ES 56715

Monterey Wastewater Reclamation Study for Agriculture

FINAL REPORT - April 1987

prepared for **Monterey Regional Water Pollution Control Agency**

MONTEREY WASTEWATER RECLAMATION STUDY FOR AGRICULTURE

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ES

FINAL REPORT

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Prepared for

MONTEREY REGIONAL WATER POLLUTION CONTROL AGENCY

April 1987

Prepared by

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3 April 1987
Ref: 56715.17

Mr. Kenneth P. De Ment, Manager
Monterey Regional Water Pollution Control Agency
220 Country Club Gate Center, Suite 34
Pacific Grove, California 93950

Dear Mr. De Ment:

Engineering-Science is proud to submit this final report of Monterey Wastewater Reclamation Study for Agriculture, the end product of a 10-year series of agreements between us and the Agency. We (your agency, ES and the University of California) have completed a world-class study of wide-ranging significance and tremendous value to water-short areas willing to use its findings.

The authors of this report conclude that use of filtered secondary municipal wastewater for irrigation of food crops consumed unprocessed is safe, based on these direct results of the study:

a. No virus was ever found on samples of crops grown with the two types of reclaimed municipal wastewater used in the study.

b. Levels of naturally-occurring bacteria on samples of effluent-irrigated crops were equivalent to those found on well-water-irrigated crop tissue samples.

c. No naturally-occurring virus was ever detected in any of the samples taken from either type of reclaimed water.

d. When pushed to the limits of their performance, through massive seeding with vaccine-grade poliovirus, both treatment processes exhibited equal ability to remove an average of five logs of seeded virus (i.e. if 100,000 units of virus were introduced to the treatment plant they would all be removed by the treatment process).

e. There was no tendency for metals to accumulate in soils or plant tissues.

Other results indicated marketability, quality and yield of crops to be comparable with produce grown with other sources of irrigation water.

We recommend full use of the projected 30 mgd flow from the regional treatment plant over the entire irrigation season of some eight months in the Castroville area, as a step in correcting the expanding seawater intrusion in the local aquifers.

The Engineering-Science team responsible for MWRSA has been enriched by the challenge and the experience of MWRSA and looks forward to the opportunity to serve the Agency with implementing water reclamation in Northern Monterey County.

Very truly yours,

Bahman Sheikh, Ph.D., P.E.
Project Manager

BS/taz/285b/8

Enclosure: Final Project Report of MWRSA

cc: MWRSA Task Force with enclosure

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LIST OF ACROYNYMS

ADWF = Average dry weather flow

AOAC = Association of Official Analytical Chemists

ANOVA = Analysis of variance

ASAR = Adjusted sodium adsorption ratio

BGM = Buffalo Green Monkey Kidney Cells

BOD = Biochemical oxygen demand

BODR = Basis of design report

CIMIS = California Irrigation Management Information System

DOHS = Department of Health Services (California)

DPD = N, N-diethyl-p-phenylenediamine

dS/m = decisiemens per meter

DTPA = diethylenetriaminepentaacetic acid

EC = Electrical conductivity

EPA = Environmental Protection Agency

FE = Filtered effluent

FE-F = Filtered effluent with flocculation

hfr = High-frequency recombination

MCFCWCD = Monterey County Flood Control and Water Conservation District

MBAS = Methylene-blue-active substances

MEM = Minimal essential medium

mmhos/cm = Millimhos per centimeter

MPN = Most probable number

MRWPCA = Monterey Regional Water Pollution Control Agency

MWRSA = Monterey Wastewater Reclamation Study for Agriculture

NM = Not measured

NPDES = National Pollutant Discharge Elimination System

NTU = Nephelometric turbidity units

O&M = Operations and maintenance

PCB = Polychlorinated biphenyl

PFU = Plaque-forming units

PVC = Polyvinyl chloride

rcf = Relative centrifugal force

rpm = Revolutions per minute

RWQCB = Regional Water Quality Control Board

SAR = Sodium adsorption ratio

SWRCB = State Water Resources Control Board

TDS = Total dissolved solids

T-22 = Title-22

WW = well water

0/3 = no fertilizer applied or 0/3 of full rate

1/3 = 1/3 of full local fertilization rate

2/3 = 2/3 of full local fertilization rate

3/3 = full local fertilization rate

chapter 1

THE CENTRAL FINDINGS OF MWRSA ARE:

1. Irrigation of raw-eaten vegetable crops and artichokes with reclaimed water was shown to be as safe as irrigation with well water based on these results:

- *a. No virus was ever found on samples of crops grown with the two types of reclaimed municipal wastewater used in the study (known as T-22 and FE).*

- *b. Levels of naturally-occuring bacteria on samples of effluent-irrigated crops were equivalent to those found on well-water-irrigated crop tissue samples.*

- *c. No naturally-occurring virus was ever detected in any of the samples taken from either type of reclaimed water.*

- *d. When pushed to the limits of their performance, through massive seeding with vaccine-grade poliovirus, both treatment processes exhibited equal ability to remove an average of five logs of seeded virus (i.e. if 100,000 units of virus were introduced to the treatment plant they would all be removed by the treatment process). The FE process appeared to require greater operator attention to consistently meet coliform standards.*

- *e. There was no tendency for metals to accumulate in soils or plant tissues.*

2. Marketability of crops grown with reclaimed water is not expected to be a problem.

3. The cost of producing reclaimed water, beyond secondary treatment and excluding transmission costs, is $67 per acre-foot for FE and $107 per acre-foot for the more expensive T-22 process.

Overleaf:

This aerial view of Site D shows the experimental aritchoke plots to the left (south) of Tembladero Slough, which drains much of Castroville's farmland to Monterey Bay. The pipe bridge at the extreme lower right supports pipelines carrying the two effluents from Castroville treatment plant to the site. The cylindrical tank at the lower left stored well water from Sea Mist Farms' neighboring well for use when needed in irrigating the control plots.

CHAPTER 1

SUMMARY

INTRODUCTION

The combination of fertile soils and long growing season makes the lower Salinas Valley in northern Monterey County, California, a rich agricultural region. Artichokes are a major crop, but a variety of annual crops is also grown: broccoli, cauliflower, celery, and lettuce are grown throughout the region. It became evident during the early 1970s that northern Monterey County's groundwater supply was decreasing because of extensive withdrawal of groundwater for agriculture. This overdraft lowered the water tables and created an increasing problem of saltwater intrusion. At the same time, wastewater treatment facilities were reaching full capacity, requiring expansion to meet the growing needs of the region.

In May 1974, the State of California Central Coast Regional Water Quality Control Board (RWQCB) completed a water quality management plan for the area that recommended "...consolidation of Monterey Peninsula, Salinas, and Castroville area municipal wastewater flows with construction of a regional treatment plant and outfall for discharge to Central Monterey Bay with reuse of reclaimed wastewater for crop irrigation and possible enhancement of the lower Salinas River." The water quality management plan recommendations recognized that wastewater reclamation had to be proven safe before regional implementation could be considered. This provided the impetus for the Monterey Wastewater Reclamation Study for Agriculture (MWRSA), which was conceived as a pilot project designed to assess the safety and feasibility of agricultural irrigation with reclaimed water.

Planning for the project was begun in 1976 by the Monterey Regional Water Pollution Control Agency (MRWPCA), the regional agency responsible for wastewater collection, treatment, and disposal in the area. Full-scale field studies began in 1980 and continued through May of 1985. During these five years, a perennial crop of artichokes was grown along with rotating annual crops of celery, broccoli, lettuce, and cauliflower. Extensive sampling of waters, soils, and plant tissues was conducted throughout the five years.

DESCRIPTION OF THE PROJECT

The site for the MWRSA field operations was a farm in Castroville. The existing 1,500 m^3/d (0.4 mgd) Castroville Wastewater Treatment Plant was selected for modification and upgrading to be used as the pilot tertiary reclamation plant for MWRSA. A portion of the secondary effluent was diverted to a new pilot tertiary treatment plant which consisted of two parallel treatment process trains. The Title-22 process (T-22) conformed strictly to the requirements of the California Administrative Code for treatment of wastewater used in irrigating food crops that may be consumed without cooking. The second process produced a treated wastewater designated as filtered effluent (FE). This is a wastewater treated less extensively than T-22 effluent. Well water produced from local wells was the control for the study.

The 12-ha (30-acre) field site was divided into two parts, demonstration fields and experimental plots. Large demonstration fields were established because farm-scale feasibility of using reclaimed water is of special importance to the growers, farm managers, and operators responsible for day-to-day farming practices.

To investigate large-scale feasibility of using reclaimed wastewater, two 5-ha (12-acre) plots were dedicated to reclaimed water irrigation, using the FE flow stream. On one plot, artichokes were grown; on the other plot, a succession of broccoli, cauliflower, lettuce, and celery was raised during the first three years of the field investigation. The crops were observed carefully for appearance and vigor. At the end of each season, they were plowed under and incorporated into the soil. Normal farming practices of local growers were duplicated on these fields with the exception of harvest, which was not carried out. Because of its experimental nature, the produce from these plots was not marketed. Six field observation days were held, and the local growers and the news media were invited to acquaint the agricultural community with the ongoing MWRSA activities and to obtain feedback regarding their perceptions, questions, and concerns.

A split-plot design was chosen for the experimental plots at Site D. This design allowed the use of two treatment variables: water type and fertilization rate. Four replicates of three types of main plots were irrigated with T-22 effluent, FE, or well water. These three water types were assigned randomly to main plots within each block or replicate to achieve a randomized complete block (i.e., each block contains all three of the main water type treatments). Each main plot was then divided into four subplots, each of which was randomly assigned a different fertilization rate treatment: the full amount of nitrogen fertilizer used by local farmers (3/3), two-thirds the full rate (2/3), one-third the full rate (1/3), and no fertilizer (0/3). The full design thus had 48 plots. This process was performed for artichokes and repeated for annual row crops, for a total of 96 plots which occupied 1.2 ha (3 acres) at Site D. This experimental design allowed comparison of both irrigation with different water types and the effect of varying fertilization rates. The fertilization rates were designed to elucidate the value of the two effluents as a supplement to fertilization.

Three separate irrigation systems were constructed to supply different water types to each main plot. Each system consisted of an underground distribution system with portable aluminum pipes for both sprinkler and furrow irrigation.

Before the start of the five-year field demonstration, a number of baseline studies were carried out to ascertain the uniformity of the soil on the site of the experimental plots and to ensure the safety of downwind areas from windblown aerosols during irrigation with effluents. Data gathered in baseline studies not only helped select the site and configuration, they also formed a pre-experiment documentation of soil conditions for comparison with conditions at the end.

METHODS USED IN THE STUDY

Artichokes were grown in the experimental fields from May 1980 until May 1985. Artichokes are perennial plants which are typically cut back to the ground each May. Row crops were planted in rotation starting in May 1980 and ending in April 1985. Row crops grown were broccoli, cauliflower, celery, and four varieties of lettuce: head, romaine, green leaf, and red leaf. Local farming practices were followed throughout the project.

Composite samples of the three irrigation waters were taken over a three- to five-day period at each irrigation event. The composite samples were divided into subsamples for metal and chemical analysis. Grab samples of irrigation water were collected for bacteriological and biochemical oxygen demand (BOD) analyses. During furrow irrigation of row crops, tailwater samples were collected from runoff. Water samples were analyzed for 10 metals and 16 chemical parameters.

During the first three years of field studies, surface soil samples were taken for bacteriological analyses within two days after irrigation. Throughout the five years of MWRSA, soil profile samples were collected and analyzed for a variety of metal, chemical, and physical parameters. At each sampling event, soil samples were taken with a soil auger at depths of 30 cm (1 ft), 100 cm (3 ft), and 200 cm (6 ft). Soils were analyzed annually for metals and organic matter content. During the first two years, biannual sampling was conducted for cation exchange capacity, boron levels, and chemical parameters such as pH and salt content. After the first two years, sampling frequency was reduced to once each year.

Laboratory permeability analyses were performed during the first three years of MWRSA. In Year Four, it was decided that measurement of field infiltration rates would provide a more realistic quantification of permeability. Field infiltration rates were measured using standard double-ring infiltrometers. During Years Four and Five, field infiltration rates were measured three times in both the artichoke and vegetable fields.

Edible and residual plant tissues were sampled and analyzed for bacteria, parasites, and metals. Any portion of the plant that was left in the field after harvest was considered to be residual tissue. Plant tissues were subjected to the same bacteriological analysis as were water and soils samples.

Edible portions of the crop were collected for metals analyses at each major harvest. Crop residues were also sampled and analyzed for cadmium, zinc, and boron. Samples for nutrient analyses were taken from petioles of the most recently matured leaf. Starting in Year Two, nutrient samples were also collected at each fertilization.

Samples of edible tissue were also taken for bacteriological and metal assays from neighboring and nearby artichoke fields at distances of 15, 30, 60, 150, 300, and 1,000 m (50, 100, 200, 500, 1,000, and 3,300 ft).

Sample harvests for all crops were taken from the central portions of plots. Crops were also monitored to detect qualitative differences attributable to the different irrigation waters.

Pilot plant influent, irrigation waters, plant tissues, and soils were sampled and assayed for enteric viruses. Soil and vegetable samples were collected from the experimental plots within 24 hours of the end of an irrigation set and assayed for virus.

During the course of the virus studies, it became apparent that the *in situ* virus concentration in the pilot plant influent water was very low; thus, virus seeding studies were made to estimate the virus removal efficiency of the two pilot plant processes. The test virus used was the vaccine-strain poliovirus used in previous testing. This virus was chosen because it is a reasonable representative of enteric animal viruses, and, because it is a vaccine strain, it is safe to use.

Four groundwater monitoring wells (piezometers) were installed at a depth of approximately 2 m (6 ft) in the MWRSA demonstration fields in 1980. Piezometers were installed in the artichoke experimental subplots irrigated with different water types at the end of 1983. Four of these new monitoring wells were chosen to provide quarterly sampling for constituents, including all major and minor cations and anions. Twenty piezometers were sampled for nitrate, because it is the most mobile ion likely to affect the shallow groundwater quality. Monthly water level measurements were taken in all wells in Year Five, except at times when access to the site was not feasible because of rain.

Throughout the five-year field study, climatic parameters relevant to crop development were measured and recorded continually, analyzed periodically, and reported annually.

A field study was performed to compare aerosols generated in spray irrigation with filtered effluent and with well water.

Analysis of variance (ANOVA) was the primary statistical technique used to determine if significant differences existed between the characteristics of the soils and plants receiving different water types and fertilization treatments. The hypotheses tested were that there are no differences in the measured parameters due to (1) water types, (2) fertilization rates, and (3) interactions between water types and fertilization rates.

RESULTS OF PUBLIC HEALTH STUDIES

Virus Survival

Monitoring for the presence of naturally occurring animal viruses showed that the influent to the two pilot processes (Castroville unchlorinated secondary effluent) contained measurable viruses in 53 of the 67 samples taken. The median concentration of virus was 2 plaque-forming units per liter (PFU/L); 90 percent of the samples contained less than 28 PFU/L. During the approximate five-year period, no *in situ* viruses were recovered from the chlorinated effluent of either process.

No viruses were recovered from any of the crop samples. This was also the case for the soil irrigated with the reclaimed water.

Virus Seeding of Plants and Soil

Although no *in situ* viruses were recovered from irrigated plants and soil, it was important that an estimate be made of the ability of virus to survive under these conditions. Virus survival measurements were made in the laboratory and under field conditions. In the laboratory, the times required for a 99 percent die-off in the viruses (T_{99})

ranged from 7.8 days for broccoli to 15.1 days for lettuce. In field studies in Castroville the T_{99} values were 5.4 days for artichokes, 5.9 days for romaine lettuce, 7.8 days butter lettuce.

The survival of virus in Castroville soil was determined both under environmental chamber conditions and under field conditions. The T99 values for the decay of virus under environmental chamber conditions were 5.4, 9.7, and 20.8 days for 60, 70, and 80 percent relatively humidity, respectively. In the field the T99s were 5.2 and 4.8 days for runs one and two, respectively. Thus, the rate of virus removal under chamber and field conditions was quite similar. No viruses were recovered from any soil section after 12 to 14 days of exposure.

Bacteria and Parasites

During the five years of the study, the quality of irrigation waters improved because of the continued improvement in treatment plant operations and storage procedures. All three types of waters, including the well water control, periodically exhibited high coliform levels. No salmonellae, shigellae, *Ascaris lumbricoides*, *Entamoeba histolytica*, or other parasites were ever detected in any of the irrigation waters.

The levels of total and fecal coliform in soils and plant tissue irrigated with all three types of water were generally comparable. No consistent significant difference attributable to water type was observed. No parasites were ever detected in soil samples. Parasites were detected in plant tissue only in Year One, and there were no differences in level of contamination between effluent- and well water-irrigated crops.

Sampling of neighboring fields detected no relationship between bacteriological levels and the distance from the field site. The aerosol transmission of bacteria was thus deemed unlikely.

Groundwater Protection

No discernible relationship existed between the quality of the shallow groundwater underlying the site and the type of applied irrigation water. An examination of all water quality data collected suggests that the groundwater quality trends were associated with trends generally applicable in irrigated areas such as increased TDS and nitrate.

Aerosols

It was concluded early in the field operations of MWRSA that aerosol-carried microorganisms from FE sprinklers were not significantly different from those generated by well-water sprinklers. This finding was verified through replications both in daytime and nightime operations to account for die-offs of organisms caused by ultraviolet rays of the sun. Subsequently reported studies by others have corroborated these findings and established the safety of aerosols from an FE spray.

Health of Field Workers

In addition to these studies, the health status of each person assigned to field tasks in MWRSA was monitored regularly through frequent questionnaires and thorough initial and exit medical examinations administered by qualified medical professionals. One hundred questionnaires were completed by personnel during the five years. No complaints could be related to contact with treated wastewater effluents. No formal epidemiological investigation was deemed appropriate or necessary for the purposes of MWRSA.

RESULTS OF AGRICULTURE STUDIES

Irrigation Water Quality

As one would expect, the two effluents had higher levels of most chemical and metal constituents than did well water. The nutrient value of both effluents was substantial. The salt content of irrigation waters was important because of the potential for deleterious effects on crops and soils. Sodium content of irrigation waters was of particular concern because high levels of sodium along with low salinity can create poor soil physical conditions, which reduce permeability.

Salinity of irrigation waters was determined by measuring electrical conductivity (EC) and total dissolved solids (TDS), as well as the concentration of boron, chloride, sodium, bicarbonate, calcium, and magnesium. Concentrations of TDS less than 480 mg/L are recommended for irrigation waters, and levels above 1920 mg/L are considered to be a severe problem. Levels of EC, TDS, boron, chloride, and sodium in the two effluents were comparable and were higher than those in well water. Concentrations of TDS in all three water types were below the "severe problem" range, but effluent TDS fell into the range of "increasing problems." Levels of magnesium and calcium were similar in all three water types. Bicarbonate levels were higher in filtered effluent than in the other two water types, which showed similar concentrations.

The sodium adsorption ratio (SAR) is a measure of the suitability of water for irrigation. Irrigation water data indicates that the reclaimed water is generally in the favorable range for irrigation, because high SAR is accompanied by similarly high salinity.

Heavy Metals in Soils

None of the nine heavy metals studied (cadmium, zinc, iron, manganese, copper, nickel, cobalt, chromium, or lead) manifested any consistent significant difference in concentration among plots irrigated with different water types. Furthermore, except in the case of copper, no increasing trends with time over the five years were observed. The gradual increase observed for copper occurred equally for all water types, and at the end of the five years, copper concentrations were still below the average for California soils. Iron was generally measured at higher concentrations in the well water than in either effluent. Zinc, however, was higher in both effluents than in well water, although the actual concentrations were on the order of 0.1 mg/L in the two effluents. At these levels, uptake by plants would be faster than accumulation from irrigation input.

Input of zinc and other heavy metals, from the commercial chemical fertilizer impurities, is far greater and accounts for the large concentration differences observed at the three soil depths sampled throughout the five years. These differences have occurred over many decades of continuous farming with regular application of fertilizers.

Heavy Metals in Plant Tissues

The same nine metals studied in the soils were also investigated in samples of the edible tissues of plants collected at harvest at each of the 96 subplots. The most important of the many results is that no consistent significant difference in heavy metal concentrations was observed between plants irrigated with either effluent and with well water in any of the 16 samplings over the five-year field trials.

Analysis of cadmium and zinc in residual tissue produced results very similar to those from edible tissues, i.e., no consistent significant difference was observed between plants irrigated with well water and with either of the two reclaimed waters. However, consistent differences in the accumulation of zinc and cadmium were observed between edible and residual tissues (higher cadmium in residual tissues and higher zinc in edible tissues for all vegetables studied). This difference in accumulation is in fact fortuitous, because it results in relatively higher zinc to cadmium ratios in the edible portion of the crops, believed to be a safeguard against cadmium bioaccumulation and the resultant health hazards.

Soil Permeability

Infiltration rates in the lettuce field were highest in those plots irrigated with well water, but these levels were not significantly different because of the great variation of infiltration rates within each water type. Infiltration rates in the artichoke field were higher than in the lettuce field. This is probably due to the fact that the artichoke field receives less irrigation water and is less frequently compacted by equipment used for field preparation.

Crop Yields

Artichoke yields were similar for all three water types; in the first two years, the different fertilization rates had no effect on yield. In the last three years, a significant effect of fertilization became apparent. All three fertilization rates showed significantly higher yields than did the unfertilized plots. There were, however, no significant differences in yield among the 1/3, 2/3, and 3/3 rates. The typical full fertilization rate may thus be in excess of the artichoke plants' requirements. The lack of fertilization effect in the first two years may have been due to the presence of residual fertilizer left by previous over-fertilization.

For most vegetables, yield was somewhat higher with irrigation with FE and Title-22 than with well water, and increases in yield with increasing fertilizer tended to level off at the 2/3 fertilizer rate. Yields of all seven lettuce crops were similar for the three different water types. Increases in lettuce yield tended to level off at the 2/3 rate.

Crop Quality

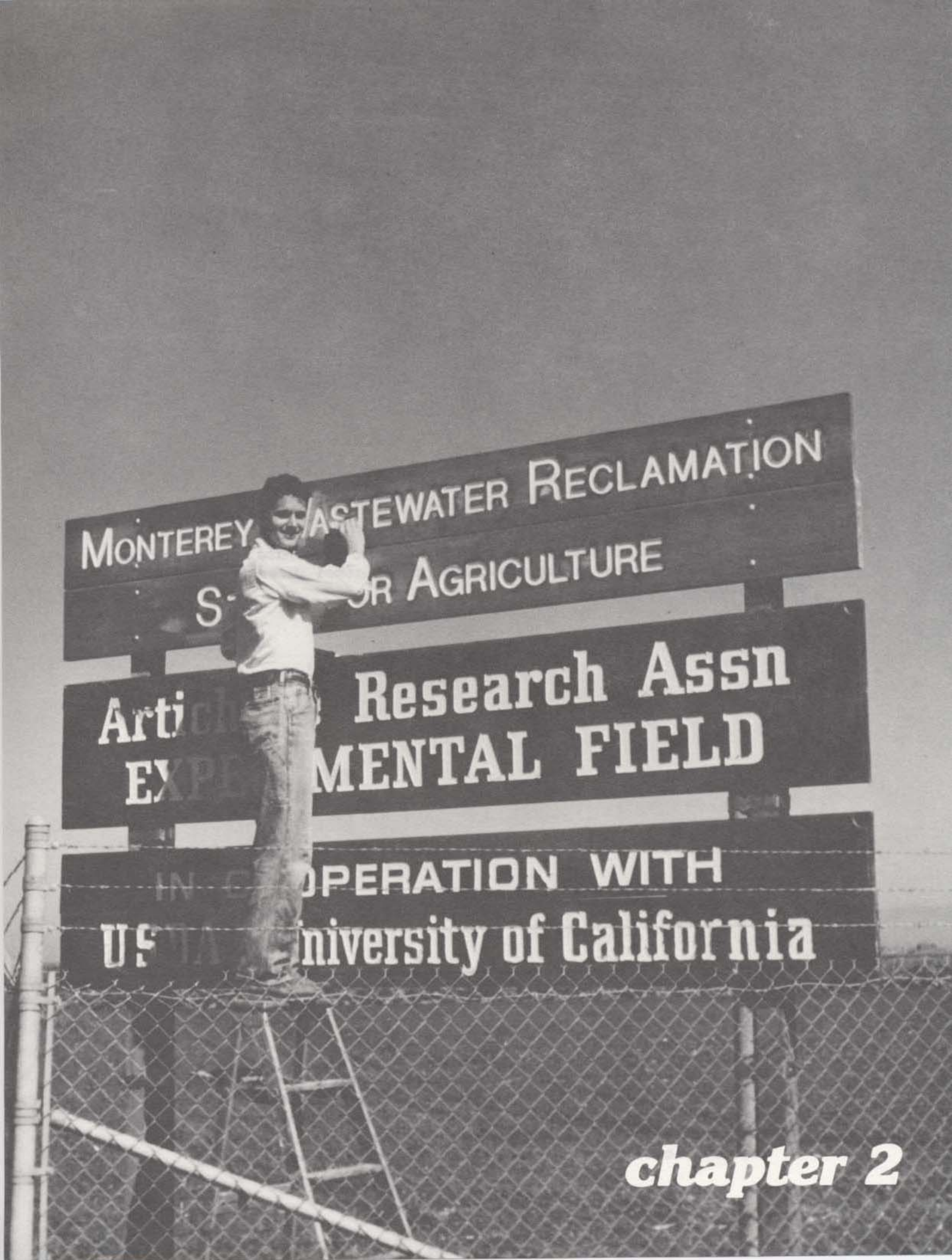
Field quality assessments and shelf life measurements uncovered no differences between produce irrigated with reclaimed water and that irrigated with well water. Visual inspection of artichoke plants in the field showed no differences in appearance or vigor of plants irrigated with different water types. Occasional problems with mouse damage were not related to water type.

Shelf life and quality of row crops were similar for all water type treatments. No problems with increased spoilage of produce irrigated with effluents were encountered.

CONCLUSIONS

- Based on virological, bacteriological and chemical results from sampled vegetable tissues, irrigation with filtered effluent or T-22 appears to be as safe as with well water.
- After five years of field experimentation (1980 to 1985), results show few statistically significant differences in measured soil or plant parameters attributable to the different water types. None of these differences has important implications for public health. Yield of annual crops is often significantly higher with reclaimed water.
- No virus has been detected in any of the reclaimed waters sampled although it is often detected in the secondary effluent.
- The T-22 process is somewhat more efficient than the FE process in removing virus when influent is artificially inoculated (seeded) at extremely high rates. Both flow streams can remove more than five logs of virus (i.e. removal to below 1/100,000 of the seeded concentration).

- Marketability of produce is not expected to be a problem.
- The cost of producing filtered effluent (after secondary treatment) is estimated to be $70/acre-ft., excluding transmission costs.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chapter 2

OBJECTIVE OF MWRSA

The principal objective of MWRSA was to generate quantitative, unbiased answers to concerns about use of reclaimed water for irrigation of vegetables.

Overleaf:

Installation of the sign erected at the corner of Site D. In 1983, the portion of MWRSA Site D that had been used for demonstration fields in the first two years was subleased to the Artichoke Research Association for conduct of field experiments in the genetics of artichoke culture. Proximity of this field research activity to MRWSA has been mutually beneficial.

CHAPTER 2

INTRODUCTION

HISTORY

It became evident during the early 1970s that northern Monterey County's groundwater supply was decreasing because of extensive withdrawal of groundwater for agriculture. This overdraft lowered the water tables and created an increasing problem of saltwater intrusion. At the same time, wastewater treatment facilities were reaching full capacity, requiring expansion to meet the growing needs of the region.

In May 1974, the Central Coast Regional Water Quality Control Board (RWQCB) completed a Basin Plan for the area that recommended "...consolidation of Monterey Peninsula, Salinas, and Castroville area municipal wastewater flows with construction of a regional treatment plant and outfall for discharge to Central Monterey Bay with reuse of reclaimed wastewater for crop irrigation and possible enhancement of the lower Salinas River." This recommendation was consistent with a subregional planning report adopted earlier by the Association of Monterey Bay Area Governments. The Basin Plan was formally adopted by the RWQCB in August 1974 and by the State Water Resources Control Board (SWRCB) in September 1974 (Reference 1).

The Basin Plan's recommendations recognized that wastewater reclamation had to be proven safe before regional implementation could be considered. The plan specified that "Where irrigation of vegetable crops is envisioned, the health risks must be eliminated to the satisfaction of all concerned agencies, farmers and the general public; this will require additional work in the form of on-farm demonstrations and careful analysis of crops produced." This recommendation provided the impetus for the Monterey Wastewater Reclamation Study for Agriculture (MWRSA), which was conceived as a pilot project designed to assess the safety and feasibility of agricultural irrigation with reclaimed municipal wastewater.

The project was organized in four phases. Planning for MWRSA was accomplished in Phase I, during which time a site for the project was selected and an Environmental Assessment (Reference 2) was completed. In Phase II, the pilot treatment plant was designed and constructed, and the experimental fields were established. Phase III, field studies, began in 1980 and continued through May of 1985. During these five years, a perennial crop of artichokes was grown along with rotating annual crops of celery, broccoli, lettuce, and cauliflower. Extensive sampling of waters, soils, and plant tissues was conducted throughout the five years. Phase IV activities included overall statistical analyses of the Phase III data, continued operation of the treatment facilities for an additional nine months to optimize the pilot treatment plant and to continue virological testing, estimation of the cost of reclaimed water, and preparation of the final report containing conclusions and recommendations. Reports have been published in all phases of the project and were made available by the Monterey Regional Water Pollution Control Agency (References 3 through 9).

Tasks still to be accomplished before implementation of regional reclamation include the design and construction of the regional advanced wastewater treatment facilities and the construction of the Castroville Irrigation Project (a water supply, storage, and distribution project).

AUTHORIZATION AND FUNDING

From the time MWRSA was first conceived, the Monterey Regional Water Pollution Control Agency (MRWPCA) directed the project as part of the agency's facility planning effort toward the regional management of wastewater. The U.S. Environmental Protection Agency (EPA) has provided 75 percent of the funding of MWRSA under the Clean Water Construction Grants Program (PL 92-500, Section 201, as amended in 1972). The State of California and the MRWPCA have each borne 12.5 percent of the cost. To offset a portion of the local share of costs, the California State Department of Water Resources provided about $60,000 in services annually. Engineering-Science was contracted by the MRWPCA to manage and perform most of the work during the four phases of MWRSA (from 1976 to 1986), with a major subcontract awarded to the University of California at Berkeley for virological studies.

OBJECTIVES

The primary objectives of MWRSA were to:

1. Generate quantitative, unbiased, and authoritative answers to the following specific questions:
   a. Is irrigation with reclaimed wastewater safe for both consumers and farm workers from the perspective of:
      i. Virus survival on crops and in soil?
      ii. Cadmium and other trace element levels in edible crops?
      iii. Bacteria survival on crops and in soil?
      iv. Aerosol transmission of bacteria and viruses?
   b. Is irrigation with reclaimed wastewater harmful to soils because of the accumulation of heavy metals and salts or because of impaired permeability?
   c. Does reclamation affect yield, quality, or growth of crops?
   d. Will consumers buy the crops irrigated with reclaimed wastewater when faced with a choice of crops grown with fresh water?
   e. Is irrigation with reclaimed wastewater feasible and economical?
2. Evaluate wastewater treatment effectiveness
3. Provide design criteria for the regional plant
4. Develop design criteria for full-scale reclamation
5. Provide field operational experience

Ultimately, the objective of MWRSA was to demonstrate the overall feasibility of wastewater reclamation in northern Monterey County.

AGENCY ROLES

MWRSA has been guided by a task force consisting of interested public agencies, grower organizations, citizens' groups, and involved individuals. Many of the MWRSA task force member agencies have actively directed elements of the overall program. The composition of the task force and its role in MWRSA are detailed in Chapter 3.

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chapter 3

THE MWRSA TASK FORCE

A multiagency task force, including federal, state, regional, local, agricultural, academic, media, and private concerns, under the direction of Walter Wong, head of the Monterey County Environmental Health Department, oversaw planning, performance, and completion of the study.

Overleaf:

Staff of the Department of Water Resources installed piezometers in artichoke subplots for monitoring of the leached fraction of the irrigation water. Over the five year period, no increase in nitrates were oberved in groundwater samples obtained from the 6 to 8-ft depth.

CHAPTER 3

MWRSA TASK FORCE

MWRSA has always been guided by a task force of agency representatives spanning federal, state, regional, and local governments, as well as the academic community, farm advisors, and local growers. The responsible staff members of these organizations brought together a wealth of varied expertise and points of view. Together, and under the continuous leadership of Chairman Walter Wong, this group provided guidance, support, constructive criticism, and a sense of mission to the project. The member agencies and their representatives on the MWRSA task force are:

Monterey County Environmental Health Department
    Walter Wong, Director (Task Force Chairman)

Artichoke Industry, Inc.
    Granville Perkins (Task Force Co-Chairman)

University of California Extension Service, Salinas
    Dr. David Ririe (Task Force Co-Chairman)
    Kurt Schulbach

Monterey Regional Water Pollution Control Agency
    Kenneth P. De Ment, Manager
    Robert S. Jaques, Agency Engineer
    Karyn Wilson, Finance Manager

Monterey County Flood Control and Water Conservation District
    Dr. Gerald E. Snow
    William Hurst

Monterey County Planning Department
    Robert Slimmon, Jr.

Monterey County Public Works Department

Bruce McClain

Monterey Peninsula Garbage and Refuse Disposal District

J. David Meyers

Representatives of Agricultural Community

Silvio Bernardi

Ed Boutonnet

Bob Epperson

Peter Stolich

Vegetable Grower-Shipper Association

Tom Merrill

Tony Leonardini

California Artichoke and Vegetable Growers Association

Hugo Tottino

Association of Monterey Bay Area Governments

Nicholas Papadakis

Central Coast Regional Water Quality Control Board

Roger W. Briggs

California State Water Resources Control Board

James Nicholas

Dr. Takashi Asano, Office of Water Recycling

U.S. Environmental Protection Agency, Region IX

Charmaine Berry, Project Officer

California Department of Health Services

Dr. James Crook

California State Department of Water Resources

Roger Lindholm

Lou Beck

Victor McIntyre

California State Department of Food and Agriculture

Harry Krade

California Coastal Commission

Les Strnad

University of California, Davis

Dr. Richard G. Burau

Dr. Robert M. Hagan

University of California, Berkeley

Dr. Robert C. Cooper

News Media

Salinas Californian

Monterey Peninsula Herald

KDON Radio

KSBW - TV

KMST - TV

Engineering-Science

Dr. Bahman Sheikh, MWRSA Coordinator

Dr. Robin Cort

William R. Kirkpatrick

MWRSA TASK FORCE MEETING OF 22 APRIL 1983 IN SALINAS

Front Row (Left to Right): Granville Perkins, Jerry Snow, Walter Wong, Takashi Asano, Jim Crook, Bob Jaques, Marit Evans, Bill Woodworth, Roger Lindholm

Middle Rows (Left to Right): Neil De Vos, Dave Deaner, Jim Nicholas, Janet Epperson, Michael Graham, Bob Epperson, Ken De Ment, John Inman

Back Row (Left to Right): Jerry Cole, Vic McIntyre, Silvio Bernardi, Richard Burau, Bob Cooper

Not in Picture: Bahman Sheikh, John McCabe

chapter 4

THE MONTEREY WASTEWATER RECLAMATION STUDY FOR AGRICULTURE

The secondary wastewater treatment plant in Castroville, California was upgraded to provide two tertiary treatment processes. One produced coagulated, settled, filtered, disinfected effluent and the other process produced a filtered secondary effluent through direct filtration. Flows from these two processes were used, along with water from a local well, to irrigate 96 subplots randomly arranged to provide four replicates of all possible combinations of the three water types and four fertilization rates. Over the five-year study period artichokes, broccoli, cauliflower, celery and lettuce were grown, sampled intensively, and tested for heavy metals, bacteria, virus, quality, and yield. Soils from the 96 plots were sampled every year and tested for heavy metals, bacteria, virus, salts, and permeability.

Aerosol transmission from sprinkler lines was studied before the start of the experiment to ascertain whether or not the experiment might pose a health hazard to nearby residents.

An opinion survey was conducted among buyers, distributors, and shippers of produce to determine if any resistance might be encountered to the marketing of vegetables grown with reclaimed water.

Overleaf:

Furrow irrigation was used for watering row crops in the later stages of their growth. This was the common local method of irrigation, duplicated in MWRSA, as were all other cultural practices.

CHAPTER 4

PROJECT DESCRIPTION

LOCALE

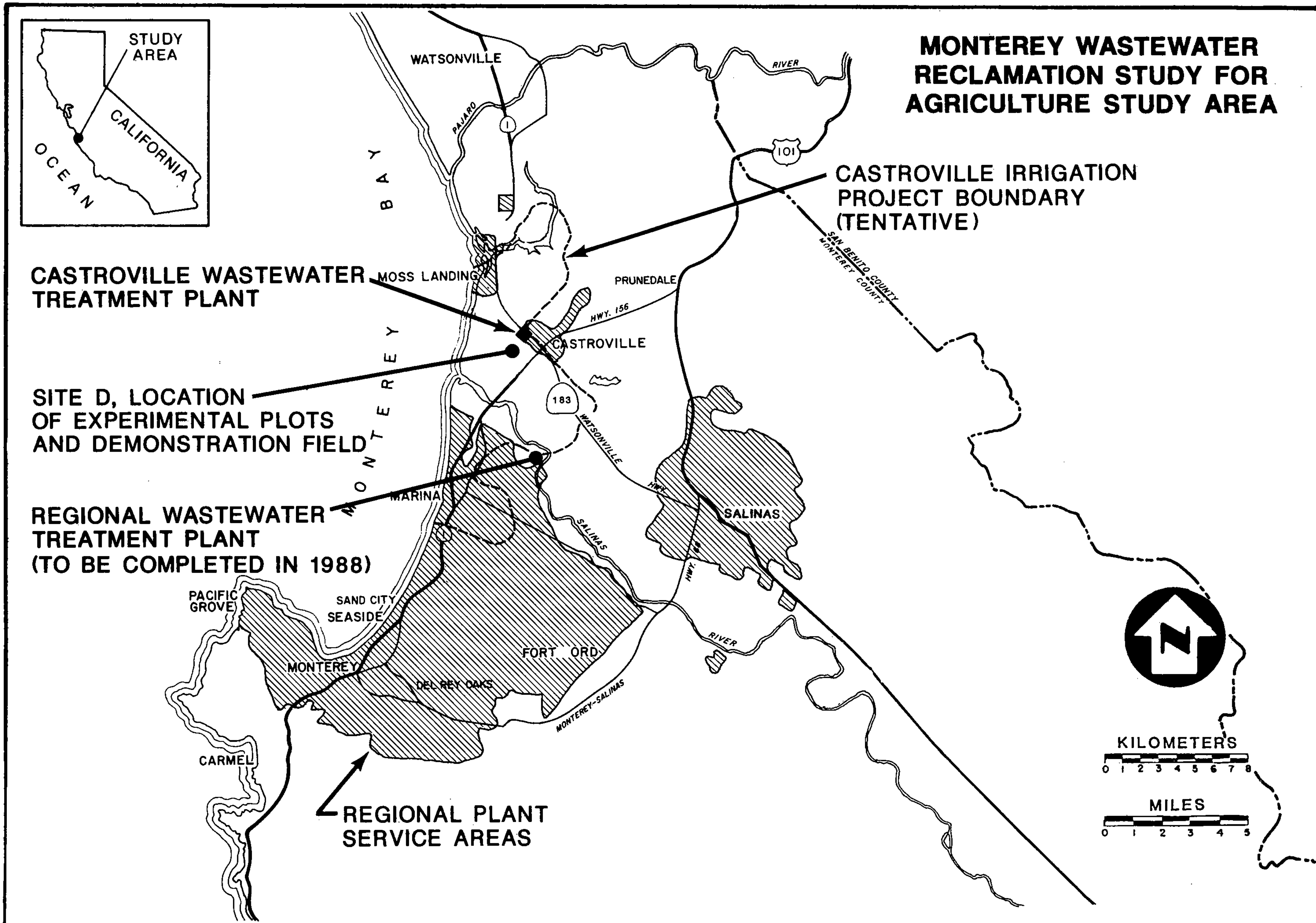
Large portions of the Monterey Regional Water Pollution Control Agency (MRWPCA) service area lie within the agricultural areas of the lower Salinas Valley. The valley is bounded by the Gàbilan Mountains on the north and to the south by the Sierra de Salinas in the northern Santa Lucia Range. Soils of the lower Salinas Valley are fertile, and the principal limitations to their use are problems with drainage and seawater intrusion.

The MRWPCA provides wastewater treatment and disposal services to the northern Monterey County communities of Castroville, Del Rey Oaks, Fort Ord, Monterey, Moss Landing, Pacific Grove, Salinas, Sand City, and Seaside, as well as to unincorporated portions of Monterey County adjacent to these communities. Figure 1 shows the location of the MRWPCA service areas.

The site for the MWRSA field operations was a farm in Castroville, California. Castroville is located in the lower Salinas Valley, within the service area of the MRWPCA, and is one of the communities that is affected by seawater intrusion. Four sites (designated sites A, B, C, and D) were studied before the final location was selected for the experimental plots and demonstration fields. The demonstration fields were used to study full-scale farm practices using reclaimed wastewater. The experimental plots were used to provide large amounts of data on crop response for statistical analysis. The selected area was Site D, whose location is also depicted in Figure 1.

The climate of northern Monterey County is cool and moist. Cool, rainy winters are followed by warm summers with little precipitation.

FIGURE 1


MONTEREY WASTEWATER RECLAMATION STUDY FOR AGRICULTURE STUDY AREA
STUDY AREA
CALIFORNIA
OCEAN
WATSONVILLE
PAJARO
RIVER
101
1
MONTEREY BAY
MOSS LANDING
CASTROVILLE IRRIGATION PROJECT BOUNDARY (TENTATIVE)
SAN BENITO COUNTY
MONTEREY COUNTY
CASTROVILLE WASTEWATER TREATMENT PLANT
PRUNEDALE
HWY. 156
CASTROVILLE
183
WATSONVILLE HWY.
SITE D, LOCATION OF EXPERIMENTAL PLOTS AND DEMONSTRATION FIELD
MARINA
SALINAS
REGIONAL WASTEWATER TREATMENT PLANT (TO BE COMPLETED IN 1988)
PACIFIC GROVE
SAND CITY
SEASIDE
MONTEREY
FORT ORD
DEL REY OAKS
MONTEREY-SALINAS
CARMEL
REGIONAL PLANT SERVICE AREAS
KILOMETERS
0 1 2 3 4 5 6 7 8
MILES
0 1 2 3 4 5

The drier summers are moderated by ocean fog. Average temperatures vary little throughout the year, ranging from about 10°C (50°F) to 18°C (64°F). The annual growing season is about 350 days long.

The combination of fertile soils and a long growing season make the lower Salinas Valley a rich agricultural region. The cool foggy summers are ideal for the production of artichokes. The area around Castroville is a national center for artichoke production. Northern Monterey County produces almost 80 percent of the artichokes grown in the United States. There are about 3,600 ha (9,000 acres) dedicated to artichoke cultivation, producing 40.5 thousand tonnes (44.6 thousand tons) in the 1984-1985 growing season. At a value of approximately $30 million, artichokes are a vital part of the local economy (Reference 10). Artichokes are the major crop of the Castroville area, but a variety of annual crops is also grown in the lower Salinas Valley: broccoli, cauliflower, celery, and lettuce are grown throughout the region.

The lower Salinas Valley is underlain by three aquifers located at approximate depths of 55, 120, and 275 m (known locally as the 180-, 400-, and 900-ft aquifers). The first wells in the area were drilled into the shallowest aquifer. When overpumping of this aquifer resulted in seawater intrusion, the shallow wells were abandoned and replacement wells were drilled into the 400-ft aquifer. Seawater intrusion following the same pattern as that seen in the 180-ft aquifer has now been observed in the 400-ft aquifer, and the drilling of wells into the 900-ft aquifer has begun.

In the Castroville area, about 4,000 ha (10,000 acres) of the 180-ft aquifer have been affected by seawater intrusion, which is progressing at the rate of about 100 ha (250 acres) per year. Intrusion has affected about 1,240 ha (3,100 acres) of the 400-ft aquifer, where the rate is a bit lower at 50 ha (120 acres) annually. The Castroville Irrigation Project, conceived by the Seawater Intrusion Subcommittee of the Monterey County Board of Supervisors' Water Advisory Commission, would serve the area that is affected by intrusion, providing imported water to those farms where wells have become unusable (Reference 11). This project would also provide a distribution system, which could be used to distribute reclaimed wastewater. Figure 1 shows the tentative boundaries for the Castroville Irrigation Project, which are based on the approximate limits of seawater intrusion of the 180-foot aquifer (Reference 12).

PILOT TREATMENT PLANT

The existing 1,500 m^3/d (0.4 mgd) MRWPCA Castroville Wastewater Treatment Plant was selected in 1977 for modification and upgrading to be used as the pilot tertiary reclamation plant for MWRSA. The tertiary portion of the plant was operated nearly continuously between September 1980 and April 1986. Operating parameters for the tertiary treatment process were varied during MWRSA Years One through Five (September 1980-April 1985), and the plant was operated in the selected optimum mode during MWRSA Phase IV (August 1985-April 1986).

The basic Castroville Wastewater Treatment Plant consists of primary sedimentation followed by a roughing filter, a complete mix activated sludge basin, which uses three mechanical surface aerators. Mixed liquor from the aeration basin is also continuously recirculated over the three-foot-deep, redwood lath, roughing filter. The biologically oxidized wastewater then passes from the aeration basin into two 3-m (10-ft) deep circular secondary clarifiers. Clarified effluent that is not pumped to the tertiary plant is discharged to a regional ocean outfall. Primary and waste secondary sludges undergo anaerobic digestion with the resultant residual solids dewatered on sand drying beds.

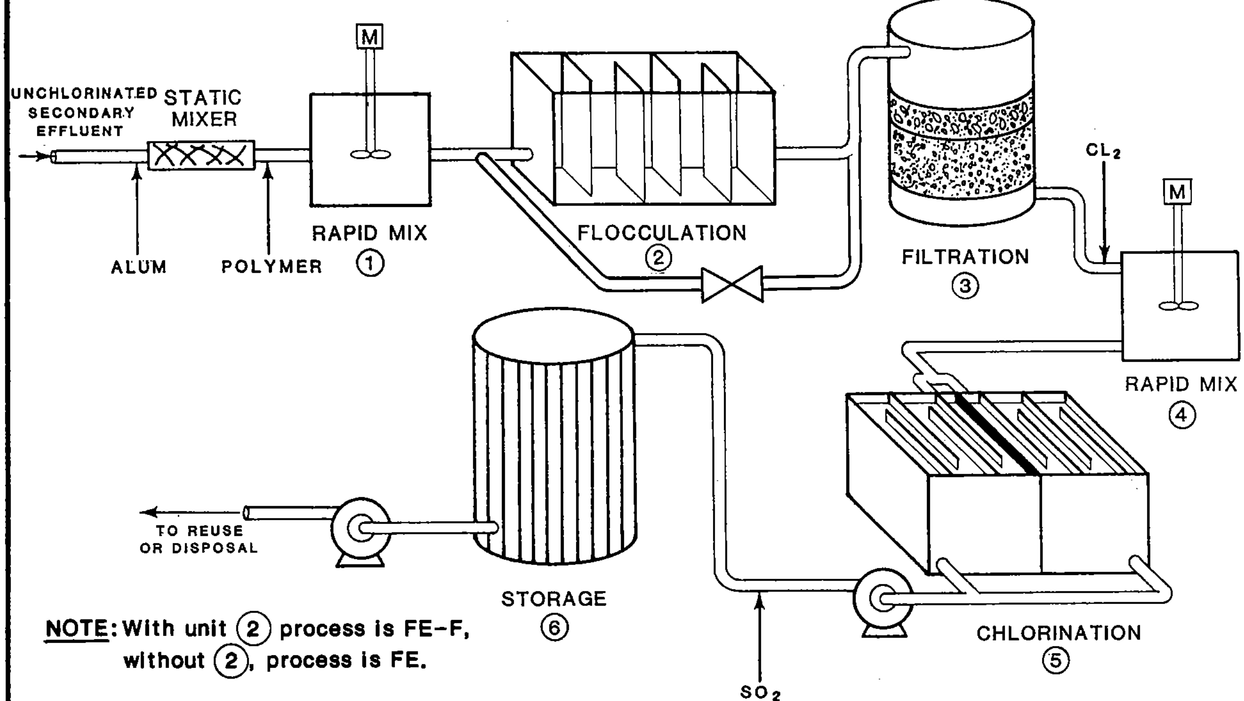
The pilot tertiary reclamation plant consisted of two parallel treatment process trains, the complete California Administrative Code Title 22 process and an abbreviated filtered effluent process. The filtered effluent (FE) process included the addition of low doses of alum (0 to 15 mg/L) and polymer (0 to 0.18 mg/L) as chemical coagulant with a combination of static and mechanical turbine rapid mixing, dual-media gravity filtration at 3.4 $L/m^2.s$ (5 gpm/ft^2), and disinfection using chlorine with a 90-minute theoretical plug flow detention time. In October 1983, flocculation chambers were added to provide a low energy brief flocculation development time. This filtered effluent, FE, flow stream with the flocculator in operation is noted as FE-F. Unless otherwise noted, subsequent discussions of FE include the effluent produced by both the FE and FE-F processes. The filtered effluent with flocculation (FE-F) flowstream is shown in Figure 2. Final effluent dechlorination using sulfur dioxide was practiced during Years One through Three of MWRSA, but was discontinued in June 1983 to ascertain any effects of a chlorine residual on the crops.

The Title 22 (T-22) process, also shown in Figure 2, conforms strictly to the health regulations in the California Administrative Code, Title 22, Division 4. Higher doses of alum (50 to 200 mg/L) and polymer (0.2 mg/L) were used in the T-22 flowstream. After chemical mixing with a static mixer, coagulation and flocculation occurs followed by sedimentation and then filtration through a dual-media gravity filter and chlorination with a 90-minute theoretical detention time plug flow contactor. Dechlorination of the Title-22 flowstream with sulfur dioxide was also discontinued in June 1983.

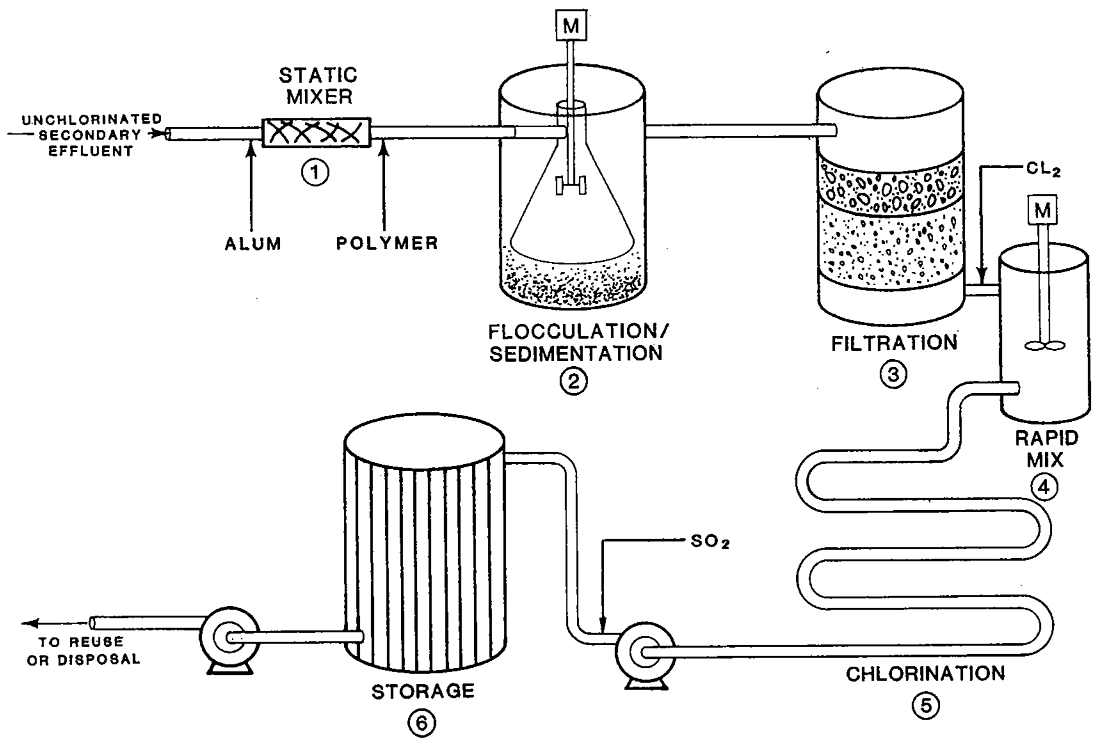
DEMONSTRATION FIELDS

Farm-scale feasibility of using reclaimed water is of special importance to the growers, farm managers, and operators responsible for day-to-day farming practices. To investigate large-scale feasibility of using reclaimed wastewater, two 5-ha (12-acre) plots in the vicinity of the experimental site were dedicated to reclaimed water irrigation, using the FE flow stream. On one plot, artichokes were grown; on the other plot, a succession of broccoli, cauliflower, lettuce, and celery was raised during the first three years of the field investigation. The crops thus raised were observed carefully for appearance and vigor. At the end of each season, they were plowed under and incorporated into the soil. Normal farming practices of local growers were duplicated on these fields with the exception of harvest, which was not carried out. Because of its experimental nature, the produce from these plots was not marketed. Six field observation days were held, and the local growers and the news media were invited to acquaint the agricultural community with the ongoing MWRSA activities and obtain feedback regarding their perceptions, questions, and concerns. Because adequate data on large-scale feasibility were obtained in the first three years of the study

PROCESS FLOWSTREAMS



FILTERED EFFLUENT WITH FLOCCULATION (FE-F)



TITLE-22 (T-22)

irrigation of the demonstration fields with reclaimed water was discontinued in Years Four and Five. Results are discussed in Chapter 8.

