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Land treatment and disposal of food processing wastes

P. G. HUNT, L. C. GLIDE, and N. R. FRANCINGUES

The food-processing industry is an enormously large and important aspect of contemporary life in the United States. It provides consumers with a varied selection of meats, vegetables, fruits, dairy products, and numerous other items. A virtual sea of canned, freeze-dried, frozen, and refrigerated items is available in neatly packaged and displayed containers. Yet, like most appealing phenomena, this attractively displayed food has less attractive waste disposal problems associated with its processing. Large amounts of water are required to clean and convey food items, and large quantities of solid waste are produced during food processing (*53*, *59*, *63*). The organic load of the wastewater is often extremely high as a result of a portion of such items as fruits, vegetables, poultry, or cheeses being swept into the processing or conveying waters (*19*, *62*). Wastewater often has high concentrations of nitrogen and phosphorus from food constituents and sodium from lye peeling (*42*). Cleaning operations also contribute to the nutrient load (*32*).

P. G. Hunt is supervisory research microbiologist, and N. R. Francingues is supervisory research sanitary engineer at the Environmental Effects Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi 39180. L. C. Gilde is director of environmental engineering for the Campbell Soup Company, Camden, New Jersey 08101.

The best and most obvious answer to waste product disposal is to collect and market the waste. This has been done in certain instances, but the unfortunate fact remains that, in general, a profitable market for waste products does not exist. Therefore, waste products must either be treated or disposed of in environmentally acceptable manners.

Considerable literature is available on conventional treatment of wastewater (*27*, *64*, *66*, *67*). Where the pollutant loads are reasonably uniform and the removal of organics and associated oxygen demand is the only requirement, conventional methods, such as trickling filters, extended air, and facultative lagoons, are very acceptable (*27*). In many instances, a municipal system with sufficient capacity to handle the processing wastewaters may be used for a fee that would be considerably less than the cost of constructing and maintaining a treatment facility. However, there are many instances where the great fluctuation in wasteload makes use of conventional systems impractical. In such locations land treatment systems are often the practical answer (*15*). In other cases the simple fact may be that a land treatment system can be constructed and operated more economically. Normally this condition exists in or close to rural areas.

Land application of solid wastes, such as manure and crop refuse, to agricultural land has been practiced and studied for quite some time, as have landfill disposal operations

(*8, 23, 25, 26, 37, 39, 51, 54, 55, 65*). The soil has a tremendous capacity to decompose and incorporate organic materials. Disposal of many solid waste products applied at reasonable rates has been accepted as an established practice. Additionally, the soil's capacity to remove and assimilate the organic portion of many liquid wastes has been well demonstrated.

In the past the primary problem encountered in land treatment of food-processing wastewater was hydraulic overloading. This remains one of the most common problems, but more restrictive discharge standards on waste treatment have focused attention on the short- and long-term removal of nutrients as well as organic material. Thus, at present a more detailed understanding of a particular land treatment site is required before a wastewater treatment system can be designed or operated properly.

However, an understanding of the land treatment system and its functioning components (plant, soil, and microorganism) is not sufficient to create a cost-effective, environmentally compatible system. Design and operation of a system that will produce the best treatment with the least cost also requires a thorough understanding of the products to be treated and the present and future discharge requirements. When the waste products are as variable as those of the food-processing industry, this fact is particularly critical. In-plant operations can make a system either function or fail. Sodium damage to crops and soil by less than judicious management of the lye-peeling operation or anaerobic odors and crop damage from excessive organic inputs from blood or paunch contents are examples of the in-plant factors that can greatly affect the performance of a land treatment system.

Various methods of conventional treatment can be used before wastewaters are applied to land. The combinations and potential benefits are numerous. Land treatment of wastewater or solids should be visualized as one part of a functioning system, and seldom will all aspects be the same for any two systems.

Waste Characteristics and Sources

Fruit and Vegetable Industry

The National Canners Association recently

Table 1. Total wastes from canned and frozen fruits and vegetables (*63*).

Product	Raw Product (10^3 tons)	Wastewater (10^6 gal)	BOD (10^6 lb)	Suspended Solids (10^6 lb)	Solids Residuals (10^3 tons)
Fruit					
Apple	1,050	2,200	38	6	290
Apricot	120	1,000	9	2	16
Cherry	190	400	5	1	26
Citrus	7,800	19,000	125	23	2,080
Peach	1,100	6,200	68	14	290
Pear	410	1,200	17	5	140
Pineapple	900	500	18	7	400
Other fruit	460	3,700	9	5	70
Fruit Subtotal	12,030	34,200	289	63	4,312
Vegetables					
Asparagus	120	1,300	1	1	42
Bean, lima	120	1,100	3	10	19
Bean, snap	630	4,800	14	9	130
Beet	270	1,000	26	14	90
Carrot	280	1,000	14	8	140
Corn	2,480	5,500	110	55	1,620
Pea	580	3,100	35	13	74
Pumpkin, squash	220	300	9	2	55
Sauerkraut	230	100	3	0	76
Spinach, greens	240	2,000	7	4	33
Sweet potato	150	400	15	6	
Tomato	5,000	14,500	70	35	400
White potato	2,400	8,200	110	130	910
Other vegetables	1,400	5,600	84	42	460
Vegetable subtotal	14,120	48,900	511	329	4,049
Total	26,150	83,100	800	392	8,561

Table 2. Characteristics of dairy-processing industry wastes (*2*).

	Receiving Station	Bottling	Cheese-Making	Creamery	Con-densery	Dry Milk	General Dairy
Gallons of waste per 1,000-lb daily intake	175	250	200	110	150	150	340
Character of waste	Whole milk washings	Whole milk washings	Whey, casein washings	Butter-milk washings	Spoiled milk washings	Spoiled milk washings	Casein, milk washings
Waste constituents							
Total solids (ppm)	1,141	1,483	1,528	2,422	2,793	2,407	1,483
Suspended solids (ppm)		536	751	664	754		536
BOD (ppm)	509	567	998	1,246	1,291	485	567
pH		5.3	7.0	7.7	7.8		5.3

estimated that the fruit and vegetable canning and freezing industry encompassed 1,838 plants employing 167,000 persons. Table 1 provides estimates of the raw products, biochemical oxygen demand (BOD), suspended solids, and solid residuals generated. Citrus, tomatoes, corn, and white potatoes (excluding dehydrated potatoes) account for 67 percent of the raw tonnage, 57 percent of the wastewater, 52 percent of the BOD, 62 percent of the suspended solids, and 72 percent of the solid residuals.

The major steps for water use as well as generation of solids and dissolved residuals are washing and sorting, peeling, blanching, and processing (*63*). The washing and rinsing of the new products constitute a major source of wastewater. The volume of water may be as much as 50 percent of the total used in process operations. Yet these treatments are necessary for removal of soil; microbial contaminants; extraneous matter, such as leaves or stems; and occluded materials that may remain after cutting, coring, peeling, or blanching.

Significant amounts of wastewater containing high concentrations of suspended organic matter are produced during the peeling operations. The amount of suspended solids varies with the type of peeling and whether or not the vegetables have been blanched or lye-treated prior to peeling. Caustic peeling and the subsequent wash also impart a high alkaline wasteload to the plant discharge. In poorly managed plants, periodic discharge of the entire caustic bath into wastewater streams creates very undesirable wastewater characteristics.

Blanching of raw foods is commonly practiced in order to expel gases from vegetables, to wilt beans and rice, to inactivate enzymes, and to prepare products for easy placement into cans. Since little freshwater is added to the blanching operation over a normal 8-hour shift, the concentration of sugars, starches, and other soluble materials becomes high. Although small in volume, the blanch water frequently represents the largest portion of the soluble components in the liquid wastes of an entire food-processing operation.

The final major source of liquid wastes is the cleanup water produced from washing equipment, utensils, cookers, floors, and general food-preparation areas. Cleanup periods after production will normally alter the characteristics of the waste since a great deal of caustic is used, thus increasing the pH considerably above the normal character obtained when the plant is in regular operation.

The preparation of foods for freezing, starting with the planting of seeds, harvesting of crops, washing, blanching, and all other preparatory procedures, is the same as for canning with the exception of the final step of preservation. In canning preservation is accomplished by heat sterilization. In freezing, refrigeration techniques are used.

Dairy Products Industry

The dairy products industry is regularly engaged in the processing of whole milk into such items as homogenized pasteurized milk, nonfat dry milk, butter, cheese, and ice cream. Since milk is a highly perishable commodity, causing most processing plants to be located near the farm milk supply, the industry is widely spread throughout the United States.

Most dairy wastes can be categorized according to their sources as being cooling waters, spoilage and by-products, cleanup waters, or poor processing operations. Cooling waters are uncontaminated and include water condensated from vacuum pans and water from boilers and ice machines. Spoilage and by-product waters consist of unusable raw products and the products spoiled during processing and manufacturing. Buttermilk, skim milk, and whey are major sources of dairy waste. In 1968, for example, the dairy industry produced 21 billion pounds of liquid whey and dumped approximately 14 billion pounds of that amount in the sewer as waste (*9*). Cleanup waters are comprised of wash water from cans, tank trucks, equipment, and floors. The final waste source, poor processing operations, is engendered by improperly maintained equipment or careless process operations. These include spillage, freeze-on, overflow, and leakage.

As in other food-processing operations, the volume and characteristics of dairy wastewaters depend primarily on the type of plant, the availability and cost of water, and water conservation practices employed by management. Typical volumes of waste produced per 100 pounds of daily intake range from 110 gallons for a creamery to 340 gallons for a general dairy. Table 2 summarizes the volumes and characteristics for several types of processing plants. A recent wastewater survey of a multiproduct dairy revealed that 325.5 gallons of water were used per 1,000 pounds of product, resulting in BOD, suspended solids, and fat loads of 7.35, 3.59, and 2.34 pounds, respectively (*14*).

Typically, dairy wastes are slightly alkaline ($7 \leq pH \leq 9$). However, through fermentation of the lactose sugar to lactic acid and simultaneous formation of butyric acid, dairy wastes tend to become acidic rather rapidly. Casein-plant and cheese-plant wastes are notably acidic ($4.5 \leq pH \leq 6.5$) because of the whey. Dairy wastes are almost all easily degradable, highly organic wastes with few suspended solids. When discharged into a receiving stream, they impose an immediate oxygen demand.

