A Method of Flood Runoff Estimation in an Ungauged Catchment (Ok Mani) in the Highlands of Papua New Guinea

A Thesis
submitted in partial fulfilment
of the requirements for the Degree of

Master of Arts in Geography

at

Massey University

by

Joseph Ba Irai

Department of Geography, Massey University
Palmerston North, New Zealand

1996

DEDICATION

This Dissertation is dedicated to my parents, Christine (late) and Thomas. I will always cherish and treasure their love, determination and hard work in getting me this far. Without them, I would achieve nothing.

ABSTRACT

Ok Mani stream is one of the major tributaries of the Ok Tedi River in the Western Province of PNG. The catchment is located south of one of the world's biggest open-cut gold and copper mines, the Ok Tedi Copper Mine. The catchment is in one of the areas in PNG that receives the highest rainfall annually and is located within a region of very unstable geology.

One of the mine's overburden storage dumps is located in the Ok Mani catchment and it subsequently failed due to the increasing weight of the overburden. The failure resulted in major changes to the morphology, sediment loads and the biota of the stream and the rivers downstream. The fieldwork of this dissertation was part of a major investigation undertaken to locate an alternative site in the catchment to store the mine's overburden.

The dissertation presents the results of a study undertaken in the headwaters of Ok Mani stream. There is a discrepancy in the current runoff-rainfall record from the catchment, where runoff appears to be significantly greater than the rainfall. The study attempts to quantify the storm runoff from different sub-catchments and seeks to confirm or not the possibility of extra-catchment sub-surface flows into the catchment.

The results indicate that the measured runoff and rainfall are not reliable and that discrepancies between runoff and rainfall did not support the hypothesis of extra-catchment flows. There is evidence that rainfall increases significantly with increasing catchment elevation. However, the study undertaken for this thesis was very short and thus the results obtained are very limited. Therefore, further research into the sources of the excess runoff to that of the rainfall gauged at MANO4 is required before the runoff-rainfall discrepancy is put into perspective.

ACKNOWLEDGEMENTS

I am grateful and acknowledge the following individuals and groups of people who have contributed in one way or another during the course of writing this dissertation.

Mr. Richard Heerdegen (Programme Supervisor) - Senior Lecturer, Department of Geography, Massey University, New Zealand. With his extensive knowledge in the field of hydrology, the help and guidance I received during the preparation of this dissertation proved invaluable.

Mr. Arnold Moi (Fieldwork Supervisor) - Hydrologist and Mr. John Wom - Senior Hydrographer, Environment Department - Ok Tedi Mining Limited, Papua New Guinea. They managed to find time from their over-committed daily schedule to help me with my fieldwork. I thank Ok Tedi Mining Limited and the staff of the Environment Department for their logistical support during the field work.

I thank the staff and graduate students (1994 & 1995) of the Geography Department, Massey University for helping me in many little ways during my study. I also thank Professor John Flenley for offering me a place of study in the Department to undertake the programme.

I also thank the New Zealand Ministry of External Relations and Trade - Official Development Assistance (NZMERT-ODA) for offering me the scholarship to undertake the Masters programme at Massey University and their assistance in airfares to and from Papua New Guinea for the thesis fieldwork.

Finally, I thank Mrs. Sharon Humphries and family for making my stay in New Zealand a memorable one.

CONTENTS

LIST OF FIGURES

LIST OF PLATES

LIST OF TABLES

LIST OF APPENDICES

Appendix:

ABBREVIATIONS

A	-	area in square kilometres
asl	-	above sea level in metres
C_2	-	runoff coefficient of flood
cumecs	-	cubic metres per second
D	-	total rainfall depth of storm in millimetres
ELVN	-	mean channel elevation in metres
I	-	rainfall intensity in millimetres per hour
km	-	kilometres
km^2	-	square kilometres
KS	-	swamp adjustment factor of sub-catchment
L	-	main stream length in kilometres
m	-	metres
mm	-	millimetres
m/km	-	metres per kilometre
m/s	-	metre per second
m^3/s	-	cubic metres per second
NERC	-	Natural Environment Research Council
NWASCO	-	National Water and Soil Conservation Organisation
NRC	-	National Research Council
OTML	-	Ok Tedi Mining Limited
P_2	-	point storm rainfall in millimetres
PNG	-	Papua New Guinea
Q_P	-	peak flood-flow
r	-	number of revolution
S	-	slope of main stream channel
SMEC	-	Snowy Mountain Engineering Corporation
t	-	duration of storm in hour
V	-	stream-flow velocity in metres per second

Chapter 1

INTRODUCTION

1.1 Concept

River flow characteristics are closely connected with the problem of suitable design criteria for structures in water resource projects, such as spillway designs, culverts, bridges, waste and water retention dams, etc (Nemec 1972). Flood plain management, the design of hydrologic structures and other water-related investigations need to reflect the probability of extreme flood events. An appropriate estimate of this extreme flood is fundamental in ensuring that engineering designs with adequate standards of safety are achieved (NWASCO 1982). Extreme rainfall events and the resulting floods can take thousands of lives and cause billions of dollars in damage (Stedinger, Vogel and Foufoula-Georgiou 1993).

Flood peak discharge has been an essential item in the planning and construction of water resource projects for many decades and the estimation methods developed have been a major tool for engineers, hydrologists, designers and researchers. It is an important tool in the transfer of hydro-engineering information from gauged to ungauged catchments (Rao and Hsieh 1991, Zrinji and Burn 1994), for the estimation of flood flows (NWASCO 1983, Qinliang and Eagleson 1987, SMEC 1990), project design and planning (Nemec 1972, Ward 1975, NRC 1988, SMEC 1990) and other engineering, planning, hydrological and research applications (Heerdegen 1973).

1.2 Purpose of Research

The Ok Mani catchment rainfall-runoff deficiency investigation is part of a large project currently undertaken by Klohn Crippen Consultants of Canada for the Ok Tedi Mining Limited (OTML), Papua New Guinea (PNG). The objective of the project is to look at alternative mine-waste retention sites in the Ok Mani stream catchment as the current one has failed. The Hydrology Section of the Environment Department - OTML has been asked by Klohn Crippen to monitor the rainfall-runoff in the catchment. Currently, two rainfall and one stream-flow gauging stations have been established in the catchment. The data collected and analyzed so far over a period of two years has indicated that runoff is 150 percent greater than rainfall in the catchment, giving rise to an apparent hydrological paradox.

The flow discrepancy is understood to be caused by one or several of three possible factors, including: (i) errors in the gauging and analysis of current data; (ii) high rainfall in the highland areas of the catchment that is not currently being monitored; and (iii) in-flows from adjoining catchments.

The first possible cause has been looked at and dismissed as all the data gauged and analyzed has been of good quality. The second possible cause is currently being looked at. Three raingauges have been installed in the highland areas of the catchment to monitor rainfall in that region. This investigation seeks to confirm or not the existing rainfall-runoff discrepancy which will help determine the third possible cause - to establish whether there are underground flows from adjoining catchments into Ok Mani and to identify possible sources of these inflows.

