

THE FLY RIVER : A CONTINUING HYDROGRAPHIC CHALLENGE

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*"I do not know much about gods, but I think that the river
Is a strong brown god — sullen, untamed and intractable.
Patient to some degree, at first recognized as a frontier;
Useful, untrustworthy, as a conveyor of commerce;
Then only a problem confronting the builder of bridges.
The problem once solved, the brown god is almost forgotten
By the dwellers in cities — ever, however, implacable.
Keeping his seasons and rages, destroyer, reminder
Of what men choose to forget."*

T.S. ELIOT, *The Dry Salvages*

ABSTRACT

The importance of the Ok Tedi scheme of the Fly River in Papua New Guinea (PNG) is emphasized. The navigational and hydrographic problems connected with this waterway are discussed.

1. — INTRODUCTION

1.1. Large deposits of gold and porphyry copper were discovered in the Star Mountains of PNG about 40 years ago. These are adjacent to the Ok ("river") Tedi, a major tributary of the Fly River (which it joins at D'Albertis Junction), which in its turn flows southward to the Gulf of Papua (Fig. 1). In 1976, Broken Hill Proprietary Ltd. (BHP) agreed to carry out requisite investigations of the ores, which in fact form the heart of Mt. Fubilan, situated in the Western Province of PNG, at about 5°12' South, 141°08' East and at about 2 500 m above Mean Sea Level (MSL) (Fig. 2). The mountain is only about 15 km east of the Irian Java/PNG

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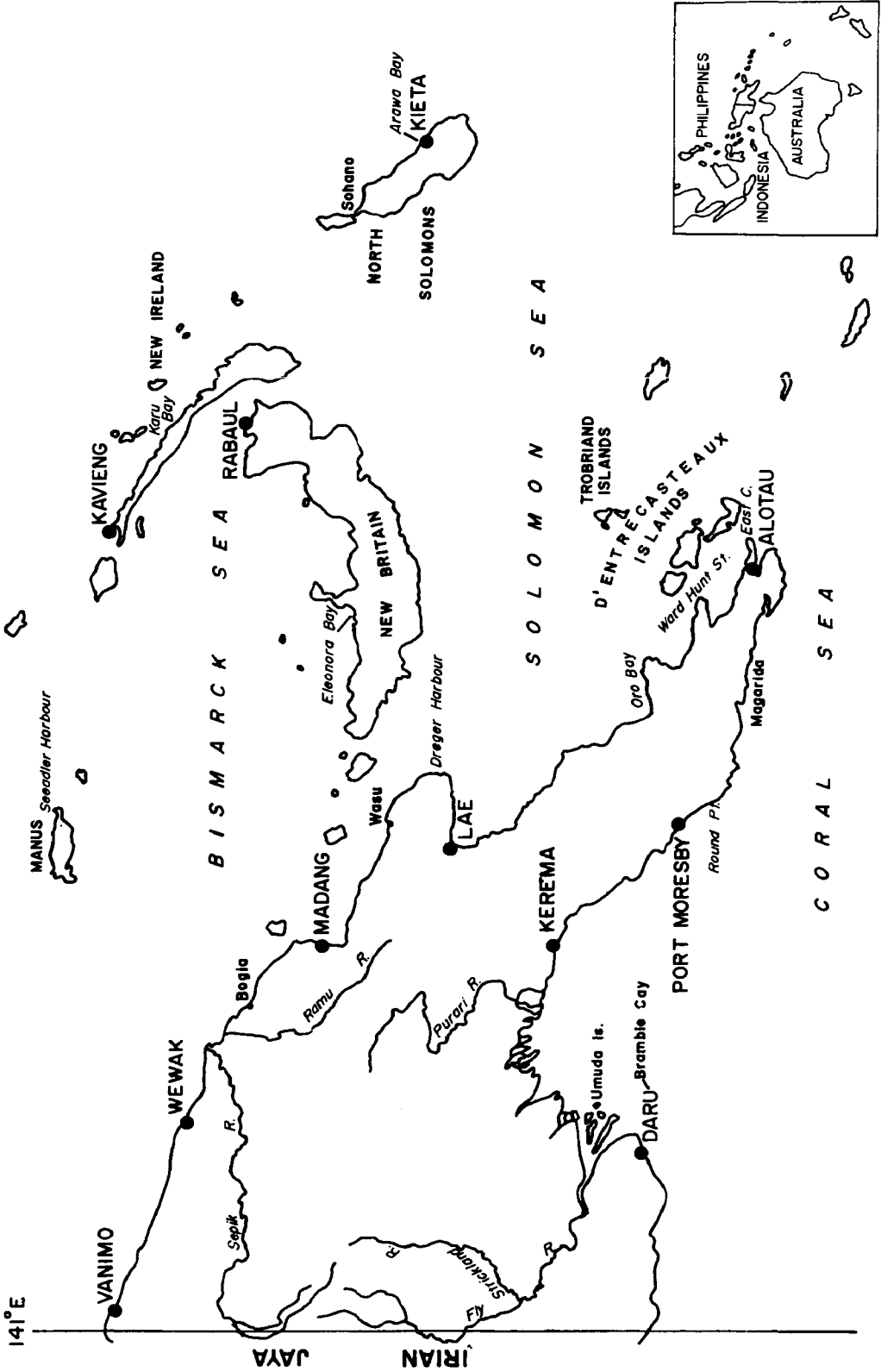


FIG. 1. — Papua New Guinea.

