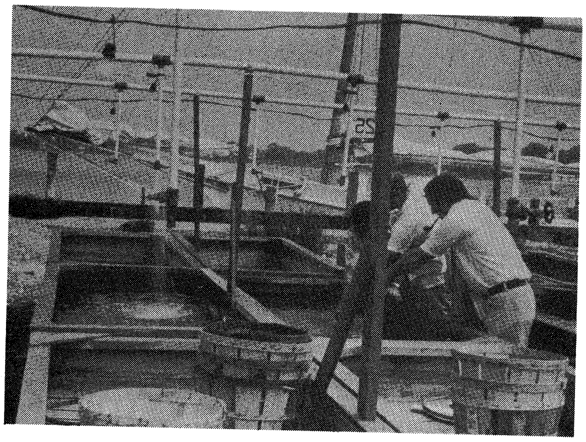

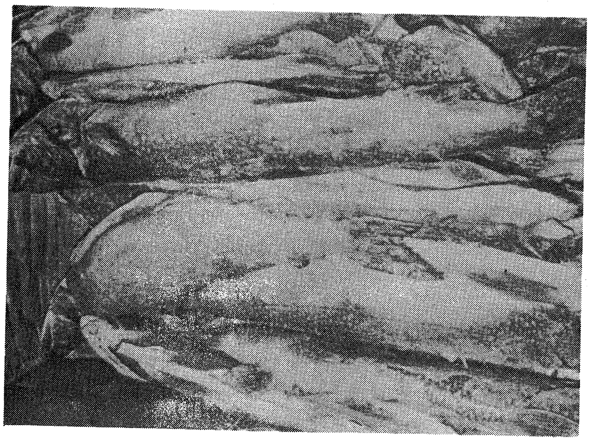

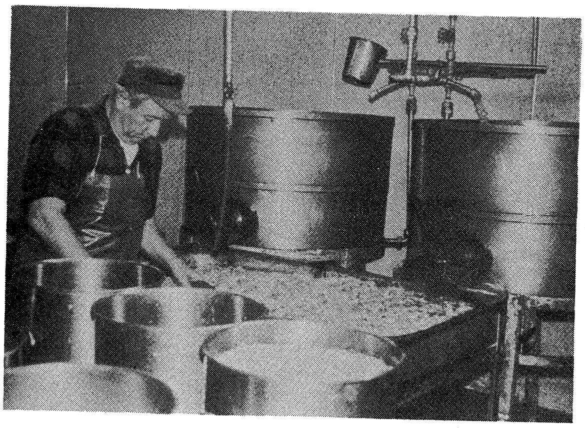

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CHARACTERIZATION AND LAND APPLICATION OF SEAFOOD INDUSTRY WASTEWATERS

by

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ABSTRACT

Bulk volume and composition of waste from seafood processing facilities were characterized for average size plants. This report illustrates the land treatment alternative for the four segments of the industry - shrimp, crab, tuna, and oyster processing. Characterization of the total raw waste varied in completeness among the various seafood categories. Substantial levels of N, P, Ca, and other nutrients were documented. Seafood waste characterization relevant to land treatment was not as comprehensive as for two other industries considered in a similar analysis, textile mills and petroleum refining (Pal, 1979, Pal 1980).

Evaluation of known parameters for land application systems reveals that soil-plant systems are capable of utilizing the seafood industry wastewater with little or no pretreatment requirements. Soil-plant assimilative capacity for the waste effluent parameters have been calculated and the land areas, necessary for the environmental compatible operation of a treatment site, are estimated. Tuna, shrimp, crab, and oyster processing require 90-150, 30-60, 12-25, and 0.5-0.8 ha, respectively for sandy loam and clay loam sites. A clay loam site when compared to a sandy loam site reduced the land needs for shrimp and crab processing but had no effect on tuna wastes. Oyster land areas were increased in going to a clay loam site. The order of land needs partially reflects the differences in sizes of typical processing facilities in each segment. A detailed design is strongly recommended prior to land treatment because of probable variations in site and waste characteristics.

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CONCLUSIONS

1) Based on the availability of relevant waste characterization data four segments of the seafood processing industry were selected for land treatment evaluation, shrimp, crab, tuna, and oyster. The raw waste from these plants contained substantial plant nutrients. The metal contents were found also to be significant relative to the land assimilative capacity. The waste characterization for seafood processing is not as comprehensive for land treatment-related constituents as those from textile and petroleum industries. This is due to the lower toxic or environmental significance of seafood wastes.

2) Typical size processing facilities for shrimp, crab, tuna, and oyster were 60,000; 50,000; 840,000; and 5,000 kg fresh seafood/week, respectively. This volume processed had a substantial impact on land area requirements. For the purposes of this report each seafood facility was assumed to operate 52 weeks/year thus the land areas generated are larger than likely for seasonal generators.

3) For the typical size processor, the land area required was the order of largest to smallest as follows, tuna > shrimp > crab > oyster.

4) When normalized to a common mass of seafood processed per week the order of land area from largest to smallest was as follows, shrimp > crab > tuna > oyster. This ordering reflects the mass of LLC waste constituents per mass of seafood processed.

5) Should seafood processing sludge or effluent be considered for land treatment instead of the raw waste, the land area would be lower than those developed in this report. The cost would also be lower.

6) A land treatment design for any seafood processing plant must be done using actual waste and site data to assure a successful system. The variations in land areas and costs can be significant.

RECOMMENDATIONS

1. More characterization of shrimp, tuna, crab, and oyster processing wastewaters is needed, in particular for metals and trace organics. This will enable a more transferable analysis of land treatment design within the seafood processing industry.

2. Seafood industry managers and personnel must be encouraged in the use of land treatment for raw waste, sludge, or effluent. It is a viable and economic technology whereby waste nutrients are conserved and recycled for crop production. Extension and continuing education programs must take a leadership role in demonstrating the use of the land treatment technology for wastewater renovation in all seafood processors categories.

3. Future research in seafood processing must be aimed at in-plant source control of nutrient losses and a higher recovery of food products. Increased in-plant efficiency may cut down the land area requirements considerably.

4. Appropriate legislative measures should be taken to assist the seafood processors in using land treatment as the most acceptable alternative and to ban any direct discharge of treated wastewaters as an approach to the national goals of zero discharge.

ACKNOWLEDGEMENTS

The authors wish to record the steady, fundamental support of the Water Resources Research Institute, Neil S. Grigg and James M. Stewart. The Department of Biological and Agricultural Engineering has continuously furthered this research as an expanding program concerning the environment. Dr. F. J. Hassler, Department Head and Dr. F. J. Humenik, Associate Head In Charge for Extension, have been particularly responsible for the success of this project. Valuable colleague was received from Dr. Philip W. Westerman. Food Science input was received from Dr. Frank Thomas and Dr. Roy Carawan. Sample collection by Dr. Jim Moore and Stewart Crane, Agricultural Engineering Department, Oregon State University and Mr. Dick Nelson, National Marine Fisheries Service, Seattle, Washington, were invaluable to completion of this report. Mr. Ken Dostal of the Industrial Environmental Research Laboratory, U.S. E.P.A., Cincinnati gave substantial background information to this study. In addition, several seafood processing plants contributed data and samples for analyses.

Laboratory efforts were effectively undertaken by Ms. June Preston and Ms. Dorothy DeBruyne.

Editorial and typing responsibilities were performed superbly by Mrs. Thelma Utley.

OBJECTIVES AND OVERALL APPROACH

Land treatment is an important industrial waste management technology. An increasing number of plant managers and corporate environmental personnel are considering the substantial benefits of land treatment for industrial waste as an approach toward the goal of zero discharge. Therefore this report is focused on the potential use of land treatment for the seafood processing industry point source category as one of several industrial categories considered under the present research program (e.g. textile mills, petroleum refining).

