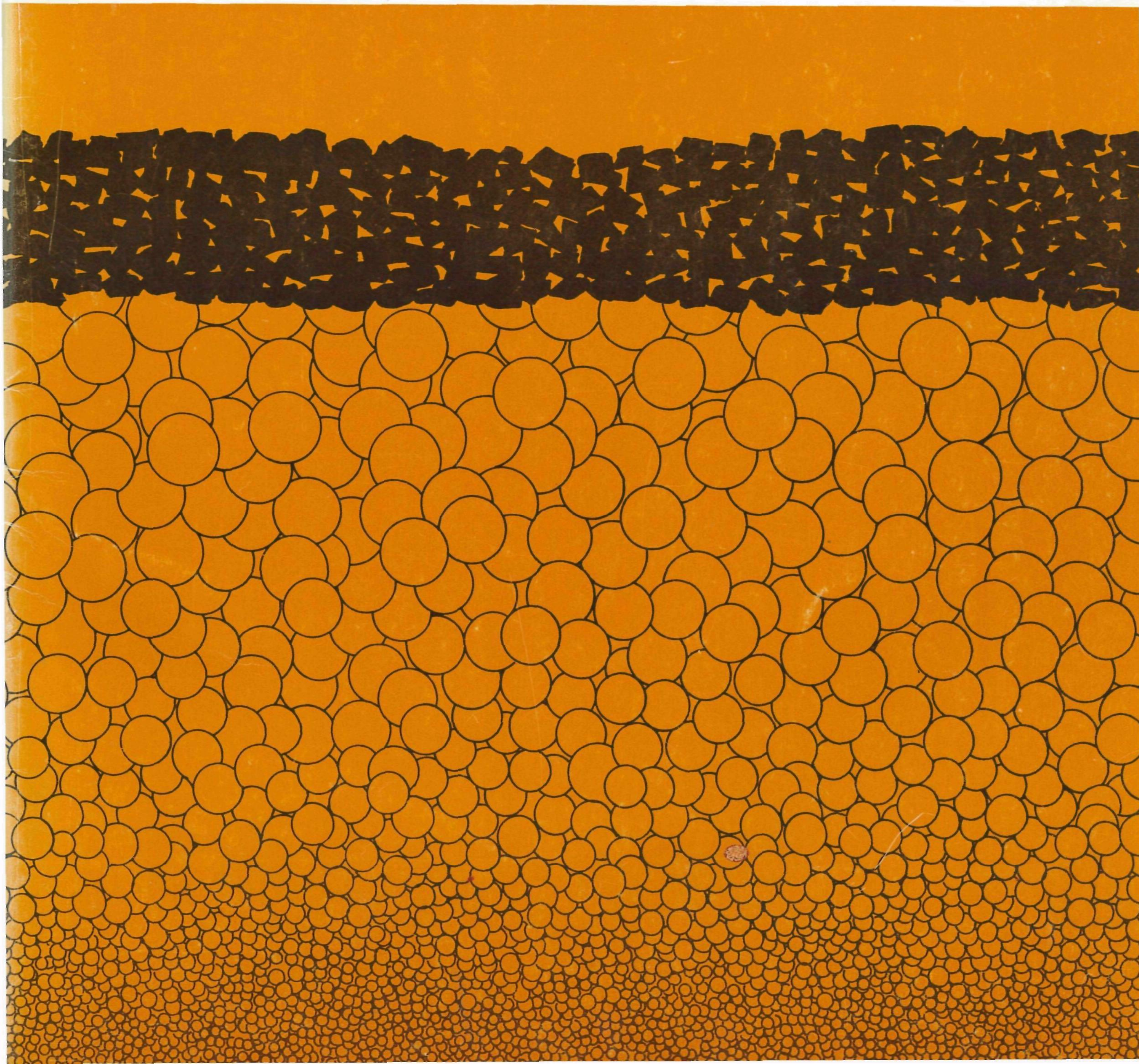
Upgrading Existing Wastewater Treatment Plants

Case Histories

EPA Technology Transfer Seminar Publication



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UPGRADING EXISTING WASTEWATER TREATMENT PLANTS—CASE HISTORIES

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NOTICE

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Part I

UPGRADING THROUGH BIOLOGICAL-PROCESS MODIFICATION

Two of the principal biological wastewater treatment processes used in the United States are activated sludge and trickling filtration. In many cases, upgrading such facilities may involve additional treatment methods, but in other instances, improvement through modification of the existing biological process may be possible. For an activated sludge plant, this may involve changing the influent feed arrangement or modifying the aeration air supply. In trickling filtration technology, replacement of rock media with deep, plastic media filters is a recent innovation. Part I presents some of the techniques that can be used to upgrade biological treatment processes.

ACTIVATED SLUDGE PLANTS

Before discussing specific improvements that can be taken to upgrade activated sludge plants, it is useful to review some of the parameters that relate to the operational efficiency of the treatment plant. Recognition of these parameters and an understanding of their importance will provide assurance that planned improvements will make available the tools necessary for operational upgrading.

Operating Parameters

The following five operating parameters are all important in the successful operation of an activated sludge plant: food/micro-organism ratio (F/M), solids retention time (SRT), sludge volume index (SVI), solids yield (Y_{BOD}), and dissolved oxygen (DO). While all of these parameters are directly involved with the biological processes taking place within the aeration tanks, it must be noted that the interrelationship between the aeration tank and secondary clarifier is such that operation of one cannot be optimized independently of the other. The physical conditions that will improve secondary clarifier performance, along with the relevant operating parameters involved, are discussed in detail in the Technology Transfer *Process Design Manual for Upgrading Existing Wastewater Treatment Plants.*[1]

Food/Micro-organism Ratio. The F/M ratio (pounds 5-day biochemical oxygen demand (BOD) added per day per pound of volatile suspended solids (VSS) in system) is used to determine the loading characteristics of the activated-sludge process. The engineer who wishes to assure the maintenance of this ratio within a plant's treatment limits will incorporate into the design the following tools:

- Process uniformity—ability to operate the process as a single treatment system

- Process flexibility—ability to rearrange aeration tank feed points to operate as conventional plug flow, step aeration, contact stabilization, or complete-mix systems

- Adequate return activated sludge (RAS) control—variable, independent, and reliable

- Adequate waste activated sludge (WAS) control-variable, independent, and reliable

- Adequate primary sedimentation—removal of debris and leveling of loadings

- Inplant laboratory control—ability to provide fast, accurate determination of system solids and biological activity

Unit removal, q_{BOD} (pounds BOD removed per pound VSS in the system), is often used instead of the F/M ratio to measure system loading. It uses the same determinations, and it requires the same tools. The volumetric loading (pound BOD added per day per 1,000 ft^3 aeration volume) may be of interest to the engineer but seldom is of much value to the operator, as it does not reflect the system's condition at the time of loading.

Solids Retention Time. The SRT (pounds VSS in system per total pounds VSS lost from system) is often referred to as the mean cell residence time, and is used to maintain process stability. A short SRT indicates the process is being limited to carbonaceous oxidation, while an extended SRT usually indicates that the process is providing both carbonaceous oxidation and at least some nitrification. A minimum SRT also means that a major portion of the biological treatment has been shifted to the solids-handling system. To achieve the optimum control of the system's SRT, the operator must have full, independent control of both RAS and WAS systems and complete process flexibility. An adequately sized, independent solids-handling system is also essential.

Sludge Volume Index. The SVI is a measurement of the settling characteristics of the mixed liquor. It is defined as the volume in milliliters occupied by 1.0 gram of mixed liquor suspended solids after settling for 30 minutes in a 1,000-ml graduated cylinder. While it is possible for these settling characteristics to be affected by excessive nitrification or formation of excessively light pinpoint floc, major changes in SVI are usually caused by the varying quantities of developing filamentous micro-organisms. Provision of the following will help insure maintenance of low SVI's:

- Quality microscopic examination equipment, which will provide the ability to directly observe micro-organism activity and maintain historic records. Daily examinations can anticipate trouble.

- Chemical-correction capabilities—provisions for oxidation, flocculation, and weight-producing chemical treatment.

Solids Yield. The Y_{BOD} (pounds waste VSS plus pound effluent VSS per pound BOD removed) value provides a measure of the solids that must be removed from the system and processed by the waste activated sludge thickeners and solids treatment facilities. To keep track of this parameter, the operator must have all the tools required for determination of the F/M ratio. The Y_{BOD} value also indicates the degree of endogenous respiration taking place within the aeration system. Endogenous respiration is directly affected by the SRT of the process.

Dissolved Oxygen. DO levels in the aeration and reaeration tanks are directly related to the biological activity taking place. The activated sludge process is an aerobic process; therefore, sufficient oxygen must be present in all parts of the process to support aerobic biological activity necessary to handle the incoming loadings. To assure adequate DO levels throughout the process, the operator must have an adequate air supply, a positive means of adjusting that supply, and a rapid means of determining DO levels within the various parts of the system.

Operational Upgrading

In the discussion of operating parameters, some of the operating tools or requirements necessary to achieve maximum efficiency and reliability were mentioned. A detailed description of these tools can show how they result in upgraded operation.

Process Uniformity. Process uniformity, i.e., the ability for the process to be run as one system, is needed especially in those facilities that were originally single aeration tanks and clarifiers, and have subsequently grown to multiple units as the flow has increased.

If process uniformity were not a major concern of the designer of these enlarged plants, a likely result would be two or more systems, each with its own idiosyncrasies. Such a condition usually results in demands for operating flexibility and control far beyond the facility's capabilities.

In upgrading existing and in designing new activated sludge plants, the designer should carefully analyze the process to assure that the system brings all of the activated solids together at least once. This can be accomplished by the common feed of mixed liquor to the secondary clarifiers or the common mixing of the RAS from multiple clarifiers. If the plant is very large, it may be necessary to force solids mixing by using an extra pump to circulate the solids within a large common RAS channel or other type of feeder system.

Process Flexibility. The EPA Technology Transfer *Design Manual for Upgrading Existing Wastewater Treatment Plants*[1] discusses directly the advantages of process flexibility in upgrading the activated sludge process. The need for process flexibility is also a must for all new facilities if they are to achieve reliably the degree of treatment required. It is impossible for the designer to anticipate every condition that may affect the efficiency of any particular activated sludge process. The operator of that process must be able to find the operating mode that best fits his conditions. These conditions may change during the year or from year to year. A truly upgraded activated sludge plant will provide the means of operating the aeration process in any one of several modes without sacrificing any of the hydraulic distribution criteria so essential to satisfactory settled sewage, mixed liquor, and RAS control.

Return Activated Sludge Control. Variable, independent, and reliable RAS control is necessary for several of the listed operating parameters. Without this tool, it is impossible to exercise adequate control over the amount of suspended solids in the system and their location within the system. Ideally, they should be where they will do the most good, in the aeration tank. To upgrade this part of the activated sludge system, the designer should make sure that each secondary clarifier is provided with an RAS system, which can be regulated over a reasonable range (usually 20 to 100 percent of clarifier design average dry weather flow capacity) and set so that it will maintain its flow independently of other process variables. If airlifts are used, their air system must be independent of all other process air systems.

If the hydraulics of RAS-system suction and discharge are relatively unaffected by varying process flows, a pair of simple, low head pumps with variable-speed-drive units will suffice. A stable system can still be produced, however, even when process flows do affect RAS-system hydraulics, by simply installing a flow-measuring device in the system and setting up a closed-loop control with the pump's variable drive units.

There is some indication at the Municipality of Metropolitan Seattle's Renton, Wash., activated sludge plant that such closed-loop controls can also be used to achieve additional stability by varying the RAS flow in conjunction with the diurnal variation of wastewater flows. Such a system has been in operation for several years at this plant, and it is believed partly responsible for the plant's very efficient (96- to 97-percent BOD removal) and reliable (no system bypasses) operation during this period. The correlation between these flows maintains constant levels of mixed liquor volatile suspended solids within the reaeration and contact aeration tanks, thereby assuring the micro-organisms a highly stable, uniform environment.

Waste Activated Sludge Control. It is very difficult to maintain an activated sludge process without accurate control of its sludge-wasting rate. The wasting rate must be known in order to determine the quantity of solids wasted from the system. Further, it is desirable to maintain the wasting rate at a reasonably constant value to insure proper operation of WAS thickeners. Because required variations in wasting rates can result from changes in both system hydraulics and process-solids concentrations, it is recommended that this control be achieved by providing positive, variable removal systems and accurate means of measuring the wasting-flow rate. By tying these two systems together with a closed-loop control, the operator is provided with complete assurance of preset dependability and a quick and easy means for making wasting-rate changes as necessary. Of course, if the wasting is made from one location in the RAS system and solids uniformity is provided by varying RAS flows diurnally with plant flow, an even more uniform rate of wasting solids is assured. This is especially true when the process is subject to large fluctuations in flow and solids loadings as a result of intermittent industrial activity.

Adequate Primary Sedimentation. Numerous activated sludge treatment plants have been installed without primary sedimentation facilities, often leading to poor performance and many operational headaches. The difficulties of maintaining the biological activated sludge process are many, and the absence of primary clarifiers adds unnecessarily to the problems of handling grit, scum, and debris-ladened raw sewage. Hourly examinations of BOD, suspended solids (SS), and chemical oxygen demand (COD) at the Sacramento County Central Treatment Plant during the early summer in 1973 indicated that the highly overloaded primary clarifiers (often less than 30 minutes' detention time) still managed to remove significant quantities of waste solids and significantly reduced the peak loadings tributary to the plant. Hourly peak COD loadings of over 2,000 mg/l were always reduced to the 500-mg/l level after passing through the primary clarifiers.

Those activated sludge plants that are now without primary treatment can be upgraded by providing reliable primary sedimentation facilities. Overall treatment efficiency and reliability could be increased by 10 to 20 percent using this time-tested tool.

Addition of chemicals to existing primary sedimentation facilities can also result in significant upgrading of activated sludge systems. An excellent example of the effect on an activated sludge process of lime and ferric additions to primary sedimentation can be found in the work done on the full-scale testing of a water reclamation system at the Central Contra Costa Sanitary District in California. This full-scale test facility confirmed that an activated sludge system immediately following primary sedimentation with chemical addition is extremely stable and can consistently maintain complete nitrification and a high degree of organic removal.[2]

Independent Solids-Handling System. Even with the best activated sludge process, occasional solids upsets or the need for rapid F/M adjustments will occur and cause excessive waste-solids discharges to the solids-handling system. If the handling, treatment, and disposal facilities do not have the capacity to accommodate these peak quantities, they will be overloaded and return a high percentage of the solids directly to the activated sludge process. Such recycling can only aggravate the already upset conditions or defeat the corrective adjustments.

Each part of the solids-handling system must have sufficient capacity to absorb such shock loadings without deterioration of its liquid return. As most activated sludge solids upsets involve bulking, flotation is usually the most practical thickening process. Flotation thickener design should be based on low solids-loading rates and should be provided with chemical feed capabilities to assure maximum solids capture under the worst conditions.

When anaerobic digestion is used for solids treatment, return of digester supernatant directly to the process flows should be avoided. If some means of lagooning or other liquid-solid storage is not available, then such liquid should be treated for both settleable and soluble solids removal before its return to the process flow.

The importance of the interdependence of an efficient, reliable activated sludge process operation and a successful waste-solids processing and disposal must be fully recognized. In many cases, an activated sludge process may be upgraded by simply improving the solids-handling system and isolating its operation from the liquid-process stream so that neither lack of capacity nor improper operation limits the amount of wasting required to maintain the most efficient F/M, SRT, or Y_{BOD} values.

Laboratory Control. For reliable, efficient operation of an activated sludge process, it is essential that provision be made for fast, accurate measurements of system loadings, efficiency, solids levels, and biological activity. This is especially true of systems that are subjected to industrial wastes or other varying flow or strength conditions. Even the small package facilities must be monitored and operated according to measured results.

In addition, every activated sludge plant should also be equipped with a microscope of sufficient power and flexibility to allow observation of micro-organism activity within the system. Routine observations can provide the operator with information that will allow him to anticipate problems and take steps to prevent them. Recent work has led to the conclusion that such a micro-organism examination will detect the deterioration of a plant's SVI (caused by bulking filamentous organisms) as long as a day before it begins to show up in the routine cylinder and solids tests. Such action will permit corrective measures to be undertaken before upset conditions occur within the plant.

Proper operating techniques, in combination with fast, accurate laboratory determinations of process parameters and routine microscopic examinations of process activity, may in themselves bring about significant upgrading of many existing activated sludge processes.

Chemical Correction Capabilities. Some activated sludge processes require chemical correction periodically to overcome externally imposed conditions that defy any other solution. Sludge bulking often falls in this category and can be caused by either hydraulic or biological upsets.

Hydraulic bulking is usually the result of peak wet-weather flows that overload the secondary clarifiers. This condition causes excessive loss of solids in the effluent and is usually accompanied by an increase in filamentous organism activity within the activated sludge biomass. At the Renton 36-mgd activated sludge treatment plant, it has been found that by applying intermittent doses of alum during periods of hydraulic overload, it is possible to reduce this loss of solids greatly and overcome any resulting development of filamentous activity. SVI's under such conditions have been kept below 120, and removal efficiency has remained high. The total cost for a wet season's application averaged only $1.65 per mgd.[3]

Biological bulking is more complex. Several facilities in California have recently experienced great success in controlling bulking caused by filamentous organisms with the continuous application of chlorine to the RAS. Hydrogen peroxide has also been used for this purpose. Use of chlorine for such biological filamentous control at the Sacramento County Central Treatment Plant is documented as a case history in part II (case 4).

Use of chlorine can also control nitrifying bacteria in plants designed for carbonaceous BOD removal only. Nitrification in the aeration tank can result in subsequent denitrification in the secondary clarifier sludge blanket. Clumps of sludge may be buoyed to the surface by nitrogen gas and leave the clarifier by the overflow weir. Because chlorine is toxic to the nitrifying bacteria, its addition to the RAS will prevent nitrification and consequent denitrification.

The important point is not which chemical is used for such controls, but that the upgraded activated sludge plant should be provided with the capabilities of applying the corrective procedures if and when a bulking problem arises. Experience indicates that there are few activated sludge plants that do not experience some bulking problems during a normal operating year.

Aeration Air Supply and Control. To maintain healthy micro-organisms in the activated sludge system, aerobic conditions are required under all loadings. Many plants can be upgraded by simply providing a great enough air supply, supplemental mechanical aeration, or other type of oxygenation capacity. Small plants are especially affected by such limitations because they usually experience very high oxygen demands during peak flow and loading periods.

Merely providing sufficient oxygen, however, is not enough to maintain the higher levels of reliability and efficiency demanded by today's treatment requirements. To assure the best results, the DO level must be maintained at the best level of support for the micro-organism activity. Even periodic drops to low DO levels can cause problems such as sludge bulking. Control tools are now available that can provide continuous monitoring for determining and maintaining DO levels. The Renton plant has used polargraphic DO probes for aeration air control for many years. Information is available on the value of such controls and on the amount of maintenance required to keep the system operable (pt. II, case 5A).

Such controls assume that variable-capacity oxygenation systems exist. As with many of the other operating tools mentioned, such flexibility must be provided to maintain optimum DO levels in the system. The final upgrading step to provide the DO-measuring equipment and the closed-loop control system to automatically control the variable-capacity oxygenation system is neither expensive nor complicated.

Conclusions

All too often upgrading of activated sludge plants has consisted either of simply providing more hydraulic capacity or of changing process modes; the importance of the so-called support systems and equipment has been overlooked. The design engineer who truly wants to upgrade an activated sludge plant to meet today's level of treatment reliability and efficiency will make sure that he has process uniformity and flexibility, positive and independent RAS and WAS control, adequate primary treatment, independent solids handling, efficient laboratory control, chemical correction capability, and sufficient aeration air supply and control. If all of these tools are available, he can fully expect the plant operator to use the relevant operating parameters to produce an effluent that will always comply with the new EPA secondary treatment effluent requirements.

TRICKLING FILTER PLANTS

Procedures for upgrading trickling filter plants fall into two main categories.

- Modifications to the existing trickling filter or operating procedures
- Provision of additional treatment in conjunction with the existing filters

Upgrading techniques can also be categorized according to whether the principal objective is handling increased loadings or improving effluent quality. Exceptions can be cited, but internal or operational modifications are generally used for increased loadings, and additional treatment processes (other than simple plant expansion) are used to provide improved effluent quality.

Modifications to Existing Filters

Three methods of improving trickling filter performance by modifying existing facilities are

- Use of a different filter media
- Increased recirculation
- Forced-draft ventilation

A fourth, less obvious, procedure involves review of present plant operation with the purpose of improving performance through better maintenance, proper operating techniques, or equipment repair. Although this last topic is not covered in this document, it should be one of the first possibilities considered when faced with inadequate performance from a trickling filter plant.[4]

Alternative Types of Media. A means of greatly increasing the capacity of a trickling filter plant is to replace rock media with synthetic (plastic) media. Two principal reasons account for the increased use of plastic media in recent years.

- A large specific surface area, approximately twice that of rock media (27 ft^2/ft^3 for the most commonly used material), allows greater slime surface per unit volume, which permits a higher volumetric BOD loading than can be achieved with rock media.
- The light weight of the media permits construction of filters up to 25 feet deep. The depth of rock filters is usually limited to approximately 5 to 6 feet.

The high loading capacities and great depth make the use of plastic media advantageous in plant expansions where space is often limited. In addition, the high allowable organic loading makes plastic media particularly applicable to treatment of strong industrial wastes. At Stockton, Calif.

(pt. II, case 3), three of six existing rock filters have been converted to plastic media filters that are designed to remove carbonaceous BOD from combined domestic and cannery wastes during a portion of the year and oxidize carbonaceous BOD and ammonia-nitrogen during the remainder of the year.

Principal U.S. manufacturers of synthetic media consisting of corrugated sheet modules are B. F. Goodrich, Envirotech, Munters, and the Enviro Development Co.

Redwood slats can also be used to replace rock media. Marketed by Neptune-Microfloc, redwood media has many of the same advantages as plastic media. Redwood media is often used in the Activated Biofilter, a proprietary coupled trickling filter/activated sludge process in which the RAS is returned to the trickling filter influent line.

Upgrading through media substituion may require other plant modifications. Use of plastic media requires a greater filter depth, which necessitates raising the height of the filter walls. Increased pumping capacity or a higher static head will often result, and modifications to the filter circulation sump may be required.

Recirculation. Increasing recirculation may be another means of improving filter performance. For lightly loaded filters, increasing circulation means increasing the contact time of the waste in the filter, and thereby increasing BOD removal. For heavily loaded filters, particularly where high-strength wastes occur, increased recirculation can provide dilution to maintain aerobic conditions as well as produce increased flow through the filter to slough biological growth and prevent media clogging.

Increased recirculation involves installing additional pumps as a minimum. Modified recirculation piping, a modified circulation sump, and increased distributor capacity possibly will also be required.

Forced-Draft Ventilation. Forced-draft ventilation can be used to prevent anaerobic conditions in trickling filters. Usually associated with deep plastic filters and strdng industrial wastes, positive ventilation can be used where natural draft is not adequate to provide sufficient oxygen transfer or where dead zones occur.

Additional Treatment Processes

Providing additional biological treatment capacity ahead of or behind the existing trickling filter can mean a substantial improvement in performance. Other types of treatment processes that can be used with trickling filters are chemical addition and effluent-polishing filtration.

Biological Treatment. Installing a roughing filter ahead of the existing filter can both improve performance (particularly if plastic or redwood media are used) and increase capacity. Normally, an intermediate clarifier would not be used, and all solids would be removed in the final clarifier.

A polishing filter following the existing clarifier can be used to provide separate-stage nitrification. Because solids production in such tertiary applications is low, the effluent can often be applied directly to a multimedia gravity filter without resultant additional sedimentation.

Installing an activated sludge system downstream from the trickling filter (ahead of the secondary clarifier) can greatly improve performance. This approach was used at Livermore, Calif. (pt. II, case 2), to attain nitrification. The roughing filter used ahead of the aeration-nitrification tank provides a reliability and an operational stability that cannot be achieved with the activated sludge process alone.

Chemical Addition. Chemicals (aluminum and ferric salts, lime, and polyelectrolytes) are being used increasingly to supplement trickling filtration.[5] Chemical addition to the primary clarifiers will, in addition to removing most of the incoming phosphorus, substantially increase BOD and SS removal. This technique can relieve overloaded trickling filters, or, where existing filters are lightly loaded, may allow nitrification to take place.

Alternatively, chemicals may be added before the final clarifiers to reduce secondary effluent BOD and SS levels. Chemical coagulants can also be used after the secondary clarifiers to improve final effluent quality. An additional clarification process will be required in this case.

Two factors that should be carefully evaluated when chemical addition is contemplated are wastewater alkalinity changes and solids-handling capacity.[4] Addition of metallic salts may deplete the wastewater's buffering capacity and reduce the pH to the level where biological activity is impaired. Caustic soda may need to be added ahead of the trickling filter (for primary chemical addition) or before effluent disposal to meet discharge requirements. Adding lime to the primary clarifiers will raise the pH and inhibit biological activity. Recarbonation through addition of CO_2 gas can be used to reduce pH.

