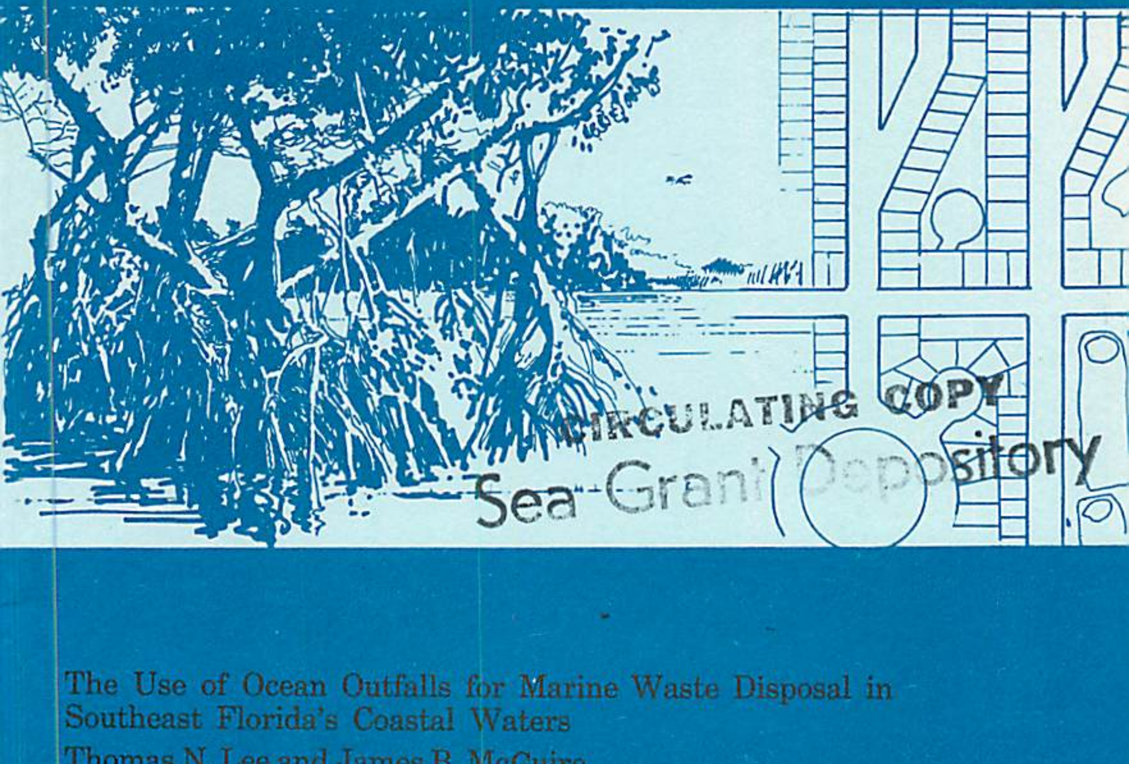
COASTAL ZONE MANAGEMENT SERIES



The Use of Ocean Outfalls for Marine Waste Disposal in Southeast Florida's Coastal Waters

Thomas N. Lee and James B. McGuire

Bulletin Number 2

UNIVERSITY OF MIAMI SEA GRANT PROGRAM

January 1973

Sea Grant

Coastal Zone Management Bulletin #2

The Use of Ocean Outfalls for Marine Waste Disposal in Southeast Florida's Coastal Waters

Thomas N. Lee *
and
James B. McGuire **

*University of Miami, Miami, Florida
**Florida Atlantic University, Boca Raton, Florida

Cover Photo: William M. Stephens

The University of Miami's Sea Grant Program is a part of the National Sea Grant Program, which is administered by the National Oceanic and Atmospheric Administration of the U. S. Department of Commerce.

NOAA Sea Grant No. 2-35147

University of Miami Sea Grant Program
10 Rickenbacker Causeway
Miami, Florida 33149
1973

FOREWARD

The Sea Grant Coastal Zone Management Bulletin Series is being offered as a method of acquainting the public with advances in the fields of coastal zone engineering and research.

Further expansion of human population into the coastal zone is assured. As this happens, conflict over the uses of this limited area's natural resources will increase inasmuch as all uses are not compatible.

The purpose of the Coastal Zone Management Bulletin Series is to summarize new research results in the management context and to stimulate discussion of new management techniques which appear to offer possible solutions to complicated socio-environmental problems.

A further aim of this Series is to present sometimes complex thoughts and concepts in a semi-technical publication which can be used by planners, developers and persons in public office.

This Bulletin is published by the University of Miami Sea Grant Program in the belief that its contents will be helpful to those concerned with the problems of the coastal zone.

