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DEMONSTRATION OF A FULL-SCALE WASTE TREATMENT SYSTEM FOR A CANNERY

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DEMONSTRATION OF A FULL-SCALE WASTE TREATMENT SYSTEM FOR A CANNERY

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ABSTRACT

In 1967, the Stilwell Canning Company was discharging a portion of their wastes to Stilwell's Municipal waste treatment system and the rest to an irrigation system. Both were inadequate; therefore, a new system had to be developed.

Stilwell Canning Company, Stilwell, Oklahoma, cans and freezes a wide variety of vegetables and fruits including spinach, strawberries, green beans, yellow squash, okra, peas, beans, white potatoes, and sweet potatoes with potatoes being the dominant product. It is situated in a small community with a population of only 2,600 and during the potato processing season has a mean population equivalent of 150,000. The company is located on a small receiving spring fed stream which has a summer flow roughly equivalent to the waste flow. Consequently, a high treatment efficiency is required in order to maintain acceptable stream standards.

To meet the imposed requirements a two-stage aeration system was designed which consists of screens to remove the large suspended particles, a minimal solids aeration unit to remove a portion of the soluble organic matter, an extended aeration unit for solids destruction and effluent polishing, and a final clarifier. This system is the first one of this design known to treat a cannery waste; therefore, an operational study of this system was undertaken.

The system was studied over one operating season and data collected on the removal efficiencies of each unit process in the system. The treatment system performed more efficiently than expected in the design assumptions. Removal efficiencies of greater than 95% were obtained for most of the processing season, even though because of plant expansion the organic and hydraulic load was higher than expected.

It has been demonstrated conclusively that (1) the Stilwell canning wastes can be treated successfully by a two-stage activated sludge process. (2) The two-stage aeration process is very stable and capable of accepting shock loads without being adversely affected. (3) The two-stage aeration process is a flexible system allowing adequate capacity for varying waste loads; that is, the units can be operated individually or in combination to match the flow and strength variations. This provides high treatment efficiencies at the lowest operational cost. (4) Any one of the units, such as the minimal solids unit, can be started up readily by recycling the mixed liquor from one of the operating units.

This report was submitted in fulfillment of Project Number 1672 OURI and Demonstration Contract Number 12060 DSB between the Water Quality Office, Environmental Protection Agency, and the University of Oklahoma Research Institute.

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SECTION I

CONCLUSIONS

On the basis of the findings from this plant scale investigation, the following conclusions are drawn:

1. It has been demonstrated conclusively that the Stilwell canning wastes can be treated successfully by a two-stage activated sludge process, without pH adjustment of the incoming wastes.

2. The two-stage aeration process is very stable and capable of accepting shock loads without being adversely affected and provides high rate of removal with high treatment efficiencies.

3. The two-stage aeration process is a flexible system allowing adequate capacity for varying waste loads; that is, the units can be operated individually or in combination to match the flow and strength variations. This provides high treatment efficiencies at the lowest operational cost required to maintain a good receiving stream quality.

4. Any one of the units, such as the minimal solids unit, can be started up readily by recycling the mixed liquor from one of the operating units.

5. The final clarifier is inadequate at the peak flows. During the peak processing season the retention time is as low as 1.15 hours.

6. Substrate removal rates in the minimal solids unit follow zero order kinetics. An average COD removal of 90% was obtained for potato wastes and 84% for vegetable waste. About 50% of the COD removed can be attributed to bio-precipitation and settling since approximately 50% of the influent COD is present in the settleable, suspended or colloidal form.

7. The extended aeration unit was very successful in effluent polishing. The average plant soluble COD were 84, 44, and 33 mg/l for sweet potato and vegetable wastes, Irish potato and vegetable wastes, and vegetable wastes alone, respectively. The corresponding BOD in the plant effluent was about 20% of the COD values, which indicated biodegradable organic removal for the system of greater than 99%.

8. Foaming problems in aeration basins can be controlled by maintaining a MLVSS level of at least 2000mg/l.

9. Loss of sludge from final clarifier during the processing of sweet potatoes was a result of nitrogen deficiency.

10. A TKN/VSS ratio of 5% in the sludge is required in order to control sludge bulking.

11. Temperature effect was not significant during the course of study.

12. The rapid fluctuations in flow and waste strength resulting from the frequent changes in products processed negated the reliability of a laboratory model in simulating a full-scale system, and therefore, they were not pursued.

13. Solids handling facilities in the system are not adequate.

14. The anaerobic digested sludge has a rubber-like consistency which may make it unsuitable as a soil conditioner.

15. The rate of digestion is extremely slow; therefore, the use of anaerobic ponds for solids disposal from a cannery waste treatment plant is probably not the optimum system.

SECTION II

RECOMMENDATIONS

Based on the results from this study the following changes and/or additions are recommended:

1. A solids disposal facility other than anaerobic ponds should be added to this system. The recommended process is primary sedimentation followed by vacuum filtration. The filter would be used to dewater the return sludge as well as the sludge from the primary clarifier. The filter cake, until a market can be developed, will be disposed of in the existing sanitary land fill.

2. A study should be initiated to find economical uses of solid waste product, which, while processing some products, amounts to more than 40 percent of the raw product purchased.

3. A second final clarifier should be added to the system. It should have a capacity large enough to increase the combined retention time of both final clarifiers to four hours.

4. The inplant piping should be improved to allow the operation of each unit separately in parallel or in series.

5. A water savings and reuse study should be undertaken to decrease the water demand. It is anticipated the water demand could be decreased by at least 30 percent, and probably 50 percent or more.

6. A study of this magnitude should be spread over a longer time period, allowing for two processing seasons. This cannery processes a variety of vegetables and fruits, some over a very short period of time, which makes it difficult to obtain enough data to reach sound conclusions.

DEMONSTRATION OF A FULL-SCALE WASTE TREATMENT SYSTEM FOR A CANNERY

SECTION III

INTRODUCTION

General

The canning industry and in particular the potato processing industry has grown very rapidly in the past decade. The 1967 and 1969 USDA (1) production figures indicated a total potato crop of 245,272,000 hundred weights in 1959 and 294,192,000 hundred weights in 1968. The total quantity of potato processed by all food industries increased from 47,824,000 hundred weights in 1959 to 69,429,000 in 1964 (there was no record on potato processed in 1968). This corresponds to approximately 19% of the total crop in 1959 and 29% in 1964. Many of these processing plants are located in rural areas or in small towns where sewage treatment facilities are not available or at least were not designed to treat a waste of high organic content. In the processing of potatoes, 20 to 50% of the processed raw potato is discharged as waste. Such waste can be composted and sold as fertilizer, used as feed for livestock, or for by-products extraction if it is economically feasible. Waste flows range from 840 gallons to 5,000 gallons per ton of raw potatoes processed, depending on the desired product. The rapid growth of the potato industry has resulted in a corresponding increased volume of waste with potentially the same increase in water pollution.

The characteristics of the potato waste are high organic strength, high starch content, large volume, low nutrients, and pH values which vary with the method of peeling used. Research on biological treatment of potato wastes reported at the initiation of this study, with the exception of that reported for lagoons, has been done using bench scale models. It is essential that these studies be related to full scale plant operation, so that high rate and modular processes can be designed and economically applied. A study supported by the Federal Water Quality Administration was undertaken for this purpose at the Stilwell Canning Company.

Stilwell Canning Company, Stilwell, Oklahoma, cans and freezes a wide variety of vegetables and fruits which include spinach, strawberries, green beans, yellow squash, okra, peas, beans, white potatoes, and sweet potatoes with potatoes being the dominant product. It is situated in a small community with a population of only 2,600 and during the potato processing season, has a mean population equivalent of 150,000. It is located on a small receiving spring fed stream which has a summer flow roughly equivalent to the waste flow. Consequently, a high treatment efficiency is required in order to maintain acceptable stream standards.

Benefiting from the grant-in-aid program of the Federal Water Quality Administration of the U.S. Department of Interior and a grant from the Economic Development

Administration Office, of the U.S. Department of Commerce, a wastewater treatment plant was constructed and started operation in May, 1969. The design was based on studies by Reid and Streebin (2) and consists of screens to remove the large suspended particles, a minimal solids aeration unit to remove a portion of the soluble organic matter, an extended aeration unit for solids destruction and effluent polishing, and a final clarifier. This system is the first one of this design known to treat a cannery waste; therefore, an operational study of this system has been undertaken.

Objective

The objective of the research is to show that high organic, large volume, nutritionally unbalanced cannery wastes can be successfully and economically treated to a high degree by a two-stage biological process. The results will be used to establish design criteria for the treatment of potato and vegetable wastes.

The scope of this research includes:

1. Characterization of the various vegetable and potato wastes as they reach the waste treatment plant.

2. Determination of waste flows.

3. Evaluation of the performance of each modular process and the entire system.

SECTION IV

LITERATURE REVIEW

A review of technical literature has been undertaken to assemble the pertinent results of other investigators. The literature cited includes three subjects: potato waste, nutrient supplementation, and other vegetables and fruit wastes. A brief summary is given below.

Potato Waste

Waste Characteristics

Cooley et al (3) studied the characteristics of several potato processing wastes. They found that the waste flow from the potato flake factory was 2643 gallons per ton of raw potato processed with a suspended solids (SS) of 23.7 lbs per ton or 1080 mg/l, and the pH of lye peeling stream was 12.6 and that a stream peeling was 7.3.

The average volume of waste per ton of raw potato from the potato flake industries as surveyed by Francis (5) was 5000 gallons with an average BOD of 59 lbs or 1720 mg/l and a SS of 91 lbs or 2580 mg/l.

Porges and Towne (6) reported a waste flow of 1990 gallons per 1000 lbs of potatoes processed into potato chips with an average BOD of 25 lbs or 1380 mg/l and a SS of 33 lbs. or 1710 mg/l.

The Potato Chip Institute and the National Technical Task Committee (7) reported an average BOD of 25 lbs per 1000 lbs. of raw potato processed, and the BOD/Solids ratio of 0.453.

Vennes and Olmstead (8) quoted, in their investigation on the potato flake waste, an average flow of 5000 gallons with a BOD of 1410 mg/l and a SS of 2180 mg/l based on one ton of raw potato processed.

Atkins and Sproul (9) studied a lye peeling french fry processing plant in Maine and found that in-plant improvements reduced the waste flow from 2520 gallons per ton of raw potato to 2310 gallons per ton, the plant composite BOD of 2460 mg/l to 1150 mg/l, the SS from 1750 mg/l to 1310 mg/l; and the COD of this waste was reduced from 3500 mg/l to 1790 mg/l. The BOD to COD ratios were, respectively, 0.7 and 0.4 before and after the in-plant improvement with lye peeling pH of 11.5 to 11.1.

Fergason et al (10) determined the BOD of the protein water from a potato starch plant to be about 3900 mg/l with a COD of 6000 to 7000 mg/l and on average BOD to COD ratio of 0.64.

Kueneman's study (11) on a primary waste treatment plant, in Idaho, indicated a waste flow of 3650 to 4200 gallons per ton of raw potatoes, COD of 2000 to 2500 mg/l, and pH of 11 to 12 using a lye peeler and 6 to 6.5 using a steam peeler. Kueneman further stated that the waste flow could be reduced to 200 to 400 gallons per ton with considerable water re-use.

Forma (12) analyzed the process wastes from several potato processing plants in Idaho and reported an average flow of 2700 gallons per ton of potato processed and a COD of 3300 mg/l.

Potato processing wastes contain some nitrogen and phosphorous. Atkins and Sproul (9) presented information indicating a BOD/P ratio of 350 to 1.

Dostal (4) in a study of two potato processing and one starch plant over a two year period reported the following data per ton of product: a waste volume of 4200 gallons, BOD of 90 lbs, COD of 210 lbs, suspended solids of 110 lbs, total phosphate of 0.6 lbs and total nitrogen of 3.5 lbs, for a BOD/N/P ratio of 100/3.9/0.7.

Reid and Streebin (2) measured a COD strength of 3190 mg/l, a COD/N ratio of 570/1 and a N/P ratio of 2.5/1 for Irish potato wastes and a COD of 4500 mg/l, a COD/N ratio of 2600/1 and N/P ratio of 0.55/1 for sweet potato wastes.

A summary of the potato waste characteristics as found in the literature is shown in Table 1.

Screening, Primary Settling and Sludge Dewatering

Screening serves to remove the coarse material that might interfere with subsequent operations in treatment, and therefore is generally used as the first step in food waste treatment. Ballance (13) indicated that all types of vibrating screens have a great advantage over the other moving screens for producing a solid fraction that is relatively low in moisture content (80%). He further stated that for potato waste a 20 mesh screen could remove approximately 35% of the total solids. Barnes (15) reported that a SS removal of 35% could be be obtained by a 10 mesh screen with a corresponding BOD reduction of 27%.

The Potato Chip Institute and the National Technical Task Committee (7) reported approximately 50% of the suspended and 90% of the settleable matter of composite potato waste stream could be removed with a 15 to 30 mesh screen.

According to investigations by Hindin and others (14) the screened solids had a COD of 108 g/l, a total solids content of 10 to 15% and a volatile solids content of 9 to 14%.

TABLE 1
POTATO WASTE CHARACTERISTICS (FROM LITERATURE REVIEW)

POTATO PROCESS FOR	Waste Flow Gal/Ton	SS lbs/Ton	SS mg/l	BOD lbs/Ton	BOD mg/l	COD lbs/Ton	COD mg/l	BOD/COD	pH Lye Peeling	pH Steam Pealing	Ref.
Potato Flake	2643	23.7	1080	33	1540	51	2320	0.64	12.6	7.3	(3)
Potato Chip	2007	36	2090	14.5	840	49.4	2860	0.293			
Potato Flour	880	19	2590	23	3140	37.3	5080	0.617			
Potato Starch	838	28.9	4140	25.8	3680	51.4	7380	0.502			
Potato Chip	3980	33	1710	25	1380						(6)
Potato Flake	5000	91	2580	59	1720						(8)
French Fry	2310		1310		1150		1790	0.4	11.3		(9)
Potato Starch					3900		6500	0.64			(10)
Various Products	2700						3300				(12)
Various Products	3650-4200						2000-2500		11-12	6.0-6.5	(11)
Irish Potato Canning							3194				
Sweet Potato Canning							4500				(2)
Potato Processing And Potato Starch	4200	110		90		210		.41			(4)

Sedimentation is the least expensive method of solid liquid separation used to remove finer suspended matter from the waste water. The experiments by Reid and Streebin (2) on settling of potato waste for one hour showed approximately 38% COD reduction with 5.1% solids in settled sludge for Irish potato and a COD reduction of 44% with 5.7% solids in settled sludge for sweet potato.

Dostal (4) reported that primary treatment of potato waste by sedimentation at an overflow rate of 800 gpd/ft^2 could remove 41, 45, 73, 21, 21 percent of the BOD, COD, SS, PO_4 and N respectively. He also reported a BOD/N/P ratio of 100/5.2/0.9 for primary clarifier effluent.

The work of Sproul and others (14) showed a SS and BOD removal of 80 and 60% respectively by primary settling at overflow rates of 600 to 1000 gal/day/sq. ft.

Activated Sludge

Buzzell and others (16) investigated the feasibility of treating the waste from a potato starch plant using a continuous flow, complete mixing activated sludge pilot unit. It was found that this system gave excellent BOD reductions even at rather high organic loadings. When units were loaded at less than 80 lbs of BOD per 1000 lbs of mixed liquor suspended solids (MLSS) per hour of aeration, BOD removals were 95% and above. At a MLSS concentration of 3500 mg/l, this loading is equivalent to 420 lbs of BOD per 1000 cu. ft. of aeration capacity per day. As the BOD loading was increased above 80 lbs, the BOD removal efficiency dropped off rapidly. The simulated waste studies had an average BOD of 3700 mg/l. It was further pointed out that foaming was a problem, and it tended to increase with decreased aeration time. No nutrients were added in this study.

Atkins and Sproul (9) studied the feasibility of treating a potato waste from a lye peeling french fry plant using a complete mixing activated sludge laboratory unit. The aeration time studies varied from 6 to 20 hours. At a 6 hour aeration time, the BOD loading ranged from 191 to 358 lbs per day per 1000 cu. ft. of aeration volume; and the MLSS concentration ranged from 3600 to 4500 mg/l. At these loading rates BOD removals of higher than 90% were maintained. The sludge could be settled satisfactorily at all aeration times studied; however, the sludge density increased with an increase in aeration time. No nutrients were added in this study. The influent pH was 11.8 and that of the treated effluent varied from 8 to 9. The corresponding COD removal was 90% and the SS removal above 90% with a sludge volume index (SVI) of 100 to 190. It was concluded that without pH adjustment, at a MLSS level of 4000 mg/l, and an aeration period of 6 to 8 hours, a BOD reduction of 95% or above could be obtained. Their study also showed that adjustment of pH did not significantly improve the treatment efficiency. The authors briefly studied the contact stabilization process. Their results showed that a 78% COD removal was possible with a contact time of one hour and stabilization time to 6 to 8 hours.

In this study the pH of the wastes was adjusted to 8.0 before feeding the treatment unit; the MLSS concentration in the stabilization unit was maintained at 4000 mg/l; and sludge returned was 33% of total volume in the contact compartment. At a contact time of 30 minutes with 2 hours of reaeration, COD removal was 49%. It was concluded that further investigation into this type of treatment would be highly desirable. Sproul et al (14) found that the growth rate for a settled steam peeling waste was about 0.0005 mg/l/hour. According to Sproul, this would indicate a BOD removal of 92% with an aeration time of 6 hours and a mixed liquor volatile suspended solids (MLVSS) of 3500 mg/l. Based on the laboratory work at the University of Maine, Sproul (17) presented a tentative design criteria for complete mixing activated sludge treatment of lye peeling potato processing waste without pH adjustment. The investigator recommended a BOD loading of 200 to 400 lbs per 1000 cu. ft. of aeration volume per day with a MLSS concentration of 3000 to 4000 mg/l and an aeration time of 8 hours. Foaming problems in the aeration tanks will be minimized if the biological solids are kept at the higher level. Reid and Streebin's study (2) on treating potato processing waste using an activated sludge system at the University of Oklahoma showed comparable results with other investigators. A minimal solids aeration unit of 3 hours detention time yielded a 50% COD reduction. The extended aeration studies showed a COD reduction of 96.5% in 17 hours of aeration time. The biosorption process was also studied, but it only yielded a 25% COD reduction. These studies further indicated that nutrients will be required to maintain a BOD/N ratio of approximately 100 to 1 which is much less than the normal combining ratio. This ratio is substantiated by Ekenfelder (33).

Trickling Filter

The use of biofilters to treat potato wastes has also been investigated. Buzzell and others (16) found that a 90% or better BOD removal was obtained on high rate filters with a loading of up to 3000 lbs BOD per acre-foot per day. Pailthrop and Filbert (18) presented data indicating that BOD could be reduced from 1680 to 280 mg/l or 84% by treating a primary settled lye peeling potato waste through to super rate Dow Chemical Company's Surfpac Filter. The recirculation ratio was 6 to 1; however, the loading rate was not given.

A summary of the organic and hydraulic loadings used for the design of aerobic biological treatment processes as obtained from the literature cited is shown in Table 2.

Anaerobic Digestion

Hindin and Dunstan (19) made studies on the treatment of the settled solids from the potato chip waste by using anaerobic digestion. Their experiments showed that mixtures of potato waste solids and raw domestic sludge can be satisfactorily treated by conventional anerobic digestion as long as the feed does not contain more than 50% potato solids. The loading rate used in their laboratory investigation was 0.075 lbs volatile solids per day per cu. ft. of digestion capacity with a detention time of 33 days. The volatile acids did not exceed 1400 mg/l in the study. It is generally acknowledged that as long as the total volatile acids are less than 2000 mg/l as acidic acid, no inhibitory effect on the activity of the methane bacteria will occur. It was concluded that the digester was under a stress when treating a feed containing 75% potato solids. This was probably due to a growth factor deficiency rather than the presence of inhibitory substances.

Ling (20), in a study of starch-gluten waste, used a model of a conventional sedimentation tank to separate the solids which were forwarded to a continuously recirculated anaerobic digestion laboratory unit. The digester was maintained at a temperature of about 95°F. This experiment showed an 80% removal of volatile solids at a loading of 0.1 lbs volatile solids per day per cu. ft. of digester volume. The author furthur pointed out that the maximum allowable loading of the digestion process had not been reached at this loading.

Both digester and anerobic lagoons give off very offensive odors (21, 22) and are unsatisfactory in the area where odors cannot be tolerated.

Nutrient Supplementation

Efficient and successful biological oxidation of organic wastes require nitrogen (N) and phosphorous (P) for the anabolic reactions, i.e. the synthesis of new cell tissue. Many industrial wastes, such as potato processing waste, do not contain adequate quantities of nitrogen and phosphorous for these reactions; hence, they require the addition of nutrients.

Servizi and Bogan (23) demonstrated that synthesis is proportional to the change in free energy of oxidation. Since the free energy for most organic compounds is the same, -3160 to -3587 cal/g COD, it follows that synthesis will be proportional to the COD reduction of the substrate or waste.

Since in bio-oxidation both the synthesis and respiration proceed simultaneously, nitrogen will be released and assimilated simultaneously. Some of the nitrogen will be recovered and reused for synthesis. Therefore, the quantity of nitrogen required depends on the aeration time. The general formula for biological cell mass has been expressed as $C_5H_7O_2N$ (23), in which 12.4% is nitrogen. Sawyer and his associates (25, 26, 27) studied the nutritional requirements of activated sludge with industrial wastes and expressed the assimilation of nitrogen in terms of a BOD to nitrogen ratio, BOD/N. They concluded maximum nutritional requirements need not be supplied in order to achieve satisfactory treatment. Critical nutritional requirements on the basis of BOD removal are estimated to be 3 to 4 lbs of nitrogen, and 0.6 lbs of phosphorous per 100 lbs of BOD_5 removed respectively. This is approximately equivalent to a BOD/N/P ratio of 150/5/1 at 20°C. A critical nitrogen deficiency tends to decrease the rate of BOD removal, impair the settling and dewatering characteristics of the sludge, and decreases the rate of sludge growth. The critical nutrient concentration was defined as the minimum amount of a nutrient which must be present to maintain BOD removals at a high rate. Any reduction of nutrient concentration below the critical amount would cause the BOD removal to fall off rapidly. The percentage nitrogen content of dried activated sludge based on volatile matter is a good index of nutrient deficiency. A value of less than 7% for nitrogen and 1.2% for phosphorous is indicative of a critical deficiency.

The maximum requirement is the maximum amount of nutrient which can be taken up by the sludge. Assuming the nutrient fully available, the sludge will tend to remove up to the maximum nutrient requirement from solution and fix it in the sludge. According to Weinberger's work (28), only nitrogen present in the form of NH_3-N is considered to be 100% available for the bacteria.

Heukelekian and others (29, 30), in their tests on a number of industrial wastes, established a BOD/N/P ratio of 100/5/1 as being generally desirable for a maximum stabilization rate. The observed BOD values included only carbonaceous oxygen demand. Jones (31), in his studies on sludge bulking, showed that the critical BOD/N ratio was 40/1, and below this value the specific growth rate decreases. He further indicated that the cell mass contained 6.5% of NH_4^+ and 9.0% of NO_3-N at the equilibrium nitrogen concentration. This was based on the assumption that all the nitrogen had been taken up by the cell. Oginsky and Umbreit (32) indicated that a nitrogen content of 1.7% in the cell mass was adequate and phosphorour, sulfur, etc., were not usually limiting. This concentration is much lower than reported by other investigators, and low concentrations generally result in sludge bulking. Sawyer (33) reported that the phosphorous requirement was about one fifth of the nitrogen requirement. Eckenfelder and Burns (34) showed a critical requirement of 4.3 lbs N/100 lbs BOD removed. This is based on their two year study of nutrient requirements at the West Virginia Pulp and Paper Company activated sludge plant; below this level organic removal efficiency was lowered.

Since most industrial wastes are deficient in nutrients, the addition of nitrogen and phosphorous in the biological treatment system is usually required. The cost of maintaining a BOD/N/P ratio of 100/5/1 in the activated sludge system, as used in general practice, is tremendous. Furthermore, the nitrate content in the treated effluent encourages heavy algae growth in the receiving water. Reid (35) pointed out that as the degree of treatment for organic removal increased, the dilution requirements for the maintenance of dissolved oxygen levels for receiving water decreased, while the dilution required for the control of nutritional pollution as measured by algae concentration tended to increase. Hence, for higher level treatment, discharged nutrients may dictate the treatment process. Komolrit, Krishnan and others (36, 37) found that with initial high biological solids concentration in the aeration vessel, carbon could be incorporated into non-nitrogen cell constituents in the absence of an exogenous source of nitrogen by first storage and later synthesis; and for a short period

TABLE 2

SUMMARY OF AEROBIC BIOLOGICAL TREATMENT RESULTS (FROM LITERATURE REVIEW)

TREATMENT PROCESS	Process Water	Organic Loading	Aeration time hr.	MLSS mg/l	Percent Organic Removal	Nutrient Supplementation	Ref.
Complete Mixing Activated Sludge	Potato Starch	4200 lbs BOD / 1000 cf-day	15	3500	95% BOD	None	(16)
Complete Mixing Activated Sludge	Lye Peel French Fry	191-3581- lbs BOD / 1000 cf-day	6	3600 4500	90% BOD	None	(9)
Contact Stabilization Activated Sludge	Lye Peel French Fry	3600 mg/l COD	1.5	4000	78% COD	None	(9)
Complete Mixing Activated Sludge	Steam Peel		6	3500 MLVSS	92% BOD	None	(15)
Minimal Solids	Stilwell	1400 mg/l COD	3		50% COD	None	(2)
Extended Aeration	Potato Waste diluted	800 mg/l COD	17		96% COD		
Contact Stabilization	with water		0.5		25% COD	None	(2)
High Rate Trickling Filters	Potato Starch	3000 lbs BOD / acre ft-day	158 gal / sf-day		90% BOD	None	(16)
Dow Chemical Surfpac Filter	Lye Peel				84% BOD	None	(18)

of time the removal efficiency would not be impared. After substrate removal, the protein was then synthesized from the carbohydrate stored in the cells by aeration in the presence of nitrogen. Using this idea, Gaudy and his associates (38, 39) studied the feasibility of reducing the nitrogen supply by controlled addition of nitrogen to the returned sludge rather than continual addition to the incoming waste. In their laboratory experiment, the nitrogen deficient waste was fed continously to a feeding aerator without addition of nitrogen; the mixed liquid was then passed to a clarifier for solids separation, from which a portion of the sludge was forwarded to an endogenous aerator where the exogenous nitrogen was added; then the sludge was recycled to the feeding aerator. It was found that with a COD/N ratio of 70/1 a solids concentration of 700 mg/l and a hydraulic detention time of 4 hours in the feeding aerator, the overall removal efficiency after settling was 96%. The substrate used was acetate; therefore the corresponding BOD/N ratio was 47/1.

Other Vegetable and Fruit Wastes

In the United States, nearly half of all vegetables and fruit produced are canned or frozen. About 90% of the peaches and pineapples, 80% of all tomatoes, 65% of the peas produced and more than 50% of all sweet corn harvested in this country are canned. Many other products such as beans, okra, spinach, collard greens, mustard greens, oranges, apples, strawberries, pumpkin, squash and mushrooms are also canned or frozen.

Since these agricultural products are highly seasonal, almost every cannery processes a wide variety of foods in its operation. Because such a wide variety of products are processed in individual canneries, various waste flows and concentrations can be found.

The characteristics of various products as presented by Mercer (40) are reproduced in Table 3. Burbank and Bumagai (41) studied the feasibility of treating pineapple waste by activated sludge. The organic constituents as measured by COD ranged from 24.1 to 32.8 lbs per ton of pineapples processed with a weighted average of 26.2 lbs per ton. The waste contained a high carbohydrate concentration which accounted for 80 to 90% of the soluble COD. As demonstrated from a completely mixed activated sludge laboratory system, carbohydrate removal was feasible; with a maximum loading rate of 17.5 lbs sugar/lb MLSS/day, 98% carbohydrate removal was obtained; however, sludge settling was poor. They further demonstrated that sludge growth was partly due to celluloseutilization, and that 80% of the COD removal was attributed to synthesis. The nutrients in the waste were sufficient for biological treatment.

The University of Oklahoma has studied the characteristics of tomato waste from an Oklahoma cannery (42). It was found that one hour of settling would reduce the COD of the lye peeling stream from 1830 to 1600 mg/l and 1550 to 1260 mg/l for the steam peeling stream. The COD of the packing stream could be reduced from 1220 to 1020 mg/l for the same settling period. The BOD of the settled lye peeling stream was 940 mg/l, and the BOD of the settled steam peeling stream was 860 mg/l. The feasibility of treating this waste has been studied in a batch unit using unacclimated sludge. After 24 hours of aeration, the COD was reduced from 1230 to 160 mg/l with a MLVSS increase from 1235 to 2405 mg/l. It was anticipated that better organic removal could be expected with well-acclimated sludge.

Gilde (43) reported on Campbell Soup Company spray irrigation system at Paris, Texas. Waste was applied at a rate of 0.25 in/day after 10 mesh screening and pretreatment for grease recovery. Flow ranged from 1.8 to 2.8 MGD, and normal application was limited to a maximum of 2 hours at a time. Extremely tight clay soils allowed very little infiltration; runoff was collected in terraces to be conducted off the field. Soluble BOD was adsorbed on the litter; wastes average 850 mg/l; and effluent as it ran off the property averaged less than 10 mg/l, with a corresponding COD of 51 mg/l. The vegetative cover of the disposal field produces a protected habitat for soil microorganisms and presents a vast area for the absorption of organic impurities; the system functions as a horizontal grass trickling filter.

Also included in the report was a study of the Napolean, Ohio, plant. Its soup processing wastes are treated by a two-stage trickling filter with intermediate aeration between the filter and settling stages. However, during the tomato season, tomato wastes were handled separately on a spray irrigation system. During 1964 to 1965 the average waste applied reached a peak of 1.4 in/day with some spray lines reaching peaks of 4 to 5 in/day. Tests results revealed that, on a mass basis, the percent reduction for COD, BOD, nitrogen, and phosphate were respectively 81, 85, 73, 65%.

Skrinde and Dunstan (44) found that trickling filters loaded from 1400 to 4000 lbs BOD per 1000 cu. ft. per day became decreasingly efficient because of excessive slime growths. Activated sludge provided satisfactory treatment under proper loading, although *Sphaerotilus* growth caused bulking and loss of suspended solids. Joint treatment with municipal sewage on a roughing filter provided reasonable BOD removal without excessive slime growth. All biological processes for treating pea wastes require supplemental nutrients.

Zinkfoose (45) described the treatment for pea waste after mixing with settled domestic sewage. Waste flows from three processing plants produced a combined flow of 5 MGD with a BOD of 850 mg/l. The waste contained very little settleable material; therefore, no primary clarification was used. The settled sewage and industrial wastes were mixed in a control structure and portions diverted to the different plants. The portion of the mixed waste diverted to the industrial treatment plant was applied to parallel trickling filters. Identical clarifiers followed each filter. Sludge was returned to the domestic plant for digestion.

Dickson (46) presented a paper on a large cannery using lagoon treatment. The Sleepy Eye, Minnesota, plant processed peas and corn with waste flows amounting to 60

TABLE 3

VOLUME AND CHARACTERISTICS OF CANNERY WASTES

Product	Waste Volume gal/case	BOD mg/l	Suspended Solids
Apples	25-40	1680-5530	300-600
Apricots	57-80	200-1020	200-400
Asparagus	70	16-100	30-180
Beans, baked	35	925-1440	225
Beans, green	26-44	160-600	60-150
Beans, kidney	18-20	1030-2500	140
Beans, lima, dried	17-29	1740-2880	160-600
Beans, lima, fresh	50-257	190-450	420
Beets	27-70	1580-7600	740-2220
Carrots	23	520-3030	1830
Cherries	12-40	700-2100	200-600
Corn, cream style	24-29	620-2900	300-675
Corn, whole kernel	25-70	1120-6300	300-4000
Cranberries	10-20	500-2250	100-250
Mushrooms	6600	76-850	50-240
Peaches	45-60	1200-2800	450-750
Peas	14-75	380-4700	270-400
Potatoes, sweet	82	1500-5600	400-2500
Potatoes, white	--	200-2900	990-1180
Pumpkin	20-50	1500-6880	785-1960
Sauerkraut	3-18	1400-6300	60-630
Spinach	160	280-730	90-580
Squash	20	4000-11000	3000
Tomatoes	3-100	180-4000	140-2000

million gallons in one season. The BOD of the pea waste averaged 1000 mg/l while the corn waste was usually twice as much. Total pond area was 38 acres or about 6.3 acres per pond. An interesting point was that the wastes from the last few days of the canning season were held during the winter in order to maintain a good algae and bacteria population for operations the following spring.

Webster (47) of Seabrook Farms Company, Bridgeton, New Jersey, made pilot plant studies on treatment of vegetable processing wastes using high rate and deep high capacity biofilters. Raw wastes were screened before being discharged to primary settling tanks. The primary effluent was split into two streams, one portion going to the deep filter, the other to the high rate filter. Both deep and high rate filters were followed by secondary settling tank. The New Jersey Department of Health required a plant effluent BOD of no more than 60 mg/l at that time. The deep and high rate biofilters were seeded with settled domestic sewage and acclimated for 16 days. More than 4000 experimental tests were made, the results of the waste analysis and the treatment efficiencies are summarized in Table 4 below.

TABLE 4

WASTE CHARACTERISTICS AFTER SCREENING AND TREATMENT EFFICIENCIES OF FILTERS

Product Processed	Flow MGD	BOD, mg/l After Screening	BOD, mg/l Primary Effluent	BOD, mg/l Final Effluent Deep	BOD, mg/l Final Effluent High Rate	Overall Removal % BOD Removed Deep	Overall Removal % BOD Removed High Rate
Peas	5.82	68	49	23	19	66.3	72.3
Beets & Corn	8.18	223	195	59	32	73.4	85.8
Lima Beans	7.56	142	125	32	31	77.7	78.5
Potato	2.76	227			22		90.3
Spinach	7.43	137					

The author concluded that the deep type filter would produce a satisfactory effluent with loadings less than 12,000 lbs BOD per acre-foot per day. The high rate bio-filter would be the most economical and would produce a better effluent quality with loads amounting to 5000 lbs per acre foot per day or less. The retention times and overflow rates for the settling tanks were 75 minutes and 1578 gallons per sq. ft. respectively.

SECTION V

DESIGN OF TREATMENT FACILITIES

Background

Before 1969, the Stilwell Canning Company wastes were divided into two streams. The strong wastes from Irish and sweet potatoes were pumped about three-fourths of a mile over a 500 foot hill to a holding lagoon and then spread on a fruit orchard. This system was not operated properly and, as a result, several problems existed, not the least of which were odors which at times were noticeable more than a mile downwind. To control odors, sodium nitrate was added to the lagoon; however, some of the fruit trees were killed. At this point the orchard owner issued an order to stop irrigation.

The weak wastes from vegetable products were discharged to the city sewage treatment system, which was designed for 6,000 people and was treating the waste from 2,600 people plus the cannery waste with a population equivalent of from 7,200 to 15,000; this completely overwhelmed the treatment plant. The effluent was discharged into Caney Creek, a spring fed stream. While the cannery was in operation, a five mile reach of the stream had no trace of dissolved oxygen. After flowing sixteen miles, Caney Creek discharges into Lake Tenkiller, a major water recreation area. For many miles downstream there were numerous complaints of odors and in general a bad rapport prevailed between the city residents and the canning company even though the cannery employs 450 people in a town of 2,600.

The problem was to provide an integrated treatment system for the canning company capable of treating the high strength, nutritionally unbalanced, large volume wastes to a degree compatible with the receiving stream. This was no small task because the organic load per shift varied by more than 60 fold, from a volume of 0.39 MGD and COD of 150 mg/l for spinach wastes to greater than 1.91 MGD and a strength of 5,500 mg/l while processing sweet potatoes.

Based on the information gathered and reported in the literature review, several treatment processes were considered including trickling filters, minimal solids, moderate solids, extended solids aeration and biosorption systems. The incoming waste in question has a very high organic strength; therefore, trickling filters and biosorption systems were deleted from consideration because they are not capable of treating high strength waste to the degree required without polishing ponds or other tertiary treatment systems. Minimal solids aeration has a high loading rate, a short solids retention time, and a high growth rate. With this process the removal rates are extremely high, the removal efficiencies low, and the MLSS highly dispersed; therefore, the process though efficient in terms of dollars per pound of COD removal, must be followed with another process. For such a high strength waste moderate solids aeration could produce effluent of good quality provided a high MLVSS concentration and low loading intensity are maintained. However, this would result in a size diseconomy. Extended aeration has a very low loading rate, about 1/100th the rate of that in minimal solids system, and a solids retention time perhaps 100 times as great. This process is efficient in terms of percentage removals for wastes of low strength; however, it would also suffer from size diseconomies for strong wastes. Therefore, a dual or two-stage aeration process was chosen.

The first stage aeration is a high rate process with high loading capacity, followed by a more efficient polished-effluent-producing process, that is, minimal solids followed by extended aeration. The two-stage system combines the desirable characteristics of both (48). The high rates of removal are provided by the minimal solids unit and effluent polishing and aerobic sludge digestion by the extended aeration basin.

Recommended Process

The design capacity of a domestic sewage treatment system is generally based on an estimation of the population to be served in the future. For example the design period may be twenty years. The design of waste treatment facilities for an industry, however, is usually based on the future production of the industry and the strength and quantity of the waste thus generated. Possible technical innovations in the industrial processes and its effect on the characteristics and volume of waste must also be considered in the development of a plan for the ultimate facilities.

The implementation of such designed facilities usually is not carried out in one stage due to economic reasons. In practice the pertinent structures will be built first to meet the immediate demand, and the facilities which can be expanded easily will be constructed later or added in stages.

The Stilwell industrial waste treatment plant was designed for a flow of 1.5 MGD with an average BOD of 1,500 mg/l which was considered adequate for the immediate future. For the ultimate plan, two alternatives were conceived. Alternative one was to build a plant for full aeration and hydraulic capacity which could be expanded to meet increased organic load with the additon of a primary settling tank and solids disposal facilities. Alternative two was to approach the designed plant capacity in steps by increasing the volume of aeration tanks but with a primary clarifier and vacuum filter sized for full hydraulic capacity and installed during the initial phase of construction. Previous studies indicated that approximately 50% of the influent COD can be removed by primary settling, but there was insufficient evidence to suggest a method of degrading the sludge economically. Primary settled sludge will normally contain 95 to 98% water. A thickener can reduce moisture content to 90%, which is higher than 65% considered as the maximum for compositing; and the moisture content is also too high for disposal directly to a sanitary landfill. Further dewatering by a process such as vacuum filtration, centrifugation, air drying, etc., will still be required leaving a solid waste disposal problem. Therefore, alternative one was selected; that is, full capacity aeration tanks were constructed without a primary clarifier and vaccum filter.

The system was designed so that it would accomplish a high degee of teatment at the design capacity without a primary settling tank. With the addition of a primary clarifier and a reactor for sludge disposal the capacity of the system will be increased by a factor of nearly two.

The two-stage aeration system designed and constructed, as shown in Figures 1 and 2, consists of No. 10 screens to remove gross solids which are trucked to an existing landfill. After screening, the waste flows to a minimal solids basin, which was designed to remove 50% or more of the soluble COD, and then to two extended areation basins in parallel, designed as effluent polishing and aerobic sludge digestion units. Aeration is followed by final clarification for solids separation. Provisions are built into the system to return the sludge to either minimal solids and/or extended aeration units with a sludge recirculation ratio of approximately one to one. Occasionally it is necessary to withdraw excess sludge from the system which is routed to an existing sludge retention pond for anaerobic stabilization.

Operational flexibility of the treatment plant at present is such that the minimal solids unit can be bypassed with waste flow going to either one or both extended aeration units. For vegetable wastes only the extended aeration units are required. Either one or both of the extended aeration units can be used, depending on the strength of the vegetable wastes to be treated. During the potato processing season, two-stage aeration is used. At present, flow from the minimal solids unit cannot be diverted to the final clarifier without passing through the extended aeration unit because of the in-plant piping configuration. If necessary, a bypass can be provided which would allow any one of the treatment units to be operated individually or in conjunction with other units so that the system can be operated as minimal solids, moderate solids, or extended aeration process, or a combination of any of these processes. Other parameters that can be controlled are the amount of sludge returned to the aeration basins and the power input to the surface aerators.

The final design criteria is given in Table 5. All the aeration basins are earth structures with concrete aprons to prevent wave erosion from the operation of the surface aerators. Final clarifer, pumping house, chemical and laboratory building, Parshall flume and other structures are made of concrete. The total construction cost for the treatment facilities was $287,435.00. Figure 3 is an aerial photograph of the treatment plant.

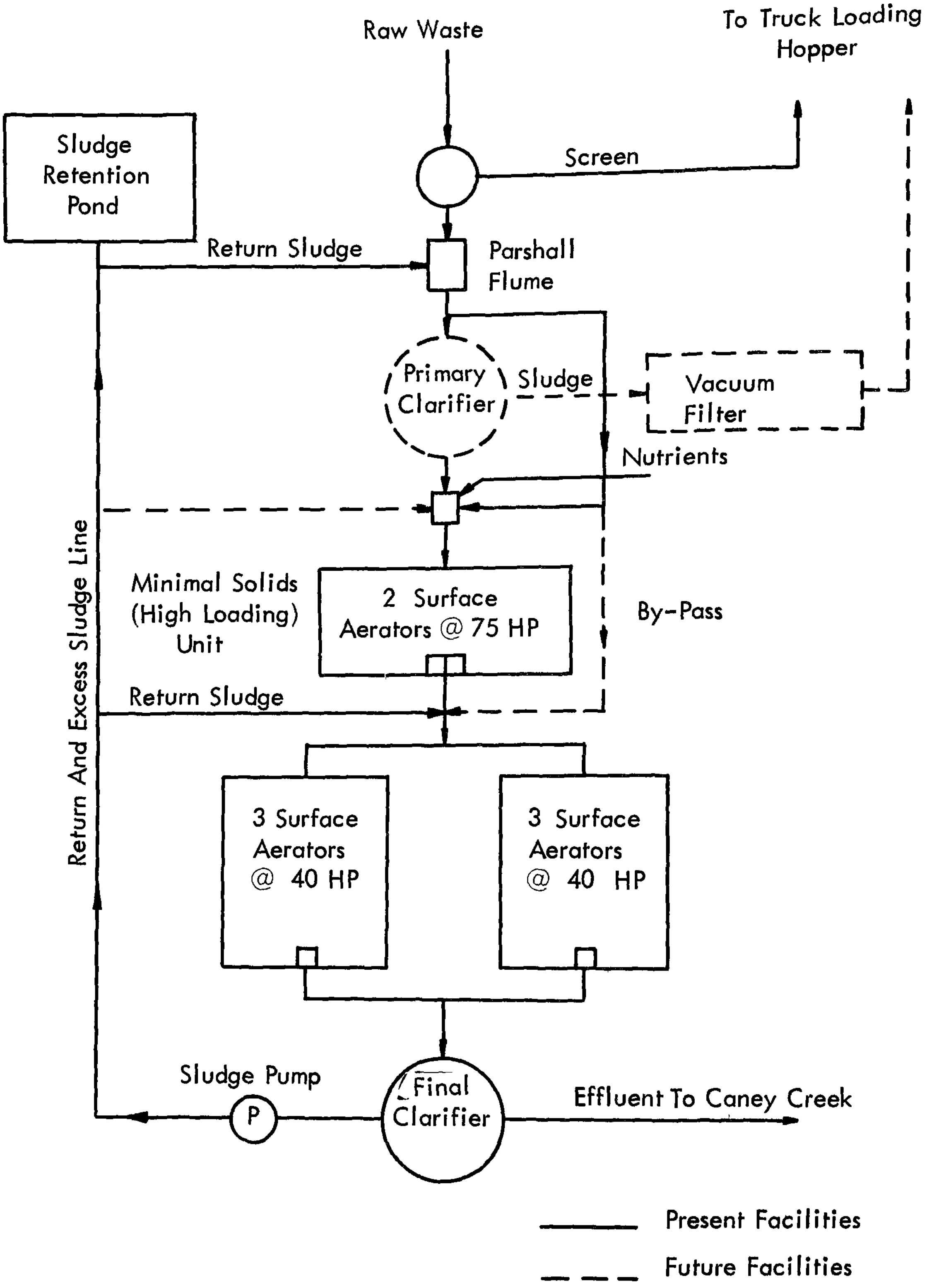


Figure 1 Flow Diagram

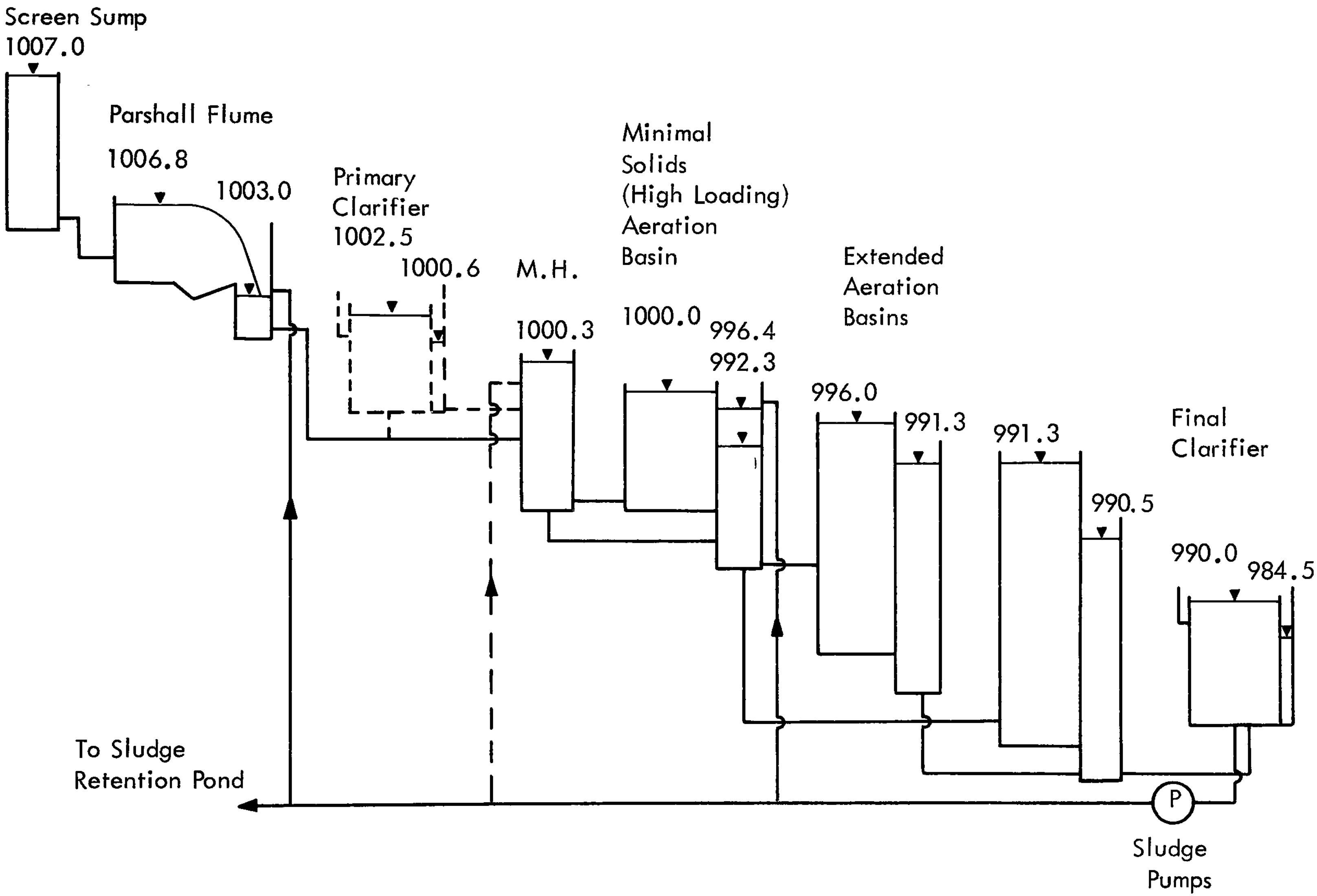


Figure 2 Schematic Flow Diagram

TABLE 5

DESIGN CRITERIA

1. Design Flow = 1.5 MGD
   BOD = 1500 mg/l = 18,600 #/day

2. Minimal Solids Unit
   Loading rate = 500 #/1000 cu. ft.
   $$\text{Volume} = \frac{18,600\ \#\ \text{BOD/day}}{500\ \#\ \text{BOD/1000 cu. ft.}}$$
   = 37,000 cu. ft.
   = .28 MG
   Use 0.30 MG
   Depth = 8 ft.
   Top = 116 ft. x 66 ft.
   Bottom = 84 ft. x 34 ft.
   HRT = 0.3/1.5 = 0.2 day = 4.8 hrs.
   O_2 required = 0.8 x lbs BOD removed
   = 0.8 (18,600) (0.4) = 6000 lbs/day
   O_2 transfer = 2 lb/hr/Hp
   Hp required = 125 hp.
   Hp provided = 2 surface aerators @ 75 Hp
   = 0.5 Hp/ 1000 gal.

3. Extended Aeration
   Loading rate = 40 lbs/1000 cu. ft.
   BOD = 0.6 (18,600) = 11,200 lbs BOD/day
   Volume = 280,000 cu. ft.
   = 2.10 MG
   Min HRT = 36 hrs. = 1.5 days
   Volume = 1.5 (1.5 MGD) = 2.25 MG
   Two basins in parallel each with volume = 1.12 MG
   Depth = 8 ft.
   Top = 232 ft. x 102 ft.
   Bottom = 200 ft. x 70 ft.
   O_2 required = 1.2 x lbs BOD removed
   = 11,200 (.95) (1.2)
   = 10,600 lbs/day
   O_2 transfer = 2 lbs/hr/Hp
   $$\text{Hp required} = \frac{10,600}{24(2)} = 220\ \text{Hp}$$
   Hp provided = 3 surface aerators @ 40 Hp per basin-total 240 Hp
   = 0.11 Hp/1000 gal.

TABLE 5
(Continued)

4. Final Clarifier
   Overflow rate = 800 gpd/ft^2
   Depth = 8 ft.
   Diameter = 50 ft.
   DT = 1.89 hrs.
   Weir loading = 10,000 gpf/day

5. Return Sludge Pumps
   2 sets of centrifugal pumps @ 500 gpm and TDH = 48 ft.

6. Chemical Feeder
   1 set dry feeder @ 1000 lbs/day

Figure 3 Aerial View of the Waste Treatment Plant

SECTION VI

PLANT SCALE STUDY

General

As has been indicated, the Stilwell Canning Company cans and freezes various kinds of vegetables. A typical production record and schedule are given in Tables 6 and 7.

The Stilwell Canning Company generally operates on the basis of a 6-day week with two shifts per day, namely 8:00 a.m. to 6:00 p.m. and 6:00 p.m. to 4:00 a.m., with a daily clean-up from 4:00 a.m. to 8:00 a.m., plus intermittent wash-down during the operation time. Their operation is highly climate dependent, and what they process depends on what is available from their contracted farms which, in turn, depends on the previous days weather. The processing flow sheets for their various products are shown in Figure A-1 through A-9, Appendix A.

Canning operations began April 22, 1969, with spinach as the major product. At this time the waste was being diverted through the domestic trickling filter waste treatment plant. This plant, located 500 feet upstream from the industrial waste plant, was overloaded and was producing an effluent with a high COD and a noticeable green color.

The plant scale study of this two-stage activated sludge system originally scheduled to cover a period from September 1, 1968 to January 1, 1969, but postponed because of a delay in construction work, actually began May 19 and ended December 5, 1969 when the cannery closed their operation for the year.

Study Approach

The primary purpose of this project was to study treatment performance and cannery waste characteristics; hence, the sampling program had to be developed to monitor the changes in waste flow and strength and to establish the effects of these changes on treatment efficiencies accordingly.

In any sampling program, considerable thought must be given to the location of sampling points. Sampling points should conform to hydraulic suitability; that is, points of high turbulence that assure good mixing should be selected. The points must also be located so that individual process unit efficiencies could be determined. Examination of the plant layout indicated that sampling from the Parshall flume, the minimal solids unit, the extended aeration unit, after the final clarifier, and the return sludge line would yield homogeneous samples that could be used to determine waste characteristics and plant efficiencies.

TABLE 6

PRODUCTION RECORD

Year*	Production Cases	Peak Month	Peak Production Cases
1966	1,494,266	October	234,311
1966	1,650,000	September	268,000
1967	1,750,000		
1968	1,800,000		
1969	1,979,000	September	295,541

*April - December

TABLE 7

1969 PRODUCTION SCHEDULE

Month	Products	Production Cases
May	Spinach, Mustard Greens, Collard Greens, Turnip Greens, Strawberries, Irish Potatoes	No record available
June	Irish Potatoes, Green Beans, Squash, Peas, Blackberries	235,923
July	Irish Potatoes, Green Beans, Okra, Peas, Squash	253,565
August	Irish Potatoes, Sweet Potatoes, Okra, Peas	263,925
Sept.	Sweet Potatoes, Irish Potatoes, Okra, Peas, Butter Beans, Green Beans, Squash	295,541
Oct.	Sweet Potatoes, Irish Potatoes, Okra, Peas, Butter Beans, Lima Beans, Squash, Turnip Greens, Mustard Greens	271,198
Nov.	Sweet Potatoes, Collard Greens, Turnip Greens, Spinach	179,452
Dec.	Spinach	17,606

Case = 24 No. 303 cans

Sampling and flow determinations were also considered within the cannery but were not run after June 13. This was due to the fact that the cannery usually processes more than three kinds of products in a shift, and the various waste streams within a process were integrated with streams from other simultaneously-operating processes before the total waste flow of one particular product can be sampled. Referring to the processing flow sheets in Figure A-1 through A-9, notice that there is a minimum of four waste streams (excluding blackberry) per product processed. Therefore, a complete analysis and flow determination of waste streams from each product processed was not practical as it would have necessitated the complete analysis of a minimum of twelve streams plus the analysis of the waste treatment system.

