Planning for Tumon Bay: the Shoreline and Seaward

File:
Army Corps -
~~Tumon Bay~~
see heading.

Planning for Tumon Bay: The Shoreline and Seaward

The Tumon Bay Planning Committee,
Department of Commerce, Government
of Guam

Technical Assistance by:

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Honolulu Engineer District
Building 230
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Purpose of this Report

The Corps was asked by Governor Calvo to assist in planning for Tumon Bay improvements. Subsequently, Mr. Jose Drego, Director, Department of Commerce, hosted a meeting to discuss problems at Tumon Bay. The Corps agreed ~~argued~~ to review the existing information and present it in a comprehensive report which would describe the environmental character of Tumon Bay.

The Corps also agreed ~~argued~~ to propose an assessment of impacts from various conceptual development options. These ranged from simple beach cleaning to major dredge and fill actions. The impact assessment we show here is based on existing information.

Next Step

The Corps would like to prepare a draft of this report for public review. The review should be coordinated by the Government of Guam and the Corps will participate in workshops.

The "Tumon Bay Planning" Committee, which has been meeting and providing the Corps with guidance, should establish some recommendations for Tumon Bay improvements and include them in the draft report for public review. These recommendations should be the product of our 4 December 1980 workshop.

SUMMARY OF ALTERNATIVE ANALYSIS

Environmental Impact: (-)=severe, (0)=moderate, (+)=minimal

Objective: Improve Marine Resources

Alternative	Environmental Impact	Further Environmenta Studies
Transplant marine life	+	No
Dredging	-	Yes

Objective: Improve Swimming

Alternative	Environmental Impact	Further Environmental Studies
Create large swimming area	-	Yes
Create several small swimming holes	0	Yes
Build onshore swimming pools	+	No
Create wide sand beaches	+	Yes
Build swimming piers	+	No
Build swimming platforms	+	No
Clean beach	+	No

Objective: Improve Boating

Alternative	Environmental Impact	Further Environmental Studies
Improve existing channel	-/0	Yes
Deepen area for waterskiing and sailing	-	Yes
Provide pier facilities in existing deepwater areas	+	No
Improve existing harbor at Agana	+	No

Objective: Control Algae

Alternative	Environmental Impact	Further Environmental Studies
Herbicides	-/0	Yes
Reduce ground water influx	-/0	Yes
Increase substrate instability	-/0	Yes
Increase wave energy	-	Yes
Mechanical Harvesting	0/+	No
Mechanical clearing the beach	+	No

Objective: Sea Cucumber Control

Alternative	Environmental Impact	Further Environmental Studies
Harvesting:		
Mechanical	-/0	Yes
Hand	0/-	Yes
Habitat Alteration	-	Yes
Deepen Reef	-	Yes
Informative Displays	+	No

Objective: Prevent "Red Tides"

Alternative	Environmental Impact	Further Environmental Studies
Unknown	Unknown	Yes

Objective: Storm Drain Control

See "Stormwater Drainage Manual"

PLANNING PROBLEMS AND CONCEPTS FOR TUMON BAY

Guam's tourist industry has worked to lure visitors to Guam and Tumon Bay with advertisements which implied sunshine, sandy tropical beaches and swimming areas, and a myriad of water-contact recreational opportunities. However, visitors find a narrow and sandy, but rocky beach, a shallow fringing reef which limits swimming and other water-contact recreation, and a lack of recreational diversity and facilities to support water-contact recreation. In order to create a more attractive tourist destination for the benefit of tourists and local residents, the Government of Guam embarked on a planning effort to increase recreational opportunities and diversity in the bay area by ~~improving~~ 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 was quick to respond to the need with the completion of the Pacific Islands Club which would provide for scuba diving gear, outrigger canoes and other floatation gear, paddle boats and hobie cats, and the construction of a amusement project, "Splashdown." A leisure sunset cruise catamaran, operated by outboard motor, has been in operation for some time.

The Government and local interests had concepts of dredging the bay to restore and enhance marine life, to widen the existing entrance channel for larger pleasure boats, to create snorkeling trails and to deepen or channelize the bay for swimming, water skiing and sailing. Specific recommendations included dredging one large or several small swimming holes, similar to those fronting Ypao Beach Park and the Guam Hilton, and dredging several channels, instead of one, for windsurfers, hobie cats and swimmers. Shoreline promenades or trails and a causeway to an enlarged offshore island were considered for passive recreational activities.

The Government has begun efforts to clean the beaches of trash, algae rafts and debris, but felt that problems dealing with stormwater, algae, sea cucumbers and red tide conditions needed to be solved in order to 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 discourgared swimmers from using the water, and rafts of algae accumulated along the shoreline created a smelly mess. Sea cucumbers were so numerous on the reef flat that waders stepping on them had their feet enmeshed in the sticky and annoying evisceration. Under certain conditions, a localized red tide condition occured off the Okura Hotel discouraging swimmers and detracting from the beauty of the bay.

IMPACT ANALYSIS OF PLANNING CONCEPTS
DREDGING AND FILLING ACTIVITIES

Dredging and filling in the marine environment are usually associated with more negative effects than beneficial ones. Impacts usually include:

a. Reduction in habitat diversity due to modification of bottom bathymetry and substrate.

b. Reduction in the abundance and diversity of marine organisms.

c. Alteration of nearshore currents and wave energy on the reef flat.

d. Continual effects of turbidity resulting from creating a fine, silty bottom or erodible fill and the erosion of the dredged material back into the water.

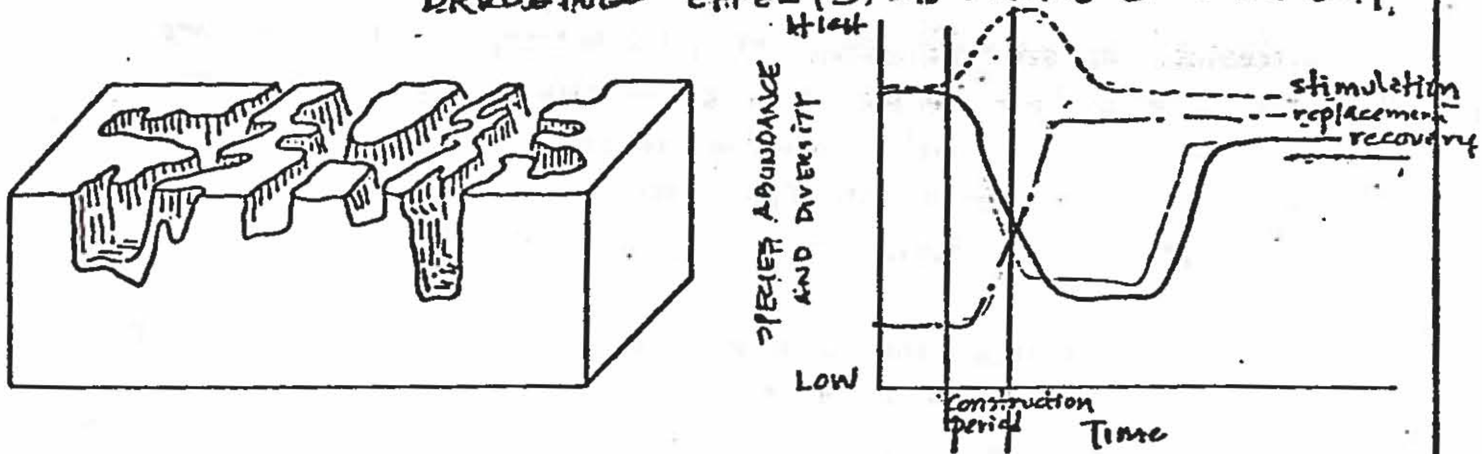
Dredging usually generates fine sediment by either resuspending material already present on the reef or grinding the limestone material comprising the reef flat. The sediment material usually settles in the dredged areas creating a slity bottom, and the aggregate not picked up by the dredge combine to make an unstable substrate which is not readily colonized by marine organisms. The sediment generated by dredging usually increases abrasion and scour damage to marine organisms especially where water current are strong. Where water currents are weak, fine sediments remain in the water column for long periods of time, effectively blocking the penetration of light through the water column creating a stress for photosynthetic benthic organisms, and increase sedimentation which can smother other benthic organisms. The erosion of dredged material back into the water aggravates turbidity and sedimentation stresses. The sedimentary material at the bottom of dredged areas are easily resuspended by increased wave or surge activity within the dredged area, contributing to continual or long-term turbidity stress. Dredging may also be a factor which can trigger dinoflagellate blooms and which can attract fish which will feed on organisms exposed and stirred up by the dredge.

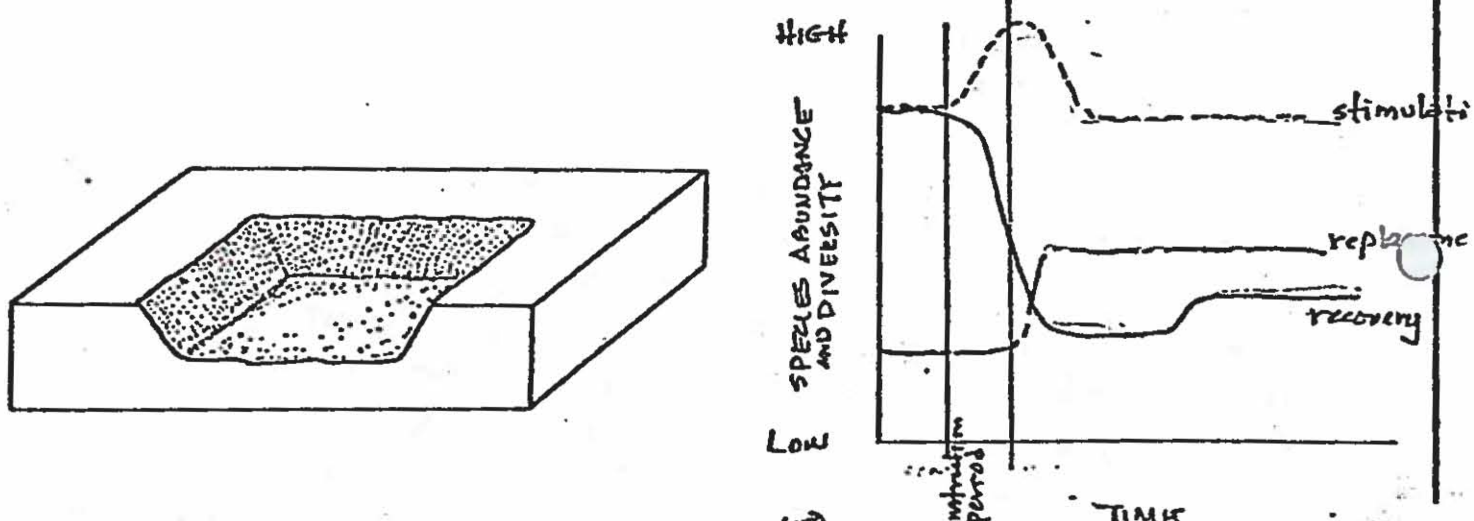
Existing data indicate that Tumon Bay's shallow reef flat limits biological productivity and species diversity in comparison to the reef margin and reef front, but that the reef provides excellent protection for the beaches from wave and surge activity. Dredging the reef flat could have some beneficial effects under certain conditions.