There are two specific objectives of the research and evaluation presented in this report,

1) to establish a general estimate of the use of land treatment technology for a number of the subcategories within the seafood processing classification. This report should be considered only as a first-order approximation since waste parameter evaluation and site characterizations are specified only as representative of typical conditions.

2) to further demonstrate the utility of a recently developed complete design procedure or methodology for land treatment of the entire waste stream from any given industry. The demonstration is for various subcategories of the seafood processing industry.

The presentation of material in this report utilizes the stage I portion, Figure 1, of an overall in-plant and land treatment methodology. A complete description of the overall design procedures and required data base can be found in Overcash and Pal (1979). Each seafood subcategory is delineated with as complete as possible chemical characterization for those parameters important when the ultimate receiver is a plant-soil system (as opposed to an

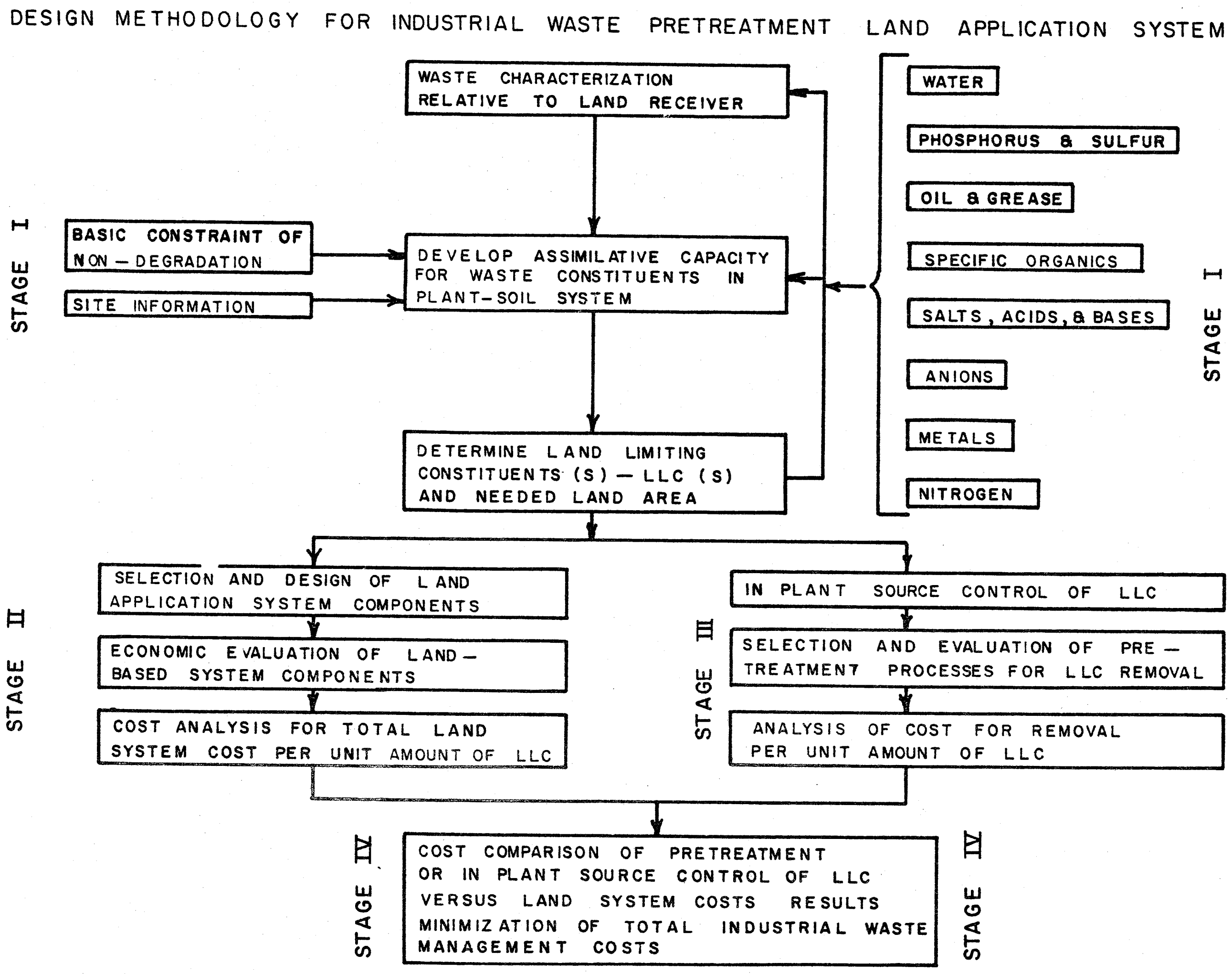


Figure 1. Design methodology for industrial land treatment systems.

aquatic system). One major gap continues to be the lack of data on specific organic compounds which may be of concern because of the presence in substantial quantity or because of probable environmental impact. Available pertinent data on waste characterization involve 10-15 constituents.

Site-specific data are equally or more critical in achieving successful design and long term performance for land treatment. Without a specific land treatment site, the detailed plant, soil, and groundwater data cannot be determined. That is, considerable variations in land area requirements, occur for a given waste stream, when a variety of site conditions are used in design calculations. The site conditions selected in this report are typical of probable land treatment sites. This report focused on two common soil characteristics as a preliminary evaluation tool, i) a sandy loam and ii) a clay loam soil. The reader should not infer that these represent extremes and that all other actual site conditions would be between these two soils. The two soils selected simply represent significantly different soil textures for the purpose of demonstrating the importance of actual land treatment site data. As described in following sections, specific site data are used to establish the plant-soil assimilative capacity for each constituent in the waste.

The land limiting constituent is determined in reference to the available waste characteristics (kg/yr) in seafood processing subcategories and the two representative sets of land treatment site assimilative capacities (kg/ha/yr). A balance between waste generation and plant-soil assimilative capacity is made on a constituent-by-constituent basis. This balance, or ratio, equals the land area needed for each parameter, with the largest area requirement being defined as the land limiting constituent(s) (LLC). An LLC analysis defines i) the parameters which are critical in determining land area requirements and ii) the actual land treatment area needed for each representative seafood processing situation covered in this report.

SUMMARY OF LAND TREATMENT DESIGN METHODOLOGY

The assessment of land treatment technology for a seafood processing facility waste follows certain well-established principles and techniques. These are sufficiently adaptable to all types of industrial waste and therefore are common to all land treatment designs. A brief review of these principles is included here and the reader may consult more detailed texts for further information (Overcash and Pal, 1979).

A single basic constraint is utilized throughout the industrial land treatment design, as follows:

> *the industrial waste, when considered on a constituent-by-constituent basis, will only be applied to the plant-soil system at rates or over such limited time spans that no land is irreversibly removed from some other potential societal usage (agriculture, development, forestation, etc).*

Such a constraint is basically one for, non-degradation of the plant-soil system and represents a fairly strong design objective. Where substantial data to meet this constraint are unavailable, the use of land treatment should be accompanied with sufficient monitoring to guage compliance relative to this constraint. Approaching industrial land treatment with this constraint appears to 1) reflect most accurately the thrust of all environmental regulations and 2) improve the probability that the design criteria used will provide long-term reliable land treatment performance.

The primary non-degradation design constraint regarding the long term effect or assimilative capacity of the soil-plant system is translated into land application rates by one or more of three calculation procedures. These three calculations are the basis for determining the assimilative capacity of nearly all industrial waste constituents,

1) decomposition or uptake rates as the basis for assimilation in the plant-soil system e.g. oils, organics, nitrogen
2) accumulation of those compounds which are relatively immobile and do not decompose to keep below predetermined critical levels, in the soils, e.g. heavy metals
3) migration of those compounds which are mobile and do not decompose and therefore assimilation over land areas such that receiving waters are not altered to a degree which would require further drinking water treatment, e.g. anionic species.