Poultry-Processing Industry

Poultry production in federally inspected plants (90 percent of total U.S. production) increased from 8.1 to 12.9 billion pounds (live weight) between 1961 and 1970 (*59*). Whole turkeys and young chickens accounted for 93 percent of the total production in 1970.

A large volume of water is used in receiving, killing, scalding, eviscerating, cooling the whole birds and parts, transporting wastes, and general cleaning. Significant amounts of soluble and suspended organic matter enter processing water, resulting in high-strength, biologically degradable wastes. A 1970 survey of 368 federally inspected plants revealed the use of an estimated 27.3 million gallons of water.

It is common practice to store live poultry after delivery to the plant for a short time in a receiving area. The feathers, manure, and dirt that accumulate may contribute from 32 to 36 pounds of BOD per 1,000 birds a day. This wasteload can be reduced substantially by dry cleaning the solid wastes, with subsequent disposal as refuse or incorporation into offal.

The first major processing operation is killing. Chicken blood has an approximate BOD of 92,000 parts per million and may contribute an organic loading of 17 pounds of BOD per 1,000 chickens. In modern plants much of the free-draining blood is collected in troughs under the conveyor lines. The blood is allowed to congeal and then is removed as a semi-solid to be sold for rendering. Collection of the blood may reduce the total wastewater strength by 35 to 40 percent (*59*).

After bleeding, the birds are scalded to loosen the body feathers and provide a first wash of the carcasses. Overflow wastewater from the scalding tank contains significant amounts of blood, feathers, dirt, manure, and fats and grease. The BOD of the scalder water has been reported to be 1,182 parts per million (*19*), with suspended solid and grease contents of 682 and 350 parts per million, respectively. Table 3 shows wastewater characteristics generated during the different processes in a poultry plant.

Immediately following scalding, a continuous stream of water washes the feathers from the carcasses to a flume where they are flushed to a central collection facility. Considerable wastewater is generated in the defeathering process and the subsequent washdown of floors and equipment during cleanup (*19*). However, a significant reduction in water use can be achieved by screening the wastewater for removal of the feathers and reuse of the screened water in the feather flume where there is no direct contact with the poultry product. In any case,

Table 3. Wastewater characteristics of different processes in a poultry plant (*10*).

Process	BOD (ppm)	COD (ppm)	Solids (ppm) Total	Dissolved	Suspended	Grease (ppm)
Scalder entry	1,182	2,080	1,873	1,186	587	350
Scalder exit	490	986	1,053	580	473	200
Whole bird wash	108	243	266	185	81	150
Final bird wash	442	662	667	386	281	580
Giblet chiller	2,357	3,959	2,875	1,899	976	1,320
Chiller I	442	692	776	523	253	800
Chiller II	320	435	514	331	183	250
Feather plume	590	1,078	894	382	512	120
Eviscerating plume	233	514	534	232	302	430
Plant effluent	560	722	697	322	375	150

Table 4. Annual total slaughter and pre-catch basin gross wasteloads and wastewater volumes (*61*).

Year[a]	Total Commercial Slaughter (10^9 lb/yr)	Wasteload per Unit (lb BOD/ 10^3 lb LWK)	Wastewater per Unit (gal/10^3 lb LWK)	Total Wasteload (10^9 lb BOD/yr)	Total Wastewater per Year (MGY)
1963	50.8	21.32	1531	1083	77,806
1966	54.9	18.73	1322	1028	72,578
1967	57.0	18.73	1322	1068	75,354
1968	60.2	18.73	1322	1128	79,584
1969	61.4	18.73	1322	1151	81,171
1970	62.8	18.73	1322	1176	83,022
1971	63.9	18.73	1322	1197	84,476
1972	65.2	18.73	1322	1221	86,194
1977	71.6	17.13	1205	1227	86,278

[a] Statistics for 1963, 1966, and 1967 are values of record for the selected years; projected values are shown for 1968 through 1977.

screening of the wastewater used in defeathering is important to avoid overloading the waste disposal system with the high volume of feathers involved.

After defeathering, the birds move into the evisceration area where water is used to flush the inedible viscera and heads into a flow-away flume system. The last step in the eviscerating area consists of a thorough washing of the inside and outside of the birds before federal inspection. Water use in the eviscerating flume reportedly accounts for 24 percent of a plant's freshwater supply (*19*). Typically, flume water has a flow of 3.1 gallons of water per bird. Gizzard cleaning requires another 3 gallons per bird, for a combined flow of 6.1 gallons per bird.

The wastewater generated in this operation contains the inedible portions of the bird in addition to blood, flesh, fat, grease, and sand and silt. Although the wastewater is screened to recover the by-products, the screened effluent still contains considerable amounts of suspended and soluble organic matter. The wastewater has a BOD content of 230 parts per million, and its large volume represents 40 to 50 percent of the BOD load in the plant effluent.

The final step in poultry processing is chilling the birds before shipment. Removal of body heat at this point is important because rapid cooling prevents bacterial decomposition, thus lengthening the market life and ensuring the proper flavor. The wastewater generated in the chilling operation contains fats, grease, blood, and meat tissues. This waste load accounts for 8 percent of the BOD load and contributes a major share of the grease load in the plant effluent. The BOD in a two-stage body chiller reportedly was 442 parts per million and 320 parts per million in the first and second chillers, respectively, while the BOD of giblet chill water was 2,357 parts per million with a grease content of 1,320 parts per million (*19*).

Meat Packing Industry

The meat-packing industry includes all plants engaged in slaughtering and/or processing of "red meat" animals. Over 4,000 plants are operating, producing 55 billion pounds of fresh, canned, cured, smoked, and frozen meat products a year. These plants vary greatly in size, ranging from small plants where the annual live weight kill (LWK) is less than 25 million pounds to large plants with annual kills of 200 million pounds or more.

In 1967 the meat-packing industry generated a gross wastewater volume of 75 billion gallons a year; this wastewater contained 1.03 billion pounds of BOD (*20*). Table 4 shows the total slaughter, gross wasteloads, and wastewater volumes for selected years between 1963 and 1967 and projections to 1977. These wastewater loads represent the raw wastewater loads prior to any treatment (pre-catch basin). The wastewater is generally characterized as being highly organic with relatively high concentrations of nitrogenous compounds, suspended and dissolved solids, and grease.

The first waste source location is where the cattle, hogs, sheep, and calves are held before they are immobilized by chemical, electrical, or mechanical means prior to entering the kill area. After immobilization, they are suspended by their hind feet for sticking and bleeding. Blood is collected in a trough underneath the conveyor. Cattle hides are removed mechanically. Hogs are not skinned, but hair is removed by scraping after the animals are scalded. The viscera are removed and separated into edible and inedible products. The paunch or first stomach of ruminants (cattle, calves, and sheep) is opened and the contents removed. Washing the carcass and internal organs takes place throughout the meat-packing process. The carcasses are further processed into different meat products. Meat-packing plants generally render edible fats into lard and edible tallow. Inedible fats are rendered into grease.

Blood constitutes a major source of BOD in the meat-packing process. The average weight of blood generated per beef (at 1,100 pounds LWK) has been reported to be 32.5 pounds, with a mean BOD of 156,500 parts per million (*62*). This results in a contribution of 4.67 pounds BOD per 1,000 pounds kill weight. Failure to recover the blood significantly increases the plant effluent BOD (*61*).

Discharge of paunch contents into the plant waste stream also increases the solid and organic loadings. The paunch content of cattle weighs an estimated 40 to 60 pounds per animal and consists of partially digested hay, grass, and corn. The BOD of rumen was estimated at 50,200 parts per million, which contributes 2.49 pounds of BOD per 1,000 pounds kill weight (*62*). Older plants discharge paunch contents directly into the sewer. However, most plants flush these wastes into a flowing stream of water that passes over vibrating or rotating screens. The separated solids are then trucked away for land disposal. The screened effluent, which contains significant amounts of suspended and dissolved solids, then passes into the plant effluent.

Another major source of organic loadings in plant effluent is the wet rendering process. The tank water that remains after the fats are drawn off and the suspended solids removed is discharged into the sewer. This tank water contains about 75 percent of the total protein content of rendering input and is a major source of BOD. The estimated average BOD of tank water is 32,000 parts per million. Some plants concentrate tank water by evaporation to about 35 percent moisture, then sell it as protein supplement. However, as much as 50 percent of the protein content is still lost to the sewer.

Solid Waste from Food Processing

All the screening, settling, and drying steps used to reduce wastewater loads directly increase solid waste production. Studies by the National Canners Association show that processing 100 pounds of raw foods for the American consumer produces about 36 pounds of waste materials. An average of 18 of these 36 pounds of waste is recovered as animal feed or by-products. Generally, only 10 percent of the raw food must be handled and disposed of as wet solid waste.

The canner's role in preserving raw foods is certainly noteworthy. If this entire food processing were done in the home instead of commercially, the 36 pounds of waste would be discharged into the sewer or handled as garbage. This would compound disposal problems and result in the loss of the 50 percent commercial recovery of waste. Table 5 shows the pounds of solid wastes produced in the processing of 100 pounds of various foods and the amount of by-product versus the final solid waste to be disposed.

Table 5. Production and disposal of solid waste from processing 100 pounds of selected foods (*16*).

Product	Total Waste Produced	Used as By-product	Handled as Solid Waste
		(lb)	
Apples	30	20	10
Beans, green	20	9	11
Beets, carrots	53	30	23
Citrus	50	45	7
Corn	65	62	3
Crab, shrimp	72	8	64
Fish	36	22	14
Olives	14	12	2
Peaches	27	5	22
Pears	36	9	27
Peas	13	9	4
Potatoes (white)	49	28	21
Tomatoes	12	2	10
Vegetables (Misc.)	32	13	19

Problems and Standards

Wastewater Problems

For 1964, the food industry discharged an estimated 688 billion gallons of water. This accounted for nearly 5 percent of the total industrial water discharged in the United States, excluding that from thermal electric power plants. The pollution problems associated with this massive use and discharge of water include, in descending order of severity, the following:

a. Copious quantities of potable water are used for food washing and processing, resulting in wastewaters containing significant amounts of oxygen demanding materials, biostimulating nutrients, and suspended solids.

b. In many instances, waste treatment needs are commensurate with seasonal production peaks.

c. Waste effluents are categorized as highly putrescrible; therefore, storage time is minimal.

d. Coloring of effluents through food processing necessitates treatment.