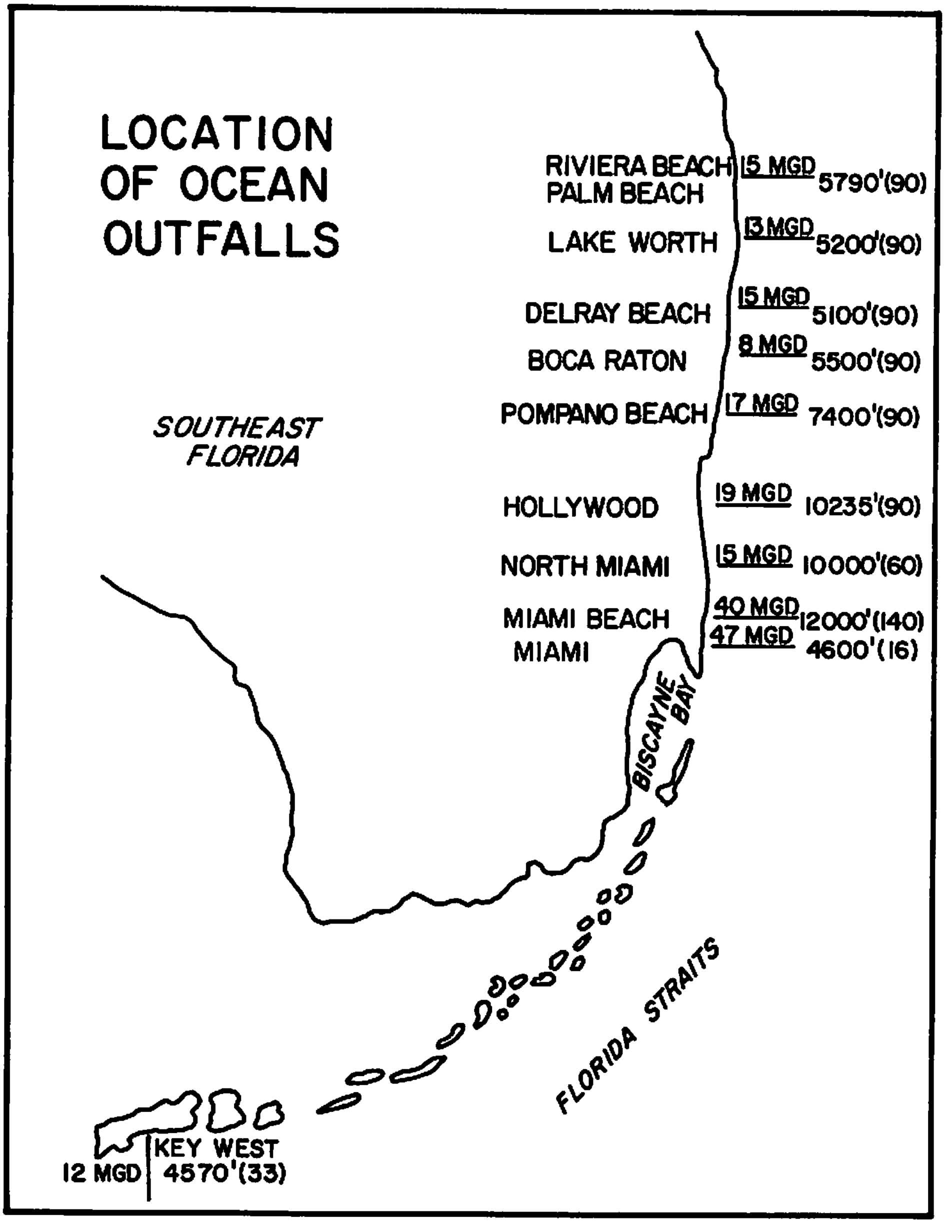


FIGURE 1 - Location of Ocean Outfalls

THE USE OF OCEAN OUTFALLS FOR MARINE WASTE DISPOSAL IN SOUTHEAST FLORIDA'S COASTAL WATERS

James B. McGuire and Thomas N. Lee

Introduction

Southeast Florida is one of the most rapidly growing areas of the United States. It is bordered on the west by swampy low lands of the Everglades and on the east by the Atlantic Ocean. With land at a premium, the ocean fringing communities turned to ocean outfalls as a means to keep pace with the population growth. Ocean disposal of sewage effluent was first begun by the city of Miami Beach in 1937. At the present time there are 10 outfalls in use and more in the planning stages. The locations of these outfalls, lengths and depths at point of discharge, are shown in FIGURE 1. The depths are given within parenthesis. Discharge rates range from 50 MGD at the Miami outfall to 2 MGD at Delray Beach. The city of Miami uses modified activated sludge treatment before discharge; however, the only treatment used by the remaining cities is grinding of solids and skimming off floating material.

