

PRELIMINARY PLANNING CONSIDERATION
FOR
BAY AND SHORESIDE DEVELOPMENT
IN
TUMON BAY, GUAM



US Army Corps
of Engineers
Honolulu District

MARCH 1981

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FOR
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THE TUMON BAY PLANNING COMMITTEE
DEPARTMENT OF COMMERCE, GOVERNMENT OF GUAM

TECHNICAL ASSISTANCE BY:

U.S. ARMY CORPS OF ENGINEERS
HONOLULU ENGINEER DISTRICT
BUILDING 230
FORT SHAFTER, HAWAII 96858

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PURPOSE OF THE REPORT

The Government of Guam is in the process of establishing a Master Development Plan for Tumon Bay. One of the planning elements consists of determining development objectives, priorities and strategies for improving and enhancing recreational opportunities and uses of Tumon Bay's waters, marine life and shoreline. To assist planning discussions and decisions, this report describes Tumon Bay's marine environment based on a review of existing information; assesses probable environmental impacts related to various development concepts expressed by representatives of the local government, private industry and the public; and identifies data gaps and areas for future study.

PLANNING PROBLEMS AND CONCEPTS FOR TUMON BAY

Guam's tourist industry is based on utilizing Guam's tropical climate and Tumon Bay's sandy beaches and waters for swimming and other water-contact recreation. However, Tumon Bay's shallow fringing reef limits swimming and some forms of water-contact recreation. A lack of facilities further limits water-contact recreational activities. In order to create a more attractive tourist destination for the benefit of tourists and local residents, the Government of Guam has recently embarked on a planning effort to increase recreational opportunities and diversity in the bay area by utilizing the bay's natural resources and encouraging the development of a water sport industry that would diversify and support water-contact recreation in the bay. Private industry already provides rental services for scuba diving gear, outrigger canoes and other flotation gear, paddle boats, hobie cats, and other amusement activities.

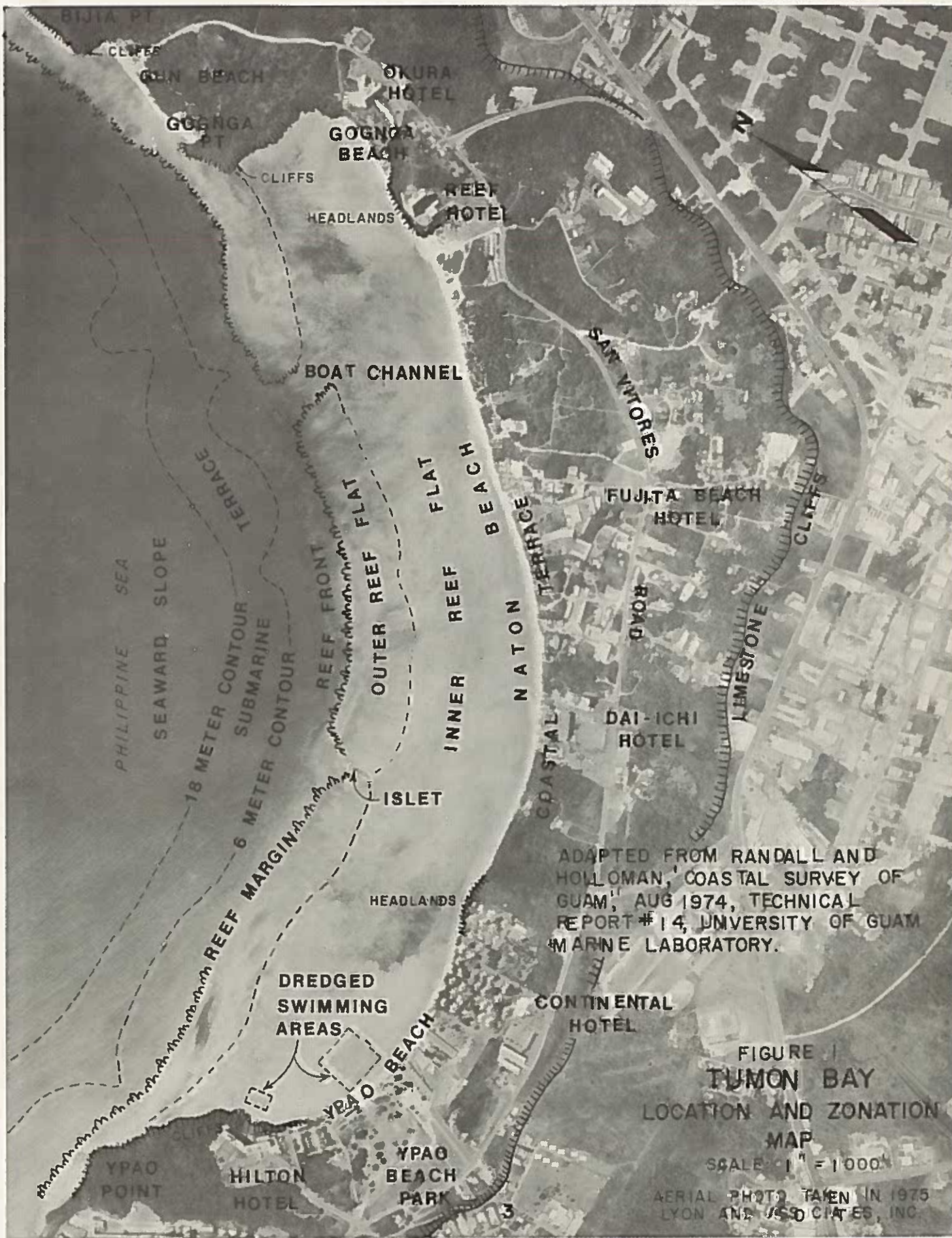
The Government and some local interests had previously identified dredging the bay as a possibility to restore and enhance marine life, to widen the existing entrance channel for larger pleasure boats, to create snorkeling trails within the bay, and to deepen or channelize the bay for swimming, water skiing, and sailing. Specific recommendations included dredging one large or several small swimming holes close to shore similar to those fronting Ypao Beach Park and the Guam Hilton; dredging several channels, instead of one, for wind-surfers, hobie cats and swimmers; and constructing surfing areas. Shoreline promenades or trails and a causeway to an enlarged offshore island were also considered for passive recreational activities. These concept were generally confined to use of Tumon Bay's inner reef flat rather than the ocean waters seaward of the reef edge.

Although the Guam Government has begun to periodically clean the beaches of trash, algae rafts, and debris, the government felt that problems dealing with stormwater, algae, sea cucumbers and red tide conditions needed to be solved in order to further enhance the beauty and recreational enjoyment of the bay. Stormwater runoff and discharges were believed responsible for the gradual erosion of the shoreline and filling of the bay. Periods of increased algae growth in nearshore waters discouraged swimmers from using the water, and rafts of algae accumulating along the shoreline created a smelly mess. Sea cucumbers were so numerous on the reef flat that waders need to avoid stepping on them or else have their feet enmeshed in the sticky and annoying evisceration. Under certain conditions, a localized red tide condition occurred off the Okura Hotel discouraging swimmers and discoloring the water degrading water aesthetics.

DESCRIPTION OF EXISTING ENVIRONMENTAL CONDITIONS

Tumon Bay including Gun Beach is located (Figure 1) between Ypao Point and Bija Point on the western coast of Guam. The bay lies at the edge of a limestone plateau which comprises the northern region of Guam. The limestone cliffs along the edge of the plateau surround the bay and attain an elevation of 15-30 feet at Ypao Point rising to an elevation of 60-80 feet at Gognga Point. The embayment includes a wide, but relatively small, coastal terrace and a broad, shallow fringing reef about 1,000-2,000 feet wide. Limestone outcrops along the shoreline divide the bay into three beach regions; Ypao Beach, Naton Beach and Gognga Beach.

The bay's geological, climatic, and oceanographic conditions influence the bay's hydrology, water quality and biologic resources. Data on the existing reef environment is derived principally from studies performed by members of the University of Guam Marine Laboratory, the Guam Department of Agriculture, Division of Aquatic and Wildlife Resources and studies performed for the Guam Bureau of Planning, Coastal Zone Management Office (Bibliography). Based on these studies, the reef is characterized by several zones (Figure 1) which will be used for the purposes of discussing and describing the existing conditions and environmental impacts of conceptual plans. Besides the resort and urban development along the shoreline, three man-made features exist on the reef flat; a dredged boat channel and two dredged swimming holes. A small natural islet composed of coralline rubble is located on the outer reef flat.



HISTORIC SITES

Twelve remnants of the Japanese defense structures from World War II are located along the Tumon Bay shoreline (Figure 2). The Guam Historic Preservation Officer indicated (29 August 1979) that the system was essentially undisturbed and was the only intact system on the island. Two large destroyed gun emplacements are located near Gognga Beach at location Z. Two small pillboxes which were in fair to poor condition were located at Naton Beach (Location B). One small "one-man" bunker and one large pillbox were located at Naton Beach (Location C). One-man cave pillbox, one small pillbox and one large heavy gun emplacement were located at Ypao Beach (Location D). The pillboxes were in good to excellent condition, and the gun emplacement was in fair condition, though it had been partly destroyed (probably to remove the 37 mm guns). Two small rock cave pillboxes in good condition and one large heavy gun emplacement were located at Ypao Beach (Location E). This emplacement appeared to have taken a direct hit from a naval gun during the war, but was partially restored. The defense structures used by the Japanese at Tumon Bay were basically constructed of scrap metal for reinforcement and concrete with bits of old tanks, water pipes, accordin wire, and reinforcing rods. Natural cave formations, beach rock, boulders, and sand were commonly utilized. Molds for the interiors were constructed of 8" x 8" timbers and sometimes (for large structures) whole coconut tree trunks.



FIGURE 2
HISTORIC SITES
TUMON BAY
FORTIFICATIONS

WATER CURRENTS

Water currents on the Tumon Bay reef flat appear to be regulated by bathymetry, tide, wave action, and wind. The data were taken incidental to other University of Guam studies; thus, the information on water currents did not reflect a continuous survey period, necessary to determine seasonal variations. In particular, the bay's hydrologic response under typhoon conditions is not documented or studied. The description of water currents provided by the existing data may reflect normal tradewind conditions, most likely periods of moderate weather, and do not provide information on conditions related to storms or changes in wind direction.

Bathymetric data for the bay is generally lacking, except for a detailed survey of the western sector of the bay performed in 1975 by the University of Guam, Engineering Technology Division, and biological transect profiles taken by various investigators (Figure 3). The profile data are not corrected to the same datum. However, the data indicate that the nearshore inner reef flat is deeper (-2 feet mean lower low water (MLLW)) than the outer reef flat (0 feet) and that greater water depths (-5 feet MLLW) are found in the middle sector of the bay near the boat channel. The western sector is shallow averaging about -1 foot MLLW. The eastern sector appears to average about -2 feet MLLW. The depth of the boat channel is not known, but may be about -3 to -4 feet MLLW based on a US Navy depth profile near the boat channel. During low tide the outer reef flat is exposed, generally isolating the inner reef flat from the Philippine Sea except for the boat channel connection. Since the tides in Guam are semidiurnal (two tidal cycles per tidal day) with considerable diurnal inequality (differences between two high waters or two low waters), the inner reef flat may be isolated or partially isolated from the sea twice every 24 hours.