EXPERIMENTAL PLOTS

Experimental Design

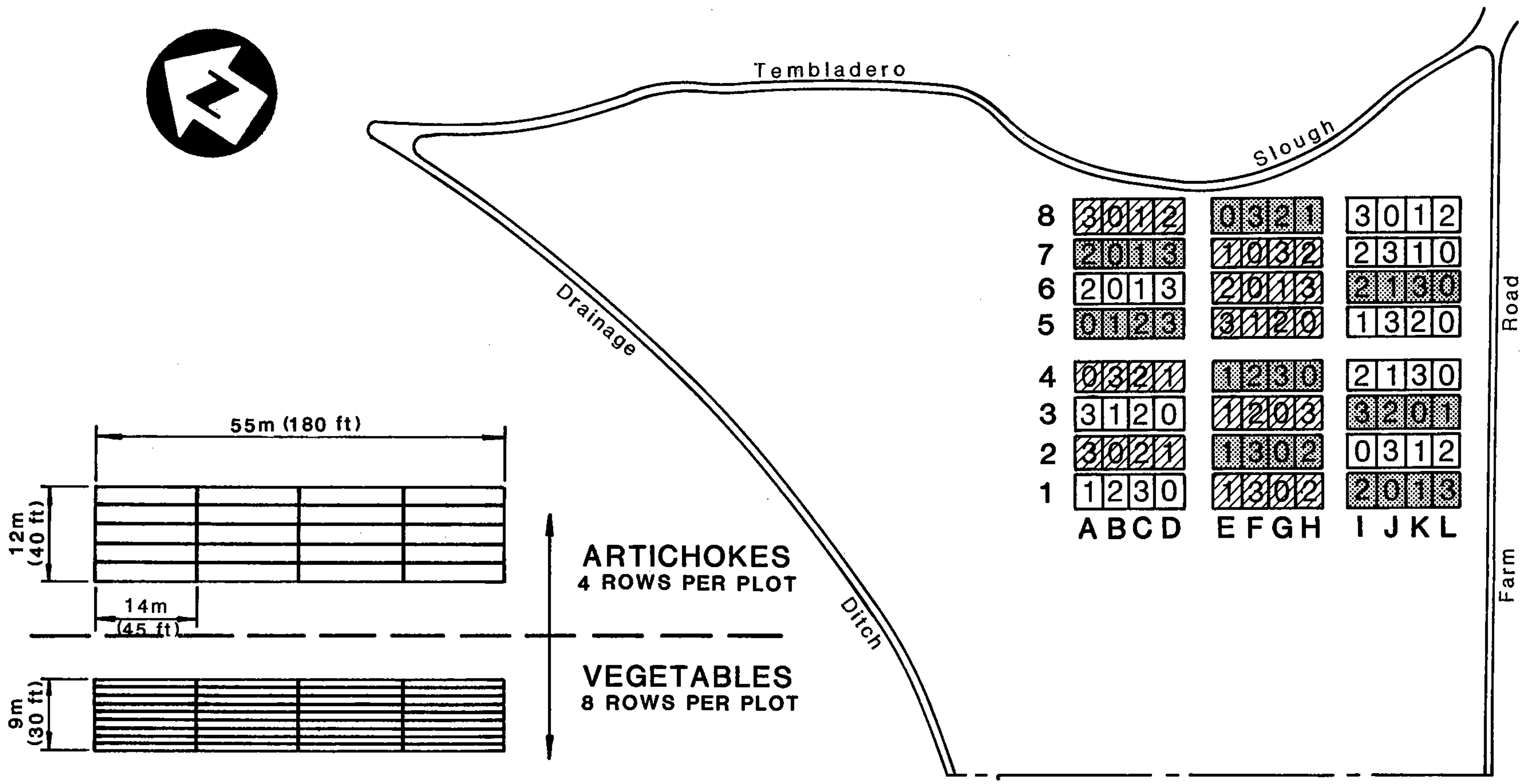
A split-plot design was chosen for the experimental plots at Site D. This design allowed the use of two treatment variables: water type and fertilization rate. Four replicates of three types of main plots were irrigated with T-22 effluent, FE, or a control of well water. These three water types were assigned randomly to main plots within each block or replicate to achieve a randomized complete block (i.e., each block contains all three of the main watertype treatments). Each main plot was then divided into four subplots, each of which was randomly assigned a different fertilization rate treatment: the full amount of nitrogen fertilizer used by local farmers (3/3), two-thirds the full rate (2/3), one-third the full rate (1/3), and no fertilizer (0/3). The full design thus had 48 plots. This process was performed for artichokes and repeated for annual row crops, for a total of 96 plots which occupied 1.2 ha (3 acres) at Site D. Artichoke plots were 12 m x 14 m (40 ft x 45 ft) and row crop plots were 9 m x 14 m (30 ft x 45 ft). Figure 3 shows the resulting pattern of experimental plots. (For a complete discussion of the split-plot experimental design, see Reference 13.)

This experimental design allowed comparison of both irrigation with different water types and the effect of varying fertilization rates. An important aspect of irrigation with reclaimed water is the nutrient value of the effluent to crops. The fertilization rates were designed to elucidate the value of the two effluents as a supplement to fertilization. The rates of fertilizer application varied with each crop, but they were always based on the standard practice in the area. The rates also varied each year because farmers in the area typically revised the amount of fertilizer they applied as a result of the observed results of the prior year's fertilizer applications.

To supply different water types to each main plot, three separate irrigation systems were constructed. Each system consisted of an

FIGURE 3

SITE D EXPERIMENTAL DESIGN



NOTES:

1 SPACING OF ROWS WAS DICTATED BY LOCAL EQUIPMENT SETTINGS. THEREFORE, THE PRIMARY UNITS OF SPACING IN THE EXPERIMENTAL COMPONENT IS IN THE ENGLISH SYSTEM.

2. SHADINGS INDICATE DIFFERENT WATER TYPES. NUMBERS REFER TO DIFFERENT FERTILIZER RATES.

LEGEND

- WELL WATER (hatched)
- TITLE-22 (stippled)
- FILTERED EFFLUENT (blank)

0 = 0/3 FERTILIZATION RATE
1 = 1/3 FERTILIZATION RATE
2 = 2/3 FERTILIZATION RATE
3 = 3/3 FERTILIZATION RATE

underground distribution system with portable aluminum pipes for both sprinkler and furrow irrigation. The distribution system for each water type had a distinctly different and noncompatible coupler to avoid the mixing of pipes used with different water types.

Agricultural Practices

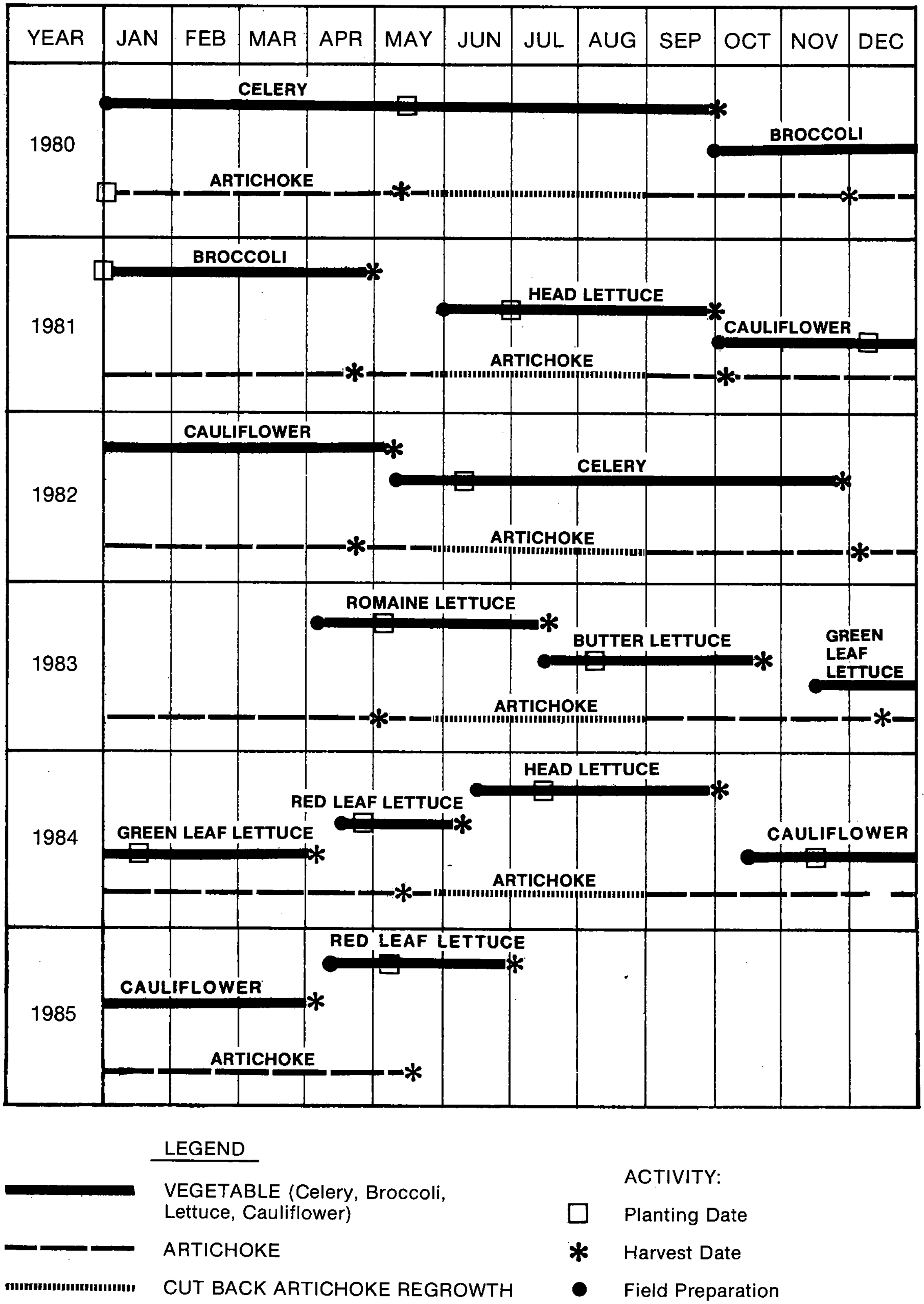
Artichokes were grown in the experimental fields from May 1980 until May 1985. Artichokes are perennial plants which are typically cut back to the ground each May. After cutback, they begin to resprout and produce their first artichokes in late September or early October. They produce continuously until May, when they are cut back again. Harvests are performed about every two weeks during the period of production. Artichokes were fertilized four times a year. A 10-10-5 fertilizer was applied in late July or early August, followed by three applications of ammonium sulfate (21-0-0) during the fall. The total nitrogen applied during the growing season varied from 314 kg/ha (280 lb/acre) in Year One to a high of 474 kg/ha (423 lb/acre) in Year Four.

Row crops were planted in rotation starting with celery in May 1980 and ending with red leaf lettuce in April 1985. Figure 4 shows the crop rotation schedule for the five years of MWRSA. Fertilization regimes varied with each crop's requirements, but all row crops received an application of 12-12-12 fertilizer before planting. Some form of nitrogen fertilizer (21-0-0, 34-0-0, or 15.5-0-0) was generally used for subsequent applications. A complete summary of the chemical fertilizer applications on the experimental plots was published in the Year Five Annual Report, Appendix E.

As with the demonstration fields, local farming practices were followed throughout the project. Sea Mist Farms provided operational guidance, assistance, and farm labor. Detailed information on all agricultural practices was published in each annual report. The appendix to each report listed all agricultural operations chronologically and provided complete descriptions of pesticide applications, irrigation, and precipitation. Standard agricultural practices for artichokes included trapping and poisoning gophers, baiting field mice, spraying pesticides or pheromones every two or three weeks, irrigating about six times per season, field cultivation, fertilizing four times

FIGURE 4

CROP ROTATION SCHEDULE



each season, harvesting about every two weeks, cutting back plants in late spring, and periodically stumping out dead stalks. Row crops were generally sprinkler and furrow irrigated, fertilized, and sprayed with herbicides and pesticides.

BASELINE STUDIES

Before the start of the five-year field demonstration, a number of baseline studies had to be carried out to ascertain the uniformity of the soil on the site of the experimental plots and to ensure the safety of downwind areas from windblown aerosols during irrigation with effluents. To assess the site's soil uniformity, soil samples were taken from grid corners at 50-m (160-ft) intervals and at three depths, and they were analyzed for heavy metal, nutrient, and carbonate/bicarbonate concentrations. (The details are fully reported in the Phase II report.) Based on this analysis, it was concluded that the selected site exhibited satisfactory uniformity. Three alternative configurations for the experimental plots were statistically analyzed, and the one representing the smallest amount of variation in soil solution pH and electrical conductivity was selected for the plot layout.

Data gathered in baseline studies not only helped select the site and configuration, they also formed a pre-experiment documentation of soil conditions for comparison with conditions at the end. Baseline aerosol studies were conducted to ensure the safety of farm workers and local residents. Details of these studies were reported in the Phase II report.

REFERENCES

10. California Artichoke Advisory Board. Personal Communication, Pat Hopper, Manager May 1986

11. Committee on Seawater Intrusion. Draft Report on Salinas Valley Seawater Intrusion Program May 1984

12. Leedshill Herkenhoff, Inc. Salinas Valley Seawater Intrusion Study, prepared for Monterey County Flood Control and Water Conservation District January 1985

13. Little, Thomas M. and F. Jackson Hills. Agricultural Experimentation - Design and Analysis. John Wiley and Sons, New York 1978

chapter 5

PUBLIC HEALTH STUDIES

Virus survival through the treatment process was studied intensively because of concerns over the direct consumption of raw vegetables. None of the 57 samples of either effluent examined over the five-year study contained any measurable naturally occurring virus. None of the plant or soil samples irrigated with effluent contained any virus.

None of the project personnel reported any health complaints related to reclaimed water.

Levels of bacteria and parasites on samples of plant tissues irrigated with effluents were never significantly different from those irrigated with well water.

Aerosol studies demonstrated the safety of the spray and aerosols from a filtered-effluent sprinkler system.

Overleaf:

Artichokes and other vegetables were sprayed with a solution containing a known quantity of deactivated poliovirus and a tracer to test die-off rate of virus with time in the field.

CHAPTER 5

RESULTS OF PUBLIC HEALTH STUDIES

PUBLIC HEALTH CONCERNS

Major public health concerns relating to irrigation of vegetables with reclaimed water are virus survival, heavy metals, bacteria, parasites, aerosols, and organic compounds. The results of specific study components relating to each of these areas are discussed in the following sections. In addition to these studies, the health status of each person assigned to field irrigation, cultivation, or sampling tasks in MWRSA was monitored regularly through frequent questionnaires and thorough initial and exit medical examinations administered by qualified medical professionals. Copies of the reports of these examinations were directly forwarded by the physicians to the Monterey County Environmental Health Officer, who has also been chairman of the MWRSA Task Force. Table 1 summarizes the project personnel health data. No formal epidemiological investigation was deemed appropriate or necessary for the purposes of MWRSA.

VIRUS SURVIVAL

In Situ Virus Monitoring

During Phase III of the MWRSA study, both the influent and the effluent of the two pilot plant process streams (T-22 and FE) were routinely monitored for the presence of naturally occurring animal viruses (for methods, see Appendix B). Such viruses are hereinafter referred to as "*in situ*" viruses to distinguish them from the viruses used in the virus seeding experiments. Table 2 presents the results of this effort. During the five-year period, no *in situ* viruses were recovered from the chlorinated effluent of either process. This amounted

TABLE 1

HEALTH SURVEILLANCE OF MWRSA PERSONNEL

Year	Total Number of Questionnaires Completed	Number of Complaints	Nature of Complaints	Related to Reclaimed Water
One	24	12	8 Phototoxic Dermatitis from Celery 1 Common Cold 3 Physician Visits	0
Two	21	3	2 Physician Visits 1 Nose Bleed	0
Three	11	1	1 Physician Visit	0
Four	22	8	2 Common Colds 3 Physician Visits 2 Muscle Strains 1 Acute Contact Dermatitis	0
Five	22	1	1 Sore Muscles	0
Total	100	25		0

Questionnaires were distributed to ES and UC field personnel at irregular and unannounced intervals soliciting information about health status, doctor visits, and diagnosis. Physicians' services were provided to project personnel, as needed.

TABLE 2

CONCENTRATION OF IN SITU ANIMAL VIRUSES IN PILOT PLANT PROCESS WATERS-PLAQUE FORMING UNITS PER LITER AUGUST 1980 TO MAY 1985

	Process Stream					
Date of	Influent		Title-22		Filtered Effluent	
Sample	Vol (L)	PFU/L	Vol (L)	PFU/L	Vol (L)	PFU/L
07 Aug 80	3.8 NEG		----[a]	----	----	----
19 Aug 80	---	---	1520	NEG	1520	NEG
29 Aug 80	3.8	9	----	----	----	----
10 Sep 80	4.6	NEG	----	----	----	----
19 Sep 80	4.2	3	3087	NEG	3078	NEG
24 Sep 80	4.6	309	3230	NEG	3230	NEG
30 Sep 80	4.6	NEG	3078	NEG	3078	NEG
07 Oct 80	4.6	5	3040	NEG	3040	NEG
10 Oct 80	4.2	27	1907	NEG	1908	NEG
14 Oct 80	4.9	NEG	3230	NEG	3230	NEG
21 Oct 80	4.9	2	3230	NEG	3230	NEG
24 Oct 80	4.9	10	3230	NEG	1900	NEG
28 Oct 80	4.9	4	3230	NEG	2850	NEG
03 Nov 80	4.9	1	3249	NEG	2470	NEG
06 Nov 80	4.9	5	3230	NEG	2166	NEG
11 Nov 80	4.9	734	3230	NEG	2014	NEG
18 Nov 80	4.9	2	3040	NEG	2280	NEG
25 Nov 80	4.9	46	3249	NEG	2330	NEG
01 Dec 80	4.9	2	3230	NEG	3230	NEG
04 Dec 80	6.8	8	3276	NEG	3276	NEG
21 Jan 81	4.6	2	3249	NEG	2421	NEG
12 Jun 81	6.0	2	----	----	----	----
17 Jun 81	6.0	2	----	----	----	----
30 Jul 81	6.0	8	----	----	----	----
04 Aug 81	6.0	1	----	----	----	----
08 Oct 81	6.0	2	3750	NEG	2650	NEG
15 Oct 81	6.0	1	----	----	----	----
22 Oct 81	6.0	3	----	----	----	----
06 Nov 81	6.0	NEG	3800	NEG	3059	NEG
13 Nov 81	6.0	5	3549	NEG	3610	NEG
20 Jan 82	6.0	2	----	----	----	----
04 Feb 82	6.0	64	----	----	----	----
05 May 82	6.0	1	3785	NEG	1552	NEG
16 Jun 82	6.0	NEG	2593	NEG	2888	NEG
22 Jul 82	6.0	NEG	3683	NEG	3028	NEG
11 Aug 82	6.0	1	3695	NEG	3683	NEG
09 Sep 82	6.0	NEG	3773	NEG	3308	NEG
12 Oct 82	6.0	9	3668	NEG	3748	NEG
08 Dec 82	6.0	NEG	3509	NEG	3744	NEG
16 Dec 82	6.0	1	3653	NEG	2801	NEG

TABLE 2 - continued

Date of Sample	Process Stream					
	Influent		Title-22		Filtered Effluent	
	Vol (L)	PFU/L	Vol (L)	PFU/L	Vol (L)	PFU/L
12 Jan 83	6.0	2	3638	NEG	2782	NEG
23 Feb 83	6.0	1	3714	NEG	2309	NEG
17 Mar 83	6.0	NEG	3714	NEG	1514	NEG
04 May 83	6.0	6	2650	NEG	3763	NEG
25 May 83	6.0	1	2384	NEG	3028	NEG
22 Jun 83	6.0	1	2536	NEG	2301	NEG
12 Jul 83	6.0	1	3702	NEG	3142	NEG
10 Aug 83	6.0	3	3710	NEG	3513	NEG
12 Oct 83	6.0	4	3691	NEG	2207	NEG
25 Oct 83	6.0	30	2763	NEG	2422	NEG
09 Nov 83	6.0	13	3713	NEG	1893	NEG
04 Dec 83	6.0	NEG	3448	NEG	3751	NEG
11 Jan 84	6.0	4	3725	NEG	3028	NEG
08 Feb 84	6.0	2	3770	NEG	1249	NEG
08 Mar 84	6.0	1	2090	NEG	3800	NEG
04 Apr 84	6.0	1	3572	NEG	2983	NEG
16 May 84	6.0	NEG	2044	NEG	870	NEG
13 Jun 84	6.0	7	2713	NEG	1794	NEG
25 Jul 84	6.0	NEG	3454	NEG	2888	NEG
22 Aug 84	6.0	26	3800	NEG	3800	NEG
12 Sep 84	6.0	22	3800	NEG	2128	NEG
31 Oct 84	6.0	2	2421	NEG	3724	NEG
26 Nov 84	6.0	17	3800	NEG	3724	NEG
12 Dec 84	6.0	NEG	3420	NEG	3686	NEG
13 Feb 85	6.0	29	3800	NEG	2660	NEG
13 Mar 85	6.0	8	2660	NEG	3705	NEG
16 Apr 85	6.0	3	3724	NEG	2812	NEG
08 May 85	6.0	3	3480	NEG	2650	NEG

[a] Process stream not sampled.

to a total of 186,025 and 159,402 L (49,213 and 42,170 gal) sampled from the T-22 and FE effluents, respectively. The influent to the two pilot processes (Castroville unchlorinated secondary effluent) contained measurable viruses 80 percent of the times sampled, averaging 22 plaque forming units (PFU) per liter ranging from 1 to 734 PFU/L.

Crops irrigated with reclaimed water from either the T-22 or the FE process were monitored for the presence of *in situ* contamination from July 1980 to April 1983. No viruses were recovered from any of these samples (see Table 3). This was also the case for the soil associated with the reclaimed irrigation water. These results are not surprising because no *in situ* virus was ever recovered from the two process waters.

Virus Seeding of Plants and Soil

Although no *in situ* viruses were recovered from irrigated plants and soil, it was important that an estimate be made of the ability of virus to survive under these conditions. A vaccine strain of poliovirus was chosen for all seeding studies as a safe, representative enteric virus. Virus survival measurements were made under both environmental chamber and field conditions. Under chamber conditions, as described in the methods section, the decay rates of deactivated vaccine strain poliovirus were measured on a variety of plants. Each time-decay measurement is reported as the geometric mean of six replicates. The plants included artichokes, broccoli, celery, and lettuce. Cauliflower was not being grown at the time of these experiments. On artichokes, the virus dieoff was log linear with a coefficient of determination (r value) of 0.996, while on other vegetables the rate of virus reduction followed two distinct phases: a very rapid decay during the first 24 hours, followed by a more gradual decay during the remaining exposure days (see Figure 5).

Possible reasons for the shape of these decay curves (linear on artichokes and two-phase on other vegetables) could be due to the relationship between the geometry of the plant, the ability of ultraviolet light to penetrate areas of virus contamination, and the rate at which the exposed vegetable surface dries. Some very limited experimental data indicate that the virus dieoff in a dark chamber is the same as that seen in a lighted one. Interestingly, the rate of drying of the

TABLE 3

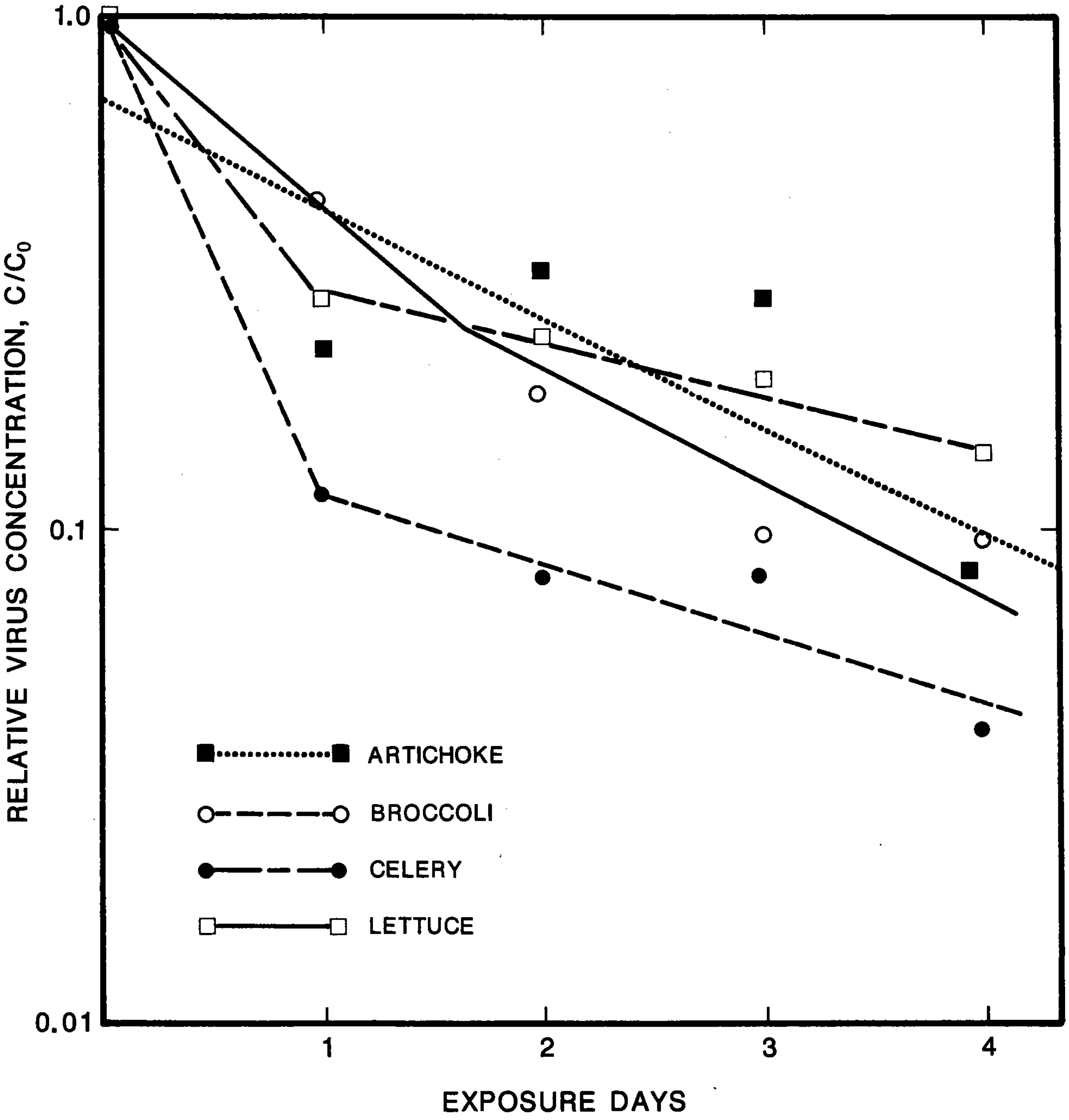
RESULTS OF ENTERIC VIRUS ASSAYS ON CROPS AND SOIL EXPOSED TO RECLAIMED AND WELL IRRIGATION WATER
JULY 1980 TO APRIL 1983

Date of Sample[a]	Crop Type	Irrigation Method	Virus Isolation Crop	Virus Isolation Soil
07 Aug 80	Artichoke[b]	Sprinkle	NEG	NEG
24 Aug 80	Artichoke[b]	Sprinkle	NEG	NEG
10 Sep 80	Celery	Sprinkle	NEG	NEG
12 Sep 80	Celery	Sprinkle	NEG	NEG
24 Sep 80	Artichoke	Sprinkle	NEG	NEG
25 Sep 80	Celery	Furrow	NEG	NEG
29 Sep 80	Celery	Furrow	NEG	NEG
10 Oct 80	Artichoke	Sprinkle	NEG	NEG
28 Oct 80	Artichoke	Sprinkle	NEG	NEG
21 Nov 80	Artichoke	Sprinkle	NEG	NEG
11 Mar 81	Artichoke	Sprinkle	NEG	NEG
08 Apr 81	Artichoke	Sprinkle	NEG	NEG
05 May 81	Broccoli	Sprinkle	NEG	NEG
13 May 81	Artichoke	Sprinkle	NEG	NEG
04 Aug 81	Artichoke	Sprinkle	NEG	NEG
09 Sep 81	Lettuce	Furrow	NEG	NEG
17 Sep 81	Lettuce	Sprinkle	NEG	NEG
24 Sep 81	Lettuce	Sprinkle	NEG	NEG
24 Sep 81	Artichoke	Sprinkle	NEG	NEG
15 Oct 81	Artichoke	Sprinkle	NEG	NEG
06 Nov 81	Artichoke	Sprinkle	NEG	NEG
04 Dec 81	Artichoke	Sprinkle	NEG	NEG
04 Feb 82	Artichoke	Sprinkle	NEG	NEG
05 May 82	Cauliflower	Sprinkle	NEG	NEG
12 May 82	Cauliflower	Sprinkle	NEG	NEG
21 May 82	Artichoke	Sprinkle	NEG	NEG
11 Aug 82	Artichoke	Sprinkle	NEG	NEG
09 Sep 82	Celery	Sprinkle	NEG	NEG
12 Sep 82	Artichoke	Sprinkle	NEG	NEG
09 Nov 82	Celery	Furrow	NEG	NEG
07 Dec 82	Artichoke	Sprinkle	NEG	NEG
15 Dec 82	Artichoke	Sprinkle	NEG	NEG
18 Jan 83	Artichoke	Sprinkle	NEG	NEG
06 Apr 83	Artichoke	Sprinkle	NEG	NEG

[a]Each date represents three separate samples of vegetable and associated soil irrigated with Title-22, filtered effluent, and well water.

[b]Irrigated with well water only.

SURVIVAL OF POLIOVIRUS ON ARTICHOKE, BROCCOLI, CELERY AND LETTUCE UNDER CHAMBER CONDITIONS



C = CONCENTRATION AT TIME INDICATED

C_0 = INITIAL CONCENTRATION

vegetables under study may be related to the shape of the observed virus decay curves. The rate of moisture loss from the vegetables during the chamber experiments shows that, in the case of all but artichokes, there is a rapid loss (12 to 15 percent) of water during the first 24 hours with very little subsequent moisture loss. Thus, the mode of drying appears very similar to the mode of virus decay. In the case of artichokes, the moisture loss was rather slow, reaching 12 percent only after 4 days of exposure. Table 4 shows the survival rates for poliovirus on the exposed plants under chamber conditions of 70 percent relative humidity and a temperature of 60°C. The rates are expressed as T_{99}, or the time in days for a two-order magnitude reduction in virus numbers. It should be noted that although the kinetics of virus reduction seems to be associated with the moisture loss rate from the exposed vegetables the overall rate of virus removal was relatively consistent with most plant types, a T_{99} of eight days, with the exception of lettuce in which a T_{99} of fifteen days was determined.

Survival of vaccine strain poliovirus on selected crops was also estimated under actual field conditions at the Castroville test site (Site D). In this situation, three _in situ_ crops (artichokes, romaine lettuce, and butter lettuce) were exposed to virus during the growing season (April to October, 1983). Virus was sprayed on selected plants of similar size, and contaminated representatives were assayed for virus concentration over periods ranging from four to twenty days (see

TABLE 4

COMPARISON OF T_{99}[a] VALUES FOR POLIOVIRUS ON LETTUCE, ARTICHOKES, CELERY, AND BROCCOLI EXPOSED TO CASTROVILLE CONDITIONS IN ENVIRONMENTAL CHAMBER

Vegetable	T99
Artichoke	8.6
Broccoli	7.8
Celery	8.4
Lettuce	15.1

[a]Time in days for 99% removal

Appendix B for methods). Figure 6 shows the results of these exposures. The data points for virus survival on artichokes each represent a median value of the log of the number of viruses recovered from each of two plants; the zero time point (baseline) was based on the geometric average of the virus recovery from four plants. The number of viruses (PFU) per plant was independent of plant weight. Thus the initial amount of virus found on the plants at time zero was accepted as a reasonable baseline for initial virus concentration. During the growing season, four runs on artichokes were completed. In the case of the two lettuce species, the number of runs was limited because of the relatively short growing season. To compensate for this, each datum point was based on the geometric mean of data from four plants, with the baseline based on the geometric mean of eight plants. Virus decay on all of the seeded *in situ* plants was log linear with time. Using the least squares method, the correlation coefficient, r, for each of the artichoke runs was -0.75, -0.92, -0.93, and -0.96 for runs 1 through 4, respectively. Thus with the exception of the first run (11 Apr 83), these data fit the curve shown. The regression curve for virus survival on the two species of lettuce, based upon r values of -0.97 and -0.93 for romaine and butter lettuce respectively, is a good fit. Tables 5 and 6 show the T_{99} values derived from these figures.

These results indicate that the average T_{99} value for poliovirus on artichokes was 5.4 days. This value is somewhat smaller than that determined in the environmental chamber study in which a T_{99} of 8.6 was estimated. This difference most likely reflects the greater variability in temperature and humidity, which may well be more lethal to viruses than the steady conditions of the environmental chamber. The T_{99} values for the two species of lettuce were of the same order as for artichokes. These values were much lower than that determined for iceberg lettuce in the earlier chamber study. This difference is probably due to the harshness of field conditions, as well as to the fact that an entirely different species of lettuce was involved.

The survival of virus in Castroville soil was determined both under environmental chamber conditions and under field conditions. In the environmental chamber study, 100 g of fresh Castroville soil was

POLIOVIRUS SURVIVAL ON CROPS IN THE FIELD

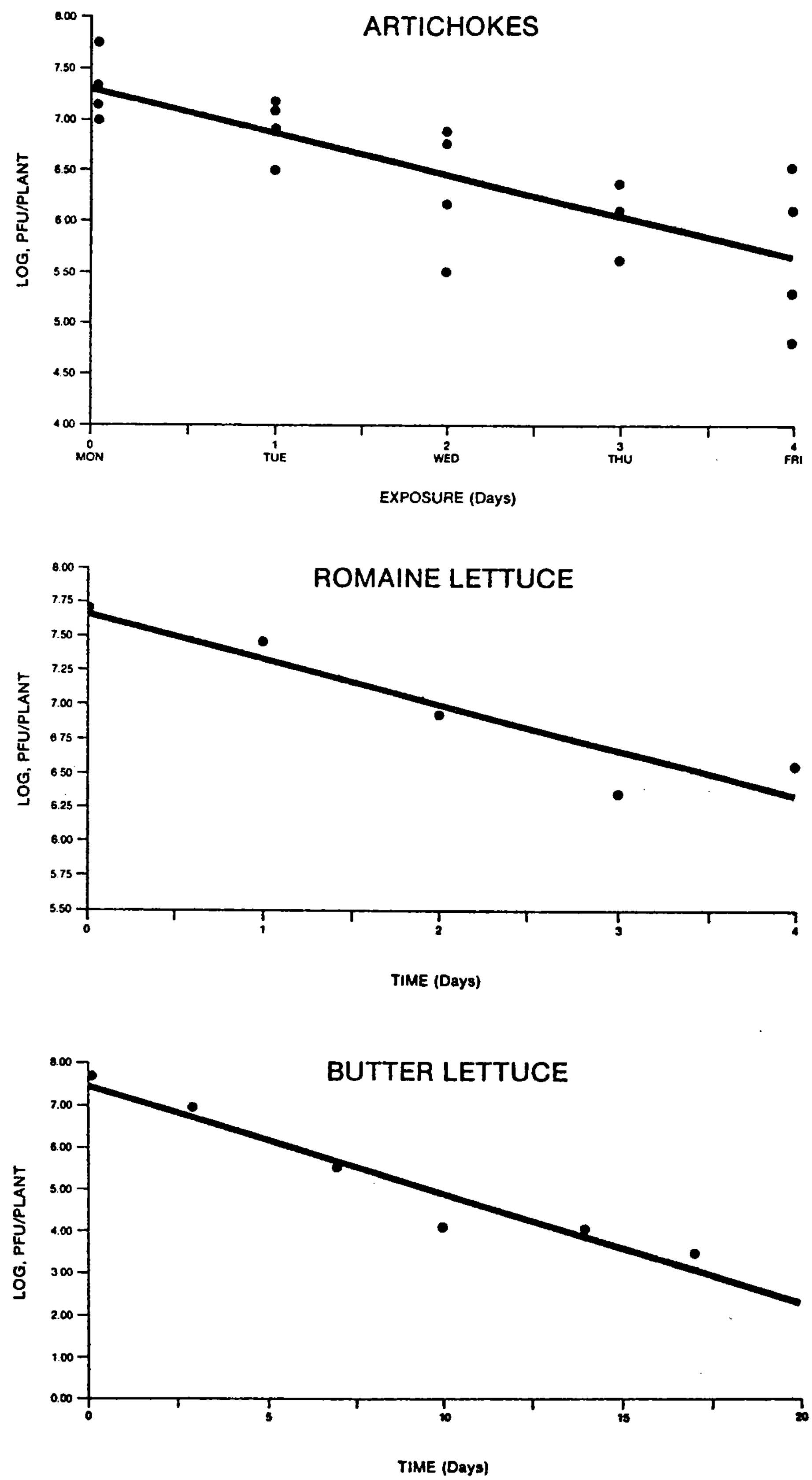


TABLE 5

T_{99} VALUES FOR POLIOVIRUS ON ARTICHOKES IN THE FIELD

Run Number	Date	T99 (Days)
1	11 Apr 83	6.9
2	9 May 83	4.6
3	23 May 83	6.8
4	6 Jun 83	3.4
Average		5.4

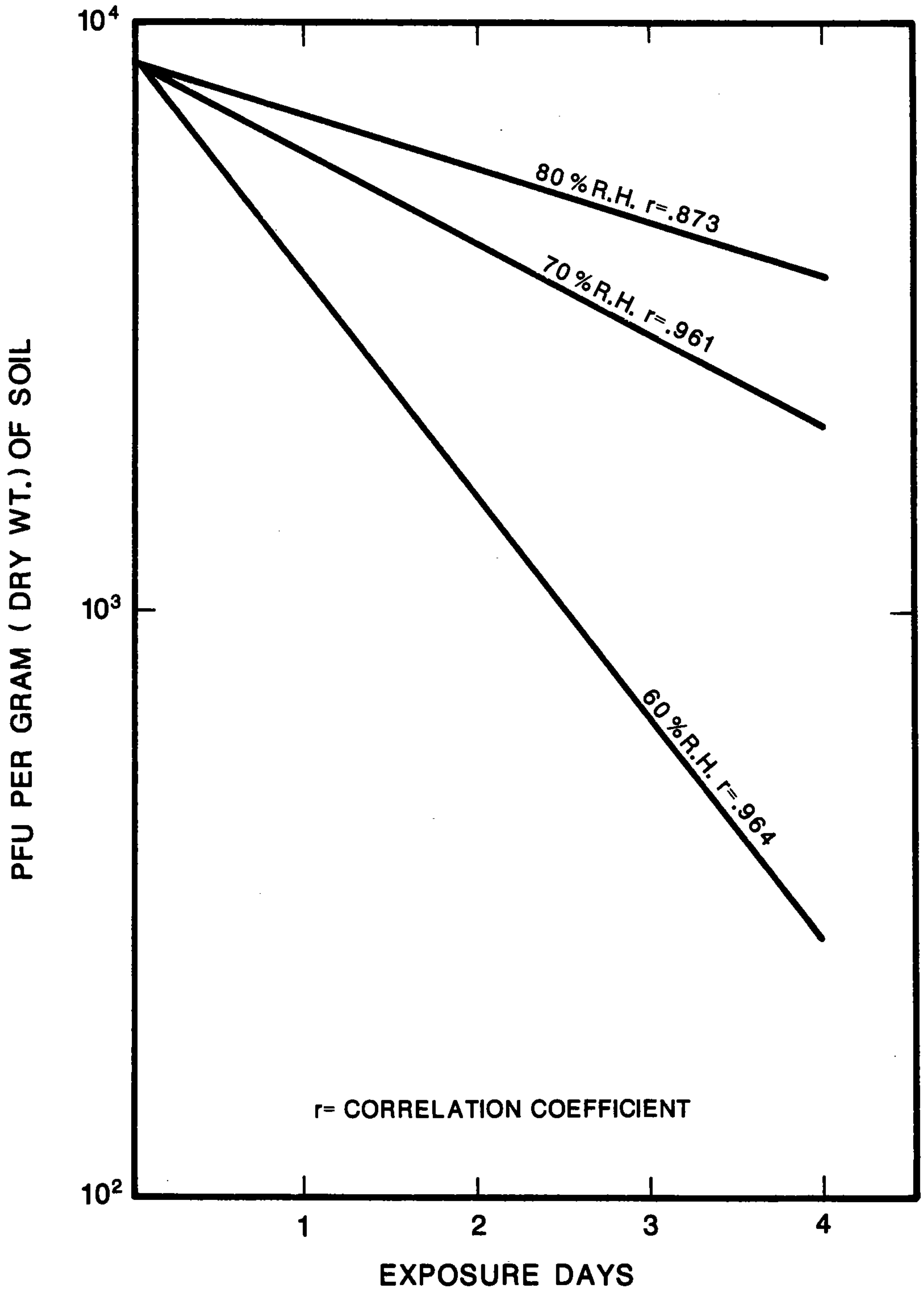
TABLE 6

T_{99} VALUES FOR POLIOVIRUS ON LETTUCE PLANTS IN THE FIELD

Lettuce Type	Date	T99(Days)
Romaine Lettuce	18 Jul 83	5.9
Butter Lettuce	18 Oct 83	7.8

inoculated with a known amount of virus and the decline in virus number was measured over time. Three runs were performed each at a relative humidity (RH) of 60, 70, and 80 percent, respectively, and a temperature of 70°C. On each sampling day, five replicate samples were selected for virus analysis. Figure 7 shows the rate of decline in the number of viruses per gram dry weight of soil. These graphs were derived from a regression analysis of the data collected. The rate of virus decay in soil is much greater at 60 percent RH than at either 70 or 80 percent. The T_{99} values for the decay of virus under these conditions were 5.4, 9.7, and 20.8 days for 60, 70, and 80 percent RH, respectively. Thus at an RH of 70 percent, the T_{99} for viruses in soil, under chamber conditions, was similar to that seen in artichokes (T_{99} = 8.6 at 70

SURVIVAL OF POLIOVIRUS PRESENT IN CASTROVILLE SOIL EXPOSED TO VARIOUS RELATIVE HUMIDITIES



percent RH) but considerably less than that found in virus contamination associated with iceberg lettuce.

The survival of animal virus in Castroville soil under field conditions was studied. The investigation involved the use of Castroville soil seeded with poliovirus and exposed to ambient conditions at the University of California's Sanitary Engineering and Environmental Health Research Laboratory in Richmond, California. This latter site was choosen because (1) the logistics of sampling soil and performing virus analysis frequently over a 20-day period made performing the study at Castroville impractical, and (2) the Richmond site is adjacent to the east shore of San Francisco Bay and has a climate very similar to that found at Castroville with foggy cool nights and mornings and sunny afternoons.

Two test runs were made during the months of June and July 1984 in 30-cm (12-inch) soil columns divided into three 10-cm (4-inch) sections. Temperature in the various soil sections was warmest and, as expected, most variable in the top and middle sections, and it was coolest and most constant in the bottom section. The highest temperature recorded in the upper section was 36°C and the lowest was 17°C. The soil temperatures were similar in both runs. The relative humidity during these time periods averaged between a low of 59 percent and a high of 78 percent. The high humidities were always recorded duing the early morning hours. The total sunlight energy measured during both test series was quite similar, averaging 442 Langleys per day.

Table 7 indicates the number of viruses recovered from soil during both test runs. The rate of virus removal was less linear during run one than during run two. This difference may well be associated with the differences in moisture content changes in the soil columns between the first and second run. The number of viruses inoculated onto each column was 1.6×10^6 and 1.9×10^7 PFU per column for runs one and two, respectively. In both cases, the top and middle sections were contaminated immediately with virus while the bottom remained virus-free throughout the exposure period. No viruses were recovered from any soil section after 12 to 14 days of initial exposure. Figure 8 shows the log reduction in virus per section with time for runs one and two for the

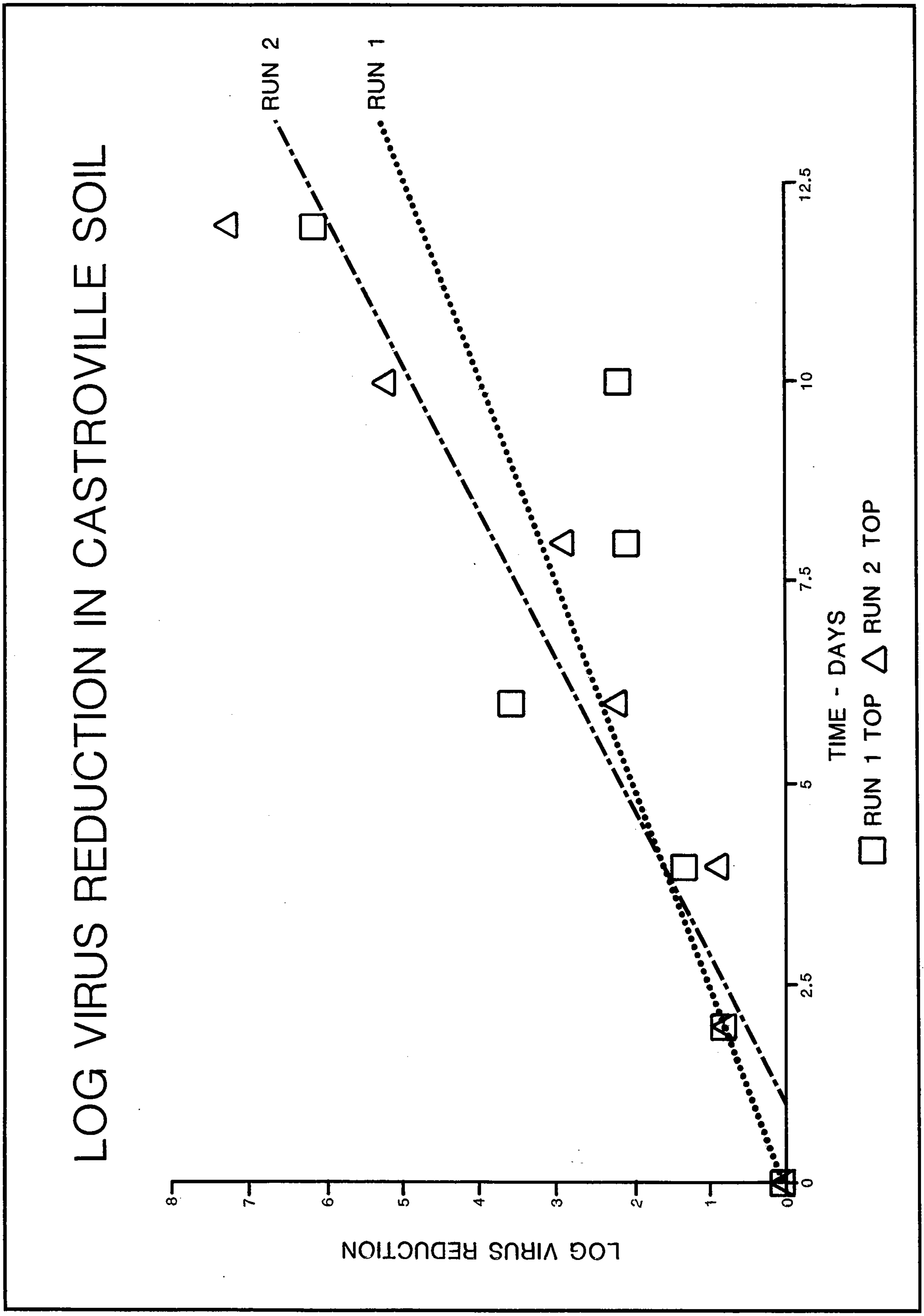
TABLE 7

POLIOVIRUS RECOVERY FROM CASTROVILLE SOIL SEEDING RUNS

Test Day	Run No. 1 Log PFU/Soil Section[a]			Run No. 2 Log PFU/Soil Section[a]		
cm:	Top (0-10)	Mid. (10-20)	Bot. (20-30)	Top (0-10)	Mid. (10-20)	Bot. (20-30)
0	6.21	5.20	0.00	7.28	4.20	0.00
2	5.43	2.78	0.00	6.48	4.07	0.00
4	4.85	1.96	0.00	6.23	3.55	0.00
6	2.53	0.00	0.00	5.08	3.55	0.00
8	4.12	1.17	0.00	4.39	1.81	0.00
10	4.00	2.33	0.00	2.11	0.00	0.00
12	0.00	0.00	0.00	0.00	0.00	0.00
14	0.00	0.00	0.00	3.49	0.00	0.00
16	0.00	0.00	0.00	0.00	0.00	0.00
18	0.00	0.00	0.00	0.00	0.00	0.00

[a] Median values

top and middle sections. The lines represent the least squares best fit. The regression coefficients for the data for runs one and two are 0.83 and 0.95, respectively. As stated previously, virus reduction in run two was much more linear than in run one. The rates of virus reduction in the middle soil column sections were similar to those seen in the corresponding top sections. As reported, in Castroville soil under environmental chamber conditions at a relative humidity of 60 percent the T_{99} was 5.4 days. In the present _in situ_ study, the T_{99}s were 5.2 and 4.8 days for runs one and two, respectively. Thus the rate of virus removal under chamber and field conditions was quite similar.


LOG VIRUS REDUCTION IN CASTROVILLE SOIL
RUN 2
RUN 1
LOG VIRUS REDUCTION
0
1
2
3
4
5
6
7
8
0
2.5
5
7.5
10
12.5
TIME - DAYS
RUN 1 TOP
RUN 2 TOP

BACTERIA AND PARASITES

Irrigation Waters

The quality of irrigation waters improved over the 5 years of the study, while treatment plant operations and storage procedures were optimized. Figure 9 depicts the total coliform levels in all three types of irrigation water sampled at each irrigation event. All three types of waters periodically exceeded the California Department of Health Services' (DOHS) required maximum level of total coliform. The DOHS specifies that the levels of total coliform in treatment plant effluent used for irrigation not exceed a 7-day running median of 2.2 MPN/100 mL with a maxiumum allowable level of 23 MPN/100 mL not to be exceeded more than once in 30 days. This standard, however, is applied to effluent measured at the treatment plant, and is not strictly applicable to irrigation waters sampled in the field. During the course of the study, it became evident that irrigation waters were exceeding these recommended levels even when total coliform levels measured at the treatment plant were below detection limits. These high levels were generated by coliform regrowth in the redwood storage tanks. Regrowth problems were substantially reduced when dechlorination of the effluent was stopped. Total coliform levels were generally highest in FE irrigation waters.

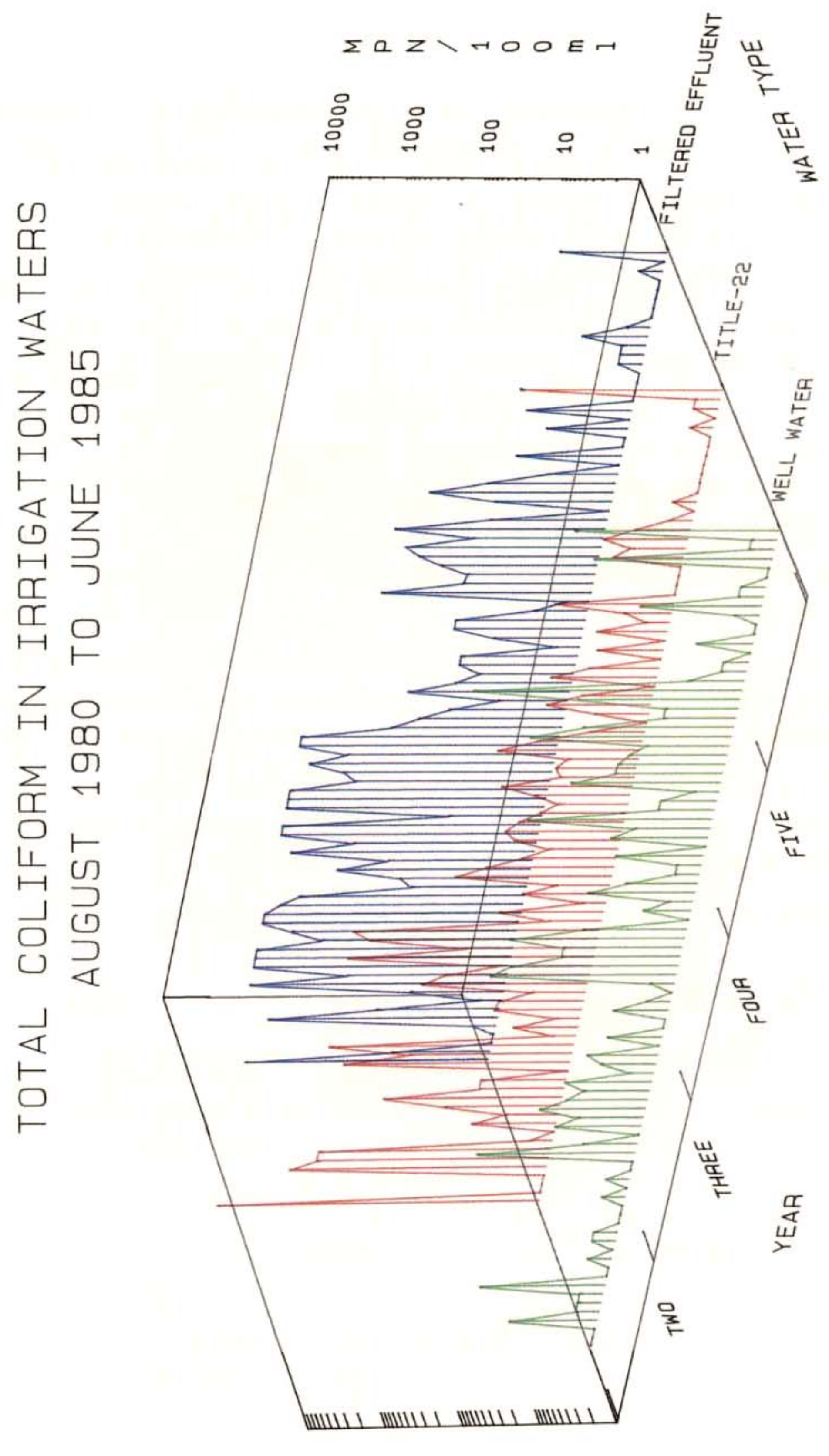
There are no DOHS standards for fecal coliform. Levels in all three water types were at or below 2 MPN/100 mL most of the time. FE exceeded this level more often than the other two water types.