Adding coagulant chemicals in trickling-filter plants will generate increased quantities of solids. Further, the sludge will have different characteristics from the sludge produced previously by primary sedimentation and trickling filtration. Care must be taken that the solids-handling, -treatment, and -disposal facilities are adequate for the biological-chemical sludge produced.

Tertiary Filtration. Multimedia, rapid sand filtration, originally developed for water treatment, is being used increasingly as a tertiary wastewater treatment process. Baumann and Cleasby[6] have done extensive work on the design requirements of wastewater filtration as opposed to water filtration. Deep filters, large grain sizes, and high loading velocities permit storage in the filters of a sufficient quantity of solids to allow reasonably long filter runs. The higher influent-solids level in wastewater treatment makes more storage capacity necessary.

Effluent quality requirements are usually not as strict for wastewater treatment as for water treatment, allowing higher effluent turbidities and SS levels to be tolerated. Effluent BOD and SS levels of about 5 mg/l can be expected with effluent filtration. Chemical coagulation is often used in conjunction with tertiary filtration.

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Part II

CASE HISTORIES

CASE 1. GREENSBORO, N.C., SOUTH BUFFALO CREEK WASTEWATER TREATMENT PLANT

The original South Buffalo Creek Wastewater Treatment Plant was built in 1931 for an ultimate population of 37,000, an average flow of 3.25 mgd, and a wet-weather flow of 6.5 mgd. The plant was adequate generally for the design load, except that the final settling tank, sludge-digestion tank, and sludge-drying beds were considerably smaller than would be called for by modern practice. These deficiencies resulted in somewhat less satisfactory treatment than ordinarily would be expected with this type of plant.

Facilities in the original plant consisted of screens, detritors, single primary and final settling tanks, two fixed-nozzle trickling filters, a digester, and sludge-drying beds.

By 1956 the flow to the plant had increased to an average of 4 mgd, of which 1.5 mgd were industrial waste. The total load to the plant was equivalent to that from 52,000 people, and the treatment efficiency was inadequate. Among the industries contributing to the plant were textile-dyeing and -finishing plants, an abattoir, a meatpacking plant, a chemical-manufacturing plant, poultry-processing plants, and metal-plating plants.

The treatment plant was upgraded in 1957-58 by replacement of screening and grit-removal facilities; addition of one primary settling tank, two trickling filters, two final tanks, and one digester; conversion of the existing final tank to chlorine contact; and replacement of the drying beds with a vacuum-filter installation.

Between 1958 and 1964, the industrial biochemical oxygen demand (BOD) contribution to the plant increased much more rapidly than expected. Industrial BOD rose from 35 percent to over 65 percent, and the overall plant BOD-removal efficiency fell from 90 percent to 70 percent.

To improve handling of the industrial loads one of the original fixed-nozzle trickling filters was converted into two aeration basins in 1964-66. Conversion involved removal of media and installation of platform-mounted mechanical aerators. The trickling filters installed in 1957 were retained as roughing filters ahead of the activated-sludge facilities.

Since the initial conversion, BOD removals have averaged above 90 percent, and have never dropped below 80 percent.

In 1970, to meet increased loads, the remaining fixed-nozzle filter was converted to aeration basins using floating aerators.

The current upgrading project includes preaeration, chemical addition for phosphorus removal, special odor-control measures, improved sludge handling, and effluent polishing with deep-bed filters. BOD and suspended-solids (SS) removals in excess of 98 percent are expected.

Design parameters of the various plant additions are detailed in table II-1, typical plant-operating data are given in table II-2, and capital costs of plant upgrading are outlined in table II-3. Flow diagrams for various stages in development of the plant are shown in figures II-1 to II-5.

Included is a possible future upgrading to provide nitrogen removal, should this be required. This upgrading might involve conversion of the 1957 trickling filters to provide nitrification after the activated-sludge treatment and addition of biological denitrification.

Table II-1—*Upgrading of South Buffalo Creek Wastewater Treatment Plant, design parameters*

Item	1931 (original plant design)	1957	1964-66	1970	1972 proposals
Design parameters:					
Design average flow, mgd	3.25	8	8	8	10.7
Design peak flow, mgd	6.50	16	16	16	21.4
Design BOD, lb/day	–	21,700	–	–	35,500
Design suspended solids, lb/day	–	18,800	–	–	27,000
Phosphorus, lb/day	–	–	–	–	900
Wastewater treatment:					
Screens	Mechanical bar screen.	Existing bar screen replaced by back-raked mechanical bar screen with hand-raked bypass screen.	No change.	No change.	Replace mechanical bar screen by new heavy-duty unit.
Grit chambers	Two detritors.	Detritors replaced by aerated grit chamber. Available air supply: 50 ft^3/min. Grit removal: tubular conveyor discharging to grit box.	No change.	No change.	Replace grit-removal mechanism with new heavy-duty bucket-type grit-collecting-and-elevating mechanism.
Preaeration tank	–	–	–	–	Volume: 1.1 million gallons. Available air supply: 4,000 ft^3/min.
Primary settling tanks	Square tank. Dimensions: 70 ft x 70 ft x 10 ft SWD. Surface area: 4,900 ft^2 Overflow rate: 670 gpd/ft^2	Old square tank retained. New round tank (80 ft diameter x 9 ft SWD) added. Flow equally divided between tanks. Total surface area: 9,900 ft^2 Overflow rate: 800 gpd/ft^2	No change.	No change.	Enclose primary tanks with positively ventilated building to exhaust air through odor-control units.
Phosphorus removal	–	–	–	–	Addition of facilities to add lime, alum, or iron salts (depending on results of pilot-plant studies) ahead of primary settling tanks.

Table II-1.—*Upgrading of South Buffalo Creek Wastewater Treatment Plant, design parameters—Continued*

Item	1931 (original plant design)	1957	1964-66	1970	1972 proposals
Secondary treatment .	Two square (200 ft x 192 ft x 7 ft deep) fixed-nozzle, stone trickling filters. Media volume: 540,000 ft^3.	Square filters retained, accepting flow from old ordinary tank. Loading: 15-lb BOD/ 1,000 ft^3 of media per day. Two new round filters (155 ft diameter x 7 ft deep) added to accept flow from new primary tank. Media volume 260,000 ft^3 loading 36 lb BOD/ 1,000 ft^3 of media per day. New filters have recirculation capacity of 9 mgd.	Use of square filters discontinued. Round filters operated as roughing filters. One square filter converted to two aeration basins with combined volume of 326,400 ft^3 and combined aeration capacity of 200 hp of platform-mounted aerators.	Second square filter converted to provide additional two aeration basins with 360 hp aeration capacity, giving total aeration volume of 655,000 ft^3 and total aeration capacity of 560 hp.	No change.
Final settling .	One rectangular tank (50 ft x 50 ft x 10 ft SWD). Total surface area: 2,500 ft^2 Overflow rate: 1,300 gpd/ft^2	Old final settling tank converted to chlorination contact tank (see below). Two new round (105 ft diameter x 9 ft SWD) tanks added to handle total plant flow. Total surface area: 17,300 ft^2. Overflow rate: 460 gpd/ft^2.	No change.	No change.	No change.
Chlorination .	None.	Contact tank volume: 25,000 ft^3 Chlorinator capacity: 4,000 lb/day.	No change.	No change.	No change.
Effluent filtration .	—	—	—	—	Preaeration followed by dual media filtration (design dependent on results of pilot-plant studies).
Residue treatment:					
Sludge thickening .	—	—	—	—	Flotation thickening of activated sludge before mixing with primary-sludge flotation unit. Surface area: 250 ft^2
Sludge digestion .	Fixed-cover digester 60 ft diameter x 23 ft SWD.	New floating-cover digester (80 ft diameter x 30 ft SWD) added as primary digester. Existing fixed-cover digester retained as secondary unit.	Digestion discontinued. Digesters retained as sludge-holding tanks.	No change.	No change.

Table II-1.—*Upgrading of South Buffalo Creek Wastewater Treatment Plant, design parameters—Concluded*

Item	1931 (original plant design)	1957	1964-66	1970	1972 proposals
Sludge dewatering	Sludge-drying beds, area: 32,600 ft^2.	New 11 ft-6-in. x 12 ft large coil spring vacuum filter (430 ft^2 surface area) added. Drying beds relegated to standby role.	No change.	No change.	Recondition existing vacuum filter and accessories. Replace filter media. Provide odor control for sludge-handling building
Ultimate disposal. .	Trucked to landfill.	Trucked to landfill.	Trucked to landfill.	Trucked to incinerator.	No change.

Table II-2.—*Typical performance of South Buffalo Creek Wastewater Treatment Plant*

Item	1957-58		1964-66		1970		Proposed
	Before upgrading	After upgrading	Before upgrading	After upgrading	Before upgrading	After upgrading	After upgrading
Characteristics of raw waste:							
Flow:							
Average day, mgd	3.7	4.5	4.9	6.6	6.8	8.9	10.7
Peak hour, mgd	10	11.5	11.5	16	16	18	21
BOD:							
Average day, mg/l	380	310	290	300	390	390	400
Average day, lb/day	11,700	11,600	11,800	16,500	22,200	29,000	35,700
SS:							
Average day, mg/l	350	240	250	260	290	300	300
Average day, lb/day	10,800	9,100	10,200	14,100	16,500	22,300	26,800
Performance of treatment units:							
Average BOD removal, lb/day:[a]							
Primary	2,300(20)	3,000(25)	3,000(25)	2,500(15)	3,200(15)	4,400(15)	9,000(25)
Trickling filter	4,700(50)	7,400(85)	5,200(60)	5,800(40)	6,600(35)	7,600(30)	8,000(30)
Activated sludge				6,500(80)	9,000(75)	14,100(85)	16,000(85)
Effluent filter							2,000(75)
Total.	7,000(60)	10,400(90)	8,200(70)	14,800(90)	18,800(85)	26,100(90)	35,000(98)
Average SS removal, lb/day:[a]							
Primary	4,300(40)	4,500(50)	5,100(50)	4,200(30)	5,000(30)	7,800(35)	13,400(50)
Secondary.	2,200(35)	3,200(70)	2,500(50)	7,100(70)	7,400(65)	8,900(60)	10,500(80)
Effluent filter							2,300(80)
Total	6,500(60)	7,700(85)	7,600(75)	11,300(80)	12,400(75)	16,700(75)	26,200(98)
BOD loading on units (1,000 lb per ft^2):							
Trickling filter	17	[b]15/36	[b]15/36	54	73	95	103
Activated sludge				25	38	26	29
Operating costs, dollars per million gallons			38.50	52.93	58.91	78.28	

[a]Figures in parentheses indicate percent.

[b]Two-stage; see table II-1.

Table II-3.—*South Buffalo Creek Wastewater Treatment Plant, capital costs of upgrading*

Date of upgrading	Item	Capital cost	
		Cost at time of upgrading	1972 cost
		Dollars	
1957	Screening and degritting	45,000	110,000
	Rehabilitation of pump and control building	150,000	365,000
	Primary settling	65,000	160,000
	Secondary process	330,000	800,000
	Final settling . .	135,000	330,000
	Chlorination facilities	25,000	60,000
	Sludge handling	300,000	730,000
	Miscellaneous	150,000	365,000
	Total, 1957 . . .	1,200,000	2,920,000
1964-66.	Modifications to secondary process. .	200,000	367,000
1970 .	Modifications to secondary process. .	100,000	133,000
1972 proposal	Renovation of screens and degritting equipment. .		60,000
	Preaeration and odor control		160,000
	Enclosure of primary tanks and odor control. .		200,000
	Phosphorus-removal facilities		75,000
	Effluent filters and aerators		450,000
	Sludge handling		250,000
	Miscellaneous		55,000
	Total, 1972 proposal		[a]1,250,000

[a]Exclusive of engineering and contingencies.

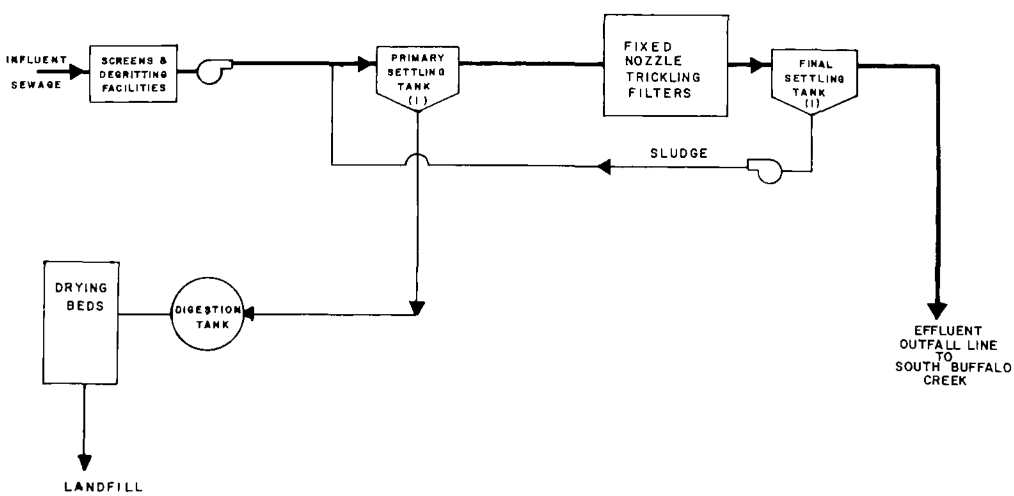

Figure II-1. South Buffalo original plant, flow diagram.

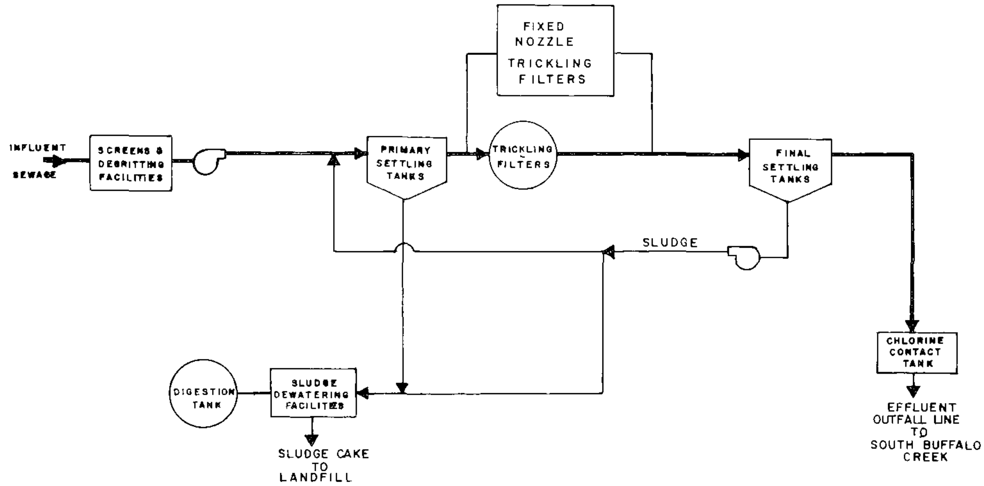

Figure II-2. South Buffalo, following first upgrade, flow diagram.

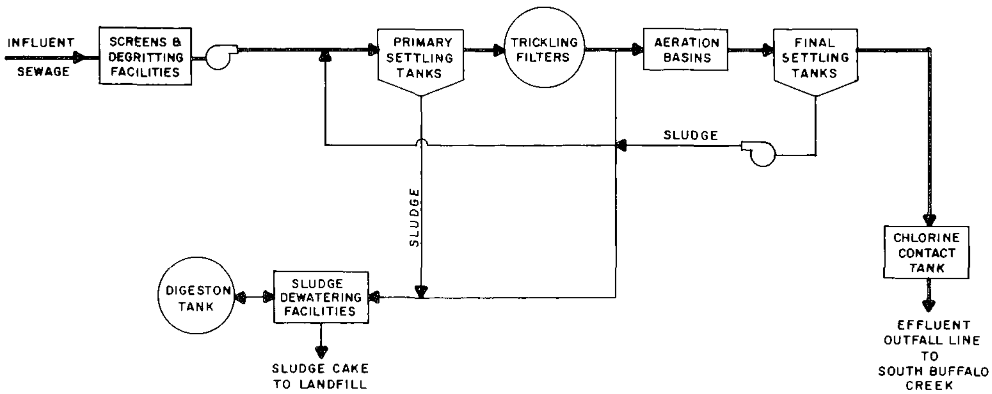

Figure II-3. South Buffalo, following second upgrade, flow diagram.

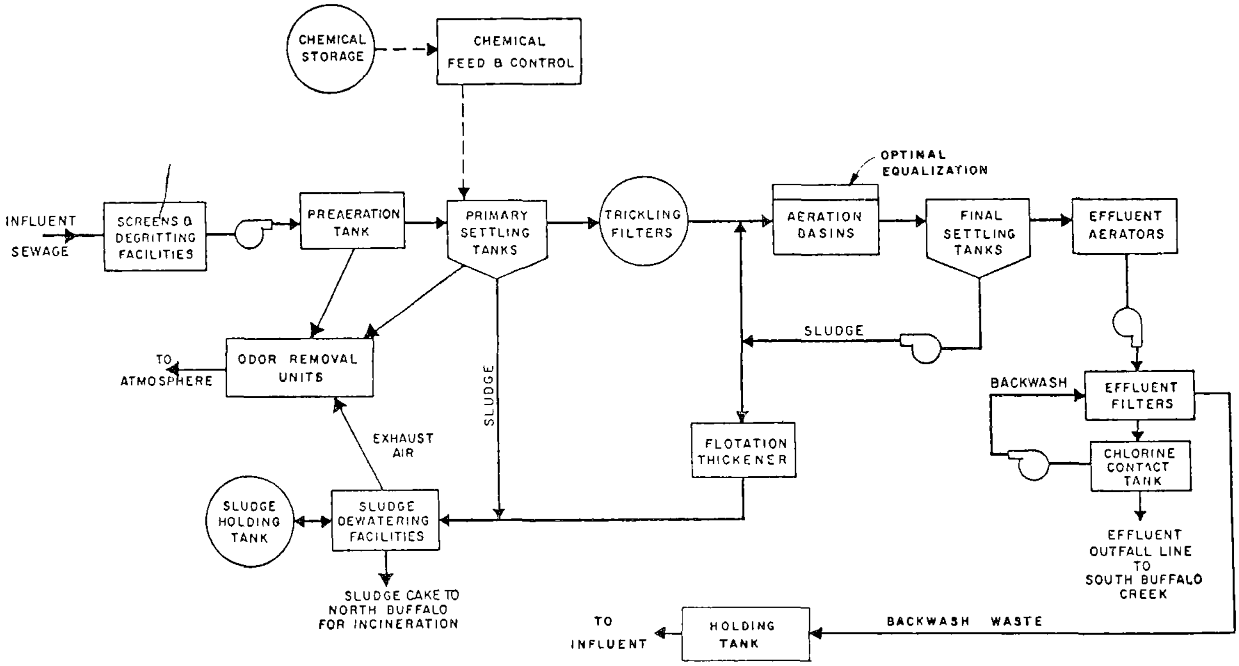

Figure II-4. South Buffalo, current upgrade, flow diagram.

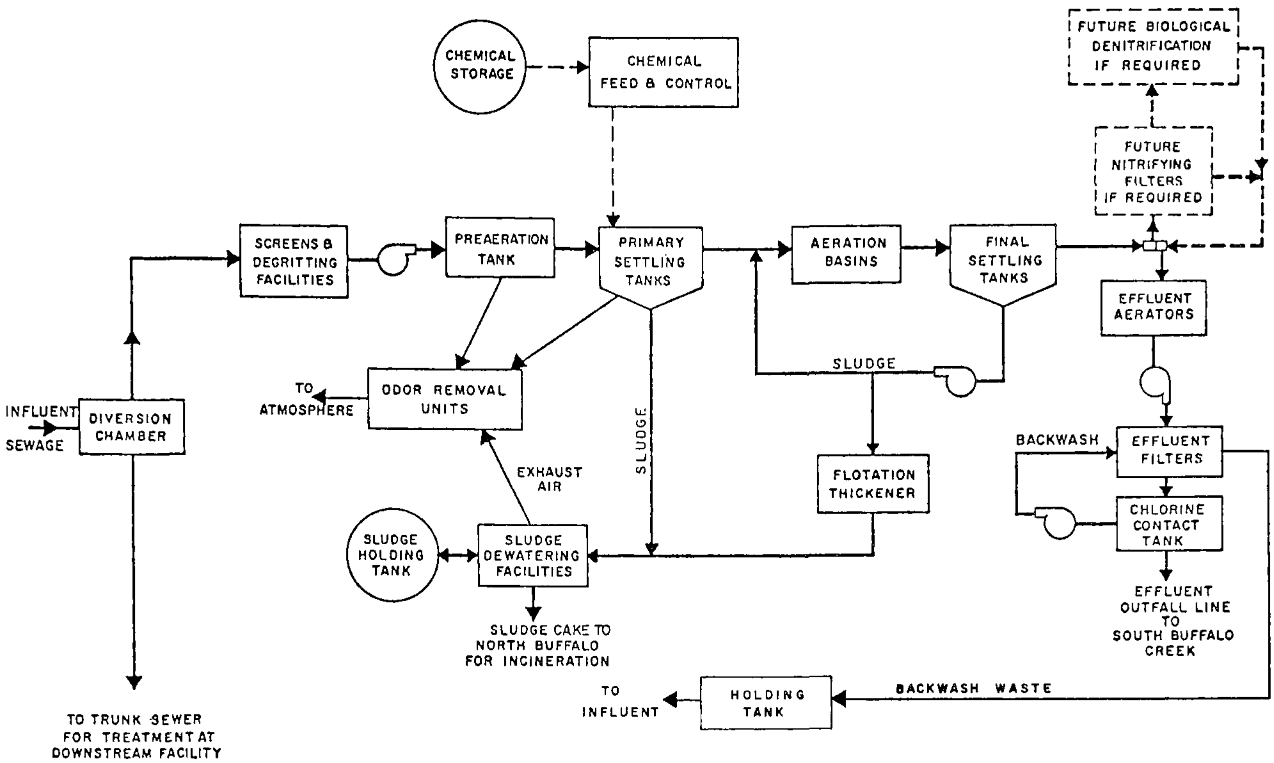

Figure II-5. South Buffalo, future upgrade, flow diagram.

CASE 2. LIVERMORE, CALIF., WASTEWATER TREATMENT PLANT

The Livermore Wastewater Treatment Plant was built in 1958 to provide secondary treatment for a domestic wastewater with an average dry weather flow of 2.5 mgd. The plant included preliminary treatment and roughing filters followed by 30-day oxidation ponds. Sludge was digested, then dewatered in lagoons. Effluent was discharged to an intermittently flowing drainage ditch. See figure II-6 for plant flow diagram and table II-4 for plant design data. Design effluent limitations were 40 mg/l BOD_5 and 40 mg/l SS. The plant achieved effluents with 45-50 mg/l BOD_5 and 45-50 mg/l SS, with no significant nitrification.

The plant was enlarged in 1967 to provide an increased degree of treatment for an average dry weather flow of 5 mgd. All existing structures were incorporated in the upgraded plant. The new plant includes preliminary treatment, roughing filters, activated-sludge secondary treatment, and pre- and postchlorination. The former oxidation ponds have been converted to the emergency holding ponds. The existing sludge-disposal system was expanded. Part of the effluent (about 20 percent) is used to irrigate a municipal golf course, an airport, and adjacent farmland. See figure II-7 for plant flow diagram and table II-5 for plant design data. Effluent limitations (Regional Water Quality Control Standards) were 20 mg/l BOD_5, 20 mg/l SS, 1 mg/l grease, 5 MPN per 100 ml coliforms (using 5-day median). The plant easily meets these standards (see table II-6 for operating data). Complete nitrification must be provided to achieve the low effluent baterial count (if nitrification is not complete, chlorine demand is inordinate because of chloramine formation, and inadequate free chlorine remains to effect the requisite high levels of disinfection).

The initial plant had a capital cost of $900,000 (1957 dollars), and an annual operating cost of $102,000 (1968 dollars). Capital cost of the expansion was $1,300,000 (1968 dollars). Annual operating cost is $270,000 (1972 dollars). Unit capital costs of upgrading are $520,000 per mgd of increased capacity, or $186 per pound per day of additional BOD_5 removal.

