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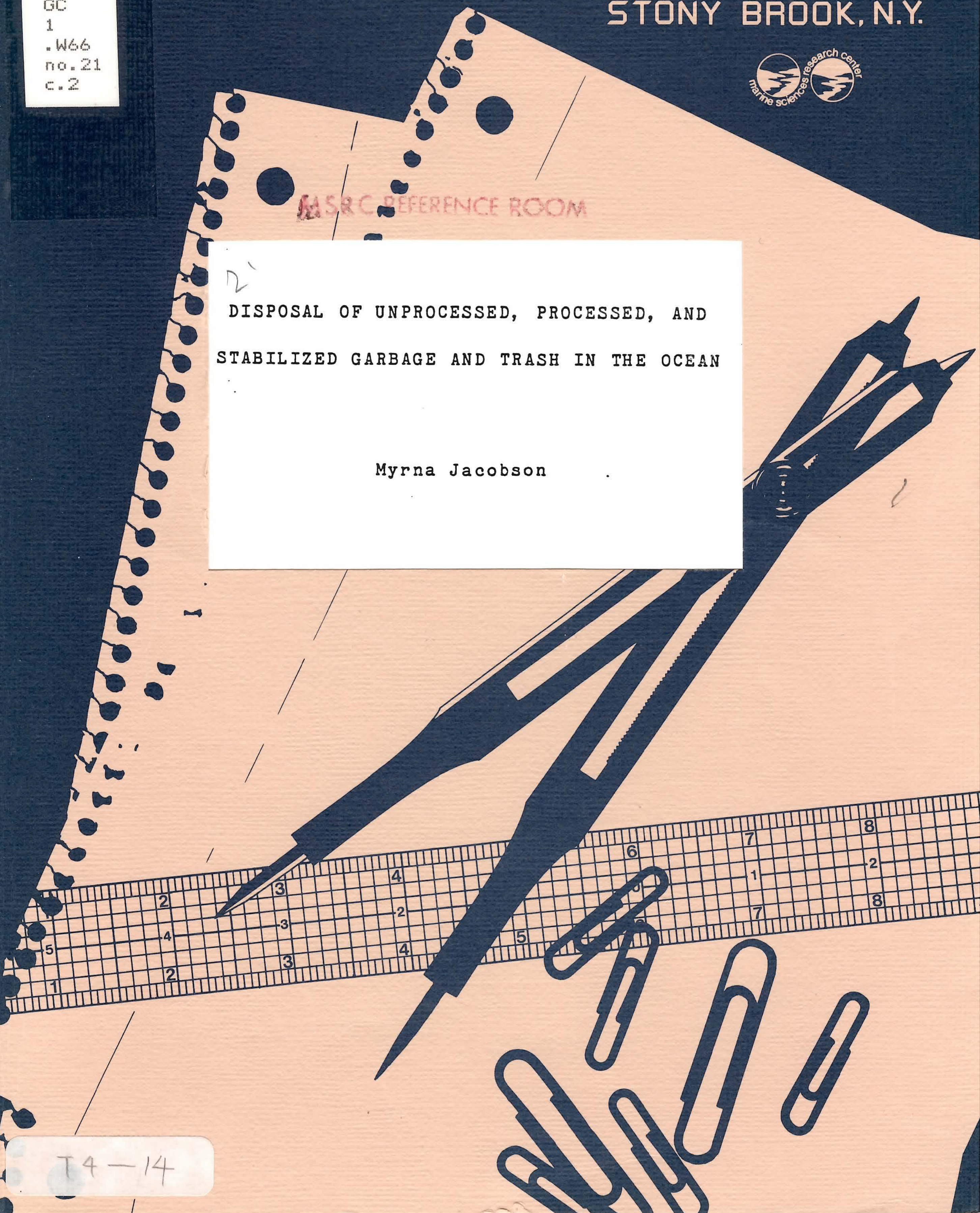

2

DISPOSAL OF UNPROCESSED, PROCESSED, AND STABILIZED GARBAGE AND TRASH IN THE OCEAN

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2

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TABLE OF CONTENTS

LIST OF TABLES

INTRODUCTION

Finding a method for disposal of garbage and trash is an increasing problem coupled to more intense industrialization, urbanization, mass production, population increase and lowering of the recycling incentives in the United States. The disposal options available in coastal regions, where the major population centers are found, are particularly limited. Landfilling of wastes, the only legal ultimate option of disposal available currently, has limited application in these areas. Landfills presently being used are filling to capacity and land for future use is at a premium. For this reason, ocean disposal of garbage and trash is an appealing alternative in coastal areas. This disposal method is not without problems because some of the components of garbage and trash are nonbiodegradable (i.e. plastics) and floatable (i.e. wood). These components may reappear on our beaches after being dumped. Offshore dumping of garbage and trash is not practiced currently, yet plankton tows in the Atlantic ocean routinely pick up tar and plastic debris. The source of this debris may be occasional oil spills, material carried from land or garbage dumped by commercial ships at sea. The additional impact caused by ocean dumping of the large amounts of garbage and trash generated by coastal communities can not be predicted at this time. Some wastes may have a purely detrimental impact on an area while some wastes may act as fertilizers to increase productivity. The latter may be considered either a positive or a negative effect depending on both the area involved and the socioeconomic climate of the times.

The concept that the ocean is a resource conflicts with its use as a waste receptacle. Within the ocean's assimilative capacity, in theory, these two concepts may coexist. A number of questions must be answered before this option for waste disposal may be seriously considered. For example, the capacity of the ocean to receive and assimilate wastes without the threat of serious impact on the environment must be assessed. The sensitivity of a particular ecosystem to perturbation must be determined. Sociological factors must be addressed because a judgment as to how unchanged or clean an environment should remain must be made at some time.

Ocean disposal methods that have been used in the past were often crude, undocumented and unplanned. As time progressed more thought was given to the site selection for disposal, the cost of disposal and the environmental impacts of dumping trash in its various forms.

The purpose of this paper is to present our current knowledge regarding environmental, sociological and economic impacts of dumping of solid wastes in the ocean. This knowledge may be used to assess future research directions.

HISTORY OF OCEAN DISPOSAL OF SOLID WASTES

Throughout recorded history, attitudes toward ocean disposal of wastes have varied dependent on the state of scientific knowledge, governmental policies and locale. In December 1675, Governor Edmond Andros, the second English governor of the colony of New York forbade any person to "cast any dung, dirt, refuse of ye city or anything to fill up ye harbor or among ye neighbors under the penalty of forthy shillings." (Park and O'connor in Ketchum, et. al.,1978). On the other hand, the 1902 Encyclopedia Brittanica called ocean disposal a "clean method" because human activity was not directly affected by waste disposal in this manner and useful waste constituents were assumed to return to humans in the form of fish, shellfish and seaweed.

The Army Corps of Engineers had jurisdiction over ocean disposal by the United States under the Refuse Act of 1899. The Army Corps required data on the characteristics and quantity of waste dumped. It then submitted proposals to Federal and State agencies for review. If favorable response was received, the disposal site was designated in the allowance letters. Materials dumped included dredge spoils, municipal and industrial wastes, radioactive wastes and solid wastes (First, 1972). Solid waste disposal in the ocean continued in most areas save N.Y.C., where, in response to mounting public pressures, this practice was banned in July of 1934. By the 1940's barging of wastes to the ocean was wide spread and rarely questioned (Zapatka and Hann Jr., 1976). As inland waterways became polluted wastes were more often barged to deeper ocean sites for disposal (Ketchum et. al., 1978). The concept of whole ocean pollution was intangible.

