# STUDIES ON THE DYNAMICS AND WATER QUALITY OF THE MUVATTUPUZHA RIVER IN RELATION TO EFFLUENT DISCHARGE

THESIS SUBMITTED TO THE UNIVERSITY OF COCHIN
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**UNDER FACULTY OF MARINE SCIENCES**

*By*

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# DECLARATION

I hereby declare that the thesis entitled, 'STUDIES ON THE DYNAMICS AND WATER QUALITY OF THE MUVATTUPUZHA RIVER IN RELATION TO EFFLUENT DISCHARGE', is an authentic record of research carried out by me under the supervision and guidance of Dr.P.N.Krishnan Nambisan and Dr.P.G.Kurup in partial fulfilment of the requirements of the Ph.D. Degree of the University of Cochin and that no part of it has previously formed the basis for the award of any degree, diploma or associateship in any University.



(A.N.BALCHAND)

# CERTIFICATE

This is to certify that this thesis bound herewith is an authentic record of the research carried out by Mr.A.N.Balchand, M.Sc., under our supervision and guidance in the Department of Marine Sciences, in partial fulfilment of the requirements of the Ph.D. Degree of the University of Cochin and no part thereof has been presented before for any other degree in any University.

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# CHAPTER 1

# INTRODUCTION

CHAPTER 1

## 1.1. INTRODUCTION

In the world of plenty of water, life on earth today finds scarcity of worthy water. In days to come when the needs are on the increase, demand for pure water shall be on the increase. To meet this, world conscience has to act right and right now, to ensure uninterrupted availability of uncontaminated water. Preservation, conservation, scientific consumption and utilisation of water warrant immediate attention.

Fresh water is one of the most scarce resources to mankind. Being limited in quantity, this resource has to be wisely conserved and as such, cautiously managed. Social, economic and industrial developments have laid their foundation on uninterrupted availability of water resources. On land, natural rivers constitute the open channel flow of fresh water forming an integral part of the environment for human life. Over-exploitation of water resources, without awareness of the environmental consequences, has led to place constraints on these natural systems.

The quantum of available fresh water held in rivers and lakes at any instant is only 0.33% of the total fresh water content on earth (<2% of all the earth's water) (Barry 1977). In recognition of this glaring fact and in order to ensure the availability of pure water to the living beings, the developed and industrialized nations have made considerable headway in studies and research to abate aquatic pollution owing to intense industrialization. Tinney 1971, Wilson 1976, Kashef 1981). In India, the desirable amount of effort has not yet been made to study and combat water pollution. Random studies and laws available in India have proved to be inadequate to match the degree of water pollution caused as a result of industrialization. Studies on water pollution with particular reference to its causes by industrial effluents need special emphasis in the present Indian context.

1.2. Water pollution

A proper definition of the term 'water pollution' is not readily evolved for universal application, since pollution, has been invariably associated with the actions of man, the varied practices and different intended uses of water body. Pollution is normally associated with changes, man-made or natural and an acceptable simple definition by the U.N.Economic and Social Council, 1968 is, 'water pollution is an impairment of water function which has, or may have, an effect on subsequent water use'.

Water pollution usually attracts attention only when living or biological systems are affected directly or indirectly. In a wider sense, it is the normal consequence of the growth and propagation of organisms including man, in or near the aquatic habitat. Article 9 of the Helsinki Rules (1964) defines water pollution as 'any detrimental change resulting from human conduct in the natural composition, content or quality of the water'. This definition was modified for the marine environment by the GESAMP (1968) as 'the introduction by man, directly or indirectly, of substances or energy into the marine environment including estuaries, resulting in such deleterious effects as: harm to living resources, hazard to human health, hindrance to marine activity, including fishing, impairment of quality for use of sea water and reduction of amenities'.

The solemn declaration at Stockholm (1972) expressed the basic human right to enjoy the environment in which he is brought up. The concern at the degradation of environment has been well voiced in this statement. Recognising the need for legislation on prevention and control of water pollution, the Government of India introduced the Water(Prevention and Control of Pollution) Act 1974, in pursuance of clause (1) of Article 252 of the constitution. The intended purpose of the Act is clearly revealed in the preamble: 'The prevention and control of water pollution and the maintenance or restoration of wholesomeness of water'.

A modified version of the above Act was introduced in 1978 as the Water(Prevention and Control of Pollution) Amendment Act, 1978 (Act 44 of 1978) to extend its coverage. The Water (Prevention and Control of Pollution) Act, 1974 defines 'water pollution' in Sec.2(e) as 'such contamination of water or such alteration of the physical, chemical or biological properties of water or such discharge of any sewage or trade effluent or of any other liquid, gaseous or solid substance into water (whether directly or indirectly) as may, or is likely to, create a nuisance or render such water harmful or injurious to public health or safety, or to domestic, commercial, industrial, agricultural or other legitimate uses, or to the life and health of animals or plants or of aquatic organisms'.

Water pollution may be defined from the scientific point of view as anything that leads to cause significant degradation or objectionable conditions in quality and/or quantity of any water course such as to adversely affect its intended use(s).

1.3. Causes and remedies

A large number of materials cause water pollution. A comprehensive classification may not easily be possible, but generally includes the following pollutants:

1. Inorganic pollutants: These include various chemicals, soluble or insoluble in water. The major source is industrial effluents which contain acids, alkalies or toxic inorganic compounds discharged from several industries such as steel, glass, cement, paints and dyes, pulp and paper etc which are origins of major inorganic wastes apart from chemical industries like plastics and resins, fertilizers, detergents, pesticides, explosives, acids etc.

2. Organic pollutants: These originate from living organisms; include domestic sewage and industrial wastes from meat works, fish processing units, fruit canneries, dairy factories, sugar mills, breweries etc.

3. Biological polluters: Presence of pathogenic bacteria or virus in sewage or inadequately disinfected sewage effluent may contaminate water. Certain bacteria such as Escherichia coli (E. coli) group are used as indicators of human or animal wastes. High levels of bacterial activity cause diseases like cholera, fever, dysentery (bacillary and amoebic), typhoid and hepatitis which are transmitted through water.

4. Thermal pollution: Hot water discharges from power stations, coal processing installations and large scale industrial houses cause increase of ambient temperature and is detrimental to aquatic life.

5. Radioactive wastes: Effluents from units processing ores and fuels, research laboratory wastes, power plant cooling waters and partly from nuclear explosions enter the water media.

6. Non-point sources: These wastes are constituted by dust, dirt, runoff, organic matter etc. Though not of much significance, compared to other pollutants, these are largely mineral and organic matter.

Regarding remedial measures against water pollution, various treatment processes have been tested and perfected in many of these cases. Sedimentation and use of coagulants are helpful in removing large quantities of suspended matter. Use of clarifiers have enhanced the results favourably. Filter beds of various designs are available now to provide water of different standards. Additional treatment facilities like activated sludge process or biological processes have been developed giving excellent results. Miscellaneous treatment systems such as those using activated carbon or hydrogen peroxide, or applying electro-dialysis, reverse osmosis, chemical precipitation, aerated lagooning etc. are now practised under many situations. Tertiary treatment systems to remove excess phosphorus or nitrogen or to bring down colour/odour of effluents are also gaining popularity.

Water quality management programmes require the identification of the relevant parameters while examining the physical, chemical and biological characteristics of the water course. Though each parameter has its own importance, these are highly inter-related. The physical parameters investigated as indices for pollution are colour, taste, odour, temperature, transparency, turbidity, absorption spectra and electrical conductivity. Water movement and volume discharge are also included depending upon the scope of the survey. Chemical parameters include a large number of chemical elements and compounds such as oxygen, combined nitrogen, phosphorus, alkali metals, alkaline earths made up of Be, Mg, Ca, Ba as cations in combination with $SO_4^{=}$ or $CO_3^{=}$, the halogens and heavy metals*. The organic chemicals may be biodegradable such as simple sugars, fats, starch etc. whereas the non-biodegradable organics constitute serious threat to human life. Pesticides, herbicides and surface active agents pose grave threat as water pollutants. The biological parameters may be sub-divided into three: (1) the pathogenic bacteria, harmful protozoa, viruses and parasitic worms, (2) intestinal organisms discharged by man and animals indicative of contamination and (3) algae and other aquatic plants indicating presence of eutrophication.

As pointed out earlier, the Water Pollution Act, 1974 envisages to draw up standards to regulate effluent discharges into various water bodies and control pollution by the issue of consent by Pollution Control Boards.

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*The term heavy metals is used in the oceanographic sense and include metal such as Cu, Zn, Cr etc. which are not really heavy.

tandards have been laid down by the Pollution Control
oards as specified by the Indian Standards 2490-1974
rescribing tolerance limits for industrial effluents
ischarged into inland surface water. These limits are
iven in Table 1. The table also gives the tolerance limits
or inland surface water for use as raw
ater for public water supply and for bathing ghats,
ish culture and irrigation, incorporated from IS: 2296-1974
o bring out the significance of the numerous parameters of
ater quality.

.4. Scope of study

The present study aims at the investigation of the
hysico-chemical features of a tropical tidal river viz.
he Muvattupuzha river. This river is expected to receive
oderate to heavy pollution loads in years to come, from
he lone industrial unit, already set up on its bank.
nlike other rivers, the geographical disposition of this
iver attains unique importance as regards its dynamics for
a) availability of natural runoff water from catchment
reas, which becomes very heavy during the monsoon season
b) regular steady availability of tail race water from a
ydro-electric power station throughout the year. The tidal
ffects are felt only upto a limited ... in this river

Table 1

Maximum Tolerance limit for inland surface waters

| Sl. No. | Characteristics | Industrial effluents (IS:2490–1974) | Raw water for public water supply | Fish culture | Irrigation |
|---|---|---|---|---|---|
| | | Maximum tolerance limit for inland surface waters | | | |
| | | | ← (IS:2296–1974) → | | |
| 1. | Temperature | Shall not exceed $40^{\circ}C$ in any section of the stream within 15 m downstream from the effluent outlet | - | - | - |
| 2. | Total suspended solids (mg/l) | 100 | - | - | - |
| 3. | Total dissolved solids (inorganic (mg/l) | - | - | - | 2100 |
| 4. | Particle aize of total suspended solids | Shall pass 850 micron IS seive | - | - | - |
| 5. | Electric conductance at $25^{\circ}C$ (mhos) | - | - | $1000 \times 10^{-6}$ | $3000 \times 10^{-6}$ |
| 6. | pH | 5.5–9.0 | 6.0–9.0 | 6.0–9.0 | 5.5–9.0 |
| 7. | Dissolved oxygen (minimum) | - | 40% saturation value or 3 mg/l whichever is higher | 40% saturation value or 3 mg/l whichever is higher | - |
| 8. | Biochemical oxygen demand (5 days, $20^{\circ}C$) (mg/l) | 30 | 3 | - | - |
| 9. | Chemical oxygen demand (mg/l) | 250 | - | - | - |
| 10. | Phenolic compounds (mg/l) as ($C_6H_5OH$) | 1.0 | 0.005 | - | - |
| 11. | Total residual chlorine (mg/l) | 1 | - | | |
| 12. | Chlorides (as Cl) (mg/l) | - | 600 | - | 600 |
| 13. | Free ammonia (as N) (mg/l) | - | - | 1.2 | - |
| 14. | Ammoniacal Nitrogen (mg/l) | 50 | - | - | - |
| 15. | Nitrates (as $NO_3$) (mg/l) | - | 50 | - | - |
| 16. | Free carbon dioxide (as $CO_2$) (mg/l) | - | - | 6 | - |
| 17. | Fluorides (as F) (mg/l) | 2.0 | 1.5 | - | - |
| 18. | Boron (as B) (mg/l) | - | - | - | 2.0 |
| 19. | Cyanides as (Cn) (mg/l) | 0.2 | 0.01 | - | - |
| 20. | Sulphides (as S) (mg/l) | 2.0 | - | - | - |
| 21. | Sulphates (as $SO_4$) (mg/l) | - | - | - | 1000 |
| 22. | Arsenic (as As) (mg/l) | 0.2 | 0.2 | - | - |
| 23. | Cadmium (as Cd) (mg/l) | 2.0 | - | - | - |
| 24. | Copper (as Cu) (mg/l) | 3.0 | - | - | - |
| 25. | Lead (as Pb) (mg/l) | 0.1 | 0.1 | - | - |
| 26. | Mercury (as Hg) (mg/l) | 0.01 | - | - | - |
| 27. | Nickel (as Ni) (mg/l) | 3.0 | - | - | - |
| 28. | Selenium (as Se) (mg/l) | 0.05 | 0.05 | - | - |
| 29. | Zinc (as Zn) (mg/l) | 5.0 | - | - | - |
| 30. | Chromium (as Cr) (mg/l) | - | 0.05 | - | |
| 31. | Hexavalent chromium as ($Cr^{+6}$) (mg/l) | 0.5 | - | - | |
| 32. | Percent sodium | - | - | - | 60 |
| 33. | Oil and grease (mg/l) | 10 | 0.1 | 0.1 | - |
| 34. | Insecticides | Absent | Absent | - | - |
| 35. | Number of coli form group (MPN/100 ml) | - | Not more than 5000, with less than 5% of the samples with value >20,000 and less than 20% of the samples | - | - |

s moderate due to the presence of a vast estuary at its mouth. The study also aims at arriving at the balancing forces of inherent self-purification of the river verses pollution loads from the factory effluents. The investigation period falls ahead of actual pollution occurrence and so the ambient conditions for a period of nearly one-and-a-half years were investigated, the analyses of which provide to formulate the inter-relations of parameters varying with seasons. Tracer experiments were carried out which revealed the dispersion and dilution characteristics of the river in the vicinity of effluent outfall. The study covers the trial-cum-capacity production periods of the factory during which effluents of various strength and quantity were discharged into the river; a few computed values are compared with the observed values. The base data along with the profiles of oxygen sag equation have been utilized to develop a mathematical model of the river with regard to its water quality.

1.5. Description of the river and its environment

The south-central part of the state of Kerala is characterised by the presence of the two large basins of Periyar river and Muvattupuzha river, extending the entire breadth of the land, sloping westward. The rivers empty

.nto the Cochin backwaters which is subjected to tidal ;ffects through the Cochin barmouth (Fig.1). The 'uvattupuzha river is formed by the confluence of 'hodupuzha, Kaliyar and Kothamangalam Ars. The 'hodupuzha Ar. joins Muvattupuzha river at Muvattupuzha, /hereas Kaliyar Ar. and Kothamangalam Ar. join together ;lightly upstream and flows as a single stream to iuvattupuzha (Figs.2 and 3). After flowing as a single ;tream upto Vettikkattumukku, the river splits into two oranches called Ittupuzha and Murinjapuzha, which reach :he Cochin backwaters at S. Talayolaparambu and N. Vaikom 'espectively. The basin area lies between 76°22'E and '6°50'E and 9°45'N and 10°05'N. The entire area enjoys :he characteristic tropical humid climate. A dry summer ;eason from February to May (pre-monsoon) is followed by :he southwest monsoon (June-September) of heavy rains and :hen, by the post-monsoon season (October-January) with 'elatively very low rainfall from scanty thunderstorms. iverage rainfall is 300 cms varying from 381 cms at 'hodupuzha to 284 cms at Koothattukulam. The summer time 'iver ~~flows~~ discharges were quite meagre (4-7 $m^3$/sec), confined to mall channels in the river bed. The large exposed areas f sandy river bed during summer served as festival grounds 'or religious ceremonies and summer time recreation. On the

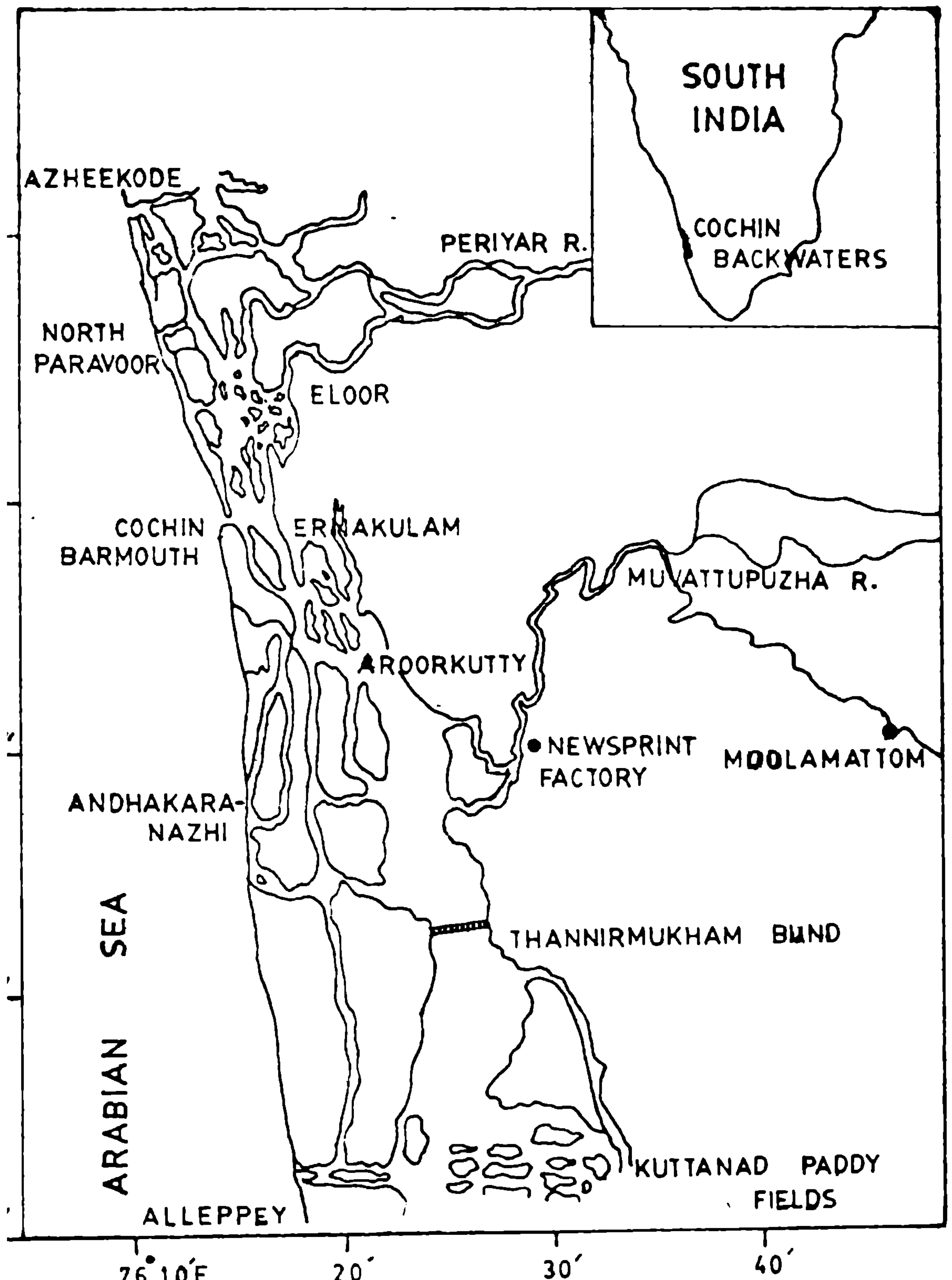
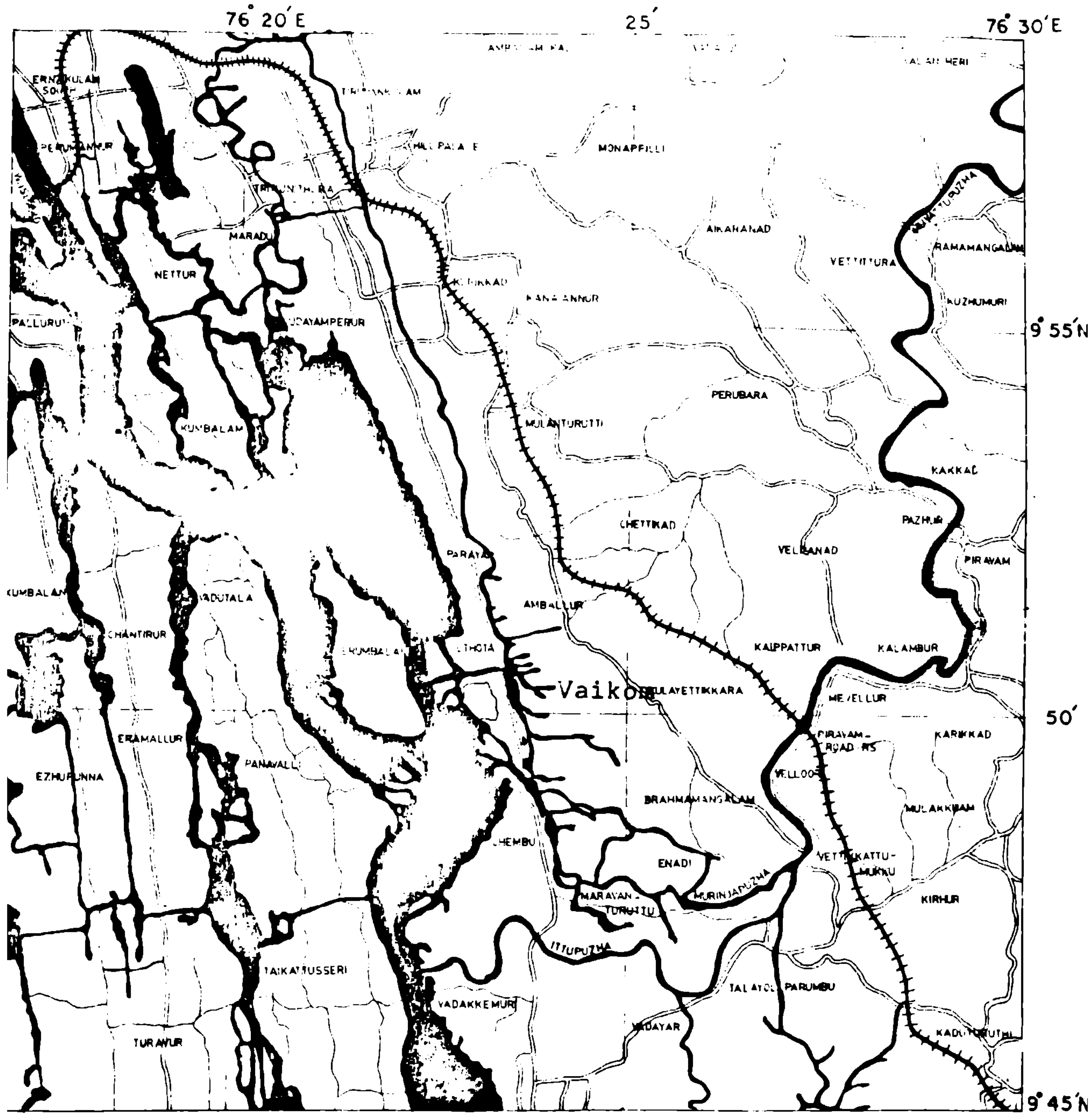



Fig.1. MAP OF COCHIN BACKWATERS AND MUVATTUPUZHA




ig.2. Map of Muvattupuzha Basin (Western Sector)

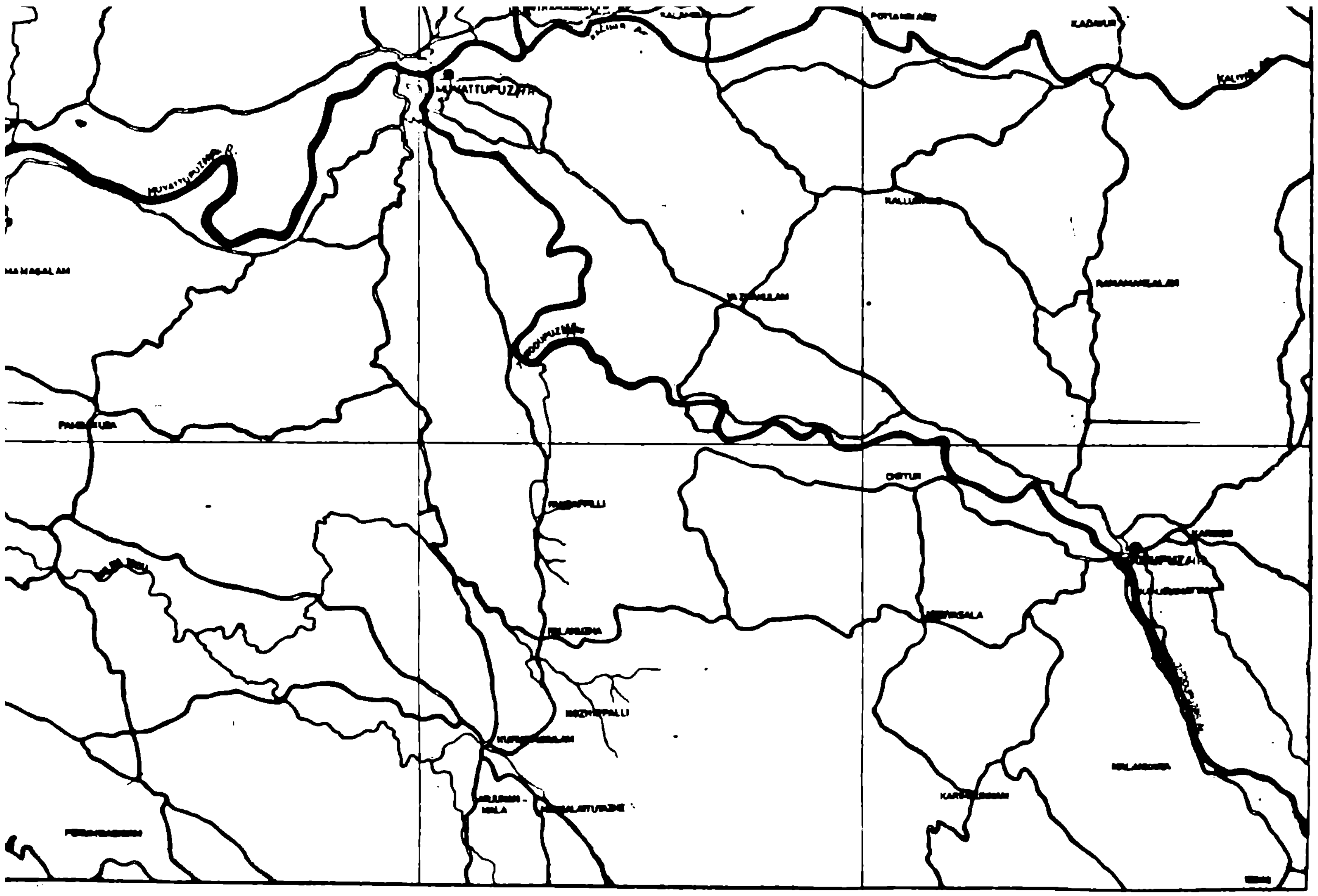



Fig.3. Map of Muvattupuzha Basin (Eastern Sector)

other hand, runoff during the monsoon season exhibited a tremendous flow regime ($\simeq$ 300 $m^3$/sec) along the course of the river. Several instances of the river overflowing its banks were retold by the people living alongside. At low to moderate flows, saline waters (5-15‰) from Cochin backwaters reached above Piravom Road Bridge (upto Pazhur) with regular tidal action.

A significant change took place with regard to the river flow characteristics since the commencement of the Idukki hydro-electric project (detailed in succeeding paragraphs) in 1976. The tail race water, 700-2770 cusecs (19.83-78.5 $m^3$/sec) was directed into Muvattupuzha river from Moolamattom power station through Thodupuzha Ar. (MVIP, 1976). This increased fresh water flow pushes back the tidal incursion from the river. The nearly constant discharge plus runoff quantity, has completely altered the ecology of the river. Bank erosion was observed to be rampant and fresh water biological specimens thrived in the river. Since then, the river flows as a stream of fresh water extending its full width. At present, the Muvattupuzha river provides abundant resource of high quality fresh water. Throughout the year, there is uninterrupted flow varying from summer minimum of around ıO $m^3$/sec (depth of water column $\approx$ 1.80 m) to heavy lischarges at 400 $m^3$/sec (depths of 4.25 m) during rainy ıonsoon season.

Characteristics of the Muvattupuzha river and its ıasin (MVIP, 1971).

| | |
|---|---|
| 'otal catchment area | : 1554 $km^2$ |
| ıaximum altitude | : 1093.6 m |
| iinimum altitude | : 1.5 m |
| lean altitude | : 170.70 m |
| 'otal length of the river including tributaries, hannels etc.) | : 121 km |
| ıctual length | : 77.25 km |
| lean slope | : 0.813 |
| ıaximum width of the basin | : 38 km |
| iinimum width of the basin | : 4 km |
| .iver bed width at | |
| Moolamattom | : 30 m |
| Malankara | : 66 m |
| Thodupuzha | : 90 m |
| Vettikkattumukku | : 120 m |

The basin seems to have been well settled since uite long as evidenced by the presence of old temples nd churches. Nearly 63% of the average population of 1585 persons per sq. mile in the lower reaches f the river are literate. The only industrial establishment n this area is the 400 tonnes per day capacity, Kerala ewsprint Mill of Hindustan Paper Corporation (HPC), waiting formal commissioning. The main occupation of the eople is agriculture with two crops of paddy. In upper egions of the river basin, rubber, pepper and other hill roduces are cultivated while in the lower regions apioca, ginger etc. are grown.

Surface wells provide good drinking water, but most f them dry up, during summer especially in the upper eaches. Estuarine conditions had existed in the lower eaches of the river. This was evidenced by the fact that ccupation of the residents of this region was salt-aking by evaporation. The drinking water requirements f the people alongside the river and also major gglomeration were met from this river since 1976 onwards.

Prior to Idukki dam discharge, the dry weather flow id not permit water transport to the upper reaches beyond ravom. But during wet season, both country and echanised boats ply upto Muvattupuzha. Now with tail ace waters from Idukki via Moolamattom power station

ugmenting water in the river to depths of around 1.8 m
ven during summer, the river is navigable throughout the
ear. Good roads and rail services form means of land
ransport in the basin area.

At present, a small section of the inhabitants of he lower basin and near the river mouth finds their living y fishing, though the yield is low. Meanwhile a major ection of people have turned their attention towards sand ollection from the river bed, for use in construction. he river bed sand is collected manually and transported by ountry boats and by road. On an average, 25 boat/lorry oads of sand is collected per day in the section between iravom Road and Maravanturuttu during fair weather easons. The Velloor panchayat collects nearly Rs 40,000/- er season by auctioning the right to collect the bed sand. here are numerous lift irrigation schemes owned by ndividuals and aided by Irrigation Department for gricultural purposes. The water of Muvattupuzha river is sed for all purposes including drinking, cooking, washing nd bathing.

.6. Water Resource Management Projects

The water resources and utilization projects with onstruction of reservoirs (Idukki, Kulamavu and heruthoni dams) to contain water from the adjacent eriyar basin and run it through a tunnel to Moolamattom ower station (MVIP-Master Plan, 1971). The tail race water rom this station would thus be discharged into Thodupuzha r. and ultimately join the Muvattupuzha river. First tage of the project was completed and the discharges tarted in late 1976. Along with this major hydroelectric roject, a few minor proposals have been suggested for tilizing the tail race waters, but these were either ropped or stand modified (MVIP-1979).

) A barrage at Arakulam to divert water to its right bank canal (R.B.C.) for irrigation purposes.

) This R.B.C. shall run across the Kaliyar Ar. and Kothamangalam Ar.

) The left bank canal (L.B.C.) to cross Thodupuzha Ar. and drain into Valiathodu at Monippilly.

) To direct a portion of the tail race water to Meenachil river basin for agricultural purposes in low fields (Kari lands) of Kottayam Taluk. This proposal is in conjunction with salt water exclusion regulators to be constructed across Ittupuzha and Murinjapuzha.

) A dam across Kaliyar Ar. along with
(i) Pareekanni scheme (ii) Mullaringad scheme
(iii) Maradi scheme and (iv) Arasikkal scheme.

) A balancing reservoir at Malankara across Thodupuzha Ar. to divert 24.21 $m^3$/sec along L.B.C. and 9.37 $m^3$/sec along R.B.C. from tail race discharges. A five day storage capacity is envisaged for this dam which could benefit a large area north and south of Thodupuzha Ar. for summertime cultivation.

Of the above proposals only the project at Malankara has been taken up and the constructions are scheduled or completion in 1985 (MVIP, 1979). The impact on the iver flow due to the diversion of water at Malankara s discussed in Chapter 5.

The 1971 project proposals on Arakulam Barrage to ivert nearly 25.5 $m^3$/sec of the estimated average tail ace discharge of 40.73 $m^3$/sec, had taken into account the equirement of a Newsprint factory at 1.13 $m^3$/sec for the irst stage and total 1.98 $m^3$/sec during the second stage. ince the effluents from this factory are accounted as % of the intake, an essential minimum dilution of 15 times

; required for the discharge at 1.19 $m^3$/sec; hence the .ver flow should be 17.85 $m^3$/sec. The inplant abstraction ; rated at 0.79 $m^3$/sec and the total requirement of the ictory is 19.83 $m^3$/sec and net balance flow would be then ).04 $m^3$/sec. Towards Kuttanad agricultural fields, the quirement of 15.17 $m^3$/sec is set apart from the diluted 'fluents. The Greater Cochin Development Authority (GCDA) iter supply scheme is provided with 1.84 $m^3$/sec of fresh iter. Thus the total requirement comes to 21.67 $m^3$/sec iich would be in any case less than the flow during June ) December in normal years. Hence during the above period, ie barrage intends to divert the entire tail race water wards irrigation of high fields. But during lean summer nths, when the flow in the river is much below the quired quantity, the factory may utilise the return flow om the ayucut plus the required balance that would be scharged from the barrage.

The 1979 Muvattupuzha Valley Irrigation Project port sets apart only 19.83 $m^3$/sec (700 cusecs) of minimum ow downstream after installing the Malankara balancing servoir which utilises the tail race water of Idukki dro-electric project. This provision o' ' ' ills short of the estimated requirements of 21.67 $m^3$/sec

.7. The Industrial Unit

The only industrial establishment installed along he course of the river is the 'Kerala Newsprint Mill', un by the Hindustan Paper Corporation (HPC) proposed under he 'Kerala Newsprint Project'(KNP). This is located at iravom Road (also called Velloor). The Rs150 crore project as a 400 tonnes per day peak capacity production of ewsprint quality paper constituting 30% chemical pulp and 0% chemi-mechanical pulp. The requirement of water 0.5-1 $m^3$/sec or more) for this pulp-paper factory (cited n Arakulam project) is to be drawn from the Muvattupuzha iver and returned (minus inplant abstraction) as effluents fter treatment. The present investigations attempt to tudy the impact of these effluents on the water quality and ilution/dispersion characteristics of the Muvattupuzha river, ased on its hydrodynamical system. The general data, roduction details and also nature and quantum of ffluent treatment and discharge pertaining to the above actory (KNP) are appended as Annexure I.

.8. Scheme of the present work

The period of study was between November, 1980 and eptember, 1982 with regular fortnightly, surface and ubsurface sampling surveys at seven stations (stations lo. I to VII) (Fig.4) along the course of the Muvattupuzha river. The sampling stations are fixed in consideration of the freshwater intake and effluent outfall points of the pulp-paper factory mentioned above. Station I is located just upstream of the intake point, whereas stations II to VI are choosen in the vicinity of the outfall. Station III is at the point of effluent injection into the river. Station VII is within 1.5 km from the river mouth at Murinjapuzha. Since the discharge of factory effluents commenced from the night of 13th March, 1982, intensive surveys at shorter interval were carried out with the view of closely monitoring the variations, if any. Few samples of the factory effluents were also collected and analysed. Two tracer tests were performed in the river during the months of May and December, 1981, as described in Chapter 6.

The thesis is presented in eight chapters including the introductory chapter. Chapter 2 deals with physical parameters of water quality like colour, odour, taste, temperature and transparency of the water of the Muvattupuzha river. Chapter 3 deals with the water quality parameters of salinity, pH, DO and BOD. The seasonal variations of these parameters and the changes

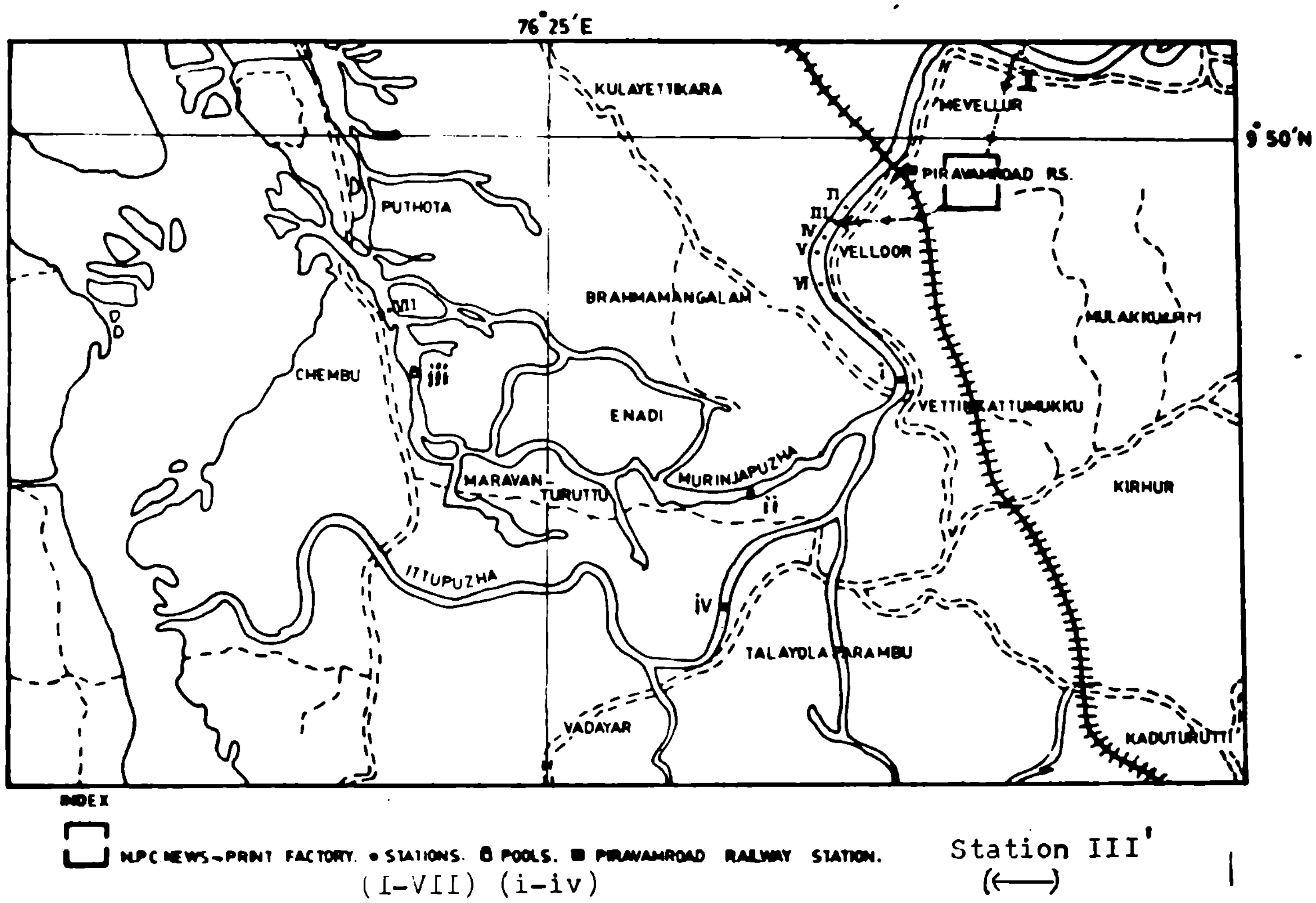



Fig.4. Map indicating Stations I–VII, pools (i–iv) in the river and the Newsprint factory along with the intake and discharge pipelines. Station III' is located near the effluent outfall.

# CHAPTER 2

# WATER QUALITY I

CHAPTER 2

# WATER QUALITY I

## 2.1. Introduction

Chemically pure water rarely occurs in nature. Numerous factors influence the quality of natural waters. The adjectives such as 'clean', 'pure', 'polluted' are used subjectively to describe the quality of water. Water is classified depending on its physical, chemical and biological characteristics and standards are thus laid down (WHO, 1971). This chapter attempts to quantify the physical parameters of water quality of the Muvattupuzha river and the effluents discharged during the trial run and production period of the factory.

Surface waters reflect the environment and the recent weather conditions to a great extent. Hydrogeochemical factors influence the colour, odour, taste and temperature and degree of mineralisation of water derived from surface runoff, underground springs etc. (Clark 1970). In addition, human settlements, overall land uses, general morphology of the catchment area, seasonal distribution of precipitation and winds contribute in deciding the quality of water.

Domestic sewage, industrial wastes, fertilizers id pesticides and mode of agriculture, arising from in-made factors responsible for water quality variations. lterations in the hydrological cycle and water resource :ogrammes such as flood control, reservoir management, /dro-electric power generation also cause considerable ianges in water quality. Accidental pollution from iemical compounds also lead to man-made alterations of the iality of surface waters (Severn-Trent Water Authority, )78).

The parameters studied and reported in this iapter are general appearance, colour, taste, odour, :ansparency and temperature. It may however be noted iat these physical parameters are not absolute indices f water pollution (Hann 1968) and depending on specific onditions, their values change considerably. Only eviations from the normal values are highlightened in iis chapter.

.2. Materials and Methods

Colour, taste and odour of river water and ffluents were judged by visual and physical senses. The eneral opinion of the residents in and around the area [illegible]

ı Hazen units by the factory are based on the method
scribed in IS: 3025-1964. Transparency of the water
ıs determined in terms of the mean of the depths ($d_m$)
disappearance and reappearance of the Seechi disc.
ıe extinction co-efficient ( $k$ ) was determined by the
ıpirical relation $k = \frac{1.7}{d_m}$ , where $d_m$ is expressed in
ters. The temperature of water samples were measured
ımediately after collection using an ordinary mercury-in-
.ass thermometer calibrated to $1/10^{o}C$. A calibrated T-S
ter was also used for in-situ observations of temperature.
ıe changes in transparency and temperature of river due
effluent discharge and seasonal variations were
udied at stations I to VII and also at station III' for
ro years and are given in Figs.5,6 and 7.

3. Results and discussion

General appearance: The Muvattupuzha river is a calm
owing stream exhibiting no active tendency for
ırbulent motion during fair weather seasons. The area
study is ideal for swimming, skiing, aquatic
orts* and other body contact recreations. The water
this river does not exhibit foaming. No visible
esence of oil, grease, tar, detritus or floating matter

s been noticed. At times litters are seen floating wn the river. In the early days of the monsoon season ne suspended particles appear in patches on the river rface and the river gradually develops turbulent motion th the advancement of monsoon. Except during the above riod, the river wields a healthy look.

The paper mill effluents altered the river wnstream to nearly 7 km with frequent appearance of oil, ease and increase in fine suspended particles. Pulp bres were observed in bands and patches. On numerous casions, froth forming was noticed in the zone of gradation. The improperly secured filter mesh at the nal outlet of the aeration tank allowed the passage of ad fishes from the lagoon to river surface, during the ghts of 26.3.1982 to 28.3.1982. Large number of blue-een algae from the final aeration tank flowed into the ver along with discharge waters, during the period 4.1982 to 21.4.1982.

Colour: The colour of natural water is caused by the esence of coloured humic substances, organic matter in lloidal form and sometimes metallic compounds of ferric on and manganese. Polluted water may contain various other coloured and mineral compounds (Thomas 1953). Colour as a quality parameter is important in domestic use of water and for aesthetic values. Excessive colour may not be harmful but is generally objectionable (Weiner 1972).

The Muvattupuzha river water indicated no noticeable colour during the period of the ambient surveys (1.10.1980 to 12.3.1982). During monsoon periods, the river exhibits turbulence and the water carries fine particles in suspension imparting a slight turbid colour. The factory analyses on the river water reported that summer values lie between 15-40 Hazen colour units which increase to maximum values around 70 Hazen units during June to August.

Once the effluent discharges commenced (180 or more Hazen colour units) brown to dark-brown bands were noticed during the periods 14.3.1982 to 17.3.1982 (initial lagoon discharge+bypassed effluents from chemical plant), 19.5.1982 to 23.5.1982 (chemical recovery plant wastes+ regular discharges from lagoon) and 13.6.1982 to 16.6.1982 (desludged cooling pond waters) downstream of the outfall. During other days, light to moderate brownish patches effluent colour of 50-70 Hazen units) remained visible along the bank nearer to the discharge point. Once again, effluent waters with colour of 90-120 Hazen units were discharged during 10.8.1982 to 13.8.1982 when only a few plants of the factory were operational. Colour of the river upstream of the discharge point indicated no deviation from its original pattern during the entire discharge period. The maximum colour of the river water during effluent discharge was recorded on 15.6.1982 as 210 Hazen units.