Deepening the reef flat allows more water to cover the reef surface, reducing exposure and temperature stresses on marine organisms, and providing an opportunity for more organisms to survive the reef flat. However, the act of dredging the reef initially destroys the existing biological community and the extent of biological recovery is dependent upon a number of factors, including water depth, water currents, bottom irregularity, species habitat preference, substrate composition and vertical relief. In general, recovery is enhanced when the amount of irregular, hard substrate and vertical relief are maximized and water currents are allowed to flush the dredged area. By comparison, dredged channels and basins have uniform surfaces and large areas of loose sedimentary material, such as aggregate and soft, silty mud. Loose and silty material provide unstable substrates that are not readily colonized by a large diversity of organisms, and, in many cases, provide for a replacement of organisms adapted for life in soft sediment environments. Providing a habitat that attracts marine organisms does not guarantee that recovery will create a habitat more diverse than the one destroyed. Modification of the environment tends to favor the recovery or colonization of one species over another, and may not select for the desired organism. 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 diverse minimizes initial destructive effects on the environment. Recovery of coral communities may take as long as 20 to 30 years to attain species abundance and diversity prior to construction. Transplanting large size coral colonies in the dredge area may help to reduce the recovery time.

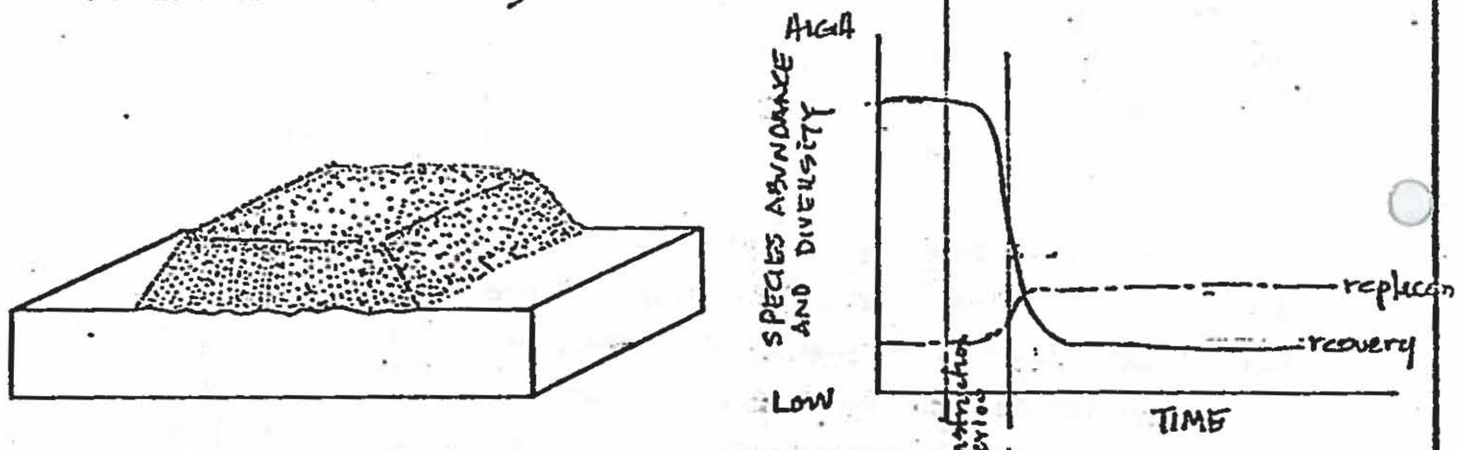
CONCEPTUAL RESPONSE OF MARINE ENVIRONMENT TO

DREDGING EFFECTS ON MARINE ENVIRONMENT.