There was no sizable ocean dumping of refuse during the time period of 1950-1975 (Loder et.al.,1973). Prior to this time, N.Y.C., Oakland, San Diego dumped part of their refuse at sea (Smith and Brown, 1968; Smith and Brown, 1971; Brown and Shenton, 1974). The proportion of different wastes dumped into the ocean in 1972 is shown in Table 1. Garbage and trash were clearly an insignificant portion of the total dumping problem. Ocean dumping was used mainly for disposal of harbor dredging spoils, industrial wastes, and sewage sludge (McIntyre and Papic, 1974).

In 1972, the Ocean Dumping Act was passed and in 1973, permits from the EPA were required for any form of ocean dumping. E.P.A. permits cover activities ranging from burial at sea to temporary permits for research and interim dumping of toxic substances. Each permit defines the dump site, the discharge rate, the allowable dumping load, and the expiration date of the permit. Also written into the permit were future implementation schedules for phasing out of ocean dumping.

In addition to the U.S. ocean dumping legislation, the 1974 Dumping at Sea Act was passed at an international conference in Oslo. The international accords mandated by the Act may play an important role in future decisions

Table 1. Wastes dumped into the ocean in 1972.

Waste type	million tons
dredge spoil	38.4
industrial waste	4.7
sewage sludge	4.5
other*	0.6

*includes construction and demolition debris, solid waste, paper, wood, plastic, rubber, other floatables, explosives, chemical munitions, radioactive wastes.

regarding refuse dumping in the oceans since they outline overall restrictions for ocean dumping. Any implementation of ocean disposal legislation on the national level must abide by the international accords. Those materials which are internationally prohibited by the Act, as of the August 30, 1975 are: organohalogens, mercury, cadmium, a persistent plastics, high-level radioactive wastes, and biological and chemical warfare agents (Ketchum et.al., 1978). Although garbage and trash are not specifically regulated by the U.S. or the International Ocean Dumping Acts, there are some components of garbage and trash (metals from printer inks and plastics and wood which are floatable and non-biodegradable), which fall into the regulated categories. Incinerator ash is not specifically regulated but it also contains prohibited substances. The amount of these substances found in garbage is quite variable.

GARBAGE AND TRASH TECHNOLOGIES

The composition of garbage and trash is dependent on sociology of the locale. The type of processing technologies used for processing garbage is a function of its composition. Attempts to come up with a general formula for raw garbage and its components have met with varying success. It is important however to try and classify components, if possible, since the rates of degradation and the presence of degraded residues differ depending on the components of the garbage.

The chemical characteristics of municipal solid wastes exclusive of glass, metal and ash are adequately represented by the formula $C_{30}H_{48}O_{19}N_{0.5}S_{0.05}$ (McIntyre and Papic, 1974). Compositional changes in the future are expected to include an increase in plastics, resulting in an increase in the sulfur content of refuse(Bascom, 1982). The average composition of residential solid wastes in 1970 may be found in Table 2. In 1970 the projection for the change in composition of waste in the future was a general decrease in bulk density and water content as the ratio of food to paper and cardboard decrease (Niessen and Chanskey from Pratt et. al., 1973). Metal and glass were expected to stay the same. Recycling restrictions on plastics or non-returnable containers were not expected to change these projections (Chemical and Engineering News, 1971).

When garbage is burned, unstabilized ash is generated. Depending on how one burns raw garbage, different residues are formed (McIntyre and Papic, 1974). Different types of burning include pyrolysis, which is an anoxic destructive distillation process. The solid is heated at somewhere between 800 and 1200 degrees celcius and different proportions of solid, liquid, and gas are produced dependent on the combustion temperature. The gas fraction increases as temperature increases. The solid residue of pyrolysis contains metals, glass and tar (Bascom, 1982). Oxic heating is another method of burning. In a fixed bed reactor, gases pass through the solid bed and ash is removed; a fluidized bed reactor keeps particles in suspension so that there is

Table 2. Composition of Garbage in 1970*

% by weight	component
43.8	paper products
2.5	wood
2.7	textiles
9.1	metal
9.0	glass
18.2	food wastes
3.1	plastic rubber leather
3.7	rocks dirt ash
7.9	garden wastes

(Loder, et. al., 1973)

more efficient heat transfer. The product of these treatments is an unstabilized ash and residuals, including cans and glass.

Detailed characterization is an important step in the process of determination of acceptability of materials for ocean disposal, but, due to the variability of the initial components of garbage and trash, characterization of the heterogeneous material resulting from burning is difficult. An initial attempt was made by First (1972). Fourteen incinerators in the Boston area were sampled. The data collected showed heterogeneity between incinerators and also variability between the laboratories doing the analysis. The latter variability reduces the value of the data. A better description can be found in Woodhead and Roethel, 1985. They did a detailed study of ash residue from an Ogdon incineration plant. They used scanning electron microscopy to classify the particle morphology and size range, and used energy dispersive X-ray analysis to observe microcrystalline structures not visible by simple X-Ray diffraction. The ash was found to contain a predominance of SiO_2 (quartz), $CaSO_{4.2}HOH$ (gypsum), $CaCO_3$ (calcite), and a large amount of amorphous material. Major elements present were silica, calcium, aluminum, lead, potassium, magnesium, copper, iron, with calcium, silica, and aluminum most abundant. Elements found in the ash which are of potential environmental concern are arsenic, cadmium, chromium, mercury,nickel, selenium, and silver. There was a large variation in particle size and morphology with fly ash spheres, flat plates, well defined crystals and amorphous material.

Garbage may be disposed of in its raw state either as loose or slurried material or it may be compacted and strapped into bales. A raw slurry of garbage is made by shredding garbage and adding sea water. Baling of garbage is done by compacting trash to make dense packets, which can then be strapped with polypropylene to facilitate machine loading onto trucks and barges. After processing by one of these methods, raw garbage can be dumped in the ocean. Although ocean disposal is not carried out today on a large scale, it was an option in the past.

A number of different dumping plans were presented by Devanny et. al.,(1970). These options include loose refuse dumping and dumping of compacted baled refuse both near and at some distance from shore. For the former trash would be delivered to dockside, loaded into barges and transported to a descrete dumping sector. This dumping sector would contain a specific amount of garbage and after reaching that concentration, dumping would be discontinued. The problem with this approach is that since garbage is approximately 50% paper and will float or remain suspended in the upper 100 meters of the water column the sector covered by floatables quickly becomes enormous. Paper, however, is easily decomposed so this may be a temporary environmental perturbation. In addition, a technology may be developed to contain the temporary floatable decomposing mass. Although the current technology of garbage separation and the high amount of nonbiodegradable material contained in garbage and trash make this first proposal unworthy of further consideration at this time, with better separation and containment technologies this option may be viable one for the future. Another option considered by Devanny et al., (1970) was dumping of compacted bales. Trash would be delivered to dockside, shredded and compacted into bales and strapped. Bales would then be loaded into barges by a rail system capable of handling 1,000 tons/day (16 hour day).

Ecological effects of dumping of raw garbage also have not been well documented. In addition, it is difficult to generalize from studies which have been done because of the variability of garbage components and differences in environments.