Marine Waste Disposal in Southeast Florida

The coastal waters are termed Class III waters, which means these waters are for body contact, recreational activities. The state bacteria standard for Class III waters is that the coliform bacteria groups shall not exceed 1000 per 100 ml as a monthly average, (either MPN or MF counts). State permission to discharge raw sewage into the

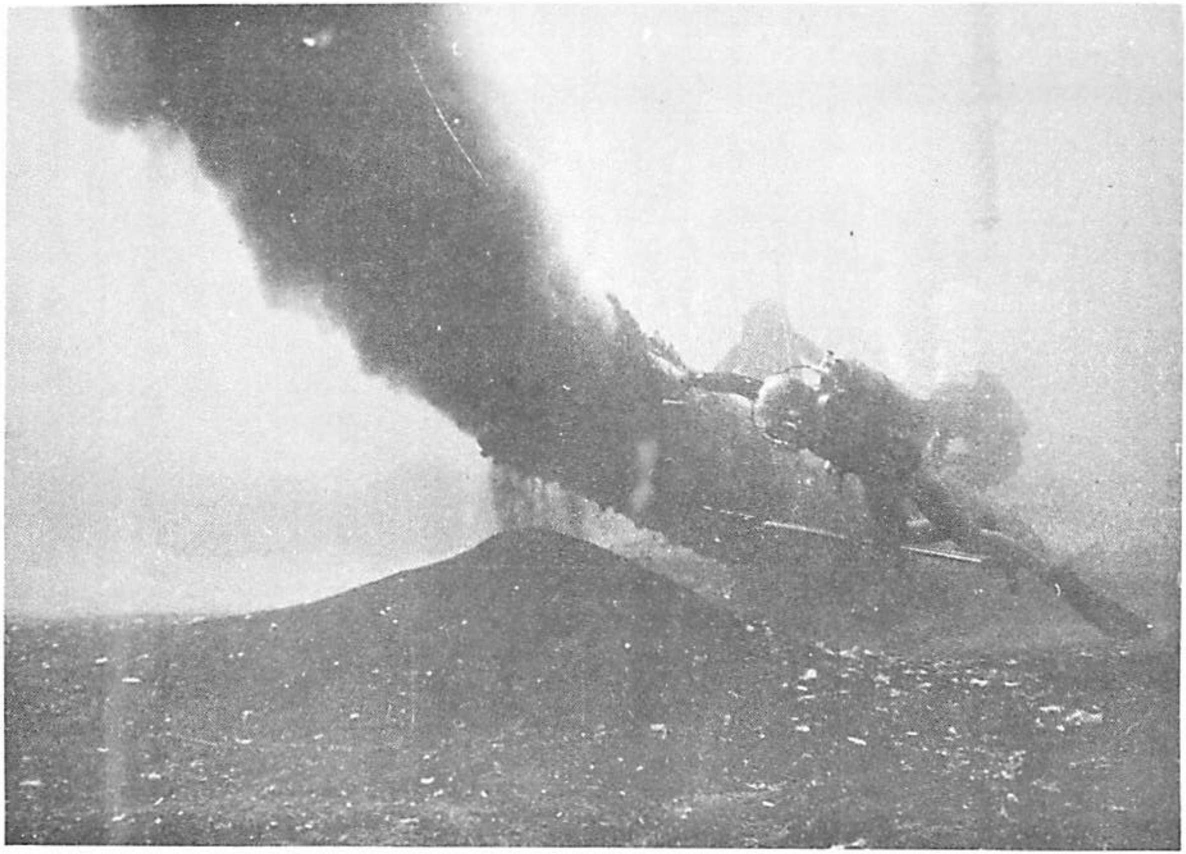


FIGURE 2 - Underwater Photograph of Pompano Outfall

coastal waters was granted under the assumption that the wastes would be highly diluted by mixing with sea water and would be carried away from the bathing beaches by the "Gulf Stream."

The width of the Continental Shelf off southeast Florida, defined by a bottom slope of 1:20, ranges from 3 nautical miles off Miami to 1 nautical mile off Boca Raton. Most of the ocean outfalls in use discharge at the 90 foot isobath; at this point the shelf steepens sharply to the east (shelf break).

The coastal waters off southeast Florida can be thought of as a narrow buffer zone for exchange between the estuaries to the west and the offshore Florida Current (Gulf Stream). The estuaries consist of interconnecting shallow embayments and lagoons with very weak land run-off except during the wet seasons of early summer and fall. These waters carry a heavy load of domestic and industrial wastes which eventually find their way to the coastal zone.

The buoyancy of the less dense sewage effluent causes it to rise to the surface forming a "boil." This vertical motion is clearly seen in FIGURE 2, an underwater photograph of the Pompano Beach Outfall. A quasi-permanent "pile" of heavier sludge is deposited beneath the discharge point, stretching 50 feet to the north-south, 25 feet east-west and 3 feet high. Once the effluent reaches the surface, it travels with the prevailing current, forming a "plume".

Coastal Circulation and Exchange Processes

Coastal water movements off southeast Florida depart from typical shelf water movements, which are controlled by tide and wind forces for two significant reasons: the extreme narrowness of the Continental Shelf

(1-3 nautical miles in width) and the close proximity of the Florida Current. The western edge of the Florida Current meanders laterally causing large fluctuations of current speed and direction in the shelf waters. Counterclockwise eddies spin off the western edge of the Florida Current and are transported northward through the coastal waters. Tide and wind induced fluctuations of the coastal waters are small in magnitude compared to the above influences of the Florida Current except in the inshore regions (water depth less than 30 feet) off Miami where the shelf widens and shoals, thus becoming more isolated from the influence of the Florida Current.