Results of these calculations for the assimilative capacity at a specific plant-soil system site are usually expressed as the mass of a constituent in the waste which is assimilated per unit land area per unit time (kg/ha/yr) or as the concentration in the soil (ppm or percent of soil weight). Thus with the basic design constraint and one or more of the individual calculations, the assimilative capacity for each constituent in the waste can be determined. This procedure is repeated in this report for each separate subcategory within the seafood processing point source category.

INDUSTRY DEFINITION

There are a large number of seafood processing industry in the Coastal regions of North Carolina and the United States. The major categories of seafood industry are:

i) fin fish handling and processing (Alewife, Eel, Croaker, Trout and Flounders, etc).

ii) processing of Crustacea (Blue crabs, shrimps)

iii) mollusks processing (Scallops, Oysters, etc)

iv) tuna and other salt water fish.

The seafood processing industry assessments by the U. S. Environmental Protection Agency have identified thirty-five significantly different categories. From these, four categories were selected in order to demonstrate the potential for land treatment of the wastes produced. These are: shrimp processing wastes, crab processing wastes, tuna processing wastes, and oyster processing wastes. This limited number of categories is due solely to the lack of adequate land treatment-related characterization of these wastes and not due to any restriction on land treatment potential.

Shrimps are canned mostly in Gulf States (Texas, Louisiana and Mississippi) and other coastal regions including Alaska. Fresh and frozen supplies of shrimps are limited to wharfs and coasts. Canned shrimps are available in markets throughout the U.S. An industrial flowchart for the various processes and waste effluent flow in shrimp canning are schematically illustrated in Figure 2.

Crab processing plants are restricted to areas near crab fishing grounds - largely in California, Alaska, Oregon, Washington and Atlantic - Mexican Gulf Coastal States. Of the total crabs canned, blue crabs account 52.8%, Dungeness crab 13%, King crab 24.6%, and Tanner or Snow crab 9.6%. Most consumer crab products are canned crabs. A crab processing and waste generation flow diagram is shown in Figure 3 for mechanized handling and canning operations. Of the 184 crab processing plants in U.S., about 50

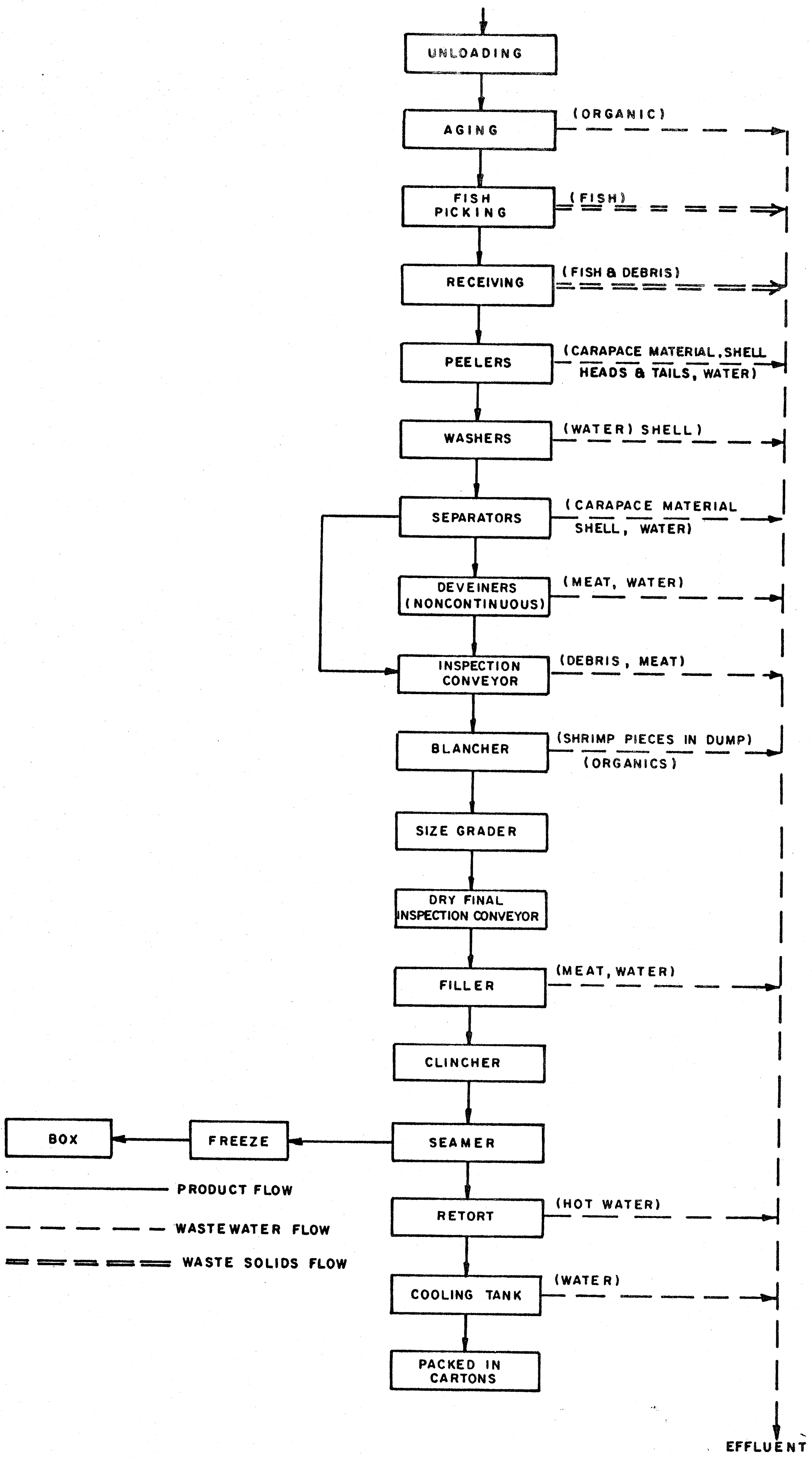
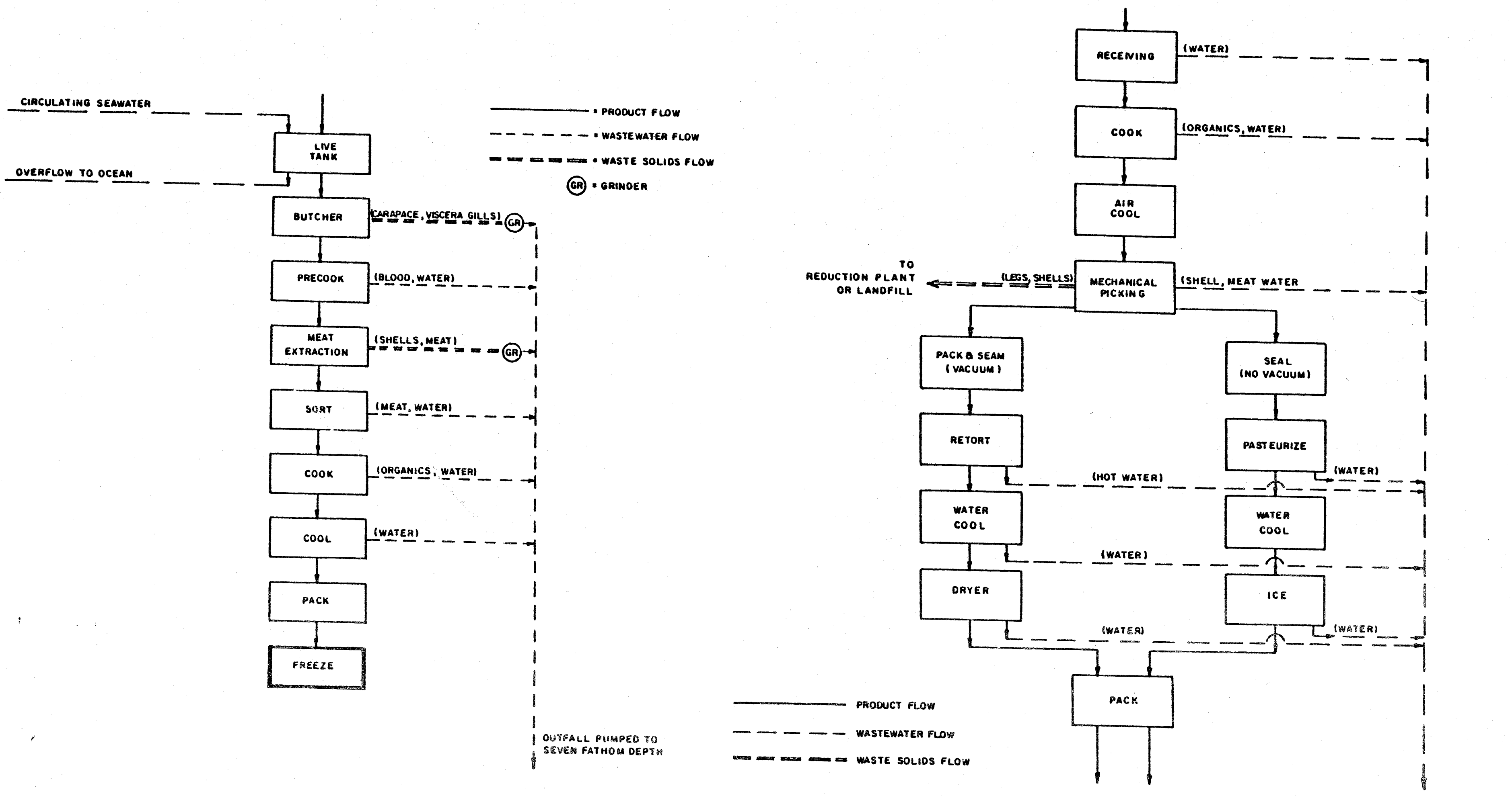