TABLE 1. SOURCE OF BATHYMETRIC DATA ON FIGURE 3

<u>Profile</u>	<u>Source</u>
A	Jones and Randall, 1972, A Marine Survey for the Okura Hotel Project.
B	Amesbury, 1978, Studies of the Biology of the Reef Fishes of Guam. Randall, 1973, Reef Physiography and Distribution of Corals at Tumon Bay, Guam before the Crown-of-thorns Starfish Predation. Randall, 1978, Guam's Reef and Beaches, Part II.
C	U.S. Navy, 1974, Nearshore Currents and Coral Reef Ecology of the West Coast Guam, Mariana Islands.
D	Randall, and Holloman, 1974 Coastal Survey of Guam. Randall, 1973 (See B above).
E	Amesbury, 1978.
F	Randall, 1978.
G	Randall, 1978.
H	University of Guam, 1974-1975, Bathymetric and Biological Survey, Tumon Bay, Phase I.



FIGURE 3
TUMON BAY
BATHYMETRY

Jones and Randall (1972, 1973) suggest that two current cells exist in Tumon Bay, and that the dynamics of both cells are a function of tidal water heights, wave activity, and bathymetric gradient (Figure 4). During flood tide, the water depth over the outer reef flat in the western part of the bay increases, permitting wave energy to transport water onto the reef flat (wave setup) creating a hydraulic imbalance which drives the currents on the reef flat eastward from the Hilton Hotel then seaward through the boat channel. In the eastern sector of the bay fronting Okura Hotel, Jones and Randall (1972) found little or no water movement except during tidal changes when a weak seaward flow through the boat channel was detected during an ebbing tide and a weak landward flow was detected during flooding tide. They attributed the lack of a measurable current to the lack of wave activity on the reef front and hypothesized that the eastern area of the bay was protected from wave activity by Amantes Point located to the east of Gognga Point.

TABLE 2. GUAM TIDE DATA

Highest Recorded Tide	+3.31 feet
Mean Higher High Water	+2.4 feet
Mean High Water	+2.3 feet
Mean Tide Level	+1.45 feet
Mean Sea Level	+1.41 feet
Mean Low Water	+0.6 feet
Mean Lower Low Water (Datum) (MLLW)	0.0 feet
Lowest Recorded Tide	-1.89 feet

Source: U.S. Department of Commerce

Current velocities on the outer reef flat at Ypao Point, measured by Jones and Randall (1973), varied from 0.30 to 0.56 knots during flood tide. The current direction was shoreward onto the reef due to wave transport. Current velocities in front of the Hilton Hotel varied from 0.10 - 0.62 knots during flood tide and increased as the tidal depth of water on the reef flat increased allowing waves to transport water into the bay. The current velocity increased to 0.66 knots during ebb tide and gradually decreased to 0 knots at slack tide. Clayshulte and Zolan (1976) found current velocities fronting the Continental Hotel to vary from 0.24 to 1 knot. The current velocities generally occur with the east to west flow of water. During flooding tide a reversal of direction was detected, but a current velocity could not be obtained from the information provided.

The bathymetric gradient appeared to be the major factor influencing current direction. The eastward flow of water during ebb tide follows the bathymetric gradient to the east, and appears stronger than the effect of the prevailing wind, which creates a weak surface flow to the west within the top 10-20 centimeters of the water surface (Jones and Randall, 1973). During slack tide, dye measurements by Jones and Randall indicated a predominant eastward current despite the prevailing northeast trades and lack of wave transport over the reef flat. The continued eastward current, although weak and barely detectable, could be the result of wind-driven water piled up in the shallow end of the bay forcing water to flow back toward the deeper parts of the bay, or the eddies created by waves entering the existing boat channel. Marsh (personal communication, 1980) suggested that the high bathymetric elevations around the islet fronting the Continental Hotel forced the water flowing eastward to converge in the deeper reef areas fronting the Hotel where an increase in current velocity was measured by Clayshulte and Zolan.

PHILIPPINE SEA

ADAPTED FROM:

1. RANDALL AND JONES, (1973). A MARINE SURVEY FOR THE PROPOSED HILTON HOTEL DREDGING PROJECT.
2. CLAYSHULTE AND ZOLAN, (1976). A STUDY OF CONTINENTAL HOTEL BEACH STORM DRAIN, WATER QUALITY AND SURROUNDING ENVIRONMENT.
3. JONES AND RANDALL, (1972). A MARINE ENVIRONMENTAL SURVEY FOR THE OKURA HOTEL PROJECT.

FIGURE 4
TUMON BAY

GENERALIZED CURRENT FLOW

---> EBB TIDE
--> FLOOD TIDE

Current measurements taken offshore at Gun Beach in 100 feet of water by the U.S. Navy in 1974 indicated a net southwesterly flow with extremely slow current velocities; a majority of measurements are less than 0.1 knot (0.15 m/second) and very few greater than 0.3 knots (0.44 m/sec).

LITTORAL MATERIALS

The unconsolidated sediments (sand, coral rubble, and boulders) on the reef flat reflect movement and sorting by waves and currents. The outer reef flat consists principally of flat limestone pavement with coral boulders tossed up by wave activity on the reef front. Sand and coralline gravel and rubble are found in layers varying in thickness from a thin veneer to a meter or more on the inner reef flat zone where the water is more quiet. The bay shoreline consists of stretches of sand and rocky limestone headlands. The beach deposits are quite deep (30 feet or more, Randall and Holloman, 1974) and are composed predominantly of shell and coral fragments reflecting their reef origin. While the shoreline is generally sand, the shoreline and nearshore waters are littered with coral rubble and aggregate washed in from the reef edge. Sediment size gradation by Clayshulte and Zolan (1978) and the Corps of Engineers (1980) indicated sorting by the reef flat currents. The Corps analysis of beach material indicates a general trend towards finer sand in the eastern sector of the bay, and better sorting (having a more consistent grain size) of sand in the western sector. Clayshulte and Zolan recorded an eastward movement of sediment discharged from the Continental Hotel storm drain. The rate of sand movement along the beach has not been studied or estimated. Based on Corps permit records, the Ypao Beach dredged swimming hole has not been maintenance dredged since 1962, and there is no indication from the Guam Department of Public Works of a need to dredge the swimming hole. The Hilton dredged swimming hole was constructed in 1973 and was recently maintenance dredged (1979-1980). The maintenance dredging cycles suggest that the volume of sand movement in the western end of the bay may be low. However, the Hilton swimming area may be intercepting sand that would settle in the Ypao swimming area.

EROSION HAZARD

The broad shallow reef flat acts as a buffer or wave dissipator, and protects the bay from significant storm wave damage by reducing incident wave energy. No data were available to determine the effects of storm waves on the littoral process in the bay. Existing data suggest that the shore is relatively stable under normal wave conditions.

A visual survey for erosion problems in Tumon Bay (Guam Shoreline Inventory, US Army Engineer District, 1980) indicated that the Tumon Bay beach system is stable under existing conditions, except for minor erosion occurring in two areas. A section of Naton Beach immediately north of the Dai-Ichi Hotel has three coconut trees with roots exposed and one toppled tree suggesting an erosion process. A section in the center of Ypao Beach may be eroding based on the presence of an escarpment at the foreshore crest. The erosion may be related to storm wave activity, but no information is available to confirm the hypothesis. No signs of erosion were noted in the area fronting the Ypao Beach dredged swimming area.

The orientation of Tumon Bay on Guam permits the land mass to shelter the bay from the prevailing northeast trades and wind driven waves. However, the bay is exposed to storm surges and typhoon waves from the northwest quadrant (Figure 5). An average of 2-3 typhoons a year pass within 180 nautical miles of Guam. While a typhoon can occur within any month of the year, it occurs more frequently in the months of August through November with peak activity occurring during the period from October through November. Wave hindcasts related to tropical storms and typhoons in the western North Pacific occurring in the period 1975-1979 indicate that during a tropical storm or typhoon about 50% of the wave spectrum approached Guam from the Northwest quadrant. About 40% of the wave heights are up to 6 feet and about 10% are over 6 feet. In comparison to the annual wave height frequency analysis, about 15% of the wave spectrum approaches Guam from the northwest quadrant in comparison with about 70% from the northeast quadrant. Storm waves and surges related to tropical cyclones can cause extensive flooding and erosion of coastal areas depending upon factors such as, wind direction and speed, state of the tide, rise in water elevation due to reduced barometric pressure, configuration of the coast and bathymetry on the reef. In spite of Tumon Bay's exposure to storm waves, a comparison of aerial photographs of the bay shoreline taken about 1960 and in 1975 (prior to Typhoon Pamela) indicated no significant change in the shoreline. Secondly, the vegetated islet on the outer reef flat, which is composed of coralline rubble tossed up by waves, has grown in size over the last 15 years (Eldredge, 1980 personal communication).

WATER QUALITY

Four sources of water quality information were available for review. Only the Guam Environmental Protection Agency monitoring of bacterial contamination, water temperature and pH covered a long time span (11 years). Zolan, et al (1978) performed a detailed chemical analysis of groundwater seepage into Tumon Bay. Clayshulte and Zolan (1976) studied the effects of stormwater discharge at the former Continental Hotel, and Marsh (1977) studied the nutrient concentrations related to phytoplankton blooms in Tumon Bay. The studies were performed over a relative short period of time, approximately one year on an irregular basis. These studies in conjunction with the oceanography studies provide some information on water quality in Tumon Bay.

Water exchange and flushing on the reef flat in Tumon Bay is considered good in the western and middle sectors of the bay. The tidal exchange is unobstructed, the shallow bathymetry permits a large percentage of water exchange during each tidal cycle, and the predominant current ensures a continuous flow of water over the reef flat. Clayshulte and Zolan measured a water volume transport in front of the Continental Hotel ranging from about 3 to 15 cubic meters per second for all tidal stages during their period of study. Jones and Randall (1972) felt that water exchange and flushing in the eastern sector of the bay in front of Okura Hotel was poor based on the slow movement of their dye patches and the complex current patterns encountered.

Nutrient measurements in Tumon Bay indicated that the bay waters contain a high concentration of nitrates due to the high volume of groundwater seeping into the bay, and that the bay water has a low concentration of phosphorus. The rate of groundwater seepage into the bay was partially measured by Emery (1977). He found a rate of flow of about 150 cubic feet per second for a 150-foot section of beach near the Reef Hotel. Zolan, et al, identified five major seepage sites in Tumon Bay located near the Hilton Hotel, Continental Hotel, Reef Hotel and the Okura Hotel. Marsh indicated that a freshwater

WAVE HEIGHT DIRECTION AND FREQUENCY RELATED TO
WESTERN NORTH PACIFIC TROPICAL CYCLONES OCCURRING
DURING PERIOD FROM 1975 - 1979



ANNUAL DEEP WATER WAVE HEIGHT DIRECTION AND FREQUENCY
FOR GUAM.