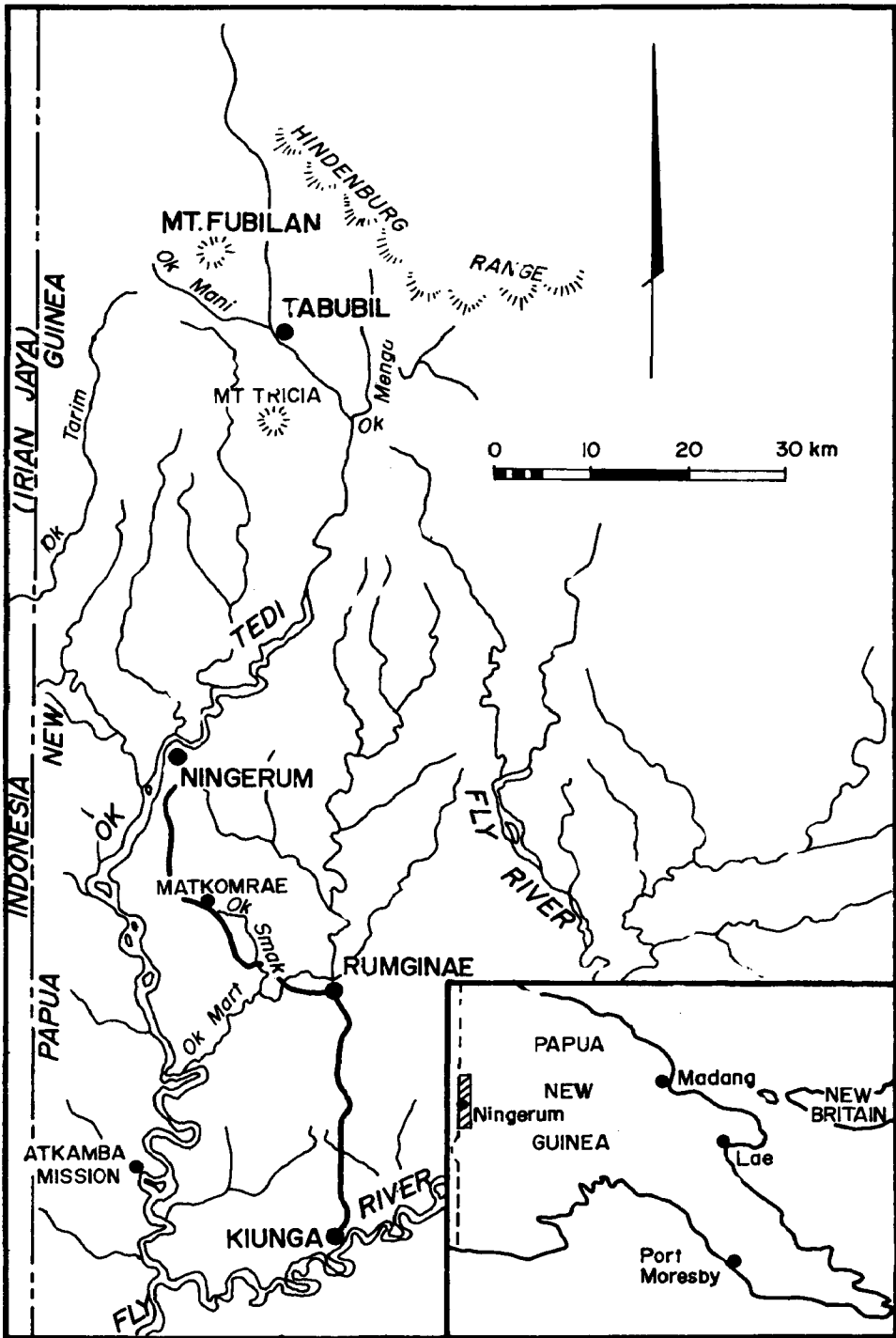


FIG. 2. — Locality plan of north-west area of Western Province, Papua New Guinea.

border and 14 km south of the geologically impressive Hindenburg Wall, which consists of a near-vertical limestone ridge rising some 500 m above the surrounding terrain for a distance of about 25 km.

1.2. The area can be reached by air, water, or now by road from Tabubil. Other road development in the area is still very limited; the principal "heavy" artery is the Fly River, which meanders through dense tropical rain forest and swampy areas extending broadly from its apparently somewhat mobile banks. From Kiunga (Fig. 3) the river runs for 840 km before entering the Gulf of Papua through a wide, quadruplicate delta system. Two of the channels are used by fishermen and traders serving settlements along the river, which, together with the Ok Tedi, serves as the main drainage for the whole project area. The land from Kiunga to the river mouth is very flat and unfortunately devoid of topographical features likely to be of any value for geodetic surveys.

Annual rainfall in the area is generally phenomenal, varying from 8 200 mm on Mt. Fubilan itself, through 7 000 mm at Ningerum to 4 700 mm at Kiunga. Rain falls on the site on 312 to 349 days of the year and statistics show an average of only seven totally clear days annually.

1.3. The region in fact constitutes a surveyor's nightmare — needless to say, the rapid erosion of the limestone is a major geomorphological problem; it involves occasional, spectacular, rock falls. When one considers the hitherto utter isolation of the site, its inimical, unhealthy climate and the vagaries of the Fly River, one might conclude with some justification that Providence had chosen the siting of such a valuable asset with a calculated cynicism; all factors combine to make this one of the worst areas in the world for man to operate in.

2. — THE FLY RIVER : A BRIEF REVIEW

2.1. This is PNG's longest river, with a flow "so great that it ranks with the world's greatest rivers : it is 1 200 km long and is navigable as far as Kiunga, 840 km from its mouth; the gradient in the lower course is very gentle, as Kiunga is only 20 m above MSL. The river is tidal for 240 km upstream and navigation is often difficult because of the tidal bores. Other hazards to navigation are the large sandbanks which constantly change position in the mouth of the river and occasional floods when the river level may rise by up to 10 m" [6]. Its watershed comprises the Star Mountains, the Victor Emanuel, Buller and Muller Ranges. The Strickland, Palmer and Alice (Ok Tedi) rivers are all tributaries of the Fly.