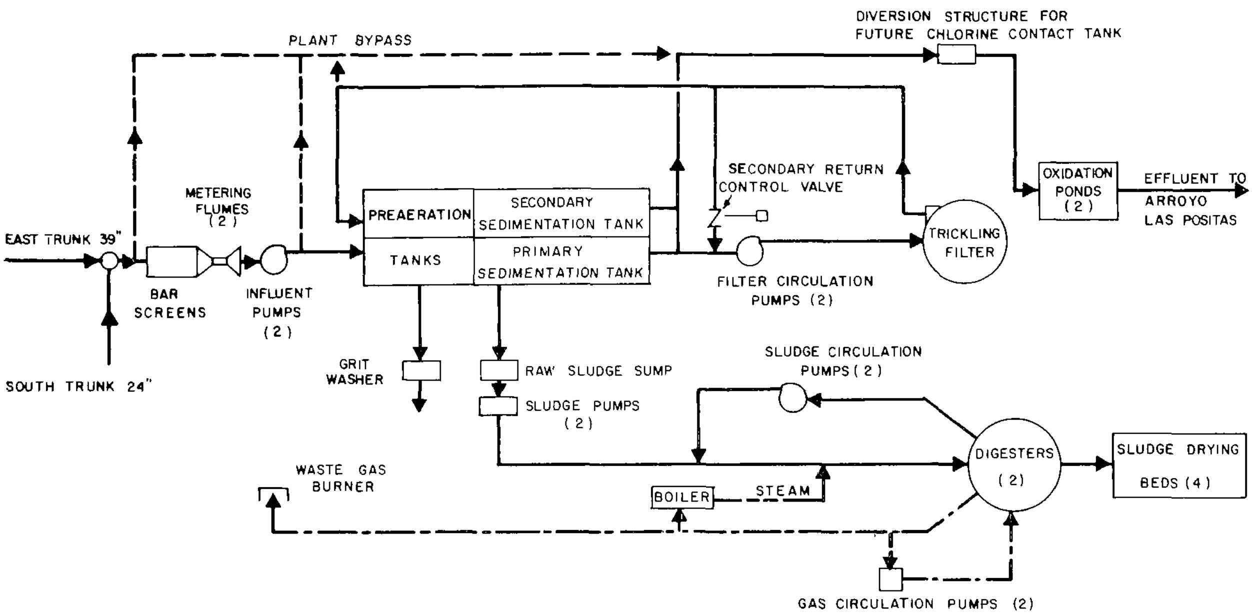

Figure II-6. Livermore Wastewater Treatment Plant, flow diagram, 1958.

Table II-4.—*Livermore Wastewater Treatment Plant design data, 1958*

Design flow, mgd:	
Average dry weather	2.5
Maximum dry weather	4.5
Peak storm rate	10
Design loadings:	
Population equivalent	28,900
SS, lb/day:	
Per capita	0.15
Design total	4,500
BOD, lb/day:	
Per capita	0.20
Design total	6,500
Preaeration tanks:	
Number[a]	2
Width, feet	19
Length, feet	38
Average water depth, feet	11.7
Detention time, hours (one tank)	0.6
Air supplied per tank, ft^3/min[b]	200
Air supplied, ft^3/gal	0.12
Maximum hydraulic capacity, mgd	10

Table II-4.—*Livermore Wastewater Treatment Plant design data, 1958—Concluded*

Primary sedimentation tank:	
Width, feet	19
Length, feet	124
Average water depth, feet	9
Effluent weir length per tank, feet	164
Detention time, hours	1.5
Mean forward velocity, ft/min	1.4
Overflow rate, gal/ft²/day at average dry weather flow	1,050
Maximum hydraulic capacity of tank, mgd	10
Assumed removal, percent:	
SS	60
BOD	35
Secondary sedimentation tank[c]	(3)
Trickling filter:	
Inside diameter, feet	110
Average depth of filter media, feet	4.25
Size of filter media, inches	2-4
Net area of filter surface, acres	0.218
Volume, acre-ft	0.92
Circulation ratio to average design dry weather flow	1.5-3
Loading:	
Rate per filter, mgd	7.5
Rate per surface acre, mgd	34.5
BOD, lb/day/acre-ft	4,600
Assumed removal, percent, filter plus secondary sedimentation:	
SS	60
BOD	75
Oxidation ponds:	
Total area, acres	37
Average water depth, feet	6
Detention time, days	30
BOD loading, lb/acre/day	28

[a]One preaeration tank used to aerate trickling-filter effluent prior to secondary sedimentation.
[b]200 ft^3/min supplied to primary aeration tank and 100 ft^3/min supplied to secondary aeration tank.
[c]Details as for primary, except removals.

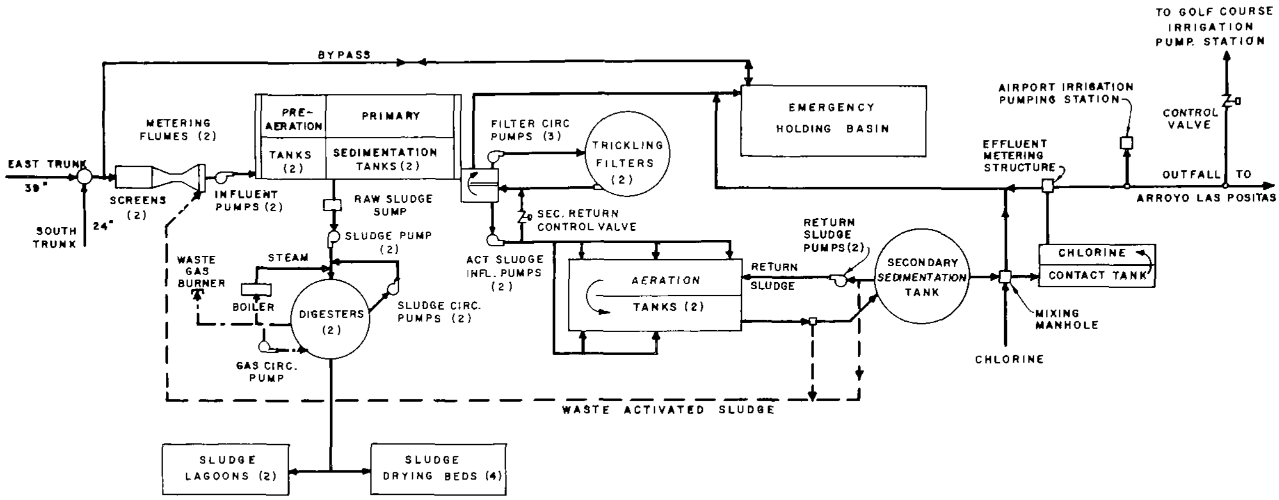

Figure II-7. Livermore Wastewater Treatment Plant, flow diagram, 1968.

Table II-5.—*Livermore Wastewater Treatment Plant, design data, 1968*

Design flow, mgd:	
Average dry weather	5
Maximum dry weather	10
Peak storm rate	18
Design loadings:	
Population equivalent	62,500
SS, lb/day:	
Per capita	0.20
Total	12,500
BOD, lb/day:	
Per capita	0.20
Total	12,500
Preaeration tanks:	
Number	2
Width, feet	19
Length, feet	38
Average water depth, feet	11.7
Detention time, hours.	0.6
Air supplied per tank, ft^3/min.	150
Hydraulic capacity, mgd	10
Primary sedimentation tanks:	
Number	2
Width, feet	19
Length, feet	124
Average water depth, feet	9
Effluent weir length per tank, feet.	164
Detention time, hours.	1.5
Mean forward velocity, ft/min.	1.4
Overflow rate, gal/ft^2/day at average dry weather flow	1,050
Hydraulic capacity, mgd	10

Table II-5.—*Livermore Wastewater Treatment Plant, design data—Continued*

Primary treatment:	
Assumed SS reduction, percent	60
SS reduction, lb/day	7,500
Assumed BOD reduction, percent	35
BOD reduction, lb/day	4,400
Trickling filters:	
Number	2
Inside diameter, feet	110
Average depth, filter media, feet	4.25
Size of filter media, inches	2-4
Net area of filter surface, acres	0.218
Volume, acre-ft per filter	0.92
Circulation ratio to average dry weather flow	1.5-3
Loading:	
Rate per filter, mgd	7.5
Rate per surface acre, mgd	34.5
BOD, lb/day/acre-ft	4,400
Assumed BOD removal, percent	50
BOD reduction, lb/day	4,000
Activated sludge aeration tanks:	
Number	2
Average water depth, feet	15
Width, feet	30
Length, feet	160
Detention time, hours, based on raw sewage flow	5.2
Air supplied, ft^3/lb BOD removed, ft^2/min	1,200
Volume per tank, ft^3	72,000
Volumetric loading, lb BOD per 1,000 ft^3	28
Return sludge, percent	10-100
Secondary sedimentation tanks:	
Number	1
Diameter, feet	90
Side water depth, feet	12
Detention time, hours, based on average dry weather flow	2.75
Overflow rate, gal per ft^2 per day at average dry weather flow	787
Activated sludge treatment:	
Assumed SS reduction, percent	88
SS reduction, lb/day	4,400
Assumed BOD reduction, percent	86
BOD reduction, lb/day	3,500
Overall plant performance:	
Assumed SS reduction, percent	96
Assumed BOD reduction, percent	96
Effluent SS, mg/l	15
Effluent BOD, mg/l	15

Table II-5.—*Livermore Wastewater Treatment Plant, design data, 1968—Concluded*

Chlorine contact tank:	
Volume, ft^3	28,000
Detention time at average dry weather flow, hours	1

Table II-6.—*Livermore Wastewater Treatment Plant, operating data, 1971*[a]

Item	Raw influent	Primary effluent	Trickling-filter effluent	Secondary effluent	Plant effluent
BOD, mg/l:					
Mean	213	127	93	9.9	7.3
High	244	156	129	16.9	12.4
Low	167	106	46	5.2	3.1
SS, mg/l:					
Mean	229	79	110	22	13
High	261	98	137	31	19
Low	187	60	74	15	8
Ammonia N, mg/l:					
Mean		40.7	32.6	1.68	.14
High		51.1	44.4	6.73	1.3
Low		33.8	22.5	.46	<.1
Nitrate N, mg/l:					
Mean				18.5	21.5
High				20.2	30
Low				16.6	14
Grease, mg/l:					
Mean					.23
High					.46
Low					.15
Coliforms, MPN per 100 ml:					
Mean					2.5
High					[b]7
Low					.4

[a]Monthly average. If value not given, item not tested for.

[b]When coliform count exceeded 5 MPN per 100 ml, flow diverted to emergency holding pond. Discharge not resumed until count of less than 5 achieved.

CASE 3. STOCKTON, CALIF., REGIONAL WASTE WATER CONTROL FACILITY

To receive increased flows and meet new requirements established by the California Central Valley Regional Water Quality Control Board, the Stockton, Calif., Regional Waste Water Control

Facility is currently being upgraded in several ways. Improvements include the construction of three plastic media trickling filters (fig. II-8), each 166 feet in diameter and 21.5 feet deep. These replace three of six rock filters, each 166 feet in diameter and 4.2 feet deep. The filters operate in two modes.

- During the fruit and vegetable canning season (approximately July through September) when the organic loading is high, the filters oxidize carbonaceous matter only with an expected 5-day BOD removal of 70 percent.

- During the noncanning season when the organic loading is low, approximately 90 percent of the carbonaceous BOD is removed, and ammonia-nitrogen is converted to the nitrate form (nitrified).

The new water quality requirements for the Stockton plant include a provision that restricts the total nitrogen concentration in the receiving water to less than 3 mg/l. During the summer canning season, the various forms of nitrogen, primarily ammonia, will be substantially removed by oxidation ponds through conversion to algal cells with subsequent algae removal in a tertiary facility. During the noncanning season, when the algal activity level is lower, the nitrate formed in the trickling filters will be converted to nitrogen gas through microbial denitrification in the ponds. During the transition periods between the two seasons, breakpoint chlorination will be used for ammonia removal. A flow diagram for the upgraded Stockton plant is shown in figure II-9 and design data are shown in table II-7.

Plant Modifications

Conversion of the existing rock media filters to plastic media involved several additional changes at the plant. To enclose the plastic media, the trickling filter walls were raised from a height of 5.0 feet to 27.5 feet. To avoid excessive weight on the existing walls and foundation, open-block construction was used rather than poured concrete. Forced-draft ventilation was used in the upgraded filters; this approach required enclosing the existing effluent channels and air vents along the bottom of the filter walls to insure that the air introduced into the filter underdrain area would be contained and directed up through the filter media. As part of the forced-draft ventilation system, foul air will be delivered from the headworks (as a part of later modifications) and directed through the trickling filter for deodorization. A new filter underdrain system was installed, with the bottom of the plastic media approximately 3 feet above the floor of the filter.

The higher flow capacity of the modified trickling filters required additional modifications in the form of larger distributors and increased recirculation pumping capacity. Trickling filter influent supply pumps were installed because, although the previous rock filters had been fed by gravity, the height of the plastic filters required pumping. The trickling filter distribution structure, which receives primary effluent, recycles trickling filter effluent, and delivers trickling filter effluent to the secondary clarifiers, had to be modified substantially to handle the increased flows and the combined operation of rock and plastic media filters. Finally, a second pipeline from the filter distribution structure to the secondary clarifier distribution structure was constructed.

Plant Performance

The Stockton plant has been operating with three plastic media filters and three rock media filters since 1973. Table II-8 shows BOD and SS removal for canning and noncanning seasons for

Figure II-8. Plastic-media trickling filters (background), constructed using foundations and structures of existing rock-media filters (foreground).

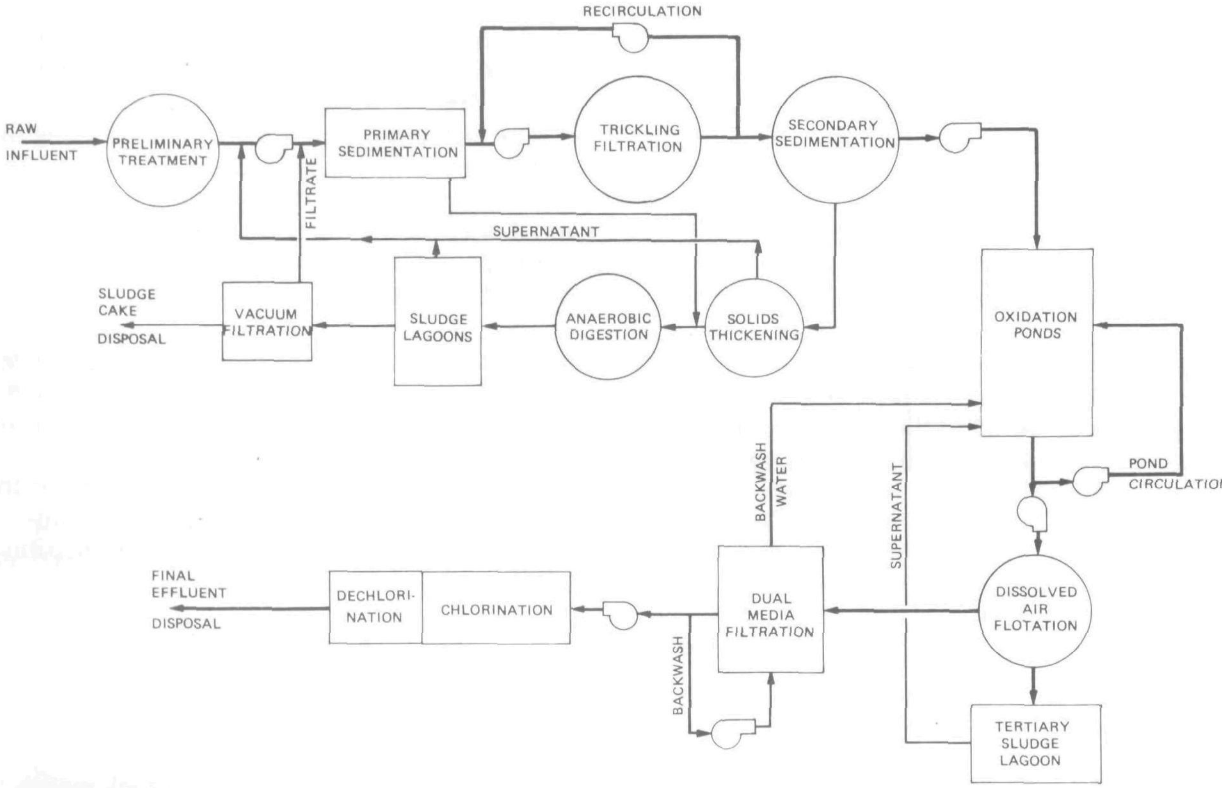

Figure II-9. Stockton Regional Waste Water Control Facility flow diagram.

Table II-7.—*Stockton Regional Waste Water Control Facility: Preliminary, primary, and secondary treatment, design data*

Parameter	Value
Flow, mgd:	
Noncanning season:	
Average dry weather flow (ADWF)	23
Peak storm rate	60
Canning season:	
Maximum month	58
Peak rate	75
Loadings, 1,000 lb/day:	
BOD:	
Noncanning season, maximum month	54
Canning season, maximum month	236
SS:	
Noncanning season, maximum month	31
Canning season, maximum month	167
Preliminary treatment:	
Bar screens: Number	3
Grift channels:	
Number	6
Velocity at 64 mgd, ft/sec	1.4
Metering flumes:	
Number	6
Throat width, feet	2.0
Hydraulic capacity, each, mgd	20
Raw sewage pumps:	
Number	4
Total capacity, mgd	116
Primary treatment:	
Rectangular tanks:	
Number	4
Width, feet	37
Length, feet	141
Depth, feet	15
Square tanks:	
Number	2
Width/length, feet	70
Depth, feet	14
Detention time, all tanks, hours:	
Noncanning season, ADWF	3.4
Canning season, maximum day	1.2
Overflow rate, all tanks, gpd/ft^2:	
Noncanning season, ADWF	800
Canning season, maximum day	2,200
Removal, percent:	
Noncanning season:	
BOD	40
SS	65

Table II-7.—*Stockton Regional Waste Water Control Facility: Preliminary, primary, and secondary treatment, design data—Concluded*

Parameter	Value
Canning season:	
BOD	20
SS	55
Secondary treatment:	
Rock-media trickling filters:	
Number	3
Diameter, feet	166
Media depth, feet	4.2
Total volume, 1,000 ft^3	270
Total hydraulic capacity, mgd	30
Plastic-media trickling filters:	
Number	3
Media depth, feet	22
Total volume, 1,000 ft^3	1,430
Total hydraulic capacity, mgd	72
Total volume, rock and plastic media, 1,000 ft^3	1,700
Recirculation pumping capacity, mgd	76
Unit loading, lb BOD per 1,000 ft^3/day:	
Noncanning season, ADWF	20
Canning season, maximum month	110
Secondary sedimentation tanks:	
Number	4
Diameter, feet	100
Side water depth, feet	12
Detention time, hours:	
Noncanning season, ADWF	2.9
Peak storm rate	1.1
Canning season, maximum day	1.0
Overflow rate, gpd/ft^2:	
Noncanning season, ADWF	700
Peak storm rate	1,900
Canning season, maximum day	2,100
Secondary treatment performance:	
Noncanning season:	
BOD removal, percent	90
Effluent BOD, mg/l	17
Effluent SS, mg/l	20
Canning season:	
BOD removal, percent	70
Effluent BOD, mg/l	120
Effluent SS, mg/l	35

1974 and 1975. Trickling filter BOD removals averaged 80 percent for the canning season and 89 percent for the noncanning season, based on primary effluent BOD concentrations of 410 and 229 mg/l, respectively.

Table II-8.—*Stockton Regional Waste Water Control Facility, performance summary*

Loading condition and year	Flow, mgd	BOD, mg/l: Raw influent	BOD, mg/l: Primary effluent	BOD, mg/l: Secondary effluent	Trickling-filter loading, lb BOD/1,000 ft^3/day[a]	BOD removal, percent: Secondary	BOD removal, percent: Primary plus secondary	SS, mg/l: Raw influent	SS, mg/l: Primary effluent	SS, mg/l: Secondary effluent	Primary plus secondary SS removal, percent
Canning season:[b]											
1974	38.2	472	413	89	79	78	81	488	88	53	89
1975	38.3	529	407	107	78	74	80	510	73	60	88
Average	38.2	500	410	98	78	76	80	499	80	56	88
Noncanning season:[c]											
1974	17.1	371	257	43	22	83	88	220	60	32	85
1975	15.3	303	200	29	15	85	90	243	52	32	87
Average	16.2	337	229	36	18	84	89	232	56	32	86

[a]Volume includes three rock-media plus three plastic-media filters.
[b]August and September.
[c]January-June, November, and December.

Secondary effluent concentrations in table II-8 represent the combined performance of rock and plastic media trickling filters. More pertinent data on plastic media trickling filtration were developed in 1972, when a pilot study was undertaken at Stockton to test the (then) proposed trickling filters.[1] A pilot trickling filter was operated to simulate three full-scale filters receiving Stockton's wastewater, with the purpose of determining BOD removals and nitrification efficiency.

Figure II-10 shows BOD removal versus loading for the pilot filter under loadings ranging from about 10 pounds BOD per 1,000 ft^3/day to over 200 pounds BOD per 1,000 ft^3/day. Observed removals agreed quite well with design removals; 90 percent at 25 pounds BOD per 1,000 ft^3/day during the noncanning season and 70 percent at 135 pounds BOD per 1,000 ft^3/day during the canning season.

Because the plastic media trickling filters are intended to remove ammonia during the non-canning season, information was sought during the pilot study on the nitrification efficiency of the filters. Table II-9 presents pilot study nitrification results for two loading conditions: light organic loading, 14 pounds BOD per 1,000 ft^3/day, and the design organic loading, 22 pounds BOD per 1,000 ft^3/day. Effluent ammonia-nitrogen concentrations averaged 1.0 mg/l for the former loading and 2.0 mg/l for the latter. Organic nitrogen removal was low, reflecting the short contact times in the trickling filter.

Cost and Schedule

The construction cost for modifying the Stockton secondary treatment facilities was about $3,700,000, and included converting three filters to plastic media, modifying the trickling filter distribution structure, and adding to piping and pumping capacity. Construction was started in January 1973, and the first of the three plastic media filters was placed in operation in July 1973 before the start of the canning season. The other two filters were placed in operation near the end of 1973.

CASE 4. SACRAMENTO, CALIF., CENTRAL WASTEWATER TREATMENT PLANT

In early June 1973, the County of Sacramento, Calif., requested that the joint venture of the consulting engineering firms of Dewante and Stowell and Brown and Caldwell determine what could be done to improve the operation of its Central Wastewater Treatment Plant. This 25-mgd, complete-mix activated sludge plant, which discharges its effluent into the Sacramento River, had been unable to meet disposal requirements during the spring of 1973 at flows of less than 15 mgd, and had indicated a complete inability to handle seasonal wastes from the local canning industry during the previous years. The major concern in the early summer of 1973 was whether the canneries would be forced to curtail their 1973 operations because of the County's inadequate sewage treatment capabilities.

The description of the problems involved in the activated sludge process, the modifications undertaken for their correction, the methods employed to complete these modifications before the canning season, and the operational results of the corrections provide insight into the design and operation of a successful activated sludge process. The experience related herein provides an opportunity to observe the reaction of a major activated sludge treatment plant to process changes. It presents the designer and operator with conclusions that have direct applicability to other full-scale situations.

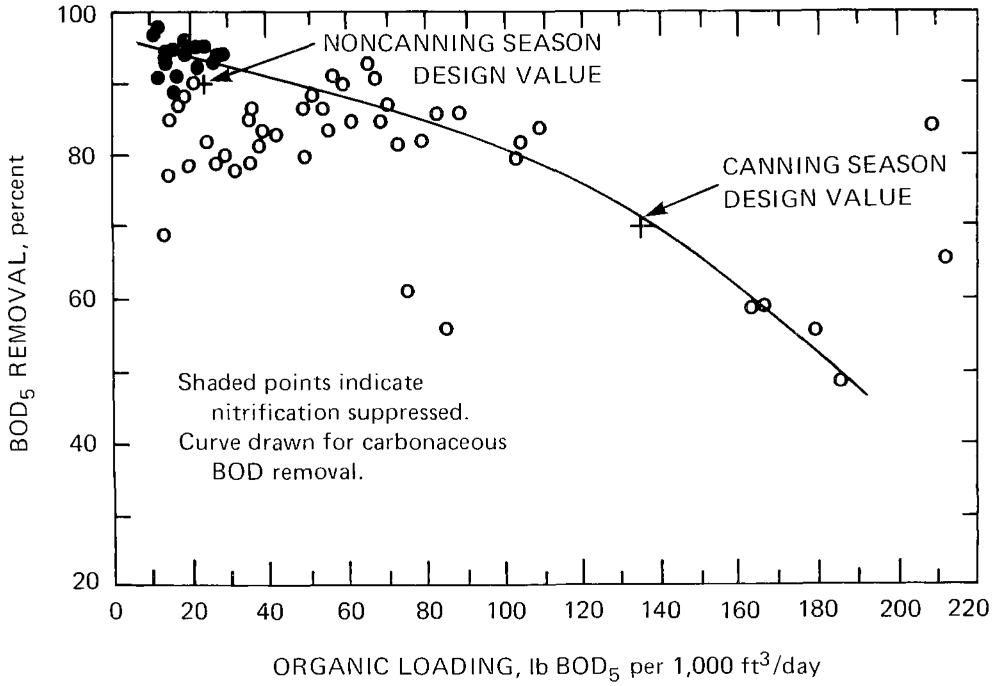

Figure II-10. Stockton pilot trickling-filter performance.