The western edge of the Florida Current can be determined from the horizontal changes in temperature, salinity, current speed, and water color. These parameters were routinely measured by the Florida Ocean Sciences Institute of Deerfield, Florida, during a three year investigation ot the outfalls off Boca Raton and Pompano funded by the Environmental Protection Agency (Lee, 1971). These measurements show the western edge of the Florida Current to be meandering in an east-west direction with horizontal displacements of 2-3 nautical miles and, at times, to extend into the shelf region. The periods of these lateral meanders are believed to range from 2 to 8 days (Lee, 1972a).

Near surface current meter measurements were obtained near the outfalls at Boca Raton and Pompano by the Florida Ocean Sciences Institute and off Miami at distances offshore similar to the Miami outfalls by the joint efforts of the University of Miami Sea Grant Program and the local Physical Oceanography Laboratory (AOML) of the National Oceanographic and Atmospheric Administration. These measurements reveal the coastal currents to be predominantly aligned with the coast in a north-south direction but containing a great amount of variability (current reversals). The flow is in a northerly direction approximately 65% of the time with speeds ranging from 0.0 to 1.5 knots and to the south 35% with similar speeds. The current records consistently show a component to the west (northwest or southwest flow) which can last for several days and is believed to be produced in part by the predominant onshore winds off southeast Florida.

The most striking feature of the current meter data is the large number of current reversals. These reversals are believed to be produced by the counterclockwise eddies which spin off the western edge of the Florida Current and are transported northward through the coastal waters. Width of the eddies range from 1 to 6 nautical miles, with downstream dimensions 2 to 3 times greater. These eddies are believed to be one of the major exchange mechanisms to mix the coastal waters with the Florida Current. The counterclockwise nature of the eddies transports water from the Florida Current into the shelf region at the north end of an eddy and transports coastal water offshore at the southern end. The frequency of occurrences of eddies large enough to flush the coastal waters suggests that the residence time of the coastal waters is on the order of one week.

Temperature measurements conducted in the coastal waters off Boca Raton and Pompano show that for the majority of the year, there is only a slight decrease in temperature with depth down to the 200 to 250 feet level. At this level the temperature decreases rapidly with depth and forms the quasi-permanent thermocline, a very stable layer which

