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A pilot tube farm has been installed at the Mililani Sewage Treatment Plant, O'ahu, Hawai'i, to study the necessary treatment of activated sludge effluent for drip irrigation. Four types of effluent will be processed: 100% effluent, 50% effluent diluted with 50% Waiāhole Ditch water plus the 100% effluent and the 50% to 50% mix after a 3-day detention in reservoir storage. Efficacy of treatment will be determined by the rate of plugging of the holes in the drip irrigation tubes and the quality of the posttreated water. The present posttreatment system consists of two-stage pressure filtration: first through No. 3 anthracite, then through No. 11 crushed granite. Filtration rate is 0.001 36-0.002 7 $m^3/s/m^2$ (2-4 gpm/ft^2). The filtrate is given chemical treatment by chlorine, bromine chloride, or chlorine dioxide at a dosage equivalent to a 10 mg/ℓ chlorine residual at the end of the drip tube line. The system and the dosages will be varied to a level that will yield least plugging. Both single-chamber and dual-chamber tubing will be tested. The tube farm is automated and is operated on a 24-hr day schedule, processing 100% effluent for 12 hr and 50 to 50% dilution for 12 hr. Backwash takes place at the end of the run. Mean values for the effluent and ditch water were respectively, suspended solids, 31 and 23 mg/ℓ; total plate count, 3 and 30 organisms x 10^3/mℓ; total coliform, 34 and 970 organisms/mℓ; and total organic carbon, 56 and 27 mg/ℓ. The volatile suspended solids content was 90% for the effluent but only 30% for the ditch water. A reuse bibliography has been compiled. A hydraulics test stand facility has been developed to study the effects of plugging on the hydraulics of emitter flow in drip irrigation lateral lines.

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RECYCLING OF SEWAGE EFFLUENT BY SUGARCANE IRRIGATION: A POSTTREATMENT STUDY
JULY 1977 TO JUNE 1978
PHASE II-B

(PROGRESS REPORT)

Technical Report No. 121

October 1978

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ABSTRACT

A pilot tube farm has been installed at the Mililani Sewage Treatment Plant, O'ahu, Hawai'i, to study the necessary treatment of activated sludge effluent for drip irrigation. Four types of effluent will be processed: 100% effluent, 50% effluent diluted with 50% Waiāhole Ditch water plus the 100% effluent and the 50% to 50% mix after a 3-day detention in reservoir storage. Efficacy of treatment will be determined by the rate of plugging of the holes in the drip irrigation tubes and the quality of the posttreated water. The present posttreatment system consists of two-stage pressure filtration: first through No. 3 anthracite, then through No. 11 crushed granite. Filtration rate is 0.001 36-0.002 7 $m^3/s/m^2$ (2-4 gpm/ft^2). The filtrate is given chemical treatment by chlorine, bromine chloride, or chlorine dioxide at a dosage equivalent to a 10 mg/ℓ chlorine residual at the end of the drip tube line. The system and the dosages will be varied to a level that will yield least plugging. Both single-chamber and dual-chamber tubing will be tested. The tube farm is automated and is operated on a 24-hr day schedule, processing 100% effluent for 12 hr and 50 to 50% dilution for 12 hr. Backwash takes place at the end of the run. Mean values for the effluent and the ditch water were respectively, suspended solids, 31 and 23 mg/ℓ; total plate count, 3 and 30 organisms x 10^3/mℓ; total coliform, 34 and 970 organisms/mℓ; and total organic carbon, 56 and 27 mg/ℓ. The volatile suspended solids content was 90% for the effluent but only 30% for the ditch water. A reuse bibliography has been compiled. A hydraulics test stand facility has been developed to study the effects of plugging on the hydraulics of emitter flow in drip irrigation lateral lines.

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INTRODUCTION

In a cooperative field test undertaken by the Water Resources Research Center, Oahu Sugar Company, Ltd., and the Hawaiian Sugar Planters' Association and funded by the City and County of Honolulu's Department of Public Works and the Honolulu Board of Water Supply, and the Hawaii State Department of Health, it was demonstrated that treated secondary domestic waste water effluent can be applied as supplemental irrigation water for sugarcane without detriment to sugar yield. The appropriate management of the effluent as a water resource, however, demands an investigation of its best application, including that through drip and subsurface irrigation systems that are now in widespread and increasing use in Hawai'i's sugar plantations.

The plugging of drip-tube orifices, due to suspended material including microorganisms in the water supply, is the cause of the present problem in existing drip irrigation systems. The severity of the problem varies among plantations and according to water source, but the plugging problem exists with even the highest quality water. The current irrigation practice is to provide pretreatment by sedimentation and/or screening followed by pressure sand filtration to eliminate above 40- to 70-μ sized material using high filtration rates ($>0.014\ m^3/s/m^2$ [$>20\ gpm/ft^2$]) with intermittent chlorination to oxidize slime growth in the drip tubes. Despite the pretreatment and chlorination, plugging is a constant problem and a subject of continual industrial research.

Plugging, of course, can be expected if secondary effluent has a residual of about 30 ppm suspended solids, consisting of residual sewage solids and microorganisms. The effluent will also contain a like concentration of biodegradable organic material that can support growth of microorganisms in the drip system. Consequently, any study of secondary effluent application in drip irrigation must include an evaluation of further treatment to insure removal of both residual solids and organics or a high degree of disinfection to keep down the population level of organisms that might result in undesirable slime growth in the transmission lines or drip tubes.

Since previous research has shown the definite suitability of secondary effluent as a sugarcane irrigation resource and the industry has committed itself to the use of the effluent, it is essential then to consider the necessary additional treatment to make drip irrigation application of the effluent feasible and practical.

Objective and Scope

The physical and chemical treatment of the Mililani Sewage Treatment Plant (STP) secondary effluent is under study for application of the effluent in drip irrigation systems with efficacy comparable to that in existing drip irrigation installations in the sugar industry. The investigation is being carried out in central O'ahu, Hawai'i, on the Mililani STP grounds. A pilot tube farm installation is used for the application of four types of effluent processed through postsecondary treatment: (1) 100% secondary treated effluent, (2) 50% secondary treated effluent diluted with 50% Waiāhole Ditch water, (3) 100% secondary treated effluent after a 3-day detention, and (4) 50% secondary treated effluent diluted with 50% Waiāhole Ditch water after a 3-day detention in a deep holding tank to simulate field storage. Efficacy of treatment and drip irrigation will be determined by the water quality after posttreatment and the rate of plugging of drip irrigation tubes.

The study will require 18 to 24 mo to complete full testing of the various treatment schemes.

All experimental work is being done in the Mililani area. A pilot tube farm has been installed on the southeast end of the Mililani STP grounds between the existing chlorinator building and chlorine contact chamber and the perimeter fence (Fig. 1). A reservoir constructed for a previous study is used to store Waiāhole Ditch water about 1 609 m (1 mile) from the STP. A gravity pipe system (0.05-m [2-in.] Class 125 PVC) conveys the water to the STP for posttreatment studies.

At the present time, the pilot tube farm system is operating on 100% effluent, and a 50% effluent and 50% ditch water dilution. Effluent application after detention in a simulated field reservoir will be studied in a subsequent research phase. The reservoir will either be an existing STP process unit adapted for this purpose or will be a new construction on the STP grounds.

Posttreatment consists of in-line screening followed by pressure sand filtration, utilizing dual-media filtration (coal and crushed granite) with filtration rates predetermined by laboratory study in pilot filters.

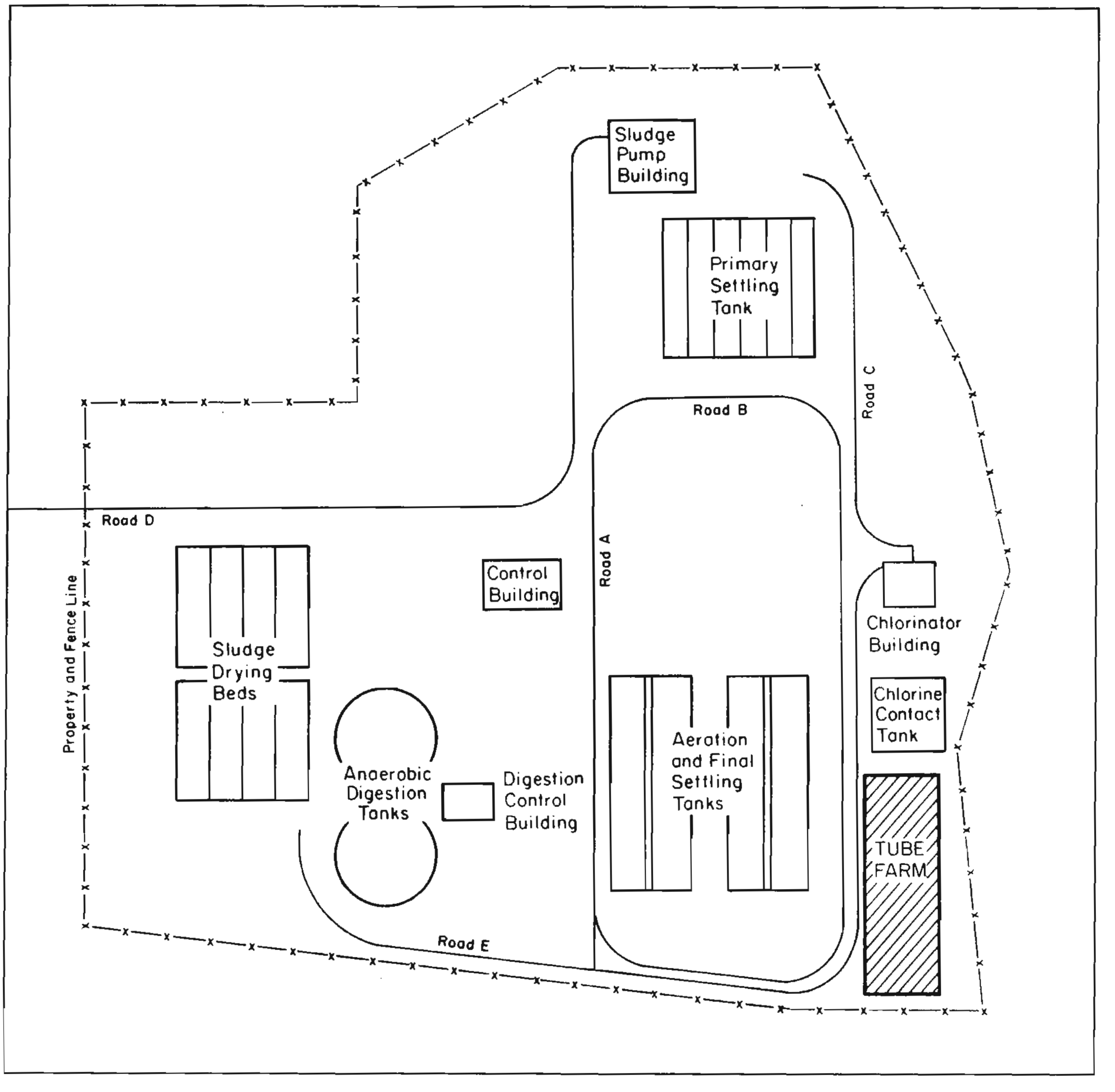


FIGURE 1. SIMPLIFIED PLAN OF MILILANI SEWAGE TREATMENT PLANT SHOWING LOCATION OF TUBE FARM

Filtration is followed by slug-feed chlorination, then by chlorine dioxide or bromine chloride application as an oxidant disinfectant treatment. There is a cluster of 3 tubes (either single- or dual-chamber) for each treatment condition with tube lengths of about 61 m (200 ft).

The effluent quality is monitored after chlorination in secondary treatment and after posttreatment, including disinfection. Parameters monitored include total solids, suspended solids, volatile suspended solids, total organic carbon, total bacterial plate count, and fecal and total coliform count. Distribution of particle-size suspended solids and effluent algal growth potential may also be assayed.

This report presents the design and the initial results obtained as of 30 June 1978. The design was evolved from a long and complicated planning effort by the full working group which began work in May 1976. Toward the end of the reporting period, field testing and data collection were about to commence.

Organization of Study

The research is a cooperative effort of the Water Resources Research Center (WRRC) and the Department of Agricultural Engineering of the University of Hawaii at Manoa, the Oahu Sugar Company (OSC), and the Hawaiian Sugar Planters' Association (HSPA), with principal funding from the City and County of Honolulu's Department of Public Works (DPW) and Board of Water Supply (BWS), and the Hawaii State Department of Health. The responsibilities of the various agencies are delineated in the Research Protocol (App. A).

The overall responsibility and direction of the project was delegated to the principal investigator, L. Stephen Lau, Director of the Water Resources Research Center. He is assisted by an Executive Group consisting of University of Hawaii faculty from various departments and the staff of the Water Resources Research Center; engineers from the Department of Health, State of Hawaii; the Board of Water Supply and the Department of Public Works of the City and County of Honolulu; and engineers from the Hawaiian Sugar Planters' Association and the Oahu Sugar Company, Ltd. The Executive Group and members of the participating staff from the cooperating agencies meet on a regular basis, approximately once a month, to review and discuss progress and to conduct detailed planning and coordination of the research.

RESEARCH DESIGN OF RECLAMATION SYSTEM

Mililani STP

The Mililani STP, an activated sludge plant designed originally for an average daily flow of 0.079 m^3/s (1.81 mgd), has been recently expanded to a capacity of 0.16 m^3/s (3.60 mgd). The original 0.079-m^3/s units used the proprietory Rapid-Bloc (Chicago Pump) system. The new mechanical aeration, complete-mix activated sludge biological treatment units, will be utilized until their capacity of 0.078 m^3/s (1.79 mgd) is exceeded, at which time the 0.079-m Rapid Bloc system will be put back into service. During the first half of 1978, the plant processed an average flow of 0.07 m^3/s (1.50 mgd). A schematic flow diagram of the Mililani STP is shown in Figure 2.

The capacity of the chlorine chamber has been increased two-fold by the expansion. The Hawaii State Department of Health disinfection standards require a detention time of 15 min for the designed maximum flow with a chlorine residual of 0.5 mg/ℓ, but the actual average detention time is over 30 min since the maximum flow is some 2.3 times the present average flow. This, and the presently installed diffused aeration mixers, should produce a more efficient disinfection system with lower bacteria and/or virus counts. A previous study by the WRRC (Lau 1976) concluded that the chlorine contact chamber, before expansion, was well mixed for the flow being currently handled.

Posttreatment System

The posttreatment system was designed to follow current industrial practices of drip irrigation flow rates, screening and filtration rates, and chlorination for chemical treatment. Other types of chemical treatment used in the study would be first applied at dosages that would yield the equivalent chlorine dosage as in industry practice. The major portion of the design was accomplished and coordinated by the HSPA, the Division of Wastewater Management, and Agricultural Engineering staff as noted in Appendix A.

There are three aspects to the testing program, as noted in the Introduction. The pilot tube farm is being operated first on 100% posttreated secondary effluent and 50% posttreated secondary effluent diluted with Waiāhole Ditch water (Fig. 3). Upon satisfactory completion of the test runs with these waters, the tube farm will be operated on posttreated secondary effluent that has been held for at least 3 days in an open reservoir. One