Figure 2. Southern non-breaded shrimp processes.



(b)

King and Tanner Crab

(a)

Blue Crab

Figure 3. Crab Processing.

percent are located in Maryland, Virginia, and North Carolina.

The annual consumption of tuna in U.S. far surpasses any other seafood. Tuna and the products derived from tuna are used for human consumption, production of pet food, and by-products. Various processes employed in tuna processing and canning including the waste effluent generation are outlined in a flow diagram, Figure 4. Nearly all tuna are canned and only small quantities are frozen. Canning facilities are located in Pacific as well as Atlantic coastal states and Puerto Rico (U.S. E.P.A., 1973).

Oyster processing is concentrated on the East Coast (Florida, Georgia, North Carolina, Maryland, Virginia, Texas, Alabama, Mississippi and Louisiana). Fresh shucked oysters are the most important product accounting for over 50 percent of the total value of all oyster products (U.S. E.P.A., 1975). A typical steamed or canned oyster process and associated waste effluent flow diagram is presented in Figure 5.

WASTE GENERATION RATE AND CHARACTERIZATION

SHRIMP

Wastes generated from shrimp processing are characterized in Table 1. Jensen (1965) estimated that 78% - 85% of the shrimp is lost in the waste when mechanical peeling is used. Shrimp processors behead and discard a significant portion of the catch at sea to minimize the degradation of product and to permit extension of fishing trips. Either sea water or fresh water is used for processing, depending on the availability and quality of water at a plant location. Peelers are the biggest water users and waste generators in shrimp processing. Blanchers and retort water are insignificant both in volume and total waste contribution. About 60% of plant effluent results from mechanical peeling. The characterization in Table 1 was from published sources (Jordan 1979 and Costa 1977) and measured values

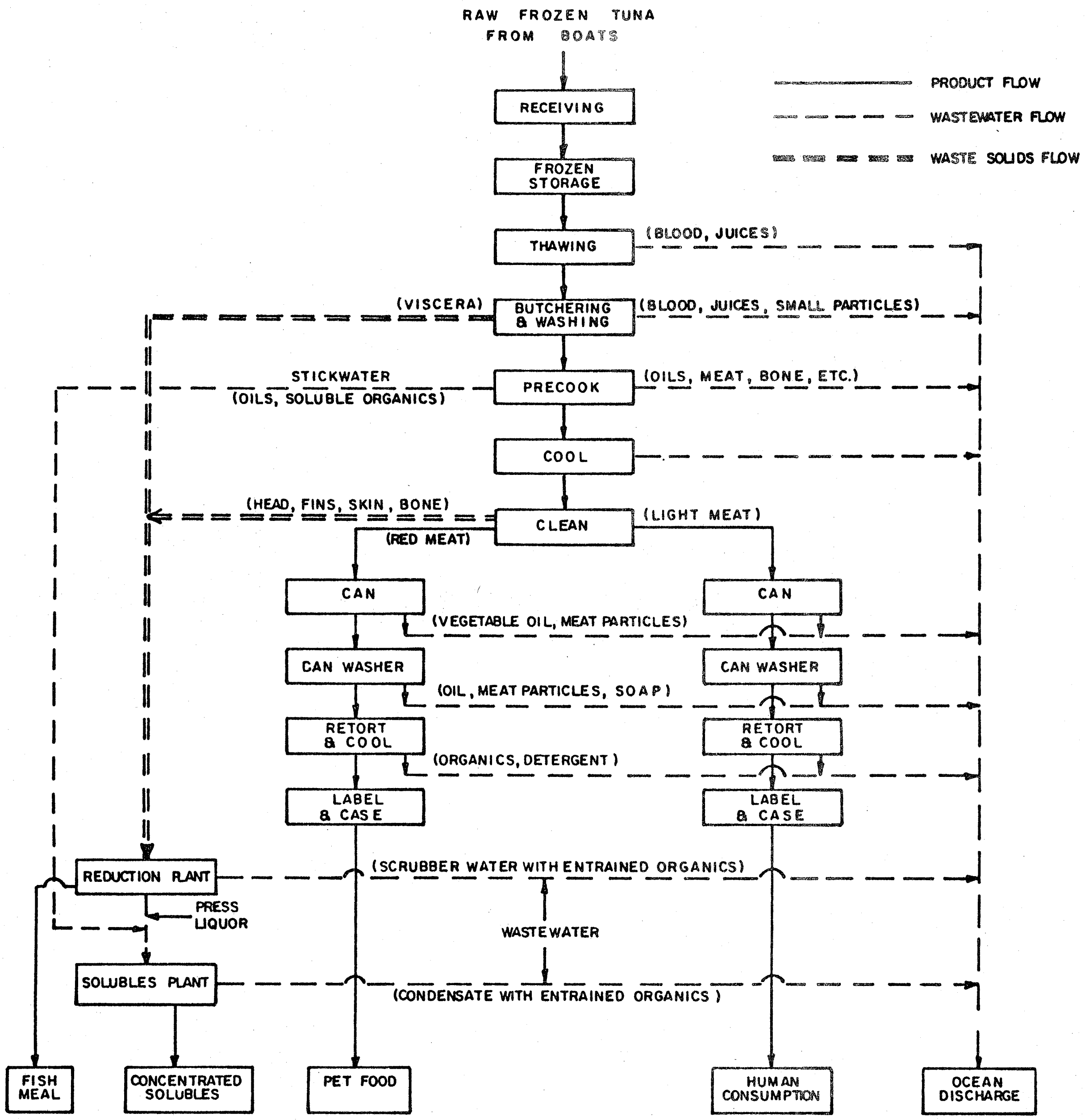


Figure 4. Tuna process.

