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MEASURING THE EFFECTS OF MAN'S WASTES ON THE OCEAN

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INTRODUCTION

Understanding the ecological effects of municipal wastewater discharged into the ocean depends on data developed by reliable measurements. Municipal wastes are largely residential sewage flavored with industrial effluent; the amount and toxicity of the latter depend, of course, on the kind and amount of industry and the local regulations. Usually this mixture is given some level of treatment in a sewage plant at which time some of the solids (grit and sludge) are removed. The remainder may be treated by aeration, bacteria, addition of various chemicals, etc. until the final effluent is a thin but complex soup containing many fine particles. Upon discharge out the deep diffuser outfalls used in California, this liquid is immediately diluted by at least 100 to 1 forming a plume which drifts off to sea with the prevailing currents.

These discharges have very little, if any, effect on man but they do have some effect on life in the sea. Now the question arises which makes this a controversial subject. Are these effects

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serious enough to require a major effort or are they of no more importance than the excavation of a building, the plowing of a field, or the concreting over of land to make an airport? Some believe that the waste disposal should be treated like these other projects with benefits algebraicly added to alleged damages and value received compared with costs. The ultimate question is: How can our society best make rational, unemotional decisions on such matters?

This paper summarizes how measurements can be made that not only define the present situation but which can be used as a basis for forecasting what future effects would be if certain changes were made in the character of the wastes discharged. These techniques have been very useful in the open coastal waters of California and probably they will be effective in estimating the effects on similar waters elsewhere.

The reader is also reminded that pollution means that a "damaging excess" of one or more materials is present. Change may or may not be evidence of damage. The amount of change in an area where pollution is suspected should be compared with the natural variations in pristine areas; often the investigator is surprised by how large the normal variability is.

MEASUREMENTS

There are several categories of things to be measured. In order of usage these are: (1) Those aspects of the ocean's shape and motion that are important to disposal, (2) the effects caused by man's construction that may be influential, (3) the nature of the material to be disposed of and the dilution at release, (4) the effect of wastes on the water, the bottom, and the sea animals.

Although this paper is primarily concerned with the last of these, each one contributes something useful to an overall understanding of the effects of municipal wastes on coastal waters. Let us consider each in turn.

(1) The physical situation is the backdrop of conditions against which effects can be measured. The information required, whether from existing data or from new measurements, includes the topography of the nearshore bottom and the exposure of the site to open ocean waves and currents. Generally, headlands (or the seaward side of islands) with steep offshore gradients are preferable for discharge because refraction by undersea contours causes wave action to be greater; morover, ocean currents are likely to be stronger. Wave statistics from wave meters and hindcasts are needed and current velocity/direction at several depths should be known for at least a year. The material of the bottom which ranges from hard rock through sand to silt and mud should be determined as it is likely to be important to construction as well as to subsequent chemical or biological measurements.

Much of the year the ocean is stratified with a relatively warm mixed surface layer of water extending 60 to 200 feet beneath the surface. Then there is the matter of turbidity, which usually is caused either by a great influx of plankton (tiny living creatures) or by storm waves roiling the bottom. Thus, temperature and clarity with depth are needed. All the above can be measured with well known instruments to obtain a reasonable picture of ocean conditions at a disposal site.

(2) The effects caused by the installation of a large structure such as a pipe may have some local importance. If the pipe is 10 feet or so (3 meters) in diameter, partly buried in a trench, and extends several miles offshore (as is common in southern California) it causes certain changes in sea life. The pipe may form a barrier to the movement of certain kinds of animals which will be more numerous on one side. Because it offers a hard rock-like substrate, sea life such as algae and colonial animals grow profusely on it. These in turn help attract fish and crabs that like the protection combined with food from the outfall. The material originally excavated for the pipe trench is now spread on the bottom and the addition of fist-sized ballast rock offer two other new variations in habitats that attract other sea animals. Changes in the sea life as it adapts to this locally changed environmental situation is best studied by direct examination with cameras or television.

(3) The material to be disposed of is best measured just before it is discharged and most treatment plants dutifully combine hourly samples into a daily composite and run it through a chemistry laboratory to satisfy state regulations. This kind

of measurement is useful for some purposes but other measurements may give a better picture of what actually happens after ocean discharge.