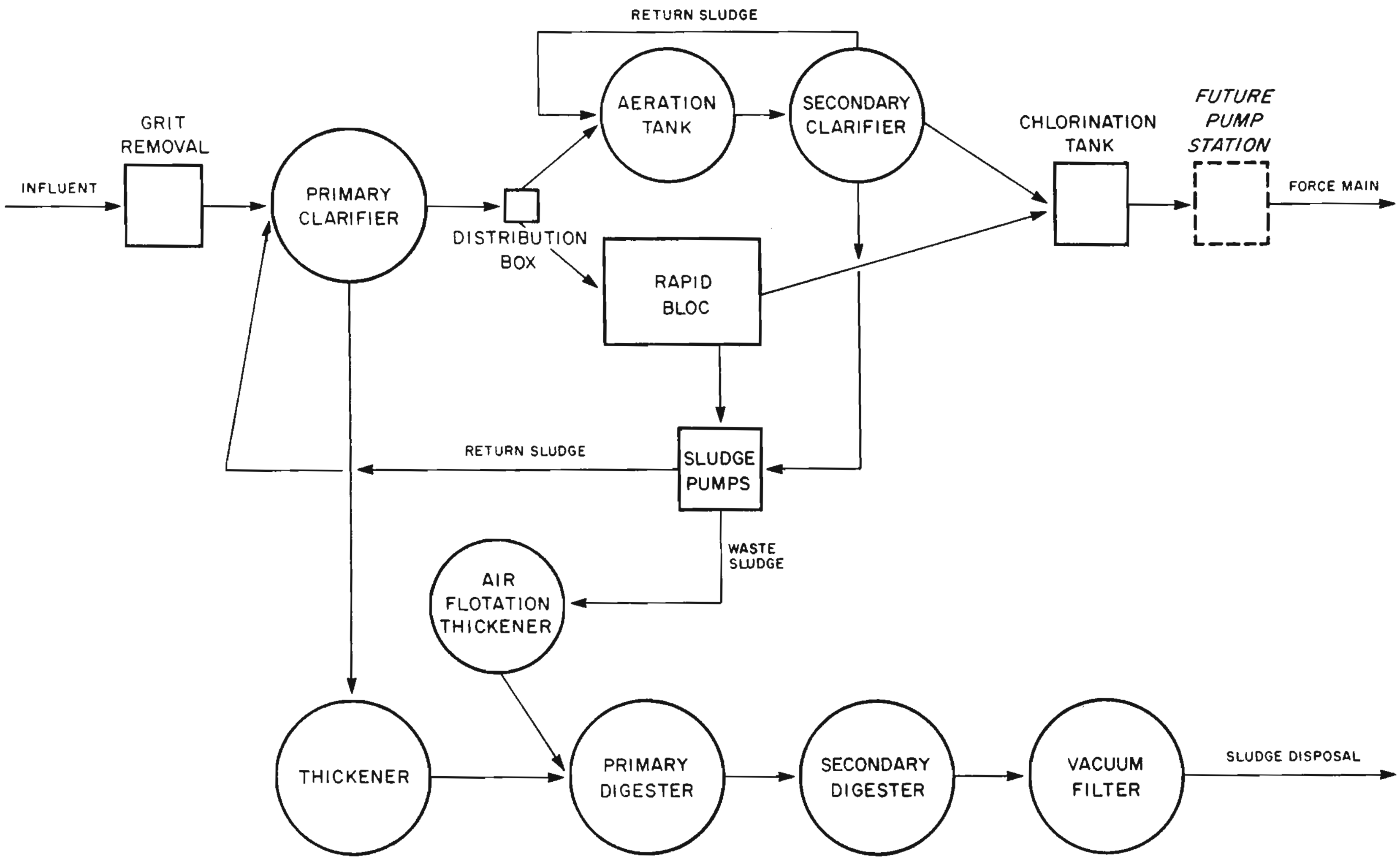
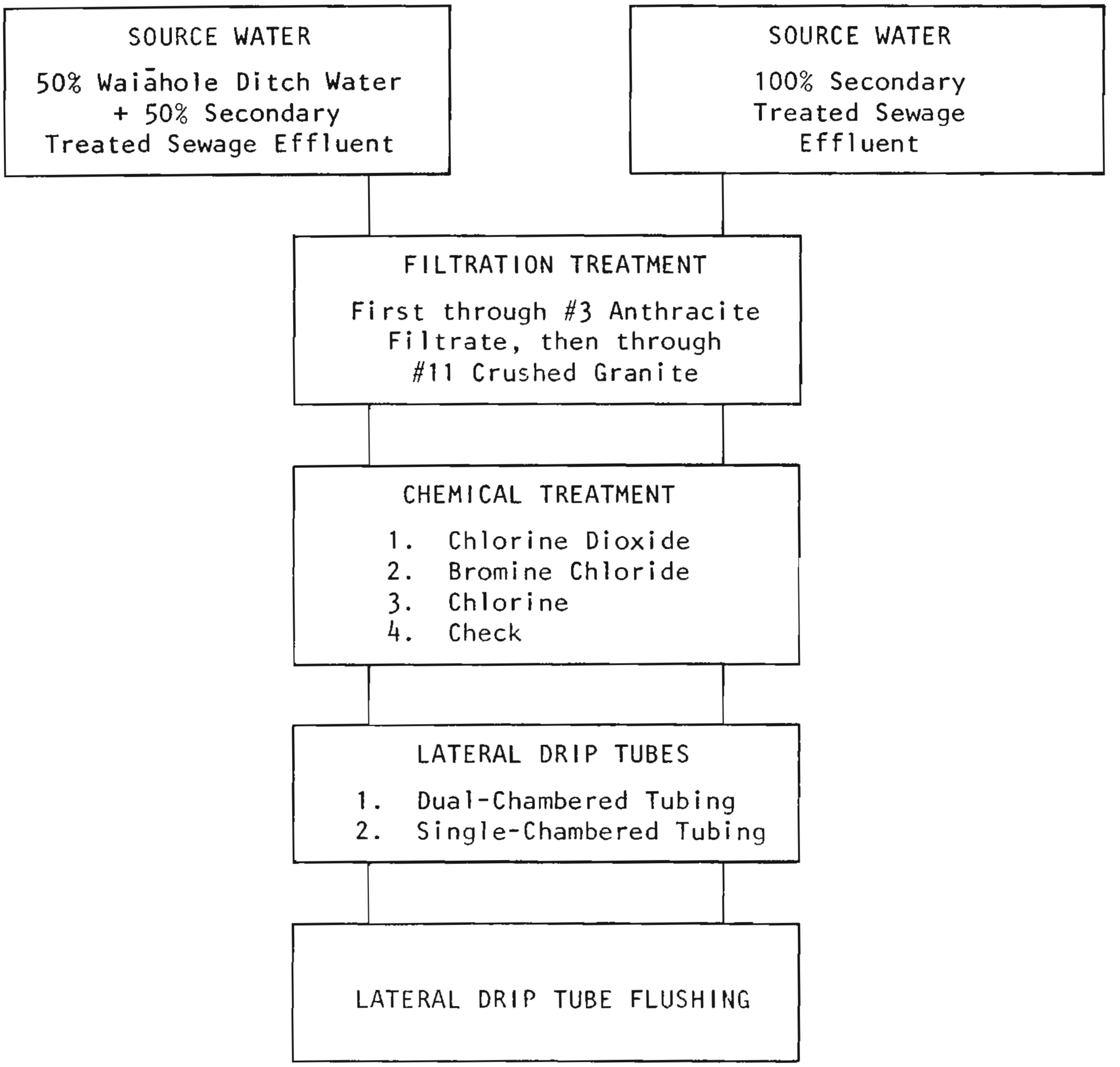


FIGURE 2. SCHEMATIC FLOW DIAGRAM OF MILILANI STP, O'AHU, HAWAI'I



SOURCE: The Experiment Station, Engineering Dept., HSPA, Honolulu, Hawai'i.

FIGURE 3. POSTTREATMENT OF MILILANI SEWAGE TREATMENT PLANT EFFLUENT FOR DRIP-IRRIGATION APPLICATION

of the Mililani STP process tanks will be used in this simulation of the Five-Fingers Reservoir of Oahu Sugar Company. This latter test will simulate the potential increase in suspended solids due to algal growth in ponded effluent. The algal growth potential (AGP) has been demonstrated under laboratory conditions (App. E). All experimental work is done on the Mililani STP grounds in the area noted in Figure 1. The tube farm layout is shown in Figure 4, and hydraulic design data are in Appendix B.

Each of the above flows is given chemical treatment by chlorination, bromine chloride, or chlorine dioxide, initially at a dosage equivalent to a 10 mg/ℓ total chlorine residual at the end of the tube line. Dosages can be varied to determine the most desirable level, i.e., the level that yields the least plugging of the drip line. A check or control will be run with no chemical treatment. Each of these treatments is applied through Anjac double- or single-chamber tubing (Table 1). Treatment efficiency is determined on the basis of drip-tube plugging; the rows of tubes are visually surveyed and flow fountains from each orifice are counted as flowing, half-plugged or plugged. A typical data sheet for this is given in Appendix C.

TABLE 1. HYDRAULIC CHARACTERISTICS OF SINGLE- AND DUAL-CHAMBER TUBING

POLYETHYLENE TUBING	INSIDE DIAMETER (in.)	ORIFICE Diameter	ORIFICE Spacing	OPERATING PRESSURE (psi)
		--------(in.)--------		
Anjac Dual Chamber	0.5	0.019	24* 96†	10
Single Chamber	0.63	0.012	24	4

NOTE: For additional information, see *1972 Reports: Hawaiian Sugar Technologists*, 31st Annual Conf., Nov. 1972 (Vaziri, C.M., and Gibson, W., pp. 18-22).
NOTE: In. x 0.025 40 = m, psi x 6 895 = Pa.
*Inner spacing.
†Outer spacing.

A schedule of operation of the tube farm is found in Figure 5 with timer schematics in Figure 6. The tube farm will be on a 24-hr operation, processing 100% effluent for a half-day and the 50 to 50% dilution for a half-day with an 11-hr operating run, 10-min flush of drip lines, 30 min for chemical treatment, 10 min for filter backwash, and additional time for purging lines.

Chemical treatment dosages were initially developed in the laboratory

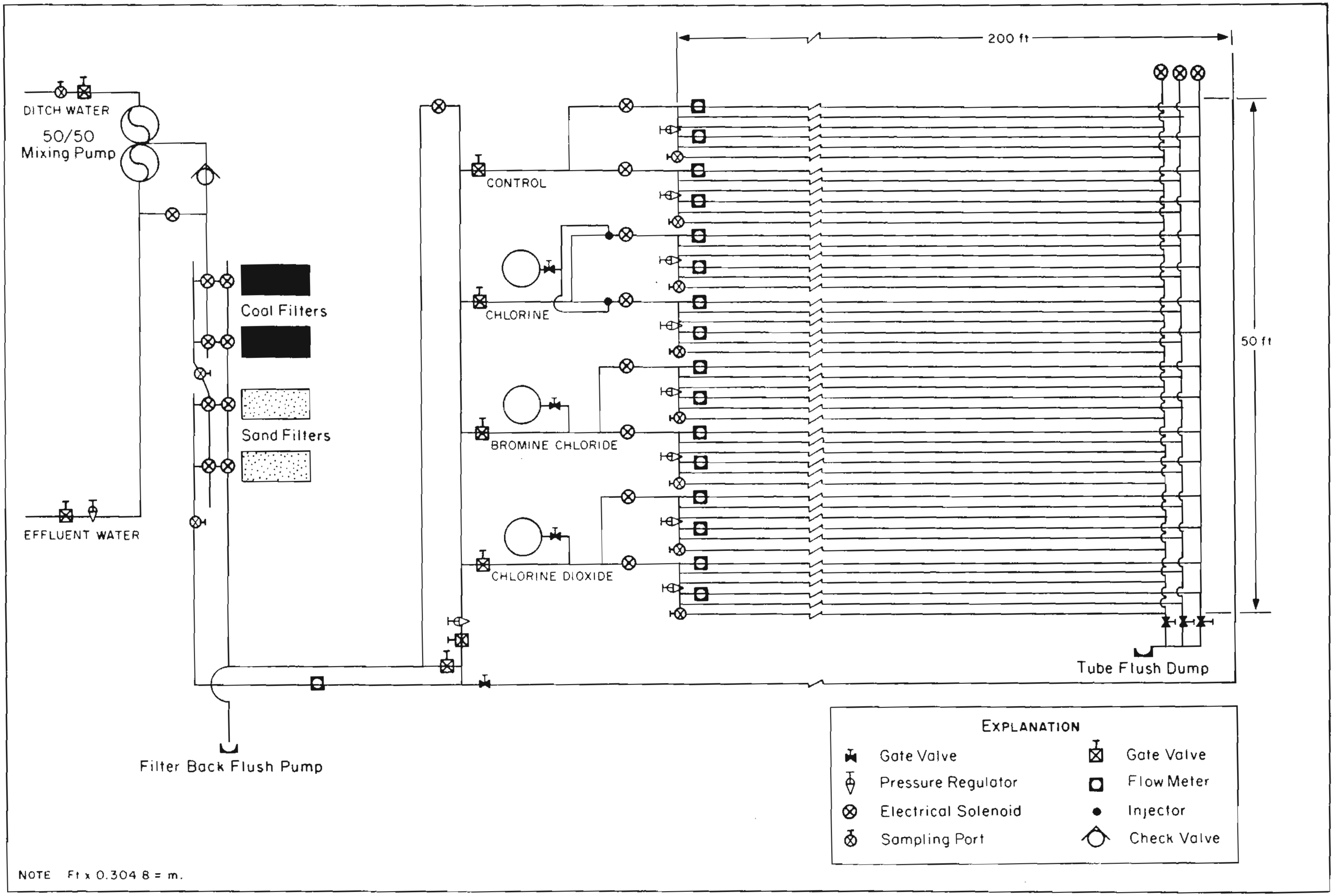


FIGURE 4. TUBE FARM LAYOUT, MILILANI, O'AHU, HAWAI'I

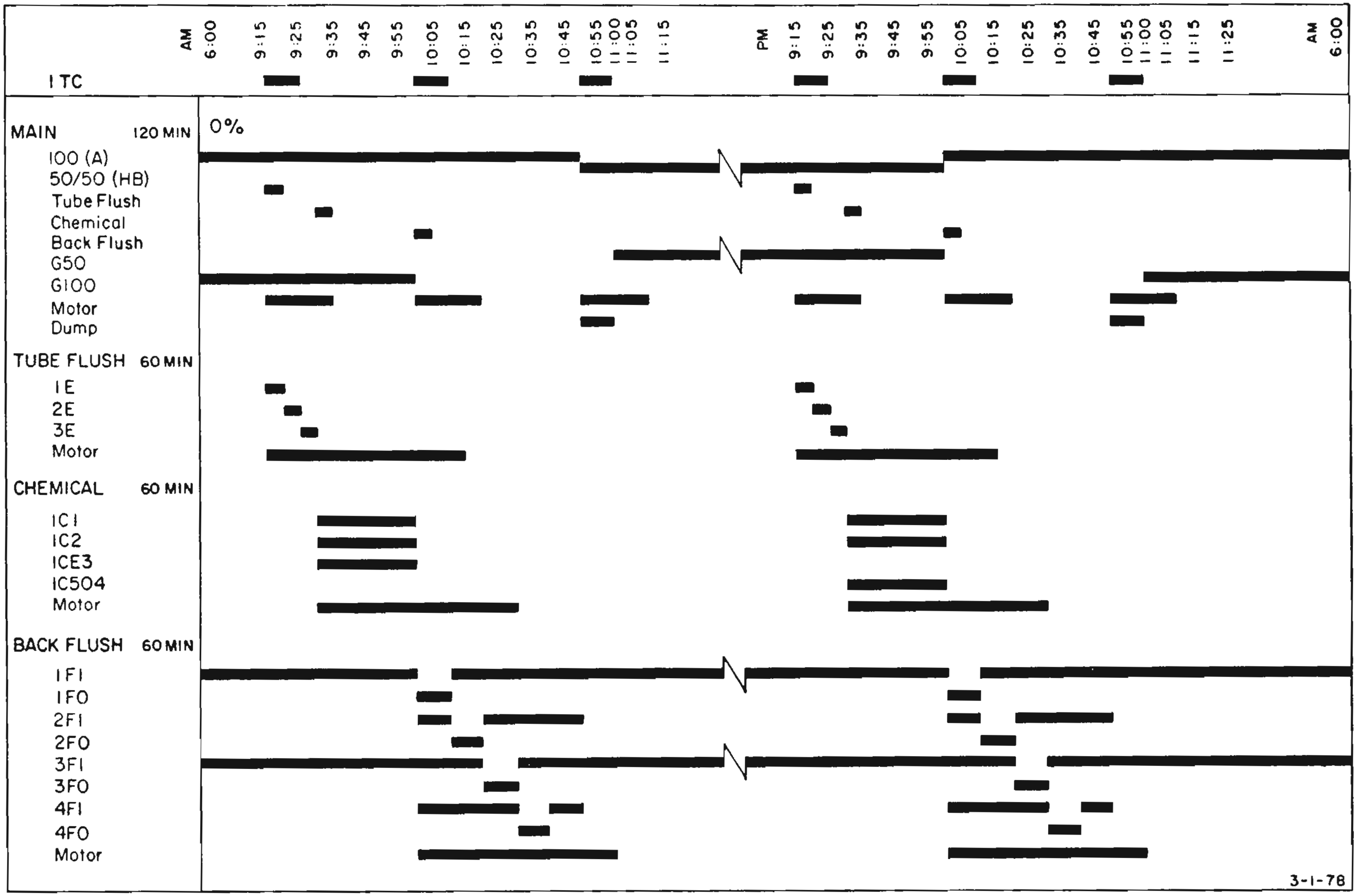


FIGURE 5. OPERATION CONTROL DIAGRAM, MILILANI STP TUBE FARM, O'AHU, HAWAI'I

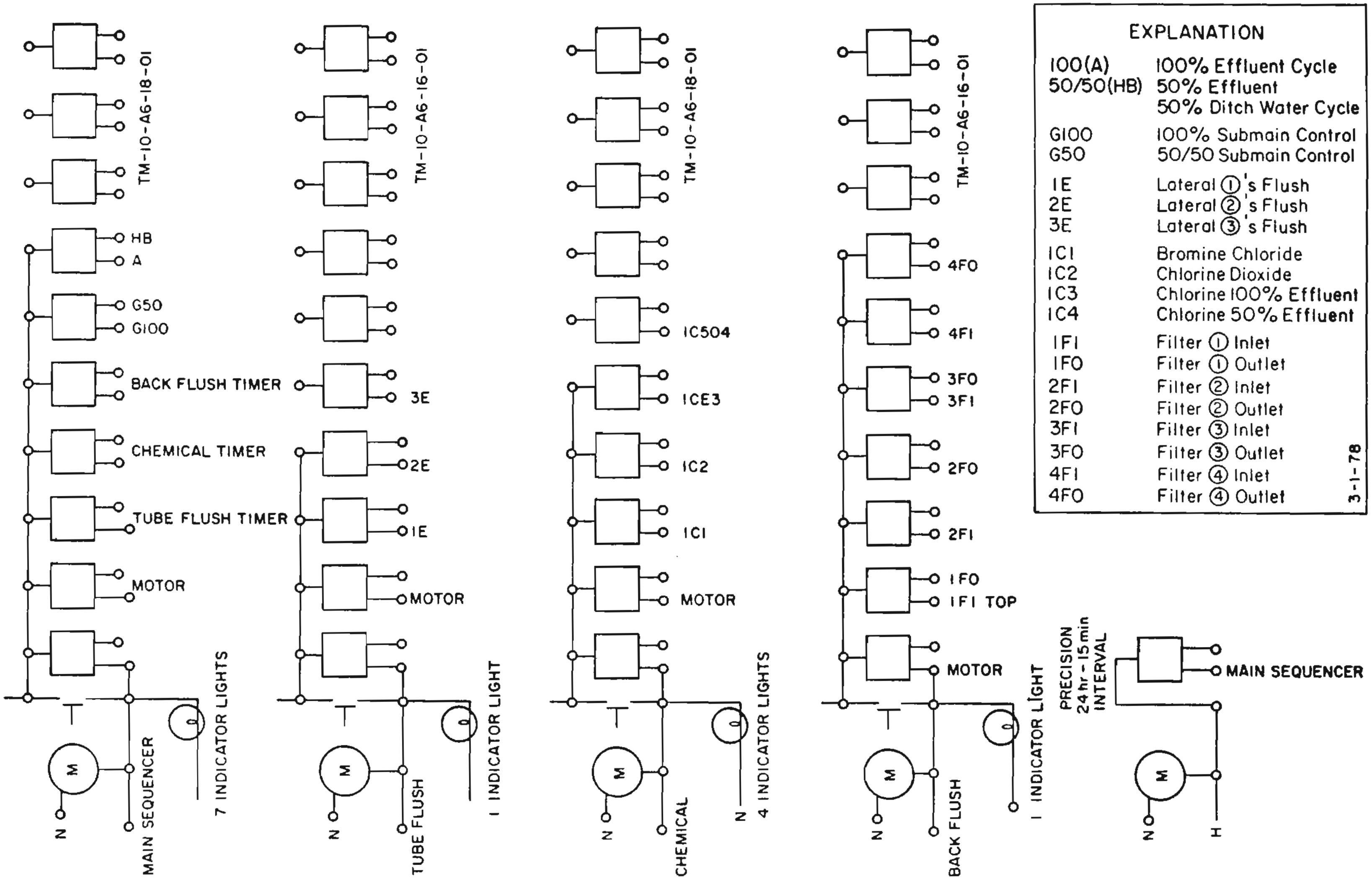


FIGURE 6. TIMER SCHEMATIC OF MILILANI STP TUBE FARM, O'AHU, HAWAI'I

with batch tests on chlorinated effluent for bromine chloride and chlorine dioxide, then adjusted in the field. Dosages applied in the start-up of the tube farm are 1 mg/ℓ BrCl and 2.5 mg/ℓ ClO_2. The chlorine application is 0.45 kg (1 lb)/24-hr or about 10 mg/ℓ. Each chemical is applied by means of a feeder pump, chlorine and bromine chloride (supplied by Dow Chemical Co.) from gas cylinders, and chlorine dioxide in solution form supplied by Hawaiian Aqua Products.