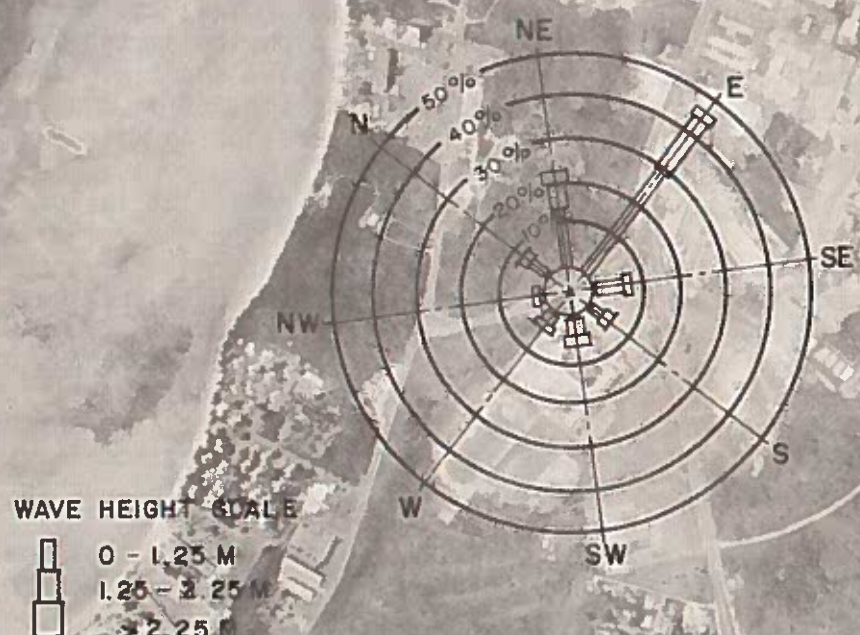


FIGURE 5
WAVE HEIGHT
CHARACTERISTICS

spring could also be found on the inner reef flat fronting the Reef Hotel. Water samples taken over a one year period by Marsh contained mean nitrate concentration of about 8 microgram-atoms per liter and a reactive phosphorus concentration of about 0.2 microgram-atoms per liter. Clayshulte and Zolan in their study of the storm drain discharge into the bay found that stormwater contained a high concentration of both phosphorus (0.128 - .750 mg/l) and nitrates (0.212 - 0.238 mg/l), but that the nitrate concentration in the groundwater seepage into the bay masked the nitrate contributions and effects of the storm drain. If cesspools are being used in Tumon Bay, they may be contributing nutrients to the groundwater entering the bay. Marsh hypothesized that an increase in phosphorus concentrations during the early part of the rainy season in April combined with the slow rate of water exchange in the eastern sector of the bay resulted in a periodic dinoflagellate bloom. During bloom conditions mean nitrate values decreased to about 4 microgram-atoms per liter and mean phosphorus values increased to about 0.6 microgram-atoms per liter. Research at the Massachusetts Institute of Technology suggests that dinoflagellate blooms may occur when benthic cysts are revived due to temperature increases or when trace metal concentrations fall below levels toxic to the dinoflagellate due to metal bonding with organic compounds carried into the bay by stormwater. Jones and Randall indicated that the bloom was an annual event occurring every April and tentatively identified the dinoflagellate as Gymnodinium. They related a Chamorro legend suggesting that the water discoloration, caused by the dinoflagellate bloom, was the blood of Father San Vittores reappearing every April to haunt his assassins. Father San Vittores was killed and his body thrown into the eastern part of the bay on 2 April 1672.

Salinity characteristics in Tumon Bay are not well documented. For the area fronting the Continental Hotel, Clayshulte and Zolan measured a salinity ranging from 31 0/00 to 34 0/00 with a mean salinity value of 32 0/00. The data suggest that salinity within 5-10 meters from the shoreline may range from 31-32 0/00, and 32-34 0/00 within 10-50 meters of the shore. They found that the discharge of stormwater into the bay created a salinity decrease of about 4 0/00 within 5 meters of the point of discharge, but no change within 10 meters of the storm drain. The information suggests that mixing action on the reef flat is sufficient to limit any salinity stress associated with storm water discharges.

Water turbidity characteristics are also not well documented. Clayshulte and Zolan found turbidity values within their storm drain study area to be consistently less than 1 NTU. Stormwater runoff turbidity ranged from about 2 to 18 NTU, but was confined to the nearshore area.

Clayshulte and Zolan verified that storm drains were sources of bacterial and heavy metal contaminants into Tumon Bay. Human use of the nearshore waters can also contribute to bacterial contamination in the bay. The long-term effect of heavy metal contribution to the bay and the response of marine organisms to long-term stormwater perturbation are not known.

MARINE LIFE

Marine life development in Tumon Bay is limited by the unstable substrates in the bay and shallow water. Randall and Eldredge (1976) mapped and described the region in the Atlas of the Reefs and Beaches of Guam. They indicated that the inner reef flat consisted mostly of sand mixed with coral, algal and mollusk debris and that the outer reef flat consisted mostly of reef-rock pavement with widely scattered boulders, rubble and localized boulder tracts.

Corals were mostly absent along the shoreward part of the inner reef flat becoming scattered and locally abundant along the seaward part of the inner reef flat. Corals were absent or rare on the outer reef flat except in the existing boat channel and in scattered shallow holes and depressions. Transect surveys on the reef flat show a significant increase in number of species between the sand zone and the outer reef flat (See Figure 6). While the transects do not usually extend into the reef front, other survey data indicate that the number of species decreases on the outer reef and increases significantly on the reef front.

ALGAE

Tsuda (in Randall 1978) characterized the algal flora in Tumon Bay during two different seasons. The number of species and the percent cover increased from the shoreline toward the reef margin, and the percent cover was higher in the months of November and December in comparison to May and June. Fifty species were found during the survey with 14 species common to the three transect sites studied during the survey. Nine species were not found in the November-December survey which were present in the May-June survey. Tsuda (1974) in a discussion of the seasonal aspects of brown algae in Guam indicated that the majority of seasonal species are most abundant between January and June. However, Tsuda notes that healthy thalli can be found throughout the year in the intertidal zone in areas of heavy surf action. Randall and Jones (1972, 1973) also added to the list of algal species recorded from Tumon Bay.

The most significant algae in the bay appears to be Enteromorpha clathrata which serves as a food source for the rabbitfish, Siganus. This alga is also a nuisance to hotel operators because of its accumulation on the beach and presence in nearshore swimming waters. The alga is concentrated along the shoreline and is present throughout the year with large monthly variations in standing crop. Mean standing crops at three sample sites ranged from 7.5 to 44.1 grams per square meter dry weight (Fitzgerald, 1977). Nearshore, Enteromorpha tolerates a wide variation in salinity and produces a rich growth due to groundwater nutrient enrichment. Wave action and wind surge appear to be major factors controlling the distribution of the alga. Forceful surge and small breaking waves during periods of high surf or high winds result in a decrease in standing crop or complete elimination of the alga thalli. Grazing by large runs of herbivorous rabbitfish can also completely eliminate the thalli. However, the holdfasts usually remain to produce a new crop of algae. Any material providing a stable substratum, including coral rubble and fragments, mollusk shells and rocks, is colonized by the algae. The alga can also form dense mats stabilizing sand particles that can withstand water current velocities 5 times the velocity which dislodges sand particles. However, shifting substrates, abrasion and burial can prevent the growth of the alga. Dessication during extreme low tides is another stress factor which may limit the distribution of the alga.



FIGURE 6
TUMON BAY
MARINE LIFE
DISTRIBUTION

CORAL

Coral zonation in Tumon Bay has been extensively studied by Randall (1971, 1973 and 1978), and Randall and Eldredge (1974). Specific site surveys by Randall and Jones (1972), Jones and Randall (1973) and the U.S. Navy (1974) contribute to the knowledge about coral distribution in Tumon Bay. Randall (1978) provides the most recent baseline study which characterizes coral distribution and physiography in Tumon Bay. Factors affecting coral distribution and zonation on the reef included water depth, tidal exposure, water temperature and substrate composition. Corals cannot tolerate long periods of emergence; thus, they are limited to submerged areas on the reef which retain water during low tide and low spring tides. Elevated water temperatures have lethal and sublethal effects on coral. Water circulation helps to reduce the variability of the water temperature, however, spring low tides drastically reduce water-flow over the reef flat resulting in increased thermal stress. Most corals require a solid and relatively stable substrate for successful growth. Sandy areas tend to be devoid of coral, and rubble areas tend to have a patchy distribution of coral. Randall found that the sandy, inner reef flat zone which retains water during low spring tides was almost devoid of coral. The rubble zone had a patchy distribution of coral, but near the outer reef margin the greatest diversity of coral on the reef could be found because of the relatively solid substrate. The outer shallow reef flat was devoid of coral due to periodic tidal exposure. In general, areas which had solid substrate and a constant cover of water produced the greatest diversity and abundance of coral on the reef flat. Randall (1973) found that the percentage of coral coverage and the number of species increased with distance from shore reaching the highest values on the reef front (Table 3). Some species were restricted in their distribution to either the reef flat or reef front, and others were found in both zones.

TABLE 3

<u>Reef Zone</u>	<u>Total Number of Species</u>	<u>Cover (%)</u>
Inner reef flat	48	5.4
Outer reef flat	37	14.9
*Reef margin	59 (26)	43.8(9)
Reef front	98	49.1
Submarine terrace	73	59.5
Seaward slope	57	50.1

*Based on use of two transect areas.

Nearly 80% of the coral on the reef flat with a diameter varying between 0-10 centimeters were found in the inner reef flat area (Randall, 1978). The large number of small corals in relation to the small number of large size corals suggests that the reef platform is an unstable environment where coral recruitment and mortality are high, preventing corals from aging and reaching a larger size. Coral in Tumon Bay is susceptible to predation by the crown-of-thorns starfish, *Acanthaster planci*, which devastated the coral on the Tumon Bay reef front during 1969 - 1970 (Tsuda, 1971). The effect of tourist-related harvesting on coral resources in the bay are not known.

Of the 7 harvestable corals identified by Hedlund (1977), four are found in Tumon Bay (Table 4). The blue coral, Heliopora coerulea, was identified as a species to be protected from overharvesting. None of the rare corals identified by Hedlund were listed in Randall's studies.

TABLE 4. Harvestable Coral in Tumon Bay

	<u>Location</u>	<u>Range Density/m²</u>	<u>Common Names</u>
<u>Acropora irregularis</u>	unknown	unknown	none
<u>Acropora acuminata</u>	inner reef flat	0.12 - 0.14	staghorn coral
<u>Fungia fungites</u>	reef front	unknown	mushroom coral
<u>Heliopora coerulea</u>	inner reef flat to reef front	0.08	blue coral

SEA CUCUMBERS

The sea cucumbers were the most prevalent group of invertebrates on the reef flat. They are a source of food in some parts of the world, but are considered a nuisance by swimmers and waders who step on them and become enmeshed in the sea cucumber eviscerate. Twelve species of sea cucumbers were found in the bay by Birkeland (in Randall, 1978) of which the black sea cucumber, Holothuria atra, comprised over half of the sea cucumber biomass in the bay. A mean holothurian population density of 15.58 individuals/10m² and an average wet weight of biomass of 3.87 kilograms/10m² were calculated. Birkeland estimated that there was approximately 3 million sea cucumbers in Tumon Bay that formed a biomass of about 824 tons. Data in Rowe and Doty (1977) indicate that half of the species of sea cucumbers found by Birkeland are sand dwellers and the other half residing on rubble or hard substrates.

FISH

Fishery resources studies in Tumon Bay were limited to standing crop measurements and fishermen creel census by the Guam Fish and Wildlife Division, and fish distribution on the reef flat by Amesbury (1978). Studies by Randall and Jones (1972, 1973) contributed to the list of species found in the bay. The Guam Fish and Wildlife data for the period 1974 to 1978 indicated that Tumon Bay was the most heavily fished inshore area on Guam. Unfortunately, realignment of the census areas in 1979 prevented an assessment of fishing activities in Tumon Bay. Fish standing crop measurements showed a general increase in fish stocks although considerable variation occurred throughout the period of record from 1968-1973. Cast net and surround net fishing were identified as major types of fishing performed on the reef flat. A reduction in cast net fishermen appeared in the data and the decline was attributed to an increase in tourist activity in the bay, as well as a loss of interest by younger residents. Gill net fishing was said to be decreasing in popularity while spin fishing and spearfishing may be increasing in popularity. Surf casting is not a major fishing activity on Guam at present.

The distribution of fish in the bay (Amesbury) appeared to be influenced by bathymetric relief, wave action and habitat preference. An increase in bathymetric relief provides an increase in habitat diversity resulting in an increase in fish diversity. Heavy wave action makes areas inhospitable to

fish and unstable substrates, such as sand and rubble, tend to bury habitat areas and reduce bathymetric relief. Amesbury found that the abundance of fish and species diversity increased from the sandy nearshore area to the coral rich outer reef flat. Species habitat preference create zonation patterns in species distribution, since species preferring particular substrates were found in specific zones. A greater abundance and diversity of fish could be expected on the reef front because of the greater depth of water, bathymetric relief and coral diversity. Amesbury's survey did not assess the use of the reef flat by juvenile forms or extend onto the reef front. However, most adult reef fish usually spend a portion of their juvenile life on the reef flat.

