AN INVESTIGATION OF THE BIOLOGICAL AND OCEANOGRAPHIC SUITABILITY OF TOGUAN BAY, GUAM AS A POTENTIAL SITE FOR AN OCEAN OUTFALL

ROBERT S. JONES, RICHARD H. RANDALL, and RONALD D. STRONG

Co-Investigators

UNIVERSITY OF GUAM MARINE LABORATORY

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By

ROBERT S. JONES, RICHARD H. RANDALL, AND RONALD D. STRONG

co-Investigators

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INTRODUCTION

Background

"Standards of Water Quality for the Waters of the Territory of Guam" contains a timetable for construction of wastewater facilities on the Island. The schedule calls for construction of facilities for the villages of Merizo and Umatac (Figs. 1 and 2) in FY 74. The approved "Master Plan for Sewerage" provides for a common system for both villages and a proposed outfall site in Toguan Bay (Figs. 2 and 3).

In order to insure that the proposed outfall and planned discharge will not constitute an adverse effect on public health in nearby villages and on persons using the adjacent waters for recreation, the Guam Environmental Protection Agency planned a survey of ocean currents at the potential outfall site. The study was also expected to provide preliminary information on the bay's biota for future preparation of an environmental impact statement, in compliance with the National Environmental Policy Act.

On August 18, 1972 a letter was forwarded from the Chairman of the Board of the GEPA to the President of the University of Guam requesting

*This work and the opinions expressed herein are those of the authors and not necessarily those of the University of Guam, The Marine Laboratory, or Government of Guam.

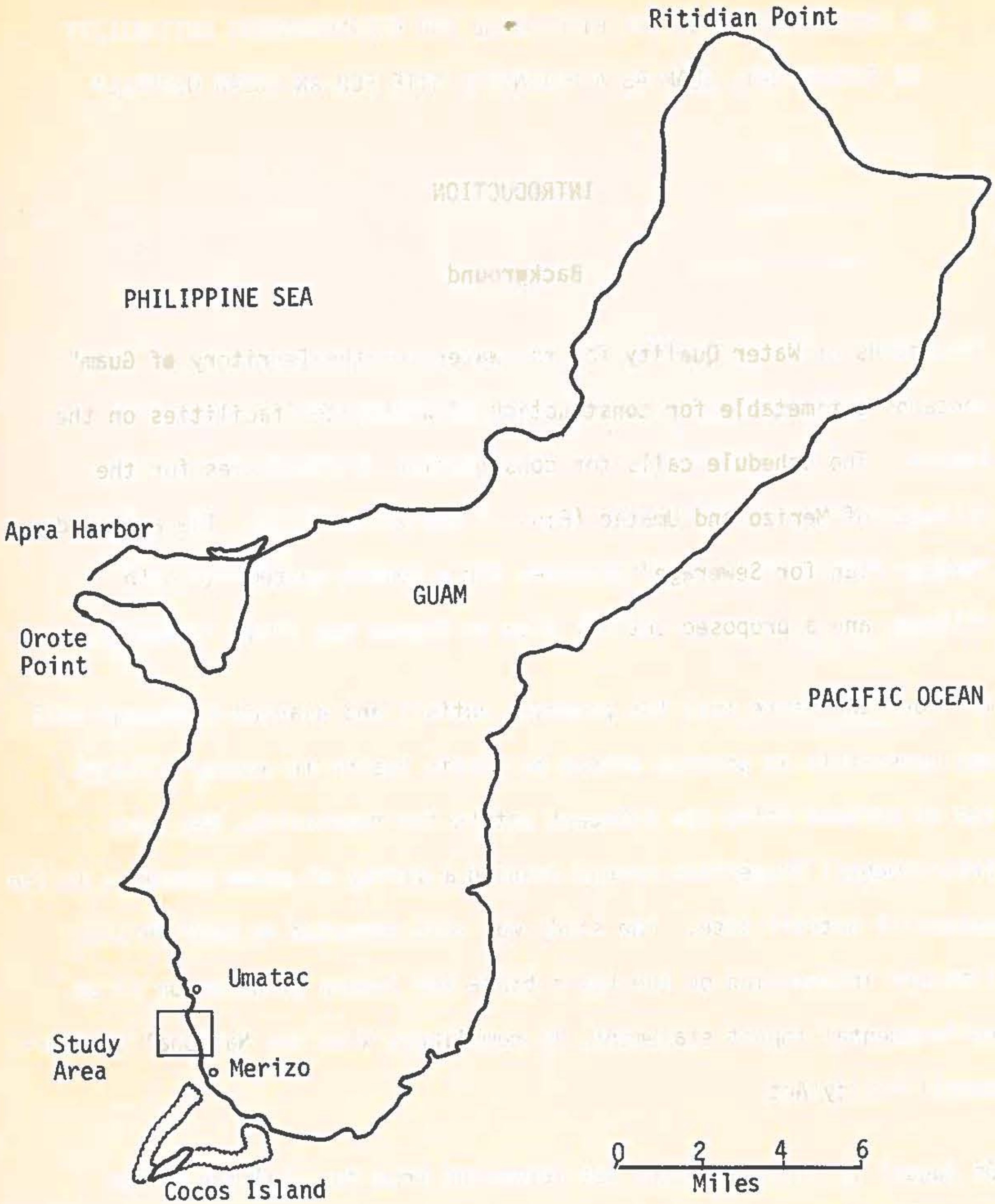


Figure 1. Map of Guam showing study area.

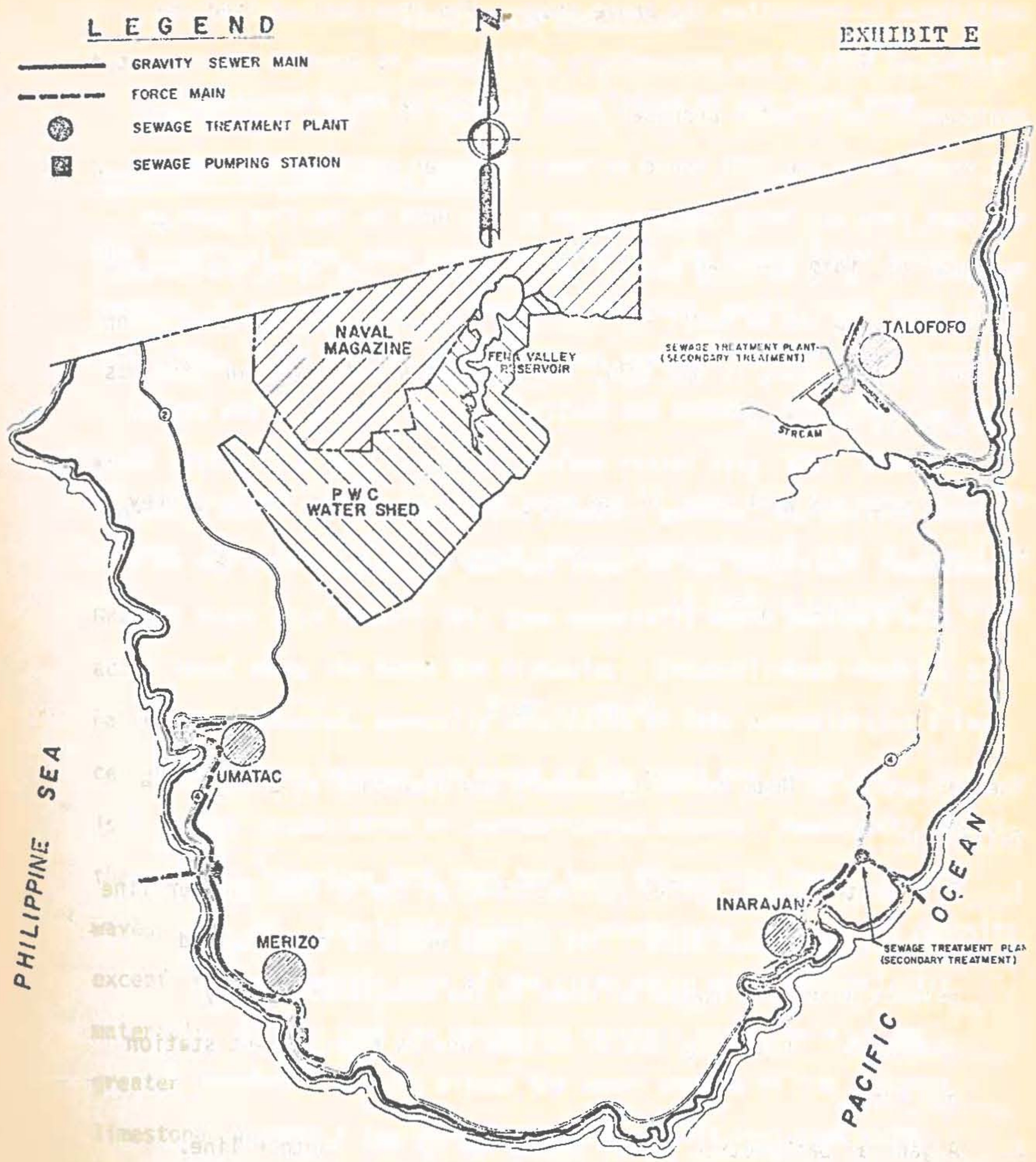


Figure 2. Map provided by GEPA to show the location of the study site.

assistance in conducting the above study. The President advised the Chairman of GEPA of the University's willingness to provide the requested assistance, in a letter proposal dated October 16, 1972. The proposal was accepted by the GEPA Board at their November meeting and a letter was sent from the Chief Administrator of the GEPA to the President on December 14, 1972 advising him of the acceptance. The first preliminary field trip occurred on April 16, 1973 and field work was completed after an annual cycle study in May 1974. Data analysis and report writing was completed in June 1974.

The only previous work done in the area was a brief (one month) survey by the U. S. Navy Oceanographic Office (Anon., 1971) in Bile Bay, just south of Toguan Bay (Fig. 7).

Scope of Work

The University of Guam Marine Laboratory was requested to provide the following:

1. A 12 month (annual cycle) current study at the 60 foot contour line opposite the Toguan River. The 60 foot depth is the required release point for sewage effluent in the Guam water quality standards. This study was to include one 24 hour current station per month.
2. A general bathymetric survey out to the 60 foot contour line.
3. A biological study containing a list of dominant marine organisms in the area likely to be affected by effluent.

RESULTS AND DISCUSSION

Physiographic and Biological Description of the Study Area

Intertidal and Supratidal Zone

The intertidal zone, both north and south of the Toguan River mouth consists of a narrow band of emergent limestone, usually less than 10 m wide (Figs. 3 and 4). At most locations the band is less than a meter in height and is greatly solution-pitted and erroded into pinnacles and knobs giving it a very irregular surface relief (Fig. 4B). Common organisms found in this region are limpets, nerites, and chitins which feed on the algal penetrated surface layer of the intertidal limestone. Grapsid crabs also inhabit this zone especially where boulders have accumulated among the knobs and pinnacles. Unconsolidated deposits are patchy and scattered, generally consisting of thin accumulations a few centimeters thick between the bases of the knobs and pinnacles. There is a greater accumulation of unconsolidated material immediately behind the emergent limestone band that has been transported there by storm waves (Fig. 4A). Bioclastic materials predominate in the beach deposits except in the immediate area of the river mouth where nonbioclastic materials, derived from the bordering volcanic rocks, make up the greater fraction. In some places the upper surface of the emergent limestone supports a low prostrate growth of salt resistant shrub, *Pemphis acidula*.

Reef Flat Platform Zone

The reef flat zone forms a rather flat featureless platform generally less than 100 m wide near the river mouth (Figs. 3 and 4C). During lower spring tides the entire platform is commonly exposed. The only water retained on the reef flat during these low tides is found in the widely scattered, shallow pools and holes. Scattered rounded basaltic boulders are imbedded in the limestone matrix near the river mouth which indicates previous reef framework accumulation there. There are no large outcrops of volcanic rock in the immediate region around the river mouth but such outcrops do occur a few hundred meters to the north and indicate that the reef flat limestone here probably forms a thin layer deposited on an older volcanic substrate. Unconsolidated sediments are virtually absent except for small accumulations in shallow holes. Even though the reef flat platform is exposed during lower tides there is generally a rather dense mat of both soft and calcareous benthic algae growing on the surface and in the shallow pools. During November, when the reef flat survey was conducted, Laurencia, Mastopohora, Acanthophora spicifera, Gracilaria, and Padina were the most common benthic algae encountered. Patches of an unidentified calcareous encrusting alga were common over the entire platform, although the greatest surface coverage was found near the intertidal zone. A few holothurians such as Holothuria atra, H. leucospilota, Actinopyga mauritania, and Stichopus chloronotus were found in some of the deeper reef flat holes. Larger foraminiferans, particularly the discoid Marginopora vertebralis, were common to abundant and intermixed within the algal mat. Corals are absent on the reef flat platform except for a few small colonies of Porites lutea, Leptastrea purpurea and Goniastrea retiformis that were found in the larger pools near the reef margin.

Submarine River Channel Zone

A submarine channel bisects the fringing reef flat platform at the Toguan River mouth (Fig. 4F). The channel is just a few meters wide and about a meter deep at the river mouth itself, but widens rapidly to about 20-25 m within 30 m of the shoreline and increases in depth to about 6-10 m. The floor of the channel consists of unconsolidated sand, gravel, and boulders but the sides of the channel are of vertical to overhanging limestone walls. There is no evidence that the channel is itself an erosional feature. Instead, the fresh water and silt carried to the bay by the Toguan River has prevented growth of the fringing reef across the channel proper. Coral grows in a seaward direction on either side of this river influenced portion of the fringing reef zone creating the channel effect. Corals were found growing on the channel walls to within a few meters of the river mouth proper. These corals can live within close proximity of the river mouth for two reasons. Most of the time river discharge is of a low volume of relatively clear water, hence the daily transport of silt is low. Because of its reduced density, the river water floats seaward as a thin layer on top of the more dense seawater, thus reducing or minimizing any effect on the corals which grow below this layer. During heavy rainfall the volume of discharge and suspended mud and silt, derived from the nearby volcanic mountain slopes, increases greatly. Observations made in the river channel (Randall, unpub. field notes; 1968) during flood conditions showed that the muddy water, though forming a somewhat thicker layer than normal, still flowed into the bay over the more dense seawater just as during nonflood discharge conditions. Some of the silt load is dropped though, as the water velocity diminishes. The material settles onto the corals below, but the species found along the channel walls and in close proximity to the river mouth are relatively silt-adjusted species. Such species are efficient at removing the silt particles so long as the frequency and duration of river flooding is not too often or great.

Reef Margin Zone

The reef margin (Fig. 4D) lacks the typical algal ridge development normally found in this zone. This is not surprising since Toguan Bay is situated on the leeward coast of Guam. The reduced wave assult is not conducive to ridge development. In the immediate area of the river mouth the reef margin ranges between 10 and 20 m in width. Even though the river is nearby, there appears to be more coral development within a zone 200 m on each side of Toguan River mouth than on the adjacent regions farthur away from the influence of the river. This general observation of greater coral growth, development, and diversity along the reef margin is also true for the reef front, and first submarine terrace zones (Fig. 4). Open surge channels along this section of reef margin are poorly developed and when present are rather shallow (2-3 m) and short (3-5 m). The best developed surge channels are found along the reef margin zone located adjacent to the river channel.

On the south side of the river channel there are several longer surge channels which are completely roofed over, forming submarine caves up to 10 m in length and several meters in width. The inner part of the reef margin is relatively flat and pavement-like with a few scattered, shallow pools, most less than a half meter deep. In general, the surface relief of the reef margin is less than 30 cm and at places is honeycombed on the outer part by numerous interconnecting holes where cavernous surge channels are present below.

The upper surface of the reef margin is generally devoid of coral growth, but the walls of inner margin pools and surge channels possess some growth. Common corals in these regions were plate-like growths of Millepora platyphylla; massive Porites lutea, P. lobata, P. reticulosa, Porites sp. 1, P. australiensis, Goniastrea retiformis, Favia pallida, Acanthastrea echinata, and Leptoria phrygia; encrusting Pavona varians, and Leptastrea purpurea. Less common corals were the ramose colonies of Acropora nasuta, A. surculosa, Millepora dichotoma, and Pocillopora meandrina. Conspicuous algae growing on the inner reef margin was Turbinaria ornata, Porolithon onkodes, and Porolithon gardineri. Although not abundant, patches of bright green Chlorodesmis fastigiata, are widely scattered on the outer edge of the zone. The holothurian Actinopyga mauritania was found in the reef margin pools and on the surge channel walls. In local areas zoanthids cover a considerable portion of the substrate on the outer part of the margin.

Reef Front Zone and First Submarine Terrace

The reef front zone forms the steep sloping section just seaward of the reef margin (Fig. 4E). Along the river channel margin the reef front drops precipitously to the channel floor. The channel floor widens rapidly in a seaward direction and is contiguous with the second submarine terrace (Fig. 4F and I). North and south of the river channel the reef front slope flattens out considerably, at about the two to four meter depth, and grades into the gently-sloping first submarine terrace (Fig. 4G). This first terrace, inturn, drops steeply to precipitously, at the 6 to 8 m depth, to the second submarine terrace, 10 to 20 m in depth (Fig. 4). About 300 to 400 m north of the river channel the first submarine terrace grades into a wide, lobate terrace that extends nearly one half mile seaward and stretches northward nearly to Umatac Bay (Fig. 7).

In the vicinity of the river channel the reef front surface and first submarine terrace are very irregular because of the presence of numerous coral developmental features such as knobs, knolls, mounds, and pinnacles of various diameters and heights. Other features contributing to this irregular surface are the presence of weakly developed submarine channel and buttress systems and various sized holes, cracks, and fissures; the floors of which, contain large rounded boulders, coarse sand, and gravel.

With the exception of the boulder rubble floors of the holes, cracks, and fissures, the surface features of the reef front and first submarine terrace supports a rich variety of corals (Table 1) and other associated reef invertebrates.

A submarine cliff 5-10 m in height borders the seaward edge of the first submarine terrace on both sides of the river channel (Fig. 4H). About 100 m north of the river channel the submarine cliff disappears where it grades into the broad first submarine terrace mentioned above.

The near vertical face of the submarine cliff is cut by deep cracks and fissures. The floor of these features are about the same level as the second submarine terrace (Fig. 4I). Coral mounds, knolls, and pinnacles are scattered along base of the cliff. The relief of these isolated structures ranges from small knolls less than a meter in height and diameter to large mounds up to 5-10 meters in height and diameter. Several caves and fissures up to 15 meters long are found on the cliff face, and overhanging ledges formed by coral growth extend outward up to 5 m at the base of the cliff.

A rich and diversified coral community grows on the submarine cliff face and a rather specialized assemblage is found growing on the walls of the fissures where light intensity is considerably reduced (Table 1). Ahermatypic corals such as Stylaster, Desmophyllum, and Distichopora are found in the caves and darker parts of the cavernous fissures. Several small ahermatypic corals have been found in the above caves and fissures which are new to Guam (See Conclusions). Calcareous encrusting algae, fleshy benthic algae, and other reef organisms form a very diversified, reef associated community along the cliff face and the cave and fissure walls.

Second Submarine Terrace

The second submarine terrace slopes gently seaward from the base of the above described submarine cliff (Fig. 4I). Depth contours for the second terrace are shown on Figure 32. These contours were determined from a series of fathometer profiles (See Bathymetry Section). The fathometer profiles show that a sharp break in terrace slope occurs just seaward of the point where the "Havaiki" current study platform was located (See Current Section). The terrace floor is relatively flat with very little relief except for numerous, isolated coral heads, knolls, pinnacles, and mounds which are scattered over its surface (Fig. 4I and J). The size of these scattered features ranges from coral heads less than a meter in height and diameter to large mounds nearly a 100 m long and 50 m wide.

The terrace floor is composed of unconsolidated sediments consisting of a mixture of bioclastics of reef origin and nonbioclastics of volcanic origin, carried to the bay by the Toguan River. Near the base of the submarine cliff the sediments generally contain a greater fraction of nonbioclastic sediments, while farther seaward the bioclastic fraction makes up the larger portion.

Benthic algae formed the most conspicuous community on the unconsolidated terrace floor. Halimeda and Udotea, with their specialized holdfasts for anchorage in the sand, formed numerous isolated patches on the floor. Upon death, these algae contribute considerably to the calcareous sediment fraction observed. Padina was also abundant wherever coral rubble was present for its attachment. Reddish-brown gelatinous patches of Shizothrix were common to abundant over the entire terrace floor.

Corals on the terrace (Table 1) are restricted, more or less, to the scattered mounds and knolls, although a few individual colonies were found widely scattered over the surface, particularly along the outer seaward margin. Coral growth on the small knobs and mounds was more or less evenly scattered over the entire surface, but on the large mounds, the greatest coral density and percentage of substratum coverage was found on the steep to vertical faced outer margins. The relatively flat-topped upper surfaces of the mounds were somewhat barren of corals but were richly covered with a variety of benthic algae. The corals found on the terrace mounds and knolls are very similar to those found on the steep face of the submarine cliff bordering the first terrace (Fig. 4H).

Other organisms inferred to be present in the terrace sediments are various burrowing gastropods and bivalve molluscs, judging from the numerous sand

Figure 3 A. Photo of Toguan Bay looking east. On the day the photo was made, there were strong westerly winds and swells. These conditions were responsible for the abnormal surf and turbulent waters seen in this normally calm bay.

Figure 3 B. Photo of Toguan Bay from point near Toguan Peak on the coastal road (Fig. 7), looking south toward Cocos Is. The research vessel "Havaiki" is anchored on the 60 foot isobath where drogues were released.

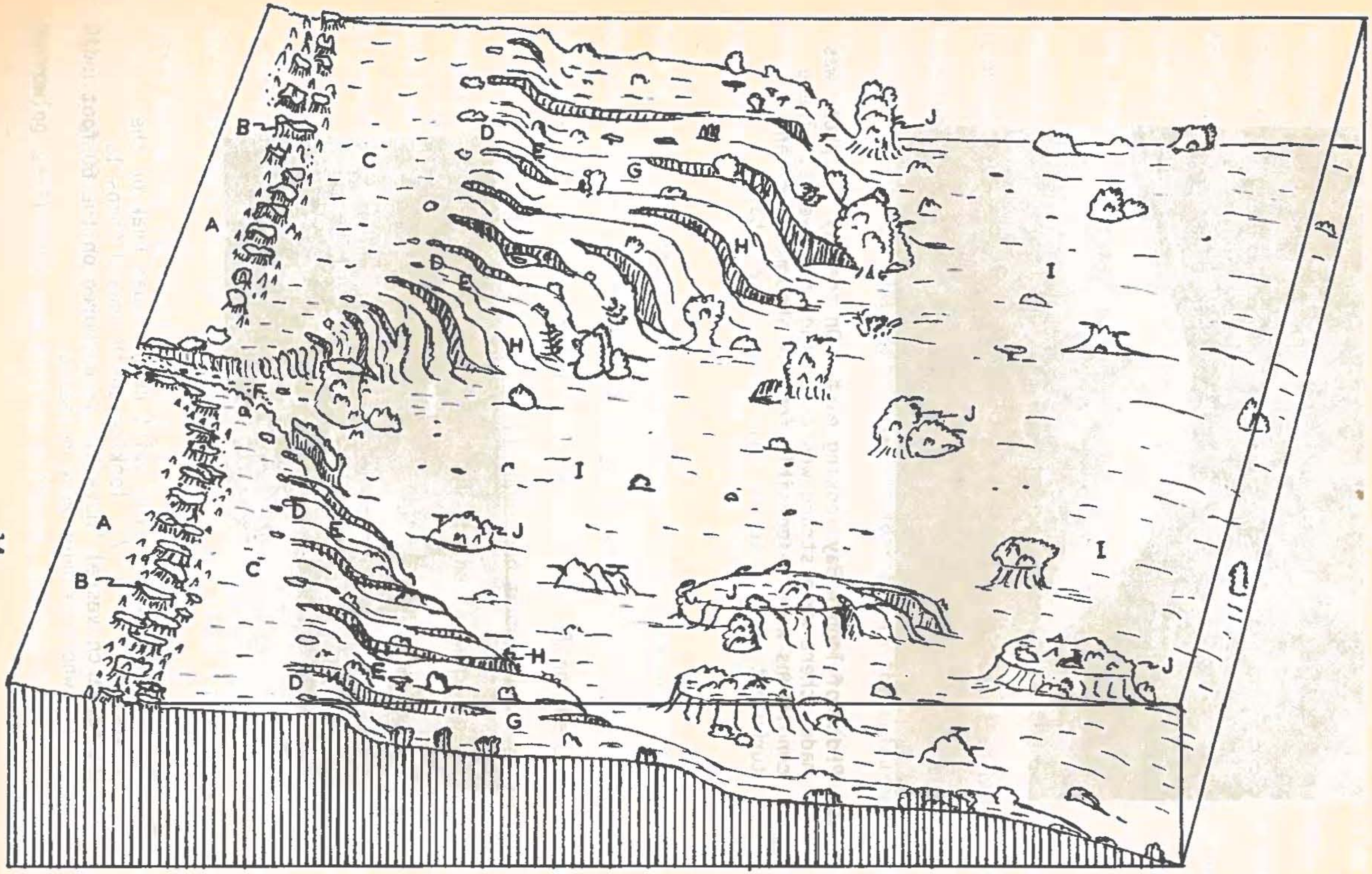


Figure 4. Three dimensional drawing of study area. The actual position and number of pinnacles, knobs, and mounds are not shown on figure.
A = Beach deposits; B = Intertidal band of emergent limestone; C = Reef flat; D = Reef margin; E = Reef front; F = Submarine river channel; G = First submarine terrace; H = Submarine cliff; I = Second submarine terrace, and J = Pinnacles, knobs, and mounds.