The Waiāhole Ditch water is passed through a 60-mesh screen prior to dilution and filtration with the secondary effluent. The filtration is done in two steps: a coarse filtration through No. 3 anthracite and a fine filtration through No. 11 crushed granite. The filters are pressure filters reconstructed to fit pilot plant size and operated at 0.001 to 0.003 $m^3/s/m^2$ (2-4 gpm/ft^2). The filters and tube farm are shown in Plate 1.

The effluent used to feed the tube farm systems is taken from the Mililani STP chlorination tank.

Hydraulics Testing

The primary purpose of the hydraulics testing is to study the effects of plugging on the hydraulics of drip irrigation lateral line emitter flow. This is being accomplished in two steps. The first step is the laboratory testing and theoretical calculation of the effects of plugging on drip irrigation lateral line hydraulics. The second step is the field installation of the lateral lines and the monitoring of the plugging vs. the flow-rate relationship. The following is a more concise summary of the hydraulic testing.

The University of Hawaii Department of Agricultural Engineering has developed a drip irrigation hydraulic testing facility (Plate 2). With this facility the inflow and outflow hydraulics of a drip irrigation lateral line can be controlled to simulate long lateral lines laid on various slopes. In addition the individual emitter flows can be collected to determine the emitter flow variation.

The test was designed to measure the flow and head loss for different percentages of plugging. At least three tubes of both types, single- and dual-chamber tubing, are being tested at each of three pressures, 20 685, 41 370, and 82 740 Pa (3, 6, and 12 psi). Plugging is simulated by simply filling the orifices at regular intervals with glue. The data are then

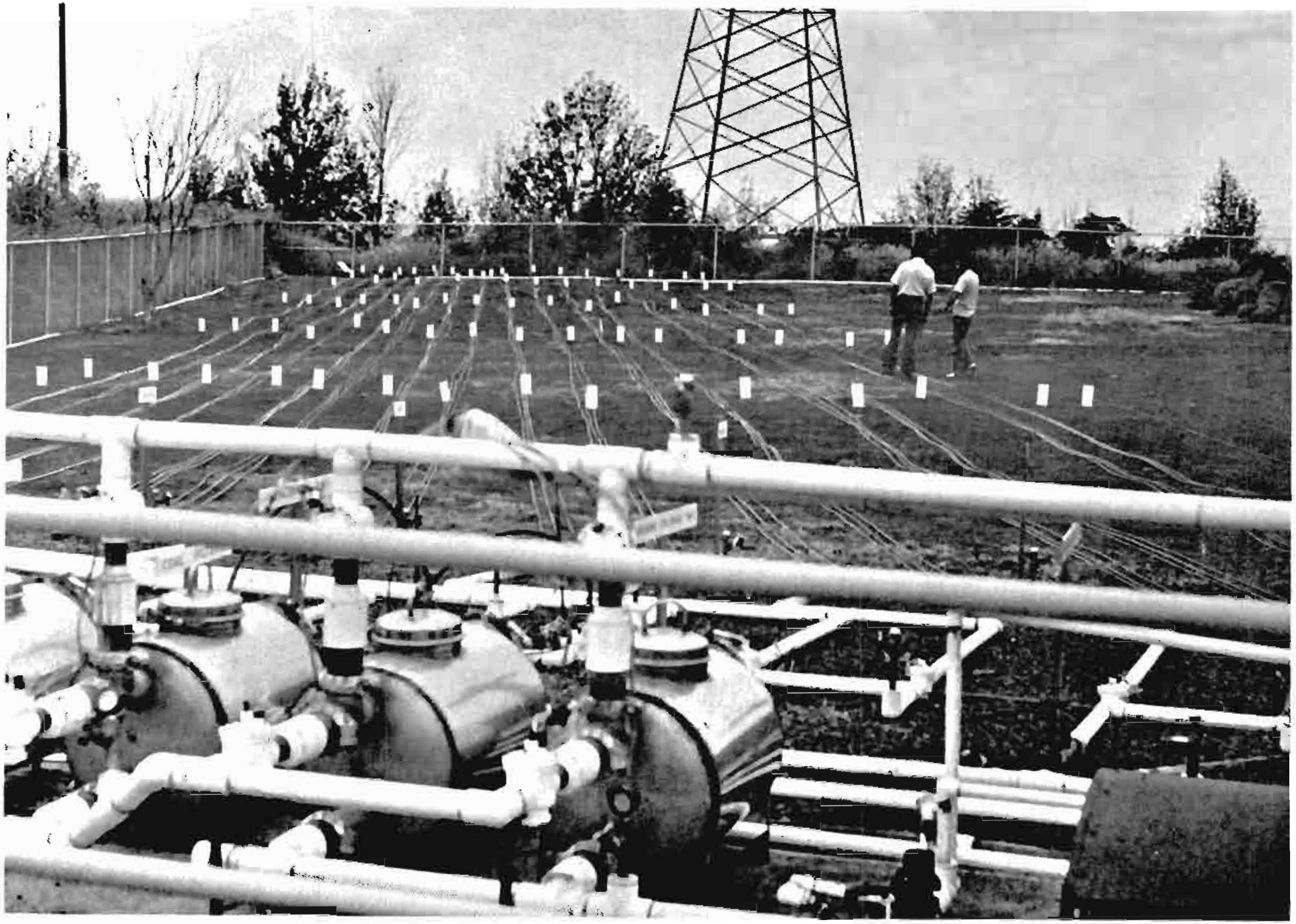
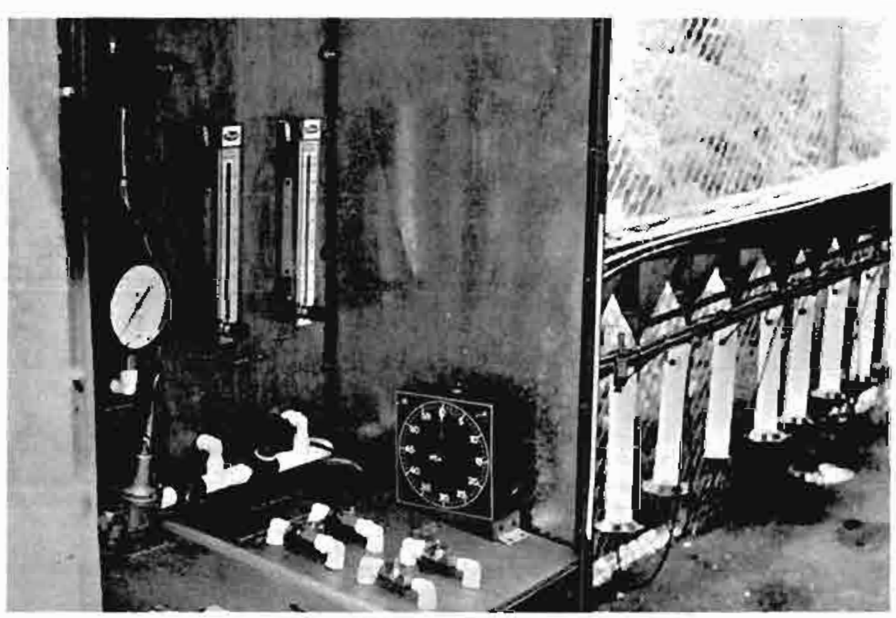


PLATE 1. FILTERS AND TUBE FARM INSTALLATION, MILILANI STP, O'AHU, HAWAI'I

A. HYDRAULIC TEST STAND



B. TEST STAND CONTROLS

PLATE 2. HYDRAULIC TEST STAND AND CONTROLS, MILILANI STP, O'AHU, HAWAI'I

collected and plotted as percent flow vs. percent plugging as shown in Figure 7. The smooth curves shown are the hypothetical curves for single- and dual-chamber tubing.

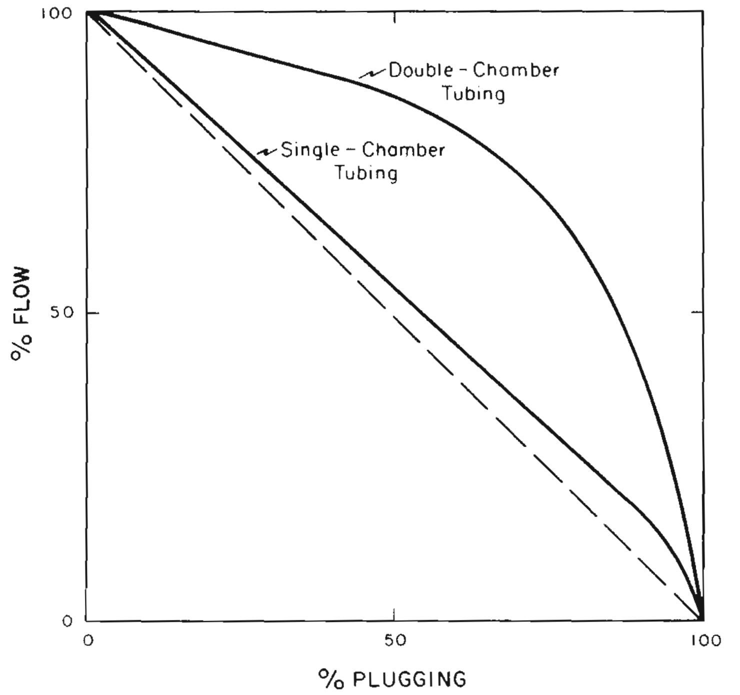


FIGURE 7. HYPOTHETICAL EFFECTS OF PLUGGING ON FLOW

The field installation relating to this hydraulic testing requires 16 volumetric flow meters. The meters are attached to one single-chamber and one dual-chamber lateral line for each of the 8 submains. Using the field data collected, the actual percent flow vs. actual percent plugging curves will be developed.

Water Quality

To assess the quality of the STP effluent and Waiāhole Ditch water used, samples were collected on a weekly basis from three locations: (1) the effluent holding reservoir used in the Phase II-A dilution study (Lau et al. 1977) of the same project, (2) the ditch water holding reservoir also used in the dilution study, and (3) the chlorination basin of the Mililani STP. Sources 2 and 3 are the ones used as input to the posttreatment system.

The secondary sewage effluent is pumped through a 0.1-m (4-in.) PVC pipe from the Mililani STP for approximately 1 609 m (1 mile) to the effluent reservoir, against a static head of 21.6 m (71 ft). The butyl rubber-lined effluent reservoir, located approximately 122 m (400 ft) from the test plots in the OSC Field No. 246, has a depth of 2.6 m (8.5 ft), a volume of 423 m^3 (14,950 ft^3). The ditch water reservoir, with a capacity of 810 m^3 (28,600 ft^3) at a depth of 3.3 m (10.75 ft), is located adjacent to the effluent reservoir. The ditch water reservoir, which draws its water by gravity from the nearby Waiāhole Ditch, has approximately the same hydraulic characteristics as the effluent reservoir. A schematic layout of the two reservoirs and piping system is shown in Figure 8.

At both reservoirs the sample was taken at about 0.9 m (3 ft) from the water's edge and about 0.3 m (1 ft) below the water surface. At the chlorination basin the sample was taken adjacent to the effluent overflow weir. All samples were grab samples. A fourth sample consisting of a 50 to 50 volumetric mix of reservoir effluent and ditch water was prepared in the laboratory.

At the time of sample collection, the chlorine residual of the collected sample was determined with a Hach field kit utilizing the orthotolidine method. A dechlorinating agent, sodium thiosulfate, was added to the sample to remove chlorine residuals. All samples used for bacteriological analysis were collected in presterilized plastic containers.

All collected samples were transported unrefrigerated to the University of Hawaii Water Resources Research Center laboratory. Whenever possible, analysis commenced within 2 hr from the time of collection. Otherwise the samples were refrigerated at 5°C with analysis commencing within 24 hr from the time of collection. All analyses were performed in accordance with *Standard methods* (APHA, AWWA, WPCF 1976).

Samples were also collected for Coulter Counter analysis to determine the sizes and distributions for particles less than 50μ in diameter. This was considered to be especially useful to study the efficiency of the filter system or the probability of plugging due to water-borne particles.

RESULTS

Because the present report is an interim progress report, it is not feasible at this time to fully integrate the results of the separate segments

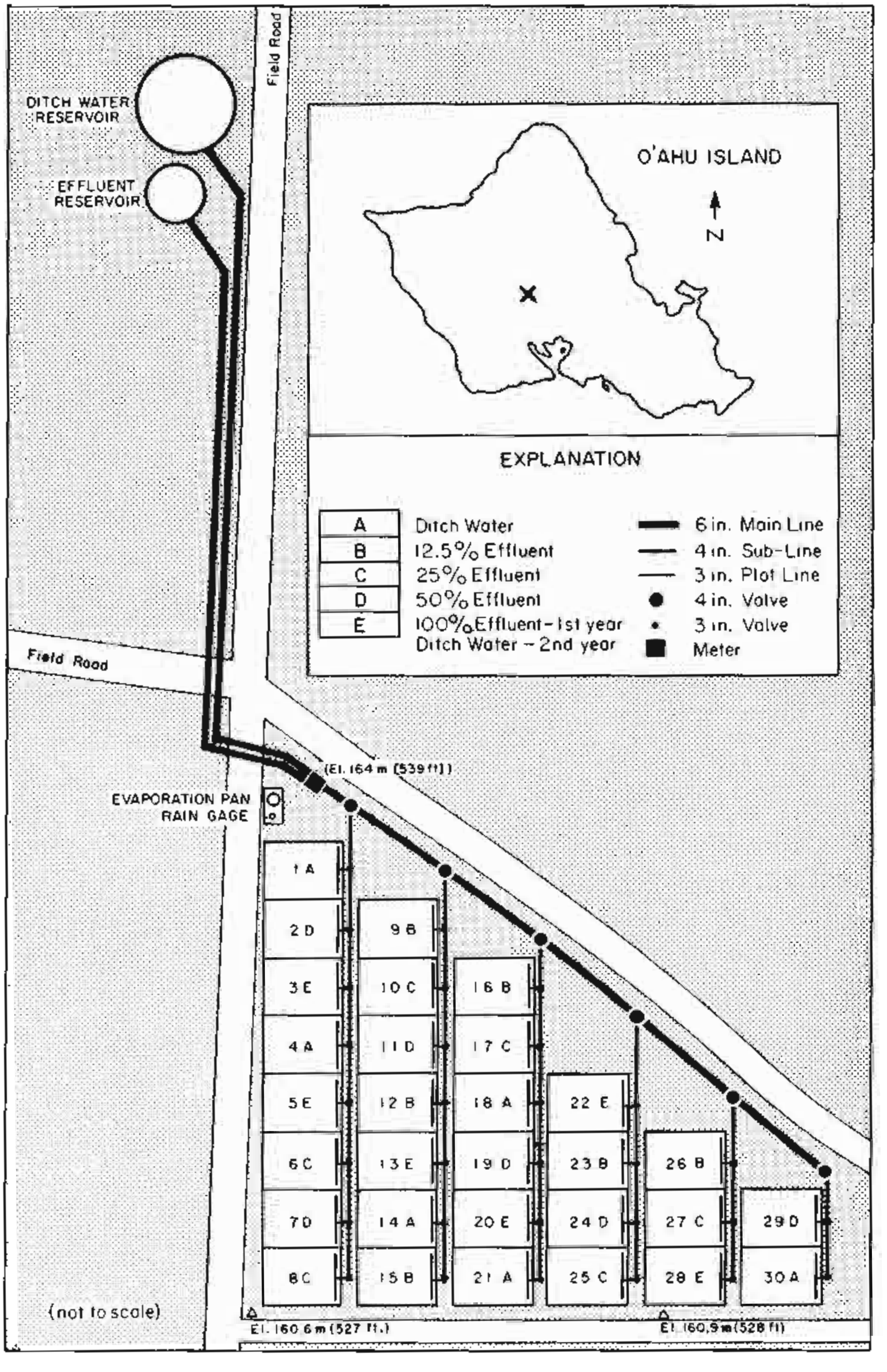


FIGURE 8. SCHEMATIC LAYOUT OF RESERVOIR AND TEST PLOTS, OSC FIELD NO. 246

of the project. Thus, the results produced for this report will be categorized into four areas: (1) Reuse Bibliography, (2) Water Quality Data, (3) Hydraulic Test Stand Data, and (4) Virus Studies.