Two fishes are seasonally abundant on the reef flat; the rabbitfish (Siganus, manahac) and the mackerel (Trachurrops crumenophthalmus, atulai). The goatfish (Mullidae), jacks (Caranx), surgeonfish (Acanthuridae), parrotfish (Scaridae) and snappers (Lutjanidae) are also commonly harvested from the reef. The rabbitfish is an important food fish throughout the Western Pacific and is traditionally favored by the local residents. Tsuda (1976) provides data on the rabbitfish food and salinity preference and temperature and oxygen tolerances. Within Tumon Bay the rabbitfish are known to graze on the green filamentous algae (Enteromorpha clathrata) and tolerate the groundwater discharges in the area. A thirteen-year harvest record for the rabbitfish did not indicate any significant patterns or cyclic trends. Years of low harvests and years of extremely high harvests were intermixed. The seasonal rabbitfish runs usually occur before or after the last quarter of the moon in April and May. Occasionally a third and fourth run may occur in June and October. While the runs are usually predictable, factors influencing the runs and the size of the runs are not known to science.

CIGUATERA

Ciguatera poisoning, is a neurological disorder caused by eating fish containing cigatoxin. The Guam Department of Public Health and Social Services indicated that ciguatera occurs infrequently on Guam, but refer to Dr. Takeshi Yasumoto, a World Health Organization consultant, who suggests that many cases of ciguatera poisoning are unreported and that the actual number of cases might be greater than statistics specify (Guam Department of Public Health, 1981).

The literature suggests that ciguatera outbreaks are triggered when the marine ecosystem is disturbed by activities such as the dredging on the reef. The hypothesis suggests that algae colonization in the disturbed area increases providing a habitat for a toxin-producing dinoflagellate. The algae provide a food source for herbivorous fish which ingest the epiphytic, toxin-producing dinoflagellate. The toxin remains in the fish but does not affect the fish. Carnivorous fish feeding on the herbivores concentrate the toxin in their flesh. When the larger, carnivorous fish are eaten a case of ciguatera occurs. The dinoflagellate responsible for producing cigatoxin has been identified as Gambierdiscus toxicus, and is present in Guam waters. No cures or antidotes for ciguatera are known, except to avoid eating fish containing cigatoxin. Monitoring disturbed marine environments and chemically sampling fish in the market caught in disturbed areas are methods available for detecting ciguatoxic fish and warning the public of a potential health hazard.

OTHER MARINE ORGANISMS

A systematic study of the distribution and physiography of the macroinvertebrate fauna in Tumon Bay has not been done. Randall and Jones (1972 and 1973) provides the best list of the invertebrate fauna in the bay; however, their surveys were limited to two specific sites in the bay. The value of the invertebrate fauna in Tumon Bay to the ecosystem or to man is not understood. Obviously, some invertebrates are used as a food source by fish and man. Others appear to serve no obvious function, except that some might contribute to nutrient recycling or reworking of the substrate. A survey in Tumon Bay of edible marine shellfish and sea urchins (Stojkovich and Smith 1978) reported the sea urchin, Echinothrix diadema, concentrated on the reef front where the sea urchin attained a population density of 0-60 per square meter (m^2). The giant clam, Tridacna maxima, was found in low numbers (17/100 m^2) in 12 meters of water on the reef slope. The pearl shell, Trochus nilotus, was found on the reef front in population densities ranging from 1.1-3.4/20 m^2 . The size of the Trochus shell increased with increased water depth. No large population of bivalves were found in the bay, although small infaunal forms were present.

IMPACT ANALYSIS OF PLANNING CONCEPTS

Detailed development planning for Tumon Bay should include development of planning objectives and the resolution of priorities and strategies to implement the plan. Some of the planning issues are presented in Table 5. The existing environmental information indicates that marine life in Tumon Bay has not been depleted or damaged to a point requiring restoration efforts by man. Presently, the distribution and abundance of marine life is limited in part by natural factors related to substrate instability, shallow water depths, and tidal exposure. Some areas on the reef flat are locally rich in coral growth and other marine life, and sufficient water depths exist for boating and swimming activities, although restricted to the eastern half of the bay. Planning discussions have focused on improving water-contact recreation on the reef flat, but snorkeling and fishing activities could take place along the reef front. Because of the conceptual nature of the plans for Tumon Bay, the probable effects of a number of future management and planning options are assessed in a general way to assist development planning.

TABLE 5. PLANNING ISSUES

<u>Problems and Needs</u>	<u>Issues Requiring Resolution</u>	<u>Types of Solutions</u>
1. Enhance marine life.	1. Is the bay marine environment in need of enhancement? 2. Is enhancement compatible with other problems and needs? 3. What resource needs to be enhanced?	1. Do-nothing. 2. Create marine life conservation district. 3. Transplant or propagate more organisms in the bay. 4. Dredge the bay to increase habitat diversity. 5. Educate bay users.
2. Improve the bay for boating, swimming, surfing and other recreational activities.	1. Should the "natural" condition of the bay be sacrificed for human recreational needs? 2. What specific natural attributes should be protected or sacrificed? 3. Should specific areas in the bay be set aside for recreation purposes, such as boating or swimming? 4. Should the bay be utilized for all purpose water-recreation or limited to certain types of recreation? If so, which types? 5. Should swimming and boating activities be intermixed? 6. Where should swimming activities be located? 7. Is frequency and quality of surf enough to justify a surf shoal?	1. <u>Improve swimming</u> (a) Dredge one large swimming area. (b) Dredge several small swimming holes along the shore. (c) Build onshore swimming pools. (d) Build a wider sand beach. (e) Build swimming platforms or piers in existing deep water areas. (f) Bus to existing deepwater areas. 2. <u>Improve surfing</u> (a) Dredge reef and construct surfing shoal. (b) Construct surfing shoal on reef front. 3. <u>Improve boating</u> (a) Improve existing channel. (b) Deepen bay for waterskiing and sailing. (c) Provide pier facilities in existing deep water areas. (d) Improve existing harbor at Agana.

TABLE 5. PLANNING ISSUES (Continued)

<u>Problems and Needs</u>	<u>Issues Requiring Resolution</u>	<u>Types of Solutions</u>
		4. <u>Improve other recreation activities</u>
		(a) Construct shoreside trail or promenade.
		(b) Enlarge offshore island and construct pier or causeway to the island.
		(c) Clean the beach periodically.
		(d) Construct or establish under-water snorkeling trails.
		(e) Increase visitor mobility.
3. Control algae growth.	Does the algae create a significant and real problem to beach users?	1. Herbicides
		2. Reducing groundwater influx
		3. Increase substrate instability
		4. Increase wave energy
		5. Mechanical harvesting
		6. Mechanical clearing of the beach
		7. Increase fish grazing
		8. Eliminate wastewater discharges.
4. Control sea cucumber population.	Does the sea cucumber population create a significant and real problem in Tumon Bay?	1. Harvesting: Mechanical Hand
		2. Habitat alteration
		3. Relocation to other reef areas.
		4. Informative Displays
5. Eliminate red tide occurrences.	What problems do red tides cause in Tumon Bay? Does state-of-the-art technology provides a method to control red tides?	Unknown
6. Eliminate storm drains that empty into Tumon Bay.	What alternatives can reasonably be implemented? What are their environmental and economic costs?	See the "Guam Stormwater Drainage Manual." Solutions could include ground injection, diversion to sewage treatment plant, improving ground permeability.
		Providing more storage or ponding areas.

DREDGING AND FILLING EFFECTS

Some of the conceptual plans for development in Tumon Bay will involve dredging and filling. Dredging will be required if the bay is improved for boating, swimming and surfing, and possibly to enhance marine life on the reef flat. Filling was considered in the enlargement of the islet and the construction of a causeway to connect the islet to the shore. The impacts of such activities can be discussed in general terms to illustrate cause-and-effect relationships before each conceptual plan is discussed separately.

In general, dredging and filling in the marine environment are associated with more negative effects to marine organisms than beneficial ones. While habitat and species diversity may be increased under certain circumstances, the results are usually achieved at the expense of those species living in the dredged or filled areas, and is dependent upon the rates of colonization, the types and growth of colonizing species, and the type of habitat created. Adverse effects may include:

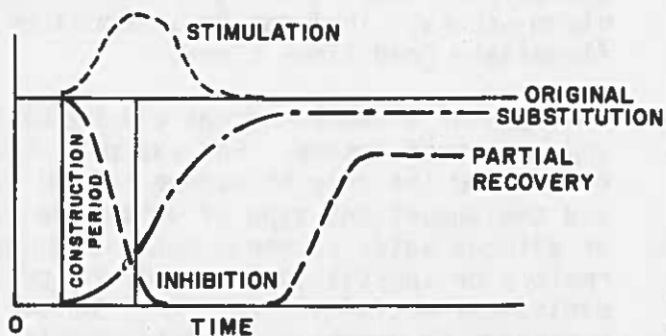
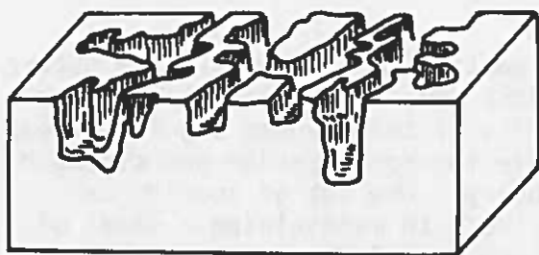
- a. Reduction in the abundance and diversity of marine species.
- b. Reduction in habitat diversity.
- c. Alteration of nearshore currents and wave energy on the reef flat.
- d. Long-term turbidity resulting from wave disturbance of fine, silty sediments, or the erosion of the dredged fill material back into the water.

The severity of impact, of course, is related to the biological richness of the existing environment, to the types of features dredged, the extent of dredging, and to the type of bottom created when the dredging is completed. Normally, dredging in sand and mud environments create little habitat or substrate change, and organisms residing in the remaining areas readily colonize the dredged area. Deepening any area can enhance marine life under certain circumstances by reducing the frequency of tidal exposure and the range of temperature fluctuations which stress marine organisms. Normally a substitution of species occurs as one species is afforded an opportunity to successfully compete and possibly replace another species. Sometimes impacts are delayed and don't appear until sometime after construction has been completed.

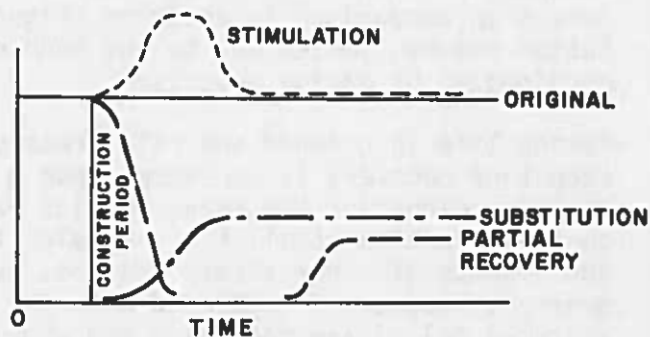
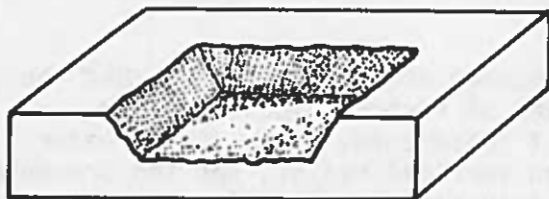
An illustration of the time-related response of the ecosystem to disturbance is provided in Figure 7. The illustration combines several responses and relates them to the type of construction activities that could occur in Tumon Bay. By whatever measure (diversity, species number, standing crop), the ecosystem prior to disturbance has an existing level of biological activity. Dredging and filling during construction initially destroys the existing biological activity; however, the water and substrate remain available for use by marine organisms. Filling, on the other hand, eliminates further use of the area by marine organisms, except for the intertidal areas at the toe of fill. The initial ecosystem response is inhibition due to the destruction of the existing biological community. However, construction may also stimulate biological activity temporarily. For example, dredging usually attracts fish, which feed on organisms exposed or suspended by dredging, resulting in a temporary increase in biological activity. Colonization of the dredged area

FIGURE 7. TIME RELATED PATTERNS OF MARINE ENVIRONMENT RESPONSE TO CONSTRUCTION DISTURBANCE.