For example, one of the most important factors is the settling velocity of the waste particles after they are mixed with and diluted by seawater. Because of a combination of chemical and electro-static effects, the particles discharged may either agglomerate or break up when mixed with seawater. After this mixing, the density and settling velocity changes and some fraction of the particles fall much faster than the rest. Those that settle more rapidly than about one centimeter in 100 seconds have a reasonable chance of landing on the bottom near the discharge point (within a kilometer or so). This reconcentration of sewage material can cause a problem. However, the more slowly settling material is so widely dispersed it cannot be concentrated any-where. The animals of the bottom gladly utilize the waste par-ticles if they are not overwhelmed by them.

We find it useful to perform two experiments under carefully controlled laboratory conditions. In the first wastewater is mixed with seawater at the minimum initial dilution ratio (usually about 100 to 1) in a settling tube and the amount of deposition of particles over a period of 2 hours is measured. This gives the volume of material that settles faster than 0.01 cm/sec and remains within 2 kilometers of an outfall.

A similar experiment using somewhat larger volumes of fluids at lower dilutions is used to determine the amounts of contaminants on the material that will settle to the bottom within 2 km of the discharge point. That is, the wastewater and seawater are mixed at 30 to 1, allowed to settle for 2 hours, the water decanted off and the settled solids collected. These are then subjected to chemical analyses that make it possible to determine the amounts of possible pollutants on the material that settles nearby; from this possible toxic effects can be forecast.

Finally, the actual dilution achieved must be measured in the sea to confirm the theoretical calculations and model experiments. This requires a precise navigation device such as Loran C which gives the boat or sample position within about 60 feet (20 meters). We usually lower a Tygon hose with an electrically driven pump on the lower end (total length 300 feet or 100 meters) and pump water from 6 to 10 levels. By thoughtfully selecting sample stations (based on temperature profiles and current drogue movements) it is possible to make measurements that define the waste field and the levels of minimum initial dilution. The values come from measuring the water pumped aboard as it flows through a nephelometer (for turbidity), or a fluorometer (for optical brighteners) or by measuring ammonia levels, or by measuring fluorescence of added Rhodamine WT dye (which does not stick to particles). The results from these various methods usually confirm each other; the maximum concentrations are deemed to be representative of minimum initial dilution.

(4) The most important effects of wastes are on the bottom and the sea animals.

Municipal waste effluents are a very thin soup that usually has between 20 and 200 milligrams per liter of solids. The bulk of the discharge is material in solution or in very tiny particles (under 4 microns). Off California, the original concentration after average initial dilution is reduced by a factor of about 200 and only the most careful sampling in large, super-clean containers, and accurate analysis (to tenths of parts per billion) can detect discharged material in solution beyond 10 kilometers from the outfall. Except for the measurements noted in the previous section we have not found chemical measurements in the water to be helpful in understanding the effects of outfalls.

We were able to collect particles in the water a kilometer or two from a large outfall by hanging bags of mussels (*Mytilus californianus*) from taut-moored buoys at wastefield depth and letting these animals do the collecting. Mussels are filter feeders and a medium sized one (7 cm) will pump about one liter of seawater per hour. The particulates are removed by the animals and measured when the mussel is taken. This is an unusual technique, useful for special purposes because contaminants, including bacteria and viruses, tend to be attached to the particles that the mussels collect.

The muddy bottom that exists around outfalls that discharge several miles offshore is where effects are most readily measured. The best tool for bottom sampling is a chain-rigged Van Veen grab which reliably snaps up a virtually undisturbed sample of one-tenth of a square meter (Word, 1974) Because sedimentation is a slow process it is important to separate the recently (last year or so) deposited material from the older deposits. Therefore, we sub-sample part of the surface of the material still in the grab to a depth of 2 cm. This sub-sample is returned to the laboratory for analysis for volatile solids or total carbon, BOD, COD, 8 metals, and chlorinated hydrocarbons.

Results from samples like the above are most easily interpreted if they are taken on an elongated grid laid out parallel to depth contours. This is because the currents which distribute the discharged material tend to flow along lines of equal depth. Depending on the size of the discharge and other matters some 15 to 30 grab stations can be arranged to adequately define the outfall effect area. A sample interpretation is given in Table 1.