Reuse Bibliography

A review of literature was undertaken. Specific topics include drip irrigation clogging or plugging, crop response, fertilization, filtration, soil physics, and water quality. The bibliography was mainly gathered from sources such as (1) The Drip Irrigation Archive and Information Center, Bio-Agricultural Library, University of California, Riverside; (2) The Famulus Galley Program for Trickle Irrigation Bibliography, U.S. Water Conservation Laboratory, Phoenix, Arizona; (3) *The Annotated Bibliography on Trickle Irrigation*, Environmental Resources Center, Colorado State University, Fort Collins, Colorado; and (4) Irrigation Reference bulletins, The Hawaiian Sugar Planters' Association, Aiea, Hawai'i. From these sources the pertinent publications were selected and filed, and this information can be made available for dissemination. The most pertinent references are listed below with annotations.

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Aljibury, F.K.; Gerdts, M.; Lang, A.; Huntamer, J.; and Levitt, G. 1974. Performance of plants with drip irrigation. *Proc. 2d Intl. Drip Irrigation Congress*, pp. 497-502, Dept. of Soil Science and Agricultural Engineering, University of California, Riverside.

Well water used with 330 ppm total dissolved solids and treated weekly with 1 ppm copper sulfate to prevent algal buildup in the trickle lines. Keywords: Clogging, trickle, algae, copper.

Avnimelech, Y. and Nevo, Z. 1964. Biological clogging of sands. *Soil Sci.* 93:222-26.

Linear correlation found between polyuronide concentration in sand extent of clogging. Decomposition rate of organic matter affects clogging in that difficult to decompose materials caused only slight clogging. High C:N ratios induced long-lasting clogging, whereas low C:N ratios caused clogging for only a short period. Organic material used consisted of casein, sawdust, sewage sludge, alfalfa meal, straw, barley meal, and starch. Keywords: Clogging, organic matter, trickle.

Bester, D.H.; Lotter, D.C.; and Veldman, G.H. 1974. Drip irrigation on citrus. *Proc. 2d Intl. Drip Irrigation Congress*, pp. 58-63, Dept. of Soil Science and Agricultural Engineering, University of California, Riverside.

After water is started in the system, fertilizer is injected, followed by untreated water to flush the lines. Water quality of 500 ppm TDS.

Used urea, monosodium phosphate, and potassium chloride. In one instance, added electrolyte caused sedimentation in turbid water, and flakes in the pipeline caused some clogging. Precipitation with phosphate occurred with well water high in magnesium. Tested various types of emitters and settled on micro-tube type with 0.64- and 0.90-mm diam openings. Well water screened with 80-mesh opening. Surface water with fine clay particles presented problem a year after use. Flaking of clay layered in pipes after drying caused blockages. Soluble salts of well water did not cause problems. Keywords: Clogging, trickle, fertilizer.

Bowell, M. 1975. Kekaha drip irrigation analysis. Irrig. Ref. No. 75-17, The Experiment Station, Hawaiian Sugar Planters' Association, Aiea, Hawai'i.

Collection of relevant data on Kekaha Sugar Co. drip irrigation system. Relatively low (6%) plugging was noted.

Bui, U. 1974. Rate of orifice plugging for single film versus extruded tube using water treated by sand filter and 120-mesh wire screen. Irrig. Ref. No. 74-01, The Experiment Station, Hawaiian Sugar Planters' Association, Aiea, Hawai'i.

Generally, drip lines fed only by sand-filtered water had less plugging than drip lines fed only by water filtered through a 120-mesh wire screen. Plugging in film tubes was lower than that in extruded tubes; increased pressure expanded and effectively unplugged tubes.

Chambers, C.W., and Clarke, N.A. 1966. Control of bacteria in nondomestic water supplies. *Adv. Appl. Microbiol.* 8:105-39.

Presents source and type of bacterial contamination in water. High degree of microbial activity in filter beds and exchange units caused by retention of particulates on the filter materials. Dead ends in water-distribution systems are prime areas for microbial development. High sediment accumulation increases chlorine depletion. Rubber can be attached by bacteria, physical control by (1) temperature (pasteurization at 143°F for 30 min or 161°F for 15 s), (2) filtration and flocculation, (3) ultraviolet light, and (4) chemical germicide (phenols, heavy metals, halogens, ozone, quaternary ammonium compounds). Extensive discussion of chlorination. Chlorination of wells may improve production. Keywords: Chlorine, clogging, bactericide, filter.

Characklis, W.G. 1973. Attached microbial growth. II. Frictional resistance due to microbial slime. *Water Res.* 7:1249-58.

Review article giving case histories of sliming problems in pipelines. Significant decrease in flow rates can occur with the buildup of mucilaginous material on the pipe. Residual organic matter in the slime, predominantly polysaccharide, with "black soot" consisting of iron and manganese oxide absorbed in the polysaccharide material. Calcium treatment tried as a remedial treatment due to its "hardening" effect on polysaccharide. Chlorine used as bactericide and because it also reacts with the polysaccharide to remove slime materials. Where high chlorine demand is present, acrolein is also a broad-spectrum bactericide and slimicide. Recent research suggests that the hypochlorite reacts with the slime polysaccharides, solubilizing the organic material. Keywords: Clogging, bactericide, chlorination, slime.

Cleasby, J.L. 1969. Approaches to a filterability index for granular filters. *J. Am. Water Works Assoc.* 61:373-81.

Need for a simple, standardized filterability test that can be applied to all suspension and that can be used to predict filter performance. Filterability index from membrane or thin filters not applicable to depth filters. Filterability index (FI) for water similar to filter performance index suggested: FI = $T \times E$/head loss, where T = impediment modulus at time, $d = (C_1 - C_2/C_1)/L_2 - L_1$, where C_1 and C_2 are suspension concentrations entering and leaving a layer, L_1 and L_2 are depths from the top of the filter to the respective sampling depths where C_1 and C_2 are measured. E = specific deposit accumulated in a particular layer up to, and particular time from, the beginning of the run, and head loss = head loss increase for the same layer and time interval. Keywords: Clogging, filtration.

______, and Woods, C.F. 1975. Intermixing of dual media and multimedia granular filters. *J. Am. Water Works Assoc.* 67:197-203.

Literature review indicates that the mixed-media filters give longer filter cycles and, in some cases, better filtrate quality than single-media sand filters. Intermixing studied with anthracitic coal, silica sand, and garnet sand. Present models for predicting intermixing not entirely satisfactory. Keywords: Clogging, filtration.

Coffman, C.R., and Godley, G.L. 1971. Low cost filter for trickle irrigation. *J. Agr. Western Australia* 12(8):198-99.

Describes construction of an 8-in. body by 1½-in. filter element with capacity of up to 80 gpm. Keywords: Clogging, filter, trickle.

Craft, T.F. 1966. Review of rapid sand-filtration theory. *J. Am. Water Works Assoc.* 53:428-38.

Reviews sand filtration from the standpoint of flow of the water through the sand medium, the removal of suspended material, and backwashing. Flow treated in terms of hydraulic theory, e.g., flow through porous medium; particle removal through direct sieving, sedimentation, centrifugal collection, Brownian movement, contact through convergence of fluid streamlines, diffusion caused by suspended-particle concentration gradient, Van der Waals effect, and electrokinetic effects; and backwashing occurring through fluidization when the flow of water is just sufficient to raise the sand grains. Sand filtration still considered an art rather than a science. Keywords: Clogging, filtration.

Davis, K.R.; Pugh, W.J.; and Davis, S. 1975. Chlorine effects on drip irrigation. *Proc. Intl. Drip Irrigation Assoc.*, pp. 92-97.

One-year study showed that chlorine (<0.2 and 0.9 ppm) was effective in preventing clogging of two types of subsurface tubing applicators (Viaflo and Anjac). The low chlorine concentration was about as effective as the high treatment rate. The single tube (Kirkhall) applicator did not have the clogging as did other double tubes, even without chlorination. Keywords: Clogging, trickle, chlorination.

Eliassen, R. 1941. Clogging of rapid sand filters. *J. Am. Water Works Assoc.* 33:926-42.

Experimental results show the time rate of removal of solid matter in different layers of the filter media (sand) and variation or removal during a run. Maximum removal of floc is at the top region of the filter for a considerable portion of a run; and as the upper pores become clogged, maximum removal is at the lower region of the filter. Floc used came from raw water (50 ppm total solids) treated with ferric sulfate and lime and solids accumulated based on iron content. Keywords: Clogging, filter.

Ford, H.W. 1976. Controlling slimes of sulfur bacteria in drip irrigation systems. *Hort. Sci.* 11:133-35.

White slime bacterial growth could be prevented by keeping lines full of water and free of oxygen between irrigation. Intermittent hypochlorination to 0.5-ppm chlorine level prevented sulfur bacterial growth. Lowering pH to 6.4 with sulfur dioxide (90 ppm) or 6.0 with HCl inhibited bacterial growth. Nonsulfur filamentous *Thiothrix nivea* was predominant species over *Beggiatoa*. Cost intermittent chlorination (1 hr before system shutdown) less than SO_2 or HCl treatments. Free chlorine of 0.5 ppm found 30 min after shutdown. Keywords: Trickle, clogging, slime.

______, and Tucker, D.P.H. 1974. Clogging of drip systems from metabolic products of iron and sulfur bacteria. *Proc. 2d Intl. Drip Irrigation Congress*, Dept. of Soil Science and Agricultural Engineering, University of California, Riverside.

Iron and sulfur bacteria were studied. It was found that 0.5 to 1 ppm iron or sulfur content can cause problems. A chlorine injection yielding a residual concentration of 0.5 ppm hypochlorous acid inhibited iron and sulfur bacterial growth.

______. 1975. Blockages of drip irrigation filters and emitters by iron-sulfur-bacterial products. *Hort. Sci.* 10:62-64.

Serious clogging caused by slime from filamentous sulfur bacteria (*Thiothrix nivea* and *Beggiatoa*), also from Fe deposits of filamentous gelatinous ochre from iron bacteria (*Gallionella ferruginea*, *Leptothrix ochracea*, *Toxothrix trichogenes*, and other nonidentifiable bacterial masses). Sulfur slime in tubing and emitters predominantly sulfur from oxidation of H_2S. Water free of air had no *Thiothrix*. Continuous irrigation eliminated sulfur slime. Iron deposits caused by oxidation of Fe^{++} or H_2S. Surface water with algae-clogged filters. Sand filters used to remove particulate matter, algae and FeS, but do not remove soluble Fe, complexed Fe, H_2S or tannin-like compounds. Tested use of NaOCl, Cl_2, H_2O_2, and pH lowering. Keywords: Clogging, bacteria, iron.

Gibson, W. 1976. Hydraulics, mechanics and economics of subsurface and drip irrigation of Hawaiian sugar cane. *Intl. Sugar J.* 78:40-44.

Orifice plugging the greatest single problem for drip irrigation. Extensive research being conducted on interdisciplinary project to solve the clogging problem. Work being done on measuring the amount and distribution of suspended particles, screen and sand filtration, particle aggregation by microbial activity, and flushing. Plugging caused by various factors, such as algal growth at the orifice, mats of aggregated solids, and salt crystallization, which occur after the flow of water has been reduced. Work being done with single- and dual-chamber trickle systems. Keywords: Trickle, clogging.

______, and McElhoe, B.A. 1974. The plugging problem—A progress report. Irrig. Rep. 60, The Experiment Station, Hawaiian Sugar Planters' Association, Aiea, Hawai'i.

Kunia tube farm experiment report indicates that under proper filtering, flushing daily, and 10 ppm 20-min daily chlorination, plugging is regularly under 10%. Includes table.

______, and Bui, U. 1975. Flushing valve for drip irrigation tubes. *Proc. Intl. Drip Irrigation Assoc.*, ed. Sterling Davis, pp. 131-36.

Development of an automatic flushing valve which stimulates the manual opening of lateral ends for free-flow flushing of the tubing. Chlorine needed to keep solids suspended so they can be flushed out. Minimum water velocity of 1 fps desirable for good flushing. Keywords: Clogging, trickle, chlorination.

Gilbert, R.G.; Nakayama, F.S.; and Bucks, D.A. 1977. "Trickle irrigation: Prevention of clogging." Paper presented to Amer. Soc. Agr. Engrs. Annual Meeting at North Caroline State University, Raleigh.

Clogging found to be directly related to the quality of irrigation water, e.g., suspended load, chemical composition, and microbial activity; various treatments tested under similar conditions. Adequate water filtration a primary requirement for reliable emitter operation, with accepted chemical treatment for biological control.

Grobbelaar, H.L., and Lourens, F. 1974. Fertilizer applications with drip irrigation. *Proc. 2d Intl. Drip Irrigation Congress*, p. 411-15, Dept. of Soil Science and Agricultural Engineering, University of California, Riverside.

Initial applications of urea, monoammonium phosphate, and potassium nitrate caused high degree of blockage. Water high in calcium and magnesium caused problems with phosphate fertilizer. Flocculation with potassium salts when solids settled out in the drippers where water velocity is lowest. Increased flow velocity by changing from 2- to 4-ℓ/hr emitters. Improved filtration capacity. Decreased pH of fertilizer to about 2 eliminated danger of fertilizer blockage. Keywords: Clogging, fertilizer, pH, acid.

Hill, R.D. 1964. Characteristics of slow sand filters for pond water filtration. *Trans. Amer. Soc. Agr. Engrs.* 7:294.

Used sodium hypochlorite (1.8-8 ppm) and brom-chlor-dimenthyl bydantoin (1-2 ppm) as disinfectants. Disinfection of raw water prior to the slow sand filter resulted in longer filter runs and larger volumes of water treated per run, but did not improve the filtration. Keywords: Trickle, chlorination, filtration, clogging.

Hilton, H.W., and McElhoe, B.A. 1974. Chemical treatment of drip irrigation water. Tech. Supp. No. 2 to Irrig. Rep. 52, The Experiment Station, Hawaiian Sugar Planters' Association, Aiea, Hawaii.

In an 80-day test, comparing various chemicals confirmed that chlorine prevents plugging. Single-wall tubing was significantly better, with respect to plugging, than bi-wall under similar testing conditions.

Jackson, L.A., and Mayhan, W.A. 1951. Chlorination maintains supply line capacity. *Water & Sew. Works*, pp. 248-52.

Carrying capacity of pipe line reduced 29% in 1 yr by organic growth. Breakpoint chlorination improved flow over period of 9 yr. Intermittent chlorination with high dosages tried later maintained flow at a low cost. Keywords: Chlorination, trickle.

Kenworthy, A.L., and Kesner, C. 1974. Trickle irrigation in Michigan orchards: Controlling rate of flow with flow regulating valves and microtubes. *Proc. 2d Intl. Drip Irrigation Congress*, pp. 275-80, Dept. of Soil Science and Agricultural Engineering, University of California, Riverside.

Microtube clogging can be caused by improperly filtered water, precipitation of calcium and iron salts, drawing-in of soil caused by self-draining feature of the system. Sodium metaphosphate injection can prevent and/or remove salt. Keywords: Clogging, trickle, polyphosphate.

Nevo, Z., and Mitchell, R. 1967. Factors affecting biological clogging of sand associated with ground water recharge. *Water Res.* 1:231-36.

Clogging of sand beds by microbial polysaccharides during groundwater recharge of waste water appears to be correlated with a decline in measured potential in the sand, which inhibits degradation of the polysaccharides. Polysaccharide decomposition was inhibited at temperatures below 20°C and polysaccharide synthesis was slow. Between 20 and 30°C both production and degradation increased with increasing temperature; however, at 37°C little polysaccharide was produced, while decomposition continued. Keywords: Trickle, clogging.

Rolston, D.E.; Rauschkolb, R.S.; Miller, R.J.; Carlton, A.B.; and Burau, R.G. 1975. Application of phosphorus to drip irrigation crops. *Proc. Int'l. Drip Irrigation Assoc.*, pp. 108-12.

Glycerolphosphate and phosphoric acid applied by trickle system. Movement of the former higher than the latter in the soil, but the difference may not be of significance as far as the plant is concerned. Suggests the use of other acids (sulfuric or hydrochloric) following phosphoric acid to avoid emitter blockage. Keywords: Trickle, phosphorus, clogging.

______; Rauschkolb, R.S.; and Hoffman, D.L. 1974. Use of glycerophosphate for fertilization through trickle irrigation systems. *Proc. 2d Intl. Drip Irrigation Congress*, pp. 416-21.

Soluble organic phosphate (such as glycerolphosphate) applied by drip irrigation as a promising alternative to slightly soluble inorganic compounds. Glycerolphosphate moved to a greater depth in soil than the inorganic phosphate. Keywords: Clogging, phosphate, trickle.

Sharp, R.B. 1956. The growth of mucus-forming bacteria in drip-feed irrigation lines. *J. Agr. Engr. Res.* pp. 83-88.

In combination with nutrient solution, mucus growth was very heavy in PVC and rubber tubing and only slight in polyethylene tubing for 14- to 28-day exposure periods. Gaseous chlorine, bromine, and bromine water did not disperse the mucus; sodium hypochlorite (10-14% chlorine) dispersed the mucus in 15 min at room temperature. Chlorine at 0.5 ppm prevents mucus growth. Concentration of chlorine decreased progressively along the line to 0.02 ppm at the end. Silver-coated sand and silver wire controlled mucus growth under laboratory conditions. Keywords: Clogging, bactericide, chlorination.

Shearer, M.N. 1975. Removing suspended solids from irrigation water *Proc. Intl. Drip Irrigation Assoc.*, pp. 124-30.

Describes the use of a continuously cleaned 200-mesh stainless steel screen. Scheduled flushing prevented plugging problems, even with the passing of 50- and 2-μ particles past the screen and sand filters. Keywords: Clogging, filtration, trickle.