2.2. The Fly may be considered as consisting of three separate sections — the delta section, the estuary section up to Everill Junction at the confluence with the Strickland, which together comprise the tidal zone, and the non-tidal zone from Everill Junction to Kiunga. River shallows occur in all zones and appear to be more mobile in the lower reaches, where general river instability and bank movement appear to be greater. This region of greater instability extends from the Everill Junction to Lewada and is considered due to the additional run-off from the

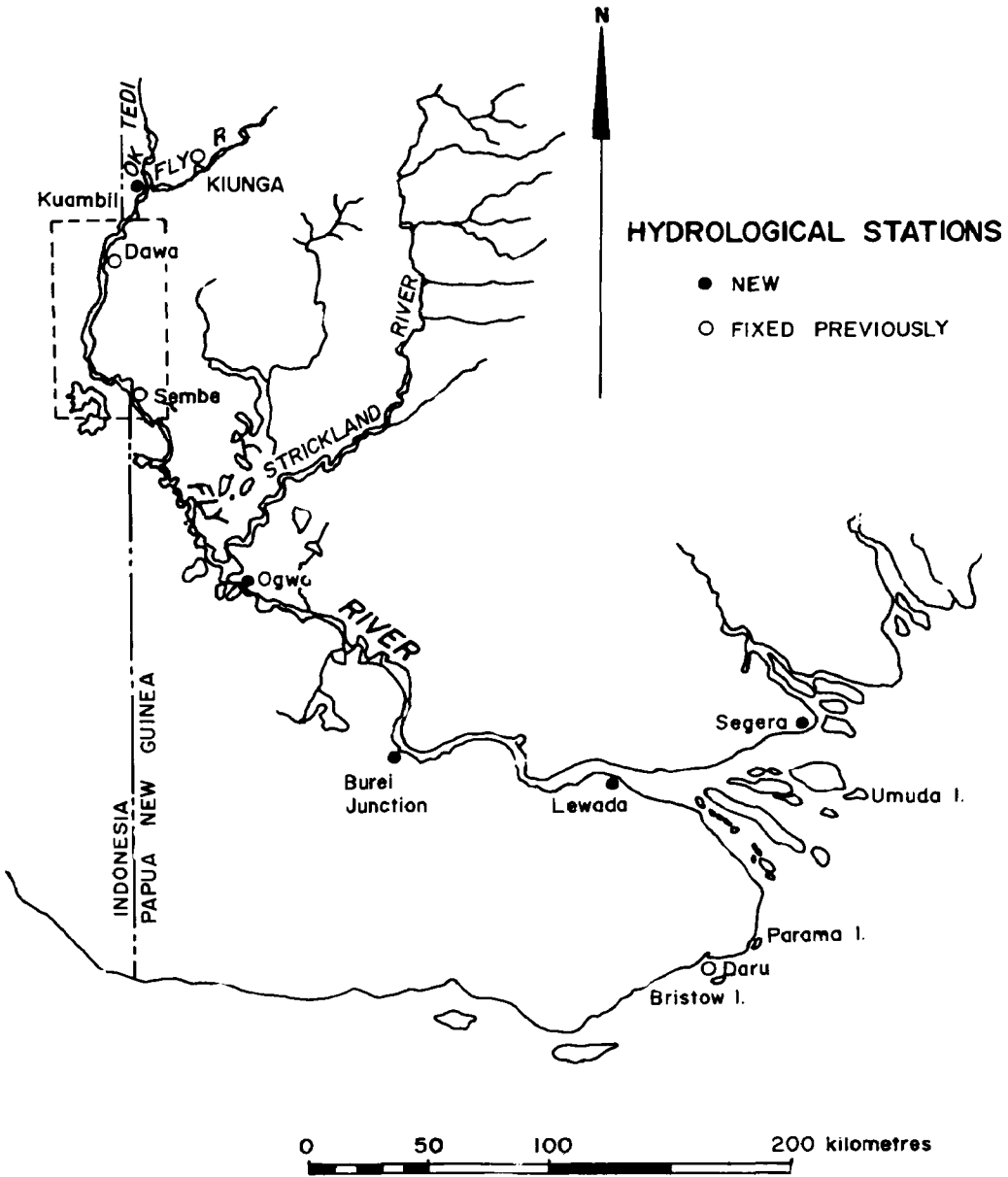


FIG. 3. — Hydrological recording stations, Fly River.

Strickland, tidal influences, bore effects and the less stable river silts which comprise the bed and the banks [2].

2.3. It seems that the river was named after HMS *Fly*, a Royal Navy survey ship in which, in 1845, Captain BLACKWOOD was engaged in investigating alternative passages through the Great Barrier Reef. He encountered a large mudbank some 10 miles offshore and suspected the presence of a large contributory river system, but no survey was attempted. Later, in 1875, D'ALBERTIS, an Italian botanist, made the first of the three explorations, and published a map in 1880. In 1885 Captain EVERILL led an expedition up the Fly and Strickland Rivers, and he was followed by Sir W. MacGREGOR in 1890. Then, between 1913 and 1929, Sir H. MURRAY led several patrols up the Fly, whilst in 1927 the most ambitious foray was made by CHAMPION and KARIS, who succeeded in proceeding all the way up the Fly and across the divide to the Sepik, which they then descended, thereby crossing PNG from south to north. In these days of accessible modern medical support and, in particular, the development of anti-malarials, it is only too easy to underestimate the trepidity of these early explorers.

2.4. The township of Kiunga was established as a base for mineral and oil exploration in 1936. Small trading vessels have plied the river from Daru to Kiunga. Local pilots were always used as no charts or plans had been produced. The first modern work in effect was done in 1974 when two Royal Australian Navy (RAN) vessels navigated up to Kiunga, taking some soundings along the way. BHP did preliminary soundings to and from Kiunga in 1977, but more detailed information was obviously required.

3. — EXPLORATORY HYDROGRAPHY IN THE FLY RIVER

3.1. In August 1977 BHP invited tenders for field examination and evaluation of the cost-effective possibility for a marine barging/shipping operation from the delta up to Kiunga. Possible port sites at Daru and Umuda, inter alia (Fig. 3), were to be looked into, the broad aims being :

- (a) bathymetry of channels leading to proposed port sites;
- (b) tidal and current studies;
- (c) seismic profiles of any areas where dredging was proposed;
- (d) river siltation and sediment studies;
- (e) general oceanographic and meteorological data gathering.

3.2. Study of all available maps, charts and aerial photography disclosed a wide variance in both geographic position and detail. In order to provide an adequate planning medium, a series of maps at a scale of 1 : 100 000 was compiled using data from aerial photography made available by the Royal Australian Survey Corps, QASCO and satellite imagery from the Remote Sensing Association of Australia.

To these "base maps" some quantitative data, made available by various sources with previous interests in the Fly River and delta, were added. This

included hydrographic, topographic, meteorological, reflection/refraction seismic, and horizontal and vertical control information.