The approach used was to classify the waste into three categories, on which the data presentation and evaluation were based. The classifications are listed below:

1. Sweet potatoes and one or more kinds of vegetables.

2. Irish potatoes and one or more kinds of vegetables.

3. Vegetables only.

This classification can be justified if the following facts are considered:

1. The cannery operates two major production lines, that is, a potato line and a vegetable line. The plant set-up is such that the sweet potatoes and Irish potatoes cannot be processed simultaneously, although it is possible for two or more vegetables.

2. The strength of the various kinds of vegetables ranged from 148 to 688 mg/l of COD, and that of Irish potatoes and vegetables and sweet potatoes and vegetables ranged from 1080 to 4229 mg/l and 2400 to 5550 mg/l of COD respectively. The difference in strength depended on the type, amount, and quality of the raw product being processed.

3. In comparison to that of potatoes, the strength of the vegetables can be considered a weak waste. On an organic loading basis (lbs COD/day/1000 cu. ft.) the potato waste contributed approximately 90% of the total load while Irish potatoes were being processed and 95% while processing sweet potatoes.

In order to monitor the variation of waste strength due to the change in production, several samples per shift were taken and analyzed immediately. A flow proportioned composite was then calculated; the shift composite samples were used in the data evaluation. The grab samples served the dual purpose of providing immediate information on the waste characteristics and plant efficiency and also helped in evaluating the effects of shock loading on the treatment system. The effects on treatment processes due to changes in waste strength could be readily observed in basins of short retention times; therefore, the plant influent and minimal solids unit were sampled three or more times during a shift while the extended aeration unit and plant effluent were sampled only once a day.

Plant Start-Up

The construction work on the treatment plant was completed on May 1, 1969; however, the plant did not start operation because of construction difficulties with the influent sewer. A temporary sewer was laid on May 12 so that the cannery wastes could be discharged to the waste treatment plant. One month later the contracted sewer line was completed.

The treatment facilities, being variations of the activated sludge process, require seeding and acclimation in order for the substrate removal process to begin. Since no activated sludge plants were available in the nearby area, primary effluent from the domestic plant was pumped to the industrial plant. Pin point floc was noticed in the minimal solids basin within a few days. One week was required for all basins to fill because of the low flow associated with green vegetable wastes and the leakage beneath the impounding dikes of the aeration basins which occurred during the start-up period. This seepage which was very noticeable at the foot of the dike slopes decreased considerably during the first two months of operation and by June only a few wet spots remained.

During the start-up period several other difficulties were also encountered. In May and early part of June, because of operational problems with the vibrating screen, it was bypassed, thus resulting in shooting flow through the Parshall flume. An accurate determination of flow was impossible due to high energy turbulence in the flume. The screen difficulties were corrected on May 27, and energy dissipating baffles were installed on June 9 in the incoming channel of the flume. Accurate flow metering was then possible. In the minimal solids unit high energy transfer from two 75 H.P. aerators and small surface area (7650 sq. ft.) of the basin combined to produce uneven flow over the collecting weir. A splash board was installed around the effluent collecting weir, and this successfully solved the problem. One of the sludge pumps failed to work on May 27 and was not repaired until June 15. Aerators in the extended aeration basins were out of order from time to time. The sludge rake in the final clarifier would not rotate until being corrected on May 30. No scum removal device or sludge flow meter were provided in the plant.

Also during this period green vegetables were the major products processed and consequently no frothing problems occurred. All sludge was returned to the extended aeration basins.

Further few grab samples of cannery processing streams were collected in the cannery and analyzed during the start-up of the treatment plant to aid in control of the system during this period. The results of the data are shown in Table B-1, Appendix B. The data after June 1 were used in the evaluation of the two-stage activated sludge treatment plant.

Operation

The operation of the two-stage activated sludge system started in May, 1969, with the processing of green vagetables, such as mustard greens, collard greens and turnip greens, as the major products. The plant scale study began in June while the major products were green beans and squash with twelve shifts of Irish potatoes, peas and squash among them. From July 1 to July 9, the products were okra, green beans and squash; and for the rest of the month, the major products were Irish potatoes, okra, green beans and squash with eleven night shifts of green beans intermingled.

In this three month period, all sludge was returned to the extended aeration units except during shifts when Irish potatoes were processed. As there was no sludge flow meter, the flow was estimated from the pump characteristic curve. This flow was 660 gpm or 0.95 MGD which was approximately equal to the inflow. For the Irish potato processing shifts, sludge was partially returned to the minimal solids unit with a sludge flow that ranged from 0.1 to 0.46 MGD. In June, when Irish potato wastes were being treated, sludge was not returned to the minimal solids unit and the MLVSS concentration was less than 1,000 mg/l there were foaming problems in both stages of aeration. It was especially serious in the first unit. However, the situation was corrected when all sludge was recycled to the minimal solids unit.

From August until November, during the time potatoes were being processed, the sludge was recycled to the minimal solids unit so the unit loading applied (lbs COD/day/lbs MLVSS) could be lowered. The excess sludge was wasted regularly into a sludge retention pond for further stabilization anaerobically.

In August, Irish potatoes, okra, and peas were the major products; and in September and October, sweet potatoes, Irish potatoes, beans, peas, and squash were the major products, with some night shifts of green vegetable processing interspersed. From November 1 to 11, sweet potatoes, collard greens, turnip greens, spinach, and Irish potatoes were processed. After November 11 through the end of the processing season, the only products processed were turnip greens and winter spinach.

Since the system was being operated experimentally it was important to determine the minimum nutrients required while processing each product or combination of products. During vegetable processing only, no nutrients were added and the treatment efficiency remained high indicating nutrients were not required. As the dominant product shifted from vegetables to potatoes the total nitrogen concentration in the system declined and on October 14 sludge bulking occurred. Ammonium nitrate with a nitrogen content of 33.5 percent was then added at the rate of 1000 lbs per day until the TKN/VSS ratio in the MLVSS increased to 5 percent and a trace of nitrogen was recorded in the effluent. Sludge bulking declined and after approximately three weeks the treatment system resumed its normal high removal efficiency. Nitrogen addition was stopped on November 21 after which only green vegetables were processed. For the entire period phosphate and pH adjustment were not required.

Analytical Determinations

In general the analysis of the two-stage activated sludge treatment system included the following.

1. Plant Influent after Screening - Total, Settled and Soluble COD; Suspended and Volatile Suspended Solids (SS & VSS); Dissolved and Volatile Dissolved Solids (DS & VDS); Total Kjeldahl Nitrogen (TKN), Ammonia Nitrogen (NH_3-N), Nitrate and Nitrite Nitrogen (NO_3-N & NO_2-N); Total Phosphate; pH; Temperature

2. Minimal Solids Unit-Mixed Liquor COD (MLCOD), Settled and Soluble COD; Mixed Liquor Suspended and Mixed Liquor Volatile Suspended Solids (MLSS & MLVSS); Dissolved Oxygen (DO); TKN, NH_3-N, and NO_3-N; pH; Temperature

3. Extended Aeration Unit and Final Clarifier - Total and Soluble Effluent COD; MLCOD; MLSS & MLVSS; DO; TKN, NH_3-N, and NO_3-N; Total Phosphate, Effluent SS and VSS; pH; Temperature

4. Sludge - SS and VSS; TKN

A few biochemical oxygen demand (BOD) and MLSS settling determinations were also performed. All laboratory analytical determinations were made in accordance with Standard Methods (48) except for some procedure changes as discussed in Appendix C.

Results

The flow data were taken from a continuous flow recorder installed in the Parshall flume at the entry to the waste treatment plant. The flow recorder charts were analyzed and flow volume was determined in million gallons (MG) per unit of time using IBM computer facilities at the University of Oklahoma.

The flow measured at the treatment plant was a combination not only of all waste streams but of infiltration into approximately 1.5 miles of sewer line between the cannery and the treatment plant, and domestic sewage from eighteen families.

The results of the flow analyses are given in Table 8, and the daily flow variation for a six day work week during the six months is shown in Figure 4.

TABLE 8

FLOW DATA

	Min.	Max.	Mean	Median
Daily Flow, MGD	0.35	1.91	1.12	1.19
Shift Flow, MG/10 hrs				
Sweet Potatoes & Vegetables	0.15	0.89	0.61	0.58
Irish Potatoes & Vegetables	0.38	0.78	0.53	0.53
Vegetables only	0.17	0.87	0.44	0.46
Daily Clean-Up, MG/4 hrs	0.01	0.23	0.13	0.13

The two-stage aeration system performed beyond expectations. The system was originally designed to treat a waste of 1,500 mg/l BOD or 2,250 mg/l of COD at a flow of 1.5 MGD. This was expected to be an adequate capacity for the near future; however, due to unforeseen circumstances, by the time the treatment plant was completed, it was operating above design capacity. During the study period, the flow reached a daily peak of 1.91 MGD and a shift peak of 0.89 MG/10 hrs which corresponded to 2.13 MGD, and an instantaneous peak of 2.4 MGD. The waste strength exceeded the design COD of 2250 mg/l for a significant portion of the canning season as related in Figure 5 and while processing sweet potatoes and vegetables it exceeded 5500 mg/l. Approximately 50% of this COD can be removed by settling. Even at the high strengths and flows while processing sweet potatoes plus vegetables, the average efficiencies for the system exceeded 95% COD removal, 94% SS and 96% VSS removal. The removal efficiencies for vegetable wastes were 82%, 80%, and 74% with regard to total effluent COD, effluent SS and VSS respectively. Only during approximately three weeks following the extremely high flows in October, as can be seen in Figure 4, which is also a period of nitrogen deficiency and sludge bulking, as can be seen later in Figure 22, did the total COD removal efficiencies drop

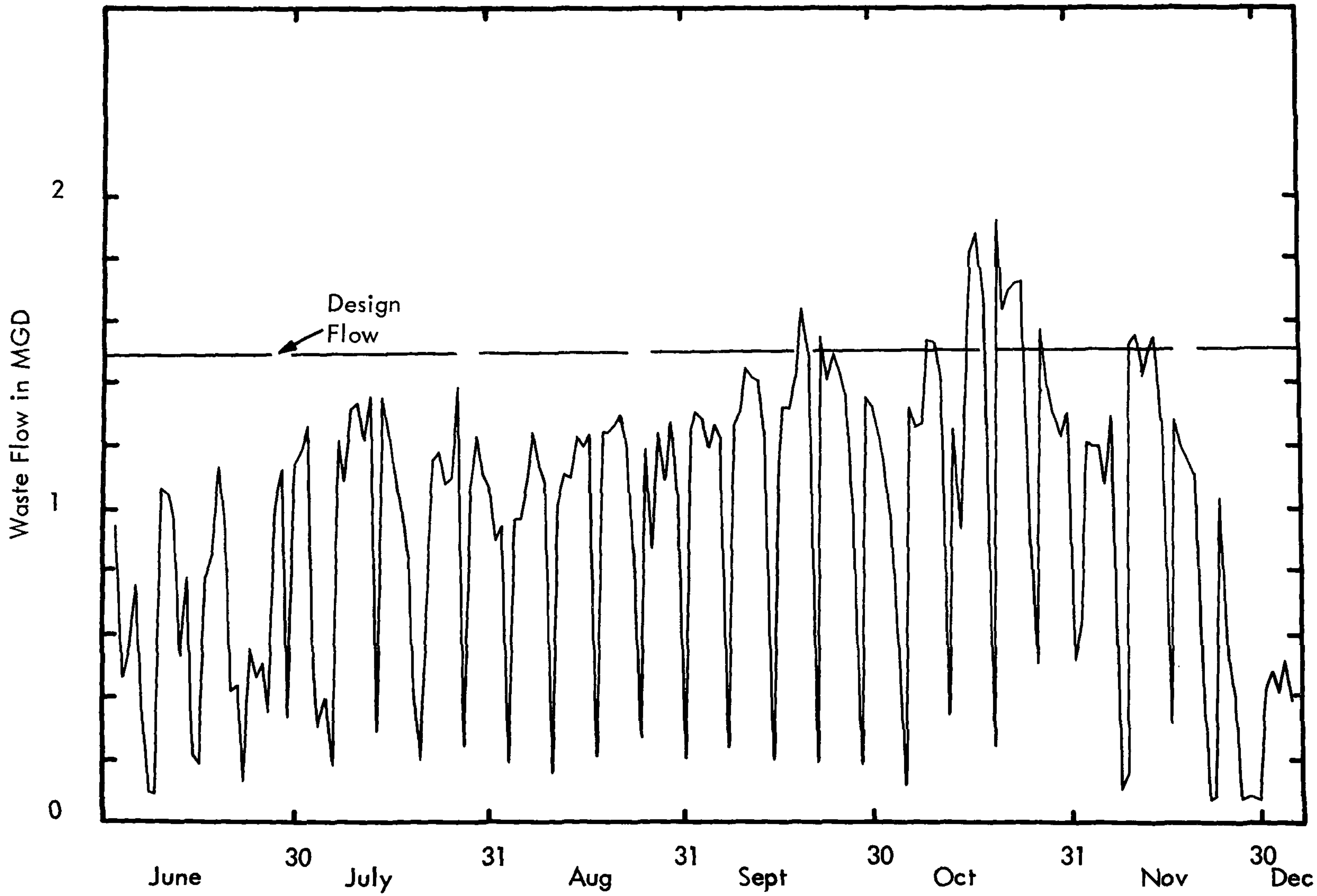


Figure 4. Daily Waste Flow Variation

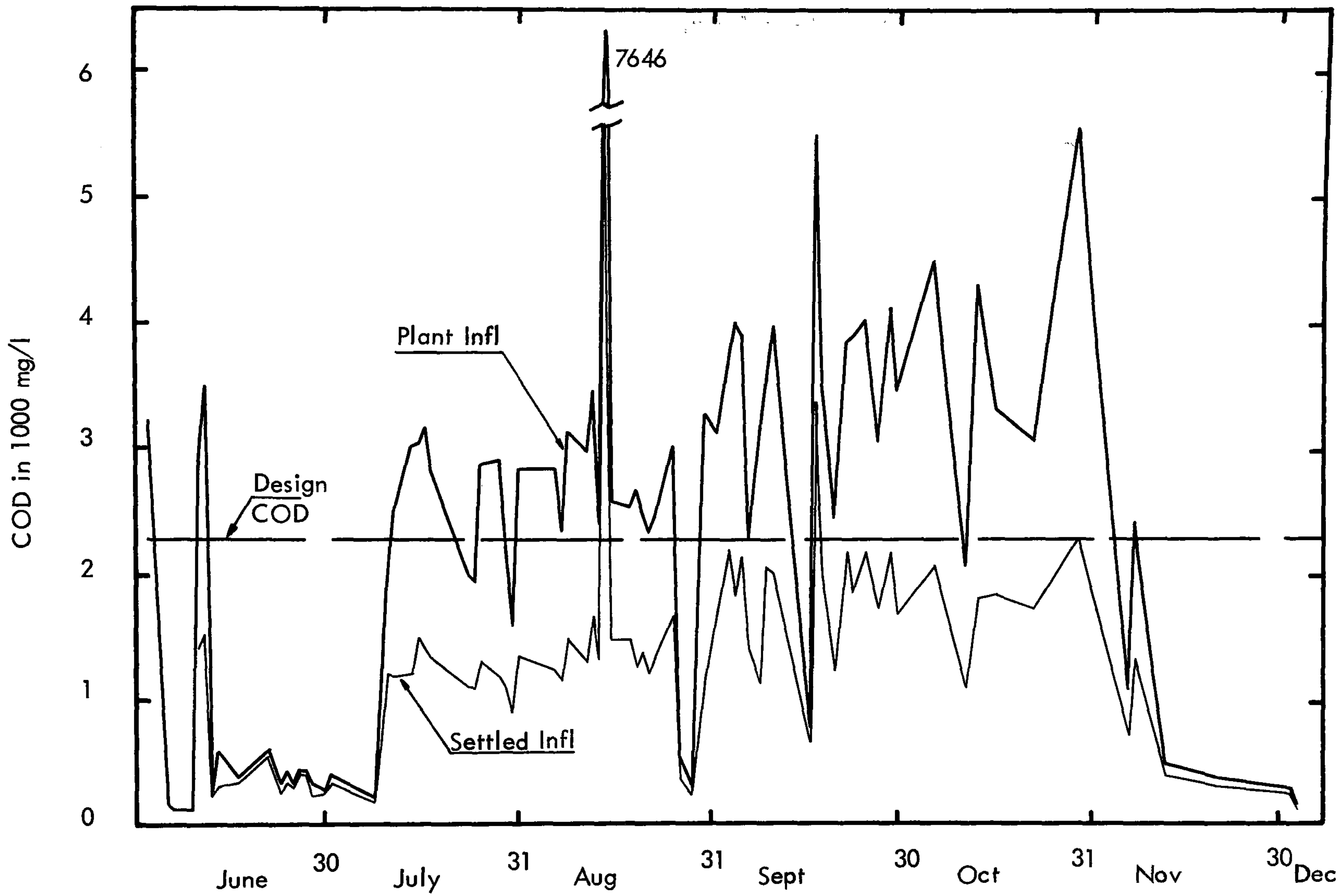


Figure 5 Plant Influent and Settled Influent COD

significantly. During this period as shown in Figure 6, the total COD removal dropped to 66% and once even to 3%, but the soluble COD in the plant effluent remained approximately the same as during normal operation as can be seen in Figure 7.

It is interesting to note that on August 14, the cannery dumped corn syrup into their waste line; this suddenly increased the COD concentration to 12,000 mg/l resulting in a total load on the system for approximately 10 hours of 53,000 lbs. Even with this extreme shock the system remained stable producing a high quality effluent as can be seen from the curve labeled plant effluent in Figures 6 and 7. However, changing from a strong waste to a relatively weak waste or the reverse affected the calculated removal efficiencies. For example changing from a shift producing a strong waste to a shift of weak waste lowered the plant removal efficiency temporarily, because the residual COD in the treatment system due to strong waste was higher than that due to weak waste. In general, changing from a weak waste to strong waste showed an increase in plant efficiency for a short period due to a dilution effect; however, the effluent concentration increased. The performance of the treatment system with regard to COD, SS, VSS, and pH are shown in Figures 6 through 10. Temperature variations of both plant influent and effluent are shown in Figure 11. During the six month operation period, as is shown in Figures 13 and 19, the dissolved oxygen concentration in all aeration basins were maintained above 1 mg/l except for two short periods in August; hence, aerobic conditions were maintained. The laboratory analyses data which include MLSS, MLVSS, DO, COD loading and removal rate, SVI, and HRT of both minimal solids and extended aeration units, are presented in Figures 12 through 23; and the sludge SS and VSS are shown in Figure 24.

Tables D-1 in Appendix D presents the influent, modular unit, and effluent analyses and plant performance for sweet potatoes and vegetables; Table D-2 for Irish potatoes and vegetables; and Table D-3 is for vegetables only.