Water Quality Data

Water quality data for the four sets of samples, covering the period 11 November 1977 to 28 June 1978, are tabulated in Tables 2 to 5. The range, mean, and median values for each water quality parameter of each sample are compiled in Table 6.

The STP chlorination tank effluent that is fed to the posttreatment system and the tube farm has a median suspended solids concentration about 50% higher than the reservoir ditch water; however, the total organic carbon median concentration in the STP effluent is about two times higher and the volatile suspended solids median concentration is about six times higher than that in the reservoir ditch water. On the other hand, the microbiological quality of the STP effluent is generally better than that of the reservoir ditch water.

The effluent sample at the treatment plant is relatively consistent over time as compared to the samples at the holding reservoir. The time variations of the samples obtained from both the effluent and ditch water holding reservoirs are affected by the quality of inflow water, the closeness of the sampling time to when the reservoir was filled, climatic conditions (rainfall-runoff), and the location of the sampling site. When water of poor quality is added to the reservoir, the reservoir sample will indicate similar poor conditions.

The elapsed time from reservoir filling to sample collection greatly

TABLE 2. WATER QUALITY OF MILILANI STP EFFLUENT (AT CHLORINATION TANK), O'AHU, HAWAI'I

Date	Chlorine Residual (mg/ℓ Cl)	Total Residue (mg/ℓ)	Suspended Solids	Volatile Suspended Solids	Total Plate Count (10^3 Col./mℓ)*	Total Coliform (No./100 mℓ)	Total Organic Carbon (mg/ℓ C)
			--------(mg/ℓ)--------				
11/22/77	1.1	346	14	10	2.92	2	--
11/29/77	1.1	330	21	--	2.79	0	--
12/06/77	0.6	330	8.5	--	2.40	28	--
12/13/77	1.0	410	6.1	4.9	4.80	0	52.7
12/19/77	0.7	352	30	27	3.10	54	50.7
12/28/77	0.7	376	38	34	5.9	62	45.7
01/04/78	0.7	390	36	32	3.7	0	43.3
01/10/78	0.6	380	54	43	1.6	90	40.0
01/17/78	0.8	398	21	19	4.2	36	43.3
01/25/78	0.8	326	16	14	2.17	4	37.1
02/01/78	0.8	352	16	14	2.12	4	39.1
02/08/78	0.7	376	46	45	1.89	36	84.5
02/15/78	0.8	370	27	23	9.80	550	40.9
02/22/78	2.1	362	24	23	0.31	--	60.1
03/01/78	1.2	346	34	20	0.41	--	60.3
03/06/78	1.2	378	30	25	0.56	28	40.3
03/13/78	2.7	354	36	36	0.59	0	34.0
03/22/78	1.3	356	31	27	1.73	0	52.1
03/29/78	0.7	366	30	26	1.28	30	55.0
04/03/78	1.3	360	22	20	1.05	6	37.4
04/10/78	1.7	354	23	23	0.80	2	65.0
04/17/78	1.7	350	25	25	0.88	2	53.6
04/24/78	2.1	360	23	18	0.34	4	43.5
05/01/78	--	338	22	22	37.60	0	33.2
05/08/78	0.8	422	49	43	2.26	0	83.9
05/15/78	0.8	446	73	65	2.68	0	156.2
05/24/78	2.0	352	24	22	0.94	5	33.3
06/01/78	1.3	372	28	24	1.06	6	39.4
06/07/78	0.7	338	33	27	2.20	9	60.0
06/14/78	1.1	386	45	43	1.39	0	70.3
06/23/78	2.0	472	35	20	0.91	67	73.5
06/28/78	1.9	430	65	55	2.42	18	84.3

*Col. = colonies.

TABLE 3. WATER QUALITY OF MILILANI STP EFFLUENT IN RESERVOIR, O'AHU, HAWAI'I

Date	Chlorine Residual (mg/ℓ Cl)	Total Residue (mg/ℓ)	Suspended Solids	Volatile Suspended Solids	Total Plate Count (10^3 Col. /mℓ)*	Total Coliform (No./100 mℓ)	Total Organic Carbon (mg/ℓ C)	Code†
			--------(mg/ℓ)--------					
12/19/77	0.4	356	47	43	1.22	20	80.2	A
12/28/77	--	350	19	15	2640	3600	28.8	-
01/04/78	--	348	18	18	1030	0	40.7	-
01/10/78	0	336	8.8	7.4	2490	0	43.5	-
01/17/78	0.1	420	20	18	450	8500	53.8	A
01/25/78	0	370	19	18	2340	130	64.0	-
02/01/78	0.3	366	28	26	21600	10	41.6	A
02/08/78	0	364	20	20	3250	12400	85.6	-
02/15/78	0.3	370	20	19	2780	32000	34.9	A
02/22/78	0	206	30	28	3110	--	75.9	-
03/03/78	0	130	6.3	6.2	35	160	30.6	-
03/06/78	0	180	11	5.8	14	0	23.5	-
03/13/78	--	--	--	--	--	--	--	B
03/22/78	0.3	380	20	17	109	5000	49.9	A
03/29/78	--	--	--	--	--	--	--	B
04/03/78	0.5	404	33	29	5.6	290	58.1	A
04/10/78	--	--	--	--	--	--	--	B
04/17/78	0	194	80	52	2780	2500	62.9	C
04/29/78	0	146	34	27	21	0	124.6	-
05/01/78	0	324	17	17	26700	0	27.7	A
05/08/78	--	--	--	--	--	--	--	B
05/15/78	--	--	--	--	--	--	--	B
05/24/78	0	378	113	96	16200	34	139.5	A
06/01/78	0	346	64	55	5400	0	84.1	-
06/07/78	0	348	34	28	21700	0	53.6	A
06/14/78	0	416	29	25	4500	0	45.4	-
06/29/78	0	414	41	34	12000	0	33.2	A

*Col. = colonies.

† A = Reservoir filled within last 3 days.
B = No water in reservoir.
C = Rain diluted sample.

TABLE 4. WATER QUALITY OF WAIĀHOLE DITCH WATER, O'AHU, HAWAI'I

Date	Total Residue	Suspended Solids	Volatile Suspended Solids	Total Plate Count (10^3 Col. /mℓ)*	Total Coliform	Total Organic Carbon	Code†
	(mg/ℓ)				(No./100 mℓ)	(mg/ℓ C)	
11/22/77	138	23	6	1.02	340	--	A
11/29/77	110	11	10	3.80	150	--	-
12/06/77	128	5.0	3.5	1.82	16	--	-
12/13/77	102	3.0	0.8	0.89	240	--	C
12/19/77	264	167	55	63	5200	71.4	A
12/28/77	2242	2040	1850	2100	20000	905.8	D
01/04/78	112	4.4	4.0	175	1080	22.5	-
01/10/78	118	6.8	3.8	48	0	29.8	-
01/17/78	108	18	5	24.8	3300	29.2	A
01/25/78	80	1	0.4	1.4	30	27.4	-
02/01/78	140	28	9	3.7	70	25.1	A
02/08/78	120	3.5	3.2	2.4	132	24.5	-
02/15/78	117	17	3.6	110	0	32.8	A
02/22/78	136	30	11	77	--	33.3	-
03/03/78	104	15	6.5	1.18	160	29.4	-
03/06/78	144	34	4.7	15.3	6300	23.5	A
03/13/78	98	2.4	1.8	1.19	50	9.4	B,C
03/22/78	180	20	11	14.9	11000	39.7	A
03/29/78	104	11	4.25	1.4	0	24.7	-
04/03/78	244	20	1.6	2.3	0	15.5	-
04/10/78	122	21	16	1.27	0	24.3	-
04/17/78	140	28	10	55	0	21.2	-
04/24/78	158	39	4.6	206	0	15.5	-
05/01/78	184	81	12	25	0	21.2	A
05/08/78	112	6.9	2.3	1.66	0	21.9	-
05/15/78	90	2.3	1.1	1.56	0	32.8	-
05/24/78	106	11	1.8	2.46	34	21.1	A
06/01/78	130	3.1	0.8	0.156	14	--	B,C
06/07/78	132	29	11	5.7	2	--	A
06/14/78	144	29	5.8	18.8	0	27.9	A
06/28/78	164	10	3	18.7	108	--	A,E

*Col. = colonies.

†A = Reservoir filled within last 3 days; B = No water in reservoir; C = Sample from concrete channel; D = Eliminate data; E = Sample from tap at STP.

TABLE 5. WATER QUALITY OF 50/50 MIX RESERVOIR EFFLUENT AND WAIĀHOLE DITCH WATER, O'AHU, HAWAI'I

Date	Total Residue	Suspended Solids	Volatile Suspended Solids	Total Plate Count (10^3 Col. /mℓ)*	Total Coliform (No./100 mℓ)	Total Organic Carbon (mg/ℓ C)
	(mg/ℓ)					
12/19/77	302	103	48	45.2	20200	60.6
12/28/77	1352	1024	925	2040	4900	471.3†
01/04/78	224	11	10	550	160	21.4
01/10/78	220	6.6	4.2	1240	40	31.5
01/17/78	242	20	13	263	5500	34.2
01/26/78	230	10	9	1880	160	63.3
02/01/78	248	29	18	950	80	29.2
02/08/78	228	11	11	1550	4400	29.4
02/15/78	240	19	11	2050	5200	33.9
02/22/78	170	33	21	2610	--	55.9
03/03/78	120	11	6.8	28	100	23.4
03/06/78	160	22	4.7	11	4100	15.4
03/22/78	278	49	16	86	1000	39.2
04/03/78	244	20	15	3.3	0	40.3
05/02/78	262	49	16	12200	0	30.8
06/07/78	248	32	21	8860	0	--
06/14/78	282	29	15	1890	0	34.2
06/29/78	292	26	21	4100	2	--

*Col. = colonies.
†Omit.

TABLE 6. SUMMARY DATA OF WATER QUALITY, 11 NOVEMBER 1977 TO 28 JUNE 1978, MILILANI, O'AHU, HAWAI'I

Sample	Chlorine Residual (mg/ℓ Cl)	Total Residual (mg/ℓ)	Suspended Solids (mg/ℓ)	Volatile Suspended Solids (mg/ℓ) [% of Susp. Solids]	Total Plate Count (10^3 Col./mℓ)	Total Coliforms (No./100 mℓ)	Total Organic Carbon (mg/ℓ C)
STP Effluent at Chlorination Basin							
Range	0.6-2.7	326-472	6.1-73	4.9-65	0.31-37.6	0-550	33.2-156.2
Mean	1.2	371	31	28 [90%]	3.34	34	55.6
Median	1.1	361	29	26	2.00	5	50.7
Reservoir Effluent							
Range	0.0-0.5	130-420	6.3-113	5.8-96	1.22-26700	0-32000	23.5-139.5
Mean	0.1	325	32	27 [85%]	5871	3078	58.3
Median	0.0	360	24	23	2710	20	51.7
Reservoir Ditch Water							
Range	--	80-264	1.0-167	0.4-55	0.156-206	0-11000	9.4-71.4
Mean	--	134	23	7.1 [30%]	29.50	973	27.1
Median	--	124	16	4.4	3.75	30	24.1
50/50 Mix Reservoir Effluent and Ditch Water							
Range	--	120-302	6.6-103	4.2-48	3.3-12200	0-20200	15.4-63.3
Mean	--	235	28	15 [54%]	2254	2559	36.2
Median	--	242	22	15	1245	130	33.9

influences the measured water-quality parameter. It has been observed that as the ditch water holding reservoir is being filled, the inflow water is muddy. This muddiness is probably due to the presence of soil and debris picked up by the water as it flowed to the reservoir in unlined channels and to bottom-scour of the unlined reservoir. The suspended solids content at the time of reservoir filling is generally high as depicted in Figure 9. As the ditch water is retained in the reservoir, the suspended material has an opportunity to settle. This results in a decrease in suspended solids during the period following reservoir filling.

Climatic conditions would also affect the quality of the reservoir waters. Wind could blow soil into the reservoir and set up surface currents that could resuspend particles. Rain could wash down soil material from the sides of the reservoir or dilute the water in the reservoir.

Several samples of ditch water were obtained from the lined concrete channel instead of the reservoir. Water from the channel had a suspended solids content of about 3 mg/ℓ, a value considerably lower than the maximum suspended solids content of 167 mg/ℓ measured at the reservoir while it was being filled. This demonstrates that a large amount of solids can be picked up as the water flows in the unlined dirt channel to the holding reservoir. However, after the reservoir water has been retained for about 1 wk, the suspended solids decreases to less than 5 mg/ℓ. Hence, holding the water in the reservoir could result in water with a suspended solids concentration comparable to the water in the concrete channel.

The high concentrations obtained for 28 December 1977 for the ditch-water holding reservoir represent the effect of an algal bloom in the reservoir. Although such algal blooms are not common, their occurrence should be recognized. The high values were considered to be an anomaly and were disregarded in the calculations for range, mean, and median values.

A measure of the organic matter in the water is given by the volatile suspended solids and total organic carbon values. The effluent contained highly volatile material, being 90% of the suspended solids. This volatile portion would be made up of carbonaceous plant and animal cell material. In contrast, the ditch water's volatile suspended solids portion was only 30%. This would indicate that 70% of the suspended solids are inorganic in nature, e.g., soil minerals. Hence, a larger portion of the suspended solids in the ditch water than in the effluent would settle out if both were left to

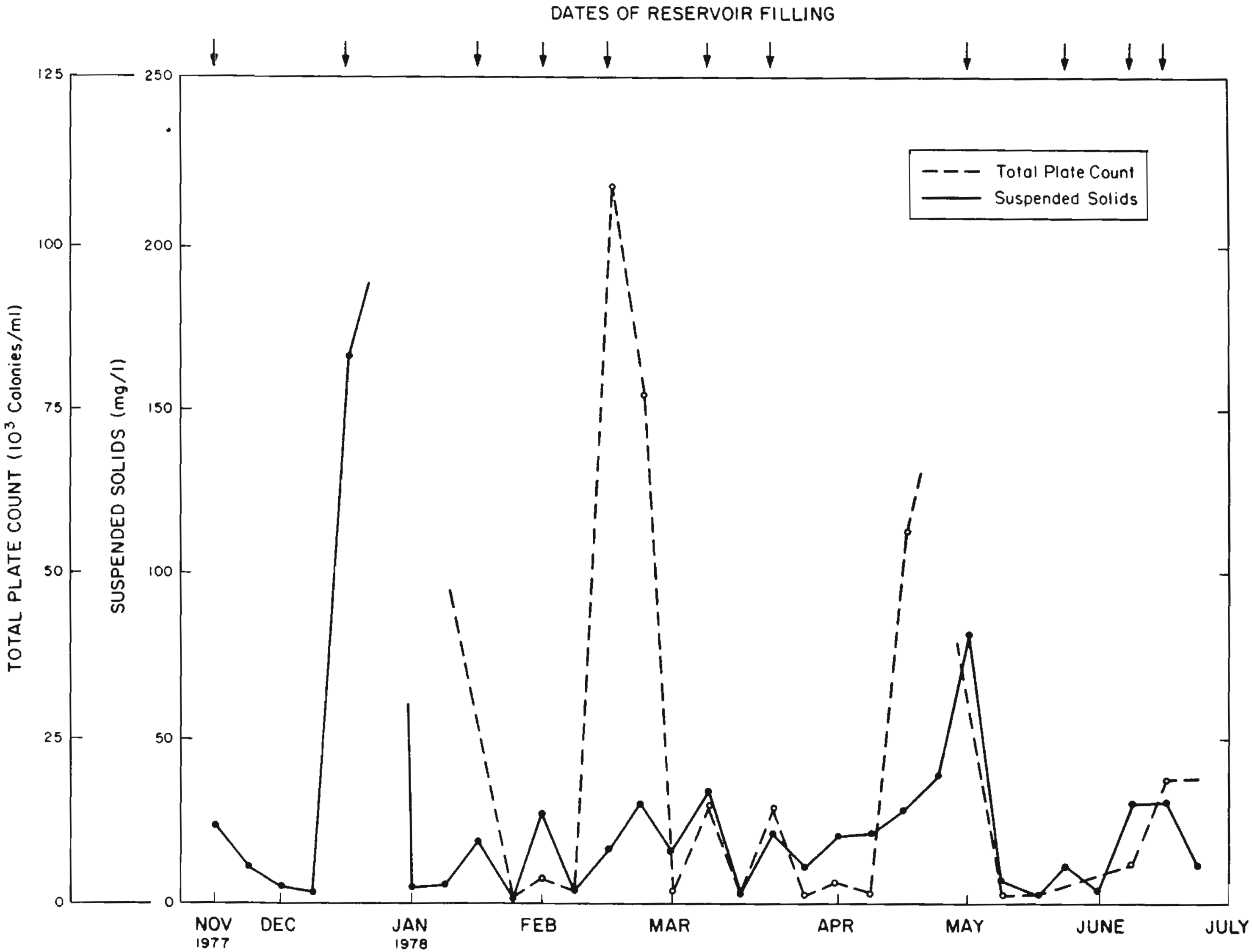


FIGURE 9. SUSPENDED SOLIDS CONCENTRATION AND TOTAL PLATE COUNT IN DITCH WATER

stand.

The chlorine residual of the effluent measured at the treatment plant varied from 0.6 to 2.7 mg/ℓ Cl_2 with a mean value of 1.1 mg/ℓ Cl_2. The chlorine residual of the effluent measured at the holding reservoir varied from 0.0 to 0.5 mg/ℓ Cl_2 with a mean value of 0.1 mg/ℓ Cl_2. It is apparent that a major portion of the chlorine in the effluent is lost while the effluent is pumped from the treatment plant to the holding reservoir. It is also clear that the chlorine residual decreases while the effluent is retained in the reservoir.

Some inverse relation can be expected between the magnitude of chlorine residual and bacterial density as given by the total plate count. The data bear out this relation (Fig. 10).