In its processed state (after burning), garbage may be dumped as loose ash remains, which contain a certain degree of metal and/or glass, or it may be stabilized prior to dumping. Unstabilized ash has been dumped in the ocean and used in landfills but its leaching properties may be detrimental to the environment. Stabilized ash has been disposed in the ocean only on an experimental basis. Stabilization is any process which tends to decrease the amount of potential for leachate production from ash. One way to stabilize ash is to combine it with lime to make a cement-like substance. Once the ash has been stabilized it may be used for roadway construction or may be formed into bricks. These bricks, while not strong enough for building construction, may be used to form artificial fishing reefs. Reefs have historically been built out of old cars, tires, and building rubble, and the potential to build fishing reefs out of the by-products of incineration must be considered as a potential disposal method.

TRANSPORTATION COSTS

Constraints which restrict where dumping may occur reflect both economic and ecological considerations. Transportation costs represent a major fraction of the total costs of any refuse disposal system. These costs increase as distance from shore increases. An economic analysis of the cost of dumping baled garbage which is compacted on shore, shredded on site and dumped an arbitrary 80 miles off shore yields a total unit cost of $6.78-7.09/ton (Devanny et. al., 1970). Depending on the inland location of the transfer station (50-150 miles inland) the cost ranges from $10.61-11.82/ ton. This difference in cost reflects additional money to needed to transport garbage to the barge site. Barge transportation costs for 20-100 miles off of shore traveling at a speed of 5-7 knots range between $.57/ton and $2.25/ton (Devanny, et. al., 1970).

The feasability of using the ocean as an ultimate disposal site for processed and unprocessed garbage and trash is dependent in part on the economics of this disposal method as compared to other methods such as land based removal to a dump site. Transportation costs associated with ocean dumping compared to land-based filling have been evaluated in several studies (Baker Inc., 1978; Devanny et. al., 1970; Metcaf and Eddy, 1968). These studies indicate that the economics of ocean dumping is strongly dependent on locale, degree of processing and the agency doing the economic appraisal.

Devanny, et.al. (1970), did a cost comparison of land-based vs. sea-based disposal of garbage considering only financial constraints of ocean dumping. The analysis may be found in Table 1. The conclusion of this study based on economics for a city such as N.Y.C. was that ocean dumping is an economically feasible option, although ecological parameters were not considered.

An economic evaluation of ocean disposal compared to landfill using the Arthur Kill Landfill site in New York and selected coastal disposal areas was prepared by M. Baker Jr. Inc. in 1978 for the Coal Waste Artificial Reef Project, which will be discussed in greater detail later. Included in this evaluation was an assessment of the costs for building reef block manufacturing plants before ocean disposal could proceed. This study found that the cost of instituting a new technology was high enough to prohibit ocean disposal by this method until some time in the future.

From an economic view, refuse should be dumped in close proximity to shore. However health, social, and ecological factors prohibit nearshore dumping. A compromise between economic, aesthetic and ecological concerns must be made.

SITE SELECTION

Pratt et al. (1973) and Rowe (1971) compared the relative benefits of dumping baled compacted wastes at a shallow site (near shore) and a deeper (offshore) dump site. These investigators considered that the main constraint on dumping of bales was that they needed to be dumped in an area where the bottom is not significantly effected by waves or bottom currents to prevent dispersion of bales. The advantages identified for dumping at a shallow site were 1) the monetary savings in terms of equipment and time, 2) a reduction of forced dumpings due to storms, 3) improved control of vessel positioning, 4) ease of monitoring of waste on the bottom, and 5) possible use of the dump site as a fish attractor. Also, organisms of the benthos in shallow areas may be more capable of dealing with stress of habitat modifications than those organisms accustomed to a more physically stable area such as the deep sea. Disadvantages of a nearshore dumpsite include: 1) the waste will be less compacted because of low hydrostatic pressure, 2) there will be competition between the use of the ocean area as a dump site and uses for recreation and commercial boating and fisheries, 3) drifting of garbage bales onshore may occur due to winds and currents, and 4) displacement of bales off the bottom is possible in the nearshore environment due to errosional phenomena and wave induced bottom currents. Advantages of disposal in deep ocean basins include: 1) a high hydrostatic pressure affords maximum compression of bales; 2) the increase in bale density decreases the possibility of displacement of bales away from the area, 3) depth affords protection from wave induced currents, and 4) there is little use by humans Disadvantages include: 1) oxygen depletion may occur in the basin as the bales decompose (this is probably not a real problem because the rate of decomposition would be slower in these environments allowing ample time for oxygen to diffuse into the immediate area), 2) difficulty in positioning of vessels in an unknown environment, and 3) difficulty in monitoring environmental effects at a deep site dump therefore introducing unknown consequences of introducing pollutants to a stenotypic animal group.

The above studies suggest general evaluation criteria however a more detailed appraisal is necessary before actual dumping of raw garbage wastes occur. Evaluation of specific sites for ocean disposal have been outlined (IEC-O Report 4460c1541, 1973). The areas covered in the outline are; The New York Bight, Charston S.C., Southern California, San Francisco, and Puget Sound. Specific oceanic site selection parameters considered in this study were: depth, bottom relief, rock types found on the bottom, temperature and salinity of the region, the stability of the mixed water layer (if there is a thermocline in the area), turbidity parameters, current velocity and direction, and wave propagation and force. In addition, the chemical characteristics of the water such as dissolved oxygen, biological oxygen demand, carbonate, nitrite, pH, phosphate and silicate are also considered. The chemical parameters are indicators of the rate of metabolism and chemical oxidation state of the water column. Abundance of silicate may indicate the presence or absence of certain species of plankton in an area. Biological parameters include overall toxicity of the garbage, and habitat change for indigenous species, species diversity changes, distribution and variability of species present, and specific bioassays. The IEC report suggests that biomass and as well as statistics on commercial fish and shellfish catches be collected. The nature and type of bottom detritus accumulated before and after dumping should be recorded (An example of the physical and chemical properties of an actual California sill dumpsite may be found in Table 3.)

As mentioned in the above, there are a number of processing and dumping schemes which have been theoretically evaluated in terms of their legal, ecological and financial constraints. The following sections highlight information on actual documented dumpings of raw garbage, unprocessed and stabilized incinerator ash. Experiments using raw and processed garbage as reefs and islands will also be covered.

RAW TRASH DUMPING

Some of the best studies on effects of dumping of trash related material are in literature concerned with paper mill effluent and mussel raft culture effects on the marine

Table 3. Physical and chemical properties of a California dump site.

Temp degrees celcius at the surface	13-20
Temp degrees celcius at the bottom	8-9
Salinity at the surface in ppt	33.3-33.8
Salinity at the bottom in ppt	34.29
Dissolved oxygen at the surface	8.0
Dissolved oxygen at the bottom	0.2

IEC-O U.S.E.P.A. contract 68-01-0796, 1974 ecosystems (Pearson and Rosenberg, 1976; Tenore, et. al., 1982). These studies detail community succession as one proceeds away from the discharge area. They are important to mention in this discussion only because paper and organics are both components of garbage. Communities dominated by small organisms with short life cycle and tolerance for sulfide exist near the immediate site of disposal. A sulfide buildup is due to decomposition of organic matter and the associated conversion of sulfate to sulfide. A grading toward a community with a greater size distribution containing organisms with longer life cycles occurs as one proceeds away from the direct disposal area.