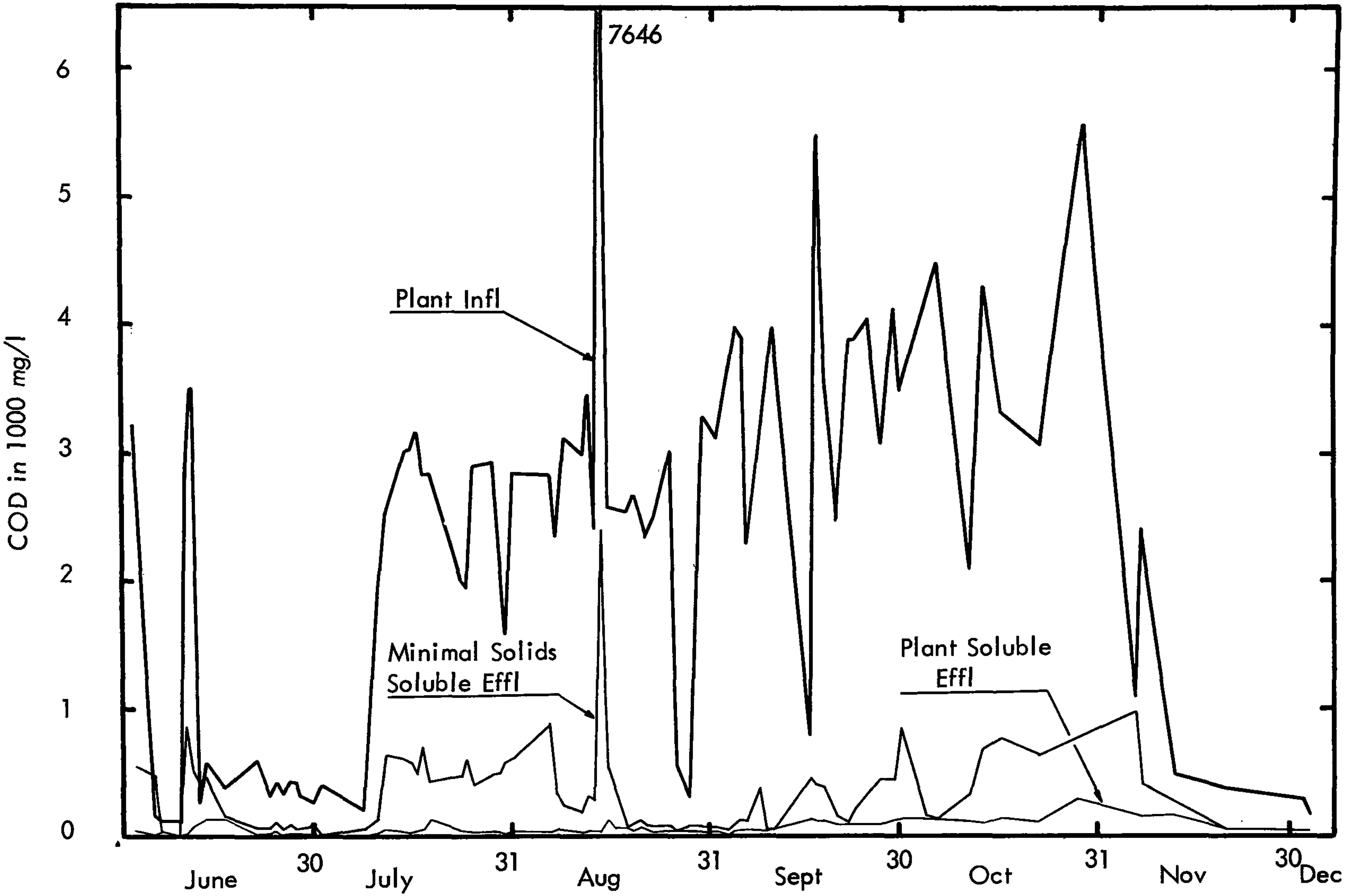


Figure 6 Treatment Plant Performance - COD

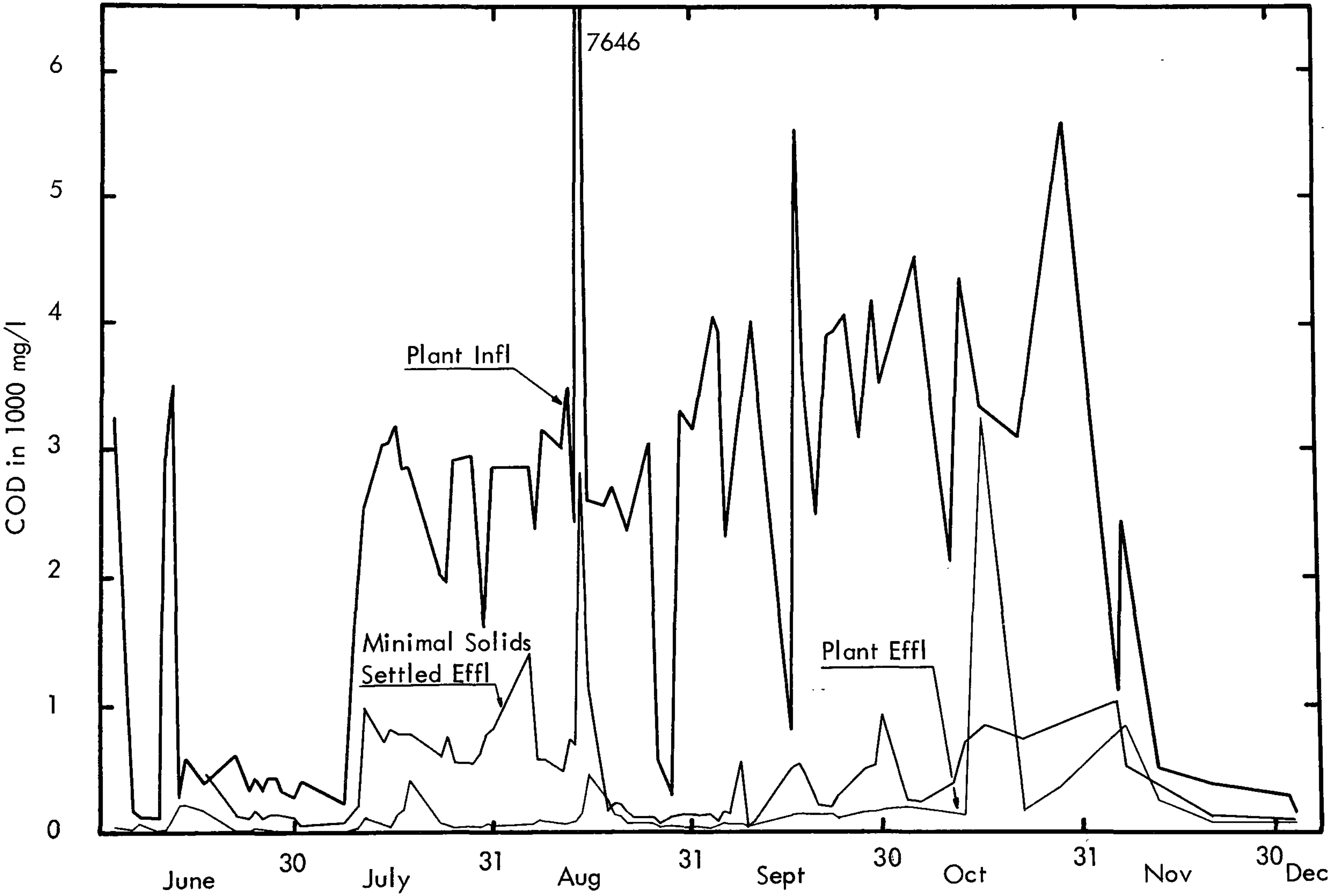


Figure 7 Treatment Plant Performance – COD

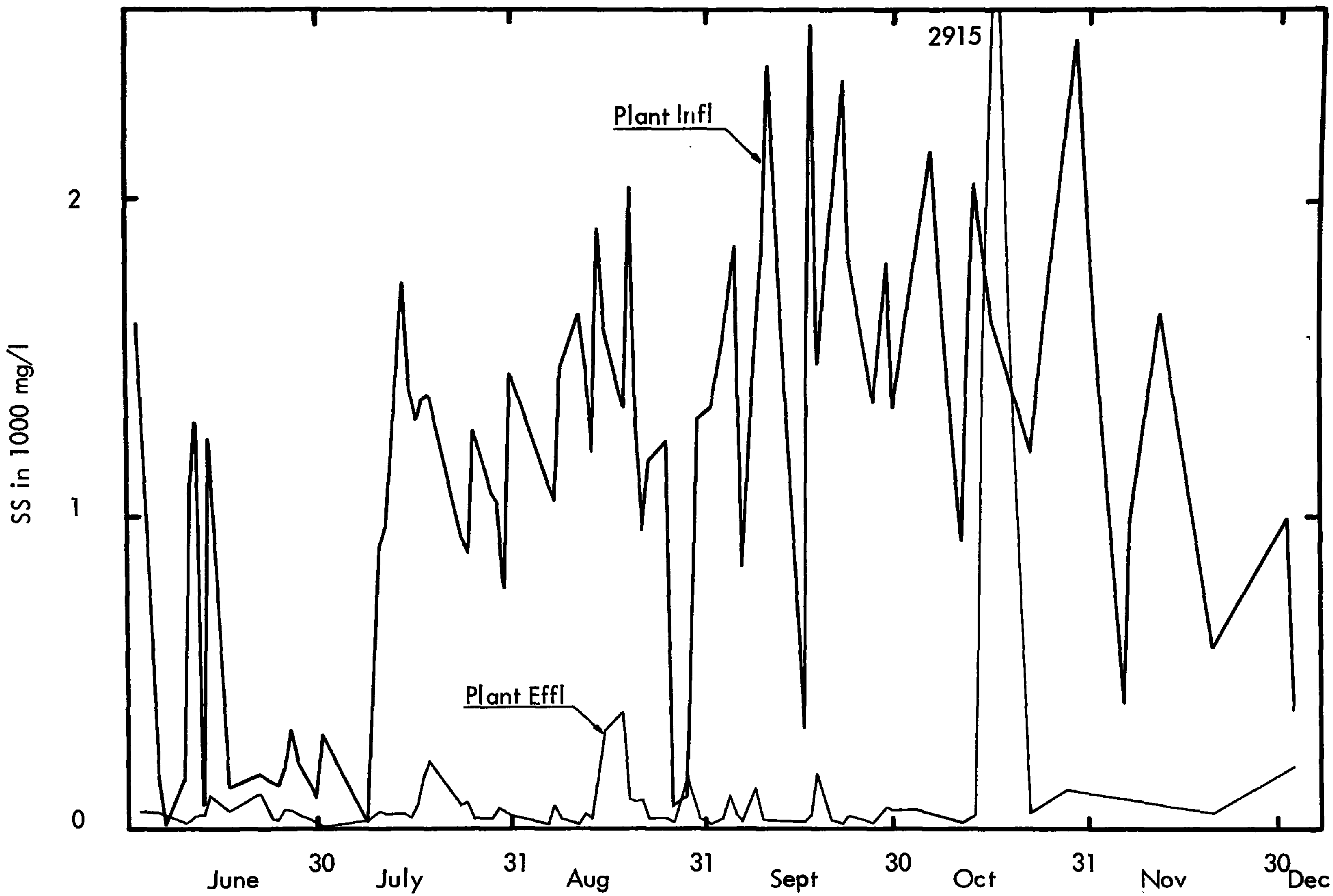


Figure 8 Treatment Plant Performance - SS

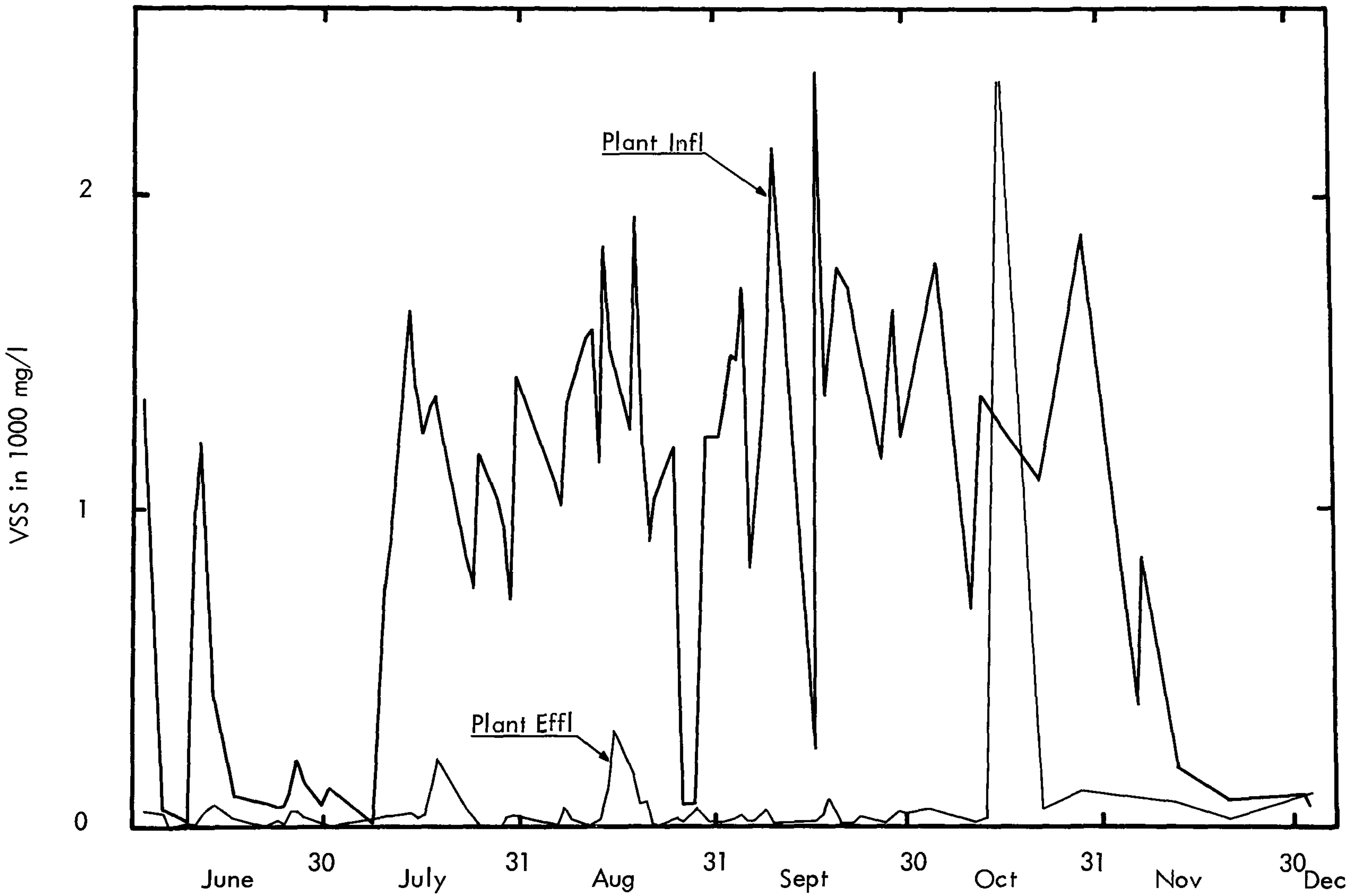


Figure 9 Treatment Plant Performance - VSS

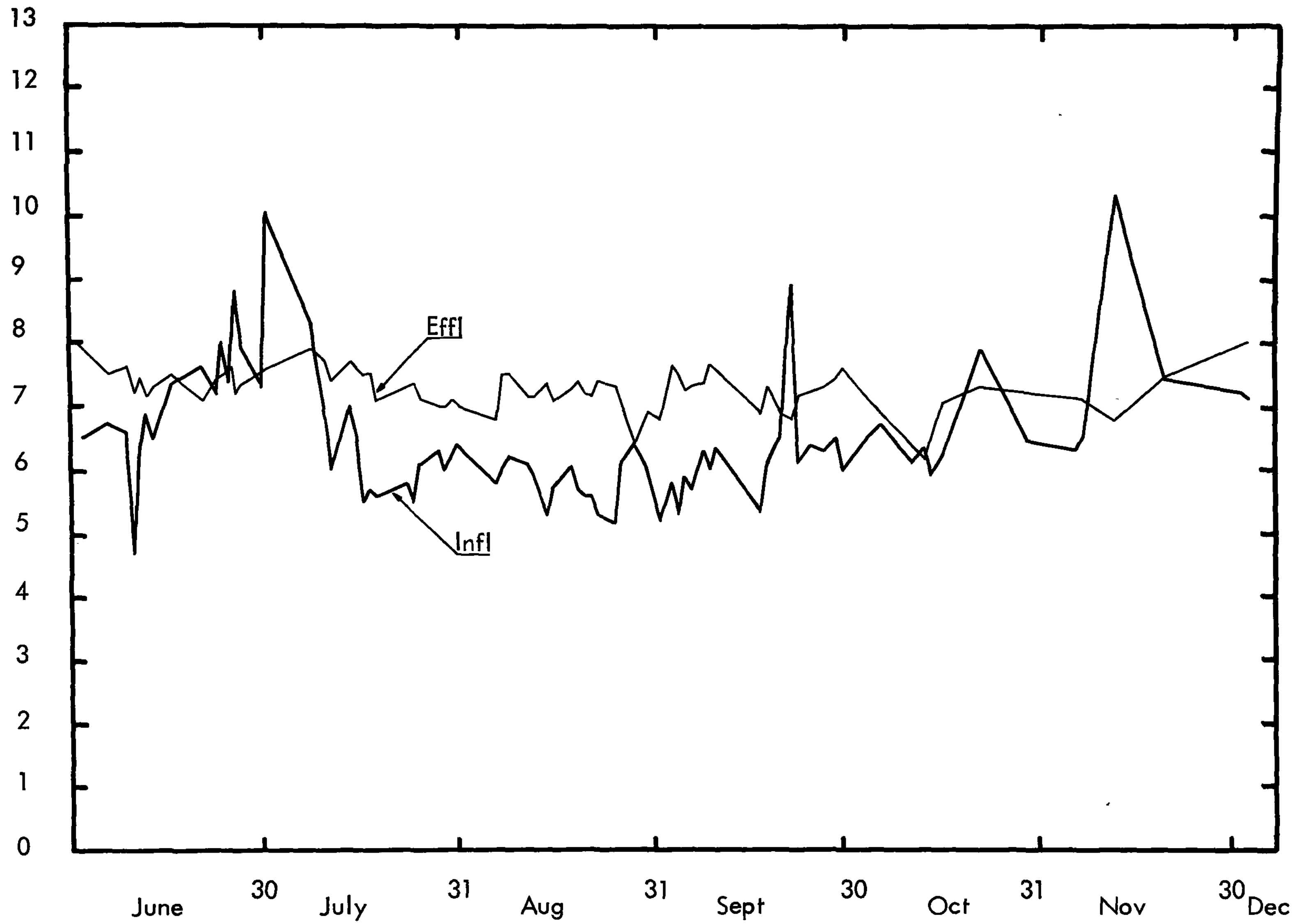


Figure 10 Treatment Plant Performance - pH

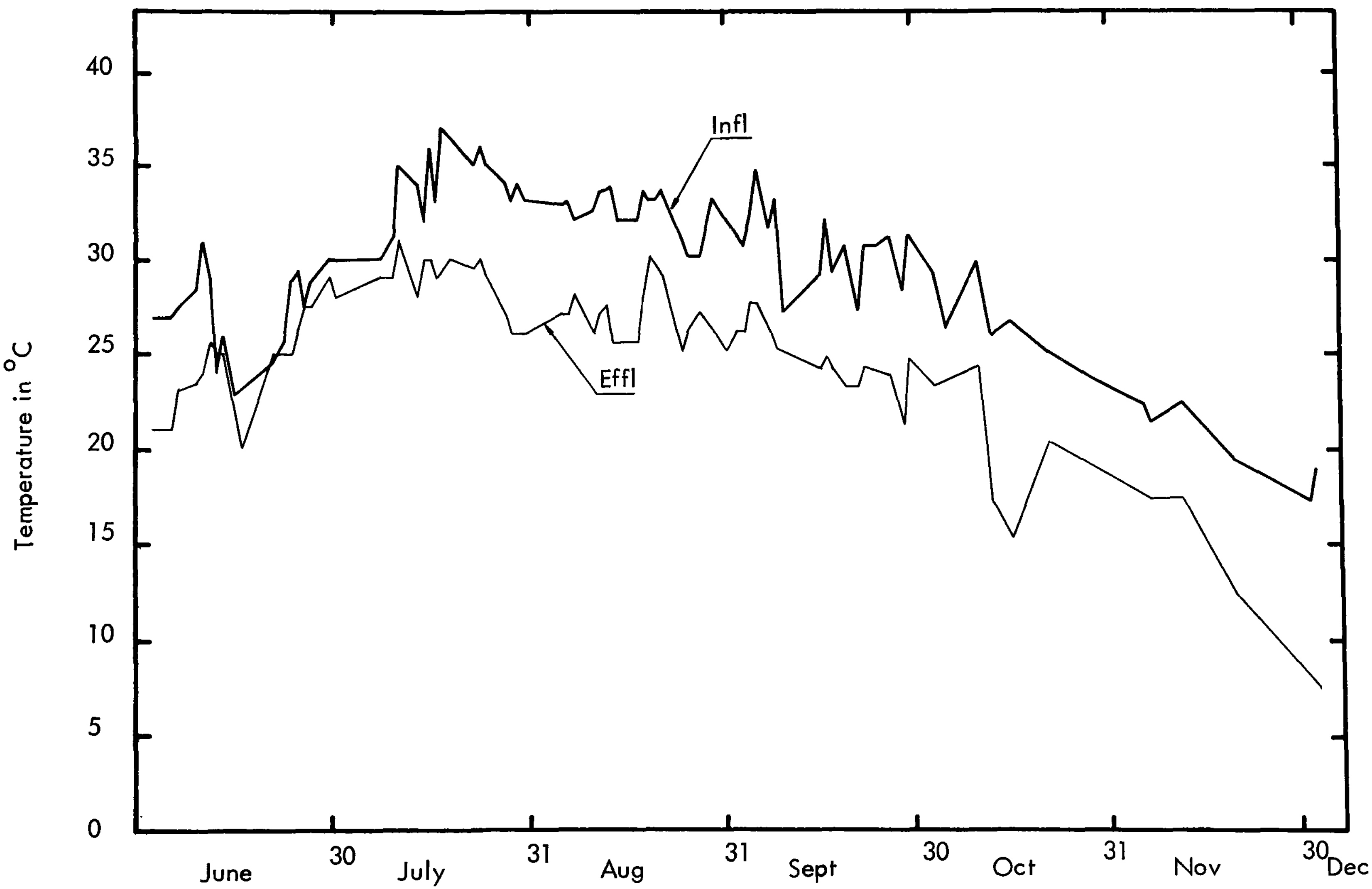


Figure 11 Temperature of Plant Influent and Effluent

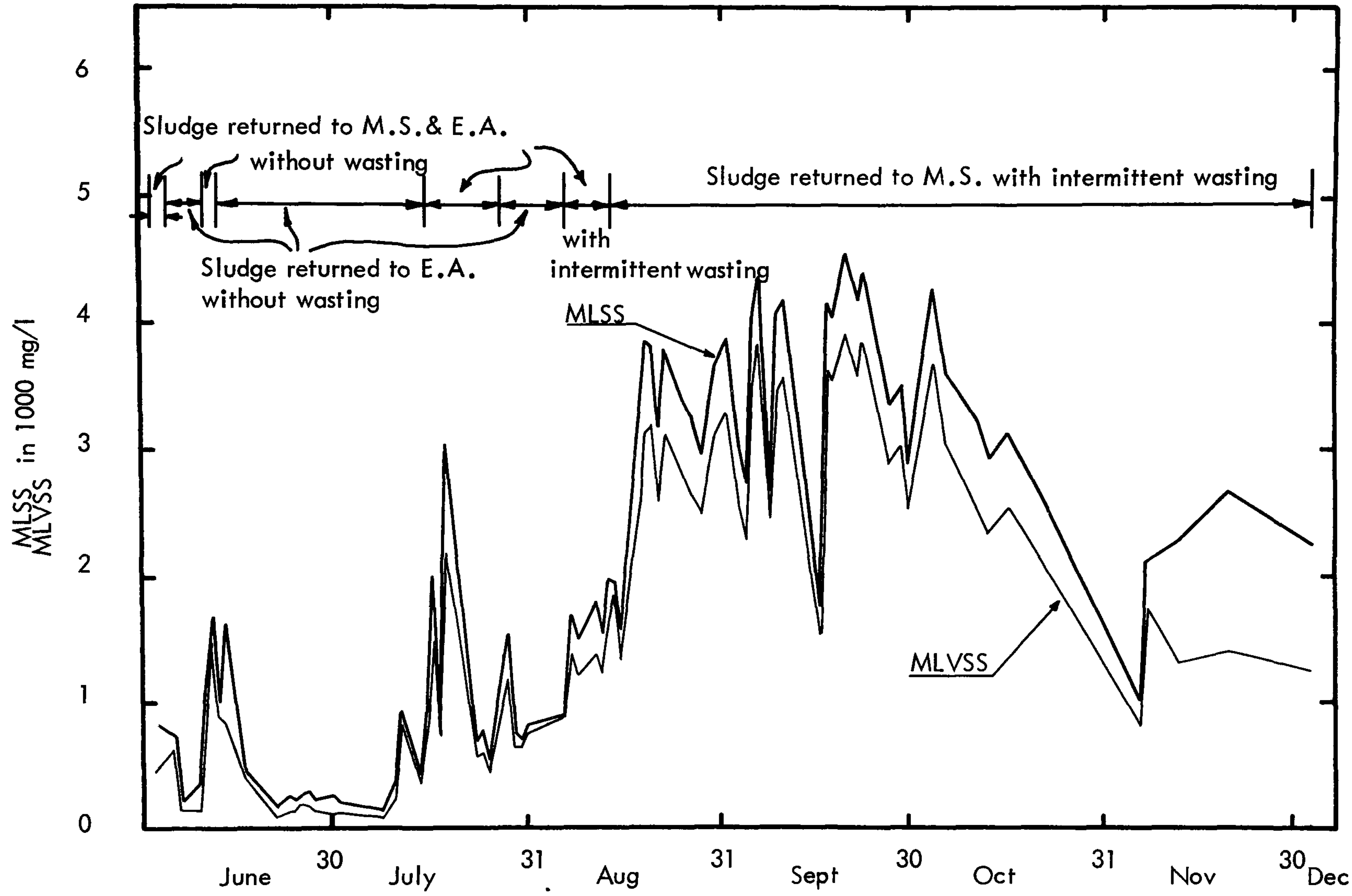


Figure 12 MLSS and MLVSS of Minimal Solids (High Loading) Unit

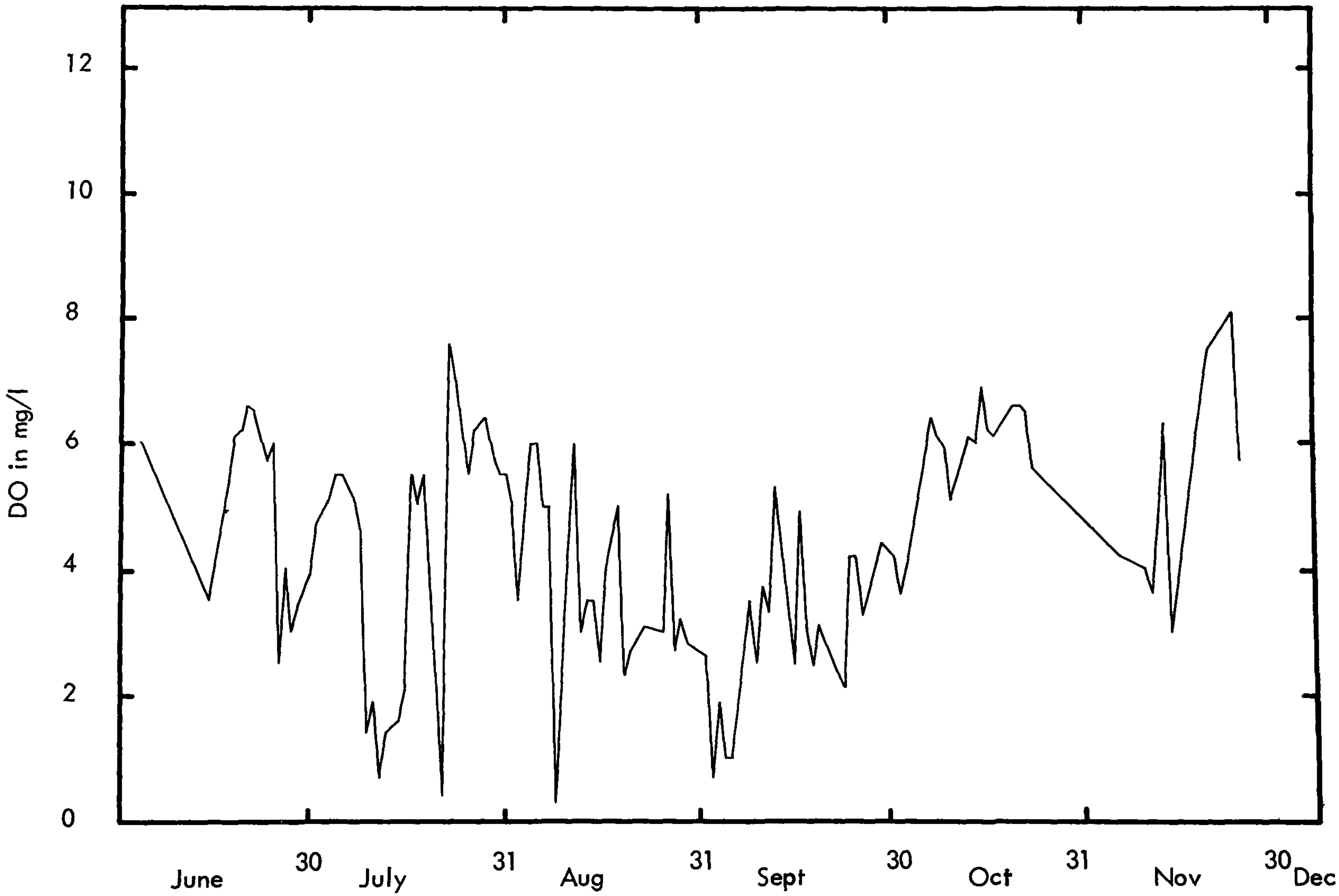


Figure 13 DO in Minimal Solids (High Loading) Unit

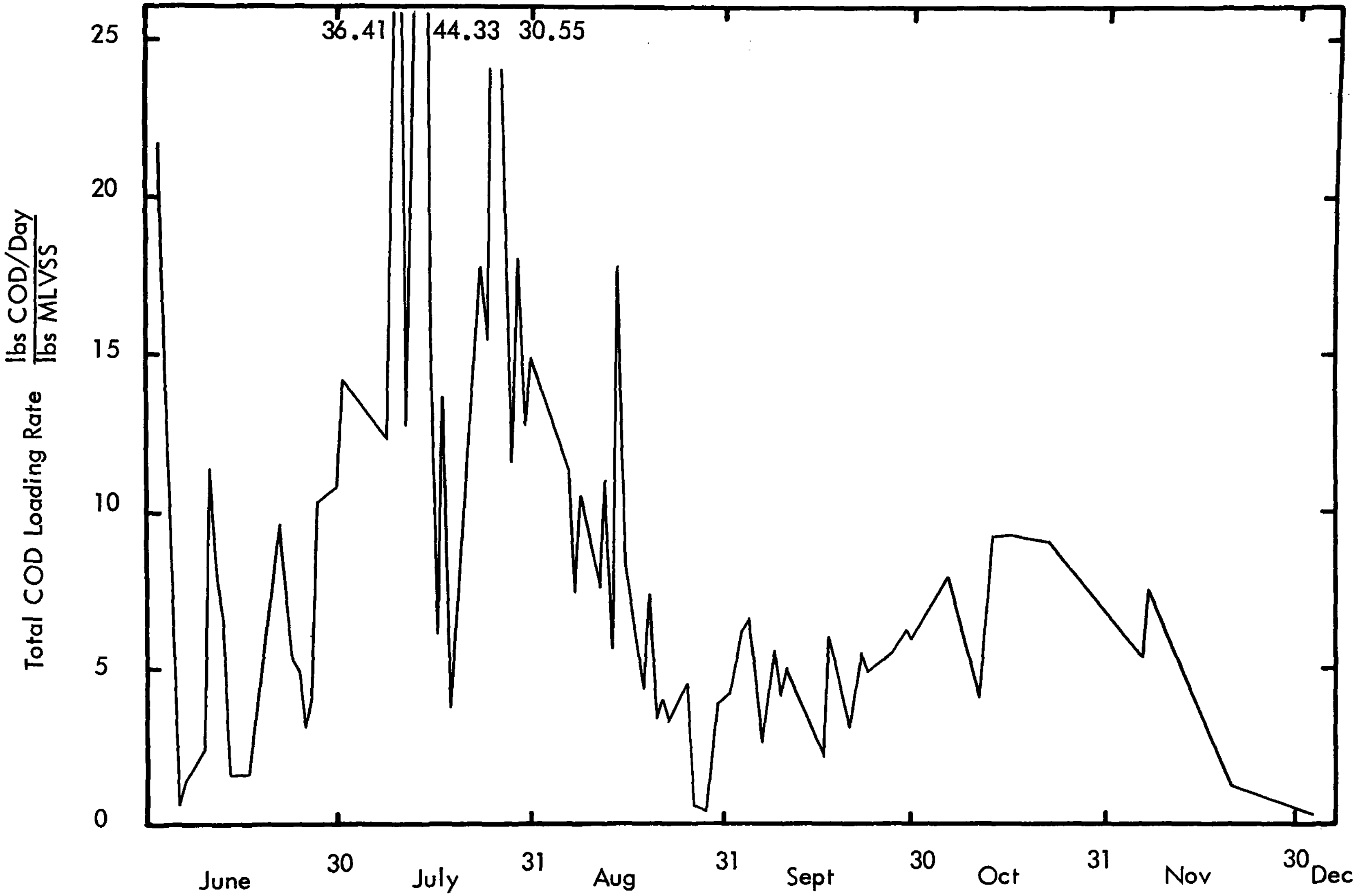


Figure 14 Total COD Loading Rate of Minimal Solids (High Loading) Unit

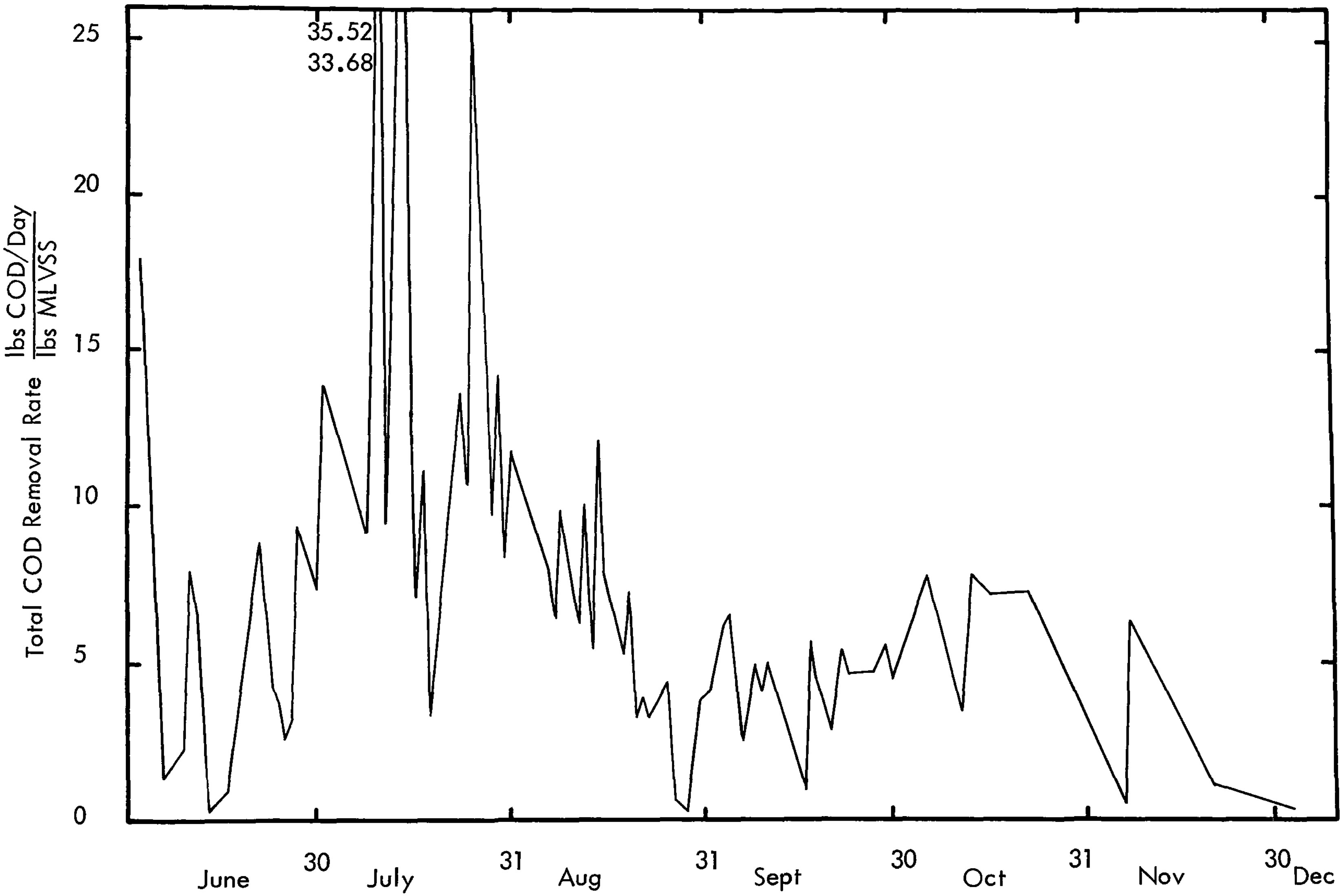


Figure 15 Soluble COD Removal Rate of Minimal Solids (High Loading) Unit

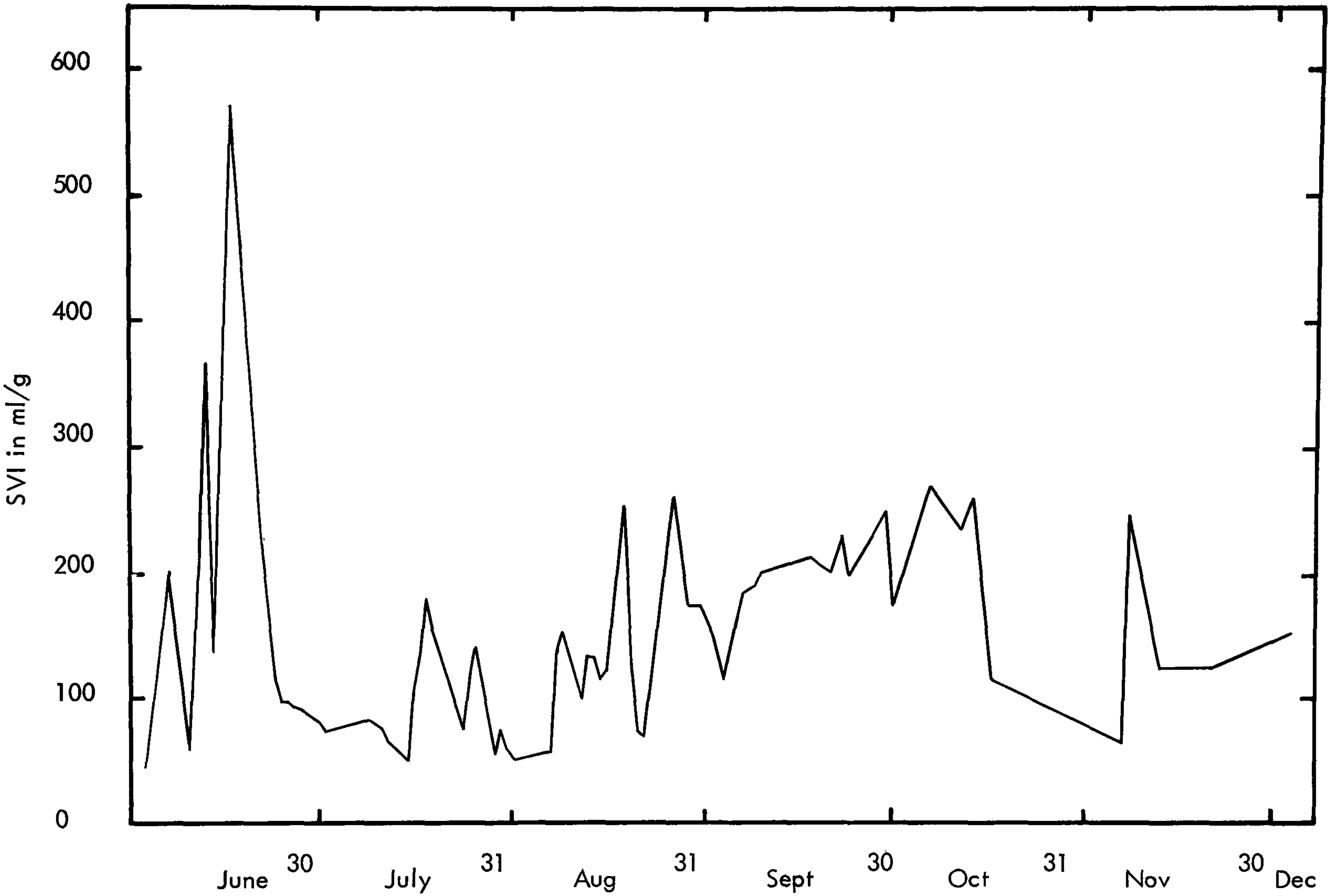


Figure 16 SVI of Minimal Solids (High Loading) Unit

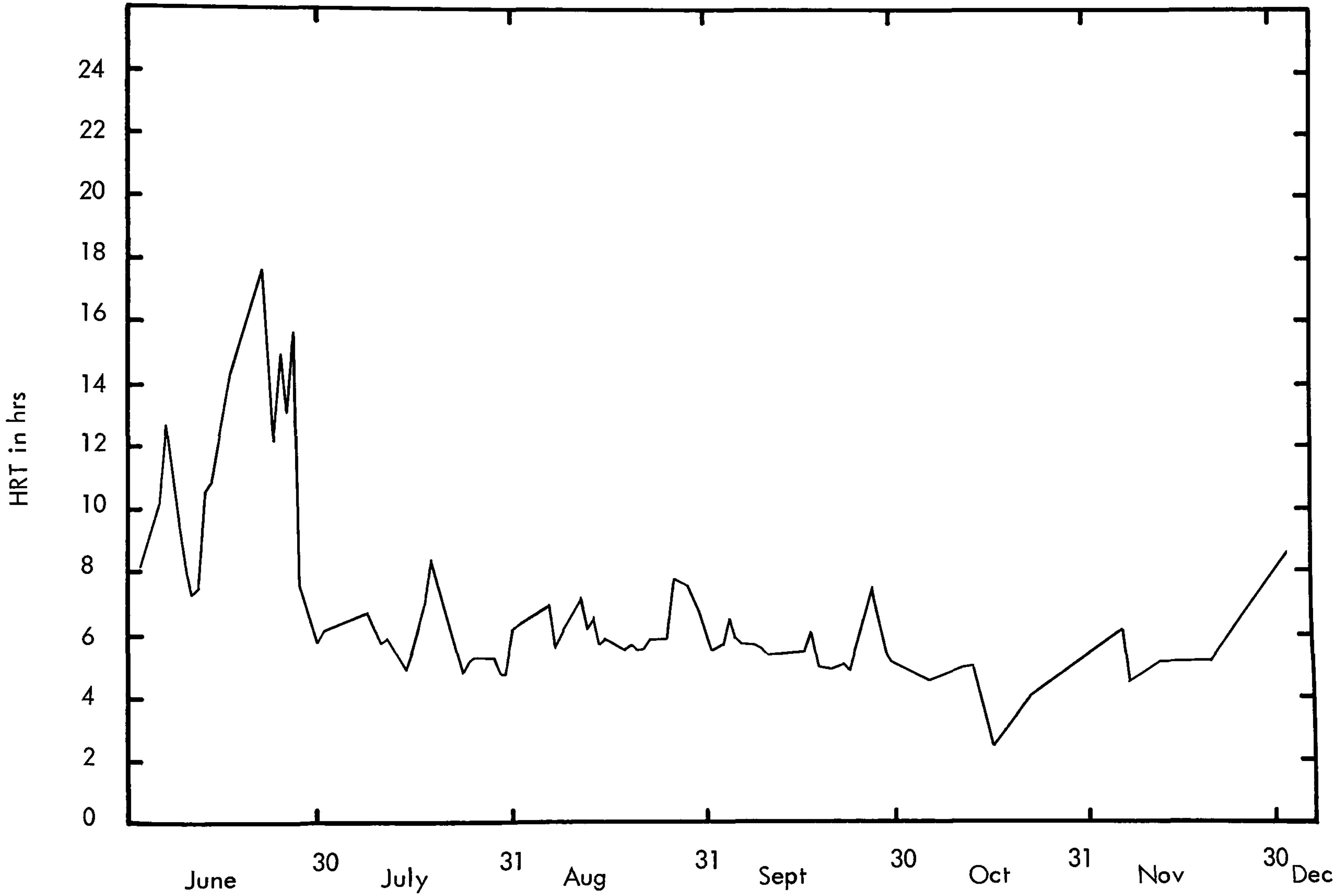


Figure 17 HRT of Minimal Solids (High Loading) Unit
Based on Influent Flow Only

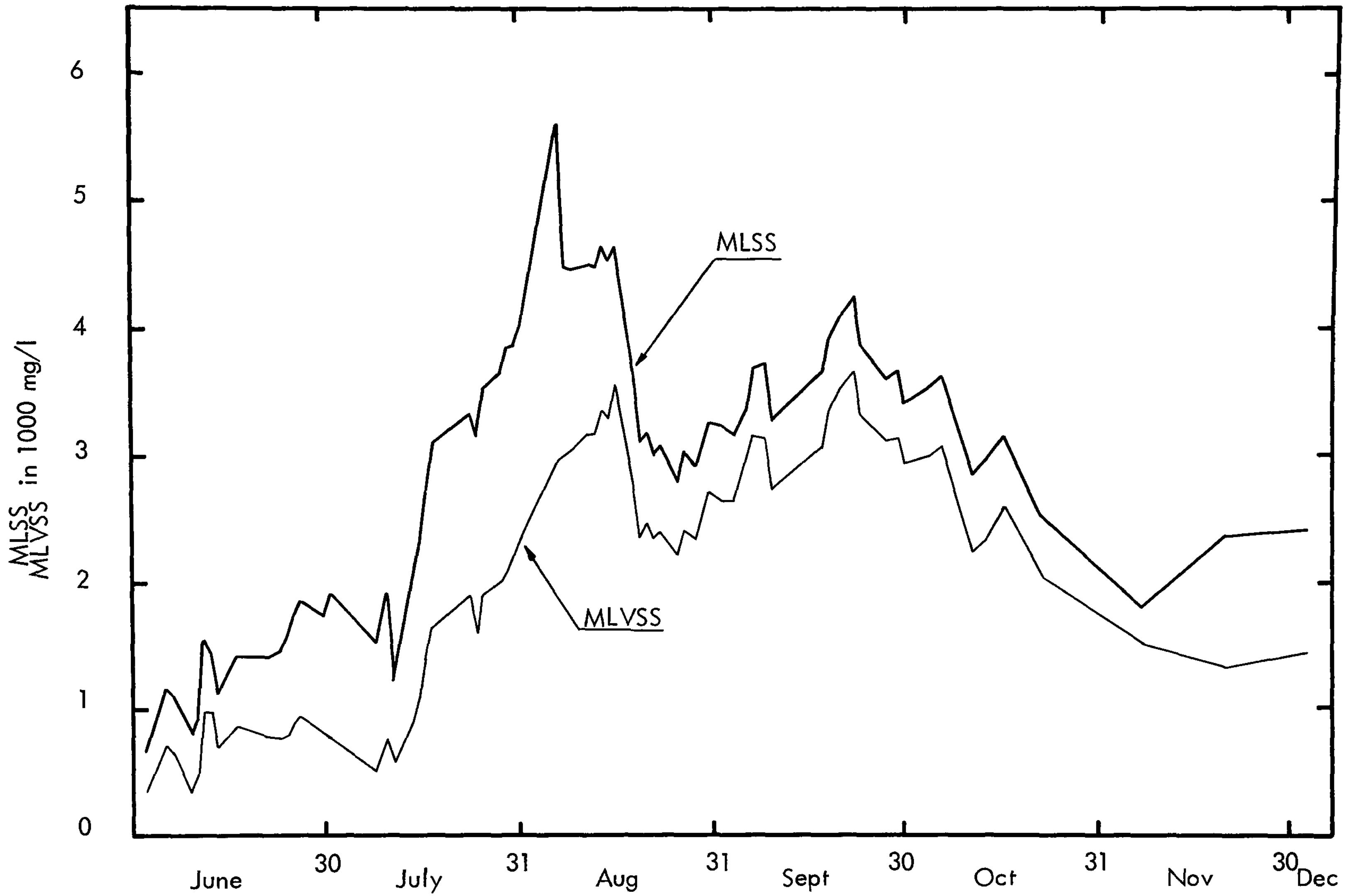


Figure 18 MLSS and MLVSS of Extended Aeration Unit

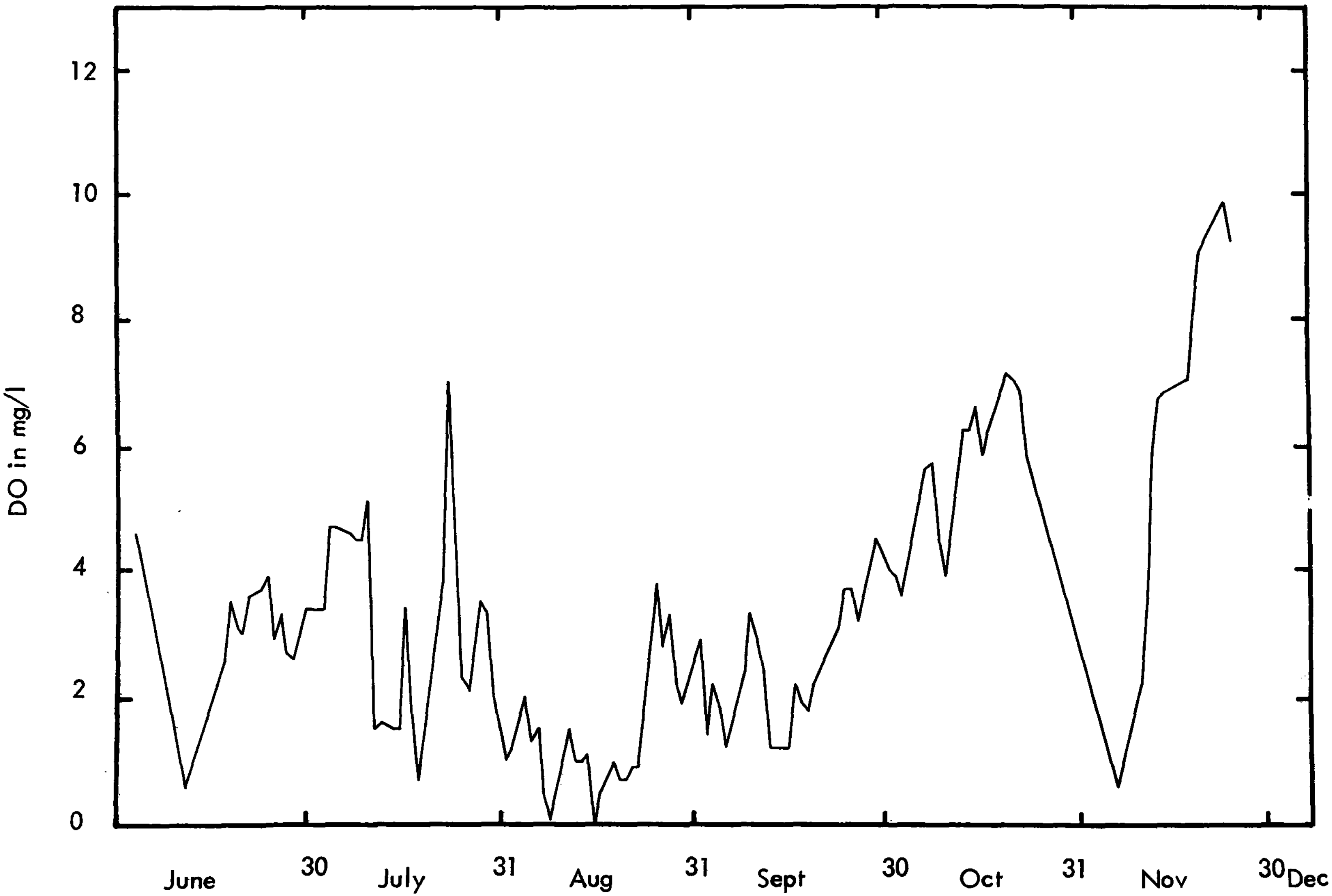


Figure 19 DO in Extended Aeration Unit

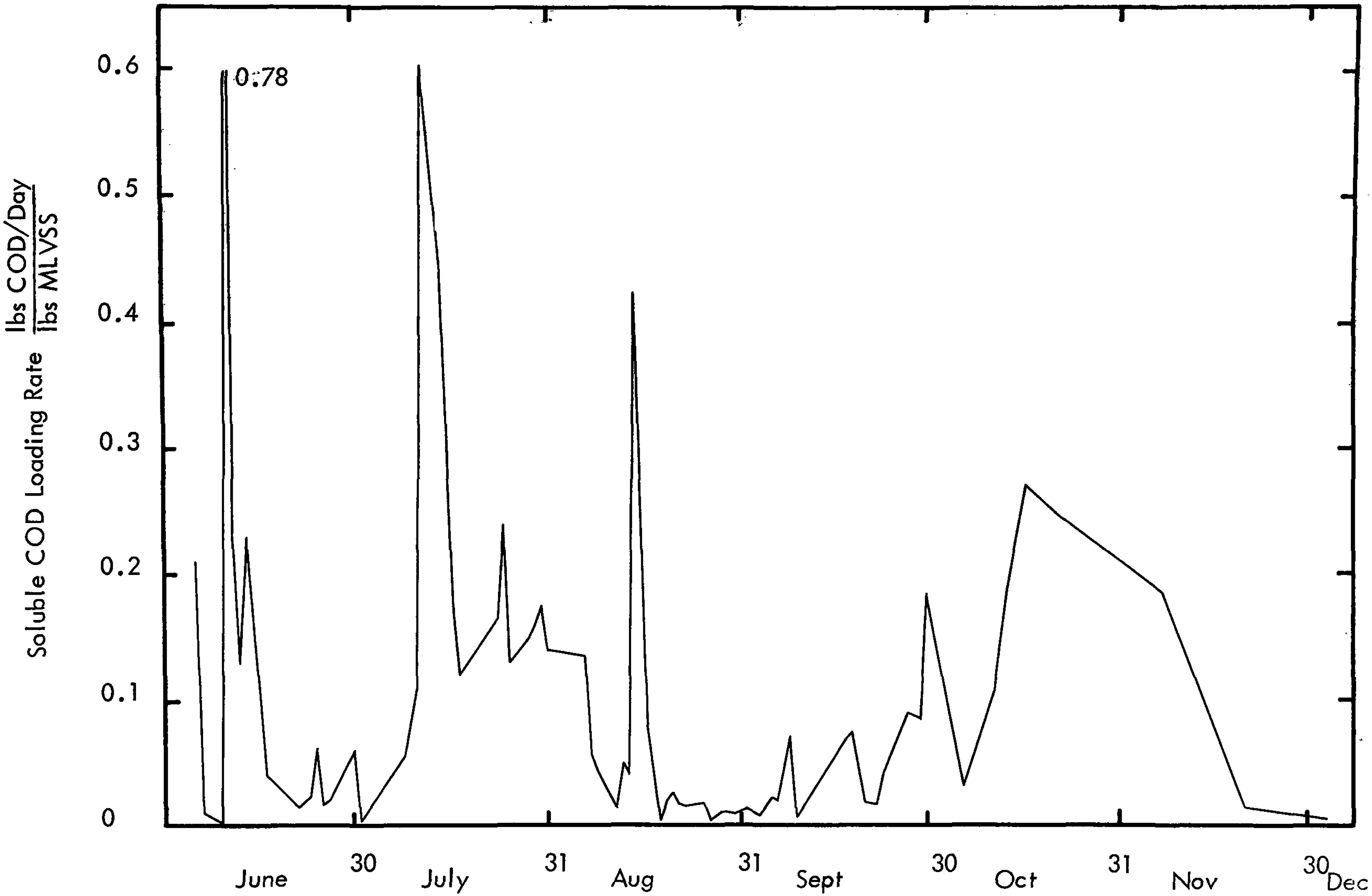


Figure 20 Soluble COD Loading Rate of Extended Aeration Unit

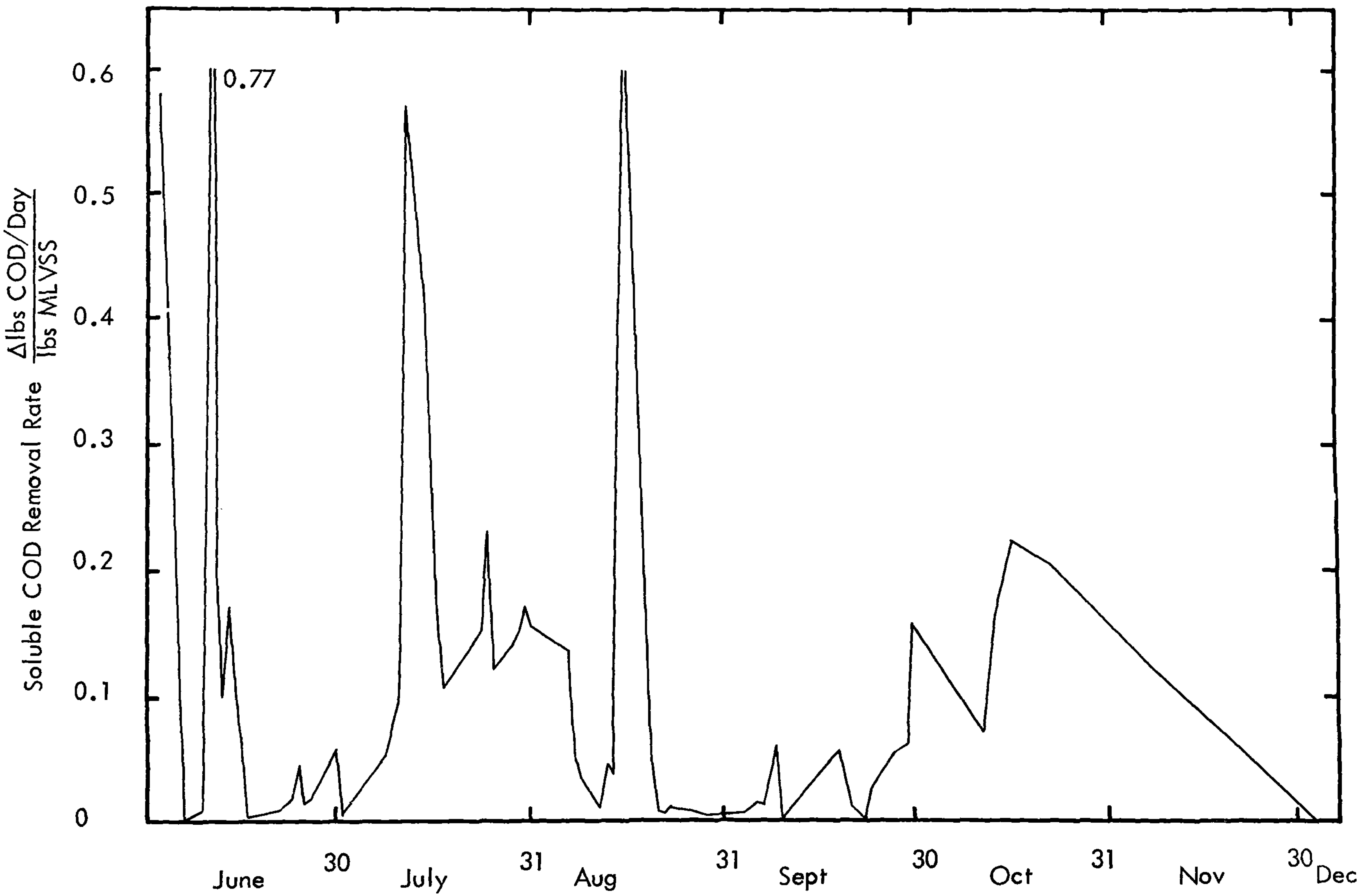


Figure 21 Soluble COD Removal Rate of Extended Aeration Unit

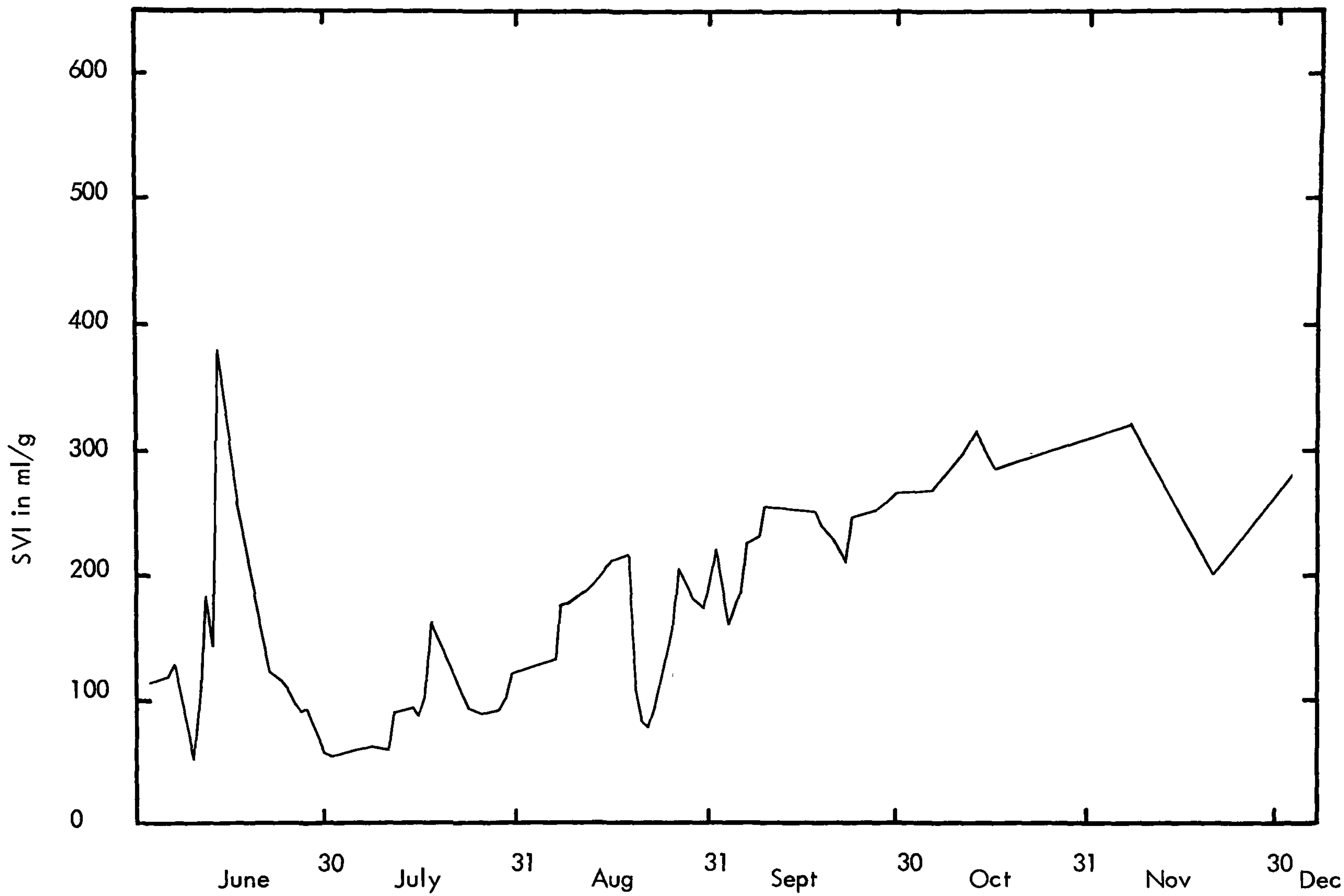


Figure 22 SVI of Extended Aeration Unit

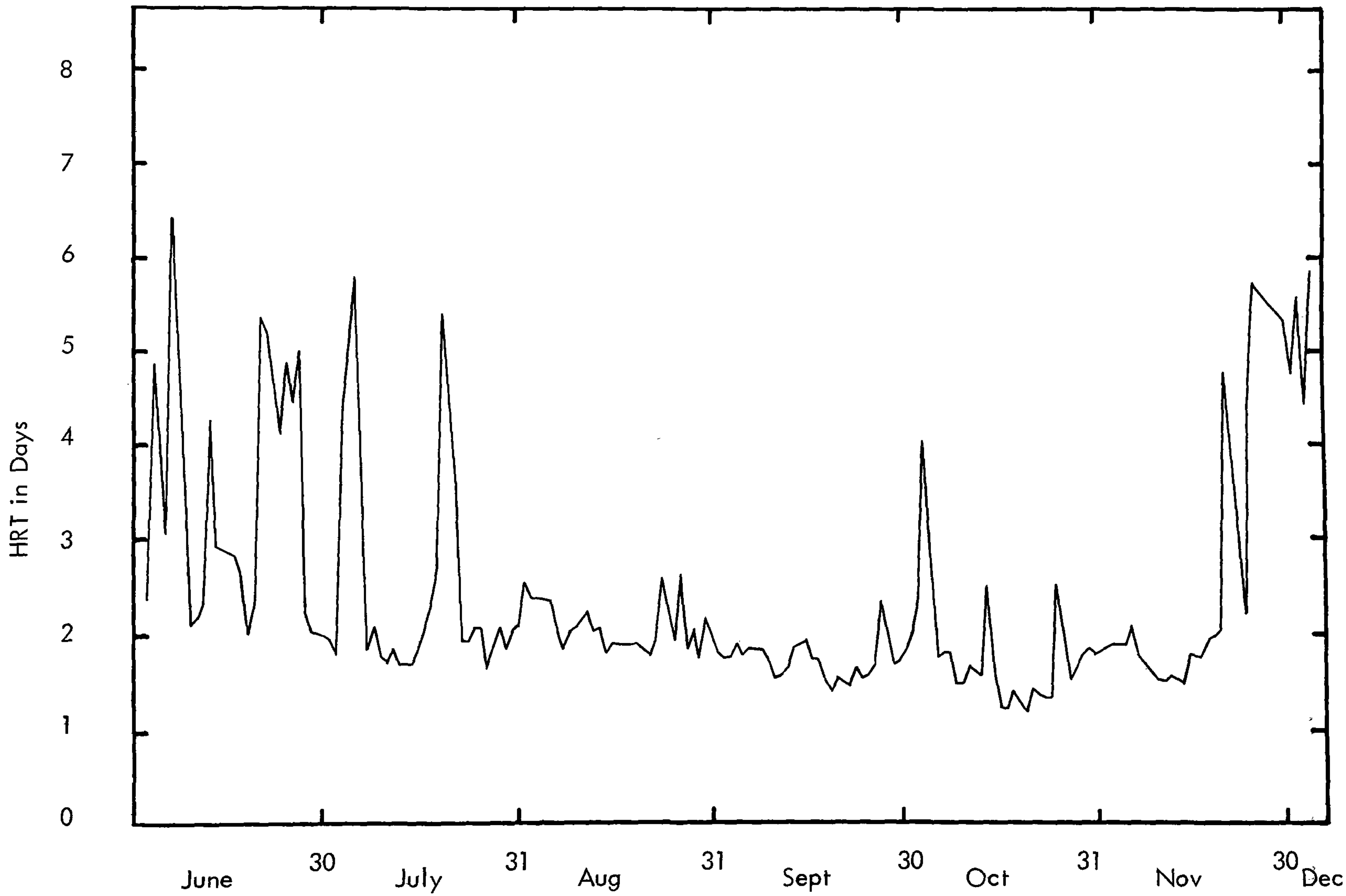


Figure 23 HRT of Extended Aeration Unit

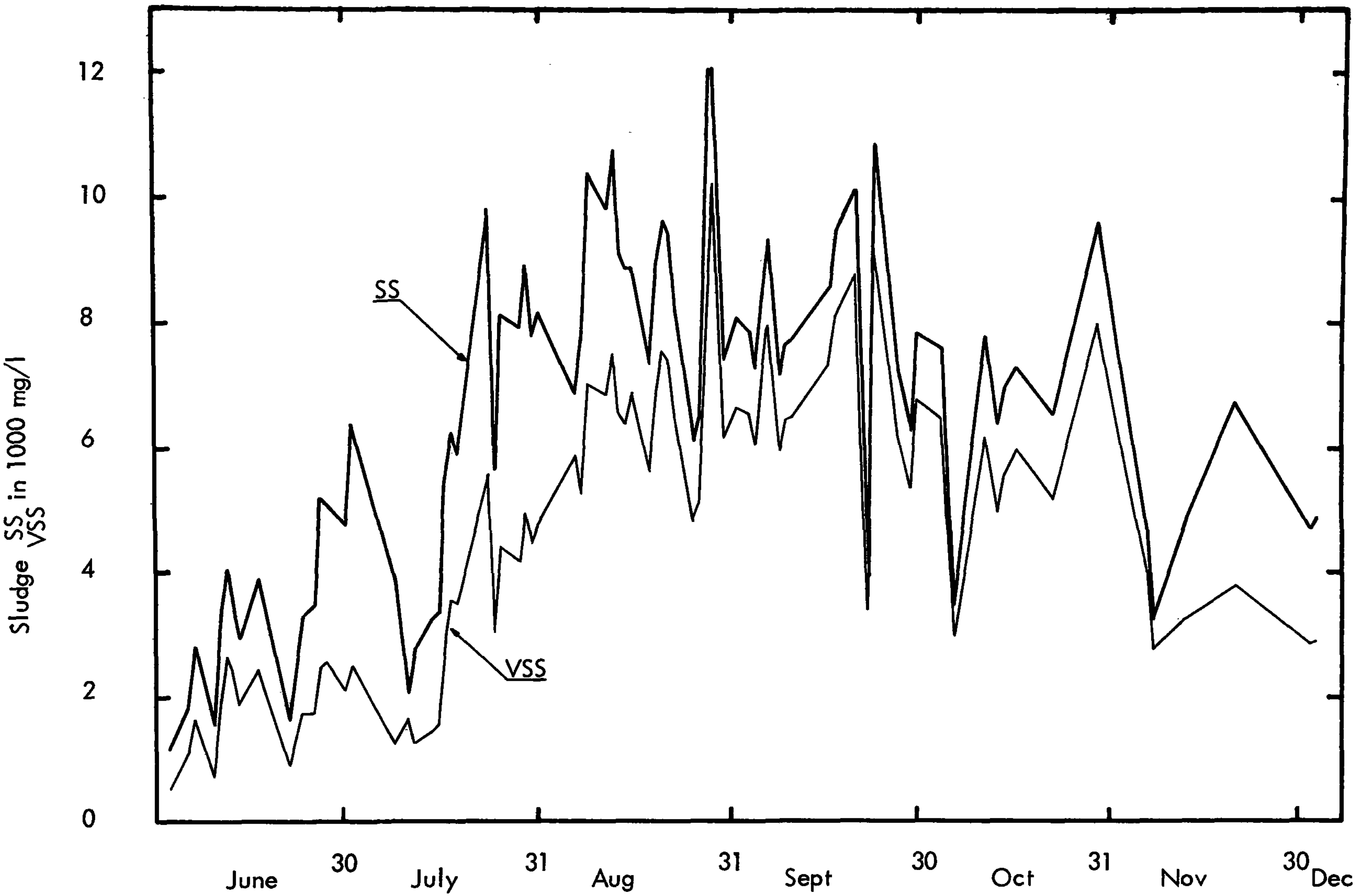


Figure 24 SS and VSS of Sludge

SECTION VII

DISCUSSION

General

The basic objective of research work in the field of waste treatment, regardless of whether it is a laboratory model or a pilot plant study, is to collect and analyze data that could be geared toward the establishment of response function under controlled conditions.

For plant scale studies, it is obvious that many factors cannot be controlled. As indicated in Section IV, the flow, waste strength, organic loading rate, etc., all fluctuated widely. Therefore, it is much more difficult and sometimes impossible to obtain such a response function. This does not negate the value of plant scale studies. It is still possible to place constraints on the loading factors and determine their reliability using statistical techniques, and it is possible to check or correlate conventional design approaches with full-scale field studies.

In this section, numerous correlations between the important parameters for all three waste categories have been developed. To develop these correlations the least square curve fitting technique was applied using the IBM 360 computer. The results were interpreted and are reported below.

Waste Flow

The waste flow for the 1969 processing season is shown in Figure 4 and flow data were summarized in Table 8, Section VI. A cyclical variation of a weekly nature is exhibited and indicates weekend shutdown. It is also evident that flow showed a trend of gradual increase with a peak in October, and then declined toward the end of the processing season. This generally reflects a rise in production; however flow is also dependent upon the type and quality of products being processed as well as seasonal variation.

In the Stilwell area the wet season generally extends from late fall to early spring; consequently, the vegetables arrive at the cannery soiled more than usual. This necessitates more wash-water in the canning operation. Potatoes, supplied from Idaho, Louisiana and Arkansas, are bruised during transportation. In the canning operation, it is the practice to recycle those potatoes through the processing line for more washing and abrasive polishing so that a consistent quality can be maintained. Thus, more water for less product results.

Waste Flow Prediction Model

Estimates of flow volume in cannery operation are needed for planning and design purposes. Data taken in the study of the Stilwell Cannery were used to develop and verify a prediction scheme which then might be used to predict flows at the Stilwell site or in predicting flows for design purposes at other locations. Not enough periods of processing of single vegetable types could be obtained during the six months of study to examine even the most commonly occurring vegetable types separately. Therefore, the indicated approach was decomposition of the flow into portions associated with each of the vegetables. The approach chosen was the linear model listed below with multiple regression estimates of the parameter.

$$F = a + bI + b_1P_1 + b_2P_2 + \dots\dots\dots\dots + b_iP_i$$

F is flow volume in gallons during the period for which production is reported; a is a constant flow associated with the cannery being in operation for the period and represents internal waste water, cooling water, clean-up, etc., which cannot be associated with individual processes; b is a coefficient; I is the infiltration and domestic sewage input below the cannery; P_i is the production in cases for the i th vegetable type, and b_i is the flow per case (fpc) for the i th vegetable type. I was estimated by base flow during nonproduction periods.

Initial analysis was done on the basis of separate shifts. The shift values were generally reasonable, although the estimated fpc for squash was negative for both shifts and for okra in the night shift. The break between shifts was based on payroll information provided by the cannery.

Observing the processes indicated that the time of division between shifts was not always reliable, as the actual processing might precede or follow the nominal shift by several hours and cause significant error in the flow breakdown between shifts. To avoid this source of error, the two processing shifts were combined and run as an individual data value. The estimates of fpc were all positive; the estimate of the constant, a, was smaller for the work day than for either shift; and the multiple correlation coefficient was higher than that for either of the individual shifts. The results of this run are shown in Table 9.

The coefficient b would normally be 1.0 but was allowed to be fitted, because it was desired to see if the estimates of infiltration by using periods of no production were reliable. Values for the coefficient much less than or greater than 1.0 would indicate unreliability. In the study, the coefficient ranged from 1.0 to

TABLE 9

ESTIMATES OF PARAMETERS

Constants	Values	t Value*
Constant a	151,700 gals	
Infiltration coefficient b	1.30	4.71
Vegetable Type	**Flow Per Case (gals)**	**t Value**
Sweet Potato	157	13.15
Irish Potato	153	12.17
Okra	6	51.00
Peas	26	2.81
Beans	72	3.06
Squash	5	0.39
Green Beans	41	8.17
Mustard Green	109	5.97
Turnip Green	69	7.54
Collard Green	35	1.71
Spinach	61	7.98

*t = 1.29 @ 10%, t = 1.66 @ 5%, t = 2.36 @ 1% levels of significance.

1.6, indicating a fair estimate; to obtain a better estimate more data must be collected.

Referring again to Table 9 only squash has a t value less than the tabulated value at the 5 percent level of significance and squash and collard greens have values less than the tabulated value of the 1 percent level of significance. This indicates a high degree of statistical reliability, since the reliability of the estimate increases with an increase in the t value.

The error analysis for this run is shown in Table 10. The sources of error in estimating this relationship are:

1. Error in flow measurement

2. Error in reporting production

3. Variability in flow per case

4. Variability in non-process water

The first source of error is normally about 5% to 10% based on the listed performance for the flow measurement device. However, several days during the study period, the capacity of the flow meter was exceeded and the flow measured manually. The error induced by measuring the flow manually is unknown.

The magnitude of the second source is uncertain. The production figures should be exact; however, it was possible some processing was partly completed and the vegetables stored and finished and reported the next day.

Errors from the third and fourth sources are due to estimating averages for values which actually show a distribution. There is certain to be some variation in fpc because of the differences in raw product quality for a vegetable type, such as seasonal variation, variation due to operating personnel and that due to a change in quantity of product processed per unit of time. The amount of water, flowing during a shift, which is not process water will vary also.

As indicated in Table 10 the multiple correlation coefficient is above .9 which indicates a relatively high correlation. The standard error of the estimate is 148,600 gallons per day which is less than 15 percent of the average flow per work day which is 969,900 gallons.

TABLE 10

ERROR ANALYSIS

Multiple Correlation Coefficient	0.906
Standard Error of Estimate	148,600 gals
Average Flow per Work Day	969,900 gals

The estimates of fpc for the eleven vegetable types are reasonable in magnitude and are in general agreement with published figures. Since the flow per case accounts for approximately 90 percent of the total average flow, it is tempting to use the values of fpc as estimates of the average amount of water associated with each case of a particular vegetable processed in this cannery. This should be cautioned against especially for products with low flow such as okra and squash.

The model can be used to predict flows at this site or used at another site by estimating the number of cases processed. The constant term can be estimated as a percentage of the average predicted flow based on assumed production and estimated fpc. In general there are infiltration sources which must also be estimated.

Waste Load

The waste flow is screened twice, once at the cannery and again upon entering the treatment plant, with solids being disposed of by burying near the cannery. As most of the particulate matter is removed at the cannery the difference in waste load before and after screening at the plant site is negligible. Therefore, samples of incoming waste were taken after screening.

Throughout the study period, COD tests were used as a measure of waste strength. BOD test were also performed at the time of COD analyses; and the BOD/COD ratio of the influent potato waste was approximately 0.7, which is comparable with that of the other investigators (15).

The characteristics of the wastes, as classified in three categories, are summarized in Tables D-1, D-2, and D-3 of Appendix D. Notice that approximately 50% of the total COD can be attributed to solids for both Irish potato and sweet potato wastes, as it can be removed after 30 minutes of settling. However, for vegetable wastes, only 15% of the total COD is settleable. It is worthy to point out that the average TKN/COD ratio for vegetable wastes is 4.8% and that of Irish potato and sweet potato is around 2%. Therefore, nitrogen supplementation is only necessary for potato wastes.

The variability in non-volatile solids for vegetable wastes alone is largely due to uncontrollable factors such as the quality of raw material, weather conditions, and water quantity used in processing. The VSS/SS ratio, as indicated in Table D-3, ranged from 9.7 to 93%, which is approximately a ten-fold difference. Much of this variability is due to field moisture conditions. Winter spinach because of wet weather had much higher inorganic solids present in the SS. Excluding winter data, VSS versus SS correlation improved; and VSS/SS ratios changed from a ten-fold to four-fold spread. The effect of non-volatile solids on a mixture of potato and vegetable wastes is depressed because of the high solids concentration in potato waste, and thus allows for a better correlation of all parameters studied.

The results of the statistical analyses of the plant influent data are listed in Table 11 and are plotted in Figures E-1 through E-20 of Appendix E. As shown in Figures E-4, E-5, E-9, E-10 and E-17 through E-20, the lines of best fit for total COD versus TVS and soluble COD versus VDS are quite consistent and appear to follow a linear model although there is considerable variability with a coefficient of variation ranging from 0.62 to 0.98. The relationships between VSS and SS, VDS and DS, TVS, and TS for both sweet potato and vegetable wastes and Irish potato and vegetable wastes show very good correlations as indicated in Figures E-1, E-2, E-3, E-6, E-7 and E-8. The equations derived for the solids relationships of vegetable wastes, as shown in Figures E-11 through E-16, do not correlate as well, because the vegetables were processed in the late fall and early winter during the rainy season and the non-volatile solids concentration varied widely due to the weather changes. If it were possible to obtain more data on vegetable wastes from the following processing seasons, the solids correlation for vegetable wastes could certainly be improved.

Substrate Removal and Biosolids Growth

The stabilization of organic wastes in the aerobic biological wastes treatment process is brought about through the metabolic activities of mixed culture heterotrophic microorganisms. A portion of the organic waste is converted to end products such as carbon dioxide and water to obtain energy for synthesis of the remaining portion into new biosolids and simultaneously to sustain life. After most of the organic waste is stabilized, or only a limited amount remains, the microorganisms then obtain the energy needed to sustain themselves by consuming their own

TABLE 11

PLANT INFLUENT STUDY

Line of Best Fit	Correlation Coefficient r	Number of Observations n
	Sweet Potatoes and Vegetables	
VSS = 0.785 SS + 117	0.922	22
VDS = 0.951 DS - 158	0.982	22
TVS = 0.89 TS - 112	0.964	22
Total COD = 0.974 TVS + 815	0.873	22
Soluble COD = 1.12 VDS + 48	0.979	22
	Irish Potatoes and Vegetables	
VSS = 0.964 SS - 32	0.994	45
VDS = 0.872 DS - 84	0.979	45
TVS = 0.948 TS - 183	0.992	45
Total COD = 0.839 TVS + 886	0.723	45
Soluble COD = 0.876 VDS + 367	0.824	45
	Vegetables	
VSS = 0.619 SS + 73	0.514	17
VDS = 0.366 DS + 106	0.572	16
TVS = 0.0946 TS + 299	0.369	16
Total COD = 0.683 TVS + 119	0.738	16
Soluble COD = 0.935 VDS + 3.8	0.871	14
	Vegetables Winter Data Excluded	
VSS = 0.502 SS + 11	0.879	13
VDS = 0.258 DS + 171	0.367	12
TVS = 0.455 TS + 92	0.63	12
Total COD = 0.517 TVS + 195	0.615	12
Soluble COD = 0.902 VDS + 19	0.819	11

protoplasm; and such a process is commonly referred to as endogenous respiration. Endogenous metabolism is a function of the active biosolids and becomes significant under food-limiting conditions. Under such conditions, microorganisms are forced to utilize their own protoplasm until all that remains is a relatively stable humus-like organic residue which resists further degradation. This inert organic residue, an insoluble and non-biodegradable fraction of the microorganisms, accumulates in the system at the rate of about 11 to 15% of the ultimate BOD removed (51).

In the biological oxidation process, Eckenfelder (52) showed that at high substrate levels the rate of substrate removal per unit of biosolids will remain constant to a limiting substrate concentration below which the rate will become concentration dependent and decrease. It is generally accepted that the substrate removal kinetics can be described by a modification of the Michaelis-Mention equation which is mathematically expressed as:

$$\frac{1}{S}\frac{dF}{dt} = K\,\frac{F}{f+F} \qquad (1)$$

in which,

$\frac{1}{S}\frac{dF}{dt}$ = rate of change of substrate (BOD or COD) per unit of biosolids with respect to time

F = substrate (BOD or COD) concentration present in the reactor

S = biosolids under aeration

K = maximum substrate removal rate

f = Michaelis Constant, equal in magnitude to the substrate concentration at which (1/S) (dF/dt) = K/2

At high substrate concentrations, F is much greater than f, then Equation (1) becomes:

$$\frac{1}{S}\frac{dF}{dt} = K$$

$$\frac{1}{S}\int_{F_e}^{F_i} dF = K \int_{t_o}^{t} dt$$

$$\frac{1}{S}(F_i - F_e) = Kt$$

$$\frac{F_i - F_e}{St} = K \qquad (2)$$

in which,

F_i = influent substrate concentration

F_e = effluent substrate concentration

t = hydraulic retention time in aeration vessel

or $$\frac{COD_i - COD_e}{MLVSS(t)} = K \qquad (3)$$

in which,

$\frac{COD_i - COD_e}{MLVSS(t)}$ is the COD removal rate designated as ΔCOD expressed in terms of $\frac{\text{lbs COD removed/Day}}{\text{lbs MLVSS}}$ or

$\frac{\text{mg COD removed/Day}}{\text{mg MLVSS}}$

COD_i = influent waste COD in mg/l

COD_e = soluble effluent COD in mg/l

t = hydraulic retention time in aeration tank in days.

From equation (3) it is obvious that for high substrate concentrations the COD removal rate follows a zero order reaction.

At low substrate concentration f is much greater than F, then Equation (1) can be expressed as:

$$\frac{1}{S}\frac{dF}{dt} = \frac{K}{f} F = K_1 F \qquad (4)$$

In a completely mixed activated sludge system, the effluent substrate concentration is assumed to be equal to the concentration of substrate remaining in the aeration vessel. Hence, Equation (4) can be written as:

$$\frac{dF}{dt} = K_1 F_e S.$$

And a material balance can be developed as below:

$$Q(F_i - F_e) = \frac{dF}{dt} V$$

$$F_i - F_e = \frac{dF}{dt} \frac{V}{Q}$$

$$F_i - F_e = \frac{dF}{dt} t$$

$$\frac{F_i - F_e}{t} = \frac{dF}{dt}$$

$$\frac{F_i - F_e}{t} = K_1 F_e S$$

$$\frac{F_i - F_e}{S(t)} = K_1 F_e \quad (5)$$

Equation (5), a general mathematical expression for first order kinetics, represents a response function for a completely soluble waste and does not include the rapid initial removal due to biosorption. If a significant portion of the COD in the waste is present in the colloidal, suspended or settleable form, then equation (5) must be modified since it only takes into consideration the soluble COD that can be removed through bio-oxidation. The particulate COD will be removed by direct settling or by adsorption (biosorption) on to the MLSS and subsequent settling. Therefore, if biosorption and settling are included then equation (5) becomes:

$$\frac{F_i - F_e}{S(t)} = K_1 F_e + I \quad (6)$$

or $$\frac{COD_i - COD_e}{MLVSS\ (t)} = K_1 COD_e + I \qquad (7)$$

where I is an intercept due to settling and biosorption.

Based on the relationships expressed in Equations (3) and (7), if ΔCOD is plotted against COD_e, the organic removal function can be readily visualized and studied. Due consideration of these basic concepts of bio-oxidation is important in the interpretation of the results obtained from this study.

The increase of bio-solids in a biological system is expressed mathematically as:

$$\Delta S = a\ BOD_{ult} (\text{or } COD) - bS \qquad (8)$$

or $$\frac{\Delta VSS}{MLVSS} = a \frac{\Delta COD}{MLVSS} - b \qquad (9)$$

in which,

ΔS = net growth of bio-solids
a = growth rate constant
b = endogenous respiration rate constant
$\frac{\Delta VSS}{MLVSS}$ = is the net growth of bio-solids per unit of time

per MLVSS expressed in terms of $\frac{\text{lbs VSS increased/Day}}{\text{lbs MLVSS}}$

or $\frac{\text{mg VSS increased/Day}}{\text{mg MLVSS}}$

Oxygen is required in aerobic biological treatment systems to provide a terminal hydrogen acceptor for catabolic reactions. The amount of oxygen required can be expressed mathematically as:

$$O_2 = a'\ \Delta COD + b'S \qquad (10)$$

or $$\frac{O_2/Day}{MLVSS} = a' \frac{\Delta COD/Day}{MLVSS} + b' \qquad (11)$$

in which,

$\frac{O_2/Day}{MLVSS}$ is the total oxygen required per day per unit of MLVSS expressed in terms of $\frac{\text{lbs } O_2/\text{Day}}{\text{lbs MLVSS}}$

a' = oxygen utilization rate constant for synthesis

b' = oxygen utilization rate constant for endogenous respiration

Modular Units and System Evaluation

Considerable data were collected on COD removal rates and remaining COD concentrations as well as MLSS and MLVSS concentrations during the course of this study. The results of the modular units study are summarized in Tables 12, 13, and 14 and plotted in Figures E-21 through E-40, Appendix E.