The investigation involved mapping the upper-most section of the catchment into sub-catchments and quantifying the flows in these sub-catchments into the Ok Mani stream. By use of flood estimation techniques, flows from the sub-catchments were estimated and compared with those from gauged sub-catchments. The extent of inflows from adjoining catchments into Ok Mani can then be established from the comparisons.

Once rainfall in the highland areas of the catchment is monitored and the extent of inflows into the catchment is established, the rainfall-runoff discrepancy in the Ok Mani catchment can then be put into perspective.

1.3 Literature Review

1.3.1 Flood Estimation Methods

Floods of extreme magnitude with a low probability of recurrence are of continuing interest to the hydrologic and engineering communities for purposes of design and planning (Pilgrim and Cordery 1993). Many estimation methods that have been developed are used to estimate magnitudes of these floods and the methods chosen vary from region to region. Despite their widespread use, the methods involve a number of assumptions (Ayoade 1988, Pilgrim 1975) of both climatic and physical catchment parameters. When these assumptions are kept to a minimum, they provide "best estimates" of floods (SMEC 1990).

Various estimation techniques of flood prediction and forecasting exist in the literature, but they can all be categorised, following Ward (1975) as; (i) empirical, (ii) statistical, (iii) analytical and (iv) modelling techniques. Which of the techniques is chosen depends on a number of factors including the purpose for which it is required, the available data and the area and characteristics of the drainage basin (Ward 1975). According to Pilgrim and Cordery (1993), the three most widely used techniques for estimating flood-flows on small drainage basins are the Rational, the U.S Soil Conservation Service and the Regional Flood Frequency methods.

The Flood Estimation Manual prepared by SMEC (1990) for the PNG Bureau of Water Resources (PNGBWR) outlined ten flood-estimation methods. Some are for rural catchments and others for urban, of any size (up to 50 000 km^2 or more) at any location in PNG depending on whether it is rural or urban and for return periods ranging from 2 years to 100 years. The procedures are principally directed to the estimation of peak flood-flows.

The flood data used to develop these estimation procedures come mostly from BWR. It has a data base containing all flood data in PNG, plus the history files and discharge rating curves for all its gauging stations. Other organisations such as OTML, Porgera Joint Venture and the National Weather Service, in certain areas, record and keep stream gauging and climatic data.

A couple of the estimation methods formulated by SMEC (1990) that more-or-less fit the Ok Mani catchment characteristics and the requirements of this rainfall-runoff anomalies investigation and applied in this research are the Rational and Regional Flood Frequency methods. The runoff coefficients for the Rational method were derived from measured flood data on thirty streams with catchment areas ranging from 5 km^2 to 350 km^2 and were related to physical catchment parameters (SMEC 1990). The Regional Flood Frequency method was based on the regression analysis of 66 flood records and various catchment and rainfall parameters. The catchments were located throughout PNG (most on the mainland) and had catchment areas ranging from 5 km^2 to 40 900 km^2. The Rational method is deemed to be more suitable than the Regional Flood Frequency method for catchments of less than 4 km^2 of area. Both methods are among many other flood estimation methods applied in areas where a record of adequate flood data does not exist (NWASCO 1982).

The Rational method is an empirical one and is one of the earliest and best-known techniques to estimate peak flows (Ward 1975). It was developed primarily for use in the design of drainage systems and is still by far the most widely used method in that application (Body 1975). Body further pointed out that it is a venerable procedure where all the essential aspects of the method were set out by Mulvany in 1851, while Kuichling (1889) and Lloyd-Davis (1906) established the method in the United States and United Kingdom respectively.

Since its inception, the method has been amended over and over to suit the climatic and physical conditions of the area to which the method is to be applied. This improves the estimation results as they fail to perform well when used outside the area or conditions under which they have been derived (Ayoade 1988). The method has been applied widely in ungauged areas in PNG (SMEC 1983 [unpublished] and 1990), Australia (SMEC 1990), New Zealand (NWASCO 1982), China (Jiaqi 1987 and Body 1975) and in many other countries for the estimation of flood-flows for water-related engineering design purposes.

Regional Flood Frequency methods have also been applied widely. For example, in the United States (Pilgrim and Cordery 1993, Kirby and Moss 1987, Jarrett 1987 and Cohn and Stedinger 1987), British Isles (NERC 1975), New Zealand (NWASCO 1982), China (Hua 1987, Zhu 1987, Cong and Xu 1987) and in Australia and PNG (SMEC 1990). For ungauged catchments or where the flood data is inadequate, regional equations have been developed which enable the estimation of flood-flows, given the catchment area and rainfall data (NWASCO 1983). The regression relationship is applied in ungauged catchments of similar areal and climatic parameters to determine an estimated flood-flow. This method is one way of extending the data base from a number of sites to cover a region.

Both Rational and Flood Frequency methods require the catchment to be divided into sub-catchments. Each of the methods require certain catchment and climatic parameters for flood-flow estimations. In this study, the choice of method to use in a sub-catchment depends on the catchment area, i.e., the Rational method is applied in catchment areas of 1 km^2 to 4 km^2 and the Regional Flood Frequency method in catchment areas of over 4 km^2.

The flood-flows in this study were measured by applying the float technique, a technique which does have its disadvantages. Firstly, floats cannot be used to take at-point stream-flow velocity and secondly floats record only surface velocities, which are higher than the average stream-flow velocity (Ayoade 1988). Float measurements made carefully under favourable conditions may be accurate to within ± 10 percent. If a nonuniform reach is selected or too few floats are used, results may be in error by 25 percent or more (DSIRNZ 1988). However, in most studies under favourable conditions, the technique has been known to give reasonable results (NRC 1988).

1.3.2 **Karst Hydrology**

The scientific discipline of hydrology, although a long-established science, cannot easily be applied to karst regions with their very complex drainage systems. A special approach is therefore necessary to understand and predict water circulation in these areas (Bonacci 1987). The literature on water circulation processes in karst regions comes from the work of numerous researchers including Sweeting (1972), Arikan and Ekmekci (1985), Gunay (1985), Jennings (1985), Bonacci (1987) and Degirmenci and Gunay (1990). However, in general, the hydrology aspect has not been dealt with thoroughly and cannot be applied appropriately in practice. Therefore the circulation of water in karst is considered as a "black box" (Bonacci 1987).

Jennings (1985) pointed out that the number of streams are usually few in karstic regions, with a low drainage density because rivers entering karst or within it lose all or part of their volume, distinct from water infiltrating through soil, underground. The surface water in karst can gradually sink through a system of small joints and fissures, but sometimes part or whole of the surface water sinks underground through a great swallow hole or a system of several smaller swallow holes (Bonacci 1987). Jennings also found that frequently a stream has a series of karst swallow holes along its course into which it loses successive fractions of its volume.