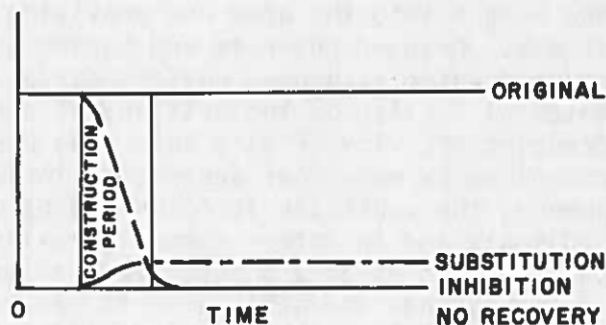
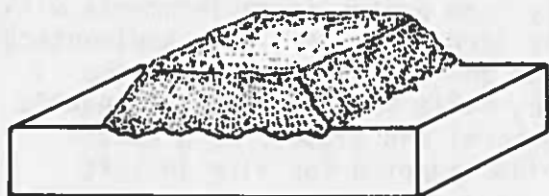
7a



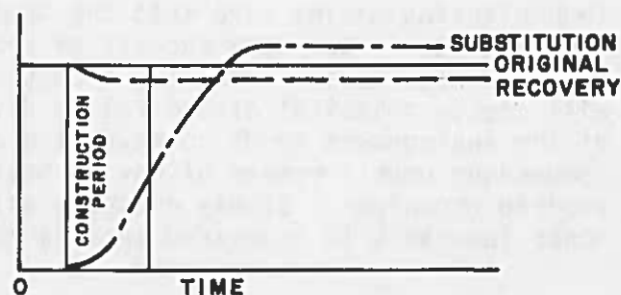
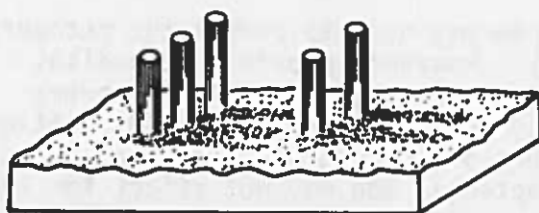
7b



7c FILLING EFFECTS



7d PILES EFFECTS



ADAPTED FROM DARNELL, 1976

may also stimulate biological activity, for example, an increase in algae productivity may occur associated with a bloom of epiphytic dinoflagellates which may produce ciguatoxin. Filling seldom results in biological stimulation, except when water exchange is interrupted or inhibited and a phytoplankton bloom occurs. In Tumon Bay, decreased circulation may stimulate a dinoflagellate (red tide) bloom.

Recovery of disturbed areas can be total or partial depending upon the nature and extent of damage. For example, blast shock waves and sediment transport can extend the area of damage beyond the limits of the dredged and fill area, and the amount and type of substrate available for colonization and strength of altered water currents can influence recovery. One set of species can replace or substitute for another, yet contribute to maintaining a level of biological activity. In Figure 7, the relative positions of the lines, representing recovery and substitution, reflect a comparison of impact and chronic effect between the types of construction depicted in the figure. For example, filling (Figure 7c) reduces recovery potential to preconstruction levels in comparison to dredging (Figure 7a and 7b) and the level of substitution may be limited due to the reduced availability of substrate that can be recolonized by marine organisms.

Marine life in dredged and fill areas can recover after disturbance, but the extent of recovery is dependent upon a number of factors, including the species colonizing the area, species habitat preference, water depth, water currents, bottom stability, irregularity and vertical relief, and the presence and absence of other stress factors, such as turbidity and sedimentation. In general, recovery is enhanced when the amount of irregular, hard substrate and vertical relief are maximized and when water currents or wave action flush the area (Figure 7a). Under normal conditions, recovery of coral communities may take as long as 15 to 40 years to attain pre-disturbance species diversity and abundance; however, full recovery may not always be possible. Water movement may enhance recovery by flushing sediments from the area, carrying nutrients and oxygen into the area and providing cool water reducing solar heating stress. Dredged channels and basins usually form protected environments with reduced water exchange, uniform surfaces and large areas of loose sedimentary material created by the settling of aggregate and fines generated by the dredging activity (Figure 7b). The unstable, silty substrate is not readily colonized by many reef organisms, including coral and algae. As a consequence, the substrate is colonized by organisms adapted for life in soft sediments and in waters normally having low wave and current energy. In comparison with an area dredged for maximizing marine life recovery, the recovery in the channel and basin area is generally inhibited and reef species are replaced. Unless the amount of loose sedimentary substrate and initial dredge damage can be controlled, recovery by surviving organisms in the dredged area can also be inhibited and colonization by species adapted to soft sediments will occur.

Transplanting marine life into the dredge area may help to reduce the recovery time and may insure some success of recovery. However, providing a habitat that attracts marine life, and transplanting cannot guarantee that recovery will create a habitat of equivalent diversity to that destroyed. Modification of the environment tends to favor the recovery of certain species over others (depending upon a number of environmental factors), and may not select for the desired organisms. Simply dredging without considering the habitat requirements favorable to a desired species may result in the colonization of

undesired species, some of which can increase hazards to recreational uses of the bay. Of course, dredging in loose, sandy areas with low biological diversity minimizes the initial destructive effects on the environment and increases the possibility of net beneficial increases in biological quality.

Filling, (Figure 7c) on the other hand, eliminates any further use of the area by marine organisms. While some species replacement is anticipated at the toe of the fill, the residual habitat in all cases will not be as extensive as the habitat destroyed, and will not, in most cases, be as diverse as the habitat and community destroyed. Reclonization and species abundance and diversity can be enhanced by providing elevated hard substrate having lots of holes, such as a rock revetment or surf shoal, in the area of deep water. The use of pile-supported structures (Figure 7d) significantly reduces the amount of damage and preserves the marine habitat and environment. Shading, however, can shift community composition to those species adapted to shaded habitat and possibly encourage the colonization of some reef flat organisms at the expense of others.

Increasing water depth over the reef flat also increases the amount of wave or surge energy that can enter Tumon Bay. At the present time, the shallow reef flat is an excellent wave energy dissipator which prevents large waves or strong surges from impinging on the shoreline, except under extreme conditions, such as those associated with a typhoon. In general, the wave height of a reformed wave on the reef flat is limited by water depth and reef width. Wave energy is proportional to the square of the wave height; thus, a slight increase in water depth over the reef flat allows a significant increase in wave energy on the reef flat (Figure 8). Similarly reducing the reef width reduces the frictional loss, allowing more wave energy to reach the shore. The characteristics of reformed waves on the reef flat cannot be easily calculated and are dependent upon a variety of oceanographic factors such as wave characteristics, water depth, reef width and bottom configuration. Figure 8 illustrates the concept and stresses maintaining the reef as a natural wave dissipator. Both a modification of water depth on the reef flat may also result in a change of wave approach to the beach, and an increase in the amount of water transported onto the reef can possibly cause a change in littoral process in the bay. A combination of the two factors has the potential for increasing the frequency of shoreline change (erosion and accretion) which may now be confined only to periods of severe storms. Shoreline setback zoning can minimize shoreline erosion damage by requiring the construction of damageable properties back from the shoreline instead of on or in close proximity to the shoreline.

Channelizing the reef flat can alter existing current patterns, and possible increase the flow of water off the reef that may be presently restricted by bathymetry. A depression in the reef or channel can decrease flow resistance and permit a greater volume of water to flow off the reef, resulting in greater littoral current velocities on the reef flat or the creation of rip currents through the reef margin. Current velocities may be particularly strong during ebb tide when both tidal water and water, carried onto the reef by waves, runoff the reef simultaneously. While increasing the number of channels in the reef may decrease the severity of these currents, the modifications can still affect shoreline stability. Depending upon channel orientation, the deeper water in the channel may allow larger waves into the bay resulting in an increase in wave energy at the shoreline possibly

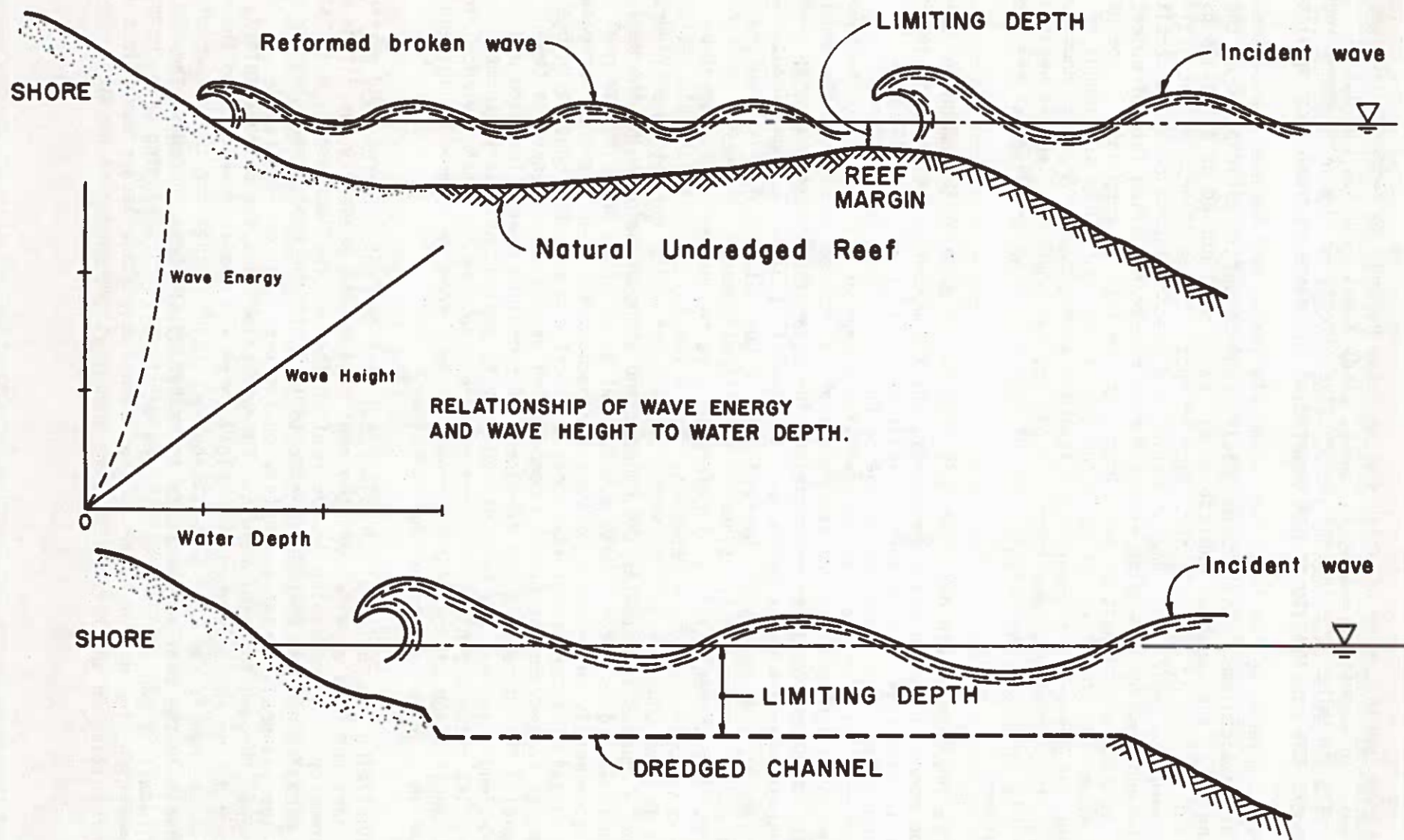


FIGURE 8. DREDGING EFFECTS ON WAVE HEIGHTS

affecting shoreline stability. If the channel is aligned perpendicular to the typhoon wave crests, the rate of shoreline erosion could be significant. If the channel is dredged close to shore, littoral material put into suspension by wave action may be transported off the reef flat by the seaward flowing currents in the channel (Figure 9).