After examination of the various complications, the high cost of establishing precise horizontal and vertical control, considering the overall budget, and the projected time frame of the study, it was decided to dispense with the traditional methods of control and fixation. A new set of base maps was produced at a scale of 1:50 000, showing all distinctive topographic features for use as control points to position the survey ship.

3.3. Field work was commenced in January 1978, essentially by Hydrographic Surveys Pty Ltd of Sydney. Vertical control for the survey was to be based on existing predicted and observed tidal information. Pressure type tide gauges were installed at Daru Island, Umuda Island, Madiri and Mugumugu. Data from these gauges was to be analysed and a datum transferred by the classical method of datum transfer from previously established tidal stations at Daru and Umuda Islands. After sufficient data was obtained, co-tidal charts based on time differences and range ratios over the delta region were then to be compiled and used in the reduction of soundings to datum.

However, due to damage sustained by the tide gauges from passing debris and the unauthorized removal of gauges by persons unknown (a very common occurrence in PNG), data acquired was insufficient for the "classical approach" to be used.

Tidal datums in the delta were then established by the comparison of spring and neap tides, using data from the gauges and observed heights at several locations. Attempts were made to train locals to read tide poles, but these proved unsuccessful.

The tidal regime in the delta region is complex, with the merging of semi-diurnal and diurnal components. Run-off of fresh river water results in the diminution of the amplitude of the tidal wave as it moves upstream, so increasing the duration of the flood tide. A tidal bore, with an amplitude of approximately 1.5 m, during the rising tide, is an added complication. Datum up-river was established using tidal data at Mugumugu and extant SMEC (Snowy Mountains Engineering Company) hydraulic data from gauging stations at Ogwa, Kiumbit and Kiunga, the tidal influence being apparent as far upstream as Ogwa.

3.4. It may be noted here that when SMEC reported, in December 1981 [1], their tidal investigations included computer-based tidal predictions based on six months' observations at the delta (Sagero River) and from three months' observations at Lewada at the mouth of the estuary. Clearly, longer-term observations were required, and continued observations enabled progressively more reliable tables to be given (see section 5). Two datums, one tidal, one non-tidal, for soundings are used in their charts; the former is that of Indian Spring Low Water (ISLW) at Lewada, the latter being the Kiunga River recorded as 5.8 m [1] [2].

3.5. Returning to the operations of 1978, previously established control stations were recovered where possible, and control extended for the installation of a two-range microwave distance measuring system; the system used was Cubic DM40 autotape. The two-range method and varying single ranges and bearings

using theodolite or sextant were used in areas where more detailed information was to be obtained.

Most of the survey was plotted using radar ranges. By establishing position from radar-range intersections and gyro compass bearings from distinctive topographic features such as creek entrances, island tangent points, etc., it was evident that the accuracy and repeatability of the plotted position was within the plottable limits and requirements of the survey. The radar used had a 48 mile range, with range display to 18.5 metres.

Fixes were taken at regular intervals as the vessel traversed the required areas, and were plotted on the base maps with notations of time and fix number corresponding with notations on the analog traces of other systems run in conjunction.

3.6. Soundings were obtained on analog record using an Elac echo sounder which was calibrated by bar-check twice daily throughout the duration of the survey. The record was annotated with all relevant data corresponding to entries in the log and vessel track plot.

3.7. From the harmonic constants and the observed tidal data, tide graphs were prepared for each day of the survey, based on the adopted datums at each tide station.

Soundings were reduced by allowing for the height of tide obtained by interpolating between tidal graphs of tidal stations upstream and downstream of the surveyed area. These reduced soundings were inked onto a sounding sheet overlying the vessel's track plot. Selected soundings and contours were then inked onto the final sounding sheets which were presented in a series of charts for the client.

Because of the tidal assumptions made, it was considered that soundings shown would be within ± 0.5 metre and this order of accuracy was verified by comparison of soundings at a common point taken at different states of tide on different days.

3.8. The area between Daru and Bristow Island (Fig. 3) was investigated as a possible port site. To assess the seabed stratum for dredgeability and use for hydraulic fill, a seismic pinger was used. The frequency, bandwidth, pulse duration and power output were adjusted to obtain a suitable analog trace for interpretation. Excellent records were thus obtained, considering the problem encountered with seismic reflection recording methods in areas with strata formed by decayed coral particles and humus debris.

Dual channel sidescan sonar was used extensively to determine the type of seabed material and channel scouring, to identify debris and to assist in the determination of the width of navigable channels. The width of scan selected was variable, and was dependent on the depth of water and definition of the required target.

Bottom samples were obtained using a "dutch grab" to confirm interpretation of the sidescan data to assess bottom stability and to determine dredgeable material.

Current velocities obtained at regular intervals were analysed and used in conjunction with SMEC hydraulic records to evaluate sediment transport rates, scouring and siltation.

3.9. In order to locate navigable channels, the survey vessel was zig-zagged from one sandbank to another. Despite occasional groundings, with the data from the echo sounder records and sidescan sonar interpolation, a chart was compiled indicating the location of channels.

In the upper reaches of the river, the vessel traversed along the right bank. Depths were found to be constant along the straight reaches of the river (4 to 12 metres); they would tend to shoal on the convex banks and deepen on the concave banks, which is a normal river tendency. At creek and river junctions, depths in excess of 40 metres were found.

Due to floating debris, some of which was submerged, navigation up-river was extremely hazardous, especially when towing the sidescan sonar.

Navigating downstream was equally hazardous due to the meanders of the river, the narrowness of the upper reaches and the five to six knot current.

The vessel proceeded successfully into Lake Bossut and 20 miles across the lake to the mission station, through dense weed growth. The mission station had an airstrip, ready supplies of food and was suited for vessel repairs of an emergency nature.

3.10. Field work was completed in March 1978, and the final hydrographic charts were completed in May. The delta is a large (120 miles across), shallow expanse of water, subject to rapid changes from smooth to extremely rough conditions.