Food-processing wastes generally contain readily biodegradable organic matter in varying concentrations. Most are nontoxic to microorganisms, but some wastes are deficient in nutrients (nitrogen and phosphorus). When wastes of this nature are discharged into natural watercourses, the inevitable biological process of "waste assimilation" is triggered. Flora and fauna flourish. Greater amounts of oxygen are required for the increased metabolic rates, growth, and reproduction. In many instances, oxygen supplies are insufficient to accommodate the demand, and herein lies the overwhelming pollutional problem.

Rapid depletion of the available dissolved oxygen forces the ecosystem into an anaerobic state, and water does not have the buffering components of iron and manganese that are present in soil and sediment. Extreme reducing conditions can occur rapidly. This, in turn, leads to formation of objectionable by-products, such as hydrogen sulfide, methyl mercapton, and indole. More importantly, it kills aerobic organisms, such as fish.

It has become rather obvious, therefore, that some form of treatment is needed prior to discharge of food-processing wastewater. The type of treatment selected depends upon factors such as the composition and concentration of the organic waste, flow quantity, variations (daily and seasonal), the level of treatment required, and the economics of respective wastewater treatment methods.

Wastewater Treatment Standards

The Federal Water Pollution Control Act Amendments of 1972--Public Law 92-500--established effluent standards for privately owned as well as publicly owned facilities. Performance and pretreatment standards for all major categories of industries have been or are presently being developed. For existing point sources, Section 301(b) of the act requires that best practical control technology currently achievable (BPCTCA as defined by EPA) will be the effluent limitation by July 1, 1977. It also specifies that by July 1, 1983, effluent limitations will require the application of the best available technology economically achieveable (BATEA) that will result in reasonable progress toward the national goal of eliminating the discharge of all pollutants.

Section 306 of the act requires new point sources to achieve the greatest degree of effluent treatment through the application of best available demonstrated control technology, processes operating methods, or other alternatives, including, where practical, a standard permitting no discharge of pollutants.

Fruit and Vegetable Freezing and Canning Industry. Interim effluent limitations and guidelines and proposed performance and pretreatment standards were set forth in the *Federal Register* (*3*). This industry was divided into three discrete subcategories for the purpose of establishing effluent limtations: (a) canned and preserved fruits, (b) canned and preserved vegetables, and (c) canned and miscellaneous specialties. This breakdown takes into consideration the raw material processed, organic and volumetric wasteload, processing operation, and plant processing capacity. Process capacity received special considerations because of the size relationship to potential environmental impacts. In early 1976, plant sizes were equated as small (0 to 2,000 tons per year), medium (2,000 to 10,000 tons per year), and large (more than 10,000 tons per year).

No limitations have been established at this time for small plants. In general, however, all three subcategories have effluent limitations placed on BOD_5, total suspended solids, and pH. BOD_5 and total suspended solids are restricted for maximum any one-day load, average daily load for 30 consecutive days, and annual average of daily values for entire discharge period (pounds per 1,000 pounds of final product). The limitations on pH have been placed on values at all times to be between 6.0 and 9.5. Additional restrictions are placed on oil and grease for the canned and miscellaneous specialty subcategory (not more than 20 parts per million).

Standards of performance for new sources and pretreatment standards for existing sources require, in addition to the above limitations, limitations on fecal coliform (most probable number not to exceed 400 counts per 100 milliliters).

Table 6 presents typical examples of the effluent limitations. No attempt was made to present all the standards for each industry because of the quantity of data involved. Refer to the *Federal Register* for a thorough discussion and complete list of these standards.

Dairy Products Industry. Effluent limitation guidelines for standards of performance and pretreatment standards for new sources for the dairy products industry point source category were published in the *Environment Reporter* (*4*). The industry has been subdivided into twelve major subcategories for the purpose of establishing selected standards and limitations. The plant subcategories include receiving stations, fluid products, cultured products, butter, cottage cheese and cultured cream cheese, natural and processed cheese, fluid mix for ice cream and other frozen desserts, ice cream, frozen dessert novelties and other dairy desserts, condensed milk, dry milk, condensed whey, and dry whey. Standards are established for plants according to either the milk equivalent of the delivered or processed product or the pounds per day of BOD_5 input to the plant.

Table 6 presents examples of dairy product effluent standards and maximum limitations for any one day. These standards address BPCTCA and BATEA in terms of BOD_5. total suspended solids, and pH. The standards for new sources are the same as those for BATEA.

Poultry-Processing Industry. Proposed performance and pretreatment standards for new sources are outlined in the *Federal Register* (*6*). These are tended to complement the pretreatment standards proposed for existing sources.

The poultry-processing segment of the meat-processing industry was subcategorized as follows: (a) chicken processor; (b) turker processor; (c) fowl processor; (d) duck processor;

and (e) further processing. The raw wastewater from all subcategories is high in organic matter and nutrients. The parameters of particular importance include BOD_5, total suspended solids, oil and grease, pH, nutrients (phosphorus and ammonia), and fecal coliform.

Effluent limitations set for BOD_5, total suspended solids, and oil and grease are expressed in terms of a unit weight per thousand live kill weight for the maximum daily and average daily values of 30 consecutive days. Additional limitations are placed on pH (6.0 to 9.0) and fecal coliforms (maximum at any time of 400 most probable number per 100 milliliters). For processors conducting by-product rendering or further processing, formulas are used to derive an additive adjustment factor to the effluent limitations on BOD_5, total suspended solids, and oil and grease. In addition to weight per thousand kill weight limitations, all categories have ppm effluent limitations on ammonia. This is generally set at a maximum of 8.0 ppm for any one day and 4.0 ppm for average daily values for 30 consecutive days.

Table 7 gives examples of maximum one-day poultry standards by subcategory. These include standards for BPTCA, new sources, and BATEA.

Meat Packing Industry. The standards and limitations discussed in this section apply to discharges from the red meat processing industry. The subcategories of this industry addressed in the *Environment Reporter* include simple and complex slaughterhouses and low- and high-processing packinghouses (*5*). Meat-packing wastes are typically classified as being highly colored (redish and brown), highly nitrogenous, and laden with significant quantities of organic and suspended matter. The standards that apply to all subcategories include limitations of BOD_5, total suspended solids, oil and grease, ammonia-nitrogen, pH, and coliforms. Table 7 lists examples of effluent standards for the maximum daily load. Limitations on NH_3-N only apply to new sources and BATEA.

Solid Waste Problems

Solid wastes are the second most important pollution concern of the food industry, the involvement of which extends from the farm to the consumer. This is abundantly clear when considering the solid wastes produced in the growing and harvesting of raw crops, processing food, and retailing and consuming the final product.

Table 6. Examples of standards for effluent from fruit, vegetable, and dairy industries (*3, 4*).

		Maximum for Any One Day, lb/1,000 lb[a]			
		BPTCA by July 77		BATEA by July 83	
		BOD	TSS	BOD Medium	TSS Medium
Canned and preserved fruits					
Apricots		2.98	4.68	0.977	1.928
Olives		5.31	8.64	1.826	3.564
Plums		0.68	2.82	0.233	0.437
Raisins		0.41	0.72	0.165	0.383
Canned and preserved vegetables					
Beets		0.81	1.55	0.375	0.919
Carrots		1.73	2.91	0.810	1.665
Dry beans		2.46	3.92	1.193	2.228
Lima beans		3.64	5.64	1.457	2.681
Condensed milk					
BOD_5 input	>10,390 lb/day	0.345	0.548	0.076	0.095
	<10,390 lb/day	0.460	0.690	0.115	0.144
Dry whey					
BOD_5 input	>15,620 lb/day	0.100	0.150	0.022	0.028
	<15,620 lb/day	0.130	0.195	0.033	0.041
Butter					
BOD_5 input	>18, 180 lb/day	0.138	0.206	0.016	0.020
	<18,180 lb/day	0.183	0.274	0.025	0.031
Cottage and cultured cream cheese					
BOD_5 input	>2,600 lb/day	0.607	1.005	0.148	0.185
	< 2,600 lb/day	0.893	1.339	0.223	0.278

[a] pH between 6.0 and 9.5 at all times.

Table 7. Examples of standards for effluent from poultry and red meat processing industries (*5, 6*).

	Maximum for Any One Day[a]							
	BPTCA by July 1977, New Source				BATEA by July 1983			
	BOD_5	TSS	Oil and Grease	NH_3-N[b]	BOD_5	TSS	Oil and Grease	NH_3-N
Duck processing								
lb/1,000 lb	1.54	1.80	0.52	0.52	0.78	0.92	0.52	-
ppm @ 2,000 gal/1,000 lb	92_e	108_e	31_e	31_e	47_e	55_e	31_e	8
Chicken processing								
lb/1,000 lb	0.92	1.24	0.40	0.40	0.60	0.68	0.40	-
ppm @ 2,000 gal/1,000 lb	55_e	74_e	24_e	24_e	36_e	41_e	24_e	8
Red meat-simple slaughterhouse								
lb/1,000 lb	0.24	0.40	0.12	0.34	0.06	0.10		
ppm @ 650 gal/1,000 lb	44_e	74_e	22_e	62_e	13_e	23_e	10	8
Red meat packinghouse								
lb/1,000 lb	0.48	0.62	0.26	0.80	0.16	0.20		
ppm @ 1,500 gal/1,000 lb	39_e	50_e	20_e	64_e	16_e	20_e	10	8

a pH limit is 6.0 to 9.0 at all times. Fecal coliform maximum limit at any time is 400 most probable number per 100 ml.

b Standard for new sources only

In some states, such as California, agriculture is by far the largest producer of solid wastes. The tonnage of stalks, leaves, and cull foods left in the field or orchards (13.1 million tons) far exceeds the solid wastes produced during food processing (2.1 million tons) (estimates by the University of California Division of Agricultural Sciences). Table 8 presents an estimate of the solid wastes produced by various food processors in California.

At the processing plant, there are many areas in which food wastes, including by-product considerations, could be reduced in volume or reused. Examples are the production of alcohol from fruit wastes and the compacting of fruit waste solids. Looking at the matter economically, however, the reclaiming of waste and by-products in some cases is as far away from accomplishment today as it was 10 or 20 years ago. In most cases it is simply cheaper to dump, landfill, spread on the land, burn, or discharge at sea rather than attempt the more costly approach of reclamation. One has to conclude that many socioeconomic factors are actively countercurrent to technological attempts to reclaim wastes.