Fills, on the other hand, obstruct, constrict or divert water flow. In Tumon Bay, for example, enlarging the islet (Figure 10) may force the eastward flow of water to converge toward the shoreline by restricting the area between the island and the shore, resulting in an increase in current velocity. In addition, the enlarged island will modify the pattern of wave approach to the shoreline. If the island is large enough to "shadow" the shore from wave action, there may be accretion in the lee of the island with resultant erosion on the either side of the accreted beach. Filling across the reef, such as the construction of a causeway from the shore to the island (Figure 11), will obstruct water flow and compartmentalize the bay creating areas of quiescent waters and poor circulation. Poor circulation can create conditions favorable for dinoflagellate blooms that degrade water aesthetics and possibly threaten human health. The placement of culverts can allow the water flow past the fill, but the use of piles in lieu of a fill causeway would not obstruct or divert the prevailing currents.

Water turbidity increases during dredging or filling due to the suspension of fine particulate matter and sediment in the water. The material can be swept away from the dredge site by water currents, but frequently settles out within the general area of the dredge site, particularly when currents and wave energy are reduced. In strong current or surge environments, the suspended material can abrade and scour marine organisms. In low wave and surge environments, the suspended material can remain suspended for long periods of time, effectively reducing light penetration through the water column, possibly inhibiting photosynthetic activity in benthic organisms. Sedimentation increases can smother benthic organisms that are attached to the bottom and cannot avoid the stress. The erosion of the dredged or fill material into the water from water fill sites or upland disposal sites can produce long-term turbidity and sedimentation stress, if not controlled. Wave or surge agitation can easily resuspend settled material and also contribute to long-term turbidity and sedimentation stress.

ENHANCEMENT OF MARINE LIFE

Whether or not marine life in Tumon Bay need enhancement is an issue to be resolved. "Enhancement" per se is a subjective concept dependent upon the perceived human qualities and use opportunities of the reef system. While marine life distribution, composition and diversity is influenced by a variety of factors including the shallowness of the reef flat, isolated areas of rich marine life are present in the bay. While man's present level of recreational activity may be damaging some marine organisms, the damage may be the result of ignorance, not malice. Thus, implementing an education program emphasizing the discreet use and protection of existing rich marine areas involves the least amount of environmental change and expenditure of human energy in relation to physically modifying the environment. While methods of enhancing marine life in the bay are available, some methods are untried and the results of their implementation may be mixed due to the lack of adequate knowledge concerning the interaction between the marine organisms and their environment and each other. The environmental advantages and disadvantages of various methods of enhancing marine life in Tumon Bay are presented on Table 6.





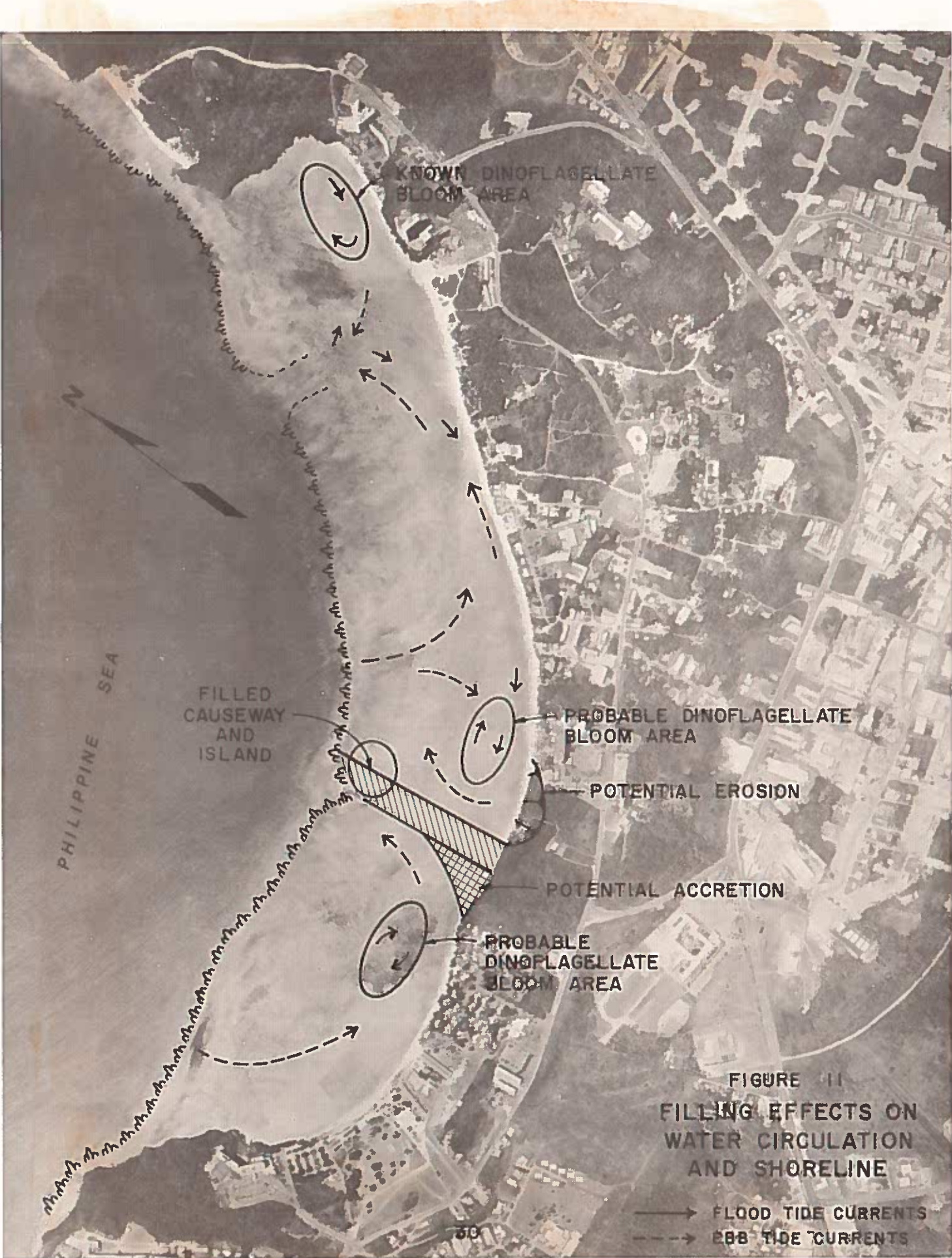


FIGURE 11
FILLING EFFECTS ON
WATER CIRCULATION
AND SHORELINE

—→ FLOOD TIDE CURRENTS
- - -→ EBB TIDE CURRENTS

TABLE 6
EVALUATION OF ALTERNATIVES TO ENHANCE MARINE LIFE

<u>Strategy</u>	<u>Methodology</u>	<u>Advantages</u>	<u>Disadvantages</u>
1. Do-nothing.	None required	Preserves the existing environment while avoiding problems associated with other alternatives.	Whether or not the marine life needs enhancement needs to be resolved.
2. Protect marine life.	Establish law or regulation creating a marine life conservation district in Tumon Bay that regulates taking or damaging marine life.	Preserves the existing environment while regulating human activities to prevent further disturbance to the environment, and allows nature to establish an optimum level of marine life development.	(1) Enforcement may be difficult in a resort area with high human activity and diversified landownership. (2) Need to determine what types of activities are compatible with the conservation district.
3. Educate bay users.	Develop education programs, tourist information booklets and an aquarium.	No physical modification on the reef.	Depends upon each individual system of values and perception of the marine environment to minimize damage to the marine life.
<u>Improve marine life</u>			
4. Increase species abundances and diversity.	Transplant benthic organisms onto the reef flat	(1) No physical modification on the reef flat. (2) Maintains reef flat for development of wading trails.	(1) Shallow waters limit the extent of habitat area which may be suitable for transplanting activities. (2) Need knowledge about habitat requirement of transplanted species, need to select suitable sites for collecting organism without damaging the environment, and need successful transplanting methods. (3) Select species to be enhanced at the neglect of other species.

TABLE 6 (contd)
EVALUATION OF ALTERNATIVES TO ENHANCE MARINE LIFE

<u>Strategy</u>	<u>Methodology</u>	<u>Advantages</u>	<u>Disadvantages</u>
5. Increase habitat diversity.	Dredging to deepen certain areas of reef flat and increase the amount of vertical relief.	(1) Increases water depth to reduce exposure and temperature stress on marine organisms.	(1) May be difficult to control dredging. The amount of rubble, sand and silt substrate must be minimized, and the amount of hard and irregular substrate maximized. (2) Dredging by its nature destroys much of the marine life. Natural recolonization will be slow. May require seeding or transplanting of species. (3) Need to know what species are desired and design habitat suitable for selected species. (4) Water currents through the area must be maintained to provide flushing without causing erosion problems. (5) The deepened area may allow increased wave energy on the reef and possibly cause shoreline erosion which could cause property damage and loss. (6) Potential increase in hazards to non-swimming waders who may fall into deep holes. (7) Loss of wading and reef foraging area. (8) Need to know the ecological successional patterns and environmental needs of desirable/undesirable habitats.

IMPROVING SWIMMING, BOATING AND OTHER WATER-CONTACT RECREATION

HAZARDS

Natural hazards exist in Tumon Bay affect both boaters and swimmers. Nearshore currents on the reef flat are strong enough to carry swimmers eastward along the shoreline, and currents are particularly strong near the existing boat channel where swimmers can be swept out to sea. The wave action and lack of entry and exit points along the reef margin make the area hazardous to novice boaters and skin divers. Improving the bay to enhance swimming and boating activities can create hazards. When the two activities are intermixed the frequency of swimmer collisions with motor or sailboats will increase. The two groups of activities may have to be separated by establishing restricted areas to prevent joint use of the water. This measure will tend to divide the bay into areas used separately for boating and swimming and will prevent each hotel from having its own joint swimming and boating facilities. Strong littoral or rip currents, and sudden drop-offs and holes created by dredging swimming holes, channels or other improvements will be hazardous to novice swimmers and to waders, and will eliminate and isolate shallow areas on the reef flat that are otherwise presently accessible to waders and fishermen.

SWIMMING

Swimming in Tumon Bay is presently limited to the two dredged areas and the existing deep water area fronting the Reef Hotel. In the middle and eastern parts of the bay, the shallow shoreline area permits wading, but swimmers need to wade out to the middle of the bay before they can swim. The western part of the bay is too shallow to permit any swimming, except in the two dredged swimming holes. Some methods used to improve swimming opportunities in Tumon Bay can include dredging swimming holes, building more shoreside swimming pools, creating wider beaches that extend into deep water areas and providing swimming piers or platforms in existing deep water areas. Gun Beach, which is located at the extreme eastern end of Tumon Bay, has an excellent sand beach and relatively deep nearshore water, but the beach is presently undeveloped as a park and is distant from hotels located on the western side of the bay. If swimming activities in the bay were limited to Gun Beach and existing deep water areas, a regular frequent shuttle bus service may need to be established. Dredging swimming holes along the shoreline should be considered with caution because the holes could cause erosion problems. An evaluation of methods is provided on Table 7.