Strong winds, coupled with strong tidal currents, constantly shifting sandbanks and the non-existence of navigation aids make navigation extremely hazardous. A previous attempt by BHP to survey a passage through the delta ended with the PNG Government vessel, *Laurabada Rua*, being grounded on a sandbank by the confused sea. The river channels also change somewhat erratically depending on the amount of flood in the river.

A suitable passage for barging operations was located in the northern approaches to the Fly River. Access for the barges to Kiunga is only possible when the river level is approximately 8 metres above the zero of the river gauge at Kiunga.

The river level is dependent on the rainfall in the upper reaches. The river has in the past been known to drop 10 metres in 24 hours (a vessel was once stranded for over three months) and in 1983 appears to have reached record low levels. The feasibility study for barge transport envisaged vessel payload capacities of some 3 500 tonnes, and 2 500 HP twin screw diesel tugs; more than 6 350 tonnes of cargo were reported stranded when nine vessels could not make the passage to Kiunga.

3.11. This initial survey showed that access through the delta up to Kiunga would normally be possible, not only for the shipment of processed ore and materials for a mining venture, but for the general development of what to date has been the poorest province in Papua New Guinea (*).

(*) *Author's Note.* Sections 2 and 3 above are largely based on Mr. G.W. HALLS' paper [3]. See Acknowledgements.

4. — WORK BY OR ON BEHALF OF BHP

4.1. Full details of work carried out by BHP were unfortunately not available to the writer, and reference was made to the SMEC reports.

During a two-week period in mid-March 1977, coverage from the north entrance of the Fly River to Kiunga was achieved with soundings to ± 0.5 m at 300 m line intervals. The result was the production of sheets at a scale of 1: 25 000, charts being reproduced from the Fly River Atlas compiled by Marine Consultants Pty (Melbourne). The Strickland River was in flood during that particular time.

4.2. During a four-week period in October to November 1977, further sounding at 50 m intervals was carried out, resulting in a total of ten sheets at different scales (1: 2000, 1: 1000 and 1: 500), covering three specific areas of the River [2].

4.3. We now turn to the work done by BHP under Mr B.E. MILLIKEN [5]. The main brief, dated late in 1978, was to map a corridor from Ningerum via Tabubil to Mt. Fubilan (Fig. 2), and thence to determine a possible pioneer road route. It was also requested by the government that the part of the Fly River forming part of the border with Irian Java be mapped to enable its banks to be fixed to an accuracy of ± 5 metres (foliage permitting) so that subsequent movement checks could be made. These would be due, for example, to barge and tug wash damage, as well as from river bank movement per se, a worry in its own right. The phrase "foliage permitting" is a problem well known to hydrographic surveyors, especially those engaged in the delineation of shore lines where mangrove swamps pose almost metaphysical problems (e.g. Ref. [4]).

BHP were also later requested to "fix" a number of survey stations along the river as datum marks for gauging and tide recording stations (Fig. 3). From these stations information would be gathered to determine if a suitable depth of water could be maintained along the river over long periods, knowing that substantial variations in river levels (well over 10 m) at Kiunga were possible.

Initial investigations showed that a survey network had been established over the project area and extended in a narrow corridor to Ningerum. However, elevation ties from this network to a trig station north of the Hindenburg Wall (HIRAN 37) showed discrepancies in excess of 40 metres.

Hence the Surveyors' tasks were :

- (a) Establish elevation control related to Mean Sea Level;
- (b) Coordinate 16 photo control survey targets within the border region of the Fly River (Fig. 4);
- (c) Coordinate 12 photo control survey targets along the access corridor between Ningerum and Tabubil;
- (d) Coordinate six new targets and at least five existing targets within the existing project survey network so as to transform it onto the survey (Fig. 4);
- (e) Coordinate five other marks along the length of the Fly River to be used as datum marks for hydrological studies (Fig. 3).

During the transportation study, Daru Island, south-west of the mouth of the river, was investigated as a possible port site. Records existed of tide gauge readings at Daru which were in turn connected by survey to an Australian Army Survey Station (HIRAN 24) on the island. Hence, this point was adopted as datum for all of the survey.

4.4. Connection of Daru to Kiunga using conventional survey techniques would have meant either the use of survey towers to clear the dense jungle, or ground surveys which zig-zagged from bank to bank up the river.