Karst springs represent a natural exit for the underground water to the surface of the lithosphere through the hydrologically active fissures of the karst mass (Bonacci 1987). Sweeting (1972) found that streams could disappear into a swallow in one river basin but reappear through a spring in another. A spring could be either an exsurgence (from seepage through karst rocks) or a resurgence (reappearance of a former surface stream) (Jennings 1985). Bogli (1980) distinguished springs as: (i) perennial; (ii) periodic; (iii) rhythmically flowing, intermittent and flow springs; and (iv) episodic. Jennings (1985) pointed out that levels and so changed with time. In the Dinaric Karst in Yugoslavia, from the studies of two karst springs, Bonacci (1987) found that at very high ground water levels (after heavy rainfall), the springs were active, and their catchment areas significantly increased. At low ground water levels (after long dry periods), the watershed lines moved inwards or shrink as water is lost to springs so that their catchment areas were considerably decreased.

A list of references is given in Section 7 of the thesis so that the reader can pursue any further reading or particular topic pertaining to flood prediction and estimation in karstic catchments.

1.4 Background Information

1.4.1 Location

The Ok Mani stream catchment is located in the Western Province of PNG. It is approximately 9.2 km NNW of the Ok Tedi mining township of Tabubil and 4.1 km SW (approximate central point) of the Ok Tedi Gold and Copper Mine site (see Figure 1.1). The catchment is located at 141^0 13' S 5^0 21' E.

1.4.2 The Province

Western province is by far PNG's biggest province by land area of 99 300 km^2. Parts of the province are amongst the areas in PNG which receive the highest annual rainfall. Western Province has the country's biggest river by volume (Fly) and the biggest lake by surface area (Murray) (Maunsell and Partners 1982) (see Figure 1.1). For many years the province was considered to be the poorest (Boyden 1974) with least changes and developments. However, the Ok Tedi Gold and Copper Mine has helped to change this situation, including changes in the economic, physical and the social environments.

1.4.3 Physical Setting

The southern part of the province is mostly low-lying land and subjected to seasonal flooding. Many of these areas are either permanently or seasonally

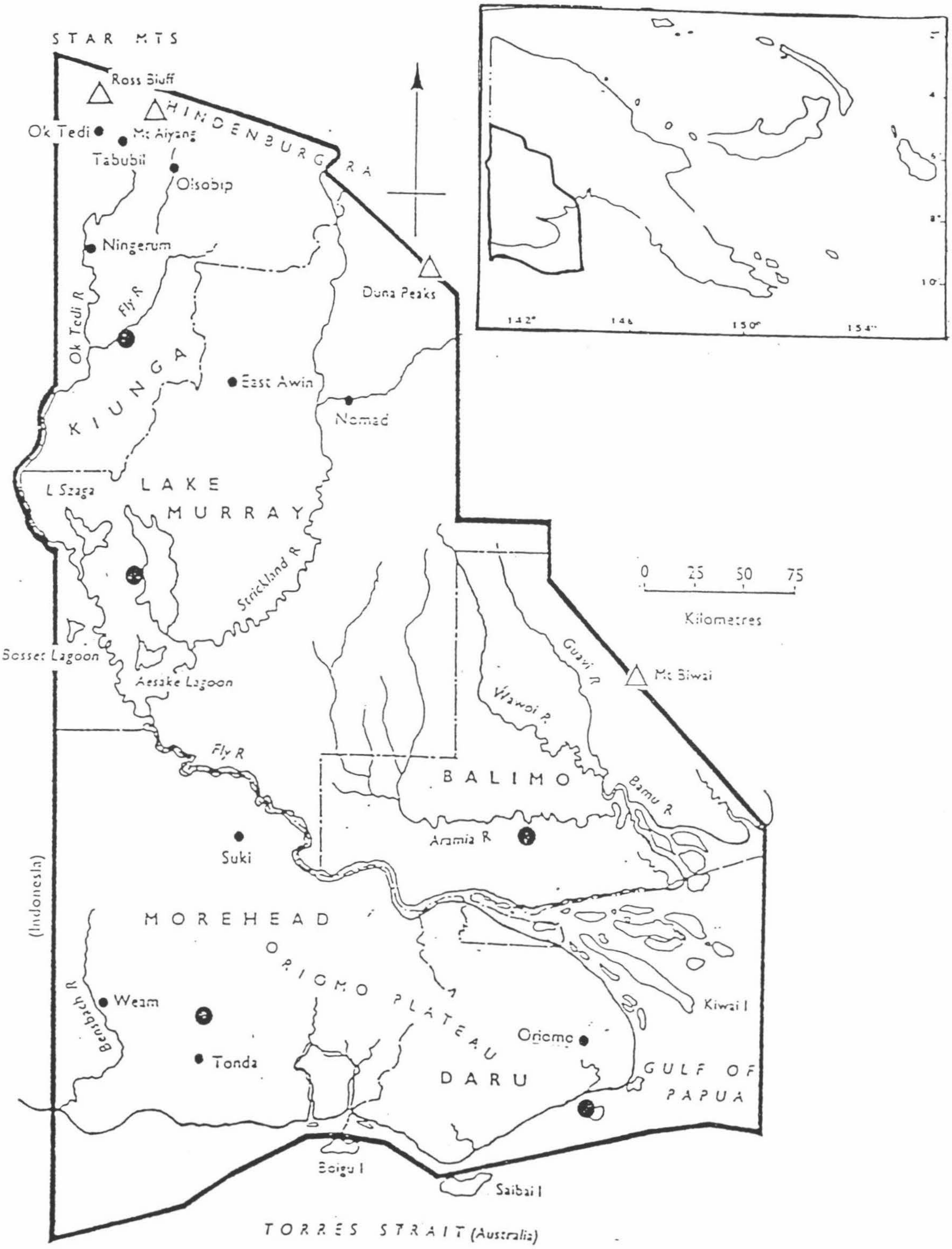


Figure 1.1: Location map: Western Province - Papua New Guinea

flooded. In the north, mountain ranges rise to over 3 500 m. Ok Mani catchment lies within the mountain ranges in the north-west of the province, about 1000 km inland from the Gulf of Papua and approximately 24 km east of the Irian Jaya (Indonesia)-PNG border (see Figure 1.1). It is characterised by rugged topography; that is, steep slopes, dense forest, and a high density network of fast flowing streams in narrow valleys.