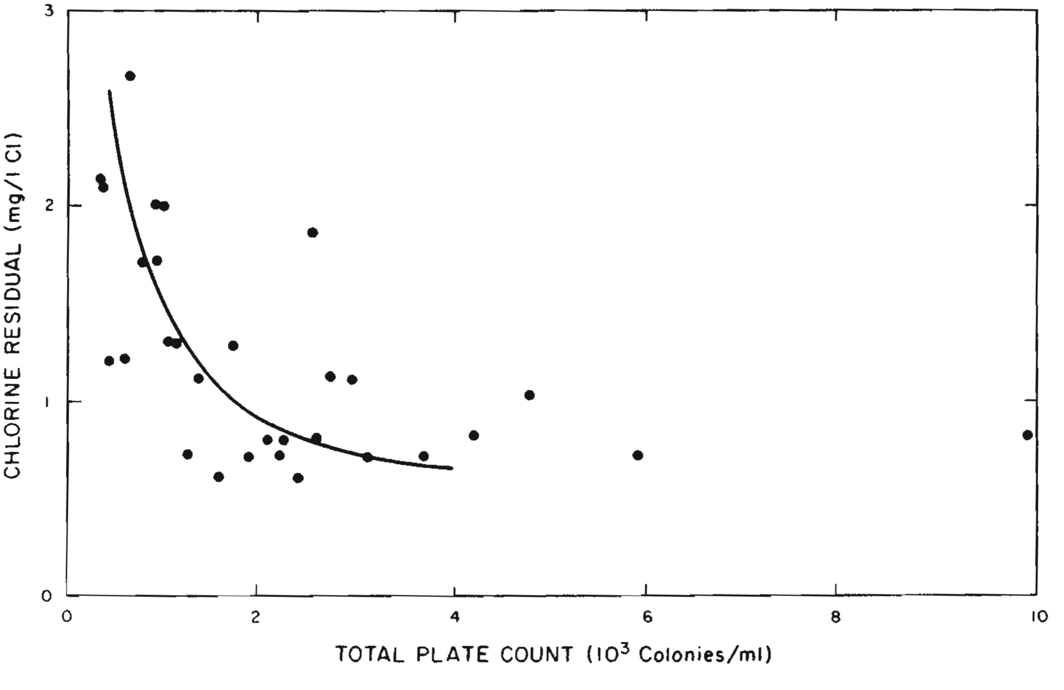


FIGURE 10. CHLORINE RESIDUAL AND TOTAL PLATE COUNT PARAMETERS FOR MILILANI STP EFFLUENT, O'AHU, HAWAI'I

The results of the Coulter Counter analyses of the particle size of the solids in the effluent indicate a uniform distribution by volume as evidenced by examples in Figures 11 and 12. This volumetric distribution seems to be consistent over time (data not shown). In terms of particle count the distribution is highly skewed. The smaller particles have a higher particle

PCL = 0.008 T = 47.5 TT = 593.7	
Sample #1	Dia. Orifice 100μ Dia. Calib. Spheres
Sampling Date 12-13-77	Aper Current
Source Mililani STP	Aperture Matching Switch
Sample Treatment	Manometer Volume 25 000
	Size Calib. Knob (null) (calibrated)
	Pk. Calib. Spheres, Ch. (null) (calibrated)
Electrolyte	K Value Total Count 830 141
Dispersant	Analyst V. Bralts
Diln. (Sample:Electrolyte) 1:19	Date 01-26-78

Geometric Mean μ^3	Volume μ^3	Diameter μ	Channel	Vol%	ΣVol%	Counts	ΣCounts	Vol. μ^3	ΣVol. μ^3
.00575	.004091	.198							
.0115	.008181	.250							
.0231	.01636	.315							
.0462	.03272	.397							
.0925	.06545	.500							
.1851	.1309	.630							
.3702	.2618	.794							
.7405	.5236	1.00							
1.481	1.047	1.26							
2.962	2.094	1.59	1	--	--	--	--	--	--
5.924	4.189	2.00	2	16.7	100	411662	664112	1724388	10325680
11.85	8.378	2.52	3	13.0	83.3	160227	252450	1342338	8601292
23.70	16.76	3.17	4	8.2	70.3	50533	92222	846705	7258952
47.39	33.51	4.00	5	7.2	62.1	22185	41689	743449	6412247
94.78	67.02	5.04	6	7.2	54.9	11092	19503	743449	5668798
189.6	134.0	6.35	7	6.0	47.7	4621	8411	619540	4925349
379.1	268.1	8.00	8	5.1	41.7	1964	3789	526609	4305808
758.3	536.2	10.08	9	4.0	36.6	770	1824	413027	3779199
1516.	1072	12.7	10	4.4	32.6	423	1054	454329	3366171
3033	2145	16.0	11	5.1	28.2	245	630	526609	2911342
6066	4289	20.2	12	12.2	23.1	293	385	1259733	2385232
12.13×10^3	8579.	25.4	13	5.6	10.9	67	91	578238	1125499
24.27×10^3	17.16×10^3	32.0	14	2.9	3.3	17	24	299444	547261
48.54×10^3	34.31×10^3	40.3	15	2.1	2.4	6	6	216839	247816
97.18×10^3	68.63×10^3	50.8	16	0.3	0.3	--	--	30977	30977
194.4×10^3	137.3×10^3	64.0							
388.7×10^3	274.5×10^3	80.6							
777.4×10^3	549.0×10^3	101.6							
1.555×10^6	1.098×10^6	128							
3.109×10^6	2.196×10^6	161.							
6.219×10^6	4.392×10^6	203							
12.44×10^6	8.784×10^6	256.							
24.88×10^6	17.57×10^6	322							
49.75×10^6	35.14×10^6	406							
99.50×10^6	70.27×10^6	512							
199.0×10^6	140.6×10^6	645							
398.0×10^6	281.1×10^6	812.							
796.0×10^6	562.2×10^6	1024							

Average Particle Volume = 15.548, PPM = 10.32, Average Particle Diameter = 3.096.

FIGURE 11. PARTICLE SIZE ANALYSIS OF A MILILANI STP EFFLUENT SAMPLE, O'AHU, HAWAI'I: DATA SHEET

Sample #1	Date 12/13/77	Dia. Orifice 100 µ	Aper. Current
Source MILILANI STP		Dia. Calib. Spheres	Aper. Matching Switch
Sample Treatment		Manometer Vol. 25,000	
Electrolyte		Size Calib. Knob Setting (null)	(calibrated)
Dispersant		Calib. Spheres in Channel(s) (null)	(calibrated)
Dilution (Sample:Electrolyte) 1:19 20x		Analyst V Bralts	Date 1/26/78

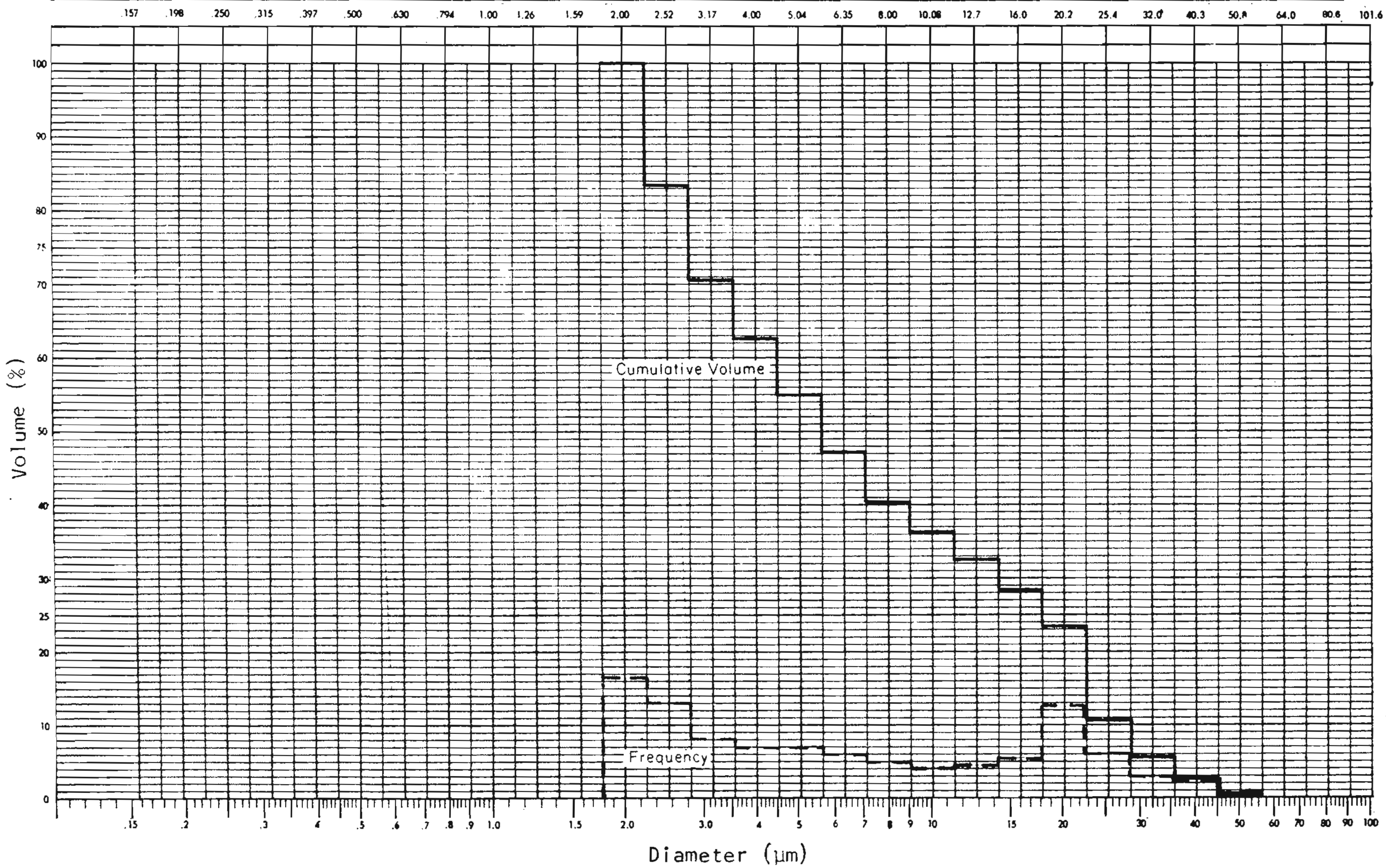


FIGURE 10. PARTICLE SIZE ANALYSIS OF A MILILANI STP EFFLUENT SAMPLE, O'AHU, HAWAI'I: GRAPHS

count than do the larger particles.

Hydraulic Test Stand Data

The results of the hydraulic testing to date have shown very good agreement with the theoretical curves. For example, in single-chamber tubing a 50% plugging was associated with a 46% reduction in flow.

It is important to note some possible bias in the hydraulic testing. The hypothetical curve for dual-chamber tubing, Figure 7, was calculated by considering plugging of the outer orifices only. This explains the exaggerated concave curve. If the inner orifices plugged at the same rate as the outer orifice, then the percent plugging vs. percent flow curve would be much more like the curves found for single-chamber tubing. Unfortunately, it has been impossible to plug only the inner orifices and still collect data.

Figure 7 suggests that the percent of holes plugged is not directly proportional to flow reduction in the lateral for all drip tubes. These results may lead one to question the test criterion for failure now set at 10% plugging. Perhaps a different numeric value or a more indicative measure, such as decrease of flow in percent, may be considered as the criterion.

Additional corroborative field results are being obtained, particularly on the subject of the dual-chamber percent plugging vs. percent flow relationship.

Virus Studies

Employing methodologies (App. G) developed by the University of Hawaii Environmental Virus Laboratory, periodic (approximately biweekly) viral analyses of the chlorinated secondary effluents of the Mililani STP indicate that the frequency of virus recovery (46%), as well as the concentration of virus (1-14 PFU/ℓ), remains essentially unchanged (Table 7). While the results suggest that the sewage treatment process is efficient in decreasing the concentration of virus in the treated effluents, they also emphasize the need for continued monitoring for virus in the chlorinated effluents.

TABLE 7. VIRUS ISOLATIONS AND CONCENTRATIONS AT MILILANI STP, JANUARY-APRIL 1977, O'AHU, HAWAI'I

	Samples Positive/Total	%	Virus* Concentration (PFU/ℓ)
Unchlorinated effluent (from secondary clarifier)	3/3	100	30/370
Chlorinated effluent (from chlorination basin)	6/13	46	1/14

NOTE: ℓ x 0.001 = m^3.
*Virus recovered as described in narrative.

APPENDICES

APPENDIX FIGURES

APPENDIX TABLES

APPENDIX A. RESEARCH PROTOCOL FOR POSTTREATMENT RESEARCH STUDY

I. Department of Public Works, City and County of Honolulu

   A. Provide dependable supply of treated secondary domestic waste water effluent direct from existing chlorination basin

   B. Allow access to and use of Mililani STP grounds for pilot tube farm installation and operation

      1. Open STP grounds during normal working day; arrange access through Division of Wastewater Management at other times

      2. Provide tube farm site in area between chlorination basin and STP perimeter fence

      3. Provide electricity and water for tube farm operation

   C. Design and assist with installation of connections for effluent flow to tube farm

      1. Provide information for link-up between chlorination basin and posttreatment system (Div. of Wastewater Management)

   D. Design and assist with installation of simulation of Five-Finger Reservoir

      1. Provide technical assistance (Div. of Wastewater Management)

      2. Use one of the STP treatment units to simulate field reservoir

II. Board of Water Supply, City and County of Honolulu

   A. Provide potable water connection from water line available at chlorinator building for disinfection in pilot tube farm

III. Oahu Sugar Company, Ltd.

   A. Assist with design and construction of reservoir and transmission line for conveyance of Waiāhole Ditch water to Mililani STP

   B. Provide Waiāhole Ditch water as required; coordinate with irrigator for dilution-study phase of Mililani research

   C. Assist with design and installation of pilot tube farm

      1. Provide technical data on plantation practice (flow rates, plugging, time of operation)

IV. Hawaiian Sugar Planters' Association

   A. Provide overall direction of field work (tube farm installation and operation)

   B. Assist with design and installation of pilot tube farm

   C. Conduct particle-size analysis using Coulter Counter

   D. Conduct field tests

      1. With and without Five-Finger Reservoir simulation

         a. 100% effluent

         b. 50% effluent, 50% Waiāhole Ditch water

2. Chemical treatments (for treatment of tube system, not effluent virus kill)
    a. Chlorine, 10 ppm free residual at tube end, 20 min/day
    b. Bromine chloride at dosage to provide equivalent of above chlorine residual
    c. Chlorine dioxide at dosage to provide equivalent of above chlorine residual
    d. Untreated
3. Criteria for failure
    a. Initially, 10% plugging as upper limit at design 15 gpm/acre/12-hr day
    b. 50% of initial height of fountain = partial plugging; no fountain = complete plugging
4. Data collection
    a. Initially, twice-weekly check of flow rates, adjust after 2 wk
    b. Initially, twice-weekly check of plugging, adjust after 2 wk
    c. Initially, twice-weekly water quality testing, adjust after 2 wk
5. Length of test
    a. Allow approximately 6-mo minimum evaluation time for each treatment

V. Agricultural Engineering, University of Hawaii
  A. Assist with design of pilot tube farm
    1. Check system hydraulics
  B. Operate posttreatment units and tube farm
    1. Day-to-day operation
      a. Adjust filtration rates
      b. Check for tube plugging
  C. Review literature on waste water effluent use in drip irrigation
    1. Compile review and disseminate to project control group
      a. Provide copy of all reference material for project files
      b. Provide annotated bibliography for Control Group

VI. Water Resources Research Center, University of Hawaii
  A. Monitor water quality
    1. Sample on twice-weekly basis effluent, ditch water, filtrate for total solids, suspended solids, volatile suspended solids, total organic carbon, total plate count, coliform bacteria, chlorine residual; provide data report

2. Conduct special studies, such as algal growth potential, as necessary

3. Collect samples and analyze for human pathogenic viruses, weekly basis

B. Collate data and submit final report

1. Submit to project recorder copies of all operating and field data, water quality and virus assay data

2. Prepare draft report by principal investigator and project recorder

C. Coordinate and manage overall project

VII. Department of Health, State of Hawai'i

A. Evaluate data against regulatory requirements

APPENDIX B. MILILANI SEWAGE TREATMENT PLANT TUBE FARM FLOW RATES

I. Calculations based on the following:

A. 16.5 gpm/acre—11 hr (9-ft row spacing)

B. Single-chamber tube (24 x 0.012 in. at 4.5 psi)
dual-chamber tube (24 x 96 x 0.019 in. at 10 psi)

C. 0.0034 gpm/ft—tube for irrigation mode

D. 1 gpm/tube additional for flushing mode

E. 10 min/day flushing mode

F. 2 tubes/submain flushing mode

G. 12 tubes/submain, 6 tubes operating/11-hr cycle

H. 200 ft/tube

I. 4 submains/system (check bromine chloride, chlorine dioxide, chlorine)

J. 4 filter tanks, 4 ft^2/tank

K. Backflush 10 gpm/ft^2, 10 min, 2 backflushes/day

II. Calculations

A. Irrigation mode flow rate (gpm)

1. Submain
(200 ft/tube)(6 tubes/submain) = 1200 ft/submain
(1200 ft/submain) (0.0034 gpm/ft) = 4.1 gpm/submain

2. System
(4.1 gpm/submain) (4 submains/system) = 16.4 gpm/system

B. Flushing mode flow rate (gpm)(orifice + flush valve flow)

1. Submain
(2 tubes/submain)(1 gpm/tube) = 2 gpm/submain
(4.1 gpm/submain) + (2 gpm/submain) = 6.1 gpm/submain

2. System
(6.1 gpm/submain) (4 submains/system) = 24.4 gpm/system

C. Irrigation mode flow rate (gpd)

1. Submain
(4.1 gpm/submain) (22 hr/day) (60 min/hr) = 5412.0 gpd/submain

2. System
(5412.0 gpd/submain) (4 submains/system) = 21 648.0 gpd/system

D. Flushing mode flow rate (gpd)(lateral flush valve only)

1. Submain
(12 tubes/submain) (1 gpm/tube) = 12 gpm/submain
(12 gpm/submain) (10 min/day) = 120 gpd/submain

2. System
(120 gpd/submain) (4 submains/system) = 480 gpd/system

E. Irrigation and flushing mode flow rate (gpd)

1. Submain
   (5412.0 gpd/submain) + (120 gpd/submain) = 5532 gpd/submain

2. System
   (5532 gpd/submain) (4 submain/system) = 22 128 gpd/system

F. Back-flush mode flow rate (gpd)

(4 ft^2/tank) (10 gpm/ft^2) = 40 gpm/tank
(40 gpm/tank) (10 min/back-flush) = 400 gal/back-flush/tank
(400 gal/back-flush/tank) (4 tanks/system) = 1600 gal/back-flush/system
(1600 gal/back-flush/system) (2 back-flush/day) = 3200 gpd/system

G. Irrigation, flushing, back-flushing flow rate (gpd)

(21 648 gpd/system) + (480 gpd/system) + (3200 gpd/system) = 25 328 gpd/system

SOURCE: The Experiment Station, Engineering Department, HSPA.