The permissible limits of colour for effluents is river water colour plus 100 units (Hazen). The IS:7967-1976 adopts the tolerance limit of colour for water after receiving discharges in marine coastal areas which includes the environment upto low tide level as 'no noticeable colour'. The general limits mentioned by Pollution Control Board for industrial effluents discharged into inland surface waters forbids discharge of effluents of colour greater than 100 units plus river water colour.

IS: 5061 (Part 1) - 1978 on guidelines for treatment and disposal of effluents of pulp, paper and board industries recognizes that colour is one of the main pollutants and gives a few suggestions for the removal of colour. As observed, the river is imparted with brown to dark brown colour mainly due to the presence of lignins and tannins while the pollution abatement system was running in full-swing. The limited lime treatment and aerated lagooning (expected removal 10%) of waste for colour reduction does not suffice to meet the limits set forth for pollution control (IS: 5061[Part I]-1978). The effluent colour should desirably be less than 30 Hazen units in order to maintain aesthetics of the river water.

c) Taste and odour: Taste and odour of water are caused by the presence of dead or live micro-organisms, decaying vegetable matter and mineral substances like NaCl, compounds of iron etc. Dissolved gases such as $H_2S$, $CH_4$, $CO_2$ or $O_2$ are also partly responsible for odour and taste of water. The investigations on the Muvattupuzha river reveal slight vegetable odour but in general, it is not at all, objectionable. The water is quite palatable. After the entry of effluents, though odour did not vary appreciably, taste became disagreeable for a few km downstream of the outfall owing to the presence of acidic paper wastes and alkaline pulp compounds. During the period between

13.6.1982 to 16.6.1982, the effluents imparted the river water a characteristic offensive odour (organic musty) of pulp-paper mill discharges and a highly objectionable taste. This effect of the discharge on taste and odour persisted for long distance downstream.

The persistent presence of undesirable taste and odour and intermittent appearance of foam caused deep concern to the inhabitants of the region.

d) Transparency: Colour and turbidity determine the transparency of the water. This is caused by the presence of coloured and suspended organic and mineral substances. The measurement of transparency using a Seechi disc is influenced by the amount of sunlight and the biological activity in the water body, besides turbidity. Also the empirical relationship used to calculate extinction co-efficient may not be of universal application (Eloranta 1978).

Studies on the transparency indicated that the river maintained low extinction co-efficient (1.14-1.50) for fairly long periods (Fig.5). During pre-monsoon, when good amount of sunlight and low flow conditions

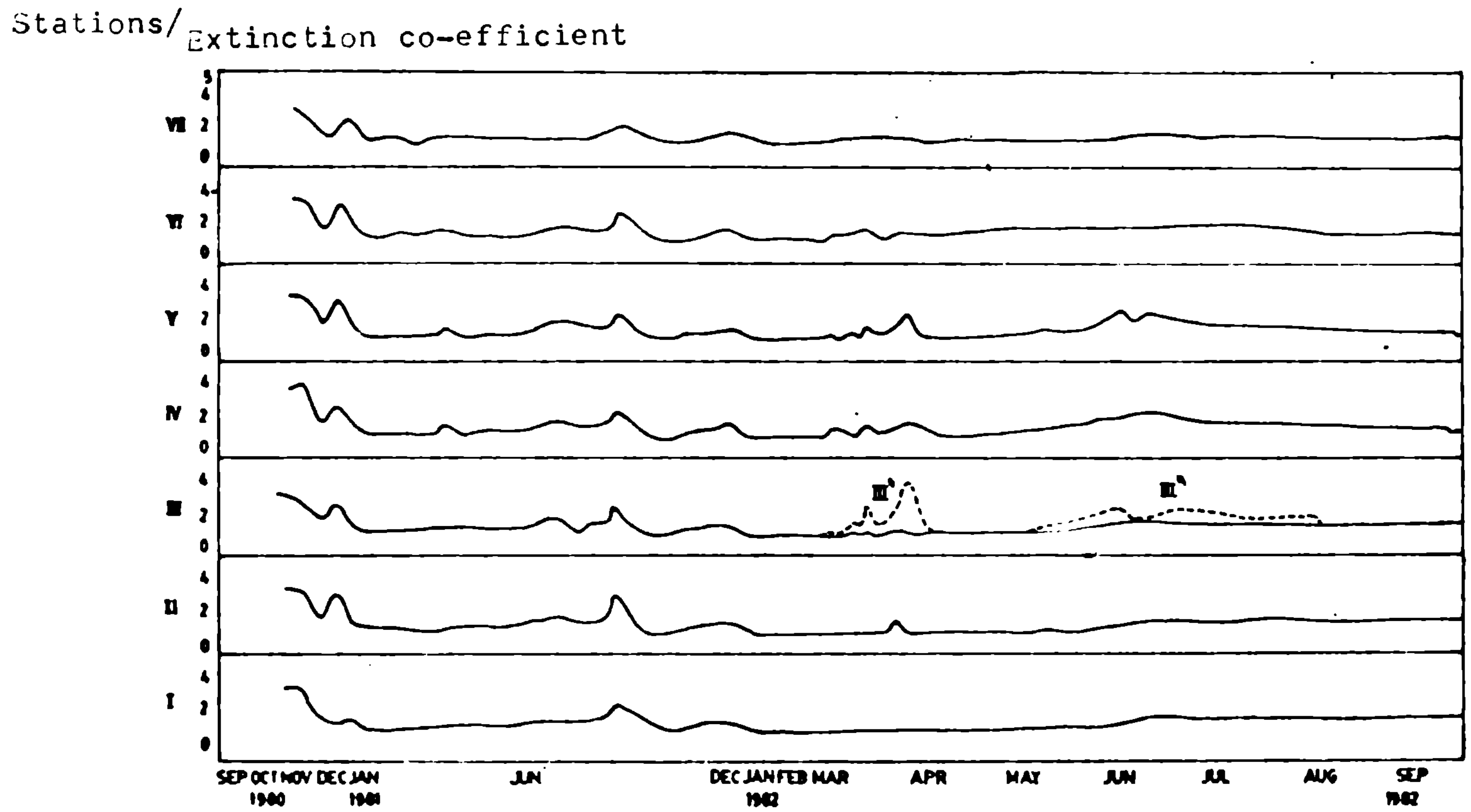



Fig.5. Variation of Extinction co-efficient ϵ at stations I to VII during November 1980 to September 1982 and at station III' during 13th March 1982 to mid-August 1982

high values (1.5-2.0)are noted during monsoon period (June-September). The higher turbidity during monsoon months are caused by the presence of fine suspended sedimentary particles brought down by the fast stream. Stations I, II and III exhibited the general trend described above, also during effluent discharge period mid-March to mid-August). Station III near the outfall showed high values of extinction co-efficient (3-4) during the period of discharge of effluents. Stations IV and V reflected these variations when values of K varied between 1.14 and 2.20 during March to April and higher values of 2 to 2.5 in June and July 1982. Station VI is only slightly affected and station VII showed no variations due to effluent discharges.

e) Temperature: This is one of the most important characteristics of water which determine the trends and tendencies of changes in its quality. Temperature of water influences the solubility of gases and their escape into atmosphere, determines the rate of biochemical self-purification and formation of secondary pollutants (Boersma 1970). Temperature is used as direct index of increased toxicity at elevated temperatures of substances like cyanides, xylene, phenols, zinc etc. on the aquatic life (Wilber, 1971). Other factors which are influenced by temperature are the ion and phase equilibria, catalytic and enzymatic reactions and biochemical processes accompanied by changes in concentration of organic and mineral substances.

Observations on temperature of the river from November 1980 to September 1982 showed a definite seasonal pattern (Figs. 6 and 7). All the stations showed identical variations in surface and sub-surface temperatures. Temperature ranged from 25.5°C during February to 30°C during April. The post-monsoon season (November 1980 to January 1981) recorded water temperatures 26.5° to 28°C while pre-monsoon values (February-May) gradually increased from 26.5°C in February to 30°C in May. During monsoon the temperature stabilized at 27°-27.5°C. The effluent water temperatures were generally 1.0° to 2.0°C higher than the river water. These higher values superimposed on the general seasonal variations gave maximum variation at station III' (0.5°-1.0°C), both at surface and subsurface, followed by stations IV and V where only slight deviation

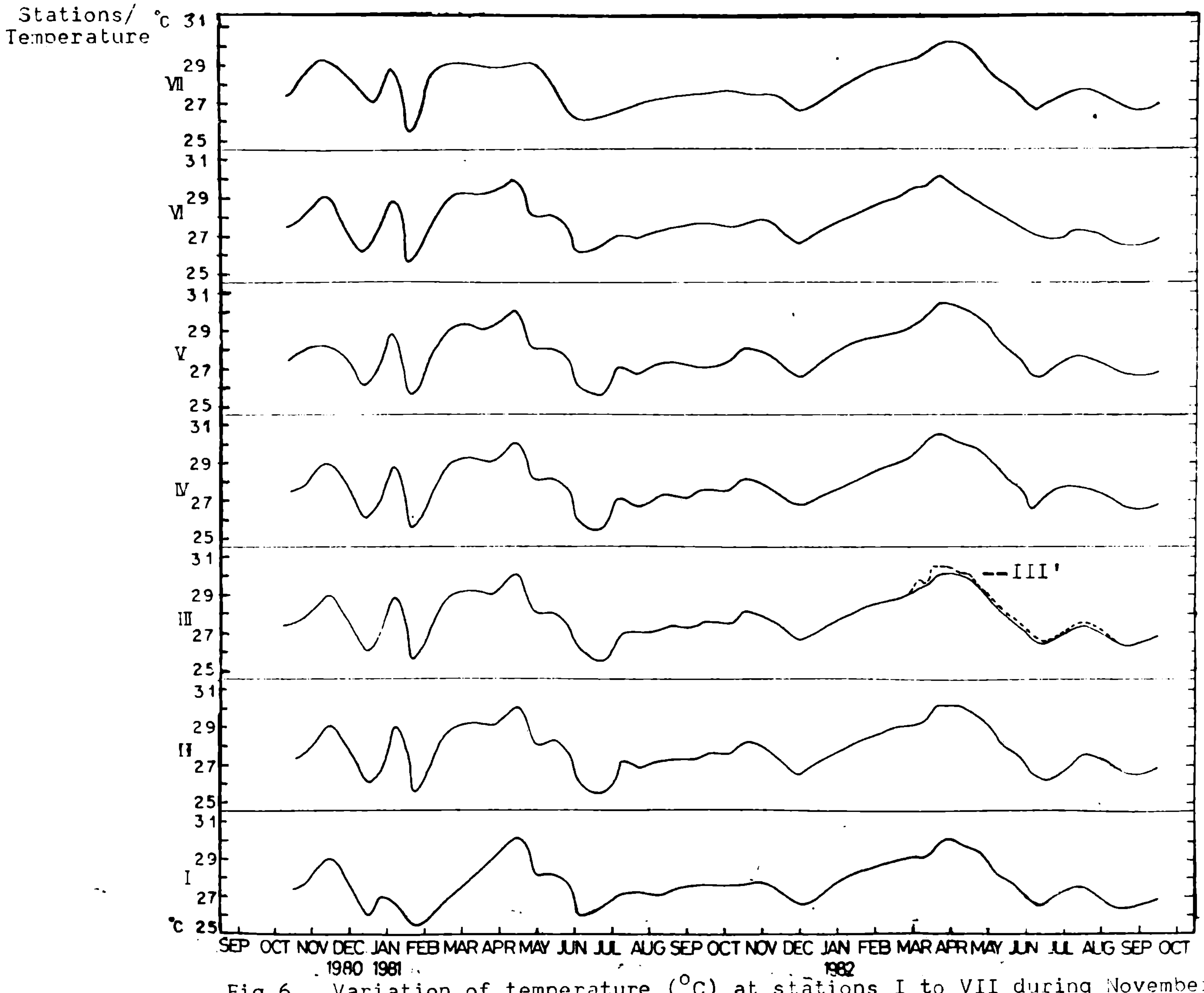



Fig.6. Variation of temperature ($^{o}C$) at stations I to VII during November 1980 to September 1982 and at Station III' during 13th March 1982 to mid-August 1982

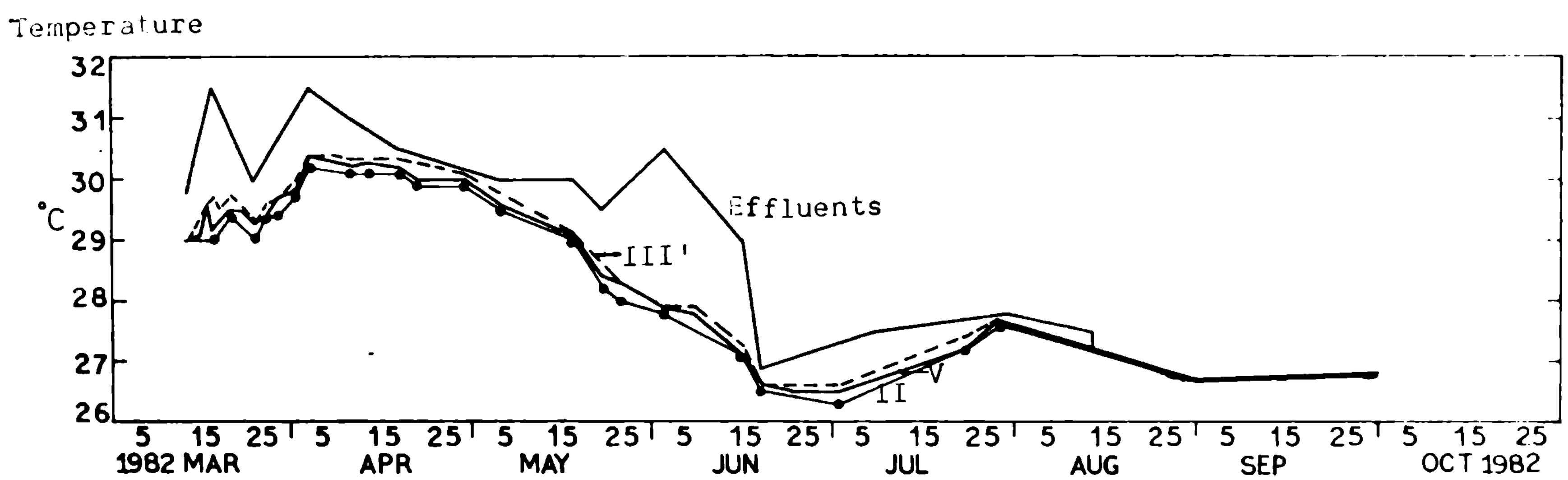



Fig.7. Variation of temperature (°C) at stations II, III' and V during the period 13.3.1982 to 30.9.1982 and that of effluents during 13.3.1982 to mid-August 1982

Thermal pollution does not at present pose a direct threat to the natural environment of the Muvattupuzha river. The available quantity of water in the river is sufficient to dissipate excess heat from the discharge. However, the higher temperatures may affect the biochemical reaction rates of degradation processes (Lester 1972) and may lead to environmental problems in course of time.

# CHAPTER 3

# WATER QUALITY II

CHAPTER 3

# WATER QUALITY II

## 3.1. Introduction

Water quality characteristics assessed in terms of chemical parameters, present precise knowledge on the standard of water intended for specific uses. The study based on chemical indices provide details of the water body on the degree of pollution and nature of pollutants apart from classifying water on the basis of its chemical composition (Otto 1979, Vo̸znaya 1979). Standards have been laid down for water quality, primarily based on the chemical aspects of water, enlisting criteria for drinking purposes, agricultural uses and industrial requirements etc. (National Water Council, 1978). The aim of such limits is to maintain the quality of water to the maximum possible extent and minimize undesirable changes, if any, that may arise out of unabated discharge of toxic pollutants.

The evaluation of the concentration and variation of certain parameters enable us to identify the factors causing such fluctuations. Though absolute concentration of a substance occurring frequently in considerable quantities is a dominant factor, difference in concentration from ambient values serves as an index for assessing pollution. Parameters indicating the quality of water which was expected to receive organic pollution loads were choosen during the preliminary surveys for detailed observations. Parameters such as salinity, pH, DO, BOD, SS and nutrients were extensively studied; investigations on organic carbon and concentration of mercury were also undertaken. This chapter presents the results of the studies on salinity, pH, DO, and BOD during both before and after the discharge of effluents from the pulp-paper factory.

3.2. Materials and Methods

a) Salinity: A clean plastic bucket was used for collection of water samples from the surface while bottom samples were collected using a Hytech bottom sampler. The determination of salinity was made by the modified Mohr's method, developed by Kundsen, using ordinary burettes and pipettes (Strickland and Parsons 1968).

A T-S meter was also employed for *in-situ* readings. Comparable values were obtained by both methods.

b) pH: The pH of the water sample was measured electrometrically at the laboratory temperature and pressure using a pH meter (Elico-model-EL 10T), immediately after the sample was brought to the laboratory. A glass indicator electrode and saturated calomel reference electrode were used. The instrument was standardised with standard buffer solutions. Figs. 8 and 9 present the surface and subsurface variations of pH at stations I-VII and at Station III'.

c) Dissolved oxygen: Dissolved oxygen in water sample was estimated by the modified Winkler method, as given by Strickland and Parsons (1968).

The water sample was taken in a BOD bottle using a rubber tube with maximum care without entrapping air bubbles. 1 ml of $MnSO_4$ solution was added by placing the pipette tip just beneath the surface of the water in the BOD bottle. This was followed by the addition of 1 ml of alkaline KI solution. The bottle was stoppered and the contents were thoroughly mixed, by vigorous shaking and the bottle was placed in a wooden box protected from light. In the laboratory, the sample was acidified with 2 ml 50% $H_2SO_4$ and once again shaken vigorously to dissolve the out into a conical flask and titrated against standardised (0.01 N) sodium thio sulphate solution to the starch end point. Figs. 10 and 11 give the variation of DO (mg/l) at surface and subsurface during the entire period of investigation.

d) BOD: Biochemical oxygen demand was determined by the method given by Martin (1968). Direct method was practised for relatively unpolluted waters (5 days, 20°C BOD, <4 mg/l) and unseeded dilution method for samples having BOD >4 mg/l. BOD of strong effluents was determined by the seeded dilution method (APHA, 1960). Figs. 12 and 13 present the variation of BOD (mg/l) at surface and subsurface at stations I-VII and station III'. Fig. 14 gives the BOD of the discharged effluents.

3.3. Results and discussion

a) Salinity: Salinity may be explained conceptually, as indicating the content of total dissolved salts in a water sample. Studies on seawater have brought out the importance of this parameter as influencing the density of seawater. Of equal importance are the processes which occur in estuaries acting as transition zones where salty seawater and freshwater interact (Dyer 1973, Pritchard 1978).

The mixing and the diffusion phenomena noticed in estuaries are largely influenced by salinity distribution within the region. Investigations on salinity have proved to be a scientific tool in studying the mixing processes and the intrusion of saline waters into river reaches by tidal action.

The entire investigation period indicated freshwater conditions at all stations in Muvattupuzha river. The tidal behaviour of the river does not exhibit upstream flow but only a periodic rise and fall of water level resulting in river discharge fluctuation (see chapter 5). Even station VII which is situated close to the river mouth does not indicate presence of saline waters (observations at surface and bottom) from the adjoining estuary during dry months, when salinity values are around 20‰ in these parts of the estuary. It is inferred that the present river discharge is adequate to keep off the salinity front from entering into the river. Hence no currents develop which are directed upstream. It may be recalled that prior to 1976, when the river discharges during premonsoon periods were feeble (less than 10 $m^3$/sec) saline waters reached well above the outfall point (upto Pazhur) and salt was extracted by solar evaporation. It is also reasonably concluded that the ground waters have now been recharged to fresh-water conditions.

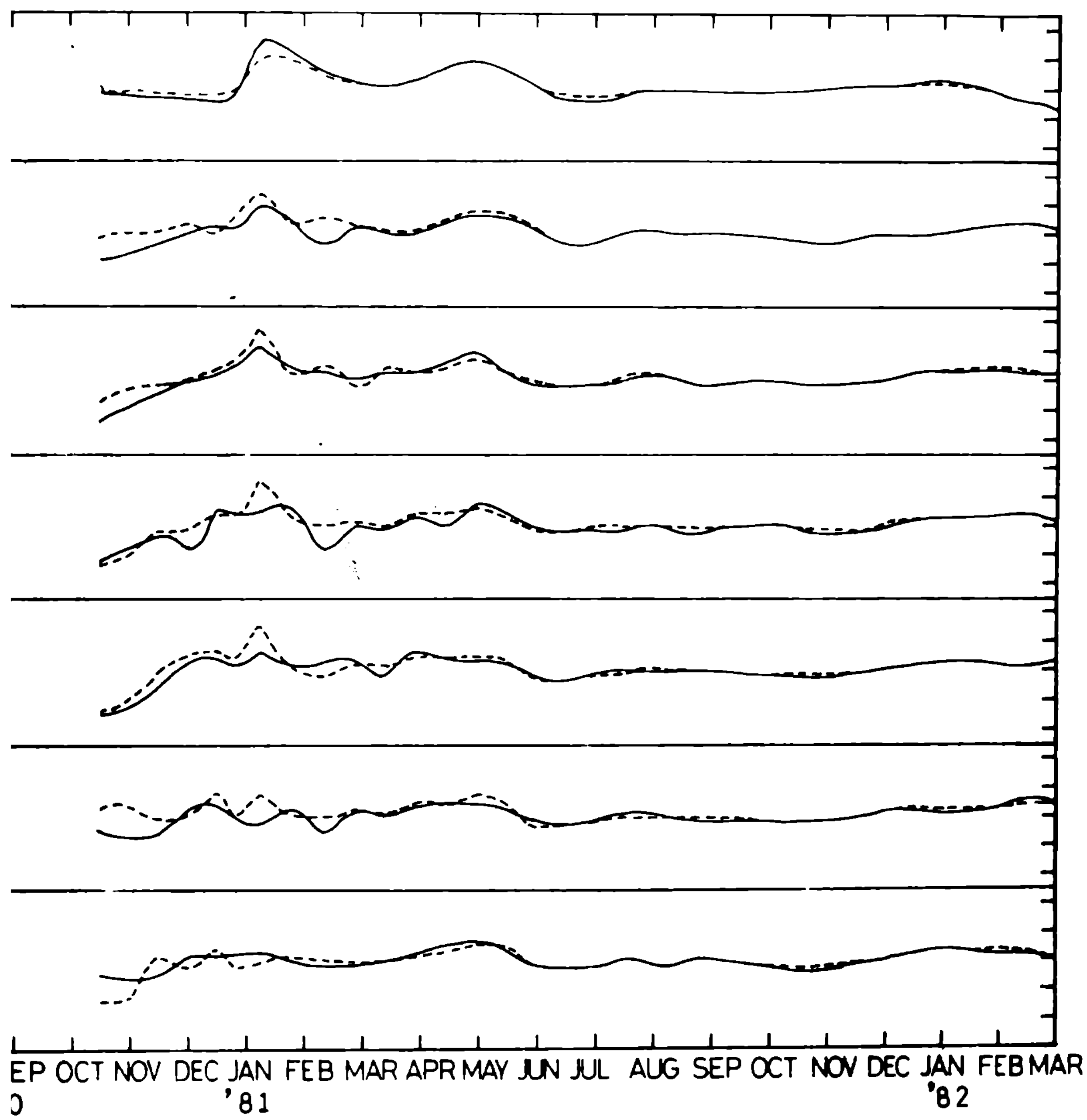
b) pH: The hydrogen-ion concentration is an important index regarding acidity or alkalinity of both natural and waste waters. pH values are affected by the nature of dissolved material and by chemical and biochemical processes. The normally observed values range from 6.5 to 7.8. Desirable values of pH for public water supplies shall be as close to 7 as possible (Nelson 1978). Variation in pH due to chemical and other industrial discharges renders a stream unsuitable, not only for recreational purposes but also for the rearing of fish and other aquatic life (Webb 1982). It has now been recognized that the tolerance range for most biological life is quite narrow and critical (George 1979). A low value may cause very rapid corrosion of hulls of ships, whereas high values bring about incrustation, brittlenessto pipes and problems during chlorination. Significantly, close monitoring of pH values for acidic or alkaline discharges enables to identify zones of pollution and other quality conditions on use of water (Clark 1977).

Investigations on pH from November 1980 to middle of March 1982 show remarkable consistency in values at all stations both at surface and subsurface (Fig.8). The pH remained mostly 7; sometimes it ranged between 6.85 and 7.20.

During the period from middle of March 1982 to September 1982 (Fig.9) when the river received effluent loads, stations I, II and III showed no variation from ambient conditions stated above. Station III' located near the outfall exhibited the maximum fluctuation ranging from 6.25 to 7.85. These features are transmitted to stations IV, V and VI in lesser magnitudes while station VII remained unaffected. The pH of effluents discharged into the river varied largely from 5.80 to 8.35 and all stations downstream of the outfall (except station VII) exhibited corresponding variations.

The river appears to be well affected by the pH of effluent waters. The ambient survey indicates pH of river water of potable quality. Since the effluent discharge commencement, seldom has the river attained its original character, the effect being pronounced for

H


EP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR
0
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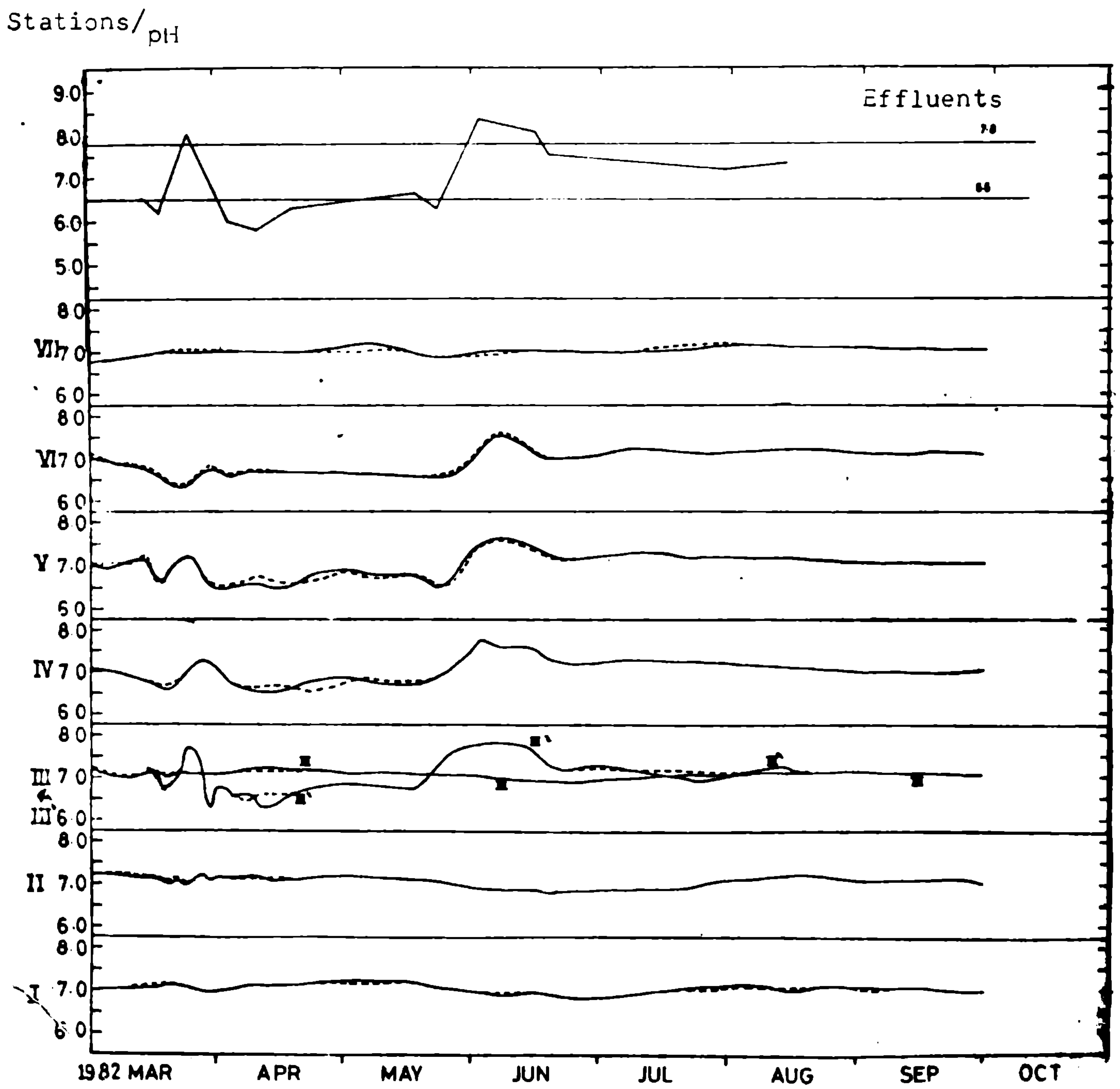



Fig.9. Variation of pH at surface (——) and subsurface (---) at stations I to VII and station III' during March 1982 to September 1982. The pH of effluents is indicated at top and the desirable pH of potable water is indicated between 6.5 and 7.8

a few km downstream (≈ 7 km). Hinge (1977) has shown that variation in pH in most rivers, brought about by effluent discharges are translated long distances downstream and the recovery is a time consuming process. IS: 7967-1976 sets the tolerance limits for pH after receiving discharges between 6.5 to 8.5 for bathing, recreation etc. and IS: 3306-1974 sets pH limits of 5.5 to 9.0 for effluents to be discharged into public sewers. IS: 2490-1974 prescribes the limits of 5.5 to 9.0 for effluent discharges. However, it is desirable that the pH lies close to 7.

c) Dissolved oxygen: This is a parameter of great importance in indicating the biological state and the ability of the water to decompose organic matter. The self-purifying capabilities of the river governed by the rates of deoxygenation and reaeration and numerous chemical and biochemical processes influencing aquatic life are controlled by the oxygen content of the water (Grande 1964). Deviations in the concentration of oxygen may be associated with pressure changes, temperature variations, chemical processes like oxidation-reduction, biochemical degradation of organic matter, breathing and photo synthesis.

Dissolved oxygen is not by itself a pollutant except under very unusual conditions such as to cause corrosion to pipe material. This parameter may be considered as a corollary quality indicator much affected by actual pollutants (Hann 1968). Though oxygen is only slightly soluble in water (14.56 mg/l at $0^{o}C$ and 7.63 mg/l at $30^{o}C$), the presence of dissolved oxygen in water bodies in substantial amounts is extremely essential for the survival of aquatic organisms and its absence leads to undesirable obnoxious odours under anerobic conditions (Doudoroff 1970, Nelson 1978). The associated features of hystopathological effects on fishes due to depletion of oxygen content in water on discharge of waste sulphite liquor from pulp mills have been discussed by Wilber (1971).

The actual quantity of oxygen present in solution is governed by the solubility of the gas, temperature, partial pressure of the gas in the atmosphere and purity (suspended solids, salinity) of the water. The quality of a water body may therefore, be inferred from the amount of oxygen present and from its chemical behaviour (Wahby 1978, Schroeder 1980).

The investigations on dissolved oxygen at stations I to VII during the period from November 1980 to 15th March 1982 (Fig.10) indicate that the Muvattupuzha river water contains high amount of dissolved oxygen. The values range from 5.5 mg/l to 11.5 mg/l. The seasonal trends were found to be the same both at surface and subsurface with nearly identical values. For the pre-monsoon period, the values were nearly stable between 7.0 mg/l and 9 mg/l. The amount of dissolved oxygen during monsoon period was generally high, 9-11.5 mg/l. The observations during post-monsoon season show wide fluctuations in DO, varying from 5.5 mg/l to 10 mg/l. The higher values in monsoon period may be due to the rains, when more amount of oxygen is readily dissolved, owing to the lowering of the temperature, the turbulence and the precipitation.

During the period of effluent discharge from 13th March 1982 to mid-August 1982, more frequent investigations were made at all stations (Fig.11). Stations I, II and III present features comparable with those of the previous year with values ranging from 7-9 mg/l during pre-monsoon and monsoon periods. But station IV and other stations downstream were affected by the effluent which indicated

Stations/Dissolved
oxygen

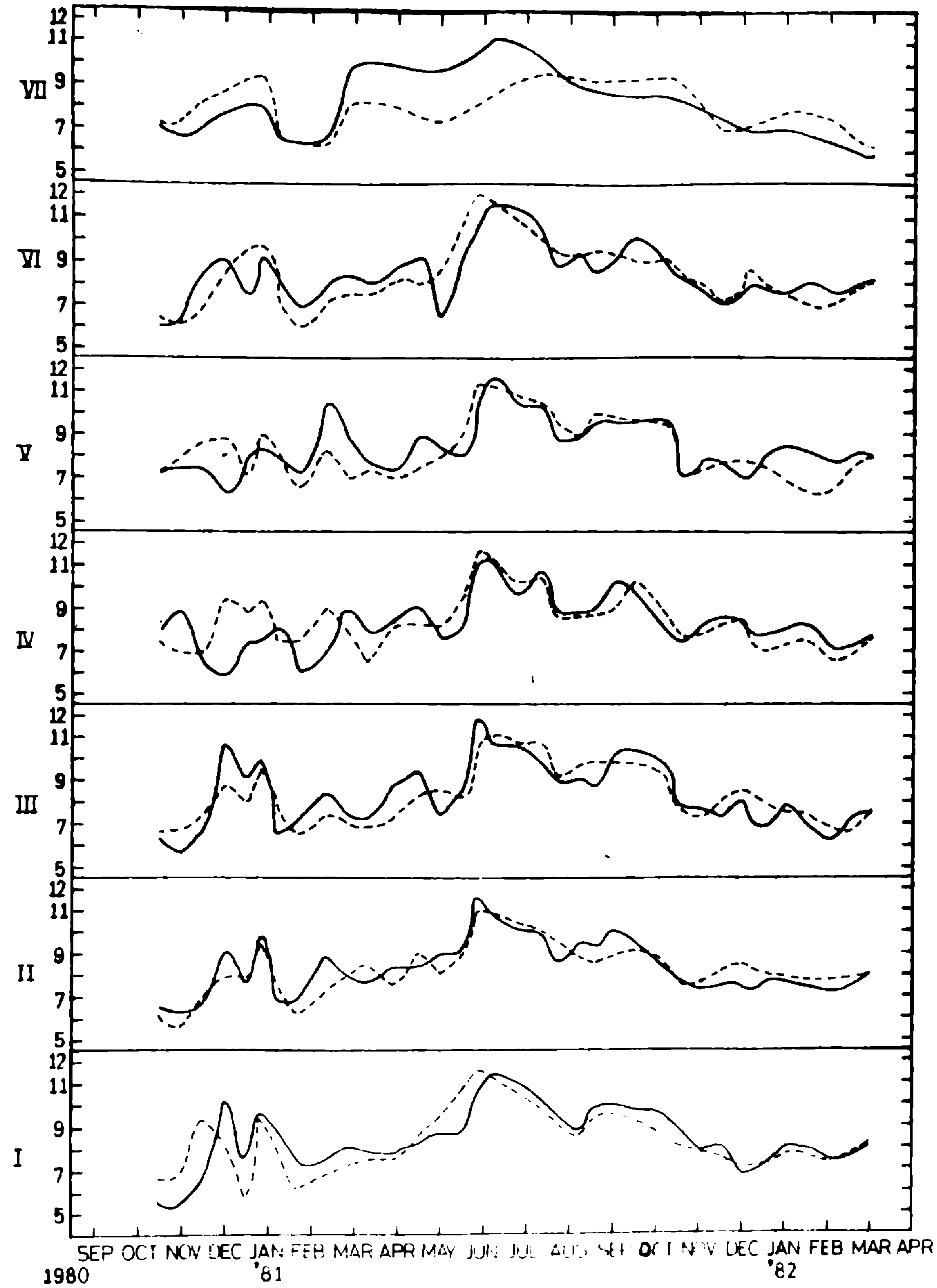



Fig.10. Variation of DO (mg/l) at stations I to VII during November 1980-15th March 1982 at surface (——) and subsurface (---)

Stations/Dissolved oxygen

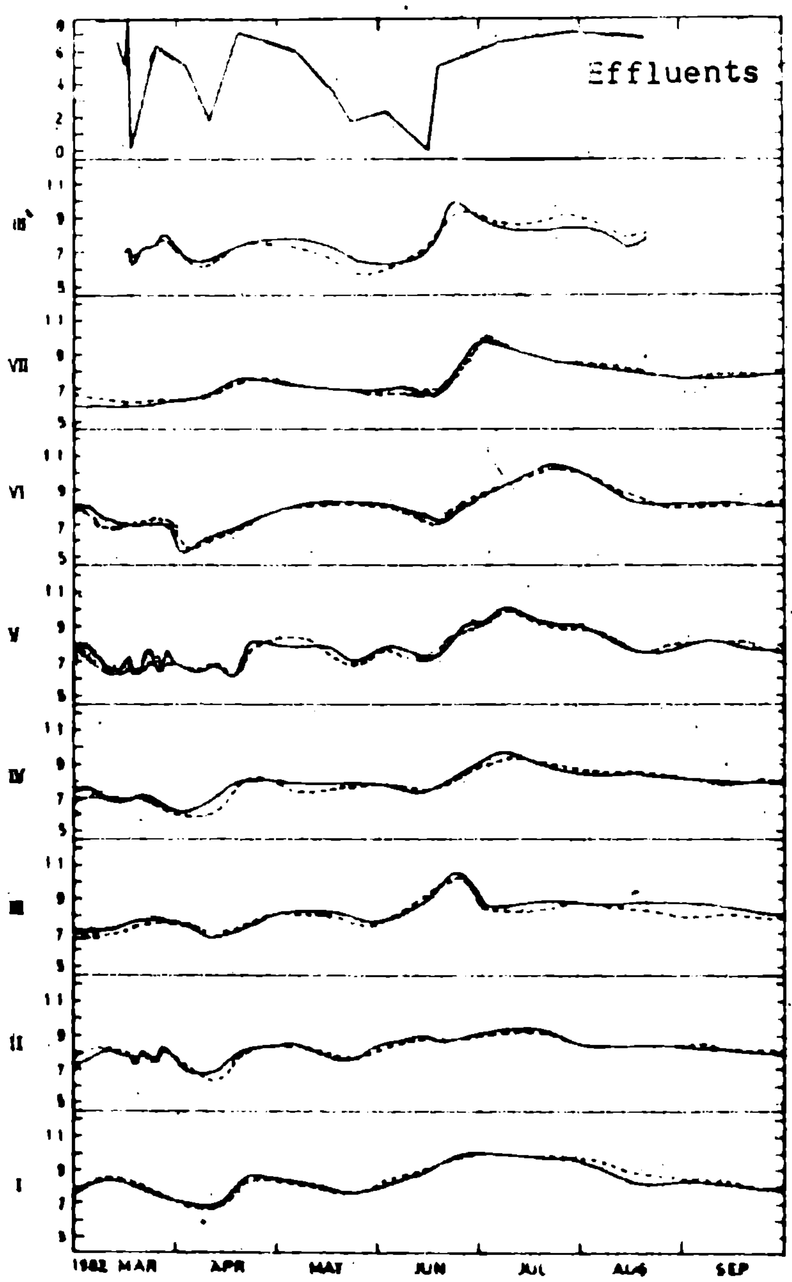



Fig.11. Variation of DO (mg/l) at Stations I to VII during March 1982 to September 1982 and Station III' during 13th March 1982 to mid-August 1982 at surface (——) and subsurface (---). The DO of effluents is given at top

lower concentrations of DO, though the seasonal variations were evident. The values were generally around 6-8 mg/l upto middle of June 1982. Thereafter the concentration at these stations showed significant increase attaining maximum values of 10 mg/l during July 1982. This increase may partly be due to the marked variation in the quality of the effluents and partly due to the monsoon rains. Stations III' which is located near the outfall also exhibited a similar trend as at stations IV to VI. Station VII located close to the river mouth, however, showed values close to 7 mg/l or less upto middle of June 1982 after which the values enhanced to 8.0-9.5 mg/l.

The dissolved oxygen present in the effluents was frequently observed to be lower than the tolerance limits of 40% saturation value or 3 mg/l, whichever is higher* (IS:2296 - 1974). On 17.3.1982 and 10.4.1982 the values were as low as 0.12 and 2 mg/l respectively. Seldom did the concentration of DO reach the near-saturation value. The period between 15.5.1982 and 16.6.1982 was particularly noted for the very low values of DO in effluents, 0 to 2 mg/l, which is considerably less than the tolerance limit. At other times, values range from 4 to 7 mg/l.

Surveys of the river prior to the discharge of effluents point out the abundant availability of water nearly saturated or saturated with dissolved oxygen. The discharge of pulp-paper effluents of very low concentration of DO resulted in the overall decrease of the ambient values. Though the level of DO in the river did not drop below the tolerance limit, it is most undesirable to discharge effluents containing very low concentration of dissolved oxygen. Such discharges exert a heavy burden on the self-purifying capacity of the river in addition to the demand that would occur by biochemical degradation of organic matter. The low concentration of DO of effluents indicates the inadequacy of the treatment carried out in the factory.

d) Biochemical Oxygen Demand (BOD): The biochemical oxygen demand is the amount of oxygen, dissolved in the water, required for the aerobic biochemical oxidation of decomposable matter present in water at a specified temperature and time. The oxygen demand may be exerted by carbonaceous material, oxidizable nitrogen and chemically reducing compounds (Klein 1972). The oxygen demand exerted is a function of the history and type of the water body or waste (Ajayi 1981). The complete stabilization of the waste takes a long time and hence for all practical purposes, the standard laboratory test for BOD is incubation for 5 days at 20°C. This test is of importance in sanitary analysis of waste water and in assessing treatment plant performance. The parameter is also useful in allocating waste loads for any water course.

In streams, excessive amounts of organic matter, cause consumption of oxygen to the extent that the amount of dissolved oxygen may be depleted to a level unsuitable to aquatic life. Eventually, addition of heavy BOD loads leads to anerobic conditions causing fish kills or migration of the life forms from the polluted zone (Farrimond 1980).

Observations on the BOD at different stations had shown that during the period prior to effluent discharges the values limit to the normally observed ones for potable water (Fig.12). During post-monsoon, the values were observed to fluctuate between 0.5 and 3.0 mg/l.