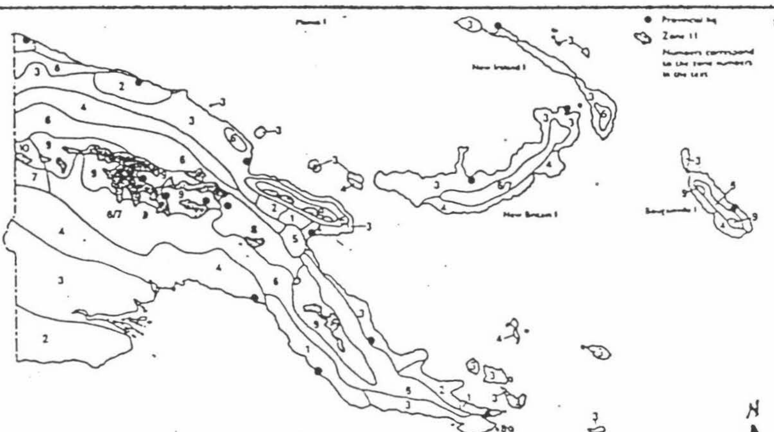
1.4.4 Climate

The climate of the Province and Ok Mani catchment is shown in Figure 1.2.1. It is divided into six climatic zones (types 2, 3, 4, 6, 7, and 10; see Rannells 1990).

Annual rainfalls in excess of 10 000 mm are recorded in the upper catchment in the mountain ranges in the north (Eagle and Higgins 1990). Monthly rainfall totals vary little throughout the year and there is very little seasonality (see Figure 1.2.2). Ok Mani catchment is located west of this region and has climate types 7 and 10 (see Figure 1.2.1). That is, the catchment has an annual rainfall of more than 3 500 mm. In contrast, in the southern part of the province, rainfall is influenced by the prevailing monsoons and trade winds which produce distinct wet and dry seasons (see Figure 1.2.2). This southern part has a high seasonality with a January-April maximum. Average annual rainfalls totalling 3 500 mm are recorded in these areas (Eagle and Higgins 1990).

1.4.5 Vegetation

The province has a mixture of environments and associated vegetation. Both upper and lower montane forest cover the higher lands in the north, foothills and low mountains. There are lowland fresh water swamps in the middle, and lowland alluvial plains and fans in the lower lands in the south of the province. Towards the coast, the province has saline and brackish swamps with beach ridges and flats along the coast (Paijmans [ed.] 1976). Ok Mani catchment is within the Lower Montane Zone. The catchment has a vegetation of mixed lower montane forest and swamp and palm forest with patches of mid-height lower montane grassland.



Climate types 1-4: up to 500 asl m
1. 1000-1500 mm of rain, May-November dry period
2. 1500-2000 mm of rain, June-October dry period
3. 2000-3500 mm of rain, variety of rain seasons
4. > 3500 mm of rain, May-October heaviest

(Source: Rannells 1990)

Climate types 5-7: 500 to 1400 m asl
5. 1500-2000 mm of rain, November-April slightly heavier
6. 2000-3500 mm of rain, December-March heaviest
7. > 3500 mm of rain

Climate types 8-10: 1400 to 3000 m asl
8. 1500-2000 mm of rain, December-April heaviest
9. 2000-3500 mm of rain, December-April slightly heavier
10. > 3500 mm of rain
11. areas above 3000 m asl, > 3000 mm of rain

Figure 1.2.1: Climate of Papua New Guinea

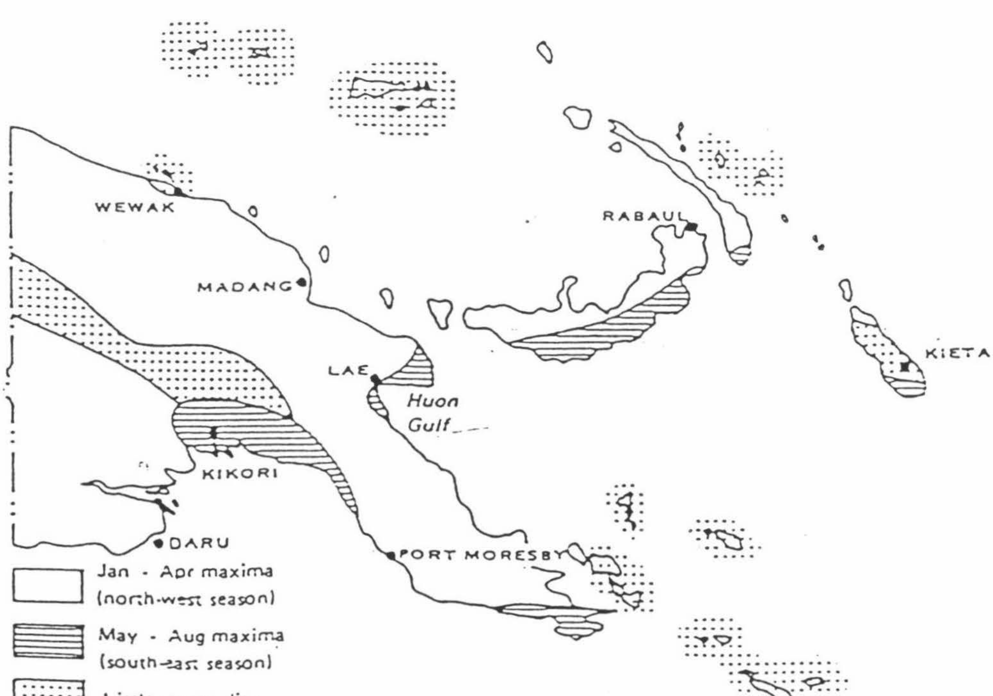


Figure 1.2.2: Seasonality of Rainfall (Source: SMEC 1990)