Description of Plant

The Central Wastewater Treatment Plant began operating in 1960 as a trickling filter plant with a design capacity of 8 mgd. In 1964, the plant was upgraded when two oxidation ponds for further treatment of the plant effluent were installed. The plant was expanded in 1969 to its present capacity and converted to the complete-mix activated sludge process.

On July 1, 1972, one-half of the flow of County Sanitation District No. 1 was diverted from the city of Sacramento main plant to the central plant. This flow included approximately 4 mgd of a 5-day-per-week industrial waste, about 23,000 pounds per day (based on dry-solids) of digested primary sludge and waste activated sludge transferred from other plants within the county's system, and up to 8 mgd of seasonal cannery wastes. In 1973, these cannery wastes were found to include over 7 tons per day of mostly inert solids (mud). Much of this mud was infected with filamentous *Thiothrix* organisms, which caused bulking in the activated sludge process. The 1972 diversion increased the plant's average annual flow to almost 15 mgd, and marked the beginning of many operational problems.

Table II-9.—*Steady-state nitrification results, Stockton pilot trickling-filter study*

Date	Loading, lb BOD/1,000 ft^3/day	Concentration, mg/l				Removal, percent	
		Influent		Effluent			
		NH_3-N	TKN[a]	NH_3-N	TKN[a]	NH_3-N	TKN[a]
Oct. 23, 1972 to Nov. 21, 1972	14	16.5	27.8	1.0	9.9	94	64
Nov. 27, 1972 to Dec. 13, 1972	22	17.5	28.9	2.0	11.0	89	62

[a]TKN = total Kjeldahl nitrogen = ammonia-nitrogen plus organic nitrogen.

Treatment at the central plant in June 1973 consisted of primary sedimentation in two clarifiers, each 100 feet in diameter and 8 feet deep; carbonaceous oxidation in four $120{,}900\text{-ft}^3$, complete-mix activated sludge aeration bays; secondary sedimentation in four clarifiers, each 115 feet in diameter and 12.5 feet deep; and effluent polishing (as required) by the two 14-acre tertiary oxidation ponds. Chlorination was provided for pretreatment odor control and posttreatment disinfection. The chlorination system was not enlarged in 1969, but its capacity and flexibility were upgraded during the summer of 1973 to provide additional treatment capacity and to allow use of chlorine for bulking control with the return activated sludge system.

Operations Before Modifications

In May 1973, the central plant treated 13.8 mgd with an influent concentration of 297 mg/l BOD and 321 mg/l SS. Plant effluent for the month averaged 27 mg/l BOD and 49 mg/l SS, for a 90.2- and 84.7-percent removal efficiency, respectively. More important, daily effluent concentrations for BOD and SS exceeded 90 mg/l three times, and the monthly effluent concentration for SS exceeded 30 mg/l. SVI's for the month averaged 360 mg/l. Effluent variability made it impossible to maintain reliable disinfection. On June 4, 1973, the State regulatory agency responsible for monitoring plant effectiveness indicated concern over plant operations and expressed a determination to set new waste discharge requirements that would necessitate immediate improvements.

Major Problems With Existing Operations

Three major problem areas were apparent. These were

- The unstable activated-sludge process
- The inadequate solids processing and disposal system
- The unknown magnitude of industrial waste loadings

Except to note how these last two items relate directly to the operation of the activated sludge process, this case history deals only with the successful upgrading of the activated sludge system.

Activated Sludge Process Problems

Six problems affected the stability of the activated sludge system.

- Inability of plant aeration and settling components to operate as a single system.
- Inadequate control of return activated sludge (RAS) rates
- Inability to maintain regulated waste activated sludge (WAS) rates
- Lack of chemical feed facilities to improve mixed liquor settling and control filamentous growths
- Difficulty in maintaining sufficient dissolved oxygen (DO) in the aeration tanks
- Variability of mixed liquor flows to final clarifiers

The magnitude of each problem was increased by the interrelationship between the process variables involved.

Single-System Operation. Figure II-11 presents a schematic layout of the activated sludge process flow system at the central plant as of June 1973. As the primary effluent flowed into the aeration bays, distribution was controlled only by the hydraulics of the Y channel and aeration bays and the position of the inlet slide gates. Once the primary effluent was distributed, there was no way, as long as all facilities were in service, for this distribution to be changed or for any intermixing to take place. This was true regardless of the position of the H channel isolating slide gates.

In addition to the isolation caused by the hydraulics of the process flows, the RAS flow from each secondary clarifier was returned only to its related aeration bay (see fig. II-12). This system assured that each aeration-bay/secondary-clarifier combination operated as its own separate activated sludge process. As a result of this loading irregularity and the resulting nonuniformity of the process, the plant operators were faced with the task of operating not one, but three or four activated sludge processes depending on the number of bay-clarifier combinations in service. This was a major obstacle to efficient operation.

RAS Control. In June 1973, RAS flow rates between secondary clarifiers and aeration bays (fig. II-12) were controlled by 12 airlift pumps, 3 in each bay. These pumps were designed to operate directly in the mixed liquor within each bay. The pump discharge weir was located 6 inches below the nominal working water surface of the bay. A sliding splash cover provided both backflow protection when the pump was out of service and the diversion necessary to direct the flow out into the bay when the pump was in operation. No method had been provided to measure the actual quantity of material being pumped through the system. Thus, there was no way the operator could really know the RAS flow. Further, the common air supply meant that whenever the aeration air supply was changed to meet the oxygen requirements within an aeration bay, the airlift pumping rate was also changed.

WAS Control. June 1973 WAS flow rates were designed to be controlled by adjustable, downward-opening slide gates in a common sludge control box (figs. II-12 and II-13). Side streams from each sedimentation tank RAS system were piped to individual compartments within the control box. Each compartment was provided with an isolating inlet mud valve and an adjustable

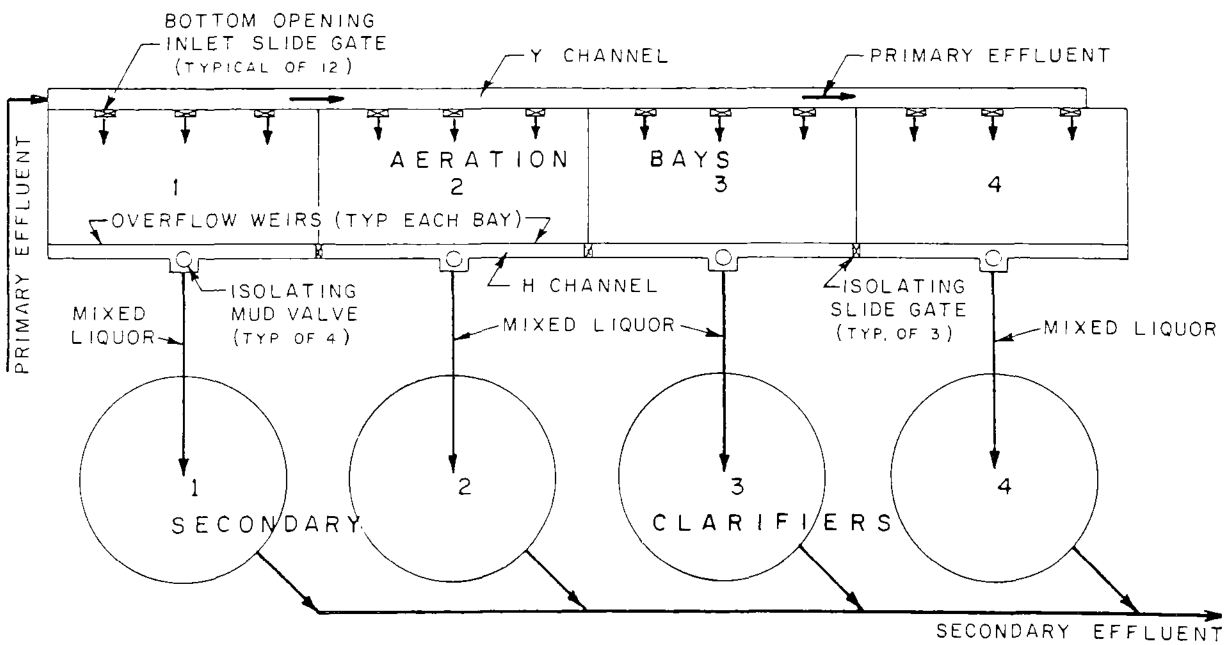

Figure II-11. Schematic layout, Sacramento process flow system.

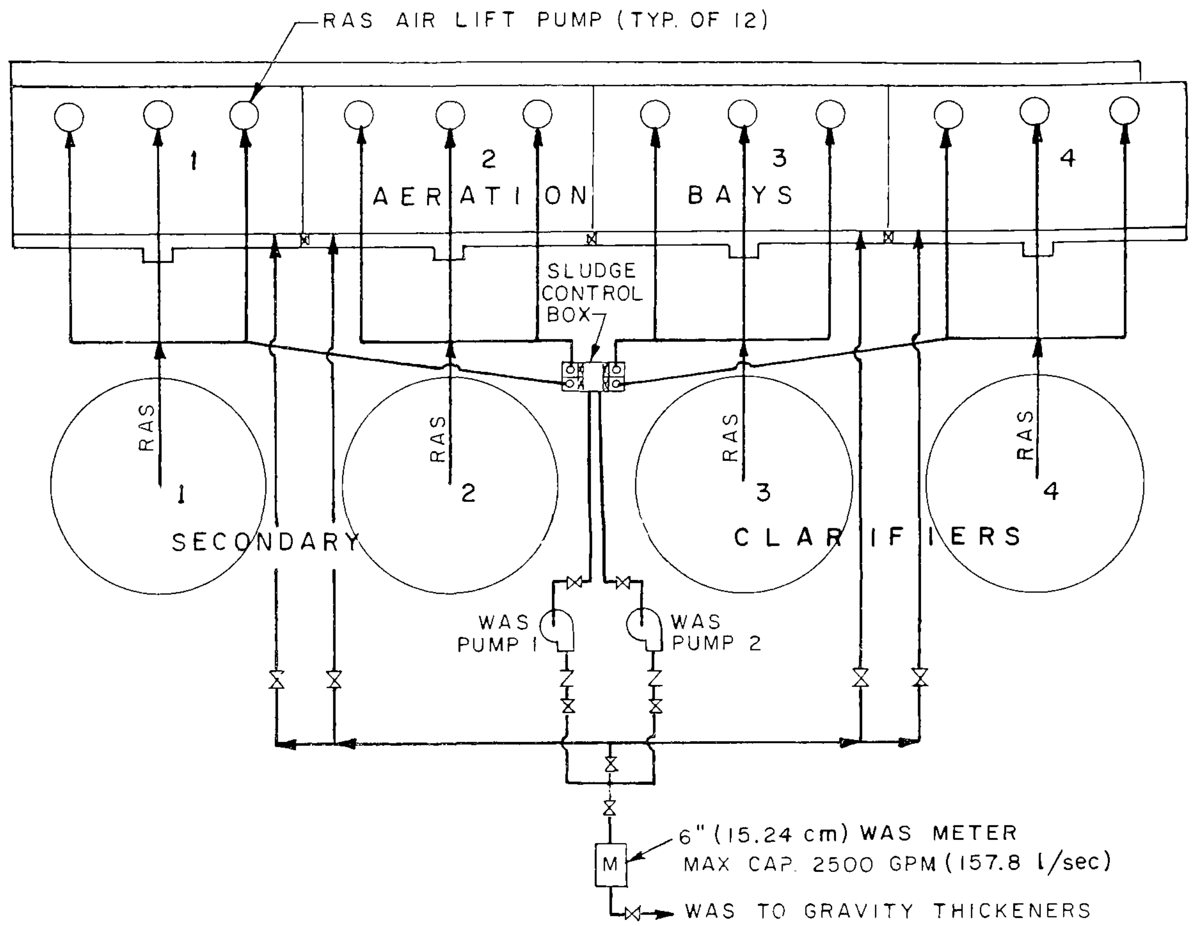

Figure II-12. Schematic layout, solids flow system.

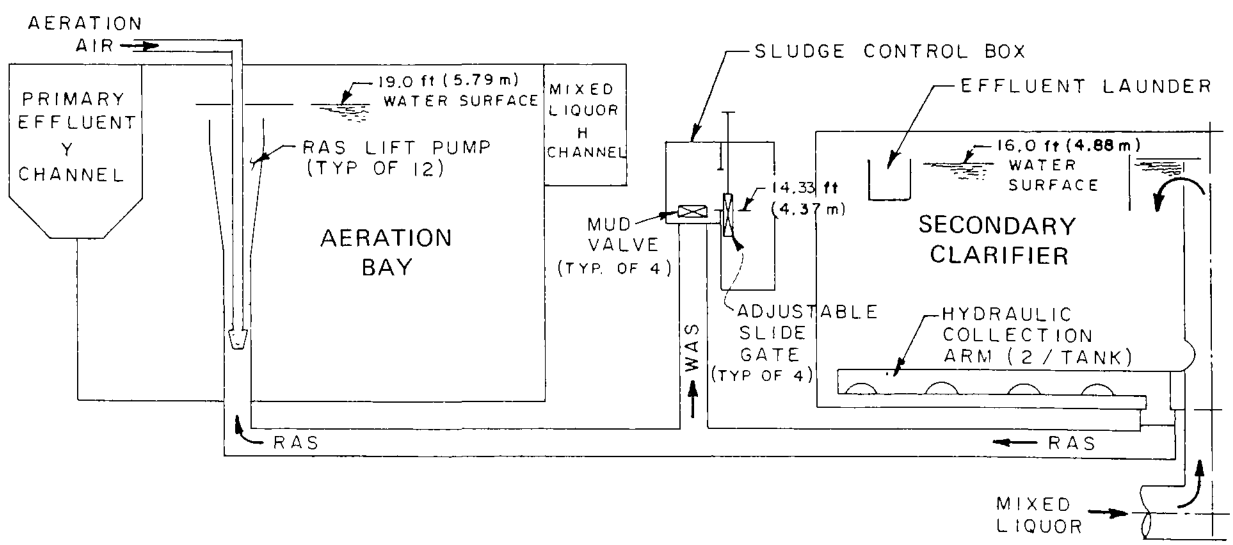

Figure II-13. Hydraulic profile, waste activated sludge removal system.

slide gate. Slide gate discharges were directed to a common control box sump from which two variable speed WAS pumps took suction. WAS pump speed control was regulated by the WAS level in the control box sump. A 6-inch, 2,500-gal/min capacity, magnetic flowmeter was provided to record the WAS pump discharge flow.

WAS side streams from the RAS systems could not be stabilized, and consequently waste rates were impossible to maintain. The hydraulic section shown in figure II-13 indicates how this problem occurred. The hydraulic head in the sludge control box varied in relationship to the quantity of flow being pumped through the RAS system. The friction head loss through the secondary clarifier hydraulic collection arms was said to approach 1.5 feet at a 100-percent RAS flow rate. With the additional pipeline friction involved, it is probable that at the 100-percent rate the head losses to the control box exceeded the 1.67-foot hydraulic limitation necessary to assure WAS flow over the fixed bottom lip to the adjustable slide gate opening.

These conditions, when coupled with the difficulty in determining the rate of RAS flow and in maintaining its stability, made it impossible to keep a uniform WAS flow rate to the gravity thickeners. This, in turn, made it impossible to determine the most efficient way to operate these thickeners. Consequently, the solids treatment and disposal systems were frequently overloaded with dilute waste activated sludge, and the solids retention time within the activated sludge process was uncontrollable.

Chemical Feed Facilities. Except for a minor iron supplement system, no activated sludge chemical feeding facilities were provided at the central plant. By early June, however, a contract had been awarded for the installation of a sludge-bulking-control chlorination system. This work, however, was part of a major modification to the plant's chlorination system and was not scheduled to be in operation until the end of August 1973.

Aeration Air Control. Figure II-14 shows the schematic layout of the air distribution system to one of the four aeration bays. To adjust the air feed to the aeration bays, it was necessary to operate 32 air distribution pipeline valves (8 per bay) and from 4 to 12 RAS airlift pump supply control valves (up to 3 per bay). Unless all valves were adjusted at the same instant, readjustment for a new air feed rate required several readjustments for each valve. Plant operators reported that it was not unusual for them to spend up to 4 hours readjusting the entire system when such a feed-

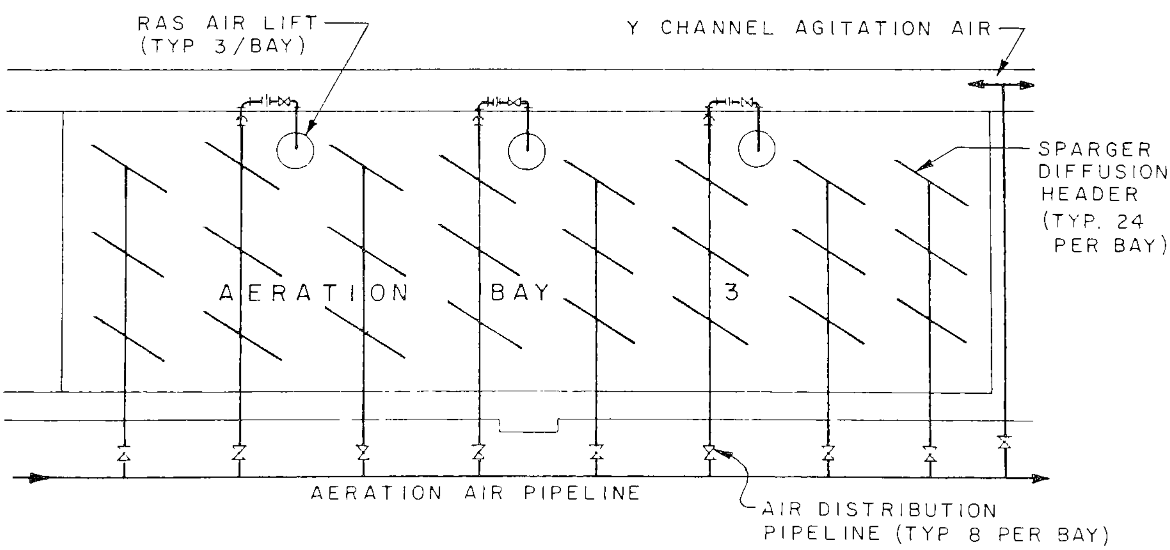

Figure II-14. Schematic layout, aeration air distribution.

rate change was required. As the plant loads often changed significantly over a period of several hours, such feed-rate changes were required often to attempt to operate all systems at optimum efficiency. That the plant was operating as separate, multiple activated sludge plants compounded this problem.

Agitation air for the Y channel was also supplied by the aeration air system and, consequently, was also subject to the variations described above. The Y channel agitation air diffuser was installed about 2 feet off the bottom of the channel and the area beneath the diffuser seemed to be always filled with septic debris. The H channel required no agitation air because it usually operated at a minimum water level.

Final Clarifier Operation. The major immediate problem affecting the plant's effluent quality was the inability of the circular secondary clarifiers to retain the suspended solids (fig. II-15). Several times a week significant quantities of activated sludge were lost with the effluent. This loss, when coupled with the lack of RAS and WAS control, made accurate control of system solids impossible. The clarifiers were sized for a 600-gal/day/ft^2 surface loading at average design loadings of 25 mgd. This is a conservative loading and indicates that the clarifier upsets were either the result of solids overloading within the activated sludge process or that individual clarifiers were receiving much higher surface loadings as a result of hydraulic imbalance caused by variability of mixed-liquor flows. These flows, as indicated earlier, were controlled by the aeration tank influent distribution system and could be radically altered by the unequal operation of the RAS system.

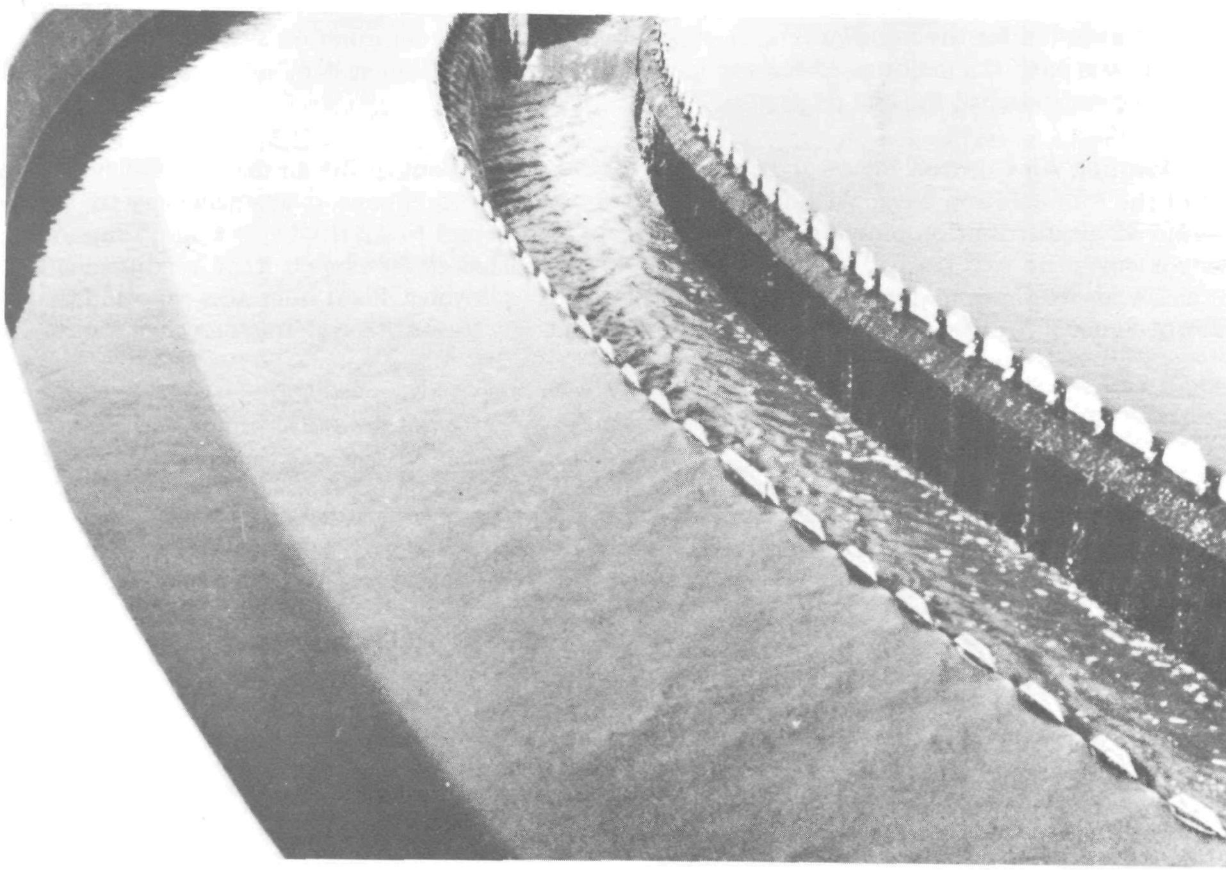

Figure II-15. Secondary Clarifier, June 7, 1973. (Note solids bulking to the surface and overflowing with the effluent on the outer weir surface. Inner weir surface handling only clear effluent. Effluent suspended solids for that day averaged 79 mg/l.)

Process Modifications and Immediate and Subsequent Operation

The need to solve the plant's problems before the canning season started dictated a very tight time schedule and mandated success on the first attempt. Fortunately, most of the modifications were interrelated and, therefore, one solution often helped to solve more than one problem. Because the central plant is scheduled to be abandoned when the new regional system is completed in 1980, any modifications have to last slightly more than 7 years.

Schedule and Cost. Actual construction of the modifications to the activated sludge system commenced with the installation of the H-channel equalizing weirs on July 2, 1973, and ended when the entire plant was placed on a new mode of operation on July 28, 1973. Estimates indicate that the work cost less than $175,000.

Single-System Operation. To assure that the entire plant operated as a single activated sludge system, it was necessary to have the primary effluent and RAS mixed before distribution to the aeration bays and to have all secondary clarifier RAS flows thoroughly intermixed before their reintroduction into the flow stream. How these criteria were met is shown in figures II-16 and II-17.

Aeration bay 1 was transformed into an RAS reaeration bay with new RAS pumps arranged to discharge from each secondary clarifier to the reaeration bay through a common trough. Mixed liquor overflow weirs for aeration bay 1 were blocked and the RAS level in the bay forced to rise until sufficient head was developed to allow the intermixed reaerated RAS to flow out into the primary effluent in the Y channel via the bay's three bottom-opening inlet gates. These gates thus became outlet gates. Normally only the gate nearest to the Y-channel intake operates, thereby assuring maximum mixing with the primary effluent. However, high plant flows or excessive RAS flow rates have occasionally required all three gates to be opened. Additional gates are opened whenever the RAS reaeration bay level becomes excessively high. To assure minimum Y-channel water levels at higher flows, it was necessary to remove the overflow slot weirs from the remaining complete-mix aeration bays, thereby lowering their normal operating level about 6 inches.