But during premonsoon and monsoon seasons the highest value of BOD was 2.0 mg/l only. The surface and subsurface values nearly coincided during the entire period of investigation and the general temporal variations were identical at all stations(I to VII).

tations/BOD

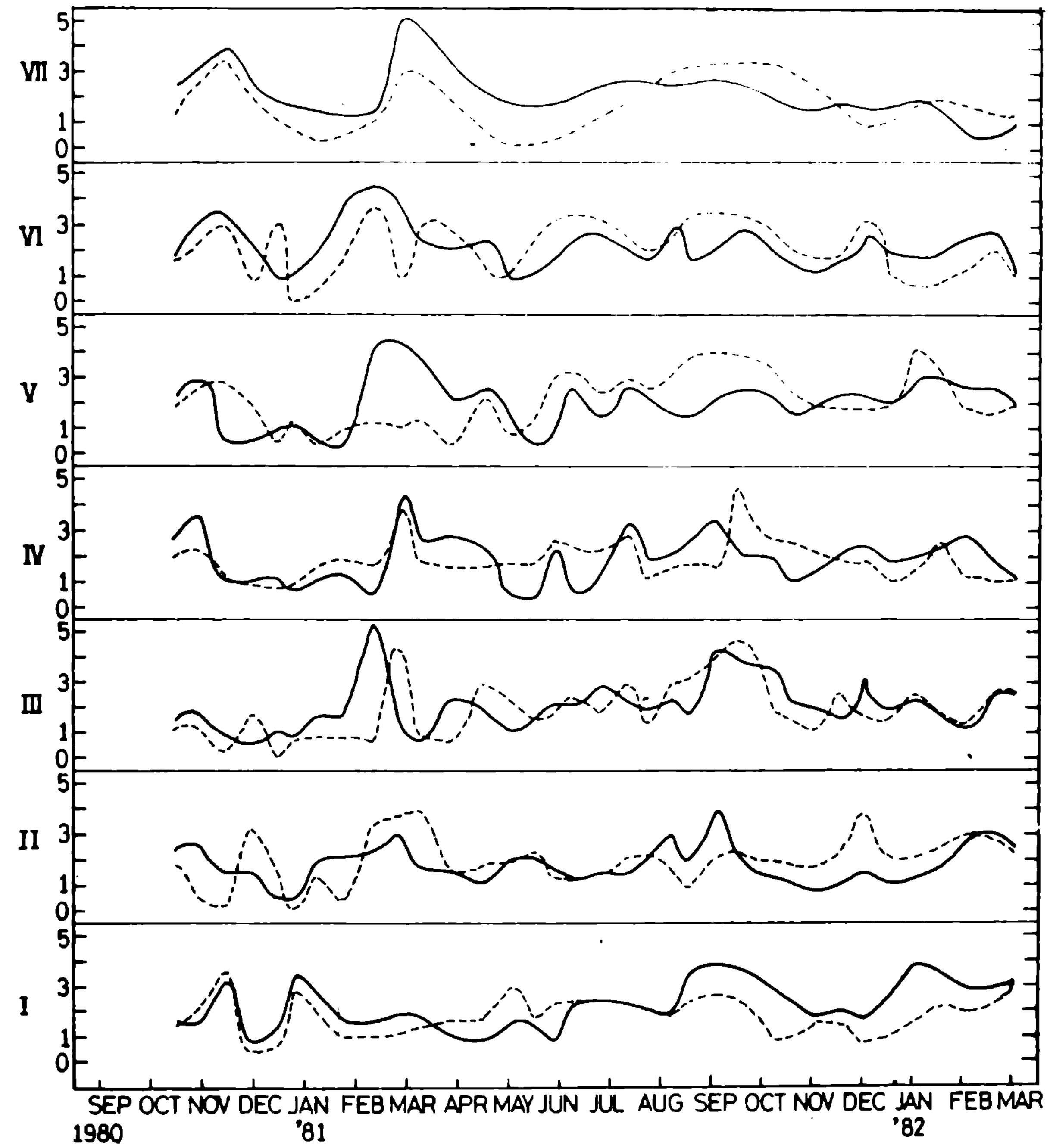



Fig.12. Variation of BOD (mg/l) at stations I to VII during November 1980-15th March 1982 at surface

During the period from middle of March 1982 to end of September 1982 (Fig.13) when frequent surveys were made consequent to the discharge of effluents by the factory .The upstream stations I , II and station III, located perpendicular to the outfall, indicated the ambient conditions, as discussed above. Station III', near the outfall, where the effluents directly mixed with the river water, gave the maximum variation in the BOD content. The analyses of effluents for its BOD exhibited two significant periods, 16.3.1982 to 18.3.1982 and 22.5.1982 to 16.6.1982 when effluents of BOD 250 mg/l and 500 mg/l or more were discharged, respectively. A very high value of BOD 5000 mg/l for effluents was observed during middle of June, 1982. These discharges had altered the BOD at stations IV to VII downstream of the outfall. Observation at station III' gave maximum values of 16 mg/l and 45 mg/l during the above periods whereas station IV recorded 15mg/l and 32 mg/l respectively. At stations V and VI the peak values during middle of June were observed as 14 and 6 mg/l of BOD respectively. In addition to the above observation, the results of analyses of BOD at these stations gave higher values than at upstream stations and those observed during the period prior to the effluent discharges.

Stations/BOD

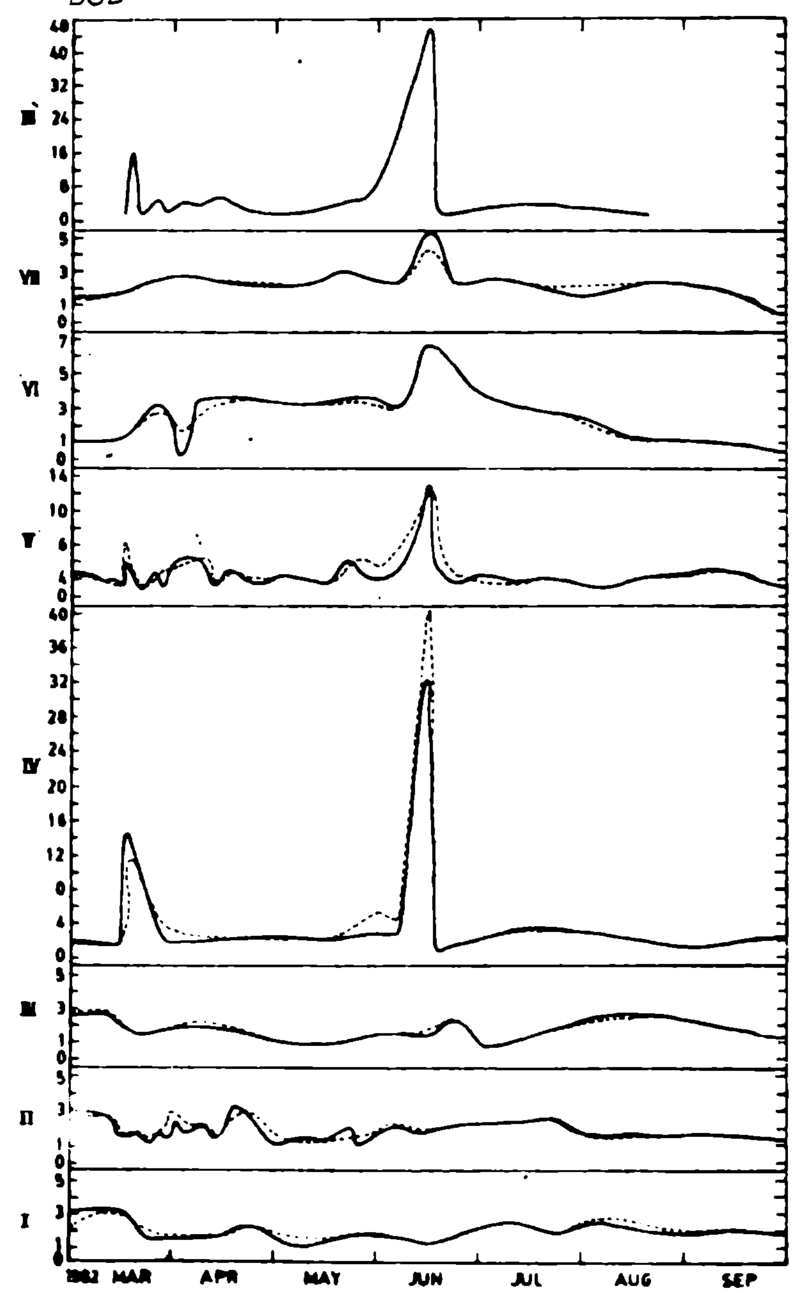



Fig.13. Variations of BOD (mg/l) at stations I to VII and station III' during March 1982 to September 1982 at surface (—) and subsurface (---)

BOD values at station IV were between 2 mg/l and 4 mg/l and at station VI between 3 mg/l and 4 mg/l. Station VII, located near the river mouth also retained the characteristic higher values as at stations IV, V and VI. At this station the BOD values were between 2 and 3.5 mg/l.

The analysis of effluents clearly indicated that on three occasions, the BOD of the discharged effluent were well above the tolerance limit of 30 mg/l (Fig.14). The worst condition occurred on 15th June 1982, when the effluent BOD was 5000 mg/l. It may be noted that all the downstream stations responded sharply to such discharge of effluents.

The relevant standard is the IS: 2490 (Part I) - 1974 on tolerance limits for industrial effluents discharged into inland surface water, which sets the BOD (5 days, 20°C) limit for pollutants as 30 mg/l and IS: 7968-1976 on tolerance limits for industrial effluents discharged into marine coastal areas which prescribes the BOD (maximum) as 100 mg/l. Reference is also made to BOD (5 days, 20°C) maximum in IS: 7967-1976 where the tolerance limits for water quality after receiving discharges, is 5 mg/l for bathing, recreation, shell fish

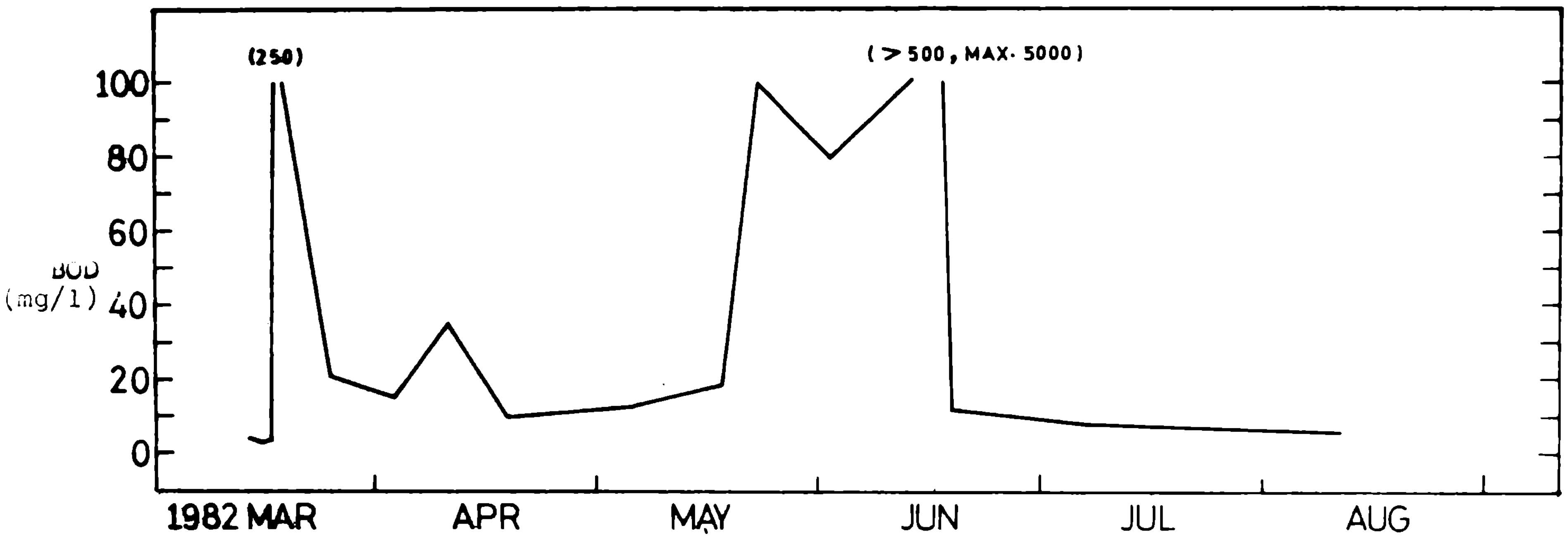



Fig.14. BOD (mg/l) of effluents discharged into the river during 13th March 1982-13th August 1982.

# CHAPTER 4

# WATER QUALITY III

CHAPTER 4

# WATER QUALITY III

## 4.1. Introduction

Most of the available water on earth are inhabited by life forms ranging from minute micro-organisms to large whales. One of the deciding criteria for the growth and propagation of life in water is the adequate supply of food and maintenance of food web (Liebig 1942). Deficiency or surplus of food tend to cause abnormal situations when the quality of water media may degrade to cause undesirable effects. Together with this imbalance, presence of toxic substances aggravate the problem of pollution.

As stated in the previous chapter, water quality standards define the limit to which a water course may be subjected to pollution. With relevance to the nature of pulp-paper effluents discharged into the river, a few more parameters have also been investigated such as the nutrients (nitrites, nitrates, phosphates), suspended solids, organic carbon content of sediments and the heavy metal, mercury. These parameters are important in the present context in estimating the degree of pollution and the efficiency of the treatment process presently deployed.

Nutrients are essential for the maintenance of biological systems. Nitrogen and phosphorus are the major nutrients taken up by phytoplanktons (algae) apart from siliceous organisms which utilize silicon. Excess input of nutrients associated with sewage, industrial wastes and intensified agriculture results in the phenomenon known as 'eutrophication'. Waste waters containing large amounts of nutrients, fertilize the stream, to support a higher level of primary production. This process causes algal bloom affecting the taste and odour of water and reduces transparency. The unmatched population increase causes further deterioration of water quality, when under exhausting food supply at the end of the bloom, the decaying algal masses further lower the oxygen content of the water, apart from any bacterial oxidation of organic matter in effluents causing oxygen depletion, ultimately turning the media anoxic. Numerous studies in this direction have promoted the pollution control systems to incorporate methods to remove excess nitrogen and phosphorus, before the effluents are discharged (Truesdale 1979, Vollenweider 1980).

Apart from the dissolved molecular nitrogen, organic and inorganic nitrogen compounds are present in water in varied proportions. The organic nitrogen compounds are formed in water by photo and biosynthetic processes by aqueous organisms and the ratio C:P and N:P concentrations are characteristically used to denote the content of organic substances in water (Riley and Chester 1971). The concentration of dissolved and particulate organic nitrogen compounds indicate seasonal variations subject to biological activity. The main inorganic nitrogen forms are the nitrite ion ($NO_2^-$), nitrate ion ($NO_3^-$), ammonia ($NH_3$ ,both free and ammonium).

Nitrites appear in water on oxidation of ammonia or on reduction of nitrates. Nitrate is reduced to nitrite by some bacteria when there is a deficiency of oxygen in the water body. Increased concentration of nitrites may be indicative of pollution (including faecal). Certain industrial and biologically purified wastes may also contain large amounts of nitrites (Owens 1978).

Generally appreciable amounts of nitrate are present in surface waters, except when intensive growth of phytoplankton occurs. High concentration of nitrates in potable water is harmful to children and may cause anaemia (Banoub 1980).

Ammonium ions and ammonia are produced by the biochemical decomposition of protein substances and their relative concentration depends on the pH of the water. An increase in concentration of ammonium ions is observed when aquatic organisms are dying off. In oliogotrophic conditions when water contains high amount of DO and for high values of oxidation-reduction potential, the concentration of ammonium ions is quite small.

Phosphorus compounds (dissolved and particulate) occur in water during certain biological processes of transformation of organic matter into inorganic substances. City sewage, drainage collections (including run-off) and certain industrial effluents introduce considerable amount of phosphates in rivers and estuaries (Anne Jones 1982). Aqueous plant organisms use phosphates during vegetation period. Other users of phosphorus compounds are zooplankton and bacteria. The content of phosphates in water is influenced by the dynamics of biological activity under natural conditions (Owens 1970).

4.2. Materials and Methods

a) Nitrite: Bendschneider and Robinson (1952) method as suggested by Grasshoff (1976) was adopted for its estimation. The nitrite in the sample was allowed to react with sulphanilamide in an acidic solution. The resulting diazo compound proportional to the initial concentration of the nitrite, was coupled with N-1 naphthyl ethylene diamine dihydrochloride forming a diazo dye. The extinction of the dye solution was measured spectrophotometrically at 545 nm. Cell-to-cell blanks and reagent blanks were also read and necessary corrections applied.

b) Nitrate: It was estimated by the method originally proposed by Mullin and Riley (1955) and later modified by Grasshoff (1976). The nitrate in the sample was reduced to nitrite by running the sample through a copper coated cadmium-granule column. A buffer solution of ammonium chloride was used to maintain a constant pH during the passage of the sample through the reductor. The quantitatively produced nitrite was then estimated as described above making corrections for any nitrite originally present in the sample.

c) Inorganic phosphate: Inorganic phosphate was estimated by the method of Murphy and Riley (1962). The samples were treated with a composite reagent containing molybdic acid and trivalent antimony. The resulting complex was reduced with ascorbic acid and the molybdenum blue solution thus formed was measured spectrophotometrically at 880 nm. Cell to cell blanks and reagent blanks were determined and necessary corrections applied.

d) Suspended solids: The suspended matter was determined by filtering a known volume of the sample through a previously weighed quantitative Whatman filter paper No.42, washing off soluble matter using distilled water, drying the paper in the funnel in an air oven (at 103-105$^{o}$C), cooling to room temperature in a desiccator and weighing the same. The results are expressed in mg/l and are presented in figures 15,16 and 17.

e) Total Organic carbon: The method developed by El Wakeel and Riley (1957) for the determination of total organic carbon was adopted. The principle of the method is that under suitable conditions, the organic carbon can be quantitatively oxidised with chromic acid. The sample was first washed with distilled water and dried at 105$^{o}$C in an air oven. It was ground to pass a 100 mesh sieve. About 0.25 gm was weighed into a conical flask, 10 ml chromic acid was added and the mixture was heated in a boiling water bath for 15 minutes. Cooled and poured the contents into 200 ml of distilled water and titrated against 0.2N ferrous ammonium sulphate solution using ferroin indicator, until a pink colour just persisted. Carried out a blank determination in the same manner but omitting the sample.

A factor of 1.15 was used to convert the values to obtain the total organic carbon and the results are expressed in percentage (Table 3).

f) Mercury: Total mercury in water was determined using a mercury analyser model MA 5800A (ECIL). Known volumes of filtered (Poleuktov 1963) acidified samples are treated with standard $KMnO_4$ (5% $w/_v$) and potassium persulphate (5% $w/_v$) solutions. Warmed the mixture in a waterbath, cooled to room temperature and made up. The excess $KMnO_4$ in samples are reduced with 1% $w/_v$ $NH_2OH.HCl$ in 12% $w/_v$ NaCl. An aliquot of the sample 10 ml (10% with respect to $HNO_3$) was treated with 2 ml 20% $SnCl_2$ solution. Allowed to react for 5 minutes and mercury was determined by the cold vapour atomic absorption technique using air free from mercury as a carrier gas. The same procedure was adopted for a series of standards and reagent blanks.

4.3. Results and Discussion

a) Nutrients: Nitrite, Nitrate and Inorganic phosphate.

The survey from 9.1.1981 to 12.3.1982 at the various stations indicates that the content of $NO_2^-$-N varies between 0.025-0.088 µg at/l, $NO_3^-$-N between 0.1-1.0 µg at/l and $PO_4^{\equiv}$-P between 0.1-0.325 µg at/l. Since the discharge of the effluents (from 13.3.1982 onwards) station II reportsthe following values (in µg at/l) $NO_2^-$-N between 0.025-0.12, $NO_3^-$-N between 0.36-1.70 and $PO_4^{\equiv}$-P 0.10-0.325. These values are more or less the same as those observed during the earlier survey. The downstream stations and station III' exhibit following concentrations for nutrients (in µg at/l).

$NO_2^-$-N varies between 0.12-0.50
$NO_3^-$-N varies between 1.70-10.60
and $PO_4^{\equiv}$-P varies between 0.455-2.45

Most of the values for $NO_2^-$-N lie between 0.3 and 0.5, $NO_3^-$-N between 6.0 and 10.0 and $PO_4^{\equiv}$-P between 0.65 and 1.25. Table 2 provides a summary of the investigations.

Table 2

Summary of Investigations on Nutrients

| od | Stations | Range of Nutrient content | | |
|---|---|---|---|---|
| | | $NO_2^-$-N µg at/l | $NO_3^-$-N µg at/l | $PO_4^{\equiv}$-P µg at/l |
| 1982 to .1982 ient ey) | II to VII | 0.025-0.0880 | 0.10-1.0 | 0.10-0.325 |
| .1982 3.8.'82 luent harge od) | II | 0.025-0.12 | 0.36-1.70 | 0.10-0.325 |
| | III', V and VI | 0.12-0.50 | 1.70-10.6 | 0.455-2.45 |
| quently rved es | | (0.30-0.50) | (6-10) | (0.65-1.25) |
| .1982 efflu- disch- ) | II and V | 0.0375-0.0875 | 0.76-1.0 | 0.10 |

A four fold, eight fold and three fold increase in the concentration of $NO_2^-$-N, $NO_3^-$-N and $PO_4^{\equiv}$-P respectively has been caused by the effluent discharges. It may be noted that on two or three occasions, the treatment lagoons (aeration ponds) experienced very heavy growth of blue-green algae and colonies of algae were also carried along with the effluent discharges into the river.

b) Suspended solids: Suspended matter enters the rivers as insoluble material like sand, silt, clay, debris from agricultural fields, algae and inorganic minerals. The above materials originate from weathering of rocks, bank erosion, biological activities, tributary inputs and also from human activities. The presence of suspended solids cause turbidity which reduces the passage of sunlight into river waters and decreases the primary production, which in turn affects the higher forms of life in the food web. Another noted feature is that the sedimentation of suspended matter destroys the spawning ground which affects the population of aquatic life.

Suspended solids has now been recognized as a pollutant based upon its undesirable effects on the fish population (Loch 1973). Alabaster (1972) reports that concentrations of suspended solids exceeding 100 mg/l are generally detrimental to river fisheries. The task force on sedimentation problems in the Trinity River (Anonymous 1970) has narrated the damage caused to salmon spawning grounds. Imeson (1981) has pointed out the roll played by suspended solids in altering the diffusion and flocculation conditions of rivers. The presence of large amounts of suspended matter in river influences its flow regime also. Itakura (1980) has shown that flow conditions tend to alter and mixing lengths of scale of turbulence reduce by the introduction of suspended matter.

This was a parameter of water quality, which closely reflected the fluctuations caused by the discharge of pulp-paper effluents. The overall values during the survey prior to effluent discharges (Fig.15) range from a minimum of 2 mg/l to maximum values of 45 mg/l. The values lower than 20 mg/l were observed for the pre-monsoon period for all stations at both surface and subsurface. Higher values during monsoon period were around 30 mg/l with values as high as 45 mg/l during the initial days of monsoon. This is due to the large amount of suspended sediments and floating matter brought down by the flood waters. The post-monsoon period exhibits

Stations/Suspended solids

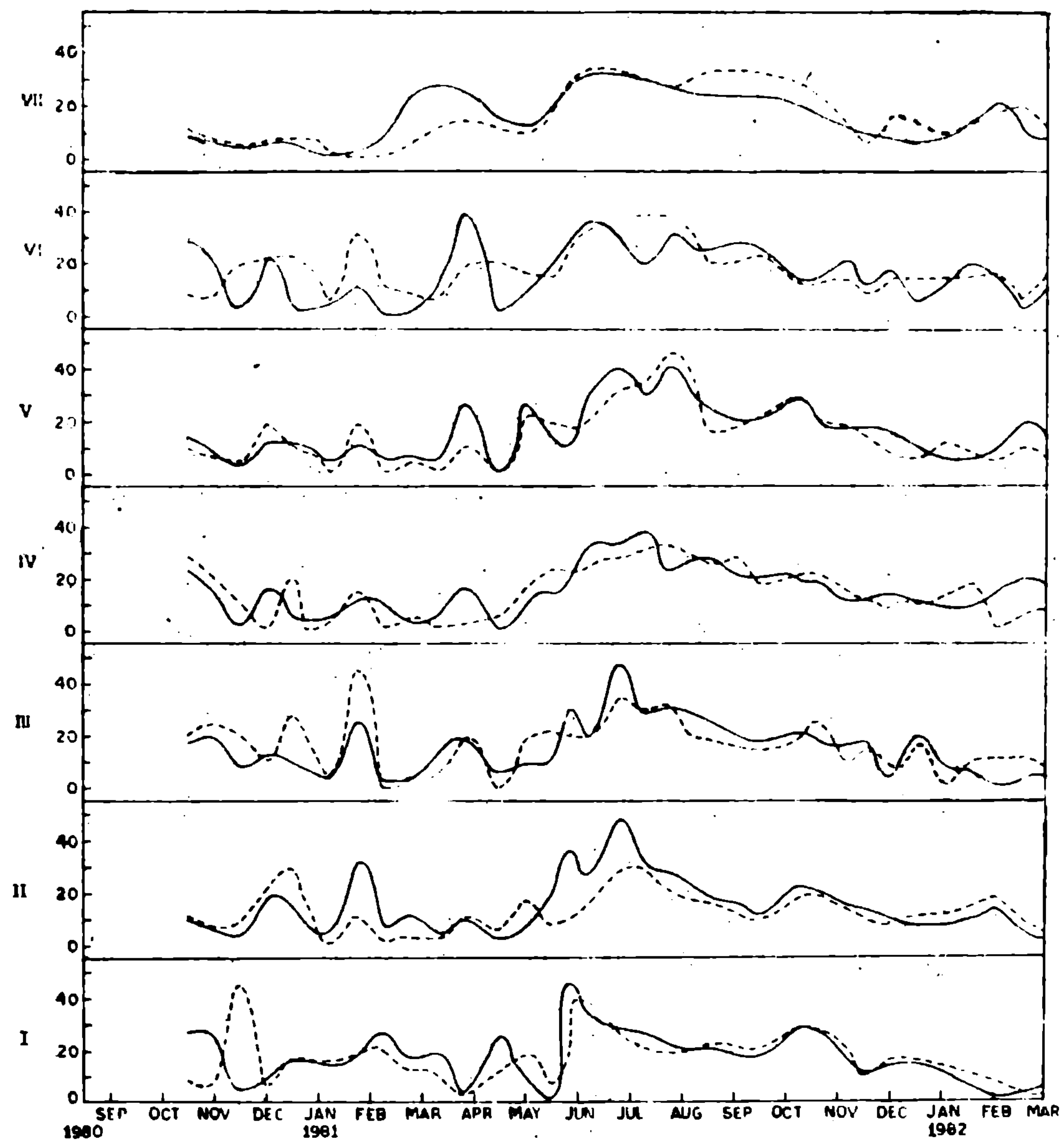



Fig.15. Variation of Suspended solids (mg/l) at stations I to VII during November 1980 to 15th March 1982 at surface (——) and subsurface (---)

transitional tendency, but the general trend is in the decreasing order for suspended solids concentration.

Since middle of March 1982, stations I, II and III maintained their original pattern of low suspended solids during pre-monsoon with slightly higher values during monsoon, when effluents from the factory were discharged (Fig.16). Station III' strikingly exhibited very high variations in its suspended solid content. The period between 13th March, 1982 to 18th April 1982 is conspicuous for the frequent fluctuations in suspended solids content (20-160 mg/l). A peak value of 200 mg/l was noticed on 15th June 1982 which was preceded by a gradual increase since 5th May, 1982 brought about by the increasing amounts of solids in the effluents.

Higher values were observed at station IV, the trend of which closely followed that at station III (Fig.16,17) The period from mid-March to mid-June 1982 indicated suspended solids of the amount between 20 to 70 mg/l, whereas for the period between 21st May and 15th June, the values picked up from 50 to 140 mg/l. Thereafter, the suspended solid content remained around 65 mg/l for 2 months, clearly indicating the influence of effluent discharges. Station V and also station VI

Stations/Suspended solids

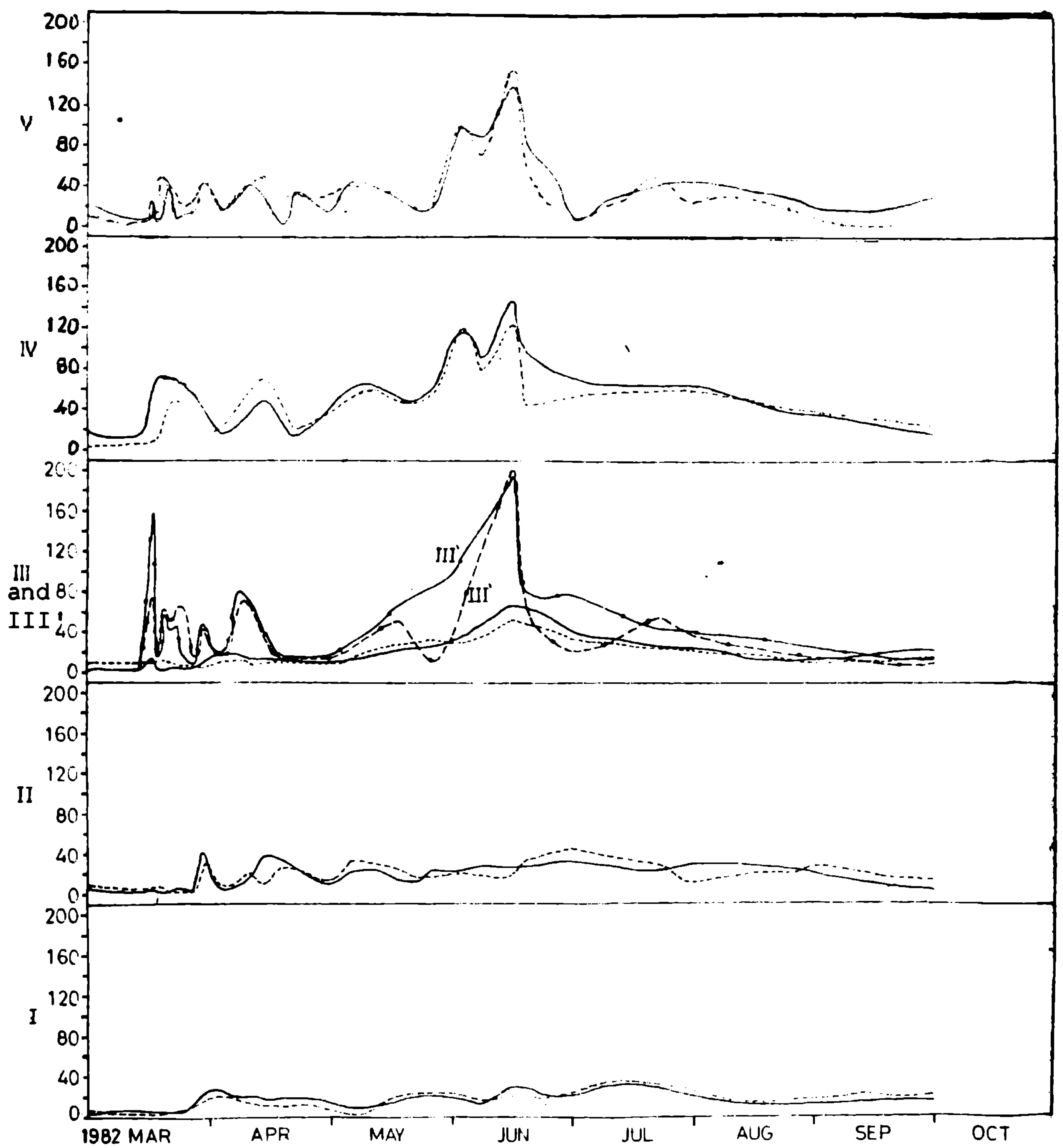



Fig.16. Variation of Suspended solids (mg/l) at stations I to V and station III' during March 1982 to September 1982 at surface (——) and subsurface (---)

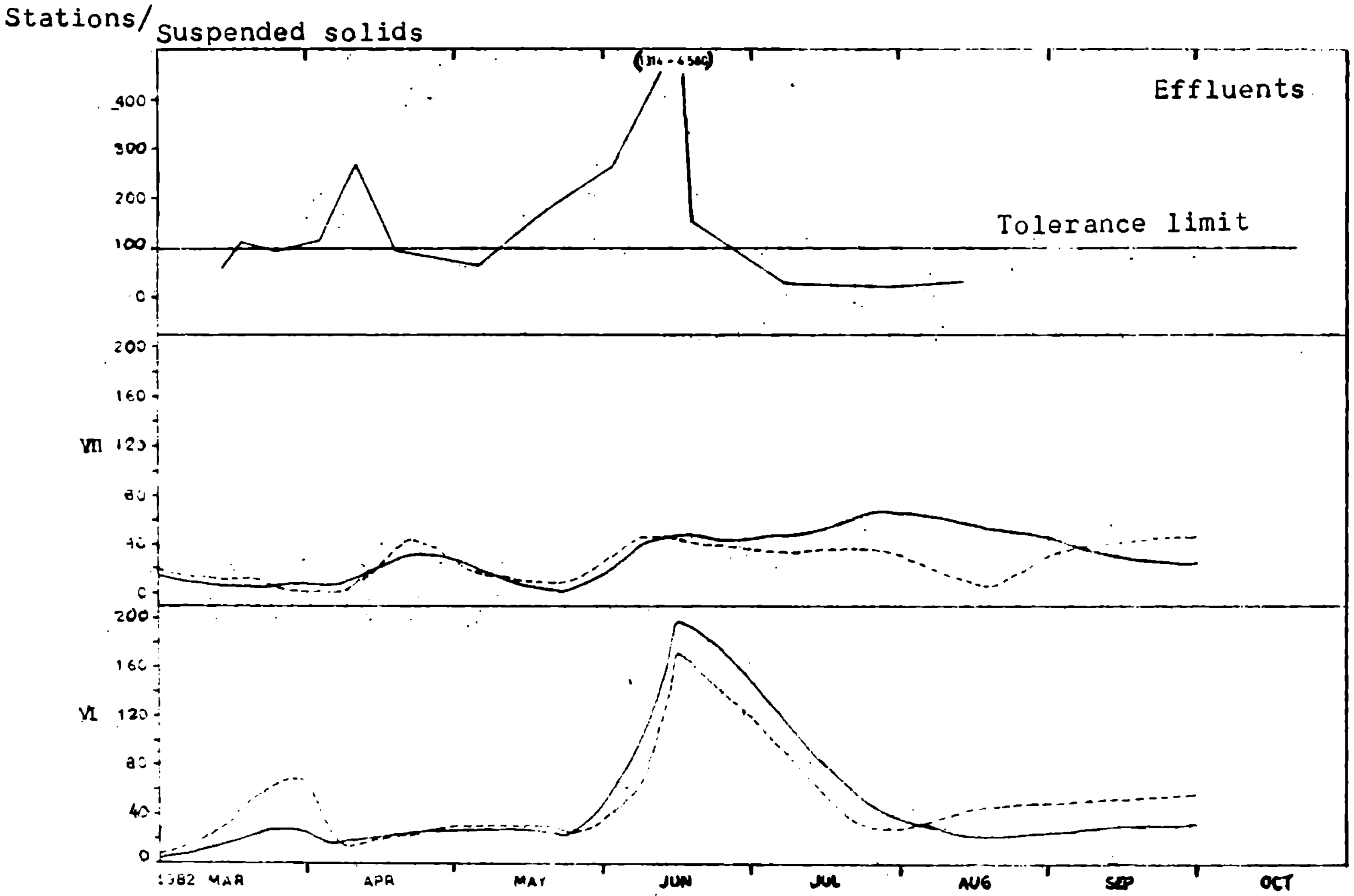



Fig. .17. Variation of Suspended solids (mg/l) at stations VI and VII during March 1982 to September 1982 and that of the effluents during 13th March 1982 to 13th August 1982 solids content. But the values are lower by about 20 mg/l at these stations from those observed at station IV. Station VII appears to be only slightly affected, with values fluctuating around 20-60 mg/l.

Samples of the effluents collected have indicated that the amount of suspended solids were higher than the tolerance limit of 100 mg/l (IS: 2490-1974). A peak value of 275 mg/l was noticed on 10.4.1982 and during the entire period between 10th May 1982 to 18th June 1982, the values were higher than the tolerance limit. During this period, very high values such as 4580 mg/l was observed on 15.6.1982 for the effluents discharged into the river. After 18th June 1982, the values came down near to 30 mg/l for the effluents.

c) Total organic carbon: The content of organic carbon in sediments is one of the important parameters connected with water quality studies in rivers and provides an estimate of the total organic matter, that is present on the river bed (organic matter = 1.724x organic carbon) (Riley 1970). The organic substances may be composed of humic acids, amino acids, hydrocarbons, lipids, lignins etc. Studies on the concentration of organic matter in the vicinity of the sources of pollution are helpful to identify the zones of pollution and partly to assess the adverse effects. The estimation of this parameter has proved to be useful in the study of diagenetic changes after the deposition of sediments containing organic matter. A few conclusions have been derived based on earlier studies (Emery 1967, Schubel 1968, Buckley 1972 and Schlesinger 1981).

1. Higher concentrations are observed in areas receiving sewage wastes or industrial effluents containing organic substances.
2. The content of organic carbon varies from a low value to more than 40%.
3. The total organic matter present in bottom sediments depend on grain size and rate of deposition.
4. Organic matter (or carbon) content is high in fine grain sediments coloured dark grey to black.
5. Higher amounts of organic matter tend to deposit in pools, outfall regions, curved portions of a river and restricted basins.
6. Heavy loads of organic matter deposited on river

bed rapidly utilizes dissolved oxygen for decomposition of organic matter and leads to the occurrence of anoxic conditions. This has deleterious effects on the benthic life and long term effects on quality of overlying water.

The results presented in Table 3 indicate that the river bed, mainly composed of coarse to very fine sand, practically contained little or no organic carbon (0-0.90%) until effluents were discharged. But the two pools [pool i near Vettikkattumukku Bridge and pool iii near station VII (Fig.4)], in which silt, clay and mud accumulated, higher amount of organic carbon (total) was observed (1.07-1.62%).

Increasing amounts of organic matter was observed consequent to the discharge of pulp-paper effluents since 13.3.1982. The upstream stations I and II retained their original character. Downstream stations IV, V and VI exhibited slight increase (0.17 to 1.45%) whereas station III' located near the outfall gave values ranging from 1.45 to 7.87%. The most important feature was the high values observed at pool i and iii (2.11 to 8.87%). Evidently suspended matter in effluents, rich in

Table 3

Results of investigation on Total Organic Carbon (%)

| Date \ Station | I | II | III | IV | V | VI | VII | III' | Pool (i) | Pool (iii) |
|---|---|---|---|---|---|---|---|---|---|---|
| 28.11.1980 | 0.14 | - | Nil | - | - | Nil | 0.90 | - | 1.07 | - |
| 25.2.1981 | Nil | 0.17 | 0.66 | - | - | - | 0.55 | - | 1.24 | - |
| 15.5.1981 | Nil | Nil | - | Nil | Nil | - | 0.59 | Nil | 1.14 | 1.38 |
| 19.6.1981 | - | Nil | - | - | Nil | Nil | 0.55 | - | 1.48 | - |
| 2.11.1981 | - | 0.35 | 0.17 | 0.14 | - | - | 0.69 | - | 1.62 | - |
| 16.12.1981 | Nil | 0.28 | - | Nil | - | Nil | 0.83 | Nil | 1.35 | 1.38 |
| 16.2.1982 | - | - | Nil | - | Nil | - | Nil | - | - | - |
| 17.3.1982 | Nil | Nil | - | - | 0.17 | - | 0.76 | 1.45 | 2.73 | - |
| 7.4.1982 | 0.17 | - | - | - | - | 1.45 | 1.17 | 1.66 | 2.11 | 2.31 |
| 22.5.1982 | Nil | Nil | - | - | 0.38 | - | 2.11 | - | 4.11 | - |
| 15.6.1982 | Nil | Nil | - | - | 1.24 | - | 2.35 | 7.87 | 8.87 | 6.69 |
| 7.7.1982 | 0.14 | Nil | - | - | 0.83 | - | 0.66 | - | 4.35 | 3.66 |
| 30.8.1982 | - | - | - | - | 0.14 | - | 0.55 | - | 2.17 | - |

organic carbon (pulp fibres, wood chips, paper bits etc.) settle in these pools and these locations are likely to become secondary sources for pollution in due course, though partial removal is expected during the annual monsoon flood period.

d) Mercury: Heavy metals have the characteristic property of being retained for prolonged periods in biological tissues (Friberg 1972, Stopford 1975). Their persistent presence and accumulation in these environments have attracted numerous toxicological studies (Swensson 1963, Underwood 1971, Diplock 1976). Metal toxicants are frequently noticed in water and air pollutants (eg.agricultural chemicals and food contaminants). Studies reveal that once metals are absorbed into human or animal body, they form stable metal complexes with sulphadryl groups and to a lesser extent with amino, phosphate, carboxylate and hydroxyl radicals of enzymes (Ochme 1978). The extent to which a system of the body will be affected depends on the selective metal-protein bonding. Generally, the digestive system is first involved during absorption of food and functions of the liver as the body filter and detoxifier are impaired. Another part of the body where storage occurs are the kidney glomeruli and tubular cells where considerable damage is often observed. Eventually the nervous system breaks down and the damage is permanent.

Recent studies reveal that inorganic mercury may be converted to methyl mercury by microbes in aquatic environments (Neville 1974, Holm 1975). Organomercury compounds, especially methyl mercury, accumulate in the muscle of fishes, swine etc (Hancock 1976). Goldwater (1972) is of opinion that alkyls are distinctly more toxic than most of the other organic or inorganic mercury compounds. The mercury toxicological standards were first placed as 'zero', but later, studies have led to the designation of certain limits (Passow 1961). Bakir, 1973 reports that the recommended safe-levels is non-accumulation of over 25 mg of methylmercury for an adult. The WHO/FAO standards recommend maximum daily levels of total mercury for adults as 0.71 mg/kg body weight and that for methylmercury as 0.48 mg/kg body weight or 0.02 to 0.05 ppm of the total diet (WHO, 1971).

Results of the analysis of total mercury in water are given in Table 4. The investigation prior to the discharge of effluents indicated that the content of mercury is $\gtrsim$ 0.0005 mg/l which lies very close to the

Table 4

Results of analysis of total mercury in river water

| Period or date | Upstream (Stns. I and II) mg/l | Outfall (Stn.III') (mg/l | Downstream (Stns.(IV-VI) mg/l | Murinjapuzha river mouth (Stn.VII)mg/l |
|---|---|---|---|---|
| April 1981 to mid-March 1982 | 0.0005 or less | 0.0005 or less | 0.0005 or less | 0.0005 or less |
| 16.3.1982 | 0.0005 | - | 0.0017 | - |
| 17.3.1982 | - | - | 0.0024 | 0.0013 |
| April and May 1982 | 0.0005 or less | 0.0013-0.0023 | 0.0008-0.0018 | - |
| 7.6.1982 | - | - | 0.0023 | - |
| 10.6.1982 | - | - | 0.0034 | 0.0017 |
| 15.6.1982 | 0.0005 | 0.05 | 0.047 | 0.0012 |
| Mid June to mid August 1982 | - | - | 0.0008-0.0013 | - |
| 6.1.1983 and 7.1.1983 | 0.0005 | 0.0016 | 0.0013 | 0.0012 |

tolerance limit of 0.0003 mg/l(IS: 7967-1976) for potable water. Observations on the content of total mercury in river water during the period of effluent discharges indicated that while upstream stations (I and II) retained their original status, locations (stations IV to VII) downstream of the outfall showed increased amounts of mercury which were well above the ambient values and tolerance limits. Higher levels of mercury concentration was first observed with the commencement of effluent discharges. On 16.3.1982 and 17.3.1982, the stations downstream of discharge point exhibited values nearly 3 times more than the previous readings, the concentrations were 0.0017 and 0.0024 mg/l respectively on these days. During the month of June, the concentrations gradually built-up corresponding to the increased discharges from the factory. On 7.6.1982, the downstream values were 0.0023 mg/l which further increased to 0.0034 mg/l by 10.6.1982. The detailed investigation on 15.6.1982 revealed the presence of very high amounts of total mercury in river water downstream of discharge point. The upstream values were once again confirmed as 0.0005 mg/l which was the ambient level observed throughout the investigation period. Near outfall (station III'), just after the mixing of effluents with river water, the concentration of total mercury was 0.05 mg/l. This value is greater than the tolerance limit for water used for bathing, recreation and fish culture by an order of magnitude 2. The river (0-5km ) downstream of the outfall exhibited concentrations around 0.047 mg/l and at river mouth (Murinjapuzha) lower values around 0.0012 mg/l were observed. The concentration of mercury decreased gradually consequent to the shutdown of the newsprint factory in mid-August. The factory on resumption of production started discharging effluents into the river by late December 1982. On 6.1.1983 and 7.1.1983, concentrations of mercury in water, higher than the ambient values were again observed:0.0013 to 0.0016 mg/l in the vicinity of outfall. A steady build up of this parameter in the river water was not observed due to the intermittent breaks in the working of the factory.

The presence of higher concentrations of mercury in the river environment is conclusively attributed to the discharge of newsprint factory effluents. The study reveals a steady background level of 0.0005 mg/l or less of total mercury in river water in the section of the river investigated. The presence of higher concentrations of mercury is only observed at the outfall and locations downstream since the discharge of effluents. The concentrations ranged from 0.0013 to 0.05 mg/l in river water.

The maximum tolerance limits for mercury in water used for bathing, recreation, shellfish and commercial fish culture, salt manufacture and harbour water after receiving discharges is given in IS: 7967-1976 as 0.0003 mg/l. Another reference is made in IS: 2490-1974 on tolerance limits for industrial effluents discharged into inland surface water, where the maximum concentration of mercury is fixed as 0.01 mg/l. The same limit is prescribed in IS: 7968-1976 on industrial effluents discharged into marine coastal areas. The tolerance limit of 0.0003 mg/l prescribed in IS: 7967-1976 is of utmost importance in the present context, because water from the river is used for purposes such as cooking, drinking and utilized also for other domestic requirements. The ambient value, 0.0005 mg/l or less, lies close to the recommended tolerance limit of 0.0003 mg/l. Hence any addition of mercury into this fluvial environment is to be regarded as a grave health hazard. The values obtained since the

# CHAPTER 5

# PHYSIOGRAPHY AND FLOW CHARACTERISTICS

HAPTER 5

# PHYSIOGRAPHY AND FLOW CHARACTERISTICS

## .1. Introduction

Studies on the fluvial geomorphology and dynamics ave in recent years attained importance in the context f increased human interference by way of resource xploitation and rapid urbanisation. Pioneer works on iver dynamics and connected aspects such as geological rocesses, bank erosion problems and landscape geomorphology ave been conducted by Powell 1875, Davis 1909 and Leopold 962 and 1964. The physical character of a river is closely nterlinked with the landscape and its watershed and is an ntegral part of the geological and meteorological conditions revailing over the entire basin area. Leopold 1953, horley 1962 and Wolman 1964 maintain the concept that a iver and its landscape along with the interrelated factors hich affect the stream flow and sediment transport onstitute a 'hydraulic system', which instantly responds o any alterations, man-made or otherwise.