No salmonellae, shigellae, *Ascaris lumbricoides*, *Entamoeba histolytica*, or other miscellaneous parasites were ever detected in any of the irrigation waters.

Soils

The levels of total and fecal coliform in soils irrigated with all three types of water were generally comparable. No consistent significant difference attributable to water type was observed. No salmonellae, shigellae, *Ascaris lumbricoides*, *Entamoeba histolytica*, or other miscellaneous parasites were ever detected in soil samples.

FIGURE 9



ENGINEERING-SCIENCE

Plant Tissue

Neither edible nor residual plant tissues showed any significant difference due to water type in levels of total or fecal coliform. No salmonellae, shigellae, Ascaris lumbricoides, Entamoeba histolytica, or other miscellaneous parasites were detected in edible or residual tissues of artichokes, broccoli, cauliflower, or lettuce. In Year One, parasites such as Entamoeba histolytica, Ascaris lumbricoides, and Taenia were found in both edible and residual celery tissue. Parasites were not limited to those crops irrigated with effluents; they were also found in tissues of crops irrigated with well water.

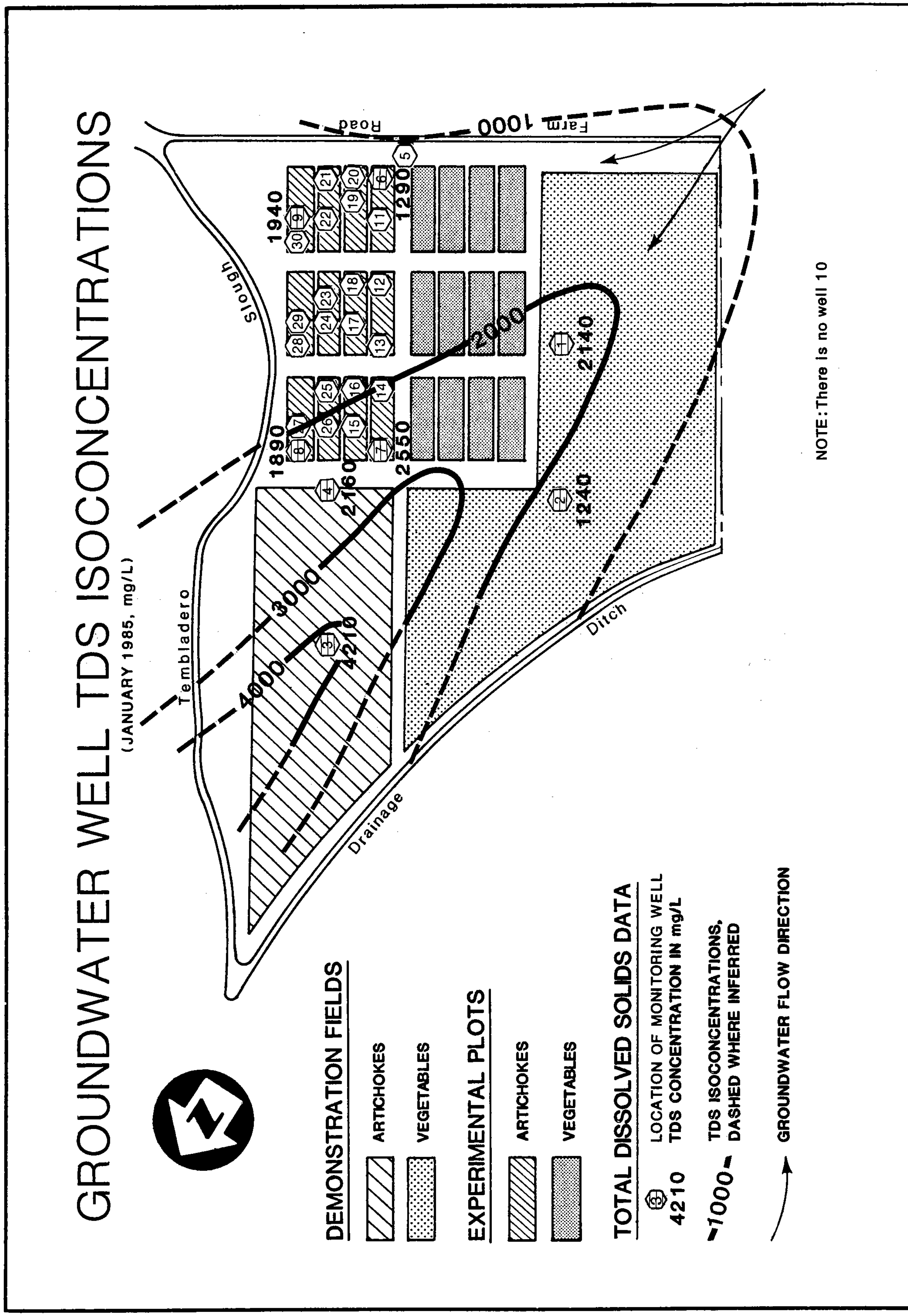
Sampling of neighboring fields detected no relationship between bacteriological levels and the distance from Site D. The aerosol transmission of bacteria was thus deemed unlikely.

GROUNDWATER PROTECTION

Groundwater quality data was collected over the five years of the MWRSA project to ascertain changes in shallow groundwater quality. If no significant change was observed in samples collected from shallow monitoring wells [depth of 5 m (15 ft)] as a result of applied irrigation water, then it could be assumed that impacts to the groundwater at greater depths would also be insignificant. Groundwater for municipal and agricultural purposes in this area is generally extracted from the "400-ft aquifer" (120-m aquifer). Figure 10 shows the locations of all monitoring wells. Only wells one through four were installed in 1980; the rest were installed in 1983. Appendix C presents the water quality data.

An examination of the data indicates that no discernible relationship existed between the shallow groundwater quality and the type of applied irrigation water. Other trends commonly associated with shallow groundwater quality in agricultural areas were observed such as downgradient increases in TDS and seasonal effects. Figure 6.6 illustrates the trend of TDS increasing in the direction of groundwater flow.

FIGURE 10


GROUNDWATER WELL TDS ISOCONCENTRATIONS
(JANUARY 1985, mg/L)
DEMONSTRATION FIELDS
ARTICHOKES
VEGETABLES
EXPERIMENTAL PLOTS
ARTICHOKES
VEGETABLES
TOTAL DISSOLVED SOLIDS DATA
4210
LOCATION OF MONITORING WELL
TDS CONCENTRATION IN mg/L
1000
TDS ISOCONCENTRATIONS, DASHED WHERE INFERRED
GROUNDWATER FLOW DIRECTION
Tembladero
Slough
Drainage
Ditch
Farm
Road
1000
2000
3000
4000
1940
1890
2160
2550
1290
2140
1240
4210
NOTE: There is no well 10

The three most common types of pollutants associated with agricultural irrigation are nitrates, TDS, and pesticides. Nitrates are the residual of fertilizer application. Historically, nitrates are percolated to groundwater not necessarily through over-fertilization, but through over-irrigation. High levels of nitrates applied to soil will eventually be taken up by plants unless moved out of the root zone by excessive irrigation. Elevated TDS levels generally result from poor irrigation water, the leaching of ions from the unsaturated zone, and over-irrigation or ponding of water. Although pesticides have been applied at Site D, they have not been monitored in the groundwater because their use is widespread in the Castroville area.

The most common types of pollutants associated with treated effluent water application are nitrate and heavy metals. Nitrate levels in the two effluents were significantly higher than levels in well water. However, an examination of the filtered effluent water quality data shows no appreciably higher concentrations of metals compared with the Title-22 or well water quality. None of the three types of applied water (filtered effluent, Title-22, or well water) exceed any of the recommended maximum concentrations of trace elements in irrigation water adopted by the SWRCB.

Nitrate appears to be the only constituent potentially indicative of application of effluent. Soluble nitrate concentrations in the perched groundwater zone beneath Site D are best recorded in the artichoke experimental plots where 24 monitoring wells were installed in 1983-1984. Appendix C, Table C.6, shows the nitrate analytical results from eight sampling events between December 1983 and January 1985. Monitoring wells 1, 2, 6, 11, and 20 show consistently higher (10-90 mg/L) than ambient (0-5 mg/L) levels of nitrate in the groundwater. In addition, monitoring wells 9, 14, 21, and 25 have shown concentrations in excess of 10 mg/L nitrate in at least three of the seven sampling events.

The highest concentrations of dissolved nitrate are associated with the July, August, and September 1984 samplings, suggesting a direct relationship between nitrogen application and groundwater nitrate levels. Fertilizers were applied at rates of 56, 135, 135, and 135 kg/ha (50, 120, 120, and 120 lb/acre) of nitrogen on the artichoke experimental plots in July, September, October, and November, respectively. Water percolating through the soil will leach nitrate derived from nitrogen fertilizers. The greater the amount of percolating water, the greater the amount of nitrate that may be leached from the root zone. There appears to be no discernible correlation between the wells with high nitrate and a particular applied water type or fertilizer rate; subplots irrigated with well water, Title-22, and filtered effluent all showed high concentrations (see Figure 3). The anomalously high nitrate values do not correlate with subplots fertilized at a particular rate; subplot 5L with well 6 installed in it had no fertilizers applied and yet it also had high dissolved nitrate. In addition, there is no relationship between water type and high nitrate values; wells 1 and 2, located in the demonstration fields presently irrigated with well water also show high nitrate concentrations.

In conclusion, an examination of all water quality data collected at the MWRSA site suggests that the groundwater quality trends are associated with trends generally applicable in irrigated areas such as increased TDS and nitrate. There is no apparent evidence of a unique contribution by filtered effluent application to the shallow groundwater quality over the five years of data reported.

AEROSOLS

A field study performed early in the operations of MWRSA concluded that aerosol-carried microorganisms from FE sprinklers were not significantly different from those generated by WW sprinklers. This finding was verified through replications both in daytime and nightime operations to account for dieoffs of organisms caused by ultraviolet rays of the sun. Subsequently reported studies by others have corroborated these findings and established the safety of aerosols from an FE spray (Reference 14).

ORGANIC COMPOUNDS

Individual organic compounds present in natural surface waters and wastewater effluents number in the thousands, although normally in trace concentrations detectable only at the part-per-billion level (Reference 15). Toxicological characteristics of these compounds depend on their concentration in the water. The MRWPCA conducts an annual sampling and analysis program on its major treatment plants' effluents.

Volatile Organics

During the 1985 sampling, grab samples from the six MRWPCA treatment plants effluents were taken and blended in proportion to their respective daily flows. Very low levels of six volatile organic priority pollutants (methylene chloride, chloroform, dichloroethene, tetrachlorothene, toluene, and ethylbenzene) and three nonpriority volatile organic pollutants (acetone, 2-butanone, and xylene) were detected in the blended waste streams. The sources of these pollutants are from the disposal of paints, paint thinners, cleaning and degreasing agents, perfumes, inks, dry cleaning solvents, dyes, and various other household products by residential and commercial users. Commercial users known to discharge these pollutants belong to the dry cleaning, industrial laundry, printing, machining, and autoshop business activities. Control of the discharge of these pollutants is being enforced through the issuance of industrial waste discharge permits to affected users, frequent onsite inspections, and monitoring of typical users belonging to each activity. Hence, levels of these pollutants are expected to remain at acceptably low levels (i.e. below the established action levels).

Semivolatile Organics

In the same sampling event, very low levels of four semivolatile organic priority pollutants [phenol, bis (2-ethylhexyl) phthalate, di-n-butyl phthalate, and diethyl phthalate] and three nonpriority semivolatile organic pollutants (4-methylphenol, 2 methylnapthalene, and benzyl alcohol) were detected. The presence of phenol and the phthalate esters: bis (2-ethylhexyl) phthalate, diethyl phthalate, and di-n-butyl phthalate are most likely the result of the washing and rinsing of plastic materials from both commerical and residential sources. Source control activities for those pollutants are aimed at the plastic forming businesses. The presence of 4-methyl phenol is most likely from the discharge of disinfectants, varnish, and raw materials for photographic developer by residential and commercial users. The presence of 2-methylnapthalene is most likely from the discharge of metal-cutting fluids, various lubricants, and emulsion breakers by residential and commerical users. The source of benzyl alcohol is unknown at this time. Source control activities for these pollutants are being directed at the machine and autoshop businesses. Hence, levels of these pollutants are expected to remain at acceptably low levels, below established action levels.

Many mechanisms (including stripping in the spray process, adsorption on soil clay particles, decay, and decomposition) contribute to the further attenuation of any organic compound that may still be present after tertiary treatment. Because of these extremely low concentrations and the existence of highly effective barriers in the irrigation process, a study of specific organic compounds was not included in MWRSA.

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chapter 6

THE WATER RECLAMATION PLANT

The pilot treatment plant performance was monitored closely over the five-year period of MWRSA. After the third year, a short detention-time flocculator was added to the FE process and operations attention was intensified. A series of test runs was conducted entailing varying chemical dose, mixing energy, and flocculation time and energy.

Seeding of influent to the tertiary systems with extremely high doses of vaccine-grade poliovirus was conducted repeatedly to compare FE and T-22 process' ability to deactivate virus. Both systems were capable of five orders of magnitude of virus removal, though the FE process required a higher chlorine dose to achieve this level of removal. The T-22 system was more reliable in meeting standards, especially under adverse operating conditions.

Overleaf:

Storage tanks and irrigation piping system.

CHAPTER 6

RESULTS OF TREATMENT PLANT STUDIES

COMPARISON OF FILTERED EFFLUENT AND TITLE-22 TREATMENT PROCESSES

The performance of the filtered effluent (FE and FE-F) and Title-22 (T-22) tertiary treatment processes during the five-year MWRSA field operations in Phase III and subsequent Phase IV pilot treatment plant operation was evaluated primarily in terms of levels of total suspended solids (TSS), turbidity, coliform bacteria, and viruses. Appendix D presents the treatment plant data analyses.

In October 1983, a small variable detention time flocculation chamber was added to the process train, and this expanded process is referred to as filtered effluent with flocculation (FE-F). A test series to determine the optimum operating parameters for the FE-F process was conducted from May 1984 through March 1985. During the test series, rapid mixer speed, flocculation detention time and energy, and alum/polymer dosage were systematically varied as described in Table 8. Based on the test series results, shown in Table 9, the following operating parameters were selected for the subsequent Phase IV operation of the pilot treatment facilities:

PARAMETER	VALUE
Rapid mixer tip speed and energy (G)	360 ft/min and 150 sec^{-1}
Flocculation theoretical detention time and energy (G)	500 sec and 35 sec^{-1}
Chemical dose	5 mg/L alum and 0.06 mg/L polymer

TABLE 8

RAPID MIX/FLOCCULATION OPTIMIZATION TEST SERIES
FE-F PROCESS STREAM

Test Series Run No.	Date Began	Alum Dose (mg/L)	Polymer Dose (mg/L)	Flocculation: Theoretical Detention Time (sec)	Flocculation: No. of Passes	Flocculation: Energy[b] (sec^{-1})	Rapid Mix[a]: Energy[c] (sec^{-1})	Rapid Mix[a]: rpm	Rapid Mix[a]: Impeller Tip Speed[d] (ft/min)
1	May 84	5	0.06	860	7	60	900	420	1,200
2	Jun 84	5	0.06	860	7	60	300	200	575
3a	Jun 84	5	0.06	860	7	60	150	125	360
3b	Jun 84	5	0.06	860	7	60	150	125	360
3c	Jul 84	5	0.06	125	1	10	150	125	360
3d	Jul 84	5	0.06	125	1	10	150	125	360
4	Sep 84	0	0	125	1	10	150	125	360
5	Oct 84	15	0.18	125	1	10	150	125	360
6	Nov 84	15	0.18	860	7	60	150	125	360
7	Nov 84	0	0	860	7	60	150	125	360
8	Dec 84	10	0.12	500	4	35	150	125	360
9	Dec 84	10	0.12	740	6	52	150	125	360
10	Jan 85	5	0.06	370	3	27	150	125	360
11	Jan 85	5	0.06	615	5	44	150	125	360
12	Feb 85	5	0	615	5	44	150	125	360
13	Mar 85	0	0.06	615	5	44	150	125	360

[a] Volume equals 0.45 m^3 (16 ft^3), system flow rate is 4.7 L/sec (75 gpm) and theoretical detention time is 95 sec.
[b] Total energy (G) imparted equally by all baffles in active sections.
[c] Energy imparted is a G value and is calculated using mixer manufacturer's theoretical steep pitch impeller power number of 0.66.
[d] To convert to m/sec multiply by 0.005.

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TABLE 9

FE-F TEST SERIES - LOG NORMAL MEAN EFFLUENT QUALITY

Series No.	Total Suspended Solids (mg/L) SE	(mg/L) FE-F	(mg/L) T-22	Percent Removal FE-F	Percent Removal T-22	Turbidity NTU SE	NTU FE-F	NTU T-22	Percent Removal FE-F	Percent Removal T-22
1	13.9	6.6	1.0	52	93	4.4	3.0	0.8	31	81
2	12.0	2.7	0.6	78	95	3.6	1.3	0.7	64	81
3a	9.0	1.6	0.5	82	94	2.9	1.0	0.5	67	84
3b	12.2	1.9	0.8	84	93	3.5	1.3	0.5	62	85
3c	11.9	1.3	0.7	89	94	3.0	0.8	0.6	73	82
3d	13.3	1.4	0.6	89	95	3.8	1.0	0.5	75	86
4	15.5	1.3	1.1	92	93	3.9	1.1	0.6	72	85
5	17.0	1.4	1.2	91	93	4.2	1.0	0.7	76	84
6	13.2	1.6	0.6	88	95	3.9	1.0	0.6	74	83
7	17.0	1.5	1.1	91	94	5.1	1.2	0.6	78	88
8	19.3	0.8	0.6	96	97	5.2	0.8	0.5	84	90
9	20.3	1.2	1.1	94	94	5.1	0.7	0.4	86	91
10	11.6	1.0	0.7	92	94	4.0	0.9	0.4	77	89
11	9.4	1.0	0.6	89	94	2.8	0.7	0.4	74	84
12	10.9	1.4	1.0	87	90	3.0	0.7	0.6	78	81
13	10.2	1.0	0.7	90	93	3.0	0.9	0.5	69	83

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Table 10 summarizes the log normal mean TSS and turbidity levels of the secondary effluent (SE, tertiary plant influent), filtered effluent (both FE and FE-F), and Title-22 effluent during the six-year pilot tertiary reclamation facilities operation. Figure 11 shows log normal mean TSS and turbidity levels during Phase IV operation.

The log normal mean turbidity of both the filtered effluent (FE and FE-F) and the Title-22 effluent was well below the DOHS standard of 2 NTU, except for the FE flow system during Year One. Both processes achieved 100 percent compliance with this standard during Phase IV. The log normal mean turbidities of 0.7 NTU for the FE-F flowstream and 0.5 NTU for the T-22 flowstream during Phase IV indicate that both flowstreams are capable of producing excellent turbidity removal.

During Phase IV, very good average overall treatment plant removals of TSS were achieved by both flowstreams, with 99.57 percent removal using the FE-F process (92 percent removal of suspended solids present in the secondary effluent by FE-F facilities), and 99.64 percent removal using the T-22 process (93 percent removal of suspended solids present in the secondary effluent by T-22 facilities) during Phase IV.

During MWRSA Years One through Five, T-22 effluent TSS and turbidity levels were lower than those for FE (FE and FE-F) by a ratio of about 2:1. During Phase IV, the optimized FE process and increased operator attention to the FE-F flow stream reduced this ratio to 1.2:1 for suspended solids and 1.4:1 for turbidity.

As shown in Appendix Table D.3, compliance with the DOHS coliform standard of 2.2 MPN/100 mL was achieved for months at a time in later years and most of the time during the nine-month-long period of intense operation in Phase IV. Both tertiary processes achieved compliance, with the Title-22 process being significantly more reliable. Table D.4 shows compliance with the DOHS requirement that no more than one coliform sample exceed 23 MPN/100 mL within a 30 day period. This criterion was violated only once in Phase IV, by the FE-F system. To comply with both the DOHS coliform standards and a proposed five log virus removal criterion, the FE-F flowstream requires a higher chlorine dose than the T-22 flowstream.

TABLE 10

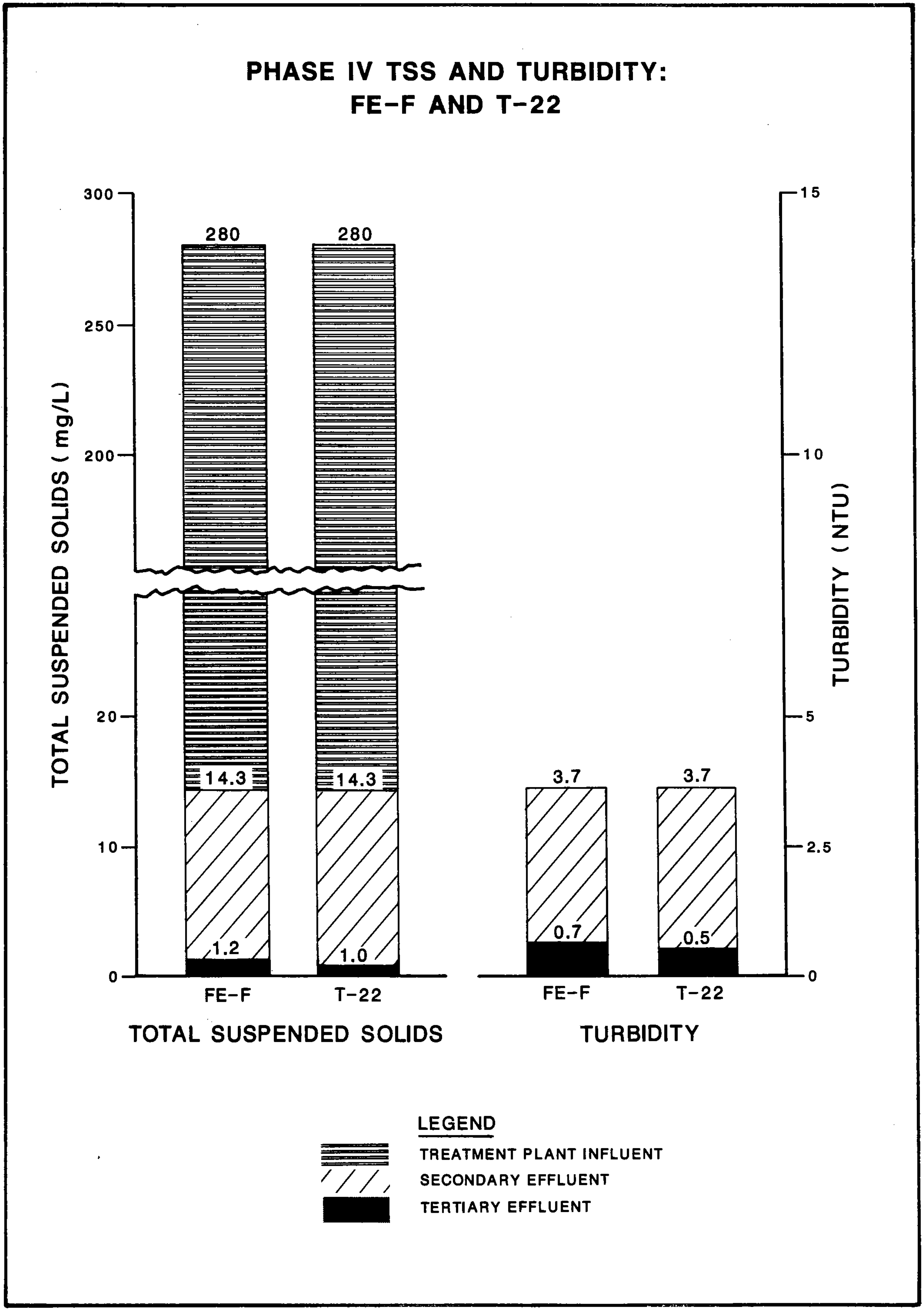
LOG-NORMAL MEAN
BOD^5, TOTAL SUSPENDED SOLIDS, AND TURBIDITY CONCENTRATIONS
IN TREATMENT PLANT EFFLUENTS FROM SEPTEMBER 1980 TO APRIL 1986
(mg/L unless otherwise noted)

	PHASE IV		YEAR FIVE		YEAR FOUR		YEAR THREE		YEAR TWO		YEAR ONE	
Parameters	No. Samples	Mean	No. Samples	Mean	No. Samples	Mean	No. Samples	Mean	No. Samples	Mean	No. Samples	Mean
BOD_5												
SE	115	12	74	14	54	11	60	8	54	8	18	22
Total Suspended Solids												
SE	157	14.3	302	13.4	282	11.2	228	10.2	220	8.7	192	12
FE	--	--	--	--	131	1.9	202	1.5	216	2.2	188	4.4
FE-F	155	1.2	286	1.6	132	1.5	--	--	--	--	--	--
FC	153	5.8	275	4.4	263	5.7	220	4.9	217	4.3	191	6.1
T-22	153	1.0	273	0.8	258	1.3	220	1.0	214	1.2	190	1.9
Turbidity[a]												
SE	155	3.7	288	3.8	217	3.2	212	3.6	218	2.9	--	--
FE	--	--	--	--	102	1.4	209	1.1	213	1.4	178	2.4
FE-F	152	0.7	282	1.1	103	1.0	--	--	--	--	--	--
T-22	149	0.5	262	0.6	195	0.9	205	0.6	211	0.5	183	0.6

[a]Nephelometric Turbidity Units (NTU).

NOTE: Means are 50th percentile values from probability distribution analyses. Data are fitted to the Pearson Type III log-normal distribution.

Key:
- SE = secondary effluent
- FE = filtered effluent without flocculator (September 1980 - September 1983)
- FE-F = filtered effluent with flocculator (October 1983 - April 1986)
- FC = flocculator-clarifier effluent
- T-22 = Title-22 effluent


PHASE IV TSS AND TURBIDITY:
FE-F AND T-22
TOTAL SUSPENDED SOLIDS (mg/L)
300
250
200
20
10
0
280
280
14.3
14.3
1.2
1.0
3.7
3.7
0.7
0.5
TURBIDITY (NTU)
15
10
5
2.5
0
FE-F
T-22
FE-F
T-22
TOTAL SUSPENDED SOLIDS
TURBIDITY
LEGEND
TREATMENT PLANT INFLUENT
SECONDARY EFFLUENT
TERTIARY EFFLUENT

It is difficult to predict the chlorine dose requirements due to the great variation in physical and chemical characteristics of the wastewater at the point of disinfection. Chlorine doses of 11 mg/L for T-22 and 15 mg/L for FE/FE-F were selected as the average doses required to achieve the desired target residuals: 3.5 mg/l for T-22 and 7.5 mg/L for FE/FE-F. These doses and residuals were chosen to achieve at least a 5 log virus removal rate based on extensive virus seeding data obtained at MRWSA during Phase IV. Each process train achieved 100 percent compliance with the DOHS standards for several consecutive months at a time with adequate chlorine doses.

Figure 12 shows monthly chlorination values during Phase IV. From August to November 1985, 100 percent FE coliform compliance was achieved. In addition, virus removal was also essentially 100 percent. To establish at what dose both bacteria and/or virus would begin to break through, the chlorine dose was gradually lowered, starting in November, and chlorine residual management watched very closely. Both average dose and dose range were substantially lowered. As expected breakthroughs began. This phenomenon coupled with winter storms which caused periodic plant upsets, resulted in the increases in bacteria and somewhat reduced virus log removal (see the following virus seeding discussion in this chapter). The end of this test period included an increased attention to chlorine residual control as well as fewer wet weather storm events. The chlorine dose was varied from hour to hour and a slightly higher residual was maintained. The response is noted in Table D.3 for Phase IV, i.e., coliform compliance rebounded through March and April back to 100 percent.

Additionally, during Phase IV (the final year of MWRSA) the ratio of chlorine dose to ammonia nitrogen concentration (Cl_2:NH_3-N) was compared to the general results as well as to specific daily bacteria reduction. This comparison is important because of the chlorine demand that ammonia present in wastewater imposes, giving rise to production of chloramine, itself a disinfectant. Throughout the nine-month test series, the average monthly ratio varied from 1.5 to 13 with the average being about 8. Table 11 shows the monthly average values. It is also

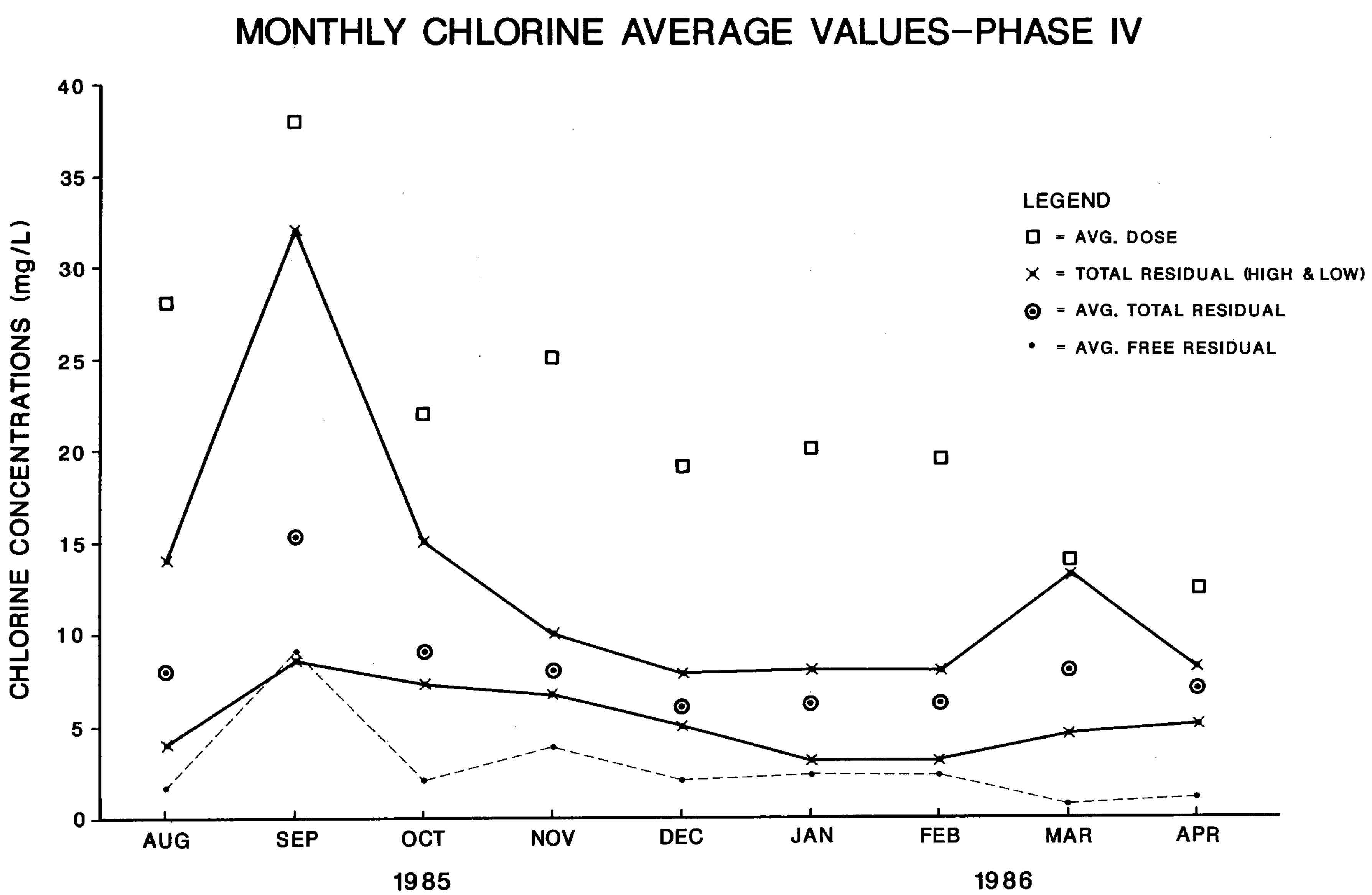

MONTHLY CHLORINE AVERAGE VALUES-PHASE IV
CHLORINE CONCENTRATIONS (mg/L)
40
35
30
25
20
15
10
5
0
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
1985
1986
LEGEND
= AVG. DOSE
= TOTAL RESIDUAL (HIGH & LOW)
= AVG. TOTAL RESIDUAL
= AVG. FREE RESIDUAL

TABLE 11

$Cl_2:NH_3$-N CONCENTRATION RATIO
PHASE IV

Month	Average NH_3-N (mg/l)	Average Cl_2 Dose (mg/l)	$Cl_2:NH_3$-N Ratio (range in parentheses)
August	2.6	28	11 (6.5-22)
September	3.0	38	13 (6.8-50)
October	3.9	22	5.6 (3.2-70)
November	3.0	25	8.3 (3.0-30)
December	3.5	19	5.4 (3.0-28)
January	1.7	20	11.6 (3.0-45)
February	1.7	19	11.3 (3.0-40)
March	4.1	14	3.4 (1.5 -16)
April	9.1	13	1.5 (1.4-7)

Note: Dose is calculated from chlorinator setting and flow rate. The pH of the secondary effluent held very steady at 7.4 throughout the period.

noted that for March and April, the free residual dropped to less than 1.0, a phenomenon consistent with the low $Cl_2:NH_3$-N ratios. This corroborates other recent experience that ammonia in well treated secondary effluents may not only stabilize the ability to control total chlorine residual, but as well, increase disinfection efficiency.

During five years of study, tests for the presence of *in situ* virus, salmonella, shigella, *Ascaris lumbricoides*, *Entamoeba histolytica*, and miscellaneous parasites in the effluents of both tertiary flowstreams were all negative. Natural virus were found in the unchlorinated secondary effluent samples 80 percent of the time.

VIRUS SEEDING

Because of the low level of *in situ* virus typical of secondary virus effluent, it was necessary to perform seeding studies to estimate the virus removal efficiency of each process. The test virus (poliovirus) was introduced into the process streams along with tracer dye

(Pontacyl Pink B) to estimate the dilution factors involved. Two preliminary tests were conducted to determine the effect of the tracer dye on the virus assay system and the effect of chlorination on apparent dye concentration. Table 12 shows that dye is not affected by the presence of chlorine. Table 13 shows that virus recovery is the same for all dye concentrations, even after two hours of exposure.

The results of these tests indicate that the chlorine doses and residuals used during the course of these studies ($\pm$10 mg/L) did not have an effect on the observed dye concentration even at exposure times up to 21 hours. Similarly, at relatively high dye concentrations, no effect was observed on virus assay system, at low levels of virus (65 to 165 PFU/mL). Thus, the acceptability of the use of this tracer dye for the intended purpose was verified.

TABLE 12

EFFECT OF CHLORINE (10 MG/L RESIDUAL) ON APPARENT
PONTACYL PINK B DYE CONCENTRATION

Elapsed Time (Minutes)	Distilled Water Fluorometer Reading	Elapsed Time (Minutes)	Secondary Effluent Fluorometer Reading
0	36	0	37
10	34	15	36
26	33	29	35
40	32	43	36
72	32	60	35
85	32	88	33
1,260	32	1,260	32

TABLE 13

THE EFFECT OF PONTACYL PINK B DYE ON POLIOVIRUS RECOVERY (PFU/0.2 mL OF TEST SOLUTION)

Dye Concentration	Exposure Time in Minutes				
(mg/L)	0[a]	10	30	60	120
0	19.3[b]	26.0	20.0	23.5	19.0
75	24.0	22.5	19.5	21.0	20.5
150	21.5	26.5	26.5	13.0	13.5
300	21.0	21.0	20.5	20.5	17.5
600	25.0	16.0	15.5	19.5	16.0

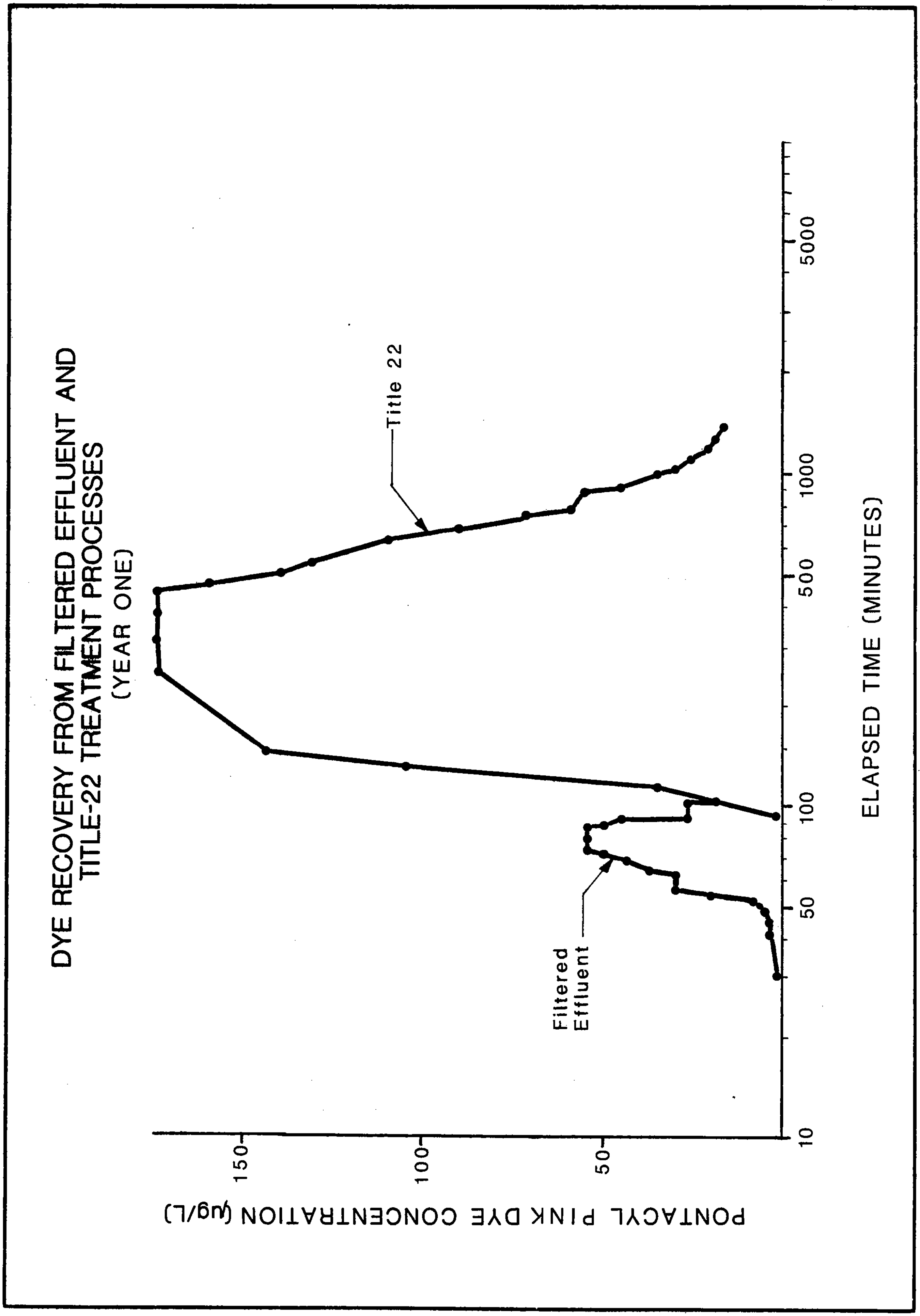
[a]Zero time data based on 12 replicate samples; all other data based on duplicates.

[b]Values are PFU/0.2 ml of test solution recovered after indicated amount of time has elapsed.

Figure 13 shows an example of the hydraulic characteristics of the two pilot processes as measured by Pontacyl Pink dye. Because of the inclusion of a sedimentation step before filtration, the detention time of the T-22 process was longer than that of the FE process. The FE process does not include sedimentation. Post-seeding virus samples were taken when the dye was at peak concentration in the effluent so that the sample would have the highest possible virus concentration. Virus samples were taken from the post-chlorination effluent of each process, and the chlorine residual immediately neutralized with sodium thiosulfate.

Table 14 tabulates the results of the virus seeding studies. The data can be logically divided into four subset periods: (1) 12 Jun 1981 to 22 Oct 1981 (Year Two), (2) 31 Jan 1984 through 23 May 1984 (Year Four), (3) 19 Aug 1984 through 01 May 1985 (Year Five), and (4) 11 Sep 1985 through 30 Apr 1986 (Phase IV). The Year Two data, were collected

FIGURE 13



DYE RECOVERY FROM FILTERED EFFLUENT AND
TITLE-22 TREATMENT PROCESSES
(YEAR ONE)
Title 22
Filtered
Effluent
PONTACYL PINK DYE CONCENTRATION (μg/L)
150
100
50
ELAPSED TIME (MINUTES)
10
50
100
500
1000
5000

TABLE 14

REMOVAL OF SEEDED POLIOVIRUS BY PILOT PLANT PROCESS
AS MEASURED IN POST-CHLORINATION EFFLUENTS

Test Date	Title-22		Filtered Effluent	
	Log Virus Removal	Cl Resid-ual (mg/L)	Log Virus Removal	Cl Resid-ual (mg/L)
Year Two				
12 Jun 81	TOXIC[a]	NM[b]	5.8	NM
17 Jun 81	TOXIC	NM	6.1	NM
29 Jul 81	7.3	NM	6.6	NM
06 Aug 81	8.3	NM	5.7	NM
15 Oct 81	7.3	NM	NM	NM
22 Oct 81	TOXIC	NM	NM	NM
Year Four				
31 Jan 84	NM	NM	6.0	NM
31 Jan 84	NM	NM	5.9	NM
15 Feb 84	NM	NM	3.9	NM
15 Feb 84	NM	NM	4.2	NM
14 Mar 84	NM	NM	4.3	NM
14 Mar 84	NM	NM	4.4	NM
02 May 84	NM	NM	4.9	NM
02 May 84	NM	NM	3.2	NM
23 May 84	NM	NM	>8.0	NM
23 May 84	NM	NM	3.3	NM
Year Five				
19 Aug 84	---[c]	19.0	---[c]	24.0
29 Aug 84	---[d]	NM	5.9	3.0
14 Nov 84	3.5	2.5	3.1	0.5
05 Dec 84	---[d]	NM	1.3	1.0
16 Jan 85	3.8	3.0	>7.7	5.5
27 Feb 85	3.2	2.5	6.4	4.0
20 Mar 85	6.2	2.0	6.3	2.5
27 Mar 85	>8.0	2.5	3.2	2.5
24 Apr 85	2.8	9.0	3.1	8.0
01 May 85	4.2	6.0	3.3	7.0
Phase IV				
11 Sep 85	>8.1	8.3	>7.0	18.4
18 Sep 85	>6.2	7.0	>7.0	14.6
16 Oct 85	>7.4	9.5	>7.6	10.9
23 Oct 85	>8.1	6.8	>8.6	11.3
06 Nov 85	>7.4	8.5	>7.8	11.1
20 Nov 85	>7.4	7.4	>7.7	11.4
11 Dec 85	>7.5	5.7	>8.1	5.0
15 Jan 86	>7.0	2.0	>7.9	3.4
22 Jan 86	>7.1	2.6	>7.9	8.7
05 Feb 86	>7.6	6.6	>8.3	8.4
26 Feb 86	5.6	5.4	3.0	0.0
12 Mar 86	>8.3	3.8	4.9	7.3
19 Mar 86	>8.2	4.0	>7.8	5.8
02 Apr 86	6.1	8.8	6.0	9.9
09 Apr 86	4.5	9.8	4.5	8.1
16 Apr 86	4.9	6.3	5.2	8.0
23 Apr 86	6.7	7.2	6.1	8.9
30 Apr 86	5.2	7.2	5.0	7.5

[a] Sample toxic to Buffalo Green Monkey Kidney cell culture.
[b] Not measured (NM).
[c] High chlorine residual.
[d] Tertiary plant malfunction.

during the summer and fall of 1981. Although the virus removal efficiency of the T-22 process was slightly higher than that of the FE system during Year Two, three samples are too few to allow attribution of significance to this difference.

During the Year Four virus seeding, only the FE process was evaluated, to concentrate on measuring the virus removal efficiency of this process. The results of these runs indicate an average log virus removal in the FE process of 4.5 ±1.0. (This does not include the >8.0 log removal of 23 May 84 which cannot strictly be included in an average. If we arbitrarily assign a value of 8.0 to the test date of 23 May 84, an average removal of 4.8 ± 1.5 results.) On the average, the virus removal efficiency of the FE process was lower than observed in the Year Two. However, the range of values was so wide that no statistically significant difference actually existed between the results of the two periods.

During Year Five, testing was conducted so that the two processes could be compared while at the same time monitoring the chlorine residual during the time periods of the virus seeding runs. In the initial virus seeding tests of this period, there were some problems with pilot plant malfunction and excess chlorine residuals. The average log virus removal during the entire period was 3.9 ±1.1 for the T-22 process and 4.1 ±1.8 for the FE process. The difference between the virus removal efficiency of the two processes appears to be nil. The average chlorine residual for the T-22 effluent was 3.9 ±2.6 mg/L and 3.8 ±2.6 mg/L in the FE effluent (excluding the high residuals of 19 Aug 84). No statistically significant relationship between chlorine residual concentration and virus removal efficiency was observed. Calculation of a relationship was made difficult because of the large number of seeding events with complete removal. Relationships between chlorine residual and virus removal were also undoubtedly complicated by the presence of different chlorine species. On the average, the chlorine residual was the same for both processes with fairly large differences occurring from run to run.

The Phase IV virus seeding study began in September 1985 and was designed to further clarify the differences, if any, between the virus removing efficiency of the two processes. Both chlorine dose and residual, in addition to ammonia nitrogen (NH_3-N), were measured during each seeding run. With few exceptions in the first 13 of these runs, the observed virus reduction was such that their final concentration in the effluents was below the detection limit of the virus assay. During the first two runs (11 Sep 85 and 18 Sep 85), the high chlorine residual in the FE process effluent (18.4 and 14.6 mg/L, respectively) could account for the high degree of virus removal observed during these times. The reason for the apparent improvement in virus removal seen in the rest of these seed runs is not clear. On the average, the chlorine residual maintained during this period of 13 runs was higher than that seen during previous periods, i.e., 6.0 $\pm$2.2 and 8 $\pm$2.7 mg/L in the T-22 and FE effluents respectively. Because a tenuous relationship was seen between chlorine residual and virus removal efficiency in earlier periods and because some of the test runs in earlier series also had some chlorine residuals of magnitude equal to those in the first part of Phase IV, it is difficult to explain the observations as a result of an average increase in chlorine residual. As shown in Table 14, during these runs virus was recovered on two occasions (26 Feb 86 in T-22 and 12 Mar 86 in the FE effluent) when the chlorine residual was reasonably close to the average. The virus assay procedures being used were the same as previously used. To verify the virus assay method on 26 Feb 86, no chlorine was applied to the FE process stream and seed virus was recovered in numbers that would be expected. During all these runs, the number of seeded viruses was being measured at the post-filter, unchlorinated stage of each process. In all instances, seed virus was recovered in a magnitude that would be expected. Thus, it appeared that the virus removal assay system was not at fault.

Table 15 summarizes the data collected during the 13 Phase IV seeding runs from September 1985 to March 1986. Because the levels of chlorine residual were higher during these seeding runs, there was some concern that insufficient chlorine neutralizer (sodium thiosulfate) was being added to the final virus sample. Excluding the two exceptionally high chlorine doses in the initial FE test runs, thiosulfate was

TABLE 15

SUMMARY OF PHASE IV VIRUS SEEDING RUNS
(11 SEP 85 TO 19 MAR 86)

Test Date	Chlorine Dose (mg/L)	Chlorine Residual (mg/L)	Log. Virus Removal	Ammonia Nitrogen (mg/L)
T-22 Process				
11 Sep 85	20.0	8.29	>8.1	5.3
18 Sep 85	18.2	6.95	>6.2	2.9
16 Oct 85	19.3	9.48	>7.4	2.7
23 Oct 85	19.5	6.83	>8.1	2.1
06 Nov 85	19.7	8.53	>7.4	2.8
20 Nov 85	19.5	7.39	>7.4	1.8
11 Dec 85	13.5	5.69	>7.4	2.2
15 Jan 86	14.9	1.97	>7.5	0.3
22 Jan 86	18.7	2.61	>7.1	0.7
05 Feb 86	18.2	6.64	>7.7	1.5
26 Feb 86	13.9	5.44	5.6	1.4
12 Mar 86	11.6	3.78	>8.3	3.7
19 Mar 86	10.7	4.00	>8.2	1.6
FE Process				
11 Sep 85	48.3	18.35	>7.0	3.5
18 Sep 85	31.5	14.64	>7.0	2.7
16 Oct 85	27.7	10.94	>7.6	2.2
23 Oct 85	26.8	11.34	>8.6	5.2
06 Nov 85	29.0	11.14	>7.8	6.6
20 Nov 85	31.1	11.38	>7.7	3.9
11 Dec 85	18.7	5.00	>8.1	2.8
15 Jan 86	20.7	3.36	5.5	0.6
22 Jan 86	22.8	8.74	>8.0	4.0
05 Feb 86	20.0	8.39	>8.4	0.9
26 Feb 86	00.0	0.00	3.0	1.6
12 Mar 86	14.9	7.26	4.9	7.6
19 Mar 86	16.1	5.80	>7.8	1.5

calculated to be present in excess. As a precaution, beginning with the 26 Feb 86 run, the amount of thiosulfate used to neutralize the residual chlorine was doubled. With the increased dose of neutralizer virus was isolated on one occasion (26 Feb 86) from the T-22 effluent but not from a subsequent run (on 12 Mar 86). Because the chlorine residual in the neutralized samples was not measured directly, there may have been instances when some chlorine residual was present for a prolonged time, although the calculated dose was in excess. As stated previously, the reason for the high level of virus removal during this phase of the seeding experiments is not clear. In the last five runs of the seeding study, seeded virus was recovered from all samples collected. The virus removal levels were similar to those obtained during the second and third periods of the virus seeding studies.

On examination of all the virus seeding results, it is clear that there is variation in the pilot plant operation and that the statistical distribution of the virus removal data may not be normal. Thus to determine if there is a difference in virus removal between the two processes (T-22 and FE), the nonparametric Wilcoxon Signed Rank Test was applied in which the differences between a set of matched pairs of observations are investigated. In this instance, 13 matched pairs of data (see Table 16) were appropriate for statistical analysis. The results of the analysis indicate that statistically there was no difference in the virus removal efficiency of either process. On the average, each process removes approximately five logs of virus.

During the course of the virus seeding studies, the effectiveness of the two pilot plant processes in removing virus before chlorination was examined. One series of experiments was conducted to determine the effect on virus-removing capability of various alum and polymer pre-filter additions to the FE process. The second series of observations included measurements of seed virus after filtration and before filtration in both the T-22 and FE processes in order to gain some insight into the contribution of this portion of the treatment process to virus reduction.

In the first series of experiments, alum and anionic polymer (Dow Anionic 825) dose applied to the filtered effluent system was varied. The influent was seeded with vaccine strain poliovirus, f-2 coliphage, and flourescent dye. A 19-L sample of post-filtration (nonchlorinated) effluent was collected when the dye concentration was obviously high, usually 10 minutes from the time of inoculation. The coliphage was included to determine the efficacy of using this virus as a surrogate for animal viruses in determining unit process efficiency. The filter loading rate was 3.4 $L/m^2.s$ (7,200 gal/sq ft.d).

TABLE 16

SAMPLES FROM PAIRED RUNS USED IN THE WILCOXON SIGNED RANK TEST TO COMPARE THE VIRUS REMOVING EFFECTIVENESS OF THE T-22 AND FE PILOT PROCESSES

Test Date	Pilot Process T-22	Pilot Process FE
12 Jun 81	7.3	6.6
17 Jun 81	8.3	5.7
14 Nov 84	3.6	3.1
27 Feb 85	3.2	6.4
20 Mar 85	6.2	6.3
24 Apr 85	2.8	3.1
01 May 85	4.2	3.3
26 Feb 86	5.6	3.0
02 Apr 86	6.1	6.0
09 Apr 86	4.5	4.5
16 Apr 86	4.9	5.2
23 Apr 86	6.7	6.1
30 Apr 86	5.2	3.1
Median	5.2	5.2

Table 17 presents the combination of doses of alum and polymers. Process mode X1 (5.0 mg/L alum and 0.06 mg/L polymer) is the combination used throughout the MWRSA study. The other doses are a combination in which 0, 50, and 100 percent of the mode X1 dose are used. In most instances, each process mode was inoculated four times with large quantities of viruses. The concentration of dye recovered in a particular sample was used as the basis for determining the dilution factor to be applied.

Table 18 shows the results of these studies. The percentage of poliovirus removal was quite variable under all process modes, and in a number of cases it was zero. The most effective mode was X3 (2.5 mg/L alum and 0.03 mg/L polymer) in which an approximate average of 89

TABLE 17

ALUM AND POLYMER DOSE REGIME FOR DETERMINING EFFECT OF DOSE ON VIRUS REMOVAL BY FILTRATION

Process Mode	Alum Dose (mg/L)	Polymer Dose (mg/L)
X1	5.0	0.06
X3	2.5	0.03
X4	2.5	0.00
X5	0.0	0.03
X2	0.0	0.00

percent virus removal was observed. The low percentage removal and large variation in results among the other modes would indicate no difference in the virus removal efficiency of these dosing modes, which include noadditions at all (X2). The 89 percent removal seen in X3 may be significantly greater than seen in the other operating modes, but it is virtually nothing when evaluating such large numbers of viruses.

The coliphage f-2 were removed to a considerable extent by the filtering process, as much as a 5-log reduction. This indicates that this bacteriophage is quite sensitive to the filtering process, with or without coagulant addition, and would not be a good surrogate virus for the measurement of the treatment plant processes. It also illustrates that a test virus must be chosen carefully when evaluating treatment systems.

The results of this series of experiments would lead one to conclude that there is little, if any, effect of coagulant addition on virus removal by filtration.

From March 1984 to April 1986, seed virus recovery measurements were made on the unchlorinated, post-filter effluent from the T-22 and FE processes. Table 19 summarizes the results of these determinations as a percentage of poliovirus removal.