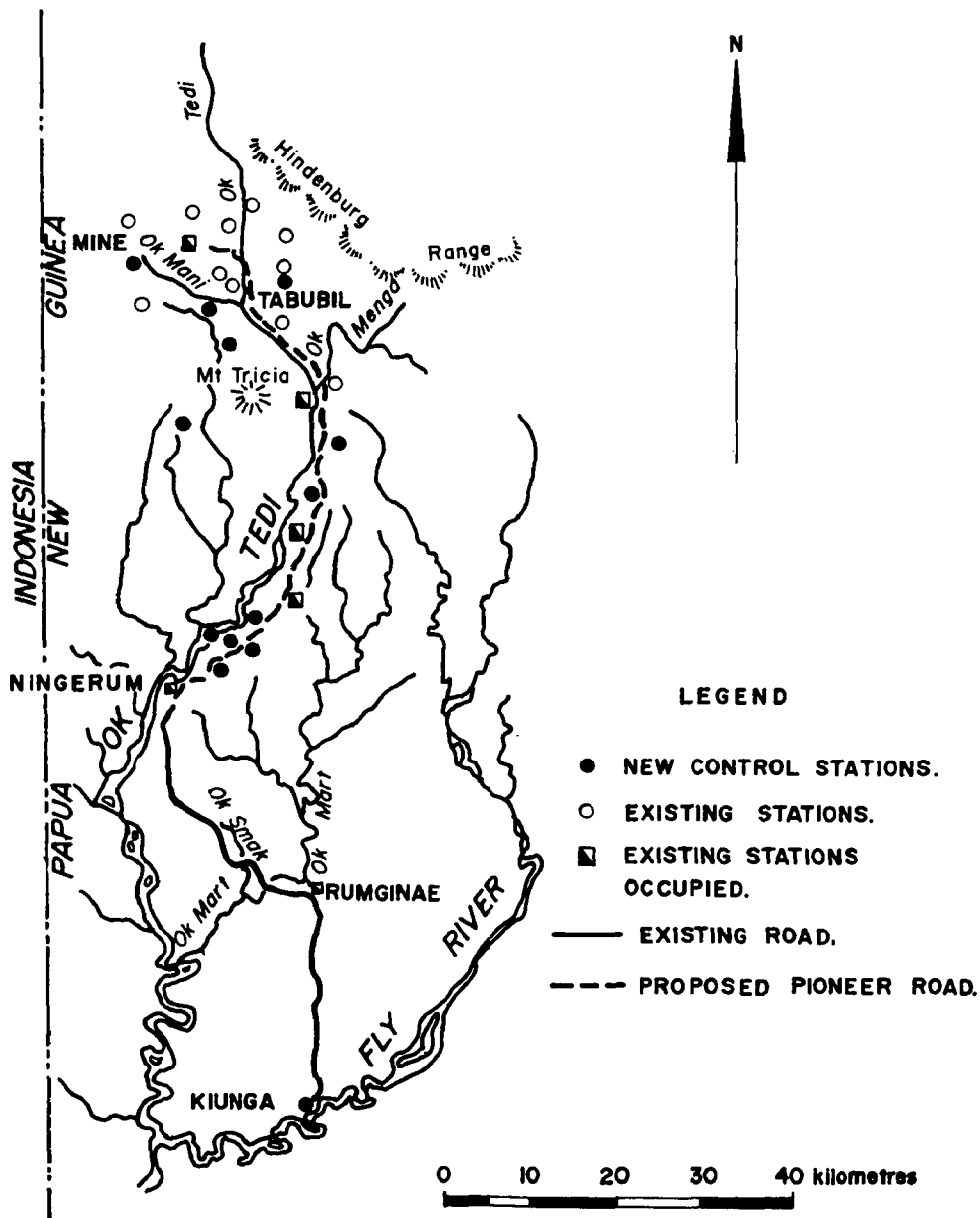


FIG. 4. — Transportation corridor and project site.

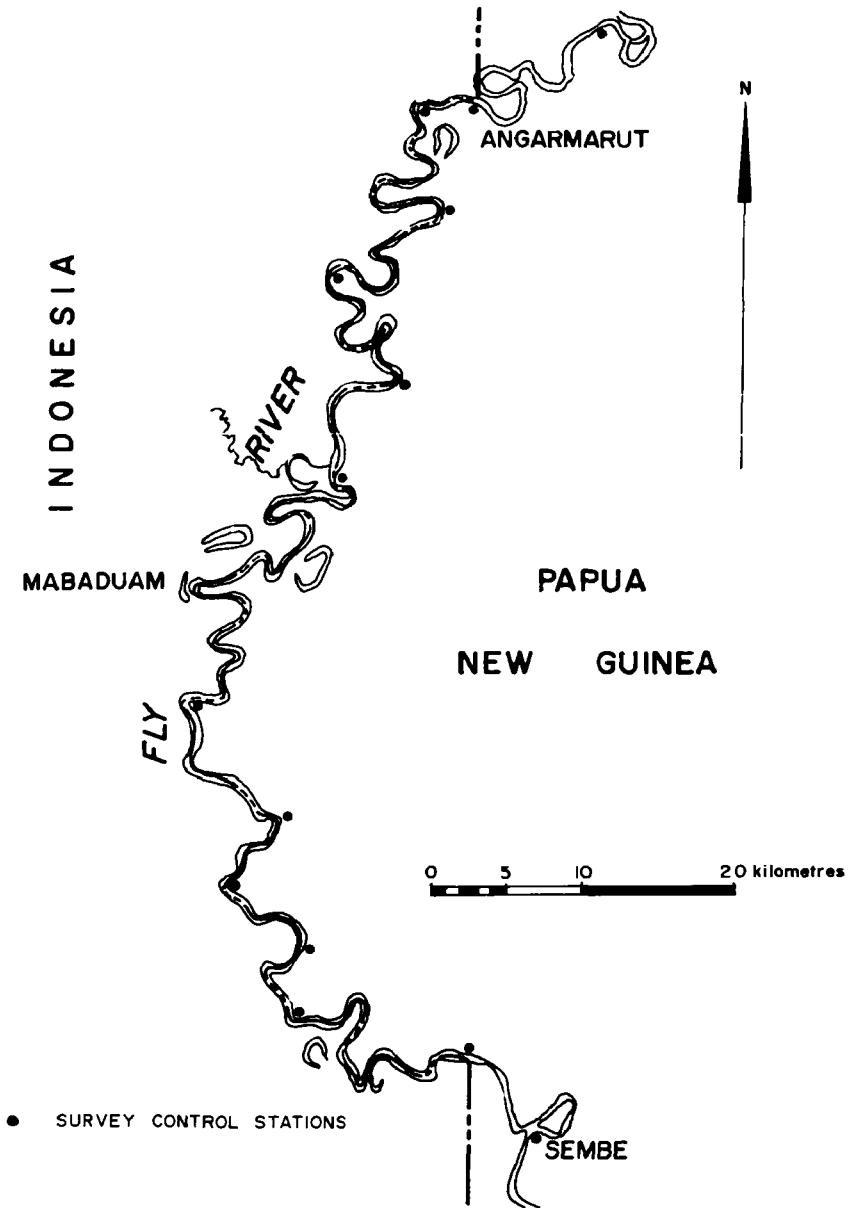


FIG. 5. — Border region of Fly River showing control stations.

However, the lack of prominent topography and the abundance of swamp would have made this method time-consuming and, therefore, very costly. Also, once in the mountain areas, added problems would result from rainfall, cloud cover and the clearance of long lines of sight from station to station. On top of all this was the monumental task of provisioning and accommodating survey and support parties for the duration of the work in remote and inhospitable country.

Hence, it was decided to investigate the use of satellite doppler positioning equipment to carry out the necessary control work. Three Magnavox MX 1502

Geociever Satellite Surveyors were purchased. Initially, only one unit was fitted with a post-processing translocation board, as the units were to be in service in June 1980, while the onboard translocation system was not due for release by Magnavox until late August of that year.