Most studies of ocean disposal do not emphasize the dumping of raw solid wastes (Bascom, 1982). Solid wastes studied are usually solidified remains from sewage treatment plants (Bascom, 1982). Dumping of raw garbage and the effects of dumping have only been documented for some areas off of the coast of California, including two sites that were 20 miles off shore of Newport beach and Monterey (Lawson and Whitesides, Jr., 1972). One site was an undescribed distance from shore off of San Francisco bay (IEC-O U.S.E.P.A. contract 68-01-0796, 1974). The U.S. Navy dumped 107,000 tons of garbage and trash between 1944 and 1970. Dumping has been terminated and incineration and landfill disposal methods are now used. In addition to the Navy, approximately 51,000 tons of garbage and trash collected from commercial vessels during the time span of

1931 to the 1970's at Long beach and San Pedro, have been dumped at a site South East of Santa Catalina Island. The rate of dumping was 623 t/y (Long beach, Newport beach, and San Pedro are all in close proximity to Santa Catalina Island, which is located off of the San Pedro channel). These garbage and trash dumping sites, located on the lower slope of the Southern San Pedro basins are characterized as impoverished areas, as are the slopes below the sills of the basin (IEC-O U.S.E.P.A. contract 68-01-0796, 1974).

Basins are considered inpoverished areas due to the low oxygen concentrations which are a reflection of the position of the sill within the oxygen minimum of the sea (below the sill is an anoxic zone). These areas were selected for dumping because it is assumed that since the area is depleted in oxygen already, no major perturbation will occur when garbage is dumped.

Total recorded dumping at this site by both Navy and commercial vessels combined was 158,000 tons of refuse. An average dump of 5,267 tons would occur after 30 years. According to Lawson and Whitesides Jr. (1972) the total dumping off Monterey and Newport beaches was 26,000 t/y in 1968 and 21,000 t/y in 1971 with 85% of this material being harbor dredge spoils. Garbage and trash from both Navy and commercial vessels then contributed between 15%-25% of total dumping activities.

Problems encountered in the disposal of wastes as a result of some commercial dumping activities at the San Pedro, Long Beach site can be extrapolated for other situations where dumping of raw garbage may occur. Surface disposal of a liquid into the water column was found to effect the productivity of the water column. Depending on the initial concentration of the organic constituents in the wastes increases and decreases in productivity were seen. The dumped materials, having a different density than the surrounding water column, apparently inhibited mixing of the materials with sea water. The trash would then proceed down the water column until it found a neutral bouyancy possibly trapping organisms from the water column as it moved. Another problem encountered was related to the use of dead reckoning, a rudimentary form of navigation, to position the vessels at the dump site. Vessels remain on station for 4-5 hours and with no position check missdumps were prevelant (IEC-O U.S.E.P.A. contract 68-01-0796, 1974).

The State of California recommended that all material being dumped at sea at the sites be reduced to a pulp by grinding or maceration and that floatables and inorganics be sorted out and disposed of by other means. However the effects of macerated garbage on the marine environment have not been adequately studied. It is not clear therefore why this recommendation was made. A more adequate form of navigation was also suggested to enable better pinpointing of the dumping area.

In addition to the dumping done by the Navy and commercial vessels, cannery wastes were dumped into San Francisco Bay from 1960- 1972 (Smith and Brown, 1971;

Lawson and Whitesides, Jr., 1972). Cannery wastes consist of ground fruit pits, skins, etc., which are seasonally disposed of. These wastes are of a higher organic content than those previously discussed. Solid residue from this plant consisted of peaches and pears with 90% of the residue consisting of as overripe peaches and pear skins. These residual solids were a pumpable consistency when mixed with water. They were transported in a 165 by 40 foot barge which had discharge pumps 5 feet below the vessel bottom (at an absolute depth of aprox. 15 feet). A 25% dilution was achieved prior to pumping and 25% additional dilution was achieved during the pumping process. Two hundred and fourty six kilotons of fruit from canneries were dumped in the Bay at an average of 22,000tons/yr 20 miles off shore. Operations usually resulted in fouling of beaches as pulp slurry advected inshore (Lawson and Whitesides Jr., 1972). The practice was terminated due to increased costs of required monitoring by the State of California. An example of on site monitoring data for cannery wastes is presented in Table 4. Monitoring was done in close proximity to the discharge pump. Subsequent visits were made to the site of the discharge.

As a result of experiences such as those discussed above, the State of California Department of Public Health and Agriculture and the USAD had provisions for dumping of garbage as of 1971. They are as follows: A) Dumping of garbage in or upon navigable waters of the state or at any point in the ocean within twenty miles of its coastline is

Table 4. Site monitoring data from a cannery dump off of San Francisco Bay.

	Observed Range	
	Min	Max
pH	3.6	3.7
Suspended Solids	29000 ppm	35400ppm
Volitile Solids	15200 ppm	18600 ppm
Settable Solids	56ml/l	61ml/l
Chemical Oxidation Demand		
settled	1432000 ppm	152000 ppm
unsettled	199100 ppm	213200 ppm
Biological Oxidation Demand ppm		
151 minutes	310 ppm	400 ppm
6 hours	3900 ppm	4400 ppm
5 days	82000 ppm	128000ppm
20 days after dump	118000 ppm	128000 ppm
% Protein	0.61	
% Charbohydrate	7.60	0.814
% Crude Fibre	7.60	8.50
% Fat	0.16	2.30
Chlorinated Hydrocarbons	0.010 ppm	0.02 ppm
Organophosphates	0.015 ppm	0.03 ppm
Cadmium	0.04 ppm	0.08 ppm
Lead	0.08 ppm	0.10 ppm
Chromium	0.02 ppm	0.02 ppm
Copper	0.01 ppm	0.04 ppm
Mercury	0.006 ppm	0.009 ppm
Zinc	0.06 ppm	0.13 ppm

considered a misdemeanor (California Health and Safety code, Chapter 4, Article 1, Section 4401). B) Removal of garbage from any vessel for dumping into any territorial waters or onto land is prohibited except for immediate incineration, approved treatment or disposal under supervision of the Director of State Department of Agriculture or delivery to a garbage licensed by the Director or the Federal Government (California Agricultural Code Division 8, Chapter 4, Section 16151). C) Garbage may be ground to a liquid state and disposed of with location and distance from shore such that it is approved for disposal (not specified). These regulations were mainly to prevent diseases of cattle sheep and swine. D) Disposal must be in a discrete and defined area. E) It shall not impair any benificial uses of offshore coastal waters. F) No visible oil or oil slick or any other floating or suspended matter shall be found along the beaches or shores. G) No toxic material which would be detrimental to human or animal, fish or plant or bird life shall be dumped. H) No turbidity changes or dissolved oxygen readings of lower than 7.0mg/l as an annual average or 5.0mg/l at any time will be tollerated. I) All vessels must notify the authorities 24 hours prior to departure to dump sites so that an observer may accompany the vessel. All trips must be logged and reports filed. Technical reports are required to be submitted quartely. They are to contain information on the quantities, and types of materials as well as the dates of discharge, sums of the quantities of material discharged during the period covered by the report. The provisions above constrained dumping activities prior to federal legislation in 1972.

One concern when dumping raw garbage at sea is the rate and the direction of transport of materials. Koh et al. (1973) worked on a mathematical model for predicting the dispersion of barged wastes in the ocean. This model probably applies best to sewage sludge effluent, cannery wastes and slurried garbage. Both theoretical model and experiments were done on dispersion and settling of barged wastes. The predictions closely matched the experimental results. To model the waste dispersion they considered that the waste has two phases: a solid phase with various densities and settling velocities and a liquid phase. Three potential methods of discharge were mentioned: discharge from the open of a hopper barge, pumping the discharge through a nozzle under a moving barge, and discharge at the surface into the barge wake. Three possible phases of dispersion occurred: a convection phase, a collapse phase, and a long term diffusive phase. When dumping raw garbage at sea one tries to minimize the area over which deleterious effects occur.