APPENDIX C. MILILANI DRIP IRRIGATION TUBE FARM PLUGGING REPORT

UNIVERSITY OF HAWAII
DEPARTMENT OF AGRICULTURAL ENGINEERING

DATE ______________
REPORTED BY __________

TEST DATA:

TUBING
(A) SINGLE CHAMBER ______
(B) DOUBLE CHAMBER ______

PRESSURE
(A) 4.5 psi ______
(B) 10 psi ______
(C) OTHER ______

CHEMICAL TREATMENT
(1) CHLORINE DIOXIDE ______
(2) BROMINE CHLORIDE ______
(3) CHLORINE GAS ______
(4) CONTROL ______

PLUGGING DATA:

1	1	1	31	31	31	61	61	61	91	91	91
2	2	2	32	32	32	62	62	62	92	92	92
3	3	3	33	33	33	63	63	63	93	93	93
4	4	4	34	34	34	64	64	64	94	94	94
5	5	5	35	35	35	65	65	65	95	95	95
6	6	6	36	36	36	66	66	66	96	96	96
7	7	7	37	37	37	67	67	67	97	97	97
8	8	8	38	38	38	68	68	68	98	98	98
9	9	9	39	39	39	69	69	69	99	99	99
10	10	10	40	40	40	70	70	70	100	100	100
11	11	11	41	41	41	71	71	71	101	101	101
12	12	12	42	42	42	72	72	72	102	102	102
13	13	13	43	43	43	73	73	73	103	103	103
14	14	14	44	44	44	74	74	74	104	104	104
15	15	15	45	45	45	75	75	75	105	105	105
16	16	16	46	46	46	76	76	76	106	106	106
17	17	17	47	47	47	77	77	77	107	107	107
18	18	18	48	48	48	78	78	78	108	108	108
19	19	19	49	49	49	79	79	79	109	109	109
20	20	20	50	50	50	80	80	80	110	110	110
21	21	21	51	51	51	81	81	81	111	111	111
22	22	22	52	52	52	82	82	82	112	112	112
23	23	23	53	53	53	83	83	83	113	113	113
24	24	24	54	54	54	84	84	84	114	114	114
25	25	25	55	55	55	85	85	85	115	115	115
26	26	26	56	56	56	86	86	86	116	116	116
27	27	27	57	57	57	87	87	87	117	117	117
28	28	28	58	58	58	88	88	88	118	118	118
29	29	29	59	59	59	89	89	89	119	119	119
30	30	30	60	60	60	90	90	90	120	120	120

FLOW DATA:

BEGINNING READING	1 ________	2 ________	3 ________
ENDING READING	________	________	________
VOLUMETRIC FLOW (gal)	________	________	________
PER TIME (min)	________	________	________

APPENDIX D. DEVELOPMENT OF CHLORINE RESIDUAL CURVES

INTRODUCTION

The practice of chlorination is designed to kill harmful organisms in the water. The bactericidal action is the result of chlorine's strong oxidizing potential on the bacterial cell's chemical structure, destroying the enzymatic processes required for life.

The rate of microbial kill depends on many factors. The primary factors are time of contact, concentration and form of the chlorine residual, and pH. The contact time and concentration are related in that a short contact time requires high concentrations of chlorine to accomplish disinfection, whereas a long contact time can produce equivalent kills with a lower concentration of chlorine. Free chlorine residual has a greater bactericidal action than combined chlorine residuals. pH determines the form of free chlorine, with lower pH favoring the more effective hypochlorous ion over the hypochlorite ion.

The reaction of chlorine in waters containing ammonia deserves some consideration. With the application of chlorine in an amount to give a chlorine to ammonia ratio up to 1, chloramines are formed. With further application of chlorine, the chloramines are oxidized to nitrogen and other gases. At the point where the chlorine to ammonia ratio is 2 to 1 the oxidation of chloramines is complete and any further applied chlorine appears as free chlorine residual. This point is referred to as the "breakpoint."

SCOPE

The treated effluent from the Mililani STP is intended to be applied as irrigation water by the drip irrigation technique. It is suspected that the growth of bacteria and other microorganisms in the effluent would greatly contribute to plugging the holes in the drip irrigation tubing, thus rendering the system inoperative. With the application of a sufficient quantity of chlorine to the effluent, the microbial population may be killed; hence, the plugging of the holes may be decreased.

PURPOSE

The purpose of this study was to develop the chlorine residual curve for the Mililani STP unchlorinated effluent. From this curve it was then desired to determine the chlorine dosage necessary to obtain a free chlorine residual of 20 mg/ℓ chlorine after a contact time of 30 min.

PROCEDURE

Test Samples

Grab samples of unchlorinated effluent were obtained from the Mililani STP. The samples were taken from the effluent channel of the secondary clarifier. The samples were placed into 0.004-m^3 (1-gal) plastic containers, transported to the WRRC laboratory for analysis, and stored at 5°C until testing.

Laboratory Analysis

1. The temperature of the sample was restored to room temperature.
2. Two hundred-milliliter (200-mℓ) portions of the test sample were placed into 500-mℓ flasks.
3. Each sample was dosed with varying volumes of a stock chlorine solution made from household chlorine bleach. The stock chlorine solution had a concentration of approximately 4 mg Cl/mℓ. The dosing of the samples was staggered at 10-min intervals.
4. The samples with the chlorine applied were swirled and allowed to stand in the dark.
5. After the required 30-min contact time, the samples were analyzed for free and total chlorine residuals.
6. Free chlorine residual was measured by the DPD colorimetric method as per *Standard Methods* (APHA, AWWA, WPCF 1975, sec. 409 F).
7. Total chlorine residual was measured by the starch-iodide method as per *Standard Methods* (APHA, AWWA, WPCF, 1975, sec. 409 A).
8. The resulting data were plotted as total chlorine residual vs. applied chlorine dosage.
9. The unchlorinated effluent sample was also analyzed for ammonia and total Kjeldahl nitrogen as per *Standard Methods*.

RESULTS

The results of this study are shown in Appendix Tables D.1 and D.2 and Appendix Figures D.1 and D.2. Appendix Tables D.1 and D.2 show the ammonia and total Kjeldahl nitrogen content of two effluent samples, one obtained on 8 May 1978 and the other on 15 May 1978. Also shown is the ratio of chlorine applied to ammonia at the breakpoint of the chlorine residual curve. Appendix Figures D.1 and D.2 are the plots of the data in Appendix Table D.3 for the chlorine residual curves for the same two effluent samples. Also found in these figures is an independent plot of the free chlorine residual vs. applied chlorine.

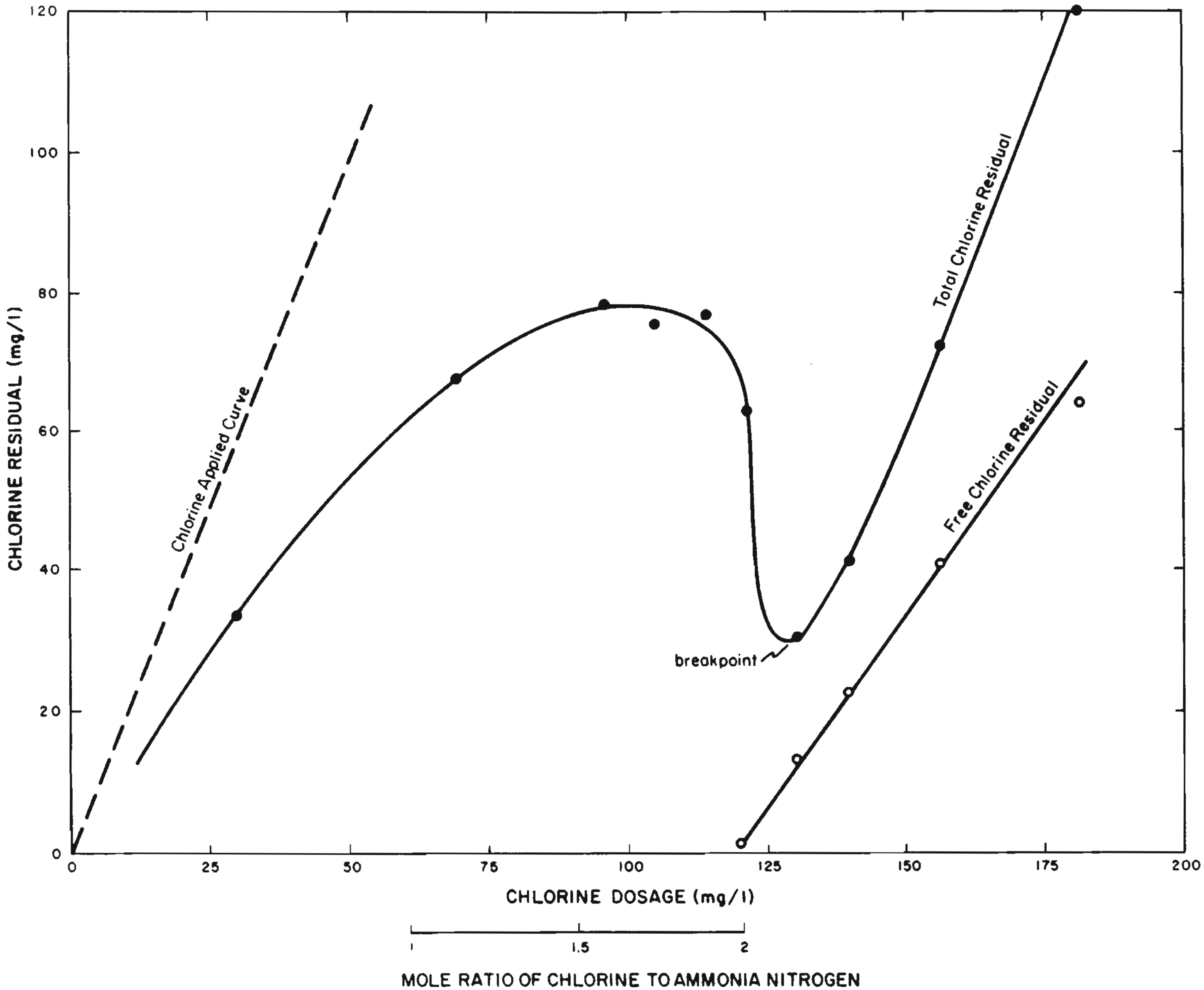
APPENDIX TABLE D.1. AMMONIA AND NITROGEN CONTENT OF TWO EFFLUENT SAMPLES, MILILANI, O'AHU, HAWAI'I

Date of Sample	Ammonia NH_3-N		Total Kjeldahl Nitrogen N
	(mg/ℓ)	(mole/ℓ)	(mg/ℓ)
05/08/78	24.22	0.001 73	34.02
05/15/78	22.26	0.001 59	37.52

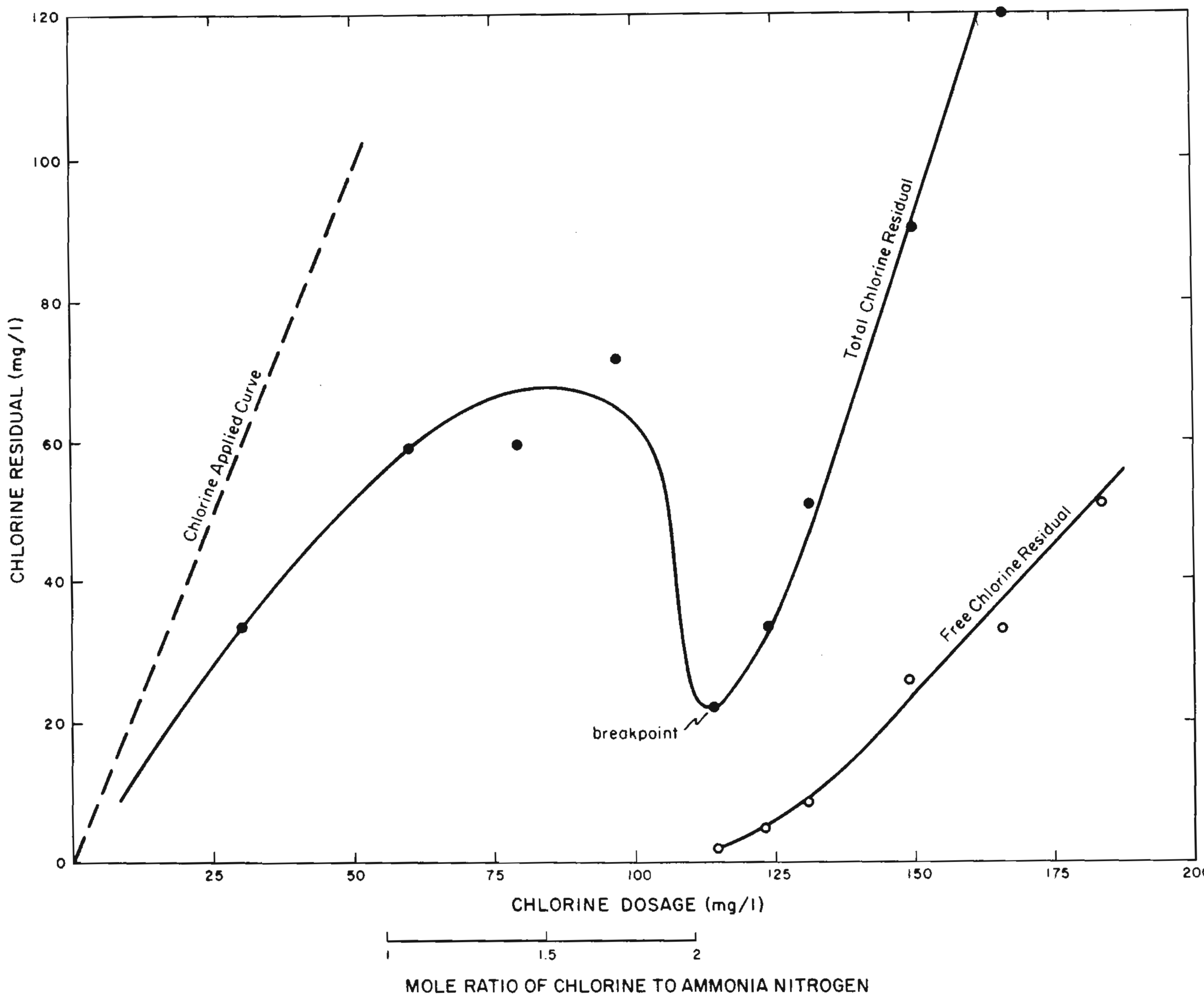
APPENDIX TABLE D.2. MOLE RATIO AT BREAKPOINT

Date of Sample	Chlorine Cl_2		Ammonia NH_3-N	Cl_2:NH_3-N
	(mg/ℓ)	(mole/ℓ)	(mole/ℓ)	
05/08/78	127	0.003 58	0.001 73	2.07
05/15/78	114	0.003 22	0.001 59	2.02

According to Appendix Figure D.1, the 8 May 1978 sample, a chlorine dosage of 138 mg/ℓ is required to obtain a free chlorine residual of 20 mg/ℓ. From Appendix Figure D.2, the 15 May 1978 sample, a chlorine dosage of 145 mg/ℓ is required to obtain a free chlorine residual of 20 mg/ℓ. Hence, if an average is applied, then a chlorine dosage of 141 mg/ℓ is required to obtain a free chlorine residual of 20 mg/ℓ after a 30-min contact time.



APPENDIX FIGURE D.1. CHLORINE RESIDUAL CURVES, 8 MAY 1978, MILILANI, O'AHU, HAWAI'I



APPENDIX FIGURE D.2. CHLORINE RESIDUAL CURVES, 15 MAY 1978, MILILANI, O'AHU, HAWAI'I

APPENDIX TABLE D.3. DATA FOR CHLORINE RESIDUAL CURVES

Cl_2 DOSAGE (mg/ℓ)	STARCH-IODIDE Cl RESIDUAL (mg/ℓ)	DPD COLORIMETRIC METHOD Free Cl	NH_2Cl	$NHCl_2$	$NHCl_3$	Total	VARYING FROM STARCH-IODIDE
		(mg/ℓ)					
		8 May 1978 Sample					
29.5	33.7	----	---	---	--	-----	--
67.4	67.4	----	---	---	--	-----	--
95.0	78.0	----	---	---	--	-----	--
104.0	75.5	----	---	---	--	-----	--
112.9	76.6	1.1	---	---	--	-----	--
121.7	63.1	0.5	9.5	---	48	58	22
130.5	30.5	13.5	3.9	0.0	12	29.4	19
139.1	41.8	22.8	0.0	0.0	20	42.8	12
156.2	72.3	41.4	6.9	0.0	26	74.3	22
181.3	120.9	63.8	4.7	0.0	53	121.5	8
		15 May 1978 Sample					
29.9	33.7	0.0	---	---	--	-----	--
58.9	58.1	0.0	---	---	--	-----	--
77.7	59.6	0.0	---	---	--	-----	--
96.2	71.6	0.0	---	---	--	-----	--
114.4	22.0	1.8	2.8	---	16	20.6	6
123.3	33.7	4.3	---	---	--	-----	--
132.2	50.3	9.1	---	---	30.6	39.7	21
149.7	90.0	25.5	---	---	52	77.5	24
166.8	121.2	33.0	---	---	94	127	5
183.7	152.1	48.5	---	---	87	135.5	11

DISCUSSION

The chlorine residual curves show some things follow the theory of chlorination and some things do not. One thing that follows the theory is the location of the breakpoint. It occurred at a Cl_2 to NH_3-N mole ratio of about 2 to 1 as stated in the theory. One thing that does not follow the theory is the type of chlorine residual present after the breakpoint is reached.