TABLE 18

SUMMARY OF PERCENT VIRUS REMOVAL FROM FILTERED EFFLUENT PROCESS POST-FILTER EFFLUENT ASSOCIATED WITH VARIOUS COAGULANT ADDITIONS

Process Mode[a]	Run No.	F-2 Bacteriophage	Poliovirus
X1	1	99.9973	0[b]
	2	99.9970	0
	3	NM[c]	0
X3	1	>99.9956	>99.0952
	2	99.9624	88.6364
	3	99.9624	98.2727
	4	99.9843	68.0952
X4	1	>99.9960	48.8235
	2	99.0000	0
	3	99.8055	60.6667
X5	1	99.9298	45.0000
	2	99.8348	0
	3	99.8967	0
	4	99.8273	0
X2	1	99.9993	0
	2	>99.9994	0
	3	99.9997	57.7778
	4	99.9994	31.6667

[a]See Table 7.10 for explanation of process mode.
[b]More viruses recovered than introduced. This is the result of the breaking up of "virus clumps" as they pass through the filter.
[c]NM = not measured.

An examination of the results indicates two relatively distinct subsets of data: one from 14 Mar 84 to 01 May 85 (Years Four and Five of Phase III) and the other from 11 Sep 1985 on (Phase IV). In the first time period (Phase III), the virus removal efficiency of the FE direct filtering process was similar in magnitude to that observed during the coagulant addition studies, averaging 61 $\pm$29.5 percent, while the T-22 process gave an average removal of 98.3 $\pm$3.9 percent. These results indicate a statistical difference between the two processes (using the Wilcoxon Signed Rank Test) and also indicate the wide variation in

TABLE 19

PERCENT POLIOVIRUS REMOVAL FROM TITLE-22 AND FILTERED EFFLUENT UNCHLORINATED, POST-FILTER EFFLUENTS

Test Date	Process Stream	
	Title-22	Filtered Effluent
Years Four and Five, Phase III		
14 Mar 84	NM	11.3
14 Mar 84	NM	0.0
02 May 84	NM	75.8
02 May 84	NM	65.0
23 May 84	NM	57.6
23 May 84	NM	55.3
19 Aug 84	99.8	95.6
29 Aug 84	99.2	48.3
14 Nov 84	99.9	99.6
05 Dec 84	----[a]	59.2
16 Jan 85	99.8	96.3
27 Feb 85	99.8	99.6
20 Mar 85	99.9	75.9
27 Mar 85	99.8	68.6
24 Apr 85	99.5	57.0
01 May 85	87.4	20.6
Phase IV		
11 Sep 85	99.9	99.7
18 Sep 85	99.6	99.0
16 Oct 85	98.7	----
23 Oct 85	99.0	----
11 Dec 85	98.7	99.4
15 Jan 86	98.4	96.0
22 Jan 86	98.7	97.5
05 Feb 86	99.5	98.7
26 Feb 86	99.0	98.7
03 Mar 86	96.8	98.0
19 Mar 86	99.4	98.0
02 Apr 86	99.6	99.6
09 Apr 86	95.0	96.8
16 Apr 86	99.0	98.4
23 Apr 86	97.5	98.4
30 Apr 86	99.0	99.0

[a]Pilot plant malfunction on T-22 stream.

efficiency associated with the FE filtration process as compared to the T-22 stream. In Phase IV, the results of the seed virus removal tests were much different. In this instance, there was no difference in the virus removing efficiency of either process. The average removal for the T-22 stream was 98.6 ±1.2 percent and 98.4 ±1.0 percent for the FE filter effluent. The major difference between the plant operation during Phases III and IV was that during Phase IV, every effort was made to have the filters freshly backwashed and the plant operating smoothly. From these data, it can be concluded that the T-22 process preceding chlorination, on average and with small variation, removes >98 percent of the seeded virus during both routine and optimized operating conditions. The FE direct filtration process is equivalent to the T-22 process when the plant is closely controlled and monitored, but if not closely controlled and monitored, the results may be very inconsistent. Thus, from the point of view of process reliability, the T-22 treatment preceding chlorination exceeds that of the FE system. The chlorination process is thus seen to be the most important step in virus inactivation, because after chlorination there were no differences in the removal efficiency of the two systems.

chapter 7

AGRICULTURAL FINDINGS

Quality of irrigation water from either effluent was in the acceptable range, for all parameters of concern to vegetable irrigation. Natural heavy metals concentrations in the surface soil were generally high, compared to other California soils and the subsoil. No additional contributions from the effluent irrigations were detected. Plant tissue heavy metals were similar for well-water and effluent-irrigated crops.

Soil permeability did not appear to be affected by irrigation with either effluent.

Crop yields were often superior in plots irrigated with reclaimed water. Crop quality was generally excellent for crops irrigated with all three water types.

From an agricultural perspective, no problems are anticipated, no precautions are needed and no changes in farming practices are necessary for use of reclaimed effluents (FE or T-22) for irrigation of vegetables.

Overleaf:

All agricultural practices, throughout MWRSA were directly parallel to those of other farmers in the area. No changes were necessitated to accomodate reclaimed water use for irrigation.

CHAPTER 7

AGRICULTURE RESULTS

This chapter summarizes the agricultural effects of irrigating crops with reclaimed wastewater. A summary of significance of all analyses of variance performed on soil and plant data is presented in Appendix C.

IRRIGATION WATER QUALITY

Tables 20 and 21 present range and median values of chemical constituents and metals in irrigation waters. As one would expect, the two effluents had higher levels of most constituents than did well water. Levels of nutrients and salts in the irrigation waters are of particular concern.

The nutrient value of both effluents was substantial. An average of 34 kg/ha (30 lb/acre) of nitrogen was applied to the experimental plots each year in the Title-22 waters; 37 kg/ha (33 lb/acre) was applied in filtered effluent. Values of other nutrients were also high. For Title-22, phosphorus levels were 10 kg/ha (9 lb/acre) and potassium levels were 52 kg/ha (46 lb/acre). Concentrations in filtered effluent were 28 kg/ha (25 lb/acre) and 66 kg/ha (59 lb/acre) for phosphorus and potassium, respectively.

The salt content of irrigation waters is important because of the potential for deleterious effects on crops and soils. Salt can affect plant growth by interfering with osmotic relationships or by specific ion toxicity resulting from high concentrations of a particular salt. The sodium content of irrigation waters is of particular concern because

TABLE 20

CHEMICAL PROPERTIES OF IRRIGATION WATERS, 19 AUGUST 1980 TO 13 JUNE 1985
(mg/L unless otherwise noted)

Parameter	Well Water		Title-22 Water		Filtered Effluent	
	Range	Median	Range	Median	Range	Median
pH[a]	6.9-8.1	7.8	6.6-8.0	7.2	6.8-7.9	7.3
Electrical conductivity[b]	400-1344	700	517-2,452	1,256	484-2,650	1,400
Calcium	18-71	48	17-61.1	52	21-66.8	53
Magnesium	12.6-36	18.8	16.2-40	20.9	13.2-57	22
Sodium	29.5-75.3	60	77.5-415	166	82.5-526	192
Potassium	1.6-5.2	2.8	5.4-26.3	15.2	13-31.2	18
Carbonate, as $CaCO_3$	0.0-0.0	0.0	0.0-0.0	0.0	0.0-0.0	0.0
Bicarbonate, as $CaCO_3$	136-316	167	56.1-248	159	129-337	199.5
Hardness, as $CaCO_3$	154-246	2,025	187-416	217.5	171-435	226.5
Nitrate as N	0.085-0.64	0.44	0.18-61.55	8.0	0.08-20.6	6.5
Ammonia as N	*-1.04	*	0.02-30.8	1.2	0.02-32.7	4.3
Total phosphorus	*-0.6	0.02	0.2-6.11	2.7	3.8-14.6	8.0
Chloride	52.2-140	104.4	145.7-841	221.1	145.7-620	249.5
Sulfate	6.4-55	16.1	30-256	107	55-216.7	84.8
Boron	0.01-9	0.08	0.01-0.81	0.36	0.11-0.9	0.4
Total dissolved solids	244-570	413	643-1,547	778	611-1621	842
Biochemical oxygen demand	0.6-33	1.35	0.7-102	13.9	*-315	19
Adjusted SAR[c]	1.5-4.2	3.1	3.1-18.7	8.0	3.9-24.5	9.9
MBAS[d]	* - *	*	0.095-0.25	0.136	0.05-0.585	0.15

[a] Standard pH units.
[b] Micromhos/centimeter.
[c] Sodium adsorption ratio, no unit
[d] Methylene-blue-active substance
*Chemical concentration below detection limit.

Detection limits are as follows:
Ammonia = 0.02 mg/L
Phosphorus = 0.01 mg/L
Boron = 0.02 mg/L
Biochemical oxygen demand = 1.0 mg/L
MBAS = 0.05 mg/L

TABLE 21

HEAVY METAL CONCENTRATIONS IN IRRIGATION WATERS (19 AUGUST 1980 TO 13 JUNE 1985)
(mg/L)

Parameter	Well Water		Title-22 Water		Filtered Effluent		Irrigation Water Criteria[a] (continuous)	Drinking Water Criteria
	Range	Median	Range	Median	Range	Median		
Cadmium	*-0.1	*	*-0.1	*	*-0.1	*	0.010	0.010[b]
Zinc	*-0.6	0.02	0.07-6.2	0.33	*-2.08	0.195	2.0	5.0[c]
Iron	*-0.66	0.1	*-2.3	0.05	*-0.25	0.06	5.0	0.3[b]
Manganese	*-0.07	*	*-0.11	0.05	*-0.11	0.05	0.20	0.05[c]
Copper	*-0.05	0.02	*-0.05	*	*-0.04	*	0.20	1.0[b]
Nickel	0.001-0.2	0.04	0.002-0.18	0.04	0.004-0.2	0.04	0.20	--
Cobalt	*-0.057	*	0.001-0.062	0.002	*-0.115	0.05	0.050	--
Chromium	*-0.055	*	*	*	*	*	0.10	0.05[b]
Lead	*	*	*	*	0.001-0.7	0.023	5.0	0.05[b]

[a]Source: Water Quality Criteria 1972; Ecological Research Series.
[b]Primary Drinking Water Criteria (metals that pose a potential adverse health effect).
[c]Secondary Drinking Water Criteria (metals that pose an aesthetic problem).

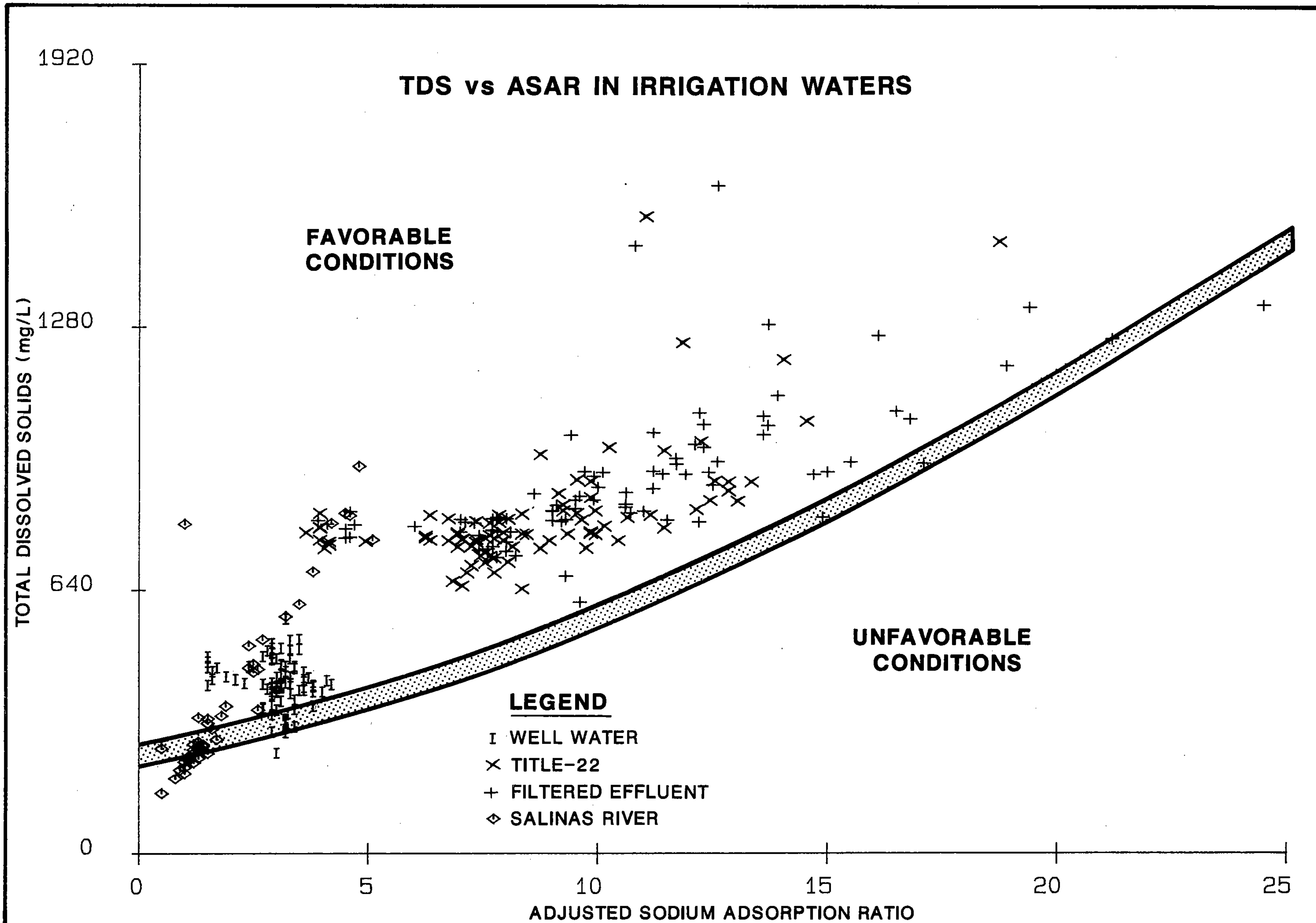
*Metal concentration below detection limit. Detection limits were as follows:

Year One	Years Two and Three	Years Four and Five
Cadmium = 0.1 mg/L	Cadmium = 0.001 mg/L	Cadmium = 0.001 mg/L
Zinc = 0.5 mg/L	Zinc = 0.02 mg/L	Zinc = 0.02 mg/L
Iron = 0.03 mg/L	Iron = 0.03 mg/L	Iron = 0.03 mg/L
Manganese = 0.05 mg/L	Manganese = 0.05 mg/L	Manganese = 0.05 mg/L
Copper = 0.02 mg/L	Copper = 0.02 mg/L	Copper = 0.001 mg/L
Nickel = 0.2 mg/L	Nickel = 0.05 mg/L	Nickel = 0.001 mg/L
Cobalt = 0.1 mg/L	Cobalt = 0.05 mg/L	Cobalt = 0.001 mg/L
Chromium = 0.2 mg/L	Chromium = 0.04 mg/L	Chromium = 0.04 mg/L
Lead = 0.2 mg/L	Lead = 0.05 mg/L	Lead = 0.001 mg/L

high levels of sodium along with low salinity can create poor soil physical conditions, which reduce permeability.

Salinity of irrigation waters is determined by measuring electrical conductivity (EC) and total dissolved solids (TDS), as well as the concentration of boron, chloride, sodium, bicarbonate, calcium, and magnesium. Concentrations of TDS less than 480 mg/L are recommended for irrigation waters, and levels above 1920 mg/L are considered to be a severe problem. Intermediate concentrations are indicative of increasing problems. Levels of EC, TDS, boron, chloride, and sodium in the two effluents were comparable and were higher than those in well water. Concentrations of TDS in all three water types were below the "severe problem" range, but effluent TDS fell into the range of "increasing problems." Levels of magnesium and calcium were similar in all three water types. Bicarbonate levels were higher in filtered effluent than in the other two water types, which showed similar concentrations. The lower bicarbonate level in the Title-22 waters was due to the addition of greater amounts of alum, which combines with bicarbonate.

The sodium adsorption ratio (SAR) is a measure of the suitability of water for irrigation. It is based on concentrations of sodium, calcium, and magnesium and may be adjusted for alkalinity (a function of carbonate and bicarbonate concentrations) to produce an adjusted sodium adsorption ratio (ASAR), which considers the tendency of calcium to precipitate or dissolve. High sodium along with low salinity can result in poor soil physical conditions due to clay swelling and dispersion (Reference 15 in Chapter 5). Figure 14 shows the generalized boundary between favorable and unfavorable soil conditions with regard to the ASAR and TDS. Irrigation water data for all three water types are also depicted, along with data from the Department of Water Resources on water quality of the Salinas River. Although ASARs of the two effluents are much higher than those observed in either well water or water from the Salinas River, the salinity of the reclaimed waters is correspondingly high. This generally puts the reclaimed water in the favorable range for irrigation.



TDS vs ASAR IN IRRIGATION WATERS
FAVORABLE CONDITIONS
UNFAVORABLE CONDITIONS
LEGEND
I WELL WATER
× TITLE-22
+ FILTERED EFFLUENT
◇ SALINAS RIVER
TOTAL DISSOLVED SOLIDS (mg/L)
1920
1280
640
0
0
5
10
15
20
25
ADJUSTED SODIUM ADSORPTION RATIO

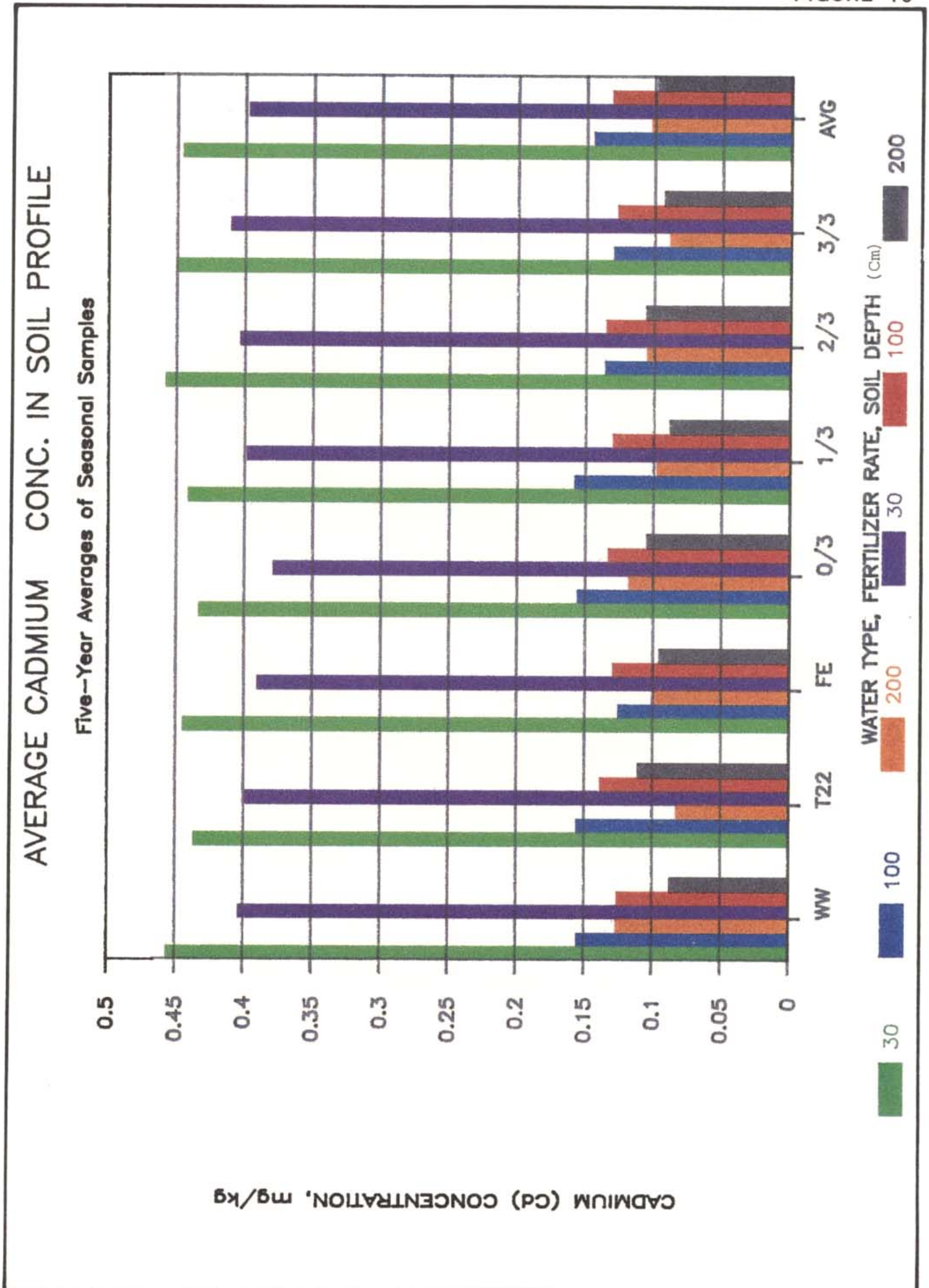
FIGURE 14

HEAVY METALS IN SOILS

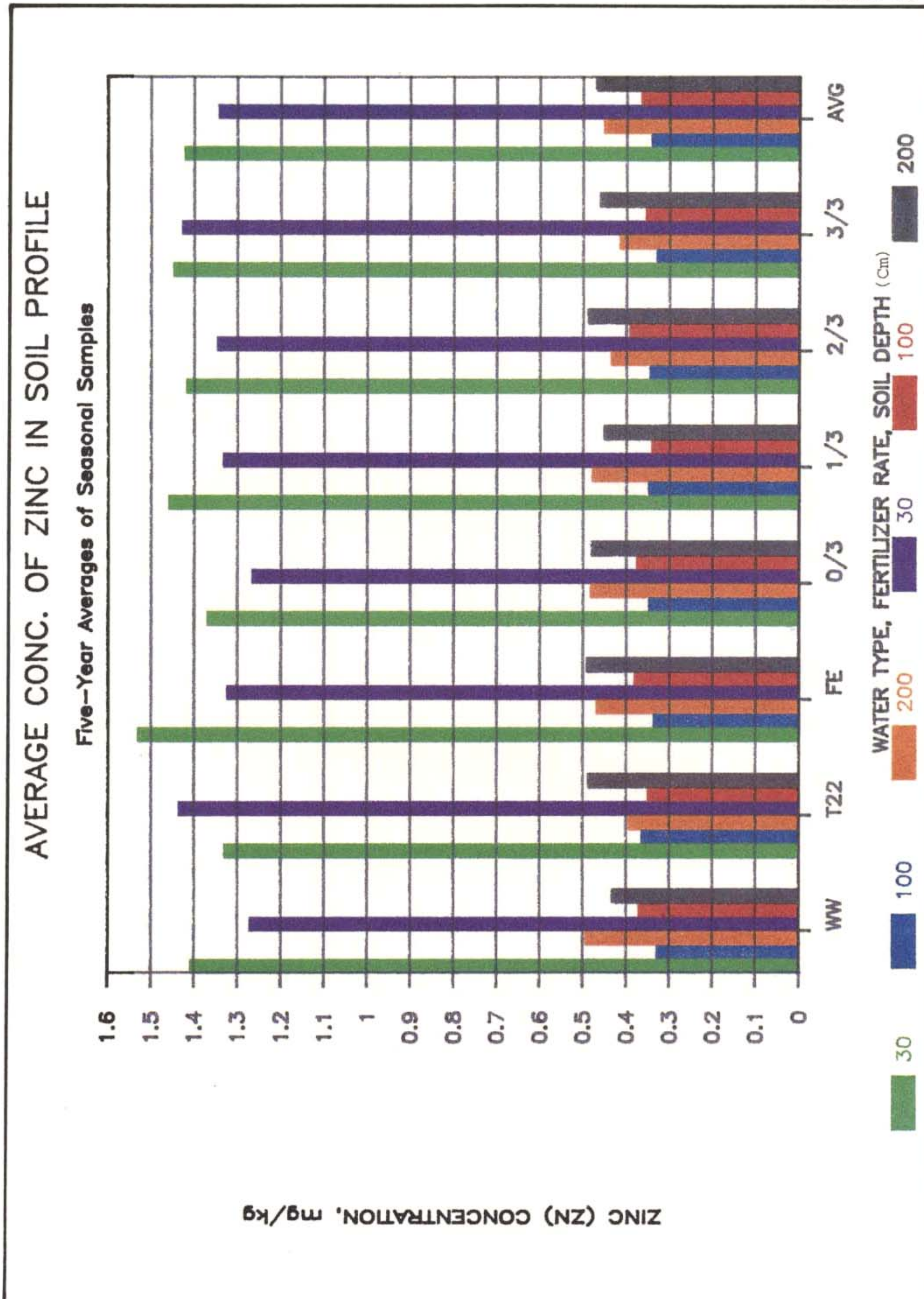
None of the nine heavy metals studied (cadmium, zinc, iron, manganese, copper, nickel, cobalt, chromium, or lead) manifested any consistent significant difference in concentration among plots irrigated with different water types. Furthermore, except in the case of copper, no increasing trends with time over the five years were observed. The gradual increase observed for copper occurred equally for all water types, and at the end of the five years, copper concentrations were still below the average for California soils. Of course, the irrigation water concentrations of these same metals were so low (below detection level for the most part) that a mathematical calculation of the theoretical input and accumulation would lead one to expect no significant accumulation or difference over the five-year period of time. For much longer periods, the same calculations would lead to the same conclusion for all metals except possibly iron and zinc (two essential plant and animal micronutrients). Iron was generally measured at higher concentrations in the well water than in either effluent. Zinc, however, was higher in both effluents than in well water, although the actual concentrations were on the order of 0.1 mg/L in the two effluents. At these levels, uptake by plants would be faster than accumulation from irrigation input.

Input of zinc and other heavy metals, from the commercial chemical fertilizer impurities, is far greater and accounts for the large concentration differences observed at the three soil depths sampled throughout the five years. These differences have occurred over many decades of continuous farming with regular application of fertilizers. Figures 15 and 16 illustrate the relationship of cadmium and zinc in soil with water types, fertilizer treatment rates, and soil depth for all data averaged over the five-year period. In these graphs, the first three histograms in each group of six represent the artichoke plots and the last three bars represent the vegetable plots. The similarity of data between these two fields is an indication of the repeatability of the experiment and further increases the confidence in the data as a whole. Figures 17 and 18 depict cadmium levels in artichoke and vegetable plots at all soil depths over the five-year study period, with

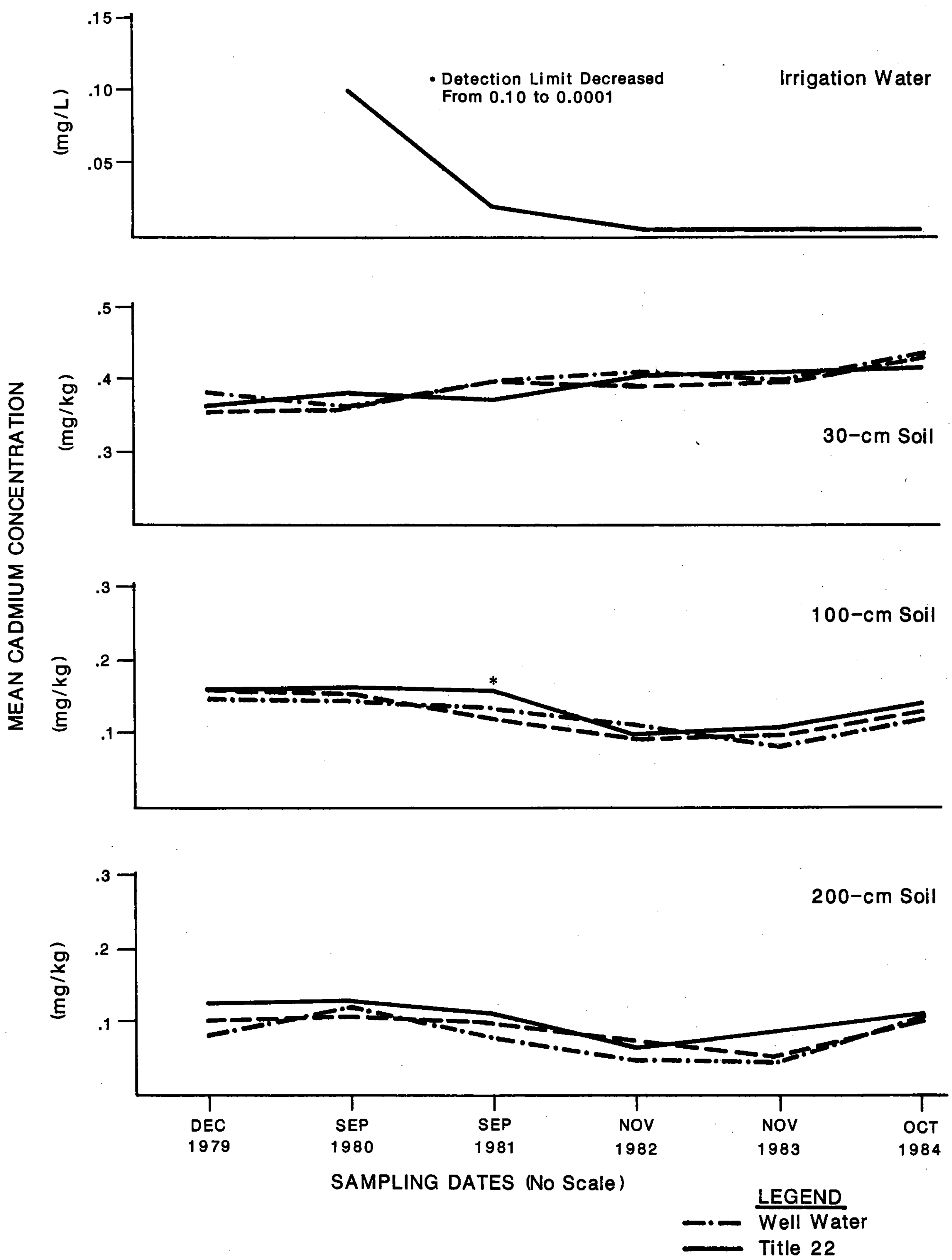
FIGURE 15



ENGINEERING-SCIENCE

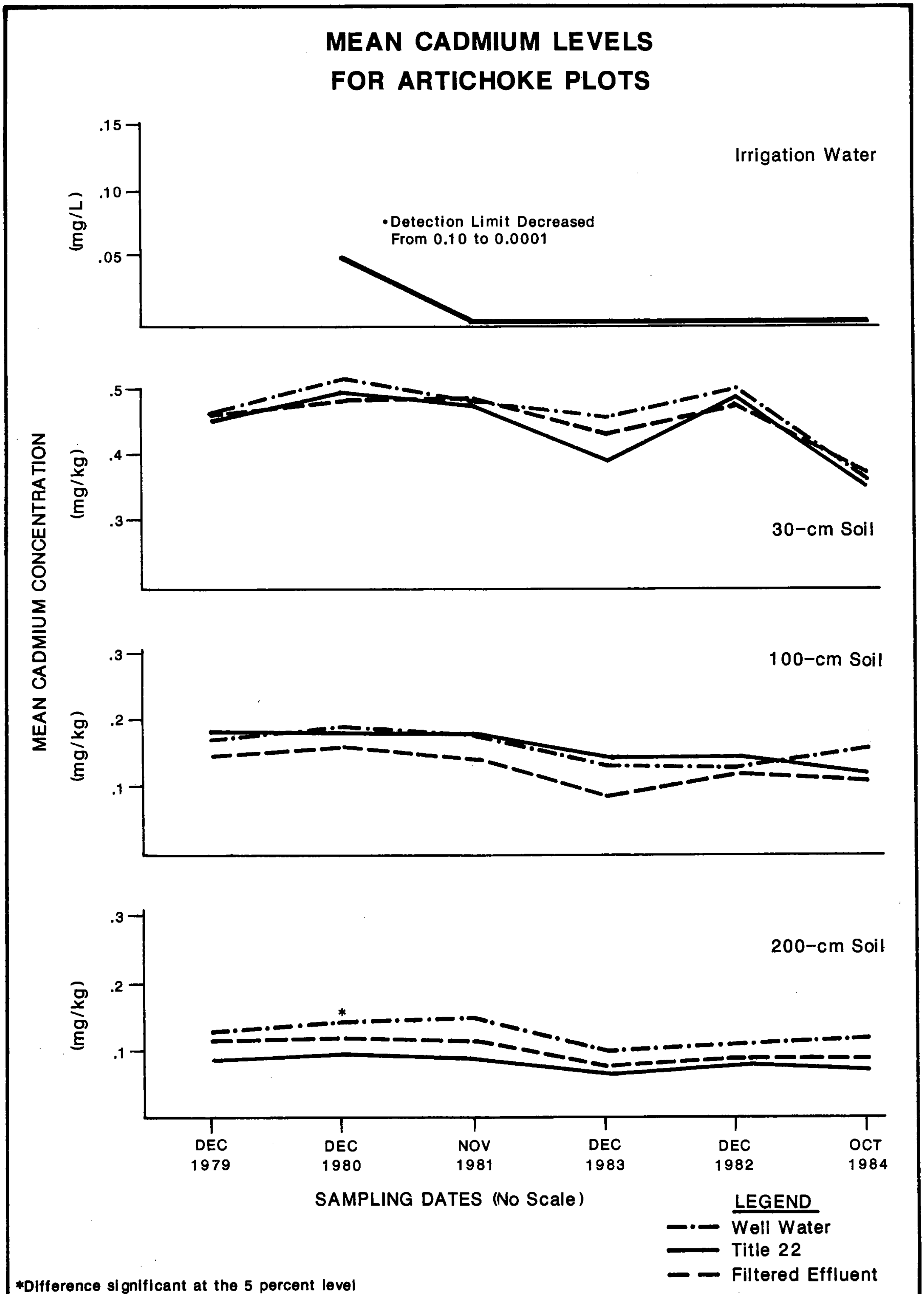

AVERAGE CONC. OF ZINC IN SOIL PROFILE
Five-Year Averages of Seasonal Samples
ZINC (ZN) CONCENTRATION, mg/kg
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
WW
T22
FE
0/3
1/3
2/3
3/3
AVG
WATER TYPE, FERTILIZER RATE, SOIL DEPTH (Cm)
30
100
200
30
100
200

MEAN CADMIUM LEVELS FOR VEGETABLE PLOTS



*Difference significant at the 5 percent level

FIGURE 18


MEAN CADMIUM LEVELS
FOR ARTICHOKE PLOTS
MEAN CADMIUM CONCENTRATION
(mg/L)
.15
.10
.05
Irrigation Water
•Detection Limit Decreased
From 0.10 to 0.0001
(mg/kg)
.5
.4
.3
30-cm Soil
(mg/kg)
.3
.2
.1
100-cm Soil
(mg/kg)
.3
.2
.1
200-cm Soil
*
DEC
1979
DEC
1980
NOV
1981
DEC
1983
DEC
1982
OCT
1984
SAMPLING DATES (No Scale)
LEGEND
Well Water
Title 22
Filtered Effluent
*Difference significant at the 5 percent level

the average concentration in irrigation water plotted for comparison. The zinc and cadmium data are fairly typical of the other heavy metals studied. Table 22 summarizes the tabulation of the five-year results of all the heavy metals analyses in soils in the artichoke plots. Each number in this table is the average of 480 to 640 individual field samples, and this only represents half the test plots. The other half of the plots were in a succession of other vegetables and produced similar results.

HEAVY METALS IN PLANT TISSUES

The same nine metals studied in the soils were also investigated in samples of the edible tissues of plants collected at harvest at each of the 96 subplots. The most important of the many results is that no consistent significant difference in heavy metal concentrations was observed between plants irrigated with either effluent and with well water in any of the 16 samplings over the five-year field trials. Table 23 summarizes the results, averaged over the five-year period. In addition, metal content of artichoke tissues from neighboring fields showed no relationship to distance from Site D.

The residual tissue of all vegetables grown was also sampled at the same frequency and analyzed for cadmium and zinc. The main purpose of this analysis was to assess the potential for bioaccumulation through the food chain should residues be used as feed for cattle and other livestock. The analysis produced results very similar to those from edible tissues, i.e., no consistent significant difference was observed between plants irrigated with well water and with either of the two reclaimed waters. However, consistent differences in the accumulation of zinc and cadmium were observed between edible and residual tissues (higher cadmium in residual tissues and higher zinc in edible tissues for all vegetables studied). This difference in accumulation is in fact fortuitous, because it results in relatively higher zinc to cadmium ratios in the edible portion of the crops, believed to be a safeguard against cadmium bioaccumulation and the resultant health hazards.

TABLE 22

AVERAGE CONCENTRATION OF HEAVY METALS IN SOIL PROFILE OF ARTICHOKE PLOTS, 1980 TO 1985
(mg/kg)

Heavy Metal	Soil Depth, Cm	Water Type WW	Water Type T22	Water Type FE	Fertilizer Rate 0/3	Fertilizer Rate 1/3	Fertilizer Rate 2/3	Fertilizer Rate 3/3	Average
Cadmium (Cd)	30	0.46	0.44	0.45	0.43	0.44	0.46	0.45	0.45
	100	0.16	0.16	0.13	0.16	0.16	0.14	0.13	0.14
	200	0.13	0.08	0.10	0.12	0.10	0.11	0.09	0.10
Zinc (Zn)	30	1.41	1.33	1.53	1.37	1.46	1.42	1.45	1.42
	100	0.33	0.36	0.34	0.35	0.35	0.35	0.33	0.34
	200	0.50	0.40	0.47	0.49	0.48	0.44	0.42	0.45
Iron (Fe)	30	49.68	41.48	45.73	39.66	43.81	47.73	51.31	45.63
	100	8.19	8.13	6.07	7.59	7.82	7.44	7.00	7.47
	200	12.59	7.79	7.65	9.61	9.72	8.98	9.08	9.35
Manganese (Mn)	30	23.30	20.21	24.53	16.01	18.64	24.18	31.86	22.67
	100	4.94	4.71	4.19	4.63	4.89	4.45	4.48	4.61
	200	6.26	4.63	5.04	5.87	5.13	5.33	4.90	5.31
Copper (Cu)	30	2.06	2.02	2.09	2.05	1.97	2.11	2.11	2.06
	100	1.57	1.84	1.40	1.60	1.73	1.43	1.65	1.60
	200	1.79	1.25	1.51	1.68	1.55	1.41	1.41	1.52
Nickel (Ni)	30	6.88	6.38	6.81	6.19	6.51	6.92	7.15	6.69
	100	0.91	0.93	0.69	0.92	0.85	0.83	0.78	0.84
	200	0.63	0.39	0.47	0.58	0.47	0.50	0.42	0.49
Cobalt (Co)	30	0.16	0.16	0.18	0.13	0.14	0.18	0.22	0.17
	100	0.09	0.09	0.09	0.09	0.09	0.10	0.09	0.09
	200	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Chromium (Cr)	30	0.15	0.13	0.15	0.14	0.14	0.14	0.15	0.14
	100	0.10	0.10	0.10	0.09	0.10	0.11	0.10	0.10
	200	0.10	0.09	0.10	0.09	0.10	0.09	0.09	0.10
Lead (Pb)	30	0.98	0.92	0.96	0.97	0.94	0.93	0.98	0.95
	100	0.64	0.71	0.54	0.66	0.65	0.56	0.63	0.63
	200	0.70	0.49	0.60	0.66	0.62	0.56	0.54	0.59

TABLE 23

AVERAGE CONCENTRATIONS OF HEAVY METALS IN EDIBLE VEGETABLE TISSUES
MONTEREY WASTEWATER RECLAMATION STUDY FOR AGRICULTURE, 1980 TO 1985
(mg/kg)

		Water Type			Fertilizer Rate			
Heavy Metal	Plant	Well Water	Title-22	Filtered Effluent	0/3	1/3	2/3	3/3
Cadmium	Artichokes	1.08	1.12	1.12	0.94	1.12	1.20	1.17
(Cd)	Vegetables	2.11	2.08	2.19	2.09	2.07	2.24	2.10
Zinc	Artichokes	31.40	33.00	27.90	33.00	30.70	30.10	30.80
(Zn)	Vegetables	20.10	26.50	28.10	24.80	27.30	28.20	29.90
Iron	Artichokes	67.10	66.60	65.80	65.30	65.40	68.80	66.60
(Fe)	Vegetables	217.00	197.00	193.00	219.00	175.00	232.00	184.00
Manganese	Artichokes	22.90	21.40	21.40	19.00	21.10	23.50	24.00
(Mn)	Vegetables	43.30	44.50	44.60	37.00	42.50	47.80	49.20
Copper	Artichokes	4.74	4.33	4.29	5.33	4.31	4.08	4.13
(Cu)	Vegetables	4.47	4.54	4.42	4.31	4.43	4.67	4.50
Nickel	Artichokes	6.59	5.58	4.79	5.53	4.75	5.48	6.84
(Ni)	Vegetables	9.42	8.72	8.57	9.05	9.40	10.10	9.28
Cobalt	Artichokes	1.85	1.69	1.72	1.78	1.75	1.75	1.75
(Co)	Vegetables	2.24	2.33	2.28	2.25	2.26	2.20	2.41
Chromium	Artichokes	1.91	1.97	1.85	1.84	1.80	1.96	2.02
(Cr)	Vegetables	2.56	2.56	2.38	2.46	2.34	2.55	2.66
Lead	Artichokes	3.40	3.16	3.16	3.00	3.32	3.38	3.27
(Pb)	Vegetables	5.12	4.26	4.67	4.71	5.07	4.47	4.48

[a] The average full nitrogen application rates for each crop were 361 lb N/acre for artichokes, 229 lb N/acre for broccoli; 321 lb N/acre for celery, 186 lb N/acre for cauliflower, and 146 lb N/acre for lettuce.

SOIL SALINITY/SODICITY

Soil salinity is determined by measuring electrical conductivity (EC) expressed as decisiemen per meter (dS/m). One dS/m is equivalent to one mmho/cm. Electrical conductivities of effluent-irrigated soils were consistently significantly higher than those measured in well water-irrigated soils. This was particularly evident for the vegetable plots, which received more irrigation water than did the artichoke plots. Levels of EC were often comparable for shallow soils in artichoke plots irrigated with all three water types, but deeper soils showed significantly higher ECs in effluent-irrigated plots.

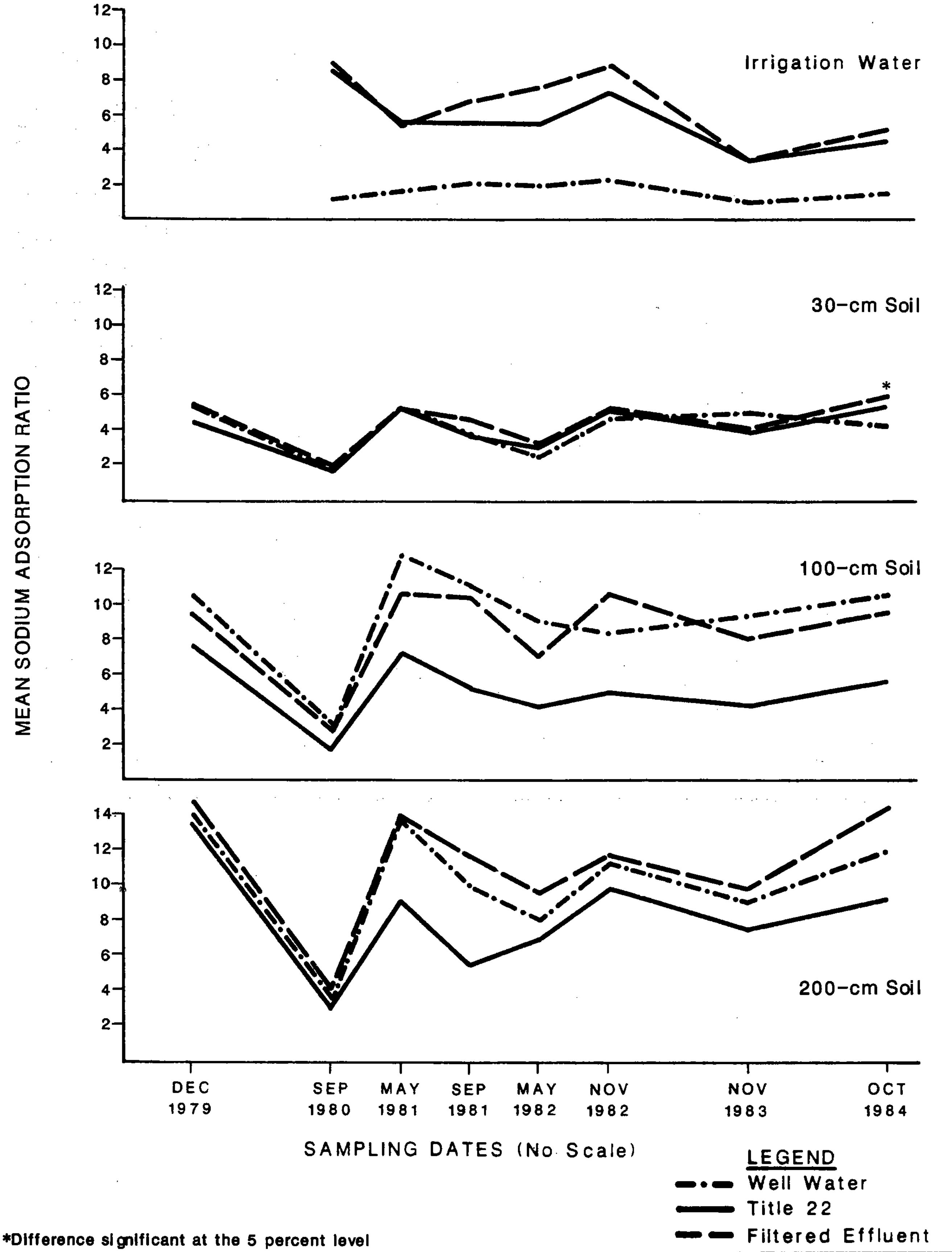
Although total dissolved salt concentrations as measured by EC were significantly affected by irrigation with reclaimed water, levels of individual constituents were often similar for all water types. There were no significant differences in boron levels due to water type treatments. Similarly, bicarbonate levels were not affected by water type.

Concentrations of chloride, calcium, magnesium, and sodium were consistently significantly higher in effluent-irrigated soils than in well water-irrigated soils. Again, the differences were more pronounced in vegetable plots than in the artichoke plots, which received less effluent in irrigation. Sodium levels (sodicities) in shallower soils showed more significant differences attributable to water type than did concentrations in deeper soils.

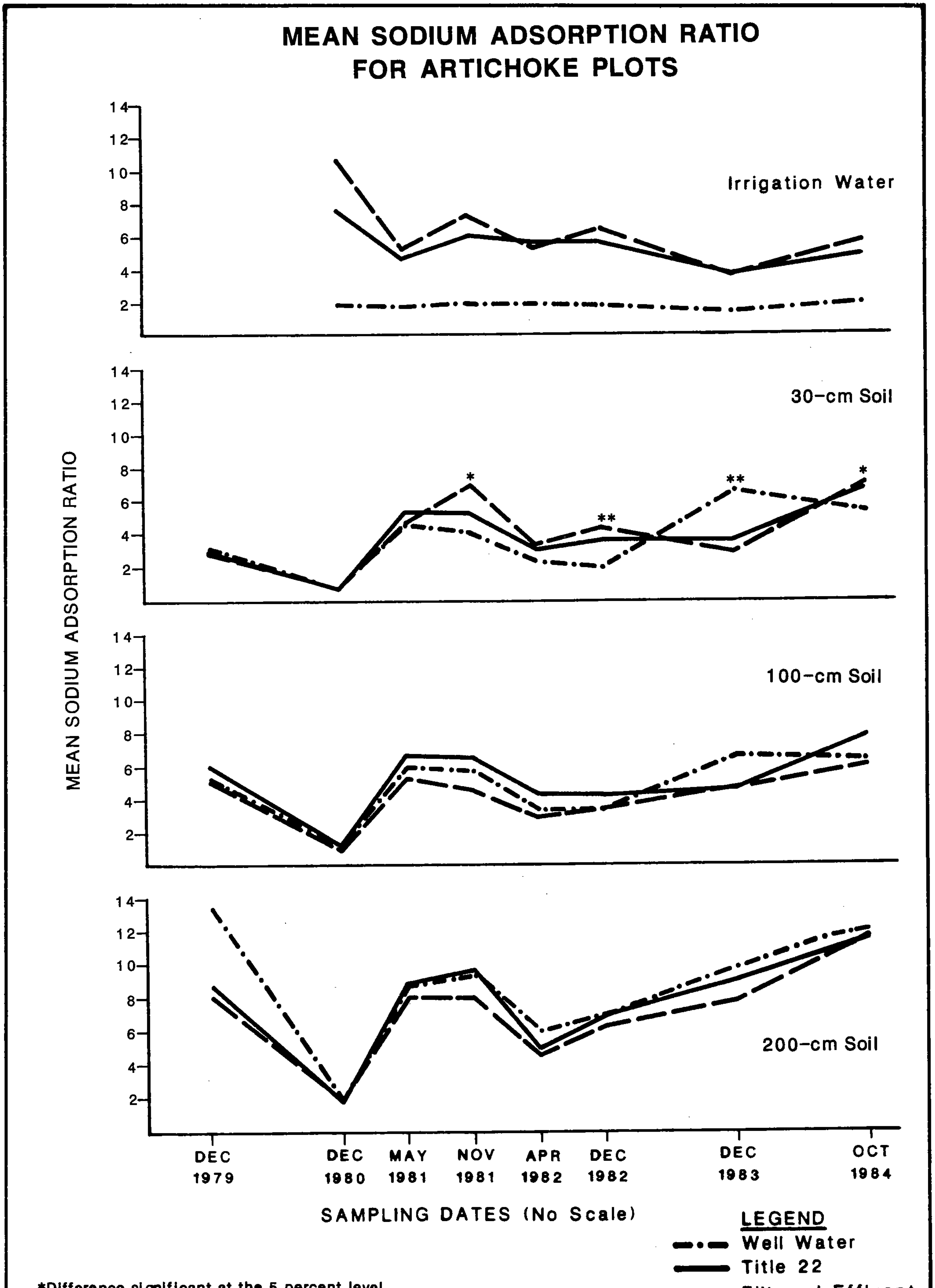
Figure 19 plots the SARs in all three soil depths over the five years of MWRSA for vegetable plots, and Figure 20 plots the SARs for artichoke plots. Because adequate soil alkalinity data were not available for some earlier sampling events, ASAR values could not be calculated for some dates. Values for SAR are thus plotted in lieu of ASARs. Values of SAR and ASAR for soils at Site D were very highly correlated (probability >99%), and use of SAR here allows presentation of a more complete picture of sodicity through time. The average SAR values of the applied irrigation waters are also depicted. Once again, although the SAR values are fairly high, salinities are also generally high. Most of the soil sampling indicated a combination of salinities and sodicities in the favorable range for agriculture (Reference 15 in Chapter 5).

A laboratory analyst is seen in this photograph preparing soil samples, after air-drying, by crushing the larger clods in a jaw-grinder. The process blends the soil samples obtained from five different spots in each subplot into one homgeneous sample representing the subplot.

MEAN SODIUM ADSORPTION RATIO FOR VEGETABLE PLOTS



*Difference significant at the 5 percent level



*Difference significant at the 5 percent level
**Difference significant at the 1 percent level

SOIL PERMEABILITY

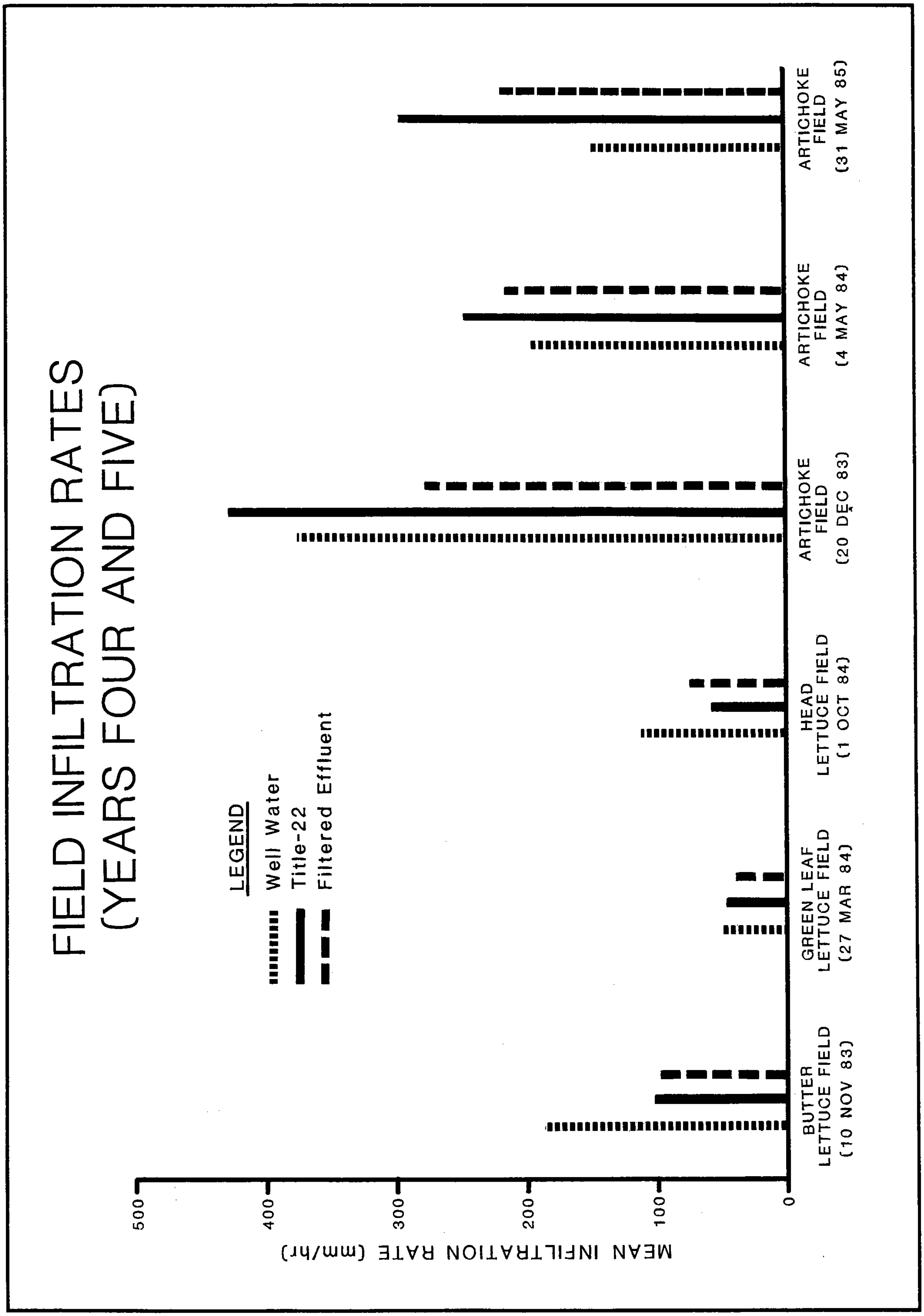
Figure 21 depicts field infiltration rates in artichoke and lettuce fields as a function of water type. Data from Years Four and Five are shown. Although infiltration rates in the lettuce field were highest in those plots irrigated with well water, these levels were not significantly different because of the great variation of infiltration rates within each water type. Infiltration rates in the artichoke field were higher than in the lettuce field. This is probably due to the fact that the artichoke field receives less irrigation water and is less frequently compacted by equipment used for field prepartion. Surprisingly, infiltration rates in the artichoke field in May 1985 were significantly higher in Title-22 irrigation plots than in well water-irrigated plots. The high average infiltration rate in the Title-22 irrigated plots is largely attributable to a single plot with an anomalously high infiltration rate, which may have been caused by the presence of a gopher hole or mouse hole in the plot. Removal of this plot from the analysis eliminates the apparent statistically significant difference between water types.