Table 1. Check list of corals and their relative frequency of occurrence at Toguan Bay. Symbols for

E = Reef front; F = Submarine river channel; G = First submarine terrace; H = Submarine cliff; I = Second submarine terrace, and J = Pinnacles, knobs, and mounds.

Table 1. Check list of corals and their relative frequency of occurrence at Toguan Bay. Symbols for relative frequency are: D = dominant, A = abundant, C = common, O = occasional, and R = rare.

	REEF MARGIN REEF FRONT & FIRST SUBMARINE TERRACE	SUBMARINE CLIFF SECOND SUBMARINE TERRACE AND ASSOCIATED MOUNDS, KNOLLS, AND PINNACLES
Stylocoeniella armata (Ehrenberg) 1834	C	A
Stylocoeniella guentheri (Bassett-Smith) 1890	-	O
Psammocora nierstraszi van der Horst, 1921	O	O
Psammocora profundacella Gardiner, 1898	O	O
Psammocora verrilli Vaughan, 1907	R	R
Psammocora (S.) togianensis Umbgrove, 1940	O	-
Psammocora (P.) haimeana Milne Edwards & Haime, 1851	O	O
Psammocora sp. 1	R	-
Stylophora mordax (Dana) 1846	C	O
Seriatopora hystrix (Dana) 1846	O	C
Pocillopora brevicornis Lamarck, 1816	O	-
Pocillopora damicornis (Linnaeus) 1758	R	A
Pocillopora danae Verrill, 1864	O	O
Pocillopora elegans Dana, 1846	O	C
Pocillopora eydouxi Milne Edwards & Haime, 1960	O	O
Pocillopora ligulata Dana, 1846	-	R
Pocillopora meandrina Dana, 1846	C	C
Pocillopora setchelli Hoffmeister, 1929	O	-
Pocillopora verrucosa (Ellis & Solander) 1786	O	C
Madracis sp. 1	R	-
Acropora abrotanoides (Lamarck) 1816	R	-
Acropora brueggemanni (Brook) 1893	O	-
Acropora convexa (Dana) 1846	O	R
Acropora diversa (Brook) 1891	R	-
Acropora humilis (Dana) 1846	C	C
Acropora hystrix (Dana) 1846	O	O
Acropora kenti (Brook) 1892	R	C
Acropora monticulosa (Bruggemann) 1879	O	-
Acropora murrayensis Vaughan, 1918	C	-
Acropora nana (Studer) 1879	R	-
Acropora nasuta (Dana) 1846	C	R
Acropora ocellata (Klunzinger) 1879	R	-
Acropora palifera (Lamarck) 1816	R	R
Acropora palmerae Wells, 1954	R	-

Table 1. (continued)

	REEF MARGIN REEF FRONT & FIRST SUBMARINE TERRACE	SUBMARINE CLIFF SECOND SUBMARINE TERRACE AND ASSOCIATED MOUNDS, KNOLLS, AND PINNACLES
Acropora rambleri (Bassett Smith) 1890	-	C
Acropora rayneri (Brook) 1892	-	R
Acropora smithi (Brook) 1893	R	-
Acropora squarrosa (Ehrenberg) 1834	R	-
Acropora surculosa (Dana) 1846	C	R
Acropora syringodes (Brook) 1892	R	O
Acropora valida (Dana) 1846	R	-
Acropora wardii Verrill, 1901	O	-
Astreopora gracilis Bernard, 1896	O	C
Astreopora listeri Bernard, 1896	O	C
Astreopora myriophthalma (Lamarck) 1816	O	C
Montipora composita Crossland, 1952	-	R
Montipora conicula Wells, 1954	O	O
Montipora elschneri Vaughan, 1918	C	C
Montipora floweri Wells, 1954	R	R
Montipora foveolata (Dana) 1846	O	C
Montipora granulosa Bernard, 1897	C	R
Montipora hoffmeisteri Wells, 1954	C	O
Montipora monasteriata (Forskaal) 1775	O	O
Montipora patula Verrill, 1869	O	O
Montipora stilosa (Ehrenberg) 1834	R	R
Montipora tuberculosa (Lamarck) 1816	O	O
Montipora verrilli Vaughan, 1907	C	C
Montipora verrucosa (Lamarck) 1816	R	C
Montipora sp. 1	R	R
Montipora sp. 2	-	R
Montipora sp. 3	-	R
Pavona clavus (Dana) 1846	O	R
Pavona minuta Wells, 1954	-	C
Pavona praetorta (Dana) 1846	-	O
Pavona varians Verrill, 1964	C	O
Pavona gardineri van der Horst, 1922	-	R
Pavona (*P.*) *pollicata* Wells, 1954	R	R
Pavona (*P.*) *planulata* (Dana) 1846	R	R

Pavona minuta Wells, 1954	-	O
Pavona praetorta (Dana) 1846	-	O
Pavona varians Verrill, 1964	C	O
Pavona gardineri van der Horst, 1922	-	R
Pavona (P.) pollicata Wells, 1954	R	R
Pavona (P.) planulata (Dana) 1846	R	R

Table 1. (continued)

	REEF MARGIN REEF FRONT & FIRST SUBMARINE TERRACE	SUBMARINE CLIFF SECOND SUBMARINE TERRACE AND ASSOCIATED MOUNDS, KNOLLS, AND PINNACLES
Pavona (P.) obtusata (Quelch) 1884	-	R
Pavona (P.) sp. 1	-	C
Pavona (P.) sp. 2	R	R
Leptoseris hawaiiensis Vaughan, 1907	R	C
Leptoseris incrustans (Quelch) 1886	R	C
Leptoseris mycetoseroides Wells, 1954	-	C
Pachyseris speciosa (Dana) 1846	-	O
Anomastraea sp. 1	R	C
Coscinaraea columna (Dana) 1846	R	O
Cycloseris cyclolites (Lamarck) 1801	-	O
Cycloseris sp. 1	-	R
Fungia fungites var. incisa Doederlein, 1902	-	R
Fuñgia paumotuensis Stotchbury, 1883	-	O
Fungia scutaria Lamarck, 1801	R	O
Goniopora columna Dana, 1846	-	R
Goniopora arbuscula Vumbgrove, 1939	O	O
Goniopora sp. 2	R	O
Porites australiensis Vaughan, 1918	C	C
Porites compressa Vaughan, 1907	-	R
Porites lichen Dana, 1846	O	C
Porites lobata Dana, 1846	C	C
Porites lutea Milne Edwards & Haime, 1851	D	D
Porites murrayensis Vaughan, 1918	C	C
Porites sp. 1	C	-
Porites sp. 2	O	O
Porites (S.) convexa Verrill, 1864	C	A
Porites (S.) hawaiiensis Vaughan, 1907	R	A
Porites (S.) horizontalata Hoffmeister, 1925	O	O
Porites (S.) iwayamaensis Eguchi, 1938	C	A
Porites (S.) sp.1	-	R
Alveopora verrilliana Dana, 1872	O	O
Favia favus (Forskaal) 1775	C	O
Favia pallida (Dana) 1846	C	C
Favia speciosa (Dana) 1846	O	C

Table 1. (continued)

	REEF MARGIN REEF FRONT & FIRST SUBMARINE TERRACE	SUBMARINE CLIFF SECOND SUBMARINE TERRACE AND ASSOCIATED MOUNDS, KNOLLS, AND PINNACLES
Favia stelligera (Dana) 1846	C	R
Favia rotumana (Gardiner) 1889	O	O
Favites abdita (Ellis & Solander) 1786	R	-
Favites complanata (Ehrenberg) 1834	O	O
Favites favosa (Ellis & Solander) 1786	O	O
Favites flexuosa (Dana) 1846	R	-
Favites virens (Dana) 1846	R	-
Oulophyllia crispa (Lamarck) 1816	O	O
Plesiastrea versipora (Lamarck) 1816	C	R
Plesiastrea sp. 1	O	R
Goniastrea benhami Vaughan, 1917	-	R
Goniastrea parvistella (Dana) 1846	C	A
Goniastrea pectinata (Ehrenberg) 1834	O	O
Goniastrea retiformis (Lamarck) 1816	A	O
Platygyra rustica (Dana) 1846	O	O
Platygyra lamellina (Ehrenberg) 1834	O	O
Platygyra sinensis (Milne Edwards & Haime) 1849	O	O
Leptoria phrygia (Ellis & Solander) 1786	O	O
Hydnophora microconos (Lamarck) 1816	O	R
Hydnophora tenella Quelch, 1886	-	O
Leptastrea purpurea (Dana) 1846	O	A
Leptastrea transversa (Klunzinger) 1879	O	R
Leptastrea sp. 1	R	R
Cyphastrea chalcidicum (Forskaal) 1775	O	C
Cyphastrea serailia (Forskaal) 1775	O	C
Cyphastrea sp. 1	R	R
Echinopora lamellosa (Esper) 1787	R	-
Diploastrea heliopora (Lamarck) 1816	R	R
Galaxea fascicularis (Linnaeus) 1758	C	R
Galaxea hexagonalis Milne Edwards & Haime, 1857	R	R
Merulina ampliata (Ellis & Solander) 1786	R	O
Lobophyllia corymbosa (Forskaal) 1775	C	O
Lobophyllia costata (Dana) 1846	C	O
Lobophyllia hemprichii (Ehrenberg) 1834	C	O

Galaxea hexagonalis Milne Edwards & Haime, 1857	R	R
Merulina ampliata (Ellis & Solander) 1786	R	O
Lobophyllia corymbosa (Forskaal) 1775	C	O
Lobophyllia costata (Dana) 1846	C	O
Lobophyllia hemprichii (Ehrenberg) 1834	C	O

Table 1, (continued)

	REEF MARGIN REEF FRONT & FIRST SUBMARINE TERRACE	SUBMARINE CLIFF SECOND SUBMARINE TERRACE AND ASSOCIATED MOUNDS, KNOLLS, AND PINNACLES
Acanthastrea echinata (Dana) 1846	C	O
Acanthastrea sp. 1	R	O
Echinophyllia aspera Ellis & Solander, 1786	R	O
Mycedium sp. 1	-	R
Desmophyllum sp. 1	-	O
Paracyathus sp. 1	-	O
Plerogyra sinuosa (Dana) 1846	-	O
Polycyathus sp. 1	R	-
Euphyllia glabrescens (Chamisso & Eysenhardt) 1821	-	O
Turbinaria sp. 1	R	R
Heliopora coerulea (Pallas) 1766	O	O
Millepora dichotoma Forskaal, 1775	O	R
Millepora exaesa Forskaal, 1775	C	C
Millepora platyphylla Hemprich & Ehrenberg, 1834	A	O
Distochopora sp. 1 (Pallas) 1776	C	A
Stylaster sp. 1	R	C
Total species	124	128
Total species for Toguan Bay	152	

trails made by the former and the valves of the latter found in the sediment.

Submarine Terrace North of Study Area

A brief description of this terrace is given in the report since it is discussed as an alternate discharge site (see Conclusions and Recommendations). The terrace forms a broad lobate-shaped, shallow platform which begins a few hundred meters north of the study area and extends to Umatac Bay (Fig. 7). It slopes gently seaward from the reef margin edge at Mamatgun Point, where it is about 3 to 5 m in depth, to about 20 to 25 m, where the degree of slope abruptly increases. Except for the narrow reef margin and reef front zones along its shoreward border, where coral growth is fairly well developed, this terrace is relatively barren of coral growth and developmental features. It has a rather flat surface with wide shallow valleys giving it an undulatory relief of generally less than one to two meters. The topography and surface of the present submerged terrace was, most probably, formed at a time when the sealevel was considerably lower. The shallow valleys which give the terrace its undulatory relief appear to be features related to joints in the older bedrock surface. The dominant community living on this terrace consists of a fleshy benthic algal mat generally less than 10 cm thick, and widely scattered soft and stony corals. The coral substrate coverage was estimated to be less than five percent.

Except for the boundaries of the fringing reef zones along Toguan Bay (Fig. 4), we first expected the bay bottom to be primarily an expanse of mud/sand bottom because of the alluvial input of the river. Under such circumstances, reef fishes would tend to concentrate primarily along the fringing reef and leave the open bottom to gobiid type species. However the system of coral mounds, described above, provide a unique mid-bay habitat for reef species. Were it not for these mounds fish species diversity would be quite low. As it is, the mounds provide the cover and food species necessary to attract a credible population of reef fishes. Table 2 is a list of some 115 species including both reef and the mud/sand bottom dwelling types that occur between mounds. The fish species assemblage is, in general, typical of this part of Guam's coast.

Table 2. Check list of fishes. Three 30 minute random counts were conducted, two in April 1973 and one in May 1974. All were made on the mounds at the 60 foot isobath.

Family/Species	April 1973a	April 1973b	May 1974
ACANTHURIDAE			
Acanthurus nigrofuscus	+	+	+
A. olivaceus	+	+	+
A. pyroferus	+	+	
A. xanthopterus			+
Ctenochaetus binotatus	+		+
C. striatus			+
Naso brevirostris			+
N. lituratus	+	+	+
N. unicornis	+	+	
Zebrasoma flavescens	+	+	
APOGONIDAE			
Apogon exostigma	+	+	+
A. frenatus	+		
A. novae-guinae	+	+	+
A. robustus	+		+
A. sp		+	
Cheilodipterus macrodon	+		
C. quinquelineata	+	+	+
BALISTIDAE			
Balistapus undulatus	+	+	+
Melichthys vidua	+	+	+
Sufflamen bursa	+	+	+
S. chrysoptera	+	+	+
BLENNIIDAE			
Aspidontis taeniatus	+	+	
Meiacanthus atrodorsalis	+	+	+
Plagiotremus tapeinosoma	+		+
P. sp	+	+	
BOTHIDAE			
Bothus mancus	+		+
CANTHIGASTERIDAE			
Canthigaster bennetti	+	+	
C. coronatus	+	+	+
C. solandri	+	+	+
CHAETODONTIDAE			
Centropyge flavissimus		+	+
Chaetodon bennetti			+

Table 2. (continued)

Family/Species	April 1973a	April 1973b	May 1974
C. citrinellus	+	+	+
C. ephippium		+	+
C. falcula		+	+
C. kleinii	+	+	+
C. lunula			+
C. mertensii	+	+	+
C. punctato-fasciatus	+	+	+
C. reticulatus		+	
Forcipiger flavissimus			+
Heniochus permutatus	+		
Holocanthus trimaculatus	+	+	
Pygoplites diacanthus	+	+	+
CIRRHITIDAE			
Cirrhitichthys serratus	+	+	+
Paracirrhites arcatus	+	+	+
P. forsteri	+	+	+
Amblygobius sp	+		
Cryptocentrus octofasciatus	+		
C. sp 1	+	+	
C. sp 2	+	+	+
Eleotriodes puellaris	+		
E. strigata	+		+
Gnatholepis deltoides	+		
Gobius ornatus	+		
Obtortiophagus koumansi	+		
Oplopomus oplopomus	+		+
Ptereleotris tricolor	+	+	+
HOLOCENTRIDAE			
Adioryx caudimacula		+	
A. spinifer	+		+
Myripristis multiradiatus	+	+	+
LABRIDAE			
Cheilinus fasciatus	+		
C. rhodochrus	+	+	+
C. sp	+	+	
Cirrhilabrus temmincki	+	+	+
Epibulus insidiator			+
Halichoeres biocellatus	+		+
H. hortulanus	+	+	+
H. margaritaceus	+		+
H. trimaculatus	+		
Hemipteronotus sp		+	
Labrichthys unilineata			+
Labroides bicolor		+	
L. dimidiatus	+	+	
Lepidoplois axillaris	+	+	
Macropharyngodon meleagris	+		

Table 2. (continued)

Family/Species	April 1973a	April 1973b	May 1974
M. pardalis	+	+	
Pseudocheilinus hexataenia			+
Pterogogus guttatus			+
Stethojulis bandenensis		+	
Thalassoma amblycephalus	+		+
T. lutescens	+	+	+
T. quinquevittata		+	
Xyrichthys taeniurus		+	+
LUTJANIDAE			
Gnathodentex aureolineatus			+
Lethrinus rhodopterus			+
Lutjanus gibbus			+
L. kasmira		+	
MONACANTHIDAE			
Oxymonacanthus longirostris		+	+
MUGILOIDIDAE			
Parapercis cephalopunctatus	+	+	+
MULLIDAE			
Parupeneus bifasciatus	+		
P. cyclostomus			+
P. multifasciatus	+		+
P. pleurostigma		+	+
OSTRACIONTIDAE			
Ostracion meleagris	+	+	+
POMACENTRIDAE			
Abudefduf johnstonianus			+
A. lacrymatus	+	+	+
Chromis hanui		+	+
C. leucurus	+	+	+
C. sp			+
Dascyllus reticulatus	+	+	+
Pomacentrus traceyi	+	+	+
P. vaiuli	+	+	+
P. sp	+		+
SCARIDAE			
Scarus lepidus		+	+
S. sordidus	+	+	+
S. venosus	+	+	+

Table 2. (continued)

Family/Species	April 1973a	April 1973b	May 1974
SCORPAENIDAE			
Pterois antennata	+		
P. volitans	+	+	
SERRANIDAE			
Cephalopholus urodelus	+	+	+
Epinephelus emoryi			+
E. fuscoguttatus		+	
E. merra			+
SPARIDAE			
Monotaxis grandoculis	+	+	+
Synodus variegatus	+	+	+
ZANCLIDAE			
Zanclus cornutus	+	+	+
TOTALS 115 spp	80	71	79

Current Studies

The yacht "Havaiki", a 50 foot sailing catamaran (Fig. 5), was chartered as an oceanographic platform. This vessel served not only as a release point for drift drogues but also as a floating laboratory, berthing, and messing facility for the research team on each of the 24 hour, monthly, current studies. The vessel was moored to a permanent buoy at a point along the 60 foot contour line (Fig. 8). Outboard chase boats, used to track drift drogues, were secured alongside the "Havaiki", when not operating.

Drogues consisting of sheet metal crosses suspended from poured foam buoys (Fig. 6) were released in pairs (one set at 1 m and one set at 5 m) from the "Havaiki", usually at two hour intervals. The drogues were fixed by hand bearing compass lines of position, normally at one hour intervals, by personnel in a chase boat lying alongside the drogue buoys. Sights were taken on previously surveyed shore points. These points were identified with day markers during daylight hours and with colored navigation lights at night. The foam buoys were equipped with cast-in-place strobe lights for night location (Fig. 6). Lines of position were plotted immediately on a chart aboard the "Havaiki" to keep a constant track of each drogue (Figs. 8 to 31). Drogues were usually recovered after passing beyond a 0.5 nautical mile arc drawn on a radius from the release point in the bay. When drifts were found to be slow, greater than three hours without crossing the arc, the drogues normally were recovered. However, recovery times varied at the discretion of the on-duty watch standers.

Simultaneously with each fix of the drogue positions, wind speed and direction were determined with a hand held anemometer and the sea and swell

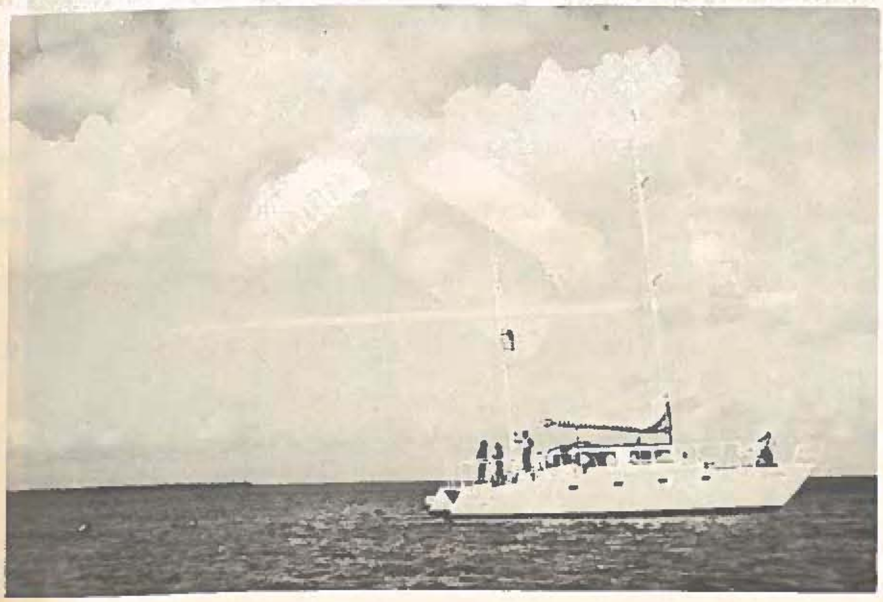


Figure 5. Photo of the Yacht "Havaiki" which served as our research platform.

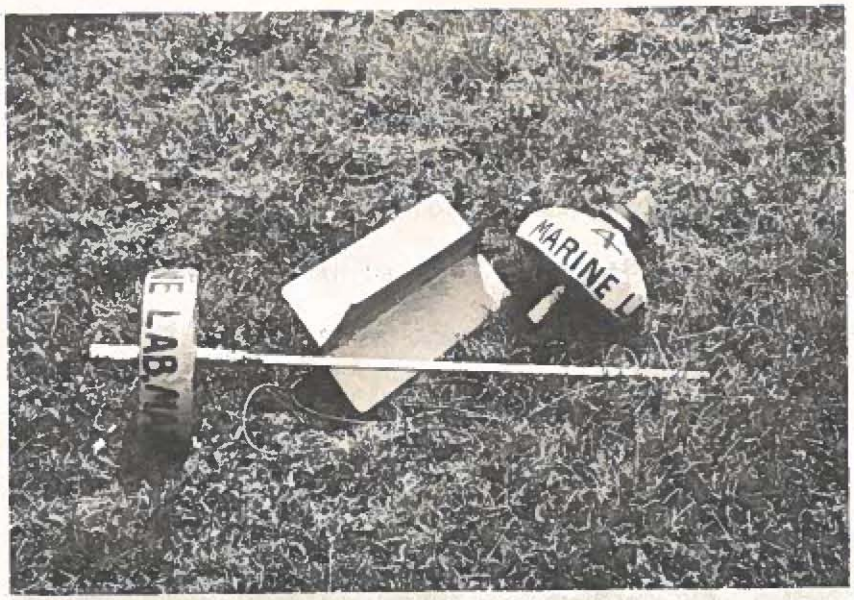


Figure 6. Photo of drogue showing the sheet metal drift cross, the strobe equipped night buoy, and the day buoy.

height and direction were recorded. A tide staff was placed at the head of the bay and read every hour. The staff readings were corrected to predicted tide times and heights at Apra Harbor, Guam (Figs. 8 to 31).

Oceanographic stations of twenty-four hour duration were occupied to insure coverage of all phases of Guam's semi-diurnal tides. Both spring and neap tides were encountered during the study. An annual cycle was considered necessary to cover seasonal variations in currents brought about by variations in the tradewinds and the tradewind induced North Equatorial Current.

Winds on Guam tend to be strong and consistently from the east and northeast (tradewinds) during the dry season from January to May. They are weak and variable during the wet season from July to November. June and December are transitional months (Tracey, et al., 1964).