The geology of the Muvattupuzha river basin, ongitudinal section of the river, the stream flow and ts dependence on rainfall and influence of tides on river ischarges are discussed in this chapter. The water resources management programmes relating to this river are also discussed, projecting the future implications of these ongoing projects on the river system.

5.2. The geological description of the region

The topographical classification of Muvattupuzha basin is as follows: (1) High lands and hills covered with forest on the eastern boundary (2) Mid-lands of gently rolling fertile country and (3) Low lands consisting of flat deltaic region interconnected by backwaters on the western side. The area generally enjoys tropical humid climate of oppressive summer and seasonal rainfall. The altitude varies from 1093.6 m to 1.5 m (M S L ).

The Muvattupuzha Valley Irrigation Project (MVIP) (1971) gives a vivid description of the geological aspects of this basin. Based on the geological formations, the region is divided into three main belts, which are oriented more or less in the North-South direction: (1) A belt of crystalline rocks (2) A belt of residual laterite and (3) A narrow belt of warkalli beds.

The eastern region of hilly lands are embedded with rocks of types (i) The precambrains (ii) The tertiaries and (iii) The recent to subrecent sediments (Paulose 1968).

black mica; at certain places garnet is also found associated with these rocks (Murthy 1976). The general colour is grey or greyish white and is of medium to coarse grain size. The western parts of the basin is covered with extensive quantities of recent sediments. Graphite occurs between Thodupuzha and Muvattupuzha which has undergone laterisation. The soil of eastern portions are rich in organic matter and the adjacent western sector of the basin is formed of laterite and gravel. The formation of warkalli beds consisting of a succession of variegated clay and sandstone and at times lignite materials are also noticeable (Paulose 1968). The sandy soil is generally of poor fertility covering the western most parts and where low lying fields are present, clay is generally found mixed with soil. The river basin does not lie in the seismic zone and no major earthquakes are reported.

## 5.3. Sand sample analysis

Bottom sediment samples were collected using a van Veen grab from all stations for the determination of size fractions. The collection dates were as following: 28.11.1980, 10.3.1981, 19.6.1981, 16.12.1981, 16.2.1982 and 15.6.1982. The results are presented in table 5 as weight percentage for each mesh size at stations I to VII and pools

Table 5. Size composition of river bed samples (weight percentage)

| Station | Pebbles >4mm | Granule 4-2mm | Very Coarse sand 2-1 mm | Coarse sand 1-0.5 mm | Medium sand 0.5-0.25 mm | Fine sand 0.25-0.125mm | Very fine sand 0.125-0.063mm | Silt <0.063mm |
|---|---|---|---|---|---|---|---|---|
| | | | | 28.11.1980 | | | | |
| I | 4.50 | 4.26 | 9.02 | 23.14 | 54.37 | 4.53 | 0.18 | Nil |
| II | Nil | 3.47 | 9.72 | 33.78 | 49.98 | 2.89 | 0.36 | Nil |
| III | 1.89 | 3.50 | 8.43 | 22.42 | 55.49 | 7.67 | 0.56 | Nil |
| IV | 3.58 | 3.37 | 12.02 | 20.40 | 50.20 | 10.19 | 0.24 | Nil |
| V | 0.20 | 2.94 | 10.33 | 21.50 | 47.34 | 17.31 | 0.36 | Trace |
| VI | 0.96 | 2.23 | 8.73 | 23.51 | 52.69 | 11.41 | 0.47 | Nil |
| VII | Nil | Nil | 0.16 | 0.19 | 21.60 | 3.30 | 73.75 | 1.00 |
| Pool I | Nil | Nil | 0.28 | 2.58 | 3.54 | 10.43 | 42.19 | 40.98 |
| | | | | 10.3.1981 | | | | |
| I | Nil | 0.58 | 11.74 | 25.86 | 37.00 | 18.56 | 6.26 | Nil |
| II | 0.16 | 3.99 | 17.48 | 25.10 | 30.35 | 20.53 | 2.40 | Nil |
| III | 0.08 | 2.06 | 8.36 | 18.89 | 39.20 | 27.39 | 4.01 | Trace |
| IV | 0.30 | 2.69 | 18.63 | 21.04 | 35.50 | 17.86 | 3.97 | Trace |
| V | 0.13 | 2.39 | 10.38 | 16.30 | 40.86 | 26.78 | 3.16 | Nil |
| VI | 2.30 | 3.30 | 8.43 | 13.73 | 37.97 | 25.62 | 8.64 | Trace |
| VII | Nil | Nil | 0.10 | 1.08 | 20.18 | 10.90 | 66.64 | 1.10 |
| | | | | 19.6.1981 | | | | |
| I | 5.65 | 7.06 | 31.40 | 32.39 | 18.24 | 4.06 | 1.20 | Nil |
| II | 4.18 | 7.88 | 36.45 | 29.84 | 17.44 | 3.29 | 0.92 | Nil |
| III | 6.62 | 12.50 | 28.29 | 27.93 | 18.63 | 5.42 | 0.61 | Nil |
| IV | 3.03 | 15.63 | 38.42 | 24.40 | 14.65 | 3.07 | 0.80 | Nil |
| V | 4.08 | 23.64 | 58.25 | 5.43 | 4.22 | 3.98 | 0.40 | Nil |
| VI | 6.99 | 16.64 | 43.36 | 19.70 | 6.93 | 3.47 | 0.91 | Nil |
| VII | 2.26 | 21.95 | 40.05 | 17.35 | 14.90 | 3.52 | 0.97 | Nil |
| Pool I | 1.14 | 4.76 | 10.88 | 14.48 | 13.69 | 14.80 | 21.96 | 18.29 |

Cont.....

| Station | Pebbles >4mm | Granule 4–2mm | Very Coarse sand 2–1 mm | Coarse sand 1.0.5 mm | Medium sand 0.5–0.25 mm | Fine sand 0.25–0.125 mm | Very fine sand 0.125–0.063 mm | Silt <0.063 mm |
|---|---|---|---|---|---|---|---|---|
| | | | | 16.12.1981 | | | | |
| I | 3.93 | 4.47 | 7.87 | 22.71 | 54.92 | 5.96 | 0.14 | Nil |
| II | Nil | 3.66 | 10.63 | 34.14 | 43.39 | 2.50 | 0.46 | Nil |
| III | 0.36 | 3.15 | 10.04 | 24.02 | 50.00 | 11.98 | 0.45 | Nil |
| IV | 0.32 | 3.83 | 5.84 | 11.76 | 49.69 | 27.39 | 1.17 | Nil |
| V | Nil | 0.32 | 5.73 | 20.96 | 51.59 | 16.59 | 2.81 | Nil |
| VI | 3.36 | 5.09 | 9.22 | 14.69 | 52.06 | 13.96 | 1.63 | Nil |
| VII | Nil | 0.69 | 0.42 | 2.34 | 7.66 | 13.02 | 66.47 | 9.40 |
| Pool i | Nil | Nil | 1.09 | 3.48 | 13.63 | 20.26 | 21.81 | 39.74 |
| Pool iii | Nil | Nil | Nil | 4.64 | 6.34 | 10.76 | 26.77 | 51.49 |
| | | | | 16.2.1982 | | | | |
| I | 1.51 | 1.73 | 10.65 | 16.73 | 43.93 | 22.14 | 3.31 | Nil |
| II | 1.06 | 1.83 | 6.59 | 22.07 | 39.73 | 25.62 | 3.08 | Nil |
| III | 1.72 | 4.61 | 14.09 | 15.51 | 36.78 | 24.87 | 2.42 | Nil |
| IV | 1.77 | 5.87 | 11.22 | 17.45 | 36.12 | 24.96 | 2.61 | Nil |
| V | 3.22 | 4.40 | 13.74 | 15.03 | 39.66 | 19.39 | 4.56 | Trace |
| VI | 0.76 | 2.73 | 13.53 | 17.53 | 38.12 | 22.10 | 5.19 | Trace |
| VII | Nil | Nil | 0.43 | 12.64 | 22.68 | 11.94 | 67.64 | 4.66 |
| | | | | 15.6.1982 | | | | |
| I | 3.76 | 24.14 | 58.80 | 6.19 | 3.70 | 2.69 | 0.72 | Nil |
| II | 3.21 | 8.44 | 48.03 | 29.39 | 8.35 | 2.02 | 0.56 | Nil |
| III | 4.28 | 25.22 | 56.24 | 5.24 | 3.84 | 2.97 | 2.21 | Nil |
| IV | 5.36 | 10.99 | 52.99 | 17.64 | 8.95 | 3.19 | 1.04 | Nil |
| V | 3.72 | 25.70 | 57.40 | 5.50 | 3.60 | 2.40 | 1.62 | Nil |
| VI | 5.75 | 16.44 | 36.83 | 28.39 | 6.50 | 3.49 | 2.13 | Nil |
| VII | 4.33 | 25.33 | 57.18 | 5.48 | 4.13 | 2.74 | 0.81 | Nil |
| Pool i | Nil | 3.67 | 10.39 | 11.26 | 14.05 | 15.66 | 11.64 | 33.41 |
| Pool iii | Nil | 1.23 | 6.36 | 18.56 | 23.15 | 17.71 | 16.94 | 14.64 |

pools are given in figure 4). The sand sample was coned and quartered. About 100 gm collected from opposite quadrants was washed with distilled water until a clear supernatant liquid was obtained. The dried sample was mechanically sieved with the set of sieves and percent composition of each size fraction was tabulated.

The results of size analysis indicate that for periods other than monsoon, major portions were composed of coarse (20-25%) and medium sand (40-50%) (1-0.5 mm and 0.5-0.25 mm size respectively) at all stations except station VII. Located near river mouth, the station VII contained medium size (20%), large amounts of very fine sand (65-70%) and traces of silt (5%). The collections during monsoon months at stations I to VII showed marked variation when higher percentage (40-50%) of very coarse sand (1-2 mm size) are noticed along with 20-25% of coarse sand and medium size sand, 4-18%. During other periods, the fraction of very coarse sand was only 8-12% at the above stations.

The results of size analysis of bottom samples from pools i and iii indicate the presence of large amount of matter of size less than 0.063 mm (silt and clay). Percentage wise, the estimation showed 15-30% during monsoon and 40-50% during other periods. About 15-20% of very fine sand was also found in pools during monsoon whereas during other times, the percentage composition of this size fraction went upto nearly 40%.

The river bed at Velloor was mainly composed of coarse to medium size sand for most of the period of the year. The river mouth at Murinjapuzha contained higher percentage of very fine sand. During monsoon season, larger size sand fractions were noticed downstream of Velloor when relatively more amount of very coarse sand was noticed along with coarse sand. The granule size fraction (4-2 mm) accounts for 15-25% during this period. It is inferred that the heavy monsoonal discharge carries away finer particles and part of the medium size fraction. However, the pools retained some part of these fractions even during monsoon period.

5.4. The longitudinal section of Muvattupuzha river

The longitudinal section of Muvattupuzha river compiled during the 1971 survey connected with MVIP, 1971 report gives the description of the topographical features of the river. Values were checked during the 1979 Malankara reservoir survey (MVIP, 1979).

The profile of the longitudinal section of Muvattupuzha river is given in figure 18. The survey

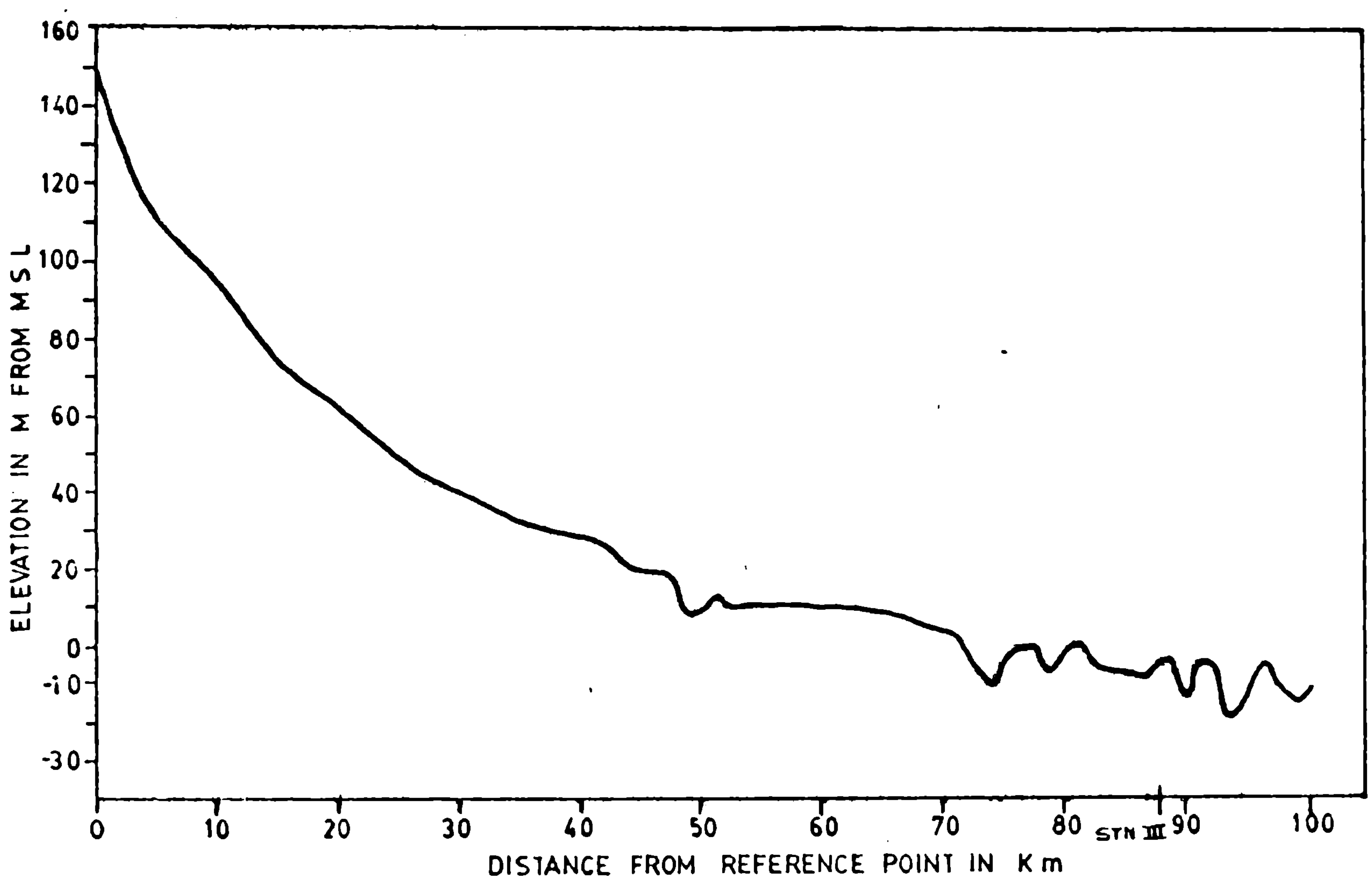



Fig.18. LONGITUDINAL SECTION OF MUVATTUPUZHA RIVER.

(Reference point is at Moolamattom)

bed level was +148.34 m (w.r.t. M S L ) and the river bed was predominantly covered with pebbles. From Moolamattom to Thodupuzha (20.5 km) the bed level dropped to +61.11 m and at Muvattupuzha (45 km) the level was +20 m. Slightly downstream a deep pool of +8.50 m was noticed. A flat bed (+10 m) was next detected extending for 15 km (53 to 67 km from reference point). Thereafter, the profile indicated a gradually sloping bed and at Piravom (78 km) the bed level was more or less equal to M S L. A noted feature was a deep pool of -10.6 m at 74.82 km. Another pool of depth -6.70 m was noticed at 79.65 km. The bed level rose to +1.70 m and thereafter sloped down to a pool -7.80 m at Velloor railway bridge (86.9 km). The level again rose to -3.90 m at a distance of 88.9 km from reference station and steepened down to another deep pool, -13.00 m at 90.5 km. This pool is just before Vettikkattumukku (90.9 km) where the bed level is -6.00 m. In Ittupuzha river, 94.5 km downstream from reference point, a pool of depth -19.50 m was also observed. In Murinjapuzha river too, a deep pool of depth -16.62 m was observed at Enadi (95.7 km). A relatively shallow pool (-13.93 m) was also noticed inside the river mouth (99.76 km). The interspace between these pools indicated bed levels of -5.00 m. The river (Murinjapuzha branch) joins Vembanad lake, 100.56 km from reference station, at bed level -10.00 m. The location of pools and their depths have been checked during the present investigation and was found to be more or less the same as reported in the above survey.

Three pools were observed between Muvattupuzha and Velloor at 48, 74.82 and 79.65 km distances from reference point. The only place where a flat bed was observed was between 53 and 67 km. One of the main features revealed from the study on longitudinal section of this river was the presence of three deep pools, downstream of Velloor. They are located at 90.5 , 94.5 and 95.7 km from the reference point (Moolamattom) with depths around -13.00, -19.50 and -16.62 m (M S L ) respectively. These pools serve as depository regions for suspended matter. Around the vicinity of Velloor, there was a slight rising slope which may have some relevance in connection with the dispersion of effluents discharged at 88.06 km point.

The portion of the river,downstream of Velloor lies at a level lower than MSL and some parts lie lower than the level of the adjoining estuary (-10 m). Lower reaches of the river used to be subjected to intrusion of saltish water during dry season from the adjoining backwaters, prior to

5.5. Structure of Muvattupuzha river

Figure 18 indicates the longitudinal profile of the river bed from Moolamattom. For a distance of 44 km from this place, the river bed maintains a steadily decreasing slope. The upper most parts of the river bed is steep, comparatively narrow and shallow. Further downstream, the width and depth of the river increase . Beyond 44 km, the river enters low lying lands and the bed level gradually goes down to M S L. A flat bed is noticed with an elevation of +10 m for a short stretch of the river (53 to 67 km) and further downstream, the river bed attains the level of M S L or even levels lower than M S L. A few deep pools are noticed in these low lying regions.

5.6. Rainfall

Rain gauges installed at Muvattupuzha, Thodupuzha, Vaikom and Velloor (figure 19) provide information on the rainfall in the Muvattupuzha river basin. The rainfall data was obtained from the 'Surface Water Year Book' compiled by the Water Resources Division, P.W.D. Peechi. Figure 20 gives the consolidated data for 45 years (1927-1971) of average monthly rainfall in mm at Muvattupuzha, Thodupuzha and Vaikom. Annual rainfall for the period 1965-1979 at the four stations is indicated in table 6. This table also

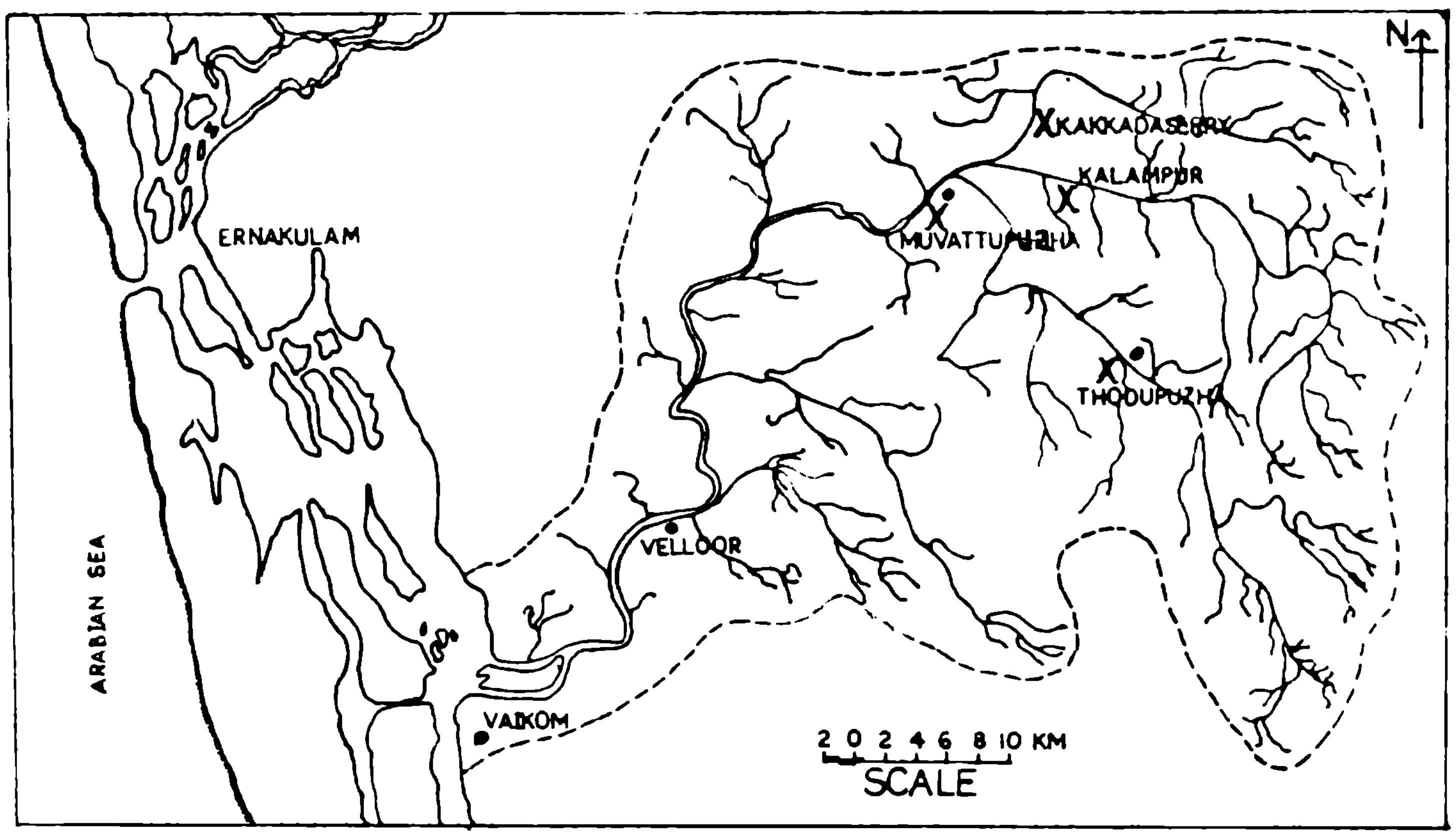



Fig.19. Map showing locations of rain gauges (•) and river discharge gauges (X)

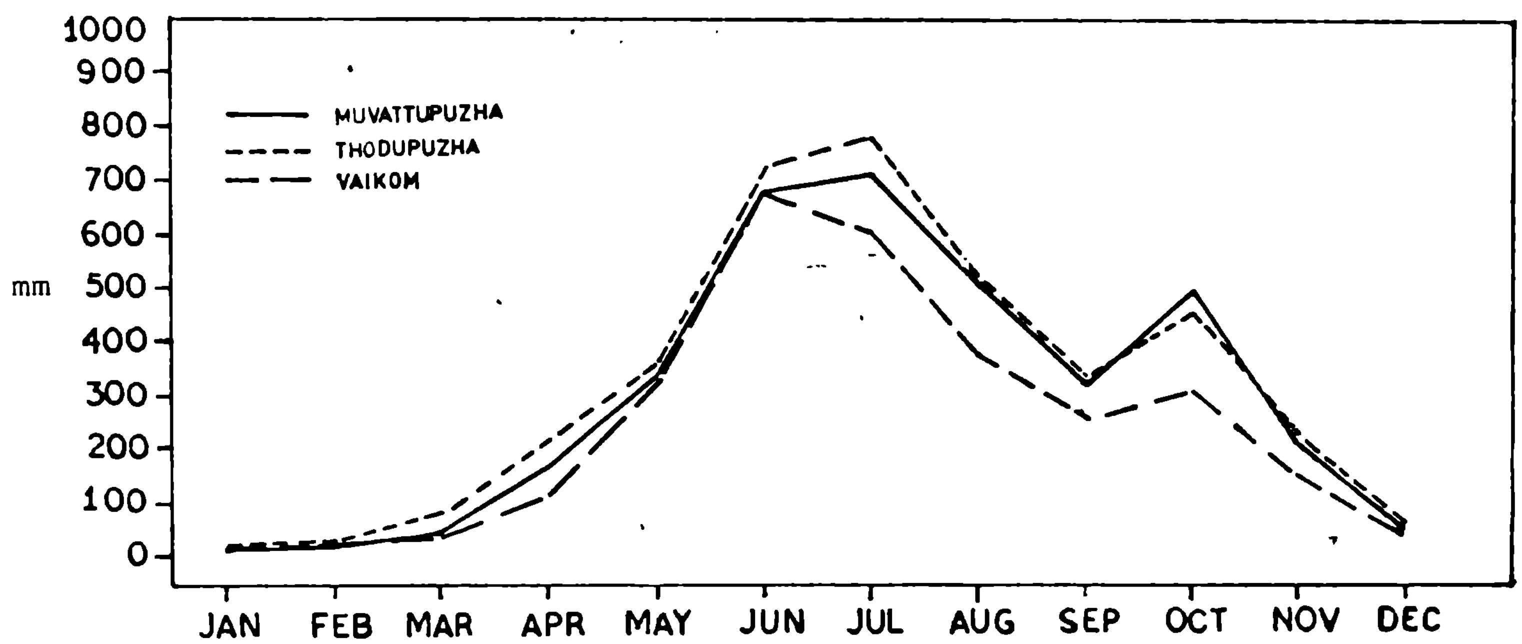



Fig. 20. Average monthly rainfall for 1927-71 at three stations

contains average annual rainfall at three stations for 53 years (1927-1979). Figures 21 a,b,c illustrate the deviation of rainfall from the average value at these stations.

During June and July, the basin area enjoys heavy rains ( ≈ 700 mm) whereas January and February are lean months ( ≈ 22 mm) (figure 20). The rainfall gradually increases from March (60 mm) to May (340 mm) and thence to maximum value during July (750 mm). The rainfall decreases from July till September (300 mm). A secondary maximum is reached during October (425 mm) and thereafter the rainfall decreases to a minimum during January. In general, the eastern parts of the river basin receive more rainfall than the western parts. This may be due to the topography of the region, with highlands of hills and forests on the eastern sector and low lying fields dominating the western sector.

Annual rainfall data (table 6) for the period 1965-1979 at four stations show that the basin received widespread rains ranging from 316 mm to 4623 mm during the period. Relatively low rainfall occurred along the western boundary of the river basin (300-2500 mm) whereas the hilly and high altitude eastern parts received moderate to heavy

Table 6. Annual rainfall for the period 1965-79 and average value for the period 1927-79, in mm

| Station / Year | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 | Average for years |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Muvattupuzha | 2115 | 2514 | 2864 | 3747 | 2990 | 2802 | 4346 | 3004 | 2647 | 2424 | 4405 | 4150 | 3649 | 3964 | 3318 | 3369 |
| Thodupuzha | 2841 | 3953 | 2516 | 4233 | 3513 | 3978 | 4102 | 3958 | 3325 | 4309 | 4623 | 3518 | 3873 | 4526 | 3684 | 3959 |
| Vaikom | 2132 | 2422 | 2932 | 3407 | 2918 | 3087 | 2846 | 1182 | 981 | 2918 | 3776 | 2107 | 3282 | 3612 | 3210 | 2674 |
| Velloor | 316 | 473 | - | 401 | 1516 | 503 | 1046 | 1083 | 1380 | 1618 | 2090 | 3637 | 1761 | 2112 | 1403 | - |

Figures 21 a,b,c show the deviation of amount of rainfall from the average value (53 year period) of 3369, 3959 and 2674 mm at Muvattupuzha, Thodupuzha and Vaikom stations respectively for the period 1965-1979. Maximum variations occurred during 1973-1975 at Vaikom (-1692 to +1102 mm) compared to the other two stations. The years 1964 and 1965 followed by 1972 and 1973 were drought years (deficit values ≈ -1000 mm). The year 1981 witnessed an intense spell of rains within a short time, but rest of the months were exceptionally dry. 1982 was another year when drought conditions prevailed resulting in power-cut (late south-west monsoon) (processed rainfall data for 1980-1982 not available). The intermediate years usually enjoyed moderate to heavy rainfall (surplus ≈ 500 mm) with the exception of one or two years. The preceding years just before drought had exhibited heavy rainfall which is evident during 1970-1971 and 1978-1979 (≈ +800 mm). The above variations in rainfall and its distribution had influenced the river discharge considerably which is subsequently discussed.

## 5.7. River discharge

The long term river discharge data is available in the Year Book on Surface Waters, Vol. II, published by the Water Resources Division, P.W.D. The data pertaining to

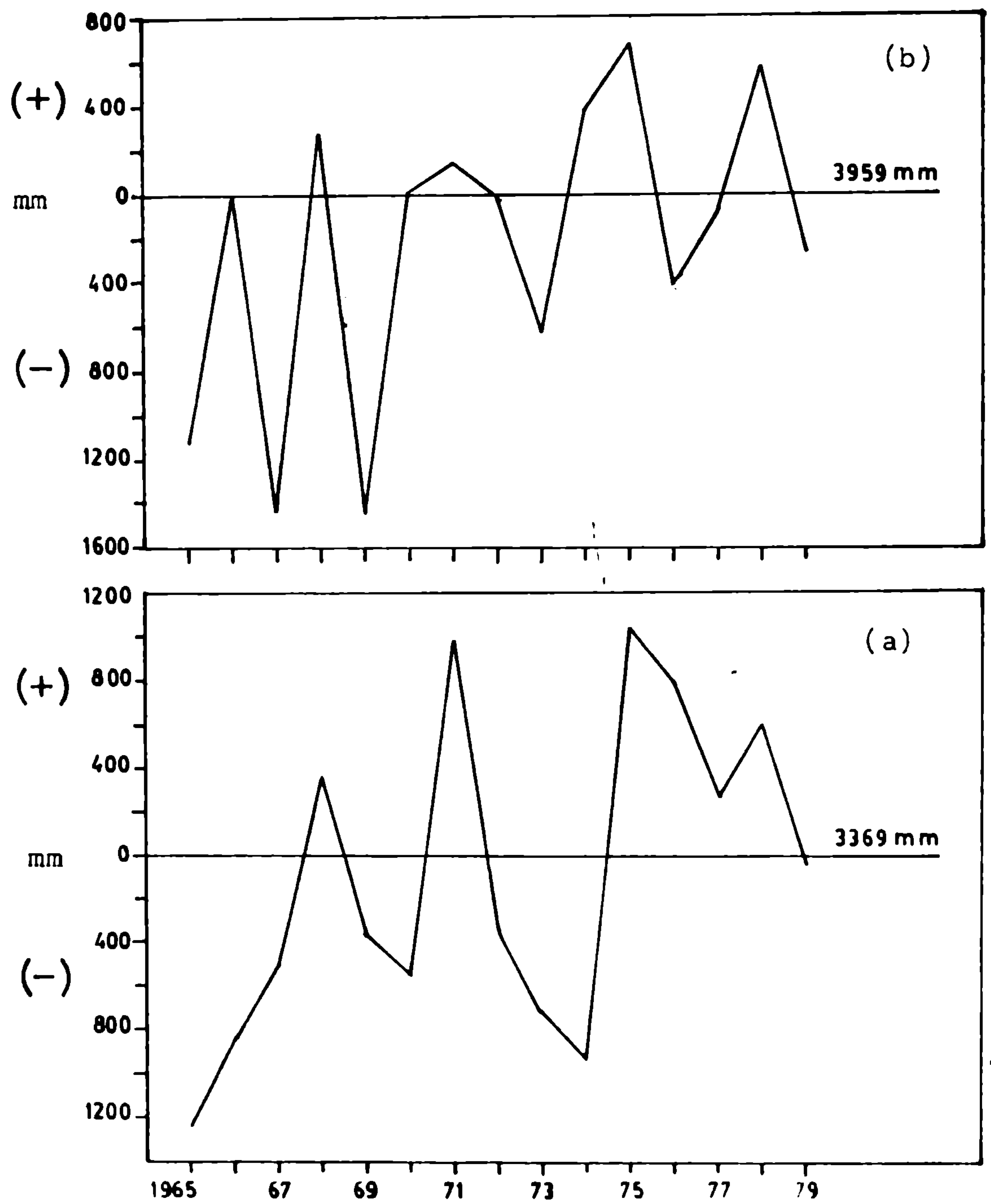



Fig.21. Deviations of annual rainfall from long term averages at Muvattupuzha (a) and Thodupuzha (b)

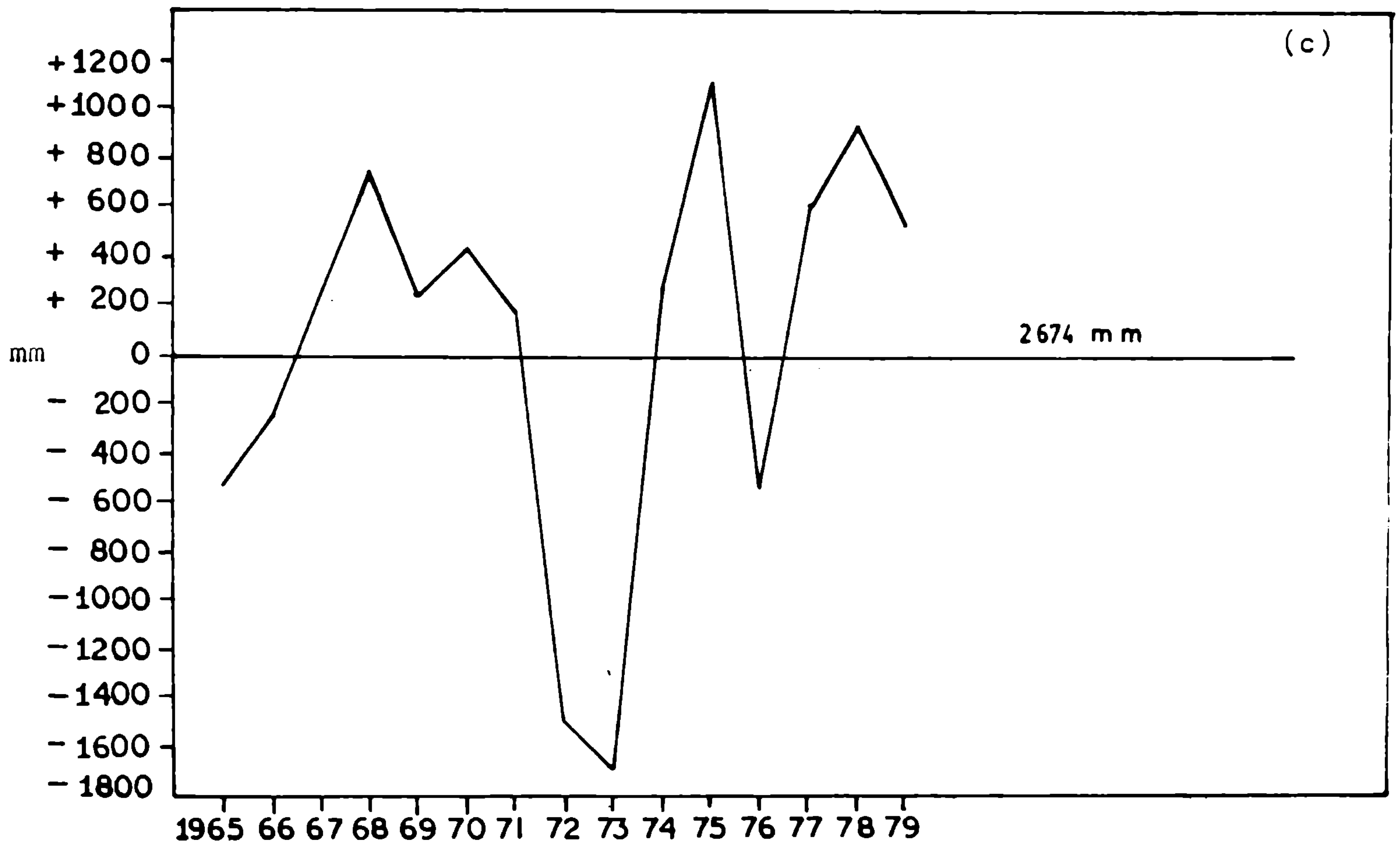



Fig.21. Deviations of annual rainfall from long term averages at Vaikom (c)

Muvattupuzha river and its tributaries are compiled in tables 7,8 and figures 22 a,b,c,d and 23. The data was computed from the daily discharge readings which was the mean of three gauge and float readings taken at 8 a.m., 12 noon and 4 p.m.

Table 7 illustrates the long term monthly averages for river discharge in million $m^3$ ($Mm^3$) for stations namely Muvattupuzha, Kalampur in Kaliyar Ar., Kakkadaserry in Kothamangalam Ar. and at Thodupuzha in Thodupuzha Ar. (figure 19). The results indicated that at Muvattupuzha station, which is located downstream of other stations, the minimum discharge occurred during February and March ($\approx$ 15 $Mm^3$/month) and maximum in July ($\approx$ 900 $Mm^3$). A slight increase was noticed in October ($\approx$315 $Mm^3$) when discharge of preceding month (September) was $\approx$ 285 $Mm^3$ and that of the following month (November) was ($\approx$ 180 $Mm^3$). This secondary peak was also noticed at Thodupuzha station [September (90 $Mm^3$) - October (118 $Mm^3$) - November (80 $Mm^3$)], whereas the other two stations (Kalampur and Kakkadaserry) showed gradually decreasing discharges. The peak discharge registered at Thodupuzha, was $\approx$ 350 $Mm^3$ in July while discharge in February-March was only around 5 $Mm^3$/month. The

Table 7. Average Monthly Discharge in Million $m^3$ ($Mm^3$)

| Station | Period | No. of years | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Muvattupuzha | 1965-1975 | 11 | 23.48 | 18.13 | 13.82 | 24.26 | 67.19 | 389.40 | 916.61 | 673.99 | 286.06 | 315.66 | 180.02 | 72.39 |
| Kalampur in Kaliyar | 1968-1981 | 14 | 10.41 | 6.57 | 6.38 | 12.16 | 33.45 | 203.11 | 397.98 | 278.05 | 140.30 | 125.39 | 97.94 | 28.96 |
| Kakkadaserry | 1972-1981 | 10 | 13.62 | 12.80 | 8.45 | 10.51 | 24.34 | 116.82 | 247.94 | 189.70 | 97.50 | 82.12 | 71.34 | 26.83 |
| Thodupuzha | 1972-1976 | 5 | 6.83 | 4.68 | 4.78 | 10.48 | 21.30 | 114.41 | 351.40 | 309.26 | 90.67 | 117.92 | 80.51 | 31.29 |

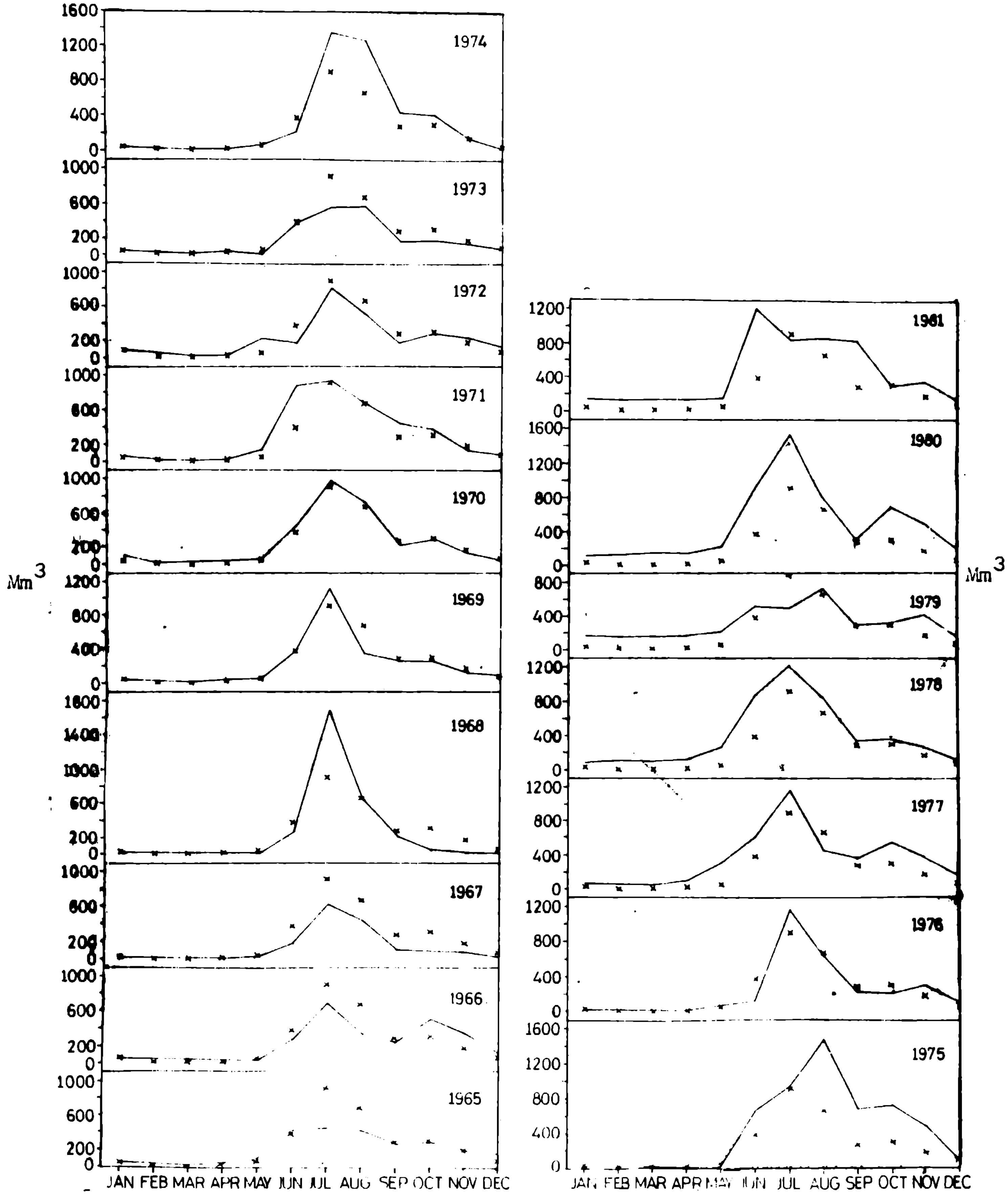
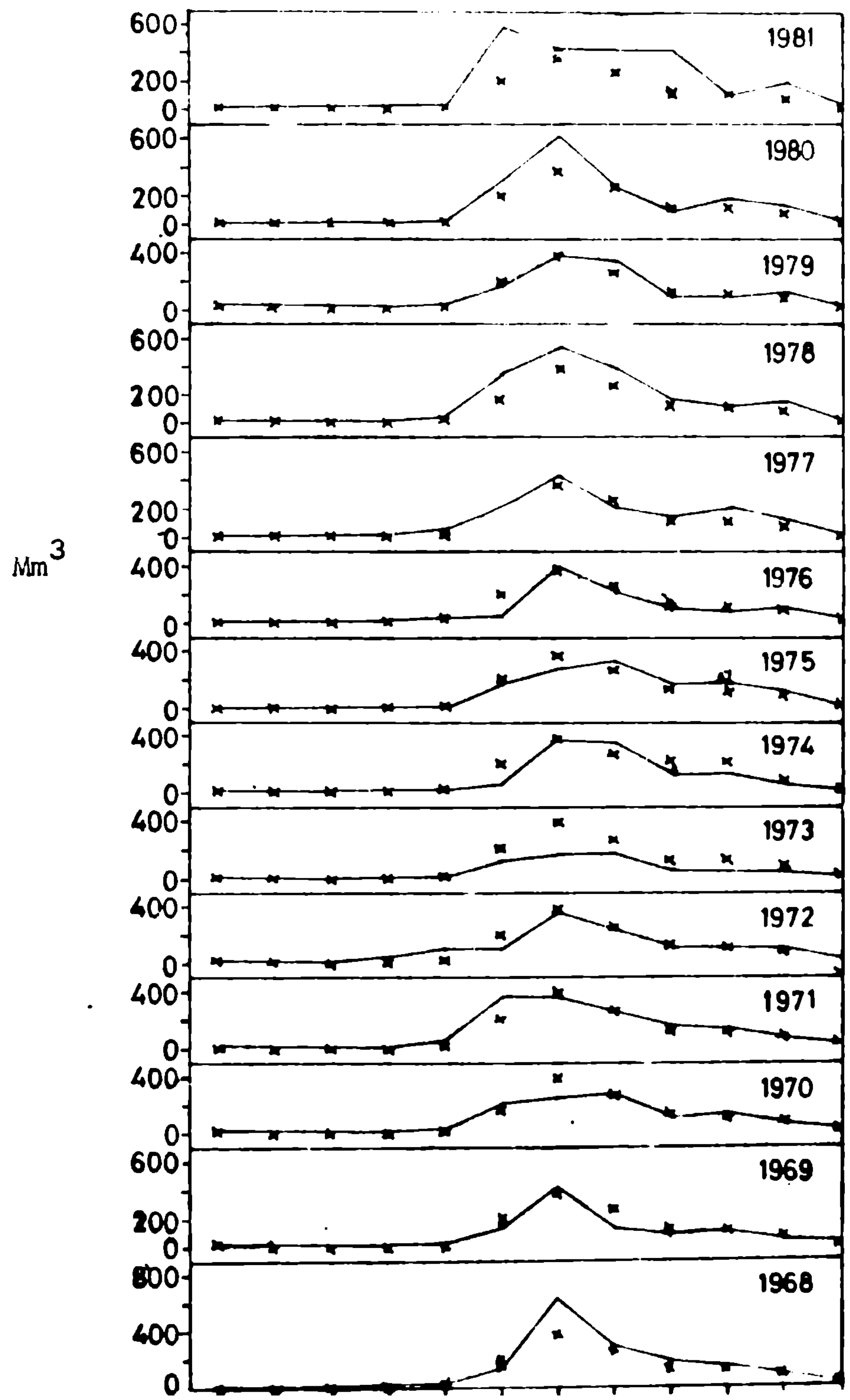



Fig.22a. Monthly discharges at Muvattupuzha station (the mark 'x' indicates long term averages)



Mm3
600
200
0
1981
600
200
0
1980
400
0
1979
600
200
0
1978
600
200
0
1977
400
0
1976
400
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1975
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1974
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1972
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1971
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1970
600
200
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1969
800
400
0
1968

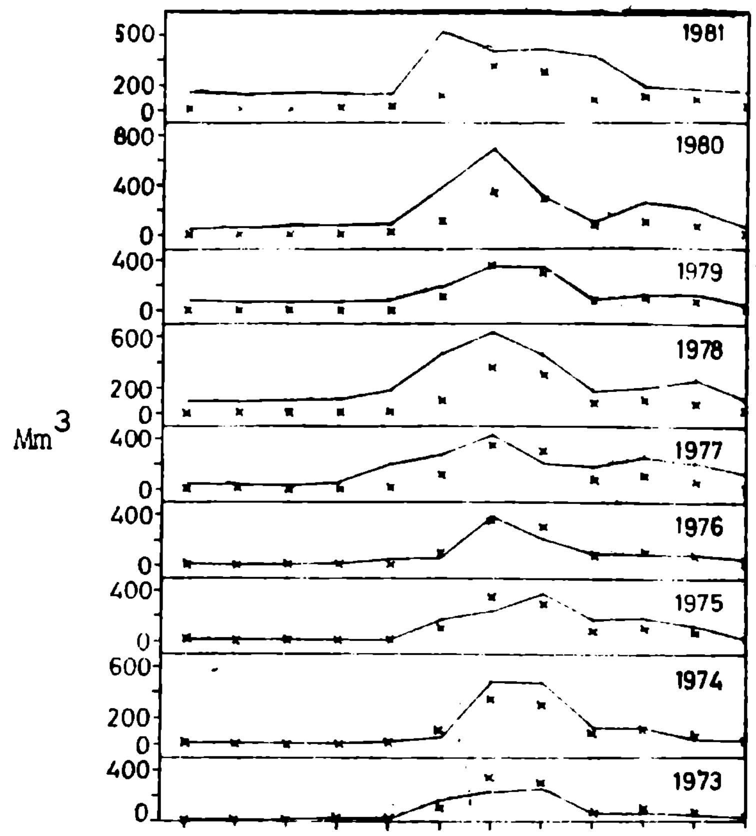



Fig.22d. Monthly discharges at Thodupuzha station

(The mark 'x' indicates long term averages)

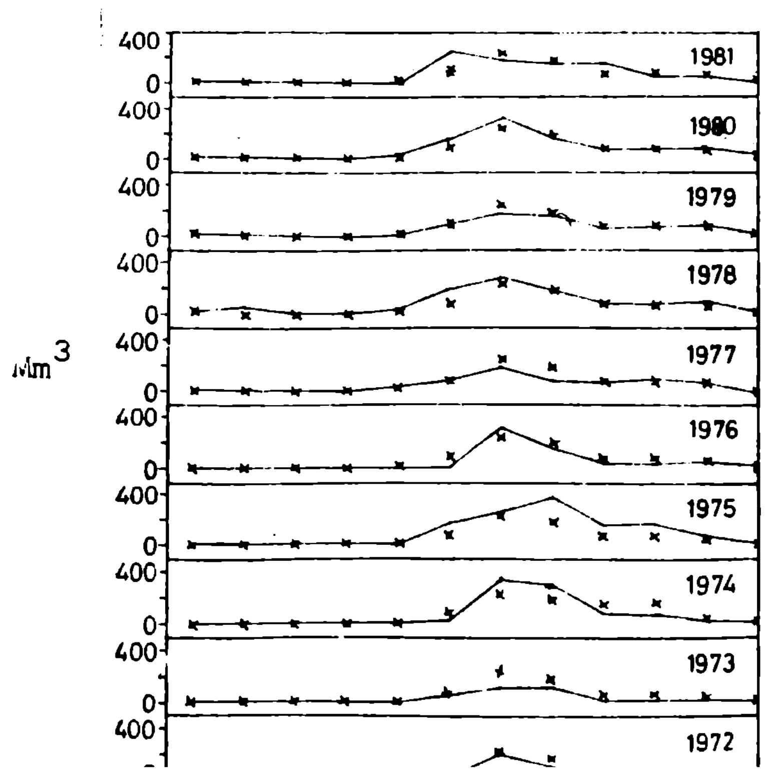



Fig.22c. Monthly discharges at Kakkadaserry in Kothamangalam Ar.