With today's competitive market, there appears to be little chance of a change in the immediate future unless prevailing economic conditions can be altered by legal restrictions or some form of subsidy. The problem is compounded by the lack of international standards or regulations. If an American food processor is to incur an added expense for waste disposal, he may not be competitive with foreign operations. Thus, there is a considerable amount of land disposal occurring, with every likelihood that there will continue to be a significant need for land disposal of soil wastes from food processing.

We will not address standards for solid waste disposal here because they are not well-defined and they relate closely to the method of disposal. For instance, if disposal is in conjunction with a municipal landfill, the standards would be those regulating the landfill operation. If spreading and incorporation into agricultural land were used, however, the standards would be those governing the application of wastes to agricultural land.

Methods of Land Treatment With Wastewater

Since soils can accommodate moderate organic loads, the limiting factors in a land treatment system for liquid wastes from food processing are the hydraulic and inorganic loads. In this regard, we prefer to classify land treatment systems according to their hydraulic characteristics. This allows land treatment systems to be visualized on a hydraulic continuum, with different methods associated with different ranges of hydraulic loading. Three methods are commonly used: overland flow (surface flooding), slow infiltration (crop irrigation), and rapid infiltration (aquifer recharge) (*44*). These methods depend, in various degrees, on three components: soil-organic matter, plants, and microorganisms. Each type of system must be maintained and operated in a manner that will allow use of these components

Table 8. Solid wastes[a] from food-processing industries in California, 1967 (*16*).

Industry	Tons of Solid Waste
Fruit and vegetable (fresh pack)	409,500
Canning of foods	750,000
Freezing of foods	170,000
Meat processing	100,000
Other processed foods	197,500
Misc. food processing	500,000
Total	2,127,000

[a] Solid wastes left in the field or orchard, estimated to be 13.1 million tons, are not included.

in association with the system's hydraulic conditions. The operational conditions may be referred to as system principles or operational criteria. In either case, they must be understood and followed in order to have a land treatment system that will accept the hydraulic load and treat both the organic and inorganic components of food-processing wastewater.

Pretreatment of Food-Processing Wastewater

Before applying wastewater to the land, it is extremely important to screen the wastes. This removes large solids. In cases where excessive quantities of grease, fats, and oils are present, a gravity grease separator is a minimum. Screening ensures that the small nozzles used for applying the wastewater uniformly on the land remain open and continue to rotate. Screening also prevents excessive applications of organic solid wasteloads to the land. Normally, very fine mesh screening is unwarranted unless there is some need to further reduce the solids loading to the fields. Practical experience indicates that screens with 2/100- to 3/100-inch openings provide a sufficient hydraulic through flow rate while simultaneously removing the major proportion of solids that can be a problem.

Grease can also be a limiting factor in land application. For this reason, at least a minimum of gravity grease separators should be used to remove free-floating grease and oils. At application rates under 1/2 inch per day, grease concentrations below 350 ppm are not normally a limiting factor. As concentrations of grease exceed 500 ppm, the application rates for some systems may have to be reduced.

Wastewater should be treated as rapidly as possible. If this is not done, the wastewaters that are readily biodegradable will become anaerobic and cause secondary odor problems when applied to the land.

Overland Flow

Where soil permeability is very low, wastewater can be treated on land by the overland flow method. The hydraulic loading rate must be low, however, in order to obtain the residence time on the soil surface necessary for removal of both the organic and inorganic constituents. Normally the loading rate is 1/2 to 2/3 inch per 6- to 18-hour period. Fortunately, wastewater may be applied for several days, normally five, before a rest period is necessary (*32*, *33*). Thus, a weekly application rate of about 1.7 to 3.3 inches per acre can be obtained. This rate is competitive with the rate for a slow infiltration system. Table 9 lists several overland flow systems.

Overland flow treatment was first used in Napoleon, Ohio, by the Campbell Soup Company (*22*). The concept of overland flow, however, was discovered by accident in the early 1950s. Company officials made the discovery while augmenting their trickling filter facility with a land treatment system to accommodate peak loads from tomato-processing and soup manufacturing plants. The soup plant had an approximate wasteload of 1.5 million gallons per day for 10 months. The tomato plant reached peaks of about 6 million gallons per day. The soil in the area varied from silt to clay loam, and initial pilot studies produced good results. However, the wastewater loads in 1954 and 1955 were excessive, causing runoff and ponding to occur. These conditions normally would have been classified as system failure. Fortunately, it was discovered that in certain areas where the

Table 9. Selected overland flow systems (*17*).

	Average Flow (mgd)	Field Area (acres)	Average Application Rate (in/day)	Soil Type
Hunt-Wesson Foods				
Davis, California	3.2	250	0.50	Clay loam
Campbell Soup Company				
Chestertown, Maryland	0.7	70	0.40	Clay
Napoleon, Ohio	4.0	335	0.45	Silty clay
Paris, Texas	3.5	385	0.35	Clay loam

Table 10. Treatment performance on a mass basis, Napoleon System, 1964-1965 (*11*).

	Percent Reduction	
	Watershed I	Watersheds II and III
COD	95	81
BOD	-	85
Total nitrogen	93	73
Phosphates	84	65
Suspended solids	97	89

wastewater flowed over the soil surface in a uniform, thin film, BOD was reduced by more than 90 percent.

C. W. Thornwaite was then asked to design a full-scale overland flow system at Napoleon. (Thornwaite had also discovered the concept, but referred to it as grass filtration, as do the Australians.) A system was also constructed at Chestertown, Maryland, for year-round treatment of 0.5 million gallons per day of poultry wastewater.

After operating for several years, the Napoleon system was intensively studied in 1964 and 1965 (*11*). The study area was a 165-acre plot divided into five natural watersheds varying in size from 11 to 56 acres. The treatment areas were 100 to 200 feet long with a slope of about 5 percent. The surface had been carefully graded for uniformity and planted to a mixture of reed canarygrass (*Phalaris arandinacea*), seaside bentgrass (*Agrostis palastris*), and red-top (*Agrostis alba*). Soil texture varied from clay to clay loam. The average volume of wastewater applied from 1961 through 1965 was 0.89 inches per day for a season of 50 spray days. The runoff was 49 percent with rainfall and 30 percent without rainfall. Chemical oxygen demand (COD) removal averaged 91 percent during this period. Table 10 summarizes the water quality performance of the system for 1964-1965.

Although the mass removal percentages for the wastewater constituents were high (95, 93, and 84 percent for COD, nitrogen, and phosphorus, respectively), the concentrations remaining in the wastewater were still rather high. This condition obviously reflects the rather potent nature of the wastewater, which averaged 916, 548, 30, and 11 ppm COD, BOD, N, and P, respectively. However, decreasing the rate of hydraulic loading on two watersheds increased the mass removal. COD reductions of 78, 80, and 89 percent were found for loading rates of 0.88, 0.78, and 0.49 inches per day, respectively. Findings for the Napoleon system corresponded to the responses of N and P removals by overland treatment of secondarily treated municipal wastewater (P. G. Hunt, unpublished data).

Increased flow rates on the soil surface from either increased application rates or steeper slopes reduced treatment efficiency. Storm runoff quality from the treatment area was monitored to determine if organic materials and nutrients were being flushed from the system. Storm events on 4 percent of the study days accounted for 18 percent of the total runoff volume, and 8, 18, and 14 percent of COD, N, and P, respectively, in the total runoff. Although these amounts of nutrients exceeded that being discharged from most agricultural watersheds in northern Ohio, it was a very small percentage of the wastewater's organic and nutrient load (*11*). It does, however, point to the value of diverting storm water from the treatment slopes.

For very potent wastewaters, such as those produced by the meat-packing industry, difficulty may be encountered during storm runoff. In these cases, the suspended solid and BOD mass load may be large enough to cause problems in meeting 30-day or daily maximum discharge limits, although the actual concentration of the storm runoff may not be very high. In such cases, a containment area with feedback capability would be needed.

The general workability of overland flow, however, can be even more strongly supported, and again the Campbell Soup Company is cited. Based on the early results of the Napoleon and Chestertown systems, the firm decided in 1960 to construct an overland flow system on a 600-acre site near Paris, Texas, to handle the wastewater from a soup-making facility (*21*, *22*, *32*, *33*). The soil at the site was severely eroded clay with a very low infiltration capacity. Considerable earth work was necessary to obtain the desired uniformly smooth soil surfaces on gentle slopes. Such earth work is still required when expansions to the

Table 11. Treatment efficiency of an overland flow system (*32*).[a]

Parameter	Mean Concentration (ppm)		Removal (%)	
	Wastewater	Section Effluent	Concentration Basis	Mass Basis
Total suspended solids	263	16	93.5	98.2
Total organic carbon	264	23	90.8	-
BOD	616	9	98.5	99.1
Total phosphorus	8	4	42.5	61.5
Total nitrogen	17	3	83.9	91.5

[a] Removals based on average of weekly data (G-4 area only).

system are made.

Upon initiation of wastewater treatment, the system functioned well for BOD, conductivity, and dissolved oxygen, as did the other systems. However, there was concern for how the system was performing for nutrient removal, especially in light of increasingly stringent water quality standards. The Robert Kerr Water Research Center, in conjunction with the Campbell Soup Company and North Texas State University, conducted an extensive study of the facility in 1968 to determine if organic material and nutrients were being flushed from the system. The details of this study were presented in several manuscripts (*21*, *22*, *32*, *33*).

The Paris experimental area had slopes 150 to 300 feet long with inclinations of 2 to 6 degrees. Application volumes varied from 0.25 to 0.50 inches per day. Application periods ranged from 6 to 8 hours. BOD removal was very good--greater than 99 percent in many cases (Table 11). As expected, the microbial population responded extremely well to these easily degradable organic components. Populations in the test plots were always higher than those in a control plot.

In addition to the expected high BOD removal, N removal was greater than 90 percent. This is an interesting phenomenon since the wastewater moved across the soil surface and supposedly did not interact extensively with plant roots, soil particles, or anaerobic microsites.