Because this part of Guam lies in a deep lee or wind shadow, there was little sea or swell action in the bay during the study periods considered. On those days when strong ocean swells and wind whipped sea conditions existed in the bay (southwesterlies), it was not possible to safely anchor the "Havaiki".

The first 24 hour station was completed in May 1973 and the last in May 1974. All months were sampled with the exception of January 1974. Marine Laboratory personnel were occupied with an off island project during the first part of this month and encountered bad weather in the latter half.

Drift drogues were chosen over in situ current meters primarily because we feel that they are a better measure of drifting water masses, with entrained sewage effluent, than anchored meters. The data in Figures 8 to 31 show the many changes of direction as water drifts out of Toguan Bay. Only a very complicated array of current meters could duplicate these data, if at all, and the cost and time involved in their operation and maintenance would have been prohibitive within the narrow budgetary confines of this project.

The drogues do have some disadvantages. Their buoys, although cast in low profile, nevertheless have a tendency to respond in part to the wind. Hence, a drogue track is often a resultant vector between wind friction on the buoy and current pressure against the drift cross. Thus the actual tracks might diverge somewhat from their original positions in the water mass over long distances. For this reason, the 0.5 nautical mile study radius was generally adhered to. Drifts of this distance or slightly beyond were considered to retain the accuracy necessary to predict the basic course of water exiting the bay. There are also differences in vector components and speeds between 1 m and 5 m drogues. The 1 m drogues drift in the upper meter of the water mass which is considerably influenced by wind friction. Thus these drogues tend to follow wind driven surface currents. The 5 m drogues are much less responsive to wind forces and surface currents acting on the buoys. Their drift follows more closely that of the general water mass. In the absence of deep currents (greater than one meter), 5 m drogues react to the same forces as 1 m drogues. The 5 m drogues are somewhat slower than the 1 m ones because of the additional line friction between the buoy and the cross, and the reduced wind response.

The differences noted above in water movements between the upper meter or so and the deeper layers is why both 1 and 5 m drogues were used. Moreover, previous experience (Jones and Randall, 1971) with an ocean outfall convinced us of the need for a two depth study. Sewage effluent regardless of the type of treatment is a low density fresh water solution. Upon injection in the marine environment, and in many cases diffuser design to the contrary, this material rises rapidly to the surface of the more dense seawater. In the absence of other energy in the system, the effluent spreads out at the atmosphere/water interface as if striking a pane of glass. Under these conditions the material would continue to spread by diffusion in all directions. Where wind sweeps across such a surface, the effluent in the upper one or two meters is carried off downwind. The 1 m drogue provides a measure of this drift. On the other hand, as the effluent travels farther from the injection point, it tends to mix vertically with deeper water layers and hence the need for the deeper set drogue.

A review of the potential, theoretical forces that may act against a drogue or water mass is necessary at this point. The wind will be considered first and as if it was the only effect. As noted above, winds on Guam vary in speed and direction with seasonal changes. However, the wind rose in Figure 7 shows the predominant winds to be from the east and northeast with a fairly frequent southeasterly component. Westerlies are uncommon and usually associated with storms.

Under normal conditions, wind funnels down the Toguan River valley and impinges upon the surface waters of Toguan Bay. The resulting friction sets the surface waters in motion to the west and west southwest. We presume that all water leaving the bay on the surface is either replaced from deeper layers or from the sides, but have no direct evidence for this mechanism. As the surface waters, driven out of the bay, approach the 0.5 nautical mile arc they emerge from the general wind shadow, caused by the island, and the velocity of the wind and resultant drift increases in speed. On days when strong northeasterlies prevail, the drift would gradually shift to a more southwesterly direction.

When southeasterlies prevail, the valley winds decline and the tendency would be for the drift to be almost directly to the north northeast. This was indeed the case for a number of drifts, for example those of Figures 8 and 9.

Fortunately, westerlies are rare and though no such periods were sampled during the study, we are reasonably certain that such winds would drive surfacing effluent onto or along the fringing reef and shore. Since these westerlies are often storm generated, the shoreward movement will frequently be assisted by swells. Figure 3A is actually a picture taken under such conditions. It is not representative of the normally calm Toguan Bay (Fig. 3B).

There is a tendency for the wind to abate in the evening and early morning hours, which should result in a considerable reduction in the amount of surface water and entrained sewage leaving the bay. This was the case for drift 7, Figures 14 and 15. Effluent might thus accumulate in the bay, possibly as a large slick, during the night and would not begin to move out until the morning winds picked up and began to blow from the east and northeast. Ironically, any attempt by a treatment plant operator to hold effluent in a wet well during the day and release it at night, for aesthetic reasons might well find the opposite effect. Tour busses topping the hill (near Toguan Peak, Fig. 7) on the Umatac side of the bay would likely be greeted by a great and foul smelling slick on the surface of this pristine bay.

Another phenomenon, but one which we have little data for, is the effect of the North Equatorial Current. The following general comments are in part from Jones and Randall (1973). Transport of water masses around islands in Marianas is similar to that for most island in the Central Pacific (Avery <u>et al.</u>, 1963). The prevalent northeast trade-winds of the area play a major role in generating the North Equatoral Current which sweeps past the islands from east to west. This great current is no doubt responsible for much of the energy that transports water along the coast of Guam. The movement of the current is presumed to be as theorized by Emery (1962), in that it tends to split on the northeast corner of the island and stream around both north and south ends. These two streams would theoretically converge somewhere to the west of the island and continue in a westerly or southwesterly direction.

As the NEC sweeps around Guam, portions of the streams may be distorted and forced into eddy systems which are further complicated by prominant headlands and local submarine topography. We suspect the presence of such eddies in or near Toguan Bay but were unable to discern them with our methods and restricted study area. These eddy currents may also alter their flow because of seasonal changes in strength and direction of the NEC.

Finally, there are also tidal currents which other studies have shown to exist along part of Guam's coastline (Jones and Randall, 1971; Jones and Randall, 1973). These currents are often bidirectional, showing current reversals with tide changes.

If the above parameters were not problems enough by themselves, it is distressing to note that all may occur at the same time, in varying degrees of magnitude and time, and either mask or enhance one another. When faced with the problem of determining whether a drift track is caused by the NEC, an eddy of the NEC, a specific tide condition, wind direction and speed, or a combination of them all, we elected to concentrate more on effect rather than cause. We may now turn our attention the actual results of our studies of the Toguan Bay current regime.

In general it is possible to say that, under conditions of the normally prevailing east and northeast winds, most drift tracks shown in Figures 8 to 31 clearly demonstrate that surface water tends to drift out of the bay and into the Philippine Sea. Only four drifts moved in a definite easterly direction (Figs. 8 and 9) although several moved southeasterly. Grounding of drogues occurred on 14 occasions during one of the 24 hour studies and many of these during the same drift cast (Figs. 8 and 9). Twelve of these groundings occurred along the fringing reef to the north of the study area, with one crossing Umatac Bay and grounding opposite Fort St. Jose (Fig. 7). In all these cases there was a strong south to south southeasterly wind blowing instead of the normally prevailing east or northeasterlies (Figs. 8 and 9). The remaining two of the 14 groundings occurred in the confines of the bay itself on both sides of the river mouth. Both were 1 m drogues and their 5 m counterparts were near grounding when recovered. No other groundings occurred during the remaining 11 field trips. West wind conditions were not encountered during the study but as noted above, there is good reason to believe that most drogue casts would ground under these conditions.

Inspection of Figures 8 to 31 show that trips I, IV, V, and VI were dominated by north and northwesterly drifts from the bay. Trip IX showed a variable condition and trips, II, III, VII, VIII, X, XI, and XII all show dominant south and southwesterly movements. The more detailed drift data in Table 3 verifies that south to southwesterly drifts dominate over the entire

Table 3. Summary of drift information based on hourly observation of drogue direction and tide. F = Flood, E = Ebb, T = Tide turning (high or low water)

Drift Direction	Tide	1 m No. (hrs.)	5 m No. (hrs.)
N-NW	F	60	66
S-SW	F	69	64
W	F	10	11
N-NW	E	36	38
S-SW	E	60	63
W	E	28	24
N-NW	T	33	37
S-SW	T	49	52
W	T	21	12

	Totals (hrs.)		% of Total drift time
N-NW	129	+ 141 = 270	37%
S-SW	178	+ 179 = 357	49%
W	59	+ 47 = 106	14%
		733	

study period. It is really not clear either from inspection of Figures 8 to 31 or the data in Table 3 whether or not there is a distinct bidirectional flow related to tide cycle. Data in the table do suggest a tendency of the drogues to move north to northwest more often on flood tides than on ebbs. No such trend seems obvious in the south and southwesterly drifts, in fact it would appear that there is about an even chance of south and southwesterly drifts occurring on either floods or ebbs (Table 3). Westerly drifts were less common (14% of the total observations) than either north and northwesterlies (37%) or south and southwesterlies (49%). The westerlies did have a tendency to appear during ebbs more often than floods.

If we assume that there is at least a weak bidirectional tendency, masked by other parameters including the wind, then the northbound floods are logical as would be southbound ebbs. As the crest of the tide wave approaches Guam from the east it would be expected to influence the southwest coast near Toguan Bay by producing a tidal current flowing from southeast to northwest. As the crest of the wave passes Guam this inshore tidal current would theoretically shift back to the southeast. However, the predicted northerly movements on flood currents might be resisted by prevailing northeast winds. The reverse is true of the possible southbound ebbs, they would be assisted by the northeast winds. Since we know so little of the NEC or its potential eddies, we are forced to assume that the wind plays a dominant role. The prevailing northeasterly winds would thus result in a higher percentage of southwesterly drifts than northwesterly ones. Moreover, when strong northerly drifts did occur from Toguan Bay, a high percentage of these drifts were assisted by the somewhat rare south and southeasterly winds (Figs. 8, 9, 14 and 15).

Table 4. Summary of drift/time information in relation to the 0.5 nm arc (Figs. 8-31). Wide variation in speeds and drogue recovery times made these data an approximation only.

Observations	Drogues 1 m	Drogues 5 m
Total number of drogues released	105	104
Total drift time	368 hrs.	377 hrs.
Range of drift time	1-12 hrs.	1-12 hrs.
Average drift time per drogue	3.5 hrs.	3.6 hrs.
No. of drogues failing to pass arc	45 (43%)	74 (71%)
Drift time for drogues failing to pass arc	158 hrs.	272 hrs.
Average drift time for drogues failing to pass arc	3.5 hrs.	3.8 hrs.
Percent of total drift time failing to pass arc	49%	75%
No. of drogues passing arc	60 (57%)	30 (29%)
*Drift time for drogues passing arc	165 hrs.	93 hrs.
Average drift time of drogues passing arc	2.8 hrs.	3.1 hrs.
Percent of total drift time passing arc	51%	25%

* Does not count drift time beyond 0.5 nm arc.

Although our drift studies show that there is little doubt that, under normal wind and oceanographic conditions, sewage effluent would escape from Toguan Bay, there is yet another point to consider. The rate of drift may itself be a problem. In many instances both the 1 and 5 m drogues drifted rapidly clear of the bay, but a significant number of them did not. These slow and often meandering drifts might well result in an accumulation of effluent in the bay during certain times. The data in Table 4 show that 43% of the 1 m and 71% of the 5 m drogues failed pass beyond the 0.5 nautical mile arc after drifting an average of 3.5 and 3.8 hours respectively. In terms of hours of drift failing to travel more than 0.5 nautical miles, the 1 m drogues consumed 43% of their total drift time without passing the arc and the 5 m ones consumed 72%. The difference in time between the 1 and 5 m drogues was expected. Although it is gratifying to know that more than half of the 1 m drogues exceeded the required (0.5 nautical miles) distance, it in no way suggests that this number is satisfactory. In short, there is a possibility that circulation in the confines of Toguan Bay may produce too slow a turnover to handle the constant release of effluent from the combined or even one of the villages. Since we have no data on anticipated volume of sewage, we cannot comment further on this matter.

A Navy oceanographic survey (Anon., 1971) was conducted in Bile Bay (Fig. 7) at a point just south of our study site. An in situ current meter was set at a depth of 50 feet. This meter ran for about one month (February) and showed an average speed of 0.15 kts with lows of 0.03 kts and highs of 0.31 kts. These speed data are in good agreement with our 5 m drift data over a 12 month period. We found a range of drift of 0.03 to 0.66 kts

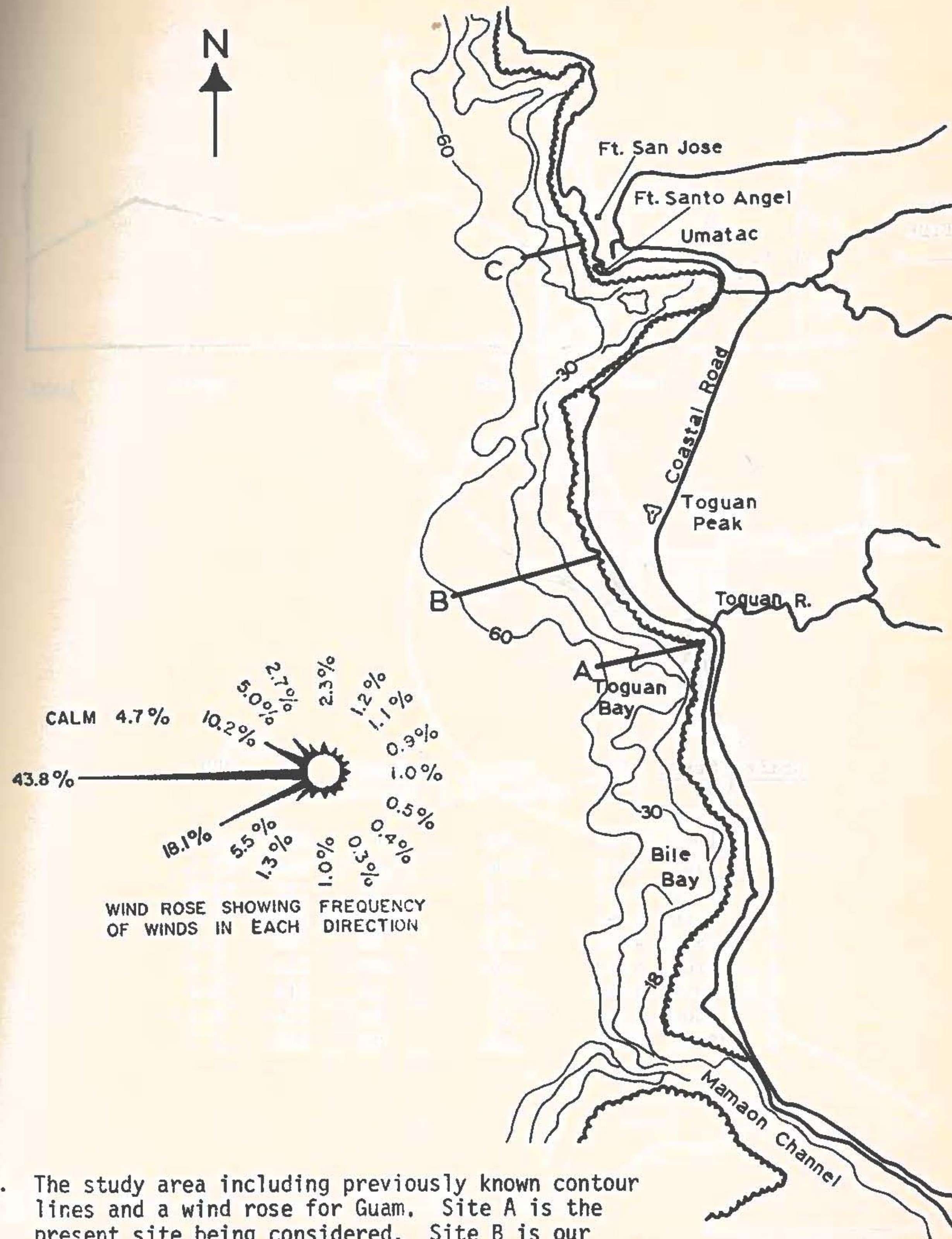
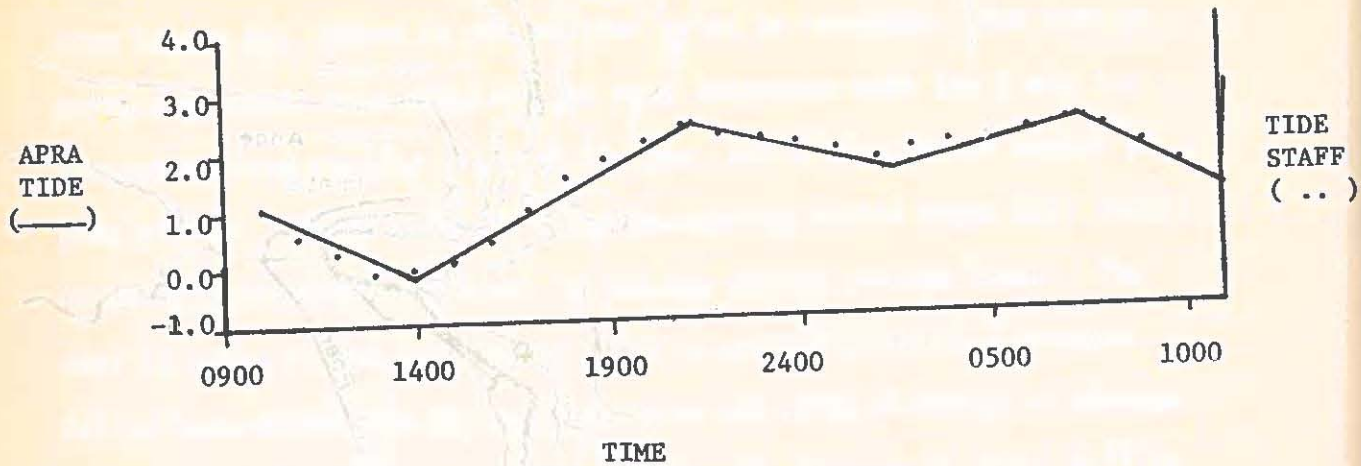


Figure 7. The study area including previously known contour lines and a wind rose for Guam. Site A is the present site being considered. Site B is our recommended site. Site C is the emergency outfall now being constructed for Umatac.



Drift	Start	ΔT	Dist. (Naut. Mi.)	Speed (Knots)	Wind Dir.	Wind MPH
1	1000	4:04	.93	.23	180	20.9
2	1100	4:05	1.06	.26	180	23.1
3	1400	3:05	.93	.30	170	22.0
4	1400	1:58	.63	.32	180	23.1
5	1800	4:00	1.15	.29	080	6.5
6	2100	5:00	.38	.08	110	7.7
7	0000	4:00	.57	.14	110	6.6
8	0400	2:00	.17	.09	110	6.6
9	0600	2:08	.10	.05	140	7.7

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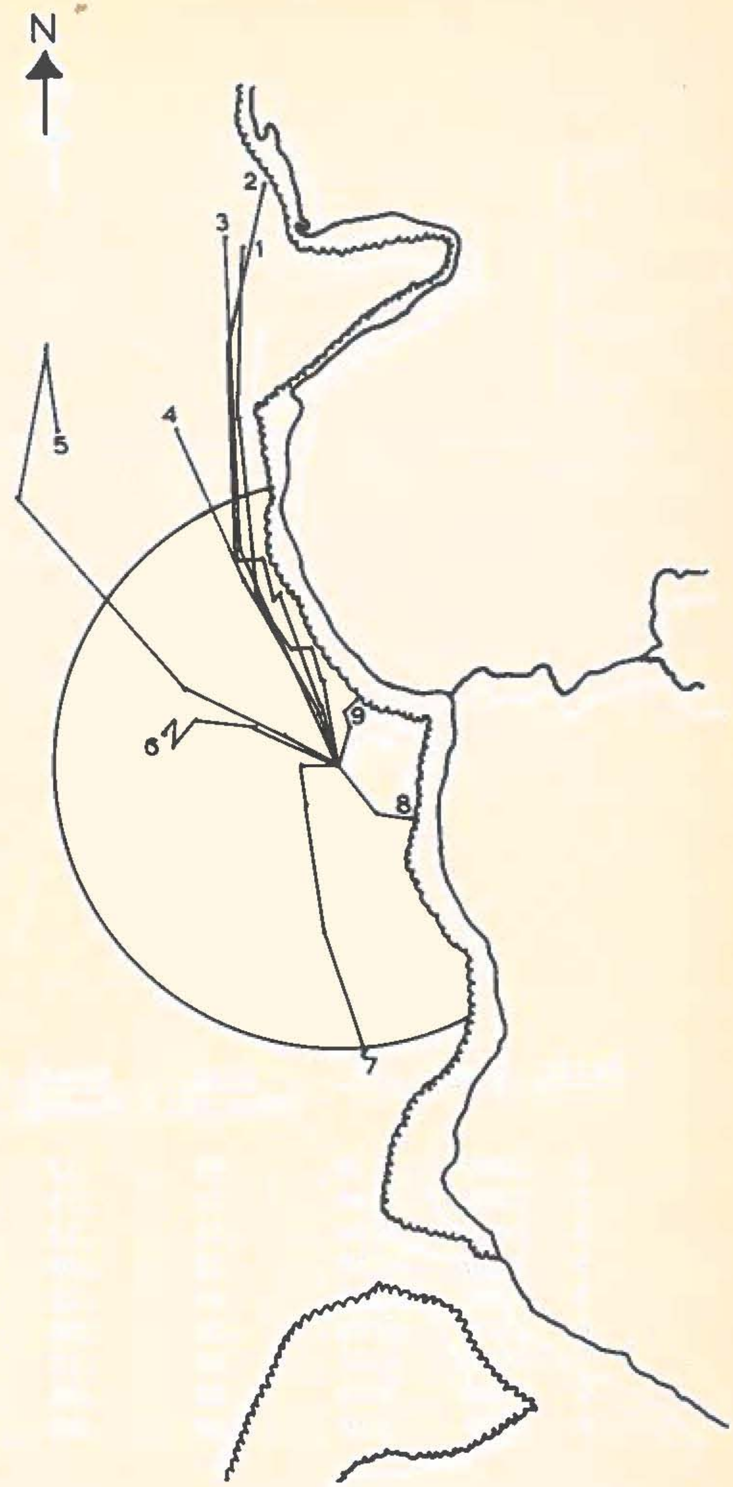


Figure 8. Trip I, 1 m drogue (May 17-18, 1973).

0.5 naut. mi.