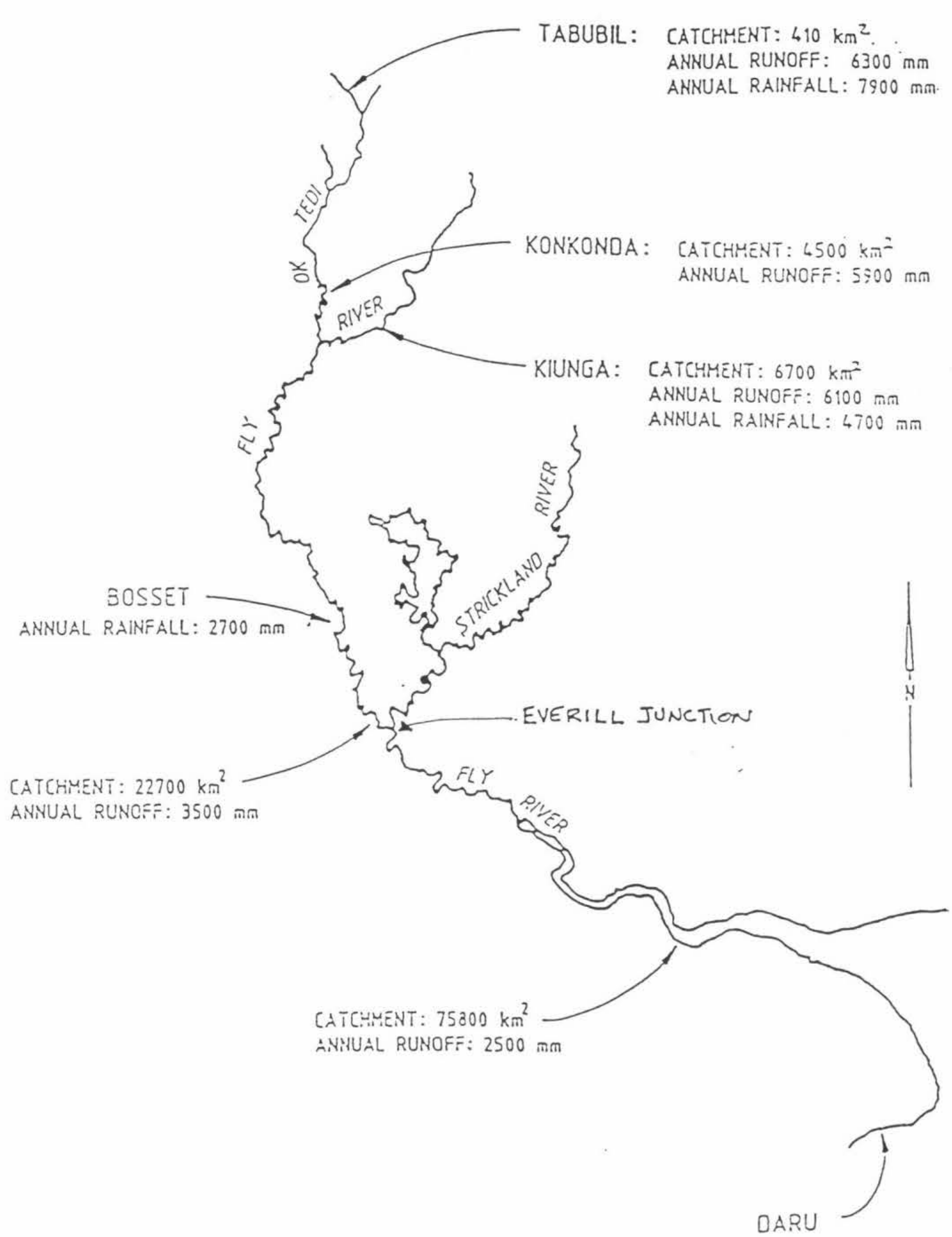
1.4.6 **Hydrology**

Ok Mani stream is one of the major tributaries of the Ok Tedi River which drains into the Fly River (see Figure 1.1). It has a catchment area of 68 km^2 and drains the area to the south and south-west of the mine. It is located within the Ok Tedi region which has a mean annual rainfall of 8 000 mm (maximum of 10 000 mm being recorded in some places in the region) and a very high annual runoff of 6 300 mm at Tabubil from a catchment area of 410 km^2 (see Figure 1.3) (Paltech 1979).

Mean daily flow of Ok Mani stream at MANO4 (OTML gauging station for the upper catchment area of 24.20 km^2) is 15 cumecs with the maximum recorded being 120 cumecs (OTML 1990 [unpublished]). Comparatively, the mean daily flow along the Fly River at Obo is about 2 400 cumecs and downstream of Everill Junction (see Figure 1.3) about 6 000 cumecs (Markham 1991).

Given a mean daily flow of 15 cumecs at MANO4 for the upper catchment of Ok Mani, the mean annual discharge is 1.296 x 10^6 m^3 and 473.04 x 10^6 m^3 per day and year respectively. With a catchment area of 24.20 km^2 x 10^6 m^2, the upper catchment from MANO4 would have an estimated mean annual depth of runoff of 19 550 mm, a figure which is some 2-3 times the annual rainfall.

Mean annual rainfall and runoff is compared with some other locations along the Fly River System in Figure 1.3. These figures are very high by world standards. For example, the most notable comparison is the Amazon River in South America. The average annual runoff is 900 mm with a catchment area of 7.18 x 10^6 km^2 (Maunsell and Partners 1982 [unpublished]). The average annual runoff from the Fly River is 2 500 mm downstream and 6 300 mm upstream at Tabubil (see Figure 1.3), which at these runoffs are respectively over 2.5 and 7 times greater than that for the Amazon River. The estimated depth of annual runoff of 19 550 mm for the upper Ok Mani catchment, is over 22 times more than that of the Amazon River. The extremely high and persistent rainfall in the upper catchment of the Fly River in the north explains these runoff characteristics.



Notes :- 1. Annual Runoff is average for total Catchment above the nominated Station.
2. Annual Rainfall is average at the nominated Station.

Figure 1.3: Catchment Areas, Rainfall, Runoff and the Fly River System

(Source: Paltech 1979)

1.4.7 **Geomorphology**

Ok Mani catchment is characterised by an extensive network of both perennial and intermittent streams between steep slopes with narrow valleys. The upper catchment from Harvey Creek (see Figure 1.4) is relatively steep with the lowest and highest elevation of 640 m and 1 560 m asl respectively within a straight line surface distance of 5 km. This gives an average valley slope of 184 m/km. The main stream flows through a narrow channel varying from 5 m to 10 m in width. Ok Mani channel is mostly boulder-bedded along this reach with no major evidence of material deposition (see Plate 1.1).

The downstream channel to the confluence at Ok Tedi River is a braided stream between 100 m to 350 m wide (see Figure 1.4). The channel in this reach is between an elevation of 400 m and 600 m asl within a straight line distance of 11 km (slope of 18.2 m/km) and is flat and wide compared with the channel upstream. The stream is cobble- to gravel-bedded (see Plate 1.2) and establishes a meandering pattern before it joins the Ok Tedi River. The dominant flow channel within this reach seem to change after storms through sediment transportation and deposition (see Plate 1.2). That is, bed material is eroded during high flows and deposited at low flows, the latter blocking existing channels, thus forcing the water to be distributed to flow in numerous channels and into new areas creating new flow channels and meanders throughout the braided channel.

Most or all the material transported from upstream is deposited in the lower reach as the flow decreases. The decrease in flow and the subsequent deposition of material is due the decrease in flow velocity and volume as a result of the decrease in channel gradient, widening, and meandering from aggradation, thus the stream's capacity or energy to transport decreases. The aggradation in this reach (see Figure 1.4 and Plate 1.2) resulted from the failure of the mine overburden dump in the Harvey Creek catchment, a tributary of Ok Mani stream, after the first year of dumping in 1991.