Minimal Solids Unit Evaluation

Figures E-21, E-22 and E-23, show the COD removal kinetics in the minimal solids unit for the three waste categories. The COD removal rates versus the soluble effluent COD in the minimal solids unit for sweet potato plus vegetable wastes, are shown in Figure E-21. The upper line is based on the total influent COD and the lower one is based on the soluble influent COD. The best-fit line for the soluble COD removal rate versus the soluble effluent COD is essentially a horizontal line, indicating that the COD removal rate is independent of the soluble effluent COD or the soluble COD in the aeration basin; that is, the organic removal rate follows zero order kinetics. Therefore, referring to Figure E-31, the average soluble COD removal rate as developed in Equation (3) is 2.55 lbs COD/day/lb MLVSS. Referring to the COD removal rate based on total influent COD versus the soluble effluent COD, the line of best fit shows a slight upward slope; however, it is reasonable to interpret it as zero order rather than first order reaction. The difference between the upper and lower lines of best fit is due to the removal of COD present in settleable, suspended or colloidal form by bio-precipitation and settling. Referring to Table D-1, Appendix D, it can be seen that from 41 to 63%, with an average of 51%, of the total influent COD can be attributed to solids and colloids. The upward slope of the line reflects the solids COD removed by settling. The difference between the intercepts of the two lines of best fit is 2.53, or 50% of the total COD removed, which corresponds very closely with the average solids COD of the influent. Since the hydraulic retention time in the aeration basin is short, ranging from 3.4 to 6.4 hours with an average of 5.26 hours, the biochemical degradation of particulate matter through hydrolysis and their subsequent removal is small and can be neglected.

For Irish potato plus vegetable wastes, as shown in Figure E-22, comparable results with that of sweet potato plus vegetable wastes were obtained; hence, the above reasoning can be applied to their interpretation. That is, soluble COD removal

TABLE 12

MODULAR UNIT STUDY OF SWEET POTATOES AND VEGETABLES

Line of Best Fit	Correlation Coefficient r	Number of Observations n
Minimal Solids (High Loading) Unit		
Based on Total Influent COD:		
$\frac{\Delta COD/Day}{MLVSS} = 5.08 + 0.00152\ COD_e$	0.387	19
Based on Soluble Influent COD:		
$\frac{\Delta COD/Day}{MLVSS} = 2.55 - 0.000359\ COD_e$	0.209	19
ML Solids COD= 1.196 MLVSS+470	0.961	19
MLVSS=0.917 MLSS-247	0.992	19
Extended Aeration Unit		
$\frac{\Delta COD/Day}{MLVSS} = 0.00118\ COD_e - 0.023$	0.694	16
ML Solids COD=1.312 MLVSS+58	0.963	17
MLVSS=0.894 MLSS-209	0.986	18

TABLE 13

MODULAR UNIT STUDY OF IRISH POTATOES AND VEGETABLES

Line of Best Fit	Correlation Coefficient r	Number of Observations n
Minimal Solids (High Loading) Unit		
Based on Total Influent COD:		
$\frac{\Delta\ COD/Day}{MLVSS} = 5.26 + 0.00963\ COD_e$	0.325	40
Based on Soluble Influent COD:		
$\frac{\Delta\ COD/Day}{MLVSS} = 2.56 + 0.00134\ COD_e$	0.106	39
ML Solids COD = 1.369 MLVSS-59	0.989	71
MLVSS= 0.839 MLSS - 28	0.996	71
Extended Aeration Unit		
$\frac{\Delta COD/Day}{MLVSS} = 0.192 - 0.000802\ COD_e$	0.129	34
ML Solids COD= 1.339 MLVSS+ 110	0.994	33
MLVSS= 0.725 MLSS - 222	0.916	34

TABLE 14

MODULAR UNIT STUDY OF VEGETABLES

Line of Best Fit	Correlation Coefficient r	Number of Observations n
Minimal Solids (High Loading) Unit		
Based on Total Influent COD:		
$\frac{\Delta COD/Day}{MLVSS} = 7.98 - 0.0387\ COD$	0.414	13
Based on Soluble Influent COD:		
$\frac{\Delta COD/Day}{MLVSS} = 5.16 - 0.0266\ COD_e$	0.446	13
ML Solids COD = 1.075 MLVSS + 12	0.952	13
MLVSS = 0.847 MLSS - 62	0.877	13
Extended Aeration		
$\frac{\Delta COD/Day}{MLVSS} = 0.0391 - 0.00038\ COD_e$	0.244	13
ML Solids COD = 1.375 MLVSS - 3.32	0.957	15
MLVSS = 0.796 MLSS - 425	0.917	15

follows zero order reaction; and the solids portion is removed by adsorption, flocculation and settling. The average soluble COD removal rate is 2.56 lbs/day/lbs MLVSS, which is essentially the same as that of sweet potato plus vegetable wastes.

Figure E-23, shows the COD removal rate versus the soluble effluent COD based on both total and soluble influent for vegetable wastes. The data are so erratic that it is impossible to develop a COD removal rate versus COD effluent relationship. This is not unusual in a system in which there is no sludge returned to the aeration basin, in other words, in a system in which the MLVSS concentration is very low (less than 500 mg/l).

The percentage of COD removals for various waste categories is summarized in Tables D-1, D-2, D-3. It can be observed that the average soluble COD removal for Irish potato and vegetable wastes in the minimal solids unit was 87%, with a range from 64 to 99%. During periods when sweet potato plus vegetables were processed, all sludge was returned to the minimal solids unit, resulting in an average COD removal of 92%, with a range from 76 to 99%. The average COD removal for vegetable wastes in the minimal solids unit was 82%.

The COD removal efficiency for vegetable wastes was lower than that of potato plus vegetable wastes; however, the average soluble COD remaining in the minimal solids unit for vegetable wastes was 66 mg/l, as compared to 349 mg/l for Irish potato plus vegetable wastes. This indicates that a much lower effluent strength can be obtained while treating only vegetable wastes.

Figure E-24 through E-29, show the MLVSS versus MLSS and the ML solids COD versus MLVSS relationships in the minimal solids unit. For all three waste categories excellent correlation coefficients were obtained. The regression coefficients for MLVSS and MLSS are close to the average MLVSS/MLSS ratios as listed in Tables D-1, D-2, and D-3. The lines of best fit for ML solids COD and MLVSS give positive intercepts which can be considered as the COD attributed to the non-volatile solids in the mixed liquor.

As there is no primary settling tank in the treatment system, and it is impossible to differentiate bio-solids from organic solids as determined by solids analysis, the entire MLVSS was used to compute the COD removal rate. Therefore, both the COD load applied and removed per day per unit of MLVSS are higher than indicated.

Extended Aeration Unit Evaluation

As stated earlier in this paper, the extended aeration unit with final clarifier serves the dual purpose of effluent polishing and solids digestion. The soluble effluent COD of the minimal solids unit is taken as the input COD load to the extended aeration unit. The effluent flow and its MLVSS concentration from the minimal solids unit, are considered as the solids load.

The correlation of soluble COD removal rates versus the plant soluble effluent COD in the extended aeration unit for the three waste categories is shown in Figures E-30, E-31 and E-32. The line of best-fit for sweet potato plus vegetable wastes indicates that the soluble COD removal rate follows first order reaction kinetics with a fair correlation coefficient, as shown in Figure E-30. The soluble COD removal rate constant designated as K_1 in Equation (8) is 0.00118. As to soluble COD removal rates for Irish potato plus vegetable wastes and that of vegetable wastes alone, no correlation could be found; however, the plant soluble effluent COD, except for one or two instances, was always less than 140 mg/l for the Irish potato plus vegetable wastes and 30 mg/l for vegetable wastes alone. The reason for the poorer correlation for the Irish potato plus vegetable wastes and vegetable wastes alone than for sweet potato plus vegetable wastes was because of the more frequent changes in product processed and the long retention time in the extended aeration basin, making it impossible to develop good correlations. As indicated in Tables D-1, D-2 and D-3, the average detention time in the extended aeration basin for sweet potato and vegetable wastes, Irish potato and vegetable wastes, and vegetable wastes alone were 1.58, 1.96 and 3.32 days respectively. Because of the long retention time and frequent changes in waste characteristics, the mixed liquor was always a mixture of many wastes. The frequent changes in waste characteristics were the result of irregularly intermingling the processing shifts of Irish potato plus vegetables and that of vegetables alone, resulting in wide COD fluctuations in the aeration basin. Sweet potato and vegetable processing was more continuous and of longer duration; and when raw supplies were exhausted, Irish potatoes and vegetables were processed in their place. Therefore, the COD fluctuations were less pronounced than in the previous case.

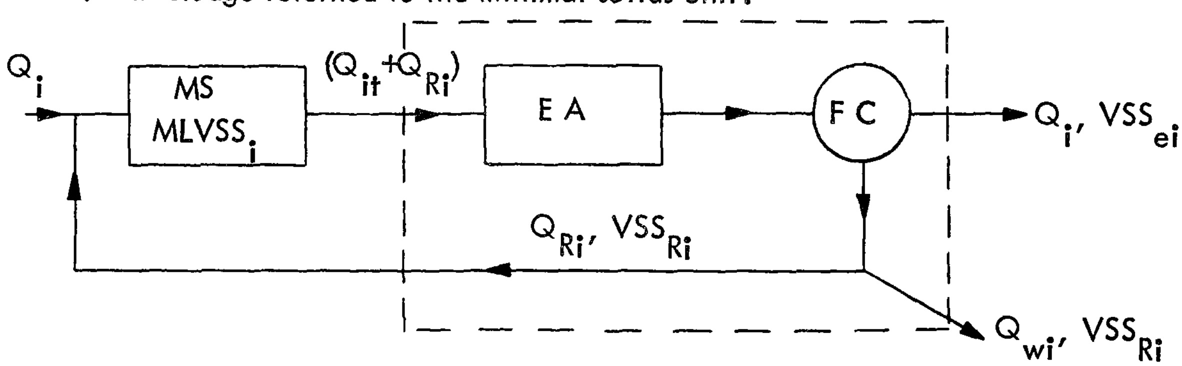
Figures E-33 through E-38, show the relationship between MLVSS and MLSS, and between ML solids COD and MLVSS for all three wastes categories. Again, excellent correlations were obtained.

Throughout this study all loading rates are expressed in terms of a unit organic load (lbs COD/Day/lb MLVSS); and no mention is made of volumetric loading, which is also often used in the field of waste treatment. Referring to Tables D-1, D-2, D-3, an average volumetric loading rate for the three waste categories in both stages of aeration can be calculated. Applied loads to the minimal solids unit based on total influent COD for sweet potato plus vegetable, Irish potato plus vegetable, and vegetable wastes alone were 1160, 714, and 86 lbs COD/Day/1000 cu. ft., respectively. When compared to conventional loading rates of 100 lbs BOD/Day/1000 cu. ft. for high rate activated sludge systems, the minimal solids unit at Stilwell is extremely efficient, with extremely high loadings. Minimal solids soluble COD loads to the extended aeration unit for sweet potatoes plus vegetables, Irish potatoes plus vegetables and vegetable wastes alone were 12.3, 12.5, and 1.74 COD/Day/1000 cu.ft. respectively. Reported loading values of 20 lbs BOD/Day/1000 cu.ft. for extended aeration systems are common. In addition to the soluble effluent COD loading from the minimal solids unit, a high solids loading was also applied to extended aeration units. An average solids loading in terms of lbs VSS/Day/cu.ft. was 0.171, 0.129, and 0.033 when processing sweet potatoes plus vegetables, Irish potatoes plus vegetables and vegetable wastes alone, respectively. Comparing the general loading rate of 0.1 lbs VS/Day/cu.ft. applied to high rate anaerobic digestors and the 0.1 to 0.2 lbs VS/Day/cu.ft. applied to laboratory aerobic digestors as reported by other investigators (50), the Stilwell extended aeration unit was subjected to fairly high loadings.

The solids removal efficiencies were a function of the products processed and the methods of operation of the system. During June, July and the first week in August, vegetables were the dominant products processed and during this period the sludge was returned to either the extended aeration unit or simultaneously to the minimal solids and the extended aeration units without intentional sludge wasting except on June 11. From August 7 to August 30, Irish potatoes plus vegetables were the dominant products and sludge was returned to either the minimal solids or simultaneously to the minimal solids and the extended aeration units with intermittent sludge wasting. Following August 30, the sludge was returned to the minimal solids unit and the excess wasted to the anaerobic sludge stabilization lagoon. From August 30 to the first part of November, either sweet potatoes or Irish potatoes were processed simultaneously with vegetables, with sweet potatoes being the dominant potato product. The sludge return schedule is shown in Figure 12.

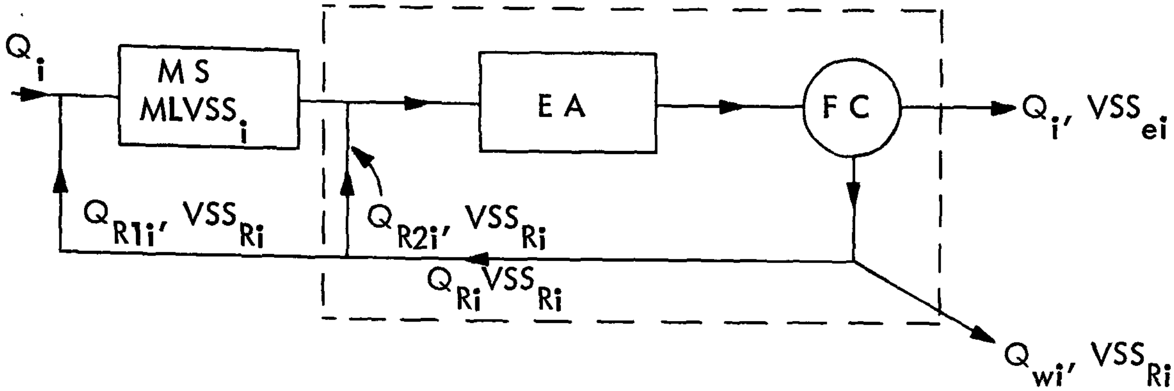
As stated previously, the extended aeration unit was designed to handle all solids with no credit being given to the minimal solids unit since the bio-solids produced were not returned directly to this unit and therefore the sludge retention time (SRT) was much less than the SRT in the extended aeration unit. The solids removal efficiencies in the extended aeration unit were computed using the following formulae:

1. All sludge returned to the minimal solids unit.



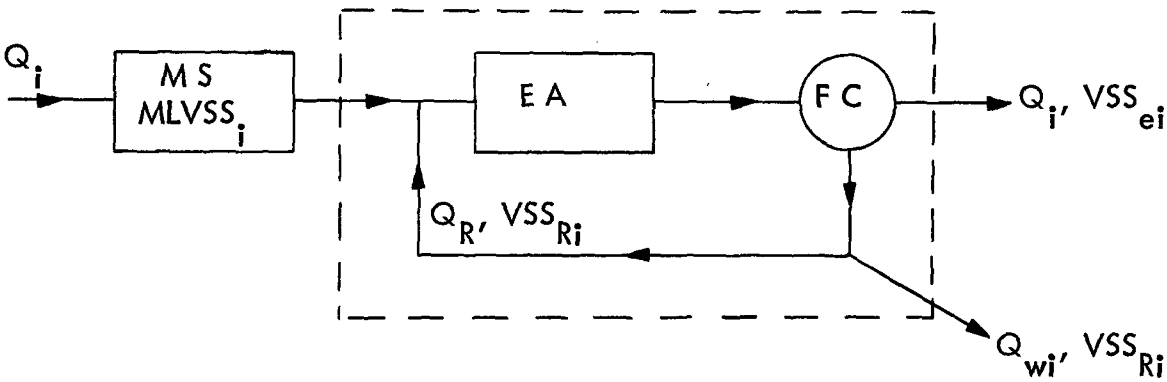
$$\text{Volatile Solids Removal} = \frac{\Sigma(Q_i+Q_{Ri})MLVSS_i - \Sigma Q_i VSS_{ei} - \Sigma Q_{wi} VSS_{Ri} - \Sigma Q_{Ri} VSS_{Ri}}{\Sigma(Q_i+Q_{Ri})MLVSS_i - \Sigma Q_{Ri} VSS_{Ri}}$$

2. Sludge returned to both minimal solids unit and extended aeration unit.



$$\text{Volatile Solids Removal} = \frac{\Sigma(Q_i+Q_{R1i})MLVSS_i - \Sigma Q_i VSS_{ei} - \Sigma Q_{wi} VSS_{Ri} - \Sigma Q_{R1i} VSS_{Ri}}{\Sigma(Q_i+Q_{R1i})MLVSS_i - \Sigma Q_{R1i} VSS_{Ri}}$$

3. All sludge returned to extended aeration units.



$$\text{Volatile Solids Removal} = \frac{Q_i MLVSS_i - Q_{wi} VSS_{Ri} - Q_i VSS_{ei}}{Q_i MLVSS_i}$$

$Q_{wi} VSS_{Ri} = 0$ if there is no sludge wasting.

The weighted average VSS removal in extended aeration was 66%, 62% and 85% respectively for sweet potato plus vegetables, Irish potato plus vegetable, and vegetable wastes only. Median and range values for the three waste categories are summarized in Tables D-1, D-2 and D-3 of Appendix D.

The computed volatile solids removal efficiences were erratic as a result of the intermittent sludge wasting procedure. In other words, a controlled sludge wasting on an even interval or continuous basis would level off the erratic removal efficiences. This is not easy, because of the large variability of the products to be processed and consequently the variation of the waste strength.

System Evaluation

The correlation of plant effluent parameters have also been studied. The results are listed in Table 15, and in Figure E-39 through E-47. Good correlations for effluent VSS versus SS relationships for all three waste categories were obtained. Effluent COD and VSS relationships are fairly good for both sweet potato plus vegetable, and Irish potato plus vegetable wastes. However, the COD versus VSS correlations for vegetable wastes alone are rather poor; this is probably due to residual effects of strong wastes from previous shifts. Although the percentage COD removal for strong waste was high, the residual effluent was of sufficient magnitude that when mixed with the low vegetable COD effluent of the following shifts it resulted in a higher plant effluent concentration than would exist if only vegetables were processed, thus lowering the observed plant efficiency. Consequently, the COD and VSS relationship of vegetable wastes was affected.

The average plant soluble effluent COD for sweet potato plus vegetable, Irish potato plus vegetable, and vegetable wastes alone were 84, 44, 33 mg/l respectively. For potato wastes this study showed a BOD/COD ratio of approximately 0.2, which is consistent with that of 0.16 to 0.30 as reported by Atkins and Sproul (15). Based on the BOD/COD ratio of 0.2, the plant effluent would have a corresponding soluble BOD of 17 mg/l for sweet potato and vegetable wastes, and 9 mg/l for Irish potato and vegetable wastes.

The plant performance data as shown in Tables D-1, D-2, and D-3, indicated an overall average COD removal of 97, 99, and 82% for sweet potato plus vegetable, Irish potato plus vegetable, and vegetable wastes alone, respectively. On a BOD basis, the removals are much higher than these figures. The plant VSS removals were 97, 98, and 74% for sweet potato plus vegetable, Irish potato plus vegetable, and vegetable wastes, respectively. The VSS in the effluent is mainly inert organics from polysaccharides resulting from bio-solids decay.

Correlations for oxygen uptake studies were poor; therefore, these studies were not reported. However, dissolved oxygen concentrations in the aeration basins were monitored frequently. Residual oxygen was detected at all times during the course of the study period. The average dissolved oxygen content in the minimal solids unit was 4.36 mg/l and ranged from 0.2 to 8.1 mg/l with a median of 4.6 mg/l. In the extended aeration basins, the average dissolved oxygen content was 3.4 mg/l with a median of 3.15 mg/l and a range of 0.5 to 9.8 mg/l.

Solids Separation and Disposal

The overall performance of an activated sludge system depends on the ability of the final clarifier to separate and retain the solids from the effluent. It is impossible

TABLE 15

PLANT EFFLUENT STUDY

Line of Best Fit	Correlation Coefficient r	Number of Observations n
Sweet Potatoes and Vegetables		
VSS = 0.711 SS - 0.741	0.899	20
Total Effluent COD = 1.356 VSS + 64.48	0.673	20
Effluent Solids COD = 0.811 VSS + 2	0.825	20
Irish Potatoes and Vegetables		
VSS = 0.892 SS - 16.45	0.93	35
Total Effluent COD = 1.431 VSS + 34.06	0.902	35
Effluent Solids COD = 1.097 VSS + 5.46	0.921	35
Vegetables		
VSS = 0.538 SS + 6.48	0.926	17
Total Effluent COD = 0.692 VSS + 34.19	0.288	17
Effluent Solids COD = 0.449 VSS + 841	0.529	17

to produce a good quality effluent unless most of the solids can be separated and returned to the system or wasted. Since the settleability of the MLSS is generally measured by the Sludge Volume Index (SVI), and the total COD removal efficiency is related to the settleability of the solids the SVI is plotted against the COD removal rates for minimal solids and extended aeration units. No apparent relation between these two parameters can be observed (refer to Figures 25 and 26). Normally, one would expect better settling at lower loading rates (extended aeration) than at high loading rate (minimal solids); however, the solids in the minimal solids unit seem to settle better than in the extended aeration unit. The reason for this apparent anomaly is not well understood. However, the better-then-expected settling in the minimal solids unit can be attributed to stabilization of the solids in the extended aeration system. Solids are recirculated from the final clarifier to the minimal solids unit. If the system was so designed that the minimal solids system could be operated separately, solids separation from this unit would be much more difficult. As indicated in Tables D-1, D-2 and D-3, the average SVI for sweet potato plus vegetable, Irish potato plus vegetable, and vegetable wastes alone in minimal solids were 197, 132, and 124, respectively and in extended aeration were 250, 147, and 126. Normal SVI varies from 55 to 150 in diffused air plants and from 200 to 300 at mechanical aeration plants (53). As presented in Tables D-1, D-2 and D-3, the highest SVI occurred in both aeration units when treating sweet potato wastes which were nitrogen deficient and had the highest waste flow. Therefore, it is postulated that inadequate nutrient feed to the system deteriorates the settleability and separation characteristics of the solids. In general the final settling tank of an extended aeration system with 24 hour aeration is designed with 4 hour detention time based on incoming waste flow. The final clarifier in this system has a detention time of only 1.89 hours based on 1.5 MGD. This lower retention time accentuates the problem of inadequate solids separation; however, if the conditions, such as nutrient addition, are maintained at the optimum, solids separation can be adequately accomplished. This has been verified by following the treatment efficiencies in the 1970 canning season. During this season, nutrients have been maintained at the optimum level, the loading rate higher than the 1969 season, and no separation problems existed until flows exceeded 2.5 MGD.

In the course of the study, excess solids were wasted to an anaerobic sludge pond. The volume of solids wasted ranged from 0.006 to 0.343 MGD with an average of 0.13 MGD and a median of 0.112 MGD. This does not include the period of sludge bulking when solids were wasted involuntarily for 16 hours per day for two weeks. The corresponding weight of solids wasted ranged from 322 to 20,451 with a mean of 7,750 lbs SS/day.

The rate of sludge stabilization in the anaerobic ponds is extremely slow. Solids were pumped to the pond for the first time in August 1969 and solids loading stopped in December 1969. No sludge was added again until late September 1970. It was anticipated that with two lagoons operating alternate years, allowing one

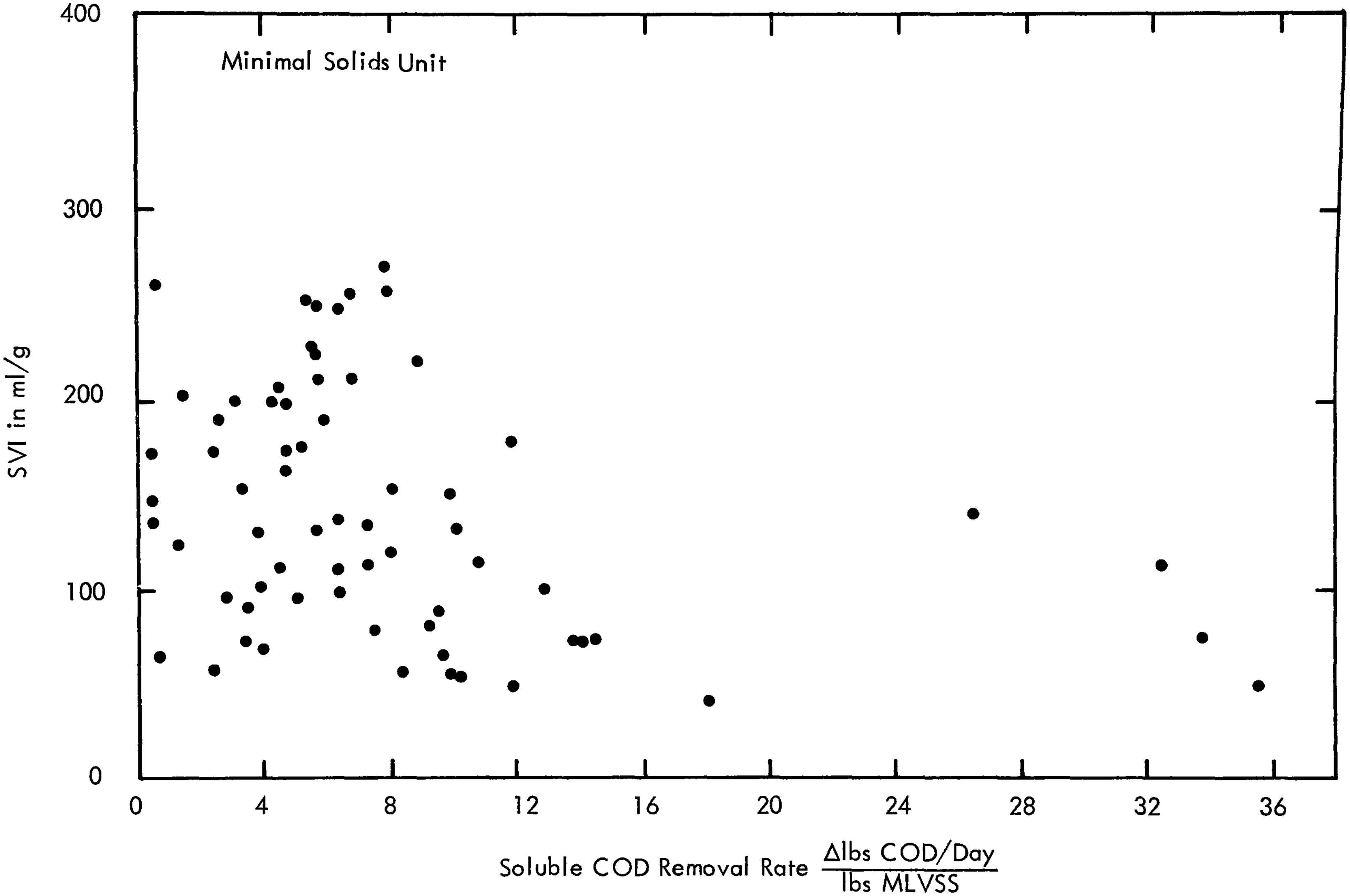


Figure 25 SVI vs Soluble COD Removal Rate

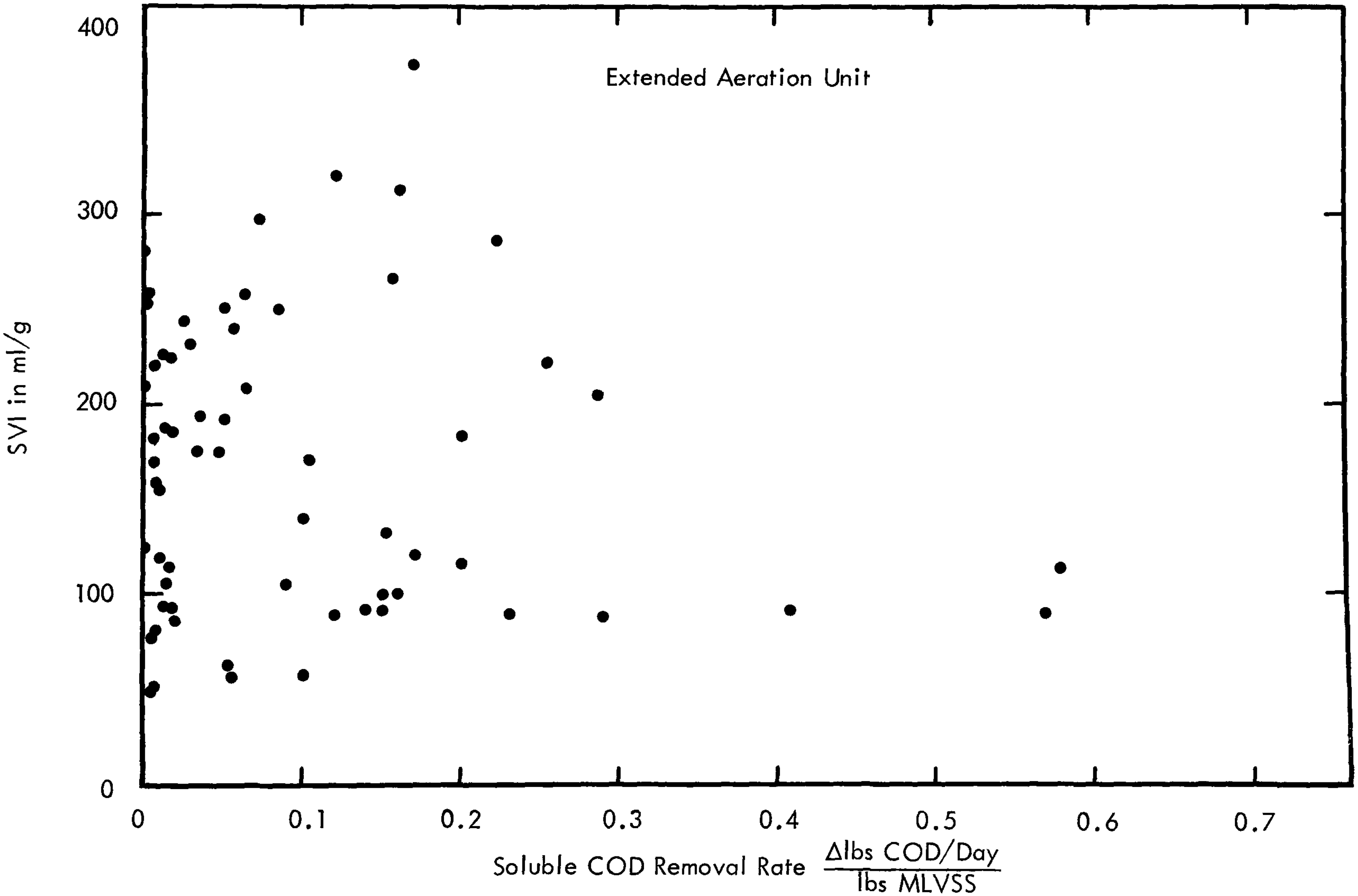


Figure 26 SVI vs Soluble COD Removal Rate

full year for digestion, the sludge would be well stabilized and would be removed from the lagoon and spread on fields as a soil conditioner. However, after one full year the sludge in the bottom of the lagoon had approximately the same consistency and color as when it was first pumped to the lagoon. The digested sludge had a rubber-like consistency making questionable its value as a soil conditioner. From these observations anaerobic digestion of the sludge may not be the most desirable or economical method of treatment.

Nutrient Requirements

Several nutrients and trace elements are essential for the metabolism of organic matter by microorganisms. These nutrients are needed only for synthesis and are released from the endogenous phase and are again available for reuse. All but nitrogen and phosphorous are usually present in sufficient quantity in the carrier water. As stated earlier in this chapter, the waste generated from sweet potato and Irish potato were deficient only in nitrogen.

In this study total Kjeldahl nitrogen was used as a measure of nitrogen content in the VSS; ammonia, nitrate nitrogen, and total phosphate in the plant effluent were also monitored. When nutrients in low concentration were detected in the effluent it was assumed that the treatment system was not deficient nutritionally; however, when high concentrations were found in the effluent, nitrogen dosage was lowered so that nutritional pollution could be prevented. A nitrate nitrogen concentration of 1 mg/l in the effluent was used as a criterion.

The TKN/VSS ratios of the returned sludge are plotted against the COD removal rates for both aeration units in Figures 27 and 28. No relationship exists between the two parameters; however, the average TKN/VSS ratios were found to be 6.38 and 6.93 in the minimal solids unit and extended aeration tank, respectively. Referring to plant effluent data as listed in Tables D-1, D-2, and D-3, the average ammonia nitrogen concentration in the effluent was 0.3 mg/l, nitrate nitrogen 1.7, and phosphate 0.14, which would indicate that the microorganisms had sufficient nutrients, except during the sludge bulking period, when the nitrogen content of the MLVSS dropped to a low of 3.1%. The situation was corrected after two weeks of nitrogen supplementation from an exogenous source. When the nitrogen level reached 4.6, settling began to improve.

When SVI is plotted against sludge TKN/VSS ratios as shown in Figure 29, a trend exists which appears to follow a hyperbolic curve the higher the TKN/VSS ratio the lower the SVI. A minimum TKN/VSS ratio of 5% is required to avoid sludge bulking and a ratio of between 5 and 10% could give a SVI below 200 provided other conditions were favorable.

It should be noted that pH is another environmental factor of importance in an activated sludge system; pH should be maintained between 6.5 to 9.0 to support a

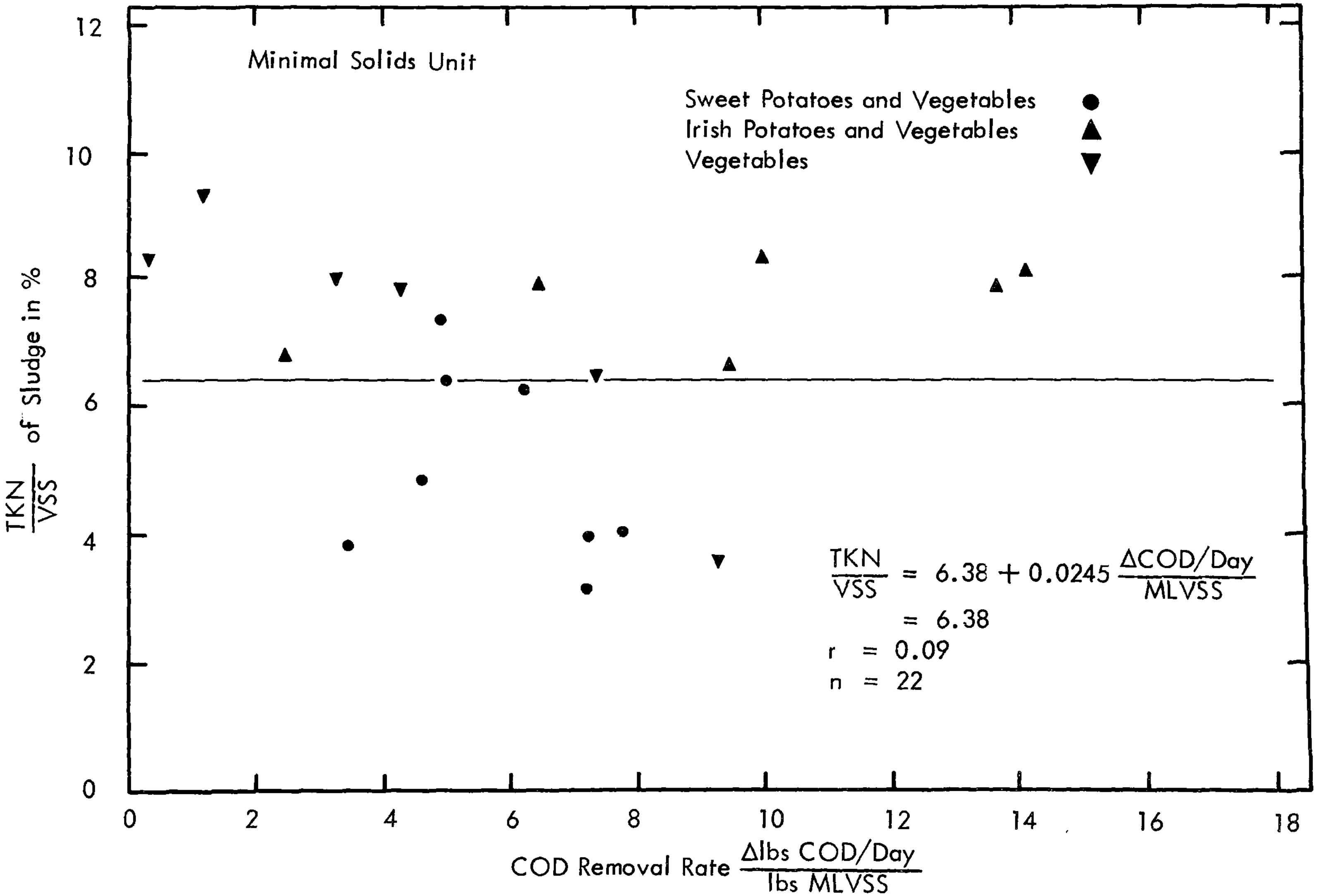


Figure 27 $\frac{TKN}{VSS}$ of Sludge vs COD Removal Rate

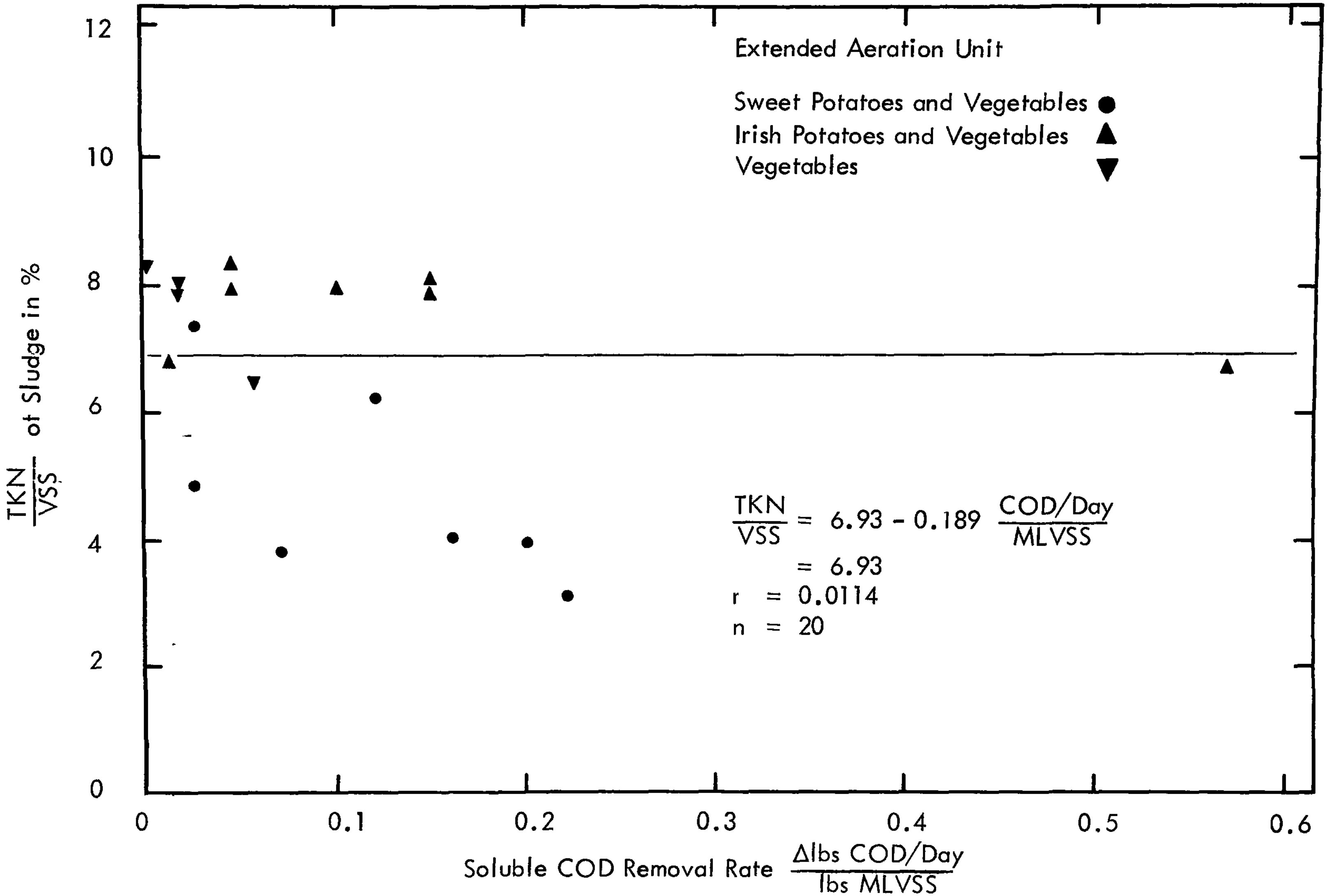


Figure 28 $\frac{TKN}{VSS}$ of Sludge vs Soluble COD Removal Rate

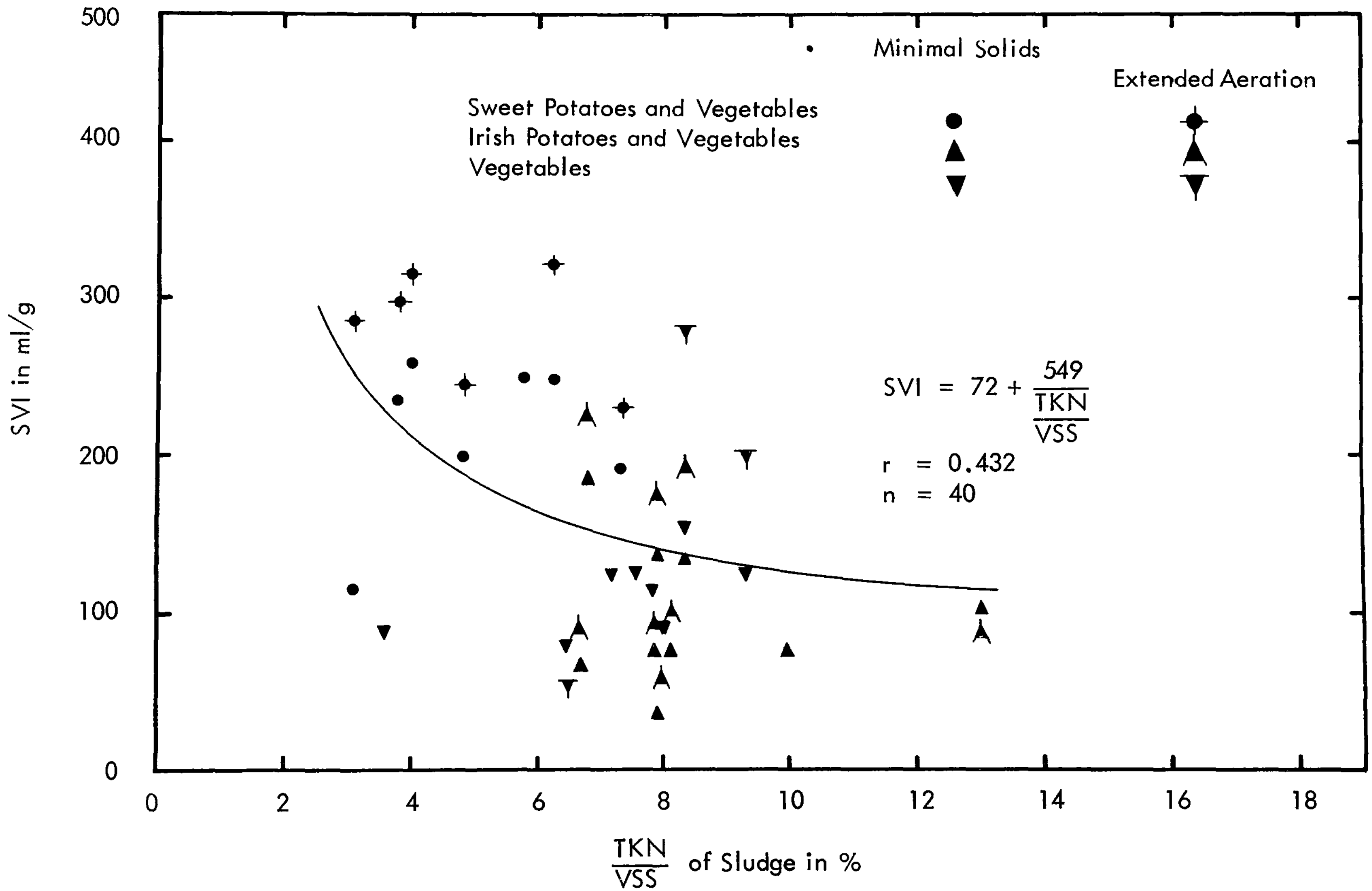


Figure 29 SVI vs $\frac{TKN}{VSS}$ of Sludge

normal bacterial culture. Below pH 6.5 the fungi will compete with the bacteria with predomination at a pH of 4.5 or below. Above pH 9.0 retardation of the metabolic rate is observed. Thus, it is important that pH be maintained at the proper level.

The variation in pH of incoming wastes, plant effluent, and each stage of the treatment process is summarized in Tables D-1, D-2 and D-3. The average incoming pH of the three wastes categories ranged from 5.9 to 7.7, although the pH reached an extreme high of 10.3 when blanching water was discharged and an extreme low of 4.6 during an Irish potato shift. During the course of the study, pH never presented any operational problems. The natural buffering capacity of the system was adequate to offset the pH variations encountered in this waste. The average pH in the minimal solids unit while treating wastes from each category ranged from 6.9 to 7.3, and that in extended aeration ranged from 6.9 to 7.2. The plant effluent had an average pH of 7.2 to 8.0. The pH variation before and after treatment is shown in Figure 9.

Cost Analysis

Cost of treatment consists of the annual fixed charge for costs of construction of treatment facilities and the annual cost of operation and maintenance. The total construction cost of the plant was $287,435. Based on an amortization over 20 years with an interest rate of 7%, the breakdown of the cost into an annual fixed charge is $27,131. The annual operation and maintenance charge is $54,691, which included $5,000 per year for major improvements. This makes a total annual charge of $74,000 per year. The annual cost does not include the cost of sludge handling. However this is not a significant cost because city equipment and personnel are used during slack periods.

From the past few year's records of the cannery operation and their future production plans, it is postulated that the cannery would operate three hundred days per year, two shifts per day and one hundred days for each of the three major product categories, namely sweet potatoes plus vegetables, Irish potatoes plus vegetables, and vegetables alone.

The waste load in terms of total pounds of COD, SS, and VSS applied and removed for each waste category is the product of the average concentration, shift flow, and total number shifts per year. The yearly waste load is the summation of the three waste categories.

The yearly waste load consists of approximately 6,527,000 lbs of COD, 3,149,000 lbs of SS, and 2,633,000 lbs of VSS; and that of plant effluent is 252,000 lbs COD, 157,000 lbs SS, and 106,000 lbs VSS, also based on average effluent concentrations. The cost of treatment is approximately 1.13 cents per pound of COD applied or 1.18

cents per pound of COD removed; 2.35 cents per pound of SS applied or 2.48 cents per pound of SS removed; and 2.81 cents per pound of VSS applied or 2.93 cents per pound of VSS removed. Compared to the reported primary treatment cost of 2 cents to 6.4 cents per pound of BOD removed for potato waste (54), the cost of treatment at Stilwell is extremely economical.

The cost analysis is summarized in Table 16.

TABLE 16

COST OF WASTE TREATMENT SYSTEM

Total Cost of Construction	$287,435
Amortization Factor: 20 years @ 7% interest 0.09439	
Annual Fixed Charge for Cost of Construction	27,131
Annual Cost of Operation and Maintenance	
2 Operators @ 1,000/month	$ 12,000
Power charge 10 months @ $2,300/month	23,000
Nutrients 6 months @ $750/month	4,500
Office supplies	500
Laboratory supplies	1,000
Equipment repair	869
In-plant improvement	5,000
Total Annual Charge	$ 74,000

Annual Waste Load COD Applied = 6,527,000 lbs

Annual Waste Load COD Removed = 6,275,000 lbs (based on total effl.)

Annual Waste Load COD Removed = 6,378,000 lbs (based on soluble effl.)

Annual Waste Load SS Applied = 3,149,000 lbs

Annual Waste Load SS Removed = 2,993,000 lbs

Annual Waste Load VSS Applied = 2,633,000 lbs

Annual Waste Load VSS Removed = 2,527,000 lbs

Annual Cost of Treatment per Unit of Waste Load:

Per Pound of COD Applied = 1.13¢

Per Pound of COD Removed = 1.18¢ (based on total effluent)

Per Pound of COD Removed = 1.16¢ (based on soluble effluent)

Per Pound of SS Applied = 2.35¢

Per Pound of SS Removed = 2.48¢

Per Pound of VSS Applied = 2.81¢

Per Pound of VSS Removed = 2.93¢

SECTION VIII

ACKNOWLEDGEMENTS

This investigation was supported by Demonstration Grant No. 12060 DSB from the Water Quality Office, Environmental Protection Agency, for which, we express our sincere appreciation.

The cooperation of the personnel at the Stilwell Department of Utilities and that of Stilwell Canning Company is gratefully acknowledged.

Thanks are extended to Mr. John R. Palafox who helped in performing numerous laboratory analyses and assistance throughout the study; to Mr. Edward Seely for his contributions in the development of the waste flow model, and to Mr. Frank C.H. Hu for his assistance in drawing all the figures and graphs in this paper.