Drift	Start	ΔT	Dist. (Naut.Mi.)	Speed (Knots)	Wind Dir.	Wind MPH
1	1000	3:30	.59	.17	180	22.0
2	1100	4:08	.76	.19	180	23.1
3	1400	4:00	.51	.13	170	22.0
4	1400	4:00	.35	.09	170	22.0
5	1800	4:05	.46	.11	080	6.6
6	2100	5:02	.30	.06	110	7.7
7	0000	4:02	.44	.11	110	6.6
8	0400	3:05	.20	.06	110	5.5
9	0600	3:00	.10	.03	140	9.9

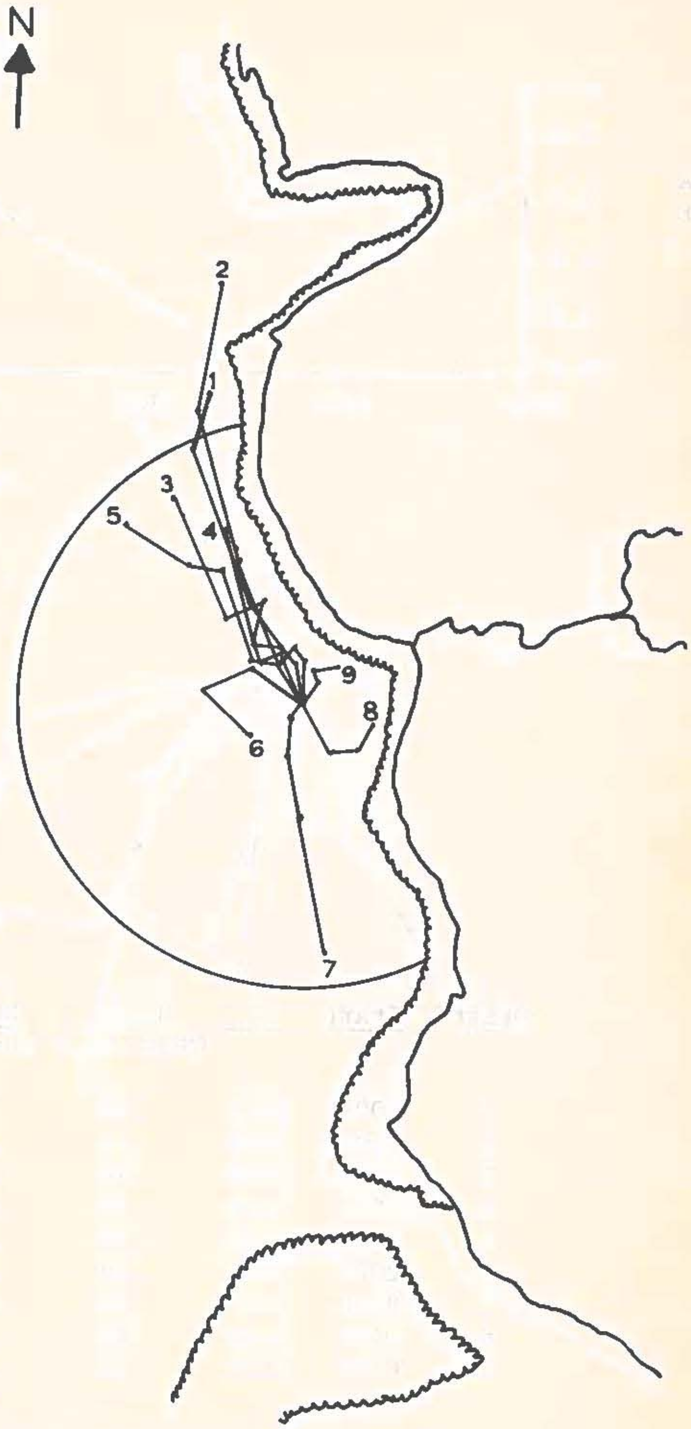
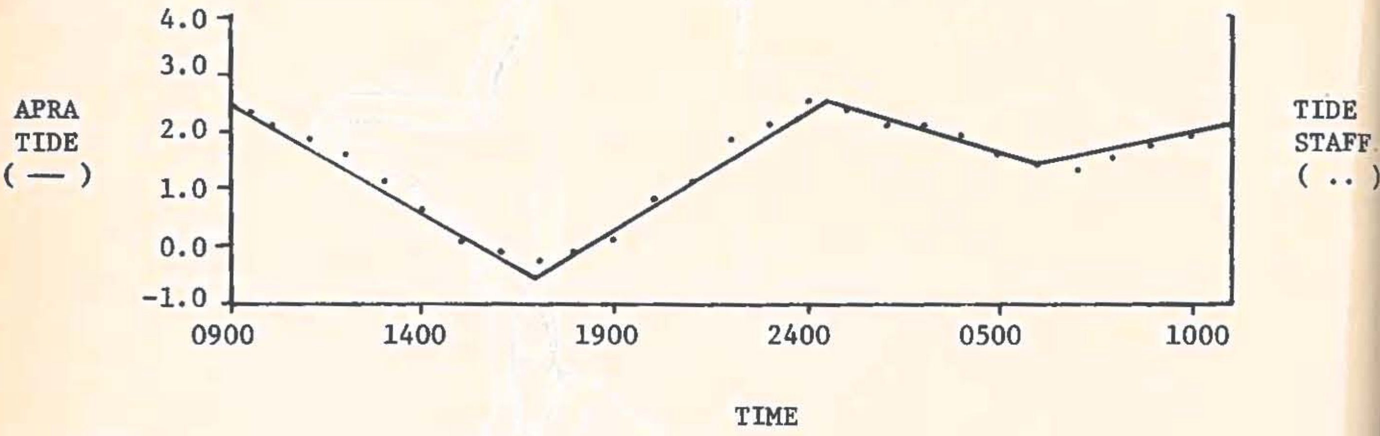


Figure 9. Trip I, 5 m drogue (May 17-18, 1973).



Drift	Start	ΔT	Dist. (Naut.Mi.)	Speed (Knots)	Wind Dir.	Wind MPH
1	1000	2:03	.65	.31	110	24.2
2	1200	3:00	.75	.25	110	25.3
3	1400	3:02	.74	.25	095	18.7
4	1600	3:06	.49	.16	090	17.6
5	1800	6:02	.39	.07	090	14.3
6	2000	5:02	.33	.07	085	11.0
7	0100	6:24	.81	.13	080	12.1
8	0400	3:10	.46	.14	075	13.2
9	0700	3:12	.56	.18	080	12.1

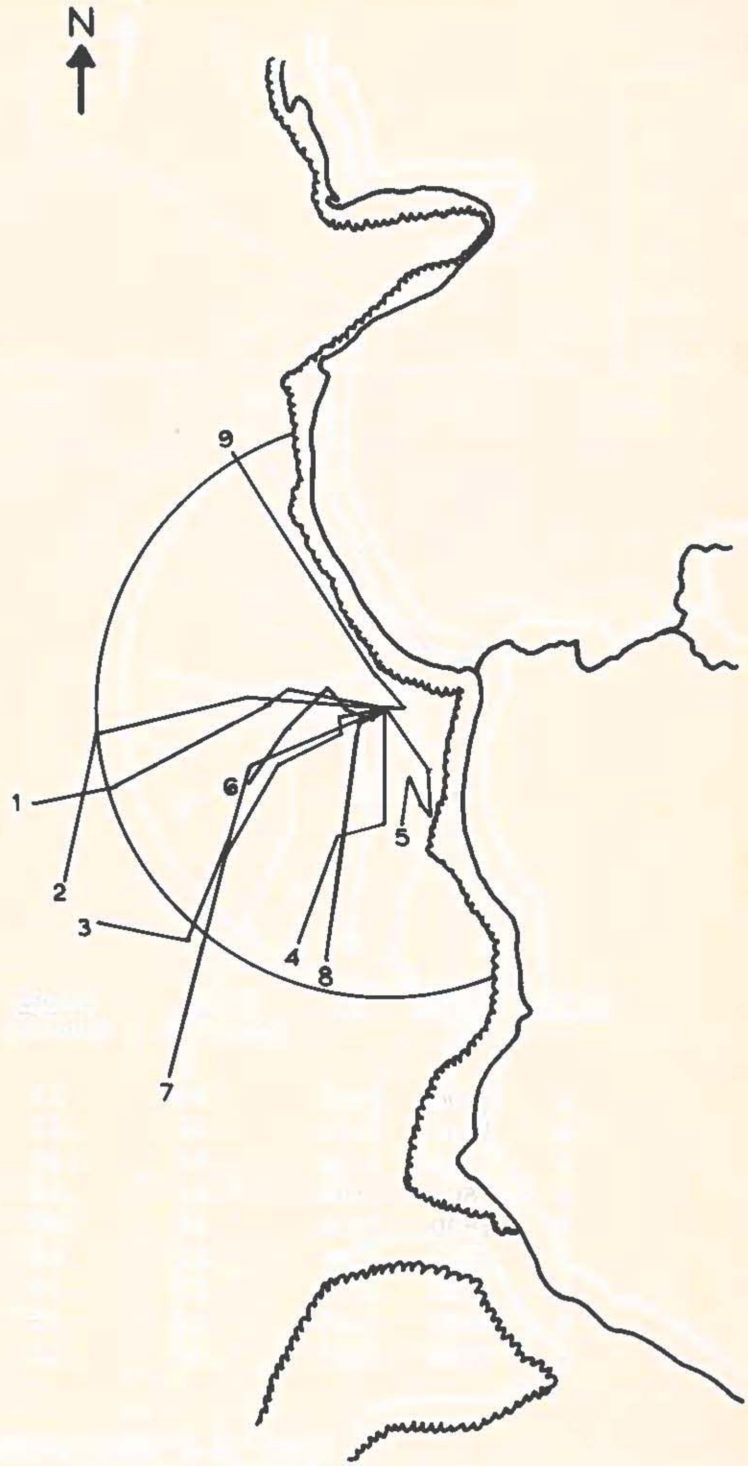


Figure 10. Trip II, 1 m drogue (June 5-6, 1973).

0.5 naut. mi.

Drift	Start	ΔT	Dist. (Naut.Mi.)	Speed (Knots)	Wind Dir.	Wind MPH
1	1000	3:02	.40	.13	110	24.2
2	1200	3:15	.41	.12	110	25.3
3	1400	3:00	.43	.14	095	18.7
4	1600	3:04	.17	.05	090	17.6
5	1800	6:00	.48	.08	090	14.3
6	2000	5:00	.21	.04	085	11.0
7	0100	6:24	.87	.14	080	12.1
8	0400	3:12	.43	.13	075	13.2
9	0700	3:07	.38	.12	080	12.1

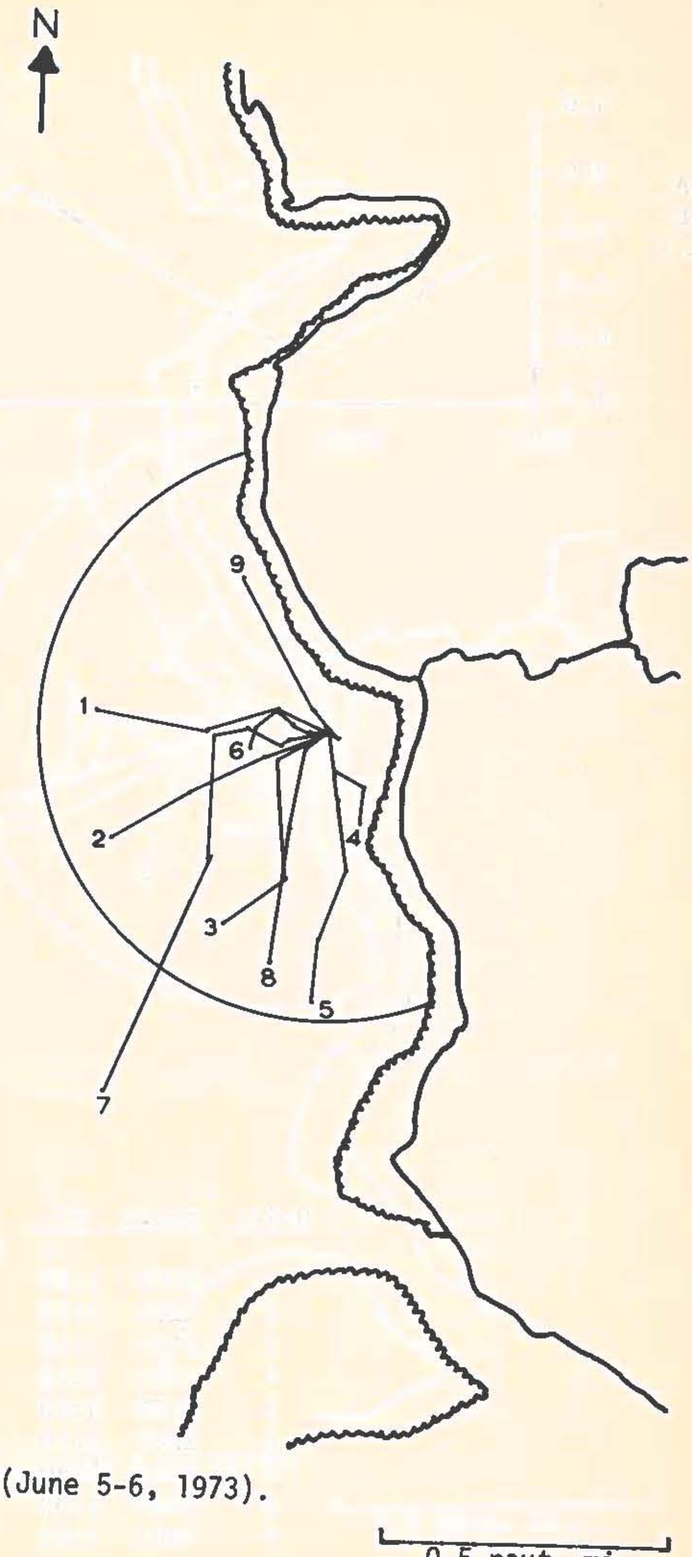
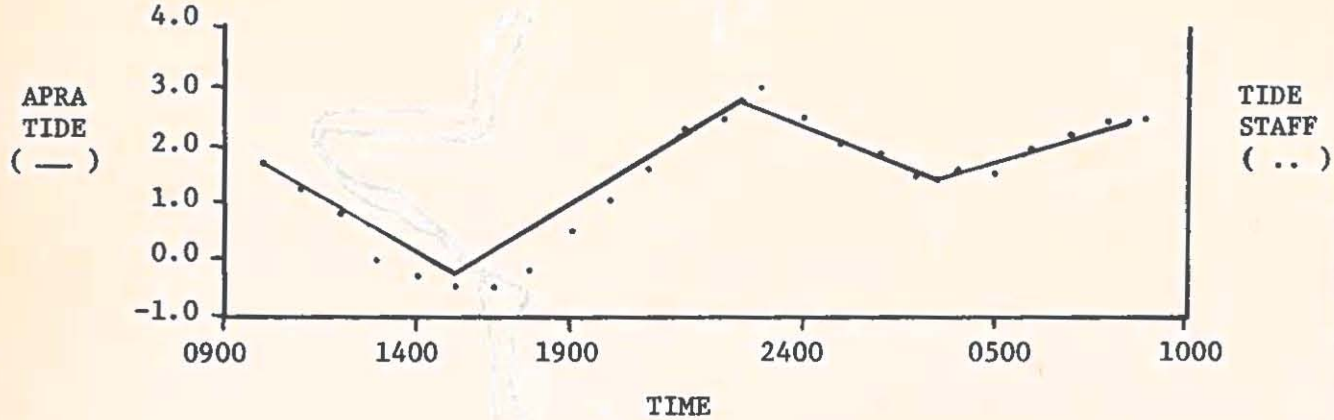


Figure 11. Trip II, 5 m drogue (June 5-6, 1973).



					Wind	
Drift	Start	ΔT	Dist. (Naut.Mi.)	Speed (Knots)	Dir.	MPH
1	1000	2:00	.36	.18	065	17.6
2	1200	3:20	.95	.29	075	22.0
3	1400	3:06	.68	.22	070	19.8
4	1600	3:10	.52	.16	070	18.7
5	1800	6:00	.61	.10	070	13.2
6	2200	5:10	.61	.12	080	11.0
7	0200	6:40	.33	.05	075	13.2
8	0400	6:00	.28	.05	070	15.4
9	0800	2:05	.19	.09	075	18.7

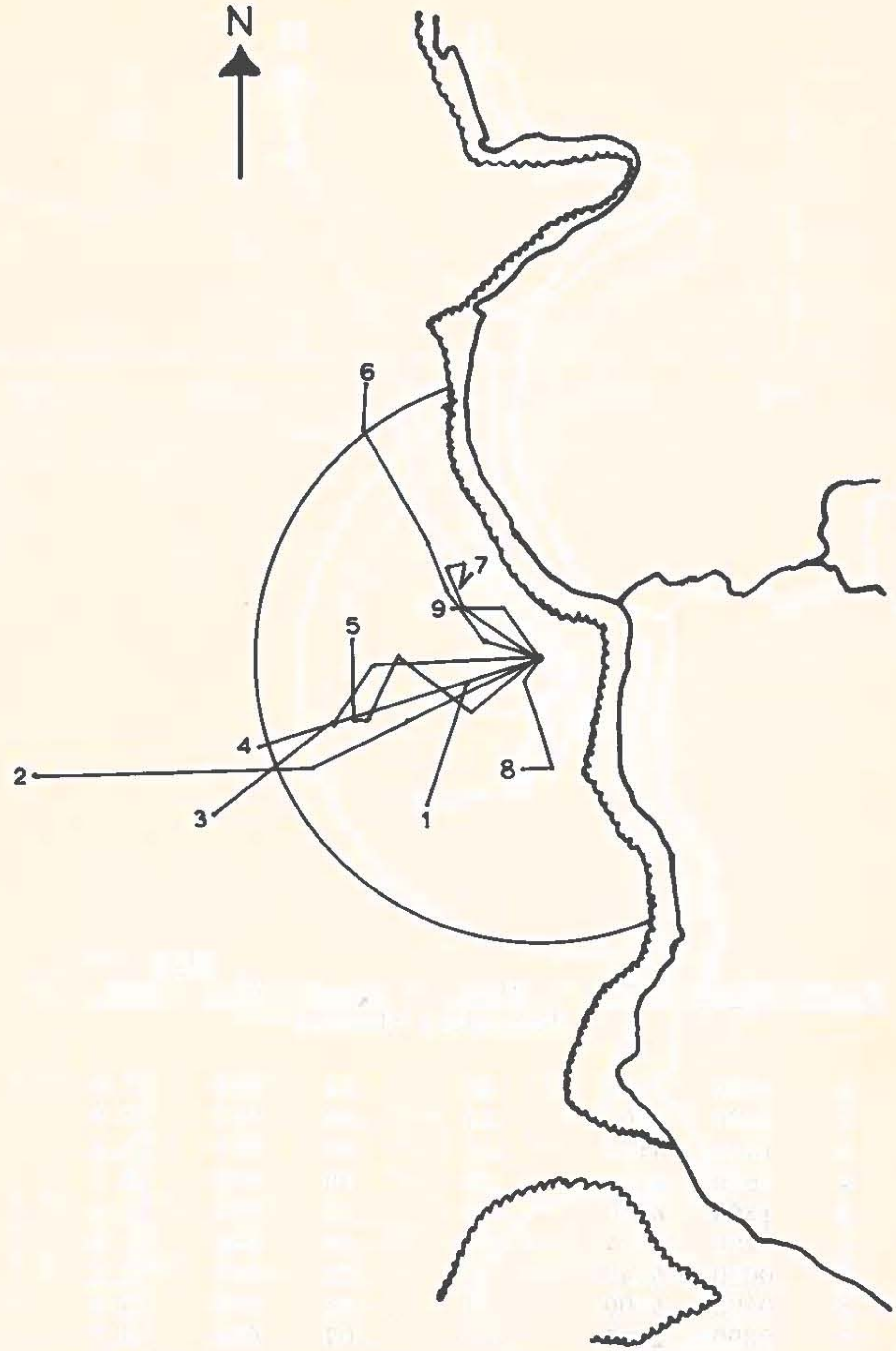


Figure 12. Trip III, 1 m drogue (July 2-3, 1973).

0.5 naut. mi.

Drift	Start	ΔT	Dist. (Naut.Mi.)	Speed (Knots)	Wind Dir.	Wind MPH
1	1000	2:00	.21	.11	065	17.6
2	1200	3:05	.24	.08	075	22.0
3	1400	4:28	.41	.09	070	19.8
4	1600	3:07	.26	.08	070	18.7
5	1800	6:10	.44	.07	070	13.2
6	2200	5:14	.54	.10	080	11.0
7	0020	6:40	.36	.05	075	13.2
8	0400	6:00	.19	.03	070	15.4
9	0800	2:05	.15	.07	075	18.7

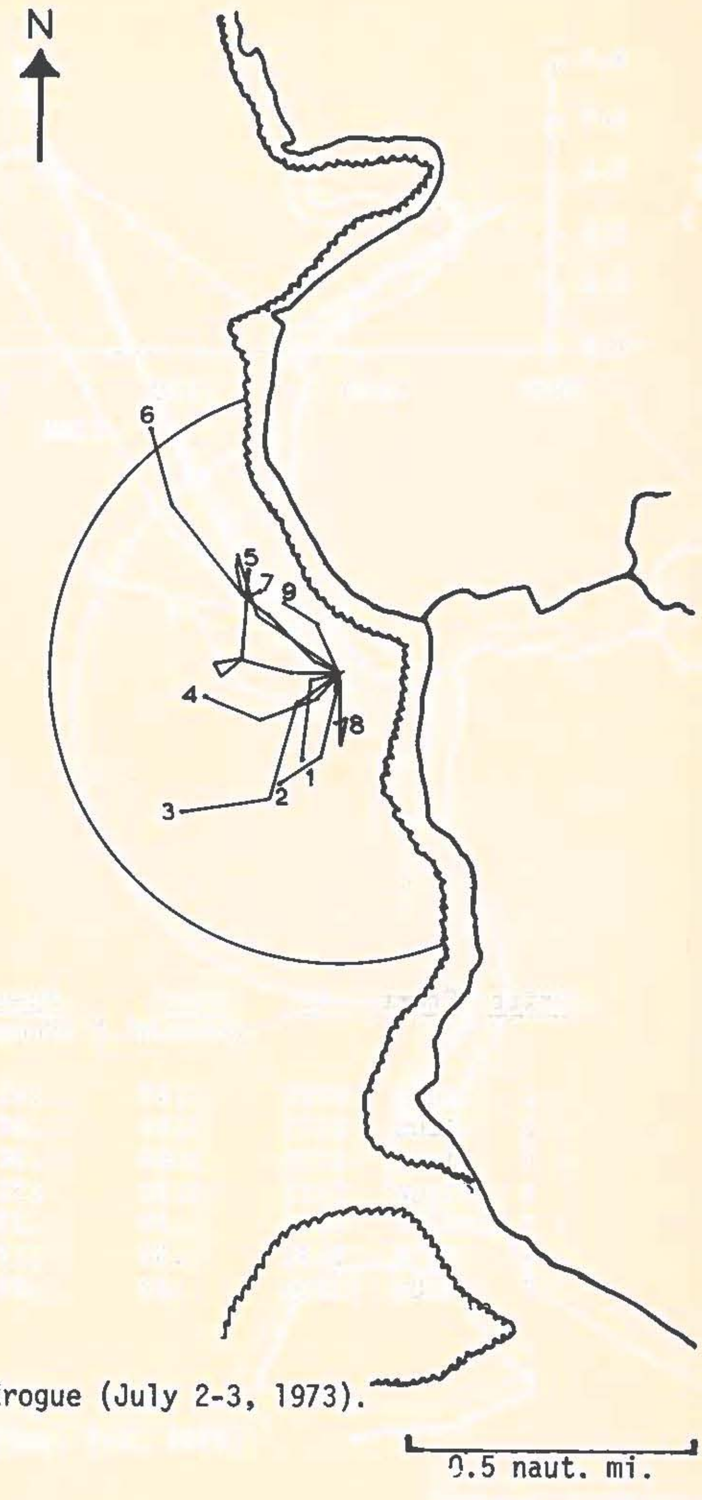
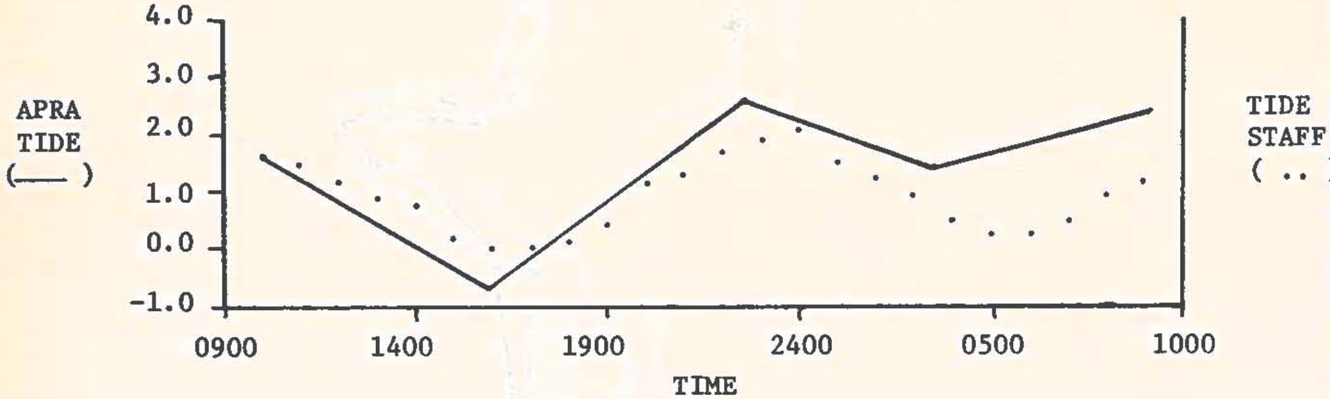


Figure 13. Trip III, 5 m drogue (July 2-3, 1973).