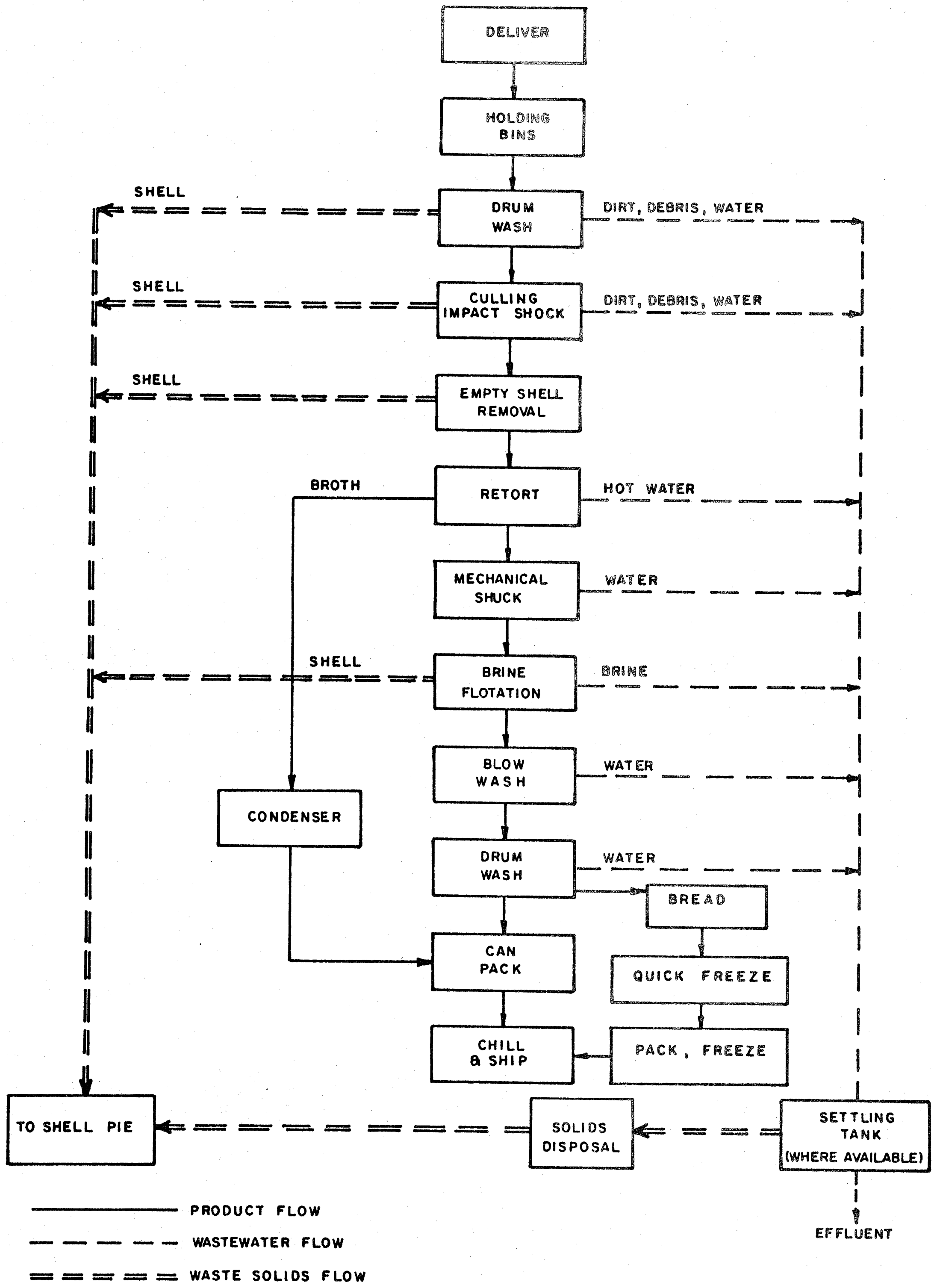


Figure 5. Typical steamed or canned oyster process.

Table 1. Waste characteristics: shrimp processing industry. Average size of a typical plant 6 x 10^4 kg of raw material/wk.

Parameter	Concentration, mg/ℓ	Mass Generation, kg/year
Nitrogen (N)	77	18,000
Ammonium-N	1.4	320
Phosphorus	18	4,100
Chemical Oxygen Demand (COD)	790	180,000
Biochemical Oxygen Demand (BOD)	490	110,000
Suspended Solids (SS)	780	180,000
Total Organic Carbon (TOC)	220	50,000
Sulfur (S)	0.67	150
Chloride (Cℓ)	72	-
Fluoride (F)	0.35	-
Calcium (Ca)	105	24,000
Magnesium (Mg)	5.2	1,200
Sodium (Na)	65	14,500
Potassium (K)	9	2,100
Oil and Grease	65	15,000
Surfactant	0.072	16
Boron (B)	0.022	-
Copper (Cu)	0.056	13
Zinc (Zn)	0.080	18
Chromium (Cr)	0.017	3.9
Strontium (Sr)	0.24	55
Lead (Pb)	<0.3	<69
Cadmium (Cd)	0.026	5.9
pH (S.U.)	6.8	-
Conductivity μmhos/cm	590	-
SAR	1.7	-
Water	-	230 x 10^6

associated with this research program. An average of these results, normalized by the percent total solids, was used to establish values in Table 1.

CRABS

Crab processing wastes are mostly generated during cooking operations and clean-up activities. Cooker condensates may have a biological oxygen demand (BOD) as high as 14,000 ppm, whereas clean-up waters may have a BOD as high as 1,400 ppm. Washing and cooling contribute 50% - 70% of the average wastewater flow. A major portion of blue crab is not edible. Approximately 86% of crab by weight is wasted in the form of body jucies, shells and entrails, of which 25% is liquid lost in cooking. The waste loads from mechanized blue crab processing exceed those of hand-pick plants. Mechanical operations produce brine wastes from the floatation tanks and from meat washing. The concentration of salt may be as high as 10% - 20%. This produces a high salt load. The details of various processes and waste generation in canning of king and tanner crab (U.S. E.P.A., 1974) are presented in Figure 3b. Table 2 indicates the approximate characteristics of various crab processing wastewaters obtained from different published sources and measured in this research. An average of several sources was used. There is a need for more complete characterization of crab processing wastewater.

TUNA

The processing of tuna is divided into several unit processes: receiving, thawing, butchering, precooking, cleaning, canning, retorting, labeling, and casing. Tuna processing generates wastes largely during thawing, butchering, washing, precooking, cooling and cleaning operations but very little waste during canning, washing and retorting operations. About 10% of total waste

Table 2. Waste characteristics - crab. Typical size plant 50,000 kg raw crab per week.

Parameter	Concentration, mg/ℓ	Mass Generation, kg/year
Nitrogen (N)	55	2,400
Phosphorus (P)	10	440
Chemical Oxygen Demand (COD)	1,100	48,000
Chloride (Cl)	550	24,000
Calcium (Ca)	36	-
Magnesium (Mg)	12	-
Sodium (Na)	360	-
Potasium (K)	34	1,500
Copper (Cu)	0.66	29
Zinc (Zn)	2.8	123
Cadmium (Cd)	0.01	0.44
Lead (Pb)	<0.3	<13
Water	-	44×10^6
SAR	13	-

flow comes from plant butchering facilities. Processing of tuna requires large volumes of fresh water, of which 65% is used in thawing. The approximate characterization of raw wastewaters from a typical tuna processing plant is shown in Table 3 (Carawan 1974, Rose 1978, and Riddle 1979).