Kothamangalam Ar. were also significant with peak discharges around 400 $Mm^3$/month and 250 $Mm^3$/month respectively. It may however be noted that summation of discharges of the three tributaries did not tally with the final discharge observed at Muvattupuzha, largely because of the topographical features of the region and the numerous outlets for agricultural purposes.

The long term averages are marked 'x' in figures 22 a,b,c and d to enable comparison with monthly discharge values at the above stations for various years. Monthly discharge data at Muvattupuzha station for the period 1965 to 1981 (figure 22a) indicate close resemblance with the rainfall. Another significant feature noticeable from the graph is the higher discharges since 1977, consequent to the commissioning of Idukki dam and power station at Moolamattom by late 1976. The discharges did not show any significant deviation from averages during January to May and in November and December till the year 1976, but discharges during June to October were largely influenced by rainfall. During June to October, for the years 1965, 1966 and 1967 the discharges were slightly lower than averages; for years 1968 to 1971, slightly higher values were noted corresponding to the amount of rainfall. The years 1972 and 1973 registered low river discharges. During the years 1974, 1975 and 1976, the river discharge equalled or were higher than averages for the period July to December (October 1976 is an exception).

Since 1977, the river discharge significantly increased by $\approx$ 100 $Mm^3$/month and this is clearly evident from the results during January to May at this station. The river basin also received good amount of rainfall during monsoon months resulting in high river discharges during the years 1977-1981. Figures 22 b and c indicate the monthly discharge at stations Kalampur in Kaliyar Ar. for the period 1968 to 1981 and at Kakkadaserry in Kothamangalam Ar. for the period 1972 to 1981 in $Mm^3$ respectively. Discharge during January to April was less than 10 $Mm^3$/month at both these stations, whereas during May, it was 30 $Mm^3$. With the event of monsoon, the discharge reached nearly 400 $Mm^3$ in July. Comparing between these two tributaries, the Kaliyar Ar. discharges slightly exceed that of Kothamangalam Ar.

Figure 22 d illustrates the discharge conditions at Thodupuzha station in Thodupuzha Ar. for the years 1973-1981. Study of flow conditions at this station is of importance in view of the tail race waters being directed along this tributary since late 1976. The river discharge during dry season was less than 10 $Mm^3$/month and during wet season, it enhanced to 300 $Mm^3$/month prior to the introduction of tail race waters. But during years 1977-1981, the discharge values registered an increase (from middle of 1977) of nearly 100 $Mm^3$/month consequent to the tail water discharges from the power station.

The annual discharges ($Mm^3$) at the four gauging stations are given in table 8. The discharge values at Muvattupuzha station varied between 1507 $Mm^3$ in 1967 to 5768 $Mm^3$ in 1980 and at Thodupuzha station, the values varied between 920 $Mm^3$ in 1973 to 3143 $Mm^3$ in 1981. Of significance in this context is the higher discharges since 1977 due to the introduction of tail race waters. Values were higher than 4000 $Mm^3$ and 2000 $Mm^3$ at Muvattupuzha station and Thodupuzha station respectively, the year 1979 being an exception. The stations in Kaliyar and Kothamangalam Ars. indicated variation in discharges ranging from 660 $Mm^3$ (1973) to 2288 $Mm^3$ (1981) and 469 $Mm^3$ (1973) to 1351 $Mm^3$ (1975) respectively.

The deviations from average values for annual river discharges are presented in figures 23 a,b,c and d for different years at stations Muvattupuzha, Kalampur, Kakkadaserry and Thodupuzha. the averages at the above

**Table 8. Annual River Discharge in Million $m^3$ ($Mm^3$)**

| Station \ Year | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 | 1981 | Average (Period) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Muvattupuzha | 2414 | 2601 | 1507 | 2921 | 2671 | 2058 | 3746 | 2774 | 2135 | 4008 | 5091 | 2924 | 4327 | 4734 | 3818 | 5768 | 5271 | 2902 (1965-1975) |
| Kalampur in Kaliyar | - | - | - | 1553 | 950 | 1019 | 1409 | 1172 | 660 | 1113 | 1244 | 982 | 1145 | 1136 | 1409 | 1688 | 2288 | 1269 (1968-1981) |
| Kakkadaserry | - | - | - | - | - | - | - | 615 | 469 | 964 | 1351 | 721 | 741 | 1199 | 849 | 1098 | 927 | 893 (1972-1981) |
| Thodupuzha | - | - | - | - | - | - | - | - | 920 | 1377 | 1301 | 1041 | 2095 | 2893 | 1645 | 2396 | 3143 | 1160 (1973-1976) |

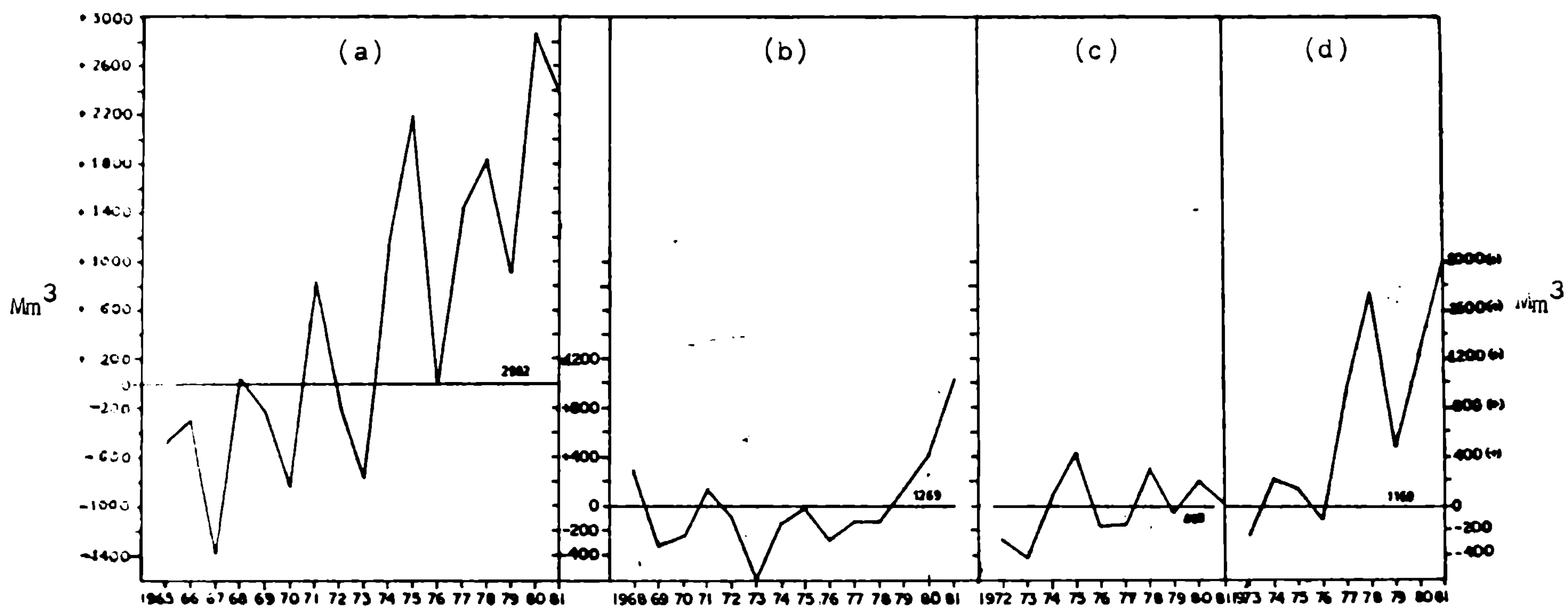


Fig. 23. Deviations of river discharge from long term averages at Muvattupuzha (a), Kalampur (b), Kakkadaserry (c) and Thodupuzha (d)

stations being 2902, 1269, 893 and 1160 $Mm^3$ respectively. A noted feature was the +ve anomalies at Muvattupuzha since 1973 (maximum +2866 $Mm^3$) and at Thodupuzha since 1976 (maximum +1983 $Mm^3$). Results at Kalampur and Kakkadaserry stations indicated that while discharge conditions were below the average value for most of the years at the former station, the discharge fluctuated around the mean value for the latter station.

The correlation between rainfall and river discharge was derived for the stations Muvattupuzha and Thodupuzha from the figures 21 a,b and 23 a,d. There exists good correlation between these two parameters as revealed from the pattern evolved in these figures. At Muvattupuzha station when rainfall was below the long term average, the river discharge fell below the mean discharge value for the period 1965-1967. This feature wasalso noted for the years 1970, 1972 and 1973. Conversely, higher discharges were associated with excess rainfall (greater than average) during the years 1968, 1971 and 1975 to 1979. The only exception was in 1974, when rainfall was less than the mean value, the river discharge was fairly large. The deviations in discharge from the mean value given in figure 23 d at Thodupuzha indicated that with lesser amount of rainfall in 1973 and 1976 (figure 21b), the discharges were below average; conversely increased discharges occurred in 1974, 1975 and 1978 on the event of heavy rains. The large positive anomalies in discharge since 1977, observed at Muvattupuzha and Thodupuzha stations are due to the combined effect of discharge of tail race waters and excess rainfall, the effect due to former being predominant over the latter.

5.8. Effect of tides on Muvattupuzha river

The Muvattupuzha river joins Cochin backwaters at North of Vaikom and south of Talayolaparambu. The two branches are called the Murinjapuzha and Ittupuzha, the former flowing on the northern wing and latter on the southern wing. The separation occurs just downstream of Vettikkattumukku, 8.50 km upstream of Murinjapuzha river mouth (figure 2). Murinjapuzha is a closed network of channels except for a few narrow outlets to agricultural fields. The tides acting at Cochin barmouth transmit their influence through the backwaters on this branch of the river in a definite manner. But in the case of the other branch, namely Ittupuzha, two open channels bifurcate at distances 11 and 8 km upstream of river mouth. River water flows through these channels to Talayolaparambu and Vadayar agricultural fields. During rainy season, water keeps flowing into the river from these channels. The exchange of significant amounts of water and further, the tidal influence acting through the backwaters on Ittupuzha renders the water balance studies more complex for this branch of the river.

During summer months, upto 1976 saline waters entered portions of the Muvattupuzha river affecting places upto Pazhur through both the branches of the river. Though no observational data or reports are now available on the extent and magnitude of the tidal effects, inhabitants of the area speak of regular upstream currents due to tides during January to April in this river. This period coincides with the lowest river flows, recorded as <15 $Mm^3$/month. The only concrete evidence for salt water intrusion is the then practice by local inhabitants to extract salt by solar evaporation of the saline river water. The tidal response of this river under the present condition is discussed in succeeding paragraphs and conclusions are drawn on the behaviour of the river under different situations of discharge.

Consequent to the discharge of tail race waters into Muvattupuzha river, in late 1976, considerable alterations took place in river flow characteristics. The augmented flow in the river was well adequate to prevent upstream entry of the salt water to reaches which were previously subjected to tidal intrusions. At present, the Murinjapuzha branch of the river is completely free from the entry of saltish water whereas in Ittupuzha, the river mouth region is slightly saline (5-10‰) during high tides. At present, the lower reaches of the river is subjected to periodic rise and fall of water level, associated with tidal fluctuations affecting the volume discharge of the river. The effect of tides acting in the above manner is felt for distances 25-30 km upstream from river mouths depending on the magnitude and period of the tides. It may be noted that the surface flow is always directed downstream.

Tidal behaviour of the river was investigated on two occasions: 9.4.1981 and 15.12.1981/16.12.1981. The results of observations, made at station III, are presented in figures 24 and 25. Figures 24a and 25a show the predicted tide at Cochin (Indian Tide Table*) for the above days. Studies were carried out on days when the tidal ranges were large.

The aim of these observations were to investigate the high and low discharge conditions in the river due to tidal fluctuations at river mouth. The variations in water level caused by the tides are indicated in figures 24b and

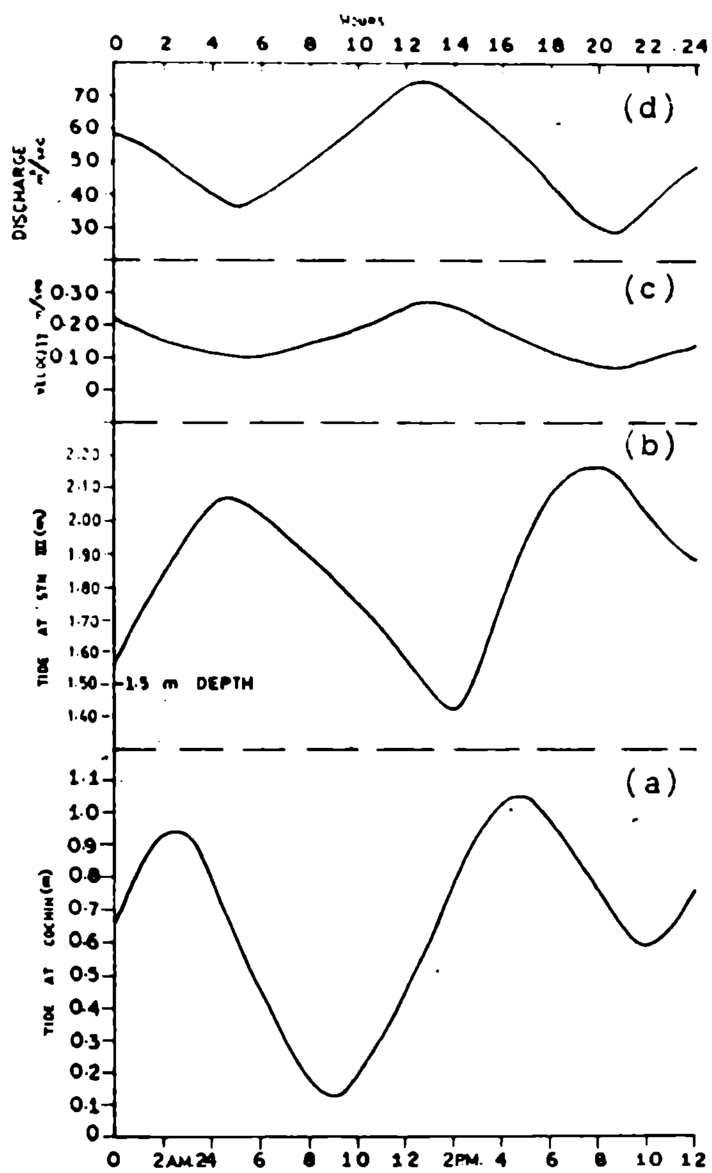



Fig.24. Diurnal variations in (a) predicted tide at Cochin, (b) observed water level at station III, (c) river flow at station III, (d) river discharge at station III on 9.4.1981.

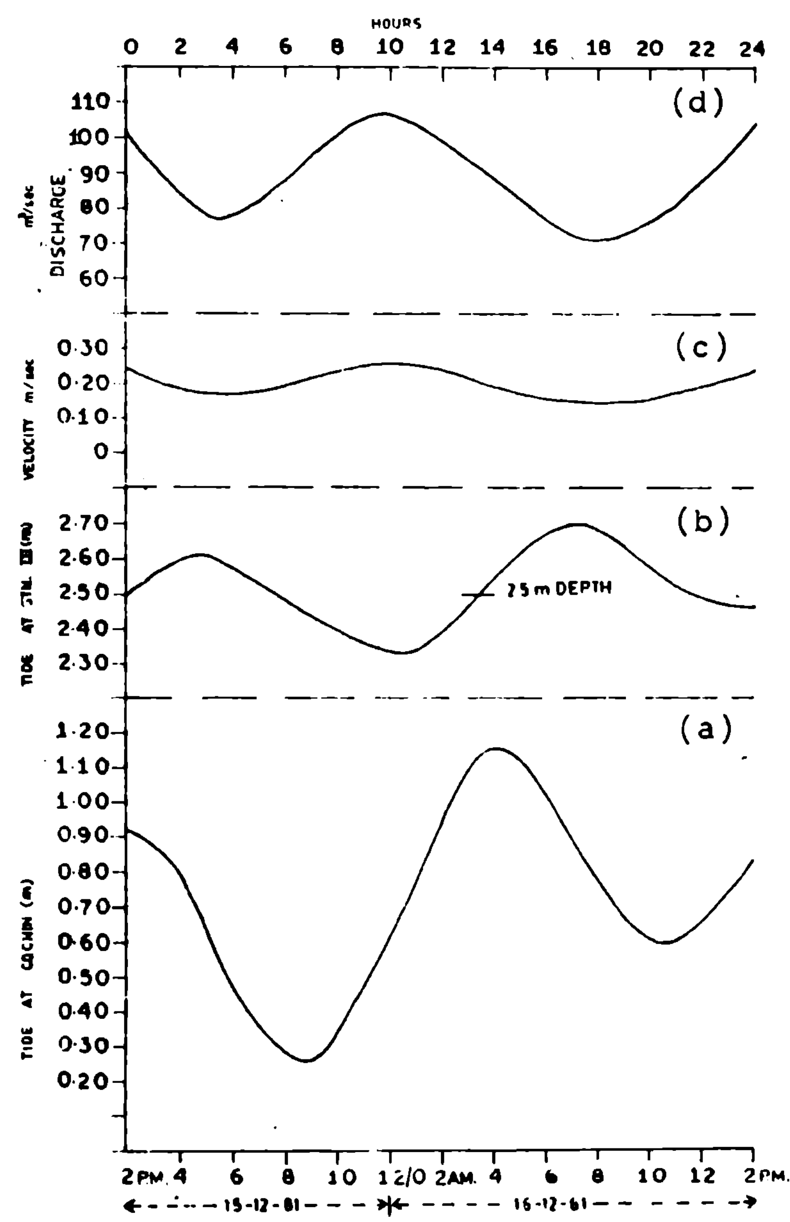



Fig.25. Diurnal variations in (a) predicted tide at Cochin, (b) observed water level at station III, (c) river flow at station III, (d) river discharge at station III on 15.12.1981 and 16.12.1981

25b and those in velocity (m/sec) are given in figures 24c and 25c. Figures 24d and 25d give the variations in river discharge ($m^3$/sec) at station III which was computed from the measured parameters.

The results of the study of tidal influence on the river on 9.4.1981 and 15.12.1981/16.12.1981 observed at station III are presented after statistical analyses in figures 26 a and b. Regression lines are drawn for velocity (m/sec) and discharge ($m^3$/sec) with the fluctuation of tides measured as vertical depth variation of water column in cm, on x - axis.

The tidal variations of water level were noted with the help of a tide pole. The velocity was recorded hourly or at shorter intervals of time as the mean of several float readings. The river discharge at definite intervals was computed from the known values of depth, width and velocity of flow and were plotted against time (figures 24d and 25d). The river has a cross-section with a flat bed and nearly vertical sides.

The study reveals that the river discharge is considerably influenced by the tides acting at the river mouths. The observations on 9.4.1981 indicated that for tides between 0.13 and 1.04 m at Cochin (figure 24) the depth of water level varied between 1.42 and 2.16 m at station III. This caused corresponding variations between 29.85 and 73.48 $m^3$/sec in river discharge. The steady discharge was 50.6 $m^3$/sec as evaluated 32 km upstream from Ittupuzha river mouth where no depth fluctuation was observed. A lag of approximately three and a half hours was associated with tidal fluctuations at station III compared to those at Cochin. The study on 15.12.1981/16.12.1981 (figure 25) indicated a similar pattern of changes in water level, velocity and discharge. The tides at Cochin varied between 0.26 and 1.16 m (from tide tables) and the steady discharge was 92.2 $m^3$/sec, evaluated at 32 km where tidal effects were absent. The depth varied between 2.34 and 2.69 m whereas the velocity altered between 0.15 and 0.26 m/sec. The river discharge ranged between 70.6 and 106.2 $m^3$/sec showing a lag of about three hours between tides at Cochin and water level variations at station III.

The influence of the tides caused only periodic rise and fall in water level and no upstream flow was observed. The change of velocity is inverse to that of change in water level. As depth of the water column increased due to high tide at river mouths, the flow velocity decreased, the net result being a reduction in river discharge and vise-versa. Under the present conditions, when river discharges are around 50 $m^3$/sec during lean season, the above phenomena holds true for any location within the river reach subjected to tides (exception is Ittupuzha river mouth region).

The results of the above investigation and values recorded are confined to only one location viz. station III at Velloor. An attempt is made using statistical analysis to evaluate certain unknown quantities from the data collected at this station. Figures 26 a and b give the lines of regression for velocity and discharge on 9.4.1981 and 15.12.1981/16.12.1981 respectively when two nearly similar tides affected the river. In the first case, figure 26a, when the velocity line was extended, it cuts the x - axis at the depth 2.46 m, such that the corresponding discharge is 27.5 $m^3$/sec. This value signifies the critical steady discharge when the downstream velocity just reduces to zero at station III for high tide and lower river discharges will permit reverse flow to develop at station III. It is obvious that for the above critical discharge value, any other location downstream of station III should experience upstream currents, when tides of nearly similar magnitude and period act on the river. The value of critical discharge noted from figure 26b was 32 $m^3$/sec. The

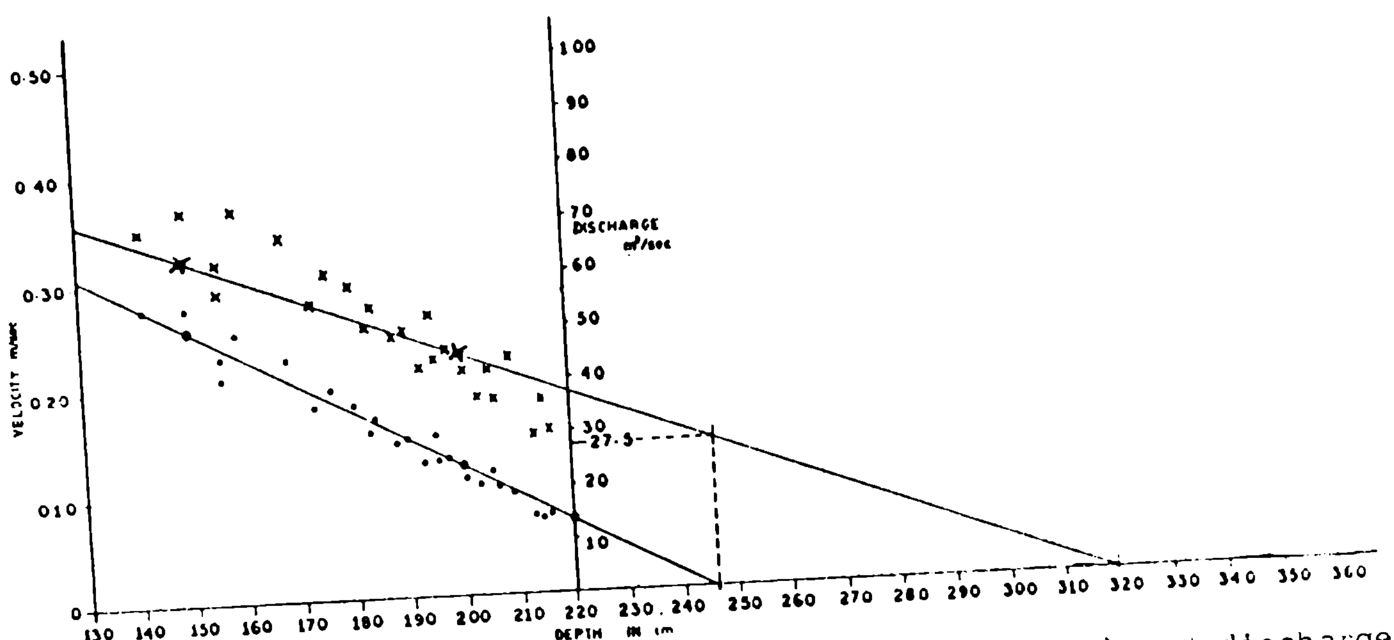



Fig.26a. Regression lines for velocity (●——●) and discharge (x——x) on 9.4.1981

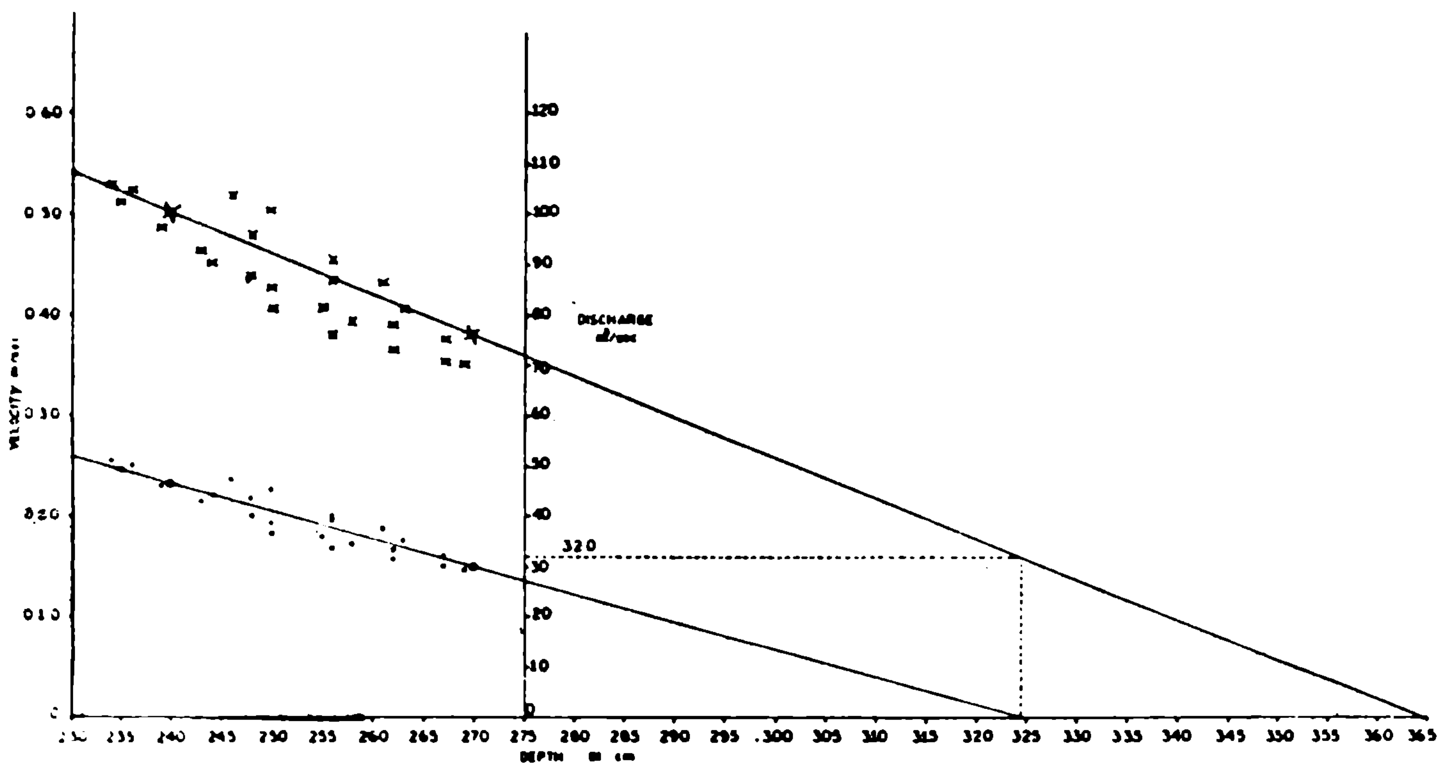


Fig.26b. Regression lines for velocity (•——•) and discharge (x——x) on 15.12.1981 and 16.12.1981

magnitude and period of the two tides, but nevertheless they represent a value derived from investigation of the river when it was subjected to tides of large magnitudes, effecting large changes in river discharge conditions. The statistical analyses does not account for the asymmetry of the high and low tides.

Assuming a steady discharge of 30±2 $m^3$/sec as a first approximation, the variation in velocity at station III will be from zero to some positive value (directed downstream) so that the discharge varies between zero and $\approx$ 60 $m^3$/sec (0-30-60 $m^3$/sec, approximately for similar tides). For a steady discharge of 50.6 $m^3$/sec, the variation was 29.85-50.6-73.48 $m^3$/sec at station III and for steady discharge of 92.2 $m^3$/sec it was 70.6-92.2-106.2 $m^3$/sec. This means that when the steady upstream discharge starts decreasing, the magnitude of variation increases and consequently for flows less than 30±2 $m^3$/sec, upstream currents gradually develop at the outfall region. The effluents discharged under such low flow conditions will be carried upstream and the problem of pollution would further aggravate. A significant reduction of the present flow rates during dry season will tend to reverse the current direction, first at river mouth and as the steady discharge gradually decreases, upstream currents will advance into the river. The phenomena of saline water intrusion will then be significant, its range and period depending on the tides which cause such motion. The effluents discharged under such a situation will pose greater problems due to the building up of concentration of the pollutants in this region under two-way flow and result in longer residence time. The overall discharge pattern for the Muvattupuzha river as a tidal river is discussed in the following paragraphs. The cut off values obtained for depth (3.20 and 3.63 m in figures 26a and b respectively) when river discharge diminishes to zero, is a hypothetical situation which can be brought about only by tides of very high magnitudes.

Figure 27 shows the tidal influence on the discharge along the Muvattupuzha river and its branches viz., Murinjapuzha and Ittupuzha on 9.4.1981 and 15.12.1981/ 16.12.1981. The Ittupuzha (12.5 km) and Murinjapuzha river (8.5 km) openings into the backwaters are indicated in the figure; station III, located perpendicular to outfall in the river is at a distance of 16.5 km upstream of Ittupuzha river mouth.

The main branch of Muvattupuzha is the Murinjapuzha,

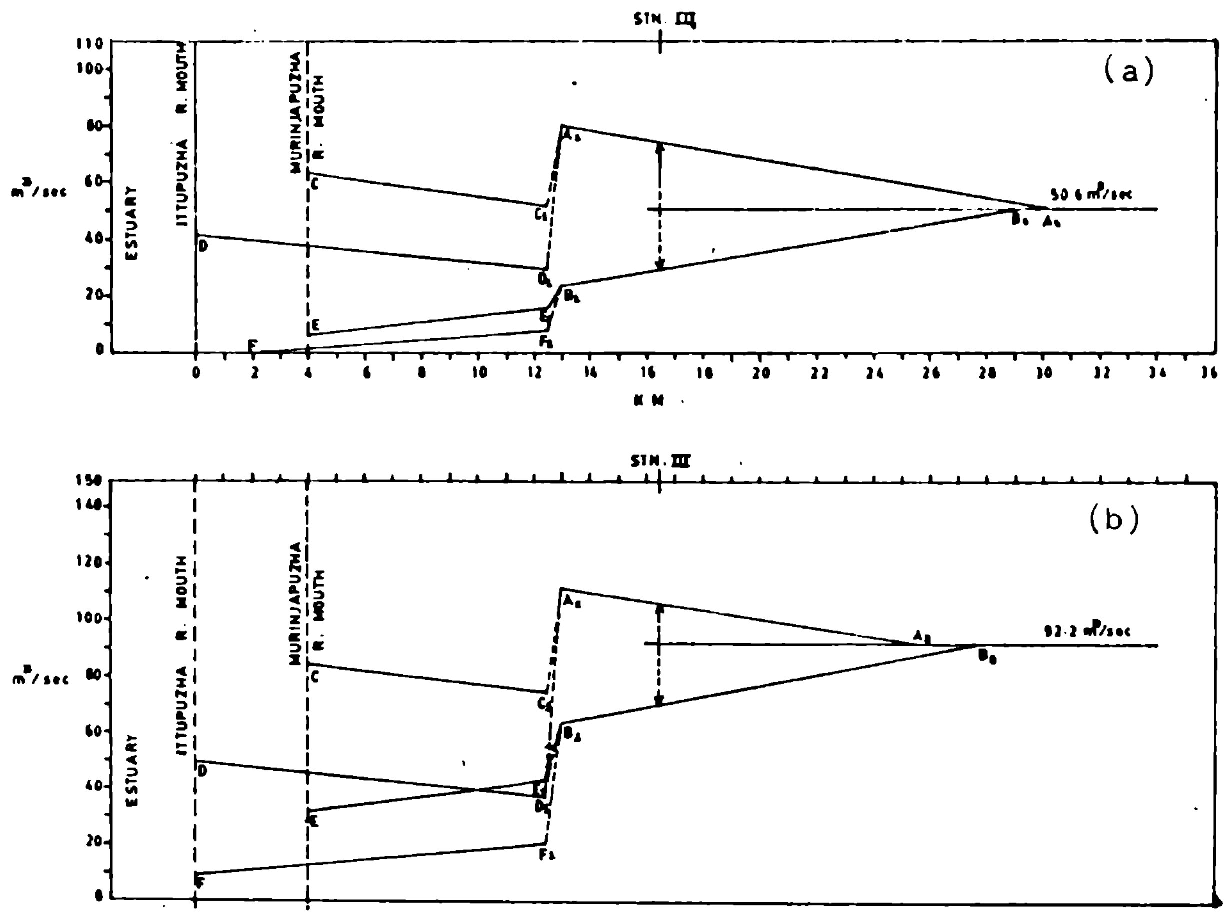



Fig.27. Maximum and minimum discharge profiles on 9.4.1981 (a) and 15.12.1981 and 16.12.1981 (b)

flowing. The maximum and minimum discharges were observed for the two days at stations located at distances of 0,4,8,12,13,16.5 and 24 km upstream of Ittupuzha river mouth. The steady discharge was estimated as 50.6 $m^3$/sec and 92.2 $m^3$/sec on the above days. The profile $A_1A_2$ for the low and $B_1B_2$ for the high tides are drawn using the maximum and minimum discharge data observed at the respective stations. The branching of the river is signified by the drop in discharge value at the 13 km point. The profiles $CC_1$ and $DD_1$ are the discharges along the Murinjapuzha and Ittupuzha under low tide conditions respectively. Similarly $EE_1$ and $FF_1$ are the corresponding profiles for discharge values in the two branches under high tide conditions.

The effect of tide was observed for distances upto 30 km in the river (figure 27a). Evidently, the low tide influenced the discharge conditions considerably (profiles $A_1A_2$, $CC_1$ and $DD_1$). Before branching of the river, the discharge was observed as 79.8 $m^3$/sec. After branching the discharges were 51.0 and 28.8 $m^3$/sec in Murinjapuzha and Ittupuzha respectively. The discharge enhanced to 63 $m^3$/sec at Murinjapuzha river mouth and 41.5 $m^3$/sec at Ittupuzha river mouth. The influence of high tide reached upto 20 km (Profiles $B_1B_2$, $EE_1$ and $FF_1$). The discharge at station III (16.5 km) was 29 $m^3$/sec. Where the river branches, it decreased to 23.6 $m^3$/sec and the total discharge divided between the two branches, the higher discharge of 15.8 $m^3$/sec being observed in Murinjapuzha and lower value in Ittupuzha which was 7.8 $m^3$/sec. The discharge at Murinjapuzha river mouth was 6.2 $m^3$/sec, whereas at Ittupuzha river mouth, saline water conditions prevailed. Practically, the discharge could not be assessed for the river reach, 0-4 km, at Ittupuzha river mouth where saltish backwaters and fresh river water mixed.

On 15.12.1981/16.12.1981 the steady discharge was recorded as 92.2 $m^3$/sec (figure 27b). The variation in water level was noticed for distances of 25.3 and 27.9 km in the river for the low and high tides respectively. Before branching of the river (13 km point) the discharge was 111.8 $m^3$/sec during low tide and 63.4 $m^3$/sec during high tide. The maximum and minimum discharge profiles for each branch during the low and high tide are shown in the figure with the same subscripts as used to describe the discharge in figure 27a.

The points $A_2$ and $B_2$ represent the distances upto which the tides cause variations in discharge. These variations in discharge gradually diminish in magnitude while proceeding from the river mouth in the upstream direction. The intersection of two profiles $A_1A_2$ and $B_1B_2$ are not at one point, coinciding with the steady discharge value, mainly because the high and low tides are not identical in many features. This was also the reason for the non-symmetry in the magnitude of deviation from the steady value at any particular location along the river (observed clearly at station III). The reasoning is applicable to both situations described in figures 27a and b.

The results of the above investigation has been utilized for simulation of discharge under different conditions. To simplify the procedure, one condition was maintained as such while forecasting the discharge under the influence of tides. The high and low tideswere considered as identical and so,the deviations in discharge produced at a location (say, station III) due to tides, prior to the branching of the river, can be assumed to be of the same magnitude. Figures 28 and 29 provide the necessary data.