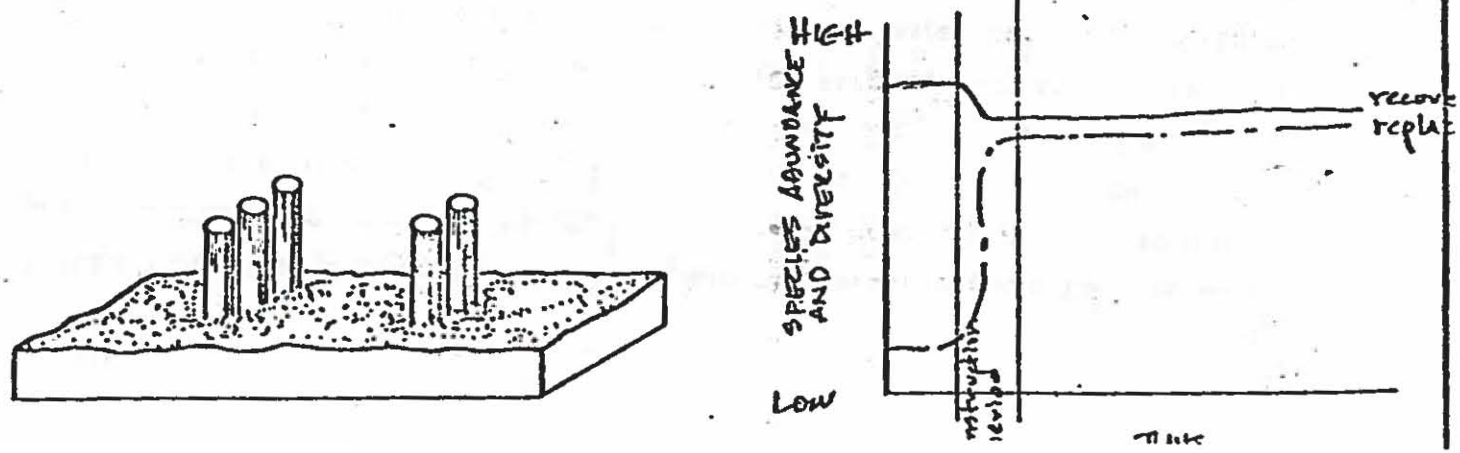




FILLING ~~AND POTENTIAL~~ EFFECTS ON MARINE ENVIRONMENT



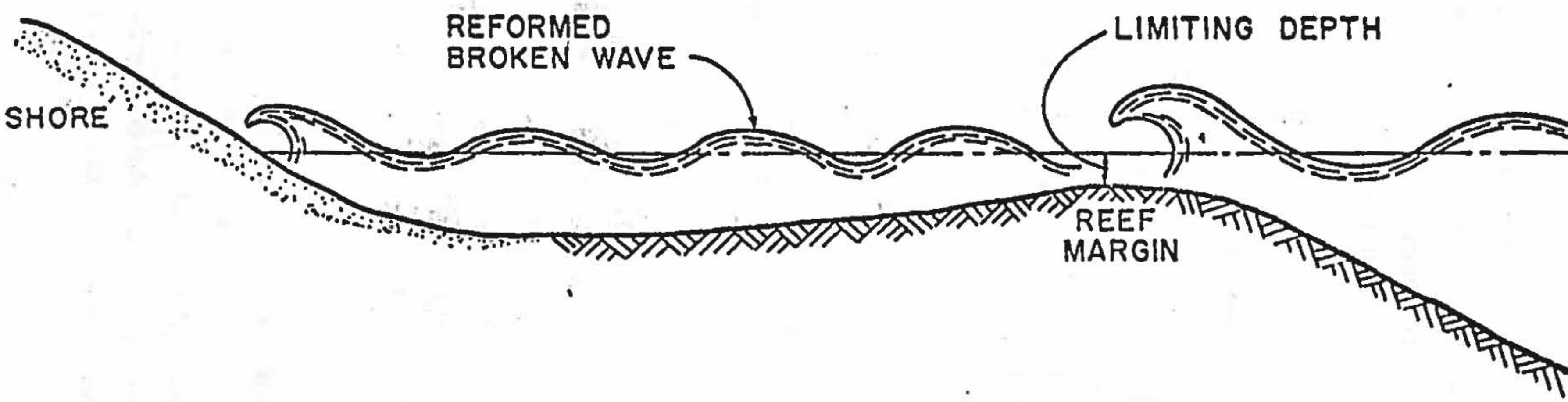
PILES AND POTENTIAL EFFECTS ON MARINE ENVIRONMENT

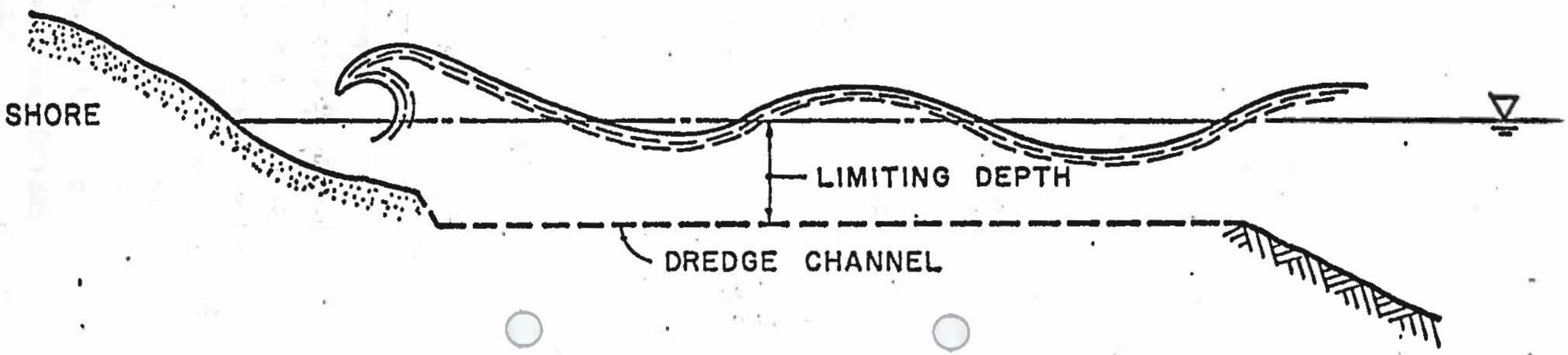


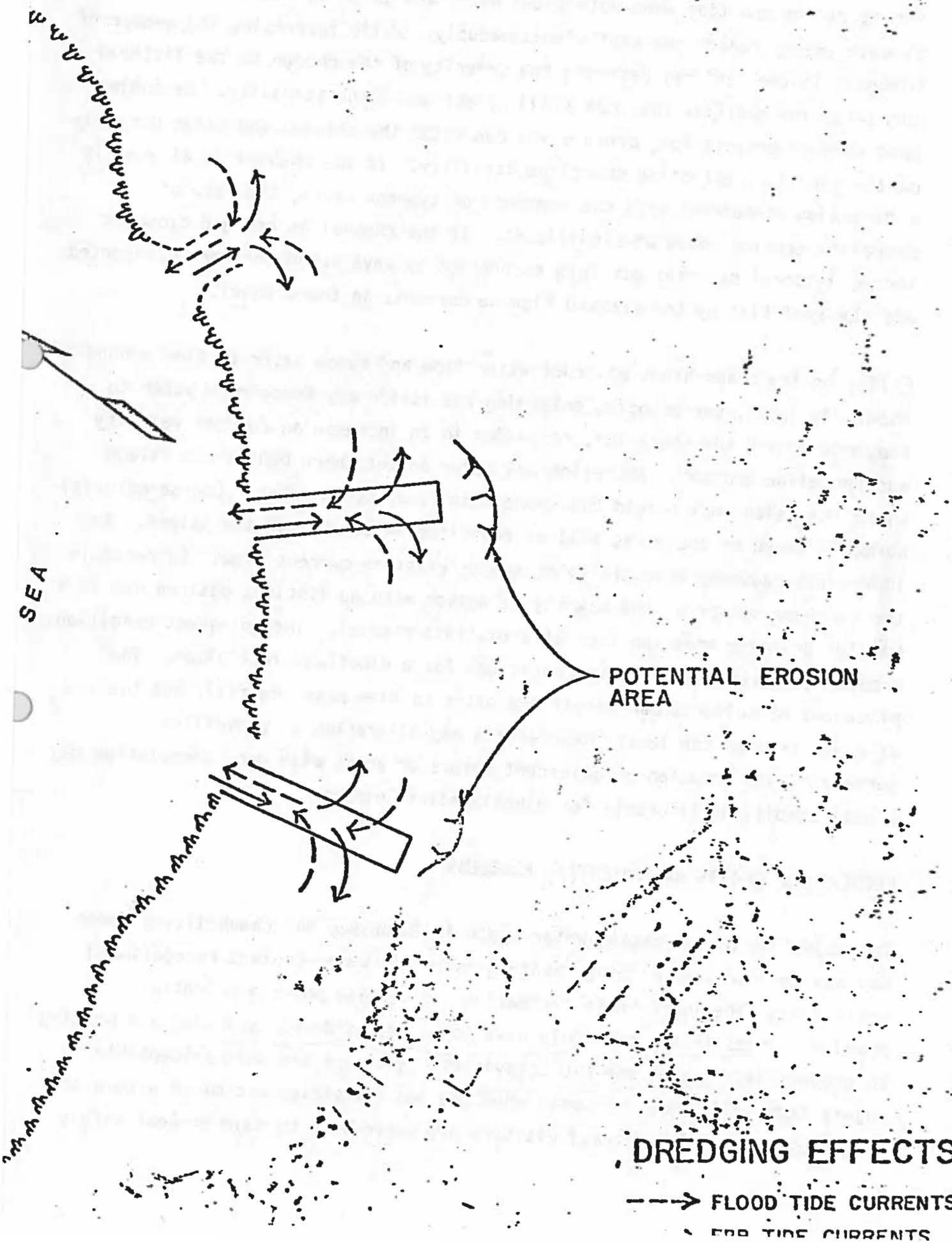
Filling, on the other hand, eliminates any further use of the area by marine organisms. While some replacement is anticipated at the toe of the fill, the replacement will not, in most cases, be as diverse as the habitat and community destroyed. The use of pile-supported structures significantly reduces the amount of damage and preserves the habitat and community. Shading, if significant, can reduce the usefulness of the pile-supported structure since organisms on the reef flat may not be adapted to shaded conditions.

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 dissipator that prevents large waves or strong surge from impinging on the shoreline, except under extreme meterological or hydrological conditions such as those associated with a typhoon. In general, wave height on the reef flat is limited by water depth. Wave energy is proportional to the square of the wave height. Thus, a slight increase in water depth can result in a significant increase in wave energy on the reef flat. The nature of reformed waves on the reef flat cannot be easily expressed and is dependent upon a variety of oceanographic factors such as wave length, water depth and bottom configuration. However, the more shallow reef flat preserved the greater the loss of wave energy in the reformed wave. An increase in wave or surge energy may also be associated with a change of wave approach to the beach and an increase in the amount of water transported onto the reef possibly resulting in a change in littoral currents in the bay. The combination of the two factors has the potential for increasing the frequency of shoreline change which may now be related only to periods of typhoons. At present, the Tumon Bay shoreline appears stable and some persons have built close to the shoreline. Any increase in shoreline change could result in property loss or damage, as well as, costs to protect the property from shoreline erosion.

Similarly, channelizing the reef could also result in increased shoreline erosion. On shallow reef flats, the flow of water off the reef may be restricted by bathymetry and a lack of a defined channel to the ocean. A channel may decrease flow resistance or permit a greater volume of water to flow off the reef, resulting in either greater littoral current velocities or


REFORMED
BROKEN WAVE
LIMITING DEPTH
SHORE
REEF
MARGIN


SHORE
LIMITING DEPTH
DREDGE CHANNEL

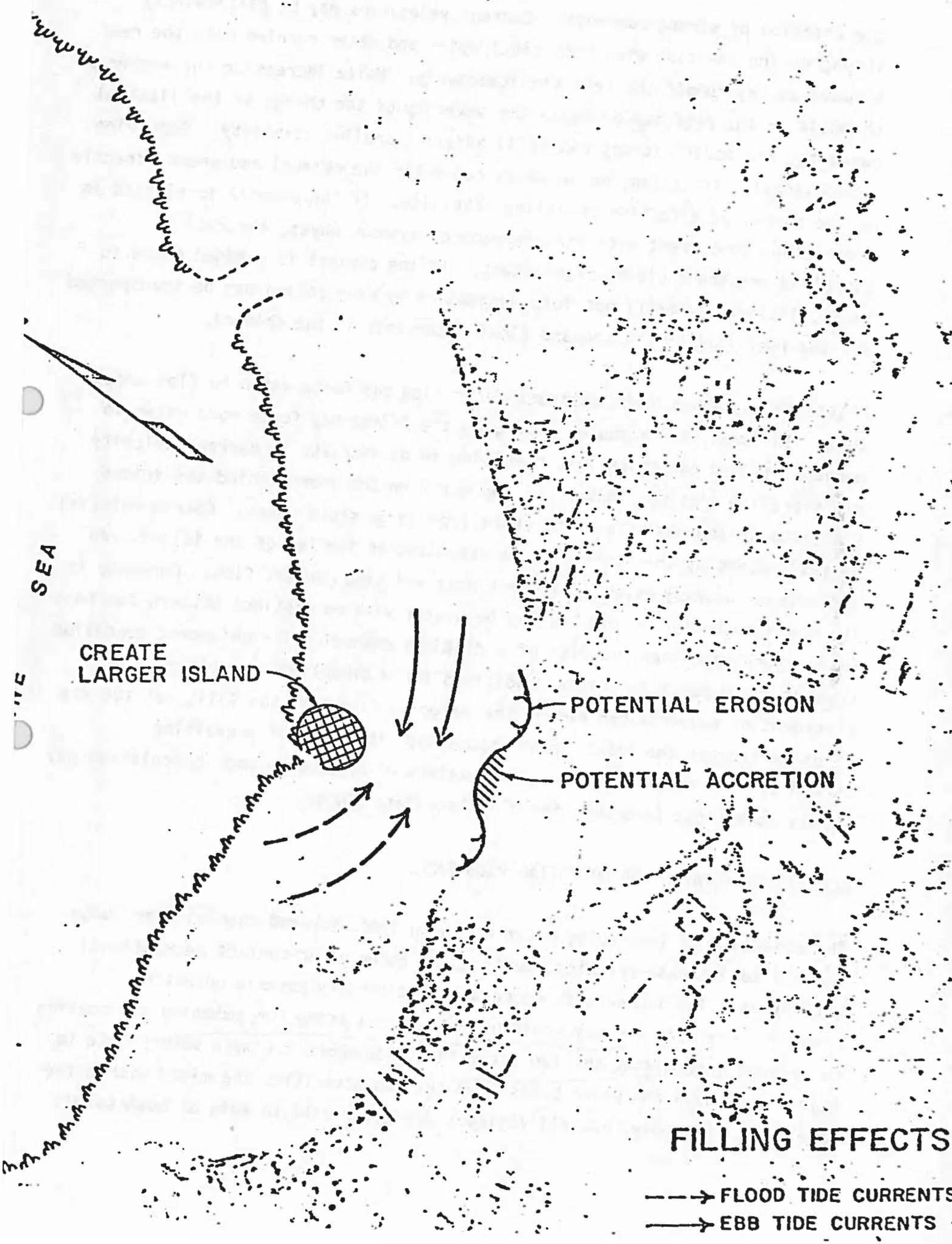

SEA
POTENTIAL EROSION AREA
DREDGING EFFECTS
FLOOD TIDE CURRENTS
EBB TIDE CURRENTS

the creation of strong currents. Current velocities may be particularly strong during ebb tide when both tidal water and water carried onto the reef by wave energy runoff the reef simultaneously. While increasing the number of channels in the reef may decrease the severity of the change to the littoral currents, the modifications can still affect shoreline stability. Depending upon channel orientation, ocean waves can enter the channel and break directly on the shoreline affecting shoreline stability. If the channel is aligned in a direction concurrent with the approach of typhoon waves, 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.

Fills, on the other hand, obstruct water flow and force water to flow around them. In Tumon, for example, enlarging the island may force more water to converge toward the shoreline, resulting in an increase in current velocity and shoreline erosion. Accretion may occur on the shore behind the island since the island may shield the shore from large storm waves. Coarse material normally moved by the waves will be deposited in the lee of the island. An impervious causeway essentially obstructs existing current flow. Currents in the southern sector of the bay may be weaker with no distinct pattern due to a smaller drainage area and lack of a distinct channel. The quiescent condition created could possibly create conditions for a dinoflagellate bloom. The placement of culverts can permit the water to flow pass the fill, but the use of piles creates the least interference and alteration of prevailing currents. The creation of quiescent waters or areas with poor circulation may create conditions favorable for dinoflagellate blooms.