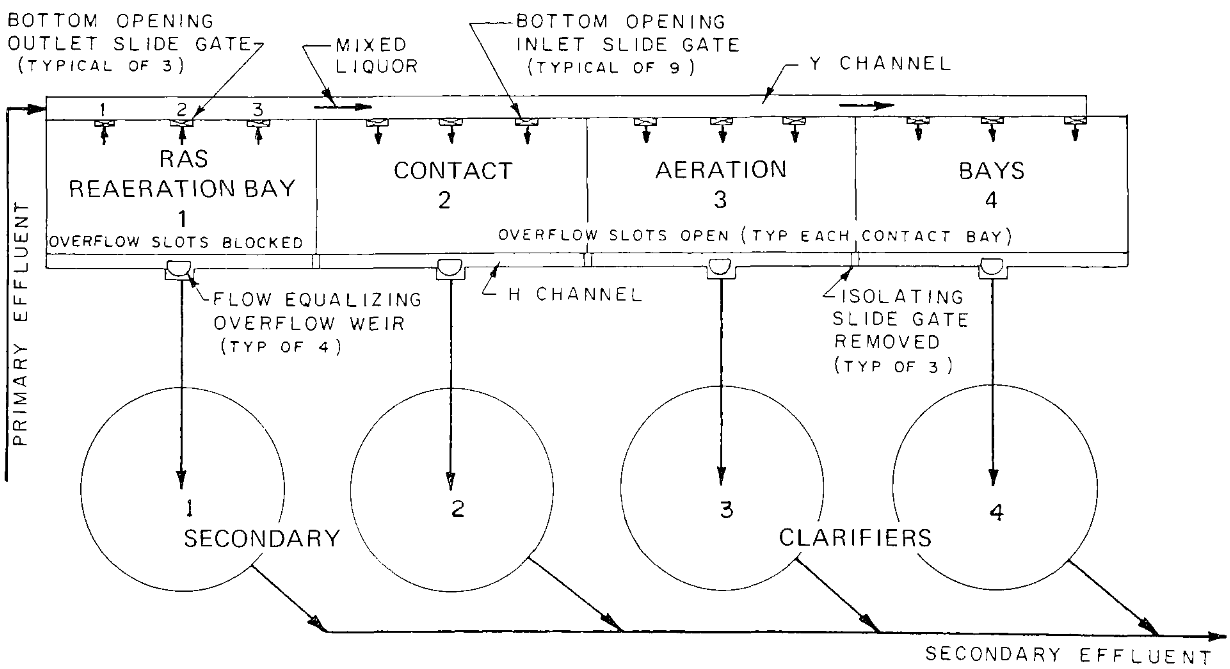

Figure II-16. Schematic layout, revised process flow system.

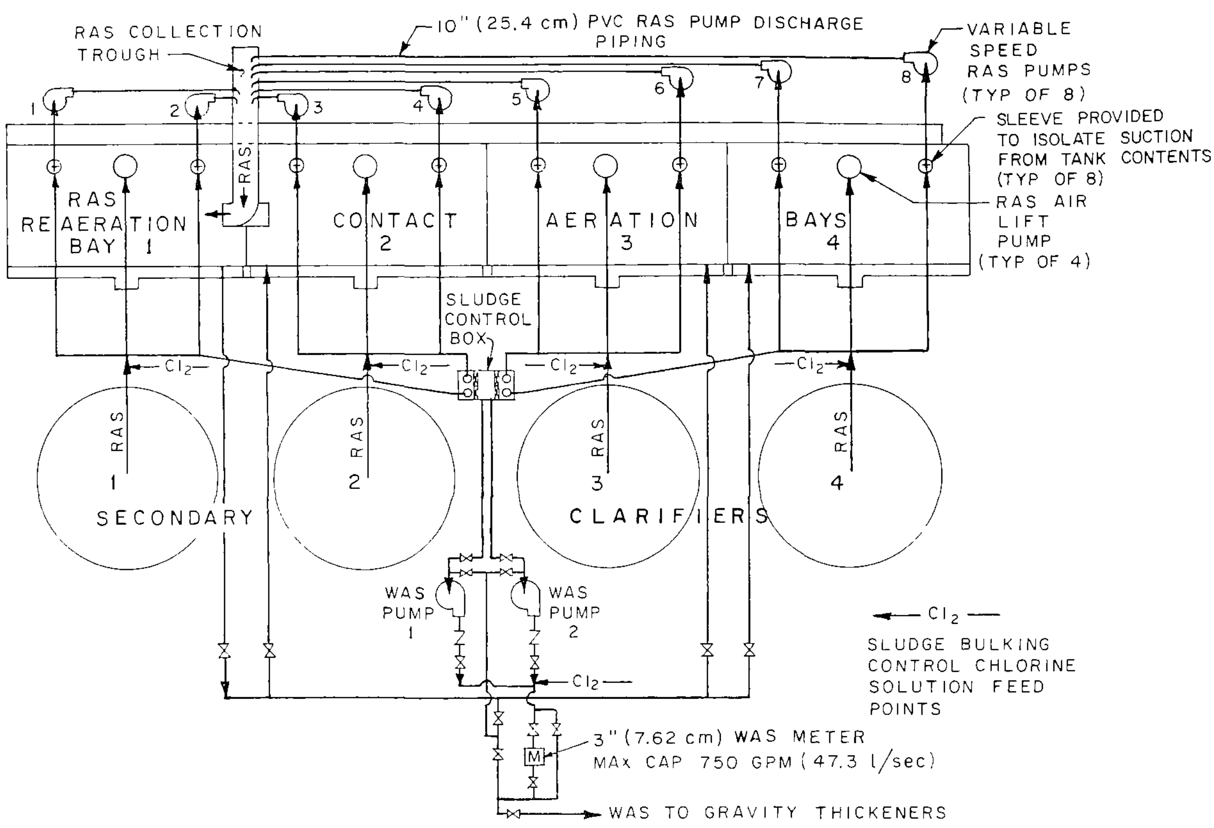

Figure II-17. Schematic layout, revised solids flow system.

With aeration bay 1 being used as an RAS reaeration bay, it was necessary to assure that the remaining three complete-mix aeration bays would distribute their mixed liquor equally to the four secondary clarifiers. This was accomplished by installing special flow-equalizing overflow weirs at each clarifier H-channel inlet (figs. II-18 and II-19). These weirs were fabricated of steel and shaped with one flat side to provide the maximum channel width for the mixed liquor that had to be transferred along the channel to the fourth inlet weir. The mixed-liquor depth within the H channel was raised to about 3 feet. An air agitation system was installed in the H channel to insure against solids deposition. The new distribution system works well, taking full advantage of the H channel depth without causing any backup into the aeration bays.

To insure that the higher water level in the RAS reaeration bay would not cause distribution problems with the aeration air system, the air diffusers within the reaeration bay were raised approximately 12 inches. This modification works extremely well, allowing the bay to operate at peak RAS flows of up to 60 percent of the average daily flow (about 15 mgd) with no distribution upset within the air supply system.

This new mode of operation has created an activated sludge process that performs as a single system capable of operating at higher solid levels, thereby maintaining lower food/micro-organism ratios during peak cannery load periods. The combination of high solids loadings in the RAS reaeration bay and lower normal loadings in the other bays also results in lower solids loadings on the secondary clarifiers, thereby improving their capability to treat bulking sludge and high hydraulic loadings.

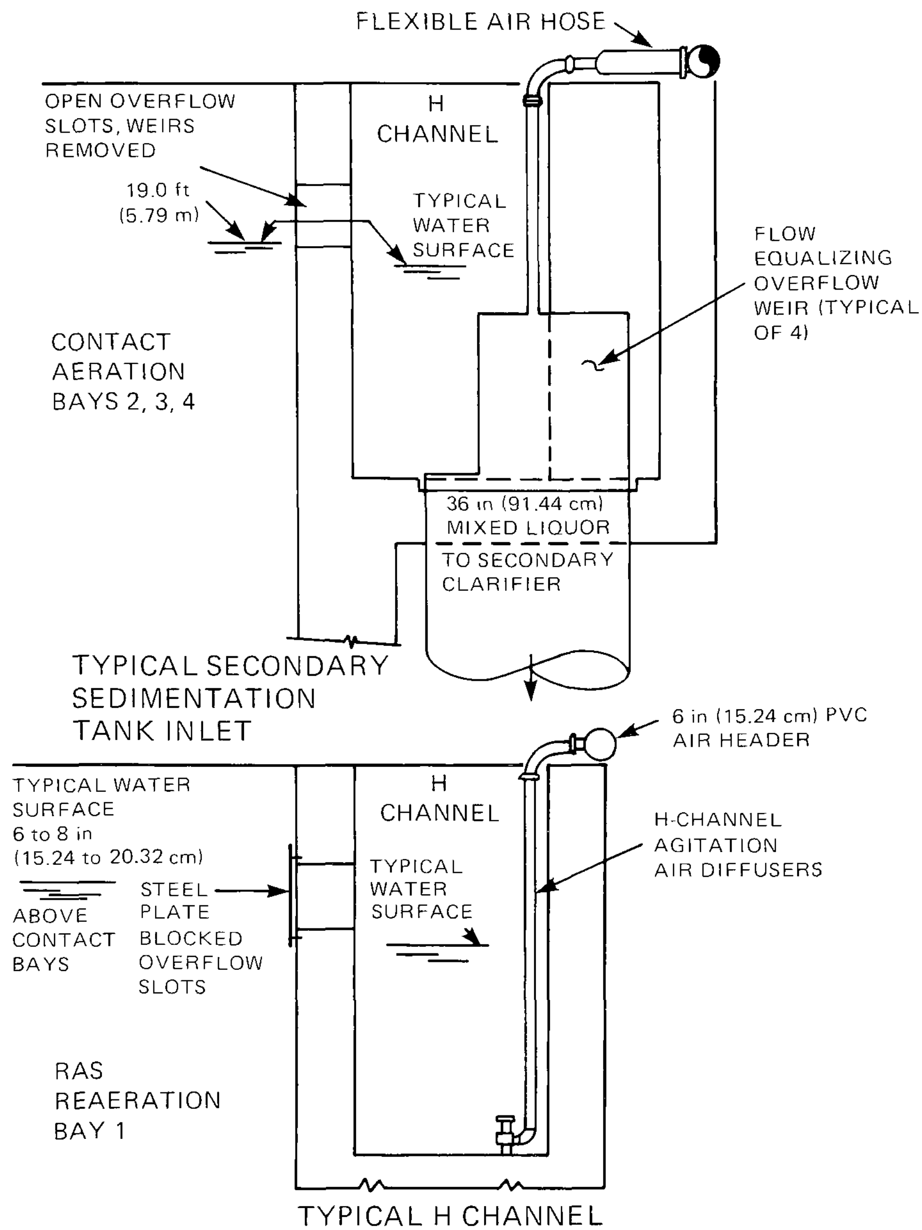

Figure II-18. H-channel cross sections.

RAS Control

Although every attempt was made to determine how the existing airlift pumps could be used to provide the required RAS control and flexibility, no solution could be found. Finally it was decided that, to meet fully the requirements for successful RAS control, at least two independent RAS pumps would have to be installed for each clarifier. Each pump would have to be variable-speed driven and capable of pumping up to 1,400-1,500 gal/min against a total head of about 15 feet. This was a difficult decision to make, because it meant that pumps and variable drives would have to be purchased and installed within a very short time.

Once the decision was made, however, an immediate search tried to locate equipment that could be delivered on or before the end of July Self-priming, nonclogging contractor pumps were

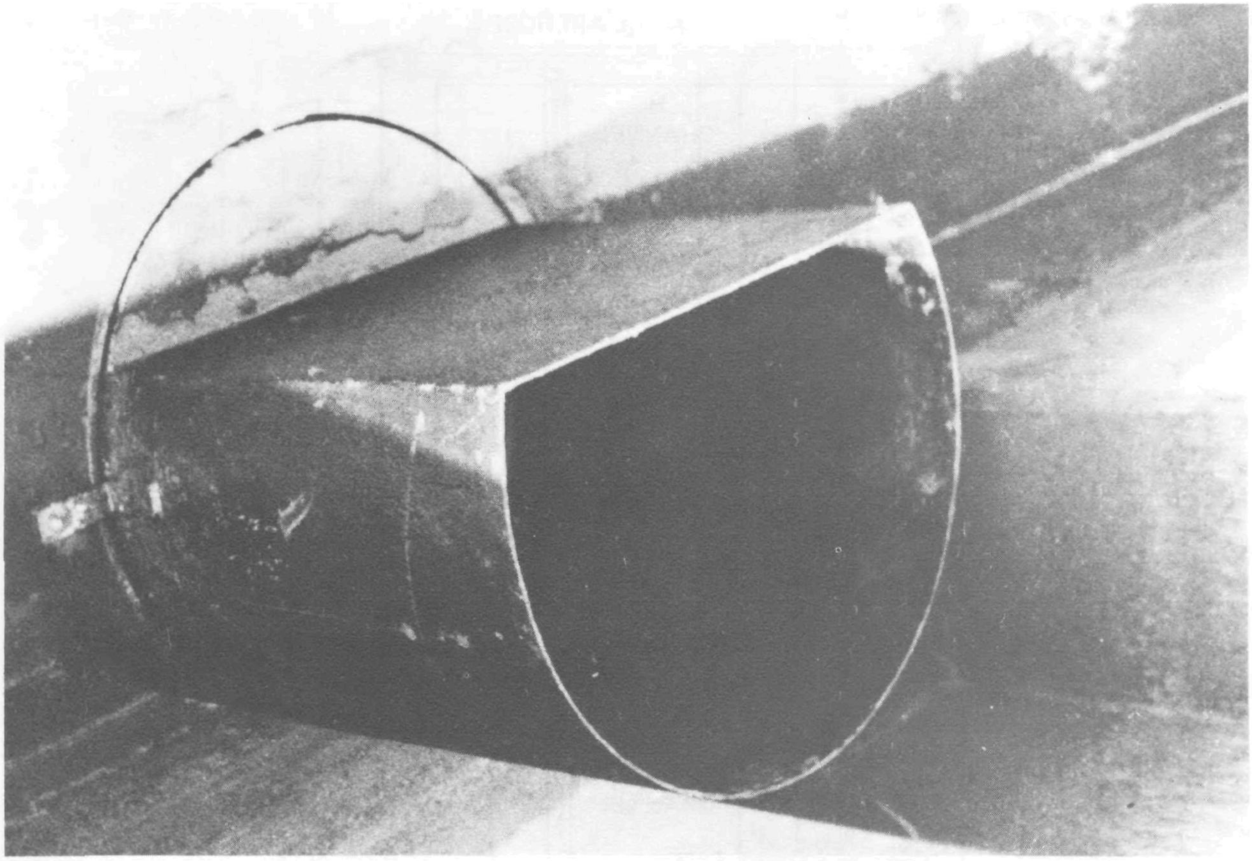

Figure II-19. H-channel flow-equalizing weir in place before plant restart, July 1, 1973. (Note anchor clips used to hold weir in place.)

found in stock, and the V-belt variable-speed drives were acquired from the municipality of Metropolitan Seattle, which was in the process of removing them from the Renton treatment plant. This arrangement made it possible to have six of the eight pumps on line by July 28, with all eight on line by the actual start of the canning season during the second week in August.

The pumps were installed on the far side of the aeration bays. Pump suctions were fabricated of lightweight steel pipe and were located so as to pull RAS from the airlift pump draft tube (figs. II-20 to II-23). The siphon on each suction proved to be no problem to the operation of the RAS pumps. The diameter of both the suction and discharge piping is 10 inches, purposely large to minimize friction head loss and thereby achieve maximum capacity from the pumps. A special steel extension sleeve was set over each modified airlift to prevent the return of the aeration bay contents to the airlift draft tube.

As shown in figure II-17, some pump discharge pipe runs were many feet longer than others; the longest was over 450 feet. All pipes except the discharge header near the pump were plastic. The steel discharge header near the pump was used to provide the connection for a direct return bypass to each tank and a thrust anchor for the entire discharge pipe run. Plastic pipe expands at a very great rate per unit temperature change, and so it was necessary to provide room for that expansion in each pipe run. Flexible joints for 10-inch pipe presented major cost and delivery problems. Therefore, it was decided to anchor the end of the pipe near the pump and allow the other end to move as required while directing its discharge into a common, open-top collection trough.

The RAS collection trough (figs. II-24 and II-25) is fabricated of plywood completely encased in fiberglass. The trough is 3 feet wide and 3 feet deep and is designed to discharge to the center of

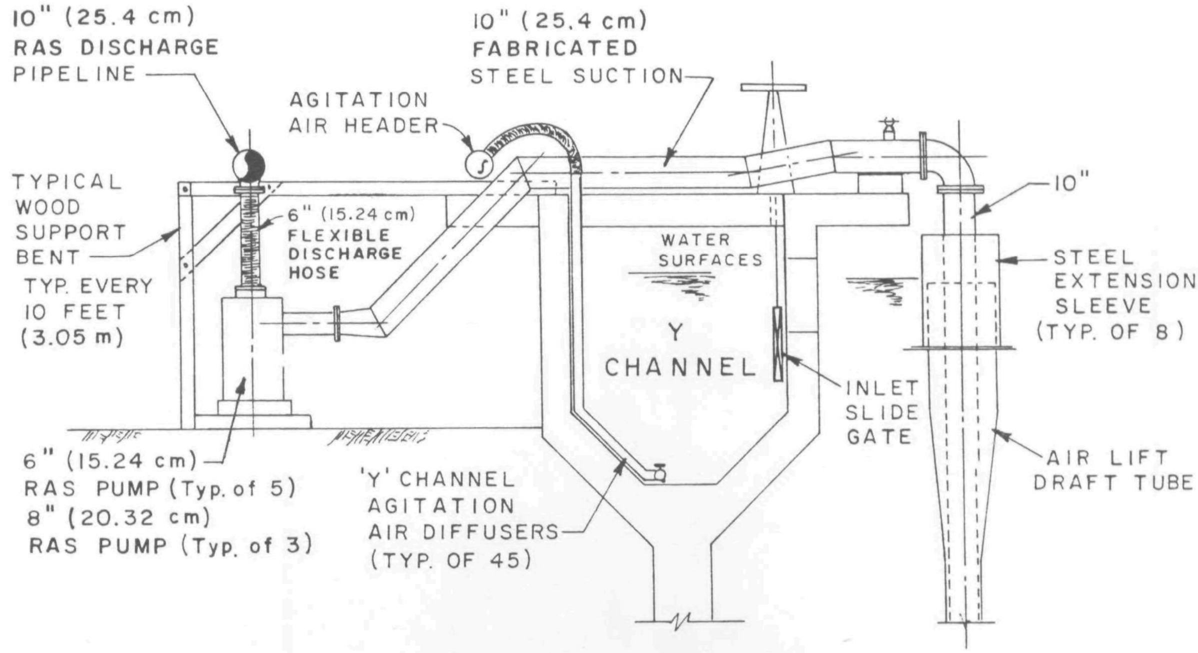

Figure II-20. Y-channel cross section.

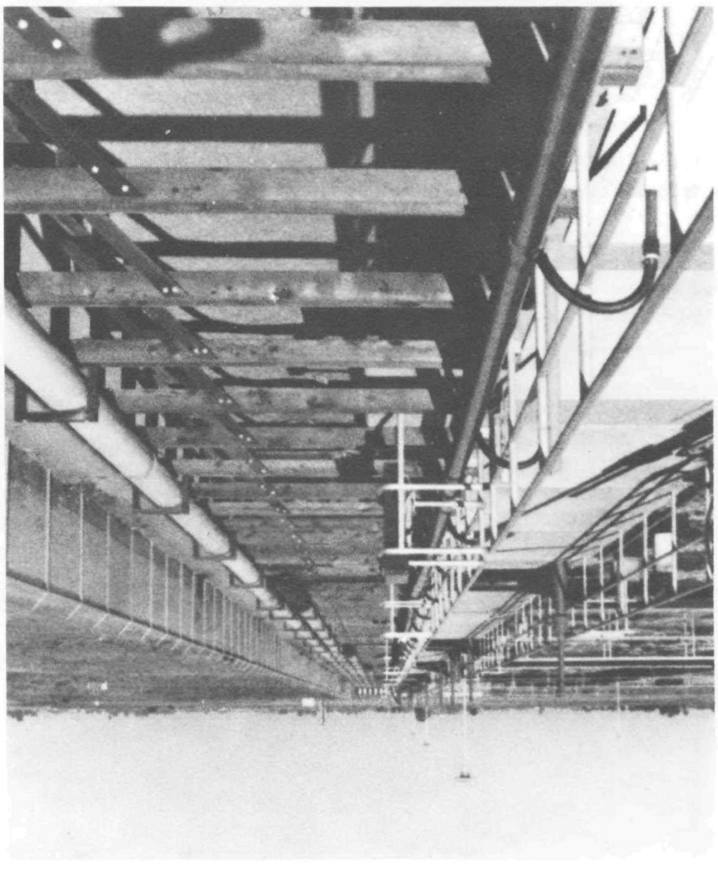

Figure II-21. Complete support system for RAS discharge piping, October 11, 1973. (Note Y-wall agitation air header and hose connections along railing at left, and guides to keep PVC piping in alignment at right.)

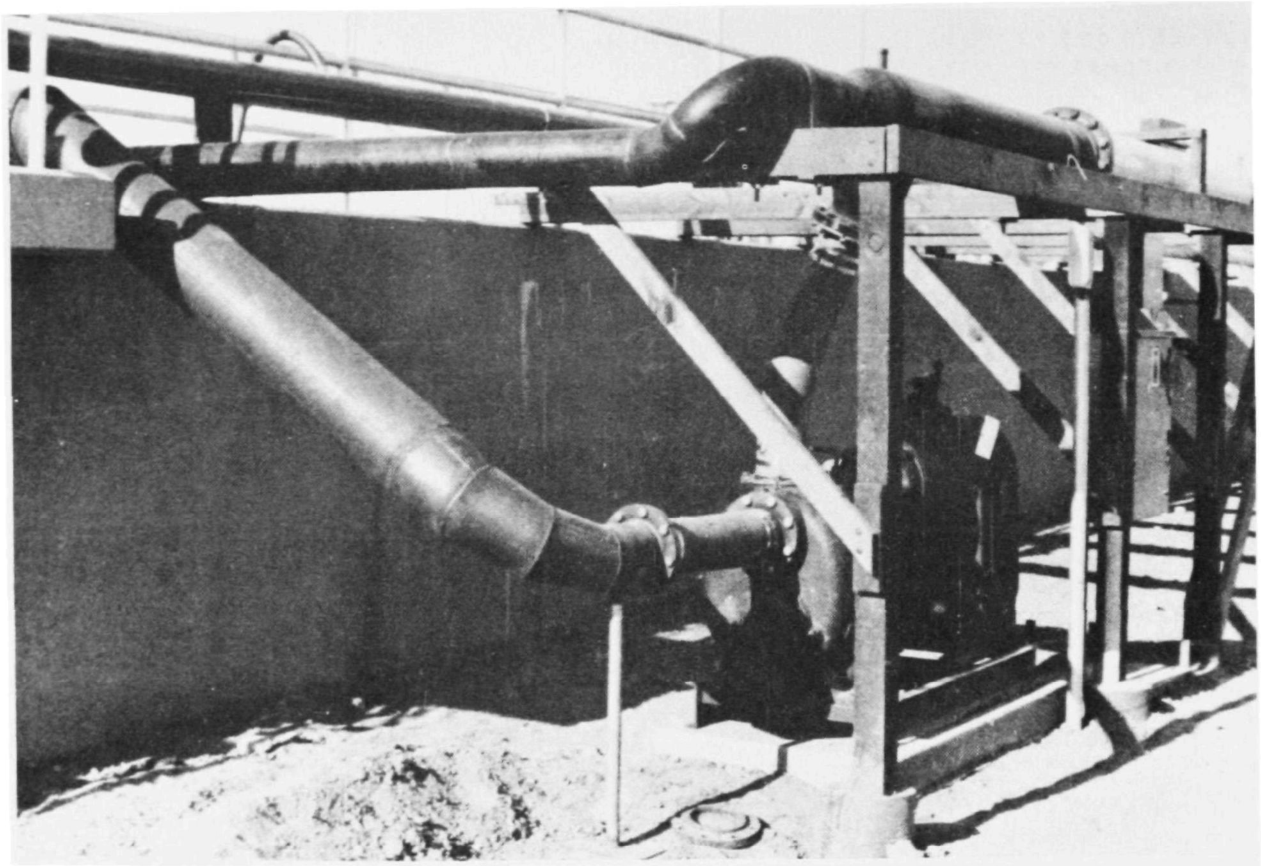

Figure II-22. RAS pump 8 at far end of aeration basin 4, August 3, 1973. (Note steel suction and discharge piping with flexible hose connections to pump. All timber supports were set in concrete.)

Figure II-23. Aeration basins 2, 3, and 4 during foaming period after cornstarch dump, August 1973. (RAS pump 3 suction and bypass discharge piping can be seen crossing over Y channel in the foreground.)