Figure 28 indicates the extent to which the river reach (measured from Ittupuzha river mouth) will be affected by tides for a range of steady discharge values (0-300$m^3$/sec). The results thus derived are dependent on the magnitude and period of the tide. Using the mean slope (0.17) of the

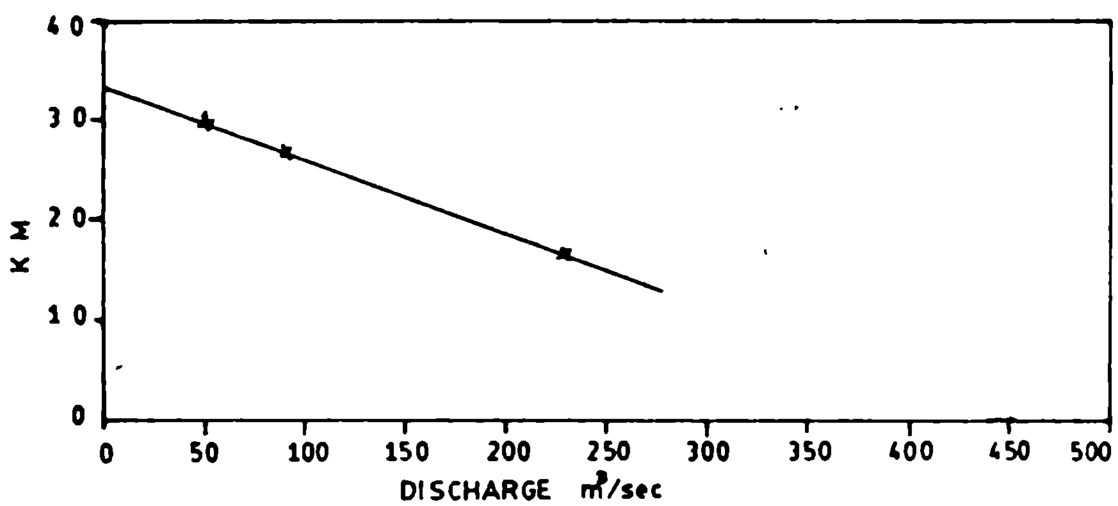



Fig.28. Extent of river stretch influenced by tides

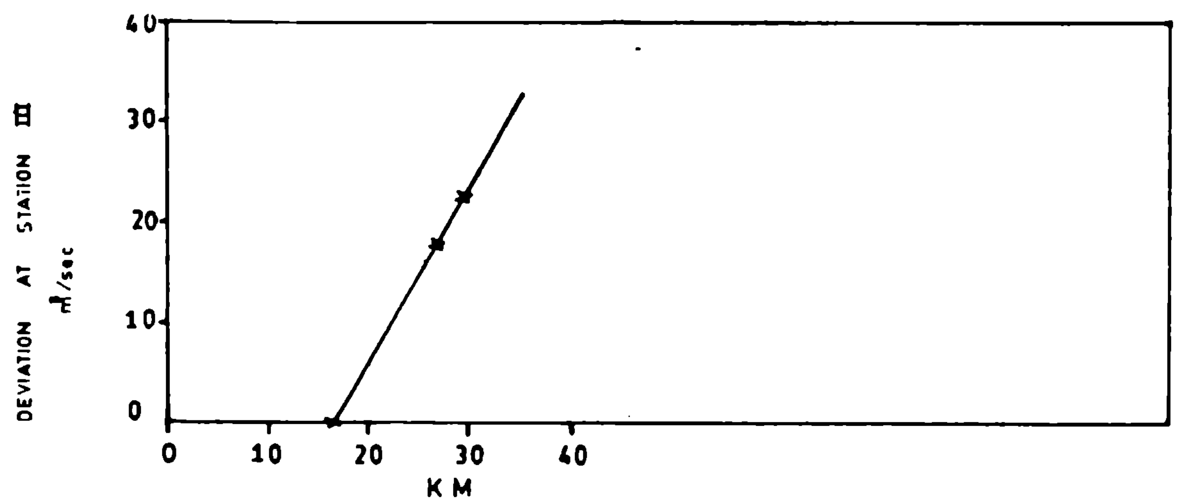



Fig.29. Deviation in discharge depending on the extent of river stretch influenced by tides

profiles ($A_1A_2$ and $B_1B_2$), the ranges of influence of tides are fixed from figures 27 a and b, which were plotted against discharge of 50.6 and 92.2 $m^3$/sec respectively. The value of 230 $m^3$/sec noted against a distance of 16.5 km was checked with field observations made on 23.6.1982, 7.7.1982 and 21.7.1982. The above value is the minimum discharge that is required to maintain the outfall region free from the influence of tides. The river reach influenced by tides for flows of 30, 50, 100 and 200 $m^3$/sec was read from the figure 29 as 31.2, 29.5, 26.0 and 18.8 km respectively.

Figure 29 is drawn with the help of deviations of discharge at station III and the respective distances of river reach affected by tides. The deviations diminish to zero at 16.5 km distance, which is the outfall region.

The flow conditions, maximum and minimum caused by the low and high tides respectively are presented in figures 30 a,b,c and d for steady discharges of 200, 100, 50 and 30 $m^3$/sec using the values derived from figures 28 and 29. The subscripts $A_1$, $A_2$, $B_1$, .......... etc. assigned to the profiles retain their original identity, as explained for figures 27 a and b. The variations at station III are presented identically to either side of the steady value and

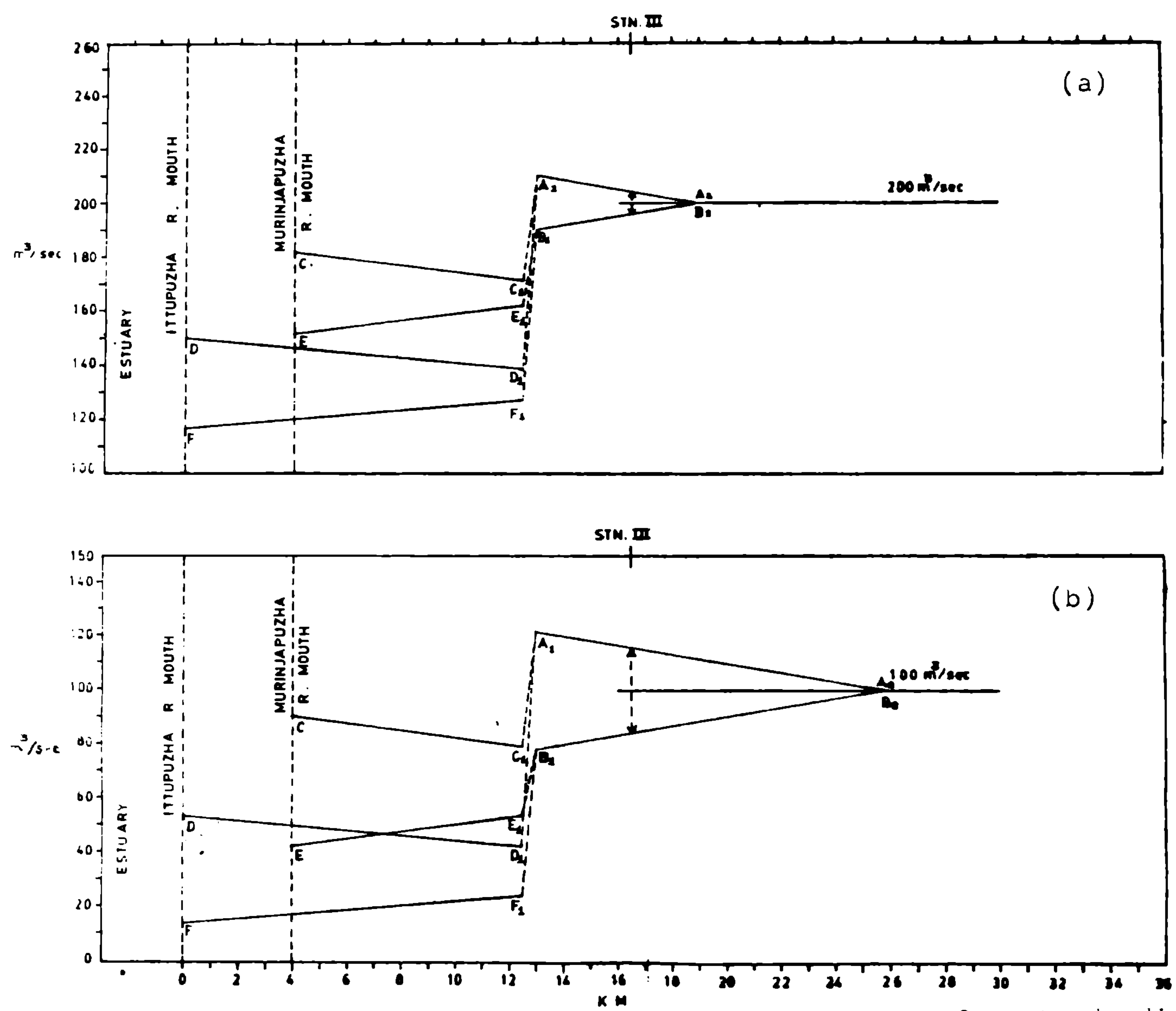
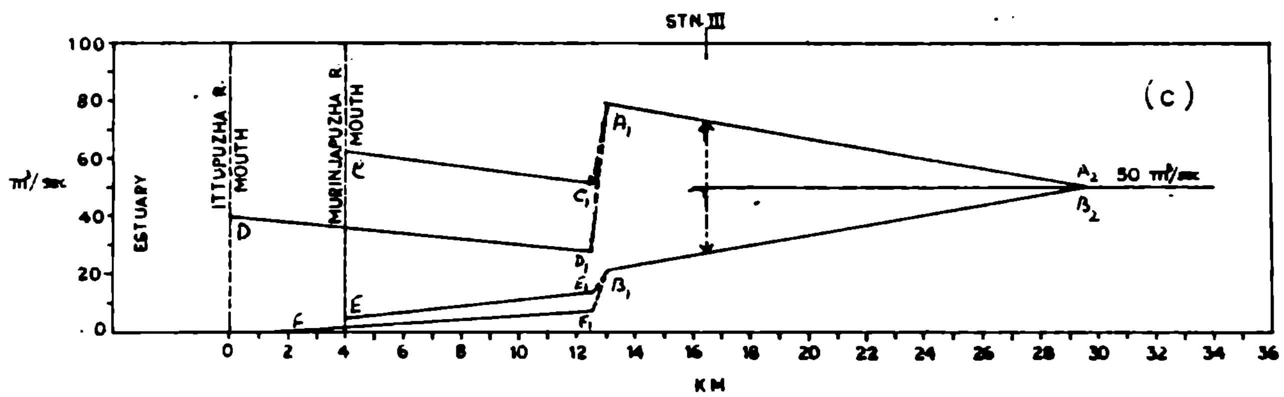



Fig.30. Maximum and minimum discharge profiles for steady discharge of 200 $m^3$/sec (a) and 100 $m^3$/sec (b)



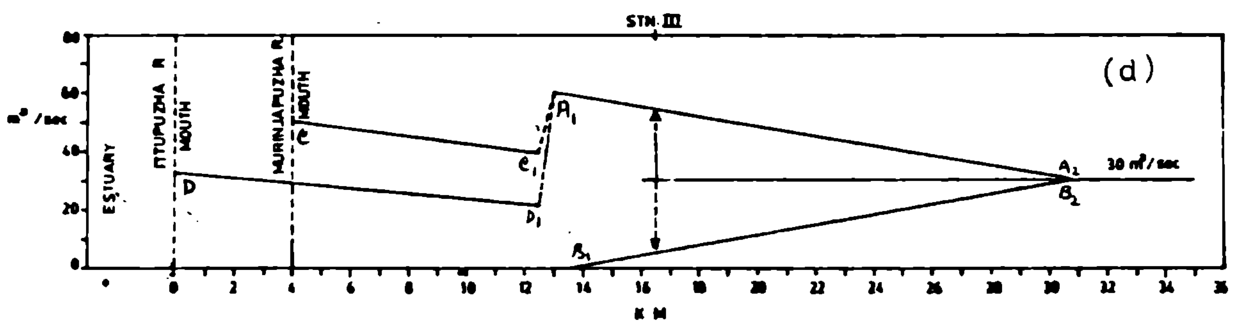




Fig.30. Maximum and minimum discharge profiles for steady discharge of 50 $m^3$/sec (c) and 30 $m^3$/sec (d)

the branching of the river results in the division of flow by volume along the two branches. The ratio of division and slope of lines of maximum and minimum discharges along each branch for the low and high tides are drawn from the figures 27 a and b. Accordingly, the figures drawn using the simulated conditions point out that for the same type of tide the influence on the river reach varies considerably for different discharges. While the river responded for distance upto 26 km for 100 $m^3$/sec, the length of the river affected is only 18.8 km for 200 $m^3$/sec discharge, all distances being measured from the Ittupuzha river mouth. The profiles and discharge values given in figure 30 b for 100 $m^3$/sec of steady discharge does not vary significantly from that indicated in figure 27b for 92.2 $m^3$/sec of steady discharge. The pattern is identical and the values are proportionately higher. But with regard to figure 30 a, where the profiles indicate discharge under the influence of tides, only slight variations are noted from the steady discharge of 200 $m^3$/sec. The range between maximum and minimum discharge is only 8 $m^3$/sec at station III and correspondingly the flow in the branches are proportionately divided. Figure 30 c gives the profiles of the maximum and minimum discharges along the river reach for steady discharge of 50 $m^3$/sec. Slight variations from the observed values are reflected in the simulated condition, due to the assumptions involved.

In figure 30 d, the steady discharge is 30 $m^3$/sec. The figure indicates that the influence of tide under such discharge condition reaches upstream distance of 31.2 km. The variation in discharge at downstream stations is indicated by the profiles of maximum ($A_1A_2$) and minimum ($B_1B_2$) discharges; the former related to a low tide and latter to a high tide. During low tide, the downstream flow gradually increases and the maximum value of discharge (60 $m^3$/sec) is attained just prior to the division of the river . The discharge varies from 39 $m^3$/sec to 50 $m^3$/sec downstream along Murinjapuzha river and between 21 $m^3$/sec and 33 $m^3$/sec downstream along Ittupuzha river. During periods of high tide (profile $B_1B_2$), the river reach downstream of 13 km in both branches of the river may experience a two way flow with salt water intrusion. The downstream flow diminishes considerably near station III and further below, the flow is practically obstructed by the flooding high tide. A point is reached where critical balance occurs between the two opposing flows.

However the above analyses may lack in producing to the assumptions involved in the process. One such case is discussed hereunder. The minimum discharge at station III is noted as 5.5 $m^3$/sec from the figure 30 d during the high tide stages (profile $B_1B_2$). At an earlier instance, the statistical analysis (figures 26 a and b) had indicated a value of $30 \pm 2$ $m^3$/sec steady discharge, in which case the flow shall diminish to zero at station III. The variation in the values obtained from the two figures is explained as follows. Figures 30, a,b,c and d are constructed by assuming that the low and high tides influence the river reach identically. It necessarily need not produce the exact reversal of conditions, as observed in figures 27 a and b where the influence of the low tide and high tide differ along the river reach. The statistical analyses (figures 26 a and b) conducted with values of one tide cycle, are largely dependent on the changing phase and magnitude of the tides. Hence the analyses may not yield concordant values for different situations, but helps to locate a value within a small range of interval. Another factor which influences the tidal flow conditions is the topography of the river bed. The river bed elevation increases gradually beyond 16.5 miles, i.e. upstream of 26.55 km measured along Murinjapuzha river effect on the flow pattern and may also limit the range of tidal influence.

The overall objectives of these simulation studies were to arrive at a quantitative picture so as to apply them to study the distribution and fate of pulp-paper effluents discharged into the river. Such analyses assume added importance in view of the modifications expected in river flow consequent to the future water resource programmes and increased multiple demands for water.

5.9. Water Resources Programmes

The 'Malankara Balancing Reservoir' project is a major proposal on water resources programme of Muvattupuzha river basin, expected to be completed by 1985. This reservoir of limited capacity utilizing the Idukki dam discharge directed down the Moolamattom power station is built across Thodupuzha Ar. There are two outlet canals, the right bank canal (R.B.C.) designed to divert water at the rate of 9.37 $m^3$/sec and left bank canal (L.B.C.) at the rate of 24.21 $m^3$/sec (figure 31). The total storage capacity will be sufficient for 5 days of continuous discharge through canals, at the end of which, the balance dead storage would be nearly 27 $Mm^3$.

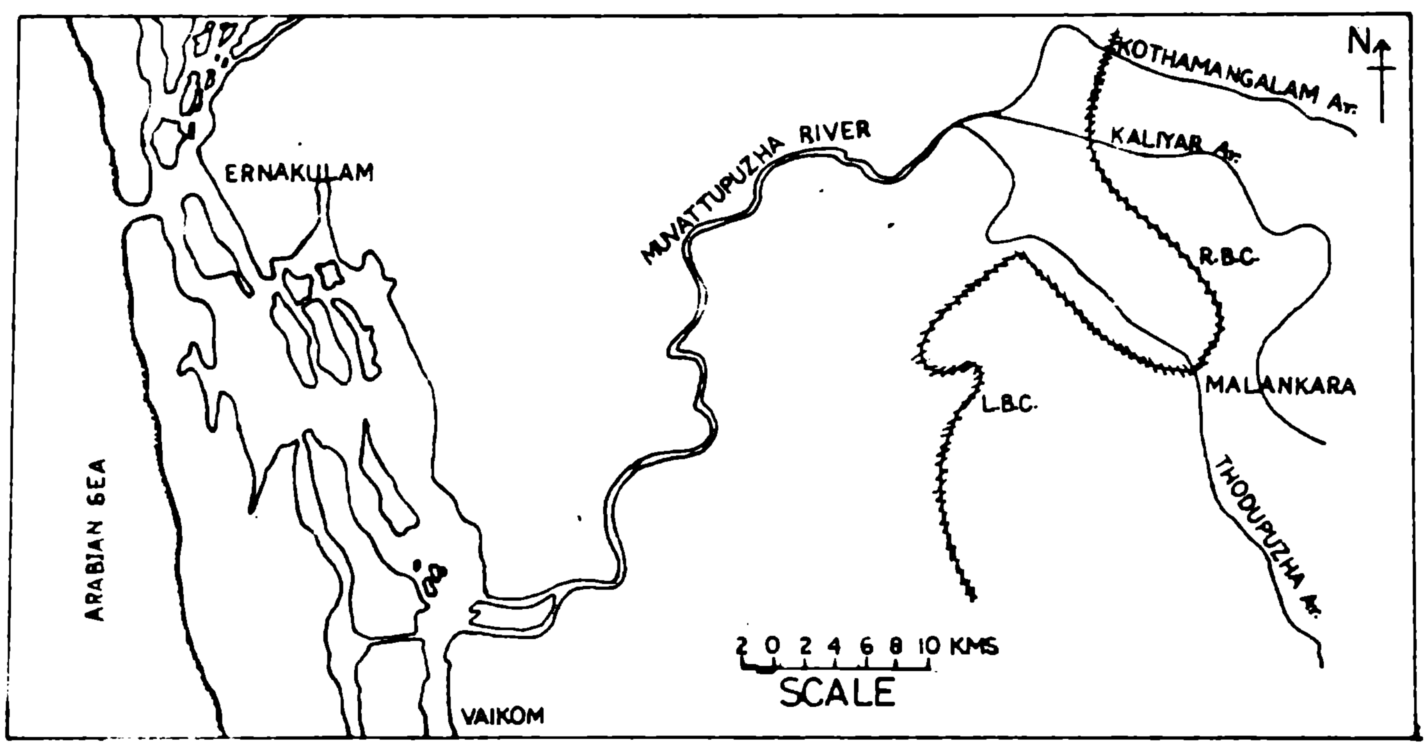



Fig.31. Right Bank Canal (R.B.C.) and Left Bank Canal (L.B.C.) attached to Malankara balancing reservoir

MVIP, 1979 points out that the main objective is to provide water for irrigation purposes to the upper reaches of the river which flows through valley ranges. This ayacut spreads over the basin covering regions around Thodupuzha Ar , Kaliyar Ar. and Kothamangalam Ar. on the right bank side and Thodupuzha Ar. and Meenachil river on the left bank. It became necessary for the R.B.C. to cut across the two Ars. at sufficiently high elevation to achieve maximum distribution. The report adds that the successful implementation of this project requires 700 cusecs (19.83 $m^3$/sec) of steady discharge downstream of the reservoir. At present there are no other proposals on Muvattupuzha river water resources programmes and other older projects are being modified or dropped.

The report MVIP, 1979 also states that the river discharge is sufficiently high during May to December to meet the requirements of agricultural fields (crops I and II), drinking water supply to Greater Cochin area and Vaikom and intake for industrial unit (Newsprint factory). Only during 3rd crop (January-April), a portion of tail race waters will have to be let out to supplement river flow. This report and the earlier Master Plan report, MVIP, 1971 do not contain any details on the tidal influence on consequent to any discharge modification. The only relevant point, pertains to salt water exclusion regulators at Murinjapuzha and Ittupuzha river mouths in an interim report MVIP, 1976 (presently this proposal is not under consideration). The following discussion brings out the possible implications on the river system consequent to the reservoir operation at Malankara.

The discharge in Thodupuzha Ar. prior to the tail race discharges were <10 $Mm^3$/month (<3.86 $m^3$/sec) for the period January to May and more than 100 $M^3$/month (38.6 $m^3$/sec) for the period between June and November as gauged at Thodupuzha bridge. Subsequently the values were enhanced to 100-120 $Mm^3$/month (38.6-46.3 $m^3$/sec) for the period January to May after the commissioning of the Idukki dam and power station at Moolamattom. The discharge is around 4 $m^3$/sec in each of the other two tributaries namely Kothamangalam and Kaliyar Ar. The discharge as measured at Muvattupuzha bridge after the confluence of all the tributaries ranges from 15-25 $Mm^3$/month ( $\approx$ 5.8-9.7 $m^3$/sec) during the period between January and May, prior to 1976 and since then the discharge indicated a sharp rise to 120 $Mm^3$/month (46.3 $m^3$/sec) or slightly more for the period January to May and still higher during June to December

(200-1000 $Mm^3$/month). Under these discharge conditions, the total requirements for drinking water and factory intake plus dilution were fixed at 21.67 $m^3$/sec (1.84+19.83 $m^3$/sec respectively) in Arakulam project proposal 1971, taking into account the minimum dilution of effluents as 15 times. In MVIP, 1979 report, this requirement is exclusively taken care of, but the minimum downstream discharge is fixed at 19.83 $m^3$/sec (700 cusecs), which is less than the value indicated in the earlier report.

To maintain a minimum discharge of 700 cusecs (19.83 $m^3$/sec) in Muvattupuzha river the contribution from Thodupuzha Ar. will have to be 11.83 $m^3$/sec or more since the discharge in the other two tributaries is $\approx$ 4 $m^3$/sec each. Hence the amount of water flowing at Malankara shall be at least 45.41 $m^3$/sec so that maximum diversion could be achieved at the rate of 33.58 $m^3$/sec through the canals. Since the commencement of tail race discharges, data from Thodupuzha station indicated that the discharge ranged between 38.6 and 46.3 $m^3$/sec during dry months. Hence after abstraction of water at the rate of 33.58 $m^3$/sec, the anticipated discharge at Thodupuzha will be around 5.02-12.72 $m^3$/sec. Thus it is clear that the quantum of

The project proposals towards limiting the steady discharge to 19.83 m$^3$/sec in Muvattupuzha river will cause active tidal incursions and introduce newer problems connected with pollution control. It may be noted that prior to the discharge of tail race water, the lower reaches of the river upto Pazhur (≈30 km) was experiencing tidal incrusions during summer months. The discharge during that time was gauged at Muvattupuzha bridge as $<25$ Mm$^3$/month ($<9.66$ m$^3$/sec) A discharge value around 30+2 m$^3$/sec permits upstream tidal currents to develop in the river, to traverse distances upto station III (effluent discharge location). For still lower discharges, the tidal incursions will easily reach locations upstream of discharge point, adversely affecting the mixing and dilution of effluents. Hence the proposed steady downstream discharge of 19.83 m$^3$/sec during 3rd crop (January-April) is not going to serve the intended purpose of diluting the effluents and support the drinking water requirements and agricultural demands.

Operating the reservoir under the present flow conditions by affecting a diversion at the rate of 33.58 m$^3$/sec would result in a situation nearly similar power station. The flow in Thodupuzha Ar. will be sufficient to meet the requirements of the reservoir and practically very little water (5.02-12.72 $m^3$/sec) will be available for downstream flow. The net reduction in flow will then amount between 60-70% in Muvattupuzha river. In other words, the net downstream discharge will vary between 13.02-20.72 $m^3$/sec and under such a situation, the lower reaches of the river ($\approx$ 30 km) will be subjected to tidal incursions. We have seen that for steady discharge of $30 \pm 2$ $m^3$/sec, the river reach downstream of Piravom road (station III) will experience a two-way flow due to tides. For still lower discharges, the extent of tidal incursion into the river will proportionately increase whereby the problem of pollution due to factory effluents will all the more aggravate. For low discharges it is likely that within the oscillatory motion set-up by the tides, the residence time of effluents in the river may be far longer than that under the present conditions.

# CHAPTER 6

# DILUTION AND DISPERSION

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# DILUTION AND DISPERSION

## 6.1. Introduction

Sanitation and disposal of waste water forms an important branch of water management. It is now universally recognized that water based carriage and disposal methods are advantageous compared to other systems such as conservancy, land disposal etc. (Barlow 1959). The relative advantages are numerous when waste is disposed of in a flowing water body. It is economical, hygienic and efficient, but improperly treated sewage or industrial effluents cause environmental problems when discharged into such water bodies. Design and location of outfall and the decomposition capacity of the receiving body are important.

Some amount of reliance can be placed on the natural processes occurring in a river viz., the self-purifying capacity and the dispersion and dilution factors. Regardless of the above factors, excess loads of waste cause hazards of pollution. Most desirable results are achieved by adequate pre-treatment of effluents subject to economical and environmental considerations (Bennett 1981).

## 6.2. Effluent Disposal

The location of effluent outfall is of primary importance. Depending on the facilities and economic viability, the effluent may be discharged either directly or after preliminary treatment or in certain cases, after complete treatment. A few considerations which are applicable in the discharge of effluents (treated or otherwise) into a stream are:

1. Discharge should be made at a safe and economical distance from the inhabited area.

2. The location of discharge should be situated below the level of surroundings.

3. The discharge point should be preferably on the leeward side of the town.

4. The sub-soil water level should be low even during the wet season.

5. Discharge timings may be regulated with respect to the seasonal and tidal variations of the flow.

6. The outfall should be placed below the low water level of the lowest tides.

7. No solid or viscous materials should be allowed to accumulate or deposit on the banks in the vicinity of outfall

8. The outfall should be as far away as possible from bathing ghats, religious or recreation centers etc.

9. The effluents should be free from debris which might collect solids.

10. The effluents should be free from floating substances.

11. Location of outfall should not impair or harm the propagation or culture of aquatic life.

In the discharge of effluents from the newsprint factory into Muvattupuzha river, most of these considerations are partially or fully neglected. The discharges have considerably impaired the quality of water in the river. The deterioration of water quality of the Muvattupuzha river due to effluent discharges have been discussed in the earlier chapters. The dilution and disposal characteristics of the river are discussed in this chapter.

6.3. Dilution

This is the principal method of disposal. In the case of the biodegradable organic substances a high percentage (80-95%) of purification is achieved by DO in diluting waters (West 1980). Conservative pollutants dilute to low concentrations or transform its state in due course of time. The dilution capacity of a water body depends on flow conditions, physical hydraulics, influence of tides, prevailing wind direction, receiving water body characteristics etc.

a) Proximity of river

Pulp-paper/newsprint factories are large industrial concerns handling voluminous quantities of water. The effluents for discharge contain large amount of soluble wastes and waste water. In the present context, intake of water is from the Muvattupuzha river from a point situated upstream of the outlet. The effluent treatment system consists of cooling ponds, clarifiers and aerated lagoons. After treatment, the wastes (liquid with suspended **solids**) are discharged into Muvattupuzha river at a point (12.5 km) upstream of Murinjapuzha river mouth. The distance between the outfall point and treatment lagoons is less than 2.5 km.

b) Mode of discharge

Two submarine pipes connected to a junction chamber on the bank are laid on river bed transverse to the river flow. The location choosen does not agree with the general pre-requisites for effluent disposal especially when toxic substances are present in the wastes. The area near the discharge and downstream is thickly populated by people who depend on the river water practically for all purposes. The river water is also extensively used for agricultural purposes and for food, fish caught from the river is regularly consumed by the local inhabitants. The outfall point is situated in the vicinity of recreational area of Piravom boat race and large number of bathing ghats are located just downstream of the discharge point. The curvature of the river 1 km downstream of outfall also affects the process of dilution. The river flow conditions are largely affected by the tides, limiting the scope for dilution during high tides. The single port discharge does not facilitate dilution of the effluents with the entire available volume of water. The formation of long bands of effluent waters (brown to dark brown) flowing along the bank adjacent to outfall is clearly visible against the background of the greenish blue river water. This indicatesthe slow mixing process and limited dilution of effluents for few km downstream. Alterations in the mode of discharge by deploying multi-diffuser systems may help to achieve better dilution.

c) Adequate water depth at discharge point

The mean depth of water is around 1.8 m at the discharge point during dry months. During monsoon, the

the amount of rainfall and resulting flow in the river. The depth of water varies between 1.5 m and 2.15 m due to the tidal fluctuations during low discharge period. Though vertical mixing takes place instantaneously at all times, transverse and longitudinal spread of effluents takes time and space under low flow conditions during lean months.

d) Large quantity of diluting waters with high DO

The Muvattupuzha river provides uninterrupted flow round the year since the commencement of the discharge of tail race waters from the Moolamattom power station. The quality of the water of this river is exceptionally good and the DO content is nearly saturated. The assimilative capacity of the river to purify organic wastes have been worked out and presented in the next chapter.

e) Strong forward currents

Any liquid waste is rapidly mixed and diluted on discharge into rivers which have strong currents at the point of outfall (Virtanen 1980). Steep river beds and high amount of turbulence aid the dilution process. In the absence of the above factors, the concentration of waste in and near the discharge point increases and the dispersion of waste is not satisfactorily achieved. The presence of tidal action can also result in the periodic rise and fall of water level without upstream currents. Under this type of tidal action, downstream flow rates are varied as observed in Muvattupuzha river. This does not help mixing and dilution of waste but leads to settlement of the sedimentary particles near the outfall site.

f) Absence of back currents

Another factor which adversely affects the process of dilution is the presence of back currents. Back currents were noticed during this investigation, downstream of the outfall pipes during lean months, extending about 250 m along the bank. The current directed upstream, returned the suspended and floating particles to the injection point. This area (10 m wide x 250 m along the outfall bank) was characteristically demarkated by the presence of waste water and decaying bottom sludge. The net result of this upstream current was to retard the process of dilution and bring about the increase in the concentration of the effluents.

6.4. Dispersion of waste in the water body

Dispersion is the process by which one medium

A large number of factors influence the dispersion (transverse and longitudinal) of the effluents in the receiving water body. For assessing the dispersion pattern at the effluent outfall region, two sets of tracer experiments were conducted prior to the commencement of the effluent discharge. To evaluate the spreading and mixing of the effluents with river water, the dispersion pattern of the tracer has been plotted on graphs (figures 33-36) and discussed.

i) Materials and methods

Analytical reagent grade KI was used as the tracer. Known concentrations of the compound dissolved in distilled water was injected continuously at a constant rate at the river surface. Water samples were collected hourly at all stations, 0.5 m below the water surface and were preserved in dark containers. At laboratory, the samples were stored in a dark chamber at $23 \pm 0.2^{\circ}C$ temperature and were analysed within 3 days.

The concentration of iodine in the sample was estimated by its catalytic effect on the rate of reduction of ceric salts by arsenious acid. The measurement can be made by a series of colorimeter readings at short intervals of time or by noting the readings after a definite time

Pipetted out 5 ml of the sample into a clear and dry colorimeter tube; added exactly 0.5 ml of 0.05N arsenious oxide and 0.5 ml of 0.05M ceric sulphate in 3.5N $H_2SO_4$ and measured fading at the end of exactly 20 minutes. The o.d was read at 360 nm. Standard solutions (10,000 µg - 0.01 µg) and blanks were also run with similar amounts of reagents. During the experiment, all the solutions were maintained at constant temperature (23$^{o}$C).

The water samples were collected from 15 stations which were located in a grid pattern. At each station (II to VI), two more additional sampling points were also located across the river (figure 32). The graphs were prepared in three sections for the river at stations II to VI in the longitudinal directions: Section 1 - stations along the outfall bank, Section 2- stations along the centre of the river and Section 3 - stations along the opposite bank of the outfall. The ambient river water concentration of the tracer was observed to be $10^{-8}$ g/l throughout the year. The phase difference of tide between stations II and VI (1.25 km apart) is negligibly very small.

ii) Ist tracer study

For understanding the effect of tides on the dispersion at the outfall region, a pilot study was

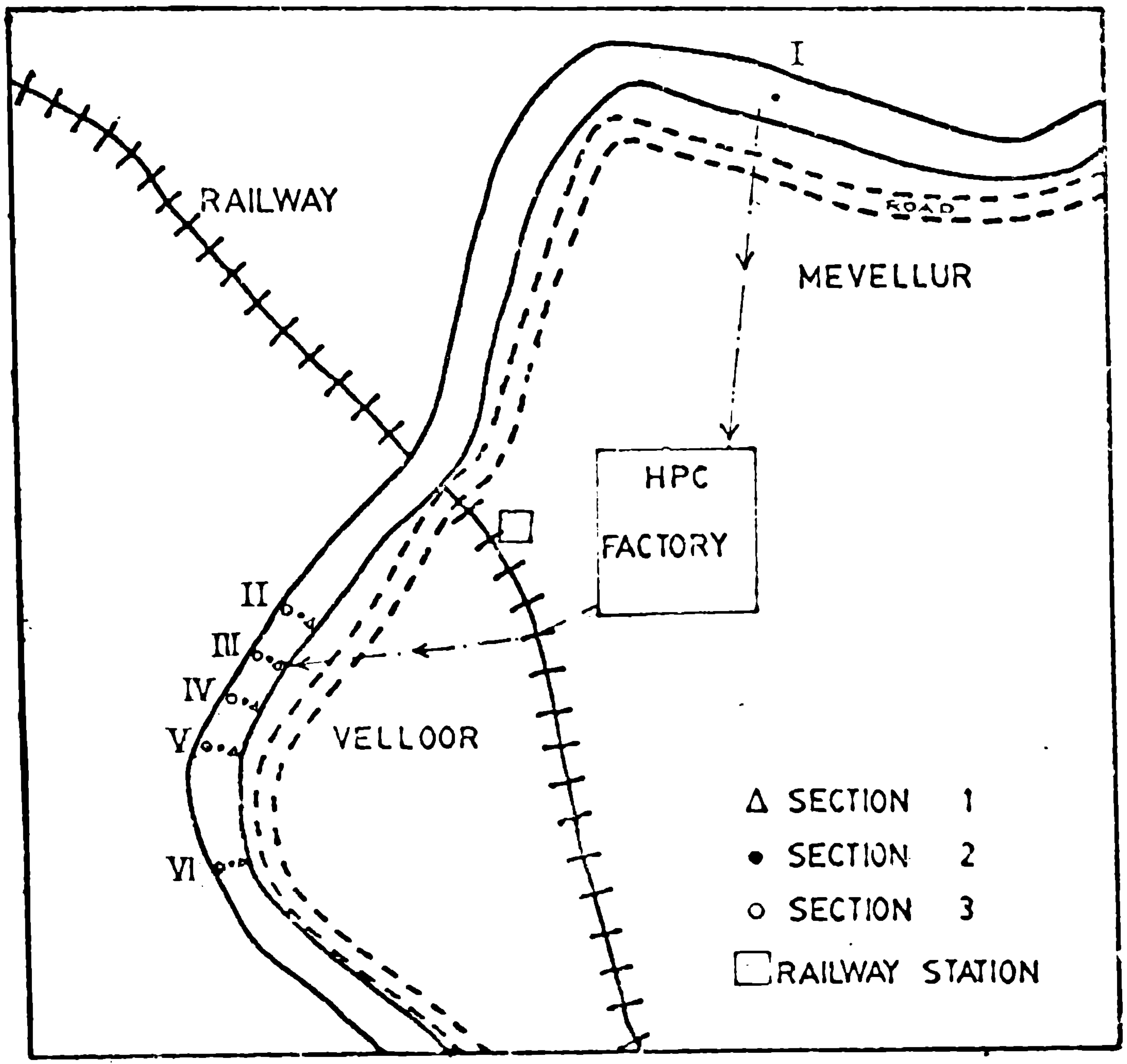


Fig.32. Map indicating location of stations along Section (1), (2) and (3).

conducted from 1 p.m. on 14.5.1981 to 1 p.m. the next day. The tracer concentration was 10 g/l, discharged at a rate 12 l/hour. The injection of the tracer chemical was made at station III (centre of the river) for 5 hours (1 p.m. to 6 p.m.) and water samples were collected at stations II to VI along the centre of the river (section 2). Figure 33 gives the graphical profile of the tracer concentrations at stations II to VI for the period of observation. Steady river discharge was 71.2 $m^3$/sec and the tidal influence caused variations ranging from 61.5 $m^3$/sec (high tide, 11.05 p.m.) and 83.6 $m^3$/sec (low tide, 5.50 a.m.) at station III. Corresponding flow variations were between 0.163 m/sec to 0.264 m/sec.

The results showed the strong influence of the tide on the distribution of the tracer. At the commencement of the experiment (1 p.m.), the tide was receeding upto 4.15 p.m. (flow gradually increasing). The peak concentration of the tracer was between 1.0 and 0.1 g/l at stations III to VI which was observed within 2 hours of injection. The build up of concentration at station III took about 50 minutes. The peaks at station IV, V and VI gradually decreased in its magnitude and the dilution factor ranged between 10 and 100 at these stations for the initial

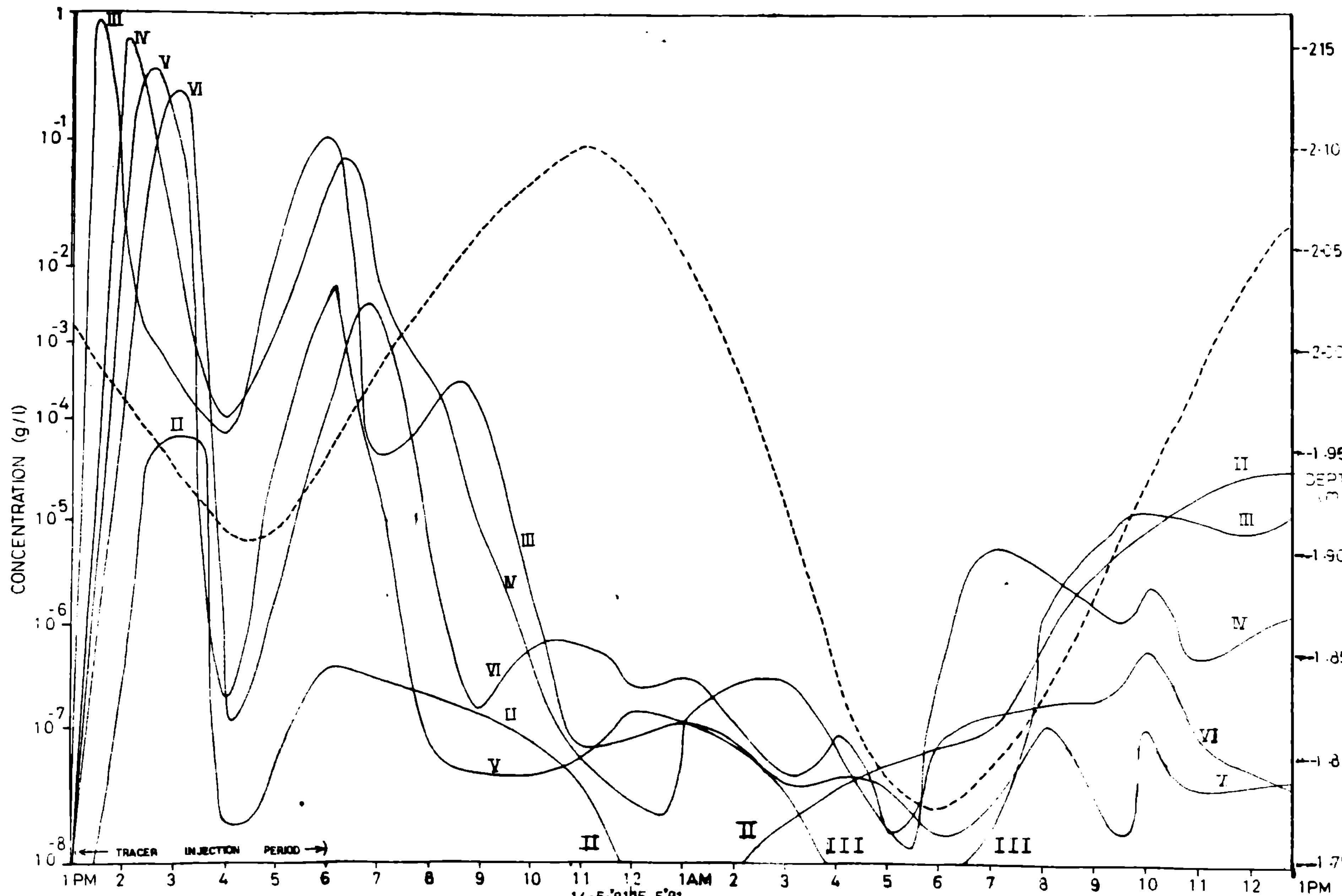


Fig.33. Profiles of the tracer concentration in g/l(——) and depth in m (---) for the first tracer study

2 hour period. Upstream station II responded in a slight manner to the introduction of the tracer when the concentration came upto $10^{-4}$ g/l. While the tracer discharge was still continuing the concentration at all stations started showing a decreasing trend with increase in flow. The lowest concentrations at time 4.15 p.m. were recorded at station II (near ambient), station VI ($10^{-7}$ g/l), closely followed by station V, station III and and IV ($10^{-4}$ g/l). The drop in concentration nearly coincided with the time of low tide. The dilution factor enhanced to $10^{6}$ times at this point. Thereafter the profiles showed an upward trend, as the discharge started decreasing due to the influence of the high tide. After exactly 5 hours, the injection of tracer was stopped and this resulted in the decrease of the concentrations at all stations. Ambient conditions were reached at station II first, after nearly 6 hours (11.45 p.m.). At stations III and IV the concentration of the tracer was $10^{-1}$ g/l at the end of injection while it was between $10^{-2}$ g/l and $10^{-3}$ g/l at stations V and VI. The concentrations at these stations gradually decreased with time. At high tide (11.05 p.m.), the concentration of the tracer was between $10^{-6}$ g/l and $10^{-7}$ g/l at all stations. As the water depth started decreasing, reaching the minimum depth by 5.50 a.m.

the concentration of the tracer also lowered to ambient value ($10^{-8}$ g/l) at station III or near-ambient values ($10^{-7}$ g/l to $10^{-8}$ g/l) at stations IV-VI. But at this stage, station II indicated the presence of the tracer in trace amounts. A significant feature was the gradual increase of concentration of the tracer when the next high tide resumed to act upon the river from 5.50 a.m. onwards. At the end of the period of investigation, when the high tide was still influencing the river flow, stations II to VI indicated concentrations ranging from $10^{-5}$ g/l to $10^{-7}$ g/l, the highest values being recorded at stations II and III.