Even more interesting was the fact that when a mass balance was done, a significant amount of nitrogen appeared to be lost by denitrification (personal communication with R. E. Thomas, EPA, Ada, Oklahoma) (*32*). Denitrification, of course, is an anaerobic process; yet the reed canarygrass was not suffering from lack of oxygen; there was no odor problem; and nitrification, an aerobic process, was occurring (*32*). These conditions would at first appear to be mutually exclusive. However, when they are viewed in the context of a marsh ecosystem or a rice field, they can be seen to fit nicely into a system having a high capacity for nitrogen removal (*41*). In such systems there is an aerobic-anaerobic double layer (Figure 1). Aerobic processes, such as nitrification, occur in the upper layer; and anaerobic processes, such as denitrification, occur in the lower layer. Nitrate thus would be formed when the nitrogen in the wastewater was mineralized and nitrified as it flowed over the soil surface and through the layer of organic debris. The highly soluble nitrate would then encounter the anaerobic zone and be denitrified. The large amounts of soluble organic material present in food-processing wastewater would ensure a high level of anaerobic respiration and the associated nitrate demand (*22*). The surface layer would always be aerobic and thus prevent the odor problem. It appears that reed canarygrass grown on an overland flow site is capable of transporting oxygen through its leaves and stems to

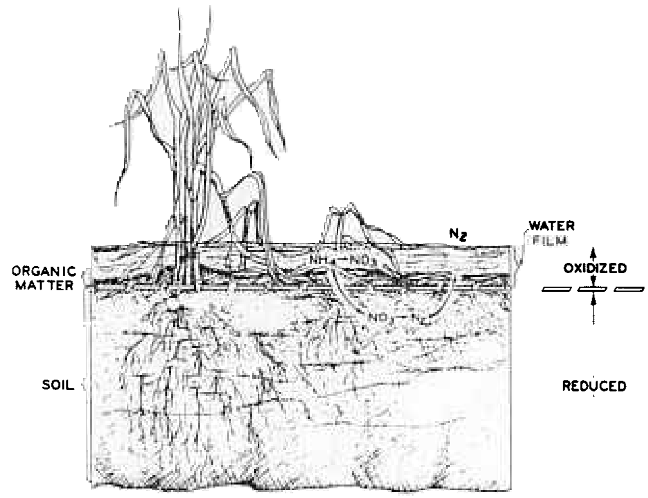

Figure 1. A schematic of conditions that would allow both aerobic and anaerobic processes to occur in an overland flow system.

roots. It would thus be able to establish a micro-aerobic site around its roots in a manner similar to marsh plant species and rice.

The double-layer theory is also consistent with the occasional requirement for a rest period. Hypothetically, if an organic layer were to accumulate to the point that oxygen demand was sufficient to turn the liquid film anaerobic, nitrification and subsequently denitrification would cease and odor problems would be encountered (Figure 2). After drying and reduction of the organic layer and its associated oxygen demand, a double-layered film of wastewater could again be formed on the soil surface.

Data on oxidation-reduction potentials were taken from soil at the Paris, Texas, overland flow system in 1973. The data clearly show the reduced nature of the soil system. Yet nitrification was occurring and anaerobic odor problems were absent, indicating the presence of an aerobic film (P. G. Hunt, unpublished data).

The removal of phosphorus has been reported to be low on overland flow systems using municipal as well as cannery wastewater (*24*, *32*). This is probably due to relatively little contact of the wastewater with soil particles and to the reduced nature of the soil. However, the addition of only stoichiometric amounts of aluminum sulfate can give high (greater than 85 percent) removals of phosphorus from raw and primary municipal wastewater and very high (greater than 98 percent) removal of phosphorus from trickling filter-secondary wastewater (personal communication with R. E. Thomas, EPA, Ada, Oklahoma, and P. G. Hunt, unpublished data).

Targuin and Dowdy (*57*) investigated the treatment of wastewater from the Peyton Packing Plant by overland flow in 1974. The rather potent wastewater (3,708, 7,850, and 153 parts per million for BOD, COD, and N, respectively) was treated through both slow infiltration and overland flow. Slopes were 150 to 200 feet long with an inclination of 1 percent. The application rates were rather high--5 inches per week--and channeling was encountered. Initially, treatment produced only 50 percent COD removal. After a more uniform plant cover was established, however, the removal rate increased to 66 percent. Similarly, rather poor treatment of Menhayden fish wastewater by overland flow was found (personal communication with Mark Mao, Louisiana State University) on a rough surface phragmites site when high rates of application were used.

These studies point to the extreme importance of having smooth soil surfaces, thick vegetative cover, slight (2 to 8 percent) slopes, and rates of 0.5 acres per inch per day or less in a functioning overland flow system. They also emphasize that extremely potent wastewaters are very difficult to treat to low concentration of nutrients because mass removals of 98 or 99 percent are required. These levels of N removal are almost unattainable for sustained periods. However, if the requirement is for NH_3 removal rather than N removal, a combination of an aerated lagoon and an overland flow system works nicely (*71*, *72*).

Slow Infiltration

This method of land treatment represents the classic concept in which wastewater interacts with the soil mantle, plant roots, and microorganisms as it percolates through the soil (*17*, *35*, *38*, *44*, *45*, *46*, *47*). Table 12 lists several systems. Numerous papers have been written on treatment of processing wastewater by such systems, but most are concerned with only the hydraulic and BOD loads (*1*, *34*, *35*, *38*, *45*, *46*, *47*).

Soil with enough fine-grained particles to provide extensive reactive surfaces and sufficient structure to allow percolation of a few inches of water per day is required. Such soil has excellent BOD removal capacities and normally has considerable phosphorus-fixing capacities (*44*). The actual phosphorus-fixing capacity depends upon the mineral composition of the soil, the soil physicochemical conditions, and the wastewater characteristics (*44*). Nitrogen, on the other hand, is not nearly so readily held within the soil and normally represents the short-range design limiting factor. NO_3-N must be below the Public Health Service standard of 10 parts per million before entering drinking water.

The cover crop is as important in slow infiltration as in overland flow. Since the soil profile of a soil infiltration system is normally aerobic, a much greater selection of cover crops is available; and in some instances a row crop, such as corn, that has a higher market value than forages can be used (*44*). However, most food-processing companies are interested in maximum wastewater renovation first and crop production second. Consequently, forage crops are normally used. They remove more nutrients and salt, minimize erosion and soil compaction,

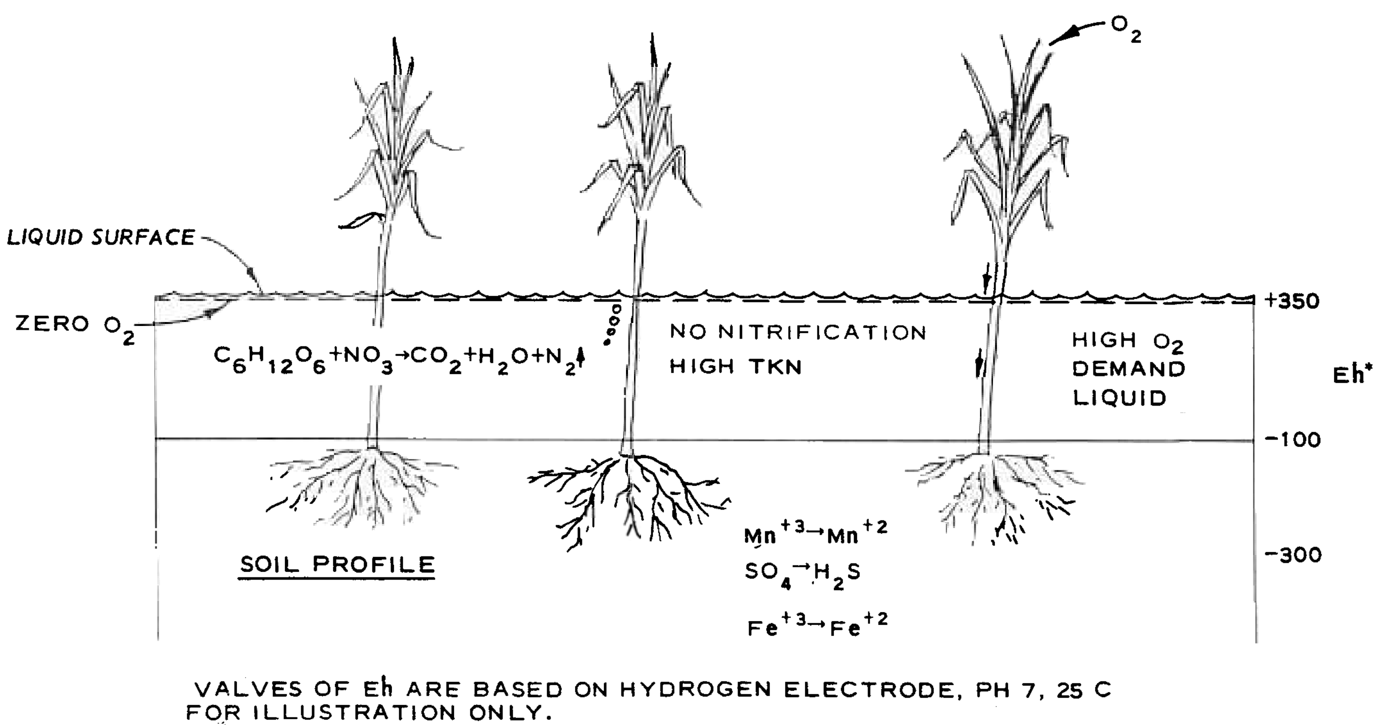

Figure 2. An overland flow surface with the anaerobic zone in the liquid flowing over the soil profile (23)

and require less preparation and harvest efforts.

An area's climatic conditions as well as site and wastewater conditions dictate the type of cover crop that can be grown. However, new developments in plant breeding occur yearly and a reasonably active program on crop improvement would probably be a sound investment for any food processor with a sizeable disposal operation. An example is Callie bermudagrass. This new plant has the capacity to remove more nitrogen and phosphorus and produce more protein than other varieties of bermudagrass. Like other bermuda grasses, Callie is dormant in the colder months. Consequently it would be less effective in northern areas. Yet the use of such plants in special areas during the warmer months might be a feasible means of lengthening the life of a treatment site.