RECREATION IMPACTS AND POTENTIAL PROBLEMS

The objective of increasing water depth in Tumon Bay and channelizing Tumon Bay was to increase swimming, boating and other water-contact recreational activities. The increase in recreational diversity poses a potential problem. Areas in the bay would have to be set aside for swimming and boating to prevent intermixing the two activities. Swimmers are more susceptible to injury from sail and power boats when the two activities are mixed within the same area. Secondly, not all visitors are water-wise to swim or boat safely



FILLING EFFECTS

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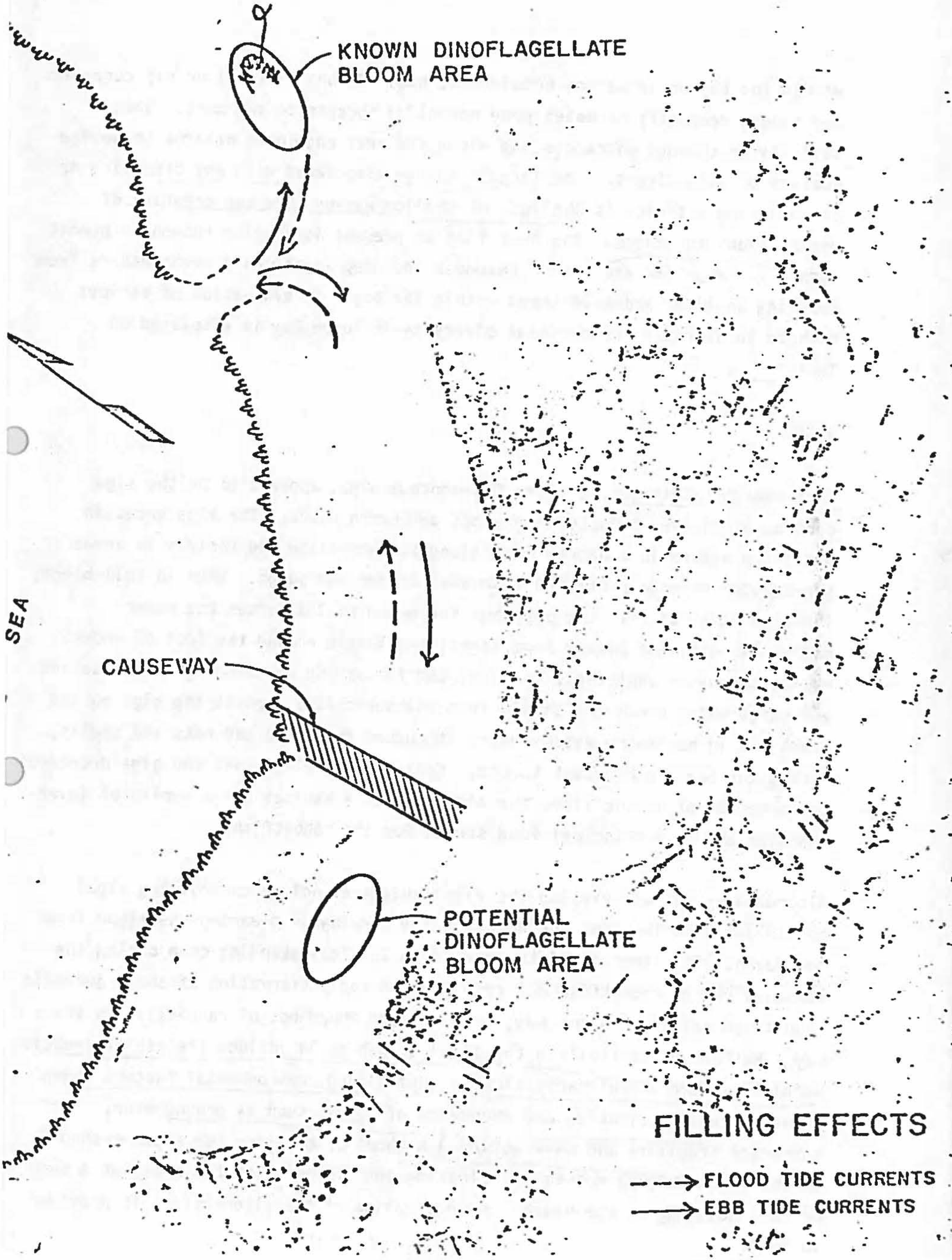

KNOWN DINOFLAGELLATE
BLOOM AREA
SEA
CAUSEWAY
POTENTIAL
DINOFLAGELLATE
BLOOM AREA
FILLING EFFECTS
FLOOD TIDE CURRENTS
EBB TIDE CURRENTS

within the bay or in waters outside the bay. Strong littoral or rip currents and sudden drop-offs or holes pose potential threats to swimmers. Wave activity in channel entrances and along the reef edge pose hazards to novice boaters or skin divers. The largest change associated with any deepening or channelizing activity is the loss of shallow wading area and creation of obstructions to waders. The reef flat at present is shallow enough to permit waders to range far and wide. Channels and deep areas can prevent waders from reaching shallow, wadeable areas within the bay. An evaluation of various methods to increase recreational diversity in Tumon Bay is displayed on Table ____.

ALGAE

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 nearshore, hide the bottom from sight, and tangle around the feet of waders, making the water unpleasant to sight and 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 or controlling environmental factors which regulate the distribution and abundance of algae, such as groundwater, 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 dump or in a hole dug on the beach. An evaluation of the alternatives is provided in Table .

TABLE ___.

EVALUATION OF ALTERNATIVES TO IMPROVE MARINE RESOURCES AND THE UTILIZATION OF THE RESOURCES

Alternative	Methodology	Benefits	Problem areas
Improve marine life.			
1. Increase species abundances and diversity.	Transplant benthic organisms onto the reef flat.	(1) Reduces extent of modification on the reef flat.	Shallow waters limit the extent of habitat area which may be suitable for transplanting activities.
		(2) Maintains reef flat for development of wading trails.	(1) May be difficult to control dredging.
2. Increase habitat diversity.	Dredging to deepen reef flat and increase the amount of vertical relief.	(1) Increases water depth to reduce exposure and temperature stress to marine organisms.	(2) Dredging by its nature destroys much of the marine life. Natural recolonization will be slow.
		(2) Provides deep swimming areas for snorkelers.	(3) Water currents through the area must be maintained to provide flushing. Hard
			(4) The amount of rubble, sand and silt substrate must be minimized.
			(5) The deepened area may allow increased wave energy on the reef and possibly cause shoreline modifications which could cause property damage and loss.
			(6) Potential increase in hazards to non-swimmming waders who may fall into deep holes.
			(7) Loss of wading and reef foraging area and the deep areas may obstruct movement on the reef flat.

TABLE ___.
EVALUATION OF ALTERNATIVES TO IMPROVE SWIMMING

Alternative	Methodology	Benefits	Problem areas
1. Create large swimming area	Dredging to deepen reef flat.	May have low maintenance costs requiring periodic dredging.	(1) May cause shoreline changes that could result in property damages and losses, and reduction in beach width. Reformed wave energy may still be great enough to create breaking waves on the beach. (2) Requires disposal of dredged material. (3) Most likely results in significant loss of marine resources on reef flat with low recovery rates.
2. Create several small swimming holes	Dredging to deepen reef flat.	(1) May have low maintenance costs requiring periodic dredging. (2) Dredging can be concentrated near shore in sandy or rubble areas with low marine abundance or diversity. (3) Preserves more of the shallow reef flat as a wave dissipator.	(1) May cause shoreline changes that could result in property damage and losses, and reduction in beach width. The effect may b less than Alternative 1. (2) Requires disposal of dredged material.
3. Build on shore swimming pools near	On shore construction of swimming pools.	(1) Eliminates modification to marine environment. Water can be obtained from wells. (2) Allows swimming in sandy beach setting without having to consider manage or destroy marine resources, such as sea cucumbers, coral or algae.	May have higher frequency of mair tenance and maintenance costs for treatment of water and cleaning the pool.

TABLE ___ (Cont'd).
EVALUATION OF ALTERNATIVES TO IMPROVE SWIMMING

Alternative	Methodology	Benefits	Problem areas
4. Create wider sand beaches.	Sand placement	Wider beach width for sun-bathing, possibly extending beach to deeper areas for swimming.	(1) Does not solve problem of lack of water depth for swimming (2) Sand resources do not seem to be available for initial construction and periodic nourishment. (3) The widened beach may be subject to greater rate of erosion with encroachment into deeper water and exposure to storm waves.
5. Swimming piers, for access to deeper water.	Pier construction using piles.	Reduces modification to the marine environment.	Swimming confined to areas with deep water.
6. Swimming platforms	Raft construction and placement	Reduces modification to the marine environment.	Swimming confined to areas with deep water.
7. Clean up rubble from beach and near shore.	Mechanical sweeping of the beach and near shore area.	Reduces modification to the marine environment.	Swimming confined to areas with deep water.

TABLE ___.

EVALUATION OF ALTERNATIVES TO IMPROVE BOATERS

Alternative	Methodology	Benefits	Problem areas
1. Improve boat access through reef	Dredging access channel	None	(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 and strong current and sudden deep holes. (3) Reduces habitat diversity with resultant loss of species abundance and diversity.
2. Expand deep water area to accomodate water skiing and sailing.	Dredging to deepen reef flat.	None	Same as Alternative 1.
3. Provide facilities to utilize existing deep water areas in the bay.	Construct facilities on the shoreline.	(1) Eliminates need to dredge. (2) Reduces marine environment modification. (3) Reduces potential impacts related shoreline changes or erosion.	None
4. Provide major 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.	Need to create intrastructure to transport people to and from Aga Harbor.

TABLE ___. EVALUATION OF ALGAE CONTROL ALTERNATIVES

Alternative	Methodology	Advantage	Disadvantage
1. Aquatic herbicide.	Spray application.	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.
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 large area, not site specific.
3. Increase substrate instability.	Increase sandy substrate by excavating nearshore and placing sand in excavated area.	(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.

Alternative	Methodology	Advantage	Disadvantage
4. Increase wave action and surge on the beach.	Deepen the reef by dredging.	Nonpolluting.	(1) Immediate reduction in mari life within dredged area with little or no biological recove (2) Alteration of currents on reef with potential for increa beach erosion and property los or damage, especially during typhoons.
5. Mechanical harvesting.	(1) Hand cutting. (2) Mechanized cutting.	(1) Nonpolluting. (2) Nearshore work is not expected to have significant effect on reef physiography.	(1) Labor intensive. (2) Needs a disposal area. (3) Must be repeatedly harvest especially during height of th growing period. May have to b done several times a year.
6. 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) Needs a disposal site. (3) May need to be repeated more than once during a year.
(a) Land disposal site.	Sanitary landfill.	Removed from recreational area.	insignificant ? Shortens life of sanitary landfill.
(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.	Algae may be reexposed by beac users digging in the sand or another storm which may erode beach.

SEA CUCUMBERS

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 affair 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 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 create displays at each hotel to inform visitors of the reef fauna to be found on the reef and potential hazards or annoyances associated with certain fauna. Table ____ evaluates the alternatives.