CONSTRUCTION OF ARTIFICAL REEFS WITH RAW BALED GARBAGE

As mentioned previously, raw garbage may be baled prior to dumping. Pollution from bales is attributable to material which escapes before sinking, refloatables from sunken bales, movement of bales from an area, and elution of discarded soluble material. In addition one may see elution of decomposition products of refuse. Biological activity may be increased or decreased and areas of the ocean floor may be lost due to physical coverage. The potentially beneficial aspects of baled garbage will be discussed in the next two sections.

Using a waste product as a resource is an appealing alternative. This section and the section on stabilized fly ash contain information on results of experiments on raw and stabilized materials used to build artificial reefs. These reefs are potential fish attractors and may act to increase local fish catches as well as local productivity. Two studies were done in the 1970's to determine if baled untreated garbage could serve as an artificial reef substrate (Pratt, et al., 1972; Loder, 1973).

Loder (1973) made baled garbage prototypes which were placed in the ocean for study. Mini bales were made using a modified hydraulic concrete testing machine. Garbage was baled with the addition of glass and metal to increase its density so that it would not float initially. After compaction, bales were wrapped in polypropylene mesh and strapped. Each bale had two tubes inserted to enable sampling of interstitial waters. Bales were either food bales or non-food bales. Food bales contained dog food in addition to the afore mentioned components. The site selected for dumping was in shallow water (20 meters). It was a sandy site with good water circulation.

After placement of bales an increase in abundance of motile organisms was observed both on and around the bales; there was settlement of <u>Spirorbis</u> (a calcareous tube-building polychaete), hydroids and a red filamentous algae on the bales; no change in the infaunal community was detected. Also it was found that there were less motile organisms surrounding the food bales. This difference was related to the degree of sulfur bacterial mat formation on the food containing bales. Certain fouling organisms settled directly on the waste material (hydroids) while others (<u>Spirorbis</u>) only settled on the inert mesh baling and strapping. Successful colonization of bales, therefore may depend on the nature of the strapping material as well as the types of organisms prevalent in the area of the dump. One reason that types of organisms settling on straps differed from those settling directly on bales may be related to the concentration of exudates emitted from the bales. Toxic exudates such as hydrogen sulfide reach low concentrations (due to diffusion phenomena) once they reach the water/bale interface. This may enable an organism to settle a few mm away from a potentially toxic environment. Organisms which settled on the strapping material may be less tollerant of these quickly diffusing chemicals than organisms which are able to successfully colonize the bales directly. Toxicity of hydrogen sulfide may vary between species. Textural differences between the baled garbage and the baling material may also be a selection criteria. Areas of crevices as opposed to smooth surfaces or edges of straps or blocks may be preferred by certain species. The bales maintained their physical integrity over the year that they were studied although they lost the metal baling clips which held the baling straps.

Chemical exudates were monitored from within the bales. pH, Eh, reactive phosphate, nitrate, nitrite, ammonium, hydrogen sulfide, and utilization of oxygen by the bales was measured in the interstitial waters. All of the chemical parameters are indicators of decomposition processes. The pH dropped slightly and then leveled off. Nitrate and nitrite decreased as ammonium and hydrogen sulfide increased. Oxygen utilization is coupled to decomposition of organic matter. Oxygen utilization increased in both food and non-food bales but reached an asymptote sooner in the non food bales. It is possible that microorganisms in the non-food bales were limited by the lower organic content. Within one month, sulfide was found to be high in both food and non-food bales.

The rate of diffusion of degradation products from the bales was high and the surrounding water was uneffected by the processes taking place in the bales. Material from the bales quickly diffused away from the area. In the case of a larger dumping of baled garbage or persistant dumping, diffusion of degradation products away from the bales may become restricted due to both the higher concentration of bales and degradation products. Some effect on the surrounding areas may be seen in this event.

Pratt et al. (1973) did a one year laboratory study on the biological effects of ocean disposal of solid wastes. This study and the previous one were done because the New England commission was considering ocean dumping as an option for the disposal of residential solid wastes and incinerator residue. Oxygen utilization, hydrogen sulfide production, and ammonium production were measured from bales of garbage that were kept in tanks of seawater in the laboratory. Dissolved organic carbon, carbohydrate and organic nitrogen species, dissolved oxygen, pH, phosphate, toxic metals, and gas production were monitored. The effect of hydrogen sulfide on the behavior of motile organisms was described and the microflora which developed on the waste surfaces was identified.

Test wastes used in this study were composed of "food", tin cans, aluminum, plastic, glass, and 72% paper. The paper component was higher than what was usually found in typical domestic wastes at the time of this study. Bales were composed of either 2.2% food or 9.8% food. Food bales were composed of paper, dog food, rice, and sugar. Blocks were placed either in a flume or in a 20 gallon tank at 9 degrees celcius. Sand bottom was used as the control in the flume. Closed tank studies were done where bales were placed into either fresh or salt water tank.

Results in this study are similar to those in the field study discussed previously. Initially a drop in pH was measured in closed tank waters due to the leaching of paper constituients such as inks from newspapers in the bales. Dissolved oxygen in the tank experiments was consumed in 6-8 days. With the disapearance of dissolved oxygen a disapearance of dissolved nitrate was also noted. Hydrogen sulfide was produced in 50 days and increased throughout the experiments. Hydrogen sulfide remained as long as degradable organic matter was present. Dissolved iron was initially high but decreased to low values as hydrogen sulfide production increased (mobilization and immobilization of metals in anoxic sediment can be explained by the interactive phenomena of formation of insoluble sulfides and formation of soluble metal polysulfides). Ammonium increased from 20-82 mg/l after 80 days in waste bales with high organic matter content. Phosphate increased from 22-32 mg/l after 50-60 days and then leveled off. Turbidity of the interstitial solution increased with time. Carbohydrates decreased to a low value but total dissolved organic carbon remained high at the end of 80 days. In the open system flume studies only carbohydrates (as measured by reducing sugars) and dissolved organic carbon were measurable. Carbohydrates were a large proportion of dissolved organic carbon found by day four in the study.

Due to the nature of carbohydrate added in the study (sugars were added to the bales) it is not clear whether the organic carbon results are due to decomposition or solubility phenomena.

The rate of gas production measured was somewhat dependent on the density of the bales as well as the rate of decomposition occurring. Denser bales have a slower rate of diffusion of gases in and out of their matrix. An attempt was made to describe the bulk properties of compressed waste in terms of permeability at different densities. The results indicate that at densities near those used in this experiment the bales are extremely impermeable. As these balés decompose, metal corrodes, and these bales may also become more bouyant. Excessive gas production may add sufficient bouyancy to a bale so that it may become neutrally bouyant in the ocean. Bales have been seen to float in laboratory studies (Pratt et al., 1973). This may be a problem for the eventual instrumentation of this option of disposal. That is, with time bales may float out of the initial dump area.

A model was created to predict the rate of transfer of dissolved substances through waste deposits. This model was a modified Berner-type model using estimated diffusion coefficients (Berner, 1980).