Because the majority of stations being coordinated were located in dense tropical jungle, masts had to be fabricated to hoist the unit's antenna above the foliage so as to reduce interference. These masts were sections of aluminium tubing 2.4 metres in length coupled together by hollow brass sleeves. All told, six sections were coupled together giving a total height, with the antenna attached, of 15.4 metres. Figure 6 shows the normal configuration of a mast.

4.5. The results of the initial work were so encouraging that it was decided to undertake all major control work in the area using the doppler equipment.

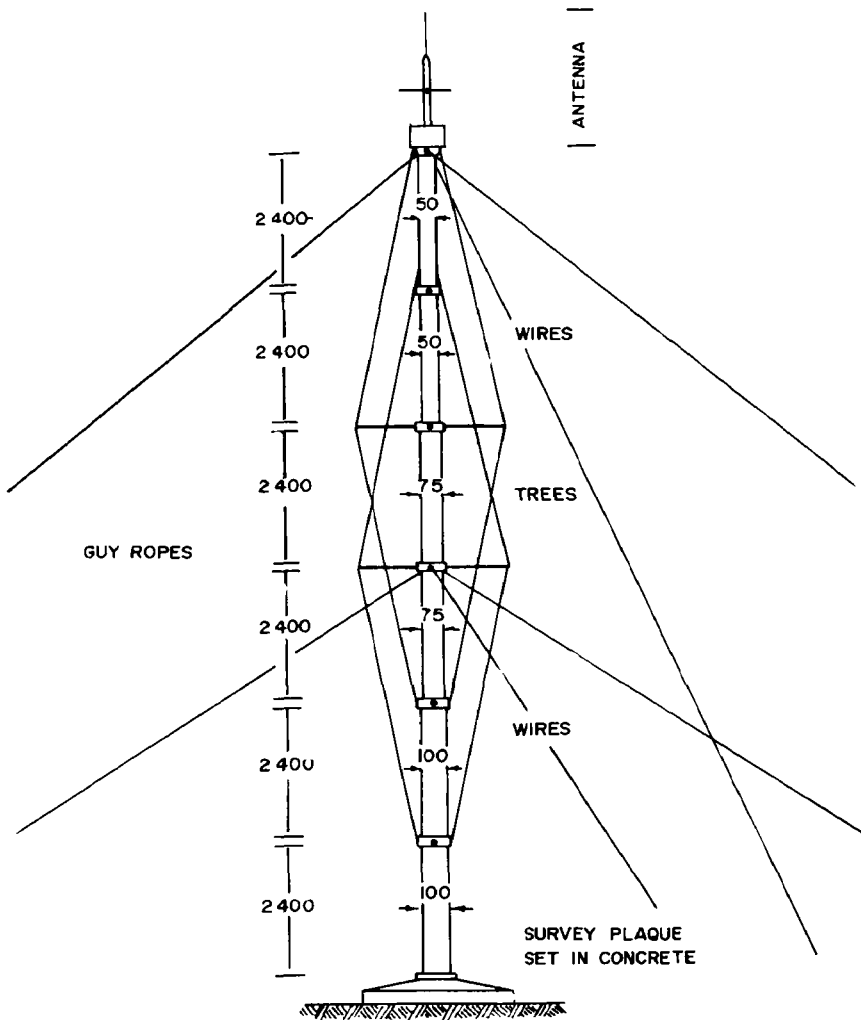


FIG. 6. — Diagram of antenna mast fully erected.

One such survey involved the establishment of a control point midway along the existing road from Kiunga to Ningerum. An Australian Army Survey station on the airstrip at Rumginae was chosen and was fixed by translocation from three days of simultaneous tracking from Ningerum and Kiunga. The values so obtained were to be used as a check for a ground survey using EDM traversing techniques and trigonometrical heighting which was being run by a control traverse for engineering design along the existing road route.

Mr. MILLIKEN concluded that the use of satellites for surveying greatly minimised the surveyor's problems of distance versus cost, without prejudicing accuracy. Over long distances the control was of major benefit for closure purposes for engineering type surveys such as roads. This was especially so where the topography of the area was not suitable for major geodetic control traverses. Its usefulness in high rainfall, inaccessible areas was proven without doubt during this survey project.

5. — LATER HYDROGRAPHIC WORK

5.1. SMEC, with the assistance of Hydrographic Surveys Pty Ltd and the Flinders University School of Land Sciences, South Australia, commenced further work early in 1981. The study had broader objectives than those of earlier work [2] which may be briefly summarized as :

- (a) The location and charting of all potential shoals which could adversely affect efficient barge operations;
- (b) The preparation of reliable navigational charts, plans, cross-section drawings and requisite river profiles;
- (c) The acquisition of sufficient tidal and river level data for the selection of suitable chart datums and for the preparation of predicted tides and river levels;
- (d) The preparation of a recommended scheme of navigational aids.

The field study covered the period from January to March 1981, but the tidal study covered a period of some 21 months, during which submersible tidal recorders (Appendix) were left in sites at Sagero River, Lewada Village and Burei Junction (Fig. 3), being visited at 3 to 6 monthly intervals for servicing and magnetic tape changes. Lewada was selected as the standard port; earlier Daru had been considered for this role, but its positioning with respect to the Torres Strait led to a greater predominance of diurnal constituents, as compared to the general semi diurnal characteristic of Fly River tides. Reference [2] includes accurate tidal predictions based on over 100 harmonic constituents based on analysis carried out by Professor G.W. LENNON.

5.2. The hydrographic work was done under the leadership of Mr. G.C. THOMPSON of SMEC and Mr. G.W. HALLS, Director, Hydrographic Surveys Pty Ltd, using equipment listed in the Appendix. The 21 m vessel M.V. *Coralita* and its Master, Captain MULLER, had also been engaged in the 1978 survey : its draught of 2.5 m was comparable to that of the barges. A 6 m "Hercules" craft was used

for all detail surveys, seven of which were carried out in both the non-tidal and the tidal zones. A total of ten river cross-sections were observed and marked at river shallows and a further five at the gauging stations.