1) The preliminary experiment shows that (1) The dispersion pattern at outfall region in the river is influenced largely by tides. (2) The initial dilution ranged nearly from 10 to 100 times at the injection point and at a point 1 km downstream of injection soon after the introduction of the tracer. This dilution is dependent on the stage of the tide. (3) The initial peak values are observed in a regular manner at regular intervals of time except at station VI located at double the distance between all other stations. (4) The slopes of the tracer profiles are nearly identical

(5) Presence of the tracer was noticed at an upstream station II though the river flow was always directed downstream. Though the diffusive processes are not clearly identified, the effect of the upstream slope (negative slope looking downstream) at the outfall region may influence the travel of the tracer to stations upstream of the injection point. (6) The presence of the tracer was clearly noticed at stations II, III and IV even after 18 hours of stoppage of injection of tracer. This feature was associated with the decrease of riverdischarge after a peak maximum discharge when concentrations of the tracer were near ambient values at all stations.

iii) IInd tracer study

Based on the conclusions derived from the Ist tracer study, a full-fledged experiment was carried out on 15.12.1981 and 16.12.1981, starting from 2 p.m. on the first day and ending at 2 p.m. on the second day. 15 stations were covered during this study and results are presented in figures 34, 35 and 36 pertaining to section (1), section (2) and section (3) respectively. The point of injection of the tracer was exactly at the outfall point. The concentration of the tracer was 2.5 g/l, discharged at a rate of 12 l/hour. The depth, velocity variations and river

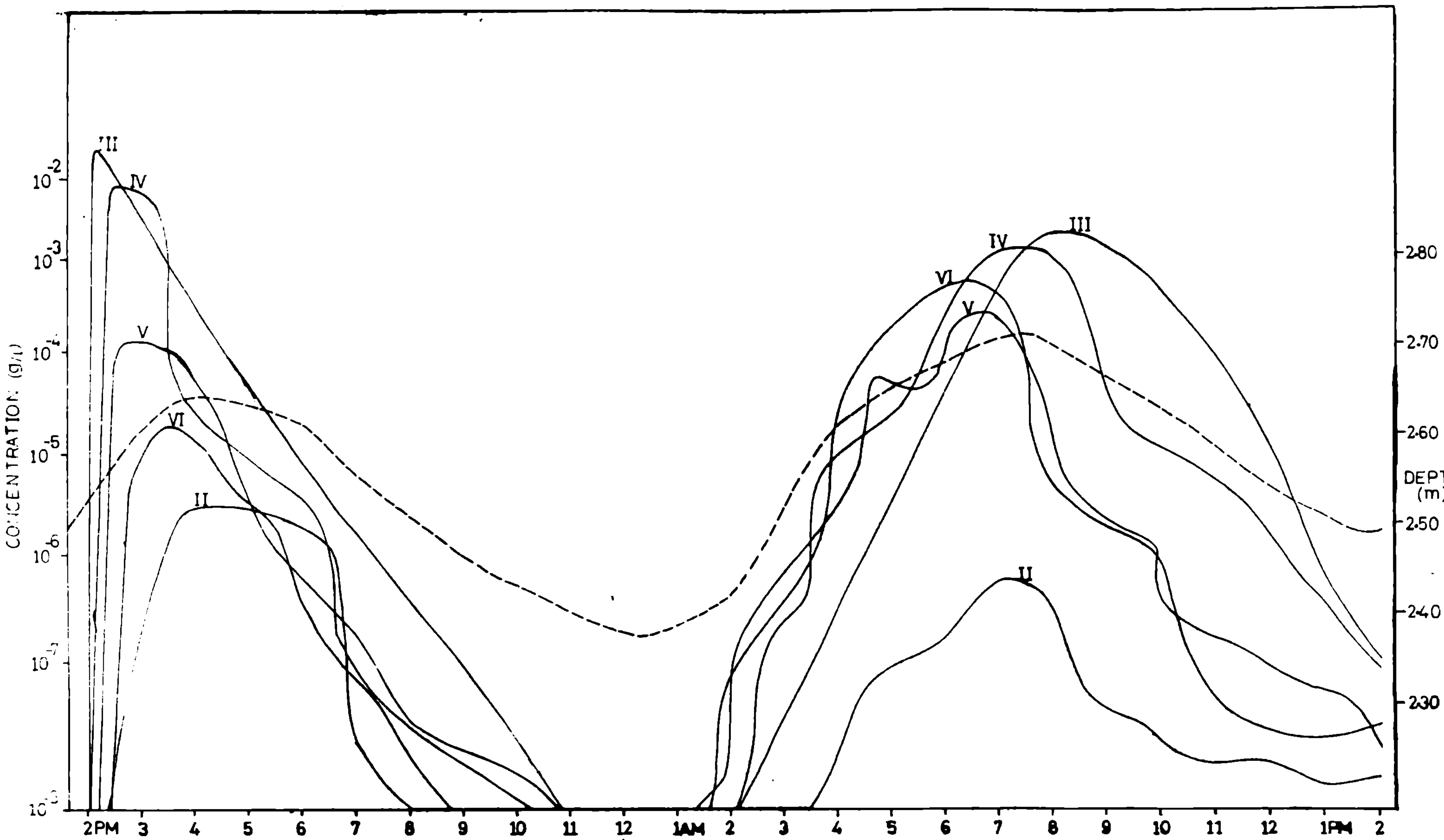


Fig.34. Profiles of the tracer concentration in g/l (——) and depth in m (---) at Section (1) for the IInd tracer study

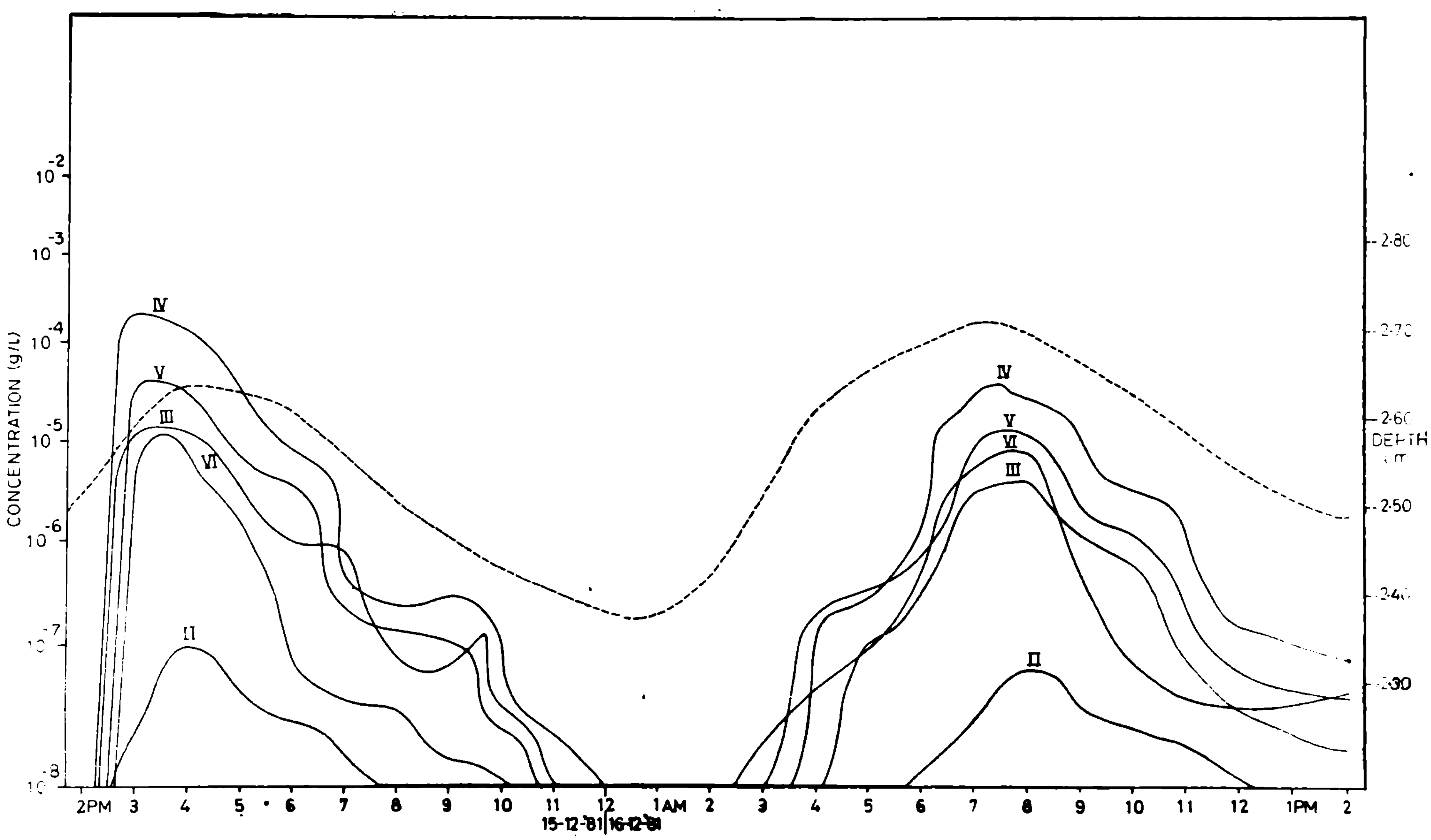


Fig.35. Profiles of the tracer concentration in g/l (——) and depth in m (---) at Section (2) for the IInd tracer study

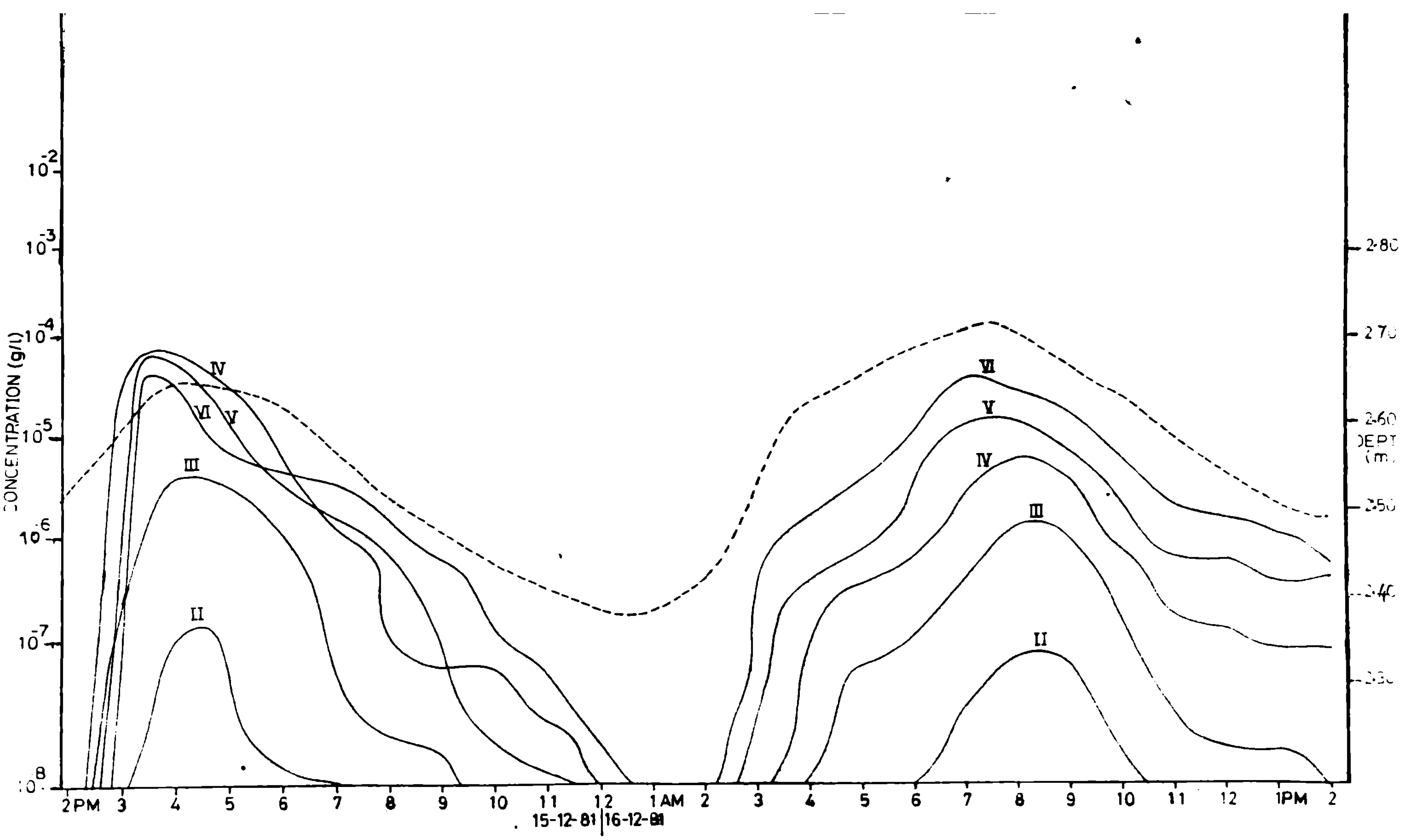


Fig.36. Profiles of the tracer concentration in g/l (——) and depth in m (---) at Section (3) for the IInd tracer study

Section 1: The stations II to VI were located along the outfall bank (figure 34), transverse to the original stations along the centre of the river. The response at station III was instantaneous on the introduction of the tracer. Peak concentration observed was just higher than $10^{-2}$ g/l which indicates nearly 100 times dilution in terms of concentration under the experimental conditions. The other downstream stations responded gradually after a time lag of 10 to 20 minutes and peak concentrations ranged between $10^{-2}$ g/l (station IV) to $10^{-5}$ g/l (station VI). The flow in the river was gradually decreasing due to a high tide (2 p.m. to 4 p.m.). Hence most stations indicated gradual decrease of concentration for some time. The upstream station II also indicated the presence of the tracer when the ambient value of $10^{-8}$ g/l, was altered to more than $10^{-6}$ g/l, but this build-up of the tracer chemical took nearly 2 hours and coincides with the low flow at 4 p.m. As the tide receeded, the concentration fell rapidly to ambient values at all stations, first at station II and lastly at station III. The ambient conditions prevailed for more than 2 hours coinciding with high charge in the river during low tide . But as the discharge decreased, the build-up of the tracer was again noticed. The peak concentration reached values between $10^{-3}$ g/l and with the highest concentration being recorded at station III. Station II also recorded the presence of the tracer (concentration $\approx 10^{-6}$ g/l). Thereafter, as time passed, the concentration gradually reduced, generally following the slope of the line indicating the depth variations.

It is noted from the graph that during periods when the flows were either decreasing or increasing due to the tidal effects, the concentration profiles of each station crossed each other on numerous occasions. This points out that downstream reaches are more or less uniformly mixed at that time when the tides are in the intermediate stages.

Section 2: The pattern (figure 35) is more or less identical to section 1 . All the stations were located along the centre of the river. The noted difference was the lower concentration of the tracer at all stations throughout the period of observation compared to that in section 1. The initial peak concentration was recorded at station IV ($>10^{-4}$ g/l but $<10^{-3}$ g/l) followed by station V at 3 p.m. on 15.12.1981 . For a period of more than 2 hours, ambient conditions prevailed at all stations (11.50 p.m. - 2.30 p.m.). When the low discharge condition was established by 8 a.m. (16.12.1981), station IV reported the highest concentration (between $10^{-4}$ g/l and $10^{-5}$ g/l) followed by station V and VI ($\approx 10^{-5}$ g/l). The value at station III was slightly less than $10^{-5}$ g/l and station II indicated the presence in traces.

Section 3: The location of the stationswere along the bank opposite to the outfall bank, transverse to original stations II to VI (figure 36). The presence of the tracer was noticed at stations IV, V and VI between concentrations $10^{-4}$ g/l and $10^{-5}$ g/l (peak values) in about one and a half hours time after commencement of injection. Peak value at station III was between $10^{-5}$ and $10^{-6}$ g/l. The ambient values were attained as the flow increased and once again the build-up of the tracer was noticed during the high tide period (6 a.m. to 10 a.m.). But the highest concentration was observed at station VI (between $10^{-4}$ g/l and $10^{-5}$ g/l) followed by station V, IV and III. Station II reported traces of the chemical tracer during both the low discharge periods. The mixing phenomenon during intermediate stages of tides was found to follow no definite pattern after the first high tide period (7 p.m. - 11 p.m., 15.12.1981) but exhibited uniform distribution of concentration during the entire second high tide period (4 a.m. - 2 p.m., 16.12.1981).

Station-wise analysis

Station II: The highest concentrationswere observed along the outfall bank (section 1), between $10^{-5}$ g/l and $10^{-6}$ g/l during high tide periods. During other times, referring to section 2 and 3 , only trace amounts of the chemical tracer was observed, that too during low discharges. At other times, it was ambient values at this station.

Station III: The results indicatedthe presence of the tracer in concentrations as high as $10^{-2}$ g/l (peak value). But in the transverse direction, dispersion caused the presence of the tracer in amounts around $10^{-5}$ g/l (section 2). The concentration further falls to less than $10^{-5}$ g/l in section 3 (peak value).

Station IV: In section 1, the peak concentration of the tracer was very near to that at station III during both the high tideperiods ($10^{-2}$ g/l). The profiles in section II indicated that the maximum peak concentrations were about $10^{-4}$ g/l. Section III also indicated the same value.

Station V: The station on the outfall bank side (section 1) indicated peak values around $10^{-4}$ g/l. The same value was observed for this station in sections 2 and 3.

Station VI: The dispersion of the tracer had resulted in the identical distribution of the peak concentrations at all sections for this station (between $10^{-4}$ and $10^{-5}$ g/l). But slightly higher values were noted as peak concentration in section 1 as $10^{-3}$ g/l during high tide (6 a.m., 16.12.1981). The distribution of the tracer read from section 3 indicated that the values at station VI was the highest compared to the other stations during the low discharge period (6 a.m. to 9 a.m., 16.12.1981).

Generally for stations III to VI, no definite pattern was observed in the distribution of the tracer in different sections during the intermediate stages of the tide, but the trend exhibited was in conformity with the stages of the tide as seen in every section investigated.

The studies show that (1) the dilution of the tracer varies largely from $10^{2}$ times to $10^{8}$ times depending on the stage of the tide. (2) the outfall bank appears to be more affected (in terms of higher concentration) by discharge at the present outfall point. (3) dispersion causes the spread of the tracer in the transverse direction also, but the value of the concentration of tracer is lower than the corresponding value at the longitudinal section along the outfall bank for locations upto 1 km downstream. (4) the transfer of the discharged substance occurs more predominantly in the longitudinal direction than in the transverse direction. (5) the concentration of the tracer appears to be slightly greater on the outer curved portion of the river (along the bank opposite to the outfall) at station VI. (6) the study indicated the existence of transverse distribution across the outfall point; the concentration is $\approx 10^3$ times less than that at the outfall. (7) the upstream station II showed the presence of the tracer in amounts higher than the ambient values. This suggests the presence of diffusive processes, aided by the upstream slope at the outfall region to cause upstream travel of the tracer. The river flow was always directed downstream during the period of investigation. (8) at high flow periods, the presence of the tracer was not detectable above the ambient values. This suggests that rapid removal occurs after thorough mixing and spreading of the injected substance.

The dilution and dispersion characteristics of the Muvattupuzha river at the outfall region were studied by means of chemical tracer in order to assess the suitability of the location and mode of discharge of effluents. Analysing the situation with respect to the general pre-requisites for disposal of liquid wastes into a flowing stream, it was found that most of precautions were either partially implemented or were not at all looked into. This has relevance in the context as the effluents carry high amounts of toxic substances, such as mercury compounds. The factory effluents were discharged after subjecting the wastes to some amount of treatment. One major option choosen and adopted by the factory for disposal of its effluents is the scope of dilution that is available in the river. This aspect was studied by the tracer experiments conducted at the outfall site. The results point out that the extent of dilution aided by dispersion of waste were not satisfactorily achieved under the present set-up of location and mode of discharge. The location suffers drawbacks from back currents, upstream slope at discharge site and the curvature effect of the river just downstream of the outfall. The single port discharge pipes do not facilitate the mixing and spreading of the wastes.

# CHAPTER 7

# ORGANIC LOADING CAPACITY

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## 7.1. Introduction

Rivers are capable of absorbing some pollutional loads over and above the natural pollution caused by runoff and drainage from countryside. As water continues to flow from its source, a stream, once polluted may be able to regain its original water quality. This phenomena of self-purification is controlled by various physical, chemical and biological processes. Conservative pollutants may be diluted to insignificant levels or removed from liquid phase due to precipitation or adsorption. And for continued inflow of pollutants, the river stretch downstream may indicate varying water quality. It is possible to forecast the waste assimilation capacity and associated water quality with reasonable reliability. The assimilative capacity of natural waters is computed on the determination of the allowable load placed on self-purification capacity to ensure the desired water quality based on utility, practises and under prescribed conditions of natural drought or regulated streamflow. It is recognized that the waste assimilative capacity of streams and the resultant water quality are not fixed quantities but varies with streamflow variations. Also, man-made modifications towards river resources development and improved water uses may exhibit effects that are beneficial or detrimental. The principle of assimilative capacity controlled by self-purification factors depends much on the hydrologic setting, climatic conditions and stream behaviour through each reach of the river. Generally, excluding the conservative inorganic substances, the decline of residual bio-degradable organic matter along the course of a river is nearly logarithmic in character.

Stream sanitation studies help: (1) forecasting the development of river water resources and its basin and to evaluate the consequent effects on the water course (2) the enhancement of satisfactory river water quality and quantity for intended uses and (3) satisfactory disposal of wastewater and degree of treatment necessary depending on the conditions and best usage of receiving stream.

The analysis of river assimilative capacity involves the evaluation of hydrological parameters and other factors besides verification of self-purification abilities and forecast of stream conditions downstream.

Self-purification of any stream is controlled by dilution, currents, sedimentation, temperature, sunlight and oxidation-reduction processes. Relative importance and significance of each of these factors is discussed by Birdi (1979). Once sewage or other pollutional substances enter a stream, downstream water quality changes successively. Wilber (1971) describes the different zones of pollution, characteristised by its dissolved oxygen content and presence of aquatic life. The ability of rivers to purify wastes depends on numerous factors; but mathematical models recognize the rate of deoxygenation and reaeration, temperature, stream velocity, initial dissolved oxygen and ultimate BOD as the governing parameters to describe the state of affairs of a particular river receiving effluent discharges. The above parameters may exhibit seasonal and diurnal variations and quantitative assessments have to be made considering these variations. This would also imply that for economical working, the treatment of sewage or effluents need not be extended beyond the point which is necessary to maintain the stream free from pollution under worst flow conditions.

7.2. Self purification

The original model on stream sanitation was forwarded by Streeter and Phelps (1925) describing the relationship of change in concentration of BOD and DO in a stream with time. This was further developed by Velz (1939), Thomas (1948), Dobbins (1964), etc. For single point outfall, the first order reactions are given by:

$$L_t = L_o \, 10^{-(K_1+K_3)t} \quad \ldots. \quad (1)$$

$$D_t = \frac{K_1 L_o}{K_2-(K_1+K_3)} \left[10^{-(K_1+K_3)t} - 10^{-K_2 t}\right] + D_o 10^{-K_2 t} \quad ..(2)$$

where $L_o$ = Initial ultimate BOD (mg/l)

$L_t$ = Ultimate BOD after time 't' (mg/l)

$D_o$ = Initial DO deficit (deficit = saturation DO value - observed DO)(mg/l)

$D_t$ = DO deficit after time 't' (mg/l)

t = Time (seconds or days)

$K_1$ = Deoxygenation co-efficient/day

$K_2$ = Reaeration co-efficient/day

$K_3$ = +ve values for rate of removal of BOD due to sedimentation or volatilization/day

-ve values for rate of addition of BOD due to scouring of bottom deposits/day

Equation (2) is the well-known 'Oxygen Sag Equation'.

It is assumed that the wastes discharged into the river are distributed evenly across the river width and complete mixing takes place instantaneously. The modified form suggested by Dobbins (1964) has been dealt by

Tariq (1979) in detail, taking into account the different oxygen sources and demands and different cases where $K_3$ is assumed zero. Positive values of $K_3$ for rate of removal of BOD due to sedimentation or volatilization and negative values of $K_3$ for rate of addition of BOD due to scouring of bottom deposits are not considered in the present study as these processes are assumed to be absent.

Equation (2) can thence be written as:

$$D_t = \frac{K_1 L_o}{K_2 - K_1} \left[10^{-K_1 t} - 10^{-K_2 t}\right] + D_o 10^{-K_2 t} \quad \ldots (3)$$

The rate of BOD removal $K_r$ may be different from the rate of deoxygenation $K_1$ obtained from laboratory tests for a river. The stream rate ($K_r$) is calculated from the first-stage ultimate BOD values at two different stations 'A' and 'B' with distance between them expressed in flow time $t_{(A-B)}$ as per the equation

$$K_r = \frac{1}{t_{(A-B)}} \log_{10} \frac{L_A}{L_B} \quad \ldots \quad (4)$$

where $K_r$ = Rate of BOD removal in a stream/day

$L_A$, $L_B$ = Ultimate BOD at stations A and B (mg/l)

$t_{(A-B)}$ = Time between two stations A and B (seconds or days)

The above equation does not hold true for any additional BOD discharged between stations A and B. When the difference between $K_1$ and $K_r$ is significant, the equation (3) is modified as:

$$D_t = \frac{K_1 L_o}{K_2 - K_r} \left[10^{-K_r t} - 10^{-K_2 t}\right] + D_o 10^{-K_2 t} \quad \ldots (5)$$

For known values of ultimate biochemical oxygen demand ($L_o$), the initial dissolved oxygen deficit ($D_o$), and the co-efficients $K_1$, $K_2$ and $K_r$, the oxygen deficit $D_t$ at a given time 't' may be calculated. In this study, $K_r$ and $K_1$ do not vary significantly.

Biological decomposition of degradable organic matter utilizing oxygen starts immediately after waste is discharged into the stream. To compensate the loss, the atmospheric reaeration starts which is proportional to the dissolved oxygen deficit; the reaeration rate increases with increasing deficit. At a critical point ($X_c$) downstream in the river, the oxygen utilization rate equals reaeration rate. Beyond this point, the rate of atmospheric reaeration is greater than the rate of oxygen consumed and DO content begins to increase. After some time, the river completely recovers and no effect of effluents are indicated. This phenomena refers to the natural

It is possible to derive the value of critical dissolved oxygen deficit $D_c$ at the point $X_c$ which is given by the equation

$$D_c = \frac{K_1 L_o}{K_2 - K_1} [10^{-K_1 t_c} - 10^{-K_2 t_c}] + D_o 10^{-K_2 t_c} \qquad \ldots (6)$$

where $t_c$ is the time required to reach the critical point.

The value of $t_c$ can be determined from

$$t_c = \frac{1}{K_2 - K_1} \log [\frac{K_2}{K_1} (1 - \frac{D_o \{K_2 - K_1\}}{K_1 L_o} )] \qquad \ldots (7)$$

The distance $X_c$ is equal to

$$X_c = vt_c \qquad \ldots (8)$$

where $D_c$ = Critical DO deficit (mg/l)

$t_c$ = Time required to reach the critical point (seconds or days)

$X_c$ = Critical distance (m)

v = Velocity of flow in the river (m/sec or m/day)

### 7.3. Deoxygenation co-efficient $K_1$

The oxygen depletion in rivers or streams are caused by (1) the bacterial oxidation of suspended and dissolved organic matter discharged from natural and artificial sources and (2) the demand of oxygen by sludge and benthic deposits.

The deoxygenation co-efficient $K_1$ (base 10) per day is determined from the BOD bottle rate co-efficient. Several methods are proposed such as the least-square method (Waugh 1943, Young 1962), the method of moments (Moore 1950), the Thomas method (Thomas 1950), the daily-difference method (Tsivoglou, 1958) and the rapid ratio method (Sheehy 1960). Of the above, Thomas method is used in the present study to calculate $K_1$.

The Thomas method is based on the similarity of two functions. It is a graphical procedure based on the function

$$\left(\frac{t}{y}\right)^{1/3} = (2.3\ K_1 L_o)^{-1/3} + \left(\frac{K_1^{2/3}}{3.43 L_o^{1/3}}\right)t \qquad \ldots (9)$$

where y = BOD that has been exerted in time interval t (mg/l)

This equation provides a straight line defined by

$Z = a+bt$ where $Z = \left(\frac{t}{y}\right)^{1/3}$

$$a = (2.3 K_1 L_o)^{-1/3}$$

$$b = \frac{K_1^{2/3}}{3.43 L_o^{1/3}}$$

Z can be plotted as a function of t. The slope 'b' and the intercept 'a' of the line of best fit of the data can be used to calculate $K_1$.

$$K_1 = 2.61\frac{b}{a} \qquad \ldots (10)$$

The values of $K_1$ (20°C)/day computed from 30 sets of experiments are given in figure 37a. The period of study falls from January 1981 to September 1982. The figure indicates seasonal variations in the value of $K_1$. For the months June to August, the values ranged from 0.04 to 0.11 and during January to middle of May and October to December months of the year, the co-efficient varied between 0.20 and 0.31. The period from middle of May to middle of June and the month September act as transition months with values ranging between 0.11 to 0.20. The value 1.047 (Phelps 1944) was used as the temperature co-efficient to correct the rate constant to the desired temperature.

7.4. Reaeration co-efficient $K_2$

The main source of oxygen in a river is the dissolved oxygen contained in the river water. Oxygen is also augmented from tributary drainages, surface waters and ground water inflow. Other sources of oxygen replenishment in a river are reaeration from the atmosphere and photosynthetic process. Streeter and Phelps (1925) proposed two widely accepted theories, of which one states that the rate of reaeration under constant temperature and turbulent mixing conditions is directly proportional to the existing oxygen saturation deficit. The same theory is also

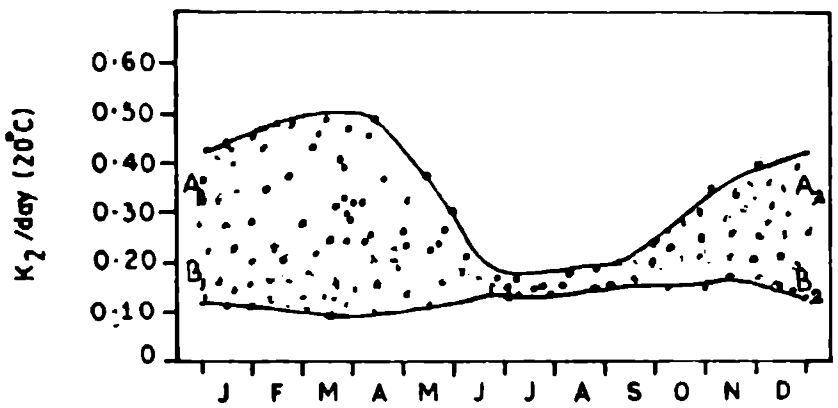


Fig.37 b. Variation of Reaeration co-efficient

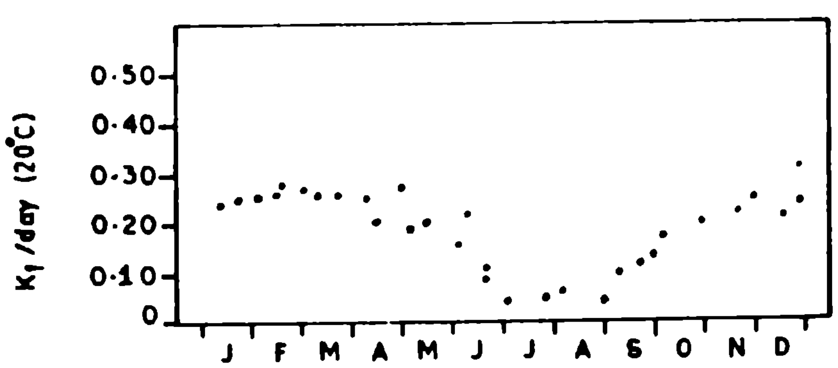


Fig.37 a. Variation of Deoxygenation co-efficient reflected in law of solubility. The transfer of oxygen governed by law of diffusion states that the rate of diffusion through water between two points is proportional to the difference in concentration between these two points. The contribution from photosynthetic process depends on the number of algae and amount of available sunlight. This process takes place only during day light hours and respiration at night institutes an outgo.

The reaeration co-efficient can be estimated by determining the characteristics of the stream and using one of the empirical formulae (table 9). The equation forwarded by O'Conner and Dobbins (1956) was used for this purpose.

$$K_2\text{/day (base 10)} = \frac{(D_L v')^{1/2}}{2.303(H')^{3/2}} \qquad \ldots \quad (11)$$

The values for $K_2$/day (20°C) are plotted in the figure 37b. The envelope $A_1A_2$ and $B_1B_2$ enclose the values of the co-efficient which were obtained for the river reach between stationsI and VII, during the period of survey November 1980 to September 1982. The fluctuation in the value of $K_2$ is caused due to the action of the tides on the river affecting both stream velocity and depth. The extent

Table 9. List of formulae for reaeration coefficient $K_2$/day

| $K_2$/day | Reference |
|---|---|
| $\frac{(D_L\ v')^{1/2}}{2.303\,(H')^{3/2}}$ | O'Conner, D.J., 1956 |
| $\frac{1105\ D^{1/2}\ S^{1/4}}{d^{5/4}}$ | O'Conner, D.J. and Dobbins, W.E., 1958 |
| $\frac{0.98\ (D\ v)^{1/2}}{d^{3/2}}$ | O'Conner, D.J., 1958 |
| $\frac{11.6\ v^{0.969}}{d^{1.673}}$ | Churchill, M.A., 1962 |
| $\frac{2.63 \times 10^{-4}\ (vSg)^{0.408}}{d^{0.66}}$ | Krenkel, P.A., 1962 |
| $\frac{3.3\ v}{d^{4/3}}$ | Langbein, W.B., 1967 |
| $24.9\ [1 + \frac{v^{1/2}}{(gd)^{1/4}}]\ (\frac{Sg}{d})^{1/2}$ | Thackston, F.L., 1969 |

D = Molecular diffusivity of $O_2$ in water ($ft^2$/sec)

$D_L$= Molecular diffusivity of $O_2$ in water ($m^2$/day)

v = Velocity of stream (ft/sec)

v'= Velocity of stream (m/day)

d = Mean depth of river (ft)

H'= Mean depth of river (m)

S = Slope of river .

in the value of $K_2$ was recorded during March and April which ranged between 0.09 and 0.51. This was the period when river discharge was generally low ($\approx$50-60 $m^3$/sec) and the effect of the tides were the maximum. But during monsoon (June-September) the flow in the river was strong and tides had little or no effect on the stream velocity. The values for reaeration co-efficient $K_2$/day were more or less constant, $\approx$ 0.18, during this period. During October-December, the value varied between 0.12 and 0.45. The temperature co-efficient value 1.024 was adopted to correct the $K_2$ value to desired temperatures.

7.5. Study of DO deficits during the ambient survey using the co-efficients $K_1$ and $K_2$.

The dissolved oxygen (DO) deficits from saturation values at stations I to VI were observed for the dates noted in the table 10 (-ve deficits indicate higher DO) content than the saturation values). The deoxygenation and reaeration co-efficients $K_1$ and $K_2$/day at respective temperatures on dates of investigation are also given in the table. These co-efficients were calculated for each of the days of observation related to stream flow conditions and did not vary by more than ±0.005 between different stations. The deficits are calculated using the

Table 10. Results of DO deficits, observed and calculated.

21.1.1981

| $K_1$/day 28.8°C | $K_2$/day 28.8°C | Station | Observed deficit | Calculated deficit (sag equation) | Calculated deficit (Thomas Nomogram) |
|---|---|---|---|---|---|
| | | I | - | - | - |
| | | II | +0.54 | - | - |
| | | III | +0.76 | +0.57 | +0.76 |
| 0.2768 | 0.2716 | IV | +0.04 | +0.75 | +0.80 |
| | | V | -0.09 | +0.07 | +0.23 |
| | | VI | +0.03 | -0.06 | +0.13 |

6.2.1981

| 25.5°C | 25.5°C | | | | |
|---|---|---|---|---|---|
| | | I | +1.57 | - | - |
| | | II | +1.75 | +1.54 | +1.52 |
| | | III | +1.51 | +1.74 | +1.52 |
| 0.3218 | 0.3645 | IV | +1.64 | +1.51 | +1.59 |
| | | V | +1.47 | +1.63 | +1.55 |
| | | VI | +1.94 | +1.46 | +1.37 |

15.5.1981

| 28.0°C | 28.0°C | | | | |
|---|---|---|---|---|---|
| | | I | -1.14 | - | - |
| | | II | -0.57 | -0.76 | +0.21 |
| | | III | +0.01 | -0.55 | -0.54 |
| 0.2888 | 0.4318 | IV | +0.20 | +0.02 | +0.13 |
| | | V | -0.18 | +0.03 | -0.18 |
| | | VI | -0.32 | -0.16 | -0.26 |

Cont..

19.6.1981

| /day .0°C | $K_2$/day 26.0°C | Station | Observed deficit | Calculated deficit (sag equation) | Calculated deficit (Thoma Nomogram) |
|---|---|---|---|---|---|
| | | I | -3.11 | - | - |
| | | II | -2.54 | -2.99 | -2.79 |
| 1316 | 0.1564 | III | -2.73 | -2.53 | -2.51 |
| | | IV | -2.73 | -2.72 | -2.82 |
| | | V | -3.30 | -2.72 | - |
| | | VI | -3.30 | -3.28 | -3.28 |

2.9.1981

| .2°C | 27.2°C | | | | |
|---|---|---|---|---|---|
| | | I | -1.37 | - | - |
| | | II | -0.90 | -1.23 | -1.05 |
| .0615 | 0.1806 | III | -1.23 | -0.89 | -1.18 |
| | | IV | -0.70 | -1.22 | -0.69 |
| | | V | -1.63 | -0.69 | -1.10 |
| | | VI | -0.97 | -1.61 | -1.56 |

oxygen sag equation and also by applying 'Thomas Nomogram' method (Thomas 1948).

The observed and calculated values for DO deficits are comparable. The calculations pertain to the period when no organic loads were placed on the river. The close agreement between the observed and calculated values are helpful to extend these analyses to a hypothetical situation to obtain the DO content on applying known BOD loads on the river.

7.6. Prediction of downstream dissolved oxygen content on imposing organic loads

The following paragraphs discuss the application of the oxygen sag equations to plot the profiles of dissolved oxygen by imposing different BOD loads on the river. The analyses incorporated the physical situation, such as the location of discharge of effluents, influence of tides and division of discharge due to the branching of the river. The river water quality/quantity parameters are first discussed, followed by those of the effluents (or organic waste loads). The objective of these analyses are to predict the effects of discharge of effluents on the river in terms of the oxygen depletion and verify the results in actual situations when the newsprint factory goes into production. The results will also be helpful to estimate the organic waste assimilative capacity of the river.

a) The parameters of the receiving water body

The river DO content was observed to be nearly saturated values during the entire period of ambient survey. Hence the value for DO is adopted as the saturation value at the selected temperature. The saturation value for dissolved oxygen is taken from tables given in APHA, 1960. The range of temperature of the river water was generally observed between 26 and 30°C. For the purpose of this study the temperature is choosen as 27.5°C. The most frequently occurring value of river water BOD (5 days) (20°C) was 1.5 mg/l. Hence this value is accepted as the BOD of the river and the ultimate BOD ($L_o$) is calculated using the reaction rate, $K_1$/day (20°C).

The discharge in the river ranged from 50 $m^3$/sec to 450 $m^3$/sec. The lowest discharge in the river (≈50 $m^3$/sec) occur during January to April every year under the present conditions. This period provides comparatively limited period also exhibits greater tidal influence on the river. The model for downstream DO using the sag equation is applied for steady discharges of 50, 100 and 200 $m^3$/sec (as measured at an upstream station where tides have no effects). Since the outfall and downstream is situated in the tidal zone, the modifications in river flow brought about by the low and high tides are also incorporated in two of the above cases.

The variations in stream velocity, depth and other parameters of the river were recorded at discharge point and downstream during the high and low tides at definite intervals of river reaches for various river discharges. Applying the values derived from studies on the interaction of tides with river, the reaeration co-efficient $K_2$/day is calculated in each case for every 2 km stretch of the river downstream of the discharge point and is corrected for the temperature of the mixture of river water and applied waste load. The values at 20°C varies from 0.09 to 0.18 and 0.38 to 0.51 during the high and low tides respectively for steady discharge of 50 $m^3$/sec and from 0.14 to 0.21 and 0.24 to 0.32 for steady discharge of 100 $m^3$/sec. Variation in $K_2$/day value brought about by tidal fluctuations for discharges >150 $m^3$/sec were less than

$\pm 0.02$ and this did not significantly affect the accuracy of operation of sag equations. A generalised value 0.18 is selected for $K_2$/day (20°C) for river discharges greater than 150 $m^3$/sec.

As far as the deoxygenation co-efficient $K_1$/day is considered, the most frequently occurring value of 0.275 at 20°C has been selected during the low discharge periods and 0.12 (20°C) for higher discharges.

The analyses presented here pertains only to the Murinjapuzha branch of the Muvattupuzha river. For the other branch, namely Ittupuzha, the oxygen balance studies become complicated by the regular exchange of water through two of its tributaries and due to the predominant tidal effectsat its opening. Observations had revealed that the Ittupuzha river mouth region wasfrequently affected by the salt water incursions from the Cochin backwaters, just sufficient to cause saline conditions. The analyses are limited to unidirectional flow and does not incorporate the presence of a two way flow or additional input sources. The active mixing processes at the Ittupuzha river mouth also cannot be considered within the formulations for sag

b) The parameters of organic waste loads

The significant parameters of effluents are the discharge rate, temperature, dissolved oxygen and BOD. It was estimated that the quantity of effluents would vary between 0.3 and 0.8 $m^3$/sec from the newsprint factory. A realistic value of 0.6 $m^3$/sec is choosen as the discharge rate for effluents taking into account the design flow of the outfall installations of the factory.

The temperature of the effluents may vary in a large range of values, say 26°C to 45°C. Considering the capacity of the treatment lagoons attached to the factory to hold a large volume of waste water, it was concluded that the temperature of the discharging effluents are likely to be close to that of the ambient temperatures. Nevertheless the temperature may be slightly higher than the surroundings due to the exothermal processes during biodegradation of organic waste. The value 30°C is adopted as the temperature of the effluents (observed values ranged between 30°C-31.5°C).

The dissolved oxygen content of the organic matter varies between zero and near saturation values, depending on the quality of the waste. But generally the oxygen content will be low, ranging between 0 and 3.5 mg/l. For the purpose of this analysis, the worst condition of zero value is adopted and incorporated for DO in the calculations.