Drift	Start	ΔT	Dist. (Naut.Mi.)	Speed (Knots)	Wind Dir.	Wind MPH
1	1000	2:05	.95	.45	125	13.2
2	1200	2:35	1.04	.40	140	18.7
3	1400	2:03	1.06	.50	140	15.4
4	1600	2:15	1.23	.53	170	18.7
5	1800	2:05	.49	.23	070	15.4
6	2030	2:30	.38	.15	070	6.6
7	2200	12:00	.62	.05	090	8.8

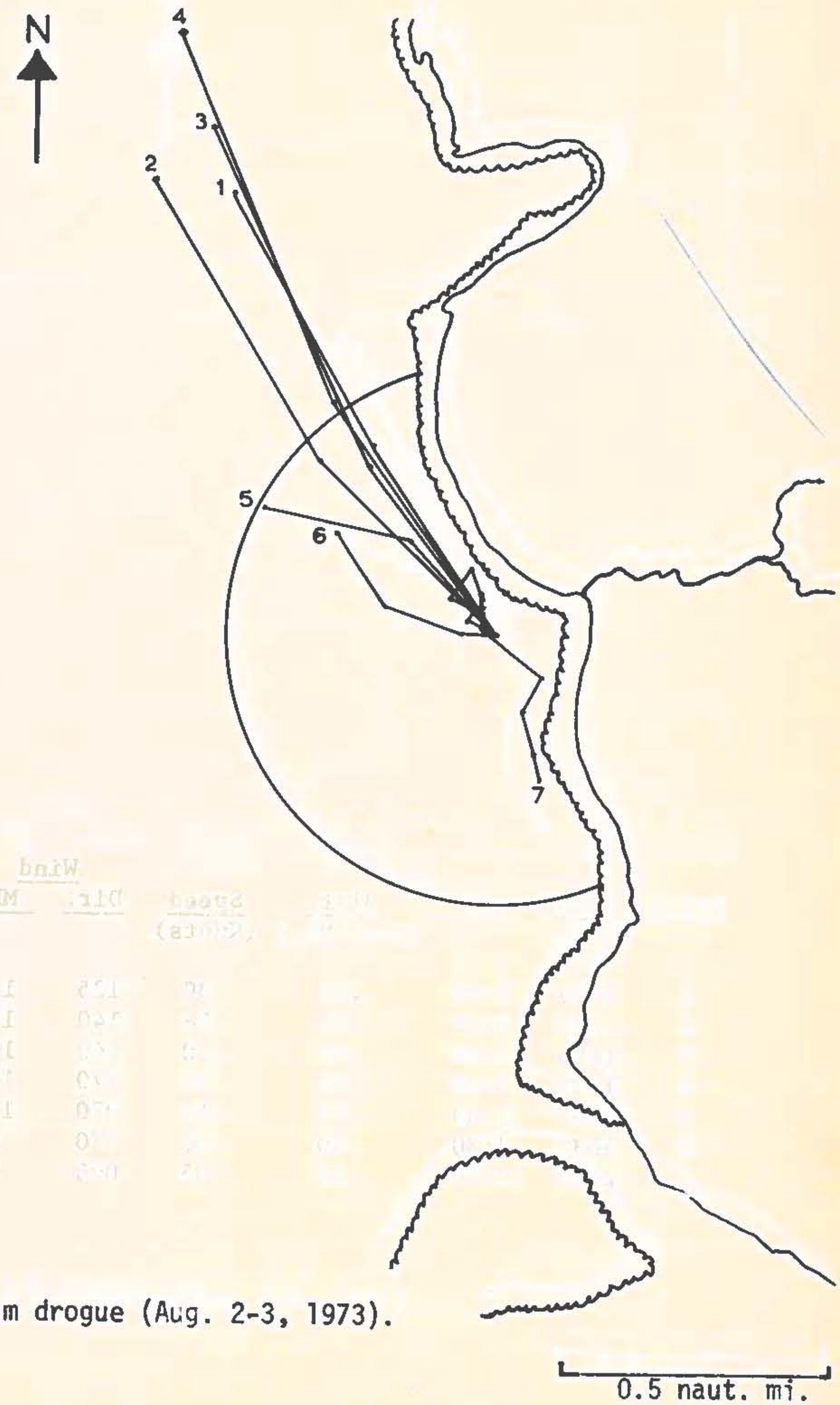


Figure 14. Trip IV, 1 m drogue (Aug. 2-3, 1973).

Drift	Start	ΔT	Dist. (Naut.Mi.)	Speed (Knots)	Wind Dir.	Wind MPH
1	1000	2:00	.59	.30	125	13.2
2	1200	2:05	.38	.18	140	18.7
3	1400	2:00	.59	.30	140	15.4
4	1600	2:05	.80	.38	170	18.7
5	1800	2:00	.29	.15	070	15.4
6	2030	2:30	.50	.20	070	6.6
7	2200	12:00	.62	.05	090	8.8

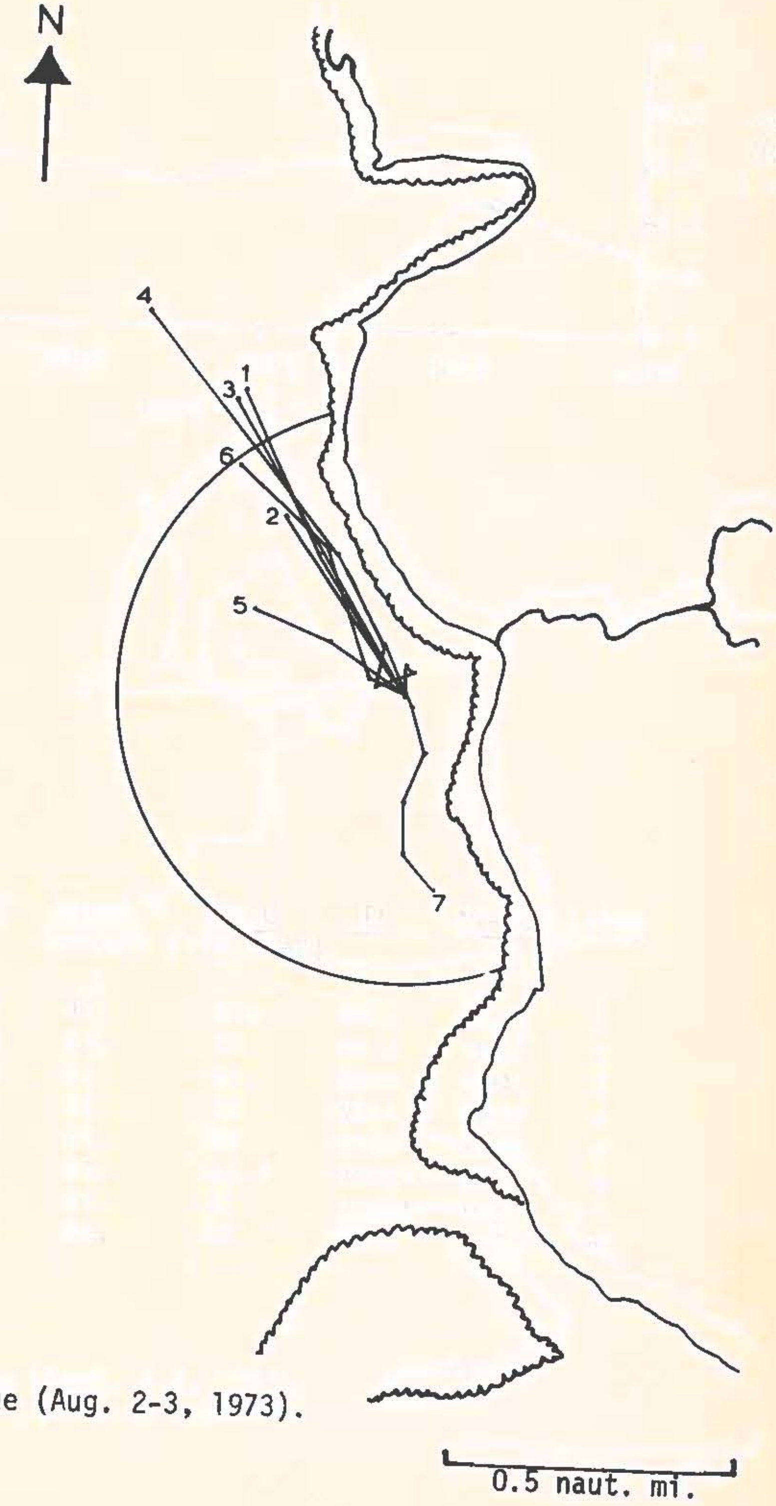
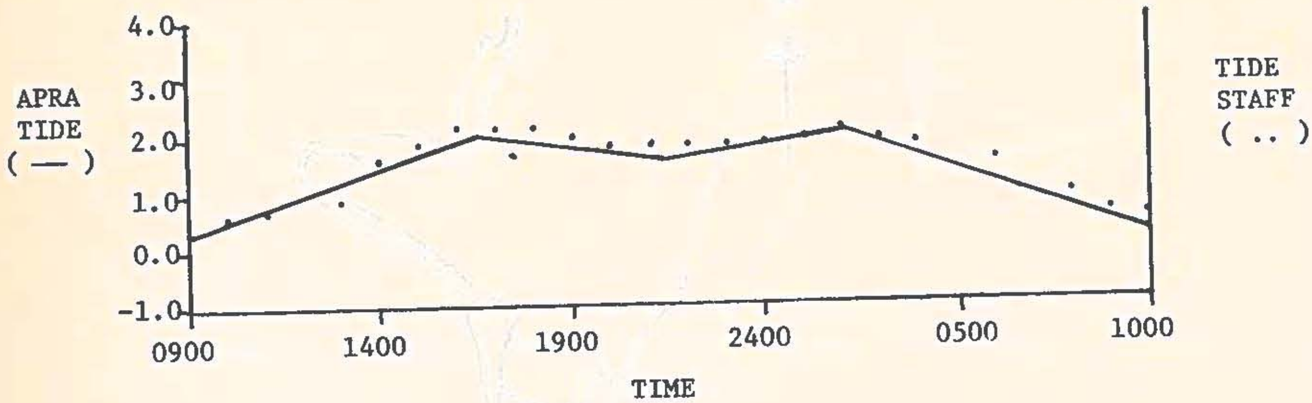


Figure 15. Trip IV, 5 m drogue (Aug. 2-3, 1973).



Drift	Start	ΔT	Dist. (Naut.Mi.)	Speed (Knots)	Wind Dir.	Wind MPH
1	1000	1:00	.11	.11	150	16.5
2	1200	1:10	.51	.43	115	11.0
3	1400	2:05	.40	.19	065	16.5
4	1600	2:22	.51	.21	055	18.7
5	1815	4:45	.70	.15	100	13.2
6	2200	12:00	1.16	.10	120	13.2
7	0000	10:10	.38	.04	125	14.3
2b	1200	1:08	.53	.48	115	16.0

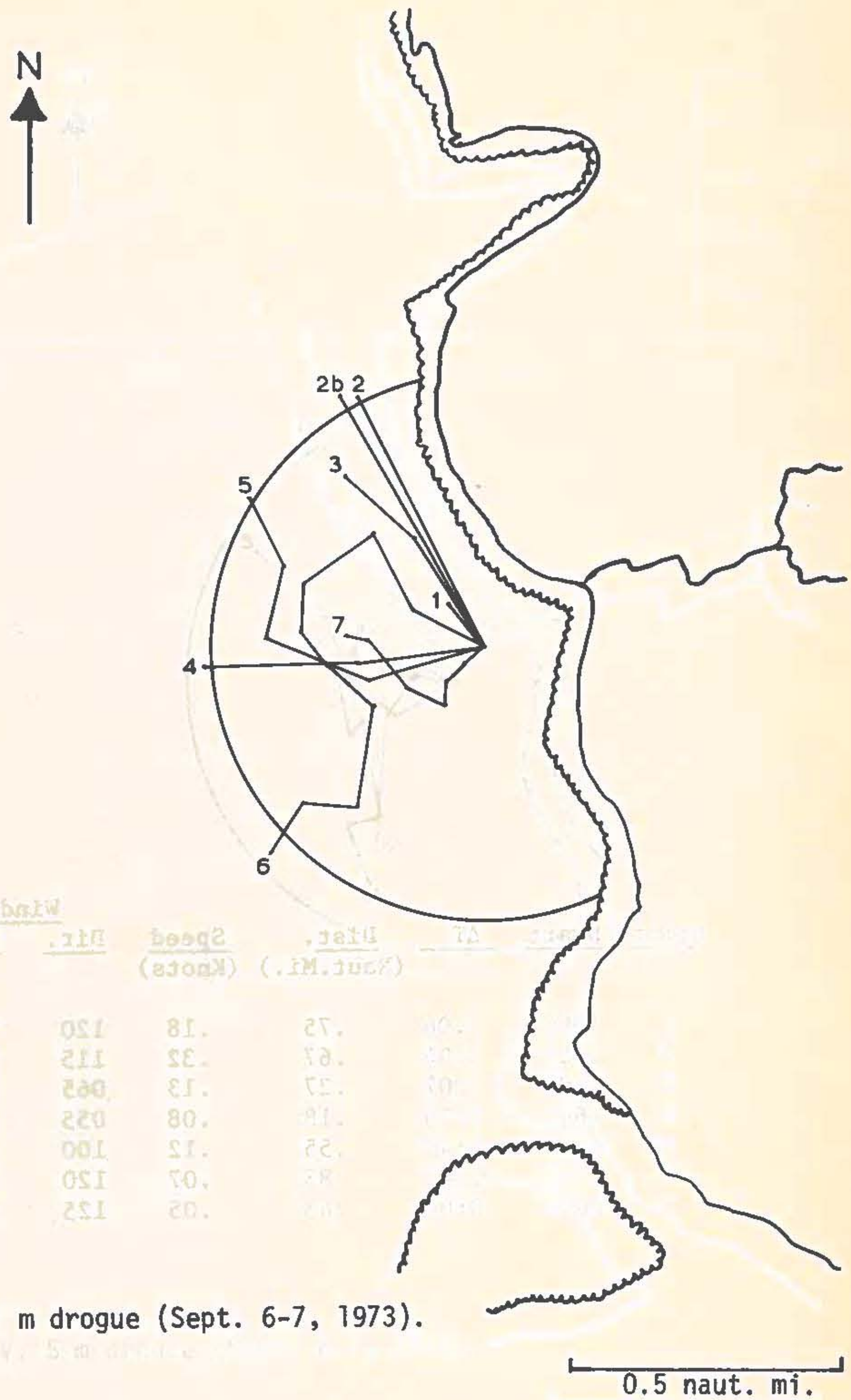
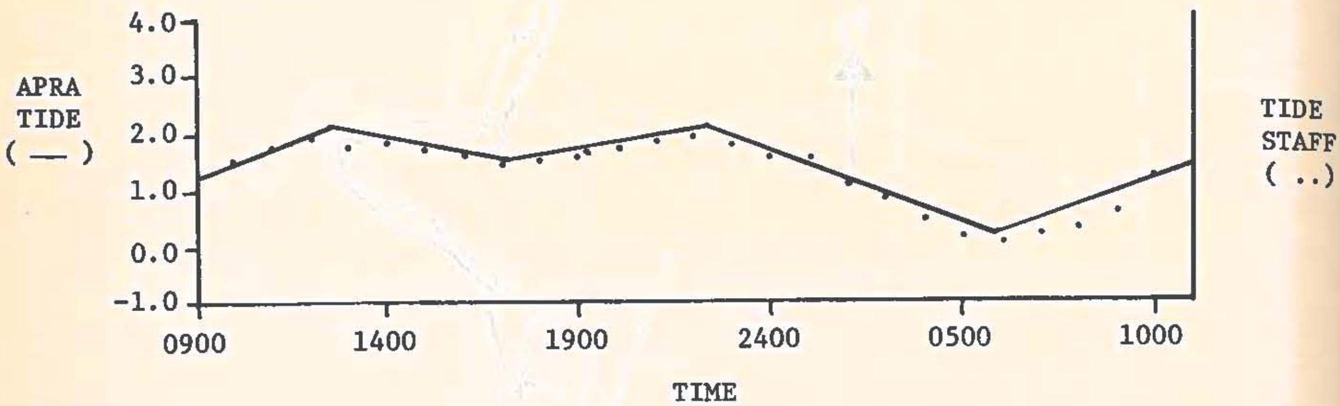


Figure 16. Trip V, 1 m drogue (Sept. 6-7, 1973).

Drift	Start	ΔT	Dist. (Naut.Mi.)	Speed (Knots)	Wind Dir.	Wind MPH
1	1000	4:06	.75	.18	120	14.3
2	1200	2:04	.67	.32	115	11.0
3	1400	2:07	.27	.13	065	16.5
4	1600	2:20	.18	.08	055	18.7
5	1815	4:40	.55	.12	100	13.2
6	2200	12:02	.83	.07	120	13.2
7	0000	8:00	.43	.05	125	12.1

Figure 17. Trip V, 5 m drogue (Sept. 6-7, 1973).



Drift	Start	ΔT	Dist. (Naut.Mi.)	Speed (Knots)	Wind Dir.	Wind MPH
1	1000	4:00	.86	.22	095	9.9
2	1400	2:00	.86	.43	100	17.6
3	1600	2:00	1.02	.51	095	13.2
4	1800	6:00	.44	.07	070	8.8
5	2400	6:00	.67	.11	035	NA
6	0600	4:00	.28	.07	040	14.3

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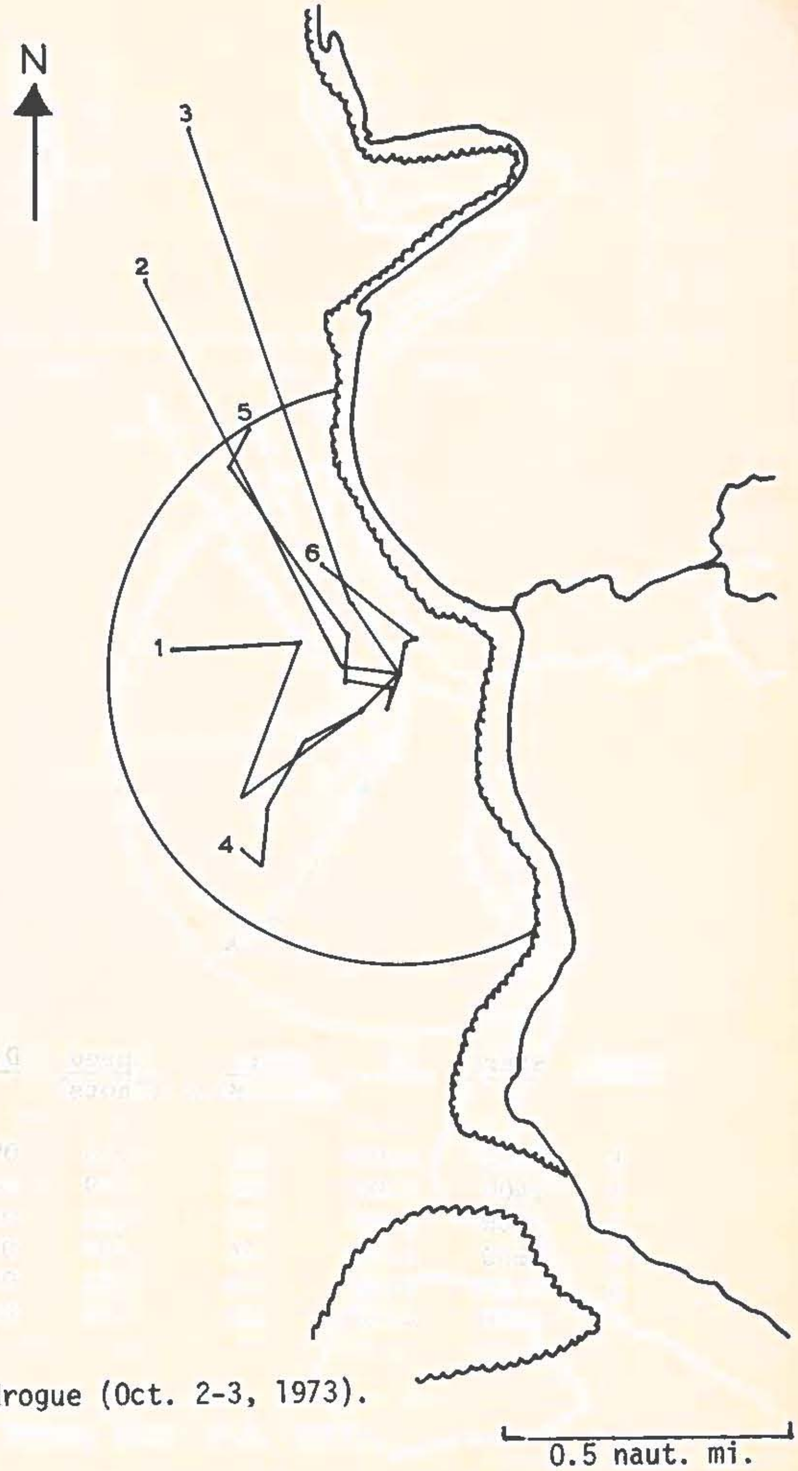


Figure 18. Trip VI, 1 m drogue (Oct. 2-3, 1973).

Drift	Start	ΔT	Dist. (Naut.Mi.)	Speed (Knots)	Wind	
					Dir.	MPH
1	1000	4:00	.51	.13	095	9.9
2	1400	2:00	.57	.29	100	17.6
3	1600	2:00	.70	.35	095	13.2
4	1800	6:00	.44	.07	070	8.8
5	2400	6:00	.63	.11	035	NA
6	0600	4:00	.25	.06	040	14.3

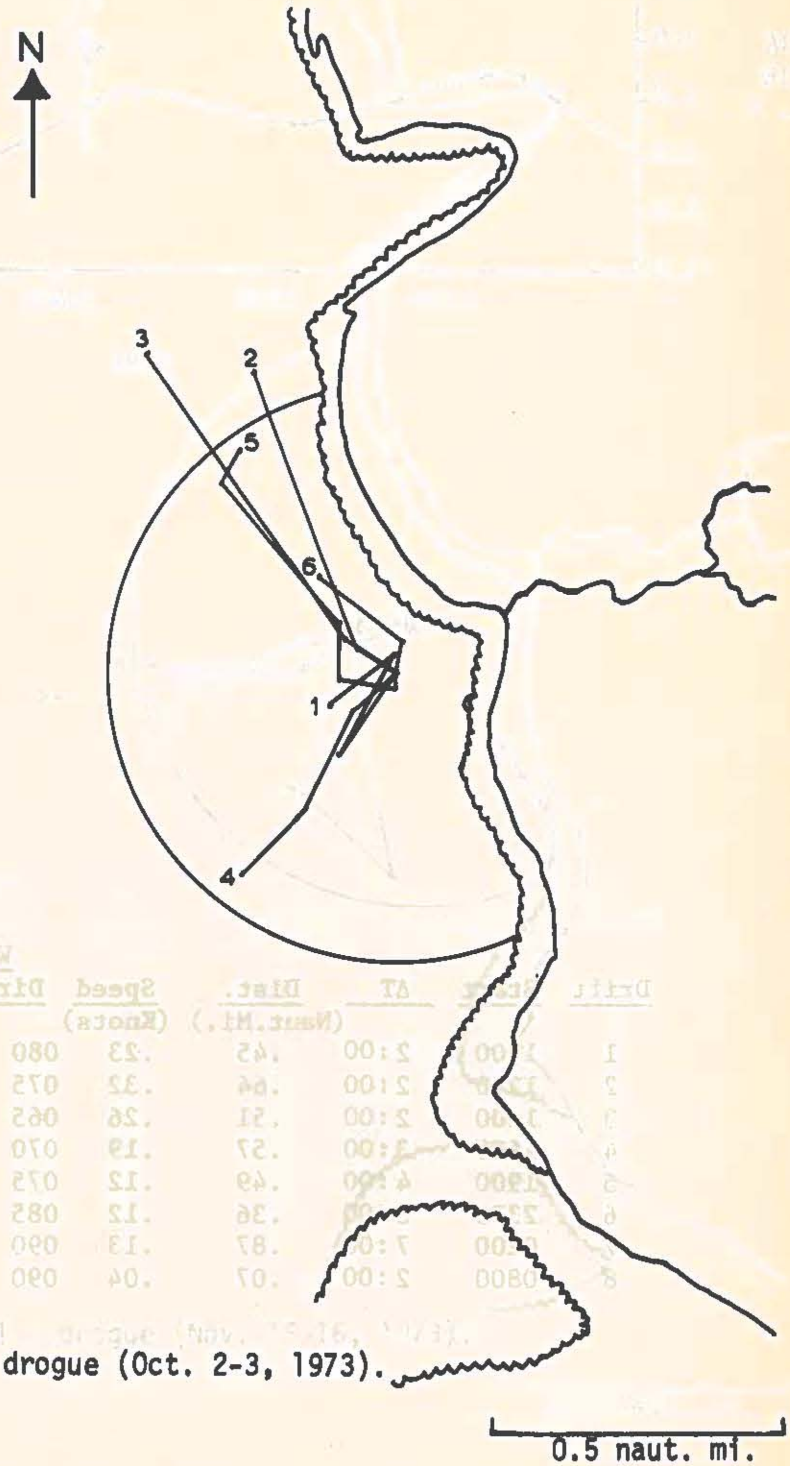
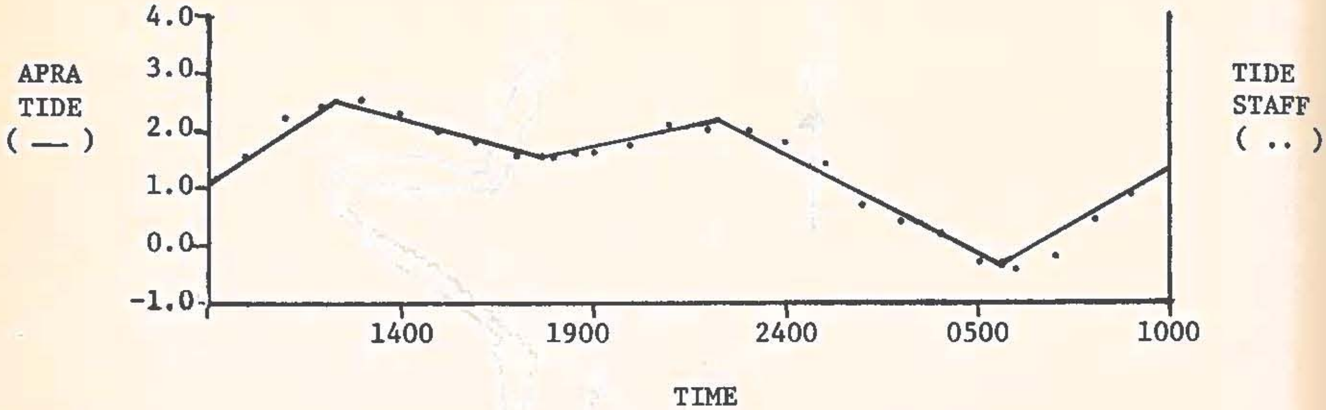


Figure 19. Trip VI, 5 m drogue (Oct. 2-3, 1973).