OYSTER

In the hand shucked oyster process, blow tanks contribute 71% - 94% of wastewater, whereas in steamed or canned oyster process 43% of waste water flow comes from the culler and shocker, 23% from washdown, 15% from the shucker and 11% from belt washing results in a large amount of suspended solids. Hot water retorting (Figure 5) of brine water used in flotation also adds to the salt load of oyster waste (U.S. E.P.A., 1975).

Oyster processing wastewater characterization is indicated in Table 4. Characterization of the oyster processing segment of the seafood industry requires a great deal of further analytical work for (i) salts and anions, (ii) metals, and (iii) other trace and specific organics. Only after adequate sampling and analysis of process wastes can a complete characterization of the generated waste be completed.

SOIL ASSIMILATIVE CAPACITY

Shrimp, crab, tuna and oyster processing wastes are of particular value for crops requiring a combination of nitrogen-phosphate fertilizers. These wastes also contain lime, sulfur, magnesium and micronutrients. Using seafood industry wastes as fertilizer or soil amendments is not an innovation. Before commercial inorganic nitrogen fertilizers were developed, farmers used organic materials to supply nitrogen including shrimp, crab and oyster processing wastes. In recent years, environmental concerns and price increases for inorganic fertilizers have renewed interest in use of nutrient-

Table 3. Waste characteristics: tuna fish processing plant. Average size of a typical plant 8.4×10^5 kg of raw materials/wk.

Parameter	Concentration, mg/ℓ	Mass Generation, kg/year
Nitrogen (N)	100	67,000
Ammonium-N (NH_4-N)	60	40,000
Phosphorus (P)	12	8,000
Chemical Oxygen Demand (COD)	1,540	1,000,000
Biochemical Oxygen Demand (BOD)	880	590,000
Suspended Solids (SS)	360	240,000
Sulfur (S)	37	25,000
Chloride (Cℓ)	500	-
Oils and Grease	320	210,000
Copper (Cu)	0.15	100
Zinc (Zn)	0.23	150
Lead (Pb)	0.026	17
pH (S.U.)	6.7	-
Conductivity μmhos/cm	520	-
Water	-	670×10^6

Table 4. Waste characteristics: oyster processing industry. Average size of a typical plant: 5,000 oysters/wk.

Parameter	Concentration, mg/ℓ	Mass Generation, kg/year
Nitrogen (N)	57	350
Ammonium-N (NH_4-N)	2.5	16
Phosphorus (P)	10	62
Chemical Oxygen Demand (COD)	900	5,600
Biochemical Oxygen Demand (BOD)	410	2,500
Suspended Solids (SS)	210	1,300
Oils and Grease	43	270
Detergent	4	25
pH (S.U.)	7.1	-
Conductivity μmhos/cm	3,700	-
Water	-	6.2×10^6

rich seafood industry wastes as a fertilizer (Costa 1977).

To assess land as a system for treating seafood processing wastes it is necessary to evaluate the behavior of the waste constituents in the terrestrial environment. For each constituent, the assimilative capacity must be determined so that compliance with the site-nondegradation constraint described earlier is maintained. The following discussion examines the various parameters found in seafood processing wastes. An approximate assimilative capacity is generated based on general site conditions. Variations of ±25% when using a specific site would not be unexpected. Thus the present analysis is to highlight the major factors controlling land treatment and to determine the approximate land requirements for these four categories of seafood processing waste.

WATER

On a well drained sandy loam, the permeability of the surface soil is expected to be high (5 to 10 cm/hr) compared to a clay loam (0.5 - 2 cm/hr). The two soils are assumed to be located on a 5% - 8% slope with 500 m of lateral distance to drainage outlets. Detailed field borings to 5 m over the site and subsequent hydraulic property testing are needed to establish the site-specific water movement properties. Hydraulic analysis reveals that about 50% of applied water appears in deep movement to groundwater for the clay loam. Simulating rain inputs from North Carolina, evapotranspiration and soil-water movement over a 25 year cycle the hydraulic assimilative capacity is determined. For year round application potential, the sandy loam could receive 2.5 cm/week while the clay loam could assimilate 1.5 cm/week.

OILS AND GREASES

Oils and greases are decomposed in the soil-plant system. The oil loss rate depends on the microbial decomposition potential in the soil-plant system. Phytotoxicity and crop tolerance of oils and greases determine the maximum critical limit beyond which land treatment is limited by the actual degradation or loss rate. An oil loss rate of 0.5% of soil weight per month, 6% oil of soil weight per year (upper 15 cm of soil), i.e., 1.3×10^5 kg oil/ha, can be decomposed annually in a well aerated clay loam. This assimilative capacity is developed from a series of laboratory and field studies (Overcash 1979). Under optimum moisture, temperature and nutrient conditions greater rates of oil decomposition have been achieved. At any one time, a maximum critical limit of oil application on a soil-vegetation system should be about 1% of soil weight. This would minimize phototoxicity for at least certain agriculturally important crops. Decomposition potential of a sandy loam was taken as 50% of that for clay loam on a preliminary calculational basis. This means that 3% of soil weight (upper 15 cm of soil) (6.7×10^4 kg oil/ha/yr) can be assimilated under normal conditions of moisture, aeration, temperature and nutrient supply. Thus the annual assimilative capacity for oils and greases is taken at 1.3×10^5 kg/ha/yr for clay loam and 6.7×10^4 kg/ha/yr for sandy loam (Pal 1978).

SPECIFIC ORGANICS

Specific organics are biodegradable at concentrations and in amounts present in seafood wastes. Biodecomposition of anionic detergents in soil-plant systems has been reviewed by Overcash and Pal (1979). These detergent types are the most commonly used in the seafood processing industry for cleaning and washing operations. The anionics can be degraded in a clay loam soil if applied at the rate of 100 ppm per month. This would give an assimilative capacity of 220 kg detergent/ha/month or 2,700 kg detergent/ha/year for the surface 15 cm of a clay loam. For a sandy loam the assimilative capacity is assumed to be one-tenth of that for clay loam. The amount of detergent that can safely be applied would then be 270 kg/ha/year.

AGGREGATE ORGANICS AND OXYGEN DEMAND

Total oxygen demand (TOD) of seafood industry wastes must not exceed the soil conditions necessary for optimal aerobic decomposition. The daily reaeration rate of a sandy loam is nearly 960 kg/ha/day and of a clay loam is 640 kg/ha/day (Carlile 1976). Calculation of the total oxygen demand of each seafood processing waste involves the following equation:

$$\text{TOD} = \text{COD} + 4.56\ (\text{NH}_4 - \text{N} + \text{Org.-N})$$

The values of TOD for each segment of the seafood processing industry described in this report are presented in Table 5. Wastes from crab and oyster processing are very low in total oxygen demand and the reaeration capacity in kg/ha/day of both soils is more than 10 times this oxygen demand on a single hectare of land. Total oxygen demand of shrimp and tuna processing wastes exceeds that of daily reaeration over one hectare land of a sandy loam or clay loam. Several hectares of land would be required to satisfactorily assimilate the constituents imposing the total oxygen demand in these seafood categories.

TOTAL NITROGEN

Seafood food processing wastes contain nitrogen (N). Land application of these wastes considers the soil assimilative capacity for the nitrogenous constituents. Nitrogen can be applied at 150% of the crop requirement on a clay loam and 125% of crop uptake on a sandy loam (Carlile 1976). These

Table 5. Total oxygen demand of the wastewaters from different segments of the seafood processing industry.