5.3. The results of the work are given in references [1] and [2] and can be summarized as follows :

- (a) The hydrographic investigations succeeded in locating and surveying five shoals in the tidal estuary, and a further seven shoals in the non-tidal section of the Fly River. Of these shoals nine are considered to be the only obstructions in the entire length of the river which are likely to cause an obstruction to the navigation of river barges. These shoals occur at Mugumugu, Sturt Island, Tidal and Minetonga Islands in the tidal section, and Wygerin, Angamarut Passage, Raggi Island, Kuambit Passage, Kawok Bar and just downstream from Kiunga in the non-tidal section of the Fly River.
- (b) The most appropriate navigation channel was located and profiled for the full length of the Fly River from landfall at Korimoro Point to the inland port at Kiunga, some 850 km upstream. Reliable navigation charts were prepared from this river profile and detail survey.
- (c) Sufficient river level and tidal data were collected at the time of the hydrographic survey, for the selection of a suitable chart datum for the entire river and for the reduction of soundings. Long-term tidal data were collected at three locations : Sagero River, Lewada, and Burei Junction, during 1981 and 1982 to enable a comprehensive tidal analysis of the river to be undertaken. Tidal prediction tables for 1982 and 1983 at these three locations were published.
- (d) Accurate hydrographic charts were prepared and published. This information has also been published together with navigational information and tidal prediction in the coloured Fly River Chart Folio (First Edition, December 1981);
- (e) A study of the requirement for, and cost of, navigational aids has also been carried out and recommendations for installation and operation of these aids to navigation were made. The recommended aids to navigation have also been shown in the Fly River Chart Folio.

5.4. Recommendations were also made :

- (a) That Lewada Village be the standard port for the Fly River, rather than Daru (for the reason given above) on Sagero River (since it offers a more suitable location for permanent installation of a tidal recorder);
- (b) That any further tidal analysis in the Fly River should incorporate :
 - installation of a further tidal station in the mixing zone;
 - incorporation of meteorological data into the analysis;
 - incorporation of fresh water run off into the computer model;
 - involvement of the Australian Institute of Marine Science at Townsville, due to their considerable experience in the Torres Strait region;
- (c) That the shoals in the tidal zone of the Fly River be resurveyed annually, and any changes identified should be included in subsequent issues of the

Fly River Chart Folio, and issued in a Notice to Mariners, and the shoals in the non-tidal zone should be resurveyed, and river cross-sections remeasured, to establish their stability/instability. If no changes are detected, then further resurveys will probably not be required unless there is a significant change in the river course in their location.

- (d) That further hydrographic surveys and foundation investigations be made to ascertain the final adopted location of landfall beacon and recommended aids to navigation. Further considerations on the latter are that :
- the installation of these aids to navigation should be let out, through the Project Engineer, to a contractor with proven international experience and reputation in this field;
 - this contract should cover the installation of all aids to navigation including the landfall beacon;
 - all aids to navigation should comply with the Papua New Guinea Department of Transport requirements, and should be standardized for easier maintenance;
 - all such aids established should comply with the IALA maritime buoyage system, to which Papua New Guinea is a signatory.

The Papua New Guinea Department of Transport has instructed that the installation, operation and maintenance of the aids to navigation are to be the responsibility of the Ok Tedi Mine. To satisfy this requirement the following recommendations are made :

- the operation and maintenance of all aids to navigation should be included in the contract for barging operations, thus making the barging contractor responsible for the safe passage of his own vessels;
- the barging contractor should hold adequate spare parts (as recommended by the supplier) for each category of aids to navigation, which are to be stored in close proximity to the Fly River;
- at least one snag barge should be made available for the maintenance of these aids.

6. — CONCLUSION

Accurate up to date charts of the Fly River are now available for the first time; shoals have been located and surveyed, comprehensive tidal analyses have been carried out and a scheme of proposed aids to navigation prepared. Recommendations for future work have been made; these include further data gathering of a hydrological, tidal and meteorological nature as well as continued surveillance of potentially mobile areas. The hydrography of the hitherto "elusive" Fly River has been established on a very impressive professional basis.

7. — ACKNOWLEDGEMENTS

A newcomer to PNG has attempted to review previously published data on the fascinating subject of the Fly River. He is particularly appreciative of the excellent work of Mr. G.W. HALLS, Director, Hydrographic Surveys Pty Ltd, and for the ready cooperation of Broken Hill Proprietary Ltd (BHP), in the persons of Mr. D.M. SCOTT (Manager, Surveying) and Mr. B.E. MILLIKEN (Chief Surveyor), the latter having been extremely generous in allowing, in other contexts, the use of material from his work. Other parties who have been most helpful have been Mr. M.J. LARMER of Arman-Larmer Surveys, Port Moresby, Mr. R.J. WEIDNER, Mr. P. ROBINSON and Dr. R.J. HIGGINS of the Ok Tedi Mining Company, and Mr. G.C. THOMPSON of the Snowy Mountains Engineering Co. (SMEC). All are very sincerely thanked. Figures 2 to 6 are reproduced by kind permission of Mr. B.E. MILLIKEN of BHP, whose work on control for the Fly River scheme was, in the author's opinion, outstanding.

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9. — APPENDIX

Equipment used for hydrographic surveys in 1981

The following equipment was used during the hydrographic survey [2]. SMEC supplied the following :

- 3 Applied Microsystems model TG 12 A submersible tidal recorders;
- 4 Bristol chart recorders;

- Tellurometer CA 100 electronic distance measuring instrument;
- Theodolite, level and other miscellaneous survey equipment;
- CB communication system;
- Chain saw and brush cutter;
- River height recorders from the three permanent gauging stations.

Hydrographic Surveys Pty Ltd supplied the following equipment :

- Cubic DM 40 A autotape dual range electronic distance measuring system;
- 3 Negretti and Zambra chart recorders;
- Toho Denton current meter;
- Raytheon model 719 echo sounder;
- Electronic maintenance support for all equipment used in the survey.

BHP supplied the following equipment :

- 3 Magnavox model 1502 satellite geocivers;
- Atlas Deso 10 echo sounder;
- Leupold Stevens tidal recorder;
- A set of AWA UHF walkie-talkies;
- Codan two-way radio.

The M.V. *Coralita* navigation equipment was also used. This included :

- Furuno radar, with discriminator and range display;
- Simrad echo sounder;
- Sailor VHF radios;
- 2 outboard motors.