Drift	Start	ΔT	Dist. (Naut.Mi.)	Speed (Knots)	Wind Dir.	Wind MPH
1	1000	2:00	.45	.23	080	26.4
2	1200	2:00	.64	.32	075	25.3
3	1400	2:00	.51	.26	065	24.2
4	1600	3:00	.57	.19	070	22.0
5	1900	4:00	.49	.12	075	22.0
6	2300	3:00	.36	.12	085	22.0
7	0200	7:00	.87	.13	090	23.1
8	0800	2:00	.07	.04	090	24.2

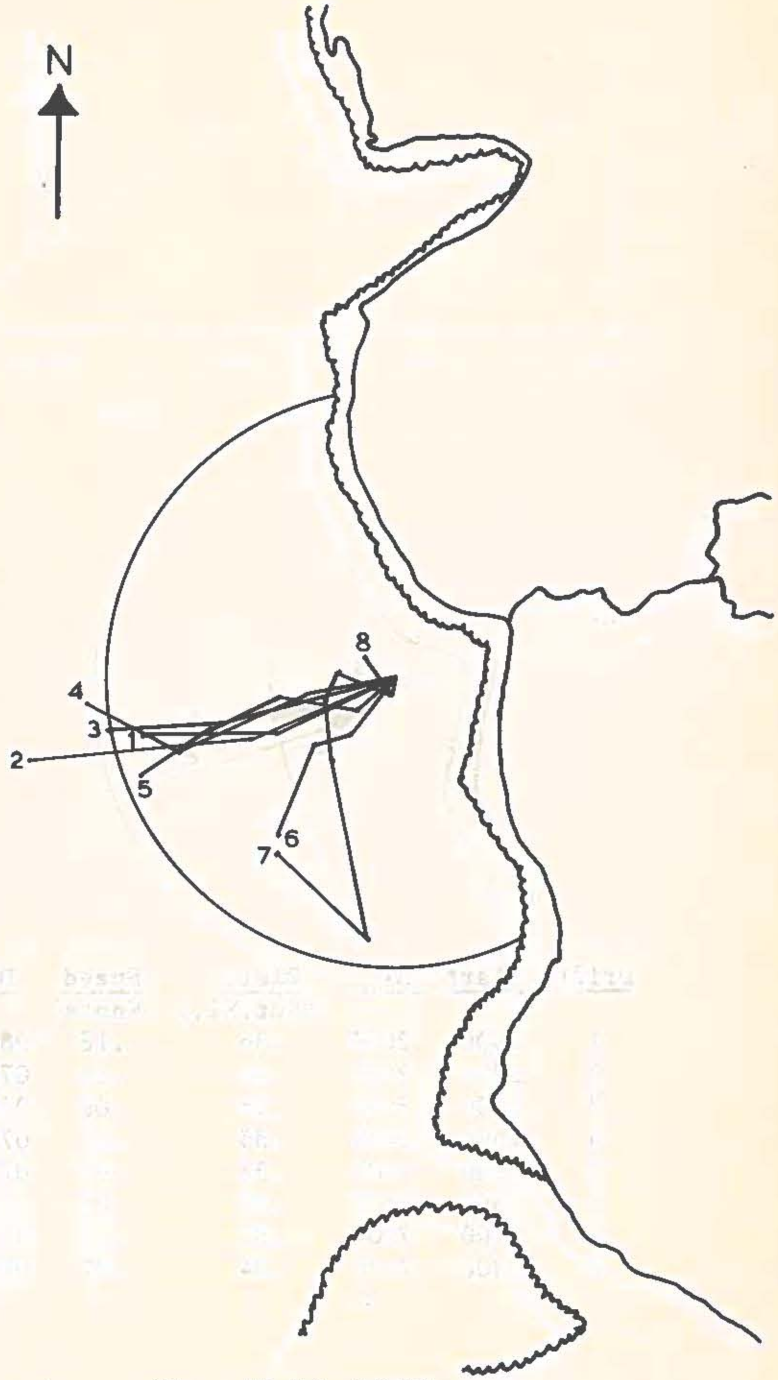


Figure 20. Trip VII, 1 m drogue (Nov. 15-16, 1973).

0.5 naut. mi.

Drift	Start	ΔT	Dist. (Naut.Mi.)	Speed (Knots)	Wind	
					Dir.	MPH
1	1000	2:00	.36	.18	080	26.4
2	1200	3:00	.46	.15	075	25.3
3	1400	3:00	.25	.08	065	24.2
4	1600	3:00	.35	.12	070	22.0
5	1900	4:00	.36	.09	075	22.0
6	2300	3:00	.28	.09	085	22.0
7	0200	7:00	.81	.12	090	23.1
8	0800	2:00	.04	.02	090	24.2

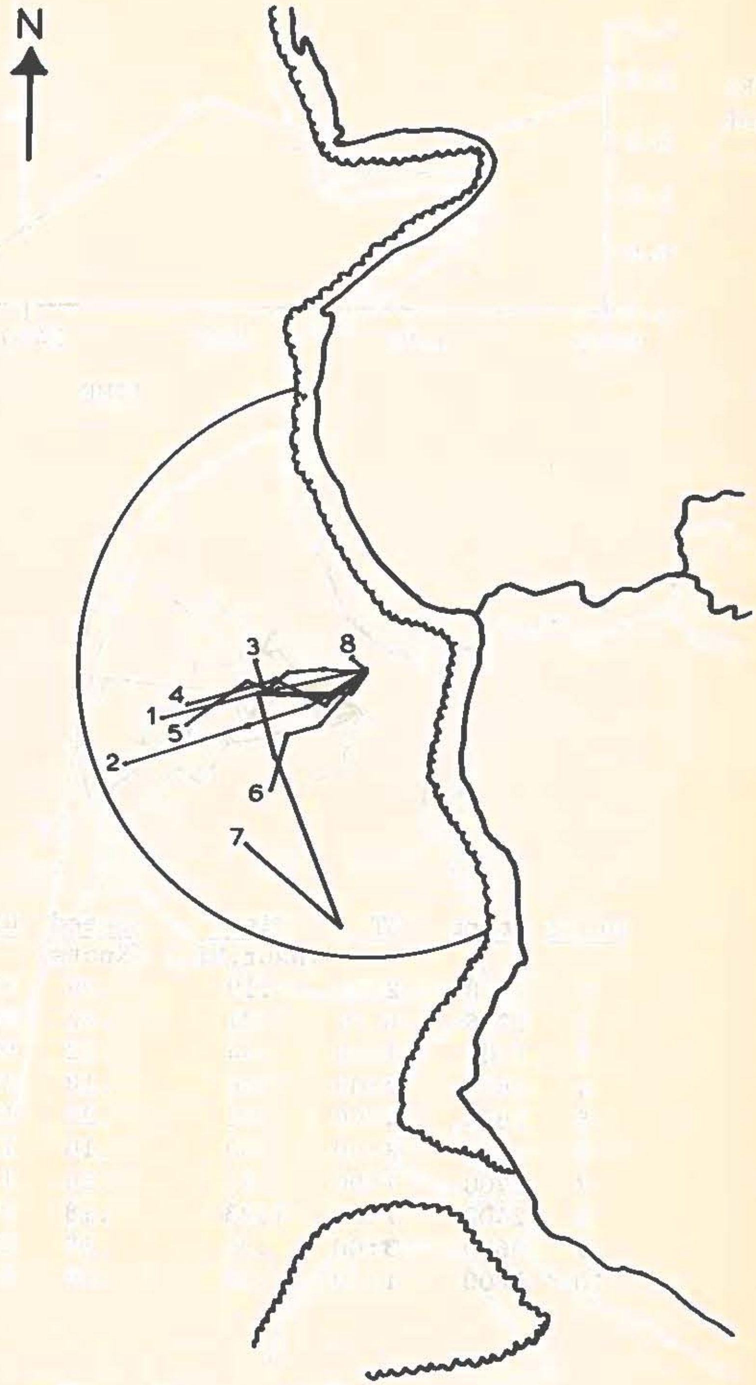
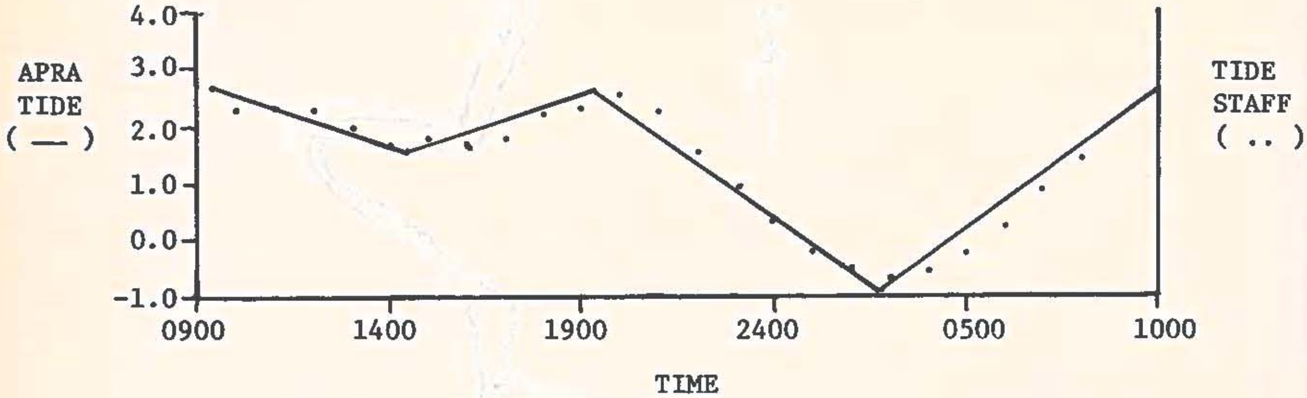


Figure 21. Trip VII, 5 m drogue (Nov. 15-16, 1973)

0.5 naut. mi.



					Wind	
Drift	Start	ΔT	Dist. (Naut.Mi.)	Speed (Knots)	Dir.	MPH
1	1000	2:00	.19	.09	090	18.7
2	1215	0.75	.31	.42	070	18.7
3	1400	2:00	.44	.22	090	17.6
4	1600	2:00	.36	.18	080	18.0
5	1800	4:00	.92	.23	100	17.6
6	2100	3:00	.30	.10	120	13.2
7	2200	7:00	.91	.13	125	12.1
8	2400	7:00	1.23	.18	095	13.2
9	0600	3:00	.30	.10	080	15.4
10	0800	1:00	.18	.18	078	15.4

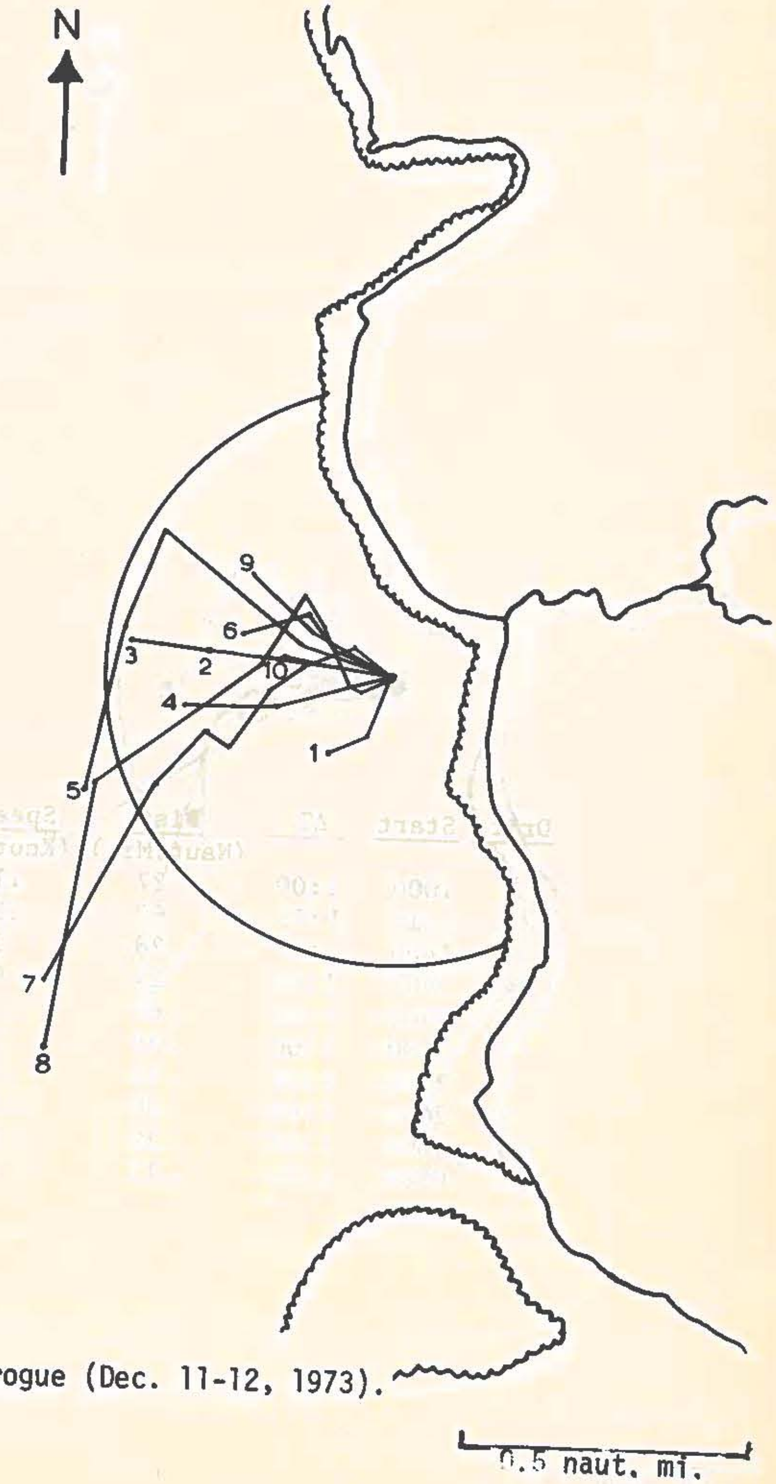


Figure 22. Trip VIII, 1 m drogue (Dec. 11-12, 1973).

Drift	Start	ΔT	Dist. (Naut.Mi.)	Speed (Knots)	Wind Dir.	Wind MPH
1	1000	2:00	.27	.14	090	18.7
2	1215	1:75	.67	.38	070	18.7
3	1400	2:00	.28	.14	090	17.6
4	1600	2:00	.17	.09	080	18.0
5	1800	4:00	.60	.15	100	17.6
6	2100	3:00	.25	.08	120	13.2
7	2200	8:00	.92	.12	125	12.1
8	2400	7:00	.99	.14	095	13.2
9	0600	3:00	.29	.10	080	15.4
10	0800	1:00	.15	.15	078	15.4

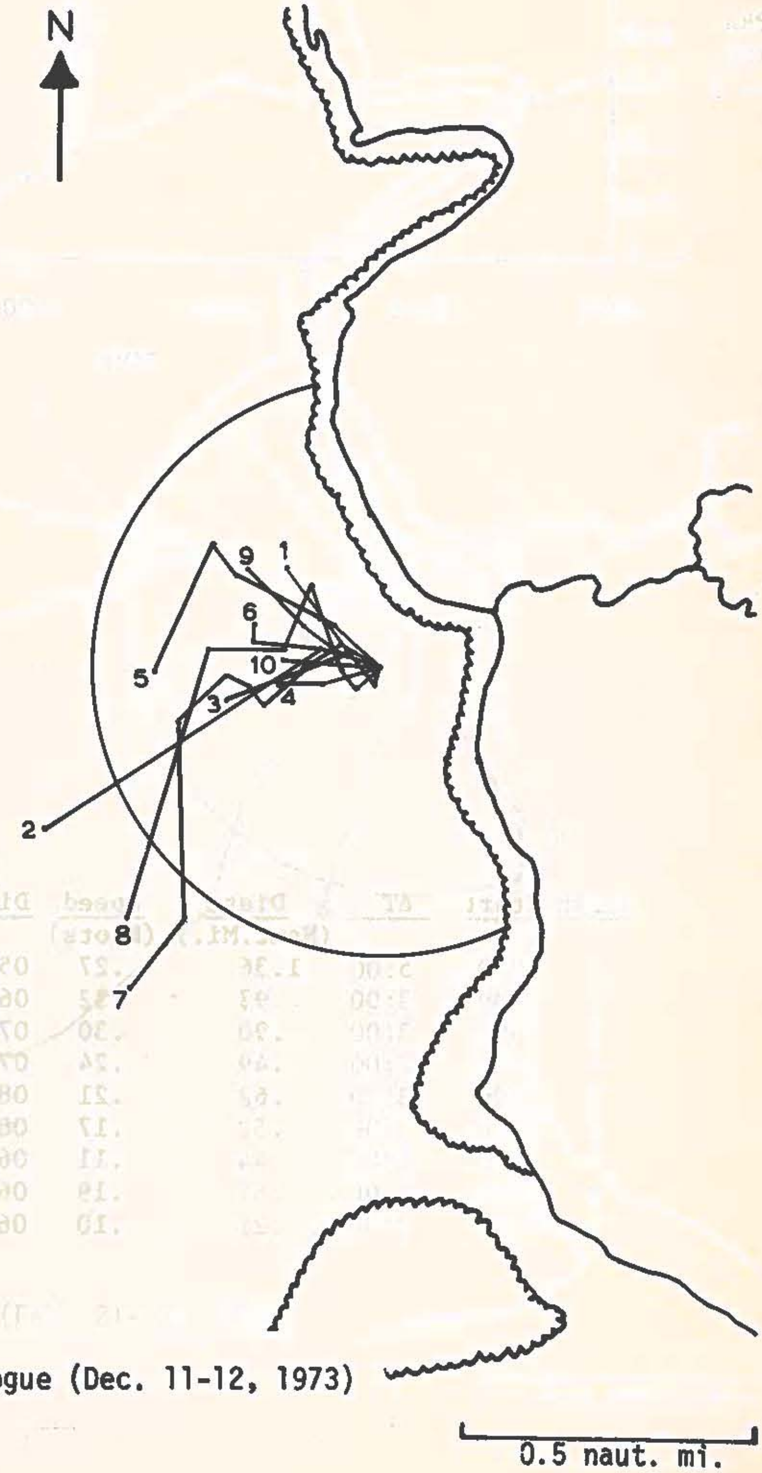
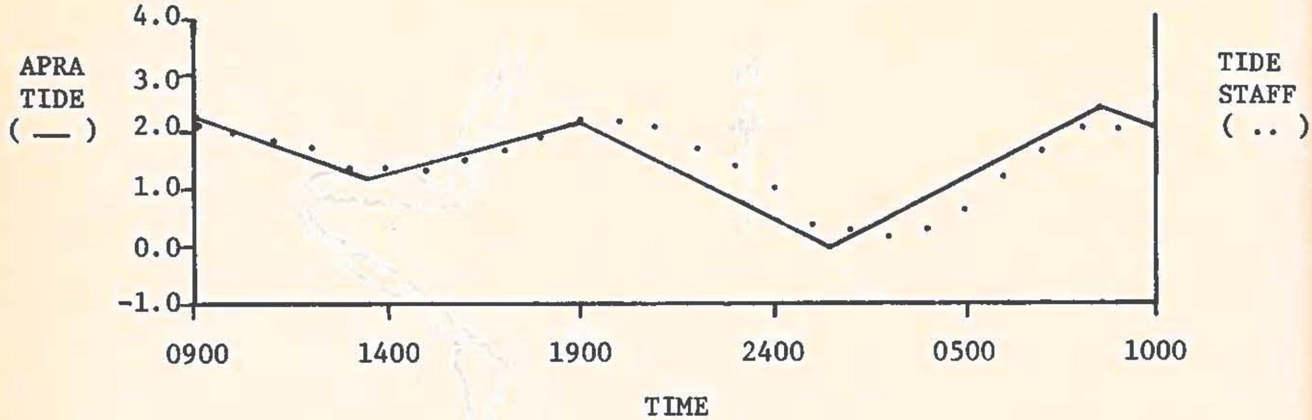


Figure 23. Trip VIII, 5 m drogue (Dec. 11-12, 1973)



Drift	Start	ΔT	Dist. (Naut.Mi.)	Speed (Knots)	Wind Dir.	Wind MPH
1	1000	5:00	1.36	.27	050	25.3
2	1400	3:00	.97	.32	068	25.3
3	1500	3:00	.90	.30	070	23.1
4	1700	2:00	.49	.24	075	17.6
5	1800	3:00	.62	.21	080	14.3
6	2100	3:00	.52	.17	080	11.0
7	2400	4:00	.44	.11	060	9.9
8	0400	3:00	.57	.19	060	14.3
9	0700	2:00	.21	.10	068	17.2

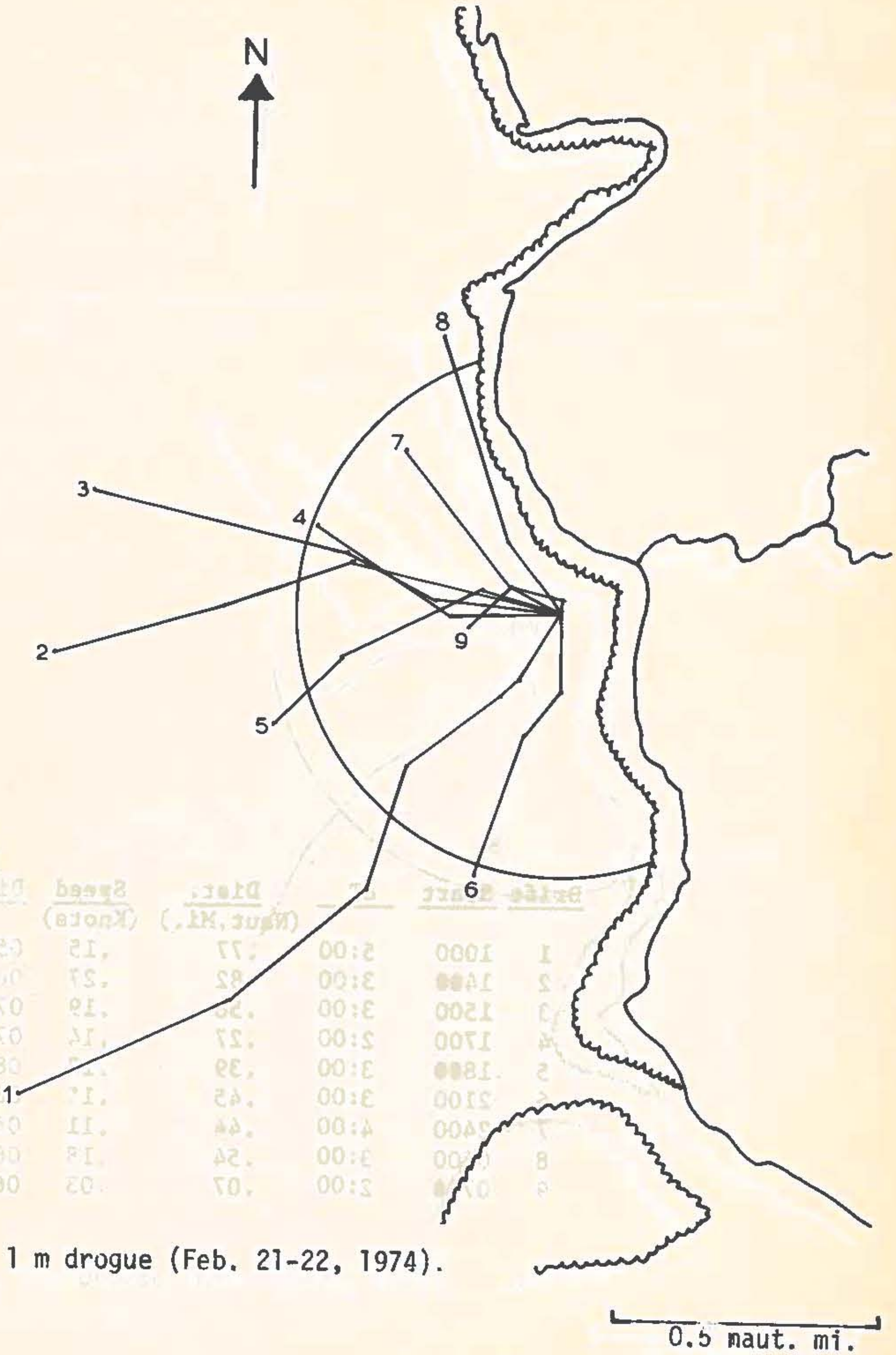


Figure 24. Trip IX, 1 m drogue (Feb. 21-22, 1974).