CROP YIELDS

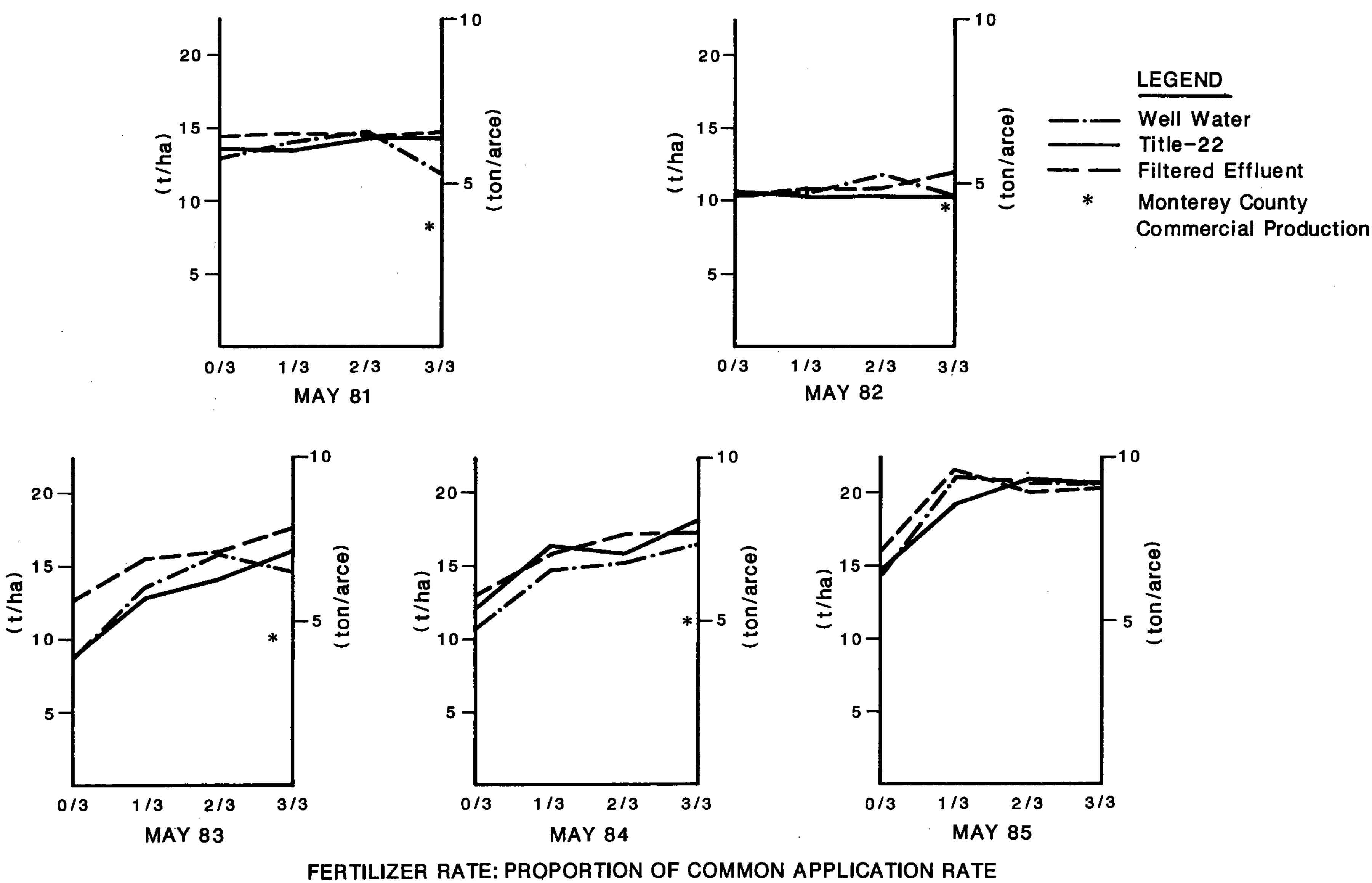
Figures 22 through 25 depict yields of artichokes, lettuce, broccoli, cauliflower, and celery graphed by water type and fertilization rate.

Artichokes

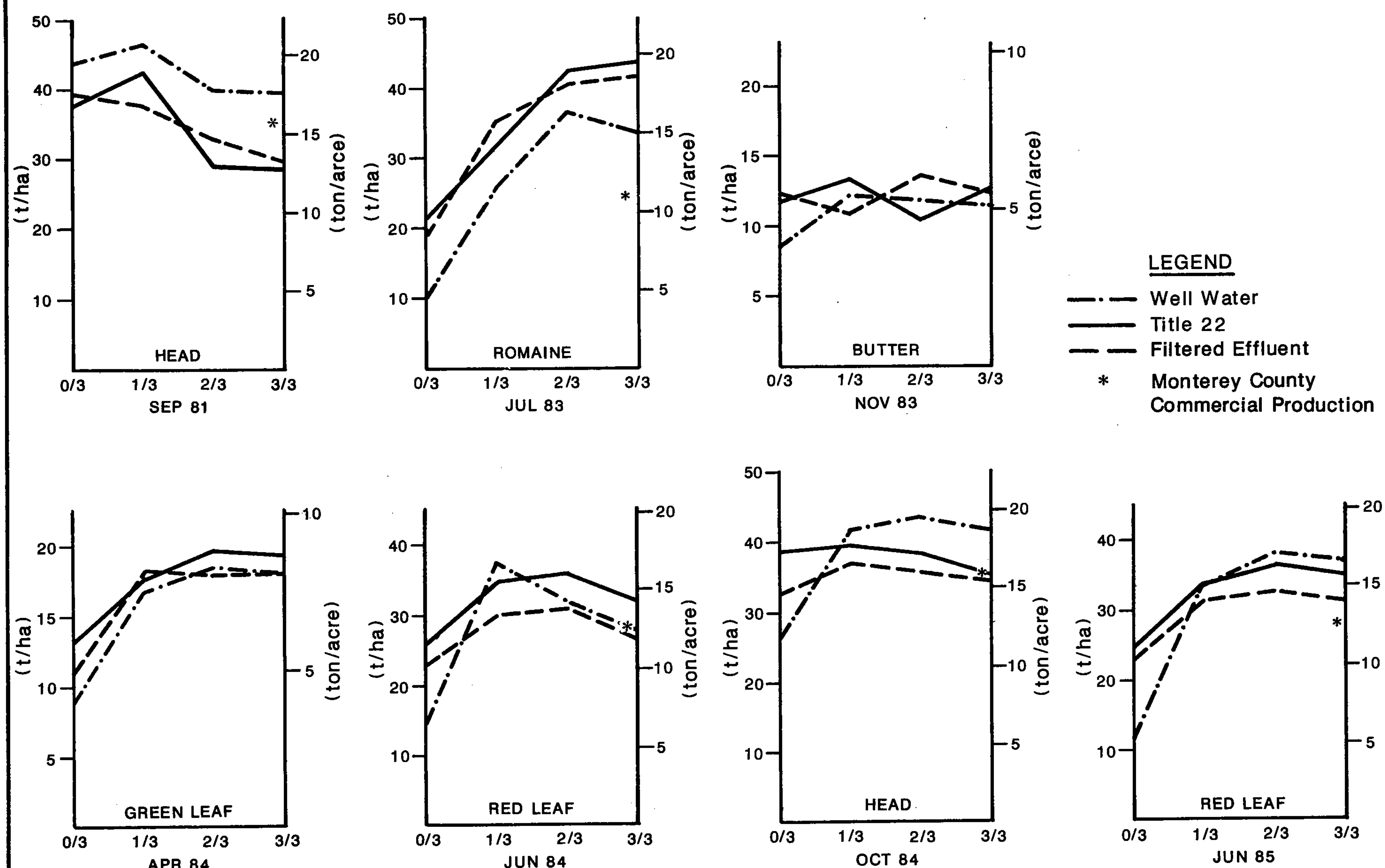
Artichoke yields were similar for all three water types; in the first two years, the different fertilization rates had no effect on yield. In the last three years, a significant effect of fertilization became apparent. There were, however, no significant differences in yield among the 1/3, 2/3, and 3/3 rates. All three fertilization rates showed significantly higher yields than did the unfertilized plots. The typical full fertilization rate may thus be in excess of the artichoke plants' requirements. The lack of fertilization effect in the first two years may have been due to the presence of residual fertilizer left by previous over-fertilization.


FIELD INFILTRATION RATES
(YEARS FOUR AND FIVE)
LEGEND
Well Water
Title-22
Filtered Effluent
MEAN INFILTRATION RATE (mm/hr)
0
100
200
300
400
500
BUTTER LETTUCE FIELD (10 NOV 83)
GREEN LEAF LETTUCE FIELD (27 MAR 84)
HEAD LETTUCE FIELD (1 OCT 84)
ARTICHOKE FIELD (20 DEC 83)
ARTICHOKE FIELD (4 MAY 84)
ARTICHOKE FIELD (31 MAY 85)

MEAN ARTICHOKE YIELD AS A FUNCTION OF FERTILIZER RATE AND WATER TYPE

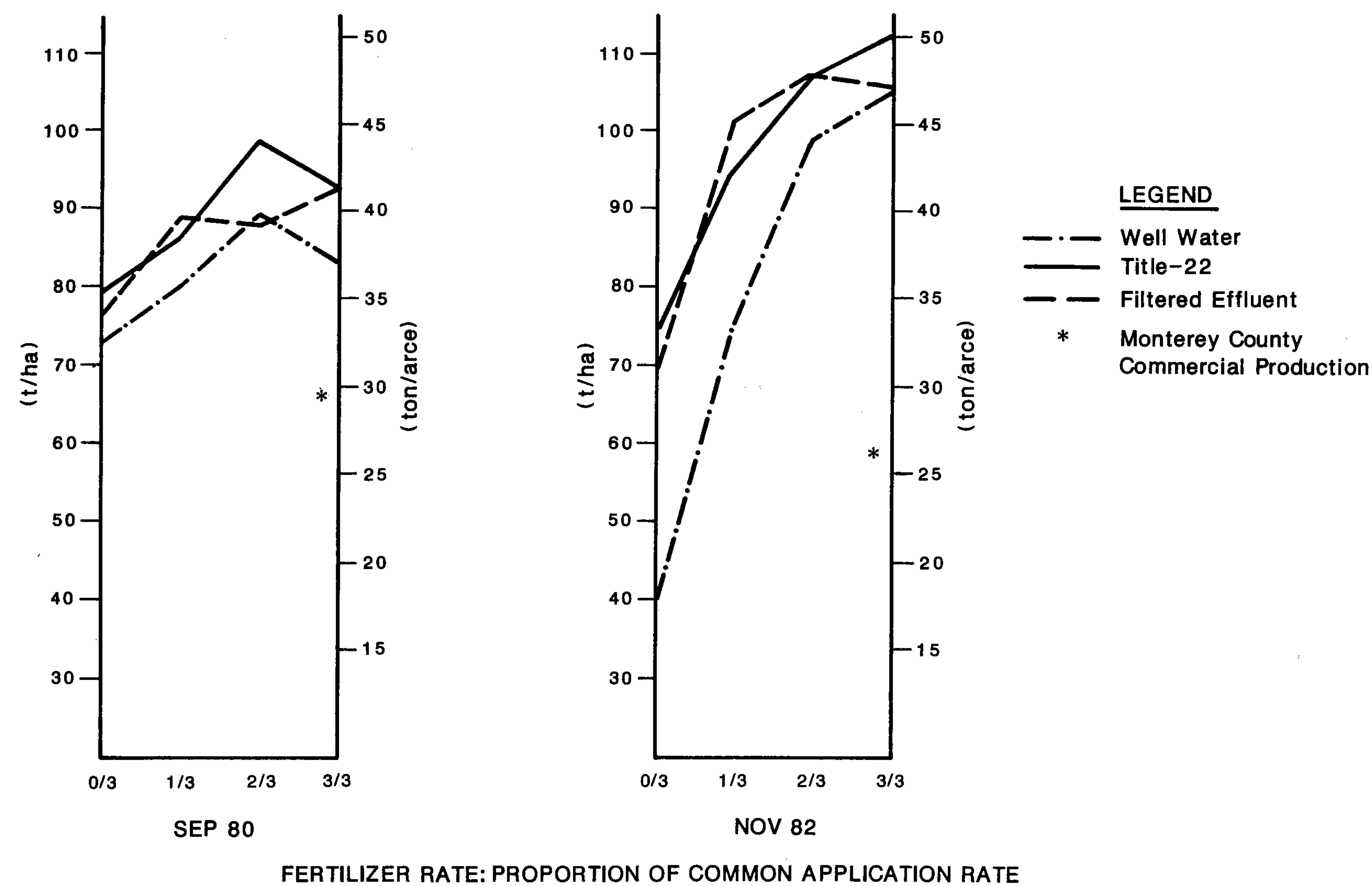


MEAN LETTUCE YIELD AS A FUNCTION OF FERTILIZER RATE AND WATER TYPE

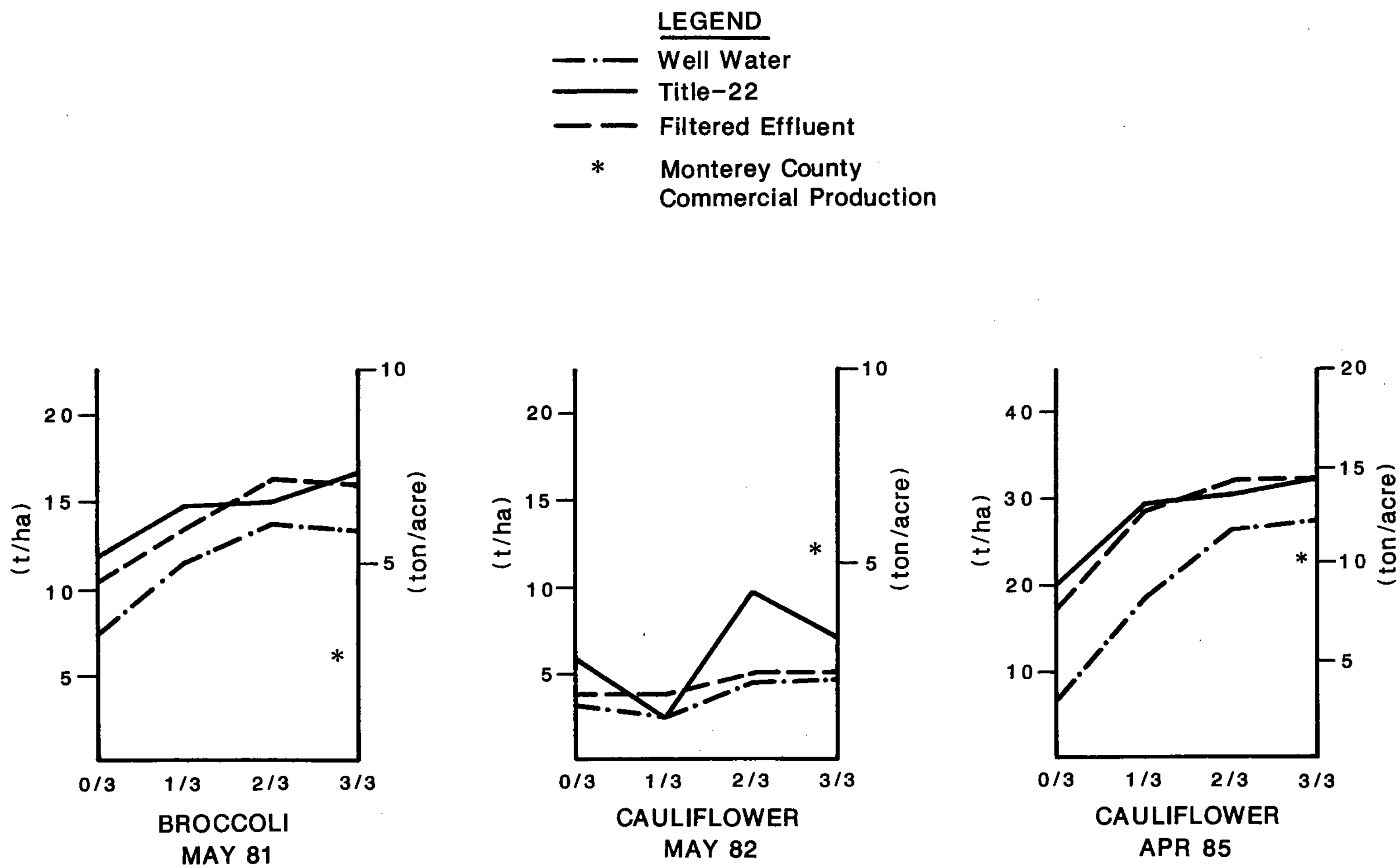


FERTILIZER RATE: PROPORTION OF COMMON APPLICATION RATE

MEAN CELERY YIELD AS A FUNCTION OF FERTILIZER RATE AND WATER TYPE



MEAN CAULIFLOWER AND BROCCOLI YIELD AS A FUNCTION OF FERTILIZER RATE AND WATER TYPE



FERTILIZER RATE: PROPORTION OF COMMON APPLICATION RATE

Multiple regression analyses of yield on tissue nutrient levels showed that nitrogen status was most highly correlated with yield. Tissue phosphorus content before cutback also explained a significant portion of the variation in yield. The relationship of phosphorus content to yield was unexpected; lower tissue phosphorus concentrations produced higher yields. The lower tissue phosphorus levels at the end of the season were associated with higher phosphorus application rates early in the season. This suggests that availability of phosphorus at the beginning of the season is important. Potassium application rates and tissue concentrations showed little relationship to yield.

<u>Lettuce</u>

Yields of all seven lettuce crops were similar for the three different water types. The effect of fertilization was significant for romaine and green leaf lettuce, as well as for the first head lettuce crop. Increases in yield tended to level off at the 2/3 rate. Red leaf lettuce and the second head lettuce crop exhibited an interaction between water type and fertilization rate. The effect of fertilization varied with water type. Well water-irrigated plots experienced a much sharper increase in yield with fertilization than did the effluent-irrigated plots. This is likely due to the fact that the unfertilized effluent-irrigated plots were still receiving a substantial amount of nutrients applied in the irrigation water.

<u>Celery</u>

The 1980 celery crop showed no effect of water type on yield, while the fertilized plots had significantly higher yields than did unfertilized plots. Yields of plots fertilized at the three different rates were similar. The 1982 crop exhibited a highly significant interaction between water type and fertilization rate. Plots irrigated with well water and Title-22 showed sharp increases in yields with each increase in fertilization rate. Filtered effluent-irrigated plots had higher yields in the fertilized than in the unfertilized plots, but there were no differences in yields among the 1/3, 2/3, and 3/3 rates. Levels of nutrients in filtered effluent were consistently higher than those in Title-22 effluent.

Broccoli

Both water type and fertilization rate had significant effects on broccoli yield. Effluent-irrigated plots produced higher yields than did plots irrigated with well water. Yields increased with higher fertilization rates, plateauing at the 2/3 rate.

Cauliflower

Yields of the first cauliflower crop were poor because of the extremely heavy rains in the winter of 1981-1982. Most of the commercial fields in the area were not harvested due to the poor quality of the crops. No significant differences due to treatment effects were evident. The 1985 cauliflower yields were significantly affected by both water type and fertilization rate. Well water-irrigated plots yielded less than plots irrigated with either type of reclaimed water. Yield also increased with fertilization rate, again leveling off at the 2/3 rate.

CROP QUALITY

Field quality assessments and shelf life measurements uncovered no differences between produce irrigated with reclaimed water and that irrigated with well water. Visual inspection of artichoke plants in the field showed no differences in appearance or vigor of plants irrigated with different water types. Occasional problems with mouse damage were not related to water type.

Shelf life and quality of row crops were similar for all water type treatments. No problems with increased spoilage of produce irrigated with effluents were encountered.

Quality and shelf life of lettuce is checked for tip burn, russet spotting, slime, injury spots, and firmness, one, two and three weeks after harvest.

chapter 8

COST OF RECLAIMED WATER

Cost of producing reclaimed water, beyond secondary treatment and excluding transmission or distribution costs, are:

Filtered Effluent	*$67/acre-ft*
Filtered Effluent with Flocculation	*$70/acre-ft*
Title-22 with 50 mg/L Alum	*$107/acre-ft*
Title-22 with 200 mg/L Alum	*$164/acre-ft*

Overleaf:

Boxes of sampled celery, packed in a manner similar to the common commercial practice, were sent to cold storage. At intervals of one, two, and three weeks, the quality (shelf life) of the vegetables in each box was judged. There were no significant differences between the quality of vegetables grown with either of the two reclaimed waters and those grown with well water.

CHAPTER 8

COST AND FEASIBILITY

COST OF RECLAIMED WATER

Preliminary capital and operations and maintenance (O&M) cost estimates were based on the design criteria presented in a separate task report in July 1986 for the three flow streams. The present worth of 20 years of operation is estimated for each of the three reclamation plant alternatives: Title-22 (T-22), filtered effluent (FE), and filtered effluent with flocculation (FE-F). It is assumed in this analysis that the reclamation plant will operate at full capacity during the entire irrigation season, an average of 250 days per year.

For each of the three process alternatives, the cost of reclaimed water, in dollars per unit volume, was determined based on the cost estimates and reclaimed water demand described above. The value of the nutrients present in each type of reclaimed water is discussed separately, also in dollars per unit volume. However, it should be noted that these values may not necessarily be tangible to the growers, especially in the initial years using reclaimed water. Water would be distributed as a blend of reclaimed water with water imported for the Castroville Irrigation Project. The uncertainty of the proportions of reclaimed water in the blend will further add to the farmers' inability to count on the fertilizer's value in the irrigation water. For these reasons, although the values are calculated and presented, they are not used to arrive at a "net cost" or "net value" computation for reclaimed water.

Table 24 presents the preliminary capital cost estimates for the 1,315-L/sec (30-mgd) average dry weather flow (ADWF) reclamation facilities for the three alternative flowstreams (T-22, FE, and FE-F). These estimates are based on the design criteria, preliminary materials

TABLE 24

PRELIMINARY CAPITAL COST ESTIMATES
TERTIARY RECLAMATION FACILITIES
MONTEREY REGIONAL WASTEWATER TREATMENT PLANT

Item	Cost ($1,000)[a]			
	T-22		FE	FE-F
	200 mg/L Alum	50 mg/L Alum		
Civil	750	750	520	520
Structural	4,920	4,900	3,580	3,770
Mechanical	8,170	5,000	2,520	2,670
Electrical	1,120	820	810	820
Instrumentation	180	180	160	160
Buildings	350	210	150	150
Subtotal	15,490	11,860	7,740	8,090
Contingencies (20%)	3,100	2,370	1,550	1,620
Total Construction Cost	18,590	14,230	9,290	9,710
Engineering (15%)	2,790	2,130	1,390	1,460
TOTAL CAPITAL COST	21,380	16,360	10,680	11,170

[a]All costs are in May 1986 dollars.

takeoffs, and May 1986 equipment prices. Costs for ancillary items such as site work, piping, electrical, and instrumentation are based on experience with similar reclamation plants. For ease of comparison and simplicity of presentation only costs of facilities beyond the level of secondary treatment are included; the costs of irrigation storage, transmission, and distribution are excluded. The total capital costs are approximately $21.4 million for a T-22 facility, $10.7 million for an FE facility, and $11.2 million for an FE-F facility, all in May 1986 dollars.

Annual O&M costs for the three alternative reclamation facilities are based on a 250-day-per-year operation at 1,315-L/sec (30 mgd), FY 1985-1986 MRWPCA salary schedules, target chemical dosages, and May 1986 chemical prices and utility rates. As with the capital costs, only O&M costs relating to facilities beyond the level of secondary treatment are included, and O&M costs for irrigation storage, transmission, and distribution facilities are excluded. Table 25 summarizes annual O&M costs for the T-22, FE, and FE-F alternatives. Total annual O&M costs are about $1,400,000 for a T-22 facility, $374,000 for an FE facility, and $376,000 for an FE-F facility, all in May 1986 dollars.

TABLE 25

PRELIMINARY ANNUAL O&M COST ESTIMATES
TERIARY RECLAMATION FACILITIES
MONTEREY REGIONAL WASTEWATER TREATMENT PLANT

Agency Cost Category	Cost ($1,000)[a]			
	T-22		FE	FE-F
	200 mg/L Alum	50 mg/L Alum		
5010 Salaries and Wages	69	69	43	43
5020 Employee Benefits	24	24	15	15
5090 Office Expense	1	1	1	1
5100 Operating Supplies[b]	1,093	360	185	185
5110 Laundry and Clothing	1	1	1	1
5140 Vehicle Operating Expense	1	1	1	1
5150 Repairs and Maintenance[c]	67	67	28	30
5160 Research and Monitoring	2	2	2	2
5170 Meetings and Travel	2	2	2	2
5190 Utilities[d]	140	140	96	96
TOTAL ANNUAL COST	1,400	667	374	376

[a]All costs are in May 1986 dollars.
[b]Includes chemicals.
[c]Estimated to be one percent of mechanical equipment capital cost.
[d]Estimated at $0.08/kWh for electrical energy and $5.72/ton for sludge disposal.

Production Cost of Reclaimed Water

The unit cost of producing reclaimed water is determined by dividing the amortized capital cost of reclamation facilities (amortized over

20 years) plus the first year's O&M cost by the amount of water estimated to be reclaimed during the first year.

As discussed previously, the full 1,315-L/sec (30-mgd) capacity of the reclamation facilities is expected to be required for irrigation during an average of 250 days per year. This amounts to 2.8×10^7 m^3 (23,000 acre-feet) per year of water reclaimed. If additional irrigation demand exists beyond this 250-day period, the unit cost would be slightly reduced.

Table 26 presents the first year unit costs of producing reclaimed water. These costs exclude any necessary irrigation storage or transmission and distribution cost, i.e., facilities (mainly pipeline and control valves) to transport the water to the irrigation sites. For comparison, it is noted that according to the Monterey County Flood Control and Water Conservation District, the cost of pumping from the pressure aquifers in the Salinas area, having a pumping head of 40 to 60 ft, is about $40 per acre-ft. This cost includes energy and equipment amortization (Reference 16).

Fertilizer Value of Reclaimed Water

Nutrients in the reclaimed water contribute significantly to the macronutrient (N, P, K) and micronutrient (B, Cu, Fe, Mn, Mo, Zn, and ten other) requirements of crops irrigated with it. To quantify the significance and monetary value of these dissolved nutrients, average concentrations of nitrogen, phosphorus, and potassium during the five-year MWRSA field study were used. As shown in Table 27, the respective quantities for N, P, and K are 10, 7, and 17 mg/L (28, 20, and 47 lb/acre-ft) in the FE and FE-F effluent. In the T-22 effluent, because of chemical coagulation, sedimentation, and apparent nitrification in the flocculator clarifier, the nutrient levels were 9, 3, and 14 mg/L (24, 7, and 38 lb/acre-ft), respectively. These concentrations were converted to loading rates and multiplied by average fertilizer costs ($/lb) currently paid by growers to purchase these same nutrients to obtain the value of each element in the effluent. The average cost values were obtained from discussions with Western Farms Fresno Division office, as well as quotes for ten different commercial fertilizer

TABLE 26

ANNUAL UNIT COST OF RECLAIMED WATER
MONTEREY REGIONAL WASTEWATER TREATMENT PLANT
($)

Cost	Tertiary Process			
	Title-22		FE-F	FE
	200 mg/L Alum	50 mg/L Alum		
Capital cost	21,380,000	16,360,000	11,170,000	10,680,000
Annual cost[a]	2,345,000	1,795,000	1,225,000	1,172,000
O&M cost[b]	1,400,000	667,000	376,000	374,000
Total annual cost	3,745,000	2,462,000	1,601,000	1,546,000
Annual cost per 1000/m^3	132	87	57	54
Annual cost per acre-foot	163	107	70	67

[a]Based on recovering capital cost funding through a municipal bond at 9 percent with 20-year terms.

[b]Assumes the annual volume of reclaimed water produced matches the projected demand of 23,000 acre-feet.

formulations used in the Salinas Valley. These costs do not include costs of labor or equipment for application, because the farmer would still need to make supplemental nitrogen applications at critical times during the growing season. The dollar value of each nutrient was discounted to account for possible losses (in case of N) and excesses (in cases of P and K), also shown in Table 27 and its footnotes.

The overall unit value of the nutrients in FE/FE-F and T-22 reclaimed waters are thus calculated to be $19 and $13 per acre-ft, respectively. The values calculated here compare conservatively with overall average values computed statewide and for the Irvine Ranch Water District in 1981 by the State Office of Water Recycling. At that time, the average value of nutrients at Irvine was reported to be $20.19/acre-foot for a filtered secondary effluent similar to the FE process. Other

TABLE 27

FERTILIZER VALUE OF RECLAIMED WATER, 1980-1985
MONTEREY WASTEWATER RECLAMATION STUDY FOR AGRICULTURE

	Average Concentration (mg/L)	Average Concentration (lb/ac-ft)	Annual Irrigation Rate (ac-ft/ac)	Average Annual Loading (lb/yr)	Fertilizer Cost[a] ($/lb)	Fertilizer Value ($/acre,yr)	Unit Value ($/acre-ft)[d]	Discounted Value[c] ($/acre-ft)[d]
FE, FE-F								
Nitrogen (N)	10	28	3.5	98	0.36	35	10	9
Phosphorus (P)	7	20	3.5	70	0.45	32	9	7
Potassium (K)	17	47	3.5	165	0.21	35	10	3
Micro-nutrients[b]	trace					0	0	0
TOTALS						101	29	19
TITLE-22								
Nitrogen (N)	9	24	3.5	84	0.36	30	9	8
Phosphorus (P)	3	7	3.5	25	0.45	11	3	2
Potassium (K)	14	38	3.5	133	0.21	28	8	3
Micro-nutrients[b]	trace					0	0	0
TOTALS						69	20	13

[a] The 1986 cost to the grower of each nutrient in the chemical fertilizers, excluding labor and equipment costs of application.

[b] Quantity, availability, and value of micronutrients in the effluents were not evaluated. In most cases, concentrations were below detection limits. Nevertheless, it should be recognized that several essential micronutrients are present in minute concentrations in the tertiary effluents.

[c] The nutrients content of the effluent is conservatively discounted in order to allow for a) ten percent demineralization and other losses associated with nitrogen species and b) 25 percent excess potassium. Growers in Salinas Valley normally add complete (N, P, K) fertilizers only at the beginning of the growing season.

[d] To convert $/1000 m^3 divide by 1.23.

estimates have ranged as high as \$41/1000 m^3 (\$50/acre-ft) (personal communication with G. Stuart Pettygrove, U.C. Davis Agricultural Extension Service).

It is expected that the reclaimed water will be blended with water from other sources in a regional agricultural distribution system. One primary possibility for such blending is the planned importation of approximately 25,000 acre-ft of water from Nacimiento and San Antonio Reservoirs. This plan is presently being studied by the Monterey County Flood Control and Water Conservation District as a partial solution to the expanding seawater intrusion into the regional aquifers. Implementation of this plan may streamline the process for parallel implementation of full-scale reuse of the 23,000 acre-ft of reclaimed water that the regional treatment plant can produce over a typical irrigation season. Blending of reclaimed water with imported surface water will mean that nutrients will arrive in irrigation water at a lower concentration and in smaller annual quantities at any given field. In this case, the relative effectiveness of N will increase significantly and P and K excesses would be avoided. The significance of this increased effectiveness is twofold: first, the region as a whole will derive the maximum nutrient value inherent in the reclaimed water, even though each individual farmer will only receive less than half the nutrient value; second, the lower concentrations, combined with an adjustment in application of Commercial fertilizers can lead to a reduced possiblity of downward movement of nitrates. Therefore, on a regional basis, the full (undiscounted) value of the nutrients might apply.

Irrigation with reclaimed effluent is not expected to involve any additional costs to the grower because of its quality. Any SAR problem that might be expected would be of a very long-term nature (probably over 50 years) and could be remedied with lime application. Annualized costs of such treatment would be relatively insignificant.

MARKETABILITY

Introduction

In 1983, a study to define key determinants of marketability of crops grown with reclaimed water was completed by an independent marketing research firm, the Marketing Arm of San Francisco. Interviews were conducted with individuals involved with produce distribution, such as wholesale and retail buyers, brokers, and store managers. Questions first focused on the need or desire for labeling produce grown with reclaimed water. The second part of the study concerned the potential for rumors or scares associated with such produce due to a lack of labeling and an "uninformed public."

The study was set up as a qualitative assessment of influences on consumer acceptance of crops grown with reclaimed wastewater.

Approach and Results

A total of 144 interviews of key individuals involved in produce distribution was conducted by a team of nine professionals between May and September of 1983. Directors of consumer affairs and public relations representing more than 5,000 stores in 47 states were interviewed, in addition to the following persons:

- 24 brokers and receivers at terminal markets throughout the U.S. and Canada where the bulk of Salinas-area produce is shipped.
- 10 buyers for major cooperative wholesalers in principal cities.
- 19 buyers and merchandisers with large chains, both at corporate and regional levels.
- 10 buyers with medium chains.
- 2 buyers with small chains.
- 15 store managers.

To avoid distorting the findings and to obtain accurate responses, interviewees were questioned about real situations analogous to the sale of crops grown with reclaimed water. For example, questions were asked about the need to label produce that was genetically altered to grow in salty water, or that was hydroponically grown, as well as produce that was grown using reclaimed water. Throughout the study, it was assumed that there was no health risk to the public from using reclaimed water to grow crops. Thus, these examples were considered analogous because each was described as yielding healthful produce, despite possible concerns by produce sellers/buyers.

The major questions asked with regard to selling and labeling concerned first whether the respondent would handle fresh produce grown by one of the measures mentioned above and, then, whether that produce should be labeled by its growing conditions. If the produce was not to be labeled, questions were asked about whether the seller would inform customers that the produce had been grown a certain way. A full copy of the interview questions is contained in Appendix F of the Year Four MWRSA Annual Report.

The responses to the interviews indicated that products would be accepted, that labels would not be considered necessary, and that factual information would be useful to respond to customer inquiries that may arise. According to federal, state, and local agency staff who were interviewed, no governmental regulation exists for labeling produce according to the water source used. Members of the produce trade who were interviewed stated that labeling would only be desirable if value was added to the item (e.g., organically grown). Good appearance of produce was found to be the major requirement of buyers. Tables 28 and 29 show the quantitative results to the questions regarding labeling, divided between those knowledgeable about reclaimed water vs. those not knowledgeable.

Questions relating to the sale of Mexican produce and the lack of public information regarding Mexican water quality were also asked of the produce trade industry. The responses showed that a number of crops, especially tomatoes and strawberries, are grown in Mexico and sold in the United States without much concern about the growing conditions. Inspections of these crops are primarily for disease, appearance, and the presence of unlisted pesticides. It was concluded that the acceptance of Mexican crops by the American consumer and the multiyear record of no problems associated with consumption of Mexican winter vegetables suggest that the public could be comfortable with buying domestic produce grown with reclaimed water.

A comparable example of using reclaimed water for irrigating food crops was found in Orange County, California, where the Irvine Company has been furrow-irrigating row crops for almost 20 years. Vegetables such as broccoli, celery, and sweet corn had been irrigated with water that met Title 22 water quality standards. This produce was then sold through normal produce channels without segregation or labeling according to the type of water used.

After obtaining responses that showed a general willingness to carry produce grown with reclaimed water without labeling, the marketability study addressed the trade's response to potential rumors regarding produce. Questions generally focused on whether rumors could be controlled, how they could be controlled, and if the risk to growers from rumors could be eliminated.

The responses to the questions showed that rumors could be controlled by acting quickly to isolate and identify the rumor and by disseminating facts about the situation. If consumers expressed concern about the health and safety of produce, the general response was that information would be provided immediately to reassure the customer that no risk to health or safety existed.

<u>Recommendations</u>

The marketability study recommended that produce grown with reclaimed water be sold unlabeled and undesignated so as to be distributed into the generic flow of produce. The following additional specific actions were recommended by both the MWRSA Task Force and growers to improve the odds of continued marketability of produce grown with reclaimed water. Three recommendations were given so that the MWRSA Task Force could minimize risks to growers:

(1) Develop clear, government-endorsed fact sheets.

TABLE 28

TRADE REACTIONS TO CARRYING
PRODUCE GROWN IN RECLAIMED WASTEWATER

	Knowledgeable About Wastewater	Not Aware of Reclaimed Wastewater	Total
Would Carry	28	12	40 (59%)
Would Not Carry	9	6	15 (22%)
Don't Know	7	6	13 (20%)
TOTAL	44 (65%)	24 (35%)	68

BASE = 68

TABLE 29

TRADE EXPECTATION ABOUT
LABELING PRODUCE FROM RECLAIMED WASTEWATER

	Knowledgeable About Wastewater	Not Aware of Reclaimed Wastewater	Total
Would Not Expect It To Be Labeled	30	16	46 (68%)
Would Expect It To Be Labeled	9	6	15 (22%)
Don't Know	5	2	7 (10%)
TOTAL	44 (65%)	24 (35%)	68

BASE = 68

(2) Support an educational information program on the use of reclaimed water for produce.

(3) Encourage wider use of reclaimed water for agricultural irrigation.

It was also recommended that growers take the following actions to minimize potential risks of rumor:

(1) Promote education of the produce trade and the public.

(2) Establish a policy for responding to potential rumors.

(3) Create a quick, honest, and aggressive means to disseminate facts.

LARGE-SCALE DEMONSTRATION

Through the first three years of MWRSA, the farm-scale production of artichokes and other vegetables, irrigated with reclaimed effluent, proved to be highly successful, free from complications, odors, discolorations, or any inconvenience to the farm workers. As a result, it was decided by the MWRSA Task Force to discontinue the large-scale demonstration component of the study and concentrate on the statistical data accumulation from the "experimental plots" component. The local farm managers, growers, vegetable processors, and others who attended the field demonstration days had unanimous positive reactions to the visible results. Often, during the demonstrations, the sprinklers would be on, spraying filtered effluent on the vegetables and operating very similarly to well water spray for all practical purposes. Large-scale feasibility of use of reclaimed water (at varying levels of treatment) is corroborated by other farm-scale water reclamation projects in other parts of California and the rest of the world. Irvine Ranch is an excellent example where tertiary-treated reclaimed water is used both for irrigation of food crops (asparagus, strawberries, cucumbers, green peppers, etc.) and for landscape irrigation of residential areas. A dual water distribution system serves potable water and reclaimed water for domestic and irrigation uses, respectively.

REFERENCES

16. Personal communication, Mohammad Zaman, Engineer, Monterey County Flood Control and Water Conservation District, 23 December 1986.

chapter 9

THE CENTRAL FINDINGS OF MWRSA ARE:

1. *Irrigation of raw-eaten vegetable crops and artichokes with reclaimed water was shown to be as safe as irrigation with well water based on these results:*

   a. *No virus was ever found on samples of crops grown with the two types of reclaimed municipal wastewater used in the study (known as T-22 and FE).*

   b. *Levels of naturally-occuring bacteria on samples of effluent-irrigated crops were equivalent to those found on well-water-irrigated crop tissue samples.*

   c. *No naturally-occurring virus was ever detected in any of the samples taken from either type of reclaimed water.*

   d. *When pushed to the limits of their performance, through massive seeding with vaccine-grade poliovirus, both treatment processes exhibited equal ability to remove an average of five logs of seeded virus (i.e. if 100,000 units of virus were introduced to the treatment plant they would all be removed by the treatment process). The FE process appeared to require greater operator attention to consistently meet coliform standards.*

   e. *There was no tendency for metals to accumulate in soils or plant tissues.*

2. *Marketability of crops grown with reclaimed water is not expected to be a problem.*

3. *The cost of producing reclaimed water, beyond secondary treatment and excluding transmission costs, is $67 per acre-foot for FE and $107 per acre-foot for the more expensive T-22 process.*

Overleaf:

Technicians shown sampling celery for microbiolgical assays.

CHAPTER 9

CONCLUSIONS

TREATMENT PROCESS EFFECTIVENESS AND RELIABILITY

Both the filtered effluent (FE) process (with or without flocculation) and the Title-22 (T-22) process are capable of effective and reliable tertiary wastewater treatment suitable for producing reclaimed water for irrigation of raw-eaten vegetables. The T-22 process, however, much more reliably produces an effluent of better quality than the FE process, with or without flocculation. Both processes are capable of meeting and exceeding state reclaimed water quality requirements, but to do so, the FE-F (or FE) process needs greater operator attention to general process control. The cost of producing reclaimed water using the Title-22 process is 1.5 to 2.3 times as high as using the FE process, with or without flocculation. The addition of the flocculation step to the FE flowstream increases the reliability of that process at a minimal cost.

HEALTH CONSIDERATIONS AND CONSUMER SAFETY

Use of reclaimed water for food crop irrigation is expected to pose no increased health threat to farm workers or others coming in contact with spray from irrigation, soil, plants, or runoff water from the fields. Measurements of all pathogenic indicators and chemical parameters in edible and residual tissues showed similar levels in effluent-irrigated and well water-irrigated crops. It is concluded by the authors of this report that safety to consumers is beyond reasonable doubt based on the findings of MWRSA:

1. No viruses were ever found in either effluent or on plants or soil.

2. Despite the lesser reliability of the FE system, there were no differences in any public health parameters among crops irrigated with the two effluents and the well water control.

3. Levels of coliform bacteria in well water often exceeded those in the two effluents.

4. Levels of bacteria in the two affluents were far lower than those typically found in surface waters. Fecal coliform levels from 700 to 12,000 MPN/100 mL have been reported from irrigation waters in western states (Reference 17).

AGRONOMIC PRACTICES

Irrigation with reclaimed water produced excellent yields of high quality produce. Cauliflower and broccoli yields were improved by irrigation with reclaimed water. Yields of lettuce and celery showed an interaction of water type and fertilization; effluent irrigation improved yields in unfertilized plots but had little or no effect on yields of plots receiving fertilizer. Artichoke yields were similar for all three water types.

Unfertilized crops had lower yields than did those that received fertilizer, but increasing rates of application often showed no significant improvement in yield. Yields of all five crops leveled off at or below 2/3 the standard local fertilizer application rate. Use of the full (3/3) local fertilization rate did not further improve yields. Thus, reductions in fertilizer applications may be possible for all of the crops.

No problem was observed with the accumulation of heavy metals in either crops or soil. Chlorine residuals in the reclaimed waters had no observable effect on crops.

With regard to salinity and sodicity, reclaimed effluent generally fell within the favorable range for irrigation based on levels of salinity, expressed as total dissolved solids (TDS), and sodium adsorption ratios (SAR). In general, high SAR is only a problem if overall salinity is low. High SARs in effluent from T-22 and FE treatments were offset by the correspondingly high levels of TDS. During the course of the study, significant reductions of permeability of effluent-irrigated soils were not noted.

MARKET ATTITUDES

The study of marketability of crops grown with reclaimed water indicated that the produce industry would carry such crops without special labeling for the buyer. In the absence of induced consumer awareness, concern about growing conditions is unlikely. The food marketing trade felt that should negative rumors ever occur regarding crops grown with reclaimed water, then information could be provided for the consumer as reassurance that risks to health or safety did not exist. Factual information on the use of reclaimed water was considered desirable as an aid to respond to customer inquiries. Business risks to growers from negative rumors were considered extremely low because of the rarity of such rumors and the ability to readily contain such rumors. It was also concluded that a favorable precedent had been established by the Irvine Company (in Orange County, Southern California), which for almost 20 years has been irrigating row crops, orchard wholesale nursery and landscape plants, and vebetables with reclaimed water every year on an ever-expanidng scale. The products of crops have been marketed through normal market channels with no known problems.

FEASIBILITY OF RECLAIMING WATER IN MONTEREY COUNTY

The combination of factors that are necessary to make wastewater reclamation feasible are:

(1) Water shortage

(2) Increasing water demand

(3) Increasing cost of developing new water sources

(4) Proximity of a source of reclaimed water to areas of use and need

(5) Acceptance by the agricultural community, the intermediaries, and the consumers

(6) Cost competitiveness of treatment to levels satisfactory to all concerned

These conditions have been documented elsewhere and in this report. It is concluded that wastewater reclamation (using the FE process) for irrigation of raw-eaten vegetable crops is feasible. The provision of state-required safeguards is assumed and is accounted for in estimating the cost of the production of reclaimed water at the quoted rates.

IMPLEMENTATION OF WATER RECLAMATION

It is most likely that wastewater reclamation in northern Monterey County will be undertaken in conjunction with plans of the Monterey County Flood Control and Water Conservation District (MCFCWCD) for supplying Salinas River water (from Nacimiento and San Antonio reservoirs) to the Castroville farming areas. The reason for proposing this joint development is that a piped distribution system is contemplated in the MCFCWCD scheme, aimed at stopping and possibly reversing seawater intrusion into the aquifers. This distribution system could also serve to distribute reclaimed water, blended with the imported surface water, to the points of use. The above scheme, known as the Castroville Irrigation Project, would supply about 25,000 acre-feet per year, while wastewater reclamation, over an eight-month irrigation season, would supply at least another 23,000 acre-feet. If all the costs of this distribution system were paid through assessments and fees by the growers as presently proposed, introduction of reclaimed effluent into the system would remain economically feasible. However, if part of the distribution cost were to be assigned to water reclamation, the affordability of reclaimed water may be jeopardized.

The California Department of Health Services (DOHS) must first approve the recommended FE-F treatment process. Any process which does not follow the precise treatment steps stipulated in Title-22 of the California Administrative Code must be certified as adequate by the DOHS.

The authors of "Irrigation with Reclaimed Municipal Wastewater" recommend that in California it would be prudent to apply for appropriation of the water that is to be reclaimed (Reference 15 in Chapter 5). Although, with recent amendments to the water codes, it is no longer required to obtain a permit to divert effluent for irrigation (instead, a "change in point of discharge, place of use, or purpose of use of treated wastewater" can be petitioned), it may still be advantageous for the MRWPCA to apply for a permit from the State Water Resources Control Board. The permit procedure for water use provides for a public process through which potential claims to the water are aired and resolved. It establishes a priority date and, once issued, it effectively prevents upstream water users from claiming ownership (Reference 15 in Chapter 5). Because the effluent would normally be discharged to the ocean, there would be no downstream users. This permit process would also involve solicitation of comments from the State Department of Health Services, as well as other interested agencies.

At the same time, letters of commitment must be obtained from growers who would purchase the reclaimed water.

As a part of the application for water appropriation, a full EIR process may be expected to be required (References 18 and 19) in which water rights, water quality, public health, and other issues would be discussed. The EIR would serve as a vehicle for incorporating the comments and concerns of all interested agencies, groups, and individuals who could be affected by water reclamation in Monterey County. Because the five-year pilot field study in MWRSA already involved these agencies and groups, it is expected that the EIR process would proceed smoothly, with possible additional comments from the U.S. Fish and Wildlife Service, California Department of Fish and Game, U.S. Army Corps of Engineers, etc. MWRSA reports and studies to date should provide adequate baseline and assessment documents upon which to base an EIR.

After completing the EIR process, a preliminary design report will be prepared, more specifically defining the project and its design parameters and criteria. Comments of the county's public health agency would be considered during the EIR process.

The purveyance of reclaimed water in Monterey County would come under the authority of the County Flood Control and Water Conservation District. The MRWPCA would be the producer of reclaimed water (as permitted by the Regional Water Quality Control Boards Wastewater Reclamation Requirement program) and would wholesale it to the MCFCWCD, which would then retail the water to users. This is highly advantageous from the perspective of reclaimed water distribution. As indicated above, the district is currently planning a water importation/ distribution system to irrigate farms in the Castroville area. The objective of this system is to reduce the current overdraft of groundwater, which has caused severe, expanding seawater intrusion into the local aquifers (References 20 and 21). After the distribution system to mitigate seawater intrusion is in place, it should be hydraulically simple to introduce the additional reclaimed water supply into the system and blend it with Nacimiento/San Antonio reservoir waters. The MCFCWCD also has an on-going program to monitor chloride levels in wells affected by intrusion. Discussions for coordination of these projects are in progress even as this report goes to press (February 1987).

Implementation schedule for full-scale water reclamation from the Monterey Regional Wastewater Treatment Plant will depend on the actions of several different agencies and cannot be readily predicted at this time. However, the steps needed for implementation, their sequence and the probable length of time each step might take (after publication of this report) are indicated below:

1. Pilot Reclamation Project ends successfully with the publication of this report and conclusion of safety of reuse for food crop irrigation. February 1987

2. Regional secondary treatment plant construction is completed. Mid-1988

3. State of California Department of Health Services reacts to publication of the MWRSA Final Report.

4. Obtain Monterey County Health Department concurrence with conclusions of MWRSA Final Report.

5. Develop of a coordinated joint project between Monterey Regional Water Pollution Control Agency and Monterey County Flood Control and Water Conservation District.

6. Environmental review process. (About one year after step 5)

7. Submit application for Wastewater Reclamation Requirements to Central Coast Regional WAter Qualtiy Control Board.

8. Obtain commitments from growers to purchase the reclaimed water.

9. Prepare a Basis of Design Report (BODR) for the tertiary process facilities and for transmission/distribution system. (About one year after step 7)

10. Obtain water rights. This is an optional step and can be taken at any time.

11. Arrange funding from state reclamation loan fund or other sources.

12. Design reclamation facility. (About one year, after step 8)

13. Design transmission and distribution systems. (About one year, concurrent with step 11)

14. Construction. (About two years, after steps 11 and 12)

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18. California State Water Resources Control Board. Personal Communication, J. Juransick, June 9, 1986

19. Martin, Cecil V. letter to Bahman Sheikh, dated June 24, 1986.

20. Leedshill-Herkenhoff, Inc. Salinas Valley Seawater Intrusion Study. 1985

21. CH2M Hill, Arroyo Seco Dam Feasibility Study, 1982

chapter 10

WE RECOMMEND:

Implement full-scale reclamation of effluent from the 30-mgd regional wastewater treatment plant for irrigation of about 10,000 acres of artichokes and other vegetables in the vicinity of Castroville to supplement another 10,000 acres to be irrigated with imported water. Implementation of this project, using the FE-F process would help counteract the presently increasing seawater intrusion in the local aquifers, in a cost-effective fashion.

Overleaf:

The subplot in the foreground received well water for irrigation and zero fertilizer. The size, color and shape of the crop in this and similarly treated subplots have always been dramatically inferior to unfertilized subplots irrigated with effluent. These readily observable facts are corroborated with yield data.

CHAPTER 10

RECOMMENDATIONS

The rationale for the following recommendations is contained in the discussions and results reported earlier in this volume. To make the project's recommendations most visible and accessible, they are simply and concisely stated below, without repeating the background and reasoning presented in the previous chapters.

(1) The MRWPCA should adopt filtered effluent (with flocculation) (FE-F) as the tertiary treatment process of choice for wastewater reclamation for vegetable irrigation.

(2) Obtain concurrence of the State Department of Health Services regarding "equivalency" of this process with the process specified in the California Administrative Code Title-22 or its "acceptability," and of Monterey County Health Department for the use of reclaimed wastewater for food crop irrigation in Monterey County.

(3) Determine the desirability of application to obtain the water rights to reclaimed water.

(4) Obtain letters of commitment from growers who would use reclaimed effluent.

(5) Prepare joint-development agreement with Monterey County Flood Control and Water Conservation District for concurrent planning, design, and implementation of wastewater reclamation at the regional plant and distribution of surface waters in the Castroville area.

(6) Prepare Basis of Design Report.

(7) Design tertiary treatment facilities and distribution system.

(8) Construct tertiary treatment facilities and distribution system.

appendix a

APPENDIX A

The celery grown in the experimental plots at Site D was harvested in November 1982. Celery was weighed to determine yield and samples were sent to the laboratory to be analyzed for microbiological, chemical, and heavy metal content.

APPENDIX A

ACKNOWLEDGEMENTS AND CREDITS

During the past ten years, a large number of people in the public and private sectors have helped create and move MWRSA along, starting with a modest work plan and resulting in a unique five-year field pilot project. Throughout all of these years and changes, scores of individuals have contributed their time and talent to ensure the success of this landmark project. To list every person whose contribution was significant would be impossible because many did their work behind the scenes. Therefore, the following list is necessarily a partial enumeration which in no way diminishes the value of the work of the rest.

The member agencies of the Monterey Regional Water Pollution Control Agency (MRWPCA), and their representatives on the agency's Board of Directors, in their wisdom continued to authorize the project even through some very difficult periods. The current member agencies and their representatives on the board are:

Del Rey Oaks:	Mr. Charles W. Benson, Chair
Castroville:	Mr. Granville Perkins, Vice Chair
Monterey:	Councilwoman Theresea Canepa
Monterey County:	Supervisor Karin Strasser Kauffman
Moss Landing:	Mr. Donald Green
Pacific Grove:	Councilman Dr. James Hughes
Salinas:	Mayor James Barnes
Sand City:	Mayor David K. Pendergrass
Seaside:	Councilman Theron J. Polite
Fort Ord:	Lt. Col. Leo Laskas

The following agency staff members, past and present, have been highly supportive and helpful in all phases of MWRSA:

Sid Brooks, Past Agency Manager

Dudley Lapham, Past Agency Manager

Hal Boudreau, Past Agency Manager

Ken De Ment, Current Agency Manager

Bob Jaques, Agency Engineer

Many others at the MRWPCA have been extremely helpful, including the plant operators, support staff, and financial department staff.