Epifaunal colonization was measured directly on the bales and also up and downstream of the bales in flume studies. In November through January the authors reported <u>Vorticella</u> (a stalked protozoan) colonies on control areas (open sand) but none on the waste bales. After three months a thick mat of bacterial succession communities was present on a surface layer on top of the block. Beggiatoa, Thiothrix, Vitreoscilla, and Achromatium are possible contributors to the sulfide bacterial mat. Erosion of this sulfide bacterial mat took place at current velocities of between 17-22 cm/sec. As currents eroded the surface paper layers off the colonies were removed (critical erosion velocity was 6 cm/sec). In addition to the anaerobic mat, there was a felty aerobic mat composed of a consortium of bacteria and fungi which were found on the blocks at current velocities between 1-22 cm/sec and were found from the interface to a depth of 1-2 mm. The extent of the aerobic mat and the presence of an aerobic mat was dependent on the position of the aerobic-hydrogen sulfide interface. At water velocities between 0.1-1 cm/sec the sulfide zone reached the surface.

After one year Actinomycetes were found in April and May. They grew to 1 cm depth in 2-3 days. The mat remained clear of other organisms for a few days after which it was colonized by ciliates and harpacticoids. These colonies had little erosion resistance and probably would not be found in a field situation. A "sulfide bacteria veil" is formed in highly stable environments (perhaps a deep sea environment). Polydora and Sprorbis (both small tube-building polychaete worms) were found colonizing control areas but not on the garbage bales. Initial colonization of unwrapped bales (paper on the outside) was done by a Thiobacterium pellicle. The species which was found both in the summer at 20 degrees celcius and in the fall at 9 degrees celcius was T. bovista. The presence of this species indicates that the hydrogen sulfide which was generated in the blocks was reaching the surface. In March-September sulfide bacteria, many ciliated protozoan species, oligochaete worms, nematodes, and harpacticoid copeopods were found on the bales. Hydrozoans and tunicates were found both on the control and waste tanks.

Infaunal populations were also studied. Capitella capatata (a small tube dwelling polychaete) was a consistant colonizer of solid waste deposits. In late summer Nereis succinea (a mobile polychaete species) replaced Capatella in some tanks. Harmothoe (another errant plate-backed polychaete) and Polidora ligini (another tube-dwelling worm) were found in the tank containing garbage. In the control tanks a large amount of Amphitrite johnstoni, and Pherusa affinis (both polychaetes) and a nemertine worm and Haliclona (the boring sponge) were found. The colonizing communities were discriminating between control tanks (sand) and the baled garbage tanks.

Reaction of benthic animals placed in contact with wastes was studied. Slurries of milled paper found downstream from eroding waste deposits provided a mass of 3 cm in thickness. Chemistry of the eroding waste deposits was also studied. The pH of the sea water extracted from shredded paper after two weeks was 5.6. The pH of the interstitial water from the bales was 5.4 after 77 days.

Pitar morrhuan and *Mercinaria mercinaria* (both hard clams) extended their syphons through the deposit. The both produced high amounts of pseudofecies in respond to the rain of paper flock. *Artica islandica* (a large offshore bivalve species) blew the waste away from the immediate area of their syphons with excurrent flow. *Palaemonetes* and *Crangon* (both small shrimp-like crustaceans) moved easily on the slurry surface. Amplescid amphipods were buried and burrowed through the waste and swam to the surface of the water. The above mentioned organisms were therefore able to survive initially in the waste.

Both Loder's 1973 and Pratt's 1972 studies are short term and somewhat superficial. They are good preliminary studies. More detailed, longer term studies are needed to determine the suitability of this method as a means of disposal. Specifically degradation products and effects of products on marine life, and change in the floatability of bales with time should be studied.

CONSTRUCTING ISLANDS AND BREAKWATERS WITH BALED RAW GARBAGE

In addition to building reefs with raw garbage, the use of garbage and trash as islands and breakwaters has been considered by a number of municipalities. In 1974 a RECAP (Resource recovery and park) island was proposed in N.Y.C. as a means of resource recovery (City of N.Y. Dept. Sanitation Report on Brooklyn Navy Yard, 1985). This Island was to be constructed as a container on the ocean floor as a land extension, filled with compacted refuse, and capped with a cement cover. A resource recovery facility with a 11,000 ton per day processing capacity would be built on the island to produce 7,7000 tons per day of refuse derived fuel. This resource recovery plant would meet 5% of the City's electrical demand. The project was never implemented due to a number of problems. An act from the State legislature was needed to clarify land ownership and the proceedings got caught up in environmental reviews. Furthermore, the environmental impact of the resource recovery plant and the island were not clearly defined, the stability of the island over time was not clarified and the costs involved were high. Essentially the N.Y. RECAP project was considered a high cost, high risk operation and was not pursued. Before making an island out of garbage and trash one must consider the nature of the gases produced during the decomposition process, which will cause bouyancy changes in the island and changes in the ambient water due to leaching effects. Careful pilot studies should be done on these factors as well as the rate of decomposition and the rate of bale replacement needed to maintain the integrity of the island.

Another municipality in Ohau, Hawaii considered using garbage both as a breakwater to create a surfing beach and extending the Honolulu Airport facility were considered (Grigg, 1969; Bogost, 1973). Neither idea was instituted due to bureaucratic and environmental reasons.

UNSTABILIZED ASH

Burning produces loose ash which is unstabilized. To ascertain the acceptable environments for disposal, a detailed study of the residues must be made. Studies on ash from coal plants have been done. In addition, one large study on garbage ash was undertaken (First, 1969). For completeness both coal ash and incinerator ash studies are included in this section.

Leaching from loose coal ash has been found to be an important factor in its toxicity (Lawson and Whitesides Jr., 1972). The rate and ultimate amount of leaching of trace metals is an important indicator of the environmental acceptability of a substance. Vandersloot and Wijkstra (1984) observed long and short term leaching of trace elements from a number of stabilized waste products including coal fly ash, scrubber sludge from flue gas desulfurization, blast furnace slag, domestic waste, incinerator ash and gypsum from phosphoric acid production. Differences in the degree to which the elements are tied up in the aluminosilicate matrix strongly effects leaching properties. This characteristic varies from one material to another. In addition, the effective diffusion rate of interstitial solutions varied within any one material dependent on both pH and salinity.

Bamber (1980) summerized a series of experiments done to test the effect of pulverized fuel ash and leachates of ash on the benthic fauna of the coast of England. This study is one of few if not the only study where the effects of any type of unstabilized ash has been studied in the marine environment and since coal fly ash is similar to the ash found in burned garbage residue this study and other studies on fly ash will be included in this paper.

Pulverized fuel ash (PFA) and clinker, the ash and solid residue of burnt coal, contain no organic matter. Addition of these particles to the marine environment will have some impact. When fly ash is placed into the marine environment pozzolanic aggregates may form. These aggregates are finely divided siliceous, or siliceous and aluminous material, that reacts chemically with slacked lime at ordinary temperatures and in the presence of moisture to form a strong slow-hardening cement. They are composed of PFA, aluminium, and silica and can be up to 1 meter long and have been found to be up to 7 years old (as aged by a specimen of Zirfaea, a borrowing clam, which had burrowed into them). They are succeptible to water movement and all aggregates have potential for epifaunal settlement.

Bamber (1980) examined the effect of dumping both in laboratory and field experiments. The area of the major field dumping activity was a silty region. This location was compared to a similar habitat which had a silty environment but where no dumping occurred. In field experiments both meiofauna and macrofauna were monitored.

The major effects of dumping alone were deleterious to animals irrespective of constituents of the dumped material. Recovery in ash dumps was totally by recolonization of new larvae. There was no upward migration of invertebrate species. Dumping itself was the main detriment.