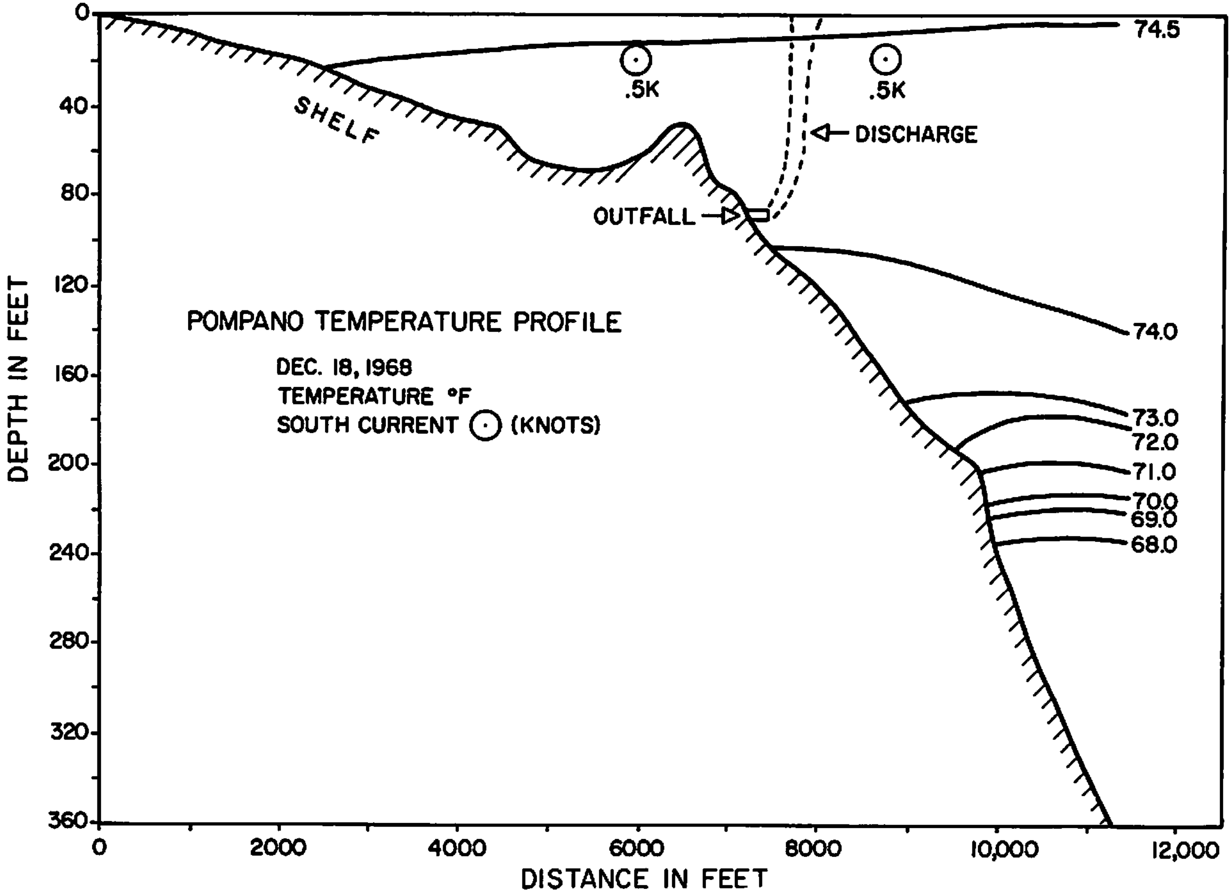


FIGURE 3 - Pompano Temperature Profile

inhibits vertical mixing (see FIGURE 3). A seasonal thermocline forms across the shelf in depths less than 100 feet in late spring and early summer; however, it usually disappears by July.

Movement of Effluent After Discharge Through Ocean Outfalls Located Near the Shelf Break

The Florida Ocean Sciences Institute used rhodamine-WT dye to tag the effluent and determine the horizontal and vertical changes in concentration. The dye was dumped continuously into the Pompano lift station sewage reservoir where it was homogeneously mixed with the effluent.

The concentration of dye in the boil and downstream in the plume was recorded underway with a fluorometer by pumping water through a continuous flow-through door at a steady rate. An initial dilution of the effluent occurs during the vertical rise to the surface which is characteristically on the order of 100:1 for outfalls located at the 90 feet isobath. The downstream dilution which occurs in the plume is on the order of 10:1, giving a total dilution of approximately 1000:1. The generally accepted coliform bacteria concentration for raw sewage is 3×10^7 T.C./100ml. We assume that the bacteria are diluted in the same manner as dye; however, the initial bacteria concentration will be further reduced by the natural bacteria die-off which occurs in sea water. Die-off in southeast Florida's subtropical waters was found by Stewart et al. (1969) to be highly dependent on the seasonal temperature changes of the coastal waters. In situ measurements of die-off revealed two characteristic values for winter and summer:

