter A, B is emitter B, etc.