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SECTION IX

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SECTION X

APPENDICES

APPENDIX A

CANNING PROCESSING FLOW SHEETS

APPENDIX A

CANNING PROCESSING FLOW SHEETS

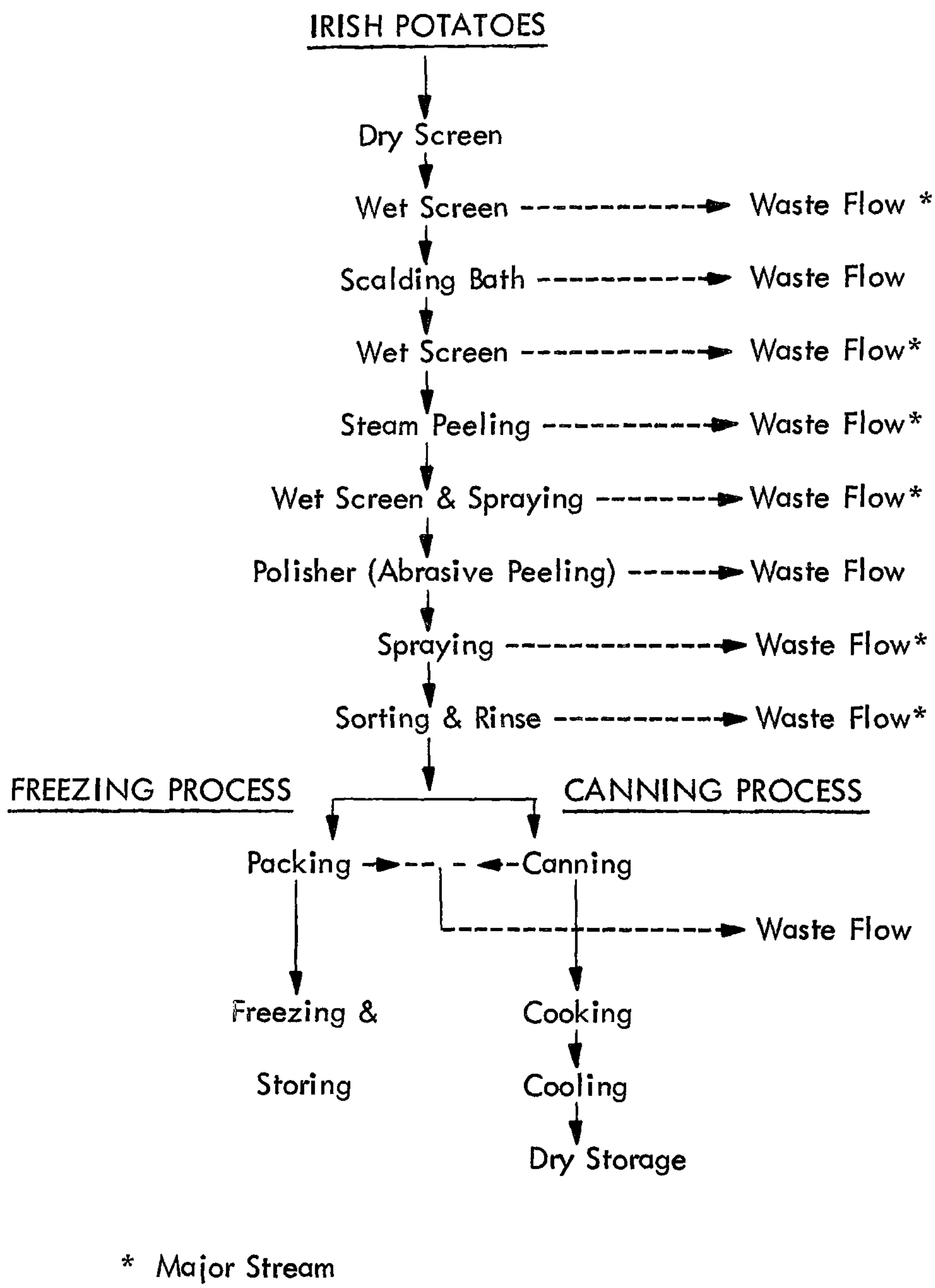


Figure A-1 Flow Sheet of Irish Potato Processing

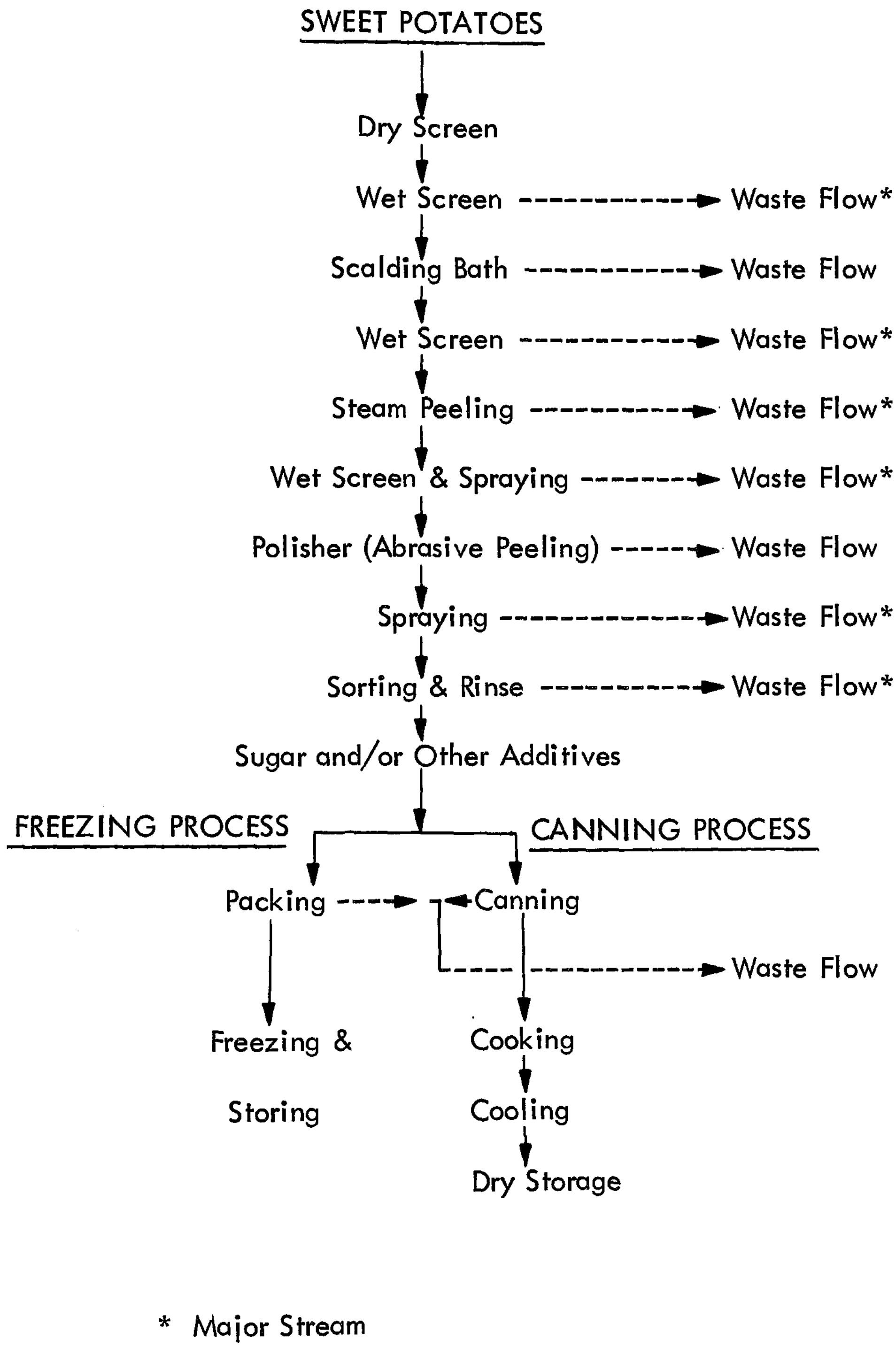
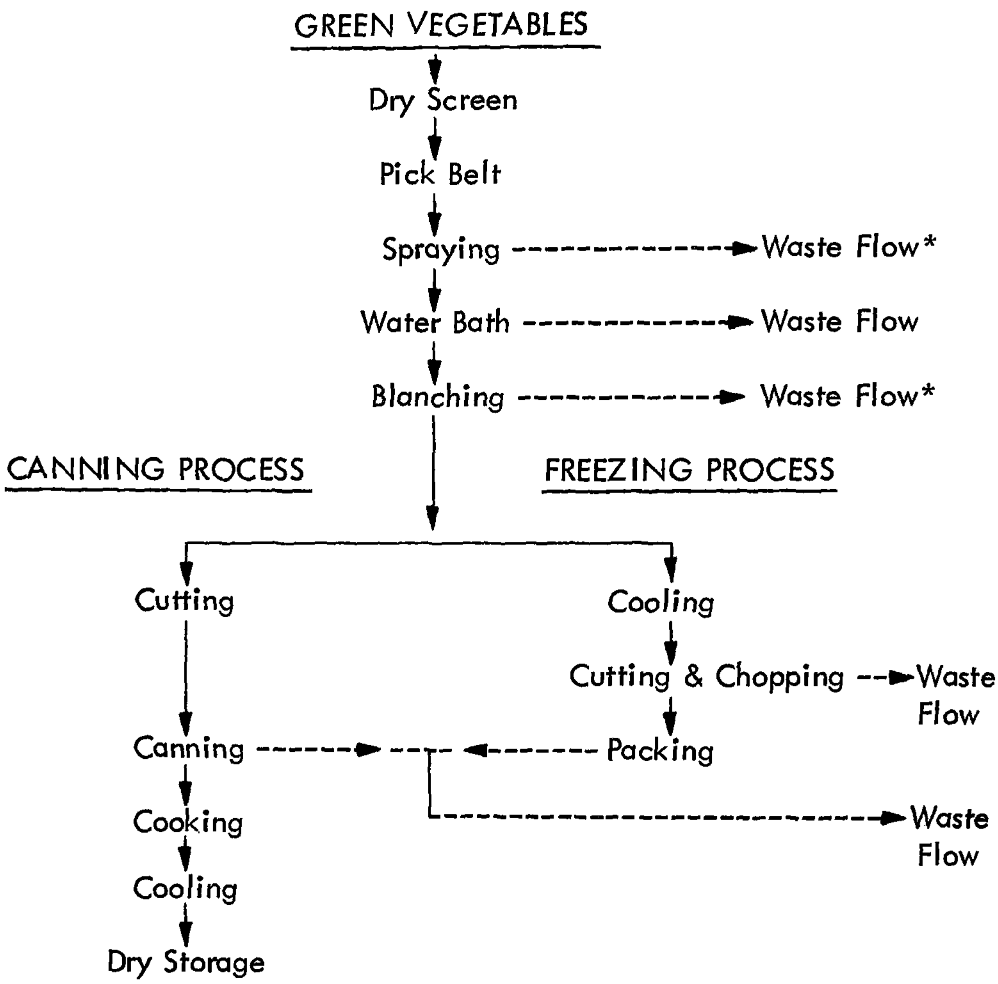
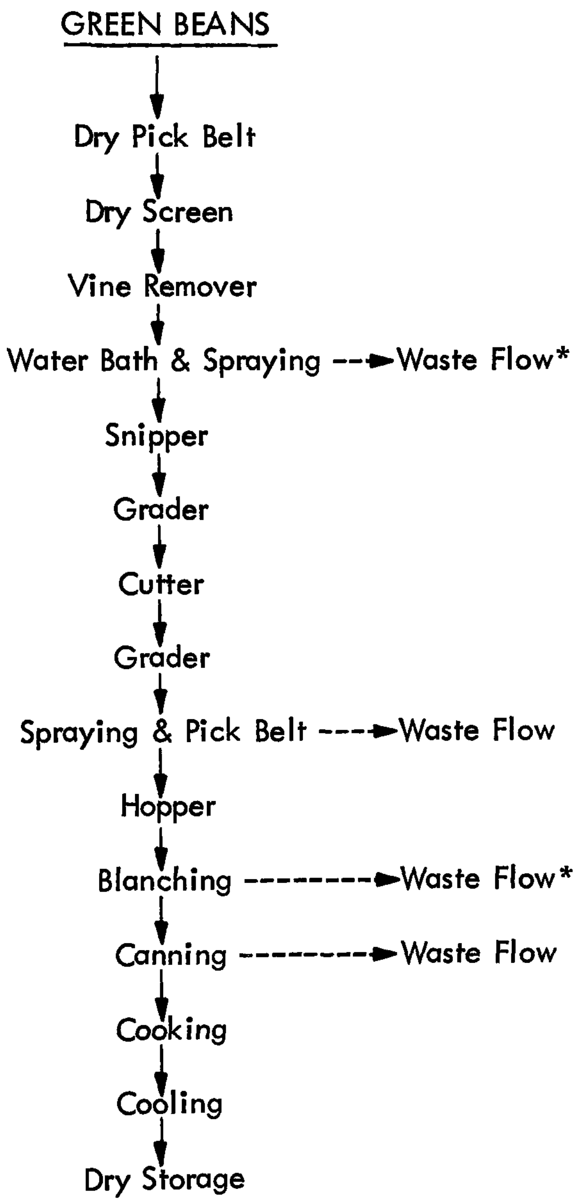


Figure A-2 Flow Sheet of Sweet Potato



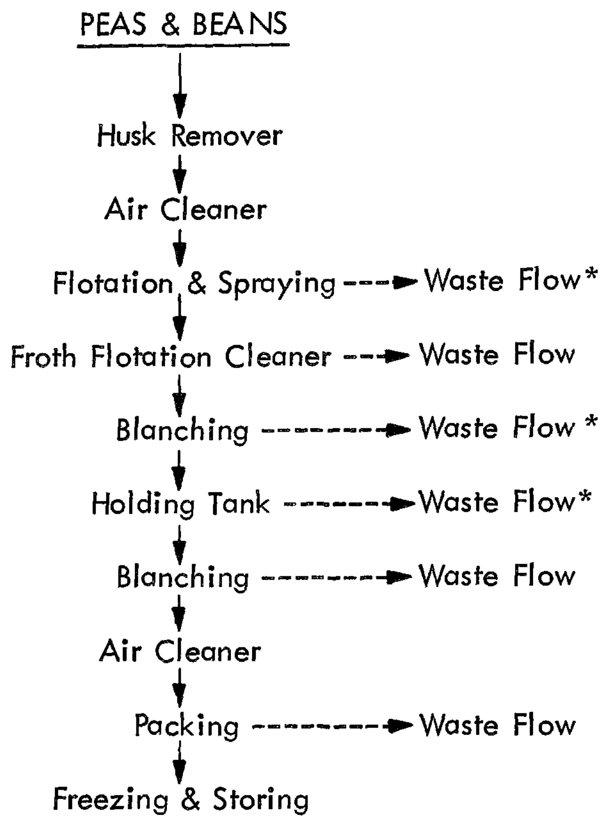
* Major Stream

Figure A-3 Flow Sheet of Green Vegetable Processing



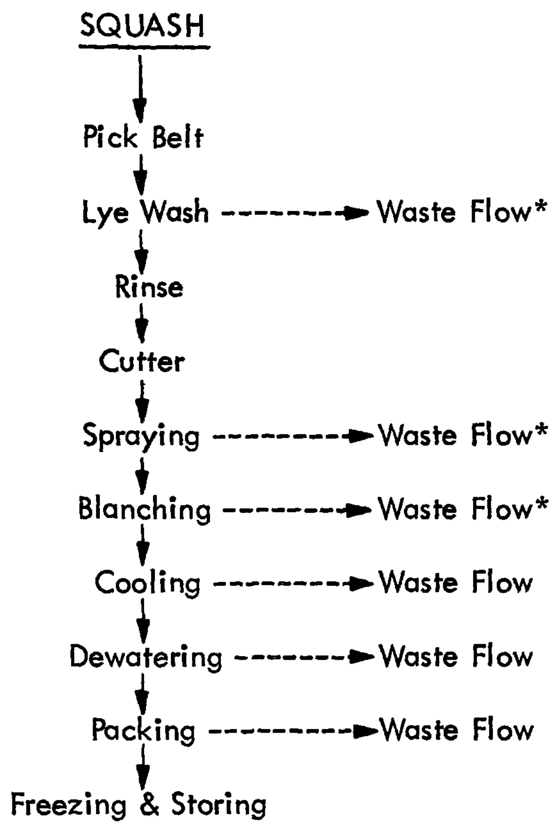
* Major Stream

Figure A-4 Flow Sheet of Green Bean Processing



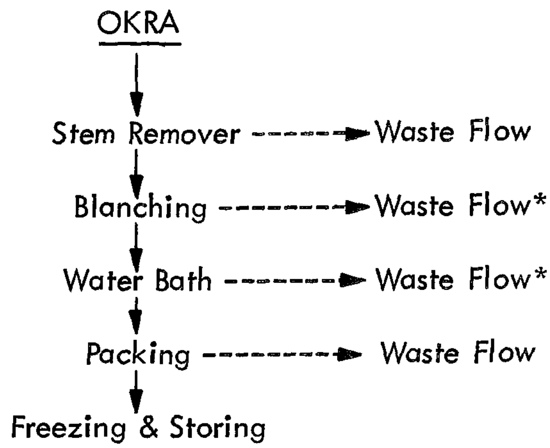
* Major Stream

Figure A-5 Flow Sheet of Peas & Beans Processing



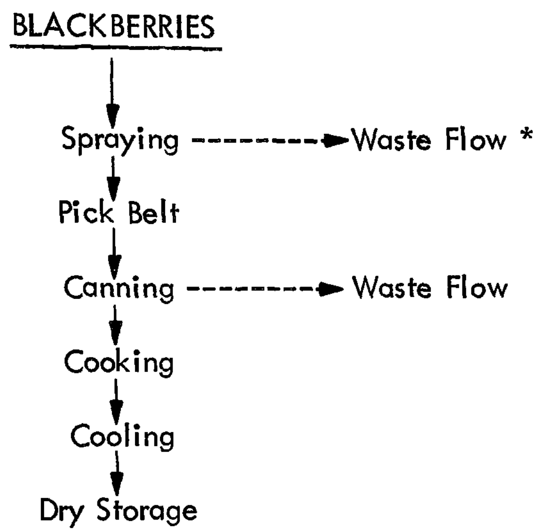
* Major Stream

Figure A-6 Flow Sheet of Squash Processing



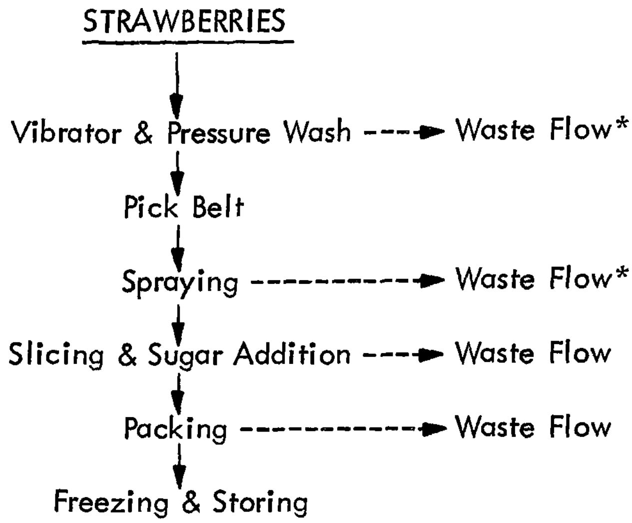
* Major Stream

Figure A-7 Flow Sheet of Okra Processing



* Major Stream

Figure A-8 Flow Sheet of Blackberry Processing



* Major Stream

Figure A-9 Flow Sheet of Strawberry Processing

APPENDIX B

ANALYSIS OF WASTE STREAMS

APPENDIX B

TABLE B-1

ANALYSIS OF WASTE STREAMS SAMPLED

Date	Product Processed*	COD mg/l	pH	Temp °C
May 19	Irish Potato	7070	6.85	
	Peeling Stream	75000	6.35	
	after settling	10600	6.35	
	Strawberry			
	Packing stream (sugar added)	13200	4.3	
	Washing stream	5100	4.5	
	Potato & Strawberry			
	Before screening	4550	6.15	
	After screening (# 10 screen)	3450	6.35	
	Collard Greens, Potato & Strawberry			
	(Strawberry packing stream excluded	650	5.8	
	Collard Green Blanching stream	187	7.3	
	Collard & Mustard Green	298	7.3	
May 22	Strawberry Washing Stream	1050	4.5	
	Strawberry Packing Stream	9100	4.2	
May 26	Strawberry & Turnip Green	910	5.3	
May 27	Strawberry Washing Stream	2350	4.45	25
May 27	Turnip Green Blanching Stream	610	7.05	30
	Turnip Green Packing Stream	298	7	25
May 28	Strawberry Washing Stream	2040	4.65	23
	after settling	1690		
	Turnip Green & Sliced Turnip Packing Stream	533	6.8	22
	Turnip Green & Sliced Turnip Blanching Stream	567	7.2	30
May 29	Turnip Green & Sliced Turnip Packing Stream	274	7	22
	Turnip & Mustard Packing Stream	410	7.1	26
June 5	Green Beans with Wash-Down Water	32	7.05	25
	Green Beans	100	7.05	27
June 6	Green Beans	152	6.7	26
	Okra Frozen	39	7.45	21
	Okra & Green Beans	112	7.05	26
June 9	Squash	440	6.7	27
	Squash & Green Beans	204	6.6	29

TABLE B-1
(Continued)

Date	Product Processed*	COD mg/l	pH	Temp °C
June 10	Squash	485	5.9	29
	Potato (all streams up to peeling and including peeling)	5340	5.2	34
	Potato after settling	1920		
	Potato soluble	1890		
June 11	Potato & Squash Waste Stream	1450	6.6	30.5
	Potato & Squash after settling	1390		
	Potato & Squash soluble	1300		
	Potato Waste Stream	4250	7.0	30
	Potato after settling	1240		
June 12	Squash Waste Stream	480	7.3	25
	Squash after settling	390		
	Squash soluble	380		
June 13	Blackberry Canning Waste	490	6.8	27

* Only those products sampled are listed.

APPENDIX C

LABORATORY ANALYTICAL METHODS

LABORATORY ANALYTICAL METHODS

Chemical Oxygen Demand (COD)

The total COD sample was withdrawn from a well mixed 500 ml sample, and the settled COD sample was taken from the supernatant of a 500 ml sample after settling for 30 minutes. Forty ml of a well-mixed sample was centrifuged for 10 minutes at 10,000 rpm in a Sorval Superspeed Type SS-1 centrifuge; the centrate was used for the soluble COD determination. The procedure as outlined in Standard Methods (49) was followed.

Solids Determination

The suspended solids concentration was determined by taking a 40 ml well-mixed sample from each unit, and from the plant influent and effluent. The sample was centrifuged for 10 minutes at 10,000 rpm, and the centrate was poured off for soluble COD and dissolved solids determinations. The pellet was then washed into a tared porcelain dish with distilled water and placed in a drying oven and evaporated to dryness at 103°C for 8 to 10 hours. The difference between the gross and tare weights times the appropriate dilution factor gave the concentration of suspended solids in mg/l. The porcelain dish containing the residue was placed in a muffle furnace at 600°C for 15 to 20 minutes, cooled in desiccator and weighed. The difference between the two gross weights times the appropriate dilution factor gave the concentration of volatile suspended solids in mg/l. The same procedure was used for determining the total dissolved and volatile dissolved soldids, except a 100 ml sample of the centrate was evaporated to dryness.

Total Kjeldahl Nitrogen (TKN)

A Labconco Micro Kjeldahl digestor Model-A was used for digestion, and a Labconco Micro Still was used for distillation of the sample. The procedure as outlined in Quantitative Bacterial Physiology Laboratory Experiments (50) was followed in Total Kjeldahl Nitrogen determination. A sample size of 2 ml was used. For ammonia nitrogen determination, a 20 ml sample size was used for distillation in the Labconco Micro Still. The distillate was collected in a 2% boric acid solution, nesslerized; and then the percent transmittance was measured in a Bausch and Lomb Spectronic 20 colorimeter at a wave length of 425 mu. Except for the sample size and distillation equipment, the method as outlined in Standard Methods (49) was followed.

Dissolved Oxygen (DO)

Yellow Springs Instrument YSI 54 Oxygen Meter was used for dissolved oxygen monitoring which was standardized against Winkler method.

pH

An Orion Model 404 Specific Ion Meter was used for all pH measurements.

Nitrate and Nitrite Nitrogen and Total Phosphate

Nitrate and Nitrite Nitrogen and Total Phosphate were analyzed and the results were used as spot checks for nutrient adequacy. Therefore, Hach methods were used in their determinations and standardized against appropriate methods as outlined in Standard Methods (49).

Settling Characteristics

The settling characteristics were determined visually by placing one liter sample of the mixed liquor in a one liter graduated cylinder and observing the volume occupied by the sludge after 30 minutes.

APPENDIX D

PLANT PERFORMANCE DATA

TABLE D-1

PLANT PERFORMANCE DATA OF SWEET POTATOES AND VEGETABLES

	Min	Max	Mean	Median
	Plant Influent Analyses			
COD, mg/l				
Total	2400	5550	3826	3880
Settled	1310	3452	2076	2050
Soluble	1220	3240	1841	1810
Solids, mg/l				
SS	970	2540	1740	1743
VSS	836	2378	1482	1478
DS	1294	3120	1849	1822
VDS	1095	2851	1600	1586
TS	2295	5660	3589	3531
TVS	1931	5229	3082	2938
VSS/SS,%	65.69	96.36	85.57	87.45
TVS/TS	76.03	92.39	85.79	86.24
pH	5.3	8.9	6.3	6.3
Temp, °C	21	33	29	30
Nutrients, mg/l				
TKN				
Total	21	119	54.5	47.5
Settled	14	35	23.7	23
NH_3-N	13.7	17.5	15.6	
NO_3-N	0.5	7.5	3.8	3.6
	Performance of Minimal Solids Unit			
COD, mg/l				
ML	2770	5240	4259	4480
Settled	41	910	362	278
Soluble	31	488	303	204

TABLE D-1

(Continued)

	Min	Max	Mean	Median
Solids, mg/l				
MLSS	2090	4420	3445	3346
MLVSS	1724	3835	2913	2884
$\frac{MLVSS}{MLSS}$, %	77.7	87.6	84.3	85.1
pH	5.9	7.3	7.0	7.0
Temp, °C	19	29	25	26
Nutrients, mg/l				
ML TKN	18	457	180	175
NO_3-N	0.01	10.0	3.6	2.2
Organic Loading Rate				
$\frac{\#COD/Day}{\#MLVSS}$	4.09	9.26	6.14	5.93
Organic Load Removal Rate				
Based on Settled Effluent COD				
$\frac{\Delta \#COD/Day}{\#MLVSS}$	4.0	7.7	5.4	5.2
Based on Soluble Effluent COD				
$\frac{\Delta \#COD/Day}{\#MLVSS}$	4.0	7.7	5.5	5.4
COD Removal, %				
Settled	74	99	90	93
Soluble	76	99	92	95
HRT, hrs	3.4	6.4	5.3	5.3
SVI, ml/g	113	261	197	200
DO, mg/l	0.7	6.9	4.1	4.2

TABLE D-1

(Continued)

	Min	Max	Mean	Median
Performance of Extended Aeration Unit				
MLCOD, mg/l	2125	5130	3788	3880
Solids, mg/l				
MLSS	1800	4265	3354	3417
MLVSS	1506	3673	2788	2832
$\frac{\text{MLVSS}}{\text{MLSS}}$, %	71.6	86.1	82.8	83.4
pH	6.0	7.5	7.0	7.0
Temp, °C	16	28	23	24
NO_3-N, mg/l	1.4	3.2	2.3	2.4
Soluble Organic Loading Rate $\frac{\text{\#COD/Day}}{\text{\#MLVSS}}$	0.007	0.271	0.082	0.055
Solids Loading Rate $\frac{\text{\#VSS/Day}}{\text{Cu. Ft.}}$	0.114	0.260	0.170	0.161
Soluble Organic Removal Rate $\frac{\Delta\text{\#COD/Day}}{\text{\#MLVSS}}$	0.001	0.222	0.073	0.054
Soluble COD Removal, %	9	99	67	72
Solids Removal, %	45	72	66	67
HRT, days	1.06	1.96	1.58	1.56
SVI, ml/g	159	320	248	250
DO, mg/l	1.0	7.1	3.7	3.6
Solids Flow, MGD	1.40	2.77	2.04	2.07

TABLE D-1

(Continued)

	Min	Max	Mean	Median
		Returned Sludge		
Flow, MGD	0.454	0.966	0.697	0.690
SS, mg/l	3295	10830	7130	7255
VSS	2760	9250	5927	6085
TKN	18	457	180	175
$\frac{TKN}{VSS}$, %	3.1	13.6	5.8	4.8
		Plant Effluent Analyses and Plant Performance		
COD, mg/l				
Total	19	344 3190*	120	128
Soluble	T	268	84	89
Solids, mg/l				
SS	10	176 2915*	61	47
VSS, mg/l	7	164 2390*	41	33
pH	6.1	7.6	7.2	7.3
Temp, °C	15	28	23	24
Nutrients, mg/l				
Total TKN	3.5	28.0	15.8	
NH_3-N	0.4	1.1	0.7	0.6
NO_3-N	0.01	17.00	1.72	0.05
Total PO_4	0.15	1.00	0.35	0.24
Plant COD Removal, %				
Total	93 3.3*	99	97	97
Soluble	95	99	97	98

TABLE D-1

(Continued)

	Min	Max	Mean	Median
Plant Solids Removal, %				
SS	87 -45*	99	95.71	98
VSS	87 -47	99	96.86	98

*Bulking sludge, solids unloaded

TABLE D-2

PLANT PERFORMANCE DATA OF IRISH POTATOES AND VEGETABLES

	Min	Max	Mean	Median
	Plant Influent Analyses			
COD, mg/l				
Total	1080	4229	2661	2713
Settled	710	1810	1290	1320
Soluble	642	1660	1179	1183
Solids, mg/l				
SS	400	2760	1285	1292
VSS	378	2690	1196	1176
DS	782	1728	1153	1160
VDS	574	1495	921	919
TS	1185	3911	2419	2441
TVS	982	3663	2113	2127
VSS/SS, %	84.4	99.9	93.6	94.2
TVS/TS	77.8	95.8	87.2	86.8
pH	4.6	7.0	5.9	5.9
Temp, °C	22	37	32	33
Nutrients, mg/l				
TKN				
Total	32.0	77.0	49.9	45.5
Settled	3.9	53.0	37.0	45.5
NH_3-N			3.5	
NO_3-N	0.21	1.10	0.72	0.85
	Performance of Minimal Solids Unit			
COD, mg/l				
ML	383	5460	2765	2315
Settled	95	1420	520	554
Soluble	49	939	349	323
Solids, mg/l				
MLSS	367	4570	2152	1690

TABLE D-2

(Continued)

	Min	Max	Mean	Median
MLVSS	216	3917	1779	1460
$\frac{MLVSS}{MLSS}$, %	54.37	96.57	82.20	83.50
pH	5.9	7.7	6.8	6.9
Temp, °C	20	32	28	28
Nutrients, mg/l				
ML TKN	21	224	83.1	52.5
NH_3-N	0.07	0.75	0.38	0.32
NO_3-N	0.16	0.25	0.20	
Organic Loading Rate				
$\frac{\#COD/Day}{\#MLVSS}$	2.41	44.33	10.55	7.79
Organic Load Removal Rate				
Based on Settled Effluent COD				
$\frac{\#COD/Day}{\#MLVSS}$	2.22	34.13	7.90	5.59
Based on Soluble Effluent COD				
$\frac{\Delta\#COD/Day}{\#MLVSS}$	2.34	35.52	8.78	6.42
COD Removal, %				
Settled	35	98	80	82
Soluble	64	99	87	86
HRT, hrs	4.7	8.3	5.9	5.7
SVI, ml/g	43	256	119	123
DO, mg/l	0.2	7.6	4.0	3.5

TABLE D-2

(Continued)

	Min	Max	Mean	Median
Performance of Extended Aeration Unit				
MLCOD, mg/l	725	4875	3017	3185
Solids, mg/l				
MLSS	685	5610	3184	3228
MLVSS	344	3580	2087	2291
$\frac{MLVSS}{MLSS}$, %	37.6	63.5	85.8	60.9
pH	6.5	8.0	7.0	6.9
Temp, °C	20	31	27	27
Nutrients, mg/l				
ML TKN	37	210	123	177
NO_3-N	0.1	8.1	4.6	5.7
Total PO_4			9.5	
Soluble Organic Loading Rate				
$\frac{\#COD/Day}{\#MLVSS}$	0.009	0.780	0.146	0.084
Solids Loading Rate				
$\frac{\#VSS/Day}{Cu.\ Ft.}$	0.047	0.237	0.129	0.135
Soluble Organic Load Removal Rate				
$\frac{\Delta\#COD/Day}{\#MLVSS}$	0.006	0.770	0.138	0.090
Soluble COD Removal, %	35	98	81	89

TABLE D-2

(Continued)

	Min	Max	Mean	Median
Solids Removal, %	10	99	62	80
HRT, days	1.48	3.38	1.92	1.82
SVI, ml/g	58	380	147	132
DO, mg/l	0.5	7.0	2.0	1.5
Solids Flow, MGD	1.37	2.28	1.94	2.01
Returned Sludge (to Minimal Solids)				
Flow, MGD	0.168	0.806	0.481	0.462
SS, mg/l	1180	12630	7025	7885
VSS	510	10220	4834	4835
TKN	84	623	359	407
$\frac{TKN}{VSS}$, %	6.7	13.0	8.4	8.0
Plant Effluent Analyses and Plant Performance				
COD, mg/l				
Total	22	440	101	62
Soluble	10	133	44	34
Solids, mg/l				
SS	8	310	71	50
VSS	T	295	47	30
pH	6.4	8	7.3	7.2
Temp, °C	21	31	27	27
Nutrients, mg/l				
Total TKN	T	14	7	7
NH_3-N	0.07	0.96	0.52	
NO_3-N	0.08	9.00	3.65	2.76

TABLE D-2

(Continued)

	Min	Max	Mean	Median
Plant COD Removal, %				
Total	86	99	97	98
Soluble	96	99	98	99
Plant Solids Removal, %				
SS	79	99	95	96
VSS	79	99	96	98
DO at Outfall, mg/l	1.8	7.3	5.2	5.4

TABLE D-3

PLANT PERFORMANCE DATA OF VEGETABLES ONLY

	Plant Influent Analyses			
COD, mg/l				
Total	148	688	388	375
Settled	129	543	323	323
Soluble	96	466	274	292
Solids, mg/l				
SS	18	1643	331	175
VSS	15	212	93	82
DS	221	678	484	491
VDS	116	415	283	275
TS	365	2321	830	676
TVS	165	568	377	372
VSS/SS %	9.68	92.86	50.11	48.57
TVS/TS	22.1	72.3	51.8	63.4
pH	6.1	10.3	7.7	7.4
Temp, °C	17	30	26	28
Nutrients, mg/l				
Total TKN	T	35	15	14
NH_3-N	T	0.87	0.38	0.45
NO_3-N	1.95	9.10	5.93	6.75
	Plant Influent Analyses Winter Data Excluded			
COD, mg/l				
Total	214	688	409	392
Settled	174	543	340	331
Soluble	109	466	295	295
Solids, mg/l				
SS	18	318	156	163
VSS	15	212	89	75

TABLE D-3

(Continued)

D	295	664	495	491
VDS	150	415	299	290
TS	365	894	656	664
TVS	165	568	390	400
VSS/SS %	39.88	92.86	61.61	65.75
TVS/TS	24.37	7.23	60.31	64.56
	Performance of Minimal Solids Unit			
COD, mg/l				
ML	132	3772	660	235
Settled	49	468	159	138
Soluble	5	148	58	55
Solids, mg/l				
MLSS	123	3289	711	254
MLVSS	63	2657	447	136
$\frac{MLVSS}{MLSS}$, %	40.82	86.03	58.67	56.80
pH	6.8	7.9	7.3	7.4
Temp, °C	10	30	24	26
Nutrients, mg/l				
Total TKN	3.5	14.0	9.9	11.0
NH_3-N	0.01	1.82	0.92	
Organic Loading				
$\frac{\#COD/Day}{\#MLVSS}$	0.34	14.16	5.21	4.15
Organic Load Removal Rate				
Based on Settled Effluent COD				
$\frac{\Delta\#COD/Day}{\#MLVSS}$	0.16	12.24	4.29	3.64

TABLE D-3

(Continued)

	Min	Max	Mean	Median
Based on Soluble Effluent COD				
$\frac{\Delta \# COD/Day}{\# MLVSS}$	0.29	3.85	4.77	3.25
COD Removal, %				
Settled	33	89	65	68
Soluble	66	98	84	83
HRT, hrs	5.1	17.6	10.6	10.4
SVI, ml/g	58	261	124	96
DO, mg/l	2.5	8.1	5.3	5.5
Performance of Extended Aeration Unit				
MLCOD, mg/l	499	3440	1285	1097
Solids, mg/l				
MLSS	800	1925	1479	1490
MLVSS	334	940	732	775
$\frac{MLVSS}{MLSS}$, %	34.17	79.44	52.93	52.04
pH	6.7	7.7	7.2	7.3
Temp, °C	7	29	23	25
TKN, mg/l	5.2	7.7		55
Soluble Organic Loading Rate				
$\frac{\# COD/Day}{\# MLVSS}$	0.005	0.210	0.035	0.020

TABLE D-3

(Continued)

	Min	Max	Mean	Median
Solids Loading Rate				
$\frac{\#VSS}{Cu.\ Ft.}$	0.027	0.121	0.060	0.057
Soluble Organic Removal Rate				
$\frac{\Delta\#COD/Day}{\#MLVSS}$	T	0.210	0.033	0.015
Soluble COD Removal, %	9	99	73	82
Solids Removal, %	68	99	85	89
HRT, days	1.59	5.51	3.31	3.16
SVI, ml/g	50	279	126	110
DO, mg/l	2.6	9.8	4.6	3.6
Solids Flow, MGD	1.211	2.678	1.844	1.886
Returned Sludge				
SS, mg/l	1560	6700	4176	4475
VSS	720	5100	2294	2450
TKN	21	350	201	224
$\frac{TKN}{VSS}$, %	3.56	15.60	8.40	8.16
Plant Effluent Analyses and Plant Performance				
COD, mg/l				
Total	5	230	55	23
Soluble	T	146	33	15
Solids, mg/l				
SS	3	202	43	25
VSS	T	102	30	20

TABLE D-3

(Continued)

	Min	Max	Mean	Median
pH	6.3	8	7.4	7.5
Temp,	7	29	23	25
Nutrients, mg/l				
Total TKN	T	28	9	7
NO_3-N	0.13	0.54	0.34	
NO_3-N	7.4	18.8	13.8	15.0
Total PO_4	0.10	0.18	0.14	
Plant COD Removal, %				
Total	37	98	82	93
Soluble	65	99	91	98
Plant Solids Removal, %				
SS	47	99	80	86
VSS	29	99	74	76
DO at Outfall, mg/l	3.5	11.0	7.9	8.3