The Task Force that oversaw the activities of MWRSA throughout these ten years was led by Walter Wong and provided the project team with necessary direction, essential critique, and warm support. The entire Task Force membership list is presented in Chapter 3.

Granville Perkins has been especially instrumental in maintaining the necessary liaisons with elected officials at all levels, to give MWRSA the visibility and political support it deserved.

Dr. Takashi Asano and Dr. James Crook have given valuable scientific and technical dialogue to the project team.

Silvio Bernardi and others at Sea Mist Farms gave the field staff valuable agricultural advice and provided farm labor whenever needed throughout the five years of Phase III. Hugo Tottino of California Artichoke and Vegetable Growers Association gave cold storage space for produce at every harvest. Dr. David Ririe and his staff at the University of California Agricultural Extension Service, Monterey County, helped with quality assessment of the produce stored for various periods of time.

Funding for MWRSA was provided through a Clean Water Step 1 grant from the U.S. Environmental Protection Agency, State Water Resources Control Board, State Department of Water Resources, and local contributions from the MRWPCA.

The Engineering-Science and subconsultant teams involved in MWRSA under contract with the MRWPCA included the following individuals:

Bahman Sheikh, Ph.D., Project Manager, Soil Scientist

Robin Cort, Ph.D., Assistant Project Manager, Ecologist, responsible for data analysis and literature updates

William R. Kirkpatrick, Sanitary Engineer, design of treatment plant and irrigation system, and operations assistance

Samuel B. Earnshaw, Field Technician, Ecologist in charge of field operations

Jo Ann Baumgartner, Field Technician, Soil Scientist, assisting with field operations

Erica Kundidzora, Sanitary Engineer

Thomas T. Jones, Chemical Engineer, consulting on computer programming

Joyce S. Hsiao, Environmental Engineer

Joanne Sweeney, Public Health Scientist

Marita L. McLaughlin, Environmental Analyst

Richard Makdisi, Hydrogeologist

Amy Skewes-Cox, Planner, responsible for literature update

Sanford Siegel, Mathematician, consultant on computer graphics and programming

Eric Storrs, Environmental Analyst

Desmid Lyon, Field and Data Management Assistant

Melanie Baltezore, Laboratory Manager

Valerie C. Haight, Microbiologist

Afsaneh Salimpour, Laboratory Technician

Edward Haynes, Laboratory Technician

Joseph Muehleck, Laboratory Technician

Jim Morris, Laboratory Supervisor

Mark Davis, Graphic Artist

Melinda M. Bury, Word Processing Production

Judith Herman, Editor

Philip N. Storrs, Technical Director

N. L. Presecan, Technical Director for treatment system design

T. G. Cole, Liaison with MRWPCA and other related projects

University of California, Berkeley

Robert C. Cooper, Ph.D., Principal Investigator for Virology (under subcontract to ES)

David Straube, Assistant to Prof. Cooper

Laura Kornstein, Virology Laboratory Technician

Michiko Irene Asao-Wells, Virology Laboratory Technician

University of California, Davis

Richard Burau, Ph.D., Soil Scientist (under subcontract to ES)

appendix b

APPENDIX B

Soil scientist reads water level and elapsed time at pre-set intervals in a double-ring infiltrometer. The infiltrometer is used to assess field intake rate (a measure of permeability *in situ*) on the different sub-plots.

APPENDIX B

SAMPLING AND ANALYTICAL PROCEDURES AND QUALITY ASSURANCE

SAMPLING METHODS

Aerosol Investigations

In addition to a survey of the published reports in the scientific literature, a field study was performed to compare aerosols generated in spray irrigation with filtered effluent to that with well water. Two Andersen six-stage impactors were placed 30 and 60 m (100 and 200 ft) downwind from sprinkler lines, and a third was placed 15 m (50 ft) upwind as a control. The impactors were placed at a height of 1.5 m (5 ft), about the height of human adult respiration. Both day and night sampling were conducted using selective and nonselective biological culture media. Samples of the irrigation water were taken at the same time as aerosol sampling to determine the bacteriological content at the source. During two sampling runs, lithium chloride was injected into the irrigation system as a tracer, and aerosols were sampled 15 m (50 ft) downwind with two all-glass impingers, as well as with two Andersen impactors.

Irrigation Water

Throughout the five years of field studies, samples of the three irrigation waters were taken at each irrigation event. Samples of the three water types were continuously composited during each irrigation. Depending on the irrigation schedule, samples were collected over a three-to-five-day period. The composite samples were then divided into subsamples for metal and chemical analysis. Grab samples of irrigation water were collected in sterilized bottles for bacteriological analysis and in unsterilized clean bottles for biochemical oxygen demand (BOD) analysis. These grab samples were stored in an ice chest and sent to the laboratory within 24 hours. Irrigation waters were sampled 91 times over the five years for 33 artichoke and 58 vegetable irrigations.

During furrow irrigation of row crops, tailwater samples were collected from runoff. Eight tailwater samples were collected during the five years of sampling. The remainder of the 58 irrigations were performed with sprinklers.

In addition to the regular irrigation water sampling, both effluents were sampled daily at the pilot plant and analyzed in their laboratory for total suspended solids, turbidity, total coliform and chlorine residual. Levels of ammonia nitrogen were also periodically assessed. Thousands of these analyses were thus completed in the course of the study.

Soil

During the first three years of field studies, surface soil samples were taken for bacteriological analyses in the fall and spring. Samples were taken with a trowel from the uppermost soil zone (15 cm (6 in.)) within two days after irrigation. Five subsamples of 20 g of soil were taken from different locations within each plot and composited to produce a 100-g sample. Locations for subsamples were chosen randomly from the inner rows of each plot. Composited soil samples were cooled and shipped to the laboratory within 24 hours. Bacteriological sampling was discontinued after Year Three because it was felt that ample data had been collected.

Throughout all five years of MWRSA, soil profile samples were collected and analyzed for a variety of metal, chemical, and physical parameters. Soil sampling was performed by the California Department of Water Resources. Soils were analyzed annually for metals and organic matter content. During the first two years, biannual sampling was conducted for cation exchange capacity, boron levels, and chemical parameters such as pH and salt content. After the first two years, sampling frequency was reduced to once each year. Biannual samples were taken at the end of the irrigation season (mid-October to mid-December) and again after artichoke cutback (mid-May). Annual samples were taken at the end of the irrigation season. A baseline soil profile sample was taken in December 1979, before the beginning of the MWRSA field operations, and analyzed for the full complement of metal, chemical, and physical parameters.

At each sampling event, soil samples were taken with a soil auger at depths of 30 cm (1 ft), 100 cm (3 ft), and 200 cm (6 ft). Soil samples gathered at the 30-cm and 100-cm depths were each a composite of five subsamples taken from within each of the 96 artichoke and vegetable plots. The 200-cm sample was taken only at the center of the plot.

During the first three years of MWRSA, a portion of the annual soil samples was used for permeability analyses performed in the laboratory. In Year Four, it was decided that measurement of field infiltration rates would provide a more realistic quantification of permeability. During Years Four and Five, field infiltration rates were measured three times in both the artichoke and vegetable fields.

Plant Tissue

At each major harvest, samples of plant tissue were collected for analysis. Edible and residual tissues were sampled for bacteriological and metals assays. Any portion of the plant that was left in the field after harvest was considered to be residual tissue.

Bacteriological Sampling

Samples of both edible and residual tissues were collected using aseptic gloves, aseptic bags, and alcohol sterilized knives. Fresh gloves were used for each plot, and knives were cleaned with alcohol before each sample. All bacteriological samples were kept on ice and shipped to the laboratory for analysis within 24 hours.

Metal Sampling

Edible portions of the crop were collected for metals analyses at each major harvest. Samples for analysis were composited from 8 to 20 plants, depending on the size of the harvestable portion of the crop. Crop residues were also sampled for analysis. The oldest leaves from 10 to 12 plants were gathered for boron assay.

Nutrient Sampling

Nutrient samples were taken from petioles of the most recently matured leaf. Samples were composited from 10 to 20 plants at each major harvest. Starting in Year Two, nutrient samples were also collected at each fertilization.

Neighboring and Random Field Sampling

In addition to sampling the experimental plots, at each artichoke harvest samples of edible tissue were also taken from the neighboring artichoke fields for bacteriological and metal assays. Because only artichokes were grown in the fields neighboring Site D, no neighboring field sample was collected at vegetable harvests. Artichokes were sampled at distances of 15, 30, 60, 150, and 300 m (50, 100, 200, 500, and 1,000 ft).

A random selection of fields in the area was also sampled for bacteriological and metal analyses at each artichoke and row crop harvest. Samples of edible tissue were collected at four locations within a randomly selected field located at least 1 km (0.6 mi) from Site D.

YIELD AND QUALITY DETERMINATION

Artichokes were harvested about every two weeks during the period from early September until the cutback in May. The sample harvest was taken from the six central plants of the two middle rows of the artichoke plots. Because of the variation in time of maturity, broccoli and cauliflower generally required two or three cuttings spaced about a week apart. The yield for celery and lettuce was determined in a single harvest, which took from one to three days, depending on the size of the crop. The sample harvest was taken from the central 8 m (26 ft) of the four middle rows of the vegetable plots.

Crops were monitored to detect qualitative differences attributable to the different irrigation waters. An experienced agriculturalist made periodic field inspections of the experimental artichoke plots. Crop evaluations were made without knowing the type of irrigation water used. Control standards of quality, as enforced by the County Agricultural

Commissioner's Office for the State Department of Food and Agriculture, were used in making these judgments.

Quality inspections for vegetable crops were performed at the same time as shelf life determinations. A portion of the sample harvest for vegetables from each plot was packed into three boxes and placed in cold storage where they were later inspected for shelf life characteristics. A representative from the County Farm Advisors Office inspected these crops, without knowing the type of irrigation water used, at intervals of approximately 7, 14, and 21 days following the harvest. Criteria used for judging celery were color, spoilage, and pithiness. Broccoli was judged for color, odor, decay, compactness, and general appearance. Lettuce was examined for tip burn, russet spotting, slime, injury spot (bruising), and firmness. Cauliflower criteria were color, shape, brown spotting, decay, riciness, stem color, and hollow stem.

ANALYTICAL PROCEDURES

The analytical methods presented in this chapter were selected for MWRSA because of their accuracy, precision, and practicality. A summary of analytical methods was published in the Year One Annual Report. Methods were refined and improved during the course of the study, and this appendix describes the latest methods used.

Standard sources of methodology were the American Public Health Association (APHA) (Reference B.1), the Association of Official Analytical Chemists (AOAC) (Reference B.2), the U.S. Environmental Protection Agency (EPA) (Reference B.3), and the American Society of Agronomy (ASA) (References B.4 and B.5).

Methods of analysis used for MWRSA can be divided into three categories according to the types of samples: (1) aqueous samples including irrigation waters, effluents, and groundwaters, (2) soil samples, and (3) plant tissue samples. Soil extracts were treated as aqueous samples; therefore, methods for their analysis were the same as for the first category.

AQUEOUS SAMPLES

Boron (Methods of Soil Analysis, 2nd Edition, 25-5. Scientific Instruments Corp. (SIC). Technical Information)

A continuous flow autoanalyzer (CFA-200, SIC) was used to determine Boron concentration. The method employed is based on the reaction of Boron with azomethinal-H dye to form a colored H_3BO_3 complex.

Carbonate, Bicarbonate (Standard Method 403)

Carbonate and bicarbonate alkalinity was determined by calculating the results of a standard alkalinity test and the phenolphthalein alkalinity.

Hardness (Standard Method 314B)

Hardness was determined by titration of an aliquot with a standardized solution of ethylenedinitrilotetraacetic acid (EDTA).

Metals and Calcium, Magnesium, Sodium, and Potassium - (Standard Method 302D, 303, 303A, and EPA methods)

At the time of analysis, an aliquot of previously acidified sample (with nitric acid) was transferred to a beaker, an amount of concentrated nitric acid equivalent to 5 percent by volume of the aliquot was added, and the sample was heated for 15 minutes at 95°C. The sample was then cooled, and increments of water were added to adjust the final volume. The sample was analyzed by atomic absorption spectroscopy according to the individual requirements of each metal. When possible, samples were acidified and analyzed directly, without digestion. During years One through Three this type of metals analysis was performed for cadmium, zinc, iron, manganese, copper, nickel, cobalt and lead. Because levels of cadmium, copper, nickel, cobalt, and lead were very low, a method was developed to concentrate metals. Metal samples in Years Four and Five were composited and analyzed using this new technique, which is detailed in the soil section under soil metal analyses.

Nitrogen, Nitrate-Nitrite (EPA Method 353.1 and SIC Technical Information)

A continuous flow autoanalyzer (CFA-200, SIC) was used to determine nitrate concentration. The method employed a copper-cadmium reductor column to reduce nitrate to nitrite. Nitrite subsequently reacted with sulfanilamide under acidic conditions and was coupled with N-(1-naphthyl)-ethylenediamine dihydrochloride to form a colored azo dye. The summation of converted nitrate (nitrate -> nitrite) and nitrite (no use of reductor column) was a measure of nitrate.

Nitrogen, Ammonia (EPA Method 350.1 and SIC Technical Information)

A continuous flow autoanalyzer (CFA-200, SIC) was used to determine ammonia concentration. Alkaline phenol and hypochlorite react with ammonia to form indophenol blue that was proportional to the ammonia concentration.

Nitrogen - Total Kjeldahl (SIC Technical Information)

The digestion for Kjeldahl nitrogen used an AD-40420 block digester (SIC) and involved sample digestion in the presence of sulfuric acid, potassium sulfate, and mercuric sulfate for 2.5 hours. Subsequently, TKN was determined by measuring ammoniacal nitrogen by a salicylate/ nitroprusside reaction.

pH (Standard Method 424)

The pH values were measured using the electrometric method, which uses a glass silver/silver chloride electrode in combination with a calomel reference electrode.

Total Phosphorus (Standard Methods 424C, 424F)

A persulfate digestion was used to convert insoluble phosphorus to orthophosphate. Orthophosphate was subsequently measured by the colorimetric ascorbic acid method (EPA order) and provided a measure of total phosphorus.

Electrical Conductivity (EPA Method 120.1)

Measurements were made with a conductivity meter and a platinum cell. The meter uses the Wheatstone bridge principle. The meter was standardized daily with a potassium chloride solution. Results were reported at 25°C.

Chloride (Standard Method 407A)

Chloride was determined by the argentometric method. In a neutral or slightly alkaline solution, potassium chromate was used to indicate the end point of the silver nitrate titration of chloride. Silver chloride is precipitated quantitatively before red chromate is formed.

Total Suspended Solids (EPA Method 160.2)

A well-mixed sample was filtered through glass fiber paper, and the residue retained was dried to constant weight at 103° to 105°C. The sample was then cooled and weighed.

Total Dissolved Solids (Standard Method 209B)

The filtrate from the total suspended solids analysis was evaporated and dried to constant weight at 180°C. It was then cooled and weighed.

Biochemical Oxygen Demand (Standard Method 507)

Samples were incubated in the dark for five days at 20°C. Reduction in the dissolved oxygen concentration during this incubation period was measured with a dissolved oxygen meter. This is a measure of biochemical oxygen demand.

Sulfate (EPA Method 375.4)

Sulfate ion was precipitated in a hydrochloric acid medium with barium chloride to form barium sulfate crystals of uniform size. The absorbance of the barium sulfate suspension was measured by a nephelometer or spectrophotometer, and the sulfate ion concentration was determined by comparison of the reading with a standard curve.

Coliform, Total and Fecal (Standard Methods 908A, 908C, and 908D)

Total and fecal coliform bacteria were quantified using multiple-tube fermentation techniques. For total coliform, lauryl tryptose broth was used for primary fermentation. The California Department of Health Services guidelines require that all positive and turbid tubes from the presumptive test be confirmed using brilliant green lactose bile broth.

At the ES Berkeley laboratory, ten percent of all confirmed tests were completed by streaking Levine Eosin Methylene Blue (L-EMB) agar, followed by inoculation of lauryl tryptose broth with typical and/or atypical colonies indicative of the coliform group. Coliform analyses of effluents performed at the pilot plant were not completed. All positive or turbid presumptive fermentation tubes were used to inoculate Escherichia coli (EC) medium for the fecal coliform MPN determination. Positive (E. coli) and negative controls were run through the entire procedure.

Salmonella and Shigella (Manual of Clinical Microbiology, Edwards and Ewing's Identification of Enterobacteriaceae, and Biochemical Tests for Identification of Medical Bacteria)

All positive fecal coliform samples were analyzed for presence of Salmonella and Shigella. Selenite and Hajna Gram-negative (GN) enrichment broths were inoculated with liquid samples. The selenite medium was used to enrich most salmonellae, including S. typhi and some shigellae. The use of GN broth increased recovery rates for salmonellae and in particular shigellae.

After enrichment, bismuth sulphite and hektoen-enteric selective agar were streaked. Bismuth sulphite agar was the most efficient medium to date for the recovery of salmonellae, including S. typhi. Hektoen-enteric agar was recommended for the recovery of shigellae (as well as salmonellae).

Triple sugar iron (TSI) and Lysine iron (LIA) agars were inoculated with isolated typical and/or atypical colonies indicative of Salmonella and Shigella. Those TSI/LIA cultures exhibiting reactions indicative of Salmonella and Shigella were used to inoculate Methyl Red-Voges Proskaver (MR-VP) medium. MR-VP culture results potentially indicative of Salmonella and Shigella were subsequently screened via API 20-E biochemical test strips to determine the identification of each culture. Additional biochemical and/or serological tests were used to confirm positive results or investigate questionable results.

ATCC Salmonella and Shigella stock cultures and negative controls were run through the entire screening procedure.

Ascaris Lumbricoides and Entamoeba Histolytica (Manual of Clinical Microbiology)

Liquid samples were concentrated and assayed using the formalin-ether sedimentation technique for the recovery of helminth eggs and protozoan cysts. This involved emulsification of the sample with phosphate buffer solution, straining through cheesecloth, and centrifuging. Formalin was added to the sample. Ether was added, and the centrifugation was repeated. The formalin and ether layers were decanted, and a microscopic examination of the sediment was performed using preparations stained with iodine solution.

Methylene Blue Active Substances (MBAS) (Standard Method 512B)

Liquid samples form a blue colored salt when methylene blue reacts with anionic surfactants, including linear alkylate sulfonate (LAS), alkyl sulfates, and alkyl polyethoxyl sulfates. The materials determined were designated methylene-blue-active substances. The salt was soluble in chloroform and the intensity of color proportional to the concentration. The intensity was measured by making spectrophotometric readings in this solvent at a wave length of 652 nm.

SOIL SAMPLES

Cation Exchange Capacity (Methods of Soil Analysis 57-3, 1965)

Air-dried soil was shaken with sodium acetate solution and centrifuged until clear. The supernatant was decanted and discarded. The process was repeated three more times. The sample was then washed in an identical manner with alcohol. The procedure was repeated, replacing the adsorbed sodium with ammonium actetate solution, decanting each wash into a volumetric flask. The collected solution was diluted to volume with ammonium acetate and sodium determined by atomic absorption as previously described for aqueous samples.

Organic Matter Content (Standard Method 209D)

Oven-dried samples were cooled in a dessicator, weighed, and ignited for two hours in a muffle furnace at 550°C. Samples were cooled and reweighed. Volatile matter content was reported as a percentage of the original sample.

Nitrogen - Total Kjeldahl (Soil SCI. Amer. Proc. 1973. Vol. 37: 480-81 and SIC Technical Information)

The digestion for Kjeldahl nitrogen used an AD-40420 block digester (SIC) and involved sample digestion in the presence of sulfuric acid and Scientific Chemical Technical (SCT) bulk powder for 2.5 hours. TKN was determined by the autoanalyzer method discussed for aqueous samples.

Nitrogen, Ammonia (Methods of Soil Analysis 33-7)

Soil ammonia was extracted with 2M KCl and subsequently determined by the autoanalyzer method discussed for aqueous samples.

Nitrogen, Nitrate-Nitrite (Methods of Soil Analysis)

A dried and ground sample was extracted with deionized water, and nitrate was determined by the autoanalyzer method discussed for aqueous samples.

Phosphate (Soil SCI Soc. Amer. Proc. 29:677-78. 1966)

Samples were extracted with 0.5M sodium bicarbonate, chosen because of its relative immunity to precipitation interferences and its common use in estimating available soil phosphorus. Phosphate was determined by the ammonium molybdate-ascorbic acid colorimetric method.

Texture (Methods of Soil Analysis 43-4, 1965)

Because most samples were fine textured, a pipette method of particle size analysis was used. Samples were dispersed using a sodium hexametaphosphate solution and transferred as a suspension to a hydrometer jar. Aliquots were removed with a pipette at a constant depth below the surface at regular time intervals, and their weights were determined. The distribution of particle sizes was then calculated, using equations derived from Stoke's Law.

Metals Extraction Methods (Methods of Soil Analysis, 1965 62-1.3 and Method of Lindsay and Norvell, 1978)

Samples were analyzed for 13 metals by two extraction procedures. Calcium, magnesium, sodium, and potassium were determined on a soil saturation extract (extraction procedure described below). The nine trace metals (cadmium, cobalt, chromium, copper, iron, manganese, nickel, lead, and zinc) were extracted with a solution of the chelating agent diethylenetriamine pentacetic acid (DTPA). This agent was used to extract the "available" metals (Reference B.9). Following these separate extraction procedures, the samples were analyzed by atomic absorption spectroscopy. See aqueous samples.

Using the DTPA extraction technique, it was found that levels of a number of metals were at or below detection limits. With the help of Dr. Richard Burau (University of California, Davis), an extraction protocol was developed to concentrate metals. The extraction used organic chelators that bind metals in the saturation paste extract. The chelators were then digested and the metals suspended in nitric acid. Each extraction contained a set of internal standards to correct for any difference in the specific metal-binding efficiency of the chelator. Samples were again quantified using an atomic absorption spectrophotometer. This extraction technique was used to analyze levels of cadmium, copper, nickel, cobalt, and lead in baseline and Year-Five soils. The chelation procedure was also used in the analysis of those metals in irrigation waters in Years Four and Five.

Saturation Paste and Extract (Methods of Soil Analysis 62-1.3, 1965)

Samples were air-dried and then blended with distilled water until a conditon of saturation was reached. The sample "paste" was allowed to stand to equilibrate and was then mixed before determining the pH. The paste was vacuum filtered, and the filtrate (extract) was then analyzed as an aqueous sample. Aqueous analyses included electrical conductivity, carbonate, bicarbonate, chloride, and the four metals mentioned above.

Sulfate (Methods of Soil Analysis 79-4.2, 1965)

Samples were extracted with ammonium acetate, and the sulfate was precipitated as barium sulfate and measured turbidimetrically.

Boron Extraction (Methods of Soil Analysis 75-4, 1965)

Samples were boiled in deionized water for five minutes and filtered. Boron was determined by the autoanalyzer method discussed for aqueous samples.

Permeability (Methods of Soil Analysis 41-4, 1965)

Air-dried soil was sieved and packed in a clear plastic cylinder, supported by a screen and filter paper. The soil surface was covered with filter paper, and water was introduced with a minimum of soil disturbance. The water level was adjusted so that the height of the soil-water column was twice the soil column length. The volume of percolate collected during a number of successive time intervals allows computation of permeability of the sample to water.

Field infiltration rates were measured using standard double-ring infiltrometers consisting of two concentric 30-cm-(12-in.-)tall cylinders, driven 15 cm (6 in.) into the soil, in the center of each plot. Water was poured into both rings, and the water level changes in the inner ring were recorded for four hours.

Coliform, Total and Fecal (Risk Assessment and Health Effects of Land Application of Municipal Wastewater and Sludges-Proceedings. Editors: Sagik and Sorber)

Twenty-five grams of soil samples were weighed aseptically into sterile phosphate buffer diluent bottles. The bottles were placed in a horizontal position in a reciprocating shaker with the diluent for 10 minutes and then assayed using conventional multiple tube fermentation techniques, as described for aqueous samples.

Salmonella and Shigella (Risk Assessment and Health Effects of Land Application of Municipal Wastewater and Sludges-Proceedings. Editors: Sagik and Sorber)

Soil samples with positive fecal coliform were weighed aseptically into sterile diluent bottles containing phosphate-buffered dilution water. The bottles were placed in a horizontal position in a reciprocating shaker for 10 minutes with the diluent and then assayed as liquid samples.

Ascaris lumbricoides and Entamoeba histolytica

Soil samples were weighed into phosphate buffer diluent bottles. The bottles were placed in a horizontal position in a reciprocating shaker for 10 minutes and then assayed using the Formalin-ether sedimentation technique, as described for liquid samples.

PLANT TISSUES

Boron (AOAC Method 3.102)

A dried and ground sample of residual tissue was ashed and extracted with sulfuric acid. Boron was determined by the autoanalyzer method discussed for aqueous samples.

Metals, Preparation (Manual for Scientific Block Digester, Models AD-20 and AD-40)

The digestion for plant metals used an AD-40420 block digester (SIC) and involved sample digestion in the presence of aqua regia. Following digestion, the samples were analyzed by atomic absorption spectroscopy. Edible tissue was analyzed for the nine trace metals, and residual tissue was analyzed for cadmium, zinc, and boron. See aqueous samples.

Nitrogen - Nitrate Extract (Method of Johnson and Ulrich, Analytical Chemistry, 1950)

Ground plant tissue was weighed into bottles and shaken with deionized water in the presence of phosphate. The samples were filtered, and the filtrate was analyzed for nitrate by the autoanalyzer method described for aqueous samples.

Phosphate (Method of Ulrich, et al., University of California Agricultural Experiment Station, 1959)

Samples were extracted with two percent acetic acid and the extract filtered. The filtrate was analyzed for phosphate colorimetrically after adding ammonium molybdate and stannous chloride. The blue phosophomolybdate color was measured at a wave length of 660 nm.

Potassium (Method of Ulrich, et al., University of California Agricultural Experiment Station, 1959)

Samples previously extracted for phosphate using two percent acetic acid were analyzed for potassium by atomic absorption. The extract was treated as an aqueous sample for determination of potassium.

Coliform, Total and Fecal (Risk Assessment and Health Effects of Land Application of Municipal Wastewater and Sludges. Editors: Sagik and Sorber)

Sixty grams of plant tissue sample were weighed aseptically into sterile bottles containing phosphate-buffered dilution water with 0.1 percent Tween-80 (a surfactant). The bottles were placed horizontally in a reciprocating shaker for ten minutes. The sample was then assayed using conventional multiple tube fermentation techniques, as discussed for aqueous samples.

Salmonella - Shigella (Risk Assessment and Health Effects of Land Application of Municipal Wastewater and Sludges. Editors: Sagik and Sorber)

Sixty grams of plant tissue samples with positive fecal coliform were weighed aseptically into sterile containers containing phosphate-buffered diluent with 0.1 percent Tween-80 and placed horizontally on a reciprocating shaker for ten minutes. The sample was then inoculated into enrichment broths and assayed as a liquid sample.

Ascaris lumbricoides and Entamoeba histolytica

Sixty grams of plant tissue sample were weighed into a high speed blender jar. A phosphate buffer diluent was added, and the sample was dispersed. The sample was then assayed using the Formalin-ether sedimentation technique as a liquid sample.

QUALITY ASSURANCE

Precision and accuracy of analytical data were assessed continually as part of the ongoing Engineering-Science Research and Development Laboratory quality assurance program. This program has been submitted to and approved by the State of California Department of Health Services.

Sample Processing

On receipt, all sample identification information was entered into a bound MWRSA sample log, which was maintained exclusively for MWRSA samples. Analyses to be performed immediately were completed. Aliquots for other analyses were preserved and stored for further processing.

Recording of Data

Raw data were entered in each analyst's laboratory notebook. Raw bacteriological data were entered into a separate data book. After completing an analysis, raw data, including standard curves, were photocopied and added to the bound MWRSA raw data logs for specific groups of analyses, e.g., metals in soil. Final data were recorded in a special MWRSA final data log with sections designated for water, soil, and plant tissue analyses. Final data records were designed for ease of transfer to computer storage. Minimal effort was required to retrieve either raw or final data for review, when needed.

Statistical Quality Control

Published precision and accuracy data exist for only some of the analytical methods used in this study. Others, particularly soils analyses, have published data pertaining to a narrow range of conditions (e.g., soil type) or to a specific concentration range.

The number of analyses to be performed as replicates and spikes was set at a minimum 10 percent. The total amount of labor expended on quality assurance was 15 percent of the total labor expended. The model for the statistical quality control is Chapter 6, "Control of Analytical Performance," from the "Handbook for Analytical Quality Control in Water and Wastewater Laboratories," U.S. Environmental Protection Agency, 1972 (Reference B.10).

MWRSA quality control data were recorded in a file separate from the general laboratory quality control data. Parameters recorded were number of replicates, mean, standard deviation and percent error, range of replicates, and percent spike recovery. The range of replicate (precision) and percent spike recovery (accuracy) charts were prepared from the data.

Analysis followed a protocol of replicates in sets of 10 performed at intervals during the entire period of the analysis. One or two spiked samples were also performed for each set. For example, in analyzing for boron with soil, 10 replicates of three samples were performed in a period of 10 days, one replicate of each of the three samples per day. Each sample was spiked once at the soil extraction stage and once at the colorimetric stage to check the accuracy of both stages of analysis. Other samples were split for analysis by other laboratories.

Reference Samples

Reference samples obtained from the Cincinnati office of the U.S. Environmental Protection Agency were run quarterly. The information obtained supplements the replicates and spikes and served as an outside check on performance.

Quality Assurance Officer

A quality assurance officer was designated before the commencement of the analytical program. The officer maintained all records, logs, etc., and had the overall responsibility for the approval and release of data obtained.

VIROLOGICAL TECHNIQUES

Virus Assay Method

Viral plaque assays were performed using Buffalo Green Monkey (BGM) kidney cells grown in plastic culture bottles. The growth medium was 45 percent Hanks minimum essential medium (MEM), 45 percent L-15 medium, and 10 percent fetal bovine serum containing 0.01 percent L-glutamine, potassium penicillin (100 units/mL), streptomycin sulfate (0.1 mg/mL), and enough 7.5 percent $NaHCO_3$ to produce a pH of 7.2 to 7.4. Cells were incubated at 37°C until confluent, generally 3 to 4 days.

Each cell culture was inoculated with 0.2 to 0.5 mL of prepared sample and incubated at 37°C for one hour to allow virus adsorption. Each bottle then received 6 mL of overlay medium consisting of MEM with Hanks balanced salts containing two percent gammaglobulin-free bovine serum, 0.1 percent milk (Difco), 0.01 percent $MgCl_2$, potassium penicillin (100 units), streptomycin sulfate (0.1 mg/mL, 0.75 percent $NaHCO_3$), 1.5 percent agar, and 0.01 percent neutral red. These overlays were incubated for three to five days at 37°C prior to counting the resultant plaques.

In the evaluation of the virus-removal efficiency of the T-22 and FE processes, bacteriophage were also used in the hope that they might act as a surrogate for the poliovirus seed. In this instance, coliphage f2 was used. The seed virus was grown in a culture of Escherichia coli, strain K12 high-frequency recombination (hfr), and further treated by centrifugation to remove bacterial debris. The seed contained approximately 1 x 10^9 plaque-forming units (PFU)/mL. Phage assay was made by the MPN method in which three tubes of bacterial growth medium were each inoculated with 10, 1, and 0.1 mL of filter effluent. Each tube was then inoculated with a minute amount of a 24-hour culture of E. coli K12 and incubated at 35°C for 24 hours. At the end of this period, each tube was confirmed for the presence of phage by placing a small drop of its contents onto a fresh lawn of E. coli on agar medium and incubated for 8 to 12 hours at 35°C. If phage is present in the applied drop, a clear spot will appear on the lawn and confirm that the associated tube contained the f2 phage.

Recovery of In Situ Virus from Water and Soil

Because the number of enteric viruses present in any of the irrigation waters was expected to be low, it was necessary to perfect a technique for concentrating the viruses. A method was used in which large volumes of water were passed through fiberglass filters, and the viruses present in the water adsorbed to the filters. The water was pretreated by adjusting 3800 L (1,000 gal) of the irrigation water to pH 3.5 using hydrochloric acid and adding aluminum chloride to a concentration of 0.0005 molar (M). This adjusted sample was then pumped through four 25-cm-(10-in.-)tall filters (Filterite Corp.), each with an effective porosity of 0.45 um. The four filters were arranged in parallel and the total flow rate through the filters was 30 to 38 L/min. The adsorbed viruses were subsequently desorbed from the filters by passing through 3 L of 3.5 percent beef extract (OXOID), buffered to pH 10 with 0.5M glycene buffer. The 3 L of eluate was then adjusted to pH 3.5, resulting in a precipitate to which viruses would be adsorbed. This precipitate was collected using a continuous flow centrifuge at 10,000 rpm [12,000 relative centrifugal force (rcf)]. The resulting pellet was then redissolved in up to 25 mL of 0.15M sodium biphosphate at pH 9.2, the pH neutralized, and the sample immediately assayed or stored at -70°C. Virus recovery efficiency using this method ranged from 25 to 70 percent, which is to be expected with these concentration methods.

The volume of pilot plant influent sample (unchlorinated secondary effluent) was usually 6 L. Each sample was adjusted to pH 3.5 and aluminum chloride added to 0.0005M; it was then filtered through a 142 mm Cox filter "sandwich." The "sandwich" was composed of an AP20 (Millipore Filter Corp.), a Cox 5-micrometer filter, and a Cox 0.45-micrometer (Cox Research Corp.) filter. The adsorbed virues were then eluted with 100 mL of pH 11.5 glycine buffer, quickly adjusted to pH 7.0, and the resultant material was assayed for virus.

Soil and vegetable samples were collected from the experimental plots within 24 hours of the end of an irrigation set. Two plants and associated soil samples were selected at random from the outside rows of test plots receiving no fertilizer and composited. In each instance, the final sample amounted to at least 50 g of material. Viruses were eluted from both plant and soil surfaces using three percent, pH 9 beef extract. The resultant eluate was then precipitated by adjusting the pH to 3.5, and the precipitate was collected by centrifugation at 12,000 rcf. The resultant pellet was redissolved in 0.15M sodium biphosphate at pH 9.2, neutralized, and assayed for virus. The development of these methods was conducted during Phase I of this study (described in detail in the 1980 Phase II report). Virus recovery efficiency using these methods ranged from 19 to 37 percent from soil and 36 to 83 percent from vegetables.

Environmental Chamber Studies

To study the survival characteristics of viruses on plants and soil, experiments were conducted in an environmental chamber that simulated the weather conditions in Castroville, California. Plants and soil were inoculated with vaccine strain poliovirus 1(LSC), exposed to chamber conditions, and the decay in virus concentration was measured over time. The environmental chamber located at the University of California's Richmond Sanitary Engineering and Environmental Health Research Laboratory, is a 6 x 2.4 m double-wall insulated structure.

Temperature and humidity control were provided by an integrated system, which includes air circulation through the chamber and an air conditioning system. Lighting is provided with an enclosed light box equipped with a mixture of F40 BL and F40 CL fluorescent lamps. The BL lamps supplied the ultraviolet spectrum of sunlight (but not the intensity), and the CL lamps supplied the wave lengths required for plant growth. The chamber was operated at a temperature of 15.6°C (60°F) and at three different relative humidities of 60, 70, and 80 percent, respectively. Known amounts of virus were sprayed onto tared test plants so that the increase in weight of the inoculated plants reflected the amount of inoculum and, thus, the zero time virus concentration. The exposed plants included artichokes, black-seeded Simpson lettuce, celery, broccoli, and head lettuce. Each plant stem or root remained immersed in water throughout the exposure period.

Representative Castroville soil was contaminated with test virus (poliovirus) by seeding the surface of a 100 g soil sample with a known quantity of virus in a volume that would saturate the sample. Virus recovery procedures were as described previously.

The survival of animal virus in Castroville soil was studied under controlled in situ conditions. The investigation involved the use of Castroville soil seeded with poliovirus and exposed to ambient conditions at the University of California's Sanitary Engineering and Environmental Health Research Laboratory in Richmond, California. This latter site was choosen because (1) the logistics of sampling soil and performing frequent virus analyses over a 20-day period made performing the study at Castroville impractical, and (2) the Richmond site is adjacent to the east shore of San Francisco Bay and has a climate very similar to that found at Castroville with foggy cool nights and mornings and sunny afternoons.

The methods used for the virus survival in soil study were as follows: Castroville soil was collected from the MWRSA demonstration site and homogenized in a soil-mixing mill. Soil columns were prepared using 30-cm-(12-in.-)long, 8-cm-(3-in.-)diameter schedule 40 PVC pipes, each divided into 10-cm (4-in.) sections. The sections were glued together with silicone cement. For each of the two runs conducted, 25 columns were prepared. Covered empty columns were placed symmetrically in a 1.5-m-(5-ft-)square excavated plot, and the plot was back filled with indigenous soil so that the top of each column was 6 mm (0.25 in.) above the soil surface. Each column was then filled with 1,640 g (3.6 lb) of homogenized Castroville soil and compacted by spraying the plot with 254 L (67 gal) of local water amounting to 8 cm (3 in.) of water. After the test columns were "irrigated" a 350-mL suspension of poliovirus in Castroville dechlorinated FE was dripped onto the surface of each column over a 2.5-hour period. This was accomplished by filling sterile plastic bags with the appropriate volume of virus seed and allowing the contents of each bag to drip onto the surface of each of the 24 soil columns. At each sample date, two columns were randomly selected and removed from the soil plot. The exception to this was at time zero when four columns were selected to establish the baseline virus concentration. In each case, the column was divided into its top, middle, and bottom section. The soil from each section was then analyzed for the number of viruses present. During each run, measurements of environmental conditions were made including (1) air temperature, (2) relative humidity, (3) daily sunlight energy in Langleys, (4) temperature of the top, middle, and bottom sections of the soil columns measured using thermisters in a control column (the 25th column), and (5) percentage of soil moisture in each section. Each selected pipe column was divided into the three sections, and the soil from each was carefully mixed. Of the mixed section, 50 g were taken for virus assay. The 50 g of soil were suspended in 3 percent beef extract at pH 10 in 0.25M glycine buffer for 10 minutes, extracted at 200 rpm on a gyrorotary shaker, and then centrifuged for 10 minutes at 2,000 rpm. Of the supernatant, 20 mL were adjusted to pH 7 and assayed for virus using previously described methods.

Virus survival on plants under in situ conditions was also studied. The method adopted required that a growing plant (or appropriate portion of same) be sprayed with a known volume of virus suspension in as uniform a manner as practicable. The average amount of virus retained on from four to eight plants immediately after spraying was used as the baseline for computing virus decay. The number of viruses present on the exposed plants at the end of any given time period was determined using elution and assay methods previously described. The test periods were one week for artichokes, 17 days for butter lettuce, and 4 days for romaine lettuce. A test plot section of plants, irrigated with well water, was set aside for these tests. On each occasion, from 12 to 15 plants were sprayed with virus suspension. The virus concentration was determined as the PFU per entire plant or artichoke rather than per weight or surface area. In this way plant growth (particularly in the case of butter lettuce) would not introduce an unknown dilution factor over the course of the test. Plants were selected at random during the experiment, and the number of viruses remaining were determined.

Virus Seeding Study

During the course of the virus studies, it became apparent that the in situ virus concentration in the pilot plant influent water was very low; thus, virus seeding studies were initiated to estimate the virus removal efficiency of the two pilot plant processes. The test virus used was the vaccine strain poliovirus (poliovirus 1 LSC) used in previous testing. This virus was chosen because it is a reasonable representative of enteric animal viruses, and, because it is a vaccine strain, it is safe to use. Because the volume of flow into the pilot plant was too large for continuous virus seeding, it was necessary to inoculate a slug of virus. The challenge seed was added to the pilot plant influent, at the splitter box to the two systems, along with a fluorescent tracer dye, Pontacyl Pink B, in order to determine the dilution factor associated with the final virus sample. For example, if only 0.01 percent of the initial dye concentration was present in the virus sample, one could assume that at least 99.99 percent of the observed reduction in virus was due to dilution. Dye measurements were made using a Turner fluorometer equipped with appropriate filters. Samples were routinely collected from the post-sand-filter flow and from the final effluent of the T-22 and FE systems. A series of tests was conducted that determined that the dye did not interfere with the assay of poliovirus and that the doses of chlorine used in the test processes did not have a significant effect on dye concentration (see Chapter 7, Tables 7.1 and 7.2 for details).

The chlorine dose, and residual of the virus sample were measured using the N, N-diethyl-p-phenylenediamine (DPD) titrimetric method, and ammonia nitrogen was measured using the selective electrode method. The chlorine residual in all virus samples was neutralized with sodium thiosulfate. Daily measurements of chlorine residual in the two effluents at the pilot treatment plant were performed by the amperometric titration method.

GROUNDWATER MONITORING

Four groundwater monitoring wells (piezometers) were installed at a depth of approximately 4 m (13 ft) in the MWRSA demonstration fields at the inception of Phase III in 1980. The sites for these wells were selected because those fields were wholly irrigated with FE at that time. When the applied irrigation water was changed to well water in the demonstration fields at the end of Year Two, these piezometers no longer provided a means of sampling irrigation leachates from the effluent. However, quarterly sampling of wells 1 through 4 continued in an effort to observe any change in hydrochemistry and to monitor the water levels across a greater area of Site D. The installation of 24 new piezometers in the artichoke experimental subplots irrigated with different water types took place at the end of 1983. Four of these new monitoring wells (wells 6, 7, 8, and 9) were chosen to provide quarterly sampling for constituents, including all major and minor cations and anions. The remaining 20 piezometers were sampled for nitrate, because it is the most mobile ion likely to affect the shallow groundwater quality. Monthly water level measurements were taken in all wells in Year Five, except at times when access to the site was not feasible because of rain.

AGROCLIMATIC MONITORING

Throughout the five-year field study, climatic parameters relevant to crop development were measured and recorded continually, analyzed periodically, and reported annually. In the first two years, a special weather station, erected to specifications for the project at the Castroville Treatment Plant, provided the needed data. In the third year, an automated, remote-controlled station, part of the California Irrigation Management Information System (CIMIS) network was placed at Site D, at the southeastern corner of the experimental plots. Both weather stations operated for several months, providing evidence of continuity and credibility before the first station was dismantled.

The climatic data are available for correlation studies. During the course of field work, the climatic data were used for irrigation scheduling and planning of other cultural practices, although other input (e.g., local farm manager's judgment or equipment/personnel availability) also played significant roles in frequently altering plans.

The weather summaries are not repeated in this report, but they are available in the annual reports. It is believed that over the five-year period of field operations, the normal range of climatic variations to be expected in the Salinas Valley was experienced, including extremes of wet and dry years and hot and cool periods.

METHODS OF DATA ANALYSIS

Analysis of Variance

Analysis of variance (ANOVA) was the primary statistical technique used to determine if significant differences existed between the characteristics of the soils and plants receiving different water types and the fertilization treatments.

ANOVA provides a statistical measure of the likelihood that differences in sample means of the measured parameters (soil and plant, heavy metals, and chemicals) are attributable to the different water and fertilizer treatments or that apparent differences simply reflect natural random variation or errors in sampling. The hypotheses tested are that there are no differences in the measured parameters due to (1) water types, (2) fertilization rates, and (3) interactions[a] between water types and fertilization rates. ANOVA estimates the probability of no significant difference at a generally accepted (but arbitrarily defined) error rate of either 5 percent or 1 percent. Statistical significance at a 5 or 1 percent level indicates that there is a 95 or

[a] Here, an interaction means that the effect of water types on a parameter is different under different fertilization rates.

99 percent chance, respectively, that differences noted in water types or fertilizer rates are not merely due to chance variation or sampling error. A more detailed discussion of the ANOVA procedure and the underlying assumptions are given in the Year One Report.

It should be noted that the occurrence of an apparently statistically significant result does not necessarily imply biological or agricultural significance. Statistical significance at the 5 percent level indicates that there is one chance in twenty that the observed difference is due to chance variation. For example, out of 1,000 analyses, 50 would appear to show statistically significant differences, even if no true differences existed. With the large number of analyses performed over the five years of MWRSA, a number of "significant" statistical analyses are undoubtedly spurious. The biological or agricultural significance of these results should be interpreted only in light of recurring results and trends observed over the years. Statistical analyses are a tool to guide the interpretation of numeric data.

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appendix c

APPENDIX C

Laboratory analyst preparing the continuous flow automatic analyzer for analysis of nitrogen in newly arrived samples of plant tissues.

APPENDIX C

INTRODUCTION

This appendix contains summaries of the results of analysis of variance performed on soil and plant tissue data collected in Phase III of MWRSA. Tables C.1 through C.4 provide an overall summary of significant differences attributable to water type and fertilization rate observed over the five years of the study. Tables C.1 and C.2 summarize significant differences due to water type and fertilization rate of vegetable plots, while Tables C.3 and C.4 summarize data for artichoke plots. Whenever an overall significant effect of water type or fertilization rate was observed, all significant differences between treatments have been calculated and indicated on these tables. Water type treatments are designated by a "W" for well water, "T" for Title-22, and "F" for filtered effluent. Fertilization rates are indicated by a "0" for no fertilizer, "1" for 1/3 the full fertilization rate, "2" for 2/3 the full fertilization rate, and "3" for the full amount of nitrogen fertilizer used by local farmers. The table shows the relationship between parameters which exhibited significant differences among treatments. For example, the designation W<T,F indicates that the well water-irrigated plots had a significantly lower level of a constituent than did either of the effluent-irrigated plots, but there were no differences between the two types of effluent-irrigated plots. The designation 0<1<2<3 indicates that all four of the fertilization rates had significant effects, with the constituent increasing with increasing fertilization rate. A dashed entry (--) in a table means that the analysis of variance detected no significant difference for that parameter. Some parameters were sampled annually, while others were measured twice a year; an "NS" entry designates that the analysis was not performed on that sampling date. All differences listed in the tables were significant at least at the 5 percent level. Differences designated by a "**" were significant at the 1 percent level.

TABLE C.1
STATISTICALLY SIGNIFICANT DIFFERENCES BY WATER TYPE OF PLANT AND SOIL SAMPLES TAKEN FROM THE VEGETABLE CROP GROWN AT MWRSA, 1979 - 1985.

YEAR	Baseline	Year One		Year Two		Year Three		Year Four			Year Five		
SAMPLE DATE	DEC 1979	SEP 1980	MAY 1981	SEP 1981	MAY 1982	NOV 1982	JUL 1983	NOV 1983	APR 1984	JUN 1984	OCT 1984	APR 1985	JUN 1985
CROP	None	Celery	Broccoli	Head Lettuce	Cauli- flower	Celery	Romaine Lettuce	Butter Lettuce	Grn Leaf Lettuce	Red Leaf Lettuce	Head Lettuce	Cauli- flower	Red Leaf Lettuce
SOIL ANALYSES													
PATHOGENS - 30CM													
Total Coliform	W,F<T **	—	—	—	—	—	—	NS	NS	NS	NS	NS	NS
Fecal Coliform	—	—	—	—	W,F<T	—	—	NS	NS	NS	NS	NS	NS
Salmonellae	—	—	—	—	—	—	—	NS	NS	NS	NS	NS	NS
Shigellae	—	—	—	—	—	—	—	NS	NS	NS	NS	NS	NS
Ascaris lumbridoides	—	—	—	—	—	—	—	NS	NS	NS	NS	NS	NS
Entamoeba histolytica	—	—	—	—	—	—	—	NS	NS	NS	NS	NS	NS
Miscellaneous parasites	—	—	—	—	—	—	—	NS	NS	NS	NS	NS	NS
METALS													
Cadmium 30cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Cadmium 100cm	—	—	NS	F<T	NS	—	NS	—	NS	NS	—	NS	NS
Cadmium 200cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Zinc 30cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Zinc 100cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Zinc 200cm	—	—	NS	W<T	NS	—	NS	—	NS	NS	—	NS	NS
Iron 30cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Iron 100cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Iron 200cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Manganese 30cm	—	W,F<T	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Manganese 100cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Manganese 200cm	—	—	NS	W<T	NS	—	NS	—	NS	NS	—	NS	NS
Copper 30cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Copper 100cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS

NS=Not sampled; See end of table for complete key to symbols

TABLE C.1
STATISTICALLY SIGNIFICANT DIFFERENCES BY WATER TYPE OF PLANT AND SOIL SAMPLES TAKEN FROM THE VEGETABLE CROP GROWN AT MWRSA, 1979 – 1985.

YEAR	Baseline	Year One		Year Two		Year Three		Year Four			Year Five		
SAMPLE DATE	DEC 1979	SEP 1980	MAY 1981	SEP 1981	MAY 1982	NOV 1982	JUL 1983	NOV 1983	APR 1984	JUN 1984	OCT 1984	APR 1985	JUN 1985
CROP	None	Celery	Broccoli	Head Lettuce	Cauli-flower	Celery	Romaine Lettuce	Butter Lettuce	Grn Leaf Lettuce	Red Leaf Lettuce	Head Lettuce	Cauli-flower	Red Leaf Lettuce
Copper 200cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Nickel 30cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Nickel 100cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Nickel 200cm	—	—	NS	W<T	NS	—	NS	—	NS	NS	—	NS	NS
Cobalt 30cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Cobalt 100cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Cobalt 200cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Chromium 30cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Chromium 100cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Chromium 200cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Lead 30cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Lead 100cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Lead 200cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Boron 30cm	—	—	—	—	—	—	NS	—	NS	NS	—	NS	NS
Boron 100cm	—	—	—	—	—	—	NS	—	NS	NS	—	NS	NS
Boron 200cm	—	—	—	—	—	—	NS	—	NS	NS	—	NS	NS
CHEMICALS													
pH 30cm	—	—	—	—	—	—	NS	—	NS	NS	—	NS	NS
pH 100cm	—	—	—	T<W	T<W	—	NS	T.F<W	NS	NS	—	NS	NS
pH 200cm	—	—	T<F	T<W	—	T<W	NS	—	NS	NS	—	NS	NS
Elect.cond. 30cm	—	W<F	W<T,F **	W<T,F **	W<T,F	W<T,F **	NS	W<T,F **	NS	NS	W<T,F **	NS	NS
Elect.cond. 100cm	—	—	W<F	—	—	W<T,F **	NS	W<T,F **	NS	NS	W<T,F **	NS	NS
Elect.cond. 200cm	—	—	—	—	—	W<T,F **	NS	W<T,F	NS	NS	—	NS	NS
Calcium 30cm	—	—	W<T,F	W<T,F **	—	W<F	NS	W<T	NS	NS	W<T,F	NS	NS

NS=Not sampled; See end of table for complete key to symbols

TABLE C.1
STATISTICALLY SIGNIFICANT DIFFERENCES BY WATER TYPE OF PLANT AND SOIL SAMPLES TAKEN FROM THE VEGETABLE CROP GROWN AT MWRSA, 1979 - 1985.

YEAR	Baseline	Year One		Year Two		Year Three		Year Four			Year Five		
SAMPLE DATE	DEC 1979	SEP 1980	MAY 1981	SEP 1981	MAY 1982	NOV 1982	JUL 1983	NOV 1983	APR 1984	JUN 1984	OCT 1984	APR 1985	JUN 1985
CROP	None	Celery	Broccoli	Head Lettuce	Cauli-flower	Celery	Romaine Lettuce	Butter Lettuce	Grn Leaf Lettuce	Red Leaf Lettuce	Head Lettuce	Cauli-flower	Red Leaf Lettuce
Calcium 100cm	—	—	—	—	—	—	NS	—	NS	NS	—	NS	NS
Calcium 200cm	—	—	—	W,F<T	—	—	NS	—	NS	NS	W,F<T	NS	NS
Magnesium 30cm	—	—	W<T,F **	W<T,F **	—	W<T,F	NS	—	NS	NS	W<T,F **	NS	NS
Magnesium 100cm	—	W<T	—	—	—	—	NS	W<T	NS	NS	W<T,F	NS	NS
Magnesium 200cm	—	—	—	—	—	—	NS	—	NS	NS	W,F<T	NS	NS
Sodium 30cm	—	—	—	W<T,F	W<T,F	—	NS	—	NS	NS	W<T,F	NS	NS
Sodium 100cm	—	—	—	—	—	—	NS	—	NS	NS	—	NS	NS
Sodium 200cm	—	—	—	—	—	W<T,F	NS	—	NS	NS	—	NS	NS
Potassium 30cm	—	—	—	—	—	—	NS	—	NS	NS	—	NS	NS
Potassium 100cm	—	—	—	F<T	—	—	NS	W<T	NS	NS	W<T,F **	NS	NS
Potassium 200cm	—	—	—	—	—	—	NS	—	NS	NS	W<T	NS	NS
Carbonate 30cm	—	—	—	—	—	—	NS	—	NS	NS	—	NS	NS
Carbonate 100cm	—	—	—	—	—	—	NS	—	NS	NS	—	NS	NS
Carbonate 200cm	—	—	—	—	—	—	NS	—	NS	NS	—	NS	NS
Bicarbonate 30cm	—	—	—	T,F<W **	—	—	NS	—	NS	NS	—	NS	NS
Bicarbonate 100cm	T,F<M	—	—	—	—	—	NS	—	NS	NS	—	NS	NS
Bicarbonate 200cm	—	—	—	—	—	—	NS	—	NS	NS	—	NS	NS
TKN 30cm	—	—	—	—	W<T	—	NS	—	NS	NS	—	NS	NS
TKN 100cm	—	—	—	—	—	—	NS	—	NS	NS	—	NS	NS
TKN 200cm	—	—	—	—	—	—	NS	—	NS	NS	—	NS	NS
Nitrate-N 30cm	F<T	—	—	—	—	—	NS	—	NS	NS	W<T,F **	NS	NS
Nitrate-N 100cm	—	—	—	—	—	—	NS	W<F	NS	NS	W<T,F **	NS	NS
Nitrate-N 200cm	—	—	—	F,T<W	—	—	NS	—	NS	NS	W<T,F	NS	NS
Ammonia-N 30cm	—	—	—	—	—	T,F<W **	NS	—	NS	NS	—	NS	NS

NS=Not sampled; See end of table for complete key to symbols

TABLE C.1
STATISTICALLY SIGNIFICANT DIFFERENCES BY WATER TYPE OF PLANT AND SOIL SAMPLES TAKEN FROM THE VEGETABLE CROP GROWN AT MWRSA, 1979 – 1985.