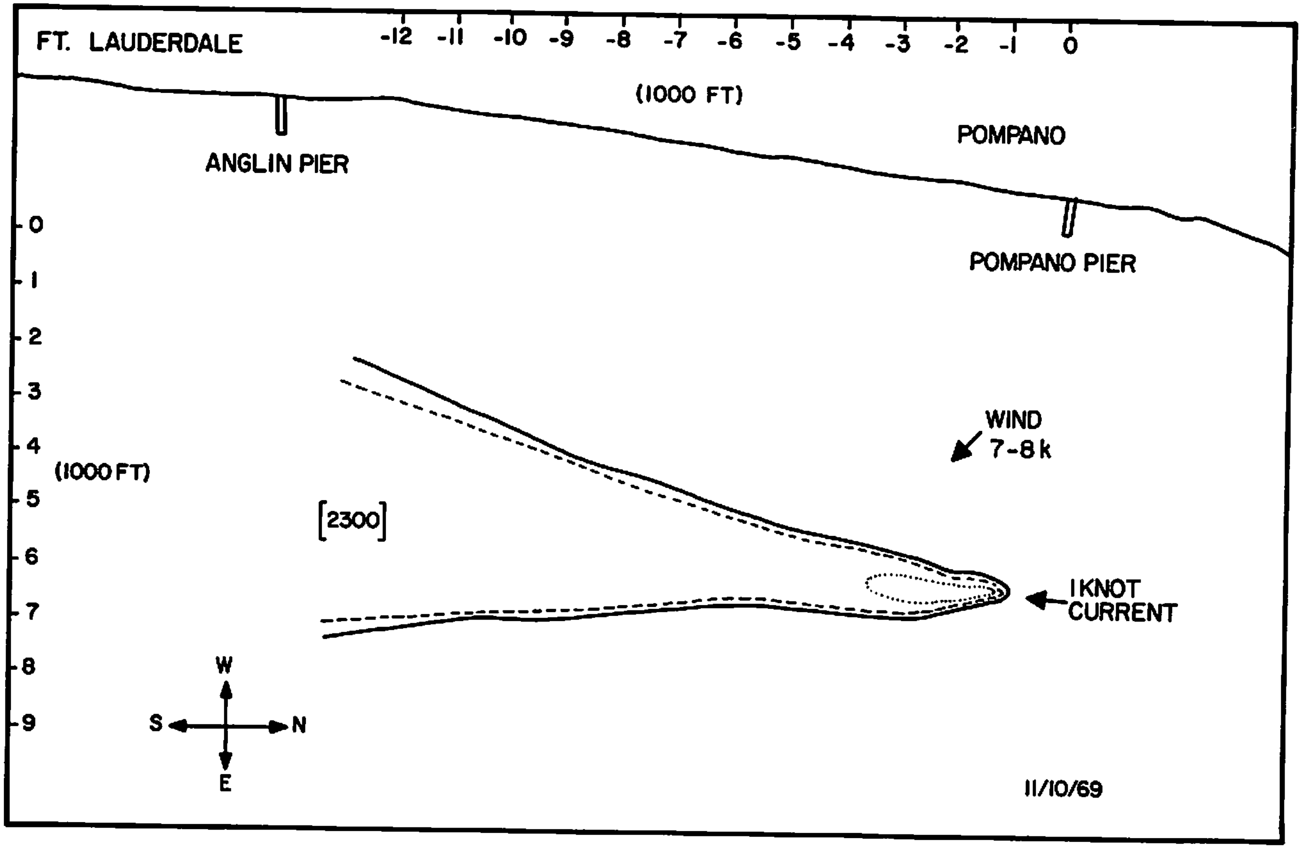


FIGURE 4 - Surface Effluent Plume from Pompano Outfall

$$\lambda_1 = 0.31/\text{hour} \quad \text{(Winter, 75°F)}$$

$$\lambda_2 = 1.55/\text{hour} \quad \text{(Summer, 85°F)}$$

where $\frac{1}{\lambda}$ = time for bacteria to die-off to $\frac{1}{e}$ of their original concentration.

During the summer bacteria die-off is very rapid and will normally reduce initial concentrations to the state standard of 1000 T.C./100 ml. within a few hundred yards of the boil. However, during the winter months (November to April), die-off is weak; and, bacteria concentrations far greater than the standard can be found several miles downstream in the plume. The high bacteria concentrations at large distances from the outfall boil were consistently found in the dye experiments of the Pompano Outfall (Lee, 1971 and 1972a), by both direct measurements of the Palm Beach County Public Health Department of samples taken in the plume and by calculating the bacteria concentration from the dye observations using the actual measured dilution and the die-off rate of Stewart (1969). The results of a typical winter dye experiment of the effluent plume from the Pompano outfall is shown in FIGURE 4. The dye concentrations measured fluorometrically in the surface effluent plume were converted to bacteria concentrations by using the observed dilutions. Contours of the state standard bacteria concentration (1000 T.C./100 ml.) were then drawn for the cases of no die-off, winter die-off, and summer die-off. The surface area inside the contours is thus judged unsafe for body contact. The bracketed values are the actual total coliform count as measured by the Palm Beach County Health Department. There is very good agreement between the total coliform count inferred from the dye concentrations and the measured values.

The dilution of the observed data with no die-off and winter die-off show a large area of surface water with bacteria count in excess of the standard for bathing waters. These areas of unsafe surface waters stretch out several miles from the outfall. At the distances from the outfall where the dye is still detectable there is little difference between the winter die-off contours and the no die-off contours. In most cases, the summer die-off contours close a short distance from the outfall restricting the polluted region to a small area downstream from the outfall.

A large number of the surface effluent plumes observed in the Pompano Outfall investigation were found to have a significant angle toward the coast (Lee, 1971). This angle is believed to be dependent largely on the strength of the onshore wind. The Pompano outfall will, in general, typify the other outfalls discharging at the shelf break off southeast Florida (60 to 140 feet). The combination of predominant onshore winds and weak die-off during the winter months makes it highly likely that the surface effluent plumes from the outfalls now discharging raw sewage in water depths ranging from 60 to 140 feet (see FIGURE 1) will, at times, intersect the bathing waters along southeast Florida with bacteria concentrations in excess of the state standard.

Movement of Effluent from the City of Miami Ocean Outfall

The movement of effluent from the city of Miami ocean outfall is quite different from the other nine outfalls along southeast Florida due to the outfalls discharge point being located one mile off Virginia Key, at the 16 ft. isobath, in the close proximity of three tidal inlets opening to Biscayne Bay; i.e., Government Cut, Norris Cut, and Bear Cut.

Due to the shallow water depth and nearness of the three inlets, water movements in the vicinity of the discharge point will be controlled predominantly by tide and wind forces. Using a mathematical model to predict the water movements in this area, we predict that effluent discharged from the city of Miami outfall will enter Biscayne Bay on approximately 80% of the flood tides. With a northerly coastal current the effluent enters the bay through Government Cut on flood tide. A southerly coastal current will transport effluent into the vicinity of Bear Cut, whereupon it will be drawn into the Bay on the flood tide. Only a strong offshore wind will prevent effluent from entering the Bay on flood tide.