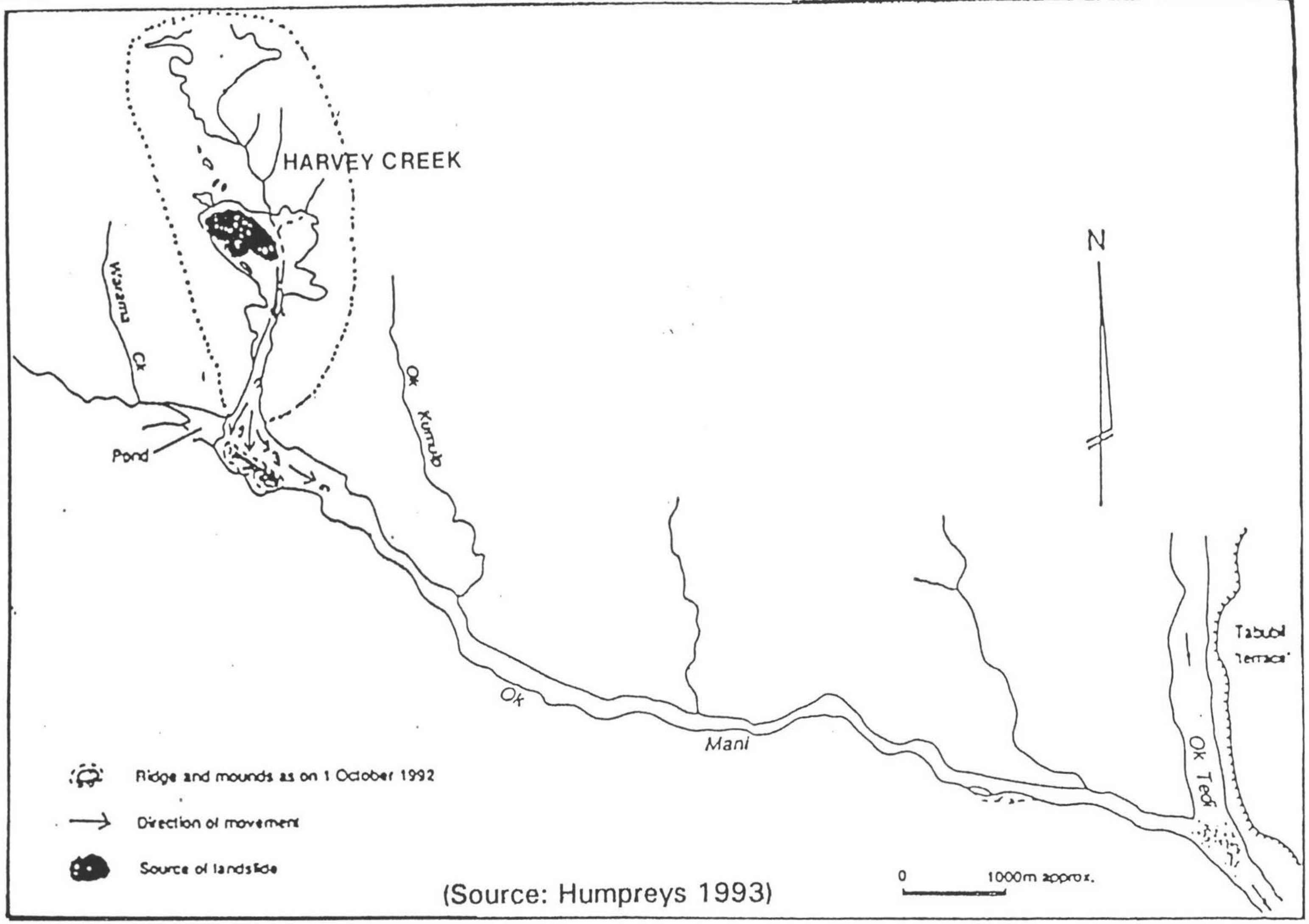


Figure 1.4: Lower Ok Mani braided channel: Harvey Creek catchment and the landslides

Plate 1.1: Upper Ok Mani stream: gravel- to cobble-bedded channel

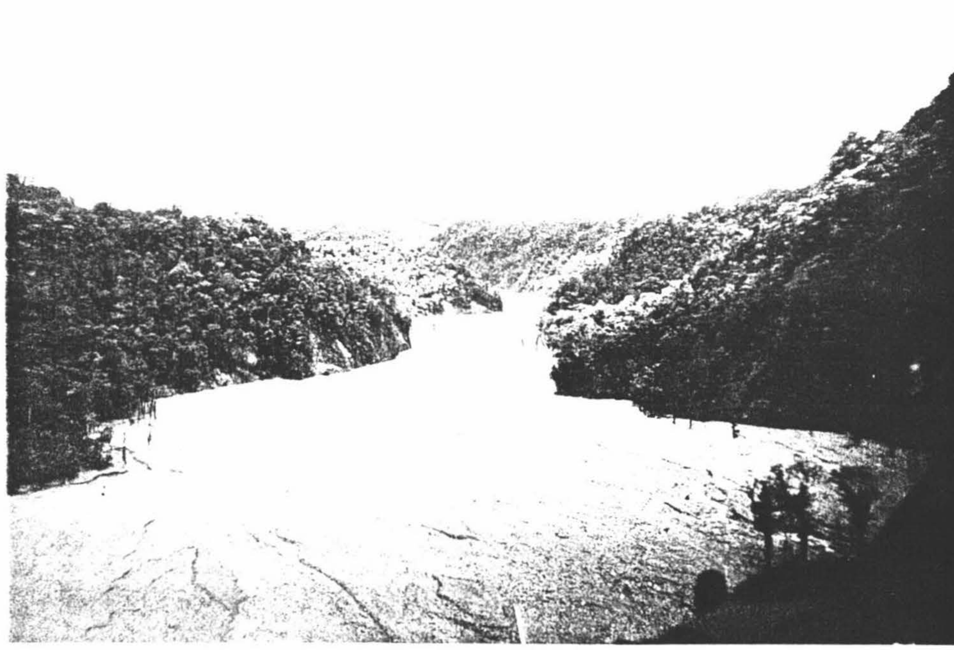


Plate 1.2: Lower Ok Mani stream: gravel-bedded and braided channel

A study carried out by Humphreys in 1993 (unpublished) in the Harvey Creek catchment found that there was a large slope failure within the catchment resulting in a massive landslide (see Figure 1.4 and Plate 1.3). The channel than adjusted to new conditions from the increase in sediment load added to and transported through the catchment. The sediment budget by Humphreys to 1991 (i.e., over the first year of dumping) showed that about 58 percent of the total rock waste added to the catchment was derived from the valley sides and the channel. In other words, 7.6 x 10^6 m^3 of mine-waste induced and accelerated the supply of a further 9.9 x 10^6 m^3 of material from within catchment into Ok Mani. Plate 1.4 shows the fan and pond upstream of Ok Mani and Harvey confluence as a result of the failure and increased sediment supply. The fan blocks the Ok Mani stream resulting in the pond upstream, thus forcing and confining the flow to the south (right of Plate 1.4) of the channel.

1.4.8 Geology

The geology of the Province, including Ok Mani and the adjacent catchments is shown in Figure 1.5. The geology of Ok Mani catchment is mainly silts (fine particles larger than those of clay but finer that than those of sand); and marls (a calcareous clay or mudstone with an admixture of calcium carbonate) in the high piedmont. Tertiary limestone extends to the north, north-west and north-east of the catchment (Loffler 1977). To the south are quaternary volcanic pyroclastic materials, both stream and air borne (Maunsell and Partners 1982).