The BOD of the organic waste varies from 2 mg/l to 1000 mg/l(or sometimes to high values of 5,000 mg/l). It was not possible to fix a probably range for the BOD (5 days) (20°C) of the effluents expected to be discharged from the newsprint factory. Hence maintaining other parameters a constant for every reach of the river, the oxygen sag equations are operated for BOD (5 days) (20°C) values of 10,30,50,100,250,500,1000 and 5000 mg/l.

c) Oxygen sag curves

The oxygen sag curves are given in figures 38,39 and 40 for steady discharges of 50,100 and 200 $m^3$/sec respectively For every steady discharge condition, two different situations arise: one due to the high tide (figure 38a, 39a) and other due to the low tide (figure 38b,39b), causing variation in flow and thereby affecting the reaeration processes. Figure 40 considers only the case of steady discharge

since flow modifications due to the tides were not significant to affect the oxygen balance, especially with large scope for dilution. The figures indicate the remaining dissolved oxygen in mg/l at various reaches of the river downstream of station III upto Murinjapuzha river mouth (0-12.5 km). The organic waste loads expressed in

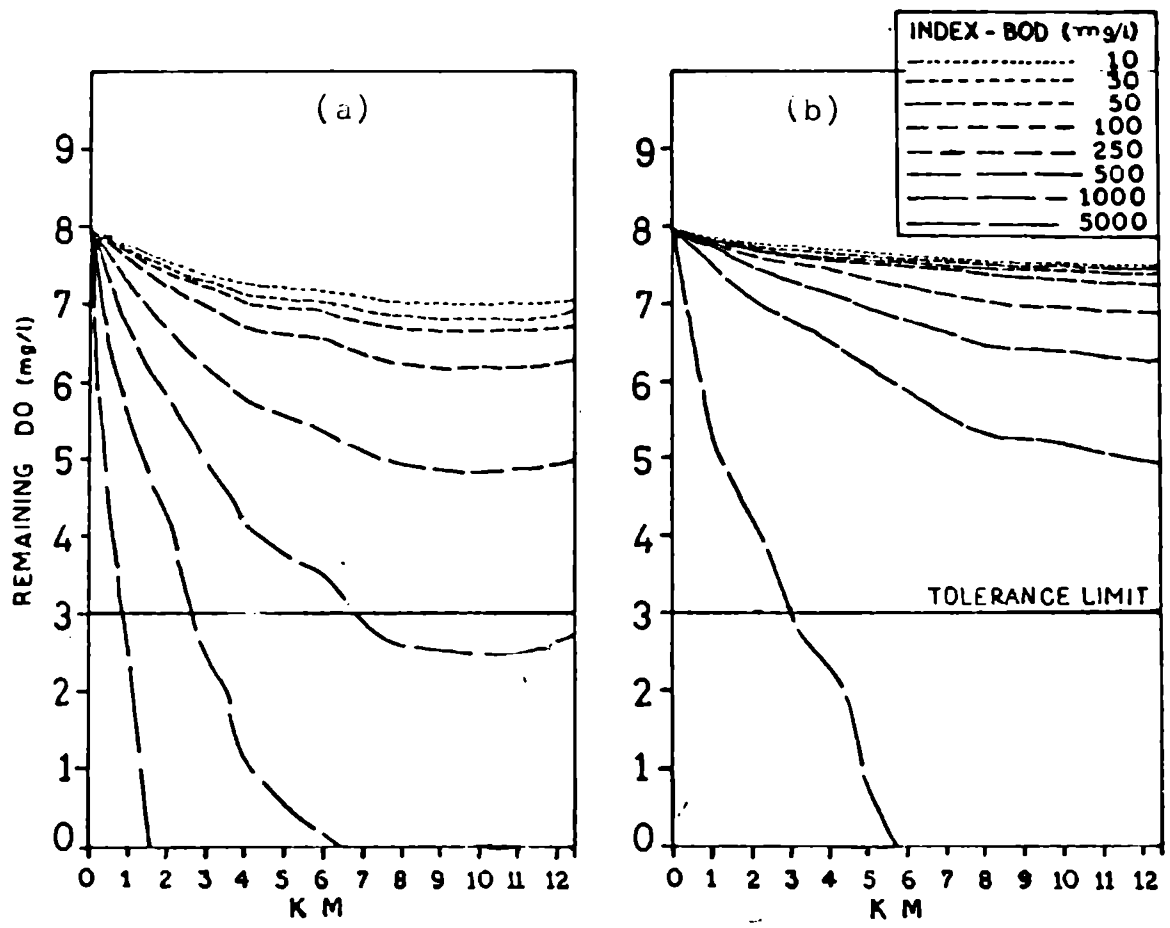


Fig.38. Oxygen sag curves for steady discharge of 50 $m^3$/sec. Fig.38a corresponds to profiles during high tide and Fig.38b corresponds to profiles during low tide

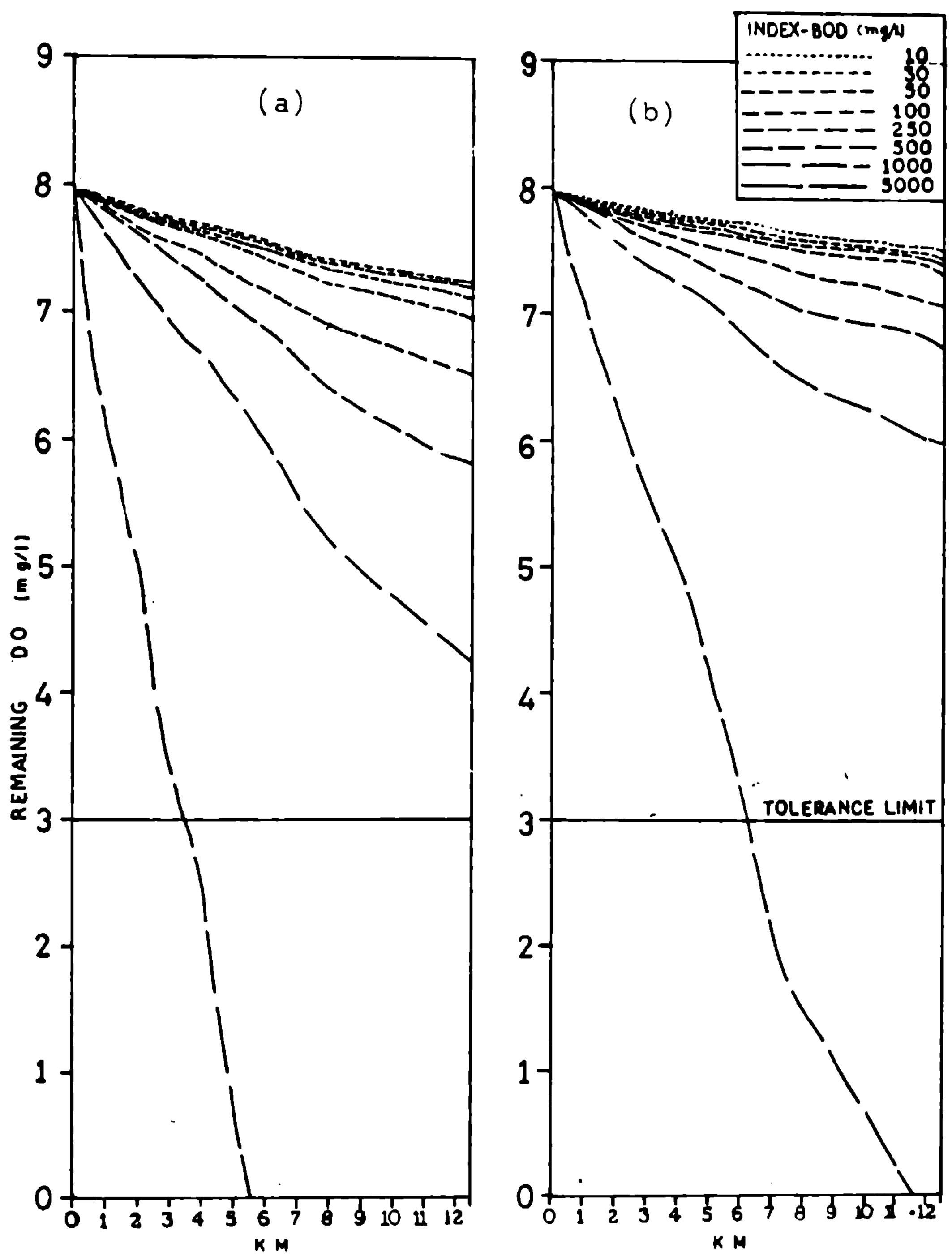


Fig.39. Oxygen sag curves for steady discharge of 100 $m^3$/sec. Fig.39a corresponds to profiles during high tide and Fig.39b corresponds to

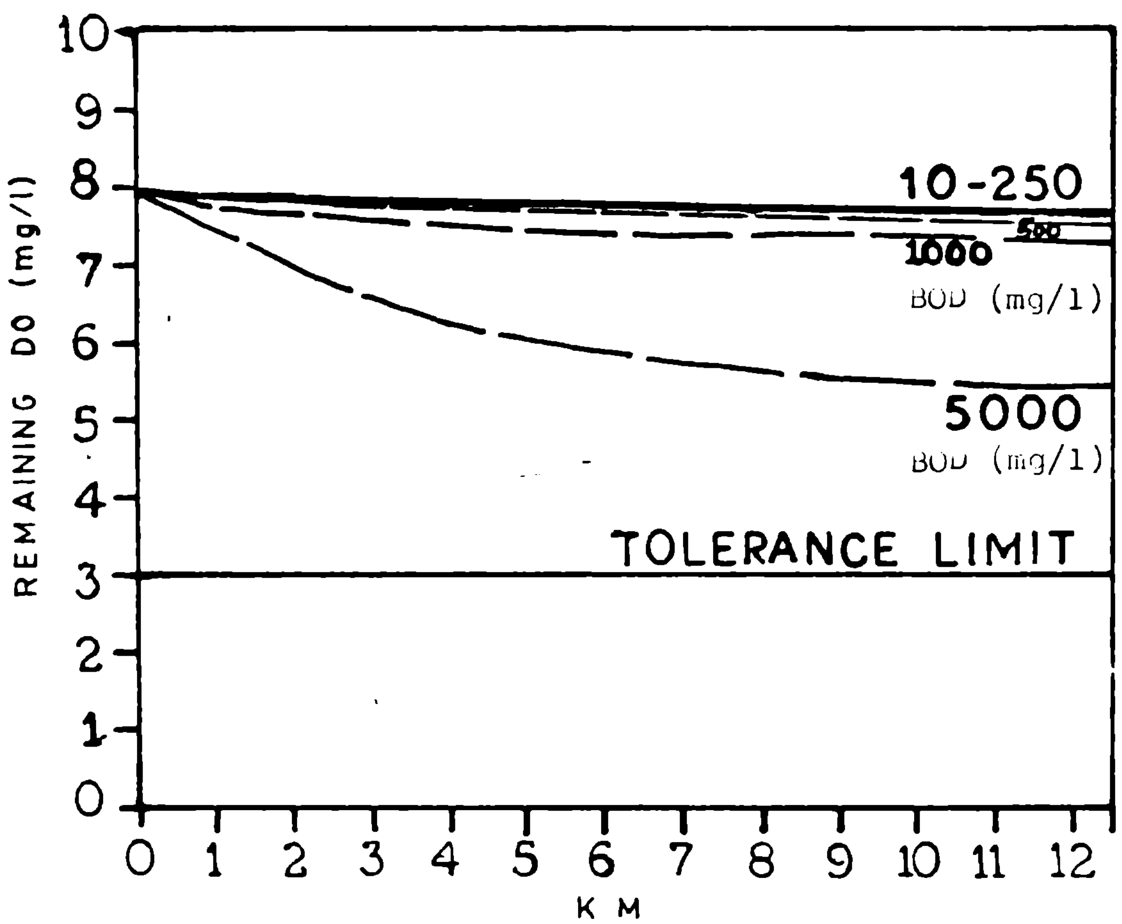


Fig. 40. Oxygen sag curves for steady discharge of 200 $m^3$/sec

ranging from 10 mg/l to 5000 mg/l (refer index in figures). All figures indicate the tolerance limit for remaining DO (chapter 3) as 3 mg/l.

Figure 38a indicates that the dissolved oxygen,sag below the tolerance limit for waste loads of 500 mg/l BOD. The critical point lies at 10 km from the discharge point (2.45 mg/l). For BOD loads greater than 500 mg/l complete depletion of oxygen is likely to occur as noted from the profiles for the 1000 mg/l and 5000 mg/l BOD. For lower BOD loads, the river DO at critical point varies between 6.95 mg/l at 18.8 km* (10 mg/l BOD) and 4.8 mg/l at 9.8 km (250 mg/l BOD). The curves obtained during the low tide (figure 38b) (i.e. river discharge is higher than at other times) indicate that the assimilative capacity of the river is enhanced to BOD values just over 1000 mg/l. The sag curve for 1000 mg/l BOD does not lower the DO below 4.5 mg/l in any part of the river. A value of 2000 mg/l BOD may not even decrease the DO below the tolerance limit. Any BOD waste loads of 500 mg/l or less would not cause the DO to sag below 6 mg/l. Both these conditions described in figures 38a and b occur at different stages of the tide for the same steady flow; comparatively, the lower sag profiles in figure 38a are to be considered to fix the give the profiles of the oxygen sag curve during the high and low tides when the steady discharge is 100 $m^3$/sec. Because of the higher dilution available to the discharged effluents, the oxygen content does not sag lower than the tolerance limit for BOD of 1000 mg/l. During high tides, when the discharge is relatively lower than at low tides, a waste load of 5000 mg/l BOD brings down the DO to near zero conditions within 6 km of outfall. Figure 40 pertains to the sag curves for a discharge of 200 $m^3$/sec. The influence of tides, though noticed at the outfall region and downstream reaches of the river, do not interfere with the calculations for the sag curves. A change in river DO is noticed for the 5000 mg/l BOD load, indicated by the maximum variation of 2.5 mg/l in remaining DO in the river. It is evident from the figure that all the profiles for different waste loads lie well above the tolerance limit and under such conditions, the demand on DO of river water is nominal due to the decomposition of organic wastes.

7.7. Verification

The predicted sag curves were verified on two dates, 17.3.1982 (figure 41) and 15.6.1982 (figure 42).

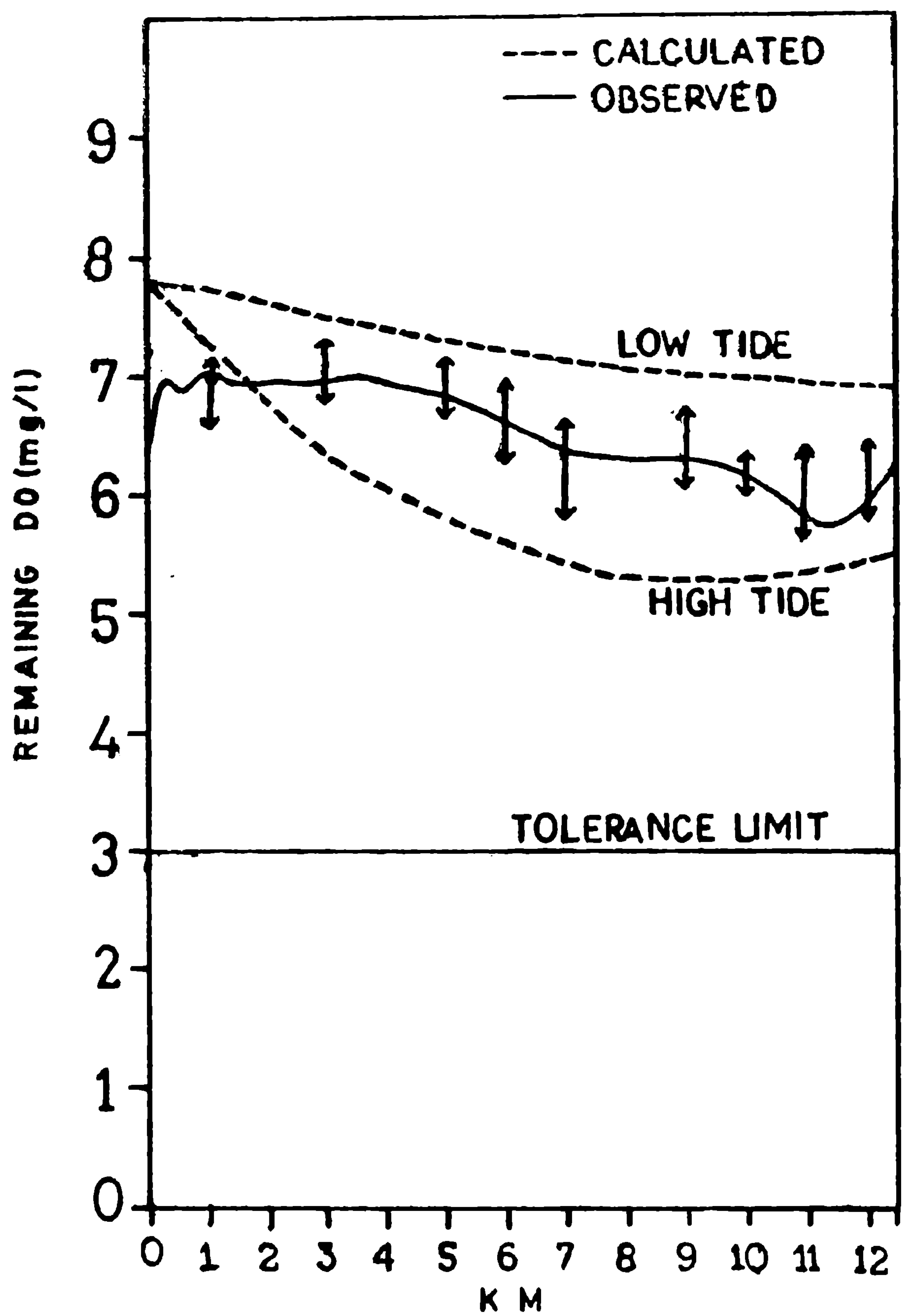


Fig. 41. Oxygen sag curve, observed and calculated on 17.3.1982

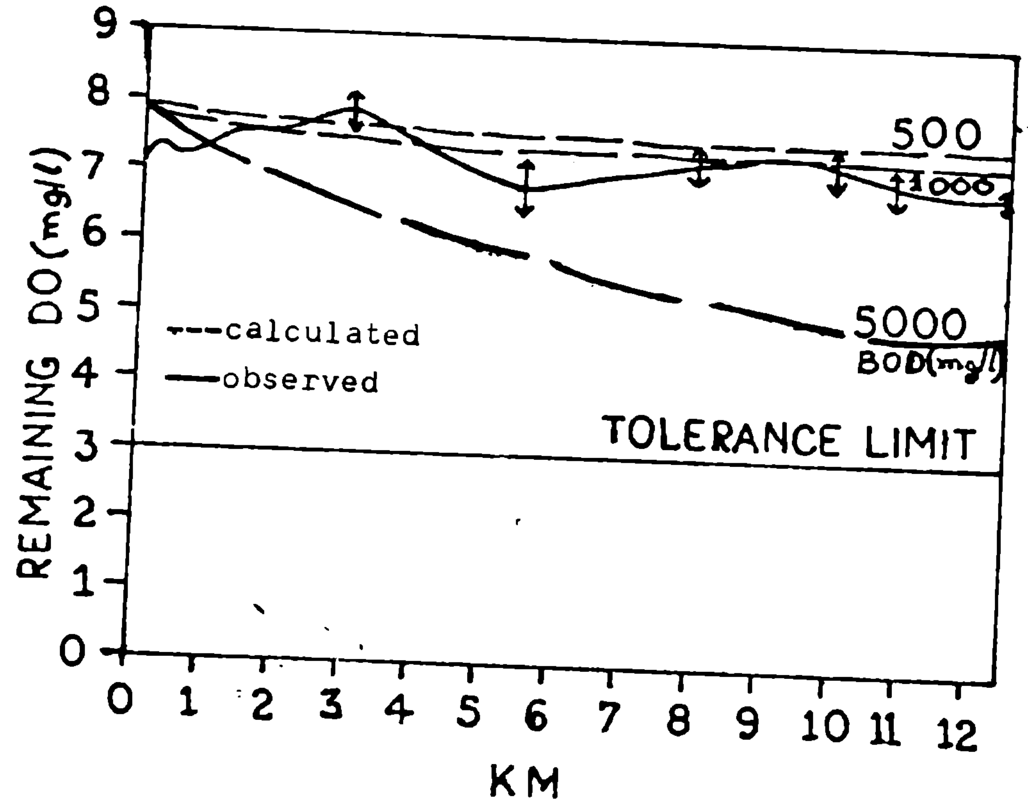


Fig. 42. Oxygen sag curve, observed and calculated on 15.6.1982.

a) Case 1: (17.3.1982)

The receiving water body characteristics were identical to the conditions adopted for modelling except that the river water temperature was slightly higher (29°C). The steady upstream river discharge was estimated as 52.8 $m^3$/sec and the influence of tides were observed similar to the conditions studied earlier. The effluent characteristics were as follows: discharge 0.6 $m^3$/sec, temperature: 31.5°C, DO = 0 mg/l and BOD = 250 mg/l. The sag curves are drawn incorporating the above characteristics.

The figure 41 indicates the calculated sag curves during high and low tides for 250 mg/l BOD load. Also the observed values of remaining DO on 17.3.1982 (24 hrs data) at respective downstream locations are plotted in the figure. The mean values are joined by a smooth curve. The close agreement between the calculated and observed values point out that the results of prediction was accurate enough to describe the downstream distribution of DO.

b) Case 2: (15.6.1982)

The steady discharge in the river was observed as 198.6 $m^3$/sec on the date of investigation, 15.6.1982. The

was insignificant. Upstream river water DO was nearly saturated and water temperature was 27.3°C. The effluent discharge rate was 1.0 $m^3$/sec and BOD varied between 500-1200 mg/l with occasionally high values of 5000 mg/l. (DO = 0 mg/l and temperature = 29°C)
The figure 42 gives the profiles of sag curve, for both calculated (500, 1000 and 5000 mg/l BOD loads) and observed, under conditions described above. Good correlation exists between the observed and calculated sag curves. The values of observed remaining DO are slightly lower than the calculated values near the outfall region (0-1 km). This is because complete mixing of effluents with river water does not occur instantaneously on discharge.

# CHAPTER 8

# SUMMARY AND CONCLUSION.

CHAPTER 8

# SUMMARY AND CONCLUSION

## 8.1. Introduction

An investigation on the dynamics and water quality of the Muvattupuzha river in relation to the water resources planning, with special emphasis on the discharge of effluents from Kerala Newsprint Factory was carried out. Fortnightly surveys of the water quality parameters were carried out at seven stations in a reach of 16 km of the river from November 1980 to middle of March 1982, prior to the commencement of discharge of effluents. Studies were also made on the flow characteristics of the river. Two field experiments were conducted to understand the dispersion pattern at the region of the outfall. Since the commencement of the effluent discharges from middle of March 1982, more detailed surveys were carried out in the river reach under study, with more number of stations. On two occasions, the downstream river stretch was severly polluted owing to strong effluent discharge. The study covers the period upto September 1982 (Annexure II). The organic waste loading capacity of the river was determined with the aid of the oxygen sag equations and the model was verified.

## 8.2. The river regime and water resource projects

The river regime located in the south central part of Kerala is of significant importance with regard to water utility and transporting facilities. The eastern portions of this river basin are high lands. The slope of the river is steep in this region and its width is comparatively small. In the mid-lands three tributaries join together. In the low lying regions (around MSL) the typical riffle-pool sequence is observed. A few deep pools are located near the river mouth. The climatic conditions favour one peak discharge period in June-July months followed by an irregular secondary peak in October. The catchment area of 1554 $km^2$ enjoys on an average 300 cm of annual rainfall. The west-ward flowing river has two outlets into the Cochin backwaters. Saline waters (5-15‰.) used to enter the river during February-April months due to tidal action till 1976.

The lowest discharges (4 to 7 $m^3$/sec) in the Muvattupuzha river occurred during February which increased to about 300 $m^3$/sec during June-July. But from late 1976 onwards the river flow conditions drastically altered subsequent to the discharge of tail race waters from Moolamattom power station (19.83-78.50 $m^3$/sec). Since then the minimum discharge (February-April) is $\approx$ 50 $m^3$/sec water incursions into the river are no more observed. The effect of tides is limited to periodic rise and fall of water level in the lower reaches of the river with no upstream currents. The river water serves all the requirements of the locality and is utilised for agriculture, domestic purposes, recreation etc.

Subsequent to the construction of Idukki reservoir and Moolamattom power station, water resources programmes were aimed at utilising a major portion of the tail race discharges for agricultural purposes. Towards this a balancing reservoir has been constructed at Malankara to divert water at the rate of 33.58 $m^3$/sec. Under the present conditions, this would cause considerable reduction in the flow downstream resulting in the development of tidal currents inside the river. The salt water intrusions may lead to alterations of the fluvial ecosystem.

8.3. Industrial unit

The factory located at Velloor on the bank of the river is 12.5 km upstream of Murinjapuzha river mouth. The newsprint mill of Hindustan Paper Corporation of 400 tonnes production capacity deploys a combination of chemi-mechanical and chemical pulping. The conventional sulphite process is adopted in this factory also. The mill requires water upto 1.5 $m^3$/sec (taking into account the principal and supporting demands) which is drawn from the Muvattupuzha river. The factory discharges treated effluents into the river just downstream of Piravom Road railway station. The treatment system mainly consists of a clarifier, a cooling pond (presently used as a sedimentation pond) and aerated lagoons (total aerators 16 numbers). The system is purported to be capable of purifying the effluents to a level below the limits laid down by the Pollution Control Board. Details of the treatment system are given in Annexure I.

8.4. Water quality

The results of the studies on the quality of the river water, effluents and the water after receiving effluents are presented in table 11.

The water quality prior to effluent discharges indicates good potable water of high standards. The water is nearly saturated with DO (6.0 to 11.5 mg/l) and pH lies within 6.85 to 7.20. Amount of suspended solids are low (2 to 30 mg/l) and BOD values are between 0.5 and 3.0 mg/l. The nutrient content is generally low and amount of mercury in river water is 0.0005 mg/l or less which lies

Table 11. Results of investigations on water quality.

| Parameter | Ambient water quality | Effluent quality | River water quality after receiving effluents | Tolerance limit (Indian Standards) | Remarks |
|---|---|---|---|---|---|
| General appearance | Calm flowing river. No presence of oil, tar etc. | Foaming, soapy appearance. Presence of oil and grease. | Foam forming tendency. Presence of oil and grease in patches. | Foaming not permitted. Oil and grease $\not>$ 0.1 mg/l. | The discharge contains drain water. |
| Colour | No noticeable colour. (<40 Hazen units) | Brown to dark brown. (50-150 Hazen units) | Brown bands and patches visible. (max. 210 Hazen units) | River water colour +100 Hazen units. | |
| Taste | Palatable | Highly objectionable. | Disagreeable | Preferably palatable. | |
| Odour | Slightly vegetable | Musty and organic (Persisting smell of mercaptans) | Not highly objectionable | Should not be objectionable | |
| Transparency (Extinction Coefficient) | Low extinction Coefficient (1.14-2.0) | - | High extinction Coefficient (2-4) | Water should be clear, and hygienic. Should give a healthy appearance. | High turbidity causes high extinction coefficient. |
| Temperature (°C) | 25.5-30 | 30-31.5 | 26-30.5 | Preferably ambient. Shall not exceed 40°C | |
| Salinity (‰) | Fresh water conditions observed throughout. | | | | No salt water incursions |
| pH | 6.85-7.20 | 5.80-8.35 | 6.25-7.85 | 6-9 Potable range 6.5-7.8 | |

(Contd...)

| Parameter | Ambient water quality | Effluent quality | River water quality after receiving effluents | Tolerance limit (Indian Standards) | Remarks |
| --- | --- | --- | --- | --- | --- |
| Dissolved Oxygen (mg/l) | 6.0-11.5 | 0-7 | 5.5-10.0 | 40% of saturation value or 3 mg/l which ever is higher | River water DO not lowered below tolerance limit. Effluent quality however does not conform to standards |
| Biochemical oxygen demand (mg/l) (5 days) ($20^{o}C$) | 0.5-3.0 | 10-5000 | 1.5-50 | $\not>$ 30 | |
| Nutrients µg at/l | | | | | |
| $NO_2^-$-N | 0.025-0.09 | Not analysed | 0.30-0.50 | - | Presence of excess nutrients may cause eutrophication. Presence of blue-green algae noticed in lagoons. |
| $NO_3^-$-N | 0.100-1.00 | | 6.00-10.00 | - | |
| $PO_4^{\equiv}$-P | 0.100-0.33 | | 0.65-1.25 | - | |
| Suspended solids (mg/l) | 2-30 | 40-4500 | 50-140 | $\not>$ 100 | |
| Total organic carbon (%) in sediments | 0-1.5 | - | 1.5-9 | - | |
| Mercury (mg/l) in river water | 0.0005 | 0.002-0.08 | 0.0012-0.05 | 0.01 for effluents, 0.0003 for drinking water | |

close to the tolerance limit of 0.0003 mg/l. The river water presents a very healthy appearance and is used for all domestic and agricultural purposes.

The studies on the quality of river water after receiving the effluents indicate that the water has been considerably polluted downstream of the outfall. The effect is significant for a few km ( $\approx$ 7 km) downstream of the outfall. Partial recovery is achieved further downstream. Colour, suspended solids, nutrients, organic carbon and mercury were studied to estimate the alterations of the river water quality.

The discharge of effluents of colour brown to dark brown imparting an unpleasant shade to river water gives a very unhealthy look. Though colour is not a pollutant by itself, it may be construed as an indicator of the ineffectiveness of effluent treatment and mostly appeals to the aesthetic values. Presence of oil, grease, floating particles of pulp fibres and frequent appearance of froth and disagreeable taste have been noticed downstream of the outfall. Transparency of the river water was also affected adversely. The pH of the discharge waste water varied between 5.80 and 8.35. The variations in pH were noticeable over long reaches of the river. The DO content of effluents

On many occasions the DO was lower than 3 mg/l or 40% of the saturation value. However the DO in river water was never lowered below the tolerance limit. The BOD of the effluents varied between 10 mg/l and 5000 mg/l. The high BOD value of discharged wastes do not conform with standards laid down by the Pollution Control Board. The river water BOD varied between 1.5 mg/l and 50 mg/l after receiving the effluents.

The factory effluents also contained large amounts of nutrients and suspended solids. The presence of blue-green algae was frequently observed in the treatment lagoons and in discharged waters. Excess nutrients are known to cause eutrophication. The suspended solids in factory effluents were generally higher than the tolerance limit of 100 mg/l. The river water which contained only 2 to 30 mg/l of suspended solids prior to discharge of effluents exhibited values around 50 to 140 mg/l since the discharge started. The solid particles settle on the river bed and are likely to turn into secondary sources for pollution. The organic carbon content of sediments collected from the pools downstream of the discharge point were high (1.5 to 9.0%). Persisting presence of mercury in levels ranging from 0.0012 mg/l to 0.05 mg/l found in the river water during the survey poses a serious environmental problem. Use of river water contaminated with mercury compounds is highly objectionable. The concentration of mercury has to be limited to levels prescribed by IS:2490 and IS:7968, IS:7967.

8.5. Physiography and flow characteristics

The discharge in the river exhibits a single peak followed by an occasional secondary peak corresponding to the amount of rainfall. The correlation between rainfall and river flow has been discussed in chapter 5 in detail. The effect of tail race discharge since late 1976 is clearly shown at Thodupuzha and Muvattupuzha gauging stations when compared to the long term averages. The studies on the interaction between the tides and river flow indicate that the lower river reach of about 30 km is affected by the tides by way of increase and decrease in river discharge corresponding to the low and high tides. Two situations are investigated in detail and the value of the minimum discharge ($30\pm2$ $m^3$/sec) is worked out for a typical tide just to prevent upstream flow at outfall point.

The studies are extended to hypothetical situations and the results of interaction of tides with river discharge are discussed. The implications of the water resources programmes are discussed in light of the tidal behaviour of the river. The commissioning of the Malankara reservoir will decrease the present discharge in Muvattupuzha river by 60 to 70% resulting in salt water incursions extending upto Pazhur, upstream of the effluent discharge point. In this event, the quality of water may not be suitable for factory requirements and the presence of a two-way flow in the river will cause severe pollution problems.

8.6. Dilution and dispersion

The dispersion pattern at the effluent outfall region was studied by conducting two tracer experiments (chapter 6). The dispersion at the outfall is not effective enough to cause the required dilution of the effluents. The location of the outfall has drawbacks with regard to the upstream slope, back currents and curvature effect apart from the deficiency in design of the diffuser port.

8.7. Waste assimilative capacity

The sag curves for waste loads ranging from 10 mg/l to 5000 mg/l BOD (5 days) (20$^{o}$C) were derived for minimum river flows caused by the influence of high tides. The effect of imposing a waste load of 500 mg/l BOD resulted in the decrease of dissolved oxygen to values lower than 3 mg/l downstream of the outfall. The relevant standards dissolved oxygen of the (river) water as 3 mg/l or 40% of saturation value, whichever is higher, after receiving the effluents. The remaining DO in river sags below the tolerance limit for BOD loads equal to or greater than 500 mg/l at points nearer to the outfall. Under the present conditions in order to maintain the entire stretch of the river downstream of outfall well above the tolerance limit for DO, a value of BOD 300 mg/l has been estimated as the maximum assimilative capacity for this river. This value accommodates the changes in hydraulic characteristics of the river and effluents within limits. It may be noted that the above value is worked out assuming instantaneous mixing of effluents with all the available river water and that the reaction is first order. The suggestion of the above capacity value does not imply that the statutory tolerance limit of BOD 30 mg/l enforced by the Water Pollution Control Board can be overlooked. In the long run presence of pools, fresh waste additions, abstraction of water, hydraulic design variations may adversely affect the oxygen balance in the river. The suggested value will no longer hold true, once the diversion at Malankara reservoir reduces discharge in the downstream reaches of the river and a two way flow is established by the tidal fluctuations acting through the Cochin barmouth.

8.8. Sludge disposal

An impending problem of pollution is connected with the disposal site for sludge material. The location is half way down the effluent pipe line and the place was formerly a paddy field. During monsoon, the entire region is flodded. The observations of the ground wells have shown that the water table slopes from this disposal land towards the river side. The sludge, contains cooling pond waste, organic matter like fibre bits pulping wood chips, cinder ash, lime-mud etc. The sludge material is not given any pre-treatment before disposal and this is likely to cause severe ground water pollution in due course. The fields may turn to be a large pool of decomposing sludge in rain water collections. The possible presence of compounds of mercury is not ruled out in this sludge material. The above practice warrants attention and review.

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ANNEXURE I

EFFLUENT DISPOSAL SYSTEM OF KERALA NEWSPRINT MILL, VELLOOR

The Kerala Newsprint Mill, Velloor a Rs 125.00 crore unit of Hindustan Paper Corporation Ltd. has an annual production capacity of 80,000 tons of newsprint paper. Newsprint will be produced from 70-80% Chemi-Mechanical pulp from Eucalyptus wood and 20-30% Sulphite chemical pulp from reeds, both available in Kerala forests. The monthly consumption of Eucalyptus will be around 13,000 tons and reeds 11,000 tons. Other items of materials required per month are as under:

| | |
|---|---|
| Coal | 8000 Tons |
| Caustic Soda | 2600 Tons |
| Salt cake | 2500 Tons |
| Lime | 2000 Tons |
| Alum | 420 Tons |
| Chlorine | 1000 Tons |
| Soap stone | 100 Tons |
| Hydrochloric acid | 10 Tons |
| Rosin (Organic) | 30 Tons |
| Furnace Oil | 28.5 Tons |

The power requirement will be around 40 MW of which .5 MW will be from inplant generation and the remaining

25 MW from the state's power grid. The mill when it starts production to its normal capacity is expected to consume 36 million litres of fresh water per day drawn from Muvattupuzha river for its various processing plants.

The elaborate and efficient effluent treatment system being installed at a cost of more than Rs 2.50 crores will ensure that the pollution of the river water due to the effluents will be negligible and within the control limits laid down by the Kerala State Board for Control and Prevention of Pollution of water.

This being a newsprint mill based on 70-80% Chemi-Mechanical pulp and 20-30% Chemical pulp, will exert only one fourth of the total pollutional load as compared to an integrated (chemical) pulp and paper mill of similar capacity elsewhere. Effective inplant pollution control measures include modern pneumatically operated gates (to divert black liquor drained in spill collection tanks to the processing units for re-use; to divert calcium hypo-chloride underflow to a clarifier; thus facilitating colour reduction) and mechanical foam breakers on various black liquor tanks.

Major pollutants of concern to the paper industry are temperature, BOD ( Biochemical Oxygen Demand), D (Chemical Oxygen Demand), colour, dissolved solids, spended solids and acidity or alkalinity. There is no ngle treatment process that can effectively remove all ese contaminants and multiple stage purifying unit is sential.

The waste water treatment system of Kerala wsprint Mill is designed to conform with Indian Standards 90 Part I to suit a paper unit of 500 tons of capacity r day.

ste water from the mill includes the following:-

Uncontaminated equipment cooling water will be discharged directly along with the processed waste water.

Process waste water, containing only minor quantities of suspended solids (low solids sewer) will flow directly into the cooling pond and mixes with clarified high solids waste water.

Process waste water containing large quantities of suspended solids (high solids sewer) will flow through effluent clarifier.

FLUENT CLARIFIER

Initial mill operation is expected to produce a rmal high solids sewer flow of 2100 litres per minute. is flow will increase to 3000 lpm during periods of version or wash down in the pulp mill, resulting in hours of detention in clarifier. The 30 m dia. clarifier ill remove all solids which will settle at nticipated temperature of 60°C. The expansion of the ill could increase normal high solids sewer flow to 000 lpm resulting in 12 hours detention. In order to xpedite the sedimentation, suitable coagulants are added. rom the effluent clarifier, fibre sludge is obtained which ontains chemicals and chemical precipitates and in ome cases different types of biochemical sludge. he sludge is of a relatively low consistency and specially, biological sludge has to be treated in a ludge thickener. The sludge will be dewatered by vacuum ilteration for truck hauling to land fill disposal. Solid astes from the mill consists of 63 Tons of cinder ash, 0 Tons of lime mud and 14 Tons of dewatered sludge per day. ll these solid wastes are to be deposited in land area set part for this purpose.

OOLING PONDS

Cooling pond No.1 will receive approximately 8000 lpm combined waste water from the mill. The etention period in the cooling pond is 2.8 days. ooling pond No.2 will have 4 days detention period. xpansion of the mill could increase normal waste water low to 30,000 lpm resulting in 1.7 days detention in ıe cooling pond 1 and 2.5 days in the second pond. The asis for design of the cooling ponds is reduction of emperature from 52°C to 40° C of waste 30,000 lpm. The area of cooling pond ).1 is 3.12 hectare and that of the cooling pond No.2 is .25 hectare. While the waste water is detained in the ooling ponds sedimentation takes place. There are arrangeents for removal of sediments from both the cooling ponds eriodically, if found necessary.

ERATION PONDS

From the cooling pond effluent is conveyed to the rimary aeration pond having an area of 5 hectare. Twelve umbers 75 HP aerators are erected here. The npurity present in the waste water in the aeration onds is mostly carbon. This carbon is removed ıccessfully by the action of bacteria. The bacteria onsumes carbon, receives oxygen from the atmosphere and onverts the carbon into carbon dioxide. This process of ırification continues.

For the effective growth of bacteria the following avourable conditions are essential:-

. Normal temperature - The temperature of the effluent becomes normal (temperature of the surroundings) in the cooling pond itself.

. Dissolved air in water - Air is mixed with water by aeration. For this purpose 12 No.of aerators are provided in the primary aeration pond and 4 Nos. in the secondary aeration pond.

. pH value of the effluent in the aeration ponds will be maintained very near to 7. Acidity or alkalinity of water is measured in pH value. The pH scale runs from 0 to 14 with 7 as the point of absolute neutrality. Water with pH value 0 to 7 is acidic and that with pH value 7 to 14 alkaline.

. Nutrients: The proportion of Carbon, Nitrogen and Phosphorus must be 100:5:1. The deficiency in Nitrogen and Phosphorus is overcome by the addition of Urea and Phosphoric acid in the effluent before it reaches aeration ponds. The quantity of urea and Phosphoric acid is determined on the basis of the quantity of flow and the amount of deficiency.

Primary aeration pond is designed to provide 90% eduction of the expected average BOD load from initial ill operation of 8700 Kg/day, requiring only 20% additional eduction in the second pond. Expansion of the mill could ouble the BOD load, concurrently reducing the first cell etention. Reduction of BOD in the first cell would drop ) 85% requiring an additional 47% reduction in the second ell. The second cell having an area of 9 hectare has ifficient detention for future loadings.

The 1200 mm diametre outfall pipe line will have a apacity for high water discharge of 50,000 lpm waste water lus allowance for rain water collected in the treatment agoons.

The three stage effluent treatment involves edimentation, cooling and aeration. Sedimentation will ffectively reduce suspended solids by about 90% and to a level f 80 ppm against Indian Standard of 100 ppm. Cooling onds are intended to reduce the temperature from 60°C to 0°C which is optimum for microbiological activity. Aerated tabilization basin will help to bring down Biochemical xygen Demand by 90% to a level of 24 ppm against Indian tandard of 30 ppm by means of oxidation in the presence f externally added nutrients (nitrogen and phosphorus). The ffluent after final treatment will be discharged into the river nd ill be subjected to prompt testing in respect of physical, hemical, bacteriological and toxicological characteristics efore its discharge. The effluent discharged into he river will in no way adversely affect the fish life or rrigation.

The characteristics of the effluent will be aintained strictly in accordance with the Indian tandards and the conditions of consent by Kerala State oard of Prevention and Control of water pollution for ischarge of trade effluents.

## ANNEXURE II

Bibliography of events

| ate | Event |
|---|---|
| .11.1980 | Survey on ambient conditions of the river commenced with fortnightly periodicity. Two tracer studies performed. |
| ).8.1981 | 'Mathrubhumi', 'Deepika' and other daily newspapers report newsprint production from Kerala Newsprint Mill in near future. Detailed report on the factory and its functioning is given. |
| ).8.1981 | 'Indian Express' news service apprehends river pollution from Newsprint Factory effluents. Article published. |
| .9.1981 | Letters to Editor, 'Indian Express' contains review on pollution from effluents. |
| ).12.1981 | 'Mathrubhumi' reports people's agitation against discharge of pulp-paper effluents into Muvattupuzha river. On 9th December 1981 more than 200 boats conduct a procession in the river protesting for the above cause. |
| 7.2.1982 | 'Malayala Manorama' paper gives a brief account of production of newsprint quality paper from imported pulp at Kerala Newsprint Mill. |
| 2.3.1982 | Ambient study completed. Clear sewer water discharged. Cooling pond filled with paper machine waste and pulp (imported) wash (pH $\ngtr 4$). Fishes in the final aeration pond perish on receiving cooling pond overflow. |
| 3.3.1982 | Effluent discharge commenced at 10 p.m. River takes up initial dose of pollutants. |

| | |
|---|---|
| 15.3.1982 | Discharge rate increased (0.10 to 0.40 $m^3$/sec). A flume of suspended particles (pulp fibres and grit) is visible upto 200 m downstream along the river bank as a distinct brown band. Gradually bands split and disperse to 500 m downstream; light brown tint imparted to river water. Suspended matter content is high. |
| 16.3.1982 | Bands not distinctly visible, but colour of river water altered in the presence of effluents containing suspended matter. Water quality studies continued. |
| 17.3.1982 | Chemical plant waste bypass into clear sewer channel which drained directly into the river. Dark brown flumes noticed in the river. Absence of aquatic animals near outfall area noted. Slight odour felt. Downstream river surveyed. Clear sewer lane blocked and diverted into final aeration pond. |
| 18.3.1982 | Intermittant functioning of paper machine and chemical plants. Low content suspended matter discharged. River water is turbid. |
| 20.3.1982 | Presence of oil noticed. No flumes but turbidity persists. A few dead fishes noticed downstream. Dead fishes come from final aeration pond. |
| 22.3.1982 | Foam seen on river surface. Brown colour bands of nearly 3 m width visible upto 500 m downstrea |
| 24.3.1982 | Slight oily appearance and brown coloured bands turn black. Pollutional loads continuously discharged. |
| 26.3.1982 | Fish death occur in final aeration pond. Dead ones carried on to river. Light black flume visible. Downstream area is turbid. Effluent loads increase. |
| 28.3.1982 | Rainfall reported in the area. Effluent discharge decreases. Dead fishes once again noticed in the river. This is probably due to the improperly secured filter mesh at final check point. |

| | |
|---|---|
| 1.4.1982 | Effluent discharge nominal. Slight colouration observed. |
| 3.4.1982 | Reduced effluent discharge, slight turbidity conditions prevail. |
| 5.4.1982 | Staff report on pollution problems at Velloor highlightened in 'Mathrubhumi' daily. |
| 7.4.1982 | Large amount of blue-green algae noticed in the river which come from effluent ponds via discharge. Clarifier pipe line chocked. Paper machine wastes run directly into cooling pond. About 2 m thick sludge deposit in cooling pond giving rise to $H_2S$ production and large amount of foam at surface is noticed. Final aeration pond has thick growth of algae. Abnormal addition of nutrients. |
| 10.4.1982 | Large number of algae colonies noticed in the river along with suspended matter. Black flumes observed near outfall. Downstream of the outfall exhibits a dark green shade. |
| 13.4.1982 | Effluent discharge increases. Algae present. Distribution of algae colonies noticed upto 5 km downstream. |
| 18.4.1982 | Heavy effluent discharge continues. Only partial mixing is obtained at outfall. |
| 21.4.1982 | Fish die in the final aeration pond. Algal concentration is reduced. Overnight rains introduce slight turbidity on river surface. Pollutional loads are stronger. |
| 29.4.1982 | Moderate discharge of wastes. River appears turbid. |
| 30.4.1982 | Newsletter from 'Indian Association for Water Pollution Control' features a full article titled 'Saving a river from industrial pollution'. |
| 5.5.1982 | Low effluent discharge. No flumes visible. Light black shade to waters along outfall bank. Downstream waters are less affected. |

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| 10.5.1982 | 'The Hindu' published an article titled 'Saving a river from Industrial pollution', pertaining to Muvattupuzha river. |
| 17.5.1982 | Higher volume of waste water discharged. Mixing area extends upto 1 km downstream. |
| 22.5.1982 | Chemical recovery plant started on 21.5.1982. Black liquor presence noticeable. A clear black coloured band 3 m wide is visible for 750 m downstream. |
| 25.5.1982 | Overnight rains cause increase in river discharg Downstream of outfall is brownish coloured. |
| 2. 6.1982 | Rainfall increases. River surface slightly turbid. Amount of mixing increase as river flow increases. |
| 7.6.1982 | Outfall region visibly affected. Downstream area upto 1 km is coloured black. The colour is noticeable at river mouth, 12.5 km away. Stronger effluent discharges. |
| 15.6.1982 | River discharge pick up due to rainfall in catchment areas. Cooling pond desludged. Ponds are drained without any check on pollutional loads. Very heavy effluent discharges ( $\approx$ 100 $m^3$/sec) cause pollution. Odour of $H_2S$ and presence of froth for 5-7 km downstream. No trace of aquatic life. Heavy load of suspended matter noted and river colour turn dark brown to pitch black. 'Indian Express' reports the admission of a writ petition before the Hon'ble High Court of Kerala seeking restrain on HPC from polluting Muvattupuzha river. Petition also seeks direction to the Board for the Prevention and Control of Water Pollution to intervene and investigate. |
| 18.6.1982 | Moderate to heavy rainfall. Desludging is over. Discharge feeble from outfall. River recovery is slow. |
| 23.6.1982 | River discharge is very heavy. Very high dilution obtained for effluents. |

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| 1.7.1982 | High river discharge. Effluent discharge rate practically negligible. |
| 7.7.1982 | River banks overflow. Outfall pipe and gates submerged. |
| 22.7.1982 | Rains continue. Effects of pollution nominal. |
| 28.7.1982 | Riverflow decreases as rainfall ceases. Once again flume is visible extending 500 m downstream. |
| 13.8.1982 | Factory partially running. Only a few sections operate. Feeble discharge of effluents. Slight turbidity noticed. |
| 14.8.1982 | Factory lockout. No effluent discharges. |
| 30.8.1982 | No effluent discharges. River characteristics generally improve. River recovers gradually. |
| 30.9.1982 | Lockout extended. No effluent discharges. River conditions improve further. Survey results indicate near ambient conditions. |
| 9.10.1982 | Lockout lifted. Factory resumes functioning Effluent discharges commence. |
| 17.12.1982 | 'Indian Express' features an account of 'A taste of the disaster in store at Velloor', connected with the water pollution of Muvattupuzha river. |
| 6.1.1983 | Effluent discharges from Newsprint Factory continue to pollute the river. |
| 7.1.1983 | Effluent discharges continue. Presence of mercury in river water noted. |