TABLE ___. EVALUATION OF SEA CUCUMBER CONTROL ALTERNATIVES

Alternative	Methodology	Advantage	Disadvantage
1. Harvesting.	(1) Hand harvesting with disposal.	(1) Does not destroy or alter reef physiography.	(1) Labor intensive, and must b done repetitively.
	(2) Hand harvesting for commercial exploitation	(2) Potential for new industry.	(2) Needs a disposal site. ?
			(3) Unknown effects on reef ecology with the reduction of s cucumber biomass. — [illegible]
			(4) Only edible sea cucumbers a 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. yes! Can be done easily
2. Habitat alteration to create unfavorable growth conditions.	Unknown, possibly dredging. Needs further scientific study of species habitat requirements.	Reduce labor intensiveness of first alternative.	(1) Possibly significant alteration of reef physiography and ecology with degradation of natural resources.
			(2) Potential for increased bea erosion and property damage or loss.

Alternative	Methodology	Advantage	Disadvantage
3. Deepen the reef.	Dredging.	(1) Reduce labor intensiveness of first alternative. (2) Reduce wader contact with sea cucumbers.	(1) Significant alteration of physiography and ecology with degradation of marine resourc (2) May not reduce sea cucumbe population; may probably creat favorable conditions for some species. (3) Reduce recreational divers limiting water contact recreat to swimmers eliminating waders
4. Informative displays.	(1) Create displays or aquariums in hotels or visitor centers. (2) Create guide tour programs of the reef flat.	(1) No environmental alterations. (2) Potential new service and employment opportunities.	Does not prevent wader contact with the sea cucumber.

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 drain structures on the beach are aesthetically displeasing and are also sources of trash and debris on the beach following periods of significant rainfall. Stormwater discharges are known to contribute to a temporary increase in water turbidity nearshore and to introduce nutrients and pollutants from the drainage area into the aquatic environment. In Tumon Bay, the increased levels of phosphorus may be linked with dinoflagellate blooms that produce a red tide condition in front of the Okura Hotel. Nutrient and salinity effects are concentrated nearshore, but masked by the input of freshwater and nitrogen from groundwater seepage. Since bathymetric monitoring is not being done, the rate of infilling in the bay due to stormwater sediments is not known. While sediment deltas have built up in front of the drainage structures, the deltas are willowed away by the littoral currents, and do not create a significant discoloration on the beach because of the calcium carbonate nature of the material in the delta. The beach is relatively stable, thus there is no evidence that the storm drains presently contribute to the gradual erosion of the shoreline. Stormwater trapped in the drainage system following periods of high rainfall become breeding places for mosquitos.

The continual construction of drainage systems that discharge into Tumon Bay will increase the problems associated with the existing storm drains. Thus, we can reference the "Storm Drainage Manual" which discusses those methods to reduce stormwater runoff and to indirectly discharge stormwater into the ocean need to be considered and possibly implemented instead of the construction of conventional drainage outlet systems. 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 that the outlet structures may act as groins along the beach or be damaged by shoreline erosion.

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 and occurs every April. The bloom has not reached proportions that are toxic to fish and has not created a public health hazard. However, Gymnodinium has been responsible for red tides, 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 eliminate 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 create a dinoflagellate bloom. The dinoflagellate cysts in the substrate may be activated by suspension in the water together with organic material from the substrate. The reduction of phosphorus concentrations in stormwater may be a possibility, but may also be difficult to achieve due to the porous nature of the ground. The technique of removing phosphorus may also require stormwater treatment system that may not be able to accommodate the quantity of stormwater associated with tropical storms. Some 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 ~~their~~ its population size.

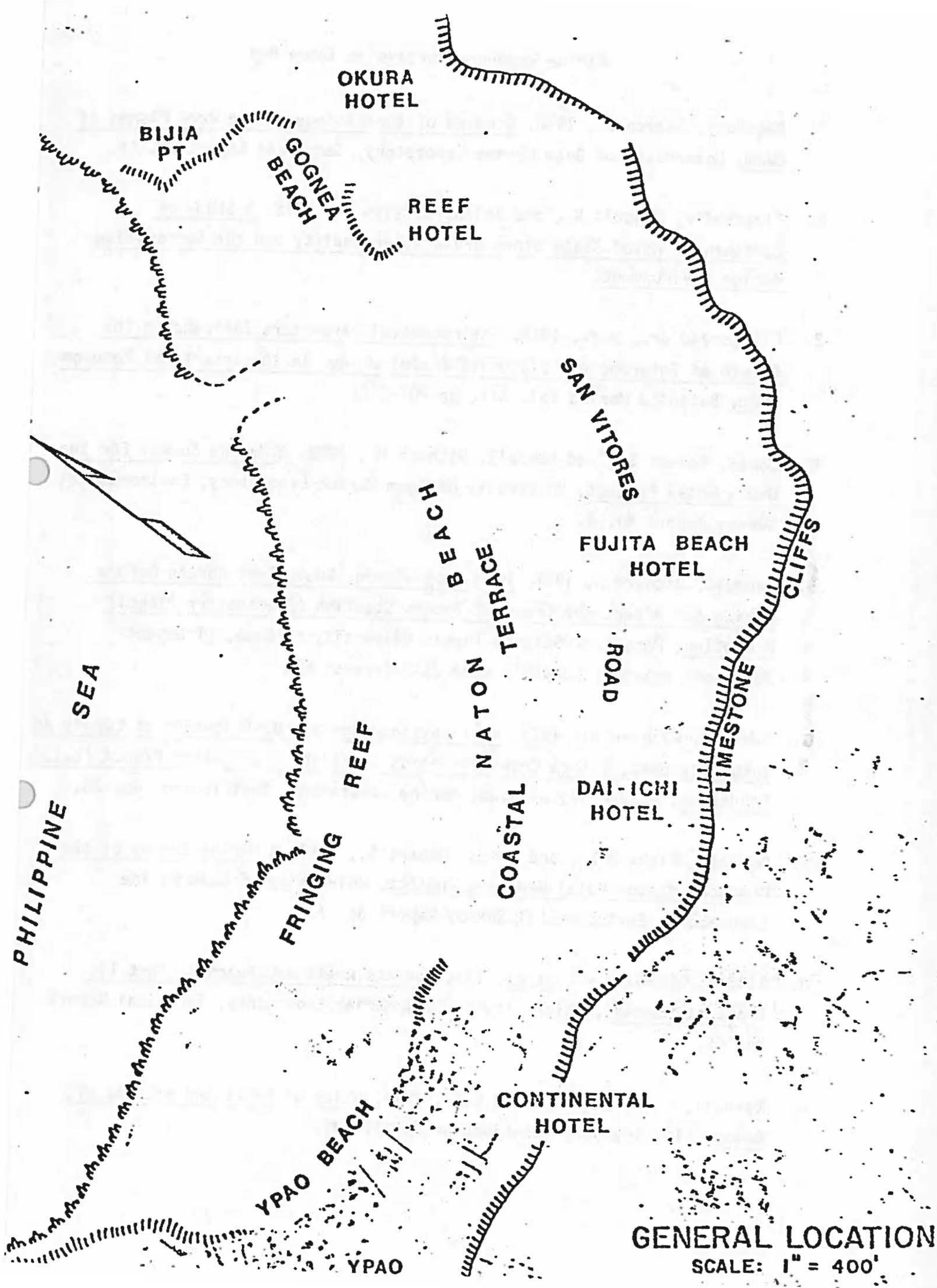
ANALYSIS OF EXISTING ENVIRONMENTAL CONDITIONS

Tumon Bay is located (Figure ___) between Ypao Point and Gognga 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 attaining an elevation of 15-30 feet at Ypao Point and rise 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 which is 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 natural geological, climatic, and oceanographic conditions influence the bay's hydrology, water quality and biologic resources. Recent 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. Based on these studies, the reef is characterized by several zones (Figure 2) which will be used for the purposes of discussing and describing the existing conditions and environmental impacts of proposed actions. Besides the resort and urban development along the shoreline and in the coastal terrace, 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.

WATER CURRENTS

Based on the results of various University of Guam environmental studies, wate 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 studies; thus, the information on water currents does not reflect a continuous survey period, which is necessary to detect seasonal variations. In particular, the bay's hydrologic response under typhoon conditions are not understood. 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 surges or changes in wind direction. Bathymetric data for the bay are lacking, except for a detailed



GENERAL LOCATION
SCALE: 1" = 400'

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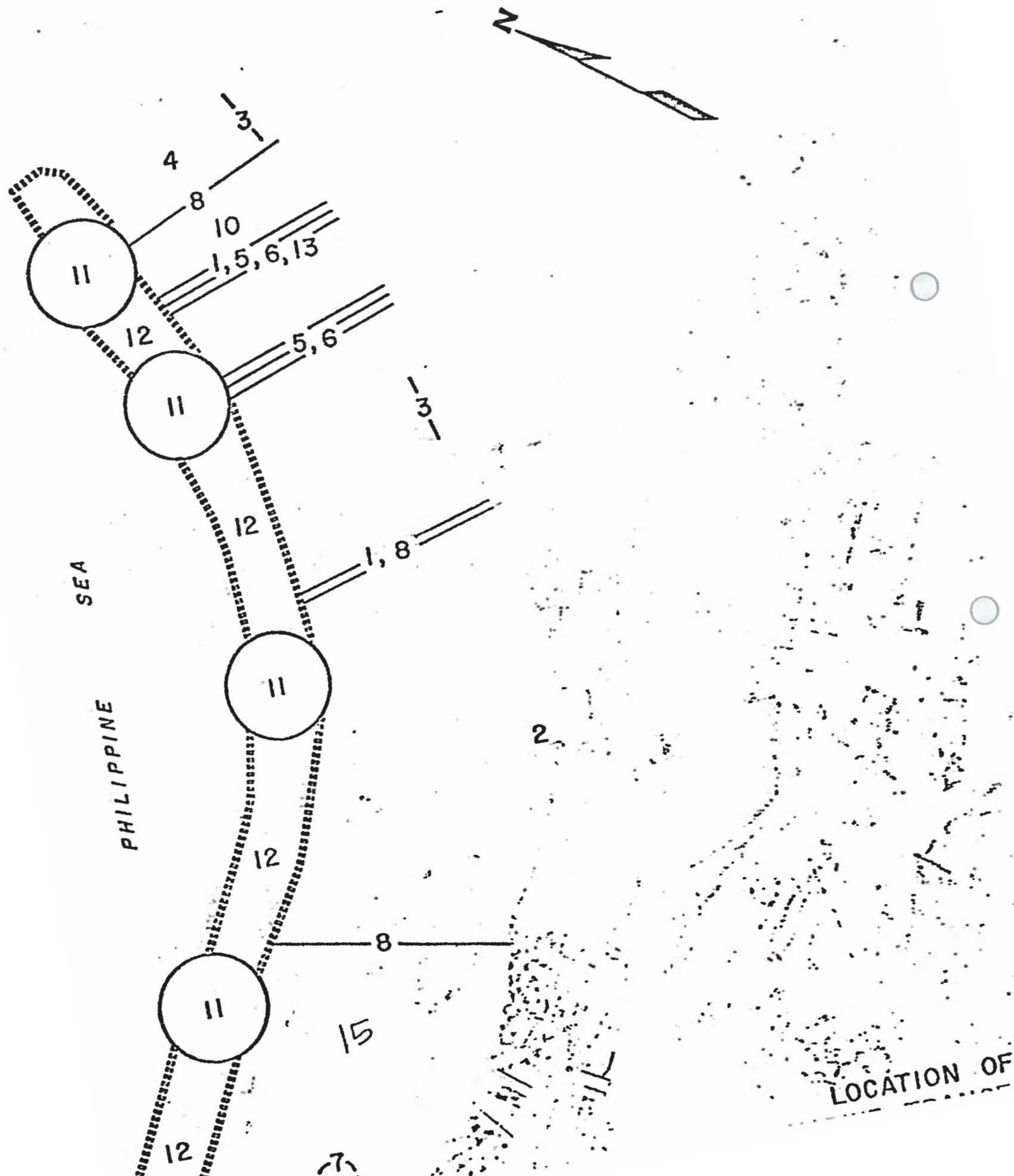