1.4.9 Ok Tedi Mine

The Ok Tedi Mining project is a substantial undertaking by world standards by OTML, a subsidiary of Broken Hill Proprietary of Australia. It is one of the largest open-cut copper and gold mines in the world and commenced operation in May 1984. The project involves the mining of Mt. Fubilan's (in the Star Mountains, see Figure 1.1) 500 million tonnes of porphyritic chlorite/monzonite ore containing 880 grams of copper and 0.66 grams of gold per tonne. It is located in one of the wettest areas of the world with an annual rainfall of more than 8 000 mm (Connell and Howitt 1991), about 2000 m asl and in the head-water catchment area of the

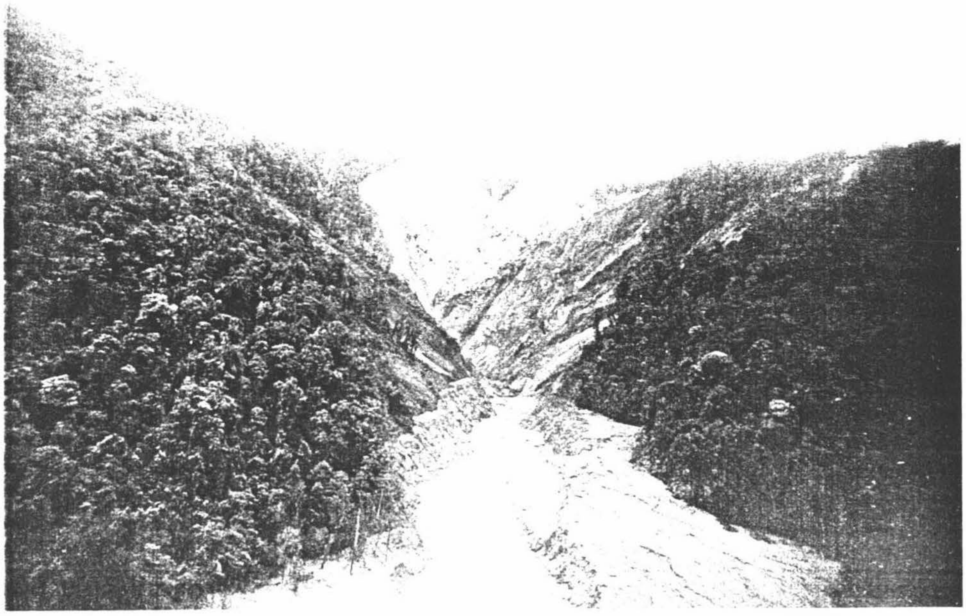


Plate 1.3: Landslides in Harvey Creek catchment due to dumping of mine overburden. Turbid streams, evident of high sediment transport

Plate 1.4: The fan and pond at Ok Mani stream and Harvey creek caused by failure of dump

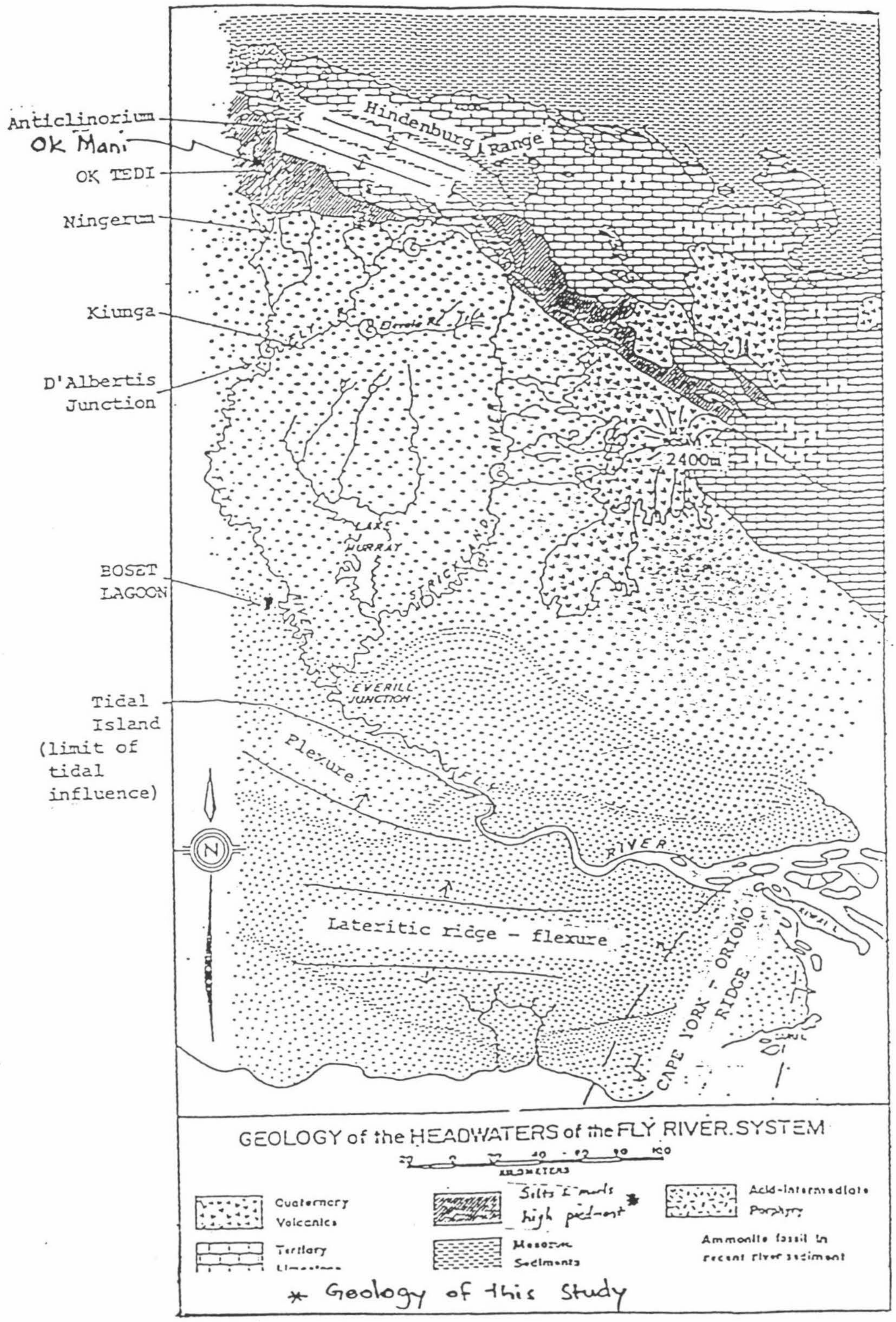


Figure 1.5: Geology of Western Province, PNG

(Source: Paltech 1979)

Fly River system, some 1 000 km inland from the Gulf of Papua (see Figure 1.1).