Some of the sea animals are sampled by the same grabs described above. These are the benthic infauna, small creatures that live in the bottom mud and do not move substantial distances. Ecologists are particularly interested in them because they must live and reproduce in the areas most likely to be affected. They are most likely to react to whatever is discharged.

When the grab is brought to the surface it is discharged onto a one mm screen; the mud is washed through leaving the animals which must then be sorted, counted and identified. Such work is fairly routine up to a point. But deciding how many samples to take, where to draw the line at identifying rare animals and how to process the data are important biological management decisions. After careful work on thousands of samples we have reached some important decisions that should be helpful to everyone facing similar problems because they give more usable information in a shorter time and with lower costs.

We do not take biological replicate samples at any station, preferring instead to sample at more locations. We identify only 26 taxa (Table 2) that indicate the response of animals to the environment. We save the rare one-of-a-kind for some scholar who has more esoteric objectives. We do not subject the data to complex mathematical manipulations but use the simple "Infaunal Index" which is derived as follows: The 25 taxa (species) are sorted into 4 feeding groups that range from animals that live only in clean water (mostly suspension feeders) to animals that prefer organic materials in the bottom (mostly deposit feeders). Then the total number of animals in each group is used in a simple formula. Infaunal Index = $100 - 33.3 \left(\frac{n_2 + 2n_3 + 3n_4}{n_1 + n_2 + n_3 + n_4}\right)$ in which n is the number of animals in each group. The index number falls between 0 and 100 and is consistent for mud bottoms in depths of 20 to 200 meters. We find that indices higher than 80 are characteristic of areas undisturbed by man and which are low in organic solids.

This brings us to the final step which is to assess the biological situation and communicate the condition of the animal communities to other persons in an understandable form. Now each sample point can be assigned 3 simple numbers that represent the main characteristic of that location. We also show the biomass (in grams per square meter) for the same location and the percent of voltile solids. When the infaunal index number drops because of the presence of excess organic materials the biomass usually goes up. These numbers can be used to define the area affected by an outfall.

The last important measurement is that of the larger sea animals that live on and just above the bottom. We use two techniques for determining their species and numbers; the bottom trawl and the baited camera. These do not give the same result but the answers are complementary. The baited camera was devised to study animals in rough or rocky areas where trawls could not be operated.

Baited cameras come in various forms but we routinely use a 35 mm, wide angle lens, 250 exposure Minolta. It is enclosed in an aluminum case that will stand about 100 atmospheres of pressure and mounted on a pipe frame shaped like the edges of a 2 meter cube. The camera's pressure housing also holds batteries, condensers, and timing circuits that operate the camera and two stroboscopic lights in synchronization. The light level is sufficient that we can use Kodachrome (ASA 40) at f 11. The bait is usually very dead squid dangled on a line about a meter in front of the lens. We usually take one frame every 3 minutes for the half hour on station (while grabs are being taken). The result is about 10 high quality slides per station that can be viewed later by biologists of several disciplines.

The otter trawl is a net that is dragged along mud or sand bottoms while being held open by a pair of otter boards. This net scoops up the animals that are on and just above the bottom such as crabs, urchins, starfish, bottom fish and rockfish. Standard trawls of 10 minutes on the bottom at 2 knots (about 1 meter per second) are customary. The net is retrieved and the catch is sorted, identified and counted on deck. Each fish is measured for standard length and examined for signs of disease or parasites. Then all are returned to the sea; only data is brought home.

The analysis and comparison of fish and large invertebrates does not give as lucid results as the infauna because the season, the water temperature, the entrance of great numbers of juveniles into the system and an invasion by predators all contribute to the statistical noise. Nevertheless, it is possible to make useful comparisons of animal communities that will show outfall effects if there are any. Examples are shown in Figures 1 and 2.

SUMMARY AND CONCLUSIONS

The devices and methods described have been successfully used on repeated occasions and are probably the best available for the assessment of the effects of man's wastes on the ocean. It is no longer necessary for the EPA or local pollution control agencies to rely on vague allegations about the biological conditions around outfalls. These can be readily measured and reduced to simple numbers that can be understood by anyone who is interested.

Table 1. Forecasts of chemical and biological changes in the sea based on a proposed change in effluent starting January 1, 1983.