For two seasons, Smith (*52*) studied a land treatment site for the wastewater from steam-cleaning potatoes. He found that COD decreased by 95 to 99 percent, with concentrations of 4 to 40 ppm present at a depth of about 60 inches in the soil. Although 958 pounds per acre of N were applied, the nitrate concentration at 60 inches was normally less than 1.0 ppm. The cover crop, a mixture of reed canarygrass and tall fescue, removed about 30 percent of the applied N. Obviously, either substantial incorporation of N into the soil or extensive denitrification occurred. The first harvest of the second season yielded 3 tons (English) per acre of good quality hay.

Adriano and associates (*1*) reported on two land treatment sites that were not functioning well for N removal. Additions of 433 and 465 pounds N per acre per year were being produced by a cannery and a milk-processing plant,

Table 12. Characteristics of selected slow infiltration systems (*17*).

Location	Wastewater	Average Flow (mgd)	Irrigated Area (acres)	Average Application Rate (in/day)	Crops	Soil Type
California Canners and Growers Thornton, California	Tomato	2.5	270[a]	0.34	Grass, alfalfa	Fine sandy loam
Sebastopol Coop Sebastopol, California	Apple	0.3	54	0.20	Grass	Clay loam
Tri Valley Growers Stockton, California	Tomato	3.0	165	0.67	Grass	Clay loam
Western Farmers Association Aberdeen, Idaho	Potato	0.5	90	0.20	Grass	Clay loam
Idaho Supreme Potato Company Firth, Idaho	Potato	0.6	80	0.29	Grass	Silt loam
Chesapeake Foods Cordova, Maryland	Poultry	0.5	40	0.50	Grass	Sandy loam
Gerber Products Company Fremont, Michigan	Food processing	0.8	90	0.33	Grass	Sand
Michigan Milk Products Ovid, Michigan	Milk	0.2	26	0.35	Grass	Sand
Stokely-Van Camp Fairmont, Minnesota	Food processing	1.5	400	0.14	Corn, peas, grass	Clay
Green Giant Company Montgomery, Minnesota	Corn, peas	1.2	360	0.12	Grass	Silty clay loam
Libby, McNeill & Libby Liepsic, Ohio	Fruit	0.6	130	0.19	Alfalfa	Clay
Cobb Canning Company Cobb, Wisconsin	Vegetables	0.2	22	0.34	Grass	Silt loam

[a] 60 acres in spray fields.

respectively. It was estimated that 76 and 65 percent of the applied N, respectively, was going into subsurface waters. The cover crop on these systems had not been harvested, and the soil incorporation and denitrification processes were unable to remove the N load.

A conservative but not totally infeasible N loading rate is one equivalent to the amount of N removed by the cover crop. Such an operational procedure might be justified where a rather permeable soil with very little N retention or denitrifying capacity was being used. Normally in a land treatment area for food-processing wastewater, a considerable amount of N is incorporated into the soil profile and the surface organic layer (*1*, *44*). In addition, the soluble organic degradation products normally cause significant amounts of denitrification to occur in the anaerobic microsites (*13*). However, as was illustrated by the overland flow systems, there is a finite limit. In general, slow infiltration systems that rely on the crop to remove less than 50 percent of the applied N are likely to have N leaching problems as they increase in age. Fortunately, this level of plant removal of N can normally be obtained in a well-managed system unless the wastewater is extremely potent.

P, as opposed to N, is neither removed by the plant in as great quantities nor removed by microorganisms. Thus, phosphate removal capacity is often the long-term design limiting factor.

There are many potentially important reactions for P. In general, however, soils containing considerable concentrations of iron and aluminum fix very large amounts of P. In fact, the fixation of P in forms unavailable to plants has been a significant agricultural problem.

Kao and Blanchard (*28*) reported that a Mexico silt loam at Columbia, Missouri, had not lost its P-fixing capacity after 82 years of fertilization. They postulated that the P level in the soil was controlled by the solubility of strengite. The distribution of inorganic and available P was similar in the fertilized and unfertilized plots.

Peck and colleagues (*43*), however, reported increased availability of P after 14 years of phosphate fertilizer application. These examples point to the acknowledged variability in the capacity of soil systems to fix P.

Langmuir maxima have been used as a measure of a soil's ability to retain P (*1*). However, it is generally acknowledged that Langmuir maxima underestimate the P-retention capacity of soils that contain significant quantities of iron or aluminum. Ballard and Fiskell reported Langmuir maxima and saturation maxima (soil saturated with 2,500 ppm P) for 42 soils in the southeastern U.S. coastal plains (*7*). They found that although the Langmuir maxima were lower than the saturated maxima, there was a significant correlation ($r = 0.986$). They suggested that Langmuir maxima were good for relative comparison of soil P-retention capacity.

In addition to the Langmuir and saturation maxima, there are several approaches to the mathematical modeling of P-retention and movement in the soil (*40*, *48*). At present there does not appear to be one clearly superior approach to a predictive model. Most suffer from the requirements of reasonably precise measurements or assumptions that are often oversimplifications of the system. However, some form of model that is reasonably accurate in predicting the minimal P-retention life of a treatment system is direly needed.

The cannery and milk-processing wastewater treatment sites previously discussed are examples of the poor results obtained by Langmuir maxima (*1*). The predicted P-retention capacities of both sites were significantly less than the actual P retained. The cannery site received P in wastewater for 20 years at 90 pounds per acre per year. The other site received P in milk-processing wastewater at a rate of 465 pounds per acre per year for 10 years. A significant portion of the retention was attributed to precipitation with calcium, which had increased significantly in the waste treatment area. In contrast to the fertilized plots described by Kao and Blanchard (*28*), the extractable P (Bray P-1) increased significantly with depth at both treatment sites (Table 13). Subsurface water was, however, generally less than 1 ppm in PO_4 concentration, and the annual removals of P were 73 percent for the cannery and 98 percent for the milk-processing plant.

For a newer system, Larson and associates (*31*) estimated that poultry-processing wastewater treated by land for 6 years had leached only 0.4 percent of the 7,700 pounds of applied P to the groundwater. The annual wastewater load was 200 inches, but P concentrations of only 0.98 and 0.91 ppm were found at soil depths of 1 and 3 feet, respectively.

The systems reported by Adriano and coworkers (*1*) illustrate the importance of crop harvest, particularly as the systems become older. P was not removed by harvest of the cover crops, and significant amounts of the P-retention life at both sites were lost. Estimates stated that 80 and 27 percent, respectively, of the P applied to the cannery and milk-processing land treatment sites could have been removed by the cover crop. In the case of the cannery site, the lack of harvest and the associated plant removal of P was dramatically important.

Rapid Infiltration

The rapid infiltration method of wastewater treatment has been used to move considerable amounts of water through limited soil surface areas. The most notable system of this type is Seabrook Farms in New Jersey, where over a billion gallons of wastewater per year have been applied for over 20 years. Groundwater well sampling during the early years indicated good removal of both organic and inorganic constituents. NO_3 did not exceed 10 ppm at any time during the first three years of operation (*56*).

The Campbell Soup Company constructed a rapid infiltration system in Sumter, South Carolina, with underdrainage that led to a pond in a natural depression. BOD removal has been very good, reducing the input concentration of 600 ppm to 10 ppm. Although the system is capable of receiving high rates of water, the average daily rate is about 0.8 inches over the entire 200 acres. Table 14 presents performance data.

The Tri-Valley Grower Plant No. 2 generates 2.5 million gallons of wastewater daily from processing tomatoes, peaches, and pears during a short summer season. The wastewater is applied to 70 acres of spreading beds. The infiltration rate varies from bed to bed, but ranges from about 2 to 20 acre-inches per day, followed by a 7- to 10-day rest. Performance data are not available. Table 15 describes other rapid infiltration systems.

Given the high surface loading rates of rapid infiltration systems, the crop-removal component is not nearly as important as it is with overland flow or slow infiltration systems. The cover crop is important, however, in maintaining a high infiltration capacity (*17*). Additionally, the coarse-grained soil normally associated with a rapid infiltration system is not nearly as effective in removing BOD as heavier textured soil (*26*). Thus, more soil contact is required. This is normally accomplished with a greater soil depth or lateral movement through the soil. Similarly, this greater soil depth or lateral movement of wastewater and the associated soil contact allow for enough surface contact to remove the wastewater P (*44*).

N removal from food-processing wastewater applied to sandy soils has not been studied extensively. The theory for high-level removal of N is available, however, from rapid infiltration treatment of municipal wastewaters. In such systems N removal depends very much upon microbial activity (*29*, *30*, *70*). The soils must be flooded and dried in cycles that will allow maximum denitrification (*12*). This is accomplished by allowing the soil to dry sufficiently to allow aerobic surface conditions and the associated nitrification. The time, of course, varies with the oxygen demand of the wastewater and the coarseness of the soil. The NO_3 thus formed is denitrified when it encounters the underlying anaerobic conditions as wastewater is applied. The soil will gradually turn anaerobic with clogging and reduced nitrification occurring. At this time, the soil will again have to

Table 13. Extractable P (Bray P-1) in soils. Values expressed on dry soil basis are averages for 2, 3, or 12 replications[a] (*1*).

Soil Depth (m)	Site 1 (ppm) Control	Corn Field	Spray Area	SD[b]	Site 2 (ppm) Control	Spray Area A	B
0.00-0.15	72	126	349	(46)	25	661	539
0.15-0.30	54	89	403	(76)	18	618	434
0.30-0.45	61	50	348	(85)	8	528	292
0.45-0.60	33	41	237	(61)	6	443	203
0.60-0.75	28	37	181	(38)	5	262	98
0.75-0.90	28	27	140	(27)	3	259	gw[c]
0.90-1.05	20	22	103	(30)	2	304	
1.05-1.20	14	25	87	(20)	gw[c]	224	
1.20-1.35	10	20	81	(35)		Gravel	
1.35-1.50	11	8	62	(25)			
1.50-1.80	10	11	60	(12)			
1.80-2.10	7	9	32	(11)			
2.10-2.40	8	6	30	(12)			
2.40-2.70	3	6	27	(14)			
2.70-3.00	3	9	39	(33)			
3.00-3.60	5	9	27	(14)			
3.60-4.20	4	4	34	(25)			
4.20-4.80	4	3	28	(21)			
4.80-5.40	4	2	33	(38)			
5.40-6.00	4	2	18	(13)			
6.00-6.60	5	2	13	(8)			

a For site 1, values are averages for 2, 2, and 12 replications for control, corn field, and spray areas, respectively. For site 2, all values are three replications.

b Standard deviation for spray area data

c Groundwater.

be dried and the cycle repeated. However, a broader base of performance data for nutrient removed by existing cannery wastewater rapid infiltration systems is sorely needed.