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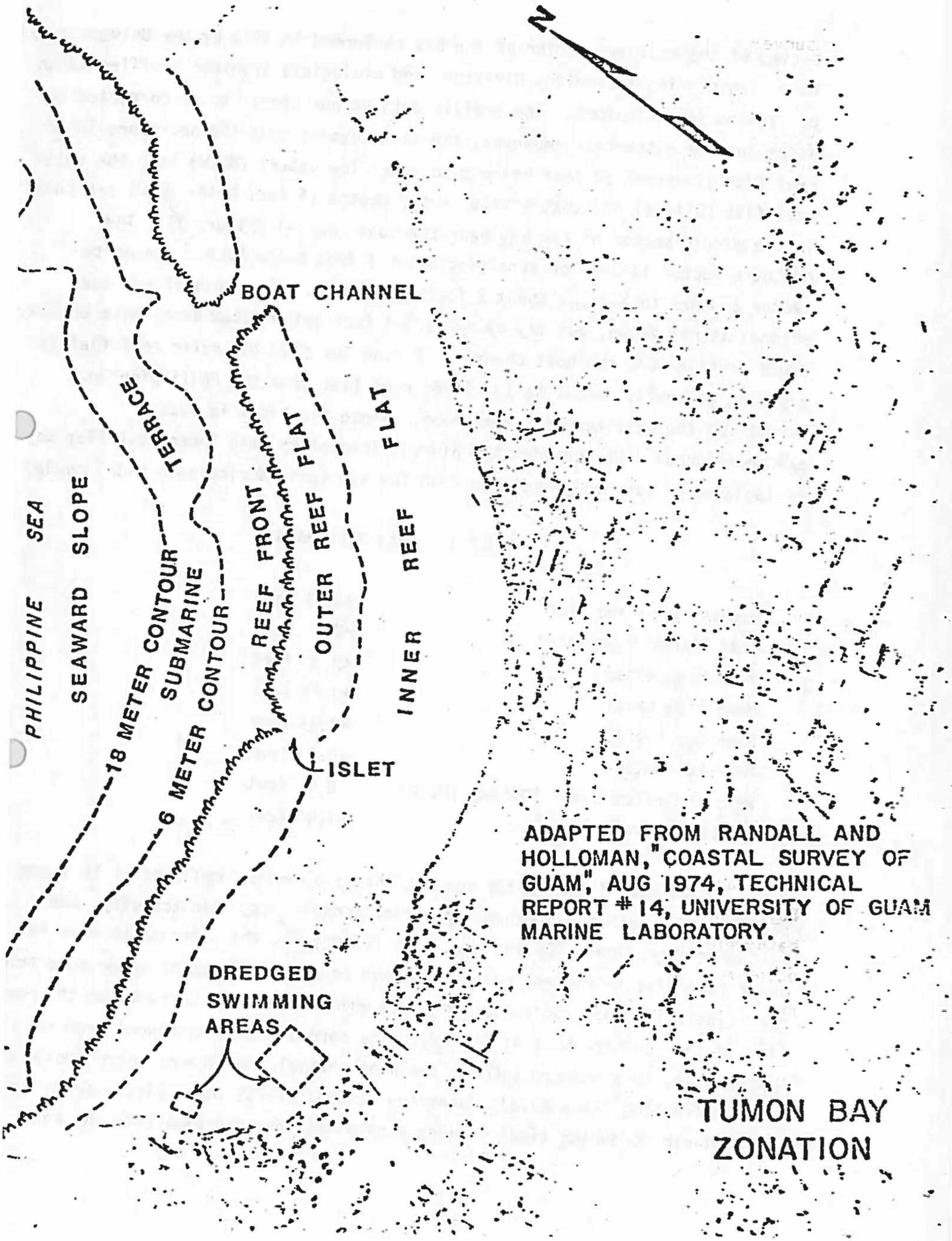


ADAPTED FROM RANDALL AND HOLLOMAN, "COASTAL SURVEY OF GUAM", AUG 1974, TECHNICAL REPORT #14, UNIVERSITY OF GUAM MARINE LABORATORY.

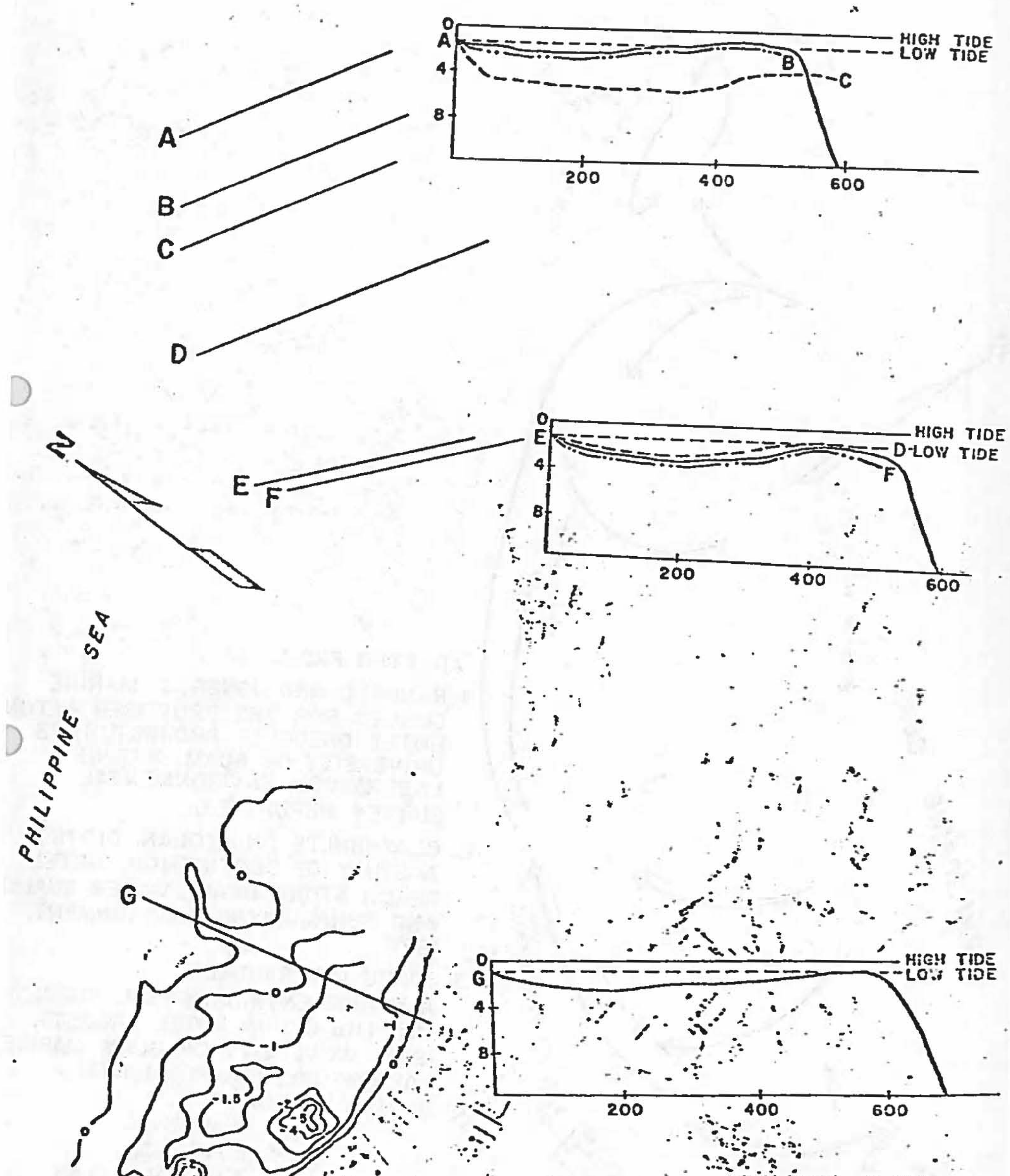
TUMON BAY ZONATION

survey of the southern sector of the bay performed in 1975 by the University of Guam, Engineering Technology Division, and biological transect profiles taken by various investigators. The profile data do not appear to be corrected to datum in some instances. However, the data suggest that the nearshore inner reef flat is deeper (2 feet below mean lower low water) (MLLW) than the outer reef flat (0 feet) and that greater water depths (5 feet below MLLW) are found in the middle sector of the bay near the boat channel (Figure 3). The southern sector is shallow averaging about 1 foot below MLLW. The north sector appears to average about 2 feet below MLLW. The depth of the boat channel is not known, but may be about 3-4 feet below datum 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 with considerable diurnal inequality, the inner reef flat may be isolated or partially isolated from the sea twice during each tidal cycle.