Segment	Total oxygen demand, kg/d
Shrimp	710
Crab	12
Tuna	4,600
Oyster	200

differences relate to the degree of moisture retention and subsequent probable denitrification. The annual uptake rate of Coastal Bermuda grass and rye (double crop system) is about 600 kg N/ha/year. Allowing 25% loss above this value, the assimilative capacity for the sandy loam soil is 750 kg N/ha/year. On a clay loam soil using the same vegetative cover, and allowing a 50% of loss rate the assimilative capacity is approximated at 900 kg N/ha/yr.

PHOSPHORUS

The assimilative capacity for phosphorus is based on crop uptake and the soil capacity to retain or fix phosphates. Annual soil fixation capacity is determined by calculating the P-adsorption maximum from soil samples collected at a site, the zone of soil assimilation (200 cm), and the projected system life (50 years). To this capacity is added the annual crop uptake of P for a double crop of Coastal Bermuda grass overseeded with rye. The resultant plant-soil assimilative capacity for phosphorus is 280 and 1,400 kg/ha/year for the sandy loam and clay loam soils, respectively.

ANIONS (CHLORIDE, BORATE, SULFATE)

The anionic species of industrial waste may be applied to land at rates determined by allowable concentrations in ground or surface waters. That is, using drinking water standards and the third calculational tool described in the land treatment design section early in this report, the required land areas were determined. For the anionic species it is more convenient to determine the land area directly for each constituent rather than calculate the assimilative capacity followed by the land area requirement. The constituent land area is what is utilized in the LLC analysis.

The water standards selected for usage were drinking water criteria, where available, so that liquid reaching receiving waters is better in quality than that required for public health standards. Concentration values are given in Table 6. Mass balance equations have been developed to determine land area as follows:

$$A = \frac{C_i - C_D}{D_r[C_D(1-\alpha) - C_r]} \; [.01\ Q] \qquad (1)$$

where

A is area, ha

C_i is the concentration of the anionic species in the industrial waste

C_D is the concentration of the anionic species in the soil-water draining to receiving waters, _e.g._ drinking water standard

D_r is the rainfall input, cm

α is the ratio of evaporative losses to rainfall as determined by geotechnical and vegetation investigation of water movement

C_r is the concentration of the anionic species in the rainfall

Q is the industrial waste volume, m^3/yr.

Table 6. Allowable anionic species concentrations for reaching receiving waters.

Parameter	Drinking water Recommendation, mg/ℓ
As	0.05
B	0.75*
Cl	250
F	1
CN	0.01
Se	0.01
SO_4	250

*Irrigation Water Criteria only.

Calculations using the above equation were performed using a 127 cm per year rainfall and an evapotranspiration of 65% of applied water (rainfall plus waste) (Carlile 1976). It must be recognized that use of equation (1) is a conservative approach since no other assimilation such as soil fixation is determined.

ACIDS, BASES, AND SALTS

These constituents are present in all irrigation waters. Assimilative capacity of bases is dependent on the soil cation exchange capacity (CEC) and base saturation. Most productive soils have a minimum base saturation of 80%. As a result of higher CEC in a clay loam compared to a sandy loam, the amount of bases that can be assimilated by clay loam is larger. For a nutrient balance among bases that compete for exchange sites in the soil, calcium level of soils should be 3 - 4 times that of magnesium and 8 - 10 times that of Na.

Soils vary in the capacity to assimilate potassium because soil fixation varies with clay mineral type. The assimilation of Ca, Mg, and K should also take into account the crop uptake and removal of the cations. From the base saturation of the total CEC it is estimated that a sandy loam can assimilate 1,100 kg Ca, 250 kg Mg, 800 kg K and 115 kg Na per hectare each year, while clay loam can assimilate three times as much of each base.

The sodium adsorption ratio (SAR) of seafood processing is less than the critical value of 10 - 12. Thus no problem of sodium accumulation in soils is anticipated. Nevertheless, the seafood processing wastes are saline and must be applied with some water of lower salt content. This might be natural rainfall or irrigation with nonsaline water to leach the accumulating salts below the root zone. The pH of the wastewaters from different segments of the seafood industry ranged from 6.7 to 7.5 and therefore is in an acceptable range.

METALS

Heavy metals assimilation in a soil-plant system is based on accumulation limits in the surface soil (15 cm) that are neither hazardous to plants and animals nor pose any hazard to surface or ground water supplies. Estimates of safe assimilation limits of a number of metals in a soil-plant system have been established for the two benchmark soils (Overcash 1979). Data in Table 7 are derived for those metals that are likely to be present in the seafood processing wastes. These wastes are relatively free of metals and the processing does not involve any operations that would increase or decrease significantly the heavy metal levels of the wastes. To minimize the heavy metals impact soil pH should be maintained at 6.5 or above.

Table 7. Metal assimilative capacities

Metal	Accumulation Limit*, kg/ha	Sandy Loam (CEC < 5 meq/100g) Annual Loading, kg/ha/yr		Accumulation Limit*, kg/ha	Clay Loam (CEC > 15 meq/100g) Annual Loading, kg/ha/yr	
		50 year life	100 year life		50 year life	100 year life
Cu	125	2.5	1.25	500	10	5
Zn	250	5	2.5	1,000	20	10
Cr	300	6	3	1,200	24	12
Sr	500	10	5	2,000	40	20
Ni	50	1	0.5	200	4	2
Cd	5	0.1	0.05	20	0.4	0.2
Pb	500	10	5	2,000	40	20

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[*] For neutral soils under aerobic conditions.

LAND LIMITING CONSTITUENTS

The land area required for safe assimilation of all waste constituents was calculated by multiplying waste generation rate with the recriprocal of assimilative capacity (Table 8). The waste constituents requiring the largest area for satisfactory stabilization in the soil-plant system were labelled as land limiting (Figure 6).

For shrimp processing wastes, cadmium was the land limiting constituent in the sandy loam site, even though the concentration was only 26 ppb. It appears that Cd is controlling because other parameters are also very low and because of the fairly conservative system lifetime of 100 years. At 50 years Cd area requirements are more nearly the same as the next limiting constituent, nitrogen. It must also be clearly recognized that the waste characteristics and water flow were not done together on several processors and hence the mass generation values may have some inherent error.

Following Cd, the nitrogen content was found to be a controlling parameter. That is, if refined analytical results lead to a substantially lower Cd generation, the land area would then be dictated by nitrogen. Water and phosphorus also require substantial areas. Thus if Cd is reduced, the fertilizer elements N, P, and water are used to design the land treatment areas.

The clay loam soil has a higher metals assimilative capacity hence Cd is not the LLC, but is still higher than expected. Water and then nitrogen are the land limiting constituents, 30 and 20 ha, respectively.