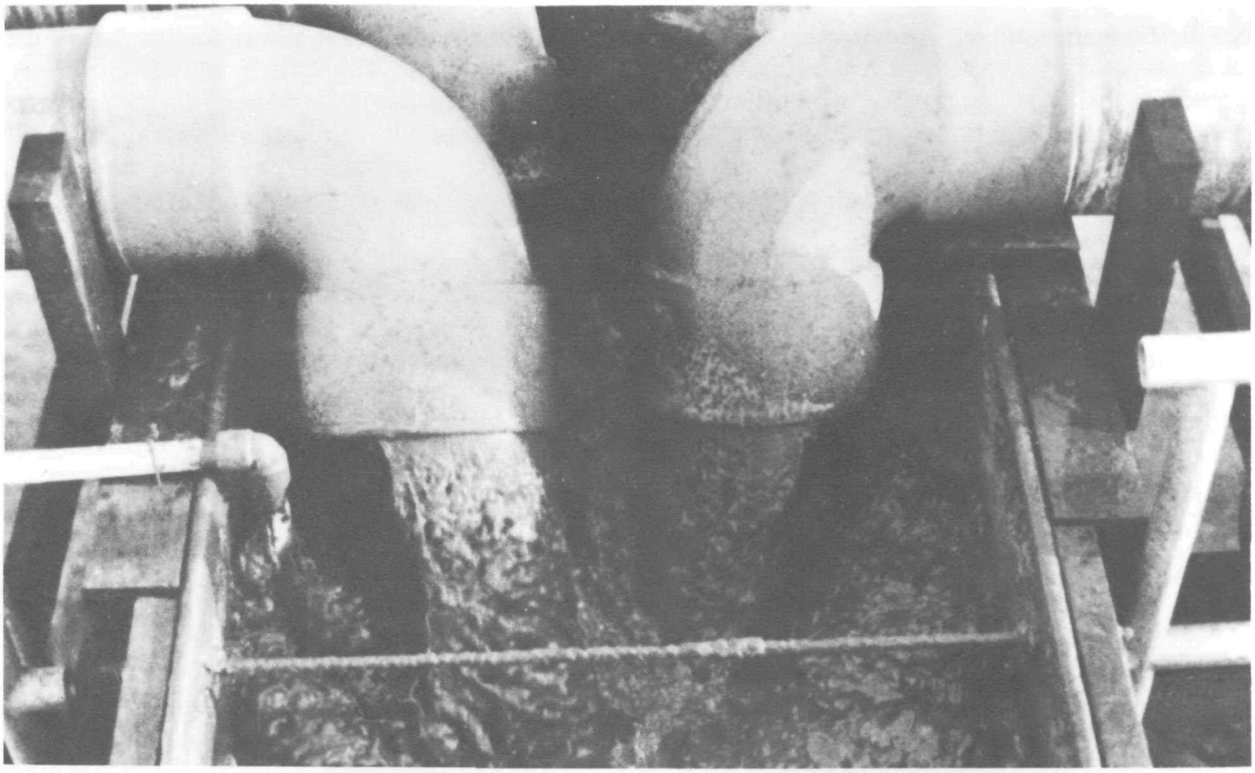

Figure II-24. Closeup of 10-inch (25.4 cm) PVC elbows discharging RAS at head end of RAS collection trough, October 11, 1973. (Small pipe at left is $FeCl_3$ feed.)

Figure II-25. Discharge end of RAS collection trough, October 11, 1973. (Curved section can be reversed if it is necessary to operate aeration basin 2 as a reaeration basin.)

the RAS reaeration bay. A removable curved section at the discharge point allows for the future use of aeration bay 2 as a second reaeration bay, should this be required. The trough, in addition to providing the space for pipeline expansion, has also been used as a point for ferric chloride addition and is equipped with a removable Cipoletti weir, which can be used to calibrate individual RAS pumps. Each RAS pump is completely independent of the other pumps and of all other process variables, and can be calibrated to provide a consistent flow-versus-speed relation.

The new RAS system provides the operator with positive control of the solids circulating within the system, regardless of other process variables. Although the system is limited in its maximum capability to about 60 percent of the plant's average dry weather design capacity, experience so far indicates that this will not be a handicap. Normal operation so far has been in the 25-35-percent range. One airlift pump has been left in the RAS system from each secondary clarifier. Although their use for clarifiers 2, 3, and 4 short circuits the reaeration bay, they can be pressed into service in emergencies.

WAS Control

The modification required to achieve the WAS control necessary for successful operation proved to be an excellent example of how many of these changes were interrelated. Once aeration bay 1 was transformed into a reaeration bay, it was possible to use some of the existing WAS discharge piping to provide a WAS system completely independent of all other process variables. Figure II-12 indicates how the original WAS system had been provided with the option of returning WAS discharge flows directly to the aeration bays instead of to the gravity thickeners. Each such aeration bay WAS discharge was protected against backflow by a tank-mounted flap valve. Once aeration bay 1 became a reaeration bay, it was a simple matter to remove its flap valve and reconnect the former discharge piping to the WAS pump suctions as shown in figure II-17.

The existing WAS pump discharge header was raised 3 feet, provided with a new 3-inch WAS magnetic flowmeter (peak capacity 750 gal/min) and a meter bypass piping connection (figs. II-26 and II-27). The existing oversized meter was removed and replaced with a valved tee designed to facilitate the reconnection of the new pump discharge to the gravity thickener pipeline.

The new WAS system allows the operator to pump from either the reaeration bay or the sludge control box sump. To assure that the new system functions independently of other process variables, it has been provided with a feedback control system that uses the signal from the flowmeter to control the speed of the pump driver. If the pump should become partially gas bound, or if the solids-concentration or pipe-carrying capacity changes sufficiently to affect the system's head loss, the pump speed is automatically adjusted to maintain the preset flow rate. This system allows the operator to preset his wasting rate with the assurance that the rate will be uniformly maintained until he wishes to make a change.

The WAS control system has worked extremely well and has made it possible to optimize gravity thickener operation. The new system uses polymers to thicken WAS from relatively good settling RAS (SVI 70-120) of less than 1 percent concentration to a concentration of 2-2.5 percent. This significantly decreases the quantity of liquid being pumped to the digesters.

In addition to providing for increased thickening efficiency, the reliability and adjustability of the WAS system has also made it possible for the plant operators to control accurately the mean cell residence time (MCRT) of the activated sludge solids. By keeping this time to between 3 and 5 days, it has been possible to minimize the formation of unstable denitrifying sludge. Secondary clarifier nitrate levels, which previously averaged 19-20 mg/l, have been reduced to 3-4 mg/l.

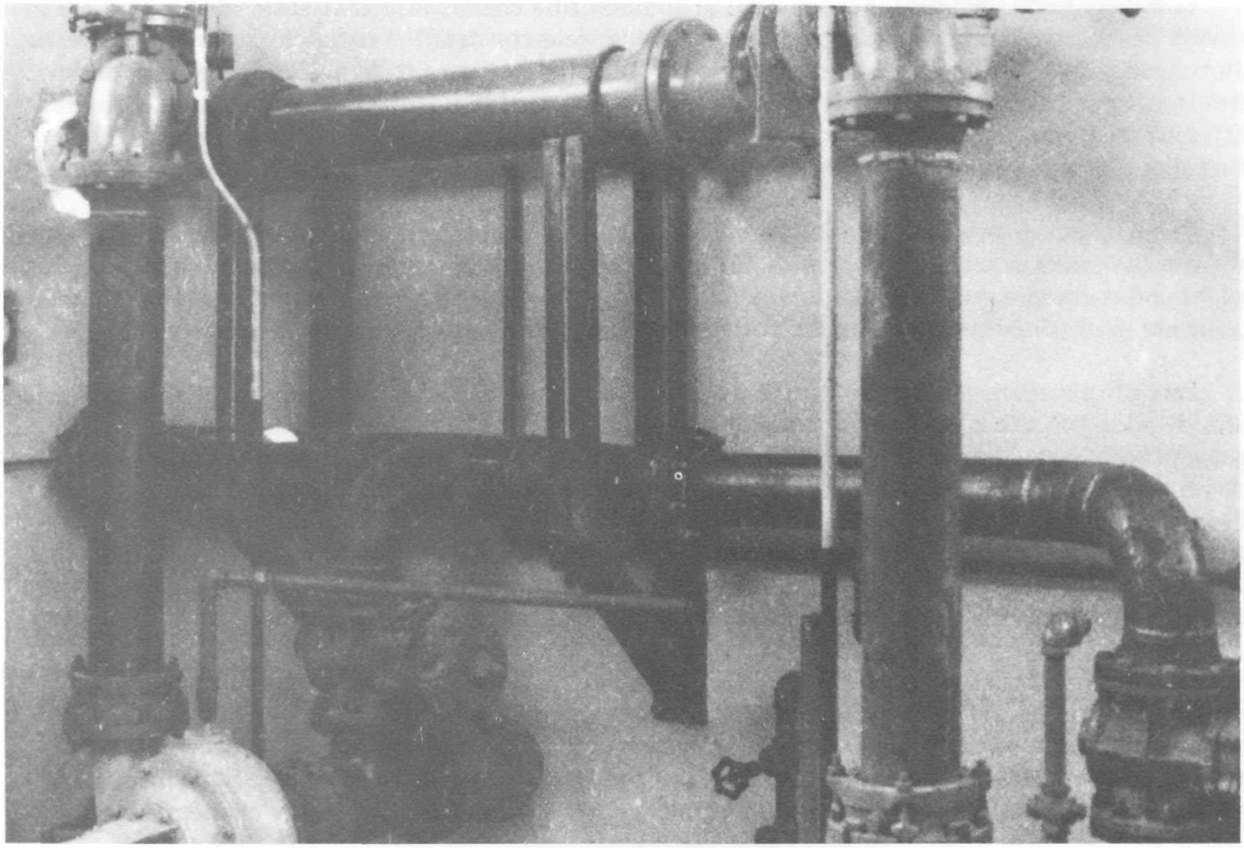

Figure II-26. WAS suction and discharge piping modifications within the WAS pump building, August 1973. (New discharge line set 3 feet (0.91 meter) above original discharge line converted to suction. Note suction valves located on new vertical connections to pump suction system.)

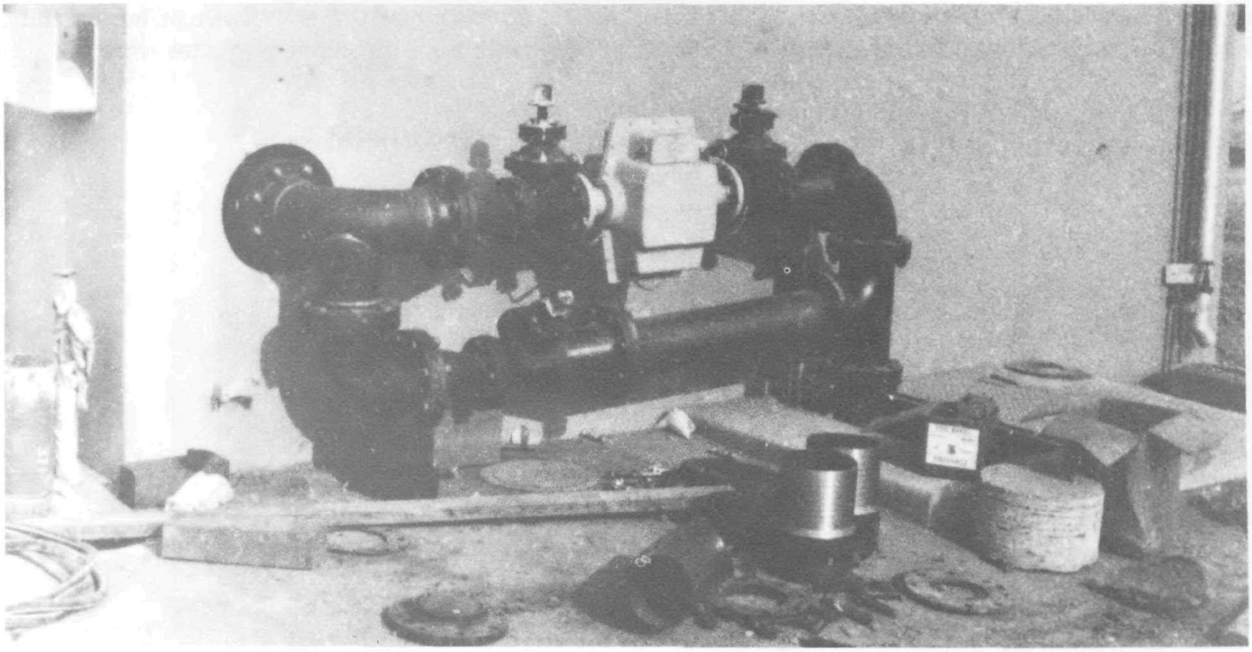

Figure II-27. WAS flowmeter installation with bypass connection, August 1973. (Meter and valves reduced to 3-inch (7.62 cm) size to assure adequate velocities through system.)

Chemical Feed Facilities. Ferric chloride and chlorine chemical feed facilities designed to provide flexibility during critical operational periods were constructed as quickly as possible. Ferric chloride chemical feed facilities were installed as indicated in figure II-28 and provided for the intermittent application of ferric chloride to the mixed liquor to improve its settling characteristics. Different feed points provide the ability to add heavy slugs of chemicals over short periods of time or smaller quantities uniformly over long periods of time.

The Y-channel secondary clarifier inlet feed points require equalizing the chemical feed between the tanks in service but provide the additional benefit of using ferric chloride's increased weight and coagulant and flocculant capabilities for improved settlement. Normally H-channel feed points are used whenever the operator anticipates clarity problems within the secondary clarifiers.

Part of this extensive ferric chloride distribution system included a continuous stream of ferric chloride added to the Y channel at the rate of approximately 700 lb/day to assure that the activated sludge process has sufficient iron to support the growth of nonfilamentous micro-organisms. Use of this nutrient supplement was one of the recommendations of a 1972-73, industry-sponsored study of plant problems; it was implemmented before June 1973 and was retained during the 1973 canning season. Once the plant's activated sludge system stabilized during the late fall of 1973, this continuous flow was stopped. In 1975, the periodic ferric chloride additions for bulking and clarity control were apparently sufficient to satisfy whatever nutrient support was required.

Before the chlorination system improvements to provide permanent sludge-bulking control were completed, efforts were made to inject chlorine into the RAS system by feeding approximately 100 lb/day to the mixed liquor inlets to the secondary clarifiers. These efforts met with some success in late July and early August, but could not cope with the increased filamentous growths that infected the system as soon as the plant began to receive the heavy cannery wastes.

Late in August 1973, the new chlorine bulking-control system became operable. Chlorine solution carrying up to 2,000 lb/day of chlorine could be injected at any of the RAS system locations shown in figure II-17. As the bulking problems with the cannery waste sludge continued and the SVI exceeded 300, the chlorine feed rate to each of the four RAS pipeline injectors was increased until the system was injecting 400 lb/day per injector (about 10 mg/l). Little effect on the filamentous growths was observed, however, until the heavy solids of the cannery wastes were di-

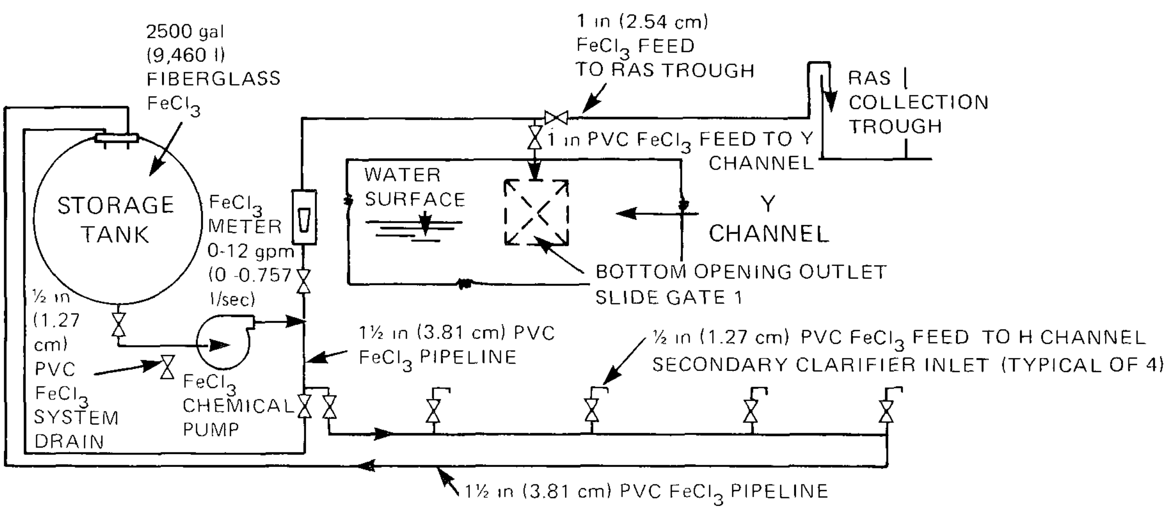

Figure II-28. Schematic layout, ferric chloride distribution system.

verted to the city main plant on September 11, 1973. Continued use of the RAS chlorination system has improved the plant's SVI level until it is now averaging below 80. Bulking control was successful during the 1974 canning season. A cannery effort to eliminate major quantities of the *Thiothrix*-infested mud also helped assure this success.

Chlorination of the RAS has proved to be another useful and effective means of controlling nitrification within the activated sludge process. Chlorine applied at the proper dose is toxic to nitrifiers, and its addition has controlled effluent nitrite and nitrate levels and allowed the plant to stabilize the operation of its disinfection system.

Aeration Air Control

With the increased stability of single-system operation and stable RAS flow rates, the need for frequent individual aeration air adjustments within the aeration system has practically disappeared. Once the air system is adjusted to maintain the 0.5-mg/l DO level in the RAS aeration bay and the 4.0-mg/l DO level in the complete-mix aeration bays, it is possible for the plant operators to compensate for increased plant loadings by simply adjusting the single output valve on the aeration blowers.

To eliminate the possible development of septic conditions that might promote the growth of filamentous organisms in the Y channel, additional agitation air was added along the bottom of the channel. Aeration air for the new H-channel (fig. II-29) and Y-channel agitation air systems was taken from the main air header pipeline before any other system feeds.

Figure II-29. H-channel agitation air system in service, August 1973. (Six- and 4-inch (15.25- and 10.16-cm) header mounted on top of wall with hose connection to diffuser units.)

Final Clarifier Operation

Minimizing hydraulic losses and operating equalizing overflow weirs within the aeration tank H channel assures equal distribution of mixed liquor to each of the four clarifiers. The remaining emergency RAS airlifts can be used for controlled relief of individual tank blowouts. The operators have discovered these airlifts to be extremely useful tools to retain solids within the system. Short periods of airlift operation distribute excessive solids from the offending sedimentation tank throughout the entire final clarifier distribution system and quickly relieve the upset condition.

When the design of the clarifier sludge-collection mechanism was reviewed with the manufacturer, it seemed that rearranging certain hydraulic orifice locations would improve operations. The manufacturer provided sketches eliminating the center orifices and adding new orifices at the outer end of each collection arm. Two of the four clarifiers were so modified. Tests with density probes indicate a significant solids-distribution difference between the modified and original units. The modified clarifiers have a uniform sludge blanket, while the original clarifiers showed a decidedly higher level of sludge at the tank periphery. The other two clarifiers are being modified as part of additional interim improvements currently being made to the central plant.

Recent Operation Experiences

For the first 26 months since the central plant (fig. II-30) began operating with these activated sludge process modifications, BOD removal efficiencies have averaged better than 96 percent, and SS removal efficiencies 94.8 percent. BOD daily and monthly average concentrations have never

Figure II-30. Aerial view of plant looking west across aeration tanks, clarifiers, and digesters at oxidation ponds and solids storage basins, October 1973. (Note location of basins in relation to rest of plant.)

exceeded 90 mg/l and 30 mg/l, respectively. Except for 4 days in September 1974 during the canning season, no daily SS effluent concentration has ever exceeded 90 mg/l. The September 1974 and September 1975 monthly average effluent SS concentrations are the only monthly effluent averages that have exceeded 30 mg/l. The tertiary oxidation ponds were taken out of service in the spring of 1974.

Figure II-31 provides monthly average BOD and SS loading comparisons for the typical noncanning month of June before and after the activated sludge modifications had been completed. The June loadings also provide an excellent picture of the loading increases resulting from the diversion of industrial waste and other treatment plant solids to the central plant in July 1972. Both BOD and SS influent loadings in 1975 are over twice the 1972 loadings, while the monthly average flow has increased less than 20 percent. The huge 1975 SS jump reflects extra solids discharged to the plant during the cleaning of digesters in upstream facilities. Note that 1975 removal efficiencies for both parameters still exceeded 96 percent.

September BOD and SS loadings in figure II-32 show the plant's ability to treat flows and loadings. The September 1974 final clarifier blowouts were the result of the inability of the WAS thickeners to handle the necessary solids loading. The units have a hydraulic limitation of 400 gal/min, which is equivalent to approximately 40,000 lb/day of WAS. During September 1974, the monthly average WAS loading was 34,800 lb/day, with a peak day of 53,600 pounds. Under these conditions the final clarifiers were forced to waste excess solids.

New flotation thickeners were put in operation after the 1976 canning season. To alleviate the solids-wasting limitation before their completion, some of the WAS was wasted through the reaeration tank drain back into the plant influent. This was done during September 1974 with excellent results. The excess WAS was removed with the heavier canning solids in the primary clarifiers and did not recycle through the activated sludge process. When tried again in September 1975, solids recycling caused a process failure. However, it was discovered that excess WAS could be safely discharged directly to the solids-storage basins (sludge lagoons).

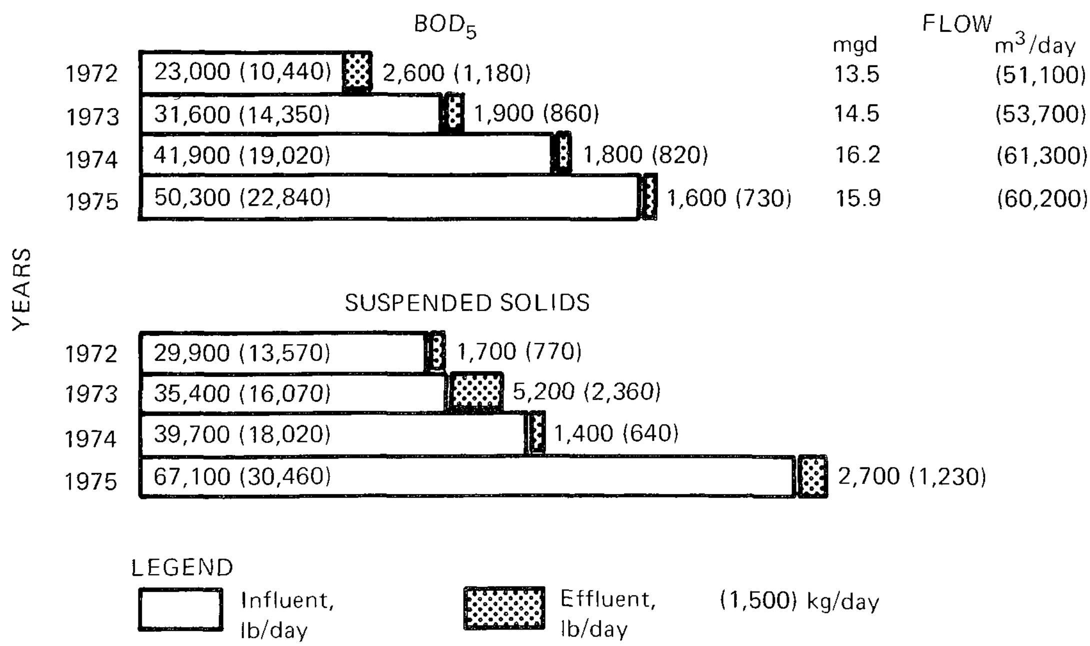

Figure II-31. Plant performance, June (noncanning season) monthly averages.

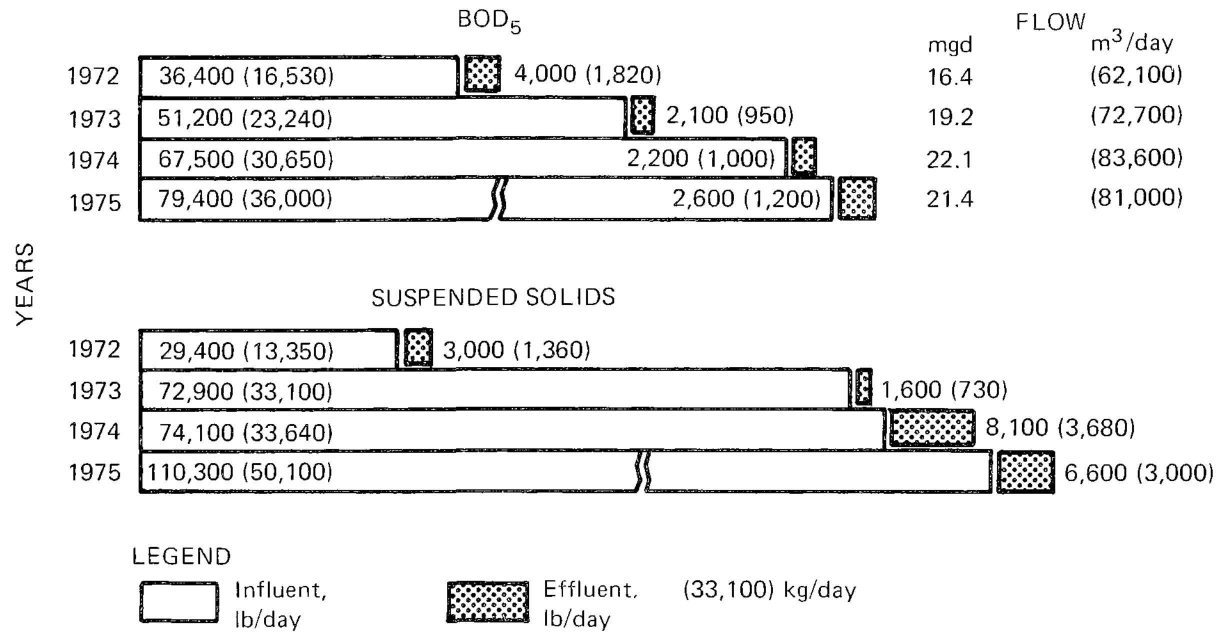

Figure II-32. Plant performance, September (canning season) monthly averages.