	Natural back-ground range	Orange County Stations B0 to B5				
		Present 1977	New effluent 1983	After 1 year 1984	After 5 yrs. 1988	1993
% Organic carbon in sediment	0.5-2.0	1.7	1.8	1.5	1.3	1.3
Escess metals in sediment (mg/kg)						
Silver	0.3	0.2	0.2	0.16	0.12	0.13
Cadmium	0.2	1.2	1.2	0.72	0.26	0.22
Chromium	23.0	17	17	13	8.5	8.2
Copper	7.0	29	29	18	8.3	7.7
Infaunal Index Numbers	75-80+	45-50	45-50	60	65	75
Total lineal distance to background conditions		8km	8km		0.5	
Solids dis-charge metric tons/yr		25,000*	8,940	8,940	8,940	
Excess standing crop of benthic organisms (metric tons)		549	848	280	110	89

*Rising to 32,300 just before changeover.

Table 2. Taxa for calculation of Infaunal Index numbers

Group 1 - Suspension Feeders (pristine area)	
Phoronis spp.	Phoronid
Amphiodia spp.	Brittle star
Sthenelenella uniformis	Worm
Ampelisca spp.	Amphipod
Paraphoxus spp.	"
Heterophoxus oculatus	"
Metaphoxus frequens	"
Group 2 - Mixture of Feeding Strategies	
Mediomastus spp.	Worm
Myriochele spp.	"
Tharyx spp.	"
Axinopsida serricata	Clam
Mysella spp.	"
Photis spp.	Amphipod
Euphilomedes	Ostracod
Group 3 - Deposit Feeders, mainly molluscs	
Parvilucina tenuisculpta	Clam
Macoma carlottensis	"
Bittium spp.	Gastropod
Spiochaetopterus costarum	Worm
Group 4 - Deposit Feeders, mainly worms (outfall area)	
Armandia bioculata	Worm
Shistomeringos longicornis (=*Stauronereis rudolphi*)	"
Ophryotrocha sp.	"
Oligochaeta, UI	"
Capitella capitata	"
Dorvelleidae, UI	"
Stenothoidae, UI	Amphipod
Solemya panamensis	Clam

$$\text{Infaunal Index} = 100-33.3\left(\frac{n_2 + 2\,n_3 + 3\,n_4}{n_1 + n_2 + n_3 + n_4}\right)$$

where n = the number of animals counted in a sample from the appropriate group.