SURFING

One suggestion was made to dredge the reef flat to deepen water depth for the construction of a surfing area. Since surfing is an activity dependent upon high wave energy, creating a surfing site on the reef flat by dredging can result in a significant increase in wave energy impacting the shoreline. The action could result in a serious shoreline erosion problem and may create strong currents that restrict swimming use on the reef. On the other hand, the creation of a surfing site offshore from the reef margin may be feasible without affecting the stability of the shoreline.

TABLE 7
EVALUATION OF METHODS TO IMPROVE SWIMMING

<u>Strategy</u>	<u>Methodology</u>	<u>Advantages</u>	<u>Disadvantages</u>
1. Create large swimming area.	Dredging to deepen the reef flat.	Provides a large swimming area in the bay.	(1) May cause shoreline changes that could result in property damages and losses, and reduction in beach width. Reformed wave energy may be great enough to create breaking waves on the beach. (2) Disposal of dredged material is required. (3) Potential ciguatera outbreak. (4) Conflicts with need to improve marine environment. Dredging results in significant loss of marine resources on reef flat. (5) Potential hazard to unsuspecting waders. (6) Potential interference with wading and fishing access.
2. Create several small swimming holes near the shoreline.	Dredging to deepen isolated nearshore reef flat areas.	(1) Dredging located near shore in sandy or rubble areas with low marine abundance or diversity. (2) Preserves more of the shallow reef flat as a wave dissipator than Alternative 1.	(1) May cause shoreline erosion that could result in property damages and losses, and reduction in beach width. The effect may be less severe than Alternative 1. (2) Potential for ciguatera outbreak.

TABLE 7 (contd)
EVALUATION OF METHODS TO IMPROVE SWIMMING

<u>Strategy</u>	<u>Methodology</u>	<u>Advantages</u>	<u>Disadvantages</u>
2. Create several small swimming holes near the shoreline (continued).			(3) Disposal of dredged material is required. (4) Potential interference with wading access and fishing activities. (5) Potential hazard to unsuspecting waders.
3. Build onshore salt-water swimming pools.	Onshore construction of swimming pools. Landscape to resemble beaches with sandy shores and sloping bottoms.	(1) Eliminates modification to marine environment. Water can be obtained from the bay. (2) Allows swimming in sandy beach setting without having to manage or destroy marine resources, such as sea cucumbers, coral or algae. (3) Avoids potential ciguatera problems related to dredging.	(1) May have higher frequency of maintenance and maintenance costs for treatment of water and cleaning the pool. (2) Discharge of pool waters may violate Guam water Quality Standards.
4. Create wider sand beaches.	Sand placement	(1) Wider beach for sunbathing, possibly extending beach to deeper areas for swimming. (2) Work confined to nearshore which has limited marine resources.	(1) Sand resources may not be available for initial construction and periodic nourishment. (2) The beach may be subject to a greater rate of erosion with encroachment into deeper water and exposure to storm waves. (3) Swimming confined to areas with deep water

TABLE 7 (contd)
EVALUATION OF METHODS TO IMPROVE SWIMMING

<u>Strategy</u>	<u>Methodology</u>	<u>Advantages</u>	<u>Disadvantages</u>
<u>Improve use in existing deep water areas</u>			
5. Swimming piers.	Pile pier construction for access to deeper water.	Reduces modification to the marine environment.	(1) Swimming confined to areas with deep water. (2) Potential visual intrusion. (3) Potential loss during typhoons.
6. Swimming platforms.	Raft construction and placement in deep water areas.	Reduces modification to the marine environment.	Same as item 5, above.
7. Shuttle people to swimming areas.	(1) Establish bus service. (2) Improve Gun Beach.	No modification to the marine environment. No modification to the marine environment.	(1) Service reliability must be insured. (2) Swimming confined to areas with deep water. (1) Distance from west end of bay is an inconvenience to prospective beach users.

BOATING

The shallow bay limits boating to the deep water areas in the middle and eastern part of the bay. Only one cruise boat, an outboard powered, catamaran, is presently operating in the bay, and the existing water depths can accommodate shallow draft boats activities within a portion of the bay without extensive modification of the bay. More extensive boating use of the bay will require extensive dredging to deepen the reef. Moderate boating use of the bay using the existing deep water areas and providing pier facilities and onshore storage of small boats may be more desirable than the construction of a larger facility in the bay. The development of commercial fishing, diving and sunset cruise activities which require larger vessels, might best be provided at an existing harbor facility, such as Agana Harbor, with a commuter or other commercial transportation provided from hotel to the harbor. The deep waters offshore from the reef fronting Tumon Bay can be used but the exposure to waves and swells limits its use to experienced boaters and swimmers. An evaluation of methods of improving boating in Tumon Bay is provided in Table 8.

RECREATION IMPROVEMENTS

Tumon Bay visitors are somewhat isolated to their hotels due to the relatively long and unattractive walks between hotels and shopping areas. Part of the problem may be related to San Vitores Road, which is unshaded and lacks rest facilities or scenic views of the bay, and to the lack of a reliable and frequent shuttle or bus service between the hotels, shopping centers and beaches. Hotels have independently provided their own sources of recreation and shopping opportunities to satisfy their guests and such action has contributed in part to the demand for individual services and facilities rather than use of combined facilities. In relation to improving Tumon Bay and its shoreside, some alternatives that were considered included the development of a shoreline promenade with shade, rest facilities, scenic views connecting hotels, beaches, shops and historic sites along the shoreline, and the establishment of a Tumon Bay shuttle bus service. The concepts of a fill causeway pile pier or trestle leading to the offshore island and the expansion of the island were developed to increase scenic and recreational diversity. Consideration should be given to using a pile mounted pier or trestle rather than a fill causeway to reduce or avoid any obstruction or interruption of water currents on the reef flat, and minimize modification of the bay as illustrated in Figure 11. Frequent and periodic cleaning of the beach to remove coral and other debris and algae can improve the recreational attractiveness of the beach without much effort. The development of snorkeling trails within existing areas with rich marine life insures immediate enjoyment of the bay without waiting for dredged areas to recolonize. An evaluation of methods is provided in Table 9.

TABLE 8
EVALUATION OF METHODS TO IMPROVE BOATING

<u>Strategy</u>	<u>Methodology</u>	<u>Advantages</u>	<u>Disadvantages</u>
1. Improve access and use of deep water areas outside the bay.	Dredging access channel to deepen.	Improves use of offshore waters without extensive modification of reef flat to provide increased recreational activities both, boating and swimming.	(1) Allow increase wave energy into the bay possibly causing a change in the shoreline and increasing erosion damage and loss. (2) Increases hazards to swimmers and waders due to collisions with boats, strong currents, and sudden deep holes. (3) Destroys natural habitat with resultant loss of species abundance and diversity. (4) Potential for ciguatera outbreaks.
	Mark the existing channel.	Eliminates any dredging on on reef and eliminates disadvantages associated with dredging.	Hazardous to poor swimmers.
2. Expand deep water area to accommodate water-skiing and sailing.	Dredging to deepen reef.	None	Same as Alternative 1, dredging, but more severe.

TABLE 8 (contd)
EVALUATION OF METHODS TO IMPROVE BOATING

<u>Strategy</u>	<u>Methodology</u>	<u>Advantages</u>	<u>Disadvantages</u>
3. Provide facilities to utilize existing deep water areas in the bay.	Construct piers, i.e., floating docks and dry storage facilities.	(1) Eliminates need to dredge. (2) Reduces modification to the marine environment. (3) Reduces potential impacts related to shoreline changes or erosion. (4) Avoids potential ciguatera problems related to dredging.	None
39 4. Provide major commercial boating facilities elsewhere.	Improve Agana Harbor for commercial boat traffic, such as charter fishing and diving and sunset cruises.	(1) Eliminates need to dredge in Tumon Bay. (2) Reduces marine environment modification in the bay. (3) Eliminates potential shoreline erosion problems in the bay. (4) Exposes fare customers to shops within Tamuning and Agana.	(1) Need to schedule buses to transport people to and from Agana Harbor. (2) Need to improve Agana Harbor to attract people, as well as accommodate boating activities.

TABLE 9
EVALUATION OF ALTERNATIVES TO IMPROVE RECREATION

<u>Strategy</u>	<u>Methodology</u>	<u>Advantages</u>	<u>Disadvantages</u>
1. Shoreside promenade.	Construction of a shore-side trail with shade, rest stops and scenic views.	Aesthetic improvements.	Landownership may create problems in development.
2. Increase visitor mobility in the bay area.	Shuttle bus system.	Aesthetic improvements.	Operation, ownership and funding of the service needs to be resolved.
3. Increase recreational diversion.	Create filled island and causeway.	Some aesthetic improvement.	(1) Reduced circulation may increase frequency of red tide occurrences. (2) Shoreline erosion may occur. (3) Loss of marine habitat may be extensive and conflicts with need to restore and enhance marine environment.
4. Clean up rubble from beach and nearshore area.	Mechanical sweeping	Aesthetic improvements and reduces need to modify the marine environment.	Operation, and funding of the activity.
5. Snorkeling trails.	Dredge trails in reef flat.	Possibly enhance marine life.	(1) Potential shoreline erosion. (2) Destroys existing marine life. Colonization may be slow, requiring other methods to enhance marine life.
	Use deep water at reef front.	Avoids modifications to marine environment.	(1) Lack of easy access or exit along reef margin. (2) Not recommended for novice swimmers. Exposure to wave hazards great.

ALGAE CONTROL

Enteromorpha clathrata, a green filamentous alga, appears to be the alga causing a nuisance to hotel operators and beach users. The alga grows in nearshore waters in a narrow band along the shoreline and thrives in areas of groundwater seepage protected from wave action and surge. When in full bloom, the alga does not fill the bay, but the green thalli darken the water near-shore, hide the bottom from sight, and tangle around the feet of waders, making the water unsightly and unpleasant for wading or swimming. Wave action and surge which break the thalli from the substrate, deposit the alga on the beach and in nearshore waters where it chokes the water and rots and smells, making the beach unpleasant to use. Contrary to belief that the alga decreases the presence of marine life, the alga creates a habitat for a myriad of invertebrates and is a principal food source for the rabbitfish.

Alternatives for alleviating the algal nuisance include controlling algal growth and distribution, and mechanically burying or clearing the algae from the beach. In either case, the reduction in algal standing crop during the seasonal run of rabbitfish may result in an early starvation of those juvenile rabbitfish settling in the bay, or a reduced abundance of rabbitfish in the bay. Methods of controlling the algal growth could include the use of aquatic herbicides, mechanical harvesting, increase grazing, or controlling environmental factors which regulate the distribution and abundance of algae, such as groundwater, wastewater seepage substrate stability and wave action. Methods of clearing the algae washed up on the beach involve mechanical clearing and disposing of the algae at a landfill or in a hole dug on the beach being careful not to use the same hole twice. In general, methods to control algal growth may be expensive and time consuming and may not be effective. Periodic cleaning may be the only reasonable solution without long-term environment modifications. An evaluation of the alternatives is provided in Table 10.