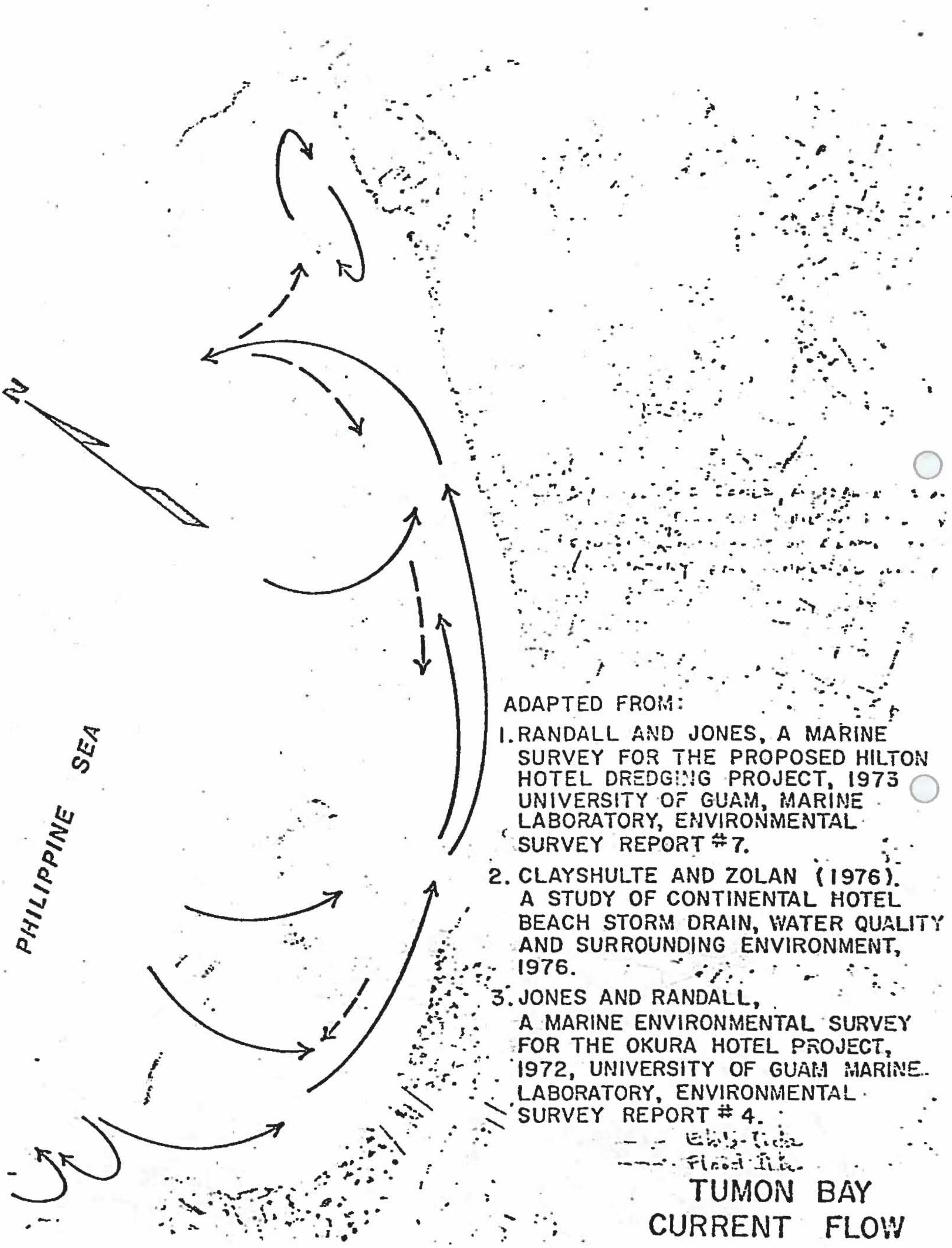
TABLE 1. GUAM TIDE DATA

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

Jones and Randall (1972, 1973) suggest that two current cells exist in Tumon Bay, and that both cells depend upon tidal conditions, wave activity, and bathymetric gradient. During high tide (Figure 4), the water depth over the outer reef flat increases, permitting wave energy to transport water onto the reef flat creating a hydraulic imbalance which drives the currents on the reef flat in the southern part of the bay. The current moves northward from the Hilton Hotel then seaward through the boat channel. In the northern sector of the bay fronting Okura Hotel, Jones and Randall (1973) found little or no water movement except during tidal changes when a weak seaward flow into the boat



TUMON BAY
BATHYMETRY



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2. CLAYSHULTE AND ZOLAN (1976). A STUDY OF CONTINENTAL HOTEL BEACH STORM DRAIN, WATER QUALITY AND SURROUNDING ENVIRONMENT, 1976.
3. JONES AND RANDALL, A MARINE ENVIRONMENTAL SURVEY FOR THE OKURA HOTEL PROJECT, 1972, UNIVERSITY OF GUAM MARINE LABORATORY, ENVIRONMENTAL SURVEY REPORT # 4.

Ebb Tide
Flood Tide

TUMON BAY
CURRENT FLOW

channel was detected during falling tide and a weak inward flow was detected on the rising tide. They attributed the lack of a measurable current to the lack of wave activity on the reef front and hypothesized that the northern area of the bay was protected from wave activity by Amantes Point located to the north of Gognga Point.

The bathymetric gradient appeared to be a major factor influencing current direction. During falling tide (Figure 5), water flows northward from the southern sector of the bay following the bathymetric gradient to the north. The tidal flow appears to be stronger than the effect of the prevailing wind, which creates a surface flow to the southwest within the top 10-20 centimeters of the water surface (Jones and Randall 1973). During flood tide ~~(figure 6)~~, the current direction is weakly reversed until such time as the water height over the outer reef flat permits wave activity to transport water from the sea onto the reef flat. During peak low tide, dye measurements by Jones and Randall (1972) indicated a northward current despite the prevailing northeast trades and lack of wave transport onto the reef flat. The continued northward current direction, 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 flo back toward the deeper parts of the bay. Current velocities measured by Jones and Randall (1972) over a short time span, ranged from 0.30 to 0.56 knots on the reef flat at Ypao Point, to 0 to 0.66 knots in front of the Hilton Hotel. Clayshulte and Zolan (1978) measured current velocities in front of the Continental Hotel ranging from 0.24 to 1 knot. Marsh (Personal communication, 1980) suggested that the high elevations around the islet force water driven over the reef flat to converge in front of the Continental Hotel where an increase in current velocity is experienced.

Current measurements taken offshore at Fafai Beach (Gun Beach) in 100 feet of water by the US Navy 1974 found a net southwesterly flow with extremely slow current velocities; a majority of measurements are less than 0.1 knot (0.5 m/second) and very few greater than 0.3 knots (0.15m/sec).

LITTORAL PROCESSES

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 northern sector of the bay, and the sand in the northern sector is better sorted (having a more consistent grain size) than sand in the southern sector. Clayshulte and Zolan recorded a lateral movement of sediment from the Continental Hotel storm drain northward from its point of entry into the bay. 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 never 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 recently maintenance dredge (1979-1980) since it was first constructed about 1973. The maintenance dredging cycles suggest that rate of sand movement in the southern end of the bay may be slow.

EROSION HAZARD

The broad shallow reef flat, which acts as a buffer or wave dissipator protects the bay from storm surges by reducing wave energy affecting the beach. No data were available to determine the effects of storm waves on the bay shoreline or shore properties. The data suggest that the shore is relatively stable except for (a) the two areas previously identified; and (b) the impacts of typhoons.

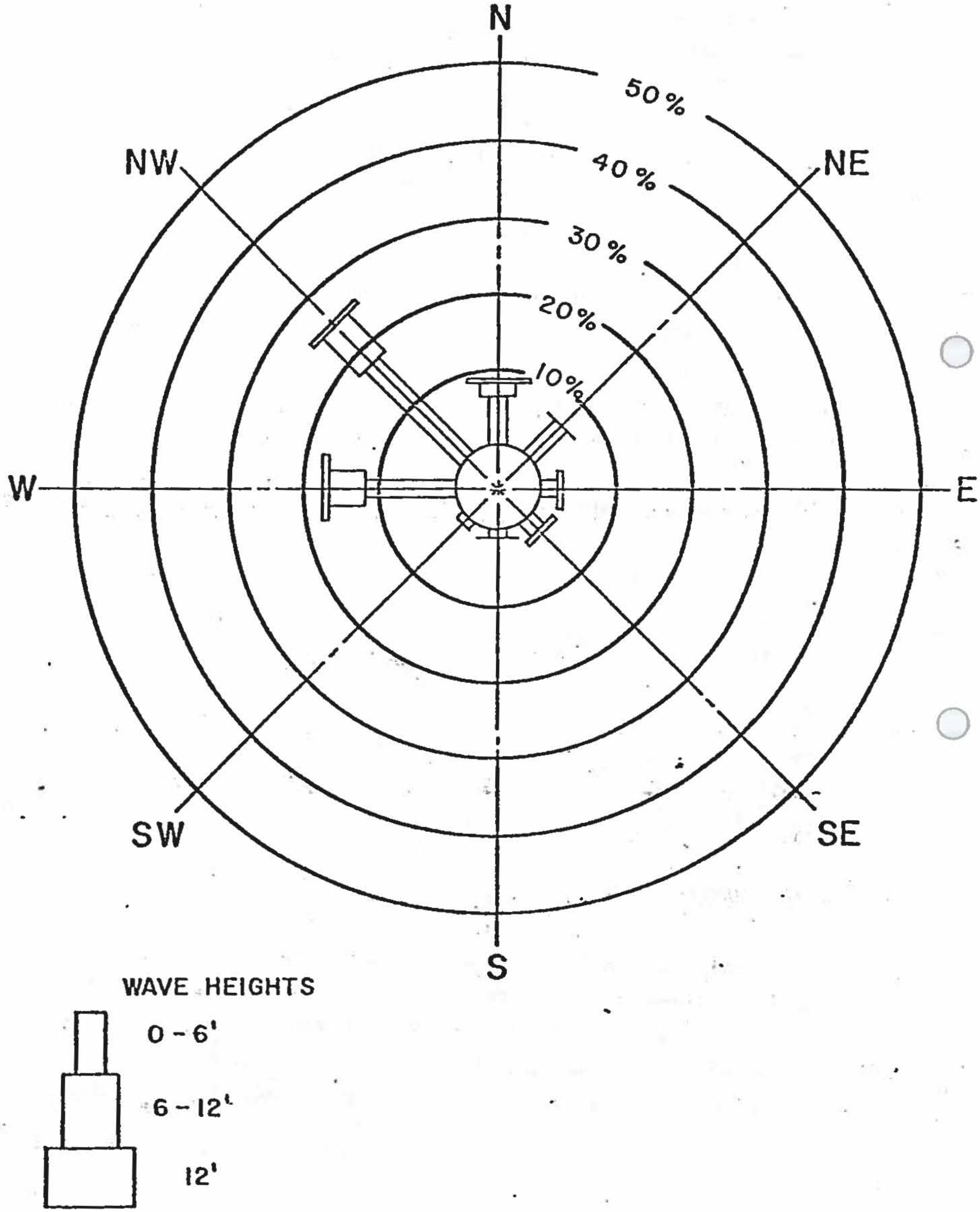
A visual survey for erosion problems in Tumon Bay (US Army Engineer District, 1980) indicated that the Tumon Bay beach system is stable under existing conditions, except for a section of Naton Beach immediately north of the Dai-Ichi Hotel where roots of three coconuts trees are exposed and another tree is toppled. The condition may reflect a slow erosion process. A beach section in the center of Ypao Beach may be eroding based on the presence of an escarpment at the foreshore crest. The potential erosion hazard may be related to storm wave activity, but no studies are 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 west and northwest. On an average 2-3 typhoons a year pass within 180 nautical miles of Guam. A typhoon can occur within any month of the year, but occurs more frequently in the months of August through November with peak activity occurring during the period from October through November. An analysis of wave heights from various directions (Edward K. Noda and Associates, undated) indicated that 41% of the waves heights varying from 0 to 6 feet and 20% of the wave heights over 6 feet were related to tropical cyclones. Specifically the analysis indicated that tropical cyclones were most likely to generate waves which approached Tumon Bay from the west and northwest. 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 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) and has become vegetated.