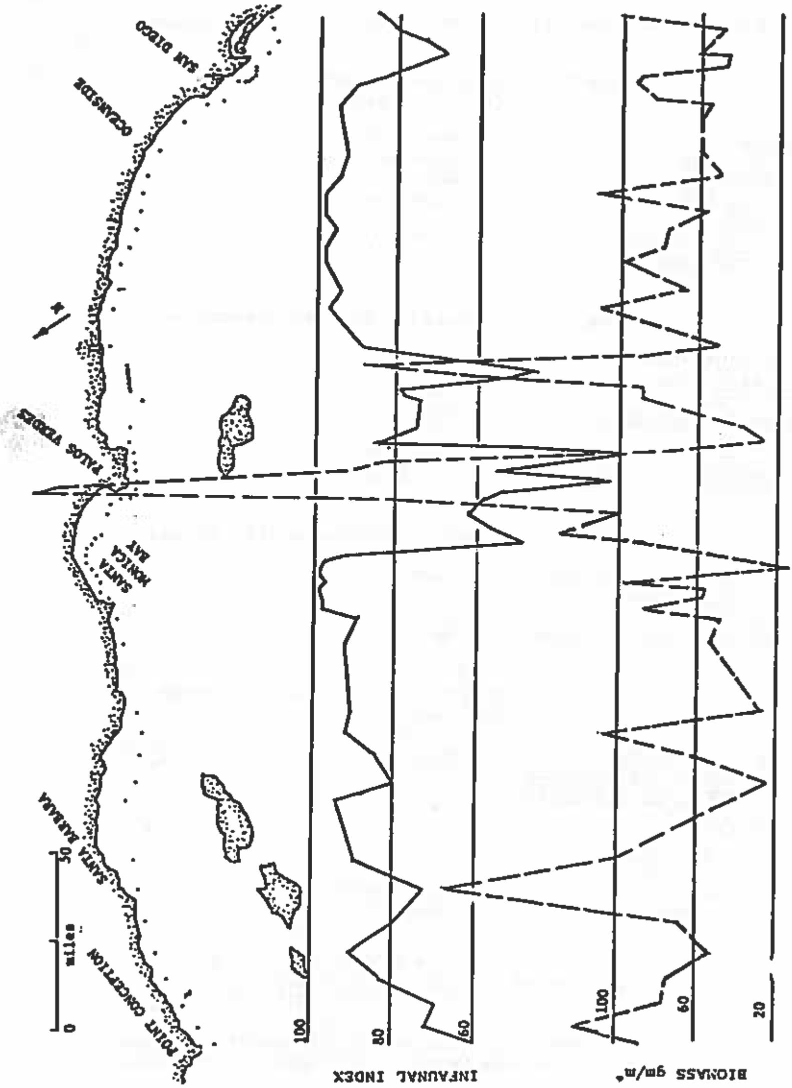

Figure 1. Infaunal index numbers and biomass for 60m depth and 10km intervals in Southern California Bight. Natural conditions exist when index ≥80 and biomass ≥ 70 gm/m^2. Note generally inverse relationship.

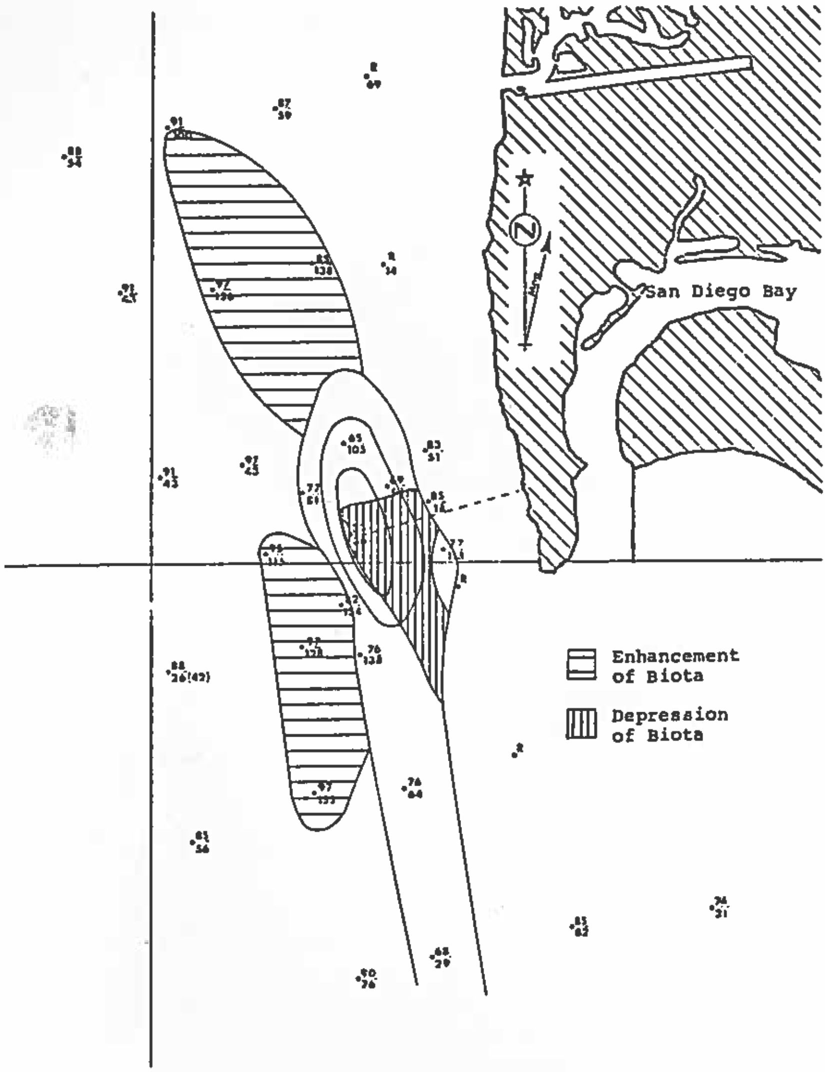

Figure 2. Infaunal index (top number) and biomass (bottom number) near San Diego outfall.