APPENDIX E

PLANT INFLUENT, MODULAR UNITS AND SYSTEM ANALYSES

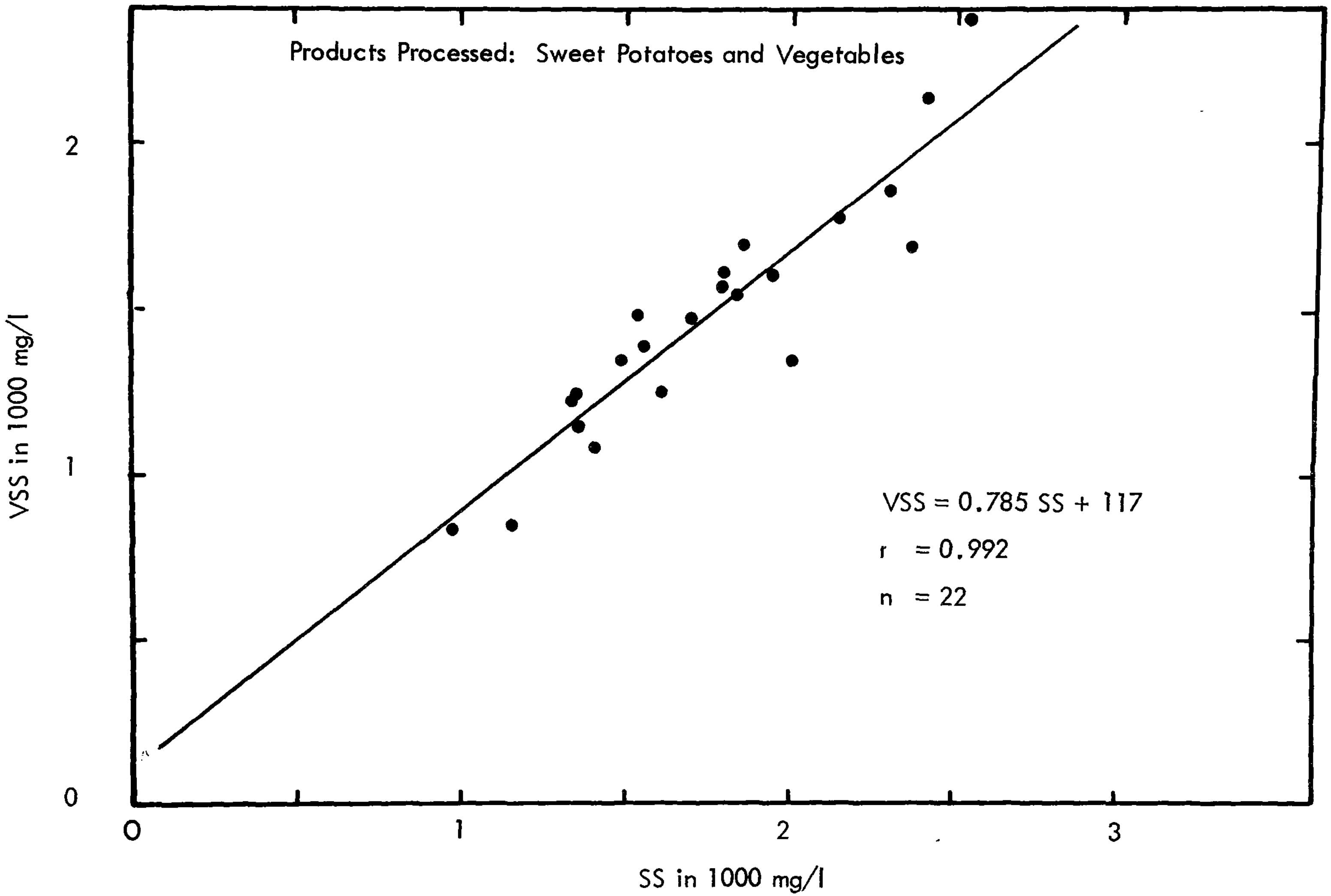


Figure E-1 Plant Influent VSS vs SS

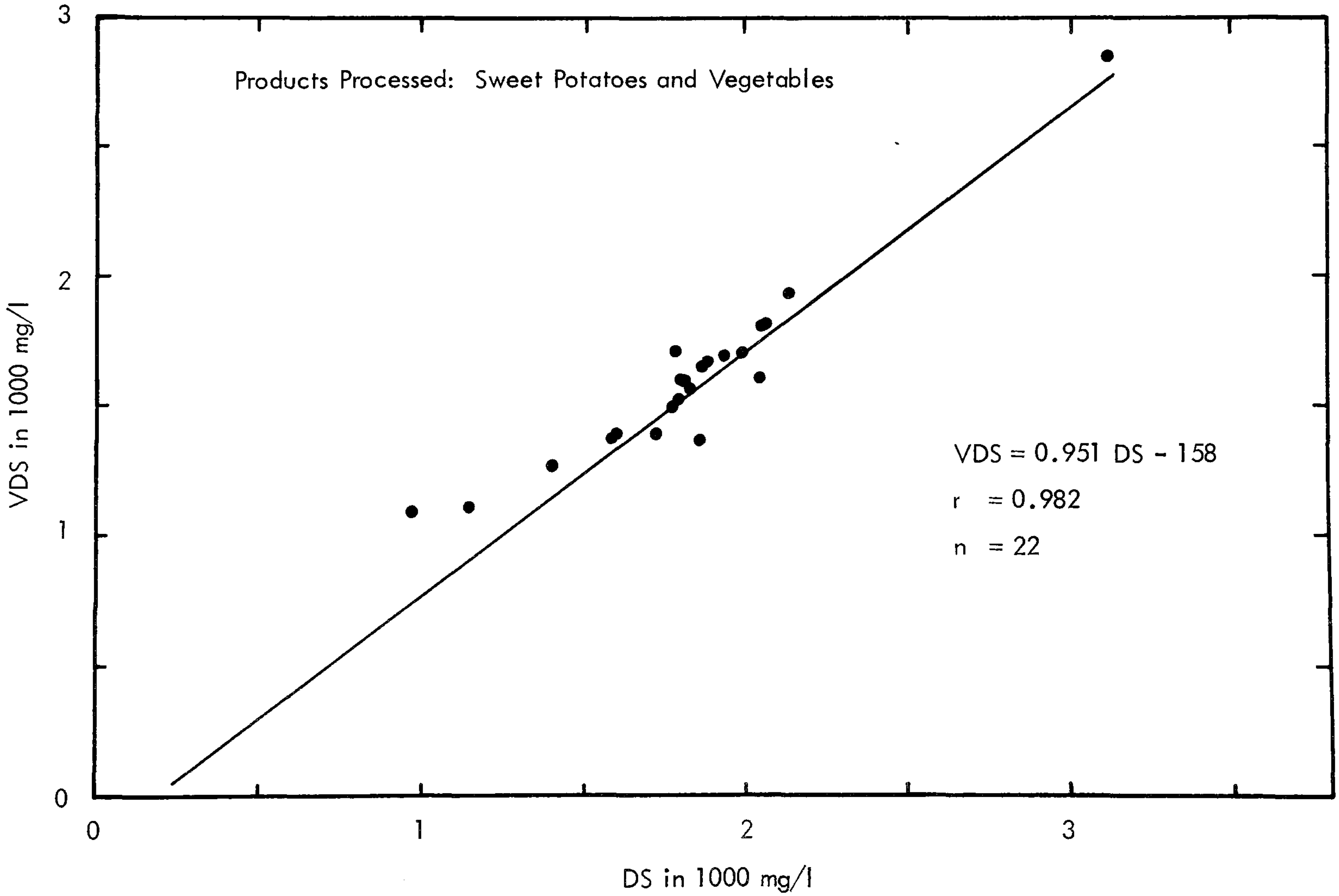


Figure E-2 Plant Influent VDS vs DS

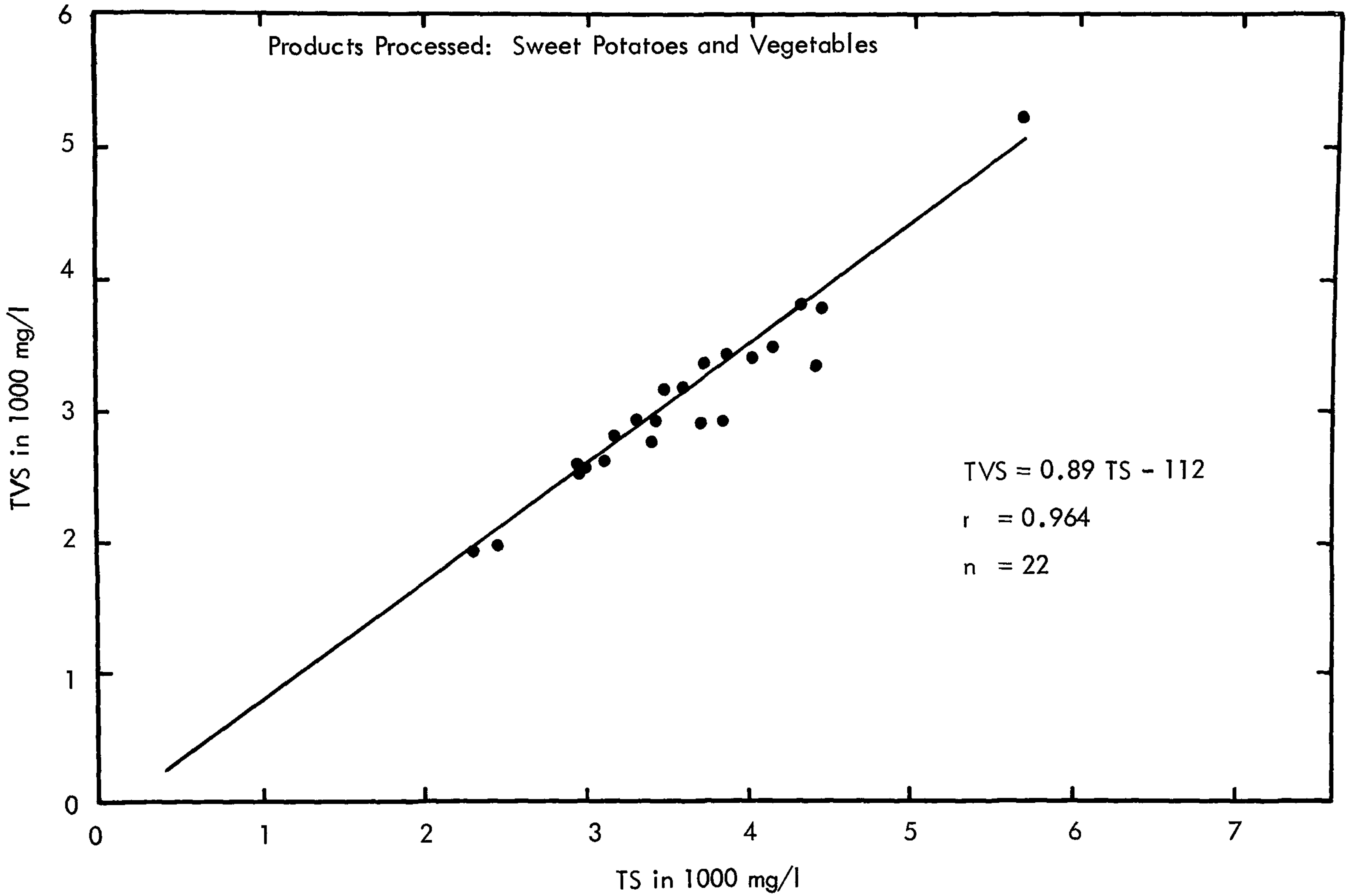


Figure E-3 Plant Influent TVS vs TS

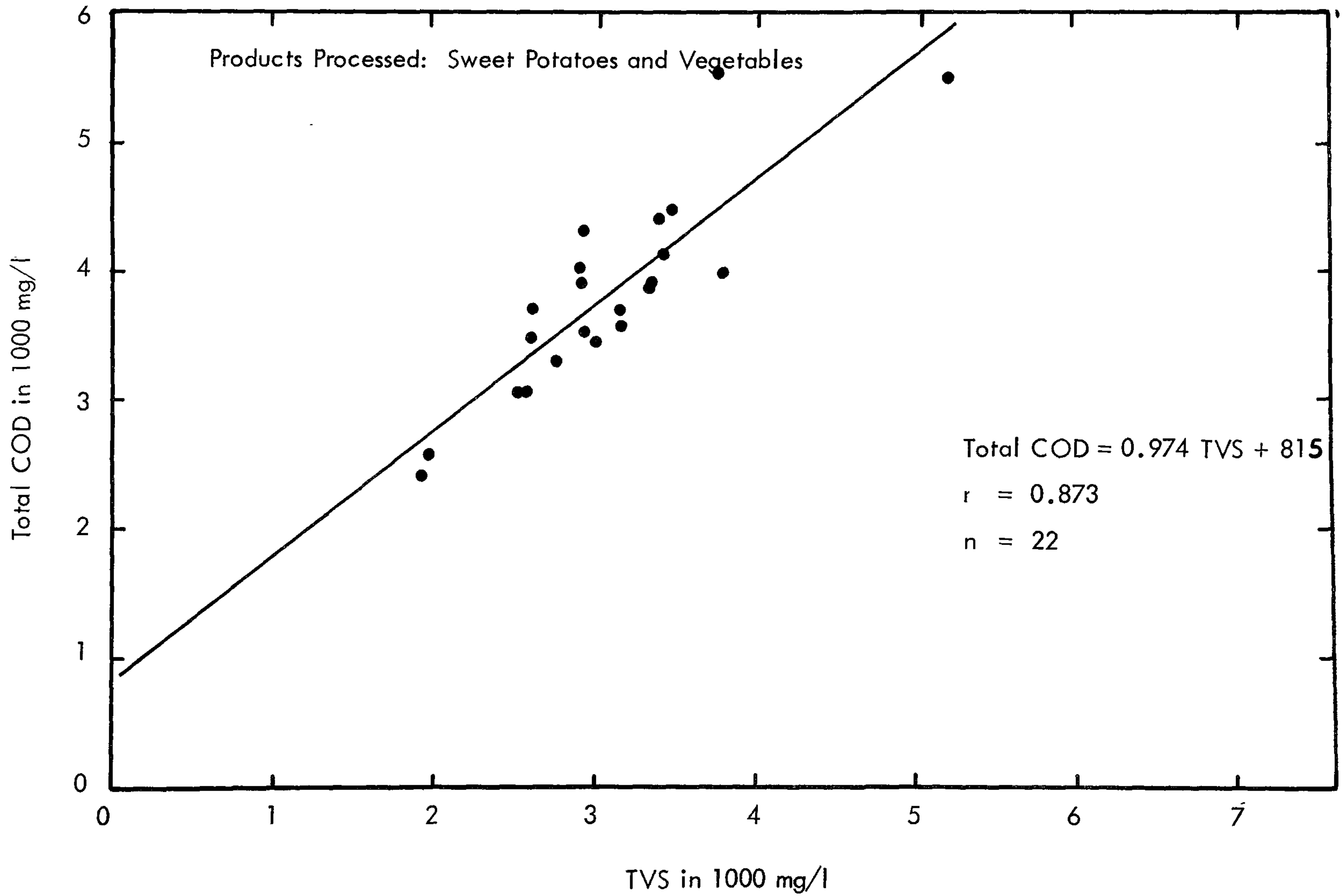


Figure E-4 Plant Influent Total COD vs TVS

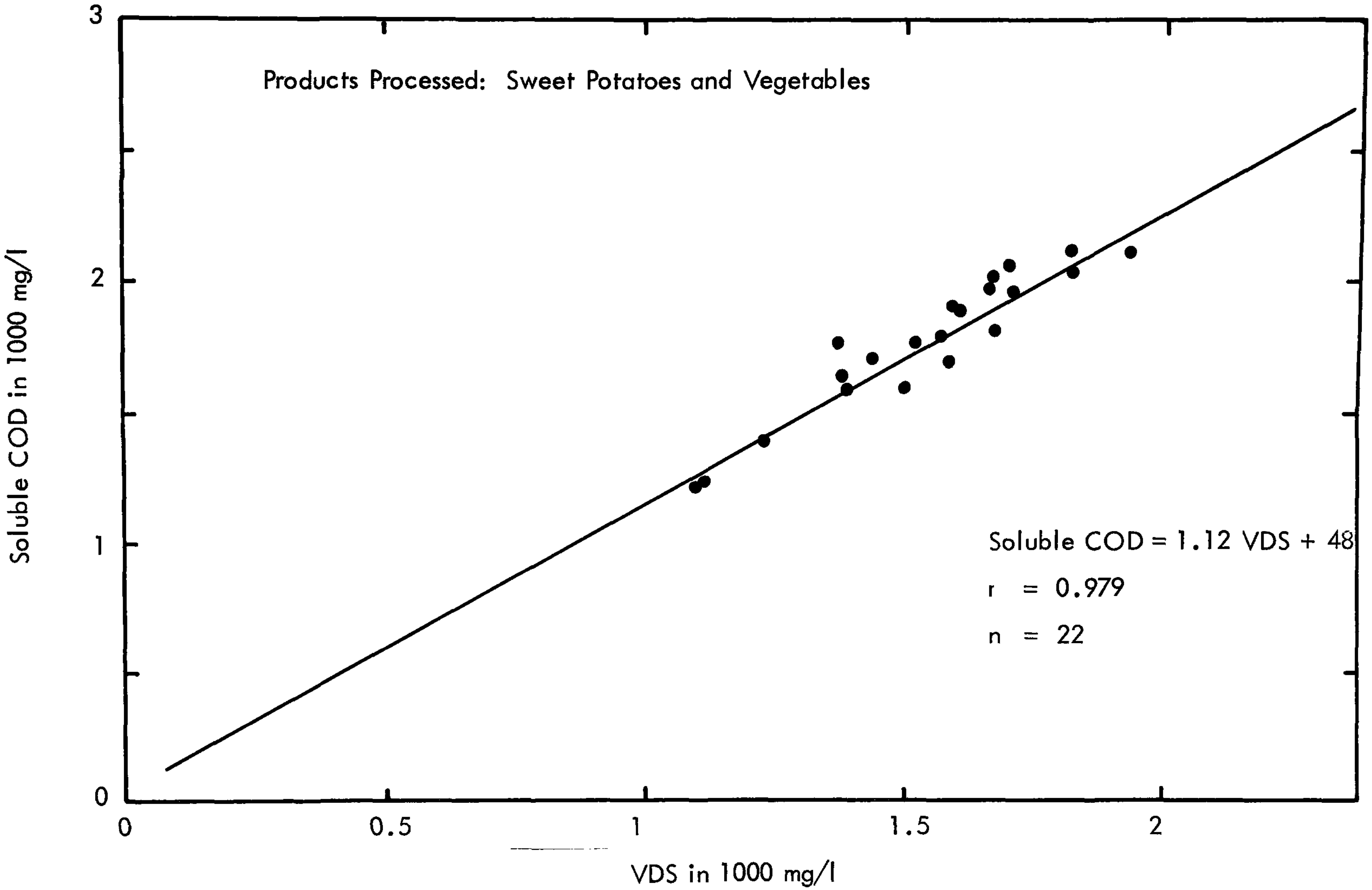


Figure E-5 Plant Influent Soluble COD vs VDS

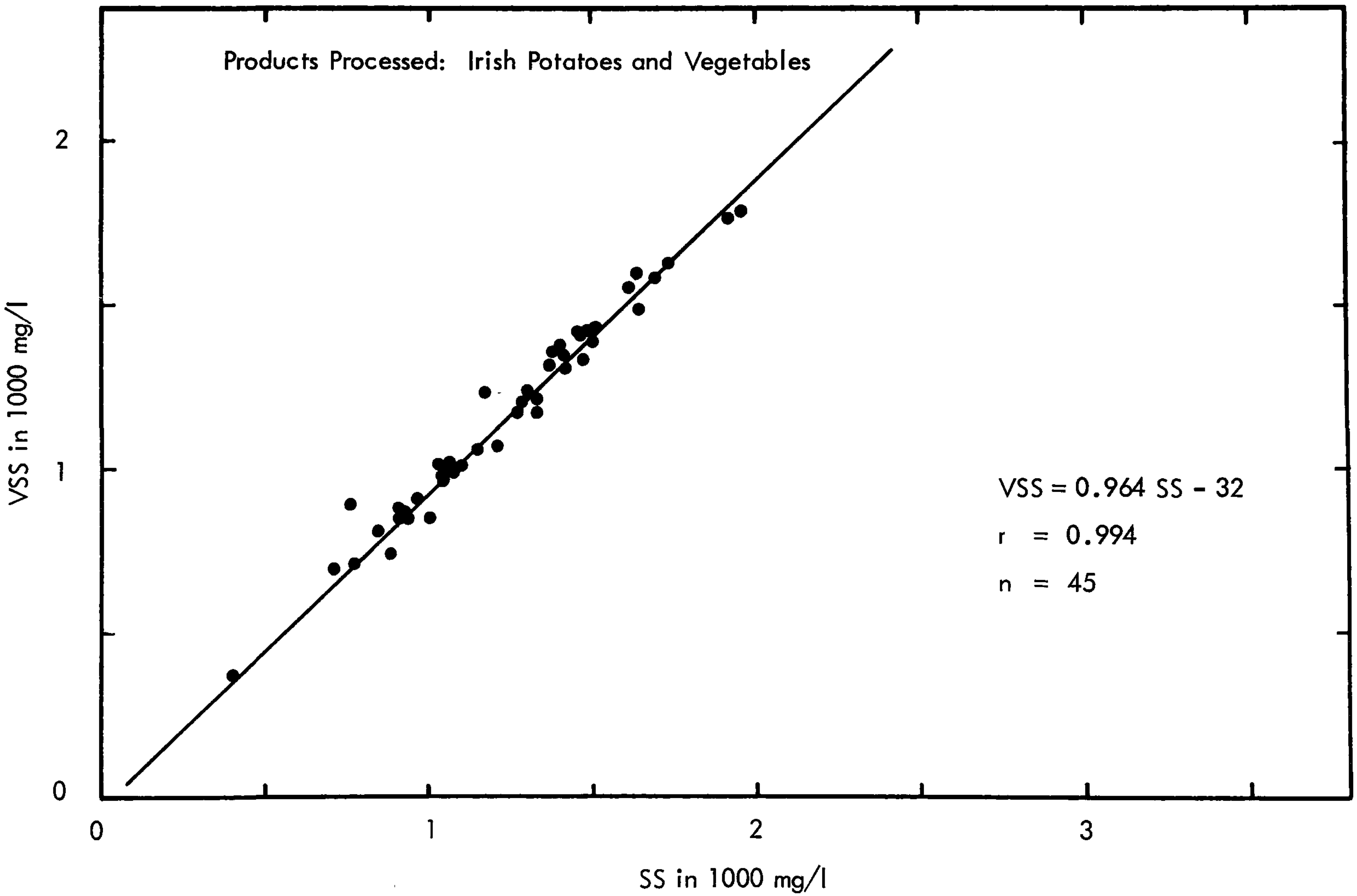


Figure E-6 Plant Influent VSS vs SS

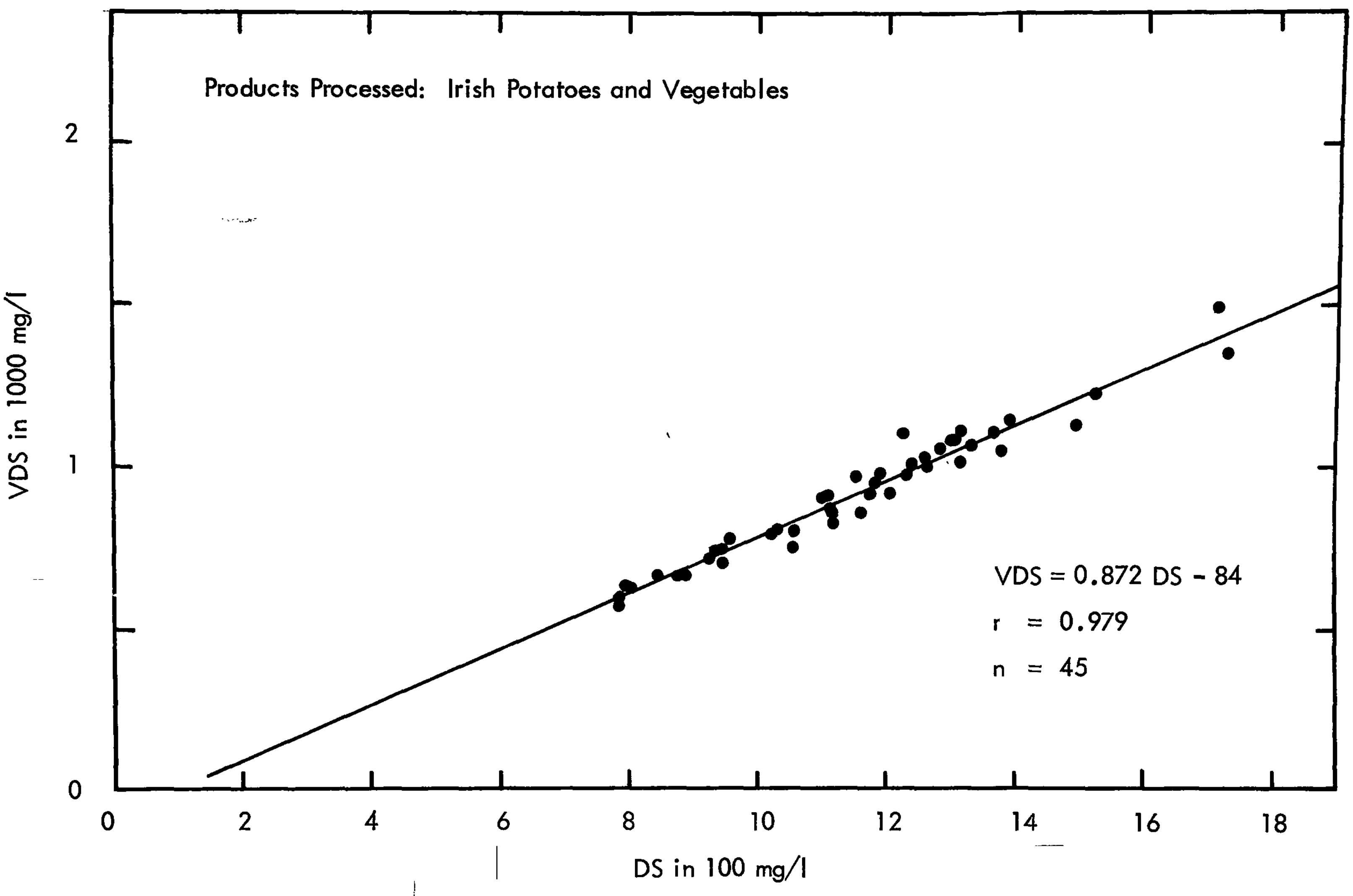


Figure E-7 Plant Influent VDS vs DS

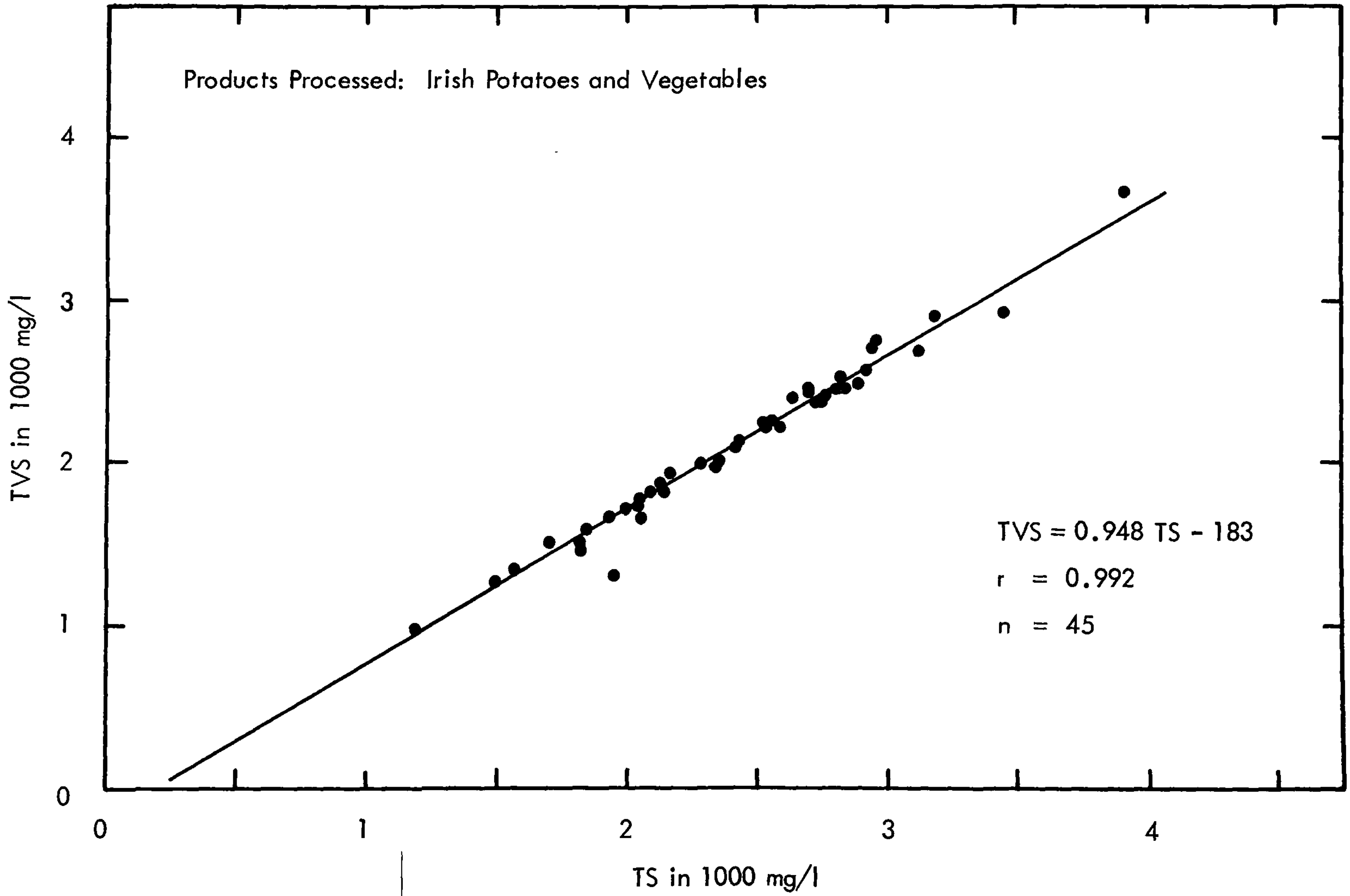


Figure E-8 Plant Influent TVS vs TS

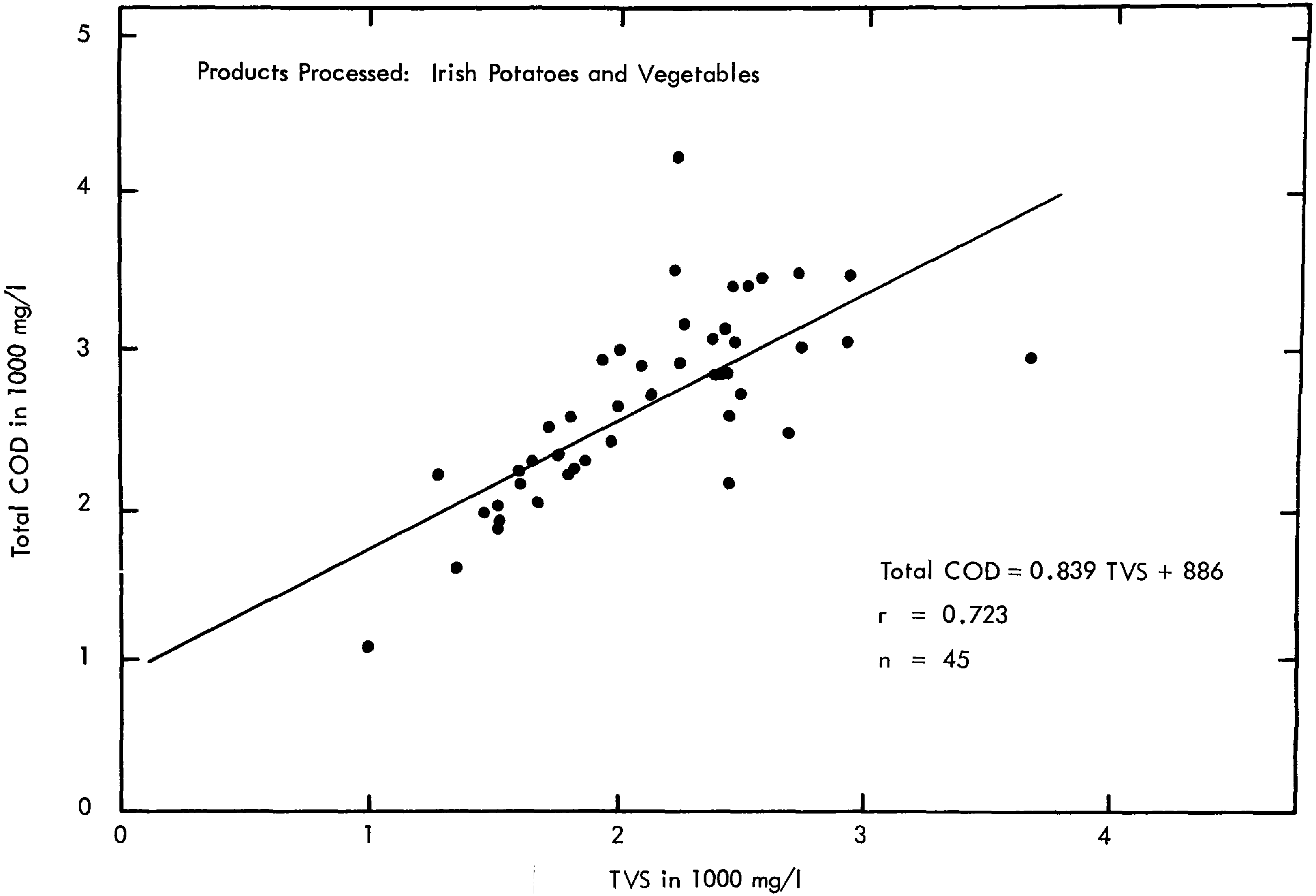


Figure E-9 Plant Influent Total COD vs TVS

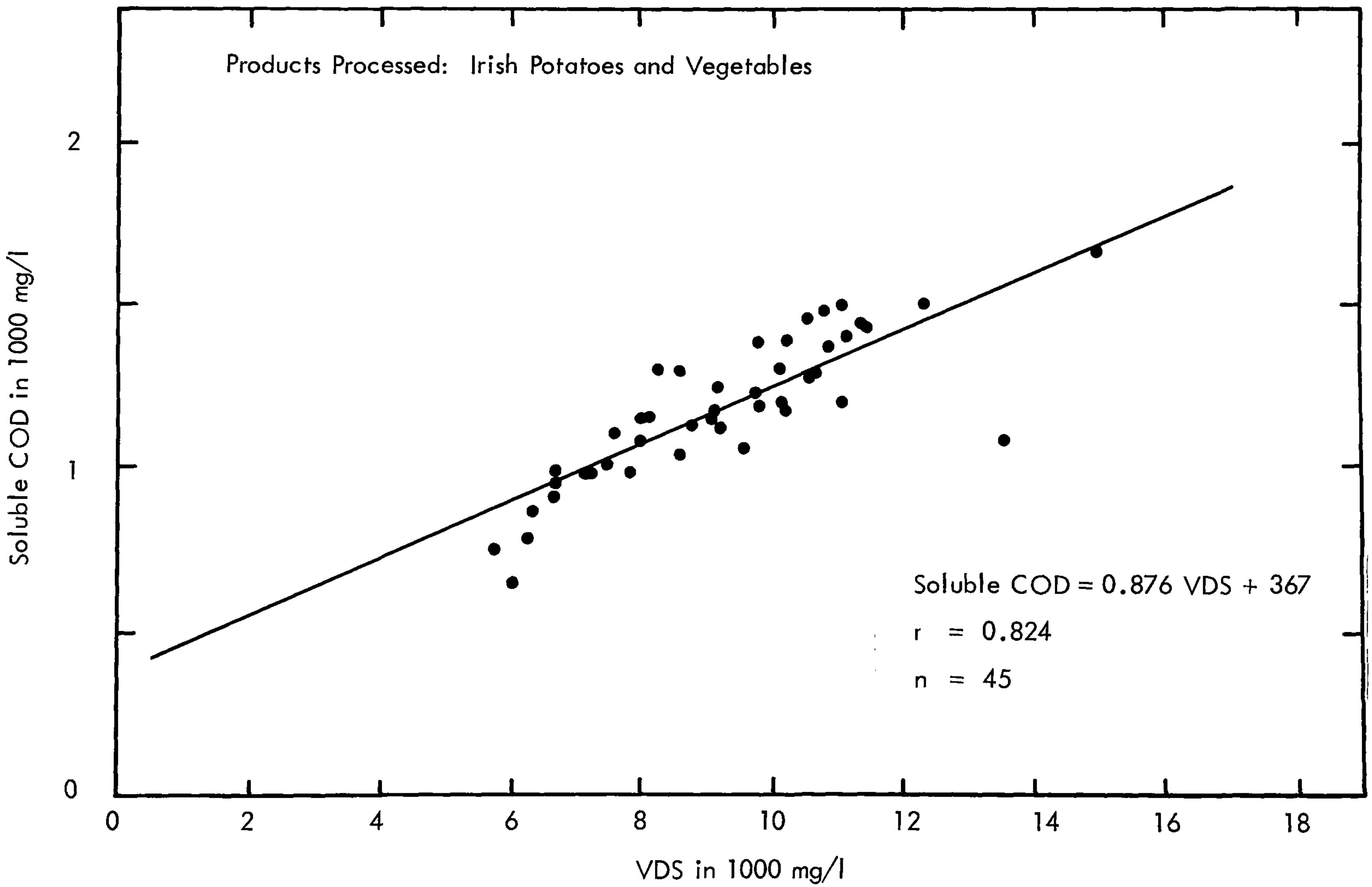


Figure E-10 Plant Influent Total COD vs VDS

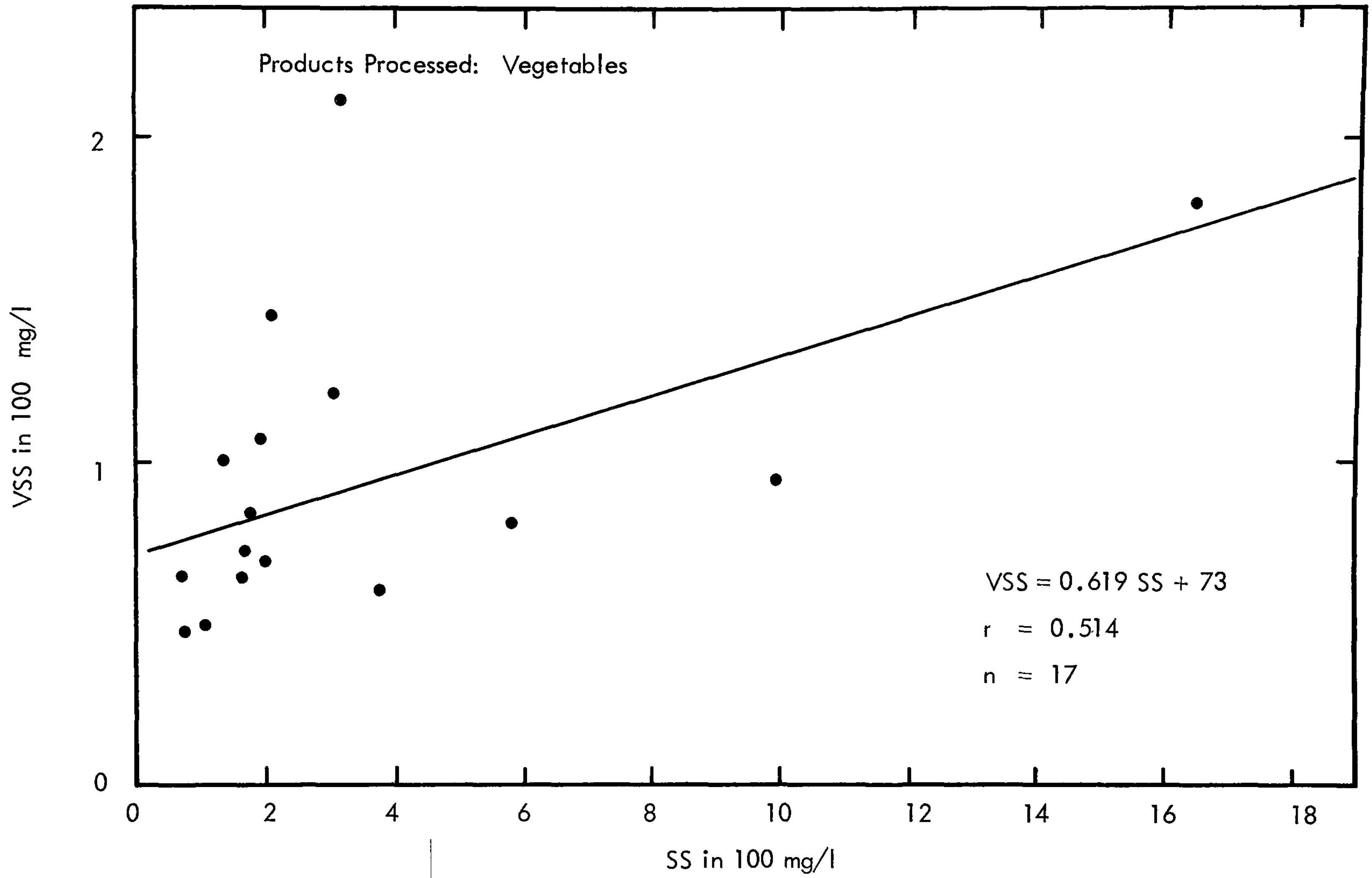


Figure E-11 Plant Influent VSS vs SS

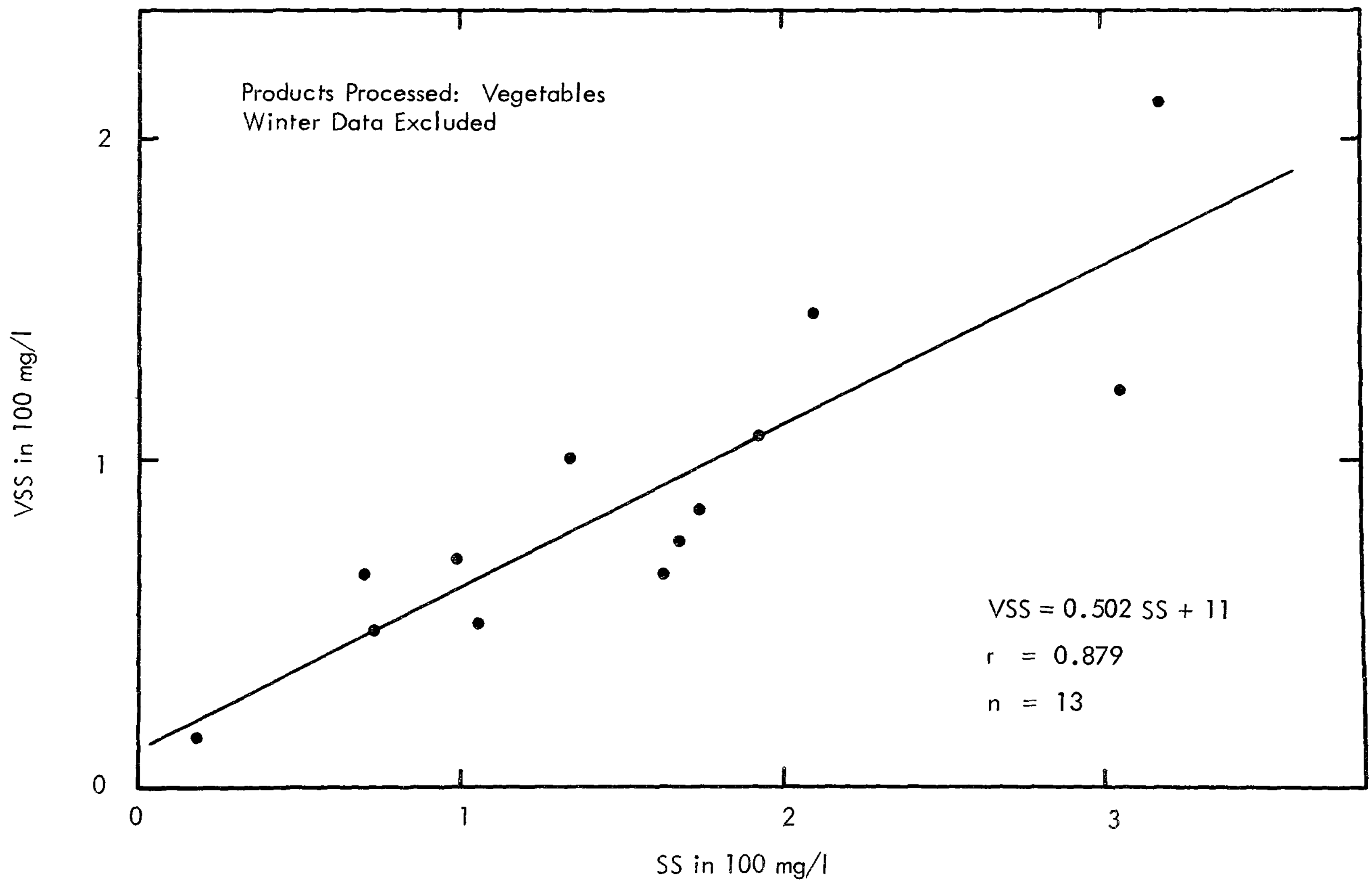


Figure E-12 Plant Influent VSS vs SS

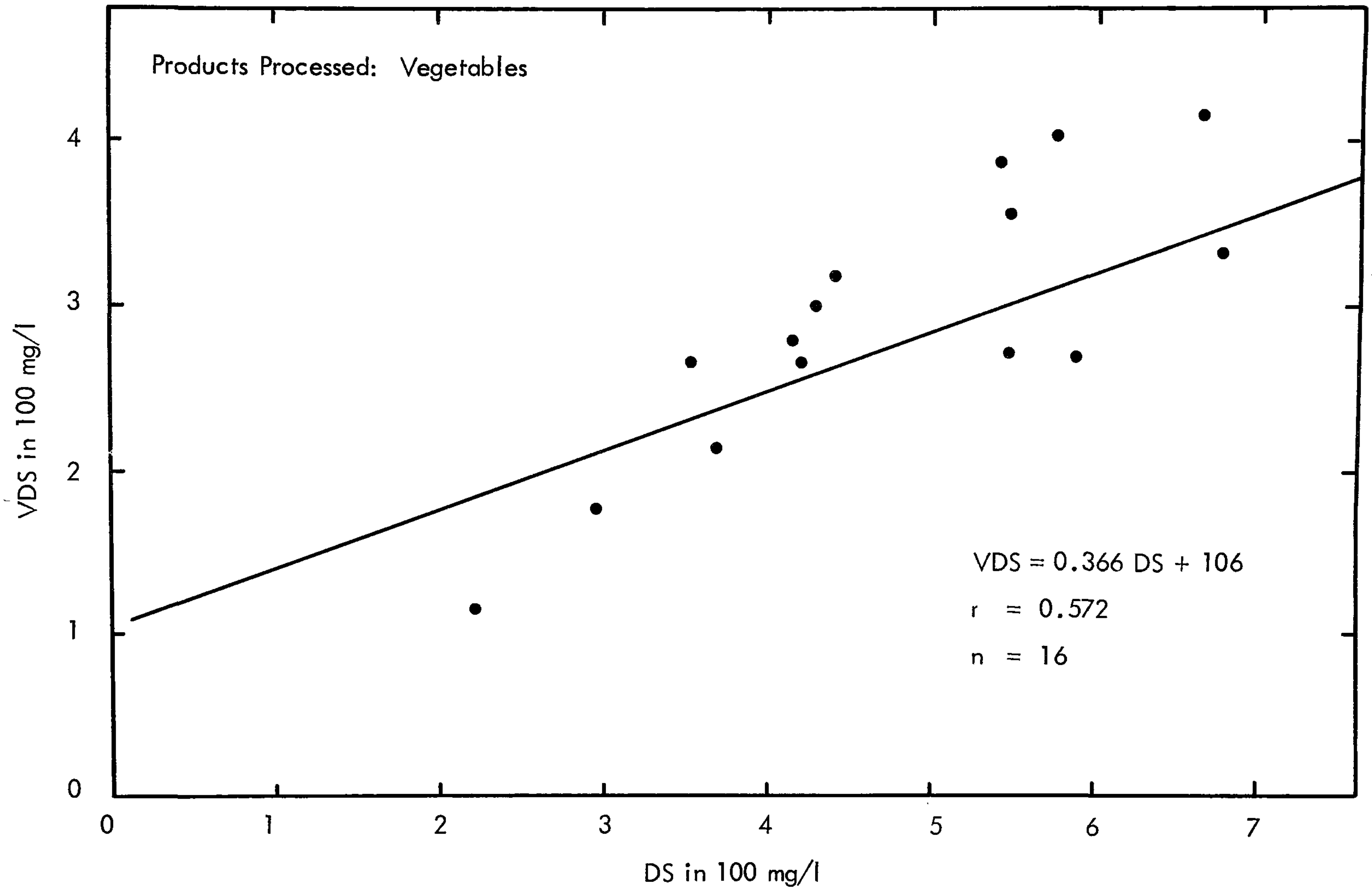


Figure E-13 Plant Influent VDS vs DS

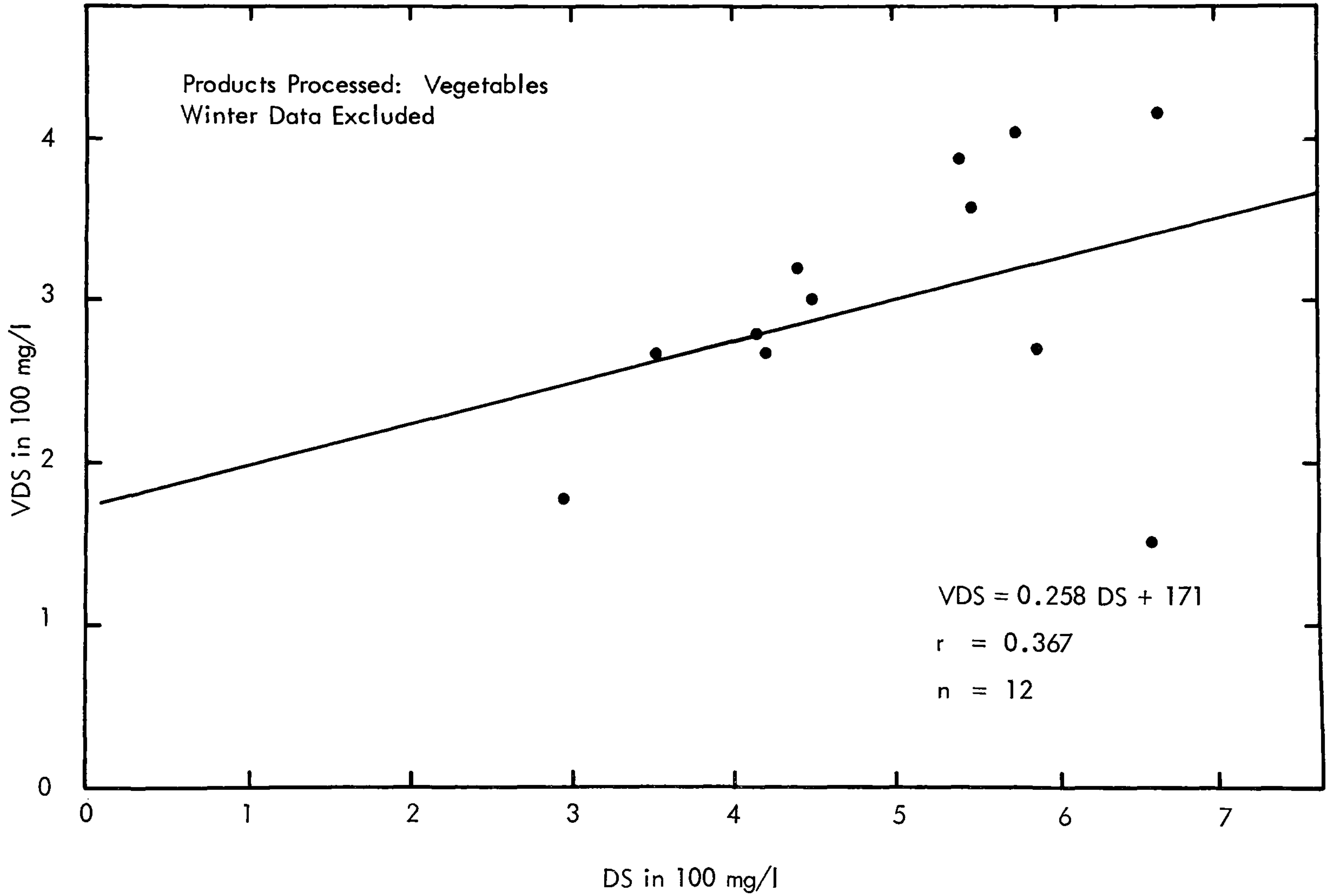


Figure E-14 Plant Influent VDS vs DS

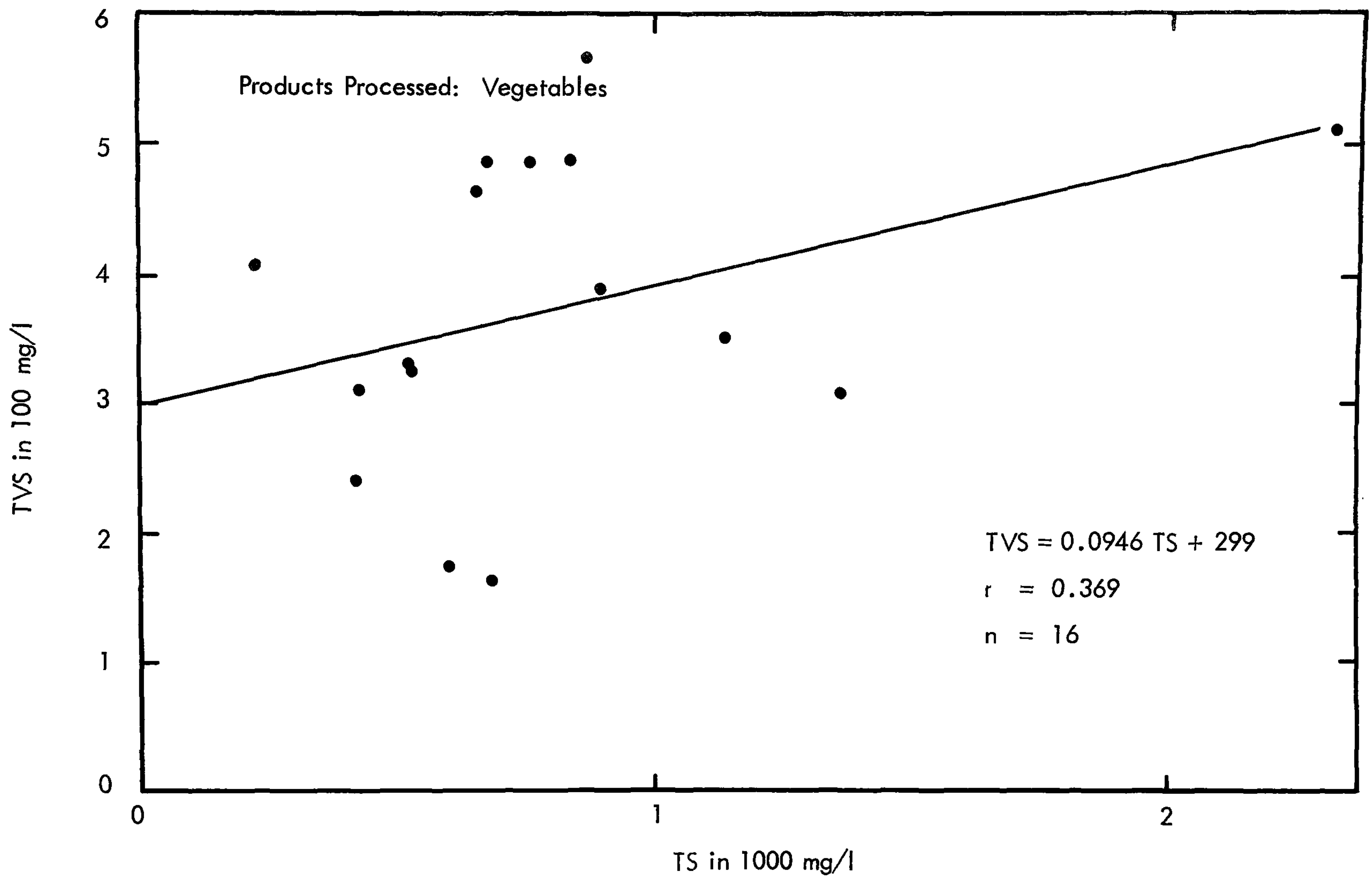


Figure E-15 Plant Influent TVS vs TS

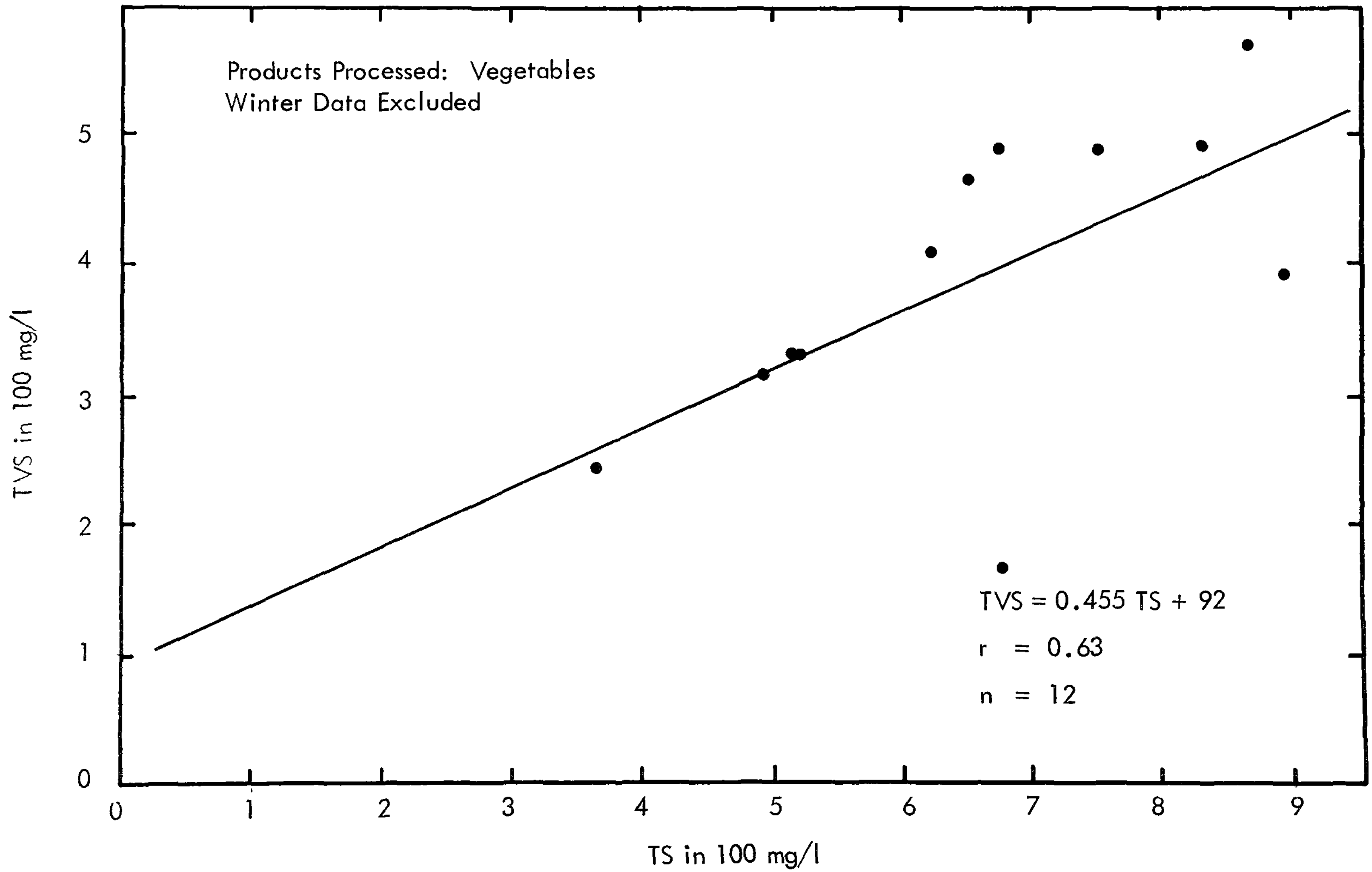


Figure E-16 Plant Inlfuent TVS vs TS

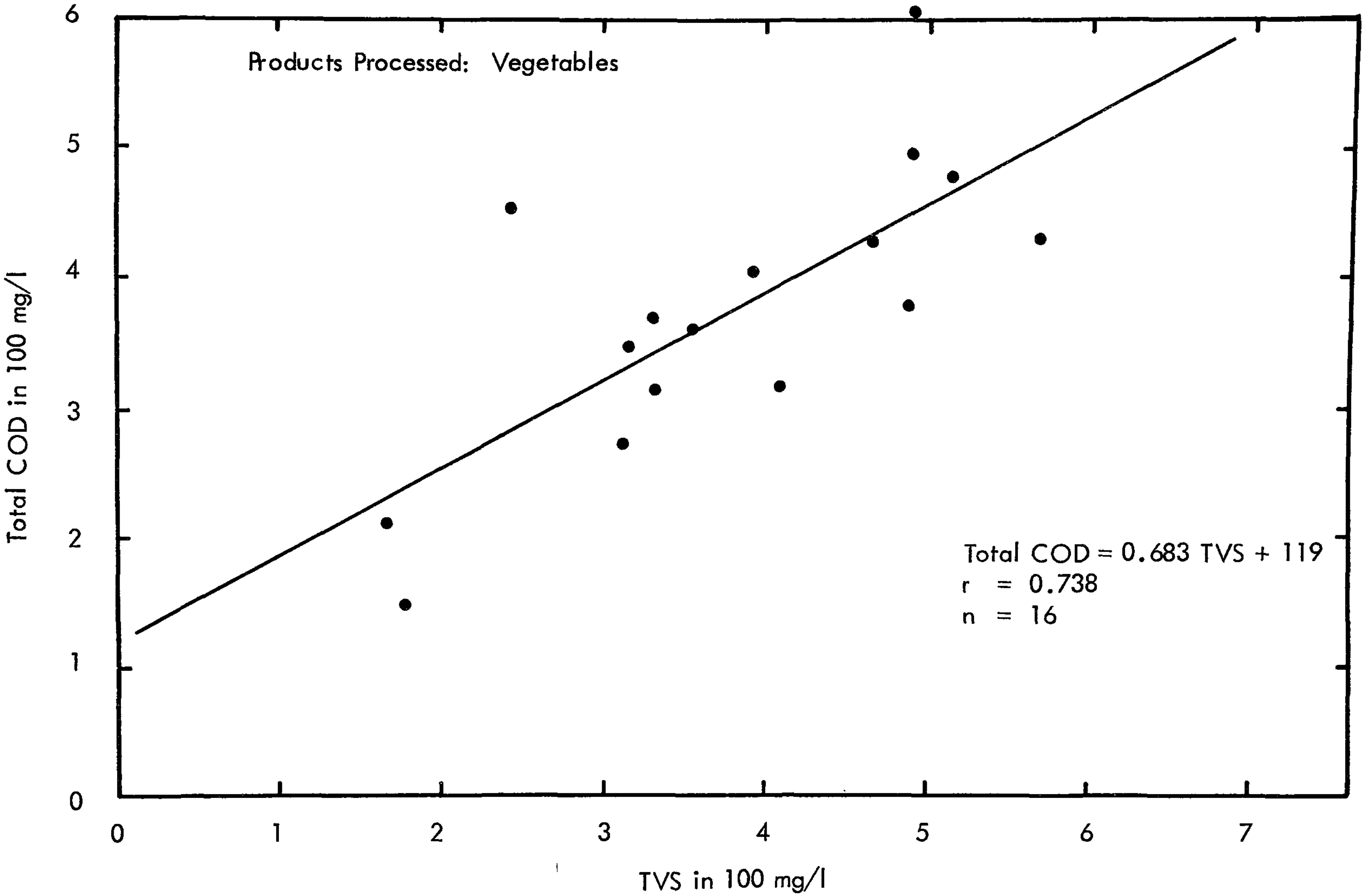


Figure E-17 Plant Influent Total COD vs TVS

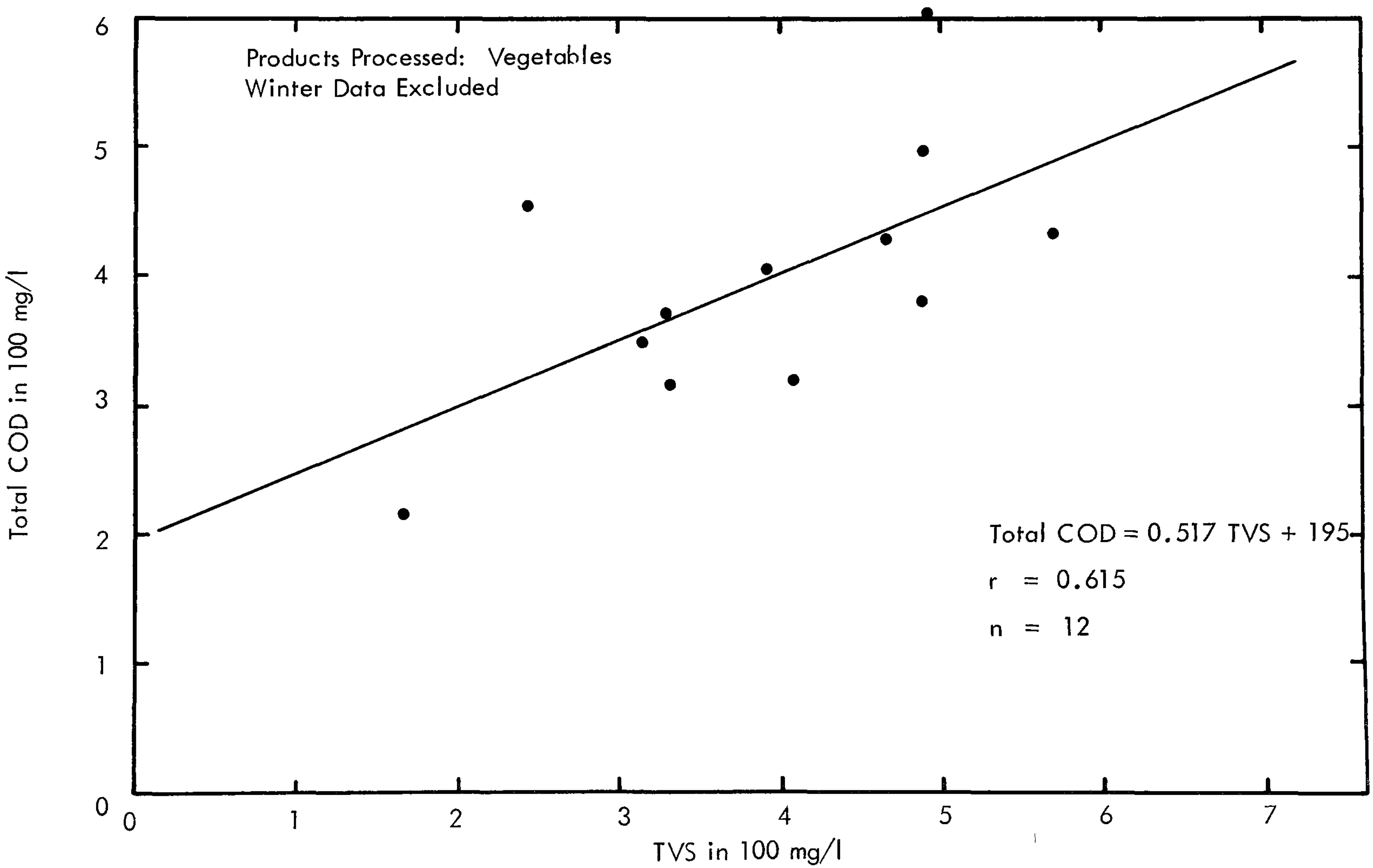


Figure E-18 Plant Influent Total COD vs TVS

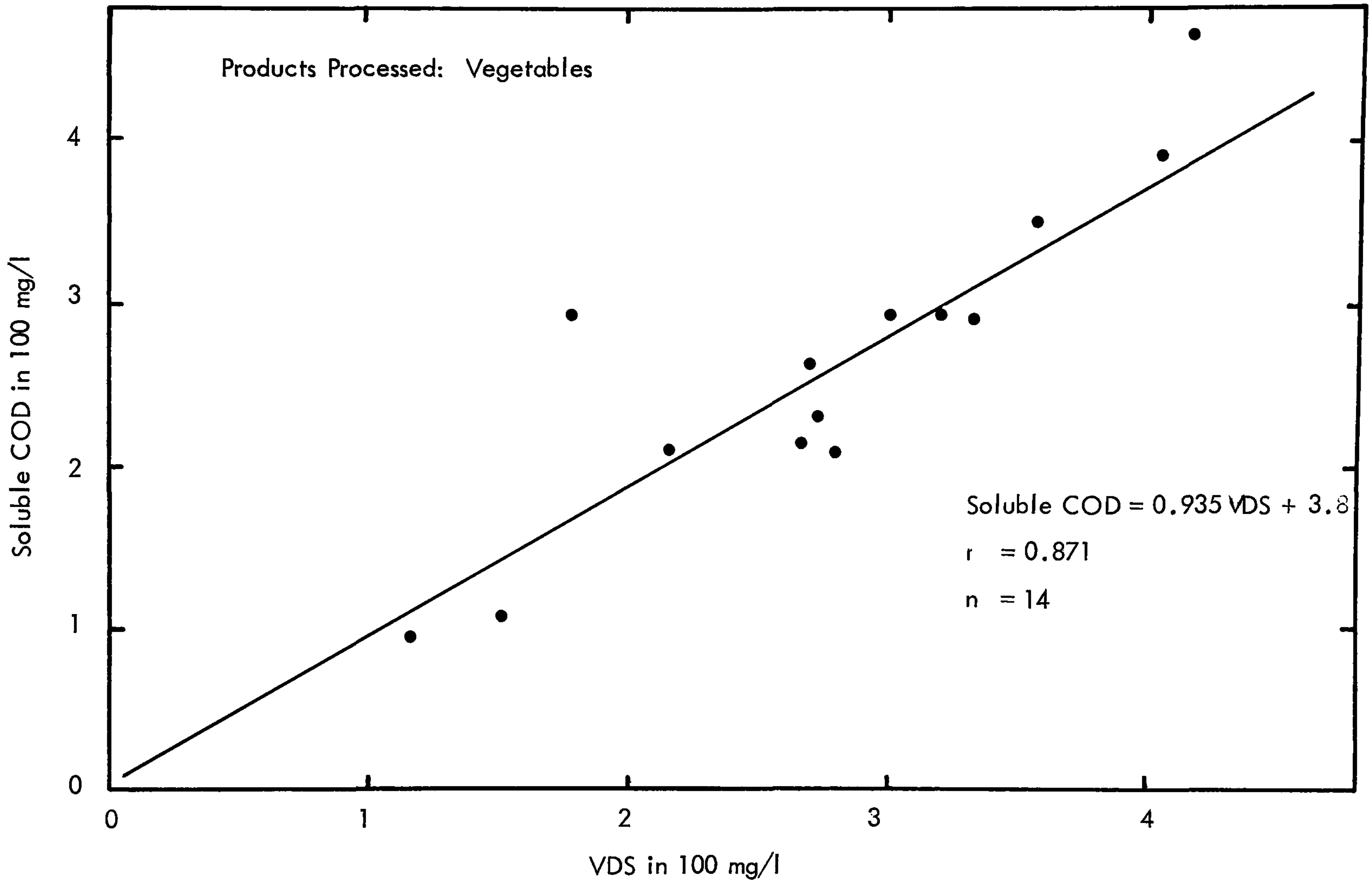


Figure E-19 Plant Influent Soluble COD vs VDS

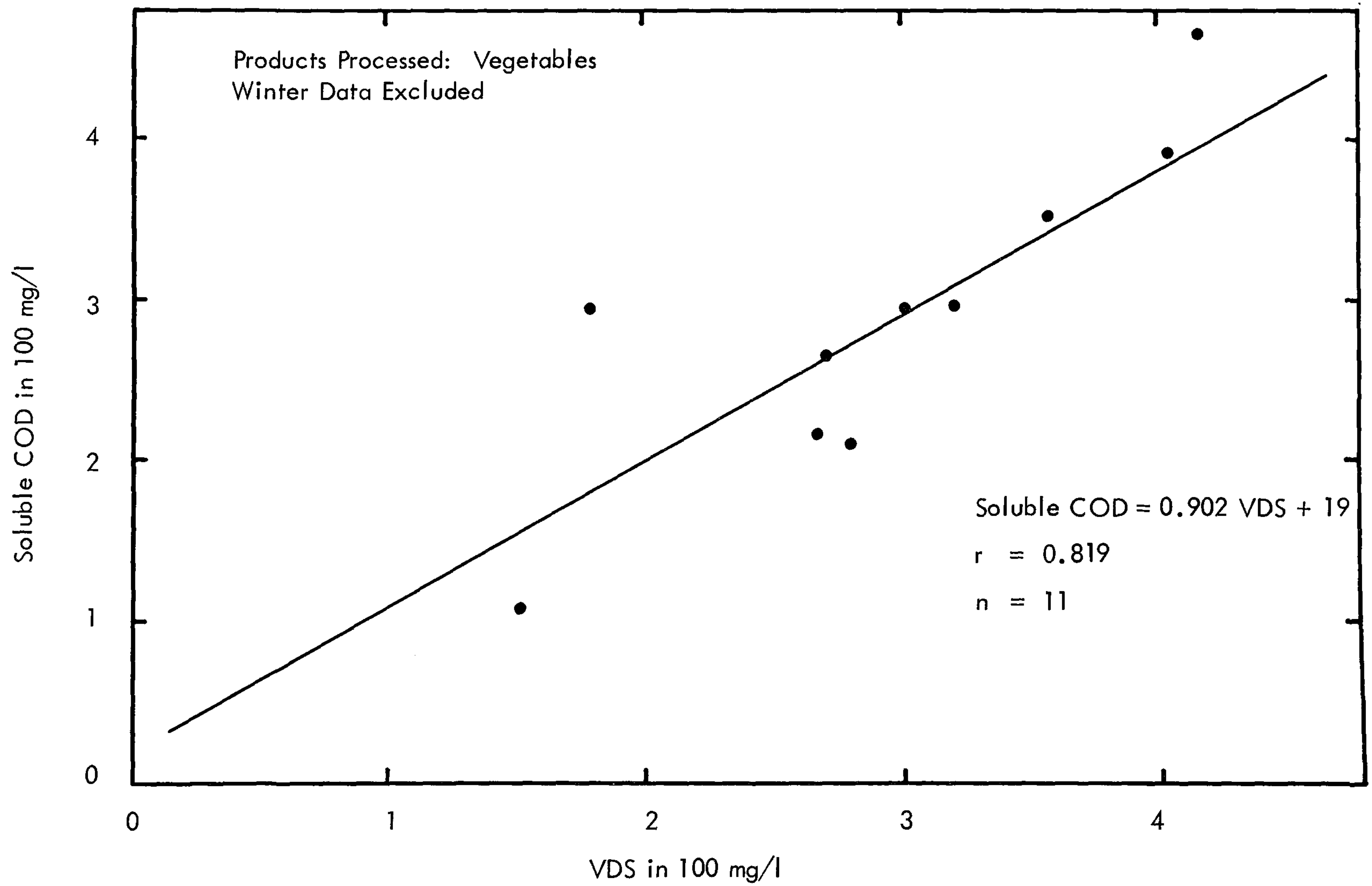


Figure E-20 Plant Influent Soluble COD vs VDS

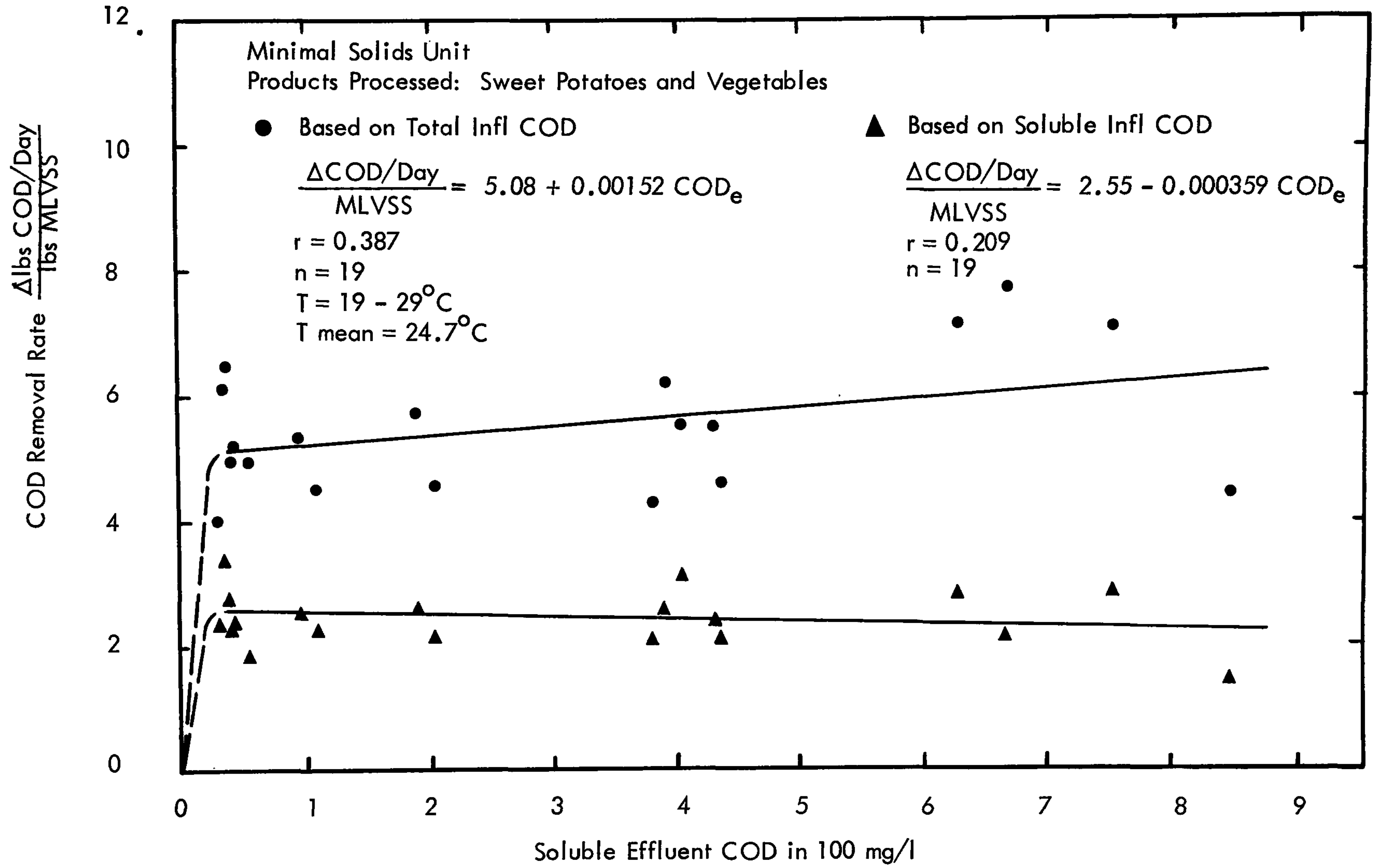


Figure E-21 COD Removal Rate vs Soluble Effluent COD

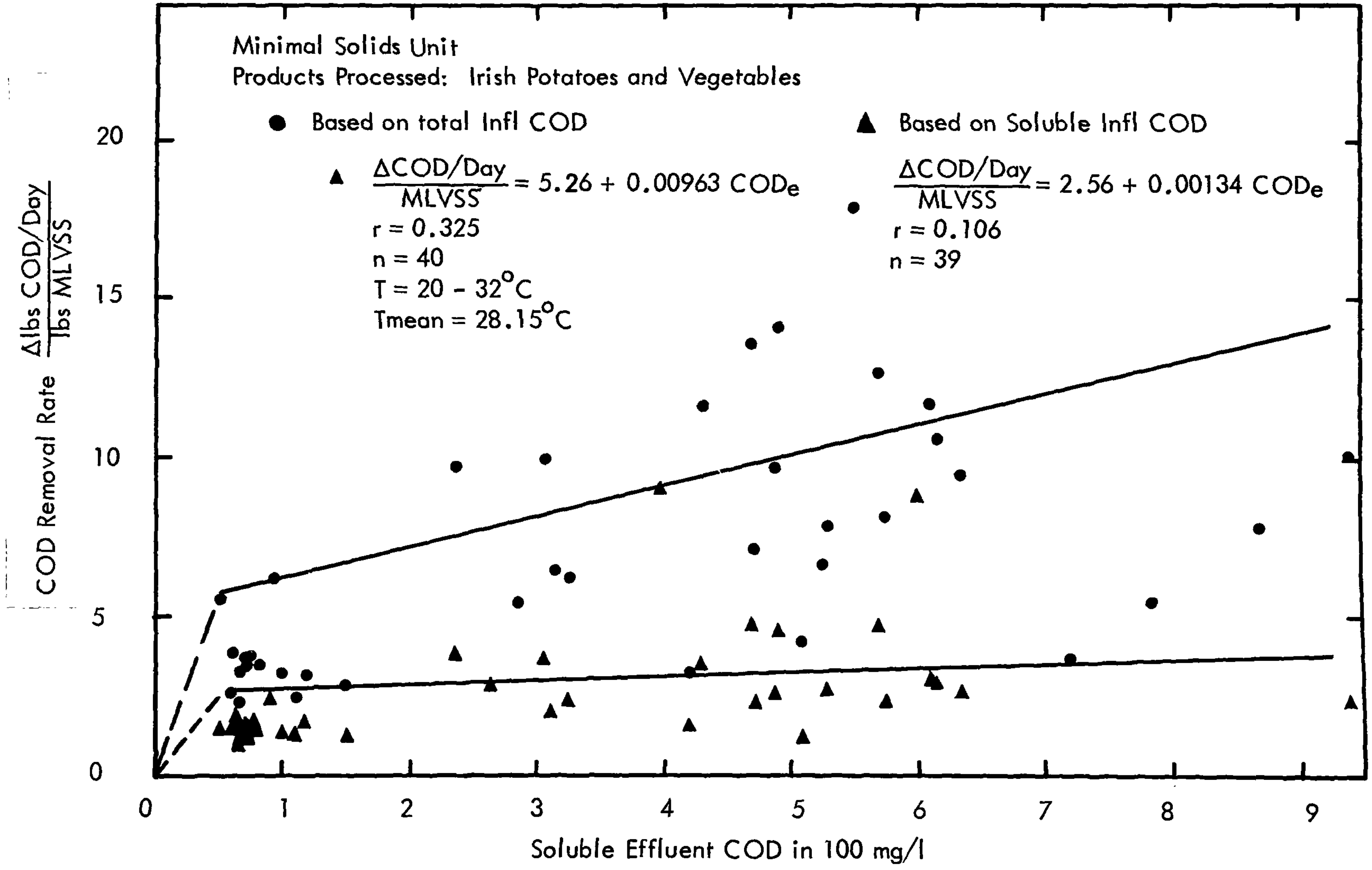


Figure E-22 COD Removal Rate vs Soluble Effluent COD

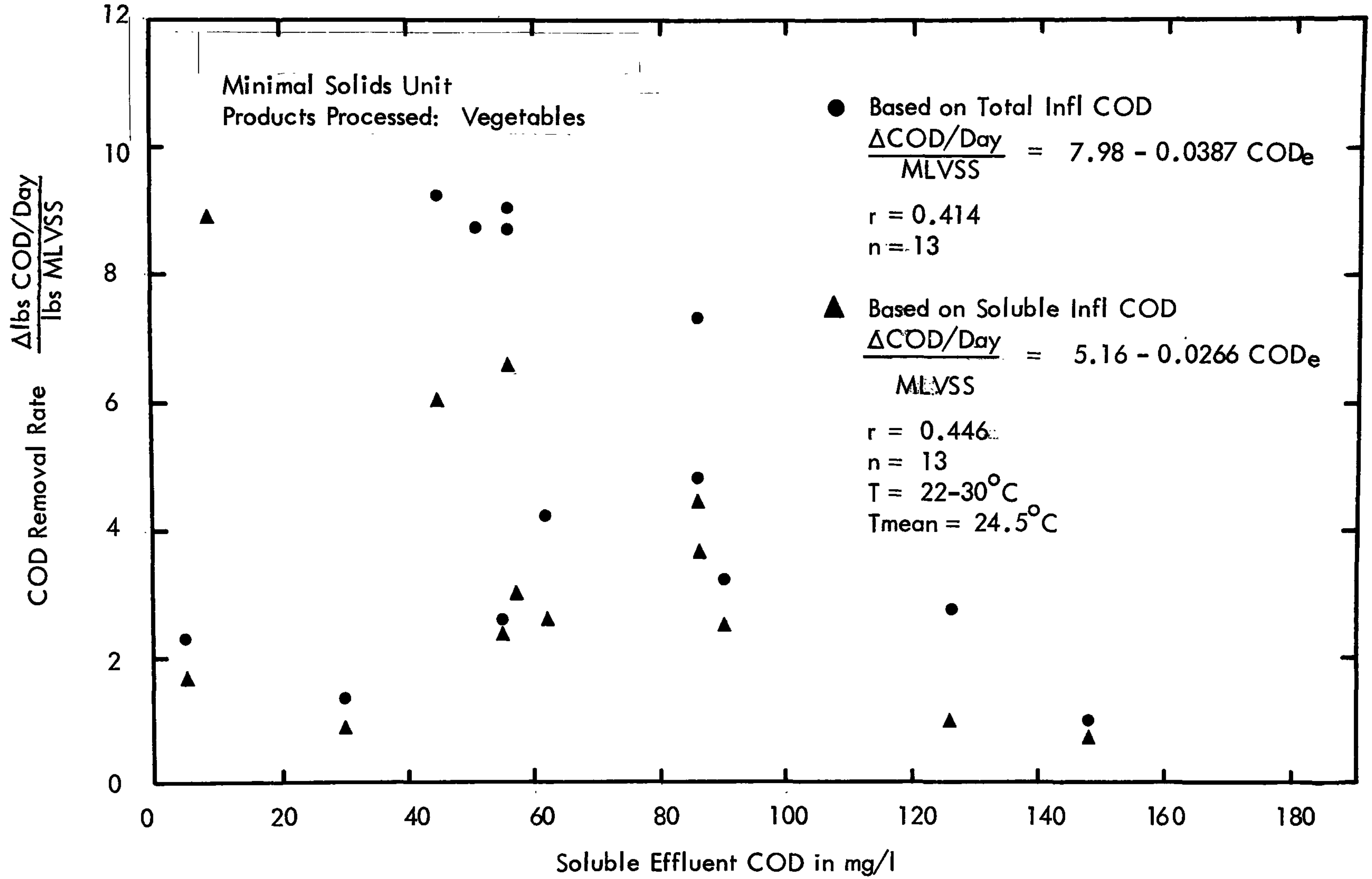


Figure E-23 COD Removal Rate vs Soluble Effluent COD

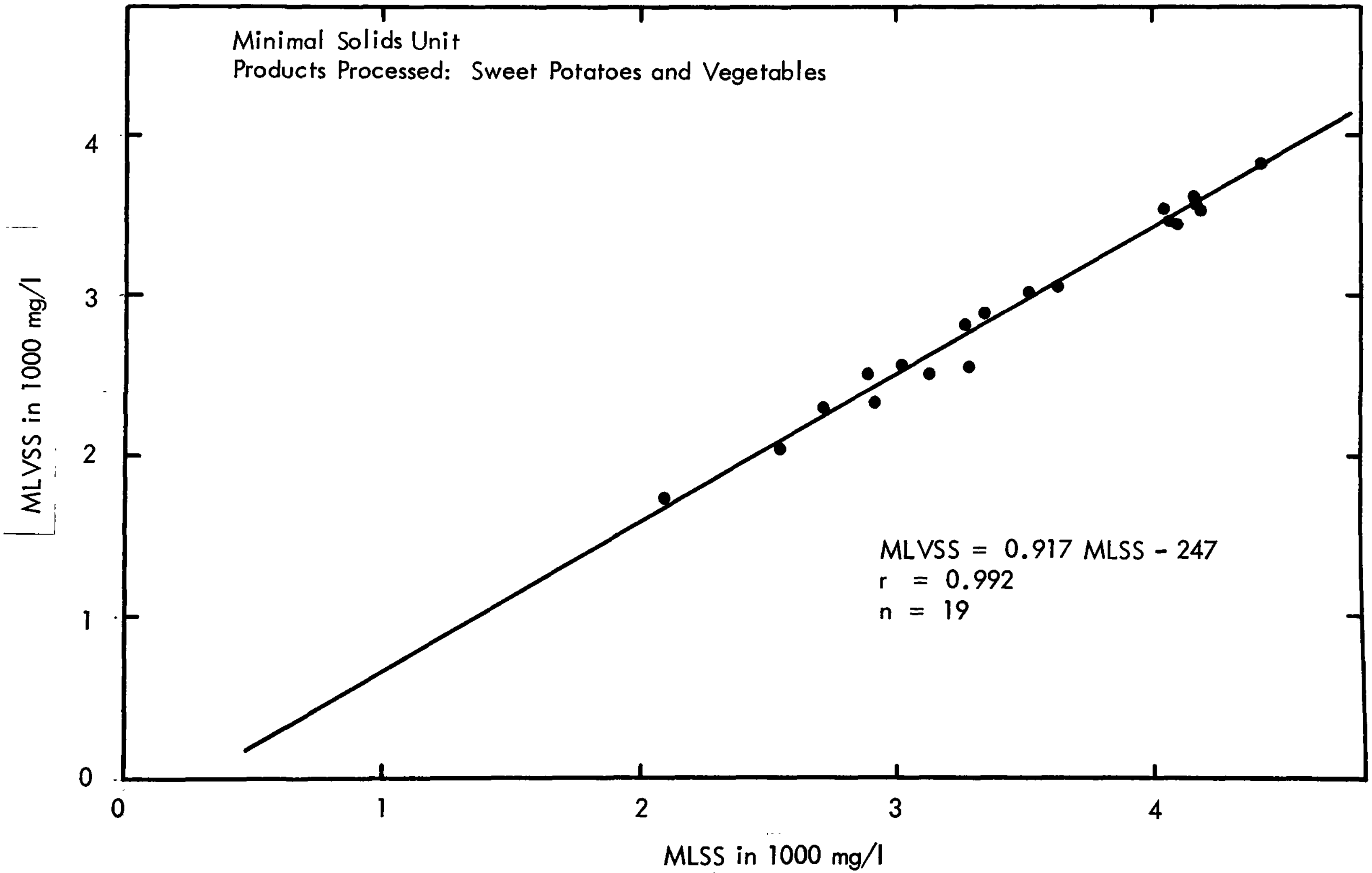