When the breakpoint is reached, the theory states that chloramines have been completely oxidized and that any more applied chlorine appears as free chlorine residual. The graphs show that after breakpoint free chlorine and trichloramines (NCl_3) are present. The only way to explain the presence of NCl_3 is that the samples were not mixed well enough to dissipate the NCl_3. Small amounts of monochloramines were also detected, but the portions were relatively small.

The free chlorine residual curve indicates that not all the applied chlorine appears as free chlorine. It seems that some of the applied chlorine is appearing as NCl_3 and the rest as free chlorine. Ironically, the total chlorine residual curve shows that essentially all the applied chlorine past breakpoint is appearing as a residual.

A comparison of the chlorine residual values obtained from the starch-iodide and DPD colorimetric methods shows some discrepancies. In the 8 May 1978 sample the DPD method gave values from 8 to 22% higher than the starch-iodide method. In the 15 May 1978 sample the opposite occurred: the DPD method gave values from 5 to 21% lower than the starch-iodide method. The differences may be largely due to the technique involved. The DPD colorimetric method has a standard curve with an effective range of 0 to 4 mg/ℓ Cl; hence, in order to measure large chlorine concentrations, dilutions are necessary. With the extra handling in making dilutions, small errors can be greatly magnified.

Considering that chlorine residuals can vary as much as 20%, a correction to the necessary applied dosage may be made. If a 20-mg/ℓ free chlorine residual is required, then a 20% correction means that a 24-mg/ℓ free chlorine residual is the goal. Hence, the necessary chlorine dosages to be applied are 142 and 150 mg/ℓ for the respective 8 May and 15 May samples. An average dosage would be 146 mg/ℓ chlorine.

Two different sewage samples were analyzed in this study. The ammonia content varied by 2 mg/ℓ and the required chlorine dosage by 6 mg/ℓ. It is recognized that the characteristics of sewage samples can vastly vary. Whether or not an adjustment to the required dosage should be made to handle a sewage with a higher ammonia content is not certain. The reliability of the chlorine application equipment is also not certain.

APPENDIX E. ALGAL GROWTH POTENTIAL STUDY

INTRODUCTION

An algal assay or algal growth potential (AGP) study is a test designed to measure the capacity of a water to support algal growth. With this test, algal growth-limiting nutrients can be identified, the availability of algal growth-limiting nutrients can be biologically determined, and the presence of compounds toxic or inhibitory to algae can be assessed.

The growth of the test alga is determined by the two parameters, maximum specific growth rate and maximum standing crop. Depending on the objectives of the assay, one or both parameters may be determined. The maximum specific growth rate is defined as the largest specific growth rate, u, occurring at any time during incubation. The u is defined as $\ln(X_2/X_1)/(t_2-t_1)$, where X_1, X_2 are the biomass concentrations at the beginning and end of the selected time interval, and $t_2 - t_1$ is the elapsed time interval in days. The maximum standing crop is defined as the maximum algal biomass achieved during incubation.

Individual investigators may have improvised algal assays to meet their specific needs. However, in order to produce comparable results the *Algal assay procedure: Bottle test* by the Environmental Protection Agency (Aug. 1971) was used as a guide.

SCOPE

The treated effluent from the Mililani Sewage Treatment Plant is intended to be used for irrigation water by drip irrigation. It is suspected that the growth of algae and other organisms contributes greatly to the plugging of holes in the drip irrigation tubing, thus rendering the system inoperative. An algal growth potential study can indicate whether or not the water will support algal growth. If the water does support algal growth, then plugging of the holes in the drip irrigation tubing can be expected.

PURPOSE

The purpose of this study was to investigate the algal growth potential of four test waters: chlorinated treated effluent, the same effluent but after placement into a holding reservoir, ditch water in a holding reservoir, and a 50 to 50 mix of the effluent and ditch waters from the reservoirs.

PROCEDURE

Test Samples

Samples for this study were obtained on 17 January 1978. The sewage effluent sample was obtained from the Mililani STP chlorine contact chamber, adjacent to the overflow weir; the reservoir effluent sample was obtained from the holding reservoir used in the Phase II-A dilution study. The effluent was placed into the reservoir the previous day. The reservoir ditch water was obtained from the holding reservoir used in the dilution study. The ditch water was placed into the reservoir the previous hour. All samples were grab samples. The samples were transported to the WRRC laboratory and stored at 5°C. Analysis was started on 18 January 1978. The 50 to 50 mixture of the reservoir effluent and ditch waters was made at the start of the study.

Preparation of Glassware

The test container was the 500-mℓ Erlenmyer flask. Each flask was rinsed with a 10% solution by volume of reagent hydrochloric acid (HCl). After the HCl rinse, the flasks were rinsed at least six times with tap water followed by at least three times with deionized water, inverted, and allowed to drain. The tops of the flasks were covered with aluminum foil and then placed in an oven at 140°C for at least 2 hr. The flasks were then stored, with tops covered, on a lab bench until needed.

Test Algae

The test alga chosen for this study was *Selenastrum capricornutum*. After the cells in the stock culture were counted, a volume of the stock culture was transferred to the test water to give a starting cell concentration of 10^3 cells/mℓ. In this study, 0.1 mℓ of stock culture per 100 mℓ of test water was used as the inoculum.

Laboratory Analysis

Each flask was rinsed with a portion of the test water to be used, and 100 mℓ of each test sample were added to their respective flasks. The proper amount of test algae was added to the flask and then swirled. The flasks were then incubated at 24 ±2°C under continuous "cool-white" fluorescent lighting: 400 ft-c for the desired number of days. Each flask was hand-swirled at least twice a day.

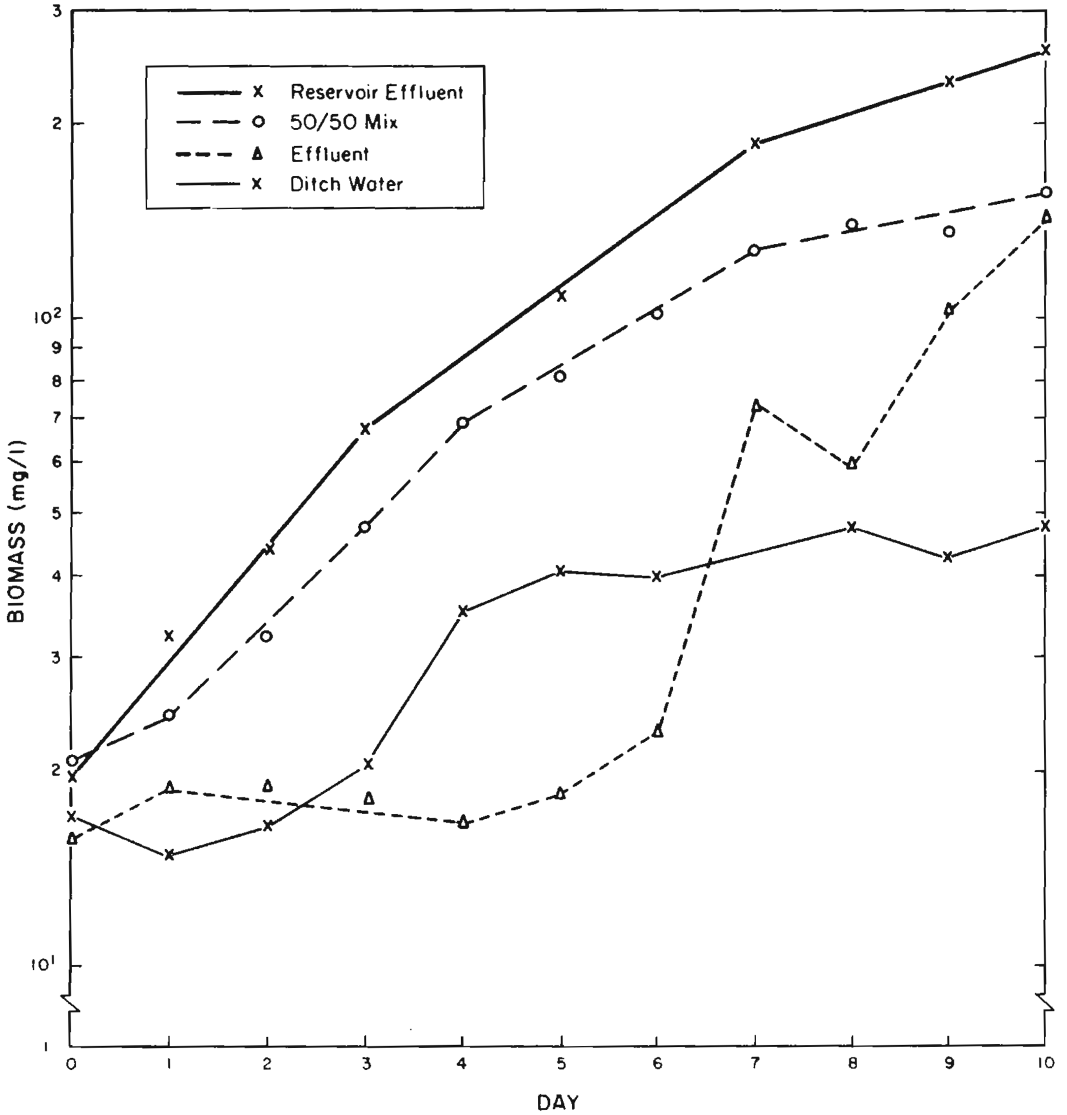
Each day three flasks from each test water were selected to be analyzed for that day. The algal cell density of each flask was measured by the Sedgwick-Rafter counting cell technique. Appendix Table E.1 summarizes the counting technique. After the cell density was measured, the biomass concentration was determined. This involved filtering the sample through a 0.45-μm glass fiber filter. The filter with the retained solids was dried overnight at 103°C, placed in a dessicator, and then weighed. The test was conducted daily for 10 days.

RESULTS

The results of the AGP study are shown in Appendix Table E.1 and in Appendix Figure E.1.

APPENDIX TABLE E.1. ALGAL-GROWTH PARAMETERS FOR THE TEST WATERS

Test Water	Maximum Specific Growth Rate (day^{-1})	Maximum Standing Crop (mg/ℓ)
Effluent at treatment plant	1.11 at day 7	146 at day 10
Reservoir effluent	0.399 at day 3	258 at day 10
Reservoir ditch water	0.548 at day 4	48 at day 10
50/50 mix reservoir effluent and ditch water	0.352 at day 4	158 at day 10



APPENDIX FIGURE E.1. AGP GROWTH CURVES

As reported in the procedure, the cell density was determined for each flask. It was intended to determine the cell density of only the algae inoculated; however, the large number of algae indigenous to the individual test waters made counting extremely difficult. Hence the reliability of the numbers obtained is questionable and is not included in this report. In future AGP studies the test waters will be filtered to remove the indigenous algae prior to inoculation with the test algae.

DISCUSSION

The effluent sample taken from the chlorine contact chamber at the sewage treatment plant appears to exhibit some inhibition of algal growth. The most obvious reason for this inhibition would be the toxicity of chlorine to the algae. Apparently a portion of the algae was killed at the time of inoculation. Then after a lag period of six days the population of both the inoculated and indigenous algae increased. Hence it appears that the effluent is not deficient in nutrients for algal growth. The maximum specific growth rate occurred at day 7. The maximum standing crop was 146 mg/ℓ at day 10.

The effluent in the holding reservoir did not show any inhibition of algal growth. This would seem strange considering that both effluents are chlorinated and are from the same source. However, the lack of inhibition can be explained. Past observations of the holding reservoir indicate that there is usually a certain amount of algae in this reservoir. It has been observed that after the effluent has been in the reservoir for about 1 wk, a green mat of algae forms on the surface of the water. When the reservoir is empty, dried masses of algae can be found on the reservoir sides.

The records indicate that 1 wk before the sampling period there was some water (effluent) in the reservoir. The effluent had been storing in the reservoir for about 3 wk. Because nutrients in the effluent are not expected to support active algal growth for 3 wk, the algae in the reservoir were probably starving. Their renewed supply of nutrients came in the effluent from the sewage treatment plant. Although the effluent was chlorinated, probably a good deal of the chlorine would be lost during transport from the treatment plant to the reservoir. The small amount of chlorine entering the reservoir probably was not enough to kill off all the algae in the reservoir.

It was observed that the algae indigenous to the effluent reservoir far outnumbered the algae inoculated into the sample. The type of algae found in the reservoir is the same as that in the treatment plant effluent. It has been suggested that the algae in the reservoir may be acclimated to the effluent. In any event, the maximum specific growth rate occurred at day 3. The maximum standing crop was 258 mg/ℓ at day 10.

The reservoir ditch water sample showed some increase in biomass. However, microscopic examination of the samples indicated the absence of the inoculated algae. What was found in the water were varieties of diatoms, ciliates, rotifers, and amoebas and brown masses of some type of plant life. These items apparently were responsible for the increase in biomass. The maximum specific growth rate occurred at day 4. The standing crop was relatively constant at about 40 mg/ℓ after day 5.

As could be expected, growth in the 50 to 50 mixture of reservoir effluent and ditch water was in between that for either one. As in the reservoir effluent, the algae indigenous to the effluent reservoir outnumbered the algae inoculated, hence making counting difficult. The maximum specific growth rate occurred at day 4. The maximum standing crop was 157 mg/ℓ at day 10.

CONCLUSION

From the results of this study it would appear that there are sufficient nutrients in the effluent to support algal growth. The resulting algal growth may cause some plugging of the holes in the drip irrigation tubing; however, with the application of a sufficient quantity of chlorine into the effluent, the growth of the algae may be depressed. In any event the solids in the four test waters may result in plugging of the drip holes. Hence, filtering of the water prior to use is recommended.

APPENDIX F. ALGAL COUNTING TECHNIQUE USING THE SEDGWICK-RAFTER COUNTING CHAMBER

The Sedgwick-Rafter counting chamber is used with a microscope for determining cell density. The chamber has known dimensions and holds 1 mℓ of water. Counting the total number of algae in the chamber will give the cell density as number/mℓ. However, to make the counting easier the concept of the strip is developed. Since a strip is a small portion of the entire chamber, the cell density can be determined by counting the number of algae in the strip and then multiplying the number of algae by the number of strips in the chamber. The size of the strip is determined by measuring its length and width with an optical micrometer under the appropriate magnification; the depth of the strip is 1 mm.

The general formula for calculating the cell density is

$$\text{Cell density, No./m}\ell = \frac{C}{S} \times \frac{1\ 000\ \text{mm}^3}{L \cdot D \cdot W} \times \text{dilution factor}$$

where C = the number of organisms counted, S = the number of strips counted, L = the length of the strip, D = depth of the strip, W = width of the strip.

For this study, a magnification of 100X was used. L = 55 mm, D = 1 mm, W = 0.7 mm.

With these values the cell density formula can be simplified as

$$\text{No./m}\ell = \frac{C}{S} \times 28.57 \times \text{dilution factor.}$$

APPENDIX G. METHODS OF SAMPLE CONCENTRATION FOR VIRAL ASSAY

Five different methods were adopted or modified for this project:

1. Polyelectrolyte 60 (PE-60). The batch (Wallis et al. 1971) and sandwich (Wallis and Melnick 1970) techniques for using the synthetic, insoluble PE-60 (Monsanto Co.), which selectively adsorbs viruses from the water medium, was used. The PE-60 was subsequently recovered and the adsorbed viruses eluted with a small volume of borate buffer (pH 9.0).
2. Polymer Two-Phase. A modification of the polymer two-phase separation method of Shuval et al. (1969) was used. Briefly, sodium dextran sulfate 500, polyethylene glycol 6000, and NaCl were dissolved in the water sample and allowed to separate overnight. The enteroviruses migrate preferentially to the dextran sulfate phase which comprises only 1 to 150 of the total volume, resulting in the effective concentration of the viruses.
3. Aluminum Hydroxide [$Al(OH)_3$]. A modification of the $Al(OH)_3$ methods as described by Wallis and Melnick (1967) was used. Briefly, the performed $Al(OH)_3$ is added to the water sample and selectively adsorbs viruses from the water medium. The $Al(OH)_3$ is subsequently recovered and the adsorbed viruses eluted with a small volume of borate buffer (pH 9.0).
4. Protamine Sulfate. A modification of the method of England (1972) was used. Briefly, protamine sulfate was added to the water sample to precipitate the viruses from the water medium. The precipitate was then recovered by filtering the entire sample through an AP-20 pad and the precipitate dissolved to recover the viruses by the addition of 1 *M* NaCl.
5. Cellulose Membrane. The method as described by Wallis et al. (1967) was used. Briefly, $MgCl_2$ was added to the water sample which had been adjusted to pH 5.0 to 5.5 and the entire sample filtered through a 0.45-μ cellulose membrane (Millipore Corp.). Under these conditions the cellulose membrane adsorbs viruses, which can then be eluted with a small volume of borate buffer (pH 9.0).