WATER QUALITY

Water quality data for Tumon Bay are not extensive. 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

WAVE HEIGHT OCCURENCE VERSUS WAVE DIRECTION DUE TO WESTERN NORTH PACIFIC TROPICAL CYCLONES PERIOD 1975 - 1979.



and Zolan (1976) studied the effects of stormwater discharge at the 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 previously mentioned 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 southern and middle sectors of the bay. The tidal exchange is unobstructed and the shallow bathymetry permit large volumes of water to exchange during each tidal cycle. 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 16 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 northern sector of the bay in front of Okura Hotel was poor because of 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 (in March 1977). He found a rate of flow of about 150 cubic feet per second for a 150-foot section beach near the Reef Hotel. Zolan, et al, identified 5 major seepage sites in Tumon Bay located near the Hilton Hotel, Continental Hotel, Reef Hotel and the Okura Hotel. Marsh indicated that a freshwater 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. 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 northern sector of the bay results in a periodic dinoflagellate bloom.[1] The blooms never reached proportions to cause fish kills or major outbreaks of ciguatera. Jones and Randall indicated that the bloom is an annual event that may have occurred over many years. They mention a Chamorro legend suggesting that the water discoloration

[1] Research at the Massachusetts Institute of Technology suggests blooms occur when [illegible] copper [illegible] concentrations [illegible]

caused by the dinoflagellate bloom was the blood of Father San Vittores that appeared each April to haunt his assassins. Father San Vittores was killed and his body thrown into the northern part of the bay on 2 April 1672. Marsh found that during bloom condition mean nitrate values decreased to about 4 microgram-atoms per lier and mean phosphorus values increased to about 0.6 microgram-atoms per liter. Clayshulte and Zolan in their study of a storm-water 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 concentrtion in the groundwater seepage into the bay masked the nitrate contributions and effects from storm drain.

Salinity characteristics in Tumon Bay are not well documented. For the area fronting the Continental Hotel, Clayshulte and Zolan measured a salinity ranging from 31o/oo to 34o/oo with a mean salinity value of 32o/oo. The data suggest that salinity within 5-10 meters from the shoreline may range from 31-32o/oo, and 32-34o/oo within 10-50 meters of the shore. They found that the discharge of stormwater into the bay created a salinity decrease of about 4o/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 stormwater discharges.

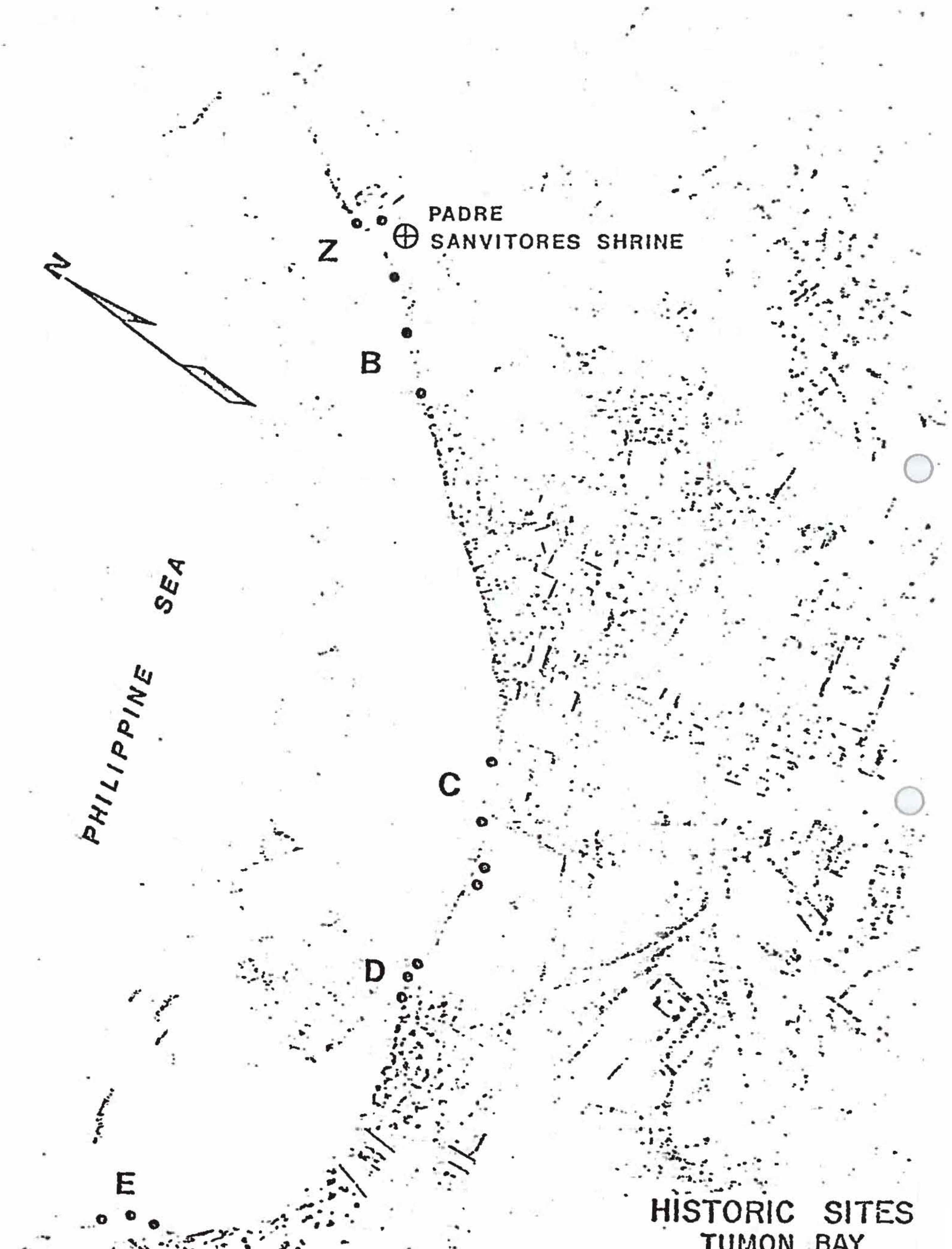
Water turbidity characteristics are also not well documented. Clayshulte and Zolan found turbidity values within their storm drain study area to be consistently less than 1 NTU. Stormwater runoff turbidity ranged from about 2 to 18 NTU, but was confined to the nearshore area.

Clayshulte and Zolan did find that storm drains were sources of bacterial and heavy metal contaminants into Tumon Bay. However, human use of the nearshore waters also contribute to bacterial contamination in the bay. The long-term effect of heavy metal contribution to the bay is not known.

HISTORIC SITES.

Twelve remnants of the Japanese defense structures from World War II at Tumon Bay are located along the Tumon Bay shoreline (Figure __). The State Historic

Preservation Officer indicated (29 August 1979) that the system appeared essentially undisturbed and was the only intact system on the island. Location Z had two large destroyed gun emplacements near Gognga Beach. Both emplacements appeared to have been destroyed by internal explosions. There was also evidence of fire. Location B, Naton Beach, had two small pillboxes which were in fair to poor condition. Location C, Naton Beach, some times considered Tumon Beach, had one small "one-man" bunker (similar to be one at Location A) and one large pillbox. Both structures were in excellent condition. Location D, Ypao Beach, had a one-man cave pillbox, one small pillbox and one large heavy gun emplacement. 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). Location E, Ypao Point Beach, had two small rock cave pillboxes in good condition and one large heavy gun emplacement. This emplacement appeared to have taken a direct hit from a naval gun during the war. It had been partly restored, though obviously not by professionals. The defense structures used by the Japanese at Tumon Bay were basically constructed of scrap metal for reinforcement and concrete. Bits of old tanks, water pipes, accordian wire, and reinforcing rods were commonly used. Natural cave formations, beach rock, boulders, and sand were utilized. Molds for the interiors were constructed of 8" x 8" timbers and sometimes (for large structures) whole coconut tree trunks.



HISTORIC SITES
TUMON BAY
FORTIFICATIONS

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 transects 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 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 future crop of algae. Any material providing a stable substratum, including coral rubble and fragments, mollusk shells and rocks, is used by the algae. The alga can also form dense mats that stablize sand particles and that can withstand water movement having velocities 5 times that required to dislodge sand particles. However, shifting substrates, abrasion and burial can prevent the growth of the alga. Dessication resulting from extreme low tides is another stress factor which may limit the distribution of the alga.

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 waterflow over the reef flat and increase 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 reef margin was devoid of coral due to continuous 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 ___). Some species were restricted in their distribution to either the reef flat or reef front, and others were found in both zones.

Table __

Reef Zone	Species	Cover
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 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).

Of the 7 harvestable corals identified by Hedlund (1977), four are found in Tumon Bay (Table __). 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 __. Harvestable Coral in Tumon Bay

	Location	Range Density/m^2	Common Names
Acropora irregularis	unknown	unknown	
Acropora acuminata	inner reef flat	0.12 - 0.14	staghorn coral
Fungia fungites	reef front	unknown	mushroom coral
Heliopora coerulea	inner reef flat to reef front	0.08	blue coral

OTHER MACROINVERTEBRATES

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 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 <u>Trochus</u> shell increased with increased water depth. No large population of bivalves were found in the bay, although small infaunal forms were present.

The sea cucumbers ~~was~~ were the most prevalent group of invertebrates on the reef flat. They are a source of food in some parts of the world, and 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, <u>Holothuria atra</u>, comprised over half of the sea cucumber biomass in the bay. A mean holothurian population density of 15.58 individuals/ m $10m^2$ and an average wet weight of biomass of 3.87 kilgrams/$10m^2$ 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.

FISH

Studies of fishery resources in Tumon Bay are limited to standing crop measurements and fishermen creel census by the Guam Fish and Wildlife Division, and a study of fish distribution on the reef flat by Amesbury (1978). Studies by Randall and Jones (1972, 1973) also provide a list of species found at two survey sites in the bay. The Guam Fish and Wildlife data indicate that Tumon Bay was the most heavily fished inshore area on Guam. However, realignment of the census areas prevents 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 lost interest by younger residents. Gill net fishing was said to be decreasing in popularity while spin fishing and spearfishing may be increasing in popularity.

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. Heavy wave action makes areas inhospitable to fish. Unstable substrates, such as sand and rubble, tend to bury habitat areas. 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, batnymetric 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 (Trachurops crumenopthalmus, 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 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 does not indicate any significant patterns or cyclic trends. Years of low harvests and years of extremely high harvests are 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.