In order to verify the model and obtain water quality data, a cooperative dye tracing and sample collection investigation was initiated with the University of Miami, Miami Physical Oceanographic Laboratory of NOAA (AOML) and the city of Miami. In addition, the Environmental Protection Agency and the Dade County Pollution Control participated in making bacteria and nutrient determinations. Rhodamine-WT dye was pumped continuously into the Virginia Key treatment plant on the flood tide and tracked by boat using a fluorometer and from an airplane using photography. The results of the dye tracking are shown in FIGURE 5. The wind was from the northeast at about 10 knots and the coastal current was to the south at approximately 0.2 to 0.3 knots. The dye entered Bear Cut and passed beneath Bear Cut bridge in approximately three hours after surfacing over the outfall, which agrees remarkably well with the model predictions. Coliform bacteria counts were found to be below standard levels at most positions in the dye plume; however, extremely high counts are believed to be the result of a low chlorine residual during the morning peak pumping rates. Vertical dilutions were found on the order of 10:1 and

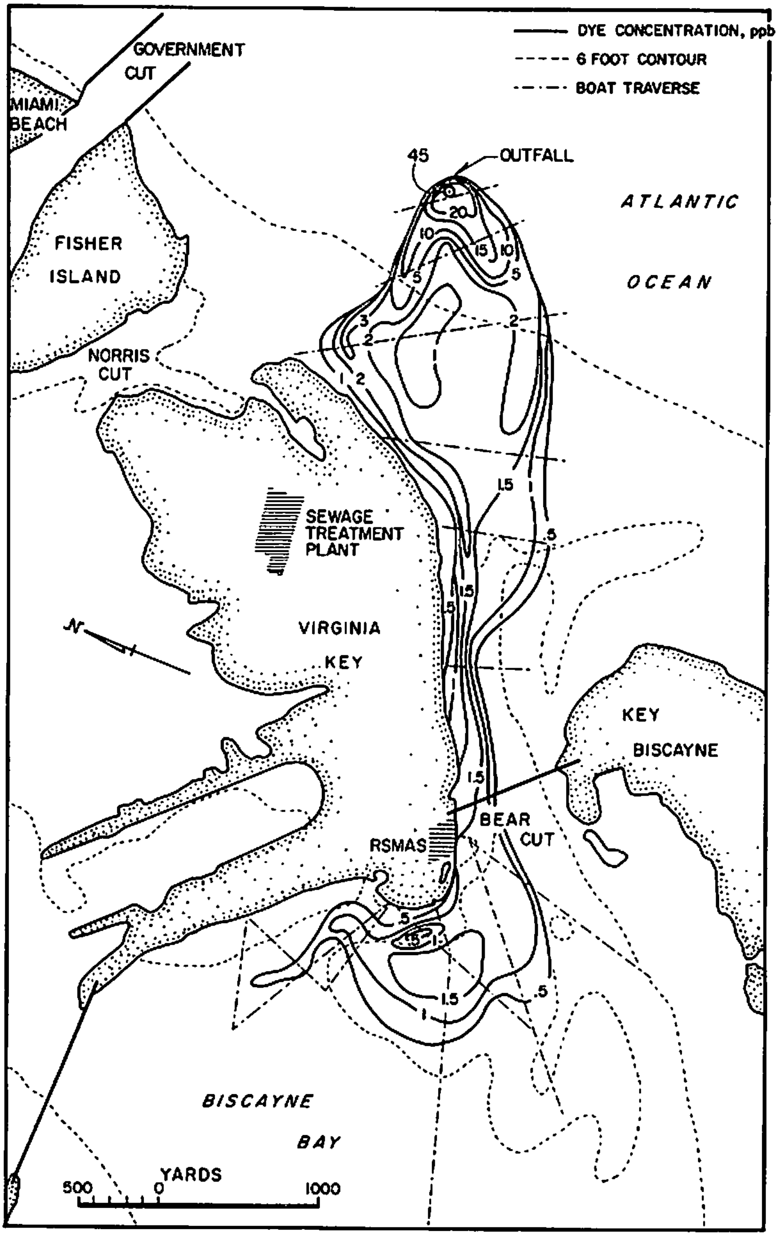


FIGURE 5 - Surface Effluent Plume from City of Miami Outfall

horizontal dilutions from the boil to Biscayne Bay were about 30:1 giving a total dilution of approximately 300:1.

The results of this investigation strongly favors the extension of the city of Miami ocean outfall. Although the city of Miami uses 70% treatment and the effluent is chlorinated for bacteria kills, high counts are occasionally produced at times of low chlorine residual. During the winter months, when die-off is weak, these areas of high bacteria counts can easily travel along the public bathing beaches of Virginia Key, Key Biscayne, and Miami Beach at levels above the state standard. The mathematical model gives a method for determining where the outfall terminus should be located in order to prevent excessive bacteria counts from entering the bathing areas.

Implications and Conclusions

Ocean outfalls along the southeast Florida coast do not discharge into the Gulf stream, but rather into a narrow strip of coastal water which is directly under the influence of the Florida Current. Due to lateral meanders of this current and production of spin-off eddies, outfalls located near the break in the shelf (60 to 140 feet) will discharge into either the coastal water, the western edge of the Florida Current or the western portion of a counterclockwise eddy. The current produced by the complicated interplay of the Florida Current with the eastern edge of the Continental Shelf will be predominantly north or south, but a sizeable westerly component often occurs.