Experiments were done on long term community development by placing 0.28 meter squared trays containing PFA in seawater. The substrates varied in the ratio of PFA and sediment used. PFA did develop a microfaunal community but at a significantly slower rate than sterilized or incinerated natural sediment particles. In addition to open tray experiments, larval settlement selection experiments were performed. Spionids (polychaetes), gastropods, lamellibranchs, and ectoprocts were presented with a number of combinations of substrate. While some larvae preferred coarser substrates and other preferred fine substrates, the substrates containing PFA inhibited metamorphosis of the larvae and they often died. In addition, while the organic nitrogen increased consistently in sterilized natural sediments the opposite trend was observed on PFA. Adult selection experiments showed that eight types of animals tested preferred sediments with the lowest PFA content. Depending on the natural sedimentation rates in the area and the stability of the pozzolanic aggregates a region may eventually be successfully colonized.

Metabolic effects of PFA on organisms was also considered. Gut analysis was done on selected species of suspension feeders and deposit feeders. After a 30 day experiment, suspension feeders usually had proportionally less ash in their guts than was present in the sediment. Deposit feeders showed varying degrees of accumulation. Nuculana minuta had almost pure PFA in its gut. This accumulation is not accountable by sorting techniques used by bivalves but rather was due to the pozzolanic aggregation in the gut possibly prompted by gut pH changes. This sort of uptake would definitely inhibit nutrient uptake. Diastylis rathkei juveniles were also observed to have a similar response.

Another measure of metabolism is respiration. Although results in this study indicate a marked inhibition of respiration the variability in the data make a conclusion difficult.

Utilization of PFA particles by tube building polychaetes was studied. PFA was found to beboth passively and actively incorporated into tubes of polychaetes. Passive utilization occurs when ash particles adhere to the mucus lining of tubes. This was seen in spionids and ampharetids. Pectinarids and Myrochele are both active tube builders and were tested to determine selection with regard to PFA particles. Both species showed a significant preference for non-PFA particles. This is due to particle size as well as organic content. More research needs to be done on the stability of the pozzolanic aggregates and the long term recovery of a dump site after cessation of dumping.

A comprehensive study on incinerator ash was directed by First (1969). It addressed the effect of floating of incinerator residue from Boston incinerators on selected marine life in both short term toxicity tests and long term growth studies. Both vertebrates and invertebrates were used studied. In addition, a field test on dispersion of garbage was done at two depths of water. Results indicate that quahog, winter flounder adults, shrimp adults, lobster, and millet are relatively immune to the effects of dumping of incinerator ash. Menhaden, lobster larvae, and sea scallops, however, showed significant mortality. Hardshelled clams showed a lower mortality rate and a higher growth rate after being exposed to the residue. Heavy metals were not accumulated to any significant degree during the time of the study and some organisms actually depurated metals.

The effect of ash on commercially important fish species was studied by Oviatt (1968). Juvenile menhaden were the most sensitive fish studied with less than 50 % surviving in 50 days of exposure to incinerator residue in concentrations exceeding 1% by weight. Sea scallops were the most sensitive bottom organism tested with significant mortality occurring at concentrations of residue greater than 3% by weight. The toxic effect were not considered serious drawbacks to the disposal program because calculations showed that in 25 years of daily disposal of 500 tons of residue over 1 square mile would be needed to reach the toxic level of 1% residue concentration.

As part of the First (1964) study several tons of incinerator residue were deposited off of the South shore of Rhode Island in 50 feet of water at 2 miles from shore. The dispersion of the material was charted and it was found that attenuation of violent free surface wave effects due to depth was insufficient to prevent the motion of lighter residue such as tin cans. Heavy storm seas resulted in large mass transport of residue so that 50 foot of depth was not thought to be a sufficient dumping depth in this region. A 200 foot deep site was also studied. This site was 18 miles off of shore. The maximum distance of can movement observed was 50 feet in several several summer months. The residue was essentially motionless for the summer. The conclusions from this study were that an offshore site would be the only acceptable site for ash disposal. Sufficient navigational aides, and detailed knowledge of currents in the area, as well as some guarantee that no dumping would be done during poor operating conditions (i.e. storm seas, darkness) was needed before an before an offshore site could be approved for dumping.
In a dump site observed at fifty feet for two months wave height of > 3 feet moved debris 50 feet, wave height of > 9 feet moved debris 100 feet, and wave height of > 12 feet moved debris 200 feet. Burnt cans disentegrate rapidly so that at a depth of > 100 to (a concentration more likely to be found in the natural environment of a dump except under storm conditions).

STABILIZED ASH DISPOSAL AND USE IN OCEAN

Work is just beginning to determine if the ash from incinerator plants can be stabilized and used as reefs in the oceans (Rothel, 1985). This new research is based on a five year study done previously on stabilized coal fly ash (Coal Waste Artificial Reef Project , CWARP). A brief summary of the work may be found in EPRI CS-3726; Nov., 1984. Coal ash and incinerator ash are similar in elemental composition although they differ in some of their gross physical properties. The differences may effect both the cementous properties and leaching properties (Woodhead and Rothel pers. comm.). The similarity of the two ash types make it possible to use information from studies of coal ash stabilization to predict the major impact of ocean disposal of stabilized ash from solid waste incineration.

Blocks for the CWARP reef were made from the stabilized by-products of coal burning, scrubber sludge and fly ash to which lime was added to increase stability. A conventional cement factory was chosen to fabricate the blocks because of the desire to use existing technology for ease of immediate mass production. Two mix combinations were made for analysis having different fly ash to sludge ratios.

For the CWARP project both laboratory and field samples were analyzed. Field samples were obtained at the site of dumping, two miles off of shore in 60 feet of water. One barge load of stabilized bricks was dumped at the site. Other smaller bricks were placed there for specific studies.

Studies that were done include: chemical analysis of block components, and compound changes as the blocks remained in the ocean; mineralogical studies; evolution of physical properties in the field and laboratory; habitation of reef blocks by fish populations; settlement and colonization by epibenthic organisms; reef effects on infauna macrobenthos; as well as laboratory studies on toxicity of the stabilized ash to flounder eggs and larvae and mussels.

The results of the chemical analysis of the coal waste blocks retrieved from the reef site after prolonged exposure to seawater indicated that only six elements (Mg, Na, K, Si, Al, and Ca) showed significant increases in concentration. Calcium, the major block component, was released at a rapid rate which decreased exponentially with time. An ion exchange process occurred that replaced the calcium with magnesium. Increases in the sodium concentration occurred beyond that which can be accounted for by diffusion exchange processes with seawater. Active exchange was implied but not documented. Increases in Si and Al were due to the loss of sludge related components. Although some minor changes in the elemental composition of the blocks occurred upon exposure to seawater, there was very little block deterioration for long exposure times.

The physical testing program concentrated on the measured and derived physical properties of ultrasonic velocity, ultrasonic attenuation, effective elastic modulus, compressive strength, density and porousity. This has been detailed in Parker et al., 1982 and Carlton and Muratore (1983). Over the course of the study the elastic modulus was monitored by measuring the velocity of sound propagation at the reef site (in situ) and on blocks which were recovered from the reef site. Compressive strength was chosen to be the most direct measure of block integrity. Velocity and attenuation measurements were also made. Experiments showed a difference in compressive strength and elastic modulus between the two mixes with the mix having the higher fly ash to scrubber sludge ratio being stronger. Blocks proved to be able to maintain strength and possibily even gain strength over the time period of this study. The strength of the blocks was mix type dependent.