Drift	Start	ΔT	Dist. (Naut.Mi.)	Speed (Knots)	Wind Dir.	Wind MPH
1	1000	5:00	.77	.15	050	25.3
2	1400	3:00	.82	.27	068	25.3
3	1500	3:00	.58	.19	070	23.1
4	1700	2:00	.27	.14	075	17.6
5	1800	3:00	.39	.13	080	14.3
6	2100	3:00	.45	.15	080	11.0
7	2400	4:00	.44	.11	060	9.9
8	0400	3:00	.54	.18	060	14.3
9	0700	2:00	.07	.03	068	17.2

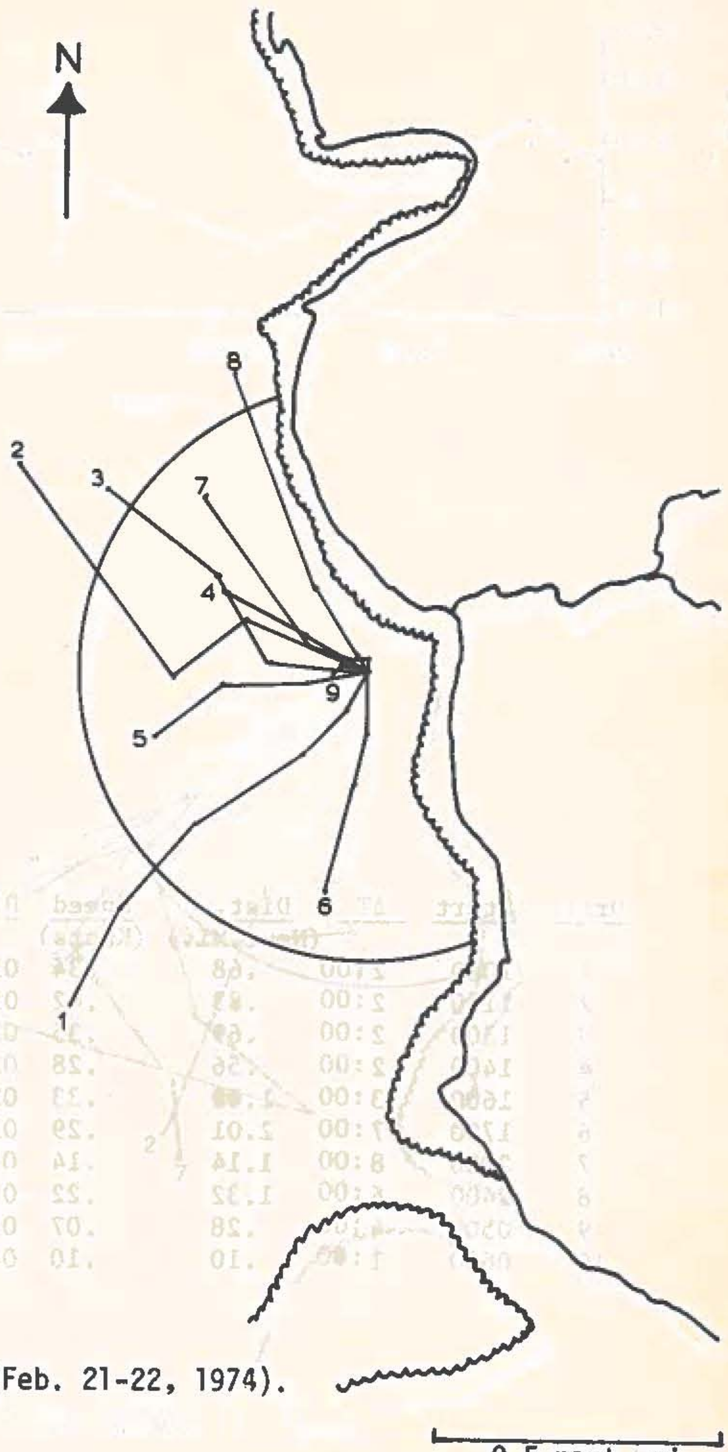
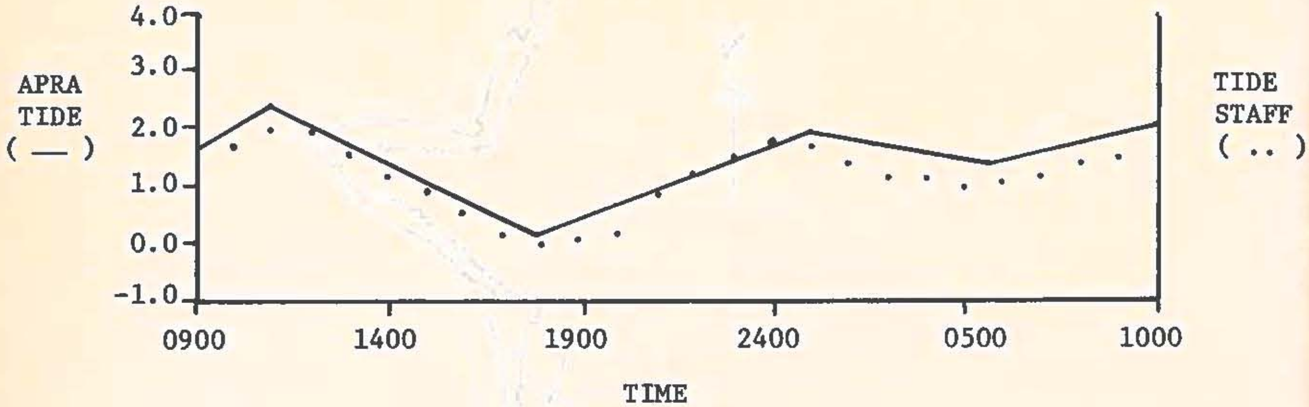


Figure 25. Trip IX, 5 m drogue (Feb. 21-22, 1974).



Drift	Start	ΔT	Dist. (Naut.Mi.)	Speed (Knots)	Wind Dir.	Wind MPH
1	1000	2:00	.68	.34	050	27.5
2	1100	2:00	.83	.42	055	26.4
3	1300	2:00	.69	.35	030	22.0
4	1400	2:00	.56	.28	022	25.3
5	1600	3:00	1.00	.33	020	18.7
6	1700	7:00	2.01	.29	010	12.1
7	2000	8:00	1.14	.14	050	20.9
8	2400	6:00	1.32	.22	065	23.1
9	0500	4:00	.28	.07	050	16.5
10	0800	1:00	.10	.10	042	16.7

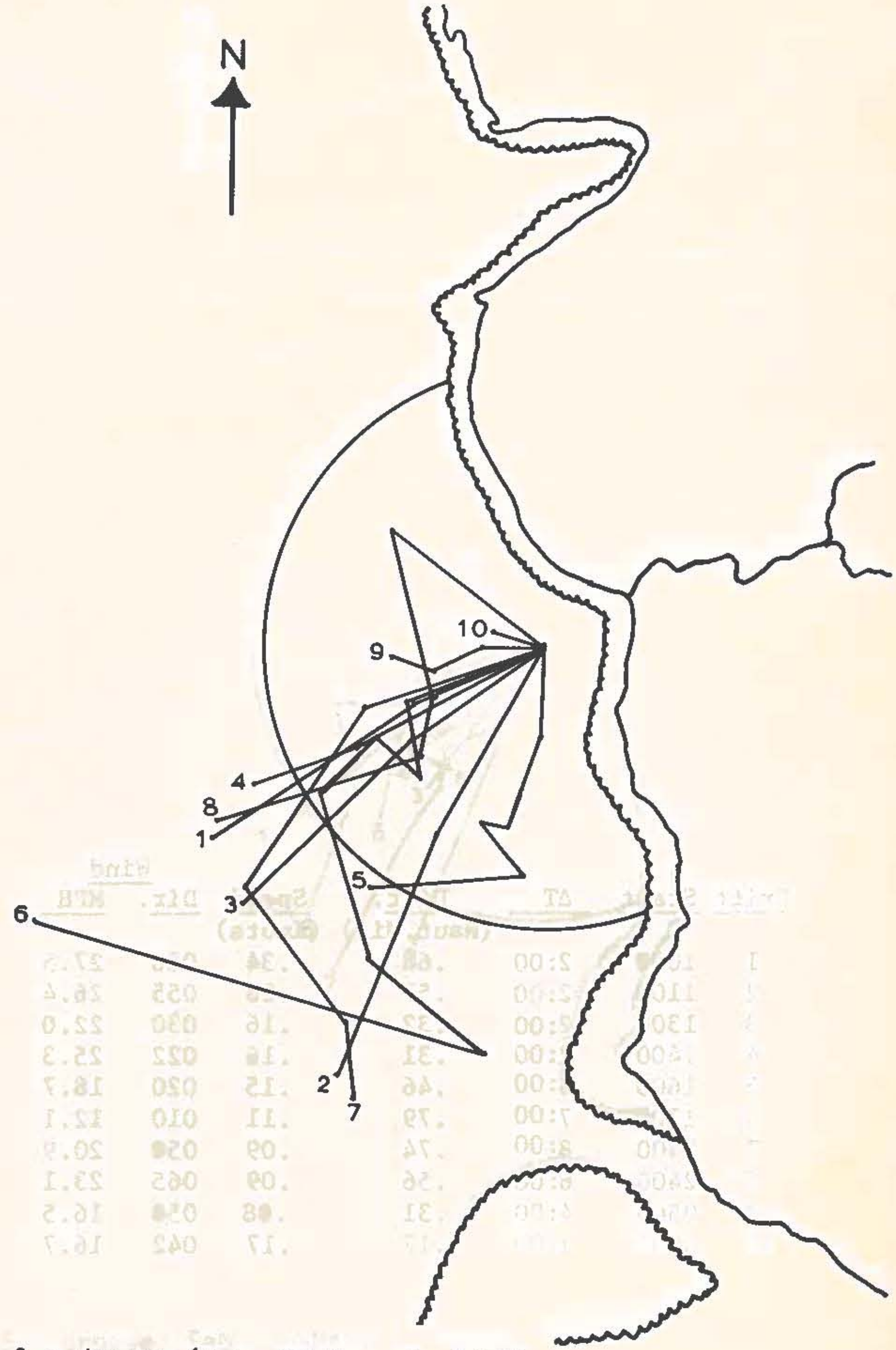


Figure 26. Trip X, 1 m drogue (Feb. 28-Mar. 1, 1974).

0.5 naut. mi.

Drift	Start	ΔT	Dist. (Naut.Mi.)	Speed (Knots)	Wind Dir.	Wind MPH
1	1000	2:00	.68	.34	050	27.5
2	1100	2:00	.57	.28	055	26.4
3	1300	2:00	.32	.16	030	22.0
4	1400	2:00	.31	.16	022	25.3
5	1600	3:00	.46	.15	020	18.7
6	1700	7:00	.79	.11	010	12.1
7	2400	8:00	.74	.09	050	20.9
8	2400	6:00	.56	.09	065	23.1
9	0500	4:00	.31	.08	050	16.5
10	0800	1:00	.17	.17	042	16.7

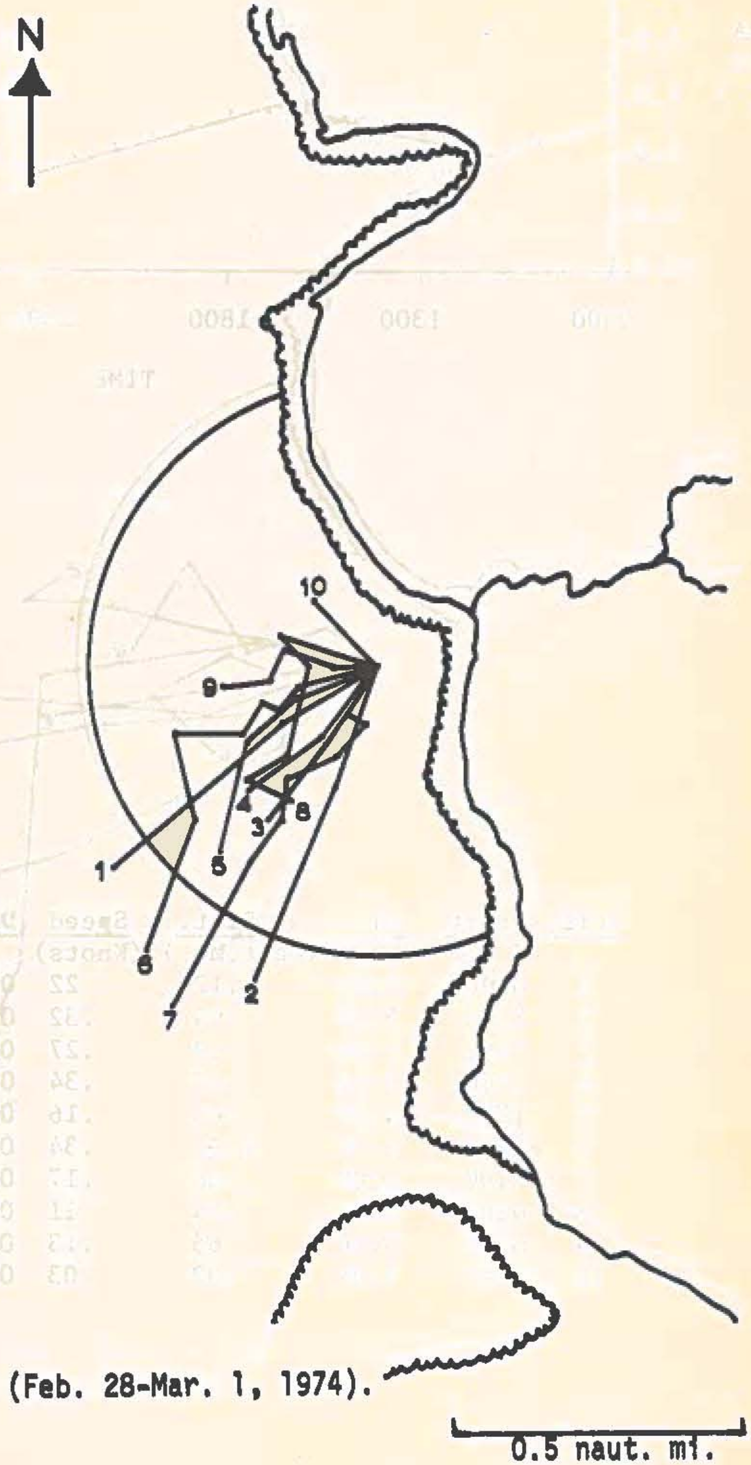
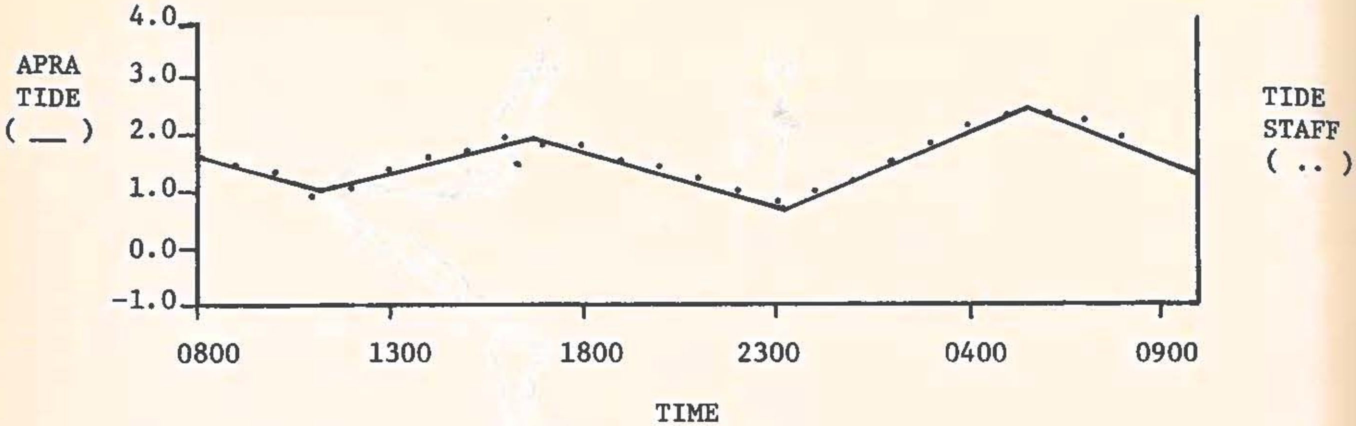


Figure 27. Trip X, 5 m drogue (Feb. 28-Mar. 1, 1974).



Drift	Start	ΔT	Dist. (Naut.Mi.)	Speed (Knots)	Wind Dir.	Wind MPH
1	0900	5:00	1.12	.22	090	23.1
2	1200	3:00	.94	.32	085	24.2
3	1400	2:00	.53	.27	090	25.3
4	1500	2:00	.67	.34	095	25.3
5	1700	4:00	.65	.16	085	18.7
6	1900	4:00	1.37	.34	080	15.0
7	2100	4:00	.66	.17	090	14.3
8	0100	5:00	.54	.11	060	12.0
9	0300	5:00	.65	.13	055	12.1
10	0600	1:00	.03	.03	060	8.8

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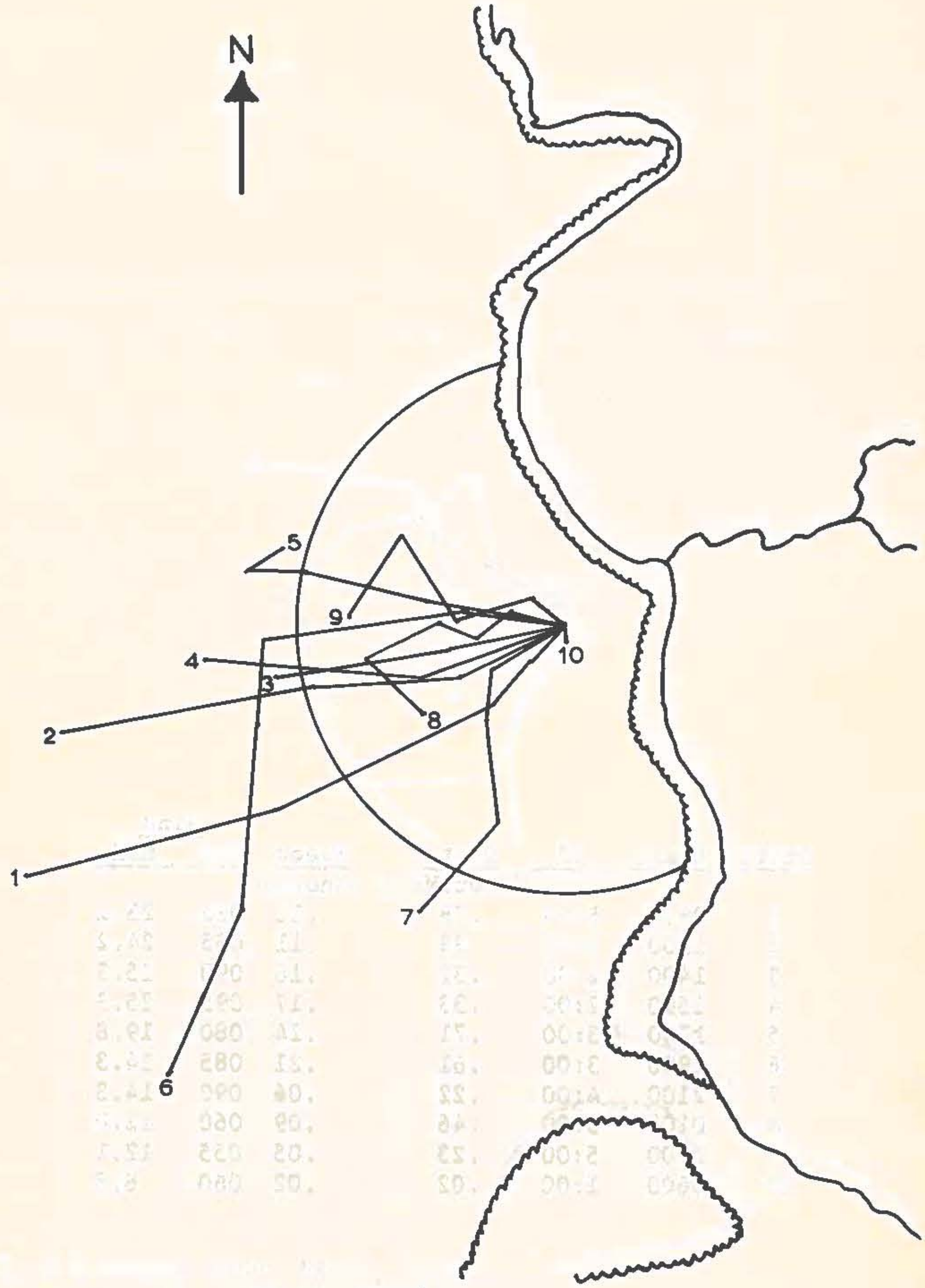


Figure 28. Trip XI, 1 m drogue (Apr. 18-19, 1974).

0.5 naut. mi.