YEAR	Baseline	Year One		Year Two		Year Three		Year Four			Year Five		
SAMPLE DATE	DEC 1979	SEP 1980	MAY 1981	SEP 1981	MAY 1982	NOV 1982	JUL 1983	NOV 1983	APR 1984	JUN 1984	OCT 1984	APR 1985	JUN 1985
CROP	None	Celery	Broccoli	Head Lettuce	Cauli-flower	Celery	Romaine Lettuce	Butter Lettuce	Grn Leaf Lettuce	Red Leaf Lettuce	Head Lettuce	Cauli-flower	Red Leaf Lettuce
Ammonia-N 100cm	—	—	W,F<T	—	—	—	NS	—	NS	NS	—	NS	NS
Ammonia-N 200cm	—	—	—	—	—	T<F	NS	—	NS	NS	—	NS	NS
Phosphorus 30cm	—	—	—	—	—	—	NS	—	NS	NS	—	NS	NS
Phosphorus 100cm	—	—	—	—	—	—	NS	—	NS	NS	—	NS	NS
Phosphorus 200cm	—	—	—	—	—	—	NS	—	NS	NS	—	NS	NS
Chloride 30cm	—	W<T<F **	W<T<F **	W<T<F **	W<T,F	W<T,F **	NS	W<T,F	NS	NS	W<T,F **	NS	NS
Chloride 100cm	—	—	W<T<F **	W<T,F **	W<T,F **	W<T,F **	NS	W<T,F **	NS	NS	W<T,F **	NS	NS
Chloride 200cm	—	—	W<T<F **	—	W<T,F **	W<T,F **	NS	W<T,F	NS	NS	W<T,F **	NS	NS
Sulfate 30cm	—	—	W<T<F	W<T	—	W<T,F **	NS	W<T,F	NS	NS	—	NS	NS
Sulfate 100cm	—	—	—	—	—	W<F	NS	W<F<T **	NS	NS	W<T	NS	NS
Sulfate 200cm	—	—	—	—	—	—	NS	—	NS	NS	—	NS	NS
SAR 30cm	—	—	—	—	NA	—	NS	—	NS	NS	W<F	NS	NS
SAR 100cm	—	—	—	—	NA	—	NS	—	NS	NS	—	NS	NS
SAR 200cm	—	—	—	—	NA	—	NS	—	NS	NS	—	NS	NS
Adj SAR 30cm	—	—	W,T<F	W,T<F	NA	—	NS	—	NS	NS	—	NS	NS
Adj SAR 100cm	—	—	—	—	NA	—	NS	—	NS	NS	—	NS	NS
Adj SAR 200cm	—	—	—	—	NA	—	NS	—	NS	NS	—	NS	NS
PHYSICAL													
Organic matter 30cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Organic matter 100cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Organic matter 200cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Cation ex.cap. 30cm	—	—	—	—	—	—	NS	—	NS	NS	—	NS	NS
Cation ex.cap. 100cm	—	—	—	—	—	—	NS	—	NS	NS	—	NS	NS
Cation ex.cap. 200cm	—	—	—	—	—	—	NS	—	NS	NS	—	NS	NS

NS=Not sampled; See end of table for complete key to symbols

TABLE C.1
STATISTICALLY SIGNIFICANT DIFFERENCES BY WATER TYPE OF PLANT AND SOIL SAMPLES TAKEN FROM THE VEGETABLE CROP GROWN AT MWRSA, 1979 - 1985.

YEAR	Baseline	Year One		Year Two		Year Three		Year Four			Year Five		
SAMPLE DATE	DEC 1979	SEP 1980	MAY 1981	SEP 1981	MAY 1982	NOV 1982	JUL 1983	NOV 1983	APR 1984	JUN 1984	OCT 1984	APR 1985	JUN 1985
CROP	None	Celery	Broccoli	Head Lettuce	Cauli-flower	Celery	Romaine Lettuce	Butter Lettuce	Grn Leaf Lettuce	Red Leaf Lettuce	Head Lettuce	Cauli-flower	Red Leaf Lettuce
Permeability 30cm	—	—	NS	—	NS	—	NS	NS	NS	NS	NS	NS	NS
Permeability 100cm	—	—	NS	—	NS	—	NS	NS	NS	NS	NS	NS	NS
Permeability 200cm	—	—	NS	—	NS	—	NS	NS	NS	NS	NS	NS	NS
Field Infilt'n.	NS	NS	NS	NS	NS	NS	NS	—	—	NS	—	NS	NS
EDIBLE PLANT TISSUE													
PATHOGENS													
Total coliform	NS	—	—	—	—	—	—	NS	NS	NS	NS	NS	NS
Fecal coliform	NS	—	—	—	—	—	—	NS	NS	NS	NS	NS	NS
Salmonellae	NS	—	—	—	—	—	—	NS	NS	NS	NS	NS	NS
Shigellae	NS	—	—	—	—	—	—	NS	NS	NS	NS	NS	NS
Ascaris lumbricoides	NS	—	—	—	—	—	—	NS	NS	NS	NS	NS	NS
Entamoeba histolytica	NS	—	—	—	—	—	—	NS	NS	NS	NS	NS	NS
Miscellaneous parasites	NS	—	—	—	—	—	—	NS	NS	NS	NS	NS	NS
METALS													
Cadmium	NS	—	—	—	—	—	—	—	F<W	—	—	—	—
Zinc	NS	—	—	—	—	—	—	—	—	—	—	—	—
Iron	NS	—	—	—	—	—	—	—	—	—	—	—	—
Manganese	NS	—	—	—	—	—	—	—	—	—	—	—	—
Copper	NS	—	—	F<T	W,F<T	—	—	—	—	—	—	—	—
Nickel	NS	—	—	—	—	—	—	—	T<F	—	—	—	—
Cobalt	NS	W<T,F **	—	—	—	—	—	—	—	—	—	—	—
Chromium	NS	—	—	—	—	—	—	—	—	—	—	—	—
Lead	NS	T,F<W	—	—	—	—	—	—	W,T<F	—	—	—	—
NUTRIENTS													
Nitrate-N fertilization	NS	NS	NS	NS	—	—	—	—	—	—	—	NS	—

NS=Not sampled; See end of table for complete key to symbols

TABLE C.1
STATISTICALLY SIGNIFICANT DIFFERENCES BY WATER TYPE OF PLANT AND SOIL SAMPLES TAKEN FROM THE VEGETABLE CROP GROWN AT MWRSA, 1979 – 1985.

YEAR	Baseline	Year One		Year Two		Year Three		Year Four			Year Five		
SAMPLE DATE	DEC 1979	SEP 1980	MAY 1981	SEP 1981	MAY 1982	NOV 1982	JUL 1983	NOV 1983	APR 1984	JUN 1984	OCT 1984	APR 1985	JUN 1985
CROP	None	Celery	Broccoli	Head Lettuce	Cauli-flower	Celery	Romaine Lettuce	Butter Lettuce	Grn Leaf Lettuce	Red Leaf Lettuce	Head Lettuce	Cauli-flower	Red Leaf Lettuce
Nitrate-N at harvest	NS	—	—	—	—	W<T,F	W<T,F **	—	—	—	—	—	W<T,F
Phosphate-P fertilization	NS	NS	NS	NS	—	—	—	W,T<F	W,T<F **	—	—	NS	W<F<T
Phosphate-P at harvest	NS	—	—	—	—	—	—	—	W<F	—	—	—	W,T<F
Potassium fertilization	NS	NS	NS	NS	—	W,F<T	—	—	—	—	—	NS	—
Potassium at harvest	NS	—	—	—	—	—	—	—	—	—	—	—	—
YIELD	NS	—	W<T,F	—	—	—	W<T,F	—	W<T,F	—	—	—	—
RESIDUAL PLANT TISSUE PATHOGENS													
Total coliform	NS	—	—	—	—	—	—	NS	NS	NS	NS	NS	NS
Fecal coliform	NS	—	—	—	—	—	—	NS	NS	NS	NS	NS	NS
Salmonellae	NS	—	—	—	—	—	—	NS	NS	NS	NS	NS	NS
Shigellae	NS	—	—	—	—	—	—	NS	NS	NS	NS	NS	NS
Ascaris lumbricoides	NS	—	—	—	—	—	—	NS	NS	NS	NS	NS	NS
Entamoeba histolytica	NS	—	—	—	—	—	—	NS	NS	NS	NS	NS	NS
Miscellaneous parasites	NS	—	—	—	—	—	—	NS	NS	NS	NS	NS	NS
METALS													
Cadmium	NS	—	—	—	F<W,T	—	—	—	—	—	—	—	—
Zinc	NS	—	W,F<T	—	—	—	—	—	—	—	—	—	—
Boron	NS	—	—	—	—	—	—	—	W,T<F	—	—	—	—

TREATMENTS: W = Well Water, T = Title-22, F = Filtered Effluent
NA = Data not available
NS = Parameter not sampled for on this date

TABLE C.2
STATISTICALLY SIGNIFICANT DIFFERENCES BY FERTILIZATION RATE OF PLANT AND SOIL SAMPLES FROM VEGETABLE CROPS GROWN AT MWRSA, 1979 - 1985

YEAR	Baseline	Year One		Year Two		Year Three		Year Four			Year Five		
SAMPLE DATE	DEC 1979	SEP 1980	MAY 1981	SEP 1981	MAY 1982	NOV 1982	JUL 1983	NOV 1983	APR 1984	JUN 1984	OCT 1984	APR 1985	JUN 1985
CROP	None	Celery	Broccoli	Head Lettuce	Cauli-flower	Celery	Romaine Lettuce	Butter Lettuce	Grn Leaf Lettuce	Red Leaf Lettuce	Head Lettuce	Cauli-flower	Red Leaf Lettuce
SOIL ANALYSES													
PATHOGENS - 30CM													
Total Coliform	—	—	—	—	—	—	—	NS	NS	NS	NS	NS	NS
Fecal Coliform	—	—	—	—	—	—	—	NS	NS	NS	NS	NS	NS
Salmonellae	—	—	—	—	—	—	—	NS	NS	NS	NS	NS	NS
Shigellae	—	—	—	—	—	—	—	NS	NS	NS	NS	NS	NS
Ascaris lumbridoides	—	—	—	—	—	—	—	NS	NS	NS	NS	NS	NS
Entamoeba histolytica	—	—	—	—	—	—	—	NS	NS	NS	NS	NS	NS
Miscellaneous parasites	—	—	—	—	—	—	—	NS	NS	NS	NS	NS	NS
METALS													
Cadmium 30cm	—	—	NS	—	NS	—	NS	0,1<2,3 **	NS	NS	0,1<2,3 **	NS	NS
Cadmium 100cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Cadmium 200cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Zinc 30cm	—	—	NS	—	NS	—	NS	1<2,3 0<3	NS	NS	0;1<2;3 **	NS	NS
Zinc 100cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Zinc 200cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Iron 30cm	—	—	NS	—	NS	0<1,3	NS	—	NS	NS	—	NS	NS
Iron 100cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Iron 200cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Manganese 30cm	—	—	NS	—	NS	—	NS	0,1<2<3 **	NS	NS	0<2	NS	NS
Manganese 100cm	—	—	NS	—	NS	—	NS	—	NS	NS	1,3<2	NS	NS
Manganese 200cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Copper 30cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Copper 100cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS

NS=Not sampled; see end of table for complete key to symbols

TABLE C.2
STATISTICALLY SIGNIFICANT DIFFERENCES BY FERTILIZATION RATE OF PLANT AND SOIL SAMPLES FROM VEGETABLE CROPS GROWN AT MWRSA, 1979 - 1985

YEAR	Baseline	Year One		Year Two		Year Three		Year Four			Year Five		
SAMPLE DATE	DEC 1979	SEP 1980	MAY 1981	SEP 1981	MAY 1982	NOV 1982	JUL 1983	NOV 1983	APR 1984	JUN 1984	OCT 1984	APR 1985	JUN 1985
CROP	None	Celery	Broccoli	Head Lettuce	Cauli-flower	Celery	Romaine Lettuce	Butter Lettuce	Grn Leaf Lettuce	Red Leaf Lettuce	Head Lettuce	Cauli-flower	Red Leaf Lettuce
Copper 200cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Nickel 30cm	—	—	NS	—	NS	0<2,3 1<3 **	NS	0<2<3 1<3 **	NS	NS	1<2,3 0<3	NS	NS
Nickel 100cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Nickel 200cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Cobalt 30cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Cobalt 100cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Cobalt 200cm	—	—	NS	—	NS	—	NS	0,1<2	NS	NS	—	NS	NS
Chromium 30cm	—	0,1,2<3	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Chromium 100cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Chromium 200cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Lead 30cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Lead 100cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Lead 200cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Boron 30cm	—	0,1<2 1<3	—	—	0,2<1	—	NS	—	NS	NS	0<2,3 1<3 **	NS	NS
Boron 100cm	—	—	—	—	—	—	NS	—	NS	NS	—	NS	NS
Boron 200cm	—	—	—	—	—	—	NS	—	NS	NS	—	NS	NS
CHEMICALS													
pH 30cm	—	—	—	2,3<0,1 **	—	2,3<0 3<1 **	NS	2,3<0,1 **	NS	NS	2,3<0,1 **	NS	NS
pH 100cm	—	—	—	—	—	—	NS	—	NS	NS	—	NS	NS
pH 200cm	—	—	—	—	—	—	NS	—	NS	NS	—	NS	NS
Elect.cond. 30cm	—	—	—	0,1<2,3 **	—	—	NS	0,1<2<3 **	NS	NS	0<1<2,3 **	NS	NS
Elect.cond. 100cm	—	—	0<2,3 1<3 **	0,1<3	—	0,1<2,3 **	NS	0,1,2<3 **	NS	NS	0<1<2<3 **	NS	NS
Elect.cond. 200cm	—	—	—	—	—	0<2,3 1<3 **	NS	0<2,3 1<3 **	NS	NS	0<1<2,3 **	NS	NS
Calcium 30cm	—	—	0,2<3	0,1<2,3 **	—	—	NS	0,1<2,3 **	NS	NS	0<1<2<3 **	NS	NS

NS=Not sampled; see end of table for complete key to symbols

TABLE C.2
STATISTICALLY SIGNIFICANT DIFFERENCES BY FERTILIZATION RATE OF PLANT AND SOIL SAMPLES FROM VEGETABLE CROPS GROWN AT MWRSA, 1979 - 1985

YEAR	Baseline	Year One		Year Two		Year Three		Year Four			Year Five		
SAMPLE DATE	DEC 1979	SEP 1980	MAY 1981	SEP 1981	MAY 1982	NOV 1982	JUL 1983	NOV 1983	APR 1984	JUN 1984	OCT 1984	APR 1985	JUN 1985
CROP	None	Celery	Broccoli	Head Lettuce	Cauli-flower	Celery	Romaine Lettuce	Butter Lettuce	Grn Leaf Lettuce	Red Leaf Lettuce	Head Lettuce	Cauli-flower	Red Leaf Lettuce
Calcium 100cm	—	—	—	1<2,3	—	—	NS	—	NS	NS	0<2,3	NS	NS
Calcium 200cm	—	—	—	—	—	—	NS	—	NS	NS	—	NS	NS
Magnesium 30cm	—	—	—	0,1<2,3 **	—	—	NS	0,1<2<3 **	NS	NS	0<1<2<3 **	NS	NS
Magnesium 100cm	—	—	—	—	—	0<2,3 1<2	NS	0<2,3 1<3	NS	NS	0<2,3 1<3	NS	NS
Magnesium 200cm	—	—	—	—	—	—	NS	—	NS	NS	—	NS	NS
Sodium 30cm	—	—	—	0,1<2	—	—	NS	—	NS	NS	0<2,3	NS	NS
Sodium 100cm	—	—	0<2,3	—	—	—	NS	—	NS	NS	0<2,3 1<3	NS	NS
Sodium 200cm	—	—	—	—	—	—	NS	—	NS	NS	0,1<3	NS	NS
Potassium 30cm	—	—	—	—	—	—	NS	0,1<2,3 **	NS	NS	0<1<2,3 **	NS	NS
Potassium 100cm	—	—	—	—	—	—	NS	—	NS	NS	0<1<2 0<3 **	NS	NS
Potassium 200cm	—	—	—	0,2<3	—	—	NS	—	NS	NS	0<2,3	NS	NS
Carbonate 30cm	—	—	—	—	—	—	NS	—	NS	NS	—	NS	NS
Carbonate 100cm	—	—	—	—	—	—	NS	—	NS	NS	—	NS	NS
Carbonate 200cm	—	—	—	—	—	—	NS	—	NS	NS	—	NS	NS
Bicarbonate 30cm	—	—	—	—	—	2,3<0,1	NS	—	NS	NS	—	NS	NS
Bicarbonate 100cm	—	—	—	—	—	—	NS	—	NS	NS	—	NS	NS
Bicarbonate 200cm	—	—	—	—	—	—	NS	—	NS	NS	—	NS	NS
TKN 30cm	—	—	—	—	—	—	NS	0,1<2 1<3	NS	NS	—	NS	NS
TKN 100cm	—	—	—	—	—	—	NS	—	NS	NS	0<1,2	NS	NS
TKN 200cm	—	—	0,2<1,3	—	—	—	NS	—	NS	NS	—	NS	NS
Nitrate-N 30cm	—	—	—	0,1<2,3 **	—	0,1<2,3 **	NS	0<1<2<3 **	NS	NS	0,1<2,3 **	NS	NS
Nitrate-N 100cm	—	—	0,1<2,3	0<2<3 1<3 **	0<1<2<3 **	0,1<2<3 **	NS	0<1<2<3 **	NS	NS	0<1<2<3 **	NS	NS
Nitrate-N 200cm	—	—	0<2,3	0<2,3 1<3 **	0<1<2<3 **	0<1<2,3 **	NS	0;1<2<3 **	NS	NS	0<1<2<3 **	NS	NS
Ammonia-N 30cm	—	—	—	—	—	—	NS	—	NS	NS	—	NS	NS

NS=Not sampled; see end of table for complete key to symbols

TABLE C.2

STATISTICALLY SIGNIFICANT DIFFERENCES BY FERTILIZATION RATE OF PLANT AND SOIL SAMPLES FROM VEGETABLE CROPS GROWN AT MWRSA, 1979 - 1985

YEAR	Baseline	Year One		Year Two		Year Three		Year Four			Year Five		
SAMPLE DATE	DEC 1979	SEP 1980	MAY 1981	SEP 1981	MAY 1982	NOV 1982	JUL 1983	NOV 1983	APR 1984	JUN 1984	OCT 1984	APR 1985	JUN 1985
CROP	None	Celery	Broccoli	Head Lettuce	Cauli-flower	Celery	Romaine Lettuce	Butter Lettuce	Grn Leaf Lettuce	Red Leaf Lettuce	Head Lettuce	Cauli-flower	Red Leaf Lettuce
Ammonia-N 100cm	—	—	—	—	—	—	NS	—	NS	NS	—	NS	NS
Ammonia-N 200cm	—	—	—	—	—	—	NS	—	NS	NS	—	NS	NS
Phosphorus 30cm	—	—	—	—	—	—	NS	—	NS	NS	—	NS	NS
Phosphorus 100cm	—	—	—	—	—	—	NS	1,2,3<0	NS	NS	—	NS	NS
Phosphorus 200cm	—	—	—	—	—	—	NS	—	NS	NS	—	NS	NS
Chloride 30cm	—	0,3<1	—	—	—	—	NS	—	NS	NS	—	NS	NS
Chloride 100cm	—	—	—	—	—	1<2,3	NS	—	NS	NS	—	NS	NS
Chloride 200cm	—	—	—	—	—	—	NS	—	NS	NS	—	NS	NS
Sulfate 30cm	—	—	—	0<1,2,3 **	—	0,1<3	NS	0<1,2<3 **	NS	NS	0<1,2,3 **	NS	NS
Sulfate 100cm	—	—	—	—	—	0<1<3 0<2 **	NS	0<1,2,3 **	NS	NS	0<2,3 1<3 **	NS	NS
Sulfate 200cm	—	—	1,2<3	—	—	0<2,3 1<3 **	NS	0,1<2,3 **	NS	NS	—	NS	NS
SAR 30cm	—	—	—	—	NA	—	NS	2,3<0,1	NS	NS	2,3<0	NS	NS
SAR 100cm	—	—	—	—	NA	—	NS	—	NS	NS	—	NS	NS
SAR 200cm	—	—	—	—	NA	—	NS	—	NS	NS	—	NS	NS
Adj SAR 30cm	—	—	—	—	NA	2,3<1 **	NS	—	NS	NS	—	NS	NS
Adj SAR 100cm	—	—	—	—	NA	—	NS	—	NS	NS	—	NS	NS
Adj SAR 200cm	—	—	—	—	NA	—	NS	—	NS	NS	—	NS	NS
PHYSICAL													
Organic matter 30cm	—	—	NS	—	NS	—	NS	—	NS	NS	0,1<2,3 **	NS	NS
Organic matter 100cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Organic matter 200cm	—	—	NS	—	NS	—	NS	—	NS	NS	—	NS	NS
Cation ex.cap. 30cm	—	—	—	—	—	—	NS	—	NS	NS	—	NS	NS
Cation ex.cap. 100cm	—	—	—	—	—	—	NS	—	NS	NS	—	NS	NS
Cation ex.cap. 200cm	—	—	—	—	—	—	NS	—	NS	NS	—	NS	NS

NS=Not sampled; see end of table for complete key to symbols

TABLE C.2

STATISTICALLY SIGNIFICANT DIFFERENCES BY FERTILIZATION RATE OF PLANT AND SOIL SAMPLES FROM VEGETABLE CROPS GROWN AT MWRSA, 1979 – 1985

YEAR	Baseline	Year One		Year Two		Year Three		Year Four			Year Five		
SAMPLE DATE	DEC 1979	SEP 1980	MAY 1981	SEP 1981	MAY 1982	NOV 1982	JUL 1983	NOV 1983	APR 1984	JUN 1984	OCT 1984	APR 1985	JUN 1985
CROP	None	Celery	Broccoli	Head Lettuce	Cauli-flower	Celery	Romaine Lettuce	Butter Lettuce	Grn Leaf Lettuce	Red Leaf Lettuce	Head Lettuce	Cauli-flower	Red Leaf Lettuce
Permeability 30cm	—	—	NS	—	NS	—	NS	NS	NS	NS	NS	NS	NS
Permeability 100cm	—	—	NS	—	NS	—	NS	NS	NS	NS	NS	NS	NS
Permeability 200cm	—	—	NS	—	NS	—	NS	NS	NS	NS	NS	NS	NS
Field Infilt'n.	NS	NS	NS	NS	NS	NS	NS	—	—	NS	—	NS	NS
EDIBLE PLANT TISSUE PATHOGENS													
Total coliform	NS	—	—	—	—	—	—	NS	NS	NS	NS	NS	NS
Fecal coliform	NS	—	—	—	—	—	—	NS	NS	NS	NS	NS	NS
Salmonellae	NS	—	—	—	—	—	—	NS	NS	NS	NS	NS	NS
Shigellae	NS	—	—	—	—	—	—	NS	NS	NS	NS	NS	NS
Ascaris lumbricoides	NS	—	—	—	—	—	—	NS	NS	NS	NS	NS	NS
Entamoeba histolytica	NS	—	—	—	—	—	—	NS	NS	NS	NS	NS	NS
Miscellaneous parasites	NS	—	—	—	—	—	—	NS	NS	NS	NS	NS	NS
METALS													
Cadmium	NS	—	—	—	—	0<2,3 1<3 **	—	—	—	—	—	0,1,3<2	3<2<0 3<1 **
Zinc	NS	—	0<1<2 0<3 **	—	—	—	—	0,1,2<3 **	—	—	0,1<2,3 **	—	—
Iron	NS	—	—	—	—	—	—	—	—	—	—	0<1<3 0<2 **	—
Manganese	NS	—	0<1<2 0<3 **	—	0<1,3 2<1	—	—	0<1,2,3 **	0<1<2,3 **	0,1<2,3 **	0,1<2,3 **	0<1<2,3 **	—
Copper	NS	—	0<2,3 1<2 **	—	—	—	—	—	—	—	—	0<2,3 1<2 **	—
Nickel	NS	—	0,1<2 **	—	—	—	—	—	—	—	—	0,1<3	—
Cobalt	NS	—	0<1,2,3	—	—	—	—	—	—	—	—	—	—
Chromium	NS	—	0,1<3	—	—	—	—	—	—	—	—	—	—
Lead	NS	—	—	—	—	—	—	—	—	—	—	—	—
NUTRIENTS													
Nitrate-N fertilization	NS	NS	NS	NS	—	0<1<2,3 **	0<1<2<3 **	0,1,2<3 **	0,1<2,3 **	0<1<2,3 **	—	NS	—

NS=Not sampled; see end of table for complete key to symbols

TABLE C.2
STATISTICALLY SIGNIFICANT DIFFERENCES BY FERTILIZATION RATE OF PLANT AND SOIL SAMPLES FROM VEGETABLE CROPS GROWN AT MWRSA, 1979 - 1985

YEAR	Baseline	Year One		Year Two		Year Three		Year Four			Year Five		
SAMPLE DATE	DEC 1979	SEP 1980	MAY 1981	SEP 1981	MAY 1982	NOV 1982	JUL 1983	NOV 1983	APR 1984	JUN 1984	OCT 1984	APR 1985	JUN 1985
CROP	None	Celery	Broccoli	Head Lettuce	Cauli-flower	Celery	Romaine Lettuce	Butter Lettuce	Grn Leaf Lettuce	Red Leaf Lettuce	Head Lettuce	Cauli-flower	Red Leaf Lettuce
Nitrate-N at harvest	NS	0<1,2	—	—	0,1<2,3 **	0,1<2<3 **	0<1<2,3 **	—	0,1<2<3 **	0<1<2,3 **	0<1<2 0<3 **	0,1<2,3 **	0<1<3 0<2 **
Phosphate-P fertilization	NS	NS	NS	NS	—	0<2,3 1<3 **	—	—	—	—	—	NS	—
Phosphate-P at harvest	NS	0<1,3<2 **	—	—	—	0,1<2,3 **	—	—	0<1<2,3 **	—	—	0,1<2,3 **	—
Potassium fertilization	NS	NS	NS	NS	—	—	—	—	0<1,2,3 **	0,1<2	—	NS	—
Potassium at harvest	NS	—	0<1,2<3 **	—	0,1<2,3	0<2 1<2,3	—	—	0,1<3	—	—	0<1<2,3 **	—
YIELD	NS	0<1,2,3 **	0<1<2,3 **	2,3<1 3<0 **	—	—	0<1<2,3 **	0<1,2,3	0<1,2,3 **	—	—	0<1<2,3 **	—
RESIDUAL PLANT TISSUE													
PATHOGENS													
Total coliform	NS	—	—	—	—	0<1,2,3	—	NS	NS	NS	NS	NS	NS
Fecal coliform	NS	—	—	—	—	—	—	NS	NS	NS	NS	NS	NS
Salmonellae	NS	—	—	—	—	—	—	NS	NS	NS	NS	NS	NS
Shigellae	NS	—	—	—	—	—	—	NS	NS	NS	NS	NS	NS
Ascaris lumbricoides	NS	—	—	—	—	—	—	NS	NS	NS	NS	NS	NS
Entamoeba histolytica	NS	—	—	—	—	—	—	NS	NS	NS	NS	NS	NS
Miscellaneous parasites	NS	—	—	—	—	—	—	NS	NS	NS	NS	NS	NS
METALS													
Cadmium	NS	—	—	—	—	0,1,2<3 **	—	—	—	1,2<0,3	—	—	1,2<0 1<3 **
Zinc	NS	0<1,2,3	0,1<3	—	—	—	—	—	0,1<3	—	0<2<3 1<3 **	0<1,2,3 **	—
Boron	NS	—	—	—	—	—	—	—	—	1,2,3<0	—	—	2<0

TREATMENTS: 0 = 0/3 Fertilization rate, 1 = 1/3 Fertilization rate, 2 = 2/3 Fertilization rate, 3 = 3/3 Fertilization rate
NA = Data not available
NS = Parameter not sampled for on this date

TABLE C.3

STATISTICALLY SIGNIFICANT DIFFERENCES BY WATER TYPE OF PLANT AND SOIL SAMPLES FROM ARTICHOKES GROWN AT MWRSA, 1979 - 1985.

YEAR	Baseline	Year One		Year Two		Year Three		Year Four		Year Five	
MAIN SAMPLE DATE	DEC 1979	DEC 1980	MAY 1981	NOV 1981	APR 1982	DEC 1982	MAY 1983	DEC 1983	MAY 1984	OCT 1984	MAY 1985
SOIL ANALYSES											
PATHOGENS - 30CM											
Total Coliform	—	—	—	—	—	—	—	NS	NS	NS	NS
Fecal Coliform	—	—	—	—	—	—	—	NS	NS	NS	NS
Salmonellae	—	—	—	—	—	—	—	NS	NS	NS	NS
Shigellae	—	—	—	—	—	—	—	NS	NS	NS	NS
Ascaris lumbridoides	—	—	—	—	—	—	—	NS	NS	NS	NS
Entamoeba histolytica	—	—	—	—	—	—	—	NS	NS	NS	NS
Miscellaneous parasites	—	—	—	—	—	—	—	NS	NS	NS	NS
METALS											
Cadmium 30cm	—	—	NS	—	NS	—	NS	—	NS	—	NS
Cadmium 100cm	—	—	NS	—	NS	—	NS	—	NS	—	NS
Cadmium 200cm	—	T<W	NS	—	NS	—	NS	—	NS	—	NS
Zinc 30cm	—	—	NS	—	NS	—	NS	—	NS	—	NS
Zinc 100cm	—	—	NS	—	NS	W,F<T **	NS	—	NS	F<W,T	NS
Zinc 200cm	—	—	NS	—	NS	—	NS	T<W,F **	NS	—	NS
Iron 30cm	—	—	NS	—	NS	T<W	NS	T,F<W	NS	—	NS
Iron 100cm	—	—	NS	—	NS	—	NS	—	NS	—	NS
Iron 200cm	—	—	NS	—	NS	—	NS	—	NS	—	NS
Manganese 30cm	—	—	NS	—	NS	—	NS	—	NS	—	NS
Manganese 100cm	—	—	NS	—	NS	—	NS	—	NS	—	NS
Manganese 200cm	—	—	NS	—	NS	—	NS	—	NS	—	NS
Copper 30cm	—	—	NS	T<F	NS	—	NS	—	NS	—	NS
Copper 100cm	—	—	NS	—	NS	—	NS	—	NS	F<T	NS
Copper 200cm	—	—	NS	—	NS	—	NS	—	NS	—	NS

NS=Not sampled; see end of table for complete key to symbols

TABLE C.3
STATISTICALLY SIGNIFICANT DIFFERENCES BY WATER TYPE OF PLANT AND SOIL SAMPLES FROM ARTICHOKES GROWN AT MWRSA, 1979 - 1985.

YEAR	Baseline	Year One		Year Two		Year Three		Year Four		Year Five	
MAIN SAMPLE DATE	DEC 1979	DEC 1980	MAY 1981	NOV 1981	APR 1982	DEC 1982	MAY 1983	DEC 1983	MAY 1984	OCT 1984	MAY 1985
Nickel 30cm	—	—	NS	—	NS	T<W,F	NS	—	NS	—	NS
Nickel 100cm	—	—	NS	—	NS	—	NS	—	NS	—	NS
Nickel 200cm	—	—	NS	—	NS	—	NS	—	NS	—	NS
Cobalt 30cm	—	—	NS	—	NS	—	NS	—	NS	—	NS
Cobalt 100cm	—	—	NS	—	NS	—	NS	—	NS	—	NS
Cobalt 200cm	—	—	NS	—	NS	—	NS	—	NS	—	NS
Chromium 30cm	—	—	NS	—	NS	—	NS	—	NS	—	NS
Chromium 100cm	—	—	NS	—	NS	—	NS	—	NS	—	NS
Chromium 200cm	—	—	NS	—	NS	—	NS	—	NS	—	NS
Lead 30cm	—	—	NS	—	NS	—	NS	T,F<W	NS	—	NS
Lead 100cm	—	—	NS	—	NS	F<T	NS	—	NS	F<T	NS
Lead 200cm	—	—	NS	—	NS	—	NS	—	NS	—	NS
Boron 30cm	—	—	—	—	—	—	NS	—	NS	—	NS
Boron 100cm	—	—	—	—	—	—	NS	—	NS	—	NS
Boron 200cm	—	—	—	—	—	—	NS	—	NS	—	NS
CHEMICALS											
pH 30cm	—	—	—	—	—	—	NS	W,F<T	NS	—	NS
pH 100cm	—	—	—	—	—	—	NS	—	NS	—	NS
pH 200cm	—	—	—	—	—	—	NS	—	NS	—	NS
Elect.cond. 30cm	—	—	—	W<T	—	—	NS	—	NS	—	NS
Elect.cond. 100cm	—	W,T<F	W<T,F	W<T,F **	—	—	NS	W<T,F	NS	W<T,F	NS
Elect.cond. 200cm	—	—	—	W<T,F	—	—	NS	W<T,F **	NS	—	NS
Calcium 30cm	—	—	—	—	—	—	NS	—	NS	—	NS
Calcium 100cm	—	—	—	—	—	—	NS	—	NS	—	NS
Calcium 200cm	—	—	—	—	—	—	NS	—	NS	—	NS

NS=Not sampled; see end of table for complete key to symbols

TABLE C.3
STATISTICALLY SIGNIFICANT DIFFERENCES BY WATER TYPE OF PLANT AND SOIL SAMPLES FROM ARTICHOKES GROWN AT MWRSA, 1979 - 1985.

YEAR	Baseline	Year One		Year Two		Year Three		Year Four		Year Five	
MAIN SAMPLE DATE	DEC 1979	DEC 1980	MAY 1981	NOV 1981	APR 1982	DEC 1982	MAY 1983	DEC 1983	MAY 1984	OCT 1984	MAY 1985
Magnesium 30cm	—	—	—	F<T	—	—	NS	—	NS	—	NS
Magnesium 100cm	—	—	—	—	—	W<T	NS	—	NS	W<T,F	NS
Magnesium 200cm	—	—	—	—	—	—	NS	—	NS	—	NS
Sodium 30cm	—	—	—	—	W<T,F	W<T<F **	NS	—	NS	W<T,F	NS
Sodium 100cm	—	—	—	—	—	—	NS	—	NS	—	NS
Sodium 200cm	—	—	—	—	—	—	NS	—	NS	—	NS
Potassium 30cm	—	—	—	—	—	—	NS	—	NS	—	NS
Potassium 100cm	—	—	—	—	—	W,F<T	NS	—	NS	—	NS
Potassium 200cm	—	—	—	—	—	—	NS	—	NS	—	NS
Carbonate 30cm	—	—	—	—	—	—	NS	—	NS	—	NS
Carbonate 100cm	—	—	—	—	—	—	NS	—	NS	—	NS
Carbonate 200cm	—	—	—	—	—	—	NS	—	NS	—	NS
Bicarbonate 30cm	—	—	—	—	—	—	NS	—	NS	—	NS
Bicarbonate 100cm	—	—	—	—	—	—	NS	—	NS	—	NS
Bicarbonate 200cm	—	—	—	—	—	—	NS	—	NS	—	NS
TKN 30cm	—	—	—	—	—	—	NS	—	NS	—	NS
TKN 100cm	—	—	F<T	—	—	—	NS	—	NS	F<T	NS
TKN 200cm	—	—	T<W	—	—	—	NS	—	NS	W<F	NS
Nitrate-N 30cm	—	—	—	—	—	—	NS	—	NS	—	NS
Nitrate-N 100cm	—	—	—	—	—	—	NS	—	NS	—	NS
Nitrate-N 200cm	—	—	—	—	—	—	NS	—	NS	—	NS
Ammonia-N 30cm	—	—	—	—	—	—	NS	—	NS	—	NS
Ammonia-N 100cm	—	—	—	—	—	—	NS	—	NS	—	NS
Ammonia-N 200cm	—	—	—	—	—	—	NS	W,F<T	NS	—	NS
Phosphorus 30cm	—	—	—	—	—	—	NS	—	NS	—	NS

NS=Not sampled; see end of table for complete key to symbols

TABLE C.3
STATISTICALLY SIGNIFICANT DIFFERENCES BY WATER TYPE OF PLANT AND SOIL SAMPLES FROM ARTICHOKES GROWN AT MWRSA, 1979 - 1985.

YEAR	Baseline	Year One		Year Two		Year Three		Year Four		Year Five	
MAIN SAMPLE DATE	DEC 1979	DEC 1980	MAY 1981	NOV 1981	APR 1982	DEC 1982	MAY 1983	DEC 1983	MAY 1984	OCT 1984	MAY 1985
Phosphorus 100cm	—	—	—	—	—	—	NS	—	NS	—	NS
Phosphorus 200cm	—	—	—	—	—	—	NS	—	NS	—	NS
Chloride 30cm	—	W<T<F **	—	—	—	W<T,F **	NS	W<T<F **	NS	W<T,F **	NS
Chloride 100cm	—	—	W<T **	W<T,F **	W<T,F	W<T,F	NS	—	NS	W<T	NS
Chloride 200cm	—	—	—	W<T,F **	W<T,F **	W<T,F	NS	W<F	NS	W<T<F **	NS
Sulfate 30cm	—	—	—	—	—	—	NS	—	NS	—	NS
Sulfate 100cm	—	—	—	—	W,F<T	W,F<T **	NS	—	NS	—	NS
Sulfate 200cm	—	—	—	—	—	—	NS	—	NS	—	NS
SAR 30cm	—	—	—	W,T<F	NA	W<T,F **	NS	T,F<W **	NS	W<F	NS
SAR 100cm	—	—	—	—	NA	—	NS	—	NS	—	NS
SAR 200cm	—	—	—	—	NA	—	NS	—	NS	—	NS
Adj SAR 30cm	—	—	—	W<F	NA	W<T,F **	NS	T,F<W	NS	W<T,F	NS
Adj SAR 100cm	—	—	—	—	NA	—	NS	—	NS	—	NS
Adj SAR 200cm	—	—	—	—	NA	—	NS	—	NS	—	NS
PHYSICAL											
Organic matter 30cm	—	—	NS	—	NS	—	NS	—	NS	—	NS
Organic matter 100cm	—	—	NS	F<T	NS	W,F<T	NS	F<T	NS	W,F<T **	NS
Organic matter 200cm	—	—	NS	—	NS	—	NS	—	NS	—	NS
Cation ex.cap. 30cm	—	—	—	—	F<W,T	—	NS	—	NS	—	NS
Cation ex.cap. 100cm	—	—	—	W,F<T	—	F<T	NS	—	NS	—	NS
Cation ex.cap. 200cm	—	—	—	—	—	—	NS	—	NS	—	NS
Permeability 30cm	—	—	NS	—	NS	—	NS	NS	NS	NS	NS
Permeability 100cm	—	—	NS	—	NS	—	NS	NS	NS	NS	NS
Permeability 200cm	—	—	NS	—	NS	—	NS	NS	NS	NS	NS
Field Infilt'n.	NS	NS	NS	NS	NS	NS	NS	F<W<T	—	NS	—

NS=Not sampled; see end of table for complete key to symbols

TABLE C.3
STATISTICALLY SIGNIFICANT DIFFERENCES BY WATER TYPE OF PLANT AND SOIL SAMPLES FROM ARTICHOKES GROWN AT MWRSA, 1979 - 1985.

YEAR	Baseline	Year One		Year Two		Year Three		Year Four		Year Five	
MAIN SAMPLE DATE	DEC 1979	DEC 1980	MAY 1981	NOV 1981	APR 1982	DEC 1982	MAY 1983	DEC 1983	MAY 1984	OCT 1984	MAY 1985
EDIBLE PLANT TISSUE											
PATHOGENS											
Total coliform	NS	—	—	—	—	—	—	NS	NS	NS	NS
Fecal coliform	NS	—	—	—	—	—	—	NS	NS	NS	NS
Salmonellae	NS	—	—	—	—	—	—	NS	NS	NS	NS
Shigellae	NS	—	—	—	—	—	—	NS	NS	NS	NS
Ascaris lumbricoides	NS	—	—	—	—	—	—	NS	NS	NS	NS
Entamoeba histolytica	NS	—	—	—	—	—	—	NS	NS	NS	NS
Miscellaneous parasites	NS	—	—	—	—	—	—	NS	NS	NS	NS
METALS											
Cadmium	NS	—	—	—	—	—	—	—	—	—	—
Zinc	NS	W,F<T **	—	—	—	—	—	—	—	—	F<W,T
Iron	NS	—	F<W,T	—	—	—	—	—	—	—	—
Manganese	NS	—	F<W	—	—	T,F<W	—	—	—	—	—
Copper	NS	—	—	—	—	—	—	—	—	—	—
Nickel	NS	—	F<W,T	—	—	—	—	—	—	—	—
Cobalt	NS	—	—	—	—	—	—	—	—	—	—
Chromium	NS	—	—	—	—	—	—	—	—	—	—
Lead	NS	—	—	—	—	—	—	—	—	—	—
NUTRIENTS											
Nitrate-N 1st fert. app.	NS	NS	NS	—	NS	—	NS	—	NS	—	NS
Nitrate-N 2nd fert. app.	NS	NS	NS	—	NS	—	NS	—	NS	—	NS
Nitrate-N 3rd fert. app.	NS	NS	NS	—	NS	—	NS	—	NS	—	NS
Nitrate-N 4th fert. app.	NS	NS	NS	—	NS	—	NS	—	NS	—	NS
Nitrate-N major sampling	NS	—	—	—	—	—	—	—	—	—	—
Phosphate-P 1st fert. app.	NS	NS	NS	—	NS	—	NS	—	NS	—	NS

NS=Not sampled; see end of table for complete key to symbols

TABLE C.3

STATISTICALLY SIGNIFICANT DIFFERENCES BY WATER TYPE OF PLANT AND SOIL SAMPLES FROM ARTICHOKES GROWN AT MWRSA, 1979 – 1985.

YEAR	Baseline	Year One		Year Two		Year Three		Year Four		Year Five	
MAIN SAMPLE DATE	DEC 1979	DEC 1980	MAY 1981	NOV 1981	APR 1982	DEC 1982	MAY 1983	DEC 1983	MAY 1984	OCT 1984	MAY 1985
Phosphate-P 2nd fert. app.	NS	NS	NS	—	NS	—	NS	—	NS	—	NS
Phosphate-P 3rd fert. app.	NS	NS	NS	—	NS	—	NS	—	NS	—	NS
Phosphate-P 4th fert. app.	NS	NS	NS	W,T<F	NS	—	NS	—	NS	—	NS
Phosphate-P major sampling	NS	—	—	—	—	—	—	—	—	—	—
Potassium 1st fert. app.	NS	NS	NS	—	NS	—	NS	—	NS	—	NS
Potassium 2nd fert. app.	NS	NS	NS	—	NS	—	NS	—	NS	—	NS
Potassium 3rd fert. app.	NS	NS	NS	—	NS	—	NS	—	NS	—	NS
Potassium 4th fert. app.	NS	NS	NS	—	NS	—	NS	—	NS	—	NS
Potassium major sampling	NS	—	—	—	—	—	—	—	—	—	—
YIELD	NS	—	—	—	—	—	—	—	—	—	—
RESIDUAL PLANT TISSUE PATHOGENS											
Total coliform	NS	—	—	—	—	—	—	NS	NS	NS	NS
Fecal coliform	NS	—	—	—	—	—	—	NS	NS	NS	NS
Salmonellae	NS	—	—	—	—	—	—	NS	NS	NS	NS
Shigellae	NS	—	—	—	—	—	—	NS	NS	NS	NS
Ascaris lumbricoides	NS	—	—	—	—	—	—	NS	NS	NS	NS
Entamoeba histolytica	NS	—	—	—	—	—	—	NS	NS	NS	NS
Miscellaneous parasites	NS	—	—	—	—	—	—	NS	NS	NS	NS
METALS											
Cadmium	NS	—	—	—	—	—	—	—	—	—	—
Zinc	NS	—	—	—	—	—	—	—	—	—	—
Boron	NS	—	—	—	—	—	—	—	—	—	—

TREATMENTS: W = Well Water, T = Title-22, F = Filtered Effluent

NA = Data not available

NS = Parameter not sampled for on this date

TABLE C.4
STATISTICALLY SIGNIFICANT DIFFERENCES BY FERTILIZATION RATE OF PLANT AND SOIL SAMPLES TAKEN FROM THE ARTICHOKE CROP GROWN AT MWRSA, 1979 - 1985.

YEAR	Baseline	Year One		Year Two		Year Three		Year Four		Year Five	
MAIN SAMPLE DATE	DEC 1979	DEC 1980	MAY 1981	NOV 1981	APR 1982	DEC 1982	MAY 1983	DEC 1983	MAY 1984	OCT 1984	MAY 1985
SOIL ANALYSES											
PATHOGENS - 30CM											
Total Coliform	—	—	—	—	—	—	—	NS	NS	NS	NS
Fecal Coliform	—	—	—	—	—	—	—	NS	NS	NS	NS
Salmonellae	—	—	—	—	—	—	—	NS	NS	NS	NS
Shigellae	—	—	—	—	—	—	—	NS	NS	NS	NS
Ascaris lumbridoides	—	—	—	—	—	—	—	NS	NS	NS	NS
Entamoeba histolytica	—	—	—	—	—	—	—	NS	NS	NS	NS
Miscellaneous parasites	—	—	—	—	—	—	—	NS	NS	NS	NS
METALS											
Cadmium 30cm	—	—	NS	—	NS	—	NS	0<2,3 1<3	NS	—	NS
Cadmium 100cm	—	—	NS	—	NS	—	NS	—	NS	—	NS
Cadmium 200cm	—	—	NS	—	NS	—	NS	—	NS	—	NS
Zinc 30cm	—	—	NS	—	NS	—	NS	—	NS	—	NS
Zinc 100cm	—	—	NS	—	NS	2,3<1	NS	—	NS	—	NS
Zinc 200cm	—	—	NS	—	NS	—	NS	—	NS	—	NS
Iron 30cm	—	—	NS	0<2,3	NS	—	NS	0<2,3 1<3	NS	—	NS
Iron 100cm	—	—	NS	—	NS	—	NS	—	NS	—	NS
Iron 200cm	—	—	NS	—	NS	—	NS	—	NS	—	NS
Manganese 30cm	—	0,1<2<3 **	0,1<2<3 **	0<2,3 1<3 **	NS	0,1,2<3	NS	0<2,3 1<3 **	NS	—	NS
Manganese 100cm	—	—	NS	—	NS	—	NS	—	NS	—	NS
Manganese 200cm	—	—	NS	—	NS	—	NS	—	NS	—	NS
Copper 30cm	—	—	NS	—	NS	—	NS	—	NS	—	NS
Copper 100cm	—	—	NS	—	NS	—	NS	—	NS	—	NS
Copper 200cm	—	—	NS	—	NS	—	NS	—	NS	—	NS

NS=Not sampled; See end of table for complete key to symbols

TABLE C.4
STATISTICALLY SIGNIFICANT DIFFERENCES BY FERTILIZATION RATE OF PLANT AND SOIL SAMPLES TAKEN FROM THE ARTICHOKE CROP GROWN AT MWRSA, 1979 - 1985.

YEAR	Baseline	Year One		Year Two		Year Three		Year Four		Year Five	
MAIN SAMPLE DATE	DEC 1979	DEC 1980	MAY 1981	NOV 1981	APR 1982	DEC 1982	MAY 1983	DEC 1983	MAY 1984	OCT 1984	MAY 1985
Nickel 30cm	—	—	NS	0<2,3	NS	—	NS	0<1,2,3 1<3 **	NS	—	NS
Nickel 100cm	—	—	NS	—	NS	—	NS	—	NS	—	NS
Nickel 200cm	—	—	NS	—	NS	—	NS	—	NS	—	NS
Cobalt 30cm	—	0,1<2,3 **	0,1<2,3 **	0<2,3	NS	0,1,2<3	NS	1<2<3 0<3 **	NS	—	NS
Cobalt 100cm	—	—	NS	—	NS	—	NS	—	NS	—	NS
Cobalt 200cm	—	—	NS	—	NS	—	NS	—	NS	—	NS
Chromium 30cm	—	—	NS	—	NS	—	NS	—	NS	—	NS
Chromium 100cm	—	—	NS	—	NS	—	NS	—	NS	—	NS
Chromium 200cm	—	—	NS	—	NS	—	NS	—	NS	—	NS
Lead 30cm	—	—	NS	—	NS	—	NS	—	NS.	—	NS
Lead 100cm	—	—	NS	—	NS	—	NS	—	NS	—	NS
Lead 200cm	—	—	NS	—	NS	—	NS	—	NS	—	NS
Boron 30cm	—	—	—	0<2,3 **	0<1,2,3	—	NS	—	NS	0<1,2,3	NS
Boron 100cm	—	—	—	—	—	0,1,2<3	NS	—	NS	0,2<1	NS
Boron 200cm	—	—	—	—	—	—	NS	—	NS	—	NS
CHEMICALS											
pH 30cm	—	2,3<0,1 **	—	1,2,3<0 **	—	—	NS	3<2<1<0 **	NS	—	NS
pH 100cm	—	—	—	—	—	2<0,1,3	NS	—	NS	—	NS
pH 200cm	—	2<1	—	—	—	—	NS	2<0,1 3<1	NS	—	NS
Elect.cond. 30cm	—	—	—	0<1,2<3 **	0,1<2<3 **	0,1,2<3 **	NS	0<1,2<3 **	NS	0,1,2<3 **	NS
Elect.cond. 100cm	—	—	—	0,1<2,3 **	0<1,2,3 1<3 **	0<1,2,3 **	NS	0,1,2<3 **	NS	0,1<2,3 **	NS
Elect.cond. 200cm	—	—	—	0,1<3	0,1,2<3 **	0,1<3	NS	0,1<2<3 **	NS	0<1,2,3 **	NS
Calcium 30cm	—	—	0<3	0<1<2<3 **	0,1<2<3 **	0,1,2<3 **	NS	0<1,2<3 **	NS	0<2,3 1<3 **	NS
Calcium 100cm	—	—	—	0,1<2,3 **	0<1<2,3 **	—	NS	0<2<3 1<3 **	NS	0<1,2,3 **	NS
Calcium 200cm	—	—	—	—	—	0,1<2	NS	0,1<2,3 **	NS	—	NS

NS=Not sampled; See end of table for complete key to symbols

TABLE C.4

STATISTICALLY SIGNIFICANT DIFFERENCES BY FERTILIZATION RATE OF PLANT AND SOIL SAMPLES TAKEN FROM THE ARTICHOKE CROP GROWN AT MWRSA, 1979 - 1985.

YEAR	Baseline	Year One		Year Two		Year Three		Year Four		Year Five	
MAIN SAMPLE DATE	DEC 1979	DEC 1980	MAY 1981	NOV 1981	APR 1982	DEC 1982	MAY 1983	DEC 1983	MAY 1984	OCT 1984	MAY 1985
Magnesium 30cm	—	0<1<2<3 **	0,1,2<3	0<1<2<3	0,1<2<3 **	—	NS	0<1<2<3 **	NS	—	NS
Magnesium 100cm	—	—	—	0,1<2,3 **	0<1,2,3 1<3 **	—	NS	0<1,2<3 **	NS	0<1,2,3 **	NS
Magnesium 200cm	—	—	—	—	—	—	NS	0,1<2,3 **	NS	—	NS
Sodium 30cm	—	0<1<2<3 **	—	0<1,2,3 1<3 **	—	0<1,3 2<3 **	NS	—	NS	0,1,2<3	NS
Sodium 100cm	—	—	—	—	0<3	0<1,2,3	NS	—	NS	0<1,3 2<3 **	NS
Sodium 200cm	—	—	—	—	—	—	NS	—	NS	—	NS
Potassium 30cm	—	—	—	0<1,2,3 **	0,1<3	0,1,2<3 **	NS	0<1,2<3 **	NS	—	NS
Potassium 100cm	—	—	—	—	—	—	NS	—	NS	—	NS
Potassium 200cm	—	—	—	—	—	—	NS	0,1<3 1<2	NS	—	NS
Carbonate 30cm	—	—	—	—	—	—	NS	—	NS	—	NS
Carbonate 100cm	—	—	—	—	—	—	NS	—	NS	—	NS
Carbonate 200cm	—	—	—	—	—	—	NS	—	NS	—	NS
Bicarbonate 30cm	—	—	—	—	3<0,1 2<0 **	—	NS	1,2,3<0 **	NS	—	NS
Bicarbonate 100cm	—	—	—	—	—	—	NS	2,3<0 2<1	NS	—	NS
Bicarbonate 200cm	—	—	—	—	—	—	NS	—	NS	—	NS
TKN 30cm	—	—	—	—	—	—	NS	—	NS	—	NS
TKN 100cm	—	—	—	—	—	0<2<3 1<3 **	NS	—	NS	—	NS
TKN 200cm	—	—	—	—	—	0<2,3 1<3 **	NS	—	NS	—	NS
Nitrate-N 30cm	—	0,1<3	—	0<1<2<3 **	0<2,3	0<2<3 1<3 **	NS	—	NS	—	NS
Nitrate-N 100cm	—	—	—	0<2,3 1<3 **	0<1<2<3 **	0<2<3 1<3 **	NS	0<2<3 1<3 **	NS	0<2<3 1<3 **	NS
Nitrate-N 200cm	—	—	—	—	0<2,3 1<3 **	0<2,3 1<3 **	NS	0<2<3 1<3 **	NS	0,1,2<3 **	NS
Ammonia-N 30cm	—	—	—	—	—	—	NS	—	NS	—	NS
Ammonia-N 100cm	—	—	—	—	—	—	NS	—	NS	—	NS
Ammonia-N 200cm	—	—	—	—	—	—	NS	—	NS	—	NS
Phosphorus 30cm	—	—	—	—	—	—	NS	—	NS	—	NS

NS=Not sampled; See end of table for complete key to symbols

TABLE C.4
STATISTICALLY SIGNIFICANT DIFFERENCES BY FERTILIZATION RATE OF PLANT AND SOIL SAMPLES TAKEN FROM THE ARTICHOKE CROP GROWN AT MWRSA, 1979 - 1985.