A fish sampling program was initiated prior to the reef placement and continued throughout the experimental period. Principle sampling goals of the program were to determine the nature and characteristics of the populations of fish inhabiting the reef and to make comparisons between fish caught on a nearby reef and the open sea floor prior to reef placement. It was concluded that the fish populations colonizing the Coal Waste Reef were at low population densities during the first year. At the same time, the encrusting communities of epifaunal organisms which provide a potential foraging base for the fish were also not developed. By the second year both population densities and sex ratios were the same on both reefs. It is implied that as forage potential increased on the reef the fish population also increased. This was not tested. After two years an abundant fish population inhabited the artificial reef. The major change in the ecology of the area was due to the effects of placement of a reef structure. No detriment due to the nature of the reef material was noted.

The coal wastes were tested for their suitability as substrates for the settlement and growth of sessile invertebrates. Racks holding small coal waste bricks were placed just above the seabed. Settlement of both tops and bottoms of bricks was monitored. Larval settlement was studied by placing and removing bricks into the ocean for one or two months and colonization was studied by leaving sets of bricks in the ocean for protracted periods of time. Concrete bricks were used as a comparator substrate since the reef adjacent to the coal waste reef was composed of building rubble. It was clear from the larvae settlement experiments that some epibenthic larvae selected between brick types. The coal waste material showed to be a suitable substrate for larval settlement. The mix with the higher fly ash to scrubber sludge ratio was able to retain the settled community with greater consistancy. This may be due to the differential stability of the block surfaces. Colonization was similar on all materials for most species with some noted exceptions.

In addition to the bricks studied, reef to reef comparisons were made by photographic analysis. The coal waste reef was compared to a nearby building rubble reef. During the three years the faunal growth on the reef blocks were similar. Faunistic differences were due to the older preexisting community on the rubble reef. The coal waste reef was successfully colonized by epifaunal species.

Toxicity and trace element uptake was also studied. Seawater leachates derived from coal combustion wastes were tested for ther toxicity to sand shrimp, Cragon septemspinosa, and the eggs and larvae of the winter flounder. No significant mortality rates were found. Subsequent assays were made for sub-lethal effects on flounder eggs. Leachates made from a concentrated fly ash mix showed a small but significant effect on incidence of anatomical anomalies in flounder.

Aquaria were set up to study mortality, growth and uptake of metals into body parts. In addition, mussels were placed in the field on the reef to study insitu effects. Accumulation of metals seems to be mix dependent with Al, Fe, and Ni accumulated in mussels exposed to the higher fly ash ratio mix. Mussels placed on the reef did not show accumulation of metals relative to controls. Analysis of fish at the reef site indicated no unusual uptake of coal ash products.

Surveys were made of infaunal macrobenthic community before and after the placement of the reef. A total of four years of quarterly surveys were done with significant replication to describe rare species occurences. In addition a brief survey was done to appraise community changes in direct proximity of the reef. Reef placement had no measurable effect on community structure on a large scale. Small scale data indicates a possibility of community structure change in very close proximity to the reef but the data is too scant to draw definitive conclusions.

The coal waste reef had no adverse effects on the local populations of vertebrates and invertebrates. The blocks seem to maintain their integrity over the time studied. Provided technological difficulties in formulation of proper mix blends can be overcome, an artificial reef composed of ash products may be a successful way to use a waste product as a resource.

FUTURE DIRECTIONS FOR OCEAN DISPOSAL OF GARBAGE AND TRASH

Oceanic systems are dynamic and are in delicate and somewhat undefined equilibriums. Systems may exhibit direct sensitivity to an ocean dumping event or may respond to a secondary effect i.e. sudden increase of nutrient load or turbitidy. The thresholds governing community structure between increasing the productivity of an area and altering the species composition of an area are just beginning to be described (Pearson and Rosenberg, 1976; Tenore et al., 1984). Long term effects may or may not be predictable given the somewhat ordered, or somewhat chaotic progression of events which controls the ecological interactions in a marine ecosystem. More basic research on both large and small scale biological ocean dynamics is needed. In addition, directed research is needed to answer specific ecosystem questions.

The ocean may be an attractive sink for some residues after through comparative study. Research needs were outlined by the U.S.E.P.A. ocean dumping regulations and criteria in 1977 and the U.S. National Pollution Research and Development and Monitoring Plan Act of 1978 (PL 95-273) for both open ocean and coastal waters. The following is based on suggested research needs as outlined in the above act.

1) Pathways of waste materials in the marine ecosystem along with the origin and ultimate fate of pollutants should be studied. 2) Information on toxicant persistance, chemo- and biodegradation, radioactive effects, and assimilative capacity of the ocean should be obtained. 3) Basic research on degradation products of different types of organic matter should be done. 4) Representitive marine environments should be protected so that human-induced changes may be evaluated. 5) Basic physical and chemical processes in the ocean with emphasis on estuaries and coastal areas should be studied. 6) Lethal and sublethal toxicity and long term effects of toxic material on marine life should be studied. 7) Specific research on both stabilized and unstabilized ash should continue. Questions as to the leaching products and stability of both the ash and ash leachates should be considered under conditions of different pH and anoxia. 8) Public health risk information should be gathered. Pathogen pathways should be studied. Effective methods of measuring

public health dangers are needed.

Ocean dumping has both ecological and sociological non-marketable effects (Devanney et al., 1970). The ecological and sociological effects must be distinguished because effects which may be ecologically beneficial may not be socially acceptable. For instance if we dump a raw garbage into an area of poor productivity with the desire to increase a nutrient input for commercial aquaculture endeavour this may not be perceived as an improvement of environmental quality to vacationing individuals in the coastal zone. One must make the difficult determination of what ecological effects are deleterious and the extent of ecosystem change which is acceptable.

The appraisal of ecological and social effects of ocean dumping is controlled by two different philosophies. One may take a small area of the ocean which is considered to have low ecological-sociological value and use this as a dump site. The entire ocean within a refuse generation area may be divided into sectors based on sociological and ecological factors. For each area an acceptable concentration of floating suspended and sinking solid waste may be computed. Effects on marine life result from toxicity, oxygen depletion, habitat changes, while effects on humans are assessed in terms of public health, recreation, and potential to cause economic loss (Lawson and Whitesides, 1972).

Monitoring for ecological effects, is necessary. Monitoring consists of evaluation of sources and characteristics of wastes, measuring and recording concentration levels, identifying quantities and characteristics of waste materials released, assessing information on reactions and interactions of waste materials with the environment. Over a short term it is necessary to know the direct effect of dumping on benthic species and the fisheries of a specific area. Over the longer term, world wide levels of organopollutants and nutrients entering the ecosystem must be compared to pollution arising from other disposal methods (Pratt et al., 1973). An evaluation of problems associated with waste disposal needs case by case documentation (IEC-O report 4460c1541, 1973). Samples of marine organisms especially shellfish need be taken to asses public health risk due to increase in bacteria virus or heavy metals. Baseline monitoring is difficult. Variability usually masks small perturbations and one only sees an effect when a catrostrophic events occur (Hirscha, 1981). Causal relationships between dumping and changes in the environment are difficult to ascertain even in a long term monitoring program. This is because the functioning of a marine ecosystem is governed by a multitude of interacting components. We must seek to improve not only our ability to predict consequences of marine pollution but also our ability to detect, measure and understand the significance of a damage after it has occured. We must also improve our monitor capacity for long term subtle effects. This involves the initiation of basic research into the functioning of selected marine ecosystems as well as comprehensive studies of individual species behavior and physiology.

In addition to technical problem solving, the social, institutional, and economic aspects of waste management should be studied thoroughly. Effective national and international monitoring systems should be developed. Early detection of pollution as well as effective data coordination should be developed and implemented.

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