Crab processing raw waste was also evaluated for land treatment, Table 8. In the case of a sandy loam site, the metals zinc (25 ha) and

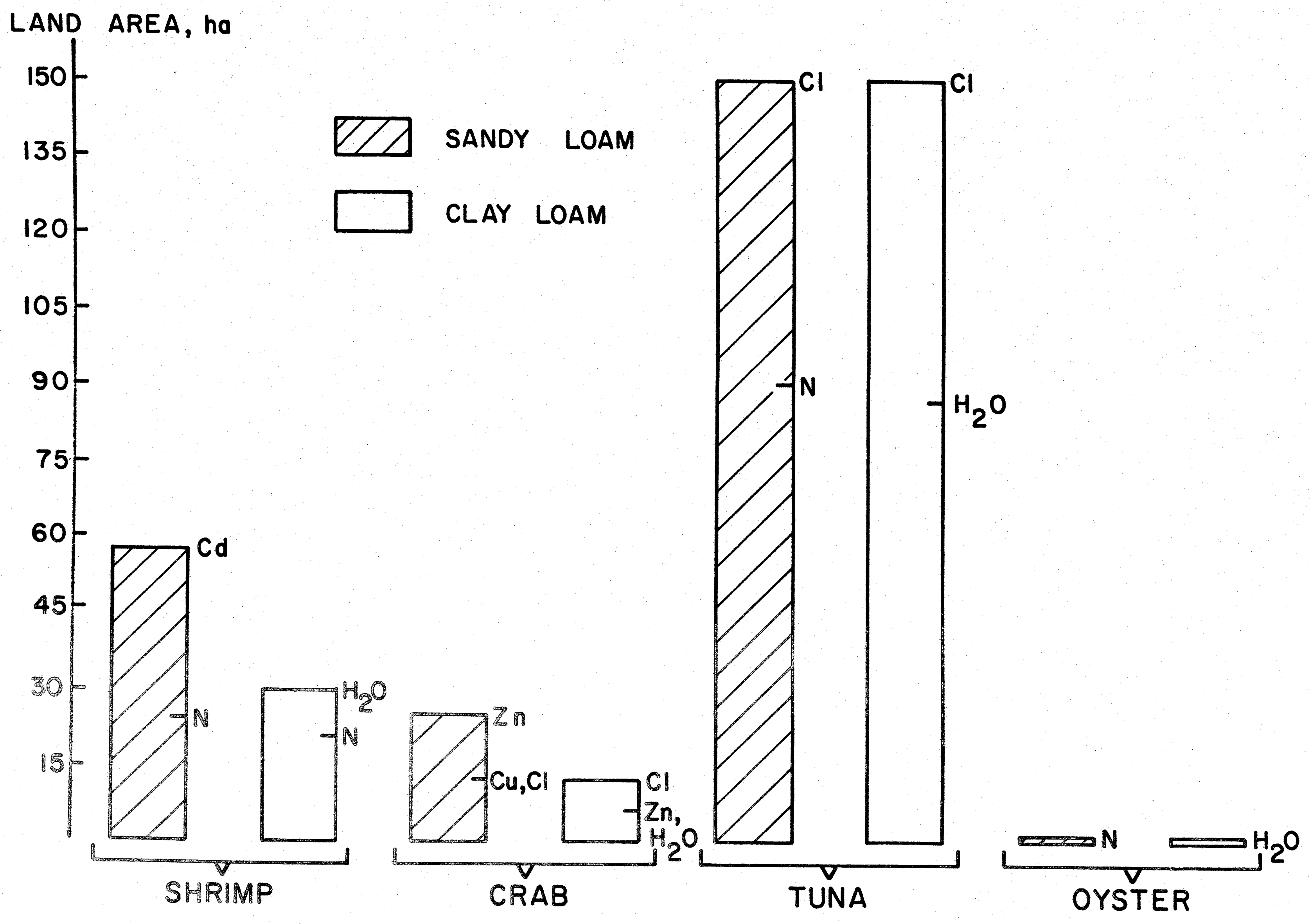

Figure 6. Land area requirements for application of seafood processing wastes.

Table 8. Land Limiting Constituent Analysis, Seafood Processing Industry.

Parameter	Assimilative Capacity, kg/ha/yr		Shrimp Waste			Crab Waste			Tuna Waste			Oyster Waste		
	Sandy loam	Clay loam	Waste Generation, kg/yr	Land Area, ha Sandy loam	Land Area, ha Clay loam	Waste Generation, kg/yr	Land Area, ha Sandy loam	Land Area, ha Clay loam	Waste Generation, kg/yr	Land Area, ha Sandy loam	Land Area, ha Clay loam	Waste Generation, kg/yr	Land Area, ha Sandy loam	Land Area, ha Clay loam
Nitrogen (N)	750	900	18,000	24	20	2,400	3.2	2.7	67,000	89	74	350	0.5	0.4
Phosphorus (P)	280	1,400	4,100	15	3	440	1.6	0.3	8,000	28	6	62	0.2	0.04
Total Oxygen Demand (TOD)	350,000	230,000	260,000	0.7	1.1	590,000	0.17	0.26	1,300,000	4	6	7,200	0.02	0.03
Sulfur (S)	105	175	150	1.4	0.9	-	-	-	25,000	0	0	-	-	-
Chloride (Cl)	-	-	-	0	0	-	12	12	-	150	150	-	-	-
Oil and Grease	67,000	130,000	15,000	0.2	0.1	-	-	-	210,000	3	1.6	270	0.004	0.002
Surfactant	270	2,700	16	0.06	0.006	-	-	-	-	-	-	25	0.09	0.009
Copper (Cu)	2.5	10	13	5	1.3	29	12	2.9	100	40	10	-	-	-
Zinc (Zn)	5	20	18	4	0.9	123	25	6	150	30	7.5	-	-	-
Chromium (Cr)	6	24	3.9	0.6	0.2	-	-	-	-	-	-	-	-	-
Strontium (Sr)	10	40	55	5.5	1.4	-	-	-	-	-	-	-	-	-
Cadmium (Cd)	0.1	0.4	5.9	59	15	0.44	4.4	1.1	-	-	-	-	-	-
Lead (Pb)	10	40	-	-	-	<13	<1.3	<0.3	17	1.7	0.4	-	-	-
Water	13 x 10^6	7.8 x 10^6	230 x 10^6	18	30	44 x 10^6	3.4	5.6	670 x 10^6	52	86	6.2 x 10^6	0.5	0.8

copper (12 ha) required the most land area with chloride also requiring about 12 ha. Use of a clay loam site reduces the land requirements for the metals such that chloride becomes the LLC. Generally, the typical crab plant requires about 50% less land than the typical shrimp processing plant. The same variations or uncertainties that were discussed for the shrimp waste characteristics are present for the crab data as well as tuna and oyster.

Of the four types of seafood processing plants, tuna waste appears to be the most concentrated and to have the highest waste generation, Table 8. Chloride concentration appears to be the controlling parameter with a land area requirement of about 150 ha. In both the sandy loam and clay loam soils, the chloride was the LLC. The second limiting parameter was nitrogen on a sandy loam site and hydraulic loading on the clay loam site. The land area needs about twice as large as those for a typical shrimp processing plant and four times that of a crab processing plant. The land area needs are reasonably large particularly since most tuna facilities are in towns or cities. However the sludge produced from tuna processing facilities is a strong candidate for land treatment since this material can be hauled to an area of available land. The land requirements for tuna processing sludge would be less than those for the raw waste given in Table 8.

The least waste characterization data was available for oyster processing facilities. From the available information the hydraulic load was the LLC followed closely by nitrogen, Table 8. The land areas are less than 1 ha for both sandy loam and clay loam sites. Compared to the other types of seafood processing facilities, the oyster plant would require considerably less land, on the order of 1% - 5% of the other facilities. A summary of all LLCs is given in Table 9.

Table 9. Summary of LLC analysis for various segments of seafood processing industry.

Segment	Land Limiting Parameters (Area in ha)	
	Sandy loam	Clay loam
Shrimp	Cadmium (59)	Water (30)
	Nitrogen (24)	Nitrogen (20)
Crab	Zinc (25)	Chloride (12)
	Copper (12)	Zinc (6)
	Chloride (12)	Water (6)
Tuna	Chloride (150)	Chloride (150)
	Nitrogen (90)	Water (86)
Oyster	Nitrogen (0.5)	Water (0.8)
	Water (0.5)	Nitrogen (0.4)

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