Since the mine's commencement, OTML has progressively removed and hauled the overburden to erodible waste rock dumps north of the mine site in the headwaters of the Ok Tedi River (Northern Dump). In 1991, OTML progressed to storing the overburden in the Harvey Creek catchment south of the mine site (Southern Dump) (see Figure 1.4). This dump failed as discussed in Section 1.4.7. The overburden in eroding dumps is incompetent and readily breaks down to fines. Eagle and Higgins (1990) found that approximately 55 percent of the overburden breaks down to a size of less than 100 microns during transport in the Ok Tedi River, a size which is readily transportable in normal flow conditions as suspended sediment.

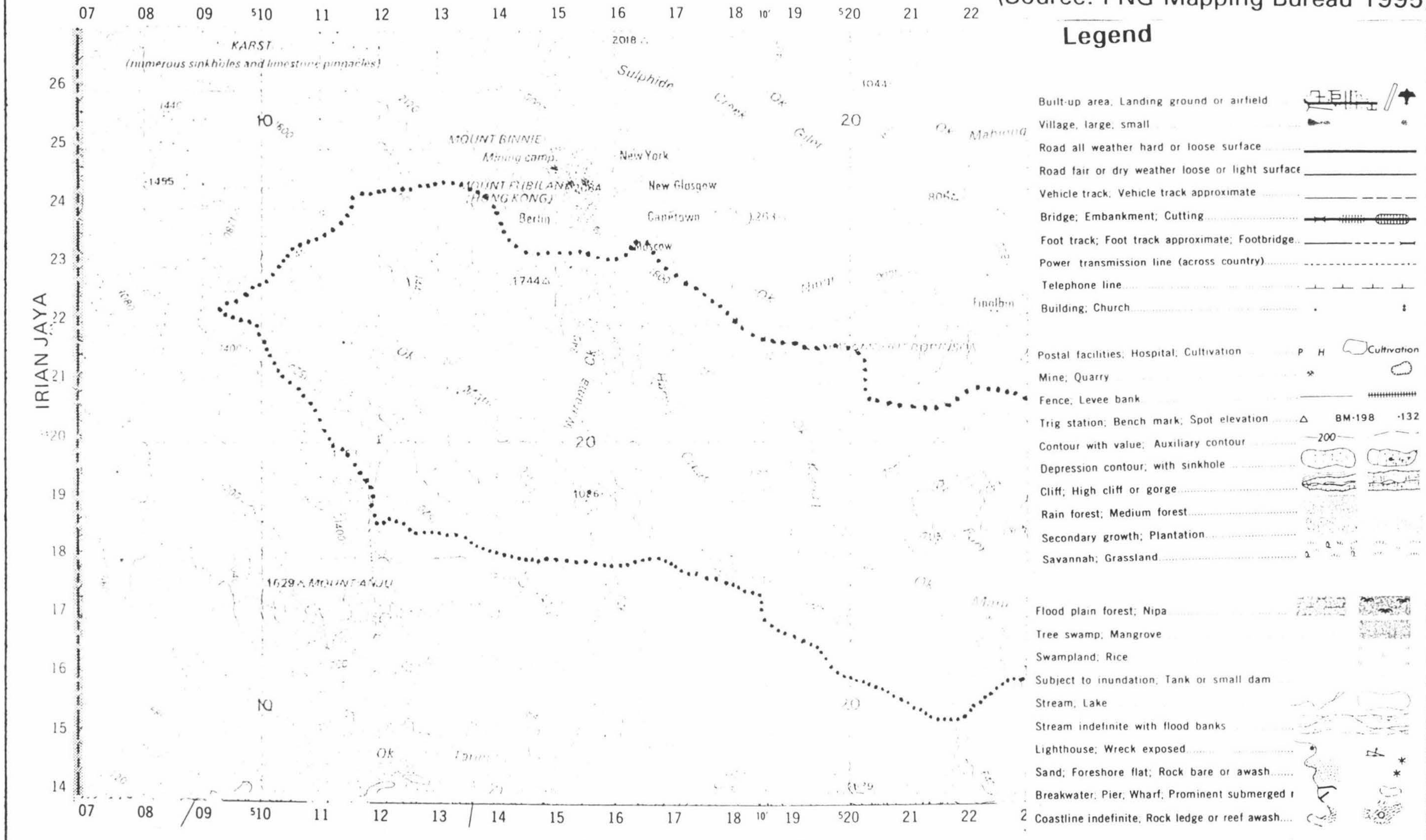
1.5 **Preliminary Observations**

Ok Mani stream is shown in Figure 1.6 and is one of the many highland streams found in the Ok Tedi region. One common characteristic of these streams is that they are fast flowing in narrow channels with high sediment load during floods. OTML spend millions of Kina (PNG's currency) monitoring the main rivers and streams in the region, including Ok Mani, Ok Tedi and the Fly River. It has installed and monitored self-recording flow and rainfall gauges and maintains a computerised data base in the Environment Department.

During the field investigations, it was observed that the streams in the upper catchment from Harvey Creek (see Figure 1.4), during normal flow are clear, with evidence of no or very little (if any) sediment transport. During and after flood events, the streams are turbid, evidence of high sediment transport due to erosion from surface flows in the catchment. Downstream from Harvey Creek to the Ok Tedi confluence, the streams to the north of the channel are always turbid (see Figure 1.4 and Plate 1.3). The high sediment concentrations in these streams are derived from the landslides and other forms of slope instability within the various sub-catchments, a common characteristic of the region.

Figure 1.6: Topographic map of Ok Mani and adjacent catchments

PAPUA NEW GUINEA 1:100 000
(Source: PNG Mapping Bureau 1995)



It was also observed that the soil within the catchment is always saturated as it rains every day (mostly heavy and for long duration) and that the dense vegetation cover prevents or reduces evaporation (inspite of the theoretical fact that the denser the vegetation, the greater the evapotranspiration). During rain events, rain was observed to fall first in the higher lands and to gradually spread to the lower land. The steep topography of the catchment promotes immediate surface runoff during a storm as observed during the field investigation.

The Ok Mani catchment is more-or-less surrounded by karst topography, especially to the north and north-west with numerous sinkholes (see Figure 1.6). The boundary of Ok Mani and the adjacent catchment immediately between north and north-west is not definite in that they "overlap" (see Figure 1.6, approximate central location at 05:25:50 S 141:11:50 E).

A number of springs are evident along the Ok Mani channel (see Plates 1.5 and 1.6 for examples). Some of these, from observations, contribute substantial amounts of water to the main stream. The springs, although there is no proof nor have measurements been carried out on them, could be the emergence of sub-surface flows from the adjacent catchment's karstic sinkholes through underground flow channels.

Plates 1.5 & 1.6: Springs: examples of underground springs along Ok Mani channel, possib ly the emergence of the streams sinking in the karst sinkholes in the adjacent catchments