Figure E-24 MLVSS vs MLSS

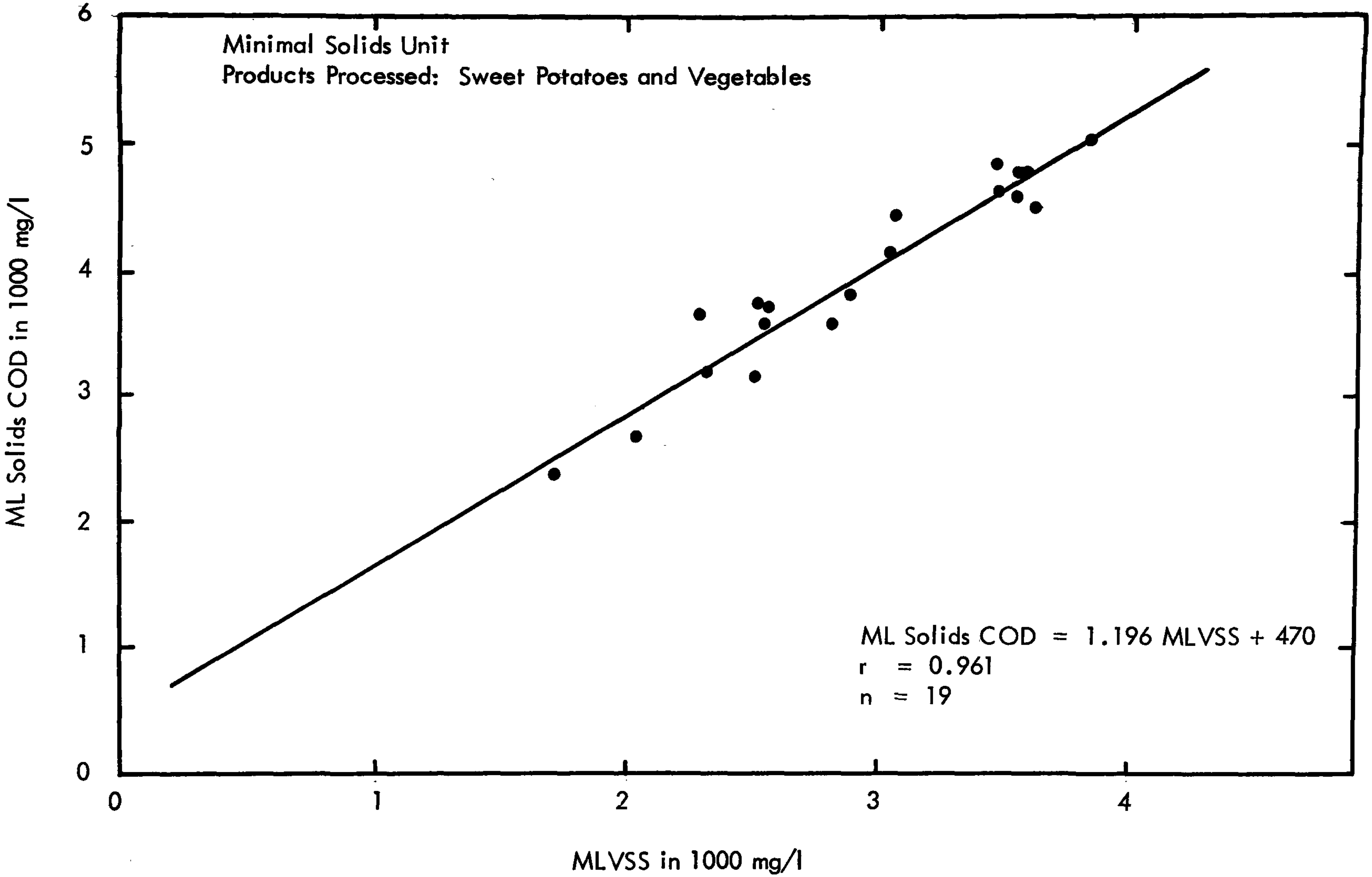


Figure E-25 ML Solids COD vs MLVSS

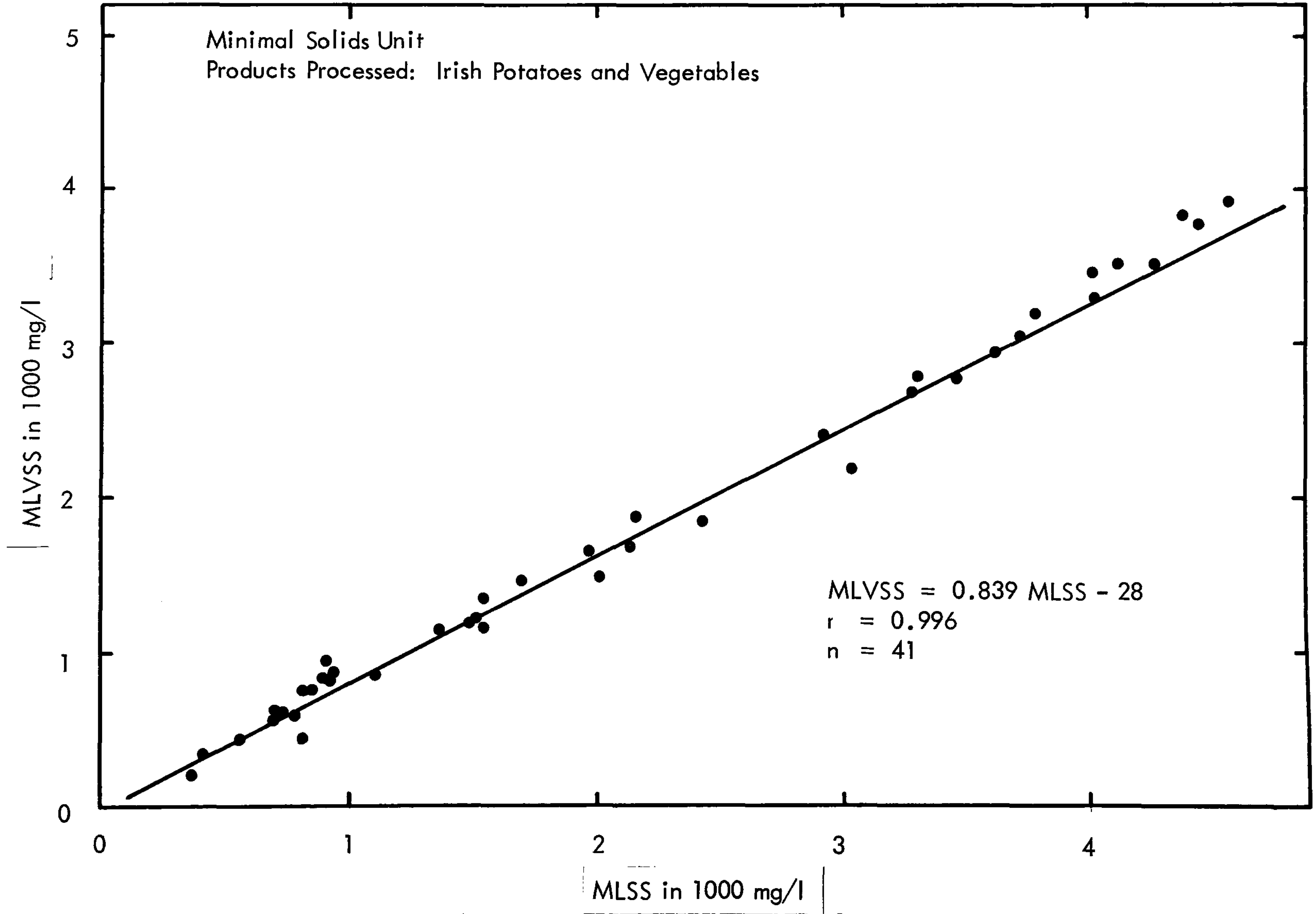


Figure E-26 MLVSS vs MLSS

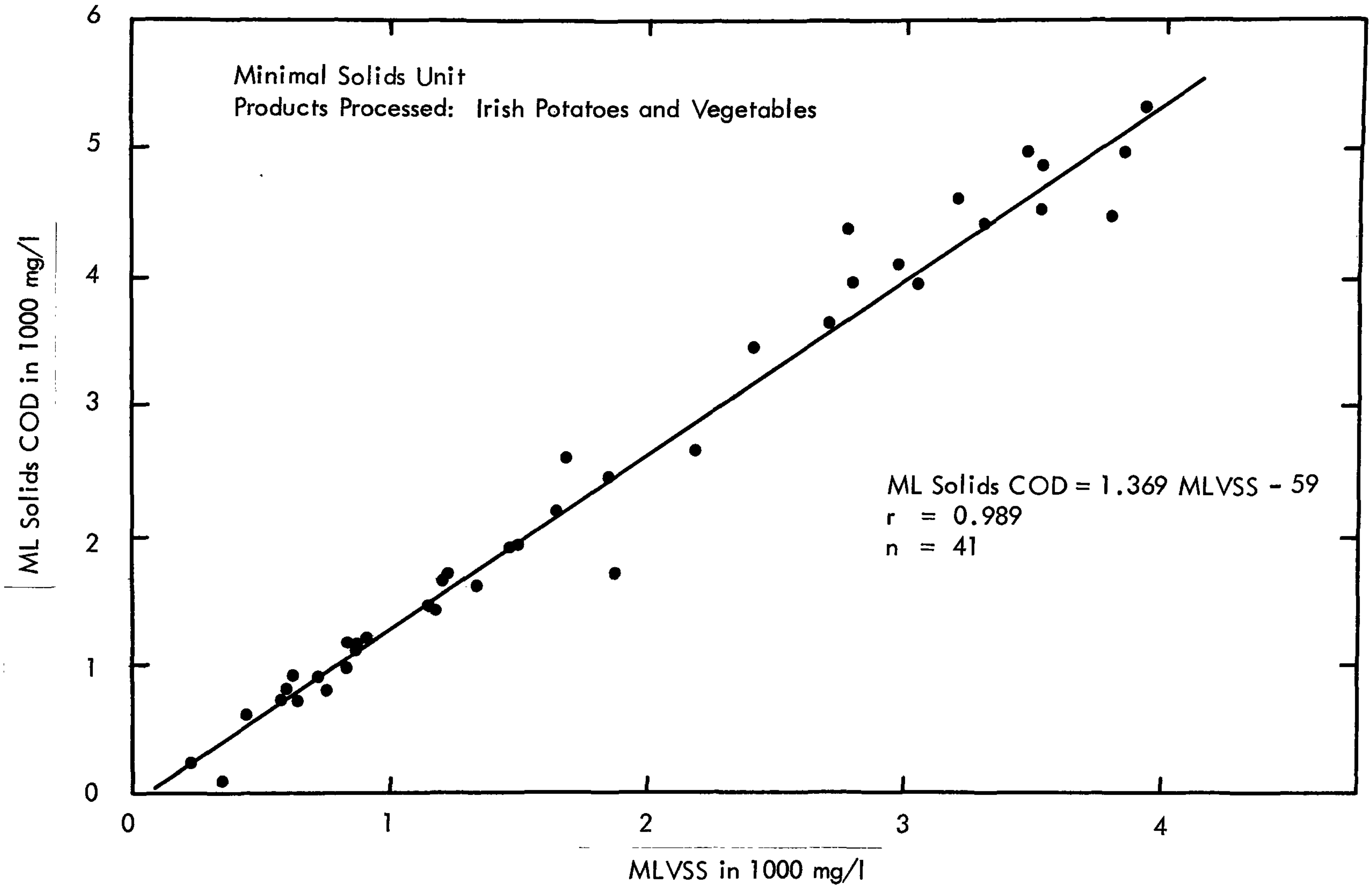


Figure E-27 ML Solids COD vs MLVSS

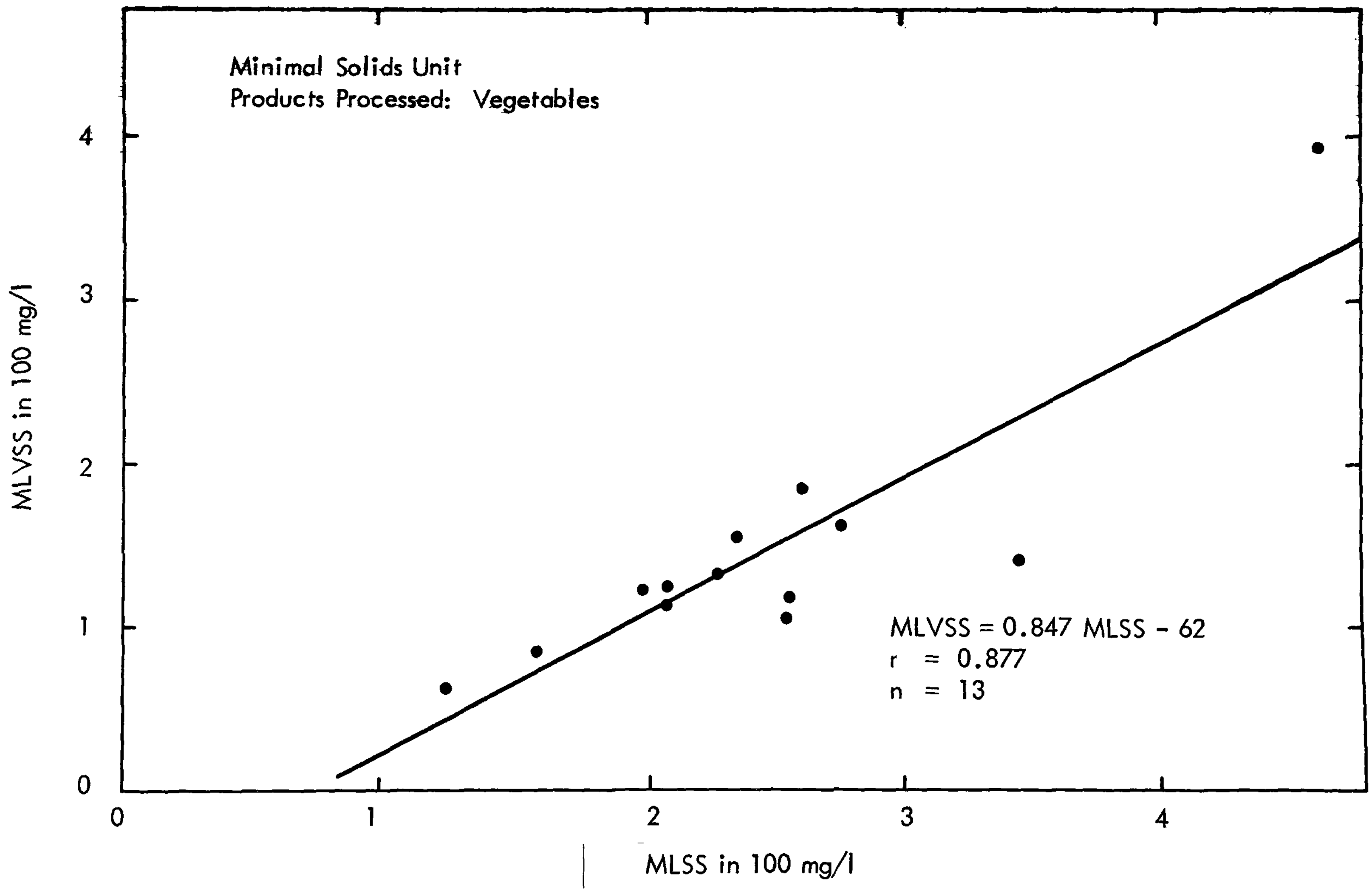


Figure E-28 MLVSS vs MLSS

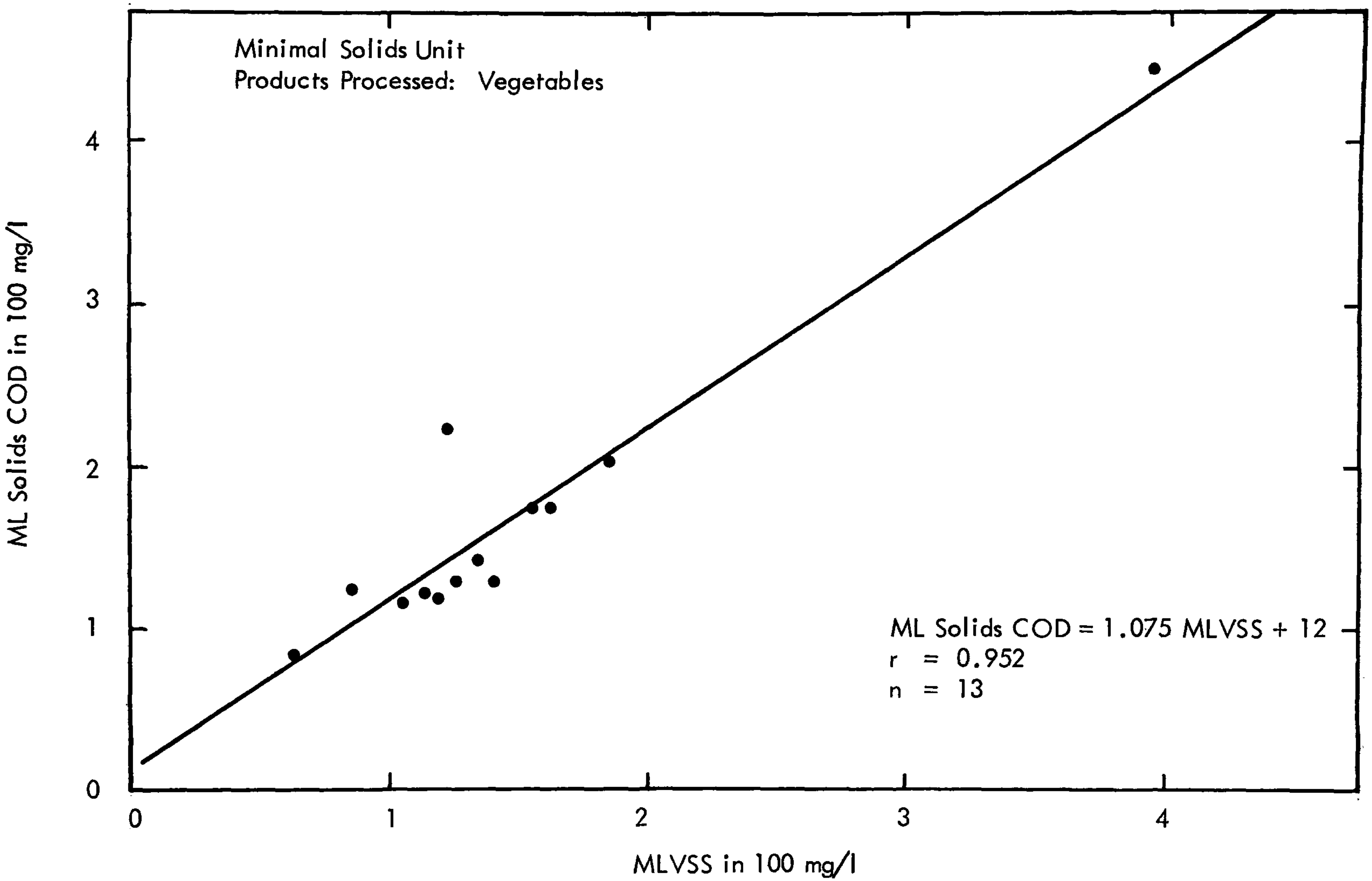


Figure E-29 ML Solids COD vs MLVSS

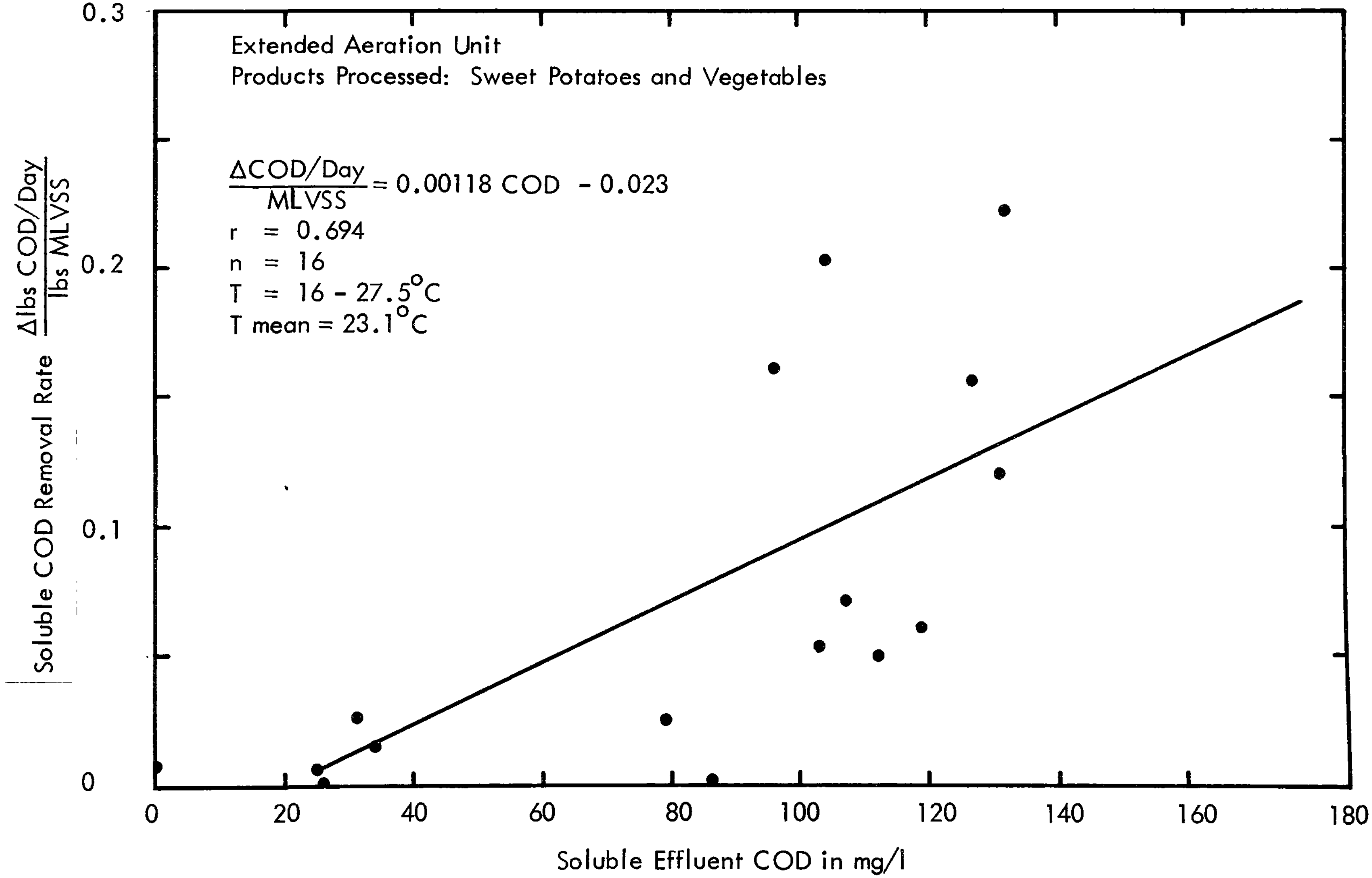


Figure E-30 Soluble COD Removal Rate vs Soluble Effluent COD

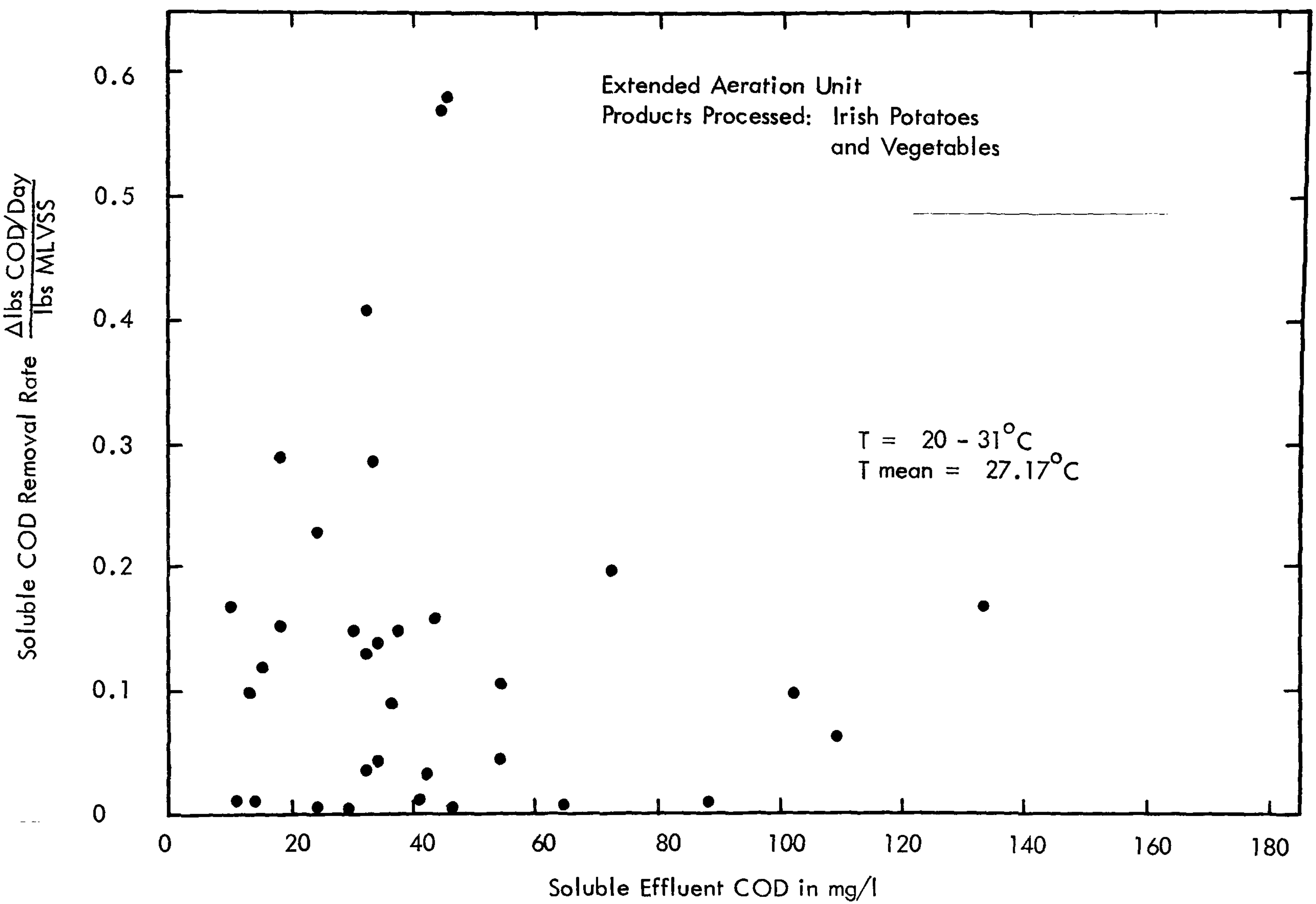


Figure E-31 Soluble COD Removal Rate vs Soluble Effluent COD

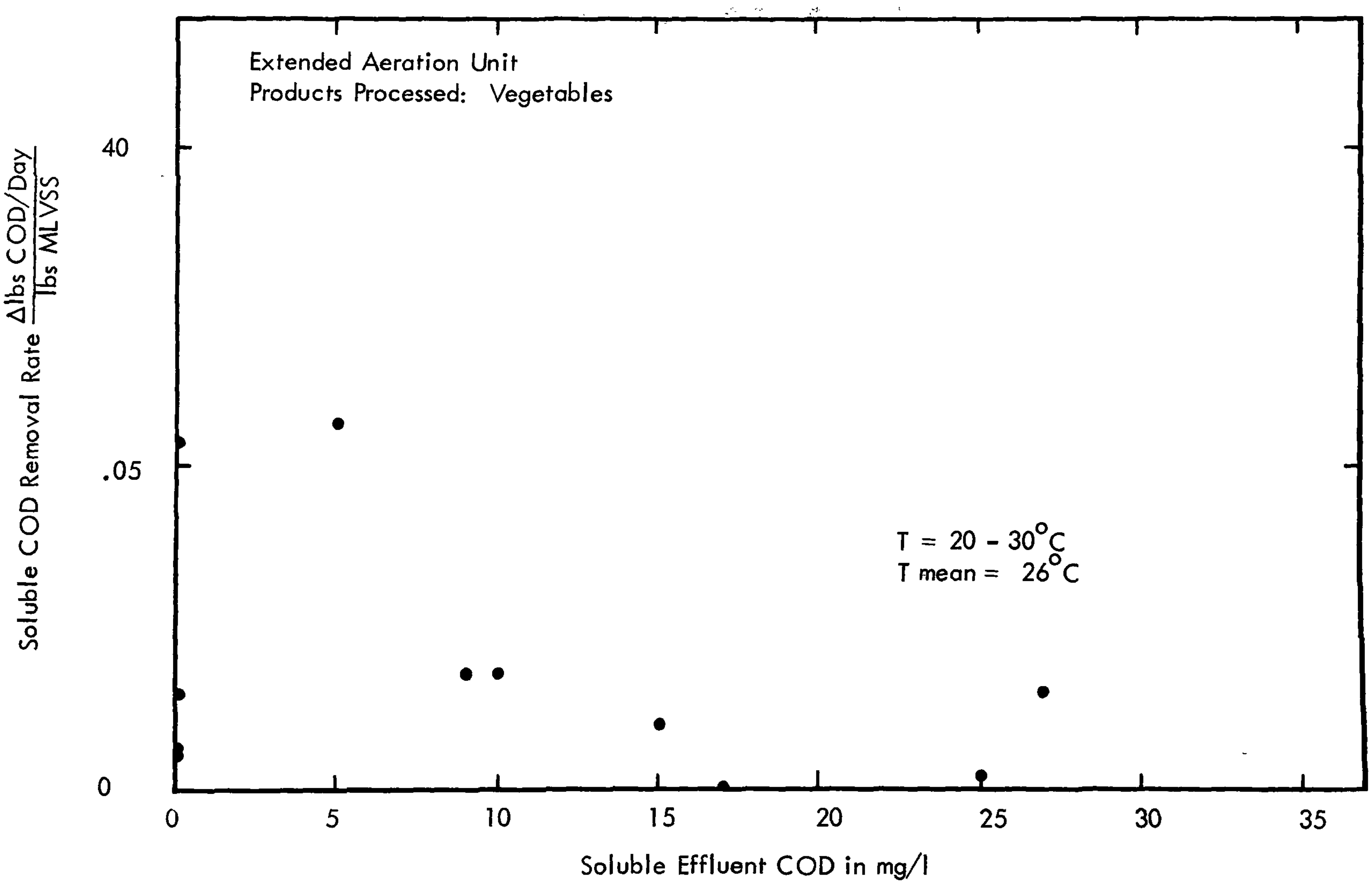


Figure E-32 Soluble COD Removal Rate vs Soluble Effluent COD

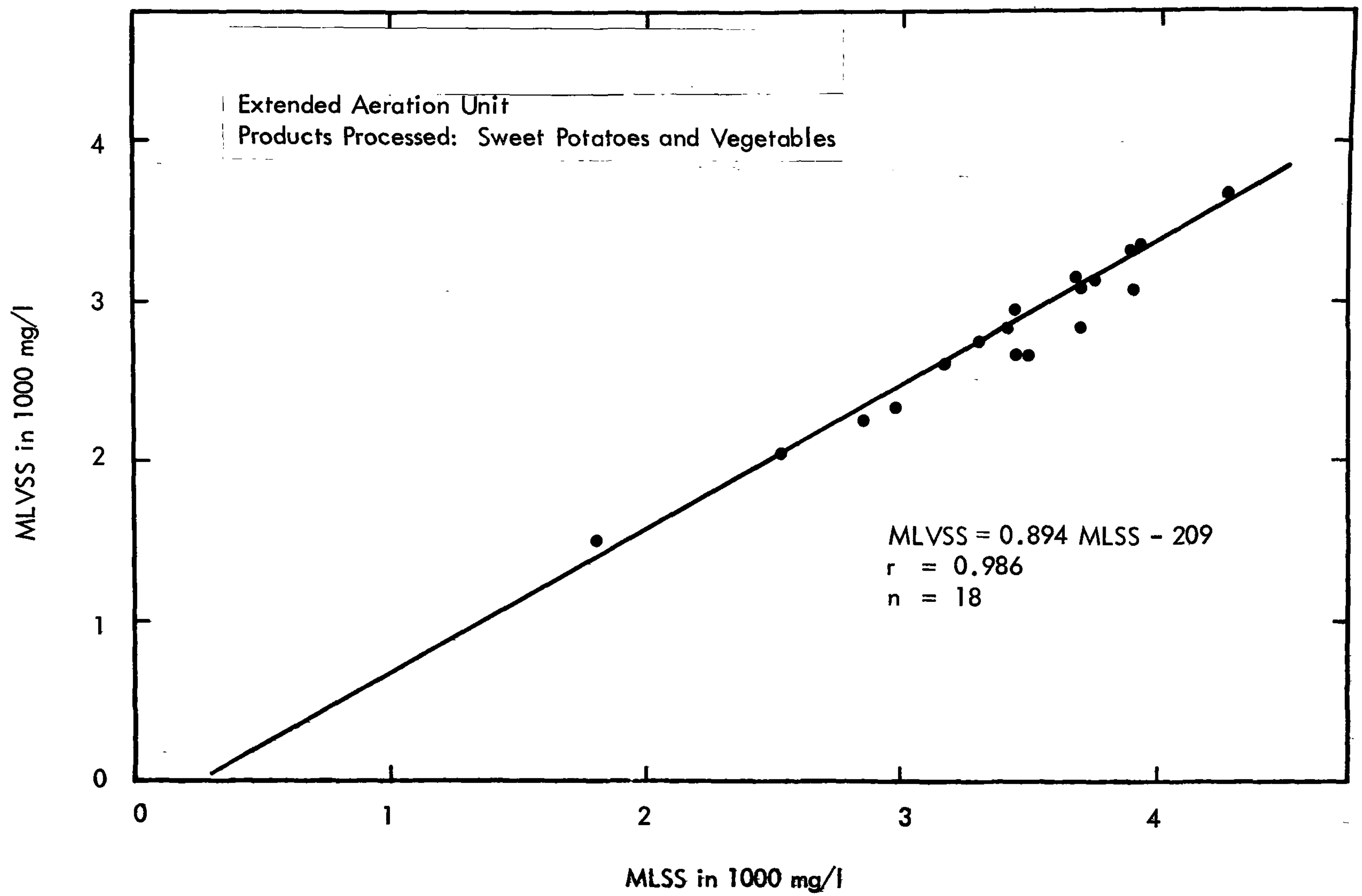


Figure E-33 MLVSS vs MLSS

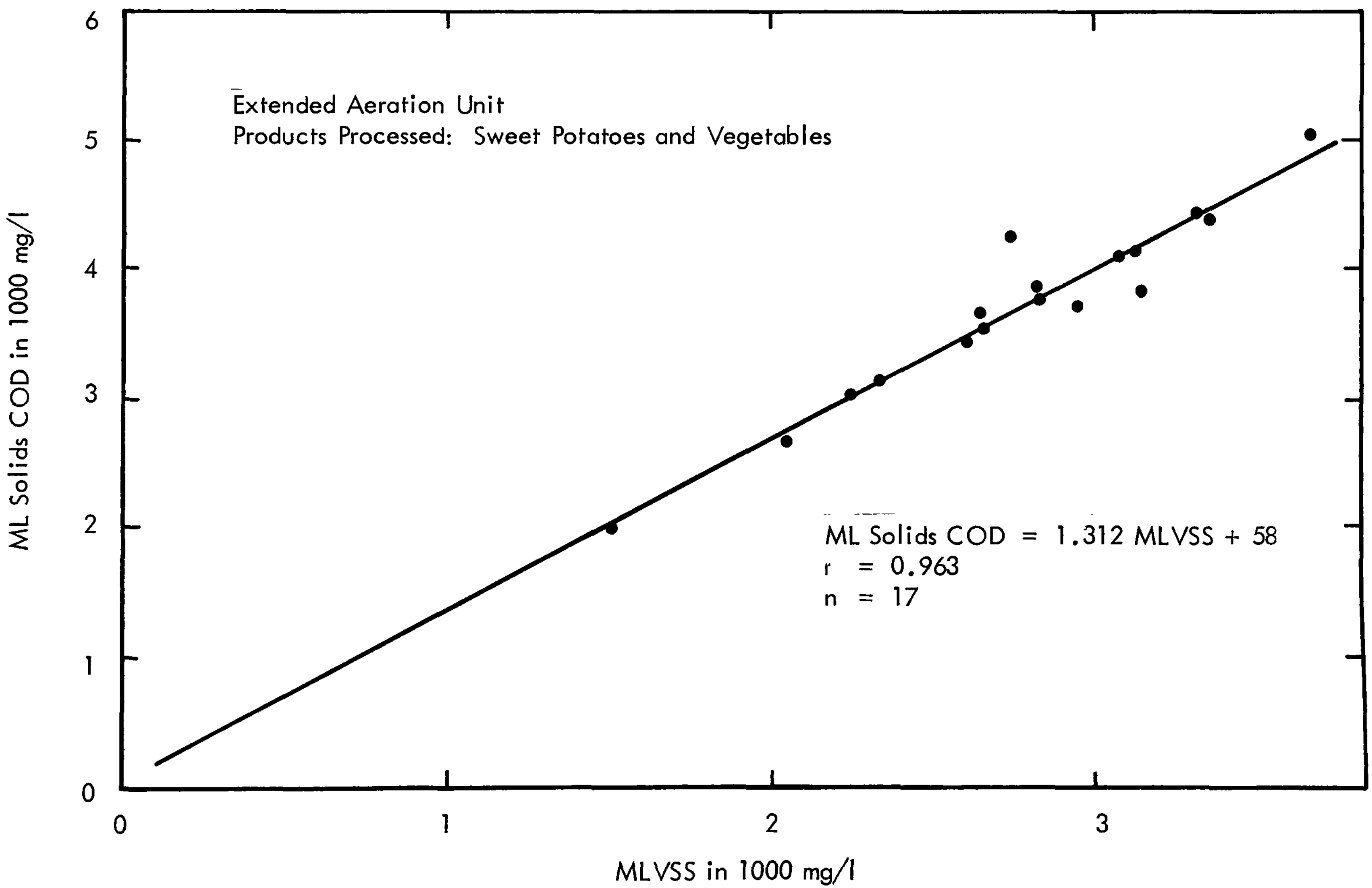


Figure E-34 ML Solids COD vs MLVSS

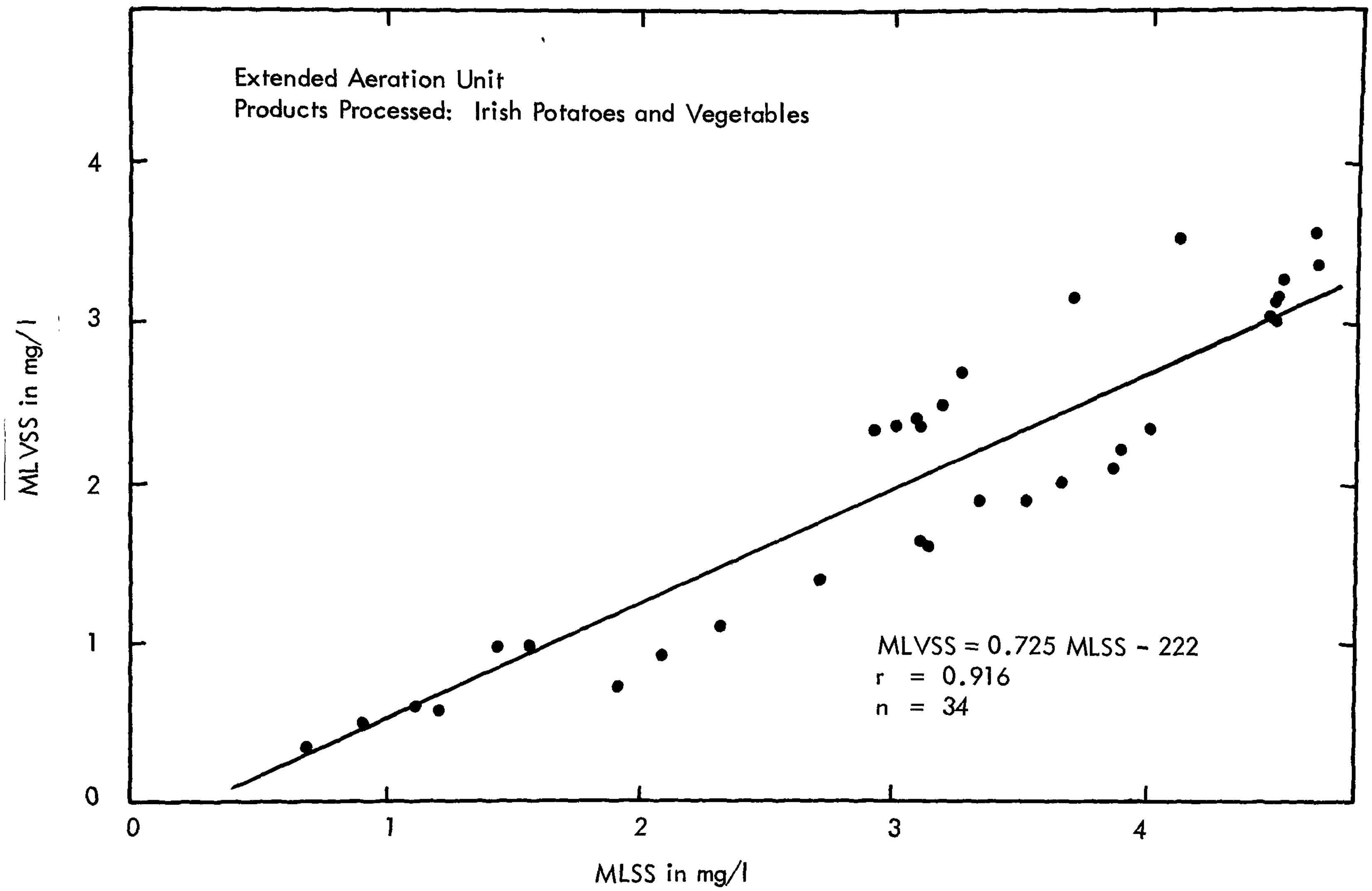


Figure E-35 MLVSS vs MLSS

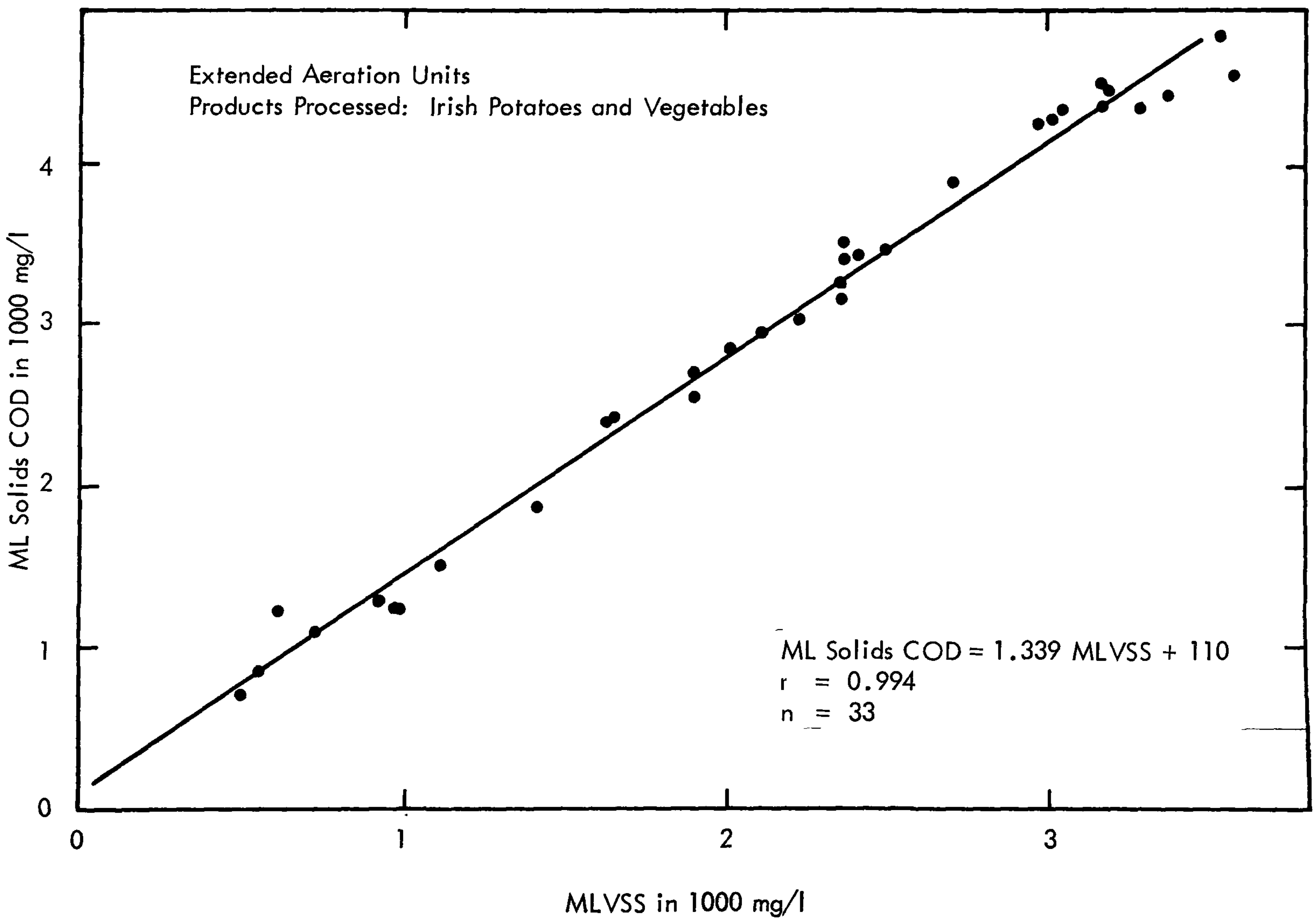


Figure E-36 ML Solids COD vs MLSS

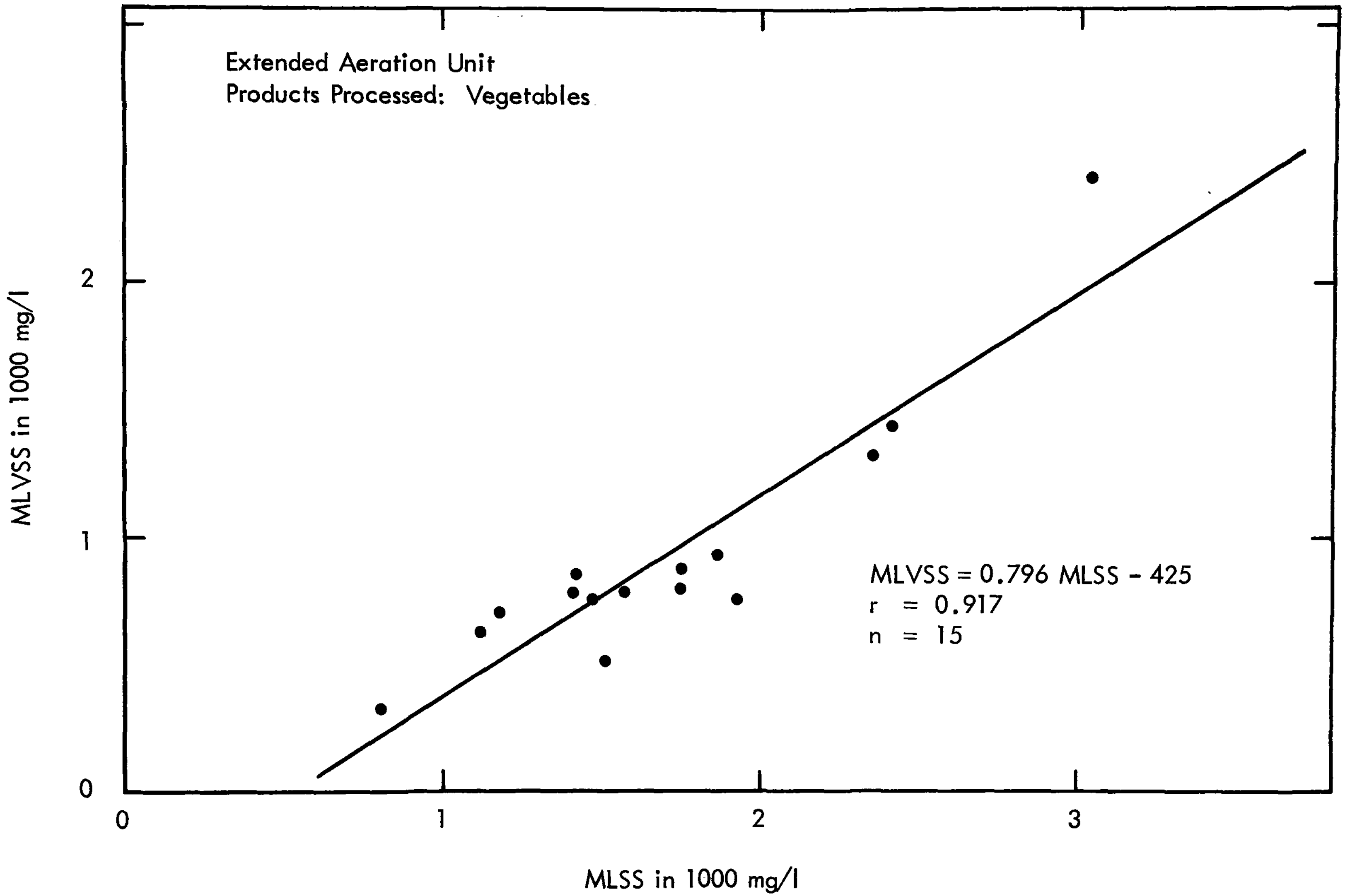


Figure E-37 MLVSS vs MLSS

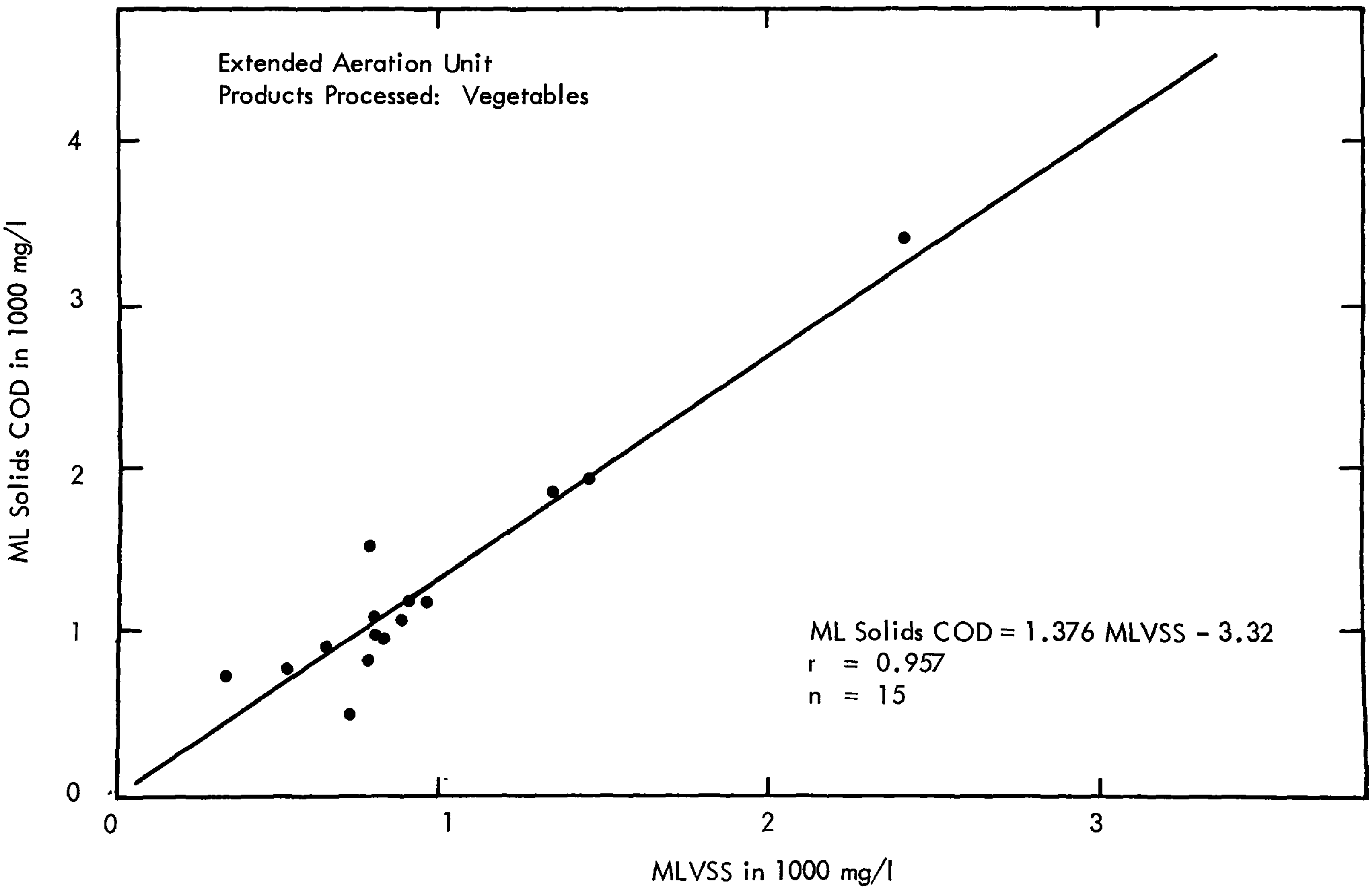


Figure E-38 ML Solids COD vs MLVSS

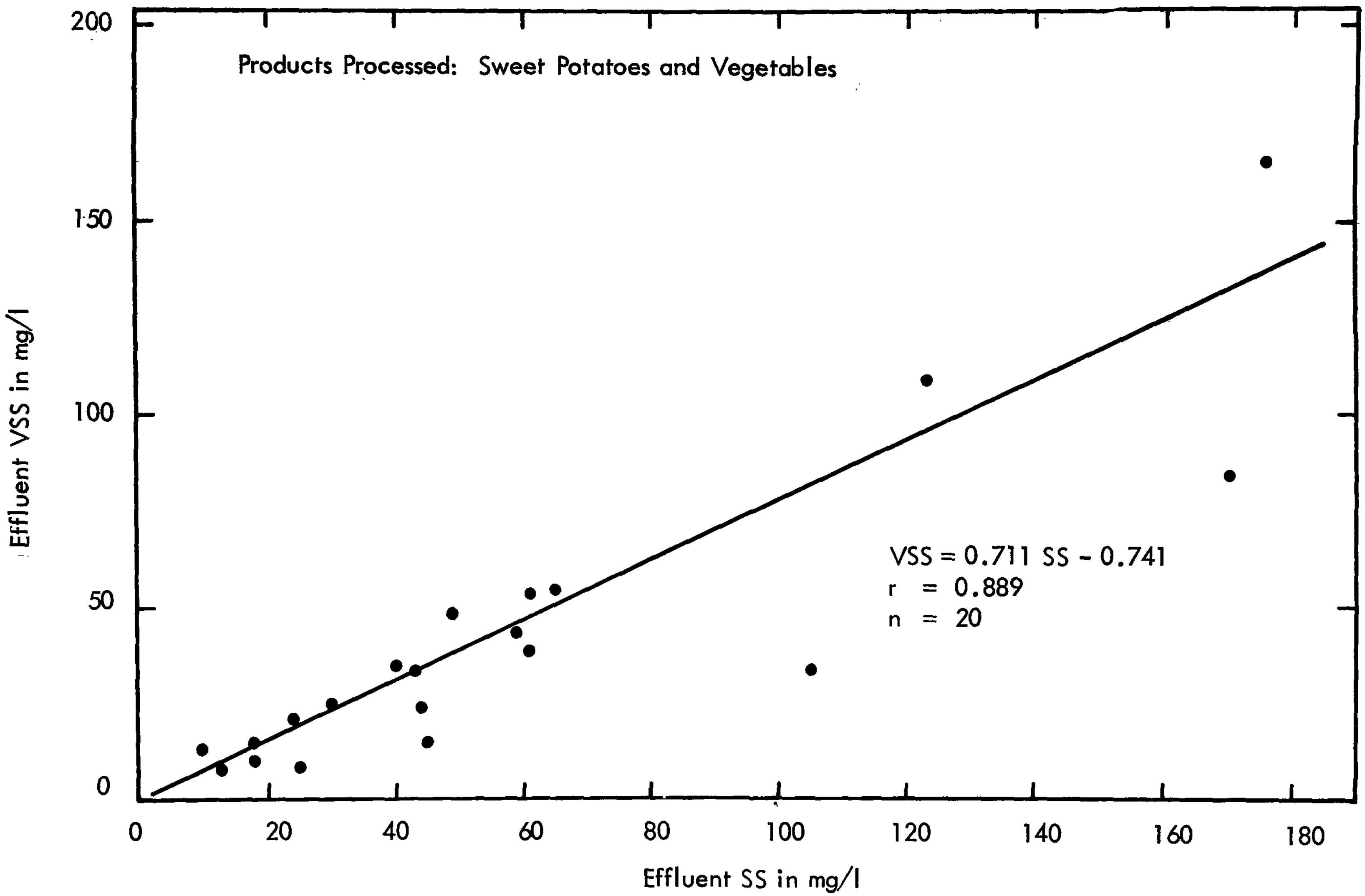


Figure E-39 Plant Effluent VSS vs SS

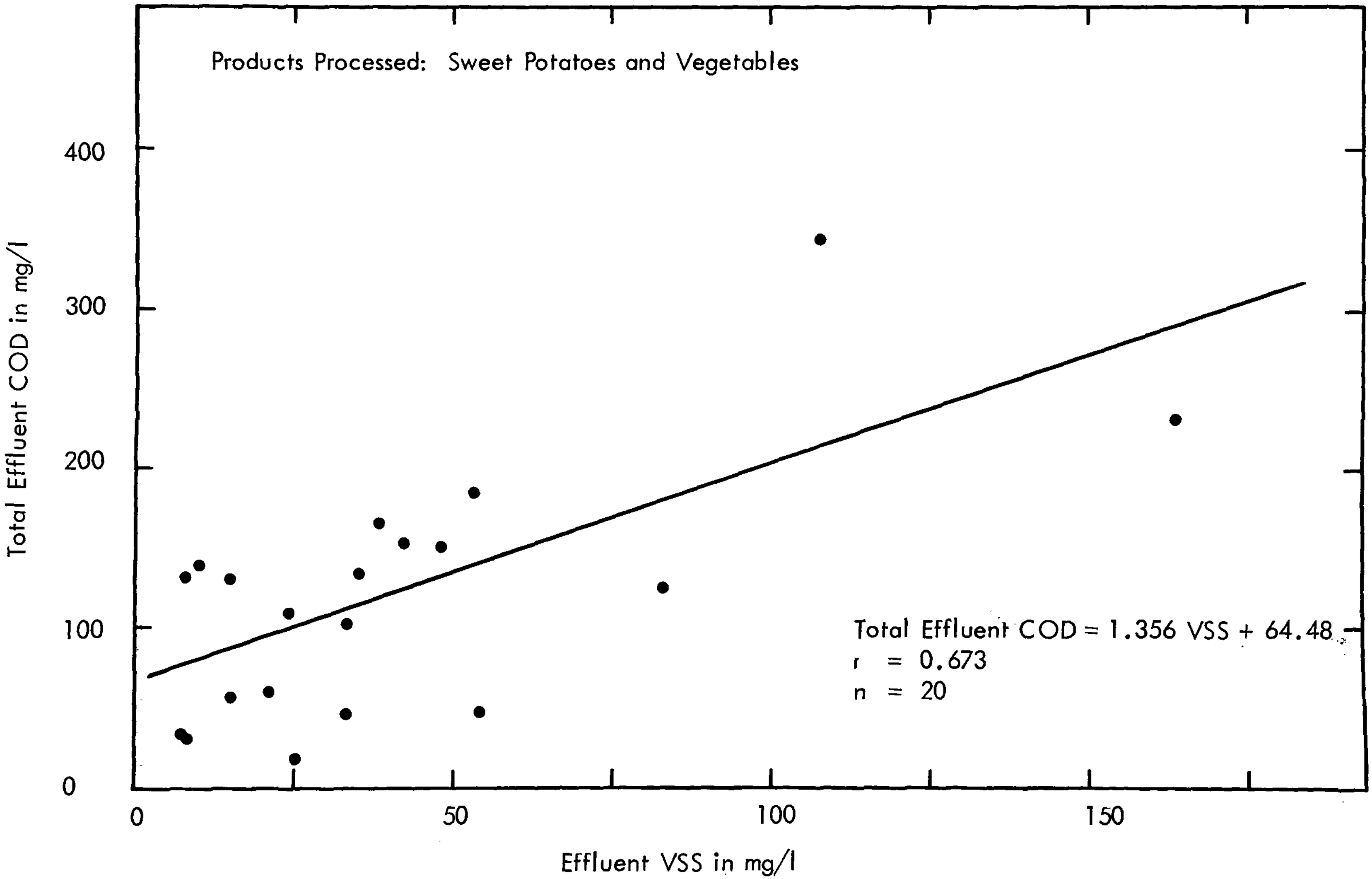


Figure E-40 Plant Total Effluent COD vs VSS

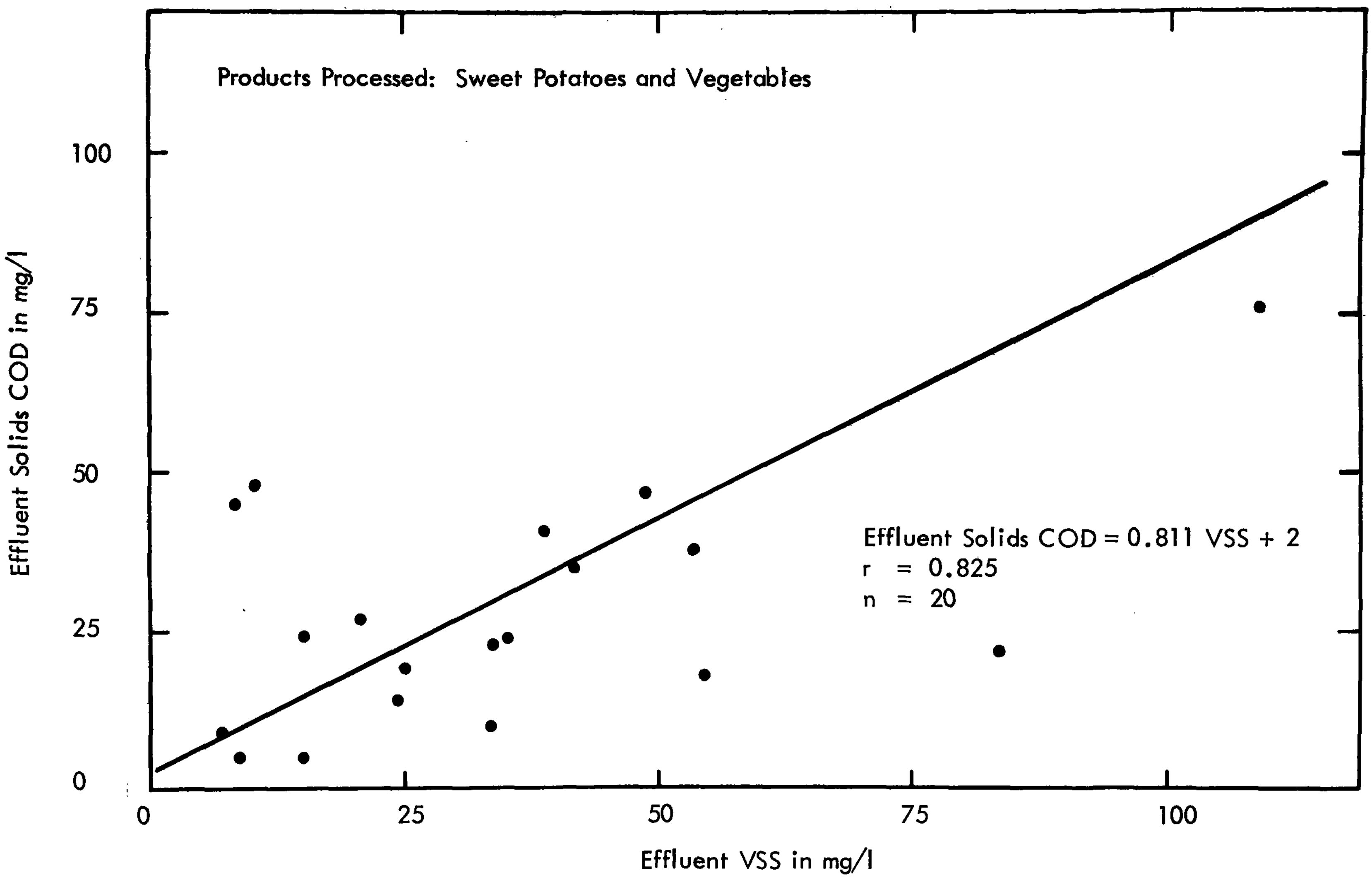


Figure E-41 Effluent Solids COD vs VSS

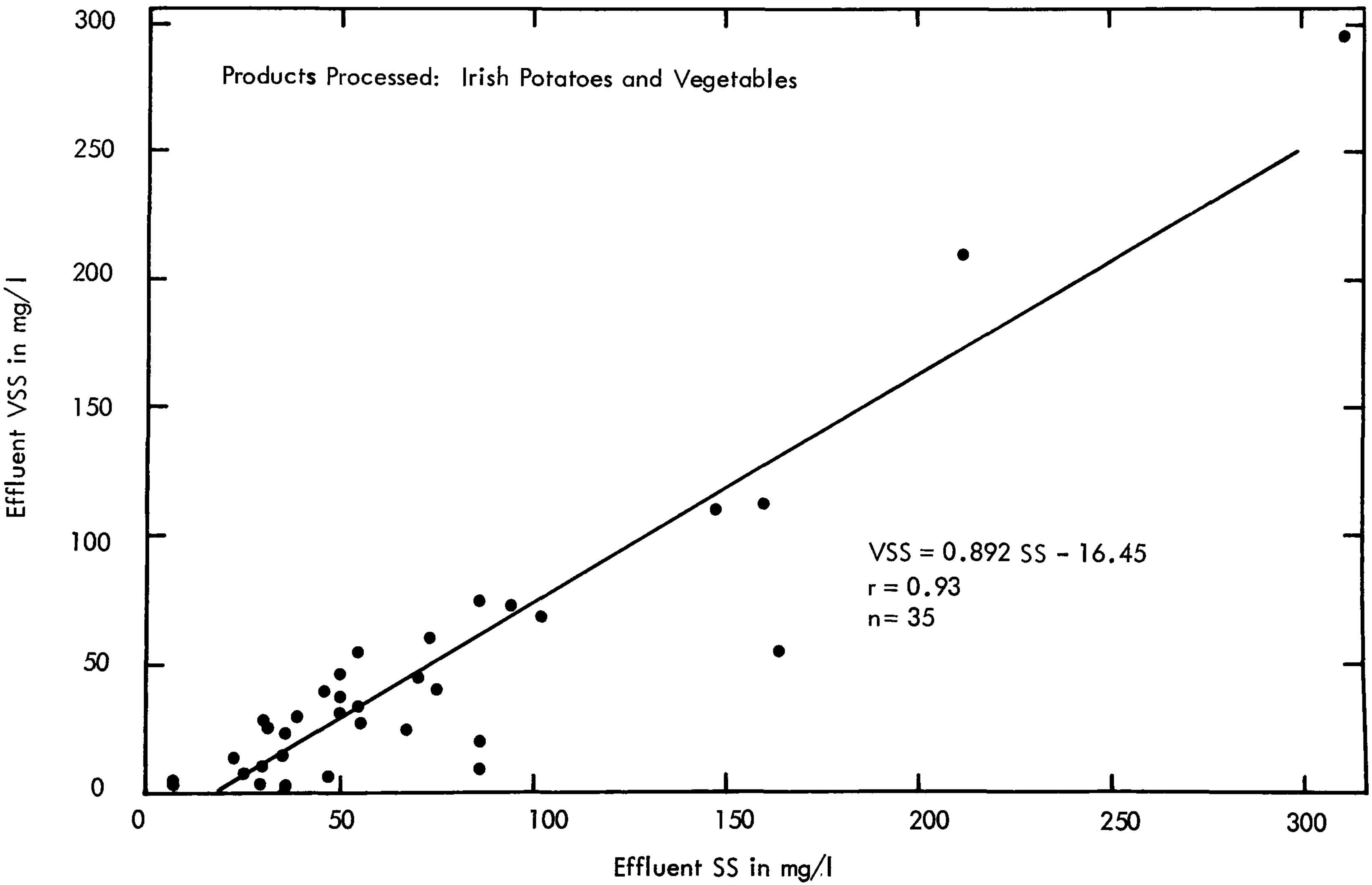


Figure E-42 Plant Effluent VSS vs SS

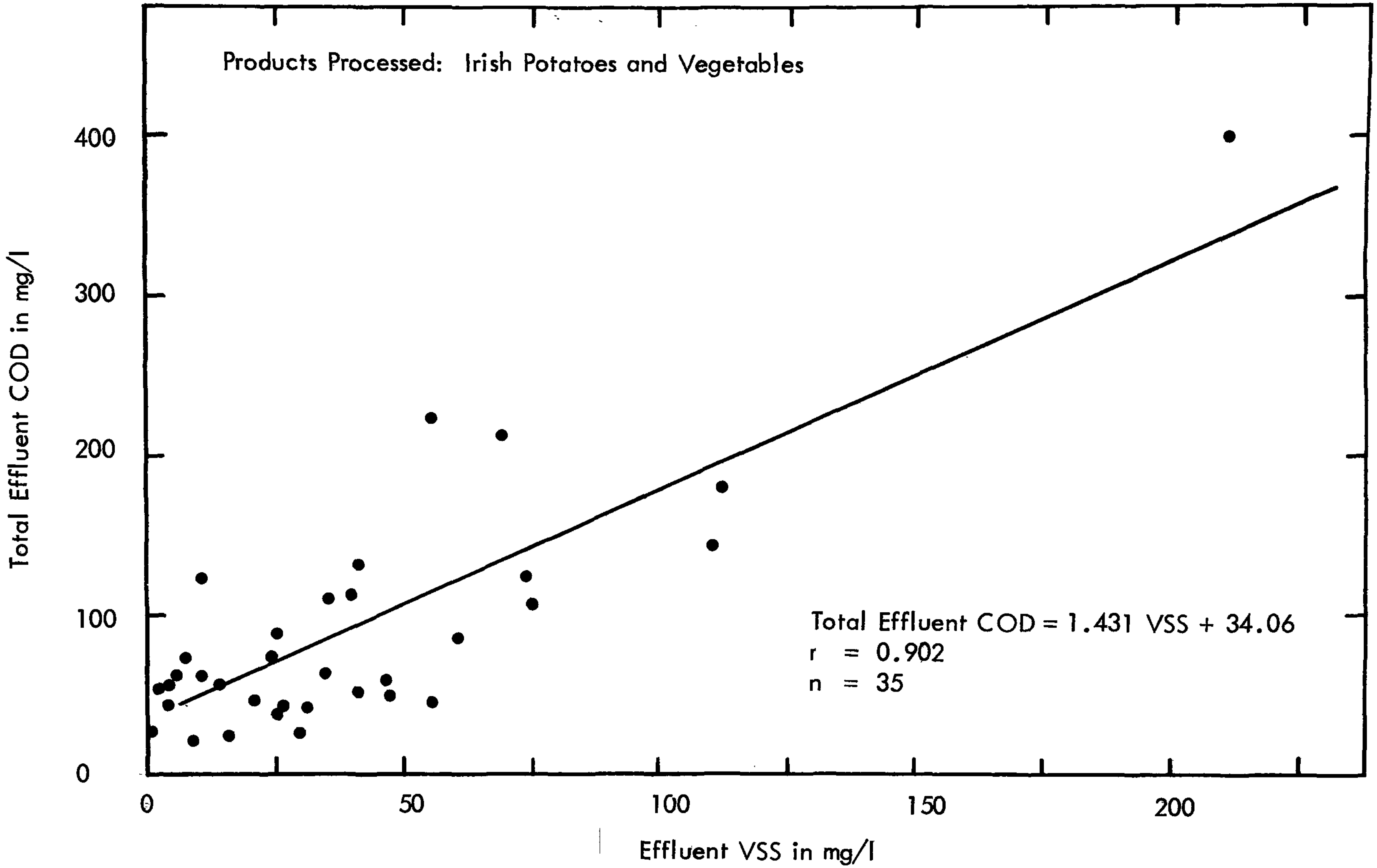


Figure E-43 Total Effluent COD vs VSS

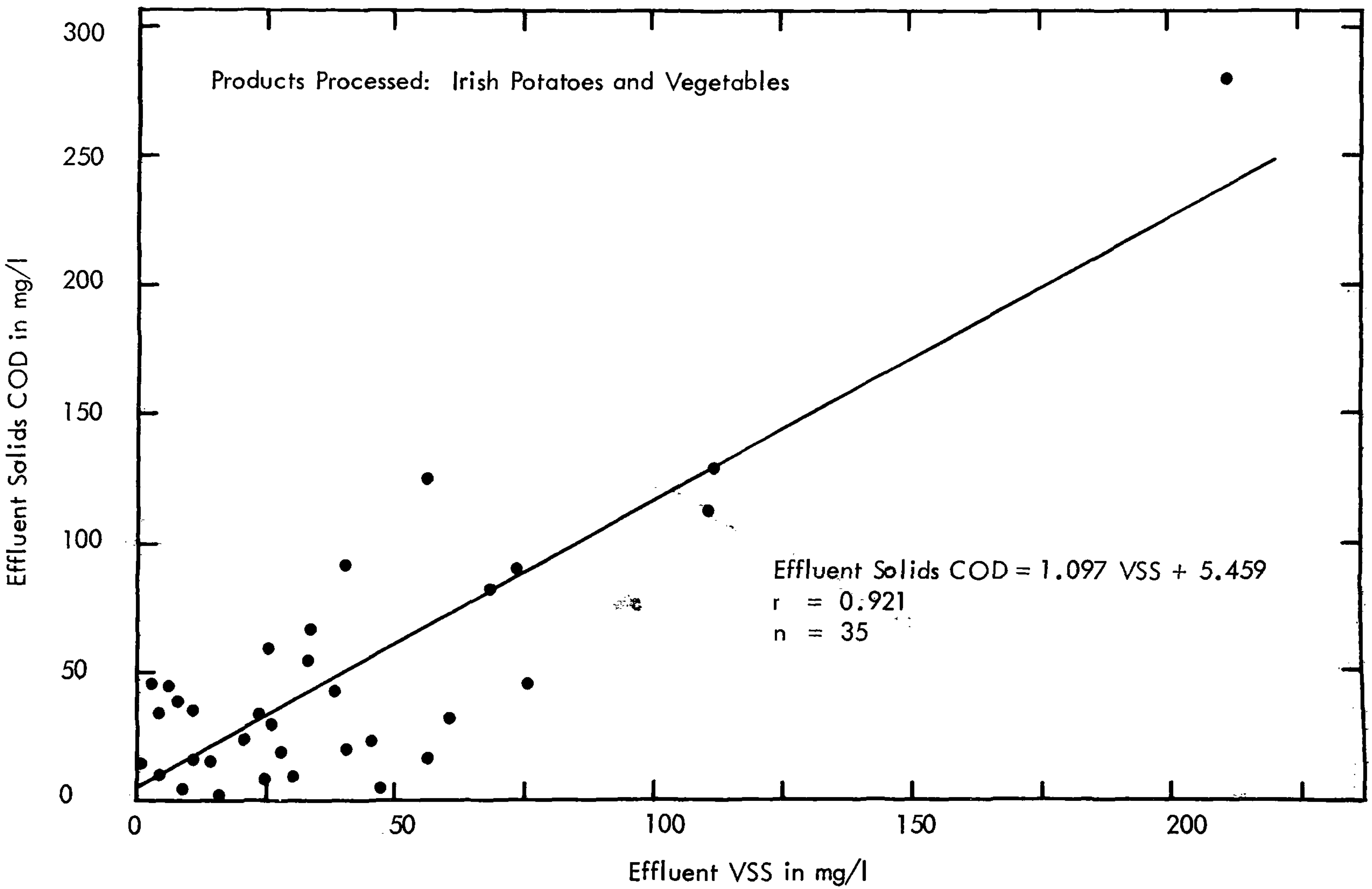


Figure E-44 Effluent Solids COD vs VSS

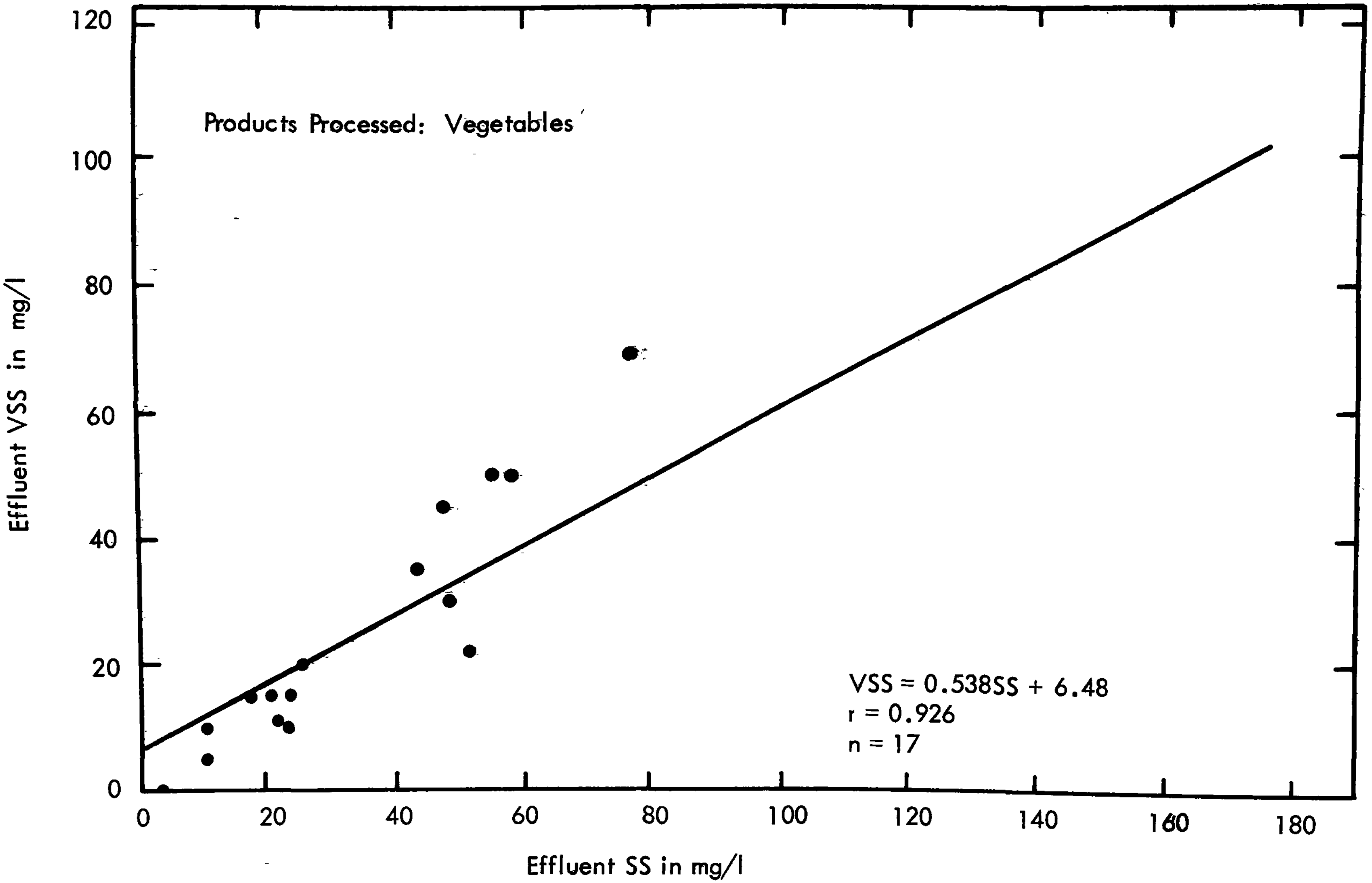


Figure E-45 Plant Effluent VSS vs SS

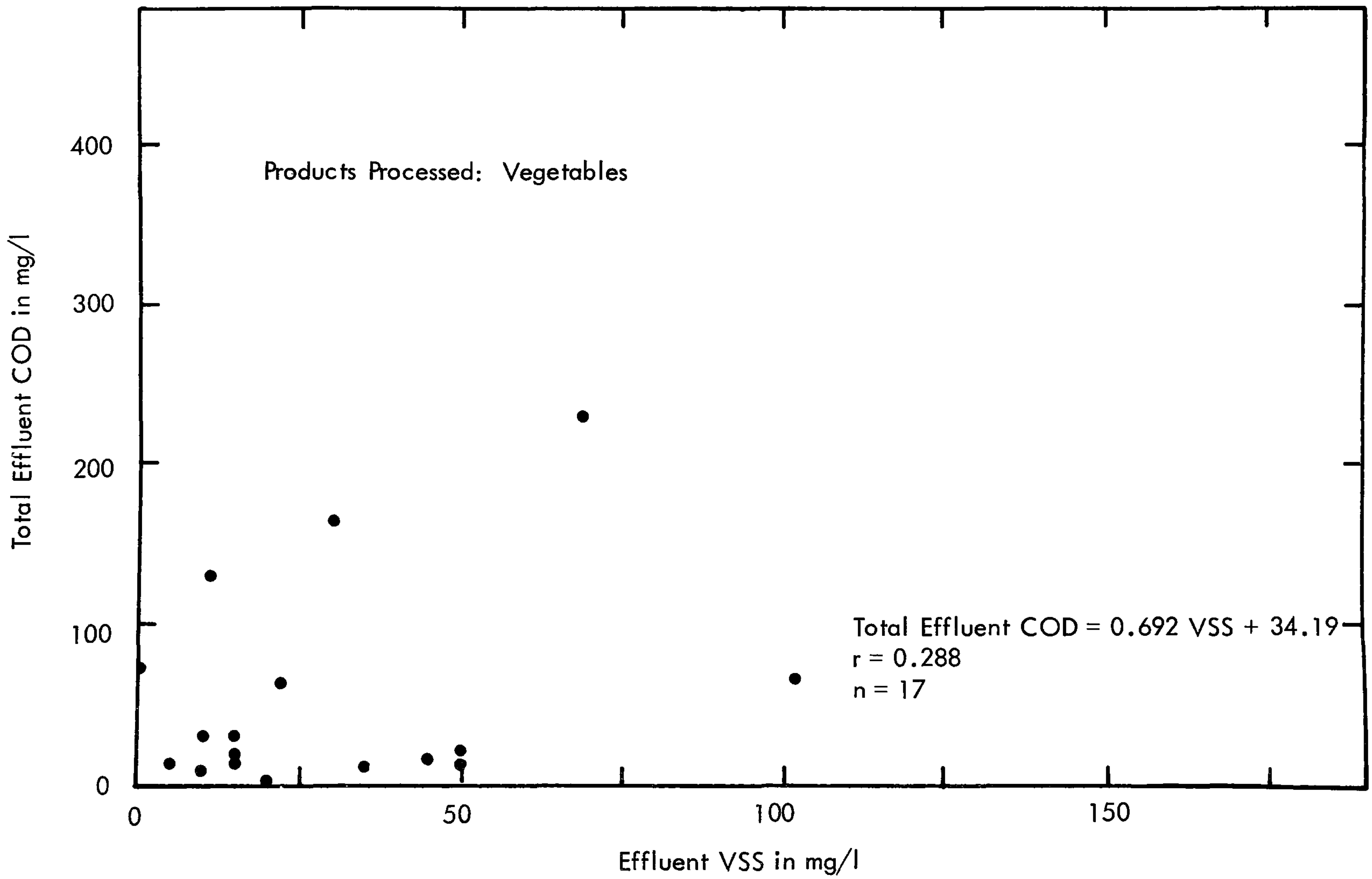


Figure E-46 Plant Total Effluent COD vs VSS

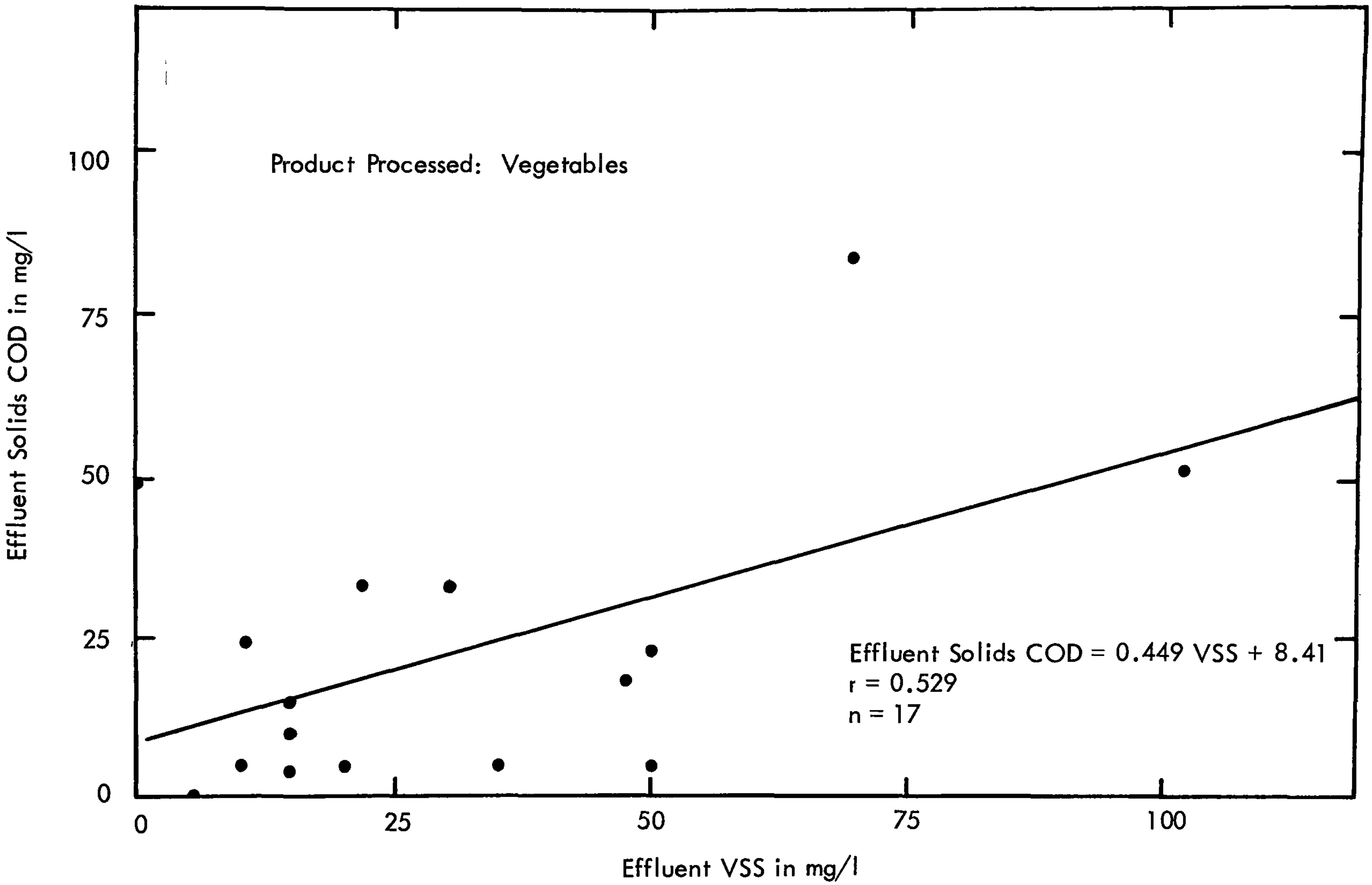


Figure E-47 Effluent Solids COD vs VSS

1	2 Subject Field & Group	
	05D	**SELECTED WATER RESOURCES ABSTRACTS** INPUT TRANSACTION FORM

5 *Organization*
University of Oklahoma Research Institute