Solid Waste Disposal

Table 16 presents data on methods for disposal of cannery and frozen food wastes in California in 1967. Greater effort obviously must be made to recycle and recover by-products. However, the uses made of a few wastes are notable. The wastes from seafood canning, for instance, are pressed into fish meal for animal feed or into fertilizer material (*36*). Tomatoes also have been pressed and dehydrated for use as dog or cattle feed. Pea vines, corncobs, and corn husks also have been used in the feed market area. Citrus peel wastes can be pressed for molasses, which can be processed, dried, and sold as cattle feed. Certain types of pits and nut shells have been converted to charcoal.

The food processor will always be faced with the disposal of solid wastes that cannot be recycled or sold as a by-product, however. Presently, this represents about one-half the solid wastes generated by the food industry. As discussed earlier, the solid wastes typically include fruit and vegetable peelings, unusable vegetable residuals, animal paunch, manure, and sludges as well as skimmings from primary treatment of liquid wastes. Most food-processing wastes are similar to some other agricultural waste products, such as crop residues or animal manure.

Current methods of disposal can be classified into three categories: landfill, spread-

Table 14. Raw wastewater and effluent characteristics of the rapid infiltration system at Sumter, South Carolina.[a]

	Raw (ppm)	Underdrainage Effluent (ppm)	Removal (percent)	Final Lagoon Effluent (ppm)	Removal (percent)
BOD	700.0	6.0	99.1	10.0	98.6
Suspended solids	470.0	20.0	95.7	25.0	94.7
Ammonia (N)	5.9	0.5	91.5	1.0	83.0
Organic nitrogen (N)	35.0	0.1	99.9	0.8	97.7
Kjeldahl nitrogen (N)	40.9	0.6	98.7	1.8	95.6
Nitrate (N)	0.0	21.7	+99.9	0.1	99.5[b]
Total Phosphorus (P)	8.2	0.8	90.9	0.7	91.5

[a] Source: System performance data, L. C. Gilde, Campbell Soup Company, Camden, New Jersey.

[b] Nitrate removal is based on the influent concentration to the lagoon; all others are based on raw.

Table 15. Selected infiltration-percolation systems (*17*).

Location	Method of Application	Average Flow (mgd)	Average Application Rate (in/day)	Soil Type
Tri-Valley Growers Modesto, California	Flood	2.5	1.5	Sand
Hunt-Wesson Foods Bridgeton, New Jersey	Spray	3.0	2.5	Sand
H. J. Heinz Company Salem, New Jersey	Spray	1.3	1.6	Sandy silt
Seabrook Farms Seabrook, New Jersey	Spray	14.0	8.0	Sand
Campbell Soup Company[a]				
Sumter, South Carolina	Spray	3.5	0.9	Sand
Yakima, Washington	Spray	4.0	1.2	Sandy loam

[a] System is underdrained at a depth of 5 feet.

Table 16. Disposal methods and food waste quantities, California, 1967 (*16*).

Method of Disposal	Tonnage	Percent of Total
Landfill operations	285,000	31
Spread on fields	110,500	12
Animal feed	276,000	30
Ocean disposal	13,250	1
Charcoal production	46,000	5
Other disposal methods	88,000	10
Nonfood wastes	101,250	11
Total	920,000	

and-cover, and composting. The landfill methods include conventional sanitary landfills, trench-and-fill operations, and simple dirt-covered pits, which have traditionally been the most common land disposal techniques for food-processing wastes. However, the steady decrease of available fill sites near the plants and the increasing quantities and concentrations of wastes have imposed overwhelming burdens on available landfill sites or resulted in the stockpiling of wastes for more economical hauls to distant sites. This, coupled with the steady urbanization of agricultural areas, which places the once isolated food-processing plants and fill sites within populated portions of a community, has drastically increased the impact of such environmental problems as odors and insects. In addition to these nuisances, the concentrated application of these moist residuals has in some cases polluted surface and groundwaters with the soluble organic materials contained in the leachate produced by these wastes.

The second method of land disposal, spread-and-cover, consists of spreading the organic wastes thinly over the land, allowing them to dry, and mechanically incorporating them into the soil or mechanically injecting them into the topsoil if the wastes are in a sludge form (subsurface injection). This type of land application has been used increasingly over the past decade because it greatly reduces the environmental impact over other land application techniques. A controlled spread-and-cover program minimizes odor, insect, and leachate problems.

An excellent example of this form of land application is the Cooperative for Environmental Improvement, Inc. (CEI), operation in Santa Clara, California. CEI was established in 1969 by a group of California canners for the sole purpose of finding an alternate solution to their acute solid waste disposal problems--caused by the loss of some of their usual disposal sites (*15*). This spread-and-disk operation for returning food-processing wastes to the soils, initiated by CEI in the 1970 processing season, has since proven highly successful and is now a widely accepted practice. CEI published a "Manual of Operations" in 1975 entitled "A Description of an Agricultural Food Residuals Disposal and Land Enrichment Operations" to aid others in establishing similar waste disposal programs.

The waste solids application rate is limited by several constraints. In comparison to the limits of effluent loading, the hydraulic loading limits, infiltration capacity, root zone permeability, and geologic permeability are less important because relatively minor amounts of water will generally be applied with the waste solids. Limits do, of course, exist on the physical incorporation of organic solids into the soil and the soil's ability to decompose solids without causing plant toxicity problems. Other factors such as SAR and pH may also limit solid waste application. All of these factors vary greatly between types of food processed and the method of processing and waste pretreatment.

Even though this alternative seems to be an environmentally sound approach to food-processing residual disposal, factors such as optimum loading rates, inactivation rates of viruses, pathogenic contamination, and soil and crop responses must be addressed for each waste product. Other problems that arise are similar to those associated with sanitary landfill operations--acquisition of large tracts of suitable land within reasonable hauling distances of the food-processing plant and possible urbanization of the disposal site area.

Composting is the third classification of land disposal. Although this is one of man's oldest techniques for building soil conditioners from organic solids wastes, it has only recently come under serious consideration as an alternative disposal method for food-processing residuals. When these high-water-content wastes are combined with dry wastes from other industries (sawdust, rice hulls, animal manures, etc.), both sources of wastes can be used to form compost to rebuild agriculturally impotent soil (*25*). However, composting has generally been found to be extremely expensive.

Agricultural Aspects

Pathogenic Problems

Where frequent grazing of a land treatment system is planned, a close check on wastewater pathogen levels should be maintained because wastewaters with organic contents as high as those of food-processing wastewaters are difficult to disinfect (*44*). Dazzo and associates (*18*) reported that *Salmonella enteritidis* and fecal coliforms survived better in soil that had previously been irrigated with cow manure slurries than in soil that had not been irrigated. Bell (*10*) reported that 10 hours of bright sunlight completely destroyed fecal coliforms on alfalfa plants (Table 17). Taylor and Burrows (*58*) found a dosage of greater than 10,000 *S. dublin* is required for contraction of salmonellosis. Bell recommended that a 20-hour

Table 17. Survival of fecal coliforms on alfalfa plants irrigated with sewage effluent, and *E. coli* and fecal coliform supplemented sewage effluent (*10*).

Hours After Irrigation Stopped	Fecal Coliforms per Grams of Dry Alfalfa			Hours of Bright Sunlight
	Sewage Effluent	*E. coli* ATTCC 11303-1 Supplemented	Fecal Coliform Supplemented	
1	1.72×10^3	3.82×10^5	1.75×10^5	1.0
6	3.8×10^1	1.1×10^1	2.25×10^3	5.9
24	0.9	2.3	1.97×10^1	9.5

period of exposure to bright sunlight be allowed before cattle graze a wastewater treatment site.

In this regard, it would also be wise not to spray irrigate close to an active grazing site with a wastewater containing significant concentrations of pathogens because of aerosol drift. Tarquin and Dowdy (*57*) detected a significant number of pathogenic bacteria colonies 400 feet downwind of a spray irrigation nozzle emitting meat-packing wastewater. They also reported a significant increase in aerosol travel with nozzle pressures. Similar findings with municipal wastewaters have also been reported.[1]

The pathogenic problem must be kept in context, however. No form of wastewater treatment will completely eliminate the possibility of a pathogen transfer, and there is no evidence to suggest that pathogenic transfer has been a significant problem in the numerous operating land treatment systems for food-processing wastewater.

Value as Irrigation Water

As mentioned earlier, the emphasis in selecting a crop for a land treatment system using food-processing wastewater must be upon wastewater renovation. This is partially because in most instances the cultural practices associated with cash crop production cause the costs to exceed returns on the crop. Forage crops are the most common cover crop in food-processing land treatment systems.

In the case of rapid infiltration and overland flow, the selection of a crop that is capable of withstanding periodic flooding and extended periods of reducing conditions in the root zone is quite important. The cover crop helps maintain rapid infiltration on coarse soils and helps prevent erosion while providing sites for organic matter accumulation and biological reactions on heavy-textured soils. Soils used for slow infiltration systems, however, have more crop management flexibility. In arid areas, the wastewater from a food-processing plant may be quite valuable. Of course, the wastewater must be of sufficient quality not to damage crops or degrade soil structure. Wastewaters vary significantly in this regard.

In 1972, Pearson surveyed 20 food-processing plant wastewaters with respect to their suitability for irrigation (*42*). These plants processed nine different foods. Table 18 shows the characteristics of these wastewaters. Electrical conductivity and sodium adsorption ratios varied greatly with the type of food being processed. Generally, the wastewaters from green beans, squash, tomatoes, corn, steam-peeled sweet potatoes, and poultry were suitable for irrigation. However, there was considerable variation from plant to plant, and some pea and lima bean plants produced questionable irrigation wastewater. Therefore, anyone planning a land treatment system should consider the quality of the specific wastewater load and the tolerance of the desired cover crops to salt and sodium. The effect of sodium on the soil, particularly in slow infiltration systems, must also be considered. Increased Na in the soil can reduce soil structure and infiltration rates (*31*). The problem is more acute for wastewaters with low levels of calcium and magnessium, a high sodium adsorption ratio (SAR). Pearson also found that the lye-peeling and brine-flotation waters could be separated to reduce the electrical conductivity and Na load of the effluent from many plants. However, considerable amounts of Na were released from potatoes after they left the peeler, indicating that the Na problem would not be solved completely by simply diverting the peeler wastewater of potato-processing plants.