The residence time of the coastal strip is believed to be defined by the mean separation time between spin-off eddies large enough to flush the coastal waters. Inspection of current meter records suggest that a reasonable estimate of the residence time is approximately one week.

When sewage is discharged from an ocean outfall, at the 90 feet isobath, the buoyancy of the less dense sewage effluent causes it to rise to the surface as a "boil." The sewage will then follow the prevailing current and spread out in a plum The sewage will dilute with sea water during the vertical assent to about 100:1 of its original concentration. The downstream dilution is rather slow providing an additional dilution approximately 10:1 at 1 nautical mile from the outfall.

The untreated sewage released from the outfalls along southeast Florida will produce a very large area of surface water which is polluted when judged by the Florida state bacterial standard for body contact. During the winter months (November to April), this area will be several miles long and several hundred feet wide with the major dimension being oriented along the direction of the prevailing current. During periods of strong onshore winds, it is believed that the surface effluent plumes can at times intersect the bathing waters with high bacteria counts.

The effluent plume from the city of Miami outfall off Virginia Key is believed to enter Biscayne Bay on approximately 80% of the flood tides through either Government Cut, Norris Cut, or Bear Cut. Periodic high bacteria counts can occur in this plume along with large nutrient concentrations that can increase planktonic growth and further increase the turbidity of Biscayne Bay.

We are facing an environmental crisis in southeast Florida. With a rapidly increasing population density, confined by the Everglades and the Atlantic Ocean, the existing waste treatment and disposal practices are severely endangering the water quality of our coastal and estuarine waters. Discharges of effluent into the inland canals, waterways, Miami River, and Biscayne Bay cannot be continued without severe degradation in water quality and biological productivity due to extremely long residence times of the estuarine waters (Lee, 1972b). Existing ocean outfalls do not discharge into the Gulf Stream. They provide little treatment; and surface effluent plumes can, at times, come ashore. State legislation requires that all waste disposal into the coastal waters must undergo 90% treatment before discharge by January 1, 1973. This requirement certainly will not be met since there are very few secondary treatment plants now under construction that will be on line with an outfall. However, secondary treatment usually does not remove nutrients, does not guarantee bacteria removal 100% of the time and is very uncertain in terms of virus removal. In addition, secondary treatment removes solid material leaving one with the problem of disposing of the sludge.

As we see it, then, the ocean outfall method of sewage disposal as presently practiced in South Florida is unsafe and a detriment to the ecology and aesthetics of the area. We believe, however, that it would be premature to say that the ocean outfall is not a reasonable method of sewage disposal, for there are many engineering options available to improve the system. Among these options we feel that the following is the most likely answer to the waste disposal dilemma:

I. Extend all of the existing outfall lines to a depth of 300 to 400 feet.

II. Install diffusers to improve the mixing and initial dilution of the effluent.

III. Provide secondary treatment before discharge with a high level of chlorination for 99% bacteria kill, and attempts should continue to find methods to locate and remove viruses.

The extension of existing outfall lines to the 400-foot depth requires only 4000 to 6000 additional feet of pipe, due to the sharp bottom slope east of the 90-foot depth along southeast Florida. Oil companies commonly lay large-diameter pipes in 600 ft. water depths. Adoption of this program will provide the following advantages:

1. The discharge point will be located below the quasi-permanent thermocline of the Florida Current and in a region of stronger currents, thus there will be greater vertical change in the horizontal velocity. These two naturally occurring oceanographic features will mix the rising effluent with the subsurface waters, which should, almost always prevent the effluent from surfacing.

2. Since the effluent is prevented from surfacing, it will not move shoreward with a wind-induced onshore surface component.

3. If the effluent does surface, the dilution which occurs on the vertical ascent will be greatly increased. This dilution, when coupled with chlorination, and better mixing provided by the diffuser system, will reduce bacteria concentrations to safe levels in the boil.

4. The effluent will be discharged into the Florida Current (Gulf Stream) a much greater percentage of time. Since the Florida Current is low in nutrients, the additions from the outfalls should not be a degrading factor.

5. We expect that the extension of outfall lines will be far more economical and can be accomplished much faster than the construction

of secondary treatment plants, thus outfall extension should initially be given construction priority.

The use of outfalls with proper treatment and depth of discharge can solve many of our existing waste disposal problems in southeast Florida. However, it is important to consider the long-range fresh water needs of the area. If it is the opinion of experts that southeast Florida will face a water shortage in the future, we must then consider the complete recycling of our wastes. In the meantime, extension of the existing outfalls is a practical solution. The construction of secondary treatment plants with 90% treatment does not negate the need to extend the length of the existing outfall lines. For even with a high level of treatment, it is still important to extend the discharge point beyond the narrow coastal strip and to keep the effluent from surfacing in order to absorb the nutrients and safeguard the bathing waters from high levels of bacteria and viruses.