Norman, Oklahoma 73069

6 *Title*
Demonstration of a Full-Scale Waste Treatment System for a Cannery

10 *Author(s)*
Streebin, Leale E.
Reid, George W.
Hu, Alan C.H.

16 *Project Designation*
EPA, WQO Contract No. 12060 DSB

21 *Note*

22 *Citation*

23 *Descriptors (Starred First)*
*Industrial Wastes, *Waste treatment, *Canneries
Aerobic treatment, Sanitary Engineering

25 *Identifiers (Starred First)*
*Food wastes, waste characteristics

27 *Abstract* The objectives in this study were to determine the removal efficiencies of a two-stage aerobic biological treatment system while processing high strength, large volume, nutritionally unbalanced cannery wastes, and to determine the waste characteristics resulting from the processing of a wide variety of fruits and vegetables.

The system was studied over one operating season and data collected on the removal efficiencies of each unit process in the system. The treatment system performed more efficiently than expected in the design assumptions. Removal efficiencies of greater than 95% were obtained for most of the processing season, even though because of plant expansion the organic and hydraulic load was higher than expected. It has been demonstrated conclusively that:

1. The Stilwell canning wastes can be treated successfully by a two-stage activated sludge process.
2. The two-stage aeration process is very stable and capable of accepting shock loads without being adversely affected.
3. The two-stage aeration process is a flexible system allowing adequate capacity for varying waste loads; that is, the units can be operated individually or in combination to match the flow and strength variations. This provides high treatment efficiencies at the lowest operational cost.
4. Any one of the units, such as the minimal solids unit, can be started up readily by recycling the mixed liquor from one of the operating units.

This report contains many figures and graphs and 43 references. (Streebin - University of Oklahoma)

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