Heavy Metals

Heavy metal concentrations in most food-processing wastewaters are very low and are not likely to have either positive or negative effects on a food-processing wastewater treatment site.

Fertility Status

Sharratt and associates (*49*, *50*) found that whey increased the growth of bluegrass. Application of 80 tons of whey produced bluegrass yields comparable to those produced by

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[1] C. A. Sorber, H. T. Bausum, S. A. Schaub, and M. J. Small. "A Study of Bacterial Aerosols at a Wastewater Irrigation Site," presented at the 48th annual conference of the Water Pollution Control Federation, Miami Beach, Florida.

Table 18. Composition of wastewater from 20 plants processing nine food products during 1967-1969[a] (42).

Processor's Code	No. Samples	CE (mmhos/cm)	Cl (meq/liter)	Na (meq/liter)	SAR	COD (mg/liter)
		Constituents[b]				
			Peas[c]			
B	35	1.1 ± 1.1	6.7 ± 11.1	7.6 ± 10.4	7.6 ± 9.8	529 ± 238
C	24	0.8 ± 0.1	0.0 ± 0.0	5.6 ± 0.9	5.5 ± 1.4	1,518 ± 832
E	12	4.7 ± 1.2	44.4 ± 14.1	41.8 ± 13.2	41.6 ± 15.5	1,681 ± 745
S	15	1.5 ± 1.2	10.6 ± 10.0	9.9 ± 9.5	11.0 ± 10.7	1,090 ± 432
T	8	3.2 ± 3.0	29.9 ± 30.8	26.5 ± 28.6	18.3 ± 18.0	1,220 ± 412
B('69)	24	0.9 ± 0.6	9.1 ± 8.4	12.2 ± 13.7	15.4 ± 15.0	653 ± 489
BB('69)	18	1.2 ± 0.7	11.1 ± 6.1	13.4 ± 9.3	19.4 ± 12.5	687 ± 354
			Green beans			
J	27	1.2 ± 0.4	6.6 ± 3.4	9.8 ± 3.1	8.5 ± 3.5	510 ± 195
U	44	0.4 ± 0.1	0.1 ± 0.7	1.6 ± 0.6	1.6 ± 0.6	744 ± 352
V	25	0.2 ± 0.0	0.0 ± 0.0	0.7 ± 0.2	0.9 ± 0.3	181 ± 52
			Squash			
S	40	0.2 ± 0.2	0.0 ± 0.0	0.9 ± 0.3	1.1 ± 0.5	294 ± 193
			Tomatoes			
Q	16	1.3 ± 0.3	4.8 ± 0.2	6.3 ± 3.5	4.5 ± 2.4	4,279 ± 1,275
X	48	1.4 ± 0.3	0.2 ± 0.8	0.4 ± 0.1	0.3 ± 0.1	6,393 ± 1,549
Y	50	1.4 ± 0.4	1.0 ± 1.8	0.4 ± 0.4	0.2 ± 0.2	6,351 ± 2,431
DD	15	0.6 ± 0.3	0.5 ± 1.4	0.6 ± 0.2	0.5 ± 0.1	1,975 ± 1,247
			Corn			
A	29	0.8 ± 0.1	2.6 ± 2.4	4.0 ± 1.9	2.9 ± 1.4	6,429 ± 1,710
B	29	0.4 ± 0.0	0.0 ± 0.0	0.8 ± 0.4	0.9 ± 0.5	5,278 ± 2,348
C	36	0.9 ± 0.2	0.0 ± 0.0	4.7 ± 2.2	4.9 ± 2.5	11,771 ± 3,897
E	7	0.8 ± 0.1	1.6 ± 2.1	2.9 ± 1.3	2.9 ± 1.2	10,505 ± 985
O	16	0.7 ± 0.0	0.0 ± 0.0	2.8 ± 0.5	2.3 ± 0.4	1,294 ± 1,138
Z	14	0.6 ± 0.0	0.0 ± 0.0	4.6 ± 0.3	5.0 ± 0.5	2,446 ± 767
BB('69)	13	0.2 ± 0.0	nd	0.4 ± 0.1	0.6 ± 0.2	3,490 ± 1,610
			Lima beans[c]			
B	35	5.5 ± 5.9	43.6 ± 42.6	48.0 ± 42.6	36.9 ± 30.7	626 ± 193
C	32	0.7 ± 0.1	0.4 ± 1.1	5.1 ± 1.1	4.9 ± 1.0	743 ± 224
E	11	3.5 ± 1.4	48.2 ± 21.6	32.0 ± 9.7	27.9 ± 8.0	1,243 ± 293
			Sweet Potatoes[d]			
M('67)	9	33.0 ± 10.8	nd	222.0 ± 84.8	122.4 ± 50.4	nd
Q('67)	11	8.6 ± 19.9	nd	67.3 ±127.1	38.6 ± 62.8	nd
M	47	15.4 ± 10.4	5.9 ± 2.7	197.0 ±154.0	115.1 ± 88.1	32,072 ± 9,602
AA	45	11.0 ± 3.9	13.0 ± 2.0	136.0 ± 56.0	78.8 ± 37.1	22,777 ± 5,333
B	60	0.4 ± 0.1	0.8 ± 2.4	2.2 ± 1.4	2.1 ± 0.9	3,742 ± 2,268
			White Potatoes[d]			
B('69)	25	0.8 ± 0.1	4.9 ± 0.6	5.5 ± 1.1	5.0 ± 2.2	1,326 ± 927
			Poultry			
W	45	0.4 ± 0.0	8.4 ± 1.8	1.5 ± 0.6	1.4 ± 0.4	904 ± 199
CC	22	0.4 ± 0.1	9.4 ± 2.1	1.8 ± 0.8	1.6 ± 0.7	796 ± 130

[a] Variabilities expressed as standard deviation of an individual measurement. Unless otherwise indicated, all samples were collected in 1968.

[b] nd = no data.

[c] All plants used a quality grader to some extent except plant C.

[d] Plant B steam-peels sweet and white potatoes. All others use lye.

the application of 930 pounds of 12-12-12 fertilizer. Alfalfa, on the other hand, was not very tolerant of whey. Application of more than 64 tons per acre per week caused most of the alfalfa to die. When as much as 384 tons were applied on the alfalfa plots, odor problems developed. This would tend to support the researchers' theory that the alfalfa suffered from oxygen deficiency induced by the high oxygen demand of the whey.

Wells and Whitton (*68*), in a survey of land treatment wastewater systems for seven dairy factories in New Zealand, found that levels of exchangeable K, Na, and Ca in the topsoil increased, but Mg levels did not. In comparison to nonirrigated crops, white clover and ryegrass grown on the wastewater irrigated sites produced significant increases in N, K, S, Cl, and Mn; the levels of Zn, Cu, B, and Mg were lower.

Wells and Whitton (*69*) also reported on the influence of meatworks effluent on soil and plant composition. A highly porous, free-draining sandy loam with a gravel subsurface received 1 inch of wastewater per day for about 15 years. A shallow loess over gravel received one-third of an inch of wastewater per day for a similar period. After treatment in an oxidation pond, the wastewater contained approximately 64, 39, 220, 14, 83, and 19 parts per million of N, Na, Ca, Mg, K, and P, respectively. N, P, K, and Ca increased in the top 2-inch layer of both soils. Table 19 presents the N, P, and K contents of white clover and ryegrass. White clover grown on the irrigated area had higher N, P. and K. Ryegrass on the irrigated areas had higher N and K only. The levels of Mn, Cu, and Sr decreased.

The Campbell Soup Company's Paris, Texas, land treatment system, at one point, received an estimated 500 pounds or more of N per acre and removed over 200 pounds per acre in harvested reed canarygrass (*32*, *44*). The grass also removed 36.5 pounds of P per acre (17 percent of that applied). Adriano and associates (*1*) investigated land disposal systems for a cannery and a dairy-processing plant. Large amounts of both N and P were applied annually: 500 and 466 pounds per acre of N and PO_4-P, respectively, for the cannery waste. The forage removed an estimated 31 percent of the N applied in both systems and 80 percent and 27 percent of the PO_4 applied from the cannery and dairy systems, respectively. These wastewaters were not excessively potent, but it should be abundantly clear that, if application is extensive, N and P will often be applied in amounts that exceed the ability of the cover crop to remove them. In these treatment sites, carbon-nitrogen ratios were narrower than those of a control area or an adjacent corn field, and the soil receiving milk wastewater had a lower ratio than the soil receiving cannery wastewater. Data presented earlier (Table 14) also indicate the accumulative effect on fertility in that the availability of P at a treatment site was considerably higher than in an adjacent corn field.

Providing such other factors as pH, oxygen status, soil structure, and disease are maintained in an adequate condition, crop production should respond favorably to the nutrient additions. However, increased fertility is indicative of a system that is becoming nutrient-saturated as well as more fertile. Such soils will certainly not be able to continue to treat wastewater at normal rates. On the positive side, however, soils that have been treated by wastewater have increased in nutrient availability and value rather than depreciated in value as would the material used in a conventional treatment plant.

Table 19. Composition of white clover and ryegrass after irrigation with effluents from meatworks (*69*).

	White Clover (%)			Ryegrass (%)		
	N	P	K	N	P	K
Control (mean)	3.2	0.21	1.65	2.7	0.20	1.9
Irrigation (mean)	5.2	0.37	2.65	4.0	0.33	3.3
Significants	**	**	**	**	NS	**

Closure

From a wastewater treatment standpoint, it is advisable to design and operate wastewater loads in a manner that prolongs the life of a treatment site. In this regard, certain cultural procedures that would be counter productive from an agricultural production point of view may be used. Two examples are additions of aluminum sulfate to wastewater before land application to reduce the availability of P and wastewater application schedules that optimize denitrification. Yet even with such procedures, properly designed and operated land treatment systems can result in both good crop production and improved water quality.

Land treatment waste systems in the food-processing industry vary greatly in their design, operation, and agricultural value with location, food products, and level of treatment required. However, two aspects should not vary: First, land treatment of waste should always be considered as an alternative. Second, design and operation of land treatment systems should be based on principles and realistic criteria rather than a laissez-faire trust in mother nature.

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