Drift	Start	ΔT	Dist. (Naut.Mi.)	Speed (Knots)	Wind Dir.	Wind MPH
1	0900	5:00	.58	.12	090	23.1
2	1200	3:00	.33	.11	085	24.2
3	1400	2:00	.32	.16	090	25.3
4	1500	2:00	.33	.17	095	25.3
5	1700	3:00	.71	.24	080	19.8
6	1900	3:00	.61	.21	085	14.3
7	2100	4:00	.22	.06	090	14.3
8	0100	5:00	.46	.09	060	12.0
9	0300	5:00	.23	.05	055	12.1
10	0600	1:00	.02	.02	060	8.8

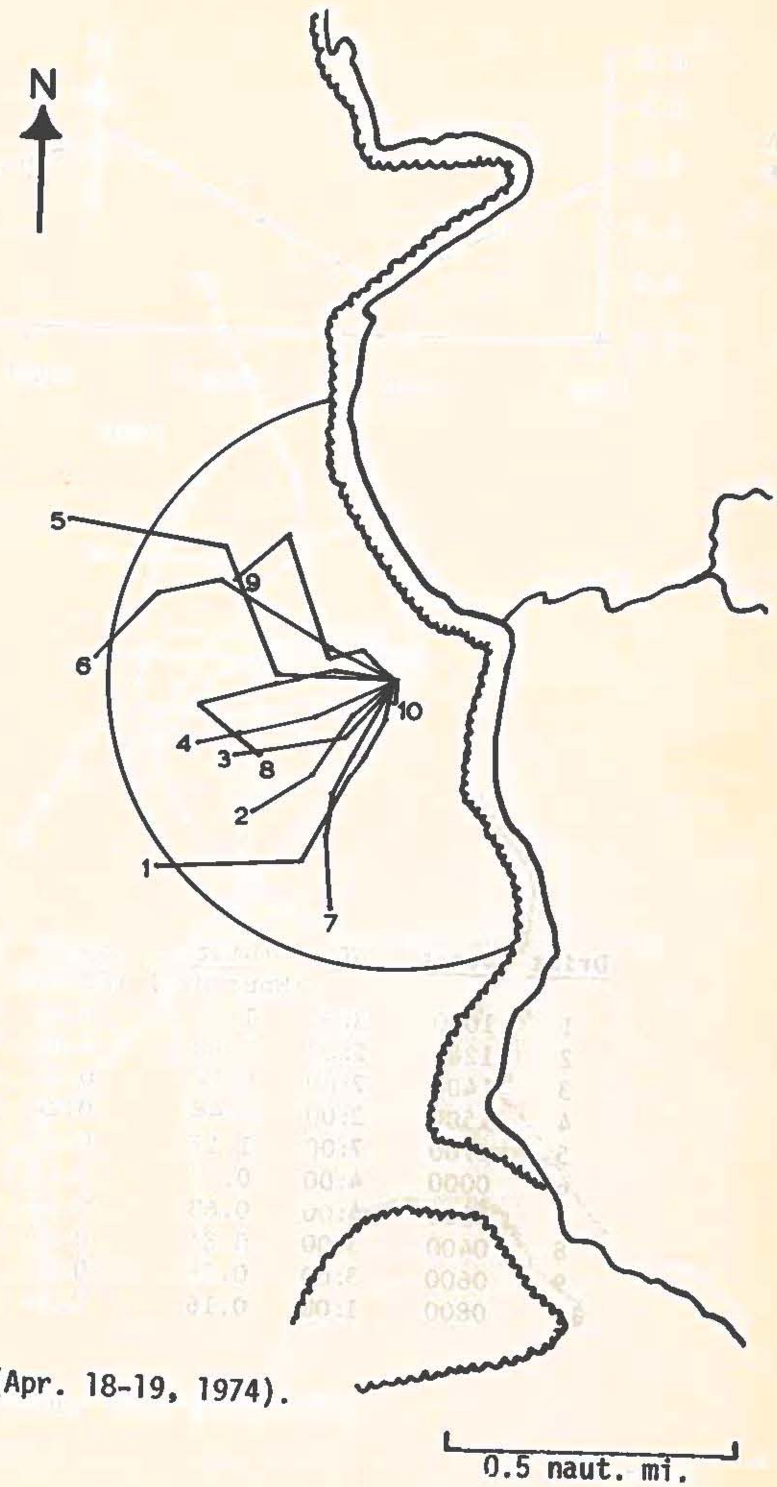
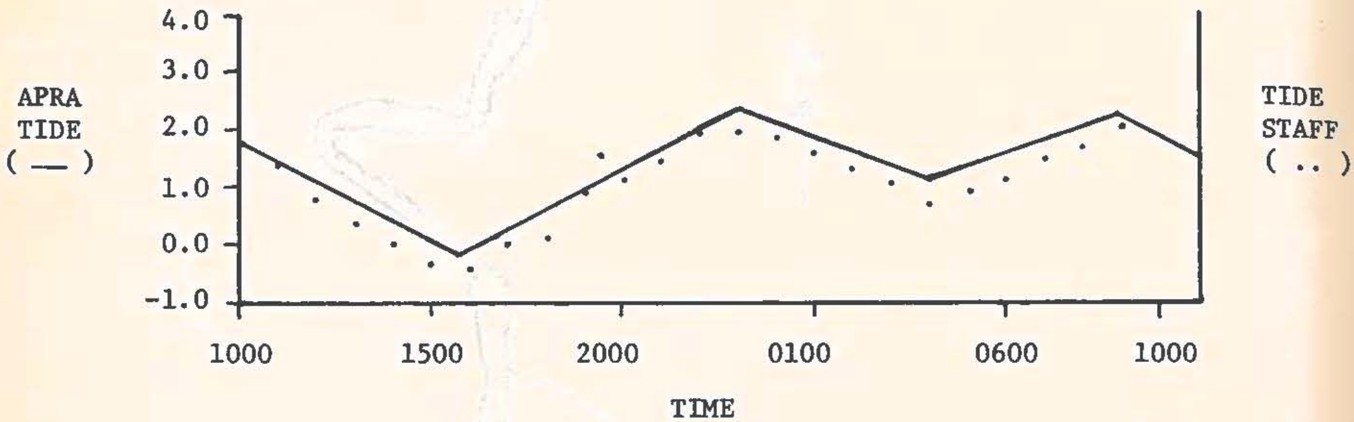


Figure 29. Trip XI, 5 m drogue (Apr. 18-19, 1974).



Drift	Start	ΔT	Dist. (Naut.Mi.)	Speed (Knots)	Wind Dir.	Wind MPH
1	1000	3:00	1.41	0.47	092	19.8
2	1200	2:00	0.89	0.45	083	22.0
3	1400	2:00	0.54	0.27	097	19.8
4	1500	2:00	0.48	0.24	095	24.2
5	1700	7:00	1.17	0.17	085	15.4
6	0000	4:00	0.52	0.13	076	17.6
7	0100	4:00	0.63	0.16	068	19.8
8	0400	3:00	0.81	0.27	060	17.6
9	0600	3:00	0.76	0.25	067	17.6
10	0800	1:00	0.16	0.16	063	17.6

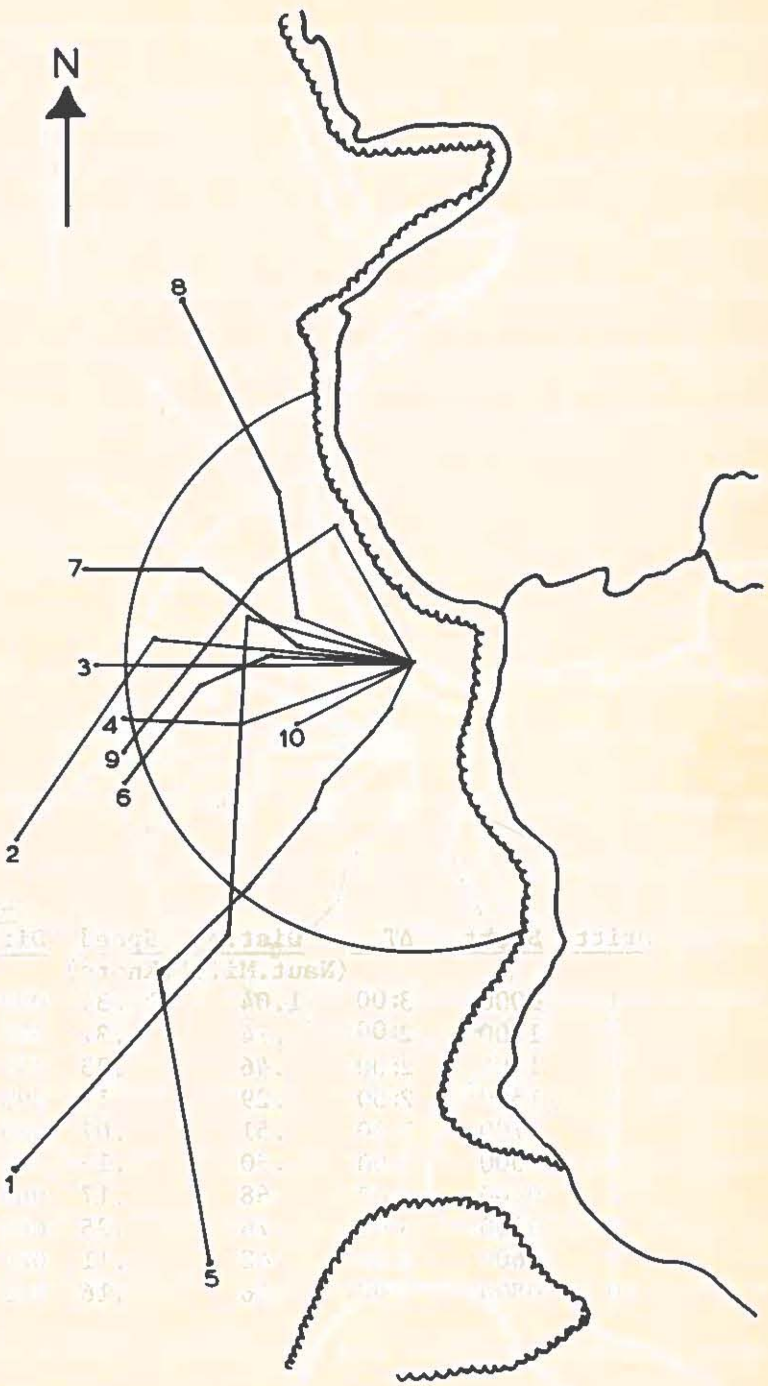


Figure 30. Trip XII, 1 m drogue (May 9-10, 1974).

Drift	Start	ΔT	Dist. (Naut.Mi.)	Speed (Knots)	Wind	
					Dir.	MPH
1	1000	3:00	1.04	.34	092	19.8
2	1200	2:00	.74	.37	083	22.0
3	1400	2:00	.46	.23	097	19.8
4	1500	2:00	.29	.15	093	24.2
5	1700	7:00	.51	.07	085	15.4
6	0000	4:00	.50	.13	076	17.6
7	0100	4:00	.68	.17	068	19.8
8	0400	3:00	.76	.25	060	17.6
9	0600	3:00	.48	.11	067	17.6
10	0800	1:00	.16	.16	063	17.6

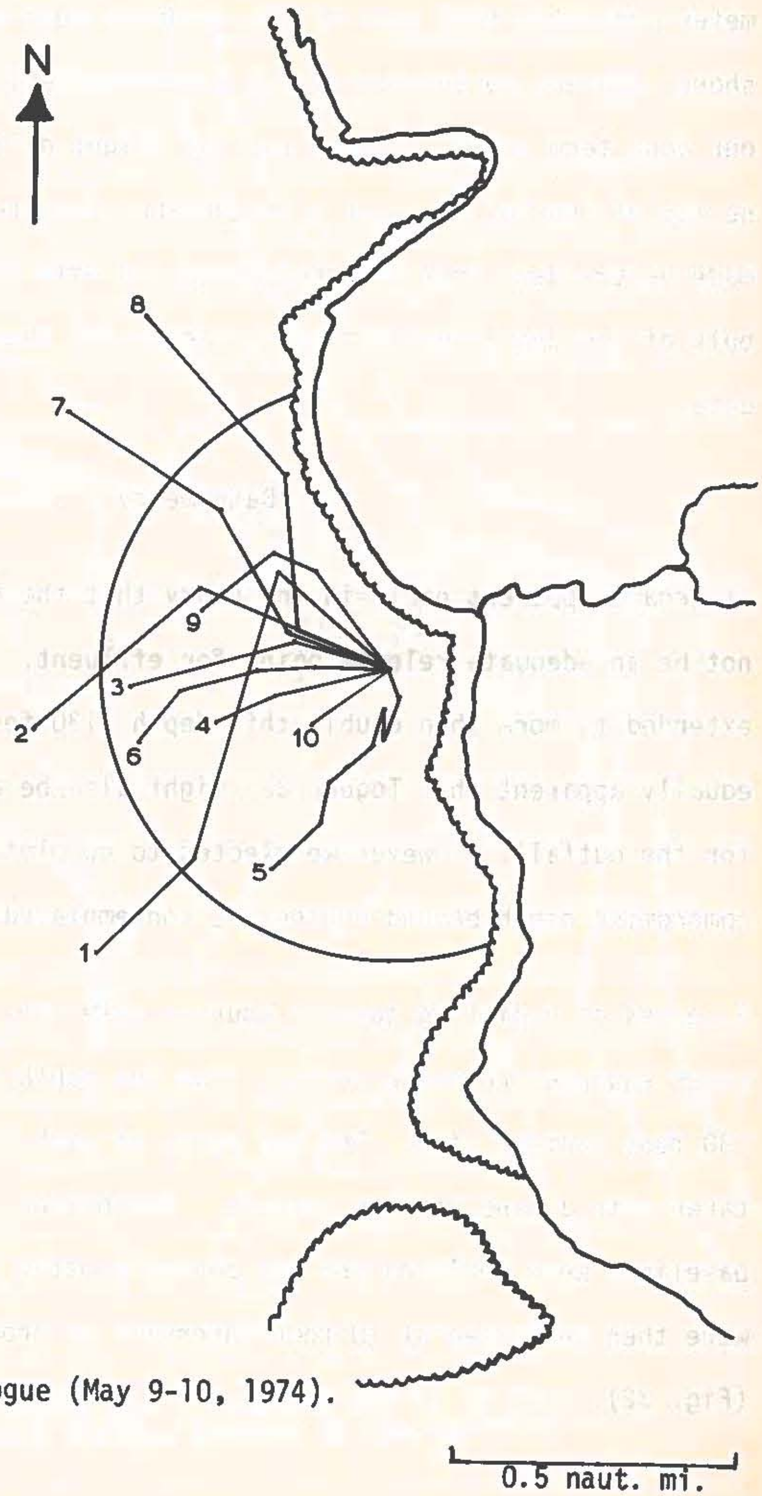


Figure 31. Trip XII, 5 m drogue (May 9-10, 1974).

for the 1 m drogues with an average of 0.22 kts. The 5 m drogues had a range of 0.03 to 0.38 kts with an average of 0.14 kts. There is, however, considerable disagreement with regard to direction. The Navy's current meter indicated that most of the readouts were easterly or toward the shore, whereas northwesterly and southerwesterly directions dominated in our long term study. Except for the slight difference in location we have no way of knowing why such a discrepancy occurred. Several dye casts were made by the Navy from the reef margin in Bile Bay and in most cases the bulk of the dye traveled seaward (westerly) thus contradicting their meter data.

Bathymetry

It became apparent early in the study that the 60 foot contour line might not be an adequate release point for effluent. Hence the survey was extended to more than double this depth (130 feet). Moreover, it became equally apparent that Toguan Bay might also be a poor choice in general for the outfall. However we elected to complete this obligation should a compromise depth beyond 60 feet be contemplated.

A series of radiating compass courses were run, using a recording fathometer equipped research vessel, from the mouth of the Toguan River to the 130 foot contour line. The end point of each line was plotted with sights taken with a hand bearing compass. Fathometer tracings for each of these baselines were analyzed and the depths plotted on a master chart. Isobaths were then connected at 10 foot intervals to produce a bathymetric chart (Fig. 32).

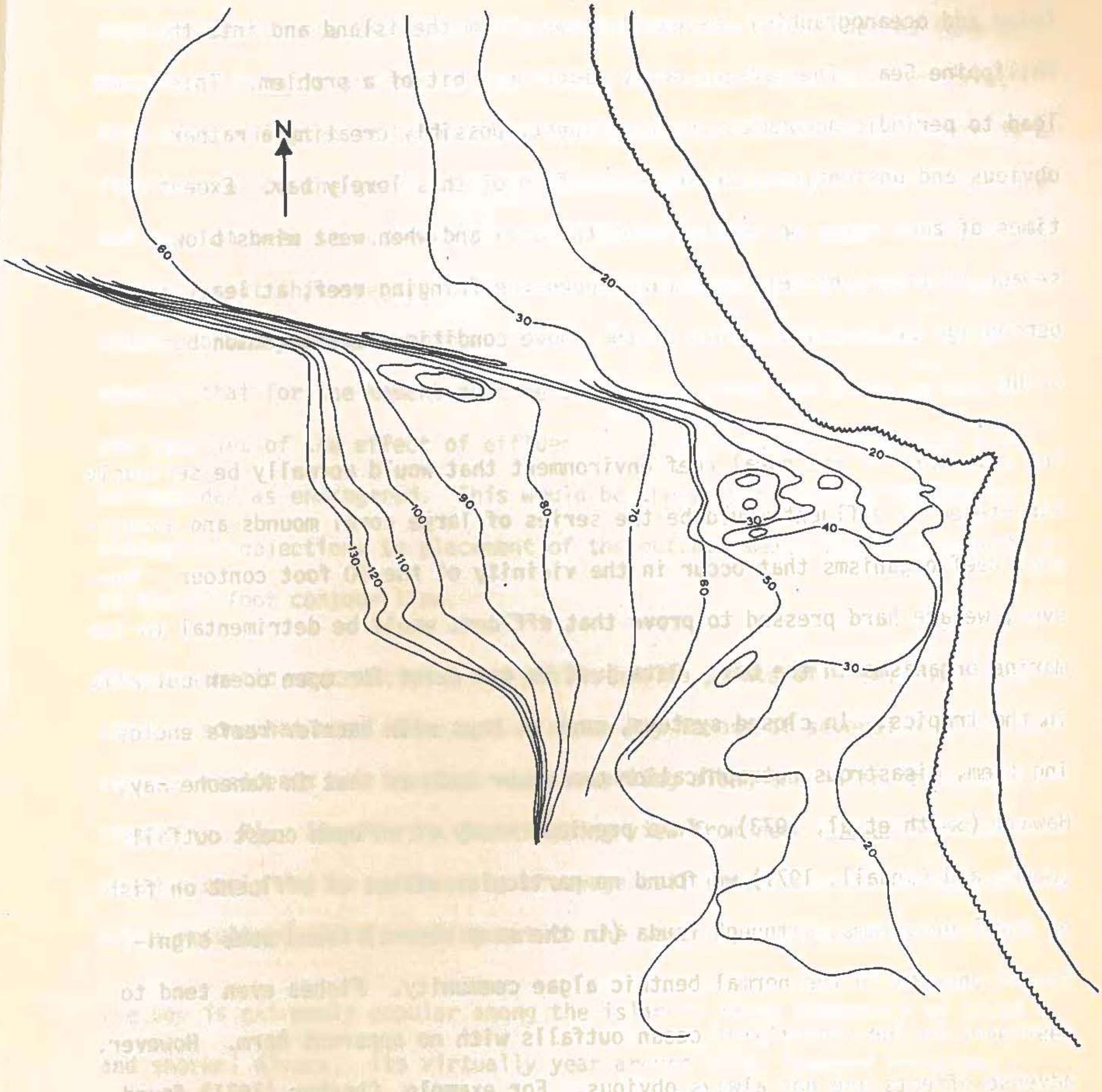


Figure 32. Bathymetry of Toguan Bay. Isobaths are in 10 foot increments. Note shallow terrace to the north of the bay.

CONCLUSIONS

It seems clear from the data presented above that sewage effluent injected at the 60 foot contour line in Toguan Bay would, under normal conditions (wind and oceanographic), be carried away from the island and into the Philippine Sea. The rate of drift might be a bit of a problem. This could lead to periodic accumulation of effluent, possibly creating a rather obvious and unsightly slick on the surface of this lovely bay. Except in times of zero water movement out of the area and when west winds blow, sewage would be unlikely to impinge upon the fringing reef, at least a high percentage of the time. Both of the above conditions are uncommon but do occur.

The only part of the coral reef environment that would normally be seriously threatened by effluent would be the series of large coral mounds and associated reef organisms that occur in the vicinity of the 60 foot contour. However, we are hard pressed to prove that effluent would be detrimental to the marine organisms in the bay. Data just do not exist for open ocean outfalls in the tropics. In closed systems, such as bays with barrier reefs enclosing them, disastrous eutrophication can occur such as that in Kaneohe Bay, Hawaii (Smith et al, 1973). In a previous study of an open coast outfall (Jones and Randall, 1971) we found no particular effect of effluent on fish or coral organisms, although Tsuda (in the same report) found some significant changes in the normal benthic algae community. Fishes even tend to aggregate in the vicinity of ocean outfalls with no apparent harm. However, adverse effects are not always obvious. For example, Chesher (1971) found liver lesions on fishes that occurred around an outfall with a high copper ion outflow. These same fishes looked healthy otherwise. In short, we simply do not know what lethal or sublethal effects sewage has on tropical organisms over a long term basis.

While most of the Toguan Bay flora and fauna is rather common, it is significant to note that there are two ahermatypic coral species (one of the genus Madracis and one in the family Astrocoeniidae) which to date, have been collected in Guam only from Toguan Bay. In addition, there is a fish species of the genus Cheilinus (a wrasse) which may be new to science and has not been seen, as yet, in any other locality on Guam. While it is unlikely that this species is endemic only to Guam, there is no evidence to the contrary at this point. Hence, Toguan Bay does have some unique species that for the moment must be considered rare; and since we are as yet ignorant of the effect of effluent on such organisms, they must also be regarded as endangered. This would be the primary reason for having biological objections to placement of the outfall among the coral mounds at the 60 foot contour line.

From aesthetic, recreational and public health points of view, the situation is somewhat more clear cut. Toguan Bay is one of several high points seen by residents and tourists when traveling along the island's coastal road (Fig. 7). It offers a breathtaking view from near Toguan Peak that would clearly not be enhanced by a sewage boil spreading out at its surface and a resultant slick trailing out to the south and southwest.

The bay is extremely popular among the island's large community of SCUBA and snorkel divers. Its virtually year around calm, leeward location; natural beauty; and complex submarine topography attract sport divers both in small groups and in large SCUBA club outings. We are of the opinion that anything short of tertiary treatment might well preclude any future use of this area for this or any other form of water related recreation.

In terms of public health, if the area is to be posted to prohibit fishing and swimming, we see no major objection to placing an outfall here. Current data do not indicate a health threat to villages or other recreational sites, during normal times.

From an engineering, construction and cost point of view, the bay is good. The river channel is a perfect place to lay an outfall line with minimum construction difficulty and cost. The ocean current data show that, by and large, the system would dilute and dispose of discharged sewage in a fairly effective manner.

The choice of the reviewing agencies (including both GEPA and Guam Department of Public Works) is then a difficult one. The decision must weigh aesthetics, recreation, and potential environmental damage against cost and ease of construction.

We are of the opinion that a far better location for the outfall would be at the 60 foot isobath on the western extremity of the broad submarine terrace to the north of Toguan Bay (Figs. 7B and 32). Construction damage would be minimal because the surface of the terrace is surprising low in coral cover. The outfall location would be sited beyond the island's wind shadow (for more rapid dispersal) and well clear of the unique environmental features of Toguan Bay. Effluent released would not interfere with an area used heavily for recreation and the resultant sewage boil and trailing slick would be far less obvious to travelers. Although our current study did not include this site per se, we feel fairly safe in saying that dilution and dispersal of effluent would be far more efficient here than in Toguan Bay. The disadvantages are increased cost, because of the extended submerged portion of the outfall line, and increased difficulty of construction due to the much harder substrate of the terrace (assuming excavation for the pipe is necessary).

Finally, it should be pointed out here that our study may be a dead issue anyway. A recent outbreak of hepatitis in the village of Umatac, blamed on poor sewage disposal practices now in existence, has resulted in a flurry of Governmental activity to build an emergency sewer outfall near Fort Santo Angel in Umatac (Fig. 7C). Although the epidemic seems to have been brought under control, work on the emergency outfall continues and we must conclude that the master plan may no longer call for joining the Umatac and Merizo sewerage systems. This is unfortunate because it may well establish precidence for the one village/one outfall concept on Guam and thus result in wall to wall outfalls. Perhaps some day we can bathe all of Guam's shores in her people's own wastes.

With regard to the village of Merizo, it may now be considered, by the agencies involved, more feasible to locate this outfall elsewhere. We feel obligated to point out that at least one proposal has been to place the outfall in Mamaon Channel (Fig. 7). In our opinion, this would be sheer folly that could lead to the closing of the highly popular Merizo waterfront. Please Government of Guam don't make that mistake in your haste to dispose of waste.

RECOMMENDATIONS

I. Do not put the outfall in Toguan Bay. It makes as much sense as putting it in Sella or Cetti Bays (or the Agana Swimming Pool).

II. Place the outfall on the western margin (60 foot isobath) of the submarine terrace north of Toguan Bay (Fig. 7B).

III. If the Toguan Bay site is chosen, place the outfall somewhere between the 80 and 100 foot isobaths (Fig. 32).

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