Summary and Conclusions

While operation of the Central Wastewater Treatment Plant has been extremely effective, it has not been routine. The continuing heavy loading of industrial wastes and treatment plant solids makes the establishment of steady-state operation very difficult. As soon as stable operation is achieved, an industrial accident or a change in upstream solids discharge creates a whole new condition. The results shown in figures II-31 and II-32 attest to the ability of the operating staff to use the system modifications to adjust and compensate for these changes. As a result of the success of these full-scale, online modifications, it is believed the following conclusions hold for activated sludge systems:

- System design must provide positive hydraulic controls to assure that the entire activated sludge process acts as one system, regardless of the number of aeration-clarifier units employed. System design must include intermixing of RAS flows and intermixing of either all mixed liquor flows or RAS flows with all aeration bay influent flows.

- RAS system design must be independent of other process variables and capable of being adjusted to meet changing requirements. Closed-loop control with variable capacity pumps and individual flowmeters provides excellent positively controlled systems.

- WAS system design must also be independent of other process variables, and must be capable of being adjusted to meet changing requirements. Closed-loop control with variable capacity pumps and individual flowmeters provides excellent positively controlled systems.

- Chemical feed systems for settling, bulking, and nitrification control are necessary tools to assure process reliability. Every activated sludge system design should be capable of using chemicals (chlorine, ferric chloride, or alum) to overcome upsets.

- Design of air control to each independent aeration bay must be positive, simple to effect, and relatively unaffected by other bay adjustments. Closed-loop control and DO probes, automatically controlled valves, and simple flowmeters provide excellent and efficient systems.

- Design of distribution systems for multiple aeration-clarifier systems should be positive and simple. This is best accomplished by providing flow-equalizing layouts and inlets with self-equalizing, high head losses. Closed-loop, automatically controlled inlet valves with integral flowmeters can be used for systems that cannot accommodate the preferred layout and inlet design.

- WAS thickening facilities must be capable of treating the maximum WAS flow imaginable under the worst possible operating conditions. WAS thickening facilities must be reliable and conservatively designed to assure the removal of bulking sludges with high SVI's. Flotation thickeners designed for loadings of approximately 10 $lb/day/ft^2$ and provided with chemical aids are the most reliable means of meeting these criteria.

- Primary sludge and WAS processing and disposal must not be allowed to recycle significant quantities of solids through the activated sludge system. Conservatively designed primary digesters (25-30 days detention) with properly designed facultative type, deep (15 feet) secondary lagoons (loaded at approximately 20 pounds VSS per 1,000 ft^2/day) provide the most positive means of controlling such recycle.

CASE 5. UPGRADING WITH AUTOMATIC DISSOLVED-OXYGEN CONTROL IN THE ACTIVATED SLUDGE PROCESS

Control of oxygen dissolution in the mixed liquor is an important parameter in the activated sludge process. The desired strategy is to add sufficient air or high-purity oxygen to meet the time-varying oxygen demand of the wastewater. Because electrical energy is one of the major operating costs of the activated sludge process, there is an economic incentive to minimize unnecessary aeration blower operation.

If the DO level in the mixed liquor drops below approximately 0.5 mg/l, oxygen becomes rate limiting and the aerobic bacteria become inactive. Too low a DO level can also lead to the growth of filamentous organisms and consequent sludge bulking. Too high a DO level, however, indicates wasted power, which can cause floc breakup if energy levels are too intense. This can result in high effluent SS levels because of poor settling characteristics. Nitrifying organism activity is reduced at DO levels below 2.0 mg/l; thus, the DO concentration should be kept above this level to insure nitrification where it is required.

Manually controlled air addition is now used at most activated sludge plants. The operator may attempt to pace oxygen transfer in proportion to the oxygen demand by turning blowers on and off or by adjusting variable-speed blowers; to insure adequate oxygenation, however, he usually provides more aeration than required. Power costs can be minimized if aeration capacity is automatically paced in proportion to the time-varying oxygen demand.

Because automatic DO control involves additional capital and operating expenses, it is generally only applicable to plants with a flow capacity in excess of 2.0 mgd.[2] Automatic DO control may be appropriate for smaller plants, however, where waste strength varies greatly and rapidly, because of industrial discharges, for example.

Presented herein are case histories of three wastewater treatment plants that use automatic DO control: the Renton, Wash., Wastewater Treatment Plant, the Palo Alto, Calif., Water Quality Control Plant, and the San Jose-Santa Clara, Calif., Water Pollution Control Plant. Data are presented that compare performance and power consumption for operation under manual and automatic control modes. These case histories are taken from *Design Procedures for Optional Dissolved Oxygen Control of Activated Sludge Processes* by Brown and Caldwell,[2] which provides a more complete discussion of automatic DO control methods and procedures.

A. Renton, Wash., Wastewater Treatment Plant

The Renton plant,[2,3] located near Seattle, Wash., commenced operation in June 1965 and was enlarged in 1973 to an average dry weather flow capacity of 36 mgd. Two oxidation tanks are provided, each with four passes. Air is supplied by six single-stage centrifugal blowers and introduced through two headers in each tank. Each header serves two passes.

Currently, the Renton plant is equipped with three 12,000-scfm, 500-hp blowers, and three 14,000-scfm, 600-hp blowers; all are supplied with 4,160-volt power. The 500-hp blowers were installed in 1963, and are driven by synchronous motors. The 600-hp blowers were installed in 1973, and are driven by squirrel cage induction motors. All blowers are located in a temperature- and humidity-controlled gallery and receive finely filtered air.

An automatic DO control system is provided and incorporates a pressure control loop in the blower feed manifold and a DO-regulated flow control loop for each of the four tank headers. Three probes are installed in each of four passes in each oxidation tank for a total of 12 probes per tank. An instrumentation and control diagram of the DO control system is shown in figure II-33 (table II-10 presents definitions for symbols used in figs. II-33, II-34, and II-37). Components include the following:

- Six single-stage, centrifugal blowers with individual suction throttle valves, and flow-regulated surge control systems
- One blower discharge manifold pressure control loop with pressure transmitter and pressure-indicating controller
- 24 DO analyzers and probes
- Two 12-point DO strip chart recorders (one recorder for each tank)
- Four DO probe selector switches (one per air header)
- Four DO controllers
- Four flow control loops for each header including orifice plate, square root extractor, recorder, totalizer, indicating controller, and piston-operated butterfly valve

Operation. The Renton plant currently receives insufficient loading to warrant use of both oxidation tanks, although both tanks are fully instrumented for automatic DO control. Using the appropriate probe selector switch (HS), the operator selects one DO probe in each two-pass tank section and uses that probe to control the airflow rate in the corresponding supply header. All DO probes are continuously monitored on a strip chart recorder (AR), and the selected control probes may be changed at any time. The output of the selected probe is transmitted to the oxygen controller (AIC), which provides an output to vary the set point of the flow controller (FIC) as required. The flow controller modulates a butterfly valve in the airflow header in accordance with the computed set flow rate.

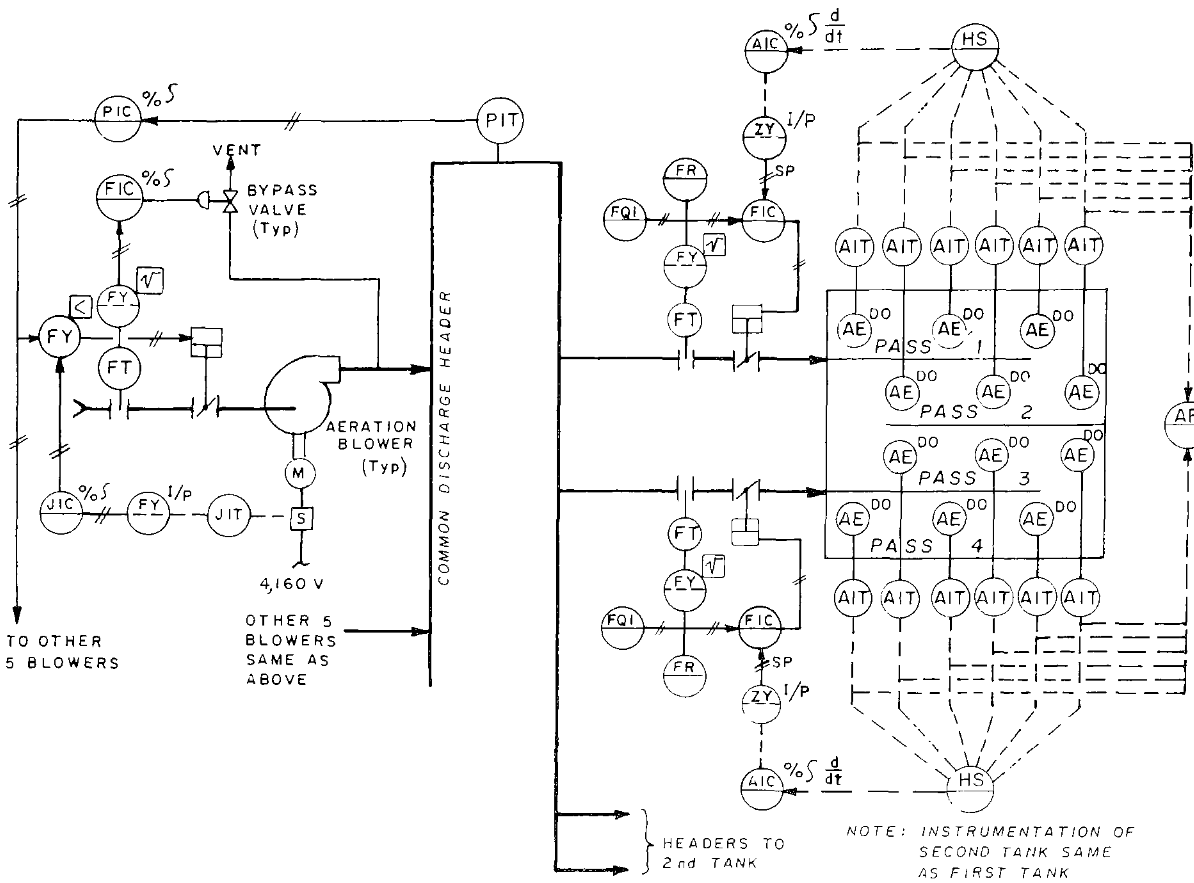

Figure II-33. Renton Automatic DO control system.

DO in the first two passes is typically maintained at 1.5 mg/l, using one of the last two probes in the second pass for control. DO in the last two passes is usually maintained at 2-2.5 mg/l, using one of the last probes in the fourth pass for control.

A constant pressure of 8 psig is maintained in the blower discharge manifold by simultaneous throttling of all blower suction valves through a pressure-indicating controller (PIC). A discharge-flow-regulated surge control system with a load control override is provided for each blower. In the event the PIC calls for the blower-throttling valve to be open for a period of time so that the blower power draw becomes excessive, the power-indicating controller (JIC) will override the PIC and throttle the blower.

Performance. The Renton plant has continuously operated under automatic DO control since 1967, except for a 13-month period beginning March 1970, when the initial oxidation tank was modified from a two-pass to a four-pass structure. During this period, all influent was diverted to the new oxidation tank. DO probes had not yet been installed in the new tank; therefore, DO data collection was performed by the plant laboratory staff. Set points on the header FIC's were determined by the laboratory using the copper-sulfate/sulfamic-acid flocculation modification to the Winkler test for DO. The FIC set points were varied once or twice a day according to directions from the laboratory. Other analyses performed in the laboratory included influent and effluent BOD and COD and sludge SVI and 30-minute settleability. These analyses were completed once a day from composite wastewater samples. Detailed data have been reported on 3 months of manual DO control in 1970 and compared with data for the same 3 months in 1971 using automatic DO control.[3] Frequency distribution plots of BOD-removal efficiency indicate that efficiency was con-

Table II-10.—*DO control symbols and definitions*

Symbol	Definition
AE	DO probe
AIT	DO level transmitter
AIC	Oxygen controller
AR	Strip chart recorder
FE	Flowmeter
FIT	Flow signal transmitter
FI	Flow indicator
FIC	Flow controller
FQI	Flow integrator
FY	Square root extractor or current/power conversion relay
FR	Flow recorder
FT	Flow transmitter
FSL	Low flow switch
HS	Probe selector switch
I/P	Current/pressure conversion
JIC	Power indicating controller
JIT	Power indicating transmitter
M	Motor
PIC	Pressure indicating controller
PIT	Pressure indicating transmitter
S	Switch
SP	Pressure switch
ST	Speed transmitter
SI	Speed indicator
ZY	Current/pressure conversion relay

Table II-11.—*Performance comparison of manual and automatic DO control, Renton Wastewater Treatment Plant, October-December, 1970 and 1971*

Parameter	Manual[a]	Automatic[b]	Percentage improvement
BOD removal efficiency, percent[c]	85	96	13.0
Sludge volume index[d]	[e]332	86	286
Air supplied:			
ft^3/gal influent	1.25	1.10	12.0
ft^3/lb BOD removed[d]	2,190	1,380	37.0
BOD removed,[d] lb/kWh	0.882	1.39	57.6

[a]Average daily flow—24.5 mgd; average BOD loading—21.3 pounds per 1,000 ft^3/day.
[b]Average daily flow—27.1 mgd; average BOD loading—31.6 pounds per 1,000 ft^3/day.
[c]Geometric mean.
[d]Arithmetic mean.
[e]Bulking problems occurred.

sistently high under automatic control and varied considerably under manual control. Data compiled on BOD-removal efficiency and other performance parameters are shown in table II-11.

It has been reported that automatic DO control significantly reduces the air required for secondary treatment. Table II-11 shows that for the tests at the Renton plant not only was the air required under automatic DO control significantly less than under manual DO control, but BOD-removal efficiency improved as well.

Maintenance. Maintenance of the DO control system with associated blowers has been judged by the plant maintenance superintendent to require minimal labor and material costs. However, some problems have been experienced with DO probe drift and moisture accumulation in the probe plugs. At least 2 of 12 probes in the operating oxidation tank have displayed excessive drift, uncorrectable by recalibration. Four probes have been taken back by the manufacturer to determine the cause of the problem.

The DO probes in the operating oxidation tanks are cleaned and calibrated once a week and recharged about once every 8 months. Cleaning and calibration of 12 probes normally requires 1½ man-hours. Recharging 12 probes normally requires 2 man-hours.

B. Palo Alto, Calif., Water Quality Control Plant

The Palo Alto Water Quality Control Plant[2,4,5] is an activated sludge facility with a current average dry weather flow capacity of 34 mgd and an average wet weather flow capacity of 53 mgd. Four oxidation tanks are provided with piping arranged for plug flow or reaeration modes of operation. Air is supplied by three 6,400-scfm, positive displacement air blowers, and delivered to each oxidation tank through a sparge ring. A 50-hp, fixed-speed mechanical mixer in each tank is used to mix the rising air bubbles with the mixed liquor.

Each of the three air blowers are 550-r/min, motor-driven units designed to deliver 6,400 scfm at 8 psig. The blowers are positive-displacement lobe-type units installed in 1972; each unit is driven by a 300-hp, wound rotor motor. Two saturated core reactor, variable-speed drive units are used to vary the speed of the three air blower motors. One drive unit is dedicated to one blower, while the other drive unit can be switched between the remaining two blowers using transfer contactors. The blowers discharge into a common manifold that delivers air to each oxidation tank through separate 14-inch risers.

A DO probe is installed in each oxidation tank and is located halfway between the mechanical aerator units and the tank dividing wall. A portable DO probe is also available to measure DO concentrations in the tanks. An instrumentation and control diagram of the DO control system is shown in figure II-34. Components include the following:

- Three positive displacement air blowers with saturated core reactor, variable-speed drive
- Four manual flow control stations for each tank, including orifice plate, flow transmitter, square root extractor, flow indicator, motor-operated butterfly valve, and a remote, manually operated valve position controller
- One flow recorder for total flow delivered to all four oxidation tanks
- Four DO probes, agitators, and analyzers
- Four fixed-speed mechanical mixers, one in each oxidation tank

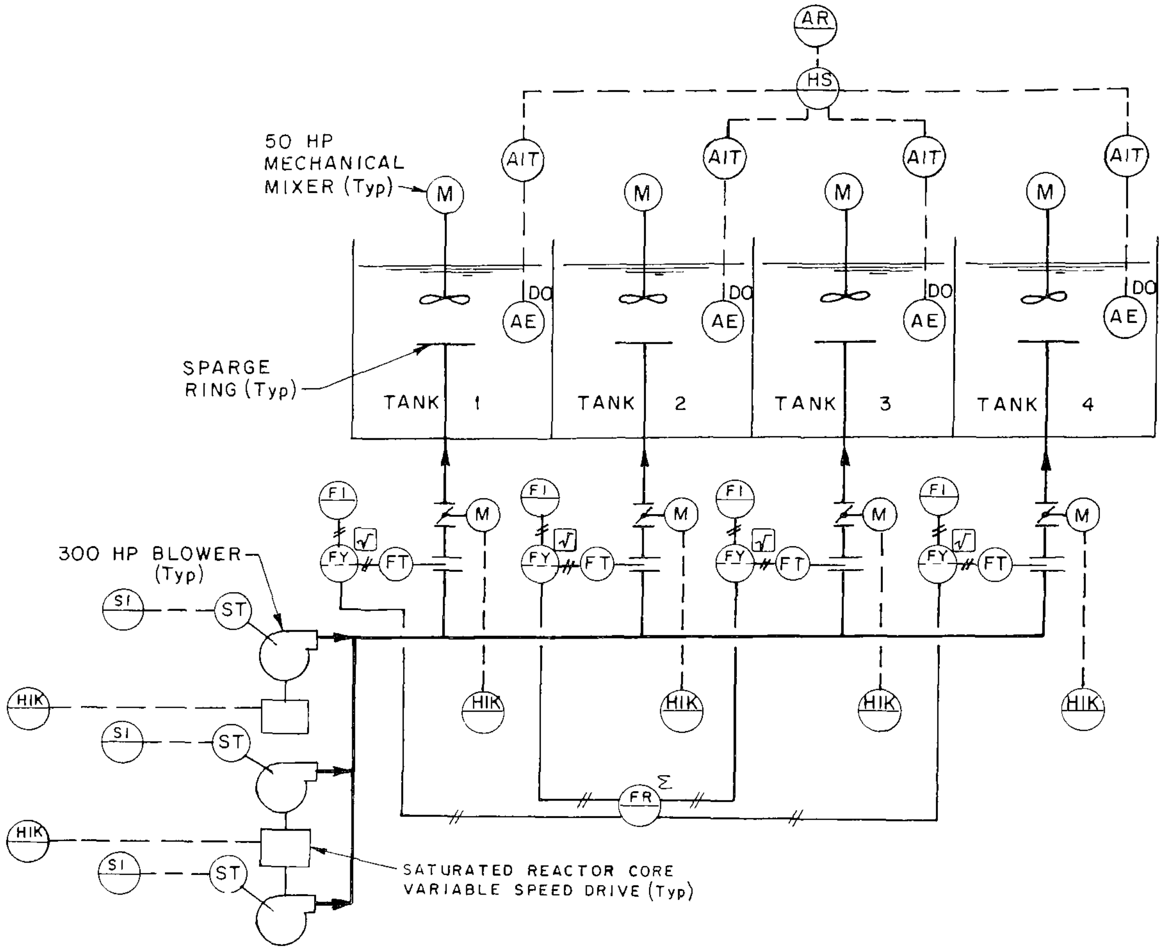

Figure II-34. Palo Alto DO control system.

- One single-channel DO recorder with a manually operated selector switch

Operation—Remote-Manual. Normally, the Palo Alto plant is operated in the conventional activated sludge mode. Each oxidation tank simultaneously receives primary effluent and discharges its effluent to an associated final tank. DO concentration in each oxidation tank is indicated on a control panel in the plant operations building. A single-channel recorder may be switched from tank to tank to record the DO level.

Based on DO concentration in each tank, the operator modulates the blower motor speed on the motor-operated butterfly valve in the corresponding tank air feed header. Normally, only two blowers are operating. Primary control of DO in the tanks is achieved with blower speed modulation, while secondary control is made with the remote-operated header feed valves. Blower speed is typically altered three times a day while the header valve positions are changed two or three times a day. The valve in the tank header farthest from the blowers is normally left fully open. DO concentration in the oxidation tanks is usually maintained at 0.5-1.0 mg/l.

Operation—Remote-Semiautomatic. In 1973, Systems Control, Inc., the city of Palo Alto (under a grant by EPA), and the California State Water Resources Control Board conducted a study to compare manual versus digital computer control of the DO control system.[4,5] Following 4 weeks of monitoring normal control procedures in the manual mode, a digital computer system was integrated into the DO control system with a programed DO control algorithm. The computer received a 4-20-mA DO signal from each probe analyzer, computed any changes required in blower flow rates, and typed out such changes on a teletype. A change in computed airflow rates of more than 100 scfm was required before a control change message was typed. Because the operator was still required to perform the blower speed change requested, this type of control is most accurately designated as computer-assisted open-loop control.

The DO control algorithm used in the test was a proportional plus integral process control program designed to compute the required change in airflow rate. On occasion, such change commands required the operator to place blowers in or out of service.

The testing program at Palo Alto was divided into three stages, summarized in table II-12. During the first stage of approximately 4 weeks, the plant was operated in the remote-manual mode as previously described. During stages 1 and 2, the header feed control valves were left in a fixed position, and the blower speed was changed only twice daily.

During the next stage of the study, data were collected on plant performance for both a 3½-week "nonintensive" and a 3-day "intensive" collection phase. The intensive data collection period encompassed the extreme operating conditions of the plant as well as an average condition. During the intensive period, all relevant data were collected every 2 hours.

During the final stage of the study, the semiautomatic DO control system, as described earlier, was activated. After a 4-week period of process stabilization relative to the new control mode, nonintensive and intensive studies of process performance were made. Data collection phase durations for the final study step were identical to those of the previous step.

Performance. Average values of plant operating variables during the first and second phases of test stages 1 and 2 are shown in table II-13.

Figures II-35 and II-36 illustrate the performance difference between the manual and semiautomatic DO control systems in maintaining a 1.0 mg/l DO set point during the intensive

Table II-12.—*Manual and semiautomatic DO control testing program, Palo Alto, 1973*

Stage	Phase	Duration	Remarks
1	—	4 weeks	Remote manual mode of operation
2	1	3½ weeks	Infrequent data collection under remote manual mode
	2	3 days	Frequent data collection under remote manual mode for average and extreme operating conditions
3	1	4 weeks	Process stabilization under semiautomatic mode
	2	3½ weeks	Infrequent data collection under semiautomatic mode
	3	3 days	Frequent data collection under semiautomatic mode for average and extreme operating conditions

Table II-13.—*Performance comparison of manual and remote semiautomatic DO control, Palo Alto Water Quality Contol Plant*

Parameter	Manual[a]	Semiautomatic[b]	Percentage improvement
BOD-removal efficiency, percent	83.9	84.2	0.3
SS-removal efficiency, percent	46.3	52.8	14.0
TOC removal efficiency, percent	53.1	59.8	10.8
COD-removal efficiency, percent	63.1	63.6	.8
Air supplied:			
ft^3/gal influent	.447	.450	—
ft^3/lb BOD removed[c]	525	448	14.7
BOD removed, lb/kWh	2.94	3.44	14.5

[a]Average daily flow—24.0 mgd; average BOD applied to oxidation tanks—24.4 lb/1,000 ft^3/day.

[b]Average daily flow—23.6 mgd; average BOD applied to oxidation tanks—28.2 lb/1,000 ft^3/day.

[c]Computed from total air supplied over testing period, average BOD in primary effluent, and reported BOD-removal efficiency.

Note.—Operating mode for manual and semiautomatic was contact stabilization. Test duration was 4 weeks for each control mode.