TABLE 10. EVALUATION OF ALGAE CONTROL METHODS

<u>Strategy</u>	<u>Methodology</u>	<u>Advantage</u>	<u>Disadvantage</u>
1. Chemical treatment to reduce or prevent growth.	Spray application of aquatic herbicide.	Ease of application.	(1) Herbicide may destroy non-target organisms and reduce long-term biological recovery. Overall effect may result in degradation of the marine environment. (2) Long-term accumulative effects are unknown. (3) Must be repeatedly applied. (4) Possibly offensive to beach users.
2. Reducing groundwater influx into the bay.	(1) Sheet piling barrier. (2) Underground concrete cap or wall. (3) Underground diversion.	(1) Nonpolluting. (2) Reduction of groundwater flow does not appear to have any effect on physiography of the reef. Needs further scientific verification.	(1) Porous nature of the substrate may permit water to flow around any barriers of caps. (2) May require application over a large area, not site specific. (3) Possible alteration of groundwater aquifer. (4) Technically difficult to accomplish.
3. Increase nearshore substrate instability to discourage algal attachment.	Increase sandy substrate by excavating nearshore and placing sand in excavated area. Increase wave action and energy along the shoreline (See item 4).	(1) Nonpolluting. (2) Excavation nearshore not expected to have significant effect on reef physiography. (3) Increases sandy area nearshore, replacing rocky habitat enhancing beach use.	(1) <u>Enteromorpha</u> can bind sand stabilizing the sand substrate and continue growing on the sand. (2) Excavation can release more groundwater which can enhance algal growth and make the water cold for swimmers. (3) May be a lack of adequate sand source on Guam. (4) Requires a disposal site for the excavated coralline material.

TABLE 10. EVALUATION OF ALGAE CONTROL METHODS (Contd)

<u>Strategy</u>	<u>Methodology</u>	<u>Advantage</u>	<u>Disadvantage</u>
4. Eliminate any waste-water discharge into the bay, if any.	Eliminate cesspool or septic tank seepage, if any, or any ground injection of wastewater	Reduces water pollution in bay without affecting reef physiography.	None.
5. Increase wave action and surge on the beach.	Deepen the reef by dredging.	Nonpolluting.	(1) Immediate reduction in marine life within dredged area with little or no biological recovery. (2) The alteration of currents on the reef has the potential for increased beach erosion and property loss or damage, especially during typhoons.
43 6. Mechanical harvesting.	(1) Hand cutting. (2) Mechanized cutting.	(1) Nonpolluting. (2) Nearshore work not expected to have significant effect on reef physiography.	(1) Labor intensive. (2) Disposal area needed. (3) Continuous maintenance requirement: Must be repeatedly harvested especially during height of the growing period. May have to be done several times a year.
7. Mechanical clearing of the beach.	Mechanized grading with a front-end loader or sand screener.	(1) Nonpolluting. (2) Nearshore work not expected to have significant effect on reef physiography.	(1) Labor intensive. (2) Disposal site needed. (3) Continuous maintenance needed: May need to be repeated more than once during a year.
(a) Land disposal site.	Sanitary landfill.	Removed from recreational area.	Shortens life of sanitary landfill.

TABLE 10. EVALUATION OF ALGAE CONTROL METHODS (Contd)

<u>Strategy</u>	<u>Methodology</u>	<u>Advantage</u>	<u>Disadvantage</u>
7. Mechanical clearing of the beach (contd).			
(b) Burial on the beach.	Clearing a trench or hole on the upper section beach and burying the algae.	Less equipment and movement of the algae. May reflect near natural decomposition of the algae.	(1) Buried algae may be reexposed by beach users digging in the sand or another storm which may erode the beach. (2) May increase oxygen demand reducing levels in the substrate affecting any infaunal organisms.
8. Increase grazing algal stock.	Stock reef with herbivorous fish.	(1) Increases fish stock in bay. (2) Uses natural grazing to reduce standing crop.	(1) Technology may not be available. (2) Fishing pressures may deplete stock faster than natural replacement. (3) Algal crop may be insufficient to support fish standing crop over long-term. Continuous fish replacement may be needed. (4) May increase feeding competition with seasonal rabbitfish runs.

SEA CUCUMBER CONTROL

Sea cucumbers form the greatest biomass on the shallow reef flat in Tumon Bay. Uninformed waders who step on a sea cucumber may have their feet and hands entangled in a sticky and annoying evisceration from the sea cucumber. The inconvenience of the situation is viewed by some as a nuisance requiring some corrective measures. Ways to reduce the conflict between man and the sea cucumber could include harvesting or relocating the sea cucumbers to keep their numbers down, altering their habitat to create unfavorable conditions which would reduce their numbers, deepening the reef to minimize wader contact with the sea cucumbers or creating displays at each hotel or information booklets to inform visitors of the reef fauna to be found on the reef and of potential hazards or annoyances associated with certain fauna. The education program may be the most reasonable solution since the other methods are untried and their effectiveness doubtful. Table 11 evaluates the alternatives.

STORM DRAINS

Five storm drain outlets are known to discharge into Tumon Bay. Only one has been the subject of a short-term scientific investigation, indicating the lack of information concerning the direct effects of stormwater discharge into Tumon Bay, although the nature of stormwater quality was investigated by the University of Guam Water Resources Research Center.

Storm water discharges are known to contribute to an intermittent and temporary increase in water turbidity nearshore and in nutrient levels in the bay. The introduction of storm water pollutants and heavy metals in Tumon Bay has not been studied and the long-term effects of the contaminants and intermittent discharges on the marine environment are not known. An increase in phosphorus levels may be linked with dinoflagellate blooms which produce a red tide condition in front of the Okura Hotel, but there may be a possibility that storm water contaminants lower the copper concentration in the water permitting the dinoflagellate blooms to occur. Storm water nutrient and salinity changes are measurable nearshore during periods of high rainfall, but long-term effects are masked by naturally high nitrogen concentrations due to ground water seepage, and by rapid mixing by water currents.

Storm drain structures on the beach are aesthetically displeasing and are also sources of trash and debris following periods of significant rainfall. Storm water trapped in the drainage system following periods of high rainfall become breeding places for mosquitos. Since bathymetric monitoring is not being done, the rate of infilling in the bay due to storm water borne sediments is not known. While sediment deltas have built up in front of the drainage structures, the deltas are winnowed away by the littoral currents, and do not create a significant discoloration on the beach because the calcium carbonate composition of the delta is similar in appearance to the beach. The beach is relatively stable, and no evidence exists to show that the storm drains presently contribute to the gradual erosion of the shoreline.

The continual construction of drainage systems that discharge into Tumon Bay will increase storm water nutrient, pollutant and sediment input associated with the existing storm drains. Alternative disposal methods contained in the "Guam Storm Drainage Manual" (in preparation by Corps and Guam Public Works) to reduce storm water runoff and to indirectly discharge storm water into the ocean need to be considered and possibly implemented in lieu of the construction of conventional drainage outlet systems. Some methods to

TABLE 11. EVALUATION OF SEA CUCUMBER CONTROL ALTERNATIVES

<u>Strategy</u>	<u>Methodology</u>	<u>Advantage</u>	<u>Disadvantage</u>
1. Harvesting.	(1) Hand harvesting with disposal or relocation. (2) Hand harvesting for commercial exploitation	(1) Does not destroy or alter reef physiography. (2) Potential for new industry in conjunction with harvesting elsewhere on Guam.	(1) Labor intensive, and must be performed repetitively. (2) Needs a disposal site. (3) Unknown effects on reef ecology with the reduction of sea cucumber biomass. (4) Only edible sea cucumbers are worth commercial harvesting. (5) Edible sea cucumber population may not be able to support long-term commercial harvesting. (6) No facilities to process edible sea cucumbers.
2. Relocation	Same as Alternative 1.	(1) Does not destroy or alter reef physiography. (2) Preserves individual organisms.	Need to find a relocation site. Labor intensive, must be performed repetitively.
3. Habitat alteration to create unfavorable growth conditions.	Unknown, possibly dredging. Needs further scientific study of species habitat requirements.	Reduce labor intensive-ness of first alternative.	(1) Possibly significant alteration of reef physiography and ecology with degradation of natural resources. (2) Potential for increased beach erosion and property damage or loss.

TABLE 11. EVALUATION OF SEA CUCUMBER CONTROL ALTERNATIVES (Contd)

<u>Strategy</u>	<u>Methodology</u>	<u>Advantage</u>	<u>Disadvantage</u>
4.	Dredging to deepen the reef.	(1) Reduce labor intensive-ness of first alternative. (2) Reduce wader contact with sea cucumbers.	(1) Significant alteration of reef physiography and ecology with degradation of marine resources. (2) May not reduce sea cucumber population; may probably create favorable conditions for some species of sea cucumber. (3) Reduce recreational diversity, limiting water contact recreation to swimmers eliminating waders.
5. Informative displays.	(1) Create displays or aquariums in hotels or visitor centers. (2) Create guide tour programs of the reef flat. (3) Create a booklet describing significant and rare marine life in Tumon Bay and potential hazards associated with other marine life.	(1) No environmental alterations. (2) Potential new service and employment opportunities.	Does not prevent wader contact with the sea cucumber.

consider in reducing storm water discharge into the bay include increasing roof top storage or rain catchment capacity and permeability of paved or covered areas, providing ponding areas and ground injection, diverting runoff flow to a sewerage treatment system designed to handle storm water runoff, and extending discharge lines further out into the bay where wave activity and currents can quickly disperse the storm water. These methods are aimed at reducing the rate of storm water flow into the bay, at providing ways of eliminating pollutants, trash and sediment associated with storm water runoff, and at increasing storm water dispersion. Of course, the control of mosquitos in water ponding areas will need to be considered during the planning. While storm drain outlets do not presently contribute to erosion of the shoreline, alterations of the littoral currents by other development in the bay may alter the shoreline processes and cause the outlet structures to act as groins along the beach.

DINOFLAGELLATE BLOOM - "RED TIDE"

The dinoflagellate bloom in Tumon Bay has not been studied. The dinoflagellate, Gymnodinium, is believed responsible for the red to yellow discoloration in the bay fronting the Okura Hotel that occurs every April. The bloom has not reached proportions that are toxic to fish and has not yet created a public health hazard. However, Gymnodinium has been responsible for red tides, which have caused paralytic shellfish poisoning, skin irritation and fish and shellfish kills in other areas of the world. At present, the occurrence of the seasonal bloom is merely a displeasing sight. Little can be done to prevent or terminate the bloom from occurring until the factors triggering the bloom are understood and the capability to predict an occurrence is improved. Consultation with world health organizations and universities monitoring red tide phenomenon will provide baseline data on which to base further scientific investigations to understand the Tumon Bay red tide phenomenon.

A suggestion to dredge a channel through the reef at the Okura Hotel in order to improve circulation and prevent future red tide blooms needs further study. The northern sector of the bay appears protected from wave energy by Amantes Point, suggesting that wave action may not be strong enough to drive currents on the reef flat during the April period when blooms normally occur. Secondly, increasing flushing may just move the dinoflagellate laden waters to another area in the bay. Dredging itself may stimulate a dinoflagellate bloom. The dinoflagellate cysts on the substrate may possibly be activated when disturbed by dredging. The reduction of phosphorus concentrations in storm water that may trigger a bloom may be difficult to achieve. The technique of removing phosphorus may also require storm water treatment system that may not be able to accommodate the quantity of storm water associated with tropical storms. Research on red tides suggests that bloom conditions occur when copper concentrations are lowered. Copper appears to have a toxic effect on the dinoflagellate and limits its population size.

CIGUATERA

The hypothesis concerning ciguatera outbreaks as a result of disturbance to the marine environment has not been scientifically verified. However, the risk of an outbreak is present due to the presence of the toxin-producing dinoflagellate in Guam. Preventative measures to monitor dredged sites for dinoflagellate blooms and to measure ciguatoxin concentrations in fish caught in the dredged area should be considered as a precaution in the interests of public health.

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Appendix A

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