YEAR	Baseline	Year One		Year Two		Year Three		Year Four		Year Five	
MAIN SAMPLE DATE	DEC 1979	DEC 1980	MAY 1981	NOV 1981	APR 1982	DEC 1982	MAY 1983	DEC 1983	MAY 1984	OCT 1984	MAY 1985
Phosphorus 100cm	—	—	—	—	—	—	NS	—	NS	—	NS
Phosphorus 200cm	—	—	—	—	—	—	NS	—	NS	—	NS
Chloride 30cm	—	2,3<1 **	—	—	—	—	NS	—	NS	—	NS
Chloride 100cm	—	—	3<1,2	—	—	—	NS	2<0,1,3	NS	—	NS
Chloride 200cm	—	—	—	—	—	—	NS	—	NS	—	NS
Sulfate 30cm	—	0<1<2<3 **	0<2,3 1<3 **	—	0<2,3 1<3 **	0,1,2<3 **	NS	0<1,2<3 **	NS	—	NS
Sulfate 100cm	—	—	—	—	0<1,2,3 1<3 **	0<1,2<3 **	NS	0<1<2,3 **	NS	0,1<2<3 **	NS
Sulfate 200cm	—	—	—	0<1,3	—	0<1,3 2<3 **	NS	0<1,2,3 1<3 **	NS	—	NS
SAR 30cm	—	3<2<1<0 **	—	3<0,1 2<0 **	NA	—	NS	1,2,3<0 **	NS	—	NS
SAR 100cm	—	—	—	—	NA	0<1,2,3	NS	—	NS	—	NS
SAR 200cm	—	—	—	—	NA	—	NS	—	NS	—	NS
Adj SAR 30cm	—	—	—	—	NA	—	NS	1,2,3<0 **	NS	—	NS
Adj SAR 100cm	—	—	—	0,2<3	NA	0<1,2,3	NS	—	NS	0,1,2<3	NS
Adj SAR 200cm	—	—	—	—	NA	—	NS	—	NS	—	NS
PHYSICAL											
Organic matter 30cm	—	—	NS	—	NS	—	NS	—	NS	—	NS
Organic matter 100cm	—	—	NS	—	NS	—	NS	—	NS	—	NS
Organic matter 200cm	—	—	NS	—	NS	—	NS	—	NS	—	NS
Cation ex.cap. 30cm	1,2<0,3	—	—	—	—	—	NS	—	NS	—	NS
Cation ex.cap. 100cm	—	—	—	—	—	—	NS	—	NS	—	NS
Cation ex.cap. 200cm	—	—	—	—	—	—	NS	—	NS	—	NS
Permeability 30cm	—	—	NS	—	NS	—	NS	NS	NS	NS	NS
Permeability 100cm	—	—	NS	—	NS	—	NS	NS	NS	NS	NS
Permeability 200cm	—	—	NS	—	NS	—	NS	NS	NS	NS	NS
Field Infilt'n.	—	—	NS	NS	NS	NS	NS	—	—	NS	—

NS=Not sampled; See end of table for complete key to symbols

TABLE C.4
STATISTICALLY SIGNIFICANT DIFFERENCES BY FERTILIZATION RATE OF PLANT AND SOIL SAMPLES TAKEN FROM THE ARTICHOKE CROP GROWN AT MWRSA, 1979 - 1985.

YEAR	Baseline	Year One		Year Two		Year Three		Year Four		Year Five	
MAIN SAMPLE DATE	DEC 1979	DEC 1980	MAY 1981	NOV 1981	APR 1982	DEC 1982	MAY 1983	DEC 1983	MAY 1984	OCT 1984	MAY 1985
EDIBLE PLANT TISSUE											
PATHOGENS											
Total coliform	NS	—	—	—	—	—	—	NS	NS	NS	NS
Fecal coliform	NS	—	—	—	—	—	—	NS	NS	NS	NS
Salmonellae	NS	—	—	—	—	—	—	NS	NS	NS	NS
Shigellae	NS	—	—	—	—	—	—	NS	NS	NS	NS
Ascaris lumbricoides	NS	—	—	—	—	—	—	NS	NS	NS	NS
Entamoeba histolytica	NS	—	—	—	—	—	—	NS	NS	NS	NS
Miscellaneous parasites	NS	—	—	—	—	—	—	NS	NS	NS	NS
METALS											
Cadmium	NS	—	—	—	0<2,3	0<1,2,3 **	—	—	—	—	0<1,2,3 **
Zinc	NS	—	—	—	—	1,2,3<0	—	—	—	—	1,3<0
Iron	NS	—	3<1,2	—	—	—	—	—	—	—	0,3<2
Manganese	NS	0<1,2,3 1<3 **	—	0<2,3	0,1<2<3 **	0<1<2,3 **	—	0<1<2,3 **	0,1<2,3	0,1<3	0,1<2,3 **
Copper	NS	—	—	—	1,2,3<0 **	1,2,3<0 **	1,2,3<0 **	—	1,2,3<0 **	—	1,2,3<0 **
Nickel	NS	—	—	—	—	0<2,3	—	—	0,2<1	—	0<2,3 1<3
Cobalt	NS	—	—	—	—	—	—	—	—	—	—
Chromium	NS	—	—	—	—	—	—	—	—	—	—
Lead	NS	—	—	—	—	—	—	—	—	—	—
NUTRIENTS											
Nitrate-N 1st fert. app.	NS	NS	NS	0,1<3	NS	—	NS	0,1<2,3 **	NS	0,1,2<3 **	NS
Nitrate-N 2nd fert. app.	NS	NS	NS	—	NS	0<1,2,3 **	NS	0<1<2,3 **	NS	0,1<2,3 **	NS
Nitrate-N 3rd fert. app.	NS	NS	NS	0,1,2<3 **	NS	0<1<3 0<2 **	NS	0<1<2,3 **	NS	0<1<2<3 **	NS
Nitrate-N 4th fert. app.	NS	NS	NS	0<2,3 1<3 **	NS	0<1<2,3 **	NS	—	NS	0<1<3 0<2 **	NS
Nitrate-N major sampling	NS	—	—	—	—	0<1,2<3 **	0,1<2,3 **	—	0<1<2<3 **	0<1,2,3 **	0,1<2,3 **
Phosphate-P 1st fert. app.	NS	NS	NS	1,2,3<0	NS	—	NS	2,3<1<0 **	NS	—	NS

NS=Not sampled; See end of table for complete key to symbols

TABLE C.4
STATISTICALLY SIGNIFICANT DIFFERENCES BY FERTILIZATION RATE OF PLANT AND SOIL SAMPLES TAKEN FROM THE ARTICHOKE CROP GROWN AT MWRSA, 1979 - 1985.

YEAR	Baseline	Year One		Year Two		Year Three		Year Four		Year Five	
MAIN SAMPLE DATE	DEC 1979	DEC 1980	MAY 1981	NOV 1981	APR 1982	DEC 1982	MAY 1983	DEC 1983	MAY 1984	OCT 1984	MAY 1985
Phosphate-P 2nd fert. app.	NS	NS	NS	—	NS	1,2,3>0 **	NS	—	NS	—	NS
Phosphate-P 3rd fert. app.	NS	NS	NS	—	NS	—	NS	—	NS	1,2,3>0 **	NS
Phosphate-P 4th fert. app.	NS	NS	NS	—	NS	—	NS	—	NS	—	NS
Phosphate-P major sampling	NS	—	—	—	—	—	1,2,3>0 **	—	1,2,3>0 **	—	1,2,3>0 **
Potassium 1st fert. app.	NS	NS	NS	1,3>0	NS	—	NS	1,3>0 3>2 **	NS	2,3>0 3>1 **	NS
Potassium 2nd fert. app.	NS	NS	NS	—	NS	—	NS	1,2,3>0 **	NS	2,3>0 3>1 **	NS
Potassium 3rd fert. app.	NS	NS	NS	—	NS	—	NS	1,2,3>0 **	NS	1,2,3>0 **	NS
Potassium 4th fert. app.	NS	NS	NS	1,2,3>0 3>1 **	NS	1,2,3>0 **	NS	1,2,3>0 3>1 **	NS	—	NS
Potassium major sampling	NS	—	—	—	—	1,2,3>0 **	1,2,3>0	1,2,3>0 **	1>0 **	1,2,3>0 **	1,2,3>0 **
YIELD	—	—	—	—	—	0<1<2,3 **	0<1<3 0<2 **	0<1,2,3	0<1,2,3 **	—	0<1,2,3 **
RESIDUAL PLANT TISSUE PATHOGENS											
Total coliform	NS	—	—	—	—	—	—	NS	NS	NS	NS
Fecal coliform	NS	—	—	—	—	—	—	NS	NS	NS	NS
Salmonellae	NS	—	—	—	—	—	—	NS	NS	NS	NS
Shigellae	NS	—	—	—	—	—	—	NS	NS	NS	NS
Ascaris lumbricoides	NS	—	—	—	—	—	—	NS	NS	NS	NS
Entamoeba histolytica	NS	—	—	—	—	—	—	NS	NS	NS	NS
Miscellaneous parasites	NS	—	—	—	—	—	—	NS	NS	NS	NS
METALS											
Cadmium	NS	—	—	—	—	—	—	—	—	—	—
Zinc	NS	—	—	—	—	1,2,3>0 **	—	—	—	—	1,2,3>0 **
Boron	NS	—	—	—	—	—	1,2<0,3 **	—	—	—	—

TREATMENTS: 0 = 0/3 Fertilization rate, 1 = 1/3 Fertilization rate, 2 = 2/3 Fertilization rate, 3 = 3/3 Fertilization rate
NA = Data not available
NS = Parameter not sampled for on this date

TABLE C.5

MEAN VALUES OF CHEMICALS IN SHALLOW GROUNDWATER AT SITE D
1980 TO 1985
(mg/L unless otherwise noted)

Parameter	Well No. 1					
	Yr 0	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5
pH (pH units)	-	9.0	8.5	8.5	8.5	8.4
Electrical Conductivity (mmhos/cm)	2.8	3.07	3.05	1.69	1.53	2.99
Calcium	14	18	18	9	6	15
Magnesium	16	42	37	16	10	33
Sodium	-	645	641	408	345	676
Potassium	-	0.4	0.6	0.4	0.4	0.5
Total Alkalinity	-	784	743	405	512	948
Sulfate	-	253	233	97	76	202
Chloride	-	220	248	129	96	230
Boron	-	0.8	0.8	0.6	0.5	0.7
Total Dissolved Solids	-	1,970	1,980	1,210	810	1,953
Hardness	-	218	198	86	66	175
Nitrite	0.14	0.08	0.13	0.07	0.63	0.41
Nitrate	37	70	65	37	23	42
Ammonia	1.9	13.2	0.01	2.3	3.0	2.3
Phosphorus	1.8	14.0	3.3	3.1	4.1	3.2
Cadmium	0.01	0.01	0	0	0	0
Nickel	0.01	0	0.01	0.02	0.03	0.01
Total Organic Carbon	11	20	25	25	17	-
Dissolved Organic Carbon	18	-	-	-	21	13
Cobalt	-	-	-	0	0	0.01
Adjusted SAR (no units)	-	42	43	32	30	-
Manganese	-	-	0.01	0.007	0.02	0.05
Chromium	-	-	0.003	0.01	0	0
Lead	-	-	-	-	-	0

Note: These figures are averages of one to five sampling events in each year. Year 0 is baseline data obtained prior to application of reclaimed wastewater. Locations of the wells are shown in Figure 10.

Source: California Department of Water Resources

TABLE C.5 - Continued

Parameter	Well No. 2					
	Yr 0	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5
pH (pH units)	-	8.7	8.4	8.0	8.2	8.6
Electrical Conductivity (mmhos/cm)	2.78	3.13	2.61	1.07	0.87	1.74
Calcium	19	60	24	10	11	17
Magnesium	36	64	32	10	11	20
Sodium	-	547	529	229	174	367
Potassium	-	0.7	0.7	1.1	0.7	0.6
Total Alkalinity	-	426	479	299	276	486
Sulfate	-	206	208	74	47	98
Chloride	-	440	389	84	53	165
Boron	-	0.5	0.5	0.5	0.2	0.3
Total Dissolved Solids	-	2,010	1,689	740	578	1,107
Hardness	196	413	191	66	74	124
Nitrite	0.24	0.13	0.04	0.31	0.62	118
Nitrate	23	49	47	16	11	21
Ammonia	2.0	11.6	0.02	2.7	3.5	2.0
Phosphorus	2.8	15.3	3.3	4.9	4.7	2.4
Cadmium	0	0	0	0.01	0	0
Nickel	0.02	0	0.04	0.03	0.02	0.01
Total Organic Carbon	18	16	19	55	30	-
Dissolved Organic Carbon	18	-	-	-	15	14
Cobalt	-	-	-	0.003	0	0.01
Adjusted SAR (no units)	-	26	34	18	13	-
Manganese	-	-	0.003	0.22	0.08	0.05
Chromium	-	-	0.003	0.02	0	0.007
Lead	-	-	0.003	0.01	0	0.00

Note: These figures are averages of one to five sampling events in each year. Year 0 is baseline data obtained prior to application of reclaimed wastewater. Locations of the wells are shown in Figure 10.

Source: California Department of Water Resources

TABLE C.5 - Continued

Parameter	Well No. 3					
	Yr 0	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5
pH (pH units)	-	9.2	8.6	8.3	8.4	8.6
Electrical Conductivity (mmhos/cm)	3.43	3.61	4.42	4.84	5.00	5.72
Calcium	12	11	13	11	16	17
Magnesium	23	20	27	31	33	41
Sodium	-	846	1,030	1,113	1,168	1,313
Potassium	-	3.0	3.5	4.3	4.6	5.7
Total Alkalinity	-	1,070	1,190	1,173	1,174	1,208
Sulfate	-	247	320	346	357	392
Chloride	-	435	627	796	868	1,061
Boron	-	1.6	1.8	2.6	1.9	2.0
Total Dissolved Solids	-	2,250	2,700	3,343	3,214	3,590
Hardness	125	110	143	164	177	211
Nitrite	0	0.06	0.01	0.01	0.03	0.02
Nitrate	0.6	3.2	0.4	0.1	0.2	0.03
Ammonia	2.0	2.1	0.1	1.5	1.9	4.6
Phosphorus	4.7	4.3	5.4	4.5	4.0	5.5
Cadmium	0	0	0	0	0	0
Nickel	0.02	0	0.01	0.02	0.01	0.01
Total Organic Carbon	20	18	22	19	14	-
Dissolved Organic Carbon	22	-	-	-	14	16
Cobalt	-	-	-	0	0.01	-
Adjusted SAR (no units)	-	70	80	83	86	0.41
Manganese	-	-	0.51	0.88	0.99	0.41
Chromium	-	-	0	0	0	0
Lead	-	-	0.07	0.01	0	0

Note: These figures are averages of one to five sampling events in each year. Year 0 is baseline data obtained prior to application of reclaimed wastewater. Locations of the wells are shown in Figure 10.

Source: California Department of Water Resources

TABLE C.5 - Continued

Parameter	Well No. 4 Yr 0	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5
pH (pH units)	-	8.7	8.3	8.0	8.1	8.5
Electrical Conductivity (mmhos/cm)	3.09	2.52	2.94	2.86	2.13	3.09
Calcium	10	50	58	71	49	56
Magnesium	45	60	69	59	57	68
Sodium	-	409	471	504	378	600
Potassium	-	0.9	1.5	1.5	1.9	2.3
Total Alkalinity	-	344	471	694	686	885
Sulfate	-	145	207	198	127	283
Chloride	-	500	552	465	255	381
Boron	-	0.4	0.4	0.9	0.6	0.7
Total Dissolved Solids	-	1,440	1,727	1,803	1,346	1,935
Hardness	260	372	431	438	356	417
Nitrite	0.01	0.11	0.03	0.07	0.11	0.04
Nitrate	0.37	5.4	7.8	2.5	0.8	0.42
Ammonia	16.7	1.6	0.03	2.4	3.2	2.3
Phosphorus	25.0	0.6	3.2	1.0	1.6	1.7
Cadmium	0	0	0	0.003	0	0
Nickel	0.02	0.01	0.02	0.03	0.03	0.02
Total Organic Carbon	18	22	26	28	41	-
Dissolved Organic Carbon	11	-	-	-	17	12
Cobalt	-	-	-	0	0	0.01
Adjusted SAR (no units)	-	19	23	25	21	-
Manganese	-	-	0.09	0.48	1.76	0.81
Chromium	-	-	0	0	0	0
Lead	-	-	0.01	0.01	0	0

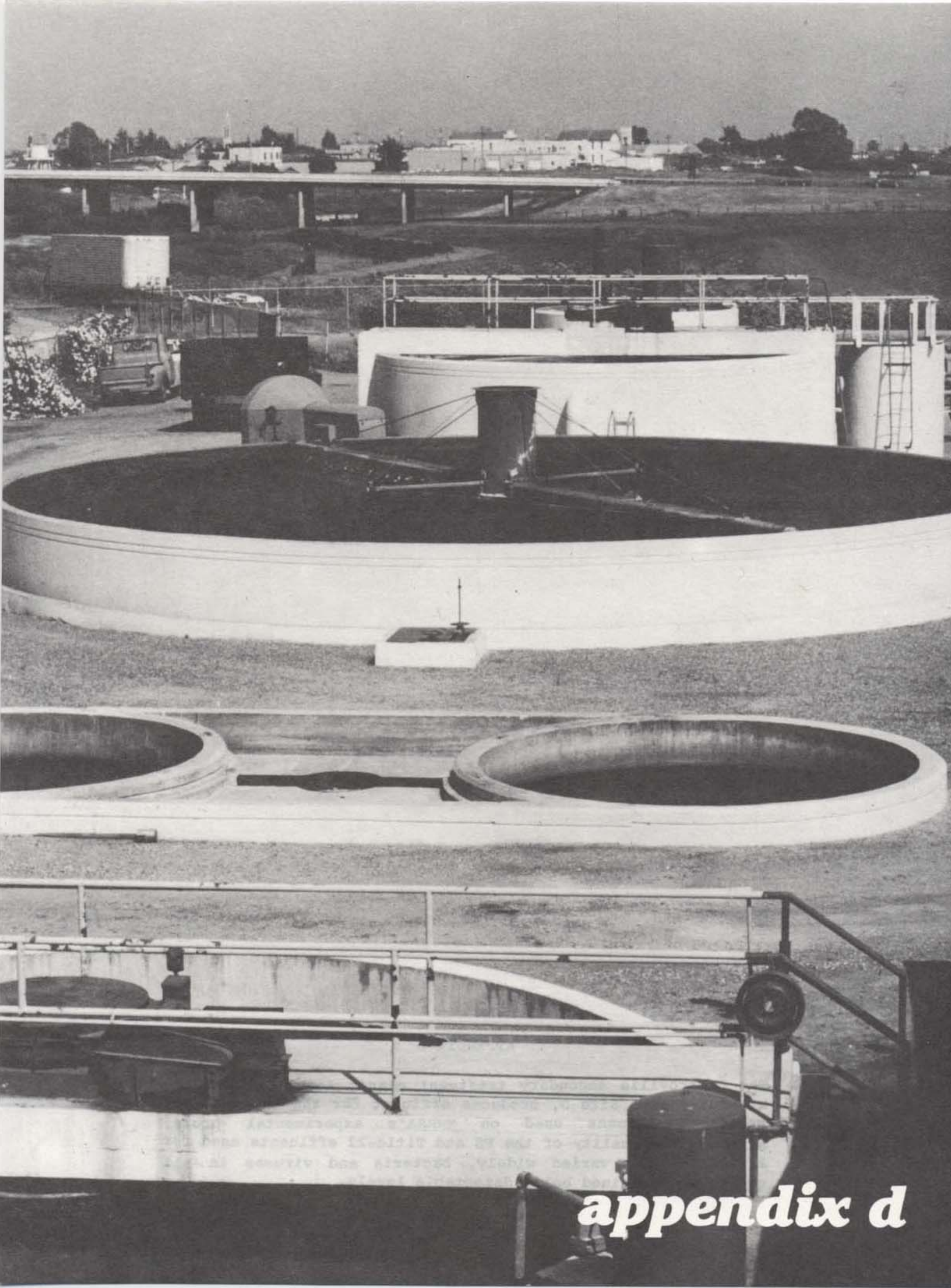
Note: These figures are averages of one to five sampling events in each year. Year 0 is baseline data obtained prior to application of reclaimed wastewater. Locations of wells are shown in Figure 10.

Source: California Department of Water Resources

TABLE C.6

NITRATE LEVELS IN GROUNDWATER
(mg/L)

Monitoring Well No.	21 Dec 83	27 Jan 84	25 Apr 84	25 Jul 84	9 Aug 84	5 Sep 84	31 Oct 84	16 Jan 85
11	1.10	1.30	2.60	57.20	83.60	48.40	19.40	33.00
12	0.00	22.90	0.00	0.00	0.00	1.30	3.30	1.80
13	3.30	6.20	0.00	0.00	0.00	0.00	0.00	0.90
14	16.50	15.40	13.20	4.40	36.30	15.80	0.00	37.40
15	4.84	7.50	9.20	0.00	1.10	0.90	3.10	4.00
16	1.54	0.00	0.00	0.00	5.50	2.20	1.10	7.90
17	0.00	18.50	1.30	0.00	4.80	1.80	0.40	4.40
18	0.00	8.80	0.00	0.00	0.40	0.00	1.30	1.30
19	4.84	15.40	4.00	0.90	1.30	1.80	0.90	1.80
20	29.70	33.00	40.50	41.80	42.90	39.60	39.20	15.40
21	2.64	2.60	1.30	15.40	13.20	16.70	8.80	3.10
22	9.68	1.80	0.40	0.00	6.20	0.00	1.10	2.20
23	3.96	0.90	6.60	3.10	9.90	9.20	10.60	6.20
24	4.84	17.60	8.80	0.00	3.30	0.00	2.80	1.30
25	11.00	8.80	14.50	0.00	14.50	0.40	3.30	3.50
26	0.00	0.00	0.00	0.00	0.00	0.90	1.30	0.00
27	4.18	13.20	3.10	0.00	1.80	0.00	0.00	0.00
28	2.20	3.10	0.00	0.00	2.20	0.00	0.00	0.00
29	6.60	3.50	4.00	0.00	1.80	8.40	2.20	0.90
30	5.94	5.30	2.20	1.30	3.30	3.10	0.00	1.30



appendix d

APPENDIX D

The Castroville secondary treatment plant, located about one kilometer from Site D, produces effluent for the two tertiary treatment streams used on MWRSA's experimental plots. Although the quality of the FE and Title-22 effluents used for irrigation has varied widely, bacteria and viruses in all crops have remained below detectable levels.

APPENDIX D

PILOT WASTEWATER TREATMENT PLANT PERFORMANCE DATA

Biochemical oxygen demand (BOD), suspended solids, turbidity, and coliform bacteria levels have been monitored for five years at the MWRSA pilot plant located at the Castroville Wastewater Treatment Plant.

Table D.1 includes six annual log normal probability distribution tables for BOD, suspended solids, and turbidity of both secondary effluent, and suspended solids and turbidity of the two tertiary effluents, Filtered Effluent (FE)/Filtered Effluent with Flocculation (FE-F), as well as Title-22 (T-22).

Table D.2 includes five annual tables showing 7-day median coliform levels for FE/FE-F and T-22. No coliform sampling was performed during Year One. Table D.3 shows monthly coliform compliance with the DOHS running median standard over a five-year period.

Table D.4 shows Phase IV compliance with the DOHS maximum coliform criterion, and Table D.5 presents daily coliform levels during the February 1986 period of noncompliance.

TABLE D.1

BOD_5, TOTAL SUSPENDED SOLIDS, AND TURBIDITY CONCENTRATIONS IN TREATMENT PLANT EFFLUENTS FROM SEPTEMBER 1980 TO APRIL 1981 BY LOG NORMAL PROBABILITY DISTRIBUTION (mg/L unless otherwise noted)

Parameter	No. of Samples	Percent Chance of Parameter Value Being Less Than or Equal to That Listed Below					
		50	80	90	96	98	99
BOD_5							
SE	18	22	29	33	a	a	a
Total Suspended Solids							
SE	192	12	20	27	37	46	55
FE	188	4.4	8.9	13.0	19.3	24.9	31.4
FE-F	--	--	--	--	--	--	--
FC	191	6.1	13.7	21.0	33.2	44.6	58.2
T-22	190	1.9	4.6	7.4	12.2	17.0	22.8
Turbidity[b]							
SE[c]	--	--	--	--	--	--	--
FE	178	2.4	3.9	4.9	6.4	7.6	8.8
FE-F	--	--	--	--	--	--	--
T-22	183	0.6	1.3	2.0	3.3	4.5	6.0

[a] Not estimated because of the small number of samples.
[b] Nephelometric Turbidity Units (NTU).
[c] Not measured during Year One.

NOTE: Values are from probability distribution analyses and are not an indication of measurement accuracy. Data are fitted to the Pearson Type III log-normal distribution, considered to produce the most representative fit for treatment plant data.

Key:
SE = secondary effluent
FE = filtered effluent before flocculator
FE-F = filtered effluent after flocculator (not used in Year 1)
FC = flocculator-clarifier effluent
T-22 = Title-22 effluent

TABLE D.1 - Continued

BOD_5, TOTAL SUSPENDED SOLIDS, AND TURBIDITY CONCENTRATIONS IN TREATMENT PLANT EFFLUENTS FROM MAY 1981 TO APRIL 1982 BY LOG NORMAL PROBABILITY DISTRIBUTION (mg/L unless otherwise noted)

Parameter	No. of Samples	Percent Chance of Parameter Value Being Less Than or Equal to That Listed Below: 50	80	90	96	98	99
BOD_5							
SE	54	8.3	15.7	21.9	31.3	a	a
Total Suspended Solids							
SE	220	8.7	14.3	18.6	24.6	29.5	34.7
FE	216	2.2	4.7	6.9	10.4	13.6	17.3
FE-F	--	--	--	--	--	--	--
FC	217	4.3	10.0	15.4	24.7	33.5	44.1
T-22	214	1.2	2.7	4.2	6.7	9.1	11.9
Turbidity[b]							
SE	218	2.9	3.9	4.6	5.4	6.0	6.6
FE	213	1.4	2.3	2.9	3.7	4.4	5.1
FE-F	--	--	--	--	--	--	--
T-22	211	0.5	1.0	1.4	1.9	2.4	3.0

[a] Not estimated because of the small number of samples.
[b] Nephelometric Turbidity Units (NTU).

NOTE: Values are from probability distribution analyses and are not an indication of measurement accuracy. Data are fitted to the Pearson Type III log-normal distribution, considered to produce the most representative fit for treatment plant data.

Key:
- SE = secondary effluent
- FE = filtered effluent before flocculator
- FE-F = filtered effluent after flocculator (not used in Year 2)
- FC = flocculator-clarifier effluent
- T-22 = Title-22 effluent

TABLE D.1 - Continued

BOD_5, TOTAL SUSPENDED SOLIDS, AND TURBIDITY CONCENTRATIONS IN TREATMENT PLANT EFFLUENTS FROM MAY 1982 TO MARCH 1983 BY LOG NORMAL PROBABILITY DISTRIBUTION (mg/L unless otherwise noted)

		Percent Chance of Parameter Value Being Less Than or Equal to That Listed Below					
Parameter	No. of Samples	50	80	90	96	98	99
BOD_5							
SE	60	8.3	14.6	19.5	26.6	a	a
Total Suspended Solids							
SE	228	10.2	15.2	18.7	23.4	27.0	20.8
FE	202	1.5	2.5	3.4	4.6	5.6	6.7
FE-F	--	--	--	--	--	--	--
FC	220	4.9	9.2	12.8	18.2	22.9	28.2
T-22	220	1.0	2.1	3.1	4.8	6.3	8.1
Turbidity[b]							
SE	212	3.6	5.0	6.0	7.4	8.4	9.4
FE	209	1.1	1.6	2.0	2.5	2.9	3.3
FE-F	--	--	--	--	--	--	--
T-22	205	0.6	0.9	1.2	1.6	2.0	2.3

[a] Not estimated because of the small number of samples.
[b] Nephelometric Turbidity Units (NTU).

NOTE: Values are from probability distribution analyses and are not an indication of measurement accuracy. Data are fitted to the Pearson Type III log-normal distribution, considered to produce the most representative fit for treatment plant data.

Key:
SE = secondary effluent
FE = filtered effluent before flocculator
FE-F = filtered effluent after flocculator (not used in Year 3)
FC = flocculator-clarifier effluent
T-22 = Title-22 effluent

TABLE D.1 - Continued

BOD_5, TOTAL SUSPENDED SOLIDS, AND TURBIDITY CONCENTRATIONS IN TREATMENT PLANT EFFLUENTS FROM APRIL 1983 TO APRIL 1984 BY LOG NORMAL PROBABILITY DISTRIBUTION (mg/L unless otherwise noted)

Parameter	No. of Samples	Percent Chance of Parameter Value Being Less Than or Equal to That Listed Below					
		50	80	90	96	98	99
BOD_5							
SE	54	11.4	19.5	25.8	34.8	a	a
Total Suspended Solids							
SE	282	11.2	16.1	19.4	23.8	27.2	30.6
FE	131	1.9	3.2	4.1	5.5	6.6	7.7
FE-F	132	1.5	2.9	4.0	5.8	7.3	9.1
FC	263	5.7	10.2	13.8	19.0	23.4	28.3
T-22	258	1.3	2.5	3.6	5.3	6.9	8.6
Turbidity[b]							
SE	217	3.2	4.4	5.2	6.2	6.9	7.7
FE	102	1.4	2.1	2.5	3.1	3.5	a
FE-F	103	1.0	1.8	2.3	3.0	3.7	a
T-22	195	0.9	1.5	2.0	2.6	3.2	3.8

[a] Not estimated because of the small number of samples.
[b] Nephelometric Turbidity Units (NTU).

NOTE: Values are from probability distribution analyses and are not an indication of measurement accuracy. Data are fitted to the Pearson Type III log-normal distribution, considered to produce the most representative fit for treatment plant data.

Key:
SE = secondary effluent
FE = filtered effluent before flocculator
FE-F = filtered effluent after flocculator
FC = flocculator-clarifier effluent
T-22 = Title-22 effluent

TABLE D.1 - Continued

BOD_5, TOTAL SUSPENDED SOLIDS, AND TURBIDITY CONCENTRATIONS IN TREATMENT PLANT EFFLUENTS FROM MAY 1984 TO APRIL 1985 BY LOG NORMAL PROBABILITY DISTRIBUTION (mg/L unless otherwise noted)

Parameter	No. of Samples	Percent Chance of Parameter Value Being Less Than or Equal to That Listed Below: 50	80	90	96	98	99
BOD_5							
SE	74	14.3	22.3	28.0	35.9	a	a
Total Suspended Solids							
SE	302	13.4	19.5	23.7	29.2	33.4	37.7
FE	--	--	--	--	--	--	--
FE-F	286	1.6	3.1	4.3	6.3	8.0	10.0
FC	275	4.4	7.6	10.1	13.8	16.8	20.2
T-22	273	0.8	1.5	2.1	3.0	3.8	4.7
Turbidity[b]							
SE	288	3.8	5.5	6.7	8.2	9.3	10.5
FE	--	--	--	--	--	--	--
FE-F	282	1.1	1.7	2.2	2.9	3.4	4.0
T-22	262	0.6	0.9	1.1	1.5	1.7	2.0

[a] Not estimated because of the small number of samples.
[b] Nephelometric Turbidity Units (NTU).

NOTE: Values are from probability distribution analyses and are not an indication of measurement accuracy. Data are fitted to the Pearson Type III log-normal distribution, considered to produce the most representative fit for treatment plant data.

Key:
- SE = secondary effluent
- FE = filtered effluent before flocculator
- FE-F = filtered effluent after flocculator
- FC = flocculator-clarifier effluent
- T-22 = Title-22 effluent

TABLE D.1 Continued

BOD_5, TOTAL SUSPENDED SOLIDS, AND TURBIDITY CONCENTRATIONS IN TREATMENT PLANT EFFLUENTS FROM AUGUST 1985 TO APRIL 1986 BY LOG NORMAL PROBABILITY DISTRIBUTION
(mg/L unless otherwise noted)

		Percent Chance of Parameter Value Being Less Than or Equal to That Listed Below					
Parameter	No. of Samples	50	80	90	96	98	99
BOD_5							
SE	115	12.3	24.2	34.6	51.0	65.6	82.4
Total Suspended Solids							
SE	157	14.3	19.2	22.4	26.5	29.5	32.5
FE	--	--	--	--	--	--	--
FE-F	155	1.2	1.9	2.4	3.0	3.5	4.0
FC	153	5.8	8.8	10.9	13.6	15.8	18.1
T-22	153	1.0	1.6	2.1	2.7	3.3	3.8
Turbidity[a]							
SE[b]	155	3.7	4.8	5.8	6.3	6.9	7.5
FE	--	--	--	--	--	--	--
FE-F	152	0.7	0.9	1.1	1.2	1.4	1.5
T-22	149	0.5	0.7	0.8	1.0	1.1	1.2

[a]Nephelometric Turbidity Units (NTU).
[b]June 1981 to April 1985.

NOTE: Values are from probability distribution analyses and are not an indication of measurement accuracy. Data are fitted to the Pearson Type III log-normal distribution, considered to produce the most representative fit for treatment plant data.

Key:
SE = secondary effluent
FE = filtered effluent before flocculator
FE-F = filtered effluent after flocculator
FC = flocculator-clarifier effluent
T-22 = Title-22 effluent

TABLE D.2

TOTAL COLIFORM LEVELS IN TERTIARY EFFLUENTS
7-DAY RUNNING MEDIANS FROM SEPTEMBER 1981 TO APRIL 1982

Total Coliform Level (MPN/100 mL)	No. of Times Value was 7-Day Running Median During Year Two	
	FE	T-22
<2	5	57
2	7	4
4	1	0
5	7	1
6	0	0
7	0	0
8	2	0
9	0	0
11	1	0
12	0	0
13	4	0
14	0	0
17	0	0
21	2	0
22	0	0
23	4	0
>23	30	0

	FE	T-22
In compliance with standard: <2.2 MPN/100 mL:	12 (19%)	61 (98%)
Out of compliance with standard: <2.2 MPN/100 mL:	51 (81%)	1 (2%)
Total No. of Running Medians:	63 (100%)	62 (100%)

NOTE: No coliform sampling of tertiary effluents was performed during Year One.

TABLE D.2 - Continued

TOTAL COLIFORM LEVELS IN TERTIARY EFFLUENTS
7-DAY RUNNING MEDIANS FROM MAY 1982 TO MARCH 1983

Total Coliform Level (MPN/100 mL)	No. of Times Value was 7-Day Running Median During Year Three	
	FE	T-22
<2	30	139
2	17	4
4	4	0
5	28	7
6	0	0
7	2	0
8	11	0
9	0	0
11	2	3
12	0	0
13	12	0
14	0	0
17	2	0
21	0	0
22	2	0
23	24	0
>23	20	0

	FE	T-22
In compliance with standard: <2.2 MPN/100 mL:	47 (31%)	143 (93%)
Out of compliance with standard: <2.2 MPN/100 mL:	107 (69%)	10 (7%)
Total No. of Running Medians:	154 (100%)	153 (100%)

TABLE D.2 - Continued

TOTAL COLIFORM LEVELS IN TERTIARY EFFLUENTS
7-DAY RUNNING MEDIANS FROM APRIL 1983 TO APRIL 1984

Total Coliform Level (MPN/100 mL)	No. of Times Value was 7-Day Running Median During Year Four	
	FE and FE-F	T-22
<2	63	120
2	58	39
4	0	1
5	22	4
6	0	0
7	11	9
8	3	0
9	0	0
11	6	0
12	1	0
13	9	0
14	0	0
17	0	0
21	0	0
22	5	0
23	0	0
>23	1	0

	FE and FE-F	T-22
In compliance with standard: <2.2 MPN/100 mL:	121 (68%)	159 (92%)
Out of compliance with standard: <2.2 MPN/100 mL:	58 (32%)	14 (8%)
Total No. of Running Medians:	179 (100%)	173 (100%)

TABLE D.2 - Continued

TOTAL COLIFORM LEVELS IN TERTIARY EFFLUENTS
7-DAY RUNNING MEDIANS FROM MAY 1984 TO APRIL 1985

Total Coliform Level (MPN/100 mL)	No. of Times Value was 7-Day Running Median During Year Five	
	FE-F	T-22
<2	76	142
2	41	15
4	0	0
5	22	3
6	0	0
7	5	0
8	10	0
9	0	0
11	6	0
12	0	0
13	0	0
14	0	0
17	1	0
21	0	0
22	4	0
23	0	0
>23	6	0

	FE-F	T-22
In compliance with standard: <2.2 MPN/100 mL:	117 (68%)	157 (98%)
Out of compliance with standard: <2.2 MPN/100 mL:	54 (32%)	3 (2%)
Total No. of Running Medians:	171 (100%)	160 (100%)

TABLE D.2 - Continued

TOTAL COLIFORM LEVELS IN TERTIARY EFFLUENTS
7-DAY RUNNING MEDIANS FROM AUGUST 1985 TO APRIL 1986
PHASE 1V

Total Coliform Level (MPN/100 mL)	No. of Times Value was 7-Day Running Median During Phase IV	
	FE-F	T-22
<2	87	98
2	26	43
4	0	0
5	13	0
6	0	0
7	0	0
8	1	0
9	0	0
11	0	0
12	0	0
13	1	0
14	0	0
17	5	0
21	0	0
22	0	0
23	0	0
>23	7	0

	FE-F	T-22
In compliance with standard: <2.2 MPN/100 mL:	113 (81%)	141 (100%)
Out of compliance with standard: <2.2 MPN/100 mL:	27 (19%)	0 (0%)
Total No. of Running Medians:	140 (100%)	141 (100%)

TABLE D.3

7-DAY RUNNING MEDIAN COLIFORM
LEVEL COMPLIANCE BY MONTH

	Percent Compliance[a]			Percent Compliance[a]	
Month	FE	T-22	Month	FE	T-22
Year Two			**Year Three**		
			May 82	100	40
			Jun 82	25	100
			Jul 82	23	100
			Aug 82	24	100
Sep 81	0	100	Sep 82	0	80
Oct 81	0	100	Oct 82	0	100
Nov 81	100	100	Nov 82	23	100
Dec 81	83	100	Dec 82	60	100
Jan 82	42	100	Jan 83	30	67
Feb 82	0	100	Feb 83	100	88
Mar 82	0	100	Mar 83	71	100
Apr 82	0	92			

[a]Compliance with 2.2 MPN/100 mL DOHS standard.
NOTE: No coliform sampling of tertiary effluents was performed during Year One.

7-DAY RUNNING MEDIAN COLIFORM
LEVEL COMPLIANCE BY MONTH

	Percent Compliance[a]			Percent Compliance[a]	
Month	FE,FE-F	T-22	Month	FE-F	T-22
Year Four			**Year Five**		
Apr 83	0	100			
May 83	53	100	May 84	100	100
Jun 83	0	50	Jun 84	84	100
Jul 83	28	89	Jul 84	53	100
Aug 83	74	100	Aug 84	100	100
Sep 83	84	100	Sep 84	100	100
Oct 83[b]	100	100	Oct 84	100	100
Nov 83	100	100	Nov 84	100	100
Dec 83	53	67	Dec 84	0	100
Jan 84	44	94	Jan 85	0	100
Feb 84	100	100	Feb 85	43	83
Mar 84	100	100	Mar 85	81	93
Apr 84	100	100	Apr 85	100	100

[a]Compliance with 2.2 MPN/100 mL DOHS standard.
[b]FE-F operation began.

TABLE D.3 - Continued

7-DAY RUNNING MEDIAN COLIFORM
LEVEL COMPLIANCE BY MONTH

Month	Percent Compliance[a] FE-F	T-22
PHASE IV		
Aug 85	100	100
Sep 85	100	100
Oct 85	100	100
Nov 85	100	100
Dec 85	100	100
Jan 86	24	100
Feb 86	0	100
Mar 86	82	100
Apr 86	100	100

[a]Compliance with 2.2 MPN/100 mL DOHS standard.

TABLE D.4

NUMBER OF SAMPLES IN PHASE IV EXCEEDING 23 MPN/100 mL

Month	FE	T-22
August 1985	0	0
September 1985	0	0
October 1985	0	0
November 1985	0	0
December 1985	0	0
January 1986	1	0
February 1986	5	1
March 1986	1	0
April 1986	0	0

DOHS standard allows no more than one sample per 30 days greater than 23 MPN/100 mL.

TABLE D.5

DAILY[a] COLIFORM LEVELS - PHASE IV - FEBRUARY 1986 (MPN/100 mL)

Date	FE	T-22
03 Feb 86	5	2
05 Feb 86	46	7
06 Feb 86	2	11
07 Feb 86	4	<2
10 Feb 86	<2	b
11 Feb 86	>2400	b
13 Feb 86	c	c
14 Feb 86	c	c
18 Feb 86	920	<2
19 Feb 86	>2400	>2
20 Feb 86	>2400	>2400
21 Feb 86	<2	<2
24 Feb 86	d	d
25 Feb 86	e	<2
26 Feb 86	2	<2
27 Feb 86	f	8
28 Feb 86	f	<2

[a] System not operated on weekends and holidays.
[b] T-22 system shut down for repairs of backwash system.
[c] Tertiary systems off because secondary plant upset due to heavy rain.
[d] Tertiary systems off to prepare for virus seeding event.
[e] No chlorination of FE system for virus recovery test.
[f] FE system chlorinated at 20 mg/L before resuming normal chlorination.

appendix e

APPENDIX E

Harvesting operations are performed selectively to pick the "marketable" heads of lettuce for yield determination. In this picture, an Engineering-Science technician works alongside professional pickers.

APPENDIX E

LITERATURE REVIEW AND BIBLIOGRAPHY

A review of the literature on the land application of wastewater and sludge has continued throughout all phases of MWRSA. Detailed literature reviews have been published yearly as part of each annual report. This appendix provides a general summary of the trends in research that have been observed over the years, and it includes a comprehensive list of the literature that has been reviewed during the course of the study. Also listed is the literature published since the publication of the last annual report.

Although the literature is too extensive for a detailed review, some publications deserve special mention. Three Water Reuse Symposia took place during the course of MWRSA, with proceedings being published by the AWWA Research Foundation (1979, 1981, and 1985). Topics covered in these symposia included water reuse policy implementation, programs, and potential; management, marketing, and financing of water reuse; municipal wastewater reuse; agricultural and silvicultural reuse; operating and monitoring water reuse systems; institutional factors; health effects and water quality criteria; and research needs in water reuse. A 1983 workshop sponsored by the U.S. Environmental Protection Agency, U.S. Army Corps of Engineers, U.S. Department of Agriculture, National Science Foundation, and University of California (Page et al. 1983) also addresssed similar issues.

In March 1984, the County Sanitation Districts of Los Angeles County (CSDLAC) published a final report of landmark research performed to assess the health effects of using reclaimed wastewater for groundwater replenishment in Southern California. The study undertook four major research tasks: groundwater quality characterization, toxicology and organic studies, percolation and hydrogeologic studies, and epidemiologic studies. It was concluded by the CSDLAC that groundwater replenishment with reclaimed water had not adversely affected groundwater quality or human health in the area.

Two manuals of particular interest to MWRSA appeared during the course of the study. The California Department of Health Services (1983) published a Manual of Good Practice for Landspreading of Sewage Sludge. In 1984, the California State Water Resources Control Board published Irrigation with Reclaimed Municipal Wastewater - A Guidance Manual (Pettygrove and Asano 1984). The latter provides information for use in planning, designing, and operating irrigation systems using reclaimed water.

Major trends in research in the areas of public health and agricultural effects of wastewater reclamation and application of sewage sludge are summarized below.

HEALTH CONSIDERATIONS

Major health concerns regarding the agricultural use of reclaimed wastewater and sludge include exposure to pathogenic organisms and organic compounds, bioaccumulation of heavy metals, and contamination of surface or groundwaters from irrigation runoff.

The concern for and effects of trace metals in land-applied waste materials and their potential transfer in the food chain have received considerable attention in the literature. High concentrations of potentially toxic elements are not generally a concern in the use of wastewater effluent for irrigation of edible crops. Most of the element loads accumulate in the sludge during wastewater treatment. Consequently, sludge-related studies represent worst-case conditions, those that cannot be expected for wastewater effluents. Much of the literature focuses on the accumulation of heavy metals in livestock fed with crops grown on sludge-amended soils. Animal feeding studies provide a method of assessing potential long-term deleterious effects of consumption of crops irrigated with reclaimed wastewaters.

The heavy metals of particular concern are copper, zinc, cadmium, chromium, lead, arsenic, nickel, and mercury. Copper, zinc, and nickel generally do not produce problems to humans through the food chain because their levels of phytotoxicity to vegetation is attained before reaching levels that would be toxic to most animals. Arsenic and mercury are usually inhibited from accumulating to hazardous levels in edible plant parts either by root barriers or diminished translocation (or both).

When livestock were fed crops grown on sludge-amended soils, with the exception of cadmium and lead, none of the metals were significantly increased in the various tissues and organs. Many studies focus on cadmium because it is one of the most prevalent and toxic elements in sludge and is efficiently deposited in the kidneys, liver, and other vital organs of animals and humans. Comparatively smaller quantities of cadmium accumulate in other tissues such as the somatic muscle, heart, brain, and blood. Excess cadmium has been associated with hypertension, emphysema, and other diseases. In livestock, it has induced microcytic and hypochromic anemia.

The transmission of disease by waterborne pathogens is another major focus of the literature. It has been well documented that raw or minimally treated wastewater used for irrigation will increase the incidence of bacterial and viral diseases in the local population. Little evidence exists to show that disease is disseminated by using secondary or tertiary treated effluents for irrigation. Much of the literature concentrates on the behavior and survival of pathogenic organisms in the soil-plant system, aerosol transport, and pathogen detection and removal. Survival times of organisms in the agricultural environment vary from 1 to 40 days on vegetables and up to several years in soils. Migration and survival time and virus adsorptivity to soils are dependent on soil properties such as soil compaction, pH, cation-exchange capacity, permeability, texture, moisture, temperature, and iron oxide levels. Adsorption also depends on the strain of virus. Clayey materials tend to adsorb viruses over a range of pH more readily than sand and organic soil. Adsorption is favored in neutral and acidic systems. The survival time of pathogens generally decreases with higher temperatures and dry soil conditions. Slower infiltration rates proved to be effective in the removal of viruses.

Aerosol studies have concluded that people working at or living near a wastewater treatment plant are not subject to a microbiological hazard from the aerosols. Aerosols emanating from effluent irrigation sites usually have a very low density of bacteria, and most microorganisms die off very quickly. Some persist, most notably Klebsiella. The literature suggests that maximum detection distance from the spray site was about 1,300 ft (400 meters).

The most common disinfecting agent used in wastewater treatment is chlorine. Up to 99.99 percent of virus inactivation occurs when breakpoint chlorination is used. Another disinfecting process that is very effective as a virucide is the use of ozone. In a comparison with chlorine, it was noted that ozone oxidizes phenols, cyanides, and pesticides more completely than does chlorine. The disadvantages of its use include a lack of residual, lesser bacterial activity, and high sensitivity to application method.

It has been documented that organic compounds can enter the food chain from the soil via crop uptake. Several reports have shown that polychlorinated biphenyls (PCBs) can be absorbed by plants in low amounts. Potential adverse effects from organics can be assessed through the use of animal studies and toxicity tests. However, there is little documentation on health implications of crop uptake of organics.

The primary adverse effect on groundwater of the application of effluent to land is nitrate contamination. Nitrate applied in excess of crop needs usually percolates through to the groundwater. Ingestion by infants of high nitrate levels in water can cause methemoglobinemia.

As mentioned earlier, soil is an effective filtering medium to prevent large numbers of pathogens, protozoa, and helminths from leaching into groundwater. Little, if any, migration of heavy metals occurs in soil. Ion exchange, adsorption, precipitation, and complexation and chelation were considered to be the major mechanisms affecting movement of heavy metals. There is some concern about the leaching of nutrients into shallow groundwater, but this can be mitigated by harvesting crops on a regular basis, thereby promoting new growth to use the nutrients.

Epidemiological studies have indicated no elevated morbidities or mortalities over 20 years of using groundwater recharged with wastewater effluents. Studies have shown that infant and neonatal mortality, birth outcomes, and infectious diseases were not associated with residency in groundwater recharge areas. Epidemiological studies of cancer and mortality are problematic in that cancer incidence and mortality would not be expected after less than 15 or 20 years of reuse. Minute amounts of trace organics leaching into groundwaters following the use of effluents for land application or groundwater recharge is a concern presented in the literature. In the short term, absorption, assimilation, and decomposition of most organics occur at a rate sufficient to prevent the release of contaminated leachate into the groundwater. However, the long-term ability for soils to remove organic constituents is unknown, and not all soils are considered to be a reliable treatment method for removal of organics. Organic mutagens and suspected carcinogens have been detected in recharge water and in groundwater following recharge. The most consistently prevalent compounds were volatile organics -- industrial solvents or byproducts of water chlorination. These compounds were not attenuated during vertical passage of water through the soil.

AGRICULTURAL EFFECTS

Research on agricultural effects of land application of wastewater and sludge has focused on two major areas: the effect on soil and the effect on crops. Soil parameters most commonly monitored are nutrient content and fate, heavy metal accumulation, salinity, infiltration rates and permeability. Crops are monitored for yield and quality, tissue nutrient levels, and tissue heavy metal uptake.

The relatively high nutrient content of reclaimed wastewater makes effluent irrigation an attractive agricultural alternative. In some cases, wastewater irrigation can provide enough nutrients to greatly supplement fertilization. Generally, wastewater irrigation shows increased levels of nitrogen, phosphorus, and potassium in the soil, with the soil removing up to 90 percent of these nutrients as the wastewater percolates into the underlying aquifer. Nitrogen is removed from the soil primarily by plant uptake; secondary factors are removal by volatilization, denitrification, immobilization in complexed organic form, and leaching into the aquifer. Leaching of nitrates into groundwater has been found in some cases of high nitrate loading, such as with sludge application. Overall, soil nitrogen levels tend to remain stable during wastewater irrigation due to the high nitrogen demand from crops. Alternatively, phosphorus can stay in the top 12 in. (30 cm) of soil for nearly a decade (clay loam soil), though studies have shown appreciable leaching occurs below 12 in. (30 cm) in sandier soil. Several studies noted an increase in topsoil phosphorous levels after 30 years of wastewater application. Potassium levels may increase; however, the rate of uptake by plants usually exceeds the rate of application. The amount of potassium that is "held" by the soil is dependent on soil type.

One major concern in wastewater application is the possibility of heavy metal accumulation in the soil, which may lead to uptake by plants, livestock, and ultimately humans. The application of small amounts of heavy metals has a potential beneficial effect by correcting plant deficiencies; however at higher levels, these same metals may become phytotoxic. Bioaccumulation is a concern particularly for cadmium, lead, and mercury. In general, application of secondary effluent onto soil causes little to no significant increase in soil heavy metal content, with any increase dependent on loading rate. In one study, the fertilizer loaded more heavy metals onto the soil than the secondary effluent. The application of raw wastewater or sludge, both of which have higher concentrations of heavy metals than secondary effluent, causes higher rates of heavy metal accumulation in the soil. Sludge application studies show that accumulation of heavy metals can rise above acceptable levels, although these levels can be avoided by modified application procedures. Soil heavy metals tend to concentrate in the top 10 in. (25 cm) of soil with little horizontal or vertical movement. In addition, the high organic matter content of soils tends to immobilize heavy metals.

Wastewaters contains more salts, with a higher proportion of sodium in relation to other dissolved cations, than do municipal water supplies. Salt accumulation in soil can result in salt accumulation in plant tissue to phytotoxic levels and the deterioration of soil physical parameters such as soil structure, infiltration rates, and permeability. Most studies reported increases in soil salinity after wastewater irrigation, but none at levels that would cause damage to crops. A few studies reported lower hydraulic conductivity after wastewater irrigation due to both higher salinity and clogging of soil pores by organic matter. The accumulation of salts can be avoided by increasing total irrigation or alternating effluent with water of a lower salt content. The pH effects of wastewater irrigation vary and are dependent on soil type and wastewater composition.

Yield, quality, nutrient, and heavy metal uptake of crops grown on wastewater-irrigated plots are pertinent agricultural concerns.

Nitrogen uptake by crops is the primary route for the removal of nitrogen from the wastewater. In general, nitrogen, phosphorus, and potassium levels in crops grown on wastewater-treated soil tend to be higher than those grown on well water-irrigated soil.

In nearly all cases, yields were increased by the application of wastewater effluent. In general, effluent-irrigated crops grew taller, had higher dry yields, increased in biomass levels, etc. The quality of the crops was equal if not better than for those crops grown on well water-irrigated soil. For sludge-treated soils, yields increased with increasing sludge application rates, except in instances where accumulation of heavy metals reached phytotoxic levels.

Much attention has been paid to the uptake of heavy metals by crops. Cadmium is of special concern because it is toxic to the kidneys and liver at certain levels. The uptake of heavy metals by plants is dependent on many factors: soil pH, moisture content, heavy metal loading rate, and the crop species.

Crops grown on soils with a high pH tend to have a lower heavy metal uptake than those grown on more acidic soils. Soils treated with sludge benefit from "liming," which increases the soil pH, and, thus minimizes plant uptake of the higher levels of heavy metals present in sludge. Saturation may increase heavy metal uptake.

No studies report plant uptake of any heavy metals to reach phytotoxic levels for wastewater irrigated crops. Although wastewater irrigation may increase levels of heavy metals in tissue, the tissue levels fall into the acceptable ranges. Many studies show that sludge ammendment of soil causes higher heavy metal uptake in some crops, with heavier sludge loading causing greater uptake. Generally, sludge application did not cause increases above phytotoxic levels. The metal contents of sludges can be monitored, and sludge can be applied at rates to prevent such problems.

Metals accumulation in crops is species dependent. For example, in one study, chard and tomato plants accumulated two to three times more cadmium than corn. In another study, wheat and lettuce took up many of the heavy metals deposited on soils, but tomatoes did not. Metals also accumulate in different parts of plants at different rates. For example, barley straw can accumulate more zinc and cadmium than the barley grain.

The research indicates that, with proper design and management, effluent irrigation systems can provide a safe, feasible method of disposing sewage effluent while providing many agricultural benefits.

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