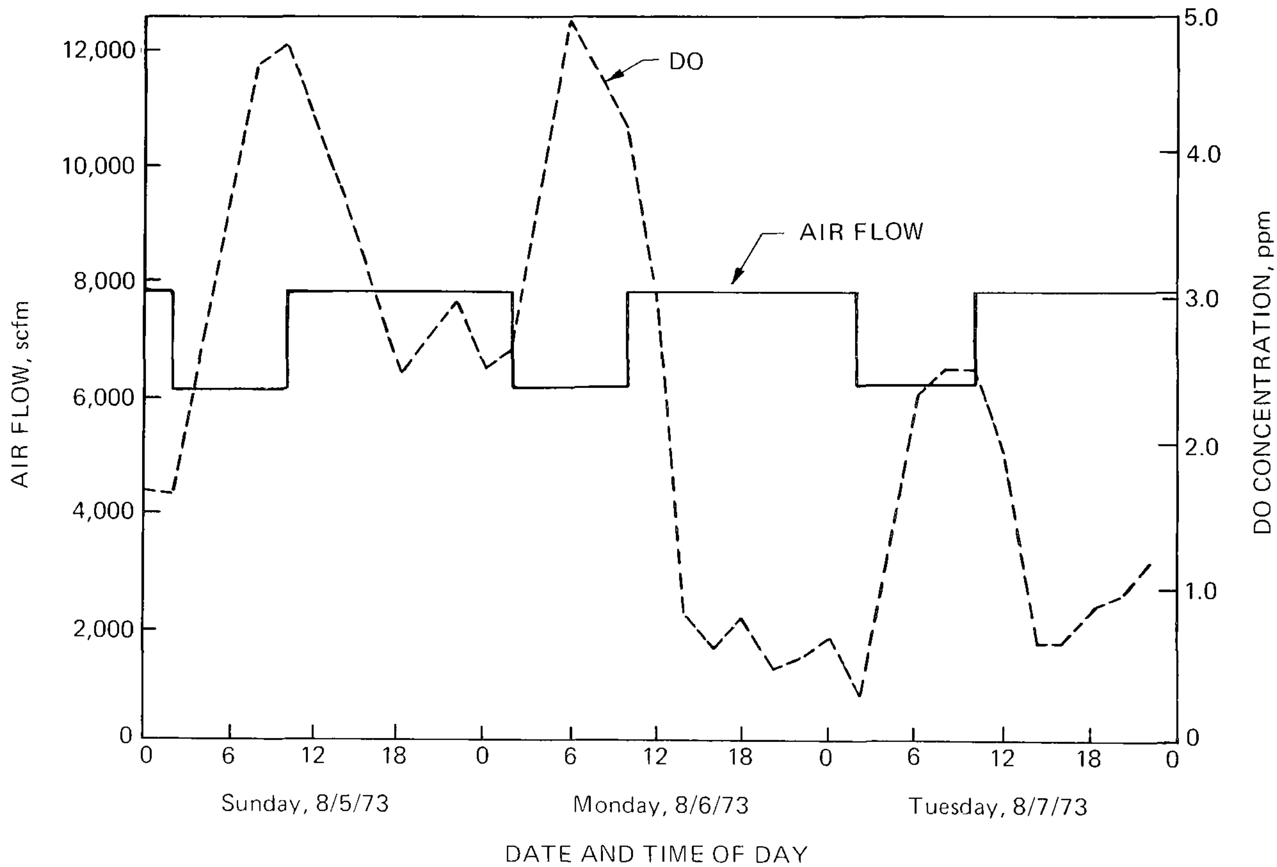

Figure II-35. DO and air flow at Palo Alto, manual DO control.

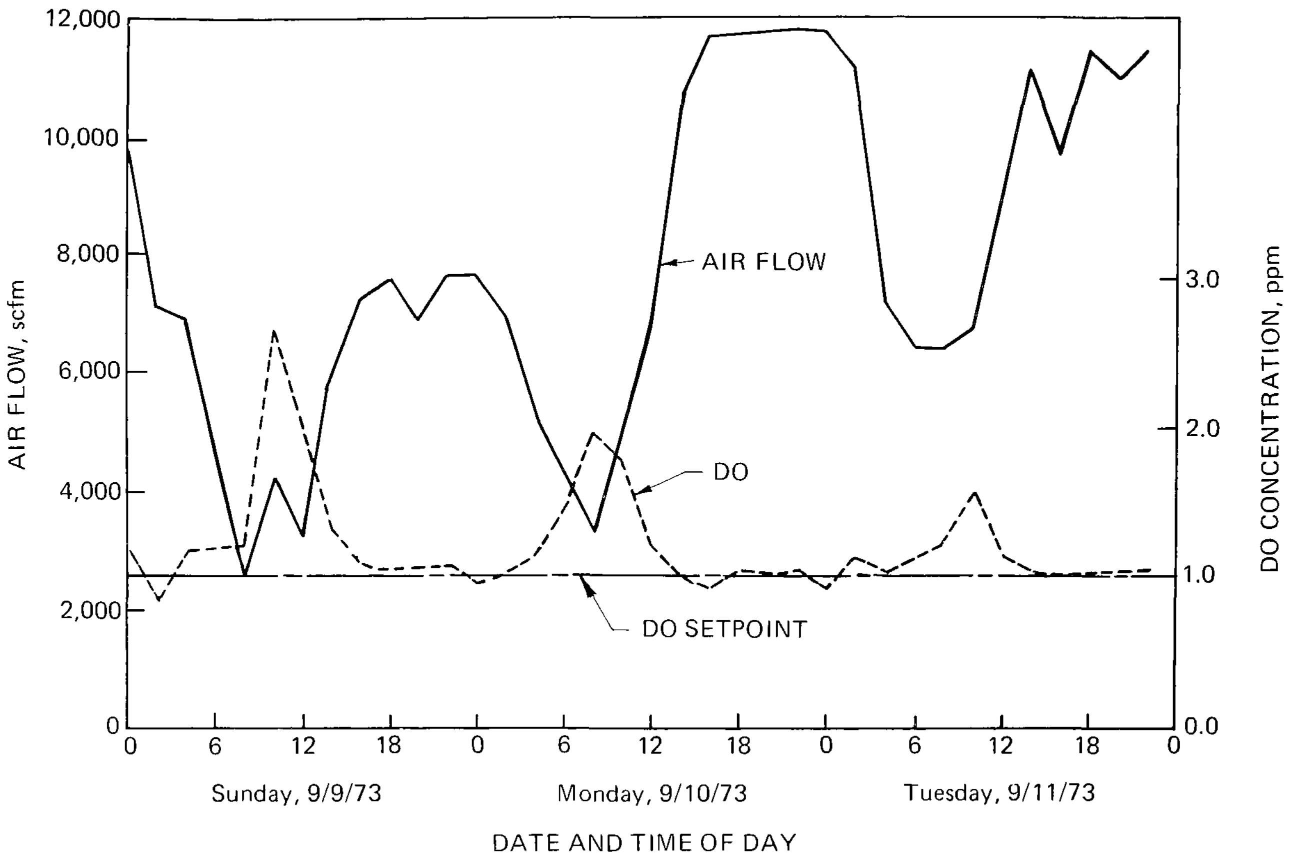

Figure II-36. DO and air flow at Palo Alto, semiautomatic DO control.

testing periods. Under manual control, wide excursions in DO concentration were experienced as shown in figure II-35. Figure II-36 shows that under semiautomatic control, the controller maintained the DO at or near set point, although substantial changes in airflow occurred because of considerable loading variation.

Four measures of pollutant-removal efficiency monitored over the manual and automatic testing periods are compared in table II-13. Although the improvements for BOD and COD removal under the semiautomatic modes were relatively slight, SS and total organic carbon (TOC) percentage removal under semiautomatic DO control show a marked improvement compared to manual control.

During both stage 1 and stage 2 tests, airflow applied to the oxidation tanks was totalized and BOD in the primary effluent was monitored. Samples were taken from the primary effluent at 4-hour intervals and combined for composite BOD analysis every 24 hours.

Assuming a linear relationship between the blower output and power consumption and a power cost of 1 cent per kWh, power costs corresponding to the air required for each mode were computed, as shown in table II-13. The computed annual cost saving for the automatic DO control system was $5,400.

Maintenance. According to the chief operator at the Palo Alto plant, DO probe calibration is typically performed once every month. During the course of the study, it was determined that preventive maintenance was required every 2 weeks; 1 man-hour was required to check all probes.

Approximately once every 3 months, about 4 man-hours were required to thoroughly check, clean, and recalibrate all probes. Recharging requires about 2 man-hours per year for all four probes.

The DO analyzers were reported to produce an electrically noisy signal with inherent oscillating variation about a specific value. Electronic filtering was employed to correct this problem.

Although no problems with computer downtime were reported during the stage 3 test, the computer did fail at other times during other phases of the testing program. Over a period of about 13 months, approximately 20 computer failures were reported, of which about 50 percent would have resulted in loss of the DO controller. If the DO contoller had been operating, the data loss affecting DO control would have been 49 hours. Because the computer operated continuously for about 14 months, the computer was capable of effecting automatic DO control 99.5 percent of this period.

Computer system failures occurred predominantly with the peripheral devices. The disk memory accounted for 70 percent of the total computer downtime.

C. San Jose-Santa Clara, Calif., Water Pollution Control Plant

The San Jose-Santa Clara Water Pollution Control Plant[2,6,7] began operation in 1964 with a design average dry weather flow capacity of 94 mgd. In 1973 the plant was expanded to a dry weather flow capacity of 160 mgd, and the plant is currently treating an average flow of 90 mgd. The plant is an activated sludge treatment facility that employs the Kraus Nitrified Sludge Interchange Process. Two tank batteries are provided, each composed of six two-pass oxidation tanks and two two-pass nitrification tanks. However, piping for each battery is arranged to permit conversion of two more oxidation tanks to nitrification tanks if desired. Wastewater may be treated using conventional, step-feed, or tapered aeration activated sludge operating modes. Normally, the oxidation and nitrification tanks are operated in the two-pass mode.

The Kraus process involves mixing a portion of the activated sludge with supernatant and digested sludge from the anaerobic digesters and aerating the combination for about 24 hours in the nitrification tanks. The mixture is then pumped to the oxidation tanks for further aeration with the primary effluent.

Two air systems are provided to deliver air to the secondary process at different pressures. The high-pressure, or diffused air, system delivers 8 psig air to all 12 oxidation and 4 nitrification tanks at a level 2 feet above the tank bottom. Air is introduced from one side of each tank pass through fine bubble diffusers. The low-pressure, or distributed air, system delivers 4 psig air to the 12 oxidation tanks at a level 5 feet below the tank surface. This system introduces air into each tank pass opposite the fine bubble diffusers and produces a much larger diameter bubble.

Six engine-driven, single-stage, centrifugal blowers supply air for the high- and low-pressure air systems. Four blowers are furnished for the high-pressure system and two for the low-pressure system. The diffused, or high-pressure, system engine-driven blowers are each designed to deliver 60,000 scfm of air at a pressure of 8 psig and are driven by 2,400-hp engines. The distributed, or low-pressure, system engine-driven blowers are each designed to deliver 85,000 scfm at 4 psig and are driven by 1,850-hp engines. The engines are trifuel units that can operate on

- A blend of digester gas and natural gas
- A blend of digester gas, natural gas, and diesel fuel
- Diesel fuel

In addition, four motor-driven rotary-lobe-type, positive displacement blowers were installed in 1970 to augment the high-pressure air system. These blowers are driven by 400-hp motors and are designed to each deliver 10,000 scfm at 8 psig.

The low-pressure air system blowers are throttled by varying engine speed through a flow control loop that senses blower manifold discharge flow. The high-pressure air system blowers are throttled by varying engine speed through a pressure control loop that senses blower manifold discharge pressure. The set point for each 4-psig and 8-psig header is currently manually derived from plant flow and experience, but will soon originate from a DO or oxidation-reduction potential (ORP) probe located near the second pass end of each tank. The set point for the main 4-psig header air flow controller is set by operating experience. Each tank header control valve is throttled by a cascade flow control loop to maintain 4 psig in the low-pressure manifold.

During the 1970-73 plant expansion, the plant's diffused and distributed air systems were placed under direct digital control using a dual computer system. The pneumatic control systems installed earlier remain intact and functional, but the computer was interfaced directly with the primary and final control elements. Control functions previously accomplished by pneumatic analog systems are now affected by either plant computer, using suitable control algorithms analogous to the pneumatic analog control functions. Four nitrification tanks were added to the original 12 tanks during the expansion. The new tanks have all-electric instrumentation, thereby eliminating the need for pressure/current and current/pressure converters. An instrumentation and control diagram of the DO control system is shown in figure II-37. Components include the following:

- Six single-stage, centrifugal, engine-driven blowers with flow-regulated surge control system, current transmitter, and high- and low-speed alarms
- Four rotary-lobe-type, positive displacement, motor-driven blowers
- One low-pressure blower discharge flow control system with pitot tube, square root extractor, flow transmitter, and flow controller
- One high-pressure blower discharge manifold pressure control system with pressure sensor, pressure transmitter, and pressure controller
- 14 low-pressure header butterfly throttling valves and flow control systems
- 12 high-pressure header butterfly throttling valves and flow control systems
- Five DO probes with analyzer/transmitter (plus five in the future)
- 10 ORP probes with analyzer/transmitter (in the future)
- Computer

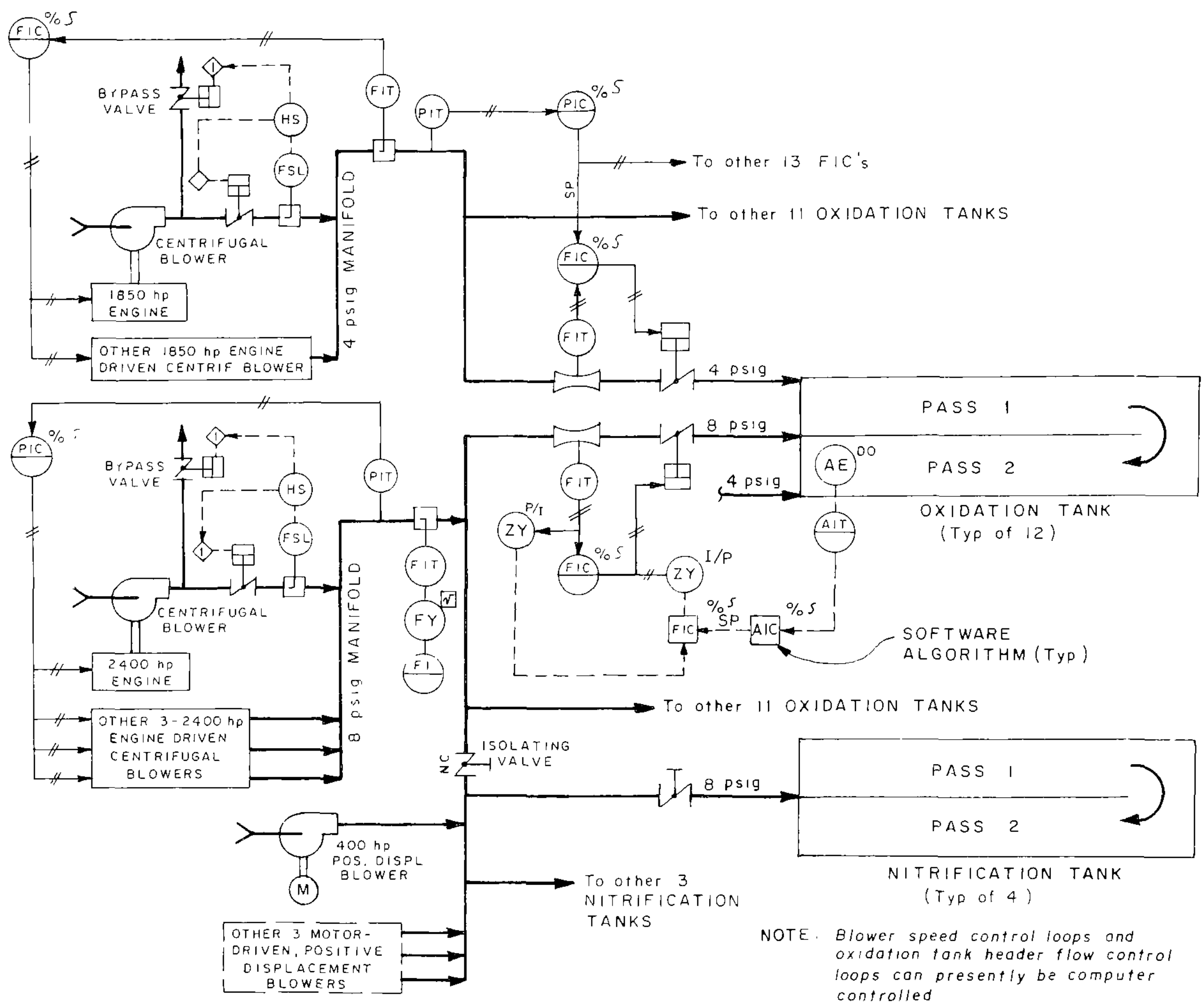

Figure II-37. Automatic DO control system, San Jose-Santa Clara Water Pollution Control Plant.

Operation. All six blowers at the San Jose-Santa Clara plant are currently computer controlled to deliver a specific flow rate for the low-pressure system and a specific pressure for the high-pressure system. However, blowers must be started and stopped manually from local control panels. The computer receives a linearized flow signal from the flow-indicating transmitter (FIT) connected to the square root extractor (FY) for the pitot tube (FE) in the low-pressure discharge manifold. Using a proportional and integral flow control algorithm, the computer develops an output signal that controls the fuel supply to the blower engine drives. The high-pressure blower speed is controlled in a similar manner with the exception that the computer receives a pressure signal from the pressure-indicating transmitter (PIT) connected to a pressure sensor in the high-pressure discharge manifold, and a pressure control algorithm is used.

The low-pressure, or distributed air, supply headers are flow controlled by the computer. The computer receives a signal from the PIT connnected to the header flow tube, inputs it to a flow control algorithm with a preset set point and outputs a control signal directly to the butterfly positioner in the header.

The high-pressure, or diffused air, supply to each oxidation tank and nitrification tank is also flow controlled by the computer. Currently, the computer receives a flow input from the FIT in each high-pressure air feed header, compares it to a set point using a proportional and integral control algorithm, and outputs valve position changes as required to the butterfly valve positioner in each air header.

At this time, the plant is installing DO probes in the effluent end of five of the oxidation tanks in one battery. At the computer console, the operator will be able to select DO, plant flow, or other variables as a control reference for computer computation of a flow control set point for the flow control algorithm in each high-pressure air feed header.

Performance. In October 1975, a DO control study test was run at the San Jose-Santa Clara plant. A DO probe was installed in the effluent end of four oxidation tanks in battery B and the DO output wired to the computer. A program called for a printout of each DO probe reading on 15-minute intervals. Testing commenced on October 21, 1975, and ran for a total of 8 days. Each oxidation tank was operated under manual DO control October 21, 23, 25, and 27, and under automatic DO control on October 22, 24, 26, and 28.

Under manual DO control, the air header feed valve on the 8-psig header to each tank was manually modulated approximately every 4 hours. The amount of valve position change required was estimated, based on the computer printout of DO in the respective tank.

Under automatic DO control, the computer modulated the air header feed valves as required to maintain a DO set point of 2.5 mg/l in each tank. The control algorithm included proportional and integral control modes. Results of the performance tests are shown in table II-14.

Table II-14 shows a general improvement in almost all performance parameters under automatic DO control. In particular, the air supplied per unit quantity of BOD removed improved over 12 percent. Improvement of this parameter would have been about 16 percent if data obtained on October 26 had been neglected. The air supplied per amount of BOD removed was inexplicably high on this day.

Table II-14.—*Performance comparison of manual and automatic DO control, San Jose-Santa Clara Water Pollution Control Plant, October 21-28, 1975*

Parameter	Manual[a]	Automatic[b]	Percentage improvement
BOD-removal efficiency, percent	84.8	85.2	0.5
SS-removal efficiency, percent	86.0	85.8	.2
Sludge volume index, mg/l	102	101	1.0
Air supplied:			
ft^3/gal influent	.89	.80	10.3
ft^3/lb BOD removed[c]	595	522	12.4

[a]Average daily flow—45.0 mgd; average BOD applied to oxidation tanks—54.3 pounds per 1,000 ft^3/day.

[b]Average daily flow—45.9 mgd; average BOD applied to oxidation tanks—56.1 pounds per 1,000 ft^3/day.

[c]Computed from total air supplied over testing period and 24-hour composites of primary effluent BOD minus secondary effluent BOD.

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METRIC CONVERSION TABLES

Recommended Units

Description	Unit	Symbol	Comments	Customary Equivalents*
Length	meter	m	*Basic SI unit*	39.37 m = 3.281 ft = 1.094 yd
	kilometer	km		0.6214 mi
	millimeter	mm		0.03937 in
	micrometer or micron	μm or μ		3.937 X 10^{-5} in = 1 X 10^4 Å
Area	square meter	m^2		10.76 sq ft = 1.196 sq yd
	square kilometer	km^2		0.3861 sq mi = 247.1 acres
	square millimeter	mm^2		0.001550 sq in
	hectare	ha	The hectare (10,000 m^2) is a recognized multiple unit and will remain in international use.	2.471 acres
Volume	cubic meter	m^3		35.31 cu ft = 1.308 cu yd
	litre	l		1.057 qt = 0.2642 gal = 0.8107 X 10^{-4} acre ft
Mass	kilogram	kg	*Basic SI unit*	2.205 lb
	gram	g		0.03527 oz = 15.43 gr
	milligram	mg		0.01543 gr
	tonne	t	1 tonne = 1,000 kg	0.9842 ton (long) = 1.102 ton (short)
Force	newton	N	The newton is that force that produces an acceleration of 1 m/s^2 in a mass of 1 kg.	0.2248 lb = 7.233 poundals
Moment or torque	newton meter	N·m	The meter is measured perpendicular to the line of action of the force N. Not a joule.	0.7375 lb-ft 23.73 poundal-ft
Flow (volumetric)	cubic meter per second	m^3/s		15.850 gpm = 2,119 cfm
	liter per second	l/s		15.85 gpm

Recommended Units

Description	Unit	Symbol	Comments	Customary Equivalents*
Velocity linear	meter per second	m/s		3.281 fps
	millimeter per second	mm/s		0.003281 fps
	kilometers per second	km/s		2,237 mph
angular	radians per second	rad/s		9.549 rpm
Viscosity	pascal second	Pa·s		0.6722 poundal(s)/sq ft
	centipoise	Z		1.450 X 10^{-7} Reyn (μ)
Pressure or stress	newton per square meter or pascal	N/m^2 or Pa		0.0001450 lb/sq in
	kilonewton per square meter or kilopascal	kN/m^2 or kPa		0.14507 lb/sq in
	bar	bar		14.50 lb/sq in
Temperature	Celsius (centigrade)	°C		(°F−32)/1.8
	Kelvin (abs.)	°K		°C + 273.2
Work, energy, quantity of heat	joule	J	1 joule = 1 N·m where meters are measured along the line of action of force N.	2.778 X 10^{-7} kw-hr = 3.725 X 10^{-7} hp-hr = 0.7376 ft-lb = 9.478 X 10^{-4} Btu
	kilojoule	kJ		2.778 X 10^{-4} kw-hr
Power	watt	W	1 watt = 1 J/s	44.25 ft-lbs/min
	kilowatt	kW		1.341 hp
	joule per second	J/s		3.412 Btu/hr

Application of Units

Description	Unit	Symbol	Comments	Customary Equivalents*
Precipitation, run-off, evaporation	millimeter	mm	For meteorological purposes, it may be convenient to measure precipitation in terms of mass/unit area (kg/m^2). 1 mm of rain = 1 kg/m^2	
Flow	cubic meter per second	m^3/s		35.31 cfs
	liter per second	l/s		15.85 gpm
Discharges or abstractions, yields	cubic meter per day	m^3/d	1 l/s = 86.4 m^3/d	0.1835 gpm
	cubic meter per year	m^3/year		264.2 gal/year
Usage of water	liter per person per day	l/person/day		0.2642 gcpd

Application of Units

Description	Unit	Symbol	Comments	Customary Equivalents*
Density	kilogram per cubic meter	kg/m^3	The density of water under standard conditions is 1,000 kg/m^3 or 1,000 g/l or 1 g/ml.	0.06242 lb/cu ft
Concentration	milligram per liter (water)	mg/l		1 ppm
BOD loading	kilogram per cubic meter per day	$kg/m^3/d$		0.06242 lb/cu ft/day
Hydraulic load per unit area, e.g., filtration rates	cubic meter per square meter per day	$m^3/m^2/d$	If this is converted to a velocity, it should be expressed in mm/s (1mm/s = 86.4 m^3/m^2/day).	3.281 cu ft/sq ft/day
Air supply	cubic meter or liter of free air per second	m^3/s l/s		
Optical units	lumen per square meter	lumen/m^2		0.09294 ft candle/sq ft

*Miles are U.S. statute, qt and gal are U.S. liquid, and